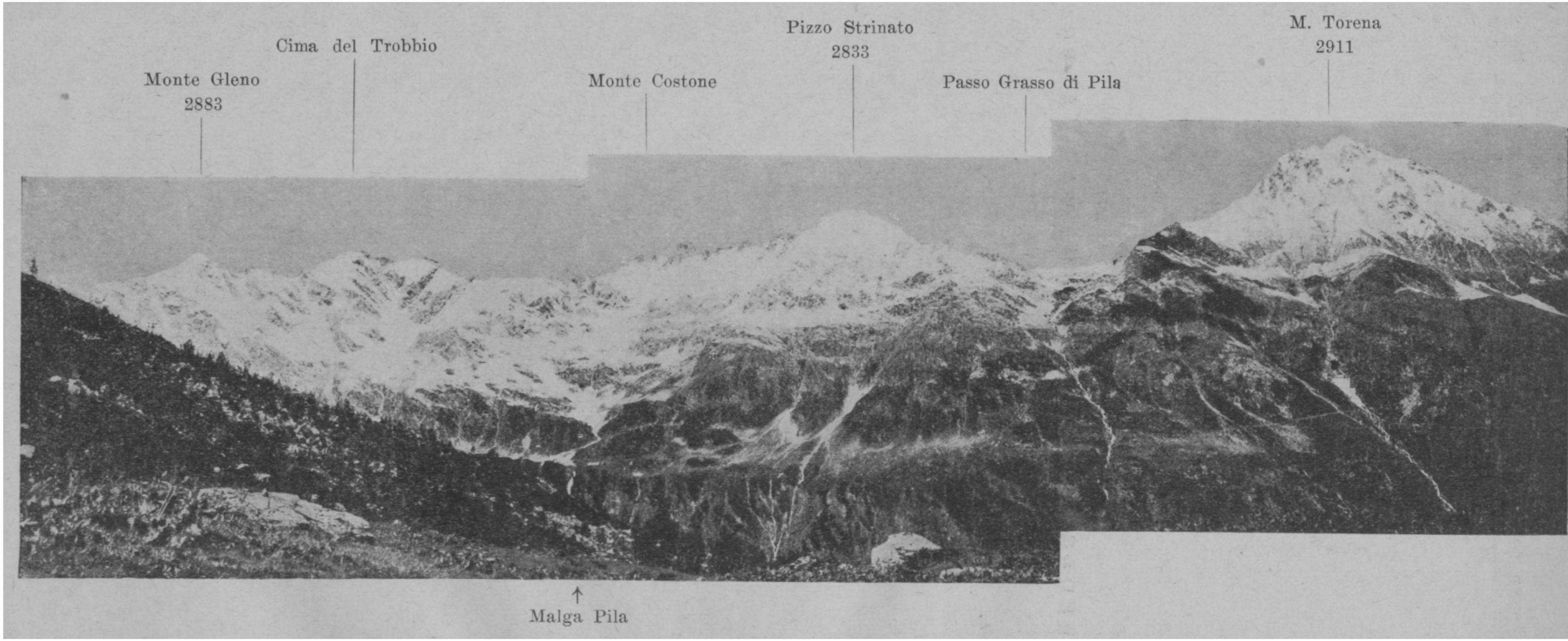
THE GEOLOGY OF THE BERGAMASC ALPS
LOMBARDIA
ITALY

by

L. U. DE SITTER

and

C. M. DE SITTER—KOOMANS.



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PREFACE.

Ever since the spring of 1926, when the field survey of COSIJN started, until august 1939 when the impending second world war and the partial mobilization of the Dutch army necessitated the abandonment of our field of activities, the geological institution of Leyden University has maintained a geological survey of the Lombardic Alps between Lake Como and Val Camonica, commonly called the Bergamasc Alps. The survey has been maintained by encouraging the students to select for their doctors thesis an object of field mapping, and assigning to them areas of the above mentioned portion of the southern Alps. The publication of this work has been supervised from the beginning to the end by Prof. Dr. B. G. ESCHER, head of the department and director of the Geological and Mineralogical Museum of Leyden. The actual field work was in the first years supervised by himself and to some extent by Dr. PH. H. KUENEN and since the summer of 1935 by the author, who gradually took over most of the supervisional work leading up to the final draft of maps and texts. From the index map, fig. 1, we can see that the work proceeded mainly from west to east and therefore the author has only been able to acquire a personal knowledge of the eastern part of the mapped area, but the work of DE WIT (24) [1]) in the mountains north of Val Taleggio and the revision by ZIJLSTRA (25) of the Salmurano culmination together with some excursions and the general stratigraphical reviews carried out by DORSMAN (19) as to the Anisian and by KROL (26) as to the Raibler-Esino boundary gave him even some personal knowledge of the western part of the area. As a guide to nearly all the field work the 1:100.000 map of Conte Cesaro Porro, published in 1903, was of great assistance, although since the whole of the area represented by this map has been remapped no parts of it have been included in our new map. The text belonging to PORRO's map has played a similar part.

Several times the survey found the „Molengraaff fund" willing to subsidise some special field work, by grants to the surveyor. SWOLFS (n°. 15); KROL (n°. 26) and ZIJLSTRA (n°. 25) profited by these grants, and last not least a substantial help to ZONNEVELD went to the preparation of the drafts of the maps. Our sincere thanks to the board of this institution for their substantial help and genuine interest in our work are offered here.

In a way the present publication is a continuation of a similar but

[1]) The numbers refter to p. 7.

smaller monograph of the Lugano district [1]) by the same author. A special fund „the Southern Alps fund" was created prior to the above mentioned monograph to assist the publication of well printed coloured maps accompanying the planned sequence of publications. To the contributors of this fund of which the Bat. Petr. Mij. and the Leidsche Geologische Vereeniging merit special mention our sincere thanks are extended here, and as many of them were closely associated with the work, either by taking part in the survey or by following its growth with interest, I hope that the result does not fall short of their expectations.

Without the personnel of the geological institution, which through many years has been helpful in assisting students and myself in preparing the material, and without the able draughtswoman, Miss C. ROEST, who draughted maps, sections and figures of the present publication and of many preceding areas on the same subject-matter, very little could have been achieved.

Many months I passed in close companionship with my younger colleagues between the lofty mountains of the Bergamasc Alps. Their zeal and juvenile enthusiasm has been a constant inspiration and made those summer months amongst the best I have ever experienced. Sincere friendships have grown out of our scientific collaboration and to them I am glad to dedicate this work.

The present paper is published under the joint authorship of my wife and myself. Although it is principally to the first part of the monograph on the petrology of the rocks, where some 28 new rock analyses from her hand are published for the first time, that the joint authorship refers, it rightly describes also our close collaboration during the whole work through many years of coöperation, as much as the preparation of the manuscripts and maps.

The whole work will be divided into three parts: Part I. Petrography of the igneous rocks, Part II. Stratigraphy, Part III. Tectonics. Literature references will appear as notes at the base of each page. The first part is accompanied by a 1:200.000 sketch map of the crystalline rocks together with the major tectonical lines. The two sheets of the 1:50.000 coloured geological map and the sections belong to the second and third parts, the two tectonical maps belong in particular to the third part.

[1]) L. U. DE SITTER. Les porphyres luganois et leurs enveloppes. Histoire géologique des Alpes tessinoises entre Lugano et Varese. Leidsche Geol. Med. XI, 1939, p. 1—61.

INTRODUCTION.

The present monographic study of the Bergamasc Alps is the result of the geological survey of this region, that has been carried on since 1926, fostered by the geological institute of Leiden University. These surveys of smaller topographical units have nearly all been published in the Leidsche Geologische Mededeelingen (except the nos. 3, 19, 20, 21, 22, 23, 24 and 25) [1]. During those 15 years of mapping the views on the stratigraphy and tectonics of the region have developed and naturally the earlier studies needed some revision. Apart from the necessity of reconsidering all the work from a general point of view, some remapping of the region of the Salmurano basement rock culmination and vicinity had become desirable because the original views of JONG (**2**, 1928) had been strongly attacked by PORRO (1933). This remapping was carried out by ZIJLSTRA (**25**). In the western part of the region the maps of RASSMUSS (1912), TRÜMPY (1928), DESIO (1927) and PHILIPPI (1897), have been used and to some extent the sheet Como of the 1:100.000 geological map of Italy. For the region of Oltre il Colle an unpublished map could be made use off by courtesy of M. W. BEYERINK. In the NE corner of the map small areas surveyed by F. WINKELAAR and A. J. DIKKERS were placed at our disposal. To all these gentlemen we extend our sincere thanks for their collaboration.

The mapped area has been restricted roughly to the Permian and Triassic strata together with the basement rock in so far as the latter occurs within that area and forms its northern border. Only one survey (TROMP, **6**) is concerned only with the basement rock and the major part of this survey falls outside our 1:50.000 maps. In accordance with an agreement with our italian collegues we left the younger Mesozoïc strata south of our area out of consideration. It must be regretted that no survey of this most interesting country has been published in the meantime except the monograph of DESIO (1929), which survey was already in course when we started our work.

The field maps are all on the scale of 1:25.000 and have been copied uniformly on a set of 1:25.000 ordnance maps kept in the Geological Museum of Leiden University. In the same Museum the collection of rock samples and microscopic slides are lodged. When reference to these collections is made the Museum numbers are mentioned. For the final preparation the uniform set of 1:25.000 maps were reduced photographically to a scale of 1:50.000 and redrafted for our purpose. The topographical names may be looked up in the index, where the location of the name on the map is facilited by a reference indicating the square on the map in which it can be found. The sections have all of them been constructed anew. The small summary of the geology of the Bergamasc Alps published by the author some three years ago [2]) was a preliminary study of the same object, which has been extended

[1]) The numbers refer to the sequence of „Contributions to the geology of the Bergamasc Alps" see fig. 1 and p. 7.
[2]) L. U. DE SITTER: La géologie des Alpes méridionales d'après les levés récents. Geol. & Mijnbouw, 1st Jrg. N. S., 1939.

here. New surveys have been published since then and in the present paper a general reviewing of the whole subject matter has taken place.

The literature on the subject of the Lombardic Alps is enormous, a complete list would contain at least up to a thousand numbers. References in this monograph are restricted to the list of modern surveys mentioned on p. 14 and 15 and to those at the bottom of each page. A complete bibliography of the Lombardic Alps and adjacent regions can be found in:

Dr. R. RITTER VON SBRIK. — Geologische Bibliographie der Ost-Alpen. München u. Berlin 1935 I & II, and 1 Fortsetzung, Innsbruck 1937.

Literature since 1937 which has come to my knowledge, is contained in a small list on p. 15 and 16.

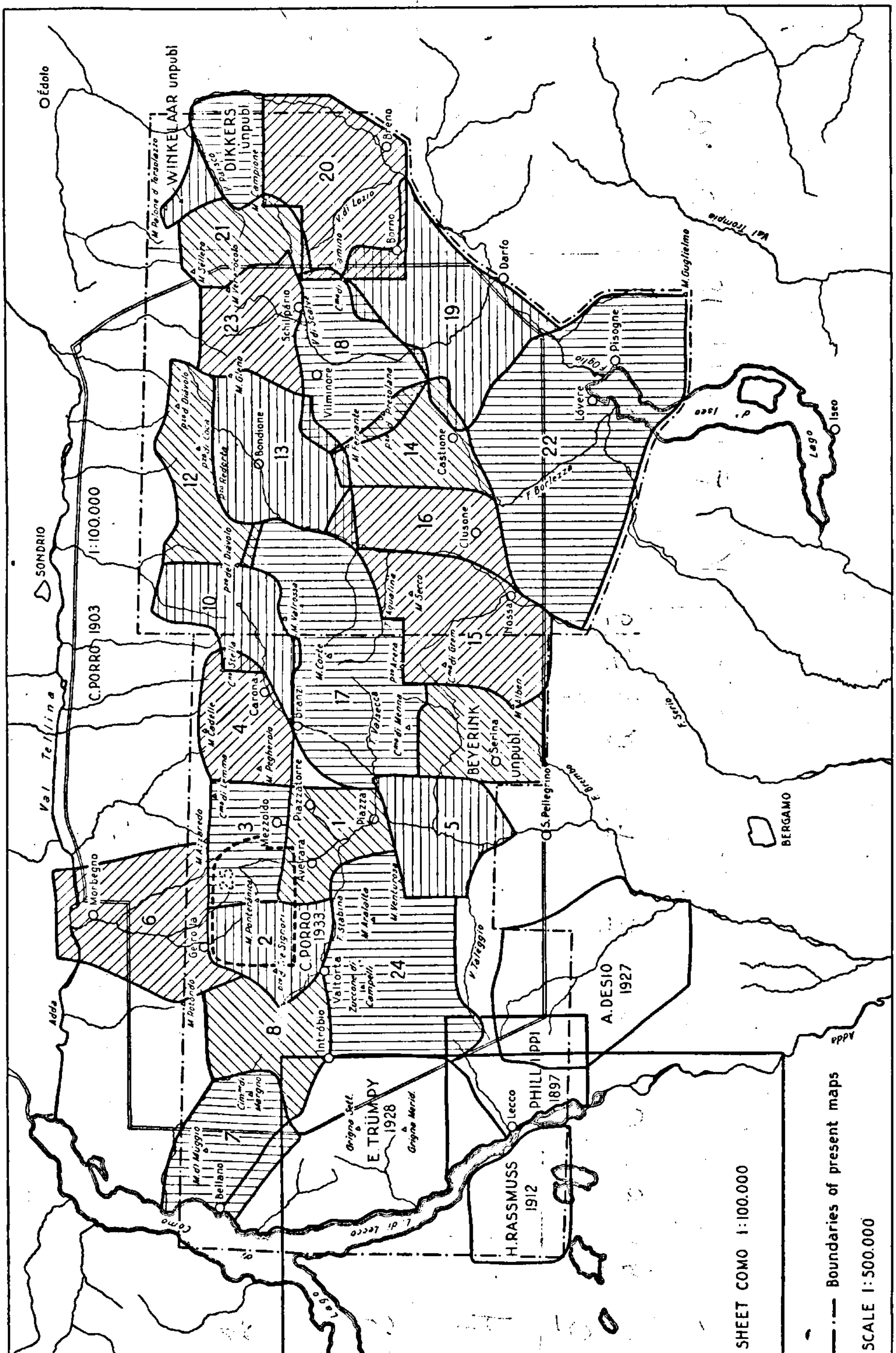

Fig. 1.
Index map of the field surveys in the Bergamasc Alps.

INDEX OF MODERN SURVEYS OF THE BERGAMASC ALPS.

No. 1. J. COSIJN, De Geologie van de Valle di Olmo al Brembo 1928, L. G. M. [1]) II, p. 251—324.
No. 2. W. J. JONG, Zur Geologie der Bergamasker Alpen, nördlich des Val Stabina. 1928, L. G. M. III, p. 48—104.
No. 3. TH. H. F. KLOMPÉ, Die Geologie des Val Mora und des Val Brembo di Mezzoldo. 1929, Diss.
No. 4. J. H. L. WENNEKERS, De geologie van het Val Brembo di Foppolo en de Valle di Carisole. 1930, L. G. M. III, p. 265—333.
No. 5. G. L. HOFSTEENGE, La Géologie de la Vallée du Brembo et de ses affluents entre Lenna et San Pellegrino. 1931, L. G. M. IV, p. 25—82.
No. 6. S. W. TROMP, La Géologie du Val del Bitto et la Tectonique des Alpes Lombardes. 1932. L. G. M. IV, p. 123—230.
No. 7. W. L. BUNING, De geologie van den Cimone di Margno en den Monte di Muggio. 1932, L. G. M. IV, p. 321—399.
No. 8. R. D. CROMMELIN, La Géologie de la Valsassina et de la région adjacente au Nord. 1932, L. G. M. IV, p. 400—459.
No. 8a. J. H. L. WENNEKERS, The Structure of the Bergamo Alps compared with that of the Northwest Highlands of Scotland. 1932, L. G. M. IV, p. 83—93.
No. 9. G. L. HOFSTEENGE, Mineragraphisch onderzoek der loodzinkertsen uit de Bergamasker Alpen. 1934, L. G. M. VI, p. 59—78.
No. 10. J. J. DOZY, Die Geologie der Catena Orobica zwischen Corno Stella und Pizzo del Diavolo di Tenda. 1935, L. G. M. VI, p. 133—230.
No. 10a. J. J. DOZY, Ueber des Perm der Süd-Alpen. 1935, L. G. M. VII, p. 41—62.
No. 11. J. J. DOZY, Beitrag zur Tektonik der Bergamasker Alpen. 1935, L. G. M. VII, p. 63—84.
No. 12. J. J. DOZY en P. D. TIMMERMANS, Erläuterungen zur Geologischen Karte der Zentralen Bergamasker Alpen. 1935, L. G. M. VII, p. 85—109.
No. 13. J. WEEDA, La Géologie de la Vallée Supérieure du Serio. 1936, L. G. M. VIII, p. 1—54.
No. 14. W. A. VISSER, Die Geologie der westlichen und südlichen Abhänge des Pizzo della Presolana und des Monte Ferrante. 1937, L. G. M. IX, p. 108—176.
No. 15. H. C. A. SWOLFS, Verslag bij de geologische kaart van de bergkam Mt. Secco—Pzo Areta en van het stroomgebied van de Torrente Riso (Valle Seriana).
No. 16. H. C. A. SWOLFS, De geologie van het westelijke deel van de Presolana-groep. 1938, L. G. M. X, p. 147—215.
No. 17. H. C. RAASVELDT, De geologie van het gebied tusschen de Brembo en de Serio noordelijk van de bergkam Monte Menna–Pizzo Arera. L. G. M. XI, p. 193—260.
No. 18. G. L. KROL, De geologie van het Valle di Scalve en het Valle Nembo. 1939, L. G. M. XI.
No. 19. L. DORSMAN, De geologie van het Val Dezzo en de Pizzo Camino, ten N.W. van het Val Camonica, en de ontwikkeling van de Valsecca in de Bergamasker Alpen. 1940, Diss. (Summary in „Geol. en Mijnb.", 2e jaarg. N. S. No. 10, Oct. 1940).
No. 20. D. A. ERDMAN, De geologie van de westhelling van het Val Camonica tusschen het dal van Borno en het Val Clegna. Diss. 1941.
No. 21. J. FABER, De geologie van het Boven Val Paisco en het Boven Valle di Scalve. 1941, Diss.
No. 22. A. MAASKANT, De geologie van het gebied tusschen het Val Seriana en de Mte Guglielmo. Diss. 1941.
No. 23. G. ZIJLSTRA, De geologie van de hoofdgraat van de Bergamasker Alpen tusschen de Monte Gleno en de Monte Verneròcolo. 1941, Diss.
No. 24. R. DE WIT, De geologie van het oostelijke Valsassina en van het Val Taleggio. 1941, Diss.
No. 25. G. ZIJLSTRA, De Perm-schubben van de Salmurano-Culminatie. Geol. en Mijnb., 3e jaarg. N. S. No. 4, April 1941.
No. 26. G. L. KROL, De Esino–Raiblergrens in de Bergamasker Alpen. L. G. M. XIII, 1943.

[1]) L. G. M. abbreviation for „Leidsche Geologische Mededeelingen".

The numbers on the indexmap agree with the numbers of the publications in this list, a sequence of „Contributions to the geology of the Bergamasc Alps".

Other surveys, which have been used for the 1: 50.000 maps, accompanying this monograph are indicated on the index map by the name of the surveyor with the date of publication, when published, or with the adjective „unpublished" when such is the case.

These published maps occur in:

E. TRÜMPY: Geologie der Grigna-gruppe am Comersee (Lombardei). Ecl. Geol. Helv. vol. 23, 1930.

E. PHILIPPI: Geologie der Umgegend von Lecco und des Resegone-Massivs in der Lombardei. Z. D. Geol. Ges. 1897.

H. RASSMUSS: Beiträge zur Stratigraphie und Tektonik der südöstlichen Alta Brianza. Geol .u. Pal. Abh., Bd. 10, 1912.

A. DESIO: Studi geologici sulla regione dell'Albenza. Mem. Soc. It. Sc. nat., vol. X, 1929.

C. PORRO: Alpi Bergamasche, carta geologica rilevata dal 1895—1901 con sezioni geologiche e „Note illustrative". Milano, 1903.

C. PORRO: Dal Pizzo dei Tre Signori al Monte Ponteranica. Mem. R. Ist. Lomb., vol. XXII della Ser. III, 1933.

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BIANCHI, A. & DAL PIAZ, G. — Il settore meridionale del massiccio dell'Adamello. Boll. R. Uff. geol. d'It. 62, 1937.

—— Atlante geologico-petrografico dell'Adamello meridionale. Regione fra lo Stabbio ed il Caffaro. Pubbl. a cura della R. Un. di Padova, 50a ad. est. Soc. geol. it. Padova 1937.

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—— Fauna anisica pigmea scoptera nelle Prealpi Bresciane. Boll. Soc. geol. It. vol. 58, 1939.

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DESIO, A. — L'opera di Antonio Stoppani ed i recenti progressi della geologia lombarda. B. S. g. it. 60, 1941.

—— Sull'origine della sorgente di Nossa in Val Seriana e sulla tettonica dei dintorni. Ist. d. Geol. etc. Un. di Milano serie G no. 28, 1943.

—— Appunti per l'escursione della Soc. Geologica italiana a S. Pellegrino (val Brembana). Ist. d. Geol. etc. Un. di Milano, Serie G no. 23, 1942.

—— Appunti ed osservazioni sul Glaciale della valle Seriana e della Valle Cavallina (BBergamo). Ist. d. Geol. etc. Un. di Milano, Serie G no. 34, 1945.

—— Appunti ed osservazioni sul Glaciale della valle Brembana (Bergamo). Ist. d. Geol. etc. Un. di Milano, Serie G no. 33, 1945.

*) The list is certainly incomplete as most of the italien publications have not reached me yet. Only the results of the older ones, before 1940, could be partly incorporated in the present study.

—— Sulla constituzione geologica dei dintorni di Trescorre Balneario (Bergamo). Ist. d. Geol. etc. Un. di Milano, Serie G no. 30, 1944.
—— Appunti sulla tettonica della valle Andrara. Ist. d. Geol. etc. Un. di Milano Serie G no. 29, 1944.
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—— e VENZO, S. — Nuovo giacimento del Pliocene superiore a Torre dei Roveri, nelle Prealpi Bergamasche. Ist. d. Geol. etc. Un. di Milano, Serie P no. 34, 1943.
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PART I.

PETROGRAPHY OF THE IGNEOUS AND METAMORPHIC ROCKS.

CHAPTER I.

THE BASEMENT SERIES.

The para-metamorphic rocks, underlying the late palaeozoïc and mesozoïc sedimentary rocks of the Alpine geosyncline, belong in the Lombardic Alps to the groups of gneisses, micaschists, quartzites and phyllites. All possible transitions between these groups are present.

The intrusive rocks in this para-metamorphic series show either a certain amount of regional metamorphism as the amphibolites or the ortho-gneisses of the Valsassina, and to a lesser degree the „gneiss chiaro", or are not affected by any serious metamorphism as the granodiorites of the Valsassina and its associated rocks. Still both para- and ortho-rocks, highly metamorphosed or not, belong to the basement series because the whole complex is unconformably overlain by Permian and Triassic volcanic and sedimentary rocks of almost non-metamorphic habit.

The relative age of the rocks of the basement complex, therefore, can only be studied by their mutual geological position, and their state of metamorphism.

The distinction between para- and ortho-metamorphic rocks is often difficult to make and dubious samples are locally numerous. However, generally speaking the para-metamorphic series show a great variability in mineralogical composition, texture and structure, whereas the ortho-rocks are much more uniform. Specific plutonic character has been proved in many instances and often the intercalation of quartzites, graphite schists and similar specific para-schists prove the para-metamorphic character of a gneiss complex. Transitions between the two main groups in the form of injection gneisses are not very numerous and restricted to the circumference of some of the larger intrusive bodies.

On the map, Plate XVI, the crystalline rocks of the Bergamasc Alps are drawn, together with the major tectonical lines.

a. The para-metamorphic series.

Regional metamorphism has transformed a sedimentary series of geosynclinal neritic habitus into a complex of unknown thickness of highly metamorphic gneisses and schists.

The field maps rarely distinguish between the different types of rocks, with exception of the maps of Tromp (6, 1932) and Dozy (10, 1935), for the simple reason that the variability of the rock types is generally too great to allow any accurate mapping.

In accordance with the generally accepted conception of the different authors, three main groups may be distinguished, viz.:

1. Alkali-felspar gneisses,
2. Micaschists and quartzites,
3. Phyllites.

The alkali-felspar gneisses are characterized by the mineral association of felspar-quartz and mica, the micaschists by quartz and mica, the phyllites by the preponderance of micas over any other constituent.

The first and second group merge completely into one another by a gradual decrease of the felspar content. The phyllites are much less frequent and are not so closely related to the first two groups.

The absence of lime in all these rocks is very conspicuous, only a few localities of marble and then of limited extension are known and only a very few rocks show a notable amount of lime.

The alumina content varies considerably. Garnet, staurolite and cyanite appear in this sequence by increasing alumina both in the gneisses and in the micaschists.

The variation field, thus roughly outlined, indicates a sedimentary series of shales, sandy shales and sands with probably a varying exomorphic infiltration of potash felspar.

1. Para alkali-felspar gneisses.

The main constituents of these rocks are:

Orthoclase	Muscovite
Albite	Biotite
Quartz	

Garnet is frequent, while, with growing alumina content, staurolite and even cyanite appear.

Accessory minerals are: Apatite, rutile, zircon, tourmaline, pyrite, magnetite, ilmenite, while as secondary minerals epidote, zoïsite, calcite, serpentine and ores are very frequent.

Plate I. Alkali felspar gneisses and micaschists.

Fig. 1. slide no. 4867. Muscovite alkali felspar gneiss from Valle di Scala at 2131 m + nicols, enlargement. 14 ×. A large orthoclase porphyroblast has grown during the metamorphosis of the rock. Numerous inclusions of quartz and mica, the latter arranged in S shaped curve showing the rotation of the orthoclase individu during its growth.

Fig. 2. slide no. 3214. Biotite-garnet-alkali felspar gneiss from southern slope of Pzo Melasc. + and // nicols, enlargement. 24 ×. Large felspar porphyroblasts full of quartz, garnet and mica inclusions.

Fig. 3. slide no. 3555. Garnet-sturolite gneiss from E side of Lago di Venina. // nicols, enlargement. 20 ×. At the base of photograph garnet crystals as inclusions in a large orthoclase porphyroblast, and at the top a large staurolite porphyroblast. The rest of the rock consists of parallel muscovite flakes, quartz (white) and felspar (gray).

Fig. 4. slide no. 4860. Garnet mica schist from Conca Largone, NW of Grumello, Val Paisco. + and // nicols, enlargement. 22 ×.
The two large garnets lie in a mica zone, mostly muscovite, at the bottom followed by a quartz-muscovite zone (+ nicols). The curving away of the muscovite flakes from the large garnet porphyroblast illustrates the internal movement of the rock during its metamorphism.

Fig. 5. slide no. 1637. Biotite-garnet schist from Bta Fioraro. //nicols, enlargement 22 ×. The rock consists of biotite and quartz with garnet porphyroblasts wholly replaced by chlorite of which two examples appear at the bottom of the photograph.

PLATE I

ALKALI FELSPAR GNEISSES AND MICA SCHISTS

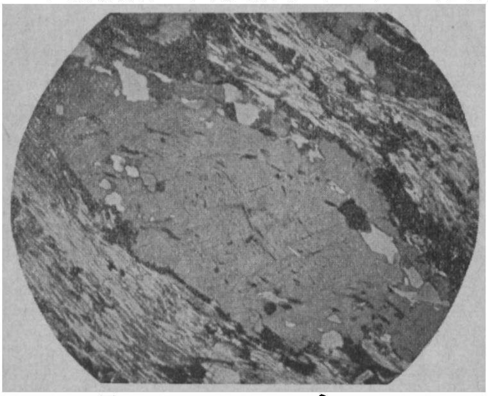


FIG. 1 Slide No. 4867

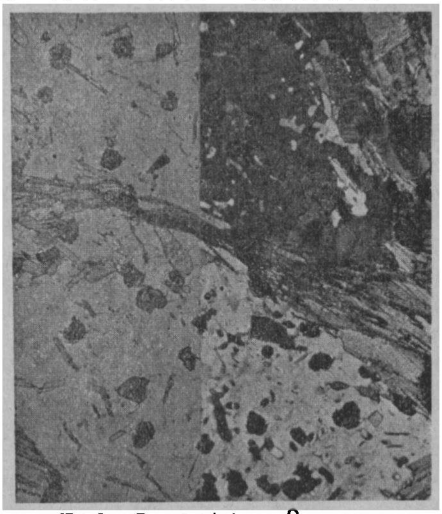


FIG. 2 Slide No. 3214

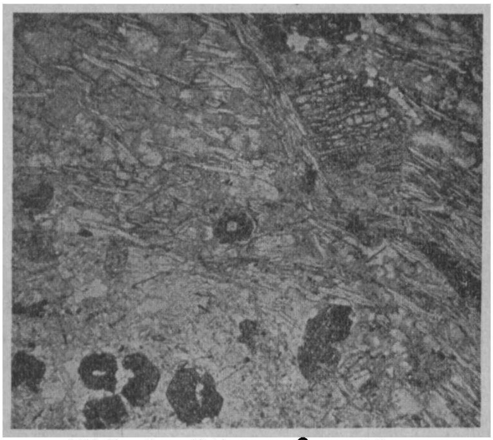


FIG. 3 Slide No. 3555

FIG. 4
Slide No. 4860

FIG. 5 Slide No. 1637

The *Felspars.* Both the orthoclase and the plagioclase have two forms of occurences viz.: 1st as porphyroblasts, 2nd in the granoblastic structure intergrown with quartz. The felspar porphyroblasts characterize the rock to a very high degree and give rise to the names of „Augengneiss" and „Knotengneiss" (compare Plate I, figs. 1 and 2). Large crystals, enclosing mostly quartz grains but often other minerals, such as mica, garnet and ores in poeciloblastic fashion, are surrounded by mica flakes, which curve around the porphyroblasts. This eye structure, due to porphyroblasts, is macroscopically very similar to the same structure occurring in the mixed gneisses of Mt. Fioraro and Laghi di Porcile, described later, but of totally different origin. With Dozy (10) we believe that felspatisation of the mica-schists or gneisses has taken place. The infiltration of felspar material occurred in liquid or gaseous form.

When mica flakes occur as inclusions in the porphyroblastic felspar we can sometimes discern by their orientation the original crystallization schistosity crossing the porphyroblast. Sometimes as in Plate I fig. 1, the inclusions indicate by their curved linear arrangement the rotation of the individual porphyroblast during its crystallization.

Quartz occurs in two forms, viz.: 1st original quartz grains more or less crystallized, 2nd as alteration product or inclusion in felspar, garnet etc. The quartz of the first group shows a granoblastic structure often together with felspar. Nearly all quartz grains have strain shadows due to irregular extinction. Combined with this phenomenon we find very often a faint lamination, due to translation surfaces developed under high stress. The same undulated habitus is shown by the quartz of the minute veins of injected quartz, which in some regions are frequently observed.

The *micas* muscovite and biotite are often both present, one or the other may be lacking alltogether. The biotite is of the ordinary brown variety, but often has been altered subsequently in chlorite.

Chlorite is a rather common constituent, but it is important to distinguish between original chlorite and the alteration product of biotite, garnet or felspars. The latter form of occurrence is very common, but the first form is restricted to some rocks. In the latter case the chlorite appears in patches and is independent of the schistosity. Instead of chlorite we then find sometimes *serpentine.*

Garnet is a very common constituent of the gneisses but it may be lacking altogether over large areas. The garnet shows in many respects similarity with the alkali felspar as it occurs in the same way as large porphyroblasts surrounded by mica flakes (Plate I fig. 4) and on the other hand widely dispersed in small individuals throughout the whole rock. It is true that, contrary to the orthoclase which in the second form of occurrence never shows idiomorphism, the garnet always is idiomorphic. Often a complete pseudomorphism of chlorite after garnet has been found.

Tourmaline occurs mostly in small prismatic crystals widely dispersed through the rock, and is rather common.

Increase of alumina content produces *staurolite* in large crystals, idiomorphic but never surrounded by mica flakes in the way of garnet and felspar (Plate I fig. 3). *Cyanite* is a much rarer constituent and then in close connection with staurolite and garnet.

Rutile in rounded prisms and as *sagenite* in bleached biotite is common.

The mineral association of orthoclase, muscovite, biotite, garnet and cyanite of the whole series of the gneisses and the lack of cordierite and sillimanite, indicate that the regional metamorphism belongs to the Biotite-Almandine-Staurolite zones of Harker or the lower Mesozone of Grubenmann.

The contradicting presence of chlorite, sericite next to minerals of deeper metamorphic zones is perhaps partly due to a second metamorphic stage of the rock. The chlorite is a newer constituent as is proved by its pseudomorphism after garnet and biotite, both primary constituents of the gneiss. Further on we shall see that the first and deepest metamorphism is probably due to a very old praepalaeözoic orogeny and the second phase probably to the Alpine orogeny.

In the Alcali-felspar gneisses can be distinguished:

Biotite Alc.-felsp. gneiss
Muscovite alc.-felsp. gneiss
Two mica alc.-felspar gneiss
Garnet alc.-felsp. gneiss
Garnet Staurolite alc.-felsp. gneiss
Graphite gneiss
and other local varieties.

Decreasing felspar content leads to the mica-schists or to the quartzites. The increase of felspar leads first to the „Augengneiss" variety and can reach a stage when almost the whole rock is build up by felspar.

This increase of felspar, as large porphyroblasts full of inclusions, is ascribed by Dozy (10) to a felspatization of the rock. We shall see later on that the intrusion of the Fioraro granite has created injection gneisses, which by a process of mylonitization have also acquired an „eye" structure. These two, macroscopically similar, eye structures have a different genesis and are microscopically quite different as can been seen by comparing fig. 1 plate I with fig. 4 plate VI.

2. Mica-schists and quartzites.

A description of the mica-schists can be brief, as they are very similar to the felspar-gneisses.

The *quartz* again always shows the undulatary extinction and often translation planes. *Biotite* and *muscovite* are mostly both present, but each can be the only representative of the mica group. *Garnet* again is a very common constituent and an increase of alumina content leads to *staurolite* and *staurolite-cyanite* schists. *Tourmaline* is common (fig. 2). Some orthoclase and plagioclase is nearly always present.

These rocks with high alumina content are found mostly in the North, North of the Orobic thrust. Specially in the region of Pzo Melasc beautiful staurolite-cyanite mica schist can be found, sometimes enriched by large tourmaline crystals.

The structure of the rock is much less granoblastic but mostly lepidoblastic. Large garnets may give it a porphyroblastic habit.

Klompé describes a garnet-biotite-schist very rich in biotite (Plate I fig. 5). The rock is build up of quartz and biotite with a few alterated garnets. Apatite and large zircons occur frequently in the biotite.

Amphibole schists have been described by Klompé and Dozy. The hornblende-epidote schist of Valle Azzarini described by Klompé is very similar to the ordinary mica schist but the place of mica has been taken by hornblende and epidote (Plate II fig. 1). Calcite and magnetite are distributed throughout the rock.

A similar rock has been described by DOZY (10) from the Pizzo di Cigola, consisting of quartz, hornblende, garnet, zoïsite, titanite and muscovite with chlorite, sericite and magnetite, having a granoblastic structure.

An interesting rock is the actinolite rock of Cima Brandà (Plate II fig 2), described by DOZY (10) which consists of actinolite, chlorite and siderite with calcite, zoïsite, rutile and magnetite. Siderite forms porphyroblasts seldom crossed by actinolite.

Other amphibole-containing rocks belong to the amphibolites and will be described in the chapter on ortho-metamorphic rocks, although their igneous origin is often uncertain.

Decrease of mica leads naturally towards the q u a r t z i t e s which are very commonly found in the whole gneiss-mica schist series. Next to q u a r t z these rocks have always some m u s c o v i t e, and all the further common constituents of the other rocks can be present in small quantaties. The structure of the quartzites is granoblastic.

An analysis of a quartzite has formerly been made by C. DE SITTER—KOOMANS in connection with the comparison made by TROMP (6) between a felsophyre and its surrounding rock, in order to prove the non-mylonitic character of the hyalytic intrusive. The surrounding rock, described as a quartzitic garnet gneiss by TROMP, consists of quartz, muscovite, biotite and chloritisized garnet and abundant tourmaline.

Plate II. Amphibole schists and foliated micaschists.

Fig. 1. slide no. 1631. Amphibole-epidote schist from Valle Azzarini. // nicols, enlargement. 38 ×.
At the bottom to the left a cluster of epidote crystals of porphyroblastic growth. The rest of the slide consists of hornblende, magnetite wih sphene rims, epidote with quartz and plagioclase.

Fig. 2. slide no. 3572. Actinolite schist from North of pt 2396 Cma Brandà. // nicols, enlargement. 14 ×.
Large syderite crystal at bottom with magnetite. Actinolite and chlorite build up the rest of the rock.

Fig. 3. Specimen no. 32492 (slide no. 1658). Mica schist from North of Pso San Marco. A well foliated mica schist due to stratification of the original sediment. The plane of photograph is parallel to the schistosity.

Fig. 4. slide no. 1658 (see fig. 3). Mica schist from North of Pso San Marco. // nicols, enlargement. 22 ×.
The rock consists of biotite and muscovite with quartz. Garnet, replaced by chlorite, epidote and quartz is present in small quantities. Tourmaline, apatite and magnetite are accessories. The stratification of fig. 3 can be seen to run from lower left hand corner to upper right hand corner by the broad band containing large biotite flakes. In the bottom right hand corner a white zone, consisting of muscovite and quartz is visible.

Fig. 5. Specimen no. 35259. Garnet-biotite schist from North of Pso San Marco.
Foliation is due to stratification of the original sediment. Garnet porphyroblasts are clearly visible.

PLATE II
AMPHIBOLE SCHISTS AND FOLIATED MICA SCHISTS

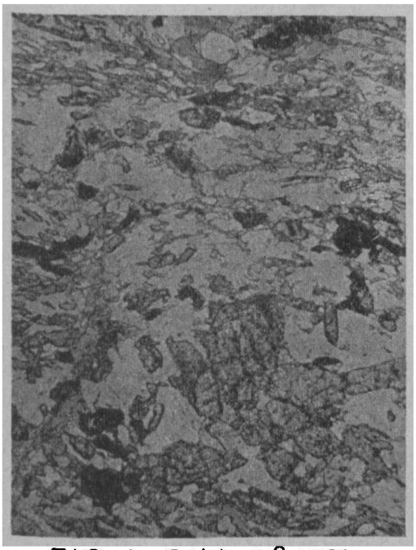


FIG. 1 Slide N° 1631

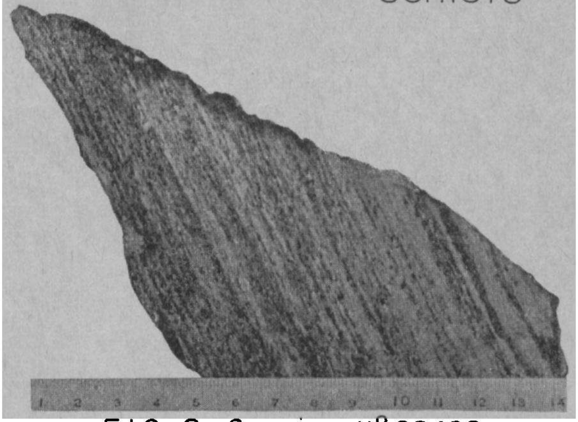


FIG. 3 Specim. N° 32492
(Slide N° 1658)

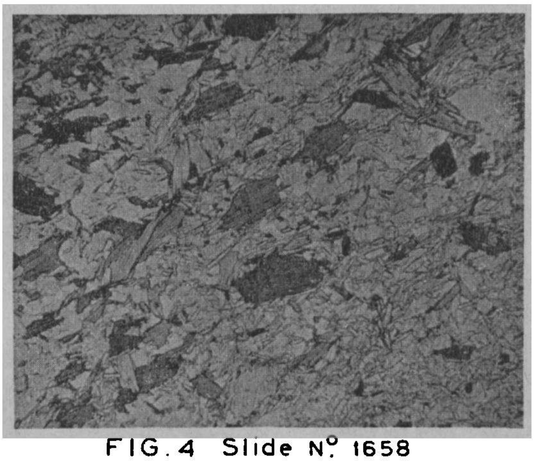


FIG. 4 Slide N° 1658

FIG. 2 Slide N° 3572

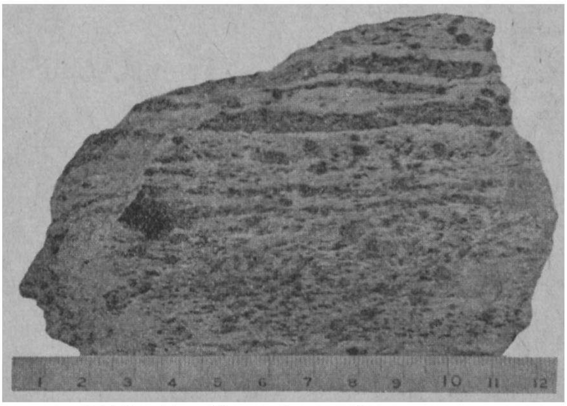


FIG. 5. Specim. N° 35259

Analysis no. 1 [1]).

SiO_2	= 78.56	si	= 532
TiO_2	= 0.04	al	= 34.1
Al_2O_3	= 8.63	fm	= 40.2
Fe_2O_3 / FeO	= 5.65	c	= 10.6
		alk	= 15.0
MnO	= 0.04		
MgO	= 1.05	k	= 0.43
CaO	= 1.44	mg	= 0.26
Na_2O	= 1.28	c/fm	= 0.26
K_2O	= 1.61		
+ H_2O	= 1.26		
— H_2O	= 0.23		
	99.89		

The analysis falls outside the eruptive field in the Niggli tetrahedron (fig. 2).

In foliated mica schists the original stratification has sometimes been preserved as a relict structure. In fig. 3 of Plate II a polished face of a garnet two mica schist has been photographed. The alteration of dark and light zones is due to biotitic and muscovite zones as shown by the microphotograph. Plate II fig. 4. The schistosity is not parallel to the stratification as the polished face is a schistosity plane which cuts the stratification obliquely.

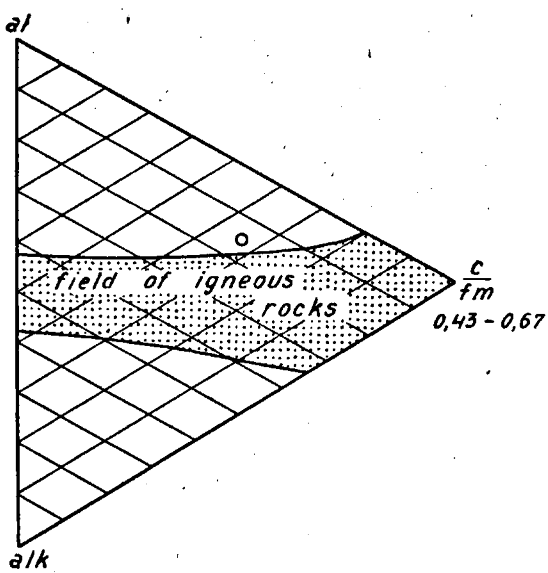


Fig. 2.
Analysis no. 1 in NIGGLI terahedron.

3. The Phyllites.

The phyllites occupy on area round the intrusion of granite of the Mt. Fioraro and a region round Ambria in the Valle di Venina and its eastern extension (Plate III fig. 1). The phyllite habitus of the rock, its soft glossy sheen, its gray slatey colour distinguish it from the mica-schists. Mineralogically they differ from the mica-

[1]) All numbers of analyses appear on the map Plate XVI, and are repeated in the Appendix: List of rock analyses of the Bergamasc Alps.

schists by the preponderance of mica, mostly muscovite or sericite and chlorite, over any other mineral. Transitions from mica-schists to phyllites are numerous, and alternations of the two groups are frequently observed. The different habitus of the phyllites compared with the mica-schists, however, must be ascribed to a lower metamorphic stage, the chlorite zone.

The phyllites have been divided in chlorite- and sericite-phyllites according to the leading mica.

The main constituents are: sericite or muscovite, chlorite and quartz. Besides these minerals garnet, tourmaline, calcite, zircon, apatite and ores have been noted.

An interesting feature are the porphyroblasts of chlorite, described by Klompé from the Mt. Fioraro, in phyllites surrounding the Fioraro granite (Plate III figs. 2, 3, 4 and 5). These porphyroblasts show often helicitic poeciloblastic structures with so-called „Streckungshöfe" (Plate III fig. 3).

Sericite occurs also as phenocrysts, but is much less conspicuous than chlorite.

Garnets seldom occur as phenocrysts and then mostly altered to chlorite and quartz.

A relict structure has been observed by Klompé when he noticed bands of chlorite and sericite not parallel to the schistosity of the rock, evidently representing the original stratification.

Transitions to mica-schists are frequent. In Plate III figs. 4 and 5 the same kind of chlorite porphyroblasts have been formed in a normal two-mica-schist with brown biotite and numerous tourmaline prisms. In other samples garnet porphyroblasts occur next to the chlorite porphyroblasts.

An increase of quartz leads naturally to muscovite schists.

Although the mineral composition and the very strongly pronounced schistosity indicate a lower metamorphic stage, the close alternation with and the numerous transitions towards biotite-bearing mica-schists indicate that the phyllites are not a strange element in the basement rock. The phyllites with chlorite porphyroblasts of the Mt. Fioraro, a type of rock restricted to this area, may have acquired their porphyroblastic structure at a later period, during the intrusion of the Fioraro granite, which was probably accompanied by strong tectonic movement with its resulting stress. Otherwise the genesis of a typical two-mica-schist with chlorite porphyroblasts is not easily understood.

One analysis has been made of a sericite phyllite

Analysis no. 2. Specimen no. 32507; slide no. 1840. Sericite-garnet-phyllite from South of Mt. Corno Stella. Surveyer Wennekers. Anal. Koomans.

A gray coloured phyllite, consisting of sericite, chlorite, garnet and ilmenite, some biotite and muscovite, a little quartz and some staurolite.

The presence of all these Al. silicates, specially staurolite is in accordance with the exceptionally high alumina content shown by the analysis. The analysis lies well outside the eruptive field and confirms the sedimentary origin of the rock.

Analysis no. 2.

SiO_2	= 43.80	si	= 118
TiO_2	= 1.45	al	= 48
P_2O_5	= 0.15	fm	= 31
Al_2O_3	= 29.92	c	= 7
Fe_2O_3	= 4.45	alk	= 14
FeO	= 4.35		
MnO	= 0.11	k	= 0.53
MgO	= 2.93	mg	= 0.38
CaO	= 2.47	c/fm	= 0.23
Na_2O	= 2.55		
K_2O	= 4.41	ti	= 2.9
$+H_2O$	= 3.04	p	= 0.16
$-H_2O$	= 0.12	h	= 28.4
CO_2	= 0.30	co_2	= 1.14
Total	100.05		

b. Ortho-metamorphic rocks of the basement series.

The highly metamorphic sedimentary series described in the foregoing chapter have been intruded in different prae-permian times by igneous rocks, either in the form of large masses or by dykes. These rocks show very distinct differences in metamorphism and in their chemical and mineralogical position. The most important units, which can be distinguished are:

Plate III. Phyllites.

Fig. 1. slide no. 3558. Sericite phyllite from Ambria, Centrale di Zappello. + nicols, enlargement 24 ×. A thick band of minutely folded sericite flakes is flanked right and left by quartzitic bands. Chlorite is more frequent in the quartzitic bands than in the sericite band. Accessories are: tourmaline, apatite, ore and calcite.

Fig. 2. Specimen no. 35272 (slide no. 1621). Chlorite sericite schist from Valle Azzarini. The green chlorite porphyroblasts are conspicuous in the white sericite-quartz schist and have grown independently of the pre-existing schistocity. Foliation is not parallel to the schistosity. Compare fig. 3.

Fig. 3. slide no. 1621. Chlorite-sericite schist from Valle Azzarini. + nicols, enlargement. 22 ×.
Large chlorite porphyroblasts (black) with larger quartz crystals in their shadow (Streckungshof). The continuation of the schistosity passing through the porphyroblast can clearly be seen in the lower half of the photograph.

Fig. 4. Chlorite two-mica schist. slide no. 1610 from south of Mt. Fioraro. // nicols, enlargement 4 ×. With the small enlargement the chlorite porphyroblasts in the two-mica schist are very conspicuous. Compare fig. 5.

Fig. 5. Chlorite two-mica schist. slide no. 1610 from south of Mt. Fioraro. // nicols, enlargement 22 ×. Comp. fig. 4.
The rock is a two-mica schist with chlorite porphyroblasts. The groundmass consists of: muscovite, biotite, quartz, plagioclase and ore. As in fig. 3 the continuation of the schistosity through the porphyroblasts is clearly discernable.

PLATE III

PHYLLITES

FIG. 1 Slide N° 3558

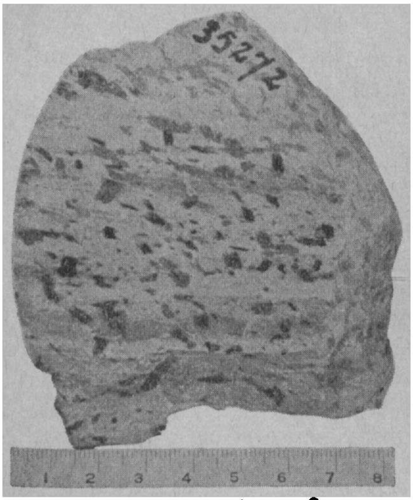


FIG. 2 Specim. N° 35272
(Slide N° 1621)

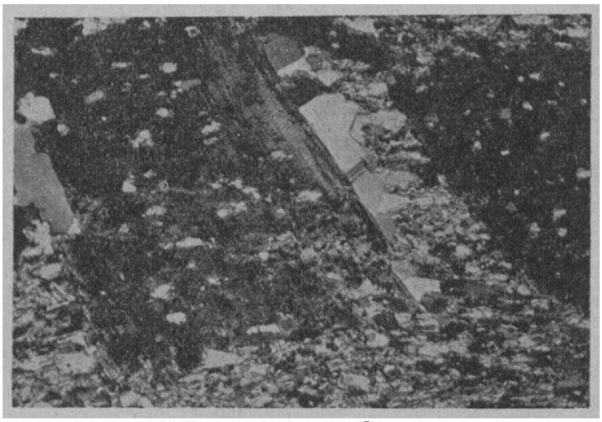


FIG. 3 Slide N° 1621

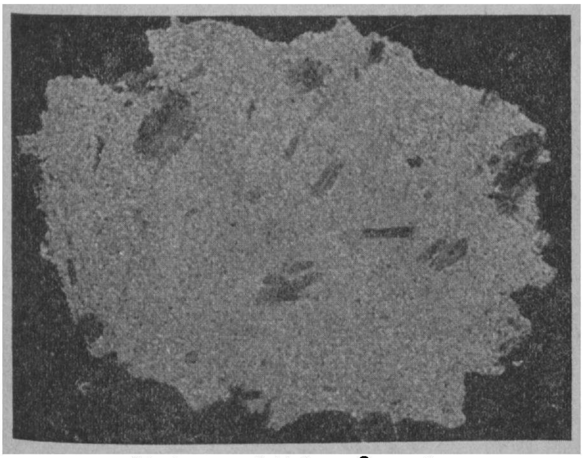


FIG. 4 Slide N° 1610

FIG. 5.
Slide N° 1610

1. The granulite of Val Sassina.
2. The gneiss chiaro masses.
3. The Mt. Fioraro granite-gneiss.
4. The Granodiorite and associated rocks of Val Sassina and Val Biandino.
5. The amphibolites and associated rocks.
6. Some small ortho-metamorphic intrusions.
7. Dykes of unknown age but probably prae-Tertiary.

1. The Val Sassina granulite.

The Val Sassina granulite is found north of the Valsassina between Introbio and Cortabbio. It is a fine grained leucocrate rock without foliation and with none or very little schistosity.

The main constituent minerals are:

quartz
orthoclase
plagioclase
with some biotite.

Accessory minerals are: zircon, ores (magnetite, pyrite), apatite and tourmaline. Secondary are: chlorite, epidote, ores, sericite etc.

The rock has a pronounced relict structure, recognisable by the idiomorphic felspars, originally phenocrysts of a porphyritic granite. These felspars, although strongly sericitized have often preserved their original zonal structure, and are free from inclusions. The rest of the rock represents a granoblastic structure of quartz and felspar with an occasional biotite flake. Quartz relicts, as present in the biotite-granulite variety described below are absent.

Sericitic pseudomorphoses after cordierite are suspected but can hardly be proved although a certain radial structure, indicating cordierite twinning, can sometimes be discerned. (Compare p. , where the presence of cordierite is described to contact metamorphism).

The biotite is strongly weathered, chloritized or altered in sericite and ore. Towards the borders of the granulite mass near Cortabbio and in the lower Val Troggia the rock is less leucocratic, and may be called a biotite-gneiss and even a biotite-amphibole gneiss (Plate IV fig. 3).

Plate IV. Granulite of Valsassina.

Fig. 1. slide no. 3112. Granulite from Cima d'Agrella.
+ and // nicols, enlargement 24 ×. Large felspar phenocrysts, wholly replaced by sericite, lie together with some weathered biotite in a quartz groundmass. The idiomorphic felspar show resorbtion.

Fig. 2. slide no. 3170. Granulite from Val Molinara.
+ nicols, enlargement 22 ×. Orthoclase crystals with zonal structure called forth by weathering of the centre of the crystal at the bottom. Plagioclase and quartz are the main constituents. Muscovite is also present. Cataclastic structure is evident.

Fig. 3. slide no. 2965. Biotite-hornblende gneiss from Val Troggia near the Centrale ellectrica. + nicols, enlargement 38 ×.
The rock consists of plagioclase, quartz, light green hornblende, brown biotite and magnetite. Schistosity is due to parallel arrangement of almost all constituents. The plagioclase has preserved its zonal structure.

Fig. 4. slide no. 3079. Biotite gneiss from E of Cortabbio. + nicols, enlargement 24 ×.
At the bottom a phenocryst of plagioclase, at the top a shattered one of quartz. The groundmass is mostly quartz and biotite. Only part of the plagioclase phenocryst is unaltered, a broad border zone has been sericitisized.

PLATE IV

GRANULITE

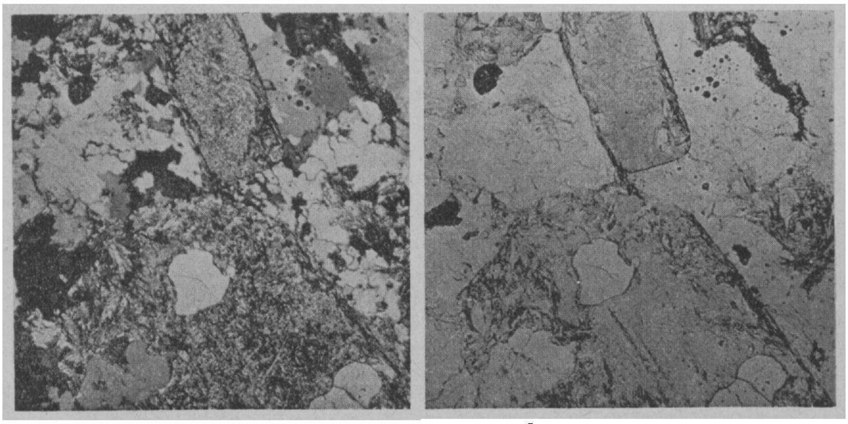


FIG. 1 Slide No. 3112

FIG. 2. Slide No. 3170

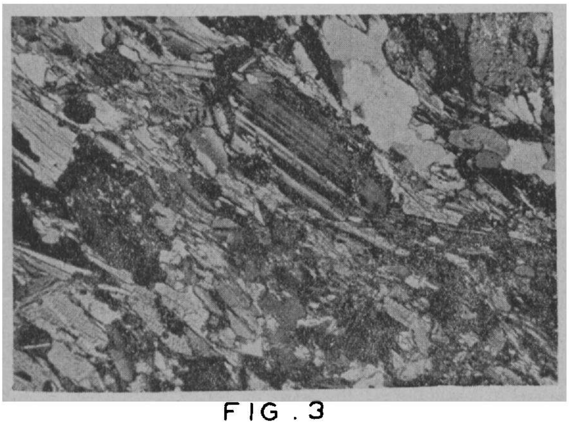


FIG. 3
Slide No. 2965

FIG. 4
Slide No. 3079

Besides the same felspar relicts quartz phenocryst relicts are found, which sometimes have preserved their original bipyramidal shape (Cortabbio Plate IV fig. 4). This quartz porphyry, though, may represent a later dyke intrusion in the Valsassina granulite.

The lack of schistosity is due to the absence of any larger quantities of mica, but the granoblastic structure, the orientation of the quartz and the felspars, and their elongated form all indicate that apart from the few relicts the rock has been submitted to severe regional metamorphism of the mesozone.

One analysis has been made of granulite:

Analysis no. 3. Granulite from Cima d'Agrella, slide no. 3111, surveyor CROMMELIN, anal. KOOMANS.

The rock consists of quartz and sericitisized, often idiomorphic, felspars, bleached biotite and some ilmenite. The structure is somewhat cataclastic.

Analysis no. 3.

SiO_2	= 71.98	si	= 429
TiO_2	= 1.36	al	= 42.5
P_2O_5	= 0.16	fm	= 36
Al_2O_3	= 12.10	c	= 5
Fe_2O_3	= 0.61	alk	= 16.5
FeO	= 3.73		
MnO	= 0.05	k	= 0.52
MgO	= 1.65	mg	= 0.41
CaO	= 0.72	c/fm	= 0.13
Na_2O	= 1.35		
K_2O	= 2.27	ti	= 6.1
$+H_2O$	= 2.84	p	= 0.36
$-H_2O$	= 0.21	h	= 64.2
CO_2	= 0.94	co_2	= 7.5
	99.97		

The granulite, together with the rocks of some intrusive dykes and the alkali-felspar ortho-gneiss of Pzo Meriggio (Vle di Venina) and some smaller occurrences of ortho-gneisses, are the only representatives of intrusive rocks, which have been submitted to the same general metamorphism as the surrounding para-metamorphic rocks. We shall see in chapter VII that this main metamorphism must be placed in prae-Cambrium times. The other intrusive rocks have not been recrystallized to any great extent and their main metamorphism has been restricted to a cataclastic structure.

2. Gneiss chiaro.

The so-called *gneiss chiaro*, light-coloured gneiss, is a distinctive type of rock, present in the lombardic alps from West to East, easily recognisable by its greenish white colour, unvariability and coarse grain.

The name of „gneiss chiari" given by STELLA [1]) to a group of leucocratic rocks, perhaps comprised some light coloured varieties of paragneisses, but may be used now with advantage to designate these leucocratic ortho-gneisses or better granite-gneisses. The gneiss chiaro is intrusive, mostly in larger masses, in the para-schists but is much less metamorphic than these latter schists

The structure of the rock is blastogranitic to porphyroblastic, coarse grained, and consists mainly of quartz, felspar and muscovite (Plate V, fig. B, 1 and 2).

Quartz is usually strongly cataclastic with strain shadows.

The felspars are orthoclase, microcline, orthoclase- and microcline-perthite and albite-oligoclase. The porphyric structure of the rock is a primary feature due to idiomorphic felspars.

The microcline seems to be partly of secondary origin and due to stress. Several orthoclase crystals show just a beginning of the crossing lamellae, others a more advanced stage where nearly the whole crystal has been taken up by the lamellation. (Plate V, fig. 3).

The muscovite, undoubtedly partly also a primary constituent, gives a faint schistose character to the rock, mostly because the cataclastic zones have preferred to pass along the muscovite flakes.

Accessory minerals are: apatite, often in large crystals, some zircon and sometimes a small amount of ore grains.

The cataclastic structure of the rock is always very pronounced by zones of crushed quartz, broken and shifted felspars etc., and increases towards the faultzones.

The varieties of this rock are small in number and due to a more or less pronounced porphyric structure or to a small increase of the darker elements. The gneiss chiaro contact with the surrounding schists has been studied by DOZY (10), TROMP and others. In the gneiss chiaro near the contact the grain becomes finer, quartz content increases, microcline disappears and sometimes enclaves of the schists are found in the gneiss chiaro. TROMP (6) even observed biotite and garnet in the gneiss chiaro. The schists have been strongly quartzified near the normal contact zone and carry sometimes some microcline. Secondary biotite flakes are found even as an increase in ore content. Very often, however, the boundary between the two rocks is a faultline and the gneiss chiaro then often is strongly mylonitisized.

Five analyses of this rock have been made.

Analysis no. 4. Gneiss chiaro from path Forno to Baita Salinoni, Cima di Lemma.

Specimen no. 32513; slide no. 1810. Surveyor: WENNEKERS; anal. KOOMANS.

A very light coloured rock with schistosity due to muscovite streaks.

Constituent minerals: quartz with strain shadows, orthoclase, plagioclase, microcline, muscovite and biotite.

The felspars contain only small sericite streaks. The biotite has been bleached.

Magma type: engadinic-granitic.

Analysis no. 5. Gneiss chiaro from Val Muggiasca (Valsassina) between Bellano and Taceno.

[1]) A. STELLA. Contributo alla geologia delle formazioni pretriasiche nel versante meridionale delle Alpe centrali. Boll. R. Com. Geol. no. 1, Roma 1894.

Specimen no. 41490; slide no. 3235. Surveyor: BUNING; anal. KOOMANS.

A light coloured violet-gray rock, less schistose than no. 4, but muscovite clearly visible.

Constituent minerals: quartz with strain shadows, orthoclase, plagioclase, muscovite, apatite and haematite.

Magma type: engadinic-granitic.

Analysis no. 6. Gneiss chiaro from top of Pizzo Cornagiera.

Specimen no. 32458; slide no. 3018. Surveyor: CROMMELIN; anal. KOOMANS.

A very light coloured rock with muscovite streaks.

Constituent minerals: cataclastic quartz, orthoclase, plagioclase, microcline, microperthite, muscovite, chlorite and haematite.

The muscovite streaks are accompanied by sericite veins. Chlorite content is perhaps due to biotite weathering.

Magma type: engadinic-granitic.

Analysis no. 7. Gneiss chiaro from Baita dell'Arete, Cima di Lemma.

Specimen no. 32504; slide no. 1812. Surveyor: WENNEKERS; anal. KOOMANS.

Light gray rock with muscovite streaks.

Constituent minerals: quartz with strain shadows, orthoclase, microcline, plagioclase, muscovite, biotite, apatite and some magnetite.

The felspars contain a few small sericite veins. The biotite is strongly bleached and has been largely altered in chlorite.

Magma type: engadinic-granitic.

Analysis no. 8. Gneiss chiaro from the Cima della Rosetta, Valle del Bito di Gerola above Morbegno. Surveyor: TROMP; anal.: KOOMANS, ref. lit. 6.

This analysis shows a rather different character from the foregoing ones. TROMP (6, p. 155) supposes that the high fm and c values and the low alk value are due to the absorption of mica schist material of the surrounding rock, as the sample had been taken very near the contact zone, and the gneiss occurs here anyhow in a very narrow zone.

Plate V. Gneiss chiaro and Fioraro granite-gneiss.

Fig. 1. Specimen no. 27447 (slide 3239). Gneiss chiaro from Mt. Muggio.
The felspars: orthoclase, plagioclase and microline are white, quartz is gray. The cataclastic structure is typical for this rock.

Fig. 2. slide no. 3579. Gneiss chiaro from East of Lago del Diavolo. + nicols, enlargement 24 ×.
The rock consists of plagioclase, muscovite and quartz, the latter showing strain shadows. A cataclastic zone right in the centre, from where a fracture plane runs between the plagioclase crystals of the top, the central one being broken and the parts slightly shifted.

Fig. 3. slide no. 3292. Gneiss chiaro from Mt. Muggio. + nicols, enlargement 78 ×.
A large orthoclase crystal shows a beginning of secondary microcline structure due to strain.

Fig. 4. slide no. 1649. Fioraro granite gneiss from between Mt. Fioraro and Mt. Azzaredo. + nicols, enlargement 26 ×.
A large twinned orthoclase phenocryst has been cracked at several places. It carries numerous inclusions and is surrounded by cataclastic quartz. Dispersed in the slide are relicts of the intruded schists, of which a small patch, consisting of dark biotite and muscovite lies against the short side of the phenocryst.

Figs. 5 and 6. slide no. 1651. Fioraro granite gneiss from North of Passo San Marco, both + nicols, 5: enlargement 2½ ×, 6: enlargement 210 ×.
The cataclastic rock consists of felspar and quartz. Fig. 6 is an enlargement of the centre of fig. 5, where a large perthite phenocryst has been split in three and the fissures being filled up by cataclastic quartz.

PLATE V

GNEISS CHIARO AND F.IORARO GRANITE GNEISS

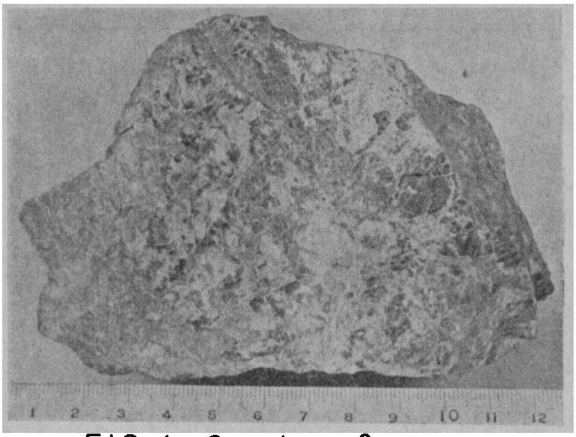


FIG. 1 Specim. N.° 27447

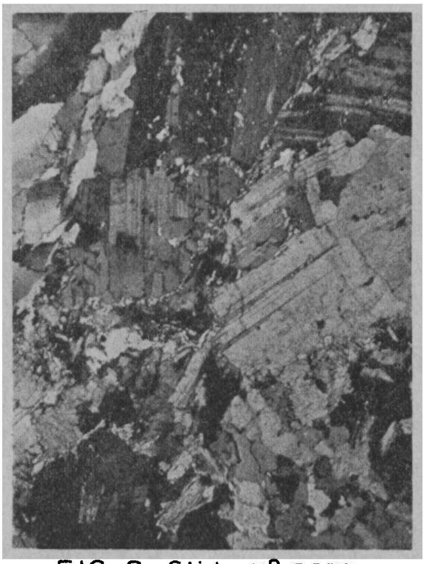


FIG. 2 Slide. N.° 3579

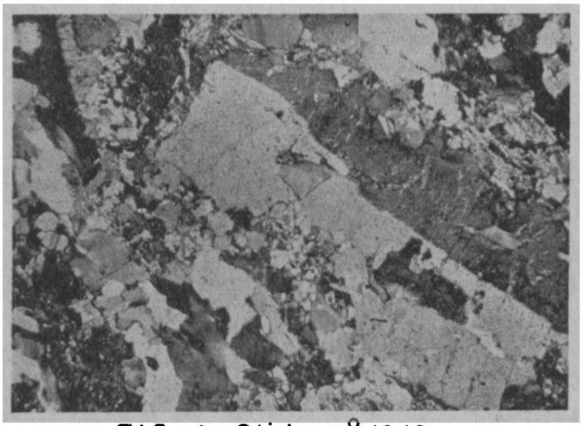


FIG. 4. Slide N° 1649

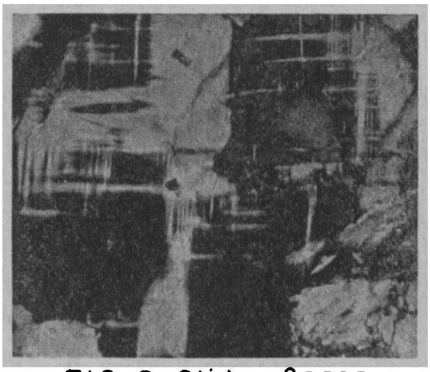


FIG. 3 Slide N° 3292

FIG. 6. Slide N.° 1651

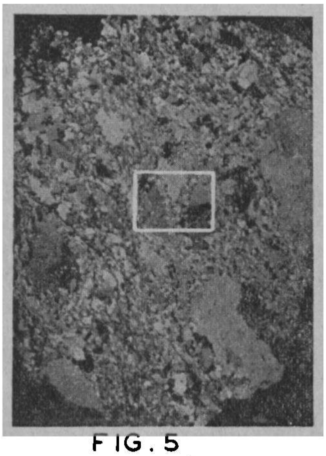


FIG. 5
Slide N.° 1651

No. of analysis	4	5	6	7	8
SiO_2	76.31	75.05	73.95	74.89	74.99
TiO_2	—	—	—	—	0.05
P_2O_5	0.10	0.10	0.14	0.12	—
Al_2O_3	13.06	13.43	13.81	12.84	11.64
Fe_2O_3	1.24	0.97	1.07	1.14	3.96
FeO	0.34	0.33	0.59	0.68	
MnO	0.02	0.04	0.04	0.03	0.04
MgO	0.48	0.78	0.58	0.63	1.18
CaO	0.95	0.77	1.23	1.09	2.17
Na_2O	3.47	3.48	2.86	3.51	2.10
K_2O	3.27	3.75	3.90	4.26	2.27
$+H_2O$	0.70	0.63	1.05	0.73	1.23
$-H_2O$	0.19	0.10	0.10	0.11	0.19
CO_2	0.08	0.38	0.71	0.22	—
	100.21	99.81	100.03	100.25	99.82
si	472	466	436.5	436	431
al	47.5	49	48	44	39.26
fm	12	10	13	13.5	27.43
c	6.5	5	8	6.5	13.35
alk	34	36	31	36	19.96
k	0.38	0.42	0.47	0.44	0.42
mg	0.36	0.35	0.40	0.41	0.37
c/fm	0.52	0.54	0.59	0.49	0.49
ti	—	—	—	—	0.21
p	0.36	0.37	0.35	0.35	—
h	18.19	14.88	24.50	16.13	—

The chemical analyses of these four specimen of gneiss chiaro clearly confirm the invariability of this type of rock already noticed in the field.

The gneiss chiaro analyses can be compared with the Aare and Gotthard granites which in many respects, viz.: general state of metamorphism, constituent minerals, probable age of metamorphism and intrusion etc. are very similar to the gneiss chiaro.

In fig. 3 this comparison has been made. Our four normal analyses are plotted together with their average in one diagram with the average of the Aare- and W. Gotthard granites [1]) and some of the individual analyses of these rocks. The following table gives the figures.

[1]) NIGGLI, QUERVAIN, WINTERHALTER: Chemismus schweizerischer Gesteine. Beitr. Geol. Schweiz, Geotechn. serie XIV, 1930.

R. A. SONDER: Differentiationsverlauf des spätpaläozoischen Granitintrusionen im zentralen und westlichen Gotthardmassiv. Schw. Min. u. Petr. Mitt. 1e Jhrg. 1921.

	si	al	fm	c	alk
Average Aare granite	413	44	11.5	6	38.5
Average W. Gotthard gr.	417	44.5	11	7	37.5
Aare granite An. 11	430	45	9	7.5	38.5
Gneiss chiaro An. 7	436	44	13.5	6.5	36
Gneiss chiaro An. 6	436.5	48	13	8	31
Gotthard granite An. 1	442	44	10	6	40
Average Gneiss chiaro	452.6	47	12	6.5	34
Gneiss chiaro An. 5	466	49	10	5	36
Aare granite An. 38	468	47	12	3	38
Gneiss chiaro An. 4	472	47.5	12	6.5	34

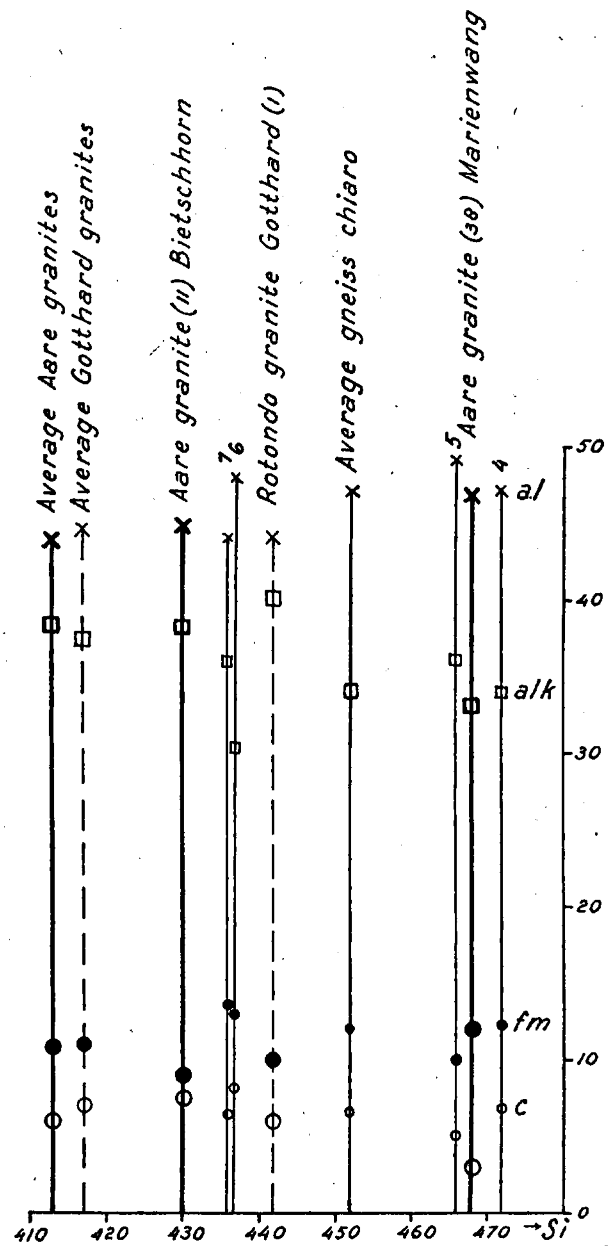


Fig. 3.

Comparison of Gneiss chiaro with Aare- and Gotthard granites.

The very great conformity of the analyses is striking, though the gneiss chiaro is distinctly more acid, and the alk is slightly lower.

The average analysis of the gneiss chiaro, for instance, is almost identical with the Aare granite An. 38.

3. Fioraro gneiss and associated injection gneisses.

The Fioraro gneiss or granite gneiss represents a distinct type of rock and deserves a description of its own, although it is microscopically very similar to the gneiss chiaro.

The rock consists of large crystals of orthoclase and microline, small plagioclase crystals and quartz. Both orthoclase and microline are always perthitic with well developed albite. Moreover the large microline phenocrysts often have numerous inclusions of unorientated small plagioclase crystals. The quartz is totally broken up and nearly always shows strain shadowing (Plate V fig. 4). The felspar crystals also are often broken and the fissures filled up with quartz fragments (Plate V fig. 5 and 6). Graphic intergrowth of quartz and felspar has sometimes been observed.

The dark elements of the rock consist of a varying amount of biotite and muscovite, together with epidote and zoïsite. However, these dark elements mostly did not belong to the original rock but are remnants of the para-schists which have been penetrated by the acid Fioraro granite magma. Thus the Fioraro granite gneiss is essentially an injection gneiss. The centre of the intrusion is almost free from dark elements, towards the border the dark bands increase in breadth and number and the macroscopical habit of the rock becomes more and more schistose and foliated. TROMP (6) describes the transition from the phyllites to the Fioraro granite passing through a series of injection gneisses to some detail.

The intrusion of the granite magma must have taken place at great depth but after the solidification of the major part of the large felspar crystals. The injection of the granitic magma happened also after the main metamorphic phase of the para-schists. Afterwards the injection gneiss was subjected to the severe strain of the Alpine orogenesis and a purely cataclastic deformation superseded the older metamorphism. The darker remnants of the para-schists have been slightly modified in their mineralogical composition, the large amount of epidote, zoïsite and sphene being undoubtedly due to termal metamorphism. From the centre of the intrusion, a long narrow stretch just south of the Mt. Azzaredo and Mt. Fioraro, the pure granite grades southwards and northwards into the surrounding para-schists by a more or less gradual increase of para-schist material. The rock then has a lenticular structure of white patches in a dark ground mass, the white patches being the injected granite-magma. The eye structure of the injection gneiss is, partly at least, due to a simple mechanical stretching of the white injected layers, a sort of mylonitization, by which the larger felspars and quartz aggregates have been separated in lenses and now appear as eyes in the darker rock (Plate VI fig. 1, 2, 3 and 4).

Four analyses have been made of the Fioraro gneiss-granite and the surrounding injection gneiss.

Analysis no. 9. Fioraro granite, from the Mt. Fioraro. Surveyor: KLOMPÉ; anal.: KOOMANS.

Specimen no. 41479; slide no. 4918.

Coarse grained, slightly porphyric rock.

Constituent minerals: Orthoclase with microperthite, microcline, quartz with strain shadows, some small plagioclase crystals often as inclusions in microcline, and biotite, as sole dark mineral, altered in chlorite and epidote. As ores we find titanomagnetite with leucoxene rim. Sericite streaks give the rock a slightly schistose habitus.

Magma type: engadinic-granitic.

Analysis no. 10. Fioraro granite-gneiss from between Pzo delle Segade and Mt. Fioraro. Surveyor: Klompé; anal.: Koomans.

Specimen no. 32476; slide no. 1674.

Light coloured coarse grained rock, slightly schistose.

Constituent minerals: Quartz, orthoclase, microcline, plagioclase, biotite, muscovite and calcite.

The calcite is cataclastic, the felspars are sericitisized with streaks of sericite between the larger minerals. Biotite and muscovite in small quantities, biotite partly chloritisized.

Magma type: leucoquartzdioritic.

The analysis is very similar to no. 9, the latter being less weathered, indicated also by the alk value of no. 10 being much lower than that of no. 9. The K_2O content is considerably lower.

Analysis no. 11. Injection gneiss from Pso di Pedena. Surveyor: Klompé; anal.: Koomans.

Specimen no. 41487; slide no. 1655.

A well foliated rock, dark layers rich in biotite alternating with white quartz-felspar „eyes".

Constituent minerals: quartz with strain shadows, microcline, orthoclase, a little plagioclase, muscovite, biotite, zoïsite and epidote.

The felspar is rather fresh, even as the biotite. In the slide the typical eye structure is hardly noticeable.

Magma type: normal granodioritic.

The K_2O percentage is rather high due to the muscovite content of the rock. Compared to the foregoing analyses a shift to the basic side is evident, as could be expected in a mixture of the rocks of nos. 9 and 10 with para-schists.

Analysis no. 12. Injection gneiss from Passo San Marco. Surveyor: Klompé; anal.: Koomans.

Specimen no. 32495.

A mica schist with „eyes" of felspar. The felspars are much smaller, and the rock is much less injected by magmatic material. The analysis is in accordance with this feature as the rock is considerably more basic (much higher fm and lower si values).

No. of analysis	Fioraro granite 9	Fioraro granite 10	Injection gneiss 11	Injection gneiss 12
SiO_2	72.46	70.67	65.60	53.91
TiO_2	0.42	0.73	1.02	1.06
P_2O_5	0.11	0.14	0.27	0.17
Al_2O_3	13.64	15.06	15.23	17.28
Fe_2O_3	1.10	0.25	1.52	2.08
FeO	1.33	1.63	3.47	7.14
MnO	0.04	0.06	0.06	0.11
MgO	0.47	1.05	1.66	3.99
CaO	1.39	2.05	2.21	4.07
Na_2O	3.65	4.01	2.02	2.71
K_2O	4.73	1.99	4.54	3.29
$+ H_2O$	0.75	0.98	2.12	3.29
$- H_2O$	0.05	0.02	0.08	0.13
CO_2	—	1.20	—	0.82
Total	100.14	99.94	99.80	100.05
si	385	360	290	163
al	43	45.5	39.5	31
fm	14	16.5	28.5	41
c	8	11.5	10.5	13.5
alk	35	26.5	21.5	14.5
k	0.46	0.24	0.59	0.44
mg	0.37	0.50	0.38	0.44
c/fm	0.55	0.68	0.36	0.32
ti	1.60	2.82	3.45	2.4
p	0.32	0.31	0.54	0.18
h	14.10	17.18	32.37	34.7

The injection gneisses found by WENNEKERS (4, 1930) north of the Laghi Porcile are very similar to those of the Mt. Fioraro. The intruded rock is here a biotite-muscovite schist with epidote and zoïsite. The intruding rock is a very coarse grained granite with abundant large quartz, large plagioclases and orthoclases and even microcline. The contact between the two rock types has lost its sharp lines the older rock being melted and corroded. The intruding magmatype is too coarse grained for an aplite but certainly is more acid than an ordinary granite.

Some analyses of this type of rock have been made.

Analysis no. 13. Injection gneiss from Laghi di Porcile. Surveyor: WENNEKERS; anal.: KOOMANS. Plate VI, fig. 5.

Specimen no. 32508; slide no. 4922.

Foliated rock, light gray with dark biotite layers alternating.

Constituent minerals: Quartz with strain shadows, orthoclase, plagioclase, microcline, muscovite, biotite, zoïsite, epidote and calcite. The plagioclase is rather sericitisized, the biotite is fresh, but may be curved by stress.

Magma type: normal granitic.

Analysis no. 14. Injection gneiss from Laghi di Porcile. Surveyor: WENNEKERS; anal.: KOOMANS.

Specimen no. 32500; slide 1839.

Well foliated rock, with large white quartz-felspar „eyes", somewhat lighter coloured than the foregoing number, due to less biotite.

Constituent minerals: quartz, plagioclase, orthoclase, microcline, muscovite, biotite, zoïsite and epidote.

Magma type: opdalitic.

Analysis no. 15. Injection gneiss from Laghi di Porcile. Surveyor: WENNEKERS; anal.: KOOMANS.

Specimen no. 41489; slide 4920.

Much less foliated rock, black and white patches.

Constituent minerals: quartz with strain shadows, orthoclase, plagioclase, muscovite, biotite, zoïsite, epidote and calcite. The felspar is strongly sericitisized, the biotite is fresh but often curved.

Magma type: normal granitic.

The analyses of the nos. 13, 14, 15 have been made of three different looking hand specimen. Chemically all three are very much the same.

Mineral composition, chemical analysis and geological habitus point to a similar genesis as the Fioraro mixed gneisses, as WENNEKERS (4) had assumed already.

Injection gneisses from Laghi Porcile.

	13	14	15
SiO_2	65.49	64.60	63.70
TiO_2	1.17	1.04	1.03
P_2O_5	0.15	0.11	0.12
Al_2O_3	14.60	15.61	15.93
Fe_2O_3	1.78	0.99	0.72
FeO	4.30	4.55	5.13
MnO	0.06	0.04	0.05
MgO	2.01	2.20	2.39
CaO	2.81	4.01	3.08
Na_2O	2.67	2.30	3.01
K_2O	3.74	3.43	3.59
$+ H_2O$	1.26	1.12	0.95
$- H_2O$	0.08	0.19	0.20
CO_2	0.16	0.13	0.11
	100.28	100.32	100.01
si	267	251	242
al	35	35.5	35.5
fm	32.5	30.5	32
c	12	17	12.5
alk	20.5	17	20
k	0.48	0.49	0.49
mg	0.38	0.43	0.43
c/fm	0.38	0.55	0.39
ti	3.70	3.03	2.87
p	0.24	0.23	0.23
h	18.12	17.01	10.02

Plate VI. Injection gneisses from Mt. Fioraro and Laghi Porcile.

Fig. 1. Spec. no. 32474. Coll. KLOMPÉ.
Injection gneiss from West of the Pso S. Marco. Eye structure due to stretching and mylonitization of the rock, which consists of injected granite magma into mica schist.

Fig. 2. Between Pzo Verobbio and Pso S. Marco. Injection of Fioraro granite magma into mica schist and formation of eye structure mostly by stretching and dynamometamorphism in general.

Fig. 3. Slide no. 1624, coll. KLOMPÉ, par. nicols, enlargement 44 ×.
Chlorite alkali felspar schist with eye structure. Pso S. Marco. A pure chlorite schist (chlorite and quartz with magnetite) carries eyes of quartz (often cataclastic) and albite. Originally there were elongated zones (still to be seen elsewhere in this slide) which have been stretched and broken up by considerable internal movements, causing finally this eye structure.

Fig. 4. Slide no. 1652, coll. KLOMPÉ, crossed nicols, enlargement 26 ×. Between Pso S. Marco and Mt. Verrobbio.
A large microcline microperthite surrounded by quartz is shown in the right half of the photograph. This is the intruded or injected Fioraro granite magma. In the left half the original muscovite paraschist appears. Injection must have taken place after the solidification of the large microcline.

Fig. 5. slide no. 4922, par. nicols, enlargement 22 ×. Injection gneiss from Laghi Porcile, Cma di Lemma.
A large white band of injected granitic material consisting of quartz and albite with some orthoclase, appears between two bands of the original schist, consisting of biotite, muscovite, epidote, zoïsite and quartz. Analysis no. 13.

PLATE VI

INJECTION GNEISSES

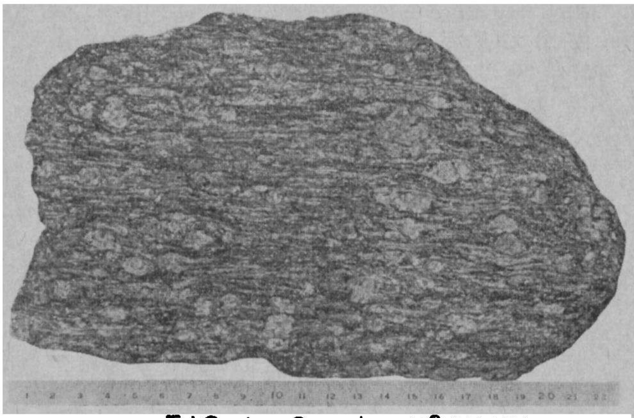


FIG. 1 Specim. No. 32474

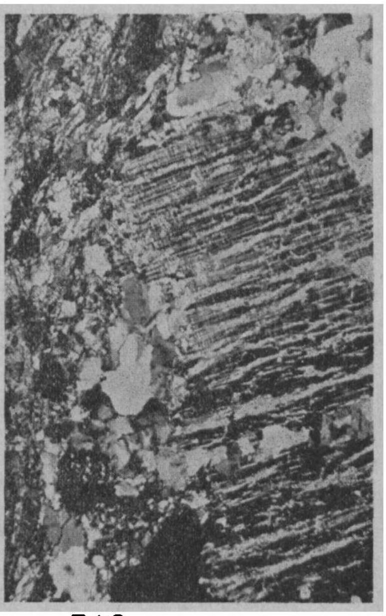


FIG. 4.
Slide No. 1652

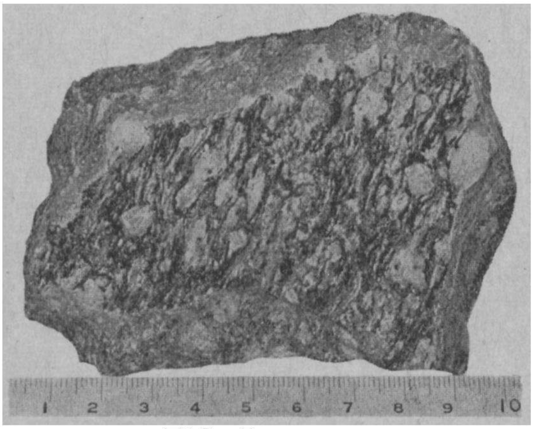


FIG. 2

FIG. 3 Slide No. 1624

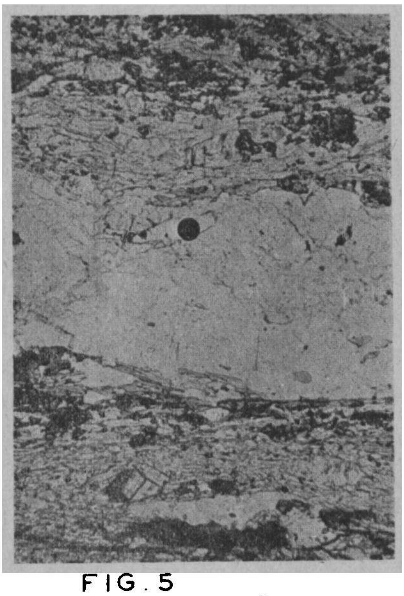


FIG. 5
Slide No. 4922

The injection gneisses round the Fioraro granite and those of the Laghi Porcile can be assembled in one diagram fig. 4, in which the percentage of Al_2O_3, Fe_2O_3(+ FeO), K_2O, Na_2O, MgO and CaO are plotted on the ordinates and the SiO_2 values on the abcis. This diagram has several striking

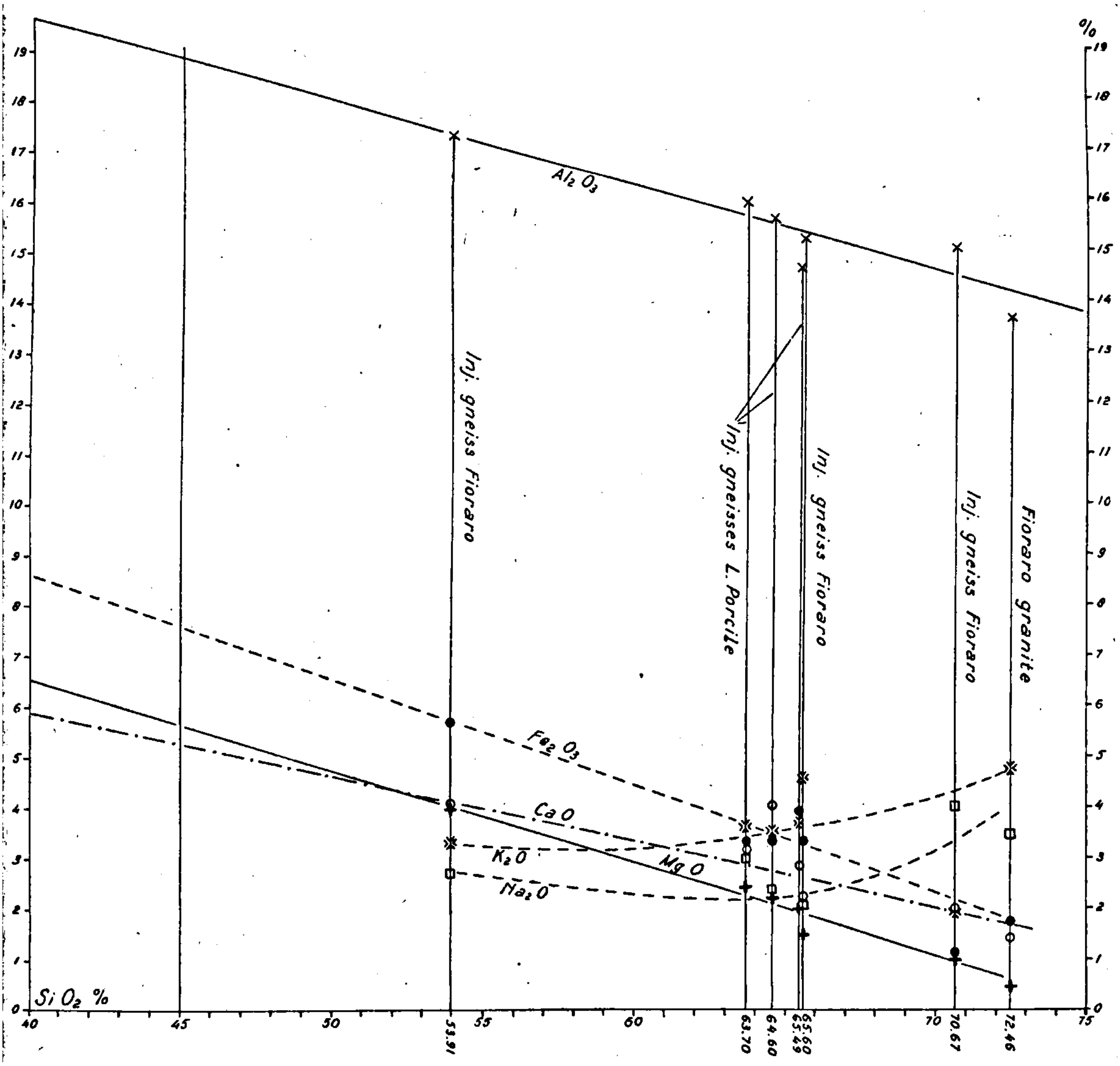


Fig. 4.

Injection gneisses diagram.

features. In the first place the Al_2O_3 points, and those of Fe_2O_3 and MgO appear to lie on straight lines. This signifies that the rocks, having a SiO_2 percentage in between the extremes of 53.9 % and 72.5 %, are mixtures of these two extremes, e. g. mixed gneisses consisting of phyllite and varying amounts of Fioraro granite. The microscopical evidence of injection gneiss is therefore confirmed in a very conclusive way by the chemical analysis. This becomes still more convincing when we notice that with decreasing SiO_2 the Al_2O_3 percentage increases together with the iron and calcium content. This is a most uncommon feature in any diagram of rock analyses with decreasing SiO_2 percentage. Usually the alumino-silicates, the felspars, decrease when the femic constituents increase. In this case however a phyllite with high alumino content, relative to its low SiO_2 content, due to its sericite habitus (in this respect comparable to the phyllite, analysis no. 2), has been mixed with a normal granite with lower Al_2O_3 content and higher SiO_2 content. The most basic injection gneiss (SiO_2 53.9 %) is still a mixture of granite and a phyllite. The composition of the pure phyllite can not be deduced from the diagram, but can not be very far removed from this point. When we continue the connecting lines to the left we find at:

45 % SiO_2 and at 40 % SiO_2

the following percentages:

18.8 Al_2O_3	and	19.5 Al_2O_3
7.6 Fe_2O_3		8.6 Fe_2O_3
5.6 MgO		6.6 MgO
5.2 CaO		5.9 CaO

Assuming that the pure phyllite had the very low SiO_2 percentage of 40 %, then the mixed gneisses would contain the following amounts of injected Fioraro gneiss:

gneiss of SiO_2 %	Fioraro gn.	gneiss of SiO_2 %	Fioraro gn.	gneiss of SiO_2 %	Fioraro gn.	gneiss of SiO_2 %	Fioraro gn.
53.91	36.5 %	64.60	75.8 %	65.60	78.9 %	72.64	100 %
63.70	73 %	65.49	78.6 %	70.67	94.5 %		

The CaO line also is comparatively straight, although the points are rather scattered, but the K_2O and Na_2O lines do not seem to be straight lines. The reason of this divergence is not clear.

The fact that the injection gneisses of the Laghi di Porcile fall very nicely in their place in the diagram, moreover, confirms the view that the two injection gneisses from Mt. Fioraro and Laghi di Porcile are very similar in origin.

4. Granodiorite and associated rocks.

In the Val Biandino an intrusion of a granodioritic magma has penetrated the alkali felspar gneiss and micaschists. The magmatic differentiations of the main mass together with its marginal granitic facies and numerous apophyses, exposed in the Vle Rossiga and upper Val Marcia, give a complete differentiation sequence of this plutonic intrusion (Buning 7, 1932).

PORRO [1]) and CROMMELIN (8, 1932) gave excellent descriptions of these rocks, which agree in nearly every respect.

The most common kind of rock is a Biotite granodiorite (Plate VII, figs. 1, 2 and 4) with quartz, orthoclase, plagioclase, and biotite as major constituents and apatite, zircon, magnetite, pyrite and tourmaline as accessory minerals (analyses nos. 22 and 23). The rock is often slightly cataclastic and in some regions of high pressure the cataclastic structure may give rise to a certain schistosity.

The plagioclase, mostly very much weathered, has a composition of some 40—45 % anorthite (CROMMELIN) and thus may be called a basic andesine.

In the more basic types a hornblende appears beside the biotite (analysis no. 24). The hornblende is generally much less affected by weathering than the biotite, the latter often being altered completely in chlorite, epidote and magnetite.

The Hornblende-granodiorite of the Cima d'Agrella where the biotite has disappeared altogether, is a more basic type of rock. The quartz content has diminished. The plagioclase also is of a slightly more basic type with 44—50 % An. The hornblende has a tendency to become a brown basaltic hornblende with low extinction angle (12°—14°), sphene appears frequently.

The most basic differentiate of the granodiorite magma is a Norite (analysis no. 33) from Val Troggia near Casa Gorè (Plate VII, fig. 3). The major components are: plagioclase, basaltic hornblende, bronzite, biotite, magnetite and spinell. The plagioclase is strongly sericitisized and the hornblende has been weathered to chlorite, talc and actinolite, whereas the bronzite has been altered to bastite. The rock is distinguished by the metallic lustre of the bronzite.

[1]) CESARE PORRO. Rocce granitiche della Valsassina. Rend. R. Ist. Lomb., serie II, vol. 31, 1898.

Plate VII. Granodiorite.

Fig. 1. Specimen no. 41478 (slide no. 3035). Biotite-granodiorite from Vle Rossiga.
A rock with granoblastic structure consisting of felspar, quartz and biotite. Analysis no. 19.

Fig. 2. slide no. 3035. Biotite granodiorite from Vle Rossiga. + nicols, enlargement 26 ×.
A large plagioclase in the centre. To the right mostly quartz. Below it a biotite, another smaller plagioclase and some orthoclase. Analysis no. 19.

Fig. 3. Specimen no. 41488 (slide no. 2972). Norite from Casa Gorè, Val Troggia.
The rock consists of plagioclase, basaltic hornblende, partly replaced by chlorite, talc and actinolite, bronzite altered into bastite, some biotite and magnetite with spinell. Analysis no. 33.

Fig. 4. slide no. 2942. Biotite-hornblende granodiorite from Bta Pianca, Val Troggia. // nicols, enlargement 22 ×.
The photograph contains a phenocryst of plagioclase, zonal structure shown by unequal sericitization, much fresh biotite, some hornblende recognisable by its strong relief. Quartz and plagioclase of the groundmass are white in the photograph. Analysis no. 24.

Fig. 5. Specimen no. 35004 (slide no. 3280). Biotite granodiorite from Vle Biagio 300 m north of Bindo.
Large felspar crystals with quartz and biotite give the rock a porphyric structure.

PLATE VII

GRANODIORITE

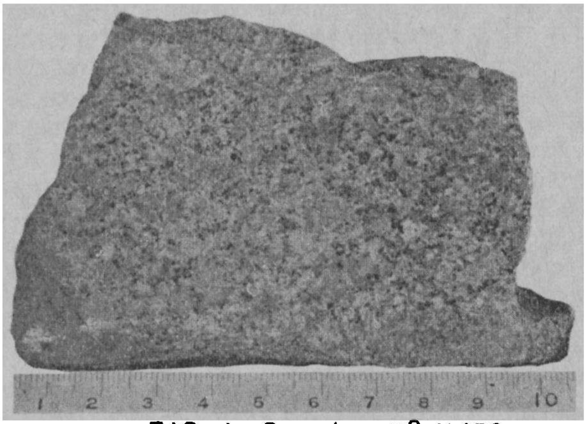


FIG. 1 Specim. N° 41478
Slide. N° 3035

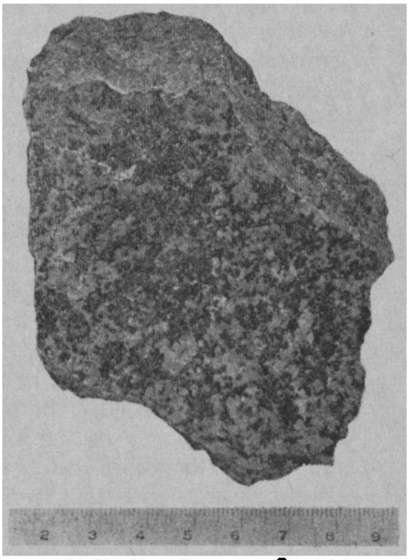


FIG. 3 Spec. N° 41488
Slide. N° 2972

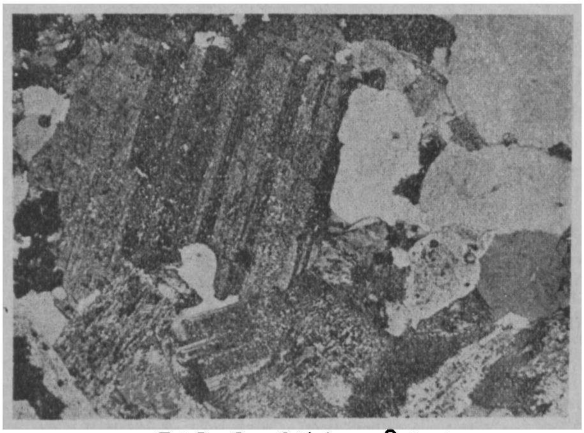


FIG. 2 Slide N° 3035

FIG. 4
Slide N° 2942.

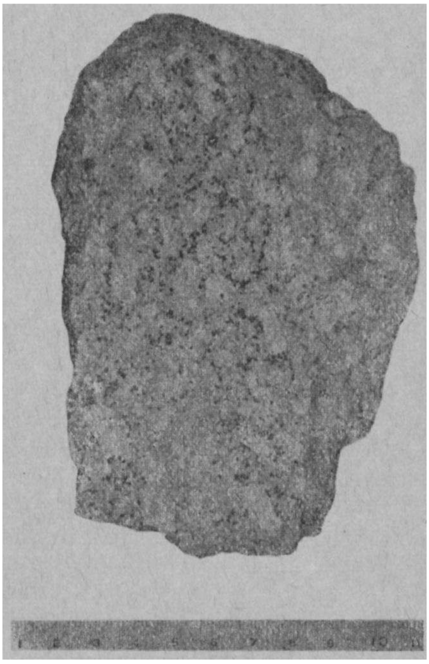


FIG. 5
Spec. N° 35004
Slide. N° 3280

PORRO[1]) describes the plagioclase as a labradorite. Both SALOMON[2]) and CROMMELIN noticed the occurrence of a spinell, which SALOMON recognized principally in xenoliths in the Norite. Pyroxene is seldom observed in the granodioritic rocks, but SALOMON describes it from some rocks of Val Troggia, according to his description of this mineral it is identical with the bronzite from our norite. PORRO[1]) also describes these rocks as pyroxene quartz diorites, a more basic type than the ordinary granodiorites and leading up to the very basic norite.

The main mass of the granodiorite of Val Biandino extends towards the west to Cortabbio, Val Sassina and is found again in the Vle Rossiga and Vle Biagio further West. The character of the rock changes, however, in these regions by a decrease of the content of plagioclase and biotite. The resulte is a porphyric granite with phenocrysts of orthoclase (analyses nos. 17, 18 and 19). The granite appears partly as a continuous mass, partly as dykes in the crystalline schists (Plate VIII fig. 1). A gradual change from granodiorite to granite has been observed between Val Crevest and Val Molinara. In the lower Troggia valley the granite dykes are numerous and near Cortabbio the granodiorite appears as rounded xenoliths in the granite, giving rise to a remarkable rock full of large dark patches of diorite in light coloured granite, which rock has been called by the surveyor „pantherskin". Plate VIII fig. 4 and 5. Analyses 20 and 29.

The orthoclase and the plagioclase of the granite are both often zonal, orthoclase has frequent Carlsbad twinning, while granophyric intergrowth of quartz and orthoclase is sometimes met with and orthoclase-perthite is not rare.

The whole rock has a reddish colour due to the orthoclase.

Both biotite and muscovite are present. Tourmaline, strongly pleochroïtic with different colours, has been frequently noted.

The close mixture of dioritic and granitic magmas of Cortabbio and their simultaneous cooling has been demonstrated by CROMMELIN (8), who observed that the idiomorphic felspars of the granite penetrate into the diorite. However, all circumstances point to a slightly younger age of the granite: the latter occurs as dykes in the diorite, and surrounds xenoliths of diorite, and never the other way round.

Aplitic differentiates of the granite occur in the Val Marcia, Vle Biagio and in the Vle Rossiga (Plate VIII fig. 3, Analysis 16). These fine grained aplites consist of quartz and felspar, with more or less muscovite and biotite. They may be slightly porphyric with orthoclase phenocrysts. The quartz is often full of liquid and gas inclusions.

Small intrusions of similar granodiorite are found near Scalluggio (analysis no. 28) in the upper Val Brembo and on the Mt. Fioraro near the border of the large granite mass of this mountain (KLOMPÉ, 3, 1929). (Analyses nos. 26 and 32).

The Scalluggio granodiorite (Plate IX fig. 3) consists of plagioclase and biotite with orthoclase and quartz. The plagioclase is strongly sericitisized in its more basic centre. The orthoclase has crystallized after the plagioclase and is less weathered. The biotite has been altered completely into chlorite with sagenite and ore. In the border of the Fioraro granite a small amphi-

[1]) CESARE PORRO. Rocce granitiche della Valsassina. Rend. R. Ist. Lomb., serie II, vol. 31, 1898.

[2]) W. SALOMON. Ueber Alter, Lagerungsform und Entstehungsart der periadriatischen granitkörnichen Massen. Tscherm. Min. u. Petr. Mitt., Bd. 17, 1898.

bole-diorite outcrop has been observed (Plate IX figs. 1 and 2). The rock consists of hornblende, plagioclase, biotite and quartz. The hornblende has been largely replaced, like the biotite, by chlorite and ores, and had a rather large content of titan, because sphene occurs frequently as alteration product. The plagioclase centres have been saussuritisized.

The kersantite described by KLOMPÉ (3) from the Passo di Pedena (Plate IX, fig. 5, analysis no. 31) belongs probably to the same magmatic intrusion. It is a remarkably fresh rock, consisting of plagioclase, hornblende and biotite with sphene, apatite, titanomagnetite, zircon and olivine.

Other diorite porphyrites described by KLOMPÉ (3) belong probably to the group of tertiary dykes described in another chapter.

Both BUNING (7), CROMMELIN (8), PORRO and SALOMON mention the contact metamorphism which the granodiorite intrusion has caused in the surrounding mica-schists. The most salient feature of this contact metamorphism is the enrichment in biotite. These biotite flakes are very fresh and have invaded the whole rock, they encircle the idiomorphic felspars and even penetrate into them. Andalusite has been observed and the presence of cordierite has been found by SALOMON. Even sillimanite, a mineral, which together with cordierite is conspicuously absent in all normal gneisses and mica-schists of this region has been found in the contact zone. From Val Biandino this author mentions a rock consisting almost exclusively of cordierite.

SALOMON ascribes the occurrence of staurolite, garnet and cyanite also to contact metamorphism. These minerals occur normally in many mica-schists of the northern region and it remains doubtfull if they are of contact metamorphic origin in this region (PORRO). There can be no doubt that a contact-metamorphic zone in the mica-schists, characterized by enrichment in biotite and andalusite, and by cordierite-sillimanite hornfels has been formed round the granodiorite intrusive mass.

The granodiorite and its aplitic, granitic and basic varieties has been the subject of an extensive chemical investigation by C. DE SITTER—KOOMANS.

The analysed rocks are described below:

Analysis no. 16. Aplite from Vle Rossiga. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 27135; slide no. 3027. Plate VIII, fig. 3.

A fine grained reddish rock forming dykes in the granite from Vle Rossiga.

Constituent minerals: a few phenocrysts of quartz and orthoclase in a fine grained matrix of quartz, orthoclase and microperthite. Orthoclase is slightly sericitisized. A little weathered biotite is the only dark mineral, limonite is a product of weathering, in the analysis indicated by the high Fe_2O_3 percentage.

Magma type: engadinic-granitic.

Analysis no. 17. Granite from Stalle di Mt. Spina, Val Troggia. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 27292; slide no. 2938. Plate VIII, fig. 1.

A light coloured coarse-grained granite dyke in mica-schists.

Constituent minerals: quartz, orthoclase, plagioclase and muscovite.

Accessories are titanomagnetite, haematite and tourmaline. The plagioclase is slightly sericitisized.

Magma type: engadinic-granitic.

Analysis no. 18. Granite from Vle Rossiga. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 27165; slide 3028.

A coarse-grained rose coloured rock with porphyric structure. The colour is due to the felspar of which the phenocrysts reach a length of 1 cm.

Constituent minerals: quartz, orthoclase, plagioclase, biotite. The plagioclase is strongly sericitisized, in contrast to the orthoclase which is very fresh. The biotite has been partly chloritisized. Limonite content rather high.

Magma type: engadinic-granitic.

Analysis no. 19. Granite from Vle Rossiga. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 41478; slide 3035. Plate VII, fig. 1 and 2.

A light-grey coloured rock with dark spots of biotite and slight porphyric structure.

Constituent minerals: phenocrysts of quartz, orthoclase, and plagioclase in a groundmass of the same composition with chloritisized biotite (limonite, calcite). The felspars are strongly sericitisized, the plagioclase has ± 40 % An.

The weathering of the rock is clearly indicated in the analysis by the low alkali content.

Magma type: engadinic-granitic to yosemic-granitic.

Analysis no. 20. Granite surrounding the hornblende-diorite of an. no. 29 from Cortabbio. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 41480; no slide available of this part of the specimen.

Plate VIII. Acid and basic differentiates of Granodiorite.

Fig. 1. slide no. 2938. Granite dyke in a mica schist from Stalle di Mt. Spina (Paradiso dei Cani). // nicols, enlargement 24 ×.
The granite dyke consists of quartz and felspar with tourmaline. Analysis no. 17.

Fig. 2. slide no. 3309. Injection gneiss from Val d'Olino (Vle Rossiga). + and // nicols, enlargement 24 ×.
A foliated gneiss, the foliation being due to injection of granitic material. The large white band to the right in the centre consists of quartz with some mica relicts. It is flanked towards the bottom by a dark band build up by biotite (largely weathered into chlorite with sagenite) and felspar. The darker band above the white band consists of sericite and biotite and is at its turn followed by a band of large quartz and felspar.

Fig. 3. slide no. 3027. Porphyric Aplite from Vle Rossiga. // nicols, enlargement 24 ×.
The rock consists of quartz, orthoclase and some plagioclase. A phenocryst of quartz at the top, phenocrysts of orthoclase occur also elsewhere in the slide. The black colour to the left of the large quartz is due to limonite. Analysis no. 16.

Fig. 4. Specimen no. 25694. „Pantherskin" from Cortabbio.
Xenoliths of biotite diorite in granite. The boundary lines between the two components are not sharply drawn and fragments of the diorite swim in the granite, the latter penetrating also into the dark diorite. Analysis granite no. 20. Analysis diorite no. 29. Compare fig. 5.

Fig. 5. slide no. 4921. Biotite diorite, zenolith in granite, from Cortabbio. // and + nicols, enlargement 38 ×.
In the centre a plagioclase phenocryst, of which the centre is rather fresh with some secondary hornblende and a broad margin totally sericitisized. The groundmass consists of fresh andesine, probably some orthoclase, numerous biotite flakes and a few hornblende crystals. Analysis no. 29.

PLATE VIII

ACID AND BASIC DIFFERENTIATES OF GRANODIORITE

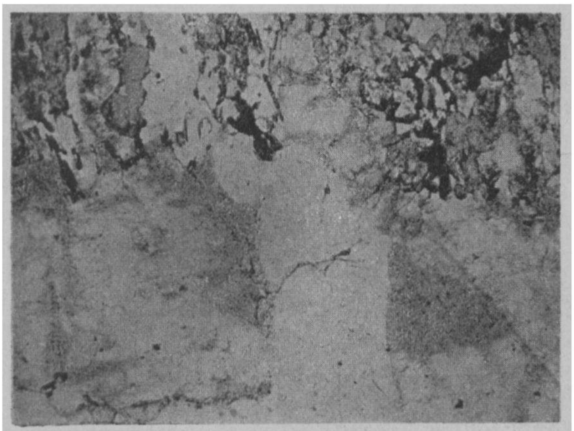


FIG. 1
Slide No. 2938

FIG. 2 Slide No. 3309

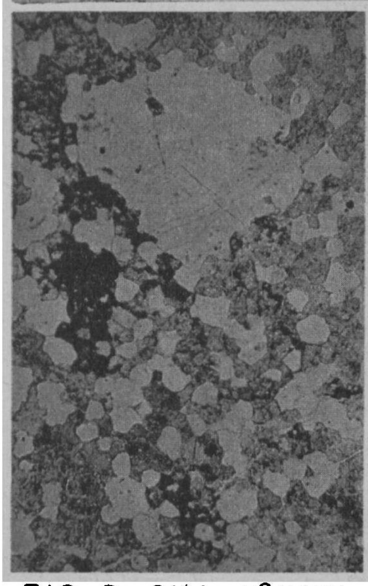


FIG. 3 Slide No. 3027

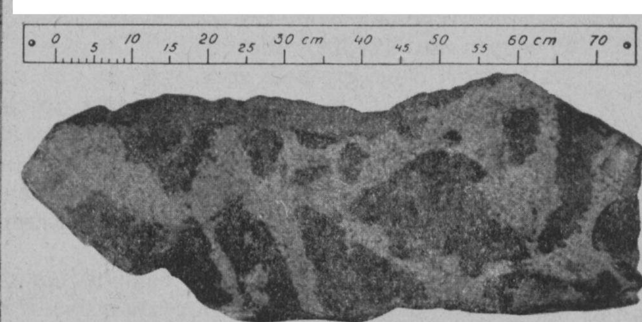


FIG. 4 Specimen No. 25694

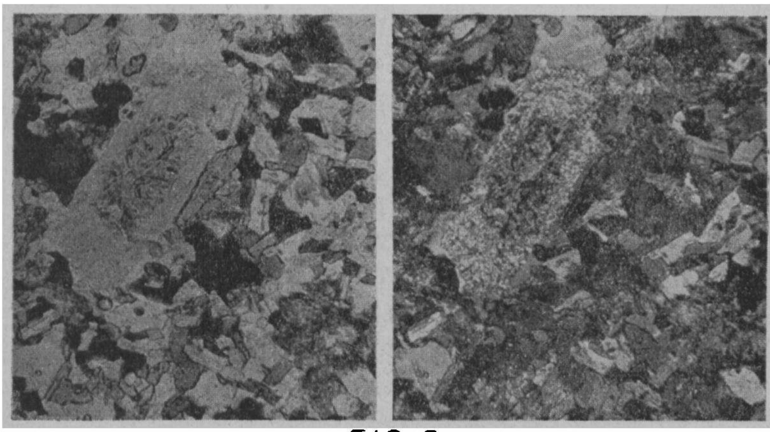


FIG. 5
Slide No. 4921

A light coloured coarse-grained, slightly porphyric rock. The boundaries of the granite and hornblende diorite are not sharp but the quartz and felspar of the granite have penetrated into the darker rock, while dark minerals lie isolated in the granite. Somewhat further from the boundaries both rocks are of normal composition.

Constituent minerals: quartz, orthoclase, some plagioclase, biotite and calcite. The plagioclase is full of sericite, the orthoclase is clear. The biotite is green but not yet altered into chlorite.

Magma type: yosemitic.

Analysis no. 21. Granite and biotite-diorite from Vle Rossiga. Surveyor: BUNING; anal.: KOOMANS.

Specimen no. 41481; slide 3273.

The hand specimen contains both granite and diorite, both rock types penetrating into one another. The analysis contains also both type of rocks and has therefore an intermediate place between granite and diorite.

The granite is light coloured and coarse grained.

The diorite is of a finer grain and has a dark grey colour.

Constituent minerals are plagioclase and biotite with a little quartz and orthoclase.

The whole rock is very fresh, the felspars are clear and the biotite is seldom weathered.

Magma type: adamellitic.

Analysis no. 22. Biotite granodiorite from Val Marcia. Surveyor: BUNING; anal.: KOOMANS.

Specimen no. 41482; slide 3253.

Dark grey, fine grained rock.

Constituent minerals: quartz, orthoclase, plagioclase, biotite, ores and calcite. The plagioclase has been strongly altered into sericite and the biotite in chlorite. In the slide appears an inclusion of sericite and biotite. The analysis indicates very strong weathering, much more than we expected from a study of the slide. This discrepancy may be due to such inclusions as noted above.

BUNING calculated the chemical composition from a quantitative mineralogical analysis; compared with our analysis:

	Calcul.	analysed
SiO_2	67.86	61.43
Al_2O_3	14.63	18.09
K_2O	4.96	2.09
Na_2O	1.94	2.97
CaO	2.20	4.23
(Mg, Fe)O	7.40	—

The lower SiO_2 content of the chemical analysis may be due solely to the fact that no inclusions were included in the calculated value. Al_2O_3 is higher and alkali content is lower in the chemical analysis, probably due to the presence of sericite and chlorite. The high CaO content is due to the presence of calcite, when we substract this mineral by combining it with the analysed CO_2 content some 2.80 % CaO remains.

A good example how a calculated and analysed chemical analysis can differ.

Magma type: opdalitic to normal quartz-dioritic.

Analysis no. 23. Biotite granodiorite from Val Marcia. Surveyor: BUNING; anal.: KOOMANS.

Specimen no. 27496; slide no. 3267.

Dark grey, fine grained rock.

Constituent minerals: plagioclase, biotite, some orthoclase and quartz, much ore with leucoxene rims, calcite.

Strong sericitization of plagioclase and total chloritization of biotite. The strong weathering is indicated in the analysis and the high fm content is due to ores. The c value is lower than in no. 22 as the rock contains less calcite.

Magma type: normal quartz dioritic to mela-quartz-dioritic.

Analysis no. 24. Hornblende granodiorite from south of Bta Pianca. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 41483; slide no. 2942. Plate VII, fig. 4.

Dark grey, fine-grained rock.

Constituent minerals: plagioclase, quartz, orthoclase, hornblende, biotite, calcite and haematite.

Strong sericitization of both plagioclase and orthoclase. The hornblende and biotite are both fresh, slight chloritization of biotite. The high content of calcite heightens the c value, lowering the alk value relatively.

Magma type: tonalitic.

The same chemical composition is shown by the analysis of GIAMMARINO of analysis no. 27, a granodiorite of Cortabbio (Val Sassina).

Analysis no. 25. Kersantite from Vle Rossiga. Surveyor: BUNING; anal.: KOOMANS.

Specimen no. 32442; slide 3299.

Dark grey, very fine-grained rock with large calcite crystals.

Constituent minerals: plagioclase, light green hornblende, biotite, orthoclase and quartz.

Sericitization of the core of plagioclase. The hornblende occurs in clusters and is fresh like the biotite. The freshness of the rock is also indicated by the analysis. The CO_2 content of the analysis shows that some calcite entered the analysis material, although the slide did not show any calcite. The calcite of the handspecimen certainly has a secondary origin.

Magma type: normal dioritic.

Analysis no. 26. Quartz diorite from Mt. Fioraro. Surveyor: KLOMPÉ; anal.: KOOMANS.

Specimen no. 41484; slide 4919. Plate IX, fig. 1 and 2.

Dark spotted, rather coarse-grained rock.

Constituent minerals: quartz, plagioclase, biotite, orthoclase and much titanomagnetite with thick leucoxene rims, some garnet.

Slight sericitization of plagioclase. Biotite occurs in two forms, the older being wholly replaced by chlorite, the new ones being fresh and very pleochroïtic.

The new biotite is probably due to contact-metamorphism caused by the Fioraro granite in which the diorite is enclosed. The garnet has probably the same origin. The analyses does not indicate any contact-metamorphism or alteration of the rock.

Magma type: normal dioritic.

Analysis no. 27. Quartz-diorite from Cortabbio. Anal.: GIAMMARINO [1]).

Analysis no. 28. Quartz-diorite from Scalluggio, Val Brembo. Surveyor: KLOMPÉ; anal.: KOOMANS.

Specimen no. 41485; slide 1679. Plate IX, fig. 3.

Dark grey rock of medium grain size.

Constituent minerals: quartz, orthoclase, plagioclase, biotite, ore with leucoxene rims, calcite and some limonite.

Sericitization of the core of plagioclase. The biotite has been replaced by chlorite and ore.

The analysis is very similar to no. 26, but the much stronger weathering is indicated by the high water content and low alk value.

Magma type: normal dioritic.

Analysis no. 29. Biotite diorite from Cortabbio. This is the analysis of the diorite inclosed in the granite of an. no. 20. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 41480; slide 4921. Plate VIII, fig. 5.

Constituent minerals: plagioclase, a little light green hornblende.

The plagioclase is an andesine and has suffered little sericitization.

The hornblende and the biotite are fresh.

Analysis no. 30. Hornblende granodiorite from N.E. of Alpe Piarola. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 41486; slide no. 2976.

[1]) NUCCORINI. Alcune note sui lavori eseguiti nell'anno 1933 nel Laboratorio chimico del Reale Ufficio Geologico. Boll. R. Uff. Geol. d'Italia, vol. LVIII, 1933.

Plate IX. Diorites and Kersantites.

Fig. 1. Spec. no. 41484 (slide no. 4919). Diorite from Mt. Fioraro.
The rock consists of large saussuritisized plagioclases, quartz, orthoclase, brown biotite and magnetite. Analysis no. 26.

Fig. 2. slide no. 4919. Diorite from Mt. Fioraro, par. nicols, enlargement 80 ×.
Reaction rims of sphene round magnetite. Analysis no. 26.

Fig. 3. Specimen no. 41485 (slide no. 1679). Diorite from Scaluggio, Upper Val Brembo.
The rock consists of plagioclase and biotite with orthoclase and quartz. Analysis no. 28.

Fig. 4. Specimen no. 35093. South of Mt. Fioraro. Xenoliths of Kersantite in Fioraro granite gneiss.

Fig. 5. Slide no. 1680, par. nicols, enlargement 36 ×. Hornblende Kersantite dyke from Pso di Pedena.
A large hornblende flake of blue-green to grass-green colour growing at the expense of biotite. At the bottom of the photograph two basal sections of hornblende together with magnetite crystals having a rim of sphene. White parts in the slide are quartz. Numerous small epidotes and some apatite appear. Analysis no. 31.

PLATE IX

DIORITES

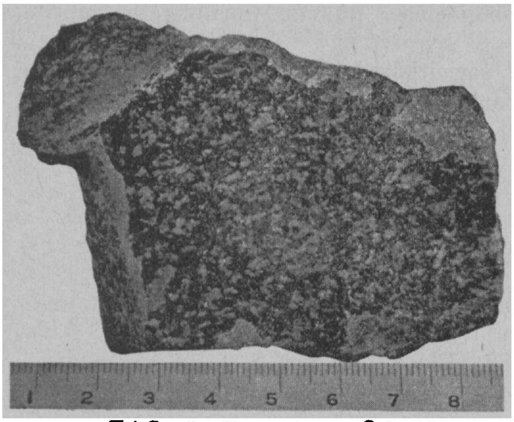


FIG. 1 Specim. N.º 41484
Slide N.º 4919

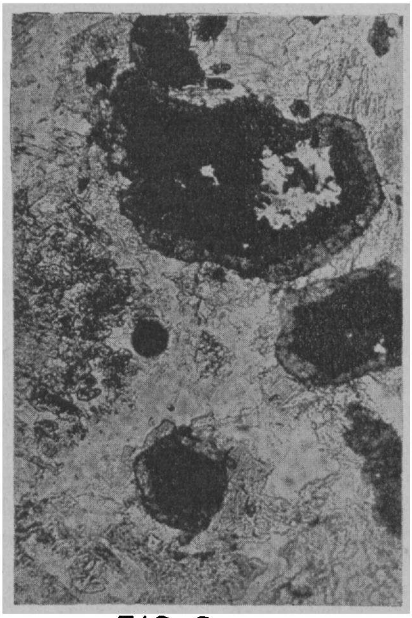


FIG. 2
Slide N.º 4919

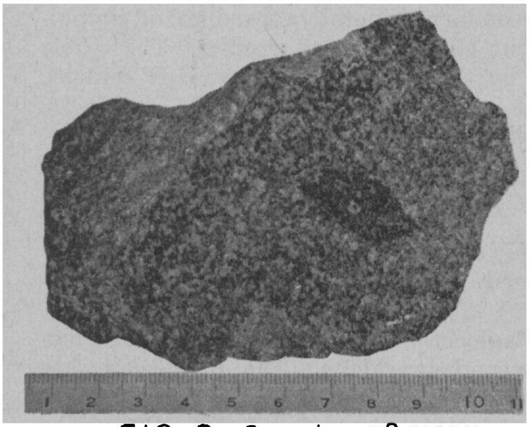


FIG. 3 Specim. N.º 41485

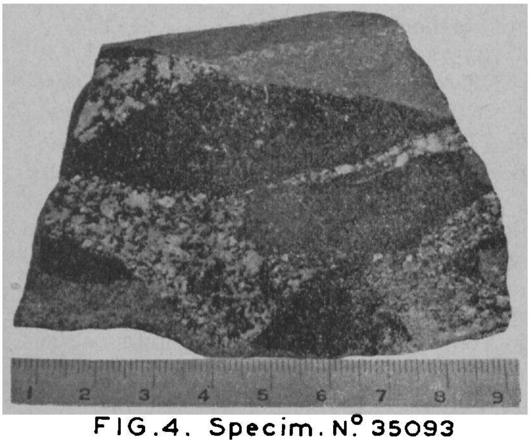


FIG. 4. Specim. N.º 35093

FIG. 5
Slide N.º 1680

A dark grey, fine-grained rock.

Constituent minerals: plagioclase, quartz, hornblende, biotite and magnetite.

The plagioclase has been strongly sericitisized with large sericite flakes and even epidote. The hornblende is a little altered, somewhat bleached, in contrast to the biotite which has been replaced largely by chlorite, epidote and ore.

Magma type: normal gabbroïd.

Analysis no. 31. Kersantite or Hornblende granodiorite from Pso di Pedena.

Klompé gave the name of Kersantite to this rock. Surveyor: Klompé; anal.: Koomans.

Specimen no. 32479; slide no. 1680. Plate IX, fig. 5.

Dark green, fine-grained rock.

Constituent minerals: quartz, orthoclase, plagioclase, hornblende, biotite, magnetite with leucoxene.

The plagioclase has suffered by sericitization. The hornblende is strongly pleochroïtic, yellow green-green-blue green, with an extinction angle of 15—18°. The hornblende is probably a secondary mineral, a product of amphibolization. The biotite is very fresh but shows sagenite needles. The whole rock is very fresh, which is confirmed by the analysis viz.: low H_2O content, high alk value.

Magma type: normal gabbrodioritic.

Analysis no. 32. Hornblende-diorite from Mt. Fioraro. Surveyor: Klompé; anal.: Koomans.

Specimen no. 41491; slide no. 1677.

A dark-grey rock of medium sized grain, with clearly visible hornblende prisms.

Constituent minerals: plagioclase, orthoclase, hornblende, biotite, magnetite, with leucoxene and secondary calcite. The plagioclase has been sericitisized, sometimes saussuritisized. The hornblende has been strongly bleached and shows little pleochroïsm, extinction angle of 16°—20°. The biotite has been replaced by chlorite with magnetite, the core is sometimes unaltered.

Magma type: c-gabbroïd. This rock and the analysis no. 30 have an exceptionally high k value, which usually is less than 0.30 with this kind of rock. It is due to the presence of orthoclase.

Analysis no. 33. Norite from NE of Casa Gorè. Surveyor: Crommelin; anal.: Koomans.

Specmen no. 41488; slide no. 2972. Plate VII, fig. 3.

A dark-grey rock of medium grain size, where the broncite is conspicuous by its metal lustre.

Constituent minerals: plagioclase, basaltic hornblende, bronzite, some biotite and magnetite together with spinell. The plagioclase is rather strongly sericitisized. The basaltic hornblende has been partly replaced by chlorite, talcum and actinolite. The bronzite has been replaced by bastite. The strong weathering can be discerned in the analysis by the high Al_2O_3 content and high water content.

Magma type: c-gabbroïd.

Granodiorite and associated rocks.

	16	17	18	19	20
SiO_2	76.05	74.00	71.66	72.28	69.83
TiO_2	—	0.10	0.10	0.07	0.17
P_2O_5	0.18	0.22	0.19	0.16	0.18
Al_2O_3	13.10	14.06	16.03	14.12	14.12
Fe_2O_3	1.43	0.62	1.26	1.31	0.55
FeO	0.25	0.63	0.59	1.51	1.12
MnO	0.02	0.04	0.03	0.08	0.09
MgO	0.29	0.62	0.49	0.97	0.92
CaO	0.43	1.01	0.63	1.78	2.31
Na_2O	3.11	2.72	1.44	2.75	2.68
K_2O	4.17	5.01	6.01	2.54	4.37
$+ H_2O$	1.09	0.98	1.38	1.34	1.60
$- H_2O$	0.07	0.05	0.17	0.11	0.26
CO_2	—	—	—	0.74	1.66
	100.19	100.06	99.98	99.76	99.86
si	489	432	410	396	369
al	49.5	48.5	54	45.5	44
fm	11	11	12	20.5	14.5
c	3	6.5	4	10.5	13
alk	36.5	34	30	23.5	28.5
k	0.47	0.55	0.74	0.38	0.52
mg	0.24	0.47	0.33	0.39	0.50
c/fm	0.28	0.56	0.33	0.52	0.89
ti	—	0.70	0.69	—	0.64
p	0.38	0.35	0.34	0.33	0.32
h	24.70	20.00	29.55	26.65	32.69
	aplite	granite	granite	granite	granite

	21	22	23	24	25	26	27
SiO_2	66.90	61.43	60.82	58.64	55.75	55.62	59.06
TiO_2	0.54	0.85	1.08	0.65	0.89	1.36	0.91
P_2O_5	0.13	0.15	0.32	0.21	0.36	0.19	—
Al_2O_3	15.67	18.09	15.62	16.64	17.25	18.18	16.71
Fe_2O_3	1.24	1.00	0.90	0.58	0.26	1.47	0.82
FeO	2.83	4.56	6.13	5.34	5.80	6.39	6.07
MnO	0.04	0.07	0.26	0.16	0.19	0.13	0.04
MgO	1.51	1.94	3.70	4.31	5.03	3.99	3.61
CaO	2.69	4.23	2.89	5.73	5.82	6.07	6.07
Na_2O	3.50	2.97	3.02	1.81	3.35	3.20	2.73
K_2O	3.04	2.09	1.94	1.62	1.89	2.42	1.37
$+H_2O$	1.23	1.35	2.94	2.36	1.42	0.95	1.69
$-H_2O$	0.20	0.19	0.05	0.15	0.14	0.07	0.09
CO_2	0.36	1.12	0.43	1.68	1.92	0.09	—
	99.88	100.04	100.10	99.88	100.07	100.13	99.17
si	292	228	216	204.5	166	161	192
al	40	39.5	33	34	30	31	32
fm	24.5	28	41	35	38	36.5	35.5
c	12.5	17	11	21	18.5	19	21
alk	23	15.5	15	10	13.5	13.5	11.5
k	0.37	0.31	0.30	0.37	0.27	0.33	0.25
mg	0.41	0.40	0.48	0.49	0.59	0.49	0.49
c/fm	0.52	0.59	0.27	0.61	0.49	0.51	0.60
ti	1.81	2.23	2.78	1.68	1.96	2.88	2.15
p	0.26	0.22	0.43	0.42	0.54	0.17	—
h	20.62	18.91	35.48	29.14	15.53	9.72	19.34
	Granite and biotite-diorite	Biotite-grano-diorite	Biotite-grano-diorite	Horn-blende-grano-diorite	Kersan-tite	Quartz-diorite	Quartz-diorite an. GIAMMARINO

	28	29	30	31	32	33
SiO_2	53.47	50.10	48.30	46.32	47.11	42.25
TiO_2	1.23	1.05	0.53	4.05	1.36	0.66
P_2O_5	0.16	0.29	0.26	0.36	0.18	0.31
Al_2O_3	19.67	18.71	18.51	17.67	15.10	20.93
Fe_2O_3	0.36	1.09	3.08	0.88	1.36	1.70
FeO	6.61	7.58	7.31	9.76	7.56	4.92
MnO	0.08	0.36	0.36	0.21	0.12	0.38
MgO	5.41	5.40	8.39	4.88	10.53	9.45
CaO	4.75	6.29	6.71	8.80	11.98	10.31
Na_2O	2.24	3.86	1.38	3.58	0.97	1.90
K_2O	1.41	2.69	1.81	1.45	1.48	1.68
$+H_2O$	4.06	1.72	3.03	1.65	1.57	4.61
$-H_2O$	0.09	0.10	0.08	0.15	0.14	0.12
CO_2	0.49	0.65	0.41	—	0.68	0.69
	100.03	99.89	100.16	99.76	100.14	99.91
si	159	129	115.5	114	106	92
al	34.5	28.5	26	25.5	20	26.5
fm	41.5	40	51	40.5	47	43
c	15	17.5	17	23	29	24
alk	9	14	6	11	4	6.5
k	0.29	0.32	0.46	0.21	0.51	0.37
mg	0.59	0.52	0.59	0.44	0.76	0.71
c/fm	0.37	0.43	0.34	0.58	0.61	0.56
ti	2.68	2.01	1.01	9.33	2.29	1.04
p	0.18	0.31	0.29	0.44	0.13	0.26
h	41.00	15.64	24.85	14.82	12.77	34.24
	Quartz-diorite	Biorite-diorite	Horn-blende-grano-diorite	Kersantite	Horn-blende-diorite	Norite

These 17 analyses allow us to represent the variation of the chemical composition of the rocks belonging to the granodiorite intrusion of Val Biandino in a Niggli differentiation diagram, fig. 5. Analysis no. 21 has been left out of the diagram because it does not represent a rock type but just a mixture of diorite and granite.

When we examine the diagram the hiatus between the si values 230 and 370 becomes striking. The normal granodioritic rocks lie between si = 158 and si = 230, the basic differentiates lie below si = 130, the acid differentiates above si = 368. The lapse of time between the intrusion of the diorite and its granitic differentiate, demonstrated by the geological fact that the diorites occur as xenoliths in the granite and never granite xenoliths in diorite, may account for the large hiatus noted above. In several analyses the points deviate from the lines. Most of these deviations must be ascribed to „weathering", because when we take into consideration the mineralogical composition, an agreement between weathered samples and deviating

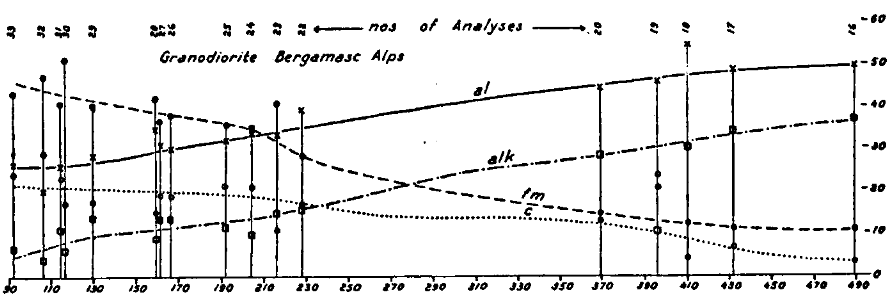


Fig. 5.

Differentiation diagram of the Granodiorite of Val Biandino and associated rocks.

points in the diagram is noticeable. In nos. 18, 19 the low alkali value, or the large difference between al and alk + c, is confirmed by a strong sericitization. In rocks with a lower si value the chloritization of the femic constituents has the same effect. A high c value is often due to calcite infiltration viz nos. 24 and 32.

The diagram agrees very well with the normal diagram of the kalk-alkali group of Niggli[1]) (fig. 6). This agreement has been noticed already by Koomans[2]) for the Lugano porphyries.

This comparison can be extended with the differentiation diagram of the Cocco diorite and Verzasca gneiss from the pennine thrust sheets described by Preiswerk[3]) (fig. 7). According to this author, who surveyed the whole region, the Cocco diorite and Verzasca gneiss, although belonging to two different tectonical units, are differentiates from the same original magma. They have both been folded entirely into the pennine thrust sheet system

[1]) P. Niggli. Gesteins- und Mineralprovinzen. Berlin 1923.
P. Niggli. Die Magmatypen. Schweiz. Min. Petr. Mitt. XVI, 1936

[2]) C. M. Koomans. Der Chemismus des Luganer Porphyrgebietes. L. G. M. IX, p. 19—77, 1937.

[3]) H. Preiswerk. Der Quartzdiorit des Cocco massives, zentralen Tessineralpen, und seine Beziehungen zum Verzasca gneiss. Schweiz. Min. Petr. Mitt. B. XI, 1931.

and therefore are anterior to this folding, probably of permo-carboniferous age, as their metamorphic state is comparable to the granites of the central masses. The Cocco diorite is surrounded by a zone of injection gneisses crossed by numerous aplite dykes. The rock consists of quartzdiorite with biotite or

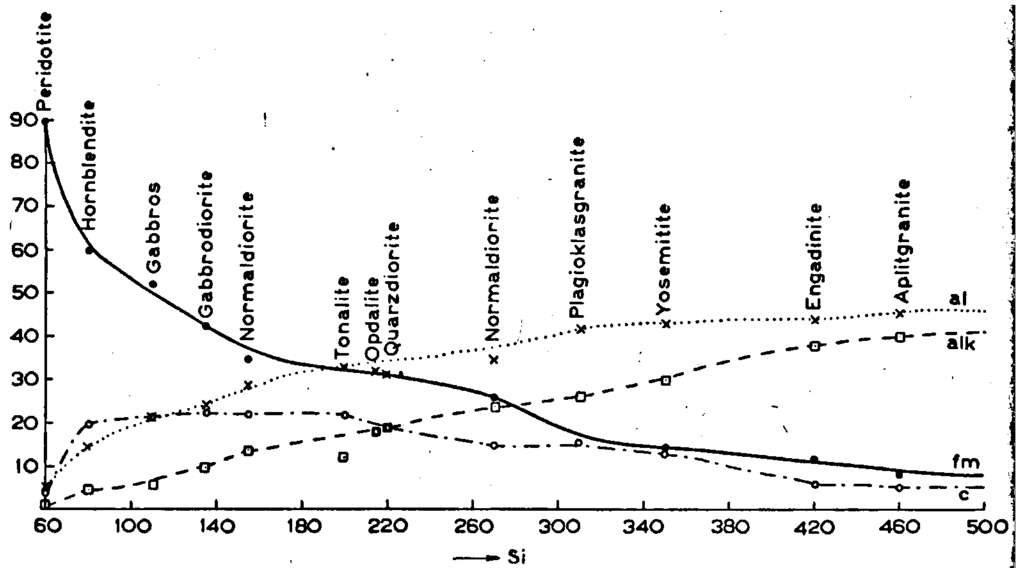


Fig. 6.

Normal diagram of kalk-alkali sequence after NIGGLI.

hornblende or both. The granitic, aplitic and pegmatitic differentiates are younger. From this cursory description the similarity of the geological features of the Cocco diorite and our granodiorite and Fioraro granite can be concluded.

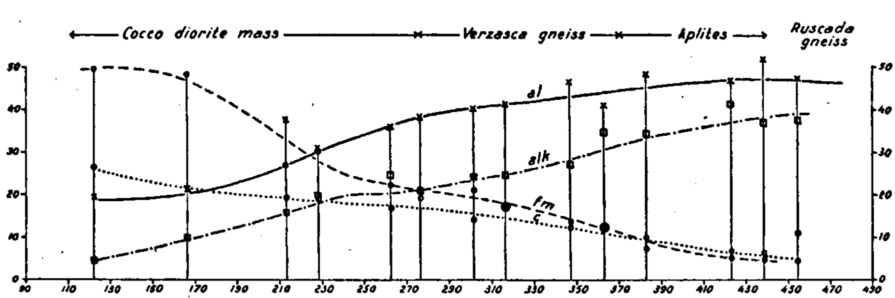


Fig. 7.

Differentiation diagram of Cocco mass and Verzasca gneiss, Ticino, after PREISWERK.

In fig. 15 p. 95 these diagrams can be compared, together with the diagram of the intrusive rocks of the Lower East Alpine thrust sheets. The agreement becomes still more apparent in comparing the points of intersection of the four lines, as has been done in the following table:

Intersection of lines	Normal kalk-alkali at si =	Bergamasc grano-diorite at si =	Lugano porphyries at si =	Lower east alpine sheets at si =	Cocco-diorite Verzasca gneiss
al/fm	200	210	210	200	220
c/alk	220	230	230	230	230
fm/alk	280	280	280	280	275

The intersection of the c and al lines is not very clear but in the lower regions of si values the lines run nearly parallel.

The chemical character of the granodiorite and the permian porphyries is therefore very similar. The Coccodiorite differentiation diagram is rather different. The fm line drops below the c line in the acid part of the diagram, the isofaly point lies at fm = 29 instead of at 31 and 34 in the other diagrams. In the last chapter we shall investigate this feature further. As we have seen before, the age of the granodiorites must be put somewhere between the time of metamorphism of the para-schists, as the latter occur frequently as inclusions in the granodiorite, and the deposition of first volcanic rocks. The granitic or porphyric dykes which cross the granodiorite in great numbers cut nowhere into the overlying permian rocks.

The fact that nobody yet succeeded in finding pebbles of granodiorite in the Verruccano conglomerates is rightly ascribed by PORRO[1]) to the fact that between the Verrucano of this district and the basement rock a considerable thickness of porphyric rocks intervenes. In such regions the Verrucano contains no other basement rock fragments either.

5. Amphibolites.

Throughout the entire series of crystalline basement rock amphibolites of different mineralogical composition occur. The most common type of amphibolite is a epidote-zoïsite-amphibolite, but zoïsite-albite-diopside- and biotite-amphibolites are common varieties. It is not always possible to distinguish clearly between para-mica-schists with hornblende and ortho-metamorphic amphibolites. Although the stratification of many amphibolites suggest a sedimentary origin, in other cases a volcanic origin is suggested.

The main constituents of the amphibolites are hornblende, quartz, plagioclase and epidote.

The hornblende is the common, strongly pleochroïtic, green hornblende though often with green-blue colours. The hornblende is always very much orientated in one direction and gives the rock a nematoblastic structure, quartz and felspar are present in varying quantities. Epidote is seldom absent, often present in large quantities. Small veins of epidote perpendicular to the schistosity can often be noticed. Zoïsite is less common and occurs together with epidote. Sphene is frequently observed, sometimes in large quantities and in well developed porphyroblastic crystals. Some amphibolites carry biotite, in others this mineral is totally absent. Pyroxenes are mostly absent but are sometimes abundant.

[1]) C. PORRO. Rocce granitiche della Valsassina, loc. cit.

BUNING (7) describes the rather long stretch of amphibolite on the eastern slope of the Mt. Muggio. The rock consists of: hornblende, orthoclase (some plagioclase) and epidote as main constituents. Sphene and apatite, zircon, rutile and ilmenite are accessories. Quartz is partly absent. In the southern part of this band of amphibolite, diopside in large crystals enters into the rock. The diopside, which carries inclusions of quartz and hornblende, is not a normal constituent of this rock but occurs in bands together with orthoclase, quartz and plagioclase, which are free from hornblende.

CROMMELIN (8) describes a well stratified amphibolite where the stratification (Plate X fig. 1) is due to alternating beds of hornblende and diopside both with a mostly completely sericitisized felspar. Some plagioclases are less weathered and have some 46 % An. The diopside layers are almost free from hornblende, but the hornblende layers always carry diopside; accessories are: sphene, quartz and apatite. This rock might be a stratified tuf or similar rock.

In the Val Troggia, east of the Ponte dei Ladri, xenoliths of amphibolites in granodiorite can be frequently observed. Magmatic corrosion is evident on the boundary lines of granodiorite and amphibolite. The amphibolite consists of hornblende and biotite with ores and a little felspar. Crystals of hornblende and of biotite have been isolated and are now enclosed in the granodiorite (Plate X, fig. 2).

Similar amphibolite inclusions in Fioraro gneiss are mentioned by KLOMPÉ (3) just south of the Mt. Fioraro. Sometimes the amphibole has been replaced locally by biotite. The same kind of magmatic corrosion and isolating of biotite crystals from the dark rock has taken place. The amphibolites are either epidote-amphibolites with epidote and zoïsite next to hornblende or zoïsite-albite-amphibolites.

The amphibolites have been described extensively by DOZY and TIMMERMANS (12). They found biotite-amphibolites, plagioclase-amphibolites and epidote-amphibolites. The biotite-amphibolite is build up by blue-green hornblende, quartz, biotite and epidote and well developed pyrite. Accessories are chlorite, zoïsite, apatite and garnet. A chemical analysis of this rock has been made by C. KOOMANS (published in 12).

Analysis no. 34.

SiO_2	= 54.26	si	= 159
TiO_2	= 1.90	al	= 27.5
P_2O_5	= 0.34	fm	= 42.5
Al_2O_3	= 15.87	c	= 15
Fe_2O_3	= 3.40	alk	= 15
FeO	= 7.83	ti	= 4.22
MnO	= 0.22	p	= 0.35
MgO	= 3.59	h	= 20.6
CaO	= 4.75	k	= 0.24
Na_2O	= 3.96	mg	= 0.37
K_2O	= 1.93	c/fm	= 0.35
$+ H_2O$	= 2.07		
$- H_2O$	= 0.04		
	100.16		
sp. grav.:	2.93		

The chemical analysis shows that the rock belongs to a normal dioritic magma.

Another biotite amphibolite, where the biotite has been altered altogether into chlorite, carried abundant sphene and magnetite porphyroblasts (Plate X, fig. 3).

Plagioclase amphibolite consisting of hornblende and plagioclase is mentioned from Foppa di Sopra. Large hornblende crystals have developed at the expense of plagioclase. This process has stopped and the hornblende does not show any crystallographic end-faces but fingers out in the plagioclase (Plate X fig. 4).

The groundmass consists of plagioclase, zoïsite, epidote, titanite, chlorite and some quartz.

Epidote amphibolites are normal amphibolites with abundant epidote. The epidote is partly the result of a later alteration of hornblende. The amphibolite north of Lago della Malgina is a coarse-grained rock with porphyroblastic hornblende of a light-green colour. The porphyroblasts are often broken and show strain shadows. The groundmass consists of a fine grained mixture of felspar, epidote-zoïsite, sphene, chlorite and muscovite (Plate X, fig. 6).

The amphibolite described by RAASVELDT (17) from the Valle del Goglio just above Gromo, Val Seriana, is probably of intrusive origin and is partly stratified by an alteration of light-green and dark-green bands (Plate X, fig. 5). Slight contactmetamorphism in the schists is assumed. The banding is folded in a way that proves the viscous nature of the rock during the cooling. Part of the rock is very dark coloured and consist wholly of hornblende. An analysis of this rock has been made by HEERTJES (17).

Plate X. Amphibolites.

Fig. 1. specimen no. 27250 (slide no. 3085/86). Diopside amphibolite from Val Sassina, between Pessina and Alpe di Cic. The rock-consists of green hornblende, diopside, plagioclase and epidote with apatite and sphene. The foliation of the rock is partly due to segregation, partly to original stratification. The darker colour goes with an increase of hornblende. The lightest bands are hornblende free and carry some garnet.

Fig. 2. slide no. 3218. Amphibolite xenolith in granodiorite from Cima d'Agrella, NW of Bta. Trincera. // nicols, enlargement 24 ×. The large hornblende crystals of the photograph belong to the amphibolite, one, in the centre, swimming in the granodiorite, which consists of plagioclase and quartz.

Fig. 3. slide no. 3704. Amphibole-chlorite schist from south of Pso di Caronella. // nicols, enlargement 24 ×. The rock consists of hornblende (grey on the photograph) chlorite and large porphyroblasts of sphene and magnetite. Strong chloritization of hornblende and perhaps of biotite.

Fig. 4. slide no. 3702. Plagioclase amphibolite from Foppa di Sopra. + nicols, enlargement 78 ×. A large hornblende crystal and some smaller ones have been arrested in their growth at the expense of plagioclase. The plagioclase in the centre has previously been broken and the parts have been shifted.

Fig. 5. Specimen no. 36051. Amphibolite from Mt. della Croce, Upper Valle del Goglio (Val Seriana). The rock consists of hornblende, albite, ilmenite, rutile and apatite (quartz?). The light bands are nearly hornblende free. The folded banding shows the viscous nature of rock during its cooling. Analysis no. 35.

Fig. 6. Specimen no. 35366 (slide no. 3705). Epidote amphibolite from North of Lago della Malgina. Large hornblende porphyroblasts in a groundmass of felspar, epidote, zoïsite, sphene, chlorite and muscovite.

PLATE X

AMPHIBOLITES

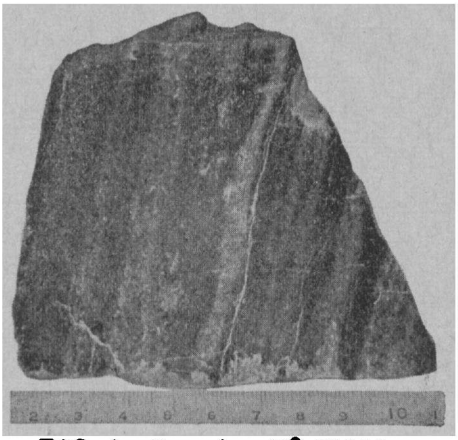


FIG. 1 Specim. N° 27250

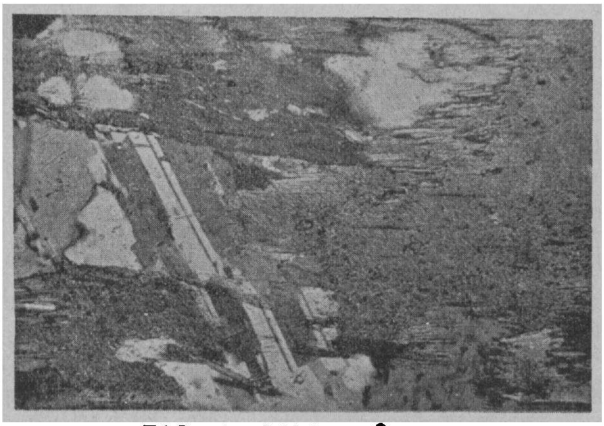


FIG 4 Slide N° 3702

FIG. 2 Slide N° 3218

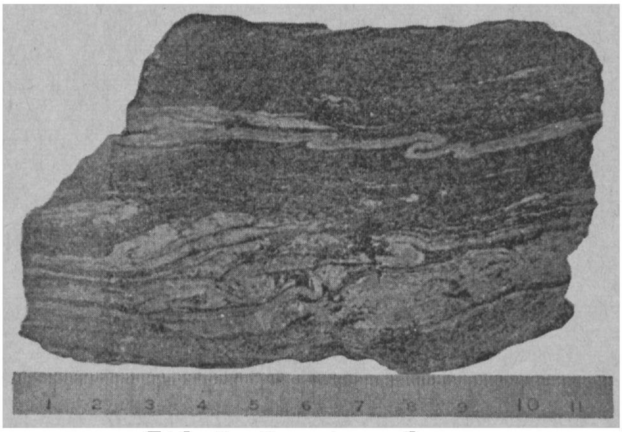


FIG. 5 Specim N° 36051

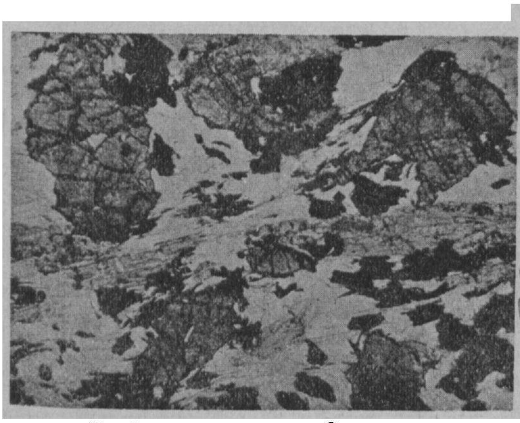


FIG. 3 Slide N° 3704

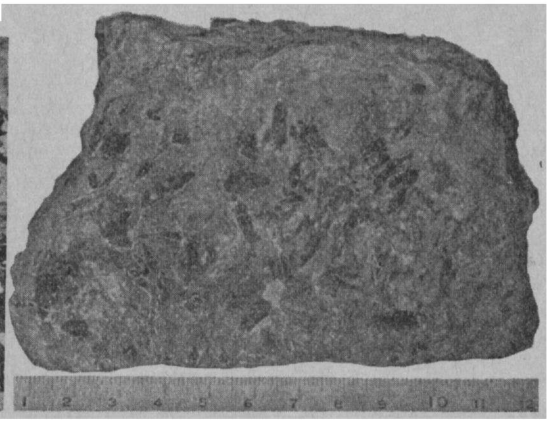


FIG. 6. Specim. N° 35366

Analysis no. 35.

SiO_2	= 48.36	si	= 108
TiO_2	= 2.22	al	= 22.5
Al_2O_3	= 16.90	fm	= 47
Fe_2O_3	= 1.14	c	= 18.5
FeO	= 6.77	alk	= 12
MgO	= 9.80	ti	= 3.7
CaO	= 7.75	h	= 10.9
K_2O	= 0.66	k	= 0.08
Na_2O	= 5.08	mg	= 0.69
$+H_2O$	= 1.40	c/fm	= 0.39
$-H_2O$	= 0.05		
	100.11		

The mineral content of this rock is: hornblende, albite, some quartz?, ilmenite, rutile and apatite. The high Na_2O content is due to albite.

6. Small ortho-gneiss occurrences.

1. Orthogneiss of Pzo Meriggio.

Dozy (10) describes a dark-coloured Ortho-alkali-felspar gneiss from the Pzo Meriggio. The rock carries 1 to 1.5 cm felspar phenocryst relicts. The main constituent minerals are: quartz, orthoclase, albite, microperthite, muscovite, chlorite and bleached biotite; accessories are zoïsite, zircon, sagenite, leucoxene, pyrite, ilmenite and the secondary minerals: siderite, limonite, calcite, chlorite and sericite.

Plate XI. Orthogneiss and prae-tertiary intrusive and volcanic rocks.

Fig. 1. slide no. 3711. Injection in orthogneiss of basic magma near Lago della Malgina. + and // nicols, enlargement 24 ×. The orthogneiss consisting of large plagioclases and quartz mostly, has been crossed or injected by some basic magma, which has isolated fragments and crystals. The photograph shows two narrow dark injection zones consisting of chlorite, quartz and epidote. The chlorite shows peculiar purple anormal extinction colour.

Fig. 2. slide no. 3656. Prae-tertiary quartz-porphyry dyke from Pso di Portula. + and // nicols, enlargement 24 ×. In a mostly sericitic groundmass phenocrysts of felspar and biotite (?) both totally replaced by quartz, appear. The fluidal structure of the rock is clearly discernable in the slide, although not visible on the photograph.

Fig. 3. slide no. 4372. Sphaerulitic quartz porphyry from Cagnoli, Val Brembo. // nicols, enlargement 4 ×. Quartz phenocrysts in a devitrified hyalitic groundmass. The perfectly round white globules are formed by chalcedony, the larger darker coloured, round patches by sphaerulites due to devitrification.

Fig. 4. slide no. 3940. Fluidal quartz porphyry from Valle Coca, 1660 m alt. + nicols, enlargement 4 ×. In a partly devitrified hyalitic groundmass appear phenocrysts of quartz (white), plagioclase, orthoclase (gray) and a few biotites. Fluidal structure of the groundmass is very pronounced.

Fig. 5. slide no. 1350. Hornblende? porphyrite from Alpe Stavello, Valtorta. // nicols, enlargement 4 ×. The rock consists of phenocrysts of plagioclase and a dark element now totally replaced by quartz and sericite and always surrounded by a narrow zone of limonite, some biotite has probably been present also.

PLATE XI

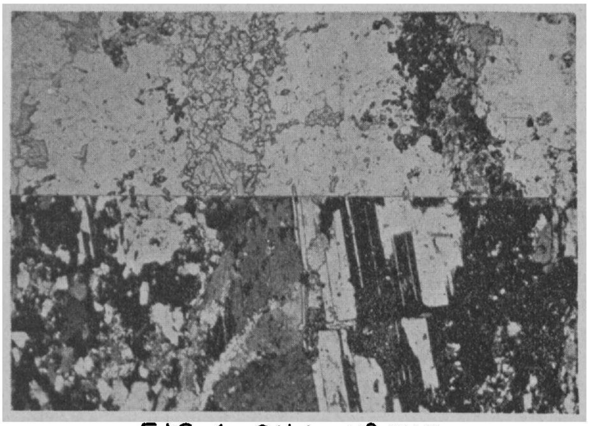


FIG. 1 Slide No. 3711

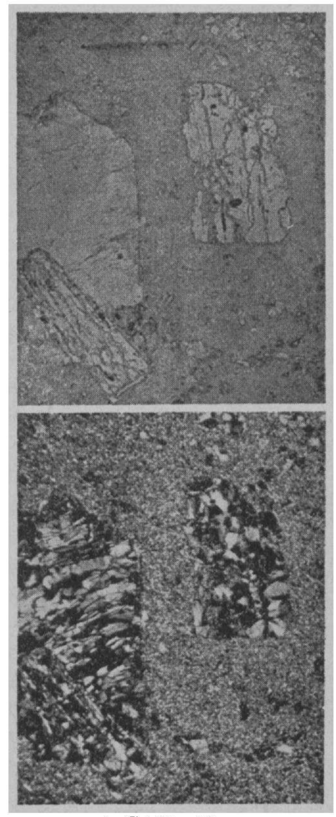


FIG. 2
Slide No. 3656

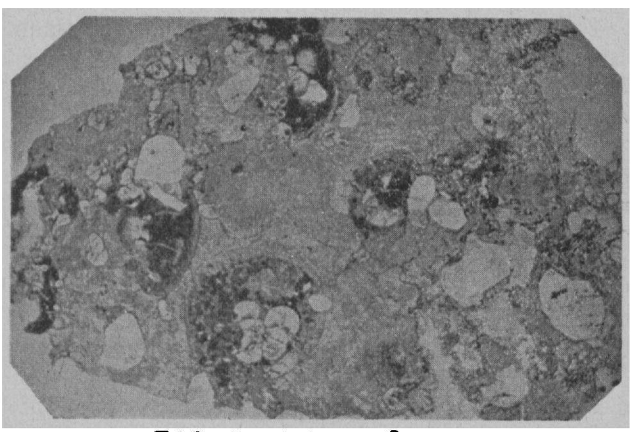


FIG. 3 Slide No. 4372

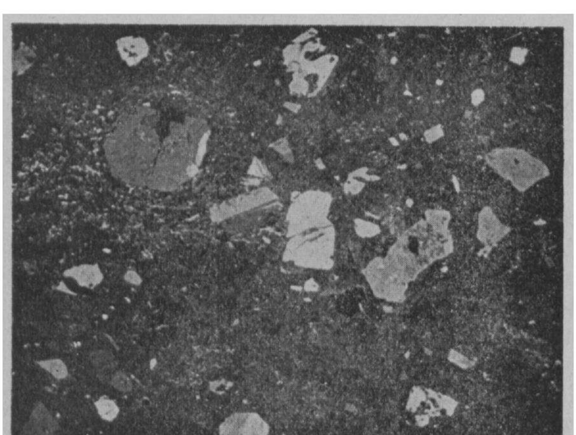


FIG. 4
Slide No. 3940

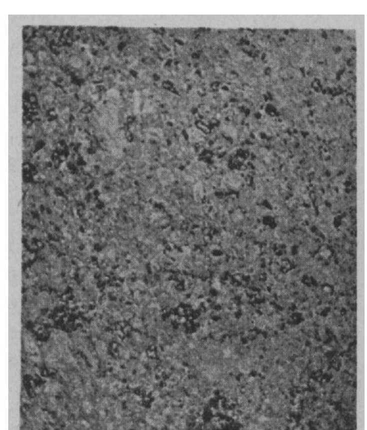


FIG. 5
Slide No. 1350

The felspar relicts are microperthite and albite, free from inclusions; the groundmass: quartz, orthoclase, albite, muscovite and biotite.

The rock grades towards the west into the normal para-alkali-felspar gneisses and to the east into the phyllites. The transition from phyllites to the ortho-rock is effected by a coarsening of the grain of the phyllites, the felspars appear as small eyes, and the phyllitic habitus disappears. The transition between the intrusive rock and the felspar gneiss and mica schists to the west is less distinct as the two rocks are very similar. DOZY presumes that the original sediments of the phyllite group and of the felspar-gneiss mica-schist group are separated here by an effusive rock of porphyric habitus. Since then the phyllites have been submitted to a less severe metamorphism, of a slightly higher zone than the mica schists.

2. Orthogneiss has been also reported by DOZY and TIMMERMANS (12) from the Lago Barbellino, from the kar above Foppa di sopra and from the amphibolites of Lago della Malgina. The last mentioned rock from L. d. Malgina is interesting as apparently a basic magma not belonging to the amphibolites has been injected into the orthogneiss (Plate XI, fig. 1). The latter rock consists of idiomorphic albite (5—10 % An), quartz and chlorite. This rock has been invaded by a basic magma, parts of it, specially albite phenocrysts, have been isolated and a peculiar injection gneiss is the final result. The basic intrusive rock consists of chlorite, in large flakes with a peculiar violet-red abnormal extinction colouring, epidote, zoïsite, ilmenite and quartz. It is much finer-grained than the acid rock. The acid rock has a cataclastic structure, due to alpine folding, but in the apparently more fine grained basic rock this structural feature is absent. This mixed gneiss occurs together with epidote-amphibolite with large hornblende porphyroblasts.

The rock of Foppa di Sopra has a blastogranitic structure and consists of albite and chlorite, with muscovite and chloritified garnet. The albite shows no, or little twinning and carries many quartz inclusions.

The ortho-gneiss from L. Barbellino has a much finer grain, a granoblastic structure and some schistosity. The main constituents are albite, quartz and chlorite and muscovite.

The ortho-gneiss of Lago Barbellino is a fine-grained rock consisting of alkali-felspar, chlorite, muscovite and quartz, with zoïsite, epidote, garnet, apatite, zircon and ilmenite. The plagioclase is an albite with 0—5 % An. and is porphyroblastic. Micro-perthite is abundant, garnet is only recognisable by its shape as it is totally altered in sericite and chlorite.

All these ortho-rocks apparently belong to a much older phase of intrusion than the gneiss chiaro or granodiorites, as they have been submitted to the same regional metamorphism as the para-gneisses.

7. Prae-Alpine dykes and pegmatites.

Several authors describe dykes of porphyritic or aplitic habitus of undefined age except that they probably are older than the group of Tertiary dykes. Some are at least of Permian age as they penetrate into Permian rocks. Still, ZIJLSTRA (25) pointed out that even the alpine dykes take a schistose habit when the surrounding Permian rock is schistose. Therefore the age of dykes on crossing the basement rock remains totally undefined.

A peculiar rock has been described by DOZY (10) from the Passo di Portula. It is a porphyric rock with large phenocrysts in a very fine grained groundmass. The phenocrysts show the shape of idiomorphic felspars, others suggest a mica phenocryst, but all of them are now filled up by quartz grains. The rock still shows a fuidal structure, but is otherwise totally recrystallized (Plate XI, fig. 2).

WEEDA (13) mentions an aplitic dyke in the basement rock from the Val Bondione reaching from Maslana in the north to south of Bondione. The rock has preserved its plagioclase phenocrysts unaltered and some quartz phenocrysts which have been flattened out.

Other porphyritic dykes described by DOZY (10) may be of prae-permian age as they occur in the basement rock, some of these rocks, however, penetrate the Permian rocks and are probably of Permian age. The porphyrites are highly weathered and carry much calcite.

The 20 m broad dyke described by TROMP (6) from Dosso Cavallo in the Vle di Bomino is a biotite-diorite porphyrite. A rather fresh rock composed of zonal plagioclase and biotite. Sphene, ilmenite and epidote are common, quartz only in the matrix. This rock may belong to the grano-dioritic intrusives but no definite opinion can be formed on the available data. Other dioritic dykes described by TROMP fall outside our map.

KLOMPé (3) mentions a hornblende porphyrite from the basement rock window of Caprile, with plagioclase phenocrysts and hornblende in the groundmass. Another dyke in the basement rock near Caprile described by the same author has dark brown hornblende phenocrysts. Both rocks are much weathered and do not offer any special features. Their age remains uncertain, but they probably belong to the group of Tertiary dykes.

Pegmatites are mentioned only from one locality, which falls just outside our map. In the north west, on the southern slope of the Vle Varrone, opposite Tremenico, BUNING (7, 1932) reports a „cava di Feldspato". The rock, which is exploited, consists of felspar and quartz. The surrounding rock is contact metamorphic and injected by pegmatitic material, and has become highly silicified. The original biotite schist has been altered in a fibrous aggregate of quartz, felspar, sericite, chlorite and some ore, with tourmaline and rutile in ½ mm long needles. The pegmatite dyke itself is some 20 m broad, very light coloured and is build up of large felspars and cataclastic quartz. These pegmatites must be closely connected with the well known pegmatites of Ogliasca and of the Mt. Legnone in the near vicinity.

CHAPTER II.

PRAE-TRIASSIC VOLCANIC ROCKS NOT BELONGING TO THE BASEMENT SERIES.

In the chapter on the stratigraphy of the Permian the occurrence of these rocks and their age will be more fully discussed. Here we will describe only the petrography.

To this group of rocks we reckon a serie of volcanic rocks, usually ascribed to the Permian, consisting of lavas and their tufs.

In general all the volcanic rocks have been very much attacked by weathering, and often little of their original structure or mineralogical composition can be reconstructed. Therefore the mapping of such rocks is often a thankless task and each surveyor has followed his own lines. The „weathering" of the rocks is not only, and probably not even principally, an atmospheric action, but ought to be ascribed to regional- and dynamometamorphism of the upper (epi-) zone. Sericitization, and to a less degree chloritization are never absent, besides internal shearing and stretching have altered the original lavas and tuffs to undefinable very fine-grained mineral associations. The original nature of the rocks, where tuffogenous material is preponderant, certainly predisposed these rocks for their metamorphism. Even in the slides it is often hardly possible to distinguish a tuff from a lava. It is even possible that volcanic action, gases and hydrothermal solutions started the metamorphic process, combined by the epi-metamorphose of the alpine orogenesis and finished off by atmospheric weathering.

Best preserved are the quartz porphyries. They are characterized by phenocrysts of bipyramidal quartz and albite (0—15 % An) and orthoclase (BUNING (7), JONG (2), DOZY (10), ZIJLSTRA (23)).

In the groundmass fluidal structures have often been observed (Plate XI, fig. 4). The quartz is strongly corroded, often broken either by the flowing of the lava or by later tectonical stress. When the quartz phenocrysts are numerous and much broken, the rock has acquired a tuffogenous character, which cannot be distinguished from a real crystal tuff.

All the felspar phenocrysts have suffered much sericitization, like the groundmass.

Several authors described sphaerulitic structures in the groundmass or round phenocrysts. The sphaerulites are supposed to be partly due to sphaerulitic devitrification of the groundmass, partly to calcedonic filling up of globular cavities. Both types can be seen on Plate XI, fig. 3. The groundmass sometimes shows granophyric intergrowth of quartz and felspar.

One quartzporphyry from the Lago di Val dei Frati has been analysed by KOOMANS (published in 10).

Analysis no. 36.

SiO_2	= 77.70	si	= 520
TiO_2	= —	al	= 40
P_2O_5	= 0.10	fm	= 18
Al_2O_3	= 10.09	c	= 6
Fe_2O_3	= 1.00	alk	= 36
FeO	= 0.59		
MnO	= 0.05	p	= 0.40
MgO	= 0.96	h	= 35.5
CaO	= 0.86	CO_2	= 5.2
Na_2O	= 3.20	k	= 0.42
K_2O	= 3.45	mg	= 0.53
$+H_2O$	= 1.40	c/fm	= 0.33
$-H_2O$	= 0.18		
CO_2	= 0.57		
	100.15		

Magma type: engadinic or engadinic-granitic.

If the rock had been fresher a continuous row of increasingly basic rocks could have been set up, as has been possible in the Lugano district. But with the material available from the Bergamasc Alps no such procedure is possible. Not a single slide with preserved phenocrysts of dark elements has been found. We have to assemble all these rocks of a more basic type than the pure quartz porphyries in the group of quartz porphyrites and porphyrites.

In some instances the plagioclases could be measured. Dozy (10) mentions ± 30—50 % An in plagioclases of the groundmass with trachytic structure. Jong (2) measured 30—40 % An, Crommelin (8) 32—42 % An and Buning (7) 30—35 % An. Phenocrysts of quartz occur in the quartz porphyrites, they are absent in the porphyrites. As mentioned above not a single unaltered phenocryst of a dark element has been preserved. The shape of the original crystals often accentuated by a dark limonitic border allows us to guess at hornblende, augite and biotite, replaced by quartz, chlorite, ore, epidote, calcite etc. (Plate XI, fig. 5).

The groundmass is either a devitrified glass, or an ordinary groundmass of felspar with some dark elements and quartz. It is always very strongly devitrified and sometimes shows a fluidal structure.

The greatest part of the volcanic rocks of the lower Permian Collio schists, however, are tuffs. They are closely associated with the porphyries and porphyrites, but are still more „weathered" than the lavas.

Agglomeratic tufs, tuf conglomerates, lithic tufs, crystal tufs and vitric tufs, transported and untransported alternate and build up large masses.

The tuffaceous character is either recognisable by the mixture of components, broken quartzes and felspars together with fragments of crystalline schists of the basement rock, or by the vitroclastic structure, glass fragments with concave shapes, of the groundmass. The amount of transportation can be judged by the degree of assortment. Often there is no assortment at all and the general conclusion is that transportation has not been over long distances.

Sericitization and chloritization, specially on cataclastic zones, has often obscured the original structure and composition of the rock. It would be vain to follow the authors in their attempts at classification and in their detailed description of these rocks, as very little is known of their relative position. Nowhere a coherent series of lavas and tufs could be set up, as for instance the Mt. Piambello in the Lugano district [1]) offered, where the sequence of eruptions could be reconstructed in great detail.

The conglomerates of mostly porphyric rocks overlying the Collio series, older than the Lower-Triassic Werfenian are called V e r r u c a n o. The pebbles and boulders of porphyric habitus have been studied to some extent. Again the same assemblage of effusive rocks has been observed, quartz porphyries, quartz porphyrites, porphyrites and tufs of various character could be distinguished. They ressemble in every respect the rocks of the Lower-Permian series, and differ from these only in their often intense dark red colouring caused by limonite. There can be no doubt that they are actually derived from the volcanoes existing in the neighbourhood.

As no typical rocks, recognisable by some very special feature are known from the Lower-Permian volcanoes, a direct and positive origin of the Verrucano boulders can not be given [2]). COSIJN (1) noticed a quartz porphyry with graphic intergrowth round the phenocrysts, which could be compared to the same phenomenon observed in some quartz-porphyry dykes of the Lugano district [1]) [3]), although the graphic structure of COSIJN is much finer and more like myrmekite.

More interesting are three occurrences of massive quartz-porphyry in the Val Camonica in the Verrucano conglomerate. One is situated on the right bank at the mouth of the river Dezzo near Gorzone and on the shores of the Lago Moro described by DORSMAN (19), the second a little higher up near Sacca on the left bank of the Oglio and the third near Fraine described by MAASKANT (22). They represent rather large homogenous bodies of an effusive rock inbetween the Verrucano clastic sediments. The rock has phenocrysts of quartz and andesine (± 30 % An), some biotite and apatite in a glass groundmass, which has a fluidal texture. A chemical analysis of this rock has been made by C. DE SITTER—KOOMANS (publ. in 22, here analysis no. 37).

[1]) L. U. DE SITTER. Les porphyres luganais entre le lac de Lugano et le Valganna. L. G. M. I, 1925.

[2]) In Part II, Stratigraphy, the occurrences of fragments of crystalline schists notably of orthogneiss (perhaps Gneiss chiaro) will be discussed.

[3]) PH. H. KUENEN. The porphyry district of Lugano west of the Valganna. L. G. M. I, 1925.

Analysis no. 37.

SiO_2	= 73.71	si	= 433.0
P_2O_5	= 0.18	al	= 47.7
Al_2O_3	= 13.77	fm	= 16.1
Fe_2O_3	= 2.02	c	= 6.8
FeO	= 0.50	alk	= 29.4
MnO	= 0.04		
MgO	= 0.49	k	= 0.27
CaO	= 1.07	mg	= 0.67
Na_2O	= 1.72	c/fm	= 0.42
K_2O	= 5.22		
+ H_2O	= 0.88		
— H_2O	= 0.22		
	99.82		

M a g m a t y p e: engadinic.

CHAPTER III.

TRIASSIC IGNEOUS ROCKS.

Only a few occurrences of igneous rocks of probably Triassic age are known in the Bergamasc Alps and all of them in the most western part near the Val Camonica. Their age determination is not absolutely safe but only very probable.

The most important one is the porphyrite intrusion of Val Dezzo. In the deep canyon of the Dezzo a max. 100 m thick lens of quartz porphyrite lies below the light coloured Esino limestone in the Buchensteiner horizon. The porphyrite has phenocrysts of quartz, plagioclase and biotite and a groundmass of plagioclase laths showing fluidal structure by their roughly parallel arrangement (fig. 1, Plate XII).

Most of the rock however is brecciated, being a mixture of porphyrite, porphyrite tufs and limestone (fig. 2, Plate XII). The porphyrite itself

Plate XII. Triassic and Tertiary dykes.

Fig. 1. slide no. 4487. Quartz-porphyrite from Via Mala, Val Dezzo. // nicols, enlargement 24 ×. The rock consists of phenocrysts of plagioclases of which a large one appears at the bottom of the photograph, quartz represented by a small triangular fragment at the top, and biotite. In some plagioclases a border zone is sericitisized, as on the photograph, others have a large black centre and a white rim, often large patches of the plagioclases have been replaced by calcite. The devitrified groundmass carries a second generation of plagioclase.

Fig. 2. Porphyrite breccie from Via Mala, Val Dezzo. The polished slab contains several limestone fragments, the largest, a black one, left bottom. Netx to it to the right a fragment of porphyrite. The matrix is a tuffaceous mixure with many limestone fragments.

Fig. 3. slide no. 4503. Porphyrite breccia from Via Mala, Val Dezzo. // nicols, enlargement 2½ ×. The slide contains two porphyrite fragments, top and bottom, and a limestone fragment wedged between them to the right. The porphyrites show a fluidal structure, quartz and felspar phenocrysts. The limestone wedge has a contact metamorphic border at its top, consisting of calcite crystals grown perpendicular to the boundary line (white in the photograph) followed by chlorite crystals against the porphyrite.

Fig. 4. Specimen no. 35519 (slide no. 3659). Diorite porphyrite dyke from Ambria. The white felspar phenocrysts and the dark hornblende phenocrysts lie in a plagioclase hornblende groundmass.

Fig. 5. Specimen no. 26846 (slide no. 4060). Hornblende diorite porphyrite dyke from Val Morta, Upper Val Seriana. White felspar and black hornblende phenocrysts can clearly be seen against the dark green groundmass.

Fig. 6. slide no. 4060. Hornblende diorite porphyrite from Val Morta. // nicols, enlargement 4 ×. Large plagioclase phenocrysts having a fresh centre, a totally sericitisized zone and a boundary zone of saussurite, the latter showing as a white border macroscopically (see fig. 5). The rock consists further of hornblende phenocrysts, sometimes replaced by epidote in a groundmass of felspar, quartz and hornblende.

PLATE XII

TRIASSIC AND TERTIARY DYKES

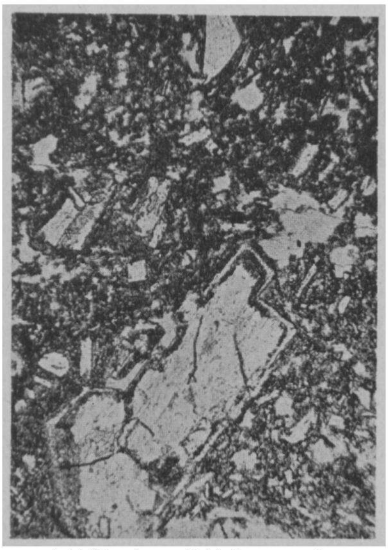


FIG. 1. Slide 4487

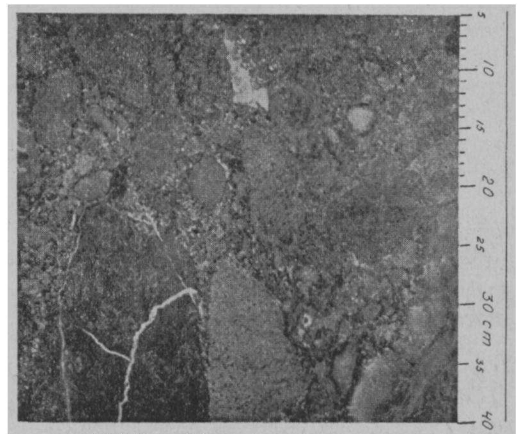


FIG. 2

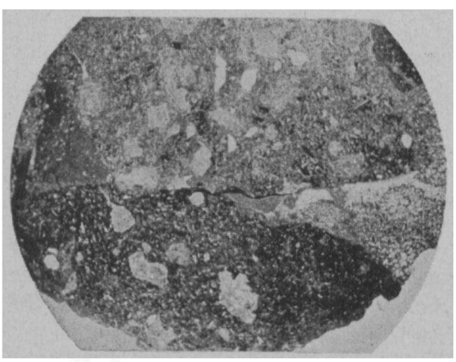


FIG. 3 Slide 4503

FIG. 4 Specim. N° 35519

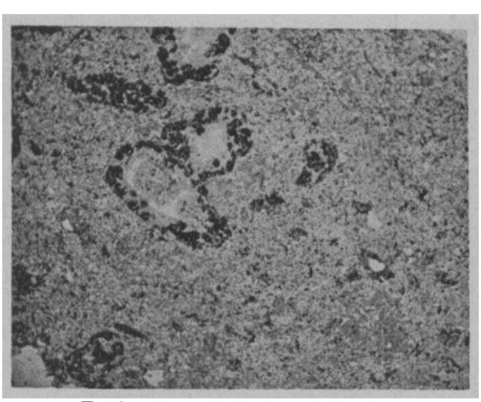


FIG. 6 Slide 4060

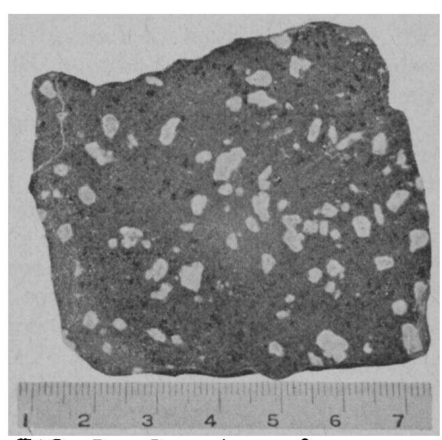


FIG. 5 Specim. N° 26846
(Slide 4060)

shows a strong assimilation of calcite, the plagioclases are mostly partially replaced by this mineral, although the fresh parts are quite clear and hardly any sericitization can be observed. The groundmass is mostly very strongly calcificated. The limestone inclusions are often marmorisized, or show a thin contact zone of recrystallized calcite and chlorite crystals, grown perpendicular to the contact boundary (fig. 3, Plate XII). Quartz phenocrysts have been broken and the cracks filled up and widened by calcite crystals. Chloritization is also present in the porphyrite and the biotite has been largely replaced by chlorite and ores, although its original shape and cleavage has been admirably preserved.

The geological occurrence of the porphyrite-tuf-limestone breccia is very similar to those of the Schwäbian Alp [1]) and an analogous genesis is very probable. An old analysis of GÜMBEL [2]) may be quoted here, although the method of analysing at that time did not reach the same exact results as more modern methods.

Analysis no. 38.

SiO_2	= 55.60	si	= 202
Al_2O_3	= 22.30	al	= 48
Fe_2O_3	= 3.50	fm	= 32
FeO	= 4.50	c	= 7
CaO	= 1.75	alk	= 13
MgO	= 1.65		
K_2O	= 3.42	k	= 0.59
Na_2O	= 1.56	mg	= 0.28
CO_2	= 2.52	c/fm	= 0.21
H_2O	= 2.42	qz	= + 50
	99.22		

Probably the CaO percentage is too low as often happened in older analyses (compare high CO_2 perc.) GÜMBEL himself pointed out that free quartz could hardly be expected in such a basic rock, but, as follows from the analysis, qz is + 50, the occurrence of free quartz is to be expected.

The pyroxene porphyrite and the associated tuf „pietra verde" of the Mt. Guglielmo, East of Lago d'Iseo are doubtless also of Triassic age, and belong to the Lower-Ladinian Buchensteiner horizon, just below the Esino limestone.

The porphyrites of Mt. Guglielmo are very much weathered. Phenocrysts are plagioclase, sericitisized or replaced by calcite, their zonal structure is always accentuated by the weathering. The anorthite percentage varies between 38—54 %. Biotite and a femic constituent, according to the shape a pyroxene, occur also as phenocrysts. In the groundmass only quartz and plagioclase laths are still recognisable.

An analysis by C. DE SITTER—KOOMANS (publ. in 22) gives the chemical composition of the Guglielmo porphyrite.

[1]) H. CLOOS. Bau und Tätigkeit von Tuffschloten. Geol. Rundschau, B. 32, 1942.

[2]) C. W. VON GÜMBEL. Ein geognostischer Streifzug durch die bergamasker Alpen. Sitz. Ber. Bayr. Ak. Wiss. 2, 1880.

Analysis no. 39.

SiO_2	= 65.70	si	= 289.1
TiO_2	= 0.73	al	= 41.6
P_2O_5	= 0.19	fm	= 27.9
Al_2O_3	= 16.07	c	= 9.1
Fe_2O_3	= 2.23	alk	= 21.4
FeO	= 1.81	k	= 0.43
MnO	= 0.10	mg	= 0.49
MgO	= 2.06	c/fm	= 0.33
CaO	= 1.92	qz	= 103.5
Na_2O	= 2.89		
K_2O	= 3.25		
$+H_2O$	= 2.37		
$-H_2O$	= 0.44		
Total	99.76		

The „pietra verde" is a tuf of the same porphyrite, occurring also on the Mt. Guglielmo but very much weathered.

CHAPTER IV.

THE TERTIARY DYKES.

Numerous dykes cross the basement rocks and the Triassic sediments. They form a distinct petrological group of igneous rocks of Tertiary age. The age can be ascertained by the fact that they are found in the youngest Triassic rocks and that they often cut through faults and other tectonical lines without interruption. Sometimes, however, they are cut off by faults, therefore their intrusion has probably been more or less simultaneous with the Tertiary tectonic deformation.

The most common type is an undifferentiated hornblende-diorite-porphyrite, but often lamprophyric differentiates are found viz.: spessartites and vintlites. A very few dykes carry a pyroxene.

The hornblende-diorite-porphyrite (Figs. 4, 5 and 6, Plate XII) contains phenocrysts of plagioclase and green hornblende. The plagioclase is always strongly altered into epidote or calcite and sericite. When the original plagioclase twinning can still be observed the broad lamellae indicate a basic plagioclase (fig. 2, Plate XIII). Orthoclase phenocrysts are seldom found and then strongly sericitisized.

The hornblende is green or brownish green with strong pleochroïsm, with mostly zonal structure of the crystals and frequent twinning. DOZY describes such phenocrysts with a granophyric mantle. Quartz occurs rarely as phenocryst.

In the matrix we find a fresh plagioclase, hornblende, quartz and sometimes orthoclase. Epidote, calcite and chlorite are common alteration products.

In the Spessartites (Fig. 1, Plate XIII) the felspar phenocrysts are rare, mostly lacking altogether. Hornblende of the same habit as in the diorites is its preponderant constituent. Epidote as alteration product is very common. Sometimes we find garnet. In the often pilotaxitic groundmass we find felspar and hornblende microlites. Calcite as alteration product is common and never absent.

Between the purely lamprophyric spessartites and the undifferentiated diorite porphyrites we find intermediate rocks, which have been called Vintlites by DOZY. The felspars are less frequent as in the diorite porphyrites. Hornblende has the same habit as in both other groups. Again epidote, calcite and chlorite are common alteration products.

Macroscopically all these rocks are fine-grained, green, compact and rather soft. The felspar phenocrysts form sometimes very striking white patches, the hornblende phenocrysts can easily be seen on a closer scrutiny of the rock (figs. 4 and 5, Plate XII).

An exception to this general macroscopical habitus is the dyke of Val d'Agra above Gandino, Val Seriana, described by MAASKANT. Here 3 cm long hornblende phenocrysts appear clearly against the white blackground of a groundmass consisting of plagioclase and a little quartz (fig. 5, Plate XIII).

In the east part of the Bergamasc Alps FABER found pyroxene diorite porphyrite. The best preserved rock of this type is that of the Mt. Campione between the upper Val di Scalve and the Val Paisco (fig. 3, Plate XIII) (Analysis no. 46).

This rock contains phenocrysts of diopside and a basic plagioclase. The diopside crystallized under high temperature and pressure before the intrusion and became unstable after the intrusion when a hornblende-quartz-felspar groundmass crystallized. The original diopside now shows reaction rims, formed under conditions of lower temperature and pressure, each individual being surrounded by a zone of a zeolite. Each side of the crystal has been covered by one crystal of zeolite, orientated parallel to the crystal face (fig. 4, Plate XIII). Faint parallel twinning and radial growth have been observed in the larger zeolite aggregations.

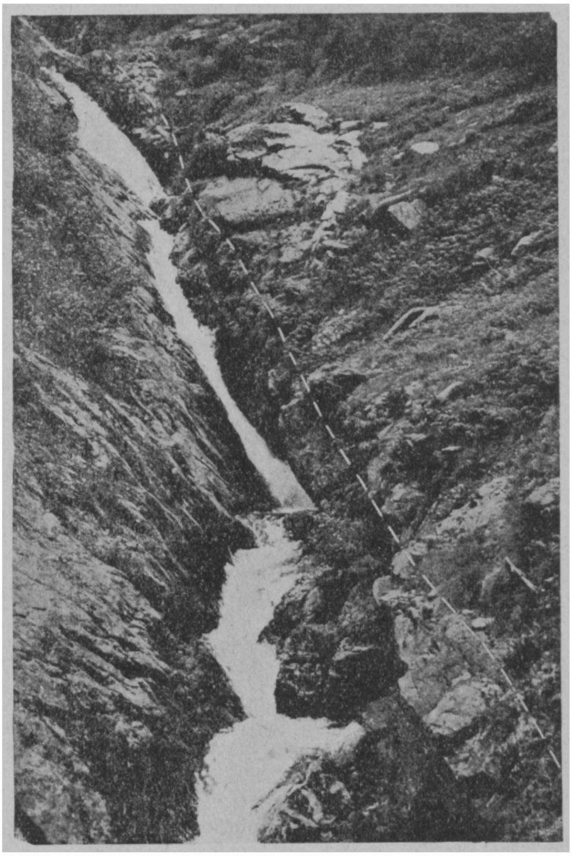


Fig. 8.

Porphyrite dyke in Collio schists.
The broken line is the boundary between porphyrite, left, and Collio schists to the right. Valle degli Orti, Upper Val di Vo, Valle di Scalve. The streamlet has eroded its bed in the softer porphyrite.

The plagioclase has been totally replaced by calcite and sericite. In the second generation we find well developed hornblende crystals smaller than the diopside and plagioclase of the first generation. In the groundmass we find again hornblende laths with a quartz-sericite filling up.

Contact-metamorphism by these dykes of the surrounding rocks, has been observed only in one single instance (see page 76) by TACCONI [1]).

ZIJLSTRA pointed out that the porphyrite dykes have acquired a schistose habitus when the surrounding rock is schistose, as is often the case with the Collio schists. When on the other hand the surrounding rock has not been affected by any metamorphism the dykes are not schistose either.

The dykes can sometimes be followed over large distances, as those of the upper Brembo valley below the Pizzo del Diavolo or those of the upper Serio valley. Mostly, however, their lateral

[1]) E. TACCONI. Di un interessante giacimento di minerali presso Leffe in prov. di Bergamo. Rend. R. Ist. Lomb., ser. II, XXXVI, 1903.

extension is very small. Sometimes they follow major or small faults, as the dykes which follows the horizontal thrustplane in the southern slope of the upper Scalve valley. This latter dyke has often been cut off or crushed by tectonical movements and therefore must have penetrated into the Triassic sediments simultaneously with the thrusting movement (KROL, FABER).

VISSER describes a dyke west of the Pizzo della Presolana near Stalle Muschelo, following a fault, which has been cut off and deplaced some 50 m by a major thrustplane of a much larger movement. The deplacement, therefore must be due to some later movement along the thrustplane, but again we observe an almost simultaneous intrusion and tectonical thrusting.

The only larger mass of hornblende-diorite is found NW of Nossa, Val Seriana. It is an intrusion of irregular shape in the Raibler limestones. No contact metamorphism of the surrounding limestone could be noticed even here.

Often the dykes being softer than the surrounding Triassic limestones or Collio schists are followed by small streamlets (ZIJLSTRA) (fig. 8).

Some new analyses have been made of these Tertiary dykes. The most striking feature of the chemical composition of these rocks is their high CaO content and corresponding high c value.

Analyses no. 40 and 44. Hornblende diorite porphyrite dyke in Norian limestones from Val d'Agra above Gandino, Val Seriana.

Surveyor: MAASKANT; anal.: KOOMANS. (Plate XIII, fig. 5).

Constituent minerals: large hornblende phenocrysts in a groundmass of plagioclase and hornblende (some quartz?).

Hornblende mostly replaced by chlorite, calcite and epidote.

Anal. no. 44 is a less weathered sample than anal. no. 40, its hornblende is fresh, the plagioclase has been saussuritisized to some extent.

Plate XIII. Tertiary dykes.

Fig. 1. slide no. 3735. Spessartite dyke from Pizzo Medasc, Upper Val Seriana. // nicols, enlargement 24 ×. The slide contains hornblende in two generations, large phenocrysts and smaller laths in the groundmass, which consists further of sericite and a little quartz. The black spots are magnetite.

Fig. 2. slide no. 4890. Hornblende diorite porphyrite from West of Ono S. Pietro, Val Camonica. + nicols, enlargement 26 ×. Large phenocrysts of a basic plagioclase and hornblende lie in a groundmass consisting of plagioclase, quartz and some hornblende.

Fig. 3. slide no. 4846. Augite porphyrite from Mt. Campione Upper Val di Scalve. // nicols, enlargement 24 ×. In the centre of the slide appears a large felspar phenocryst, totally replaced by calcite. To the left a smaller one, less distinct, is visible, and inbetween a small idiomorphic needle of hornblende. Right and left are diopside phenocrysts, each surrounded by a white zeolite border zone. The groundmass consists of hornblende laths with sericite (weathered felspar). Analysis no. 46.

Fig. 4. slide no. 4846. Augite diorite porphyrite from Mt. Campione. + and // nicols, enlargement 133 ×. The diopside crystal has been cut // (010) and shows an extinciton angle of 32°. The white zeolite border is clearly visible. To the left a part of the same crystal under crossed nicols, shows the peculiar orientation of the zeolite parallel to the crystal faces of the diopside. In one corner, top to the left, a diagonal line sharply separates two zeolite crystals each parallel to a crystal face.

Fig. 5. no. 131A. Hornblende porphyrite from Val d'Agra, above Gandino, Val Seriana. Large hornblende phenocrysts replaced by chlorite, calcite and epidote, lie in a white groundmass of plagioclase and some quartz. Analyses nos. 40 and 44.

PLATE XIII

TERTIARY DYKES

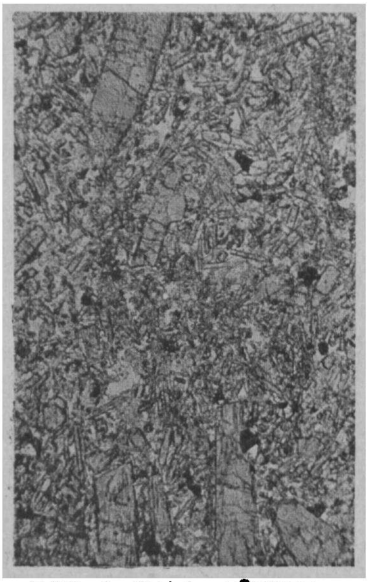


FIG. 1 Slide Nº 3735

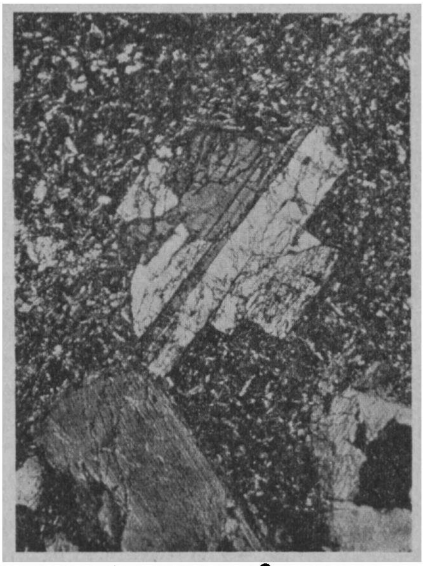


FIG. 2 Slide Nº 4890

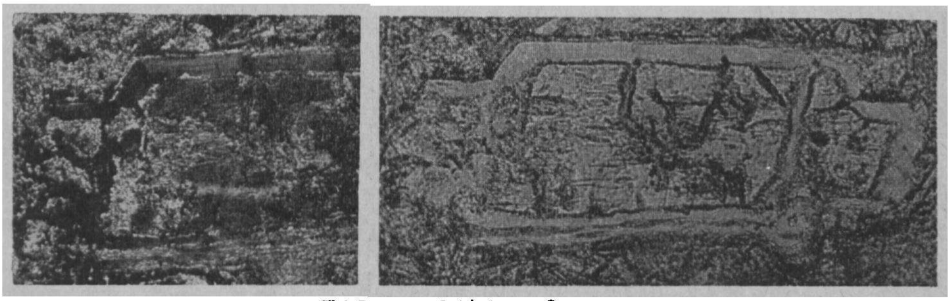


FIG. 4 Slide Nº 4846

FIG. 3 Slide Nº 4846

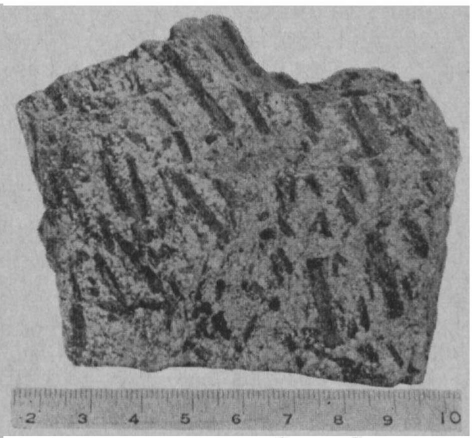


FIG. 5 Nº 131ª

Analysis no. 41. Spessartite in crystalline schists from Vle Sambuzza near Bta Vecchia. Surveyor: DOZY; anal.: KOOMANS.

Specimen no. 35519, slide no. 3665.

Constituent minerals: hornblende phenocrysts, strongly altered in calcite, epidote and chlorite, in a groundmass of hornblende, fresh plagioclase and some orthoclase, with pyrite and limonite.

Analysis no. 42. Vintlite dyke in Collio schists from Mt. Masoni, south flank. Surveyor: DOZY; anal.: KOOMANS.

Specimen no. 35520, slide no. 3662.

Constituent minerals: phenocrysts of hornblende and plagioclase. Groundmass: plagioclase, hornblende, magnetite and pyrite. Secondary minerals are: chlorite, sericite, calcite and epidote. The hornblende phenocrysts are frequently twinned and strongly pleochroïtic.

Analysis no. 43. Spessartite dyke in crystalline schists from Valle di Venina, just south of Lago di Venina. Surveyor: DOZY; anal.: KOOMANS.

Specimen no. 35523, slide no. 3667.

Constituent minerals: phenocrysts of hornblende and scarce plagioclase in a groundmass of plagioclase, hornblende with much epidote, pyrite and magnetite.

Analysis no. 45. Porphyrite dyke in crystalline schists from Val Marcia. Surveyor: CROMMELIN; anal.: KOOMANS.

Specimen no. 27134, slide no. 3006.

Constituent minerals: phenocrysts of plagioclase in a groundmass of plagioclase, quartz, much chlorite and ore.

The plagioclase has been strongly sericitisized. Chlorite is probably derived from biotite. The weathering is exceptionally strong as shown in the analysis by the high Al_2O_3 and H_2O contents. It is uncertain whether this rock must be reckoned to the Tertiary dykes or that it represents a Permian intrusive.

Analysis no. 46. Augite-diorite-porphyrite dyke in Triassic limestone from Mt. Campione, Upper Val di Scalve. Surveyor: FABER; anal.: KOOMANS.

Slide no. 4846.

Constituent minerals: phenocrysts of diopside and felspar in groundmass of hornblende, plagioclase and sericite.

The felspar phenocrysts are wholly replaced by calcite and sericite. (Plate XIII, fig. 3).

Analysis no. 47. Augite porphyrite dyke in Triassic limestone from Val Flesch south of Clusone. See E. ARTINI, Intorno a una roccia lamprofirica della Val Flesch. Atti Soc. Ital. Sc. Nat. XLII, 1903.

Constituent minerals: augite, biotite, hornblende, some plagioclase, chlorite, apatite, magnetite and much pyrite.

The analysis has been recalculated to 100 % total by eliminating H_2O, FeS_2 and CO_2 (as calcite) content.

TABLE 2.

Analyses of Tertiary dykes.

	40	41	42	43	44	45	46	47
	Hbl.-diorite porphyrite	Spess-artite	Vintlite	Spess-artite	Hbl.-diorite porphyrite	Por-phyrite	Augite porphyrite	Augite porphyrite
SiO_2	56.81	58.41	56.03	56.12	52.98	45.93	45.47	44.86
TiO_2	1.39	0.64	0.92	0.97	0.71	1.63	0.95	—
P_2O_5	0.26	0.30	0.34	0.33	0.29	0.38	0.31	—
Al_2O_3	18.00	18.27	19.57	17.13	18.03	22.27	13.86	12.00
Fe_2O_3	0.29	1.89	0.80	1.69	2.76	0.26	2.42	3.05
FeO	3.82	2.71	3.98	4.67	4.19	6.65	5.99	8.22
MnO	0.13	0.13	0.18	0.16	0.16	0.23	0.23	—
MgO	2.96	4.22	5.37	5.70	4.81	4.79	11.36	16.34
CaO	7.62	6.73	6.05	6.34	7.52	8.75	9.23	10.00
Na_2O	2.40	2.99	2.83	2.06	2.63	1.98	1.15	3.69
K_2O	1.65	1.20	1.42	2.41	1.31	1.52	1.33	1.84
$+ H_2O$	3.84	1.68	2.21	1.92	3.70	4.33	4.59	—
$- H_2O$	0.50	0.28	0.12	0.07	0.89	0.15	0.10	—
CO_2	0.24	0.36	0.28	0.22	—	0.81	2.68	—
	99.91	99.81	100.10	99.79	99.98	99.68	99.67	100.00
si	190.1	184	166	164	151.5	199	103	80
al	35.5	34	34	29.5	30.3	34	18.5	12.5
fm	26.2	32	36	40.5	36.9	34	54.5	60
c	27.3	22.5	19	19.5	23.1	24.5	22.5	19
alk	11.0	11.5	11	10.5	9.7	7.5	4.5	8.5
k	0.32	0.21	0.25	0.44	0.25	0.25	0.42	0.27
mg	0.57	0.62	0.66	0.61	0.56	0.54	0.71	0.73
c/fm	1.04	0.71	0.54	0.49	0.63	0.71	0.41	0.32
ti	—	1.5	2.1	2.1	—	3.12	1.6	—
p	—	0.38	0.36	0.35	—	0.47	0.27	—
h	—	20.6	23.0	19.3	—	38.85	35.5	—
co_2	—	1.5	1.1	0.88	—	—	8.3	—

The dykes of the Lombardic Alps have received considerable attention since the first field surveys. A complete review of the literature on this subject would be superfluous and tedious, because the petrography of these rocks is not very variable and SALOMON has already summarized the older literature. Since then the subject has been neglected until the Adamello intrusive mass became the subject of G. DAL PIAZ' and A. BIANCHI's attention. These recent studies revealed a much greater variety of lamprophyric rocks than had been known until then.

COZZAGLIO [1]) revisited, after the older surveys of Curioni, Varisco and Taramelli, the Val Camonica and its affluent rivers, noted the occurrence of numerous dykes, which were described petrographically by RINA MONTI [2]).

COZZAGLIO visited besides the mountains flanking the Val Camonica. In the Val Clegna many dykes in the Servino and Verrucano were observed near Cemma and Pescarzo. Above Ono San Pietro two dykes containing large augite phenocrysts were found. All the other dykes, including those above Losine and in the Val di Lozio, are the common hornblende-plagioclase porphyrites. Contact-metamorphism was never observed.

MELZI [3]) visited the southern affluents of the Adda between Aprica and Fusine. He noted a great frequency of dykes in the Val di Caronella and Val di Bondone in the east and a diminishing quantity in western direction. All the dykes belong to the hornblende porphyrites and show conspicuously little variety. His description of the rocks agrees in every respect with our hornblende-diorite porphyrites and spessartites.

VIGO [4]) studied the dykes of the upper Val di Scalve, which belong to the hornblende-diorite-porphyrite group and the vintlites. Plagioclase and hornblende phenocrysts, quartz in some of the dykes, in a groundmass of felspar and hornblende, sometimes with quartz.

TACCONI [5]) reports the contactmetamorphism of rhetic limestone by a dark coloured dyke near Leffe (Gandino). Vesuvianite, kaoline, garnet, epidote and diopside are among the contact metamorphic minerals. The dyke itself received no further attention.

ARTINI [6]) describes a very interesting dyke just south of Clusone. It is an ultra basic lamprophyr containing biotite, augite, hornblende, some plagioclase of acid type (!), chlorite, apatite, magnetite and much pyrite. An analysis of this rock has been made (no. 47). Because the CO_2 content was very high, calcite has been subtracted, also the FeS_2, the resulting recalculated analysis is given in the table.

No contact-metamorphism has been found.

[1]) A. COZZAGLIO. Note esplicative sopra alcuni rilievi geologici in Val Camonica. Giorn. di Mineral., Vol. V, 1894.

[2]) R. MONTI. Studi petrografici sopra alcune rocce della Val Camonica. Giornale di Mineral., Vol. V, 1894.

[3]) G. MELZI. Le porfiriti della Catena Orobica settentrionale. Rend. R. Ist. Lomb., ser. II, vol. 28, f. 8, Milano 1895.

[4]) G. VIGO. Di alcuni rocce filoniane della Valle di Scalve. Rend. R. accad. Lincei 1898, (V) VII, p. 172.

[5]) E. TACCONI. Di un interessante giacimento di minerali presso Leffe in prov. di Bergamo. Rendic. R. Ist. Lomb. sc. e lett., ser. II, XXXVI, 1903.

[6]) E. ARTINI. Intorno a una roccia lamprofirica della Val Flesch. Atti Soc. Ital. sc. nat. XLII, 1903.

SALOMON [1]) and RIVA [2]) describe the dykes of the Adamello. In his large monograph on this grand intrusive mass SALOMON reviews the results of all older investigators and makes use of the analyses and rock description of RIVA. He gives a list of 229 dykes, situated in the Adamello mass and its vicinity, including those mentioned by COZZAGLIO and others. It was SALOMON, who clearly demonstrated the Tertiary age of most of the dykes, although COZZAGLIO had already noticed in the field that they must be younger than some of the folds. The analyses and descriptions by RIVA all refer to rocks from the Adamello proper and therefore fall outside our area. The geological evidence as to the age of the basic dykes points definitely to the Tertiary. As we have pointed out already they follow the Tertiary strike and often cut through faults of Tertiary age; they sometimes follow the brecciated fault zones. Therefore it is obvious that the period of intrusion must be closely connected with the intrusion of the Adamello tonalite. This assumption is corroborated by the increase of frequency of the dykes in an eastern direction towards the Adamello mass, as noted by MELZI on the southern slope of Valtellina.

The Adamello mass itself and its surrounding mantle of Permian and Triassic rocks contain locally innumerable dykes of a much greater variety than have been found in the Bergamasc Alps. The chemical analyses of these dykes, made by recent investigators, allow us a good basis of comparison. FENOGLIO [3]) describes a quartz-biotite porphyrite, a malchite and granodiorite dykes from Val Nambrone.

BIANCHI [4]) describes a malchite from the top of the M. Costone (p. 36). When we combine these analyses with tonalite analyses from the Adamello [5]) and our analyses of lamprophyric dykes from Bergamasc Alps in one diagram, fig. 9, we notice that our hornblende porphyrites and spessartites are slightly more acid than the malchites of the Adamello, our spessartites more basic than the normal tonalites, but that the latter rocks and our diorite porphyrites, which we considered as an aschiste, non differentiated rock, are more or less identical. The granodiorite dykes of FENOGLIO are more acid than the tonalites.

The analyses of the Bergamasc dykes can be fitted without any difficulty into the differentiation diagram of the Adamello rocks. They have the same caracteristic high c value, and in general corroborate and complete the Adamello diagram very nicely. In my opinion the evidence of this diagram is so convincing that hence-forward a study of the Adamello intrusives would be incomplete when the Bergamasc dykes were left out of consideration; the latter form an integrant part of the differentiation of this Tertiary intrusive mass.

[1]) W. SALOMON. a. Die Adamello Gruppe. Abh. d. K. K. geol. R. Anst. XXI, Wien 1908. b. Geologische und petrographische Studien am Mt. Aviolo im italienischen Anteil der Adamello Gruppe. Z. D. G. G. 1890, XL, p. 450.

[2]) C. RIVA. a. Le rocce paleovolcaniche del gruppo dell'Adamello. Mem. R. Ist. Lomb. XVII, Milano 1895. b. Sopra un dicco di diorite quarzoso-micacea presso Rino, Val Camonica. Atti Soc. ital. sc.nat . XXXVI, 1896. c. Nuove osservazioni sulle rocce filoniane del gruppe d'Adamello. Atti Soc. Ital. Sc. Nat. XXXVII, 1897.

[3]) M. FENOGLIO. Studi geologico-petrografici sulla Val Nambrone. Mem. Ist. geol. R. Univ. Padova, XIII, 1938—'39.

[4]) A. BIANCHI, Gb. DAL PIAZ, Il settore meridionale des Massiccio dell'Adamello. Boll. R. Uff. geol. d'Italia, LXII, 1937.

[5]) A. BIANCHI, Gb. DAL PIAZ, La monografia geologico-petrografico sull'Alto Adige etc. Relazione dei risultati. Periodico di Mineralogia X/2, 1939, p. 176.

The striking difference between the Adamello rocks proper and the Bergamasc dykes is purely mineralogical, viz.: the absence of biotite in the Bergamasc dykes and the preponderant position of this mineral in the Adamello rocks. Tonalites and malchites always carry biotite, and FENOGLIO analysed and described even minettes. The pure hornblende facies of the Bergamasc dykes must be ascribed to different temperature-pressure conditions of the magma, intruded further away from the main intrusive mass. The time of intrusion of the lamprophyric dykes belongs to the latest stages of the intrusion period as has been proved by BIANCHI. In the Adamello the following sequence of the dykes could be observed by that author:

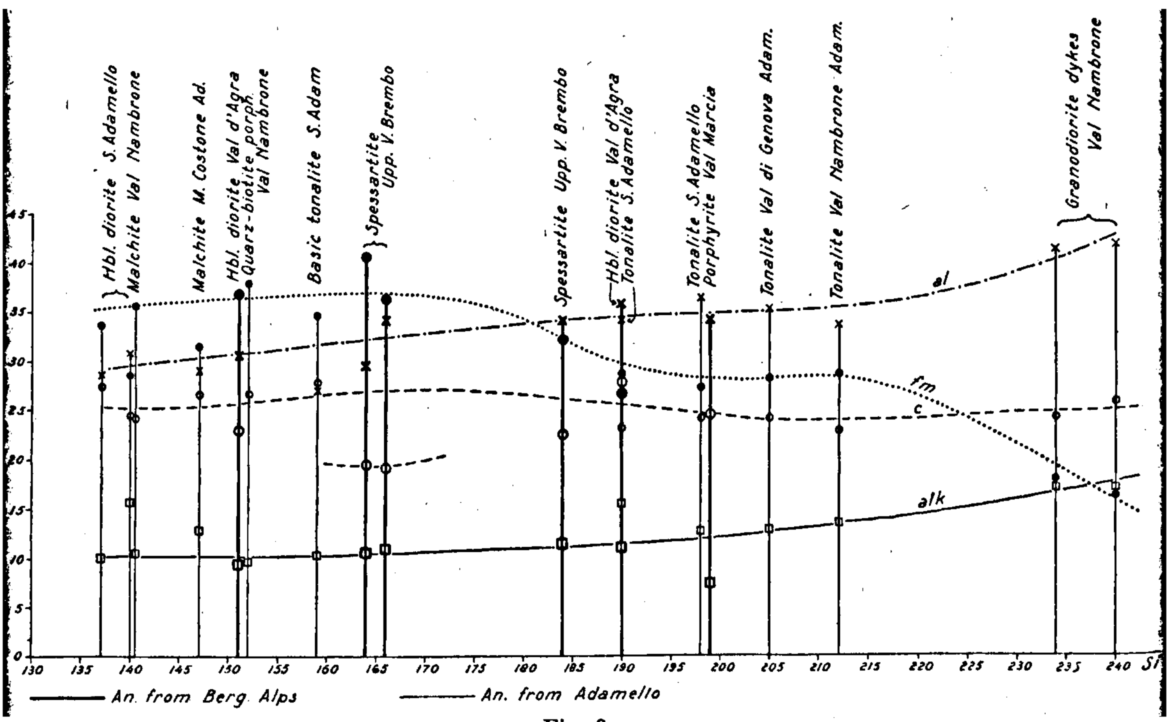


Fig. 9.

Central part of the Adamello differentiation diagram completed with analyses of Bergamasc dykes.

(1) Apophyses and aschiste dykes → (2) pegmatites aplites etc. → (3) hornblende-plagioclase porphyrites, malchites → (4) kersantites, spessartites etc. → (5) hornblende-pyroxene porphyrites.

The ordinary Bergamasc dykes belong to the 3rd and 4th periods. The ultra basic dykes carrying pyroxene (analyses 46 and 47) from Mt. Campione and from south of Clusone, Val Flesch, belong apparently to the 5th period.

In fig. 10 these two latter ultra basic dykes of Bergamasc Alps are compared to some of the Adamello complex. Again we find a very good agreement.

It must be noticed that the Hbl. facies (si = 77) and the Gabbro facies (si = 99) of Mt. Mattoni belong to the earliest intruded rocks of the main mass. These basic differentiates are found as xenoliths in the normal tonalite.

All the other analyses belong to dykes of the very last phase of intrusion. The minettes of FENOGLIO are not included in fig. 10 because they do not agree at all with the present diagram.

The repartition of the dykes as it appears on our map fig. 19 does not give a complete picture of the pattern. Only a few surveyors mapped the dykes carefully, and often only the more important ones were plotted. Notwithstanding this incompleteness the general pattern will be approximately right. In the eastern half of the area dykes are very numerous, mostly very short ones, but sometimes they can be followed over great distances, as for instance the dyke which follows the thrustplane parallel the Val di Scalve on its southern slope. The most complete picture gives the region of the central part between Corno Stella and the Pzo del Diavolo. Long dykes, with an E—W strike in the western half and turning to a NW—SE strike in the eastern half, cut through the mica-schists and Permian strata. Those with a NW—SE strike, a strike which prevails also in the whole region between the Val Camonica and Val Seriana, are distinctly not parallel to the general tectonical strike, which is E—W or even ENE—WSW.

The fact that no or very few dykes are reported south of the line Gromo—Branzi—Averara—Premana suggests that the dykes occur mostly between the Tertiary Adamello and Bregaglia masses, connecting those two large masses.

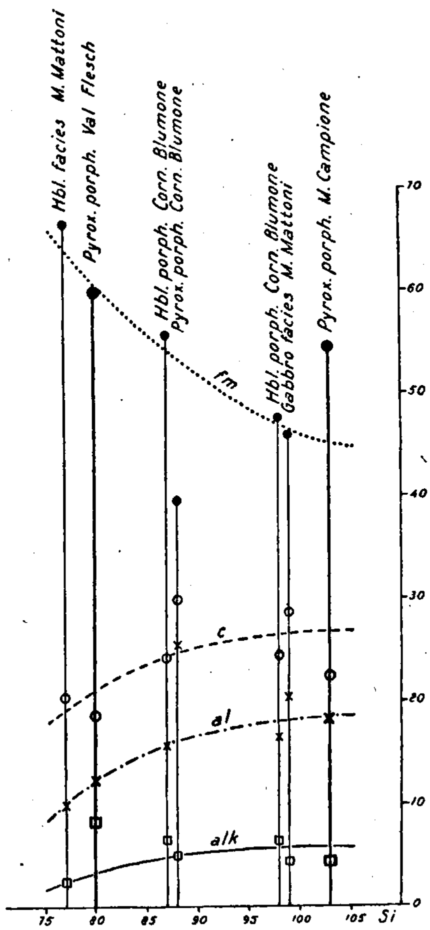


Fig. 10.

Basic part of Adamello differentiation diagram completed with two dykes from Bergamasc Alps.

CHAPTER V.

MYLONITES.

The very severe strain, to which the Lombardic Alps were submitted during the alpine orogenesis, can be judged by the frequency of mylonites in every kind of rock. The most extreme form of mylonite, when the rock-substance has been melted and partly injected in the surrounding brecciated zone, has not always been recognised as such. The older surveyors as COSIJN (1), JONG (2), CROMMELIN (8) described these ultra-mylonites as „glass lava", „basal tuffoïds" and such terms indicating their belief that a volcanic rock with a glass matrix constituted the origin. CROMMELIN (8) already noticed the presence of the same kind of rock north of the orobic faultline in the crystalline schists, but did not attribute it to any other origin than a volcanic one. TROMP (6) described felsophyric dykes in the crystalline schists which after a long discussion of the properties of the pseudo-tachylite of HALL, MOLENGRAAFF and SHAND [1]), he does not consider as ultra-mylonites. As to the basal tuffoïds of JONG (2) and CROMMELIN (8) TROMP takes an intermediate view, partly injected ultra-mylonite, partly mylonitisized porphyry. DOZY (10) discusses the problem again at some length and arrives at the conclusion that all these felsophyres and basal tuffoïds must be regarded as either ultra-mylonites of the surrounding rock or as injected „gangmylonite".

When we review the main characteristics of this rock over the whole region we must first state the fact throughout their whole extent, taken from dykes in the crystalline schists, from the basal tuffoïds of JONG (2) c. s. or from the Collio schists, the samples both macroscopically or through the microscope are identical in general habitus.

Ordinary mylonitic zones either in the basement rock or in the Permian are characterized by the well known crushed zones, rich in sericite and chlorite curving round and crossing the phenocrysts often accompanied by a set of polished faces (fig. 11). From this ordinary type of mylonitic zones we can follow step for step the development of ultra-mylonite; the fusing of the rock material by great stress and high confining pressure. The finest veins of black glasslike material develop, they become broader and enclose and penetrate along fissures into the unfused rock material. Devitrification since the fusion, has probably, changed the glass again in so far as a real glass substance ever has been formed.

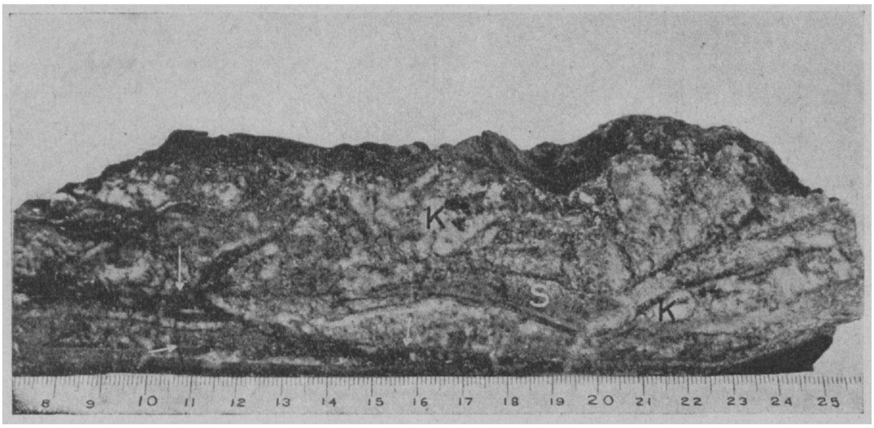
When these fine veins of black glasslike material, enclosing broken quartz and felspars and other rock fragments, unite and form dykes, DOZY (10) named them „gangmylonite", ultra-mylonite dykes. These ultra-mylonite dykes

[1]) A. L. HALL and G. A. F. MOLENGRAAFF. The Vredefort mountain land. Verh. Kon. Ac. Wet. A'dam XXIV, 1925.

S. J. SHAND. The pseudotachylite of Parys (Orange Free State) and its relations to „Trapp-Schotten" gneiss and „flinty crush-rocks". Quart. Journal Geol. Soc. 72, 1917.

cross the rock over considerable distances and probably the glass material did pass some, perhaps considerable distance along these conduits.

The mylonite dyke glass substance must have been fluid as it penetrates at both sides of the dyke into the surrounding rock in fissures and cracks and fills up cavities (fig. 4, Plate XIV). All these ultra-mylonite dykes carry



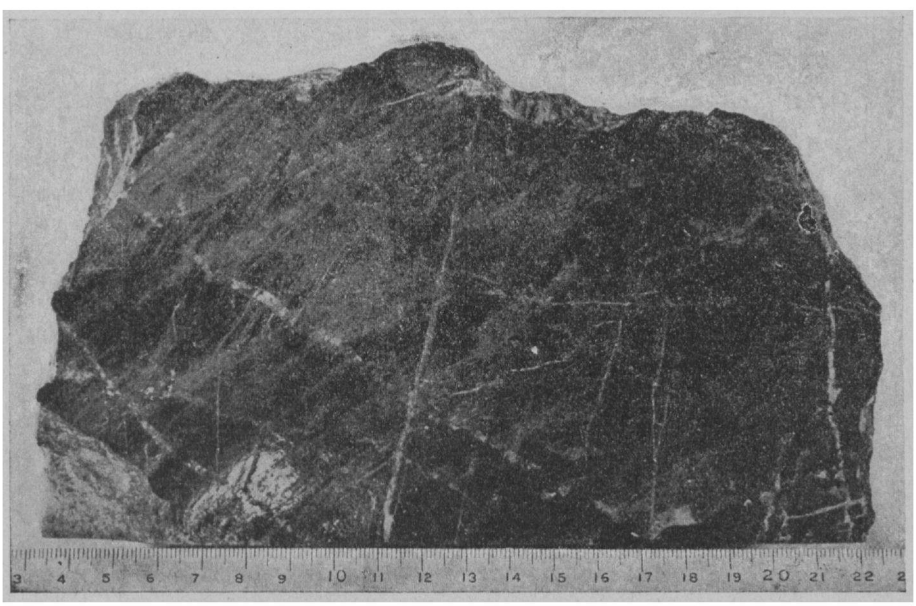


Fig. 11.

Combination of polished shearing faces with ultra mylonite veins.

a. cut and polished perpendicular to the natural polished shearing face. K = quartz, S = siderite, ultra mylonite veinlets are indicated by small arrows.

b. The natural polished shearing face.

The rock was found in screes West of the Mt. Venerocolo and is a pegmatite dyke now mylonitisized to considerable extent. The ultra mylonite has recrystallized and consists of tourmaline mostly. Apparently the tourmaline of the pegmatite was the easiest fusible material, a good example of selective fusion by mylonitisation.

quartz and felspar fragments, but rock fragments of crystalline schists can also be observed. Recrystallized tourmaline, calcite and ores have been noticed by several authors in the black mylonite dyke substance.

DOZY (10) found ultra-mylonite in the Permian Verrucano conglomerates of Lago del Diavolo and of the Pizzo del Omo, and mentions Collio sediments which are full of fine veins of mylonite (fig. 3, Plate XIV).

North of the Passo di Cigola the basal conglomerate rests on gneiss chiaro, but is sometimes seperated from it by a prae-alpine dyke, of probably Permian age. Both above the dyke and below it the rocks are penetrated by ultra-mylonite veins. The dyke is strongly metamorphosed by the alpine orogenesis, the mylonite is completely fresh, with devitrificated glass.

The so-called „basal tuffoïd" or „glass lava horizon" of JONG, COSIJN and CROMMELIN, a layer situated between the basement crystalline schists and the overlying Permian volcanics, is identical with the ultra-mylonite dyke substance of DOZY. It has the same glass matrix full of rock fragments (Compare fig. 1 a „basal tuffoïd" with nos. 5 and 6, Plate XIV). Often the basal tuffoïd consists largely of tuffaceous material and the glass substance constitutes only a small part of the rock. The tuff has then been impregnated by the ultra mylonite. The glass of the „basal tuffoïd" is as fresh as that of DOZY's ultra mylonite dykes or as in TROMP's felsophyre dykes. It seems very improbable that of all the strongly altered rocks of the Permian series only this glass substance should have been excepted from metamorphism and remained perfectly fresh. Most of TROMP's

Plate XIV. Mylonites.

Fig. 1. slide no. 1408. Ultra mylonite (pseudo tachylite) from Grassi, Valtorta. // nicols, enlargement 26 ×. A typical example of the „basal tuffoïd" or „glass lava" of older authors. Comparison with fig. 4, 5 and 6, all ultra mylonites, show the identity of these rocks. A glass groundmass with clear white quartz and other faintly visible rock fragments. Two cracks cross the slide, along one a slight displacement of two halves of a quartz crystal can be observed. The crocks are filled up by quartz.

Fig. 2. Specimen no. 19212. Ultra mylonite from E flank of Mt. Sasso, Upper Val Brembo. A glossy pitch black rock, consisting of glass, with white and gray patches: the quartz and rock fragments. The same cracks filled with quartz as in fig. 1. This ultra mylonite lies between the gneiss and, the basal conglomerate.

Fig. 3. Specimen no. 19246. Collio schist with ultra mylonite veins from Mt. Masoni, Upper Val Brembo. A gray-green coloured Collio schist (lower Permian) has been impregnated by numerous ultra mylonite veins, which have been injected in all directions along cracks and fissures.

Fig. 4. slide no. 3677. Ultra mylonite from E of Bta Dossello, Valle di Venina. // nicols, enlargement 24 ×. The ultra mylonite forms a dyke in the crystalline schists, penetrating along fissures into the neighbouring rock, separating fragments of this rock, which now swim in the glass substance.

Fig. 5. slide no. 3681. Ultra mylonite from Valle di Mt. Sasso Upper Val Brembo. + nicols, enlargement 24 ×. The glass groundmass carries fragments of quartz and irregular shaped fragments of very much altered rock, not wholly fused.

Fig. 6. slide no. 3684. Ultra mylonite from NE of the Pso di Cigola. // nicols, enlargement 24 ×. The fluidal structure of this rock is very evident. In the left bottom corner a large shattered quartz crystal. Above it, appears an elongated partly fused rock fragment, its edges being drawn out by the flow of the viscous glass mass before its cooling.

PLATE XIV

MYLONITES

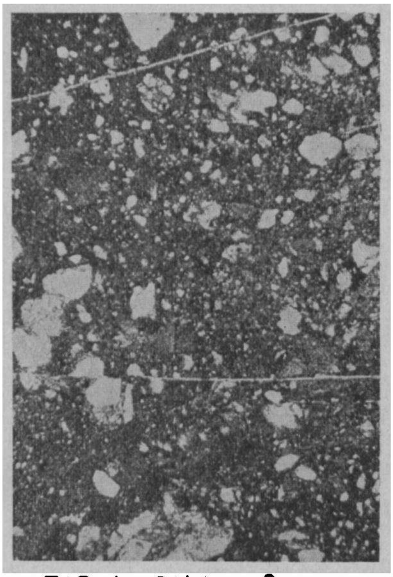


FIG. 1 Slide N° 1408

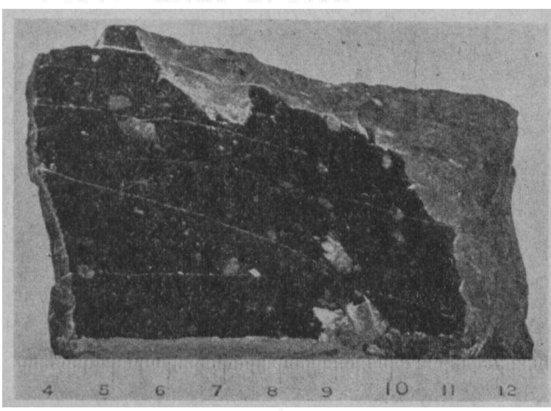


FIG. 2 Specim. N° 19212

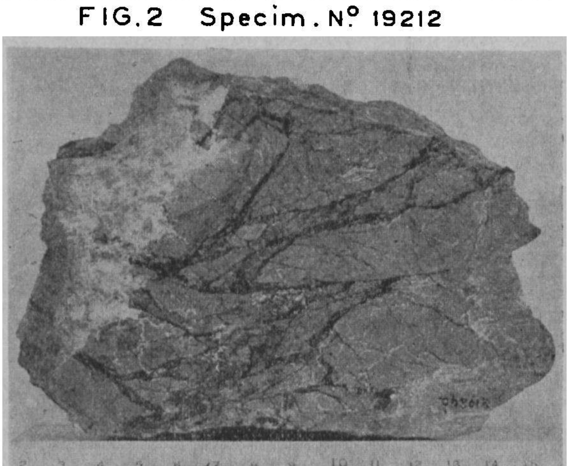


FIG. 3 Specim. N° 19246

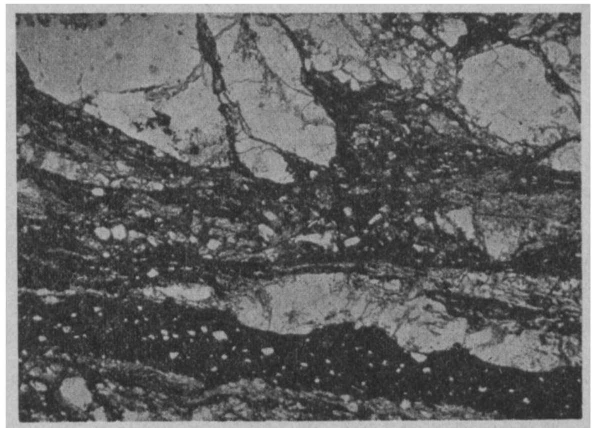


FIG. 4. Slide N° 3677

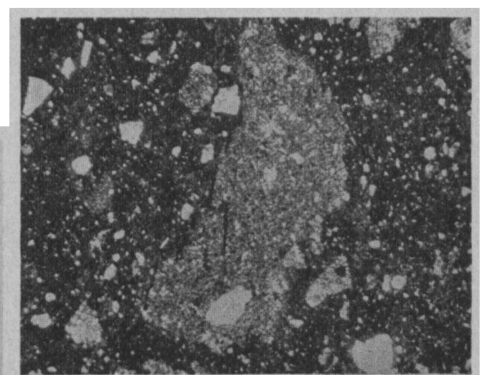


FIG. 5 Slide N° 3681

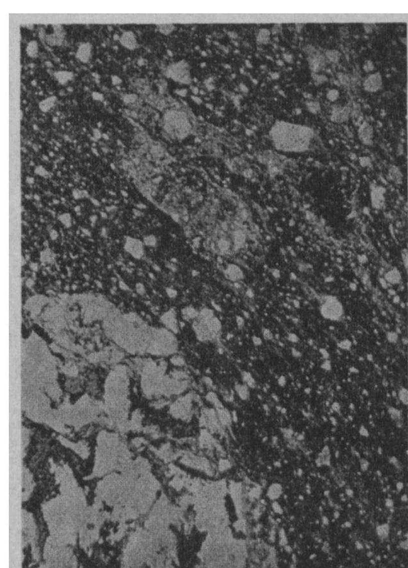


FIG. 6
Slide N° 3684

felsophyres probably are likewise ultra-mylonites, although the similarity is sometimes not so striking.

The ultra-mylonite horizon between the basement rock and the overlying permian volcanics occurs also in the area mapped by DOZY (10). Usually this horizon is much less inclined than the ultra-mylonites of the nearly vertical thrustplanes of the basement rock. DOZY assumes that the smaller pressure on the horizontal thrustplanes facilitated the injection of ultra-mylonitic fused material, thus giving rise to zones of several metres thickness.

Possibly most of the refused material has been generated on the thrustplanes in the basement rock, and has been injected in the overlying sediments, Collio or Verrucano and into horizontal thrustplanes with less pressure perpendicular to the planes.

TROMP (6) attacked the problem also from a chemical point of view. He

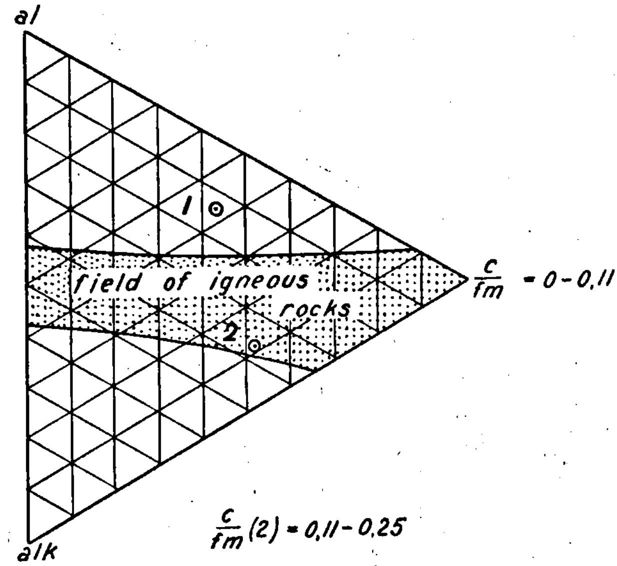


Fig. 12.

Projection of two ultro-mylonites in the igneous rock tetrahedron of NIGGLI.
1 = Analysis no. 48, Mt. Masoni (DOZY, 10).
2 = Analysis no. 49, Prati della Brussada (TROMP, 6).

compares two analyses, one of the glass substance and one of the surrounded rock (analysis no. 49 and 2). It is obvious that this comparison need not show any concurrence between the two analyses, as the fusion of the rock need not, and probably has not, affected all constituent minerals but will have acted selectively, and while the glass material may have travelled some way before solidifying at its present position. The observed differences therefore present no proof of the non mylonitic origin of the dyke. One of DOZY's purest mylonite dykes was also analysed by C. DE SITTER—KOOMANS (An. 48). The two ultra-mylonite analyses are listed below. The much higher si value of the TROMP analysis is due to the rather large quartz content of the glass in the „felsophyre” dyke.

When projected into the concentration tetrahedron of Niggli we notice that the analysis of DOZY's mylonite dyke falls outside the field of igneous rocks, a circumstance which pleads for the selective fusion action (fig. 12).

Analysis no. 48. Monte Masoni
(Dozy p. 194)

SiO_2	= 57.48	si	= 196
TiO_2	= 0.37	al	= 44.2
P_2O_5	= 0.10	fm	= 39.5
Al_2O_3	= 22.04	c	= 2.6
Fe_2O_3	= 5.02	alk	= 13.7
FeO	= 3.54		
MnO	= 0.02	k	= 0.36
MgO	= 3.30	mg	= 0.42
CaO	= 0.74	c/fm	= 0.07
Na_2O	= 2.64		
K_2O	= 2.28		
+ H_2O	= 2.19		
— H_2O	= 0.06		
	99.78		

Analysis no. 49. Prati della Brussada
(Tromp p. 195)

SiO_2	= 75.30	si	= 397
TiO_2	= 0.05	al	= 10.13
P_2O_5	= —	fm	= 42.72
Al_2O_3	= 3.27	c	= 10.13
Fe_2O_3	= 8.30	alk	= 37.0
FeO	= —		
MnO	= 0.04	k	= 0.30
MgO	= 1.21	mg	= 0.22
CaO	= 1.79	c/fm	= 0.24
Na_2O	= 5.09		
K_2O	= 3.33		
+ H_2O	= 1.32		
— H_2O	= 0.21		
	99.91		

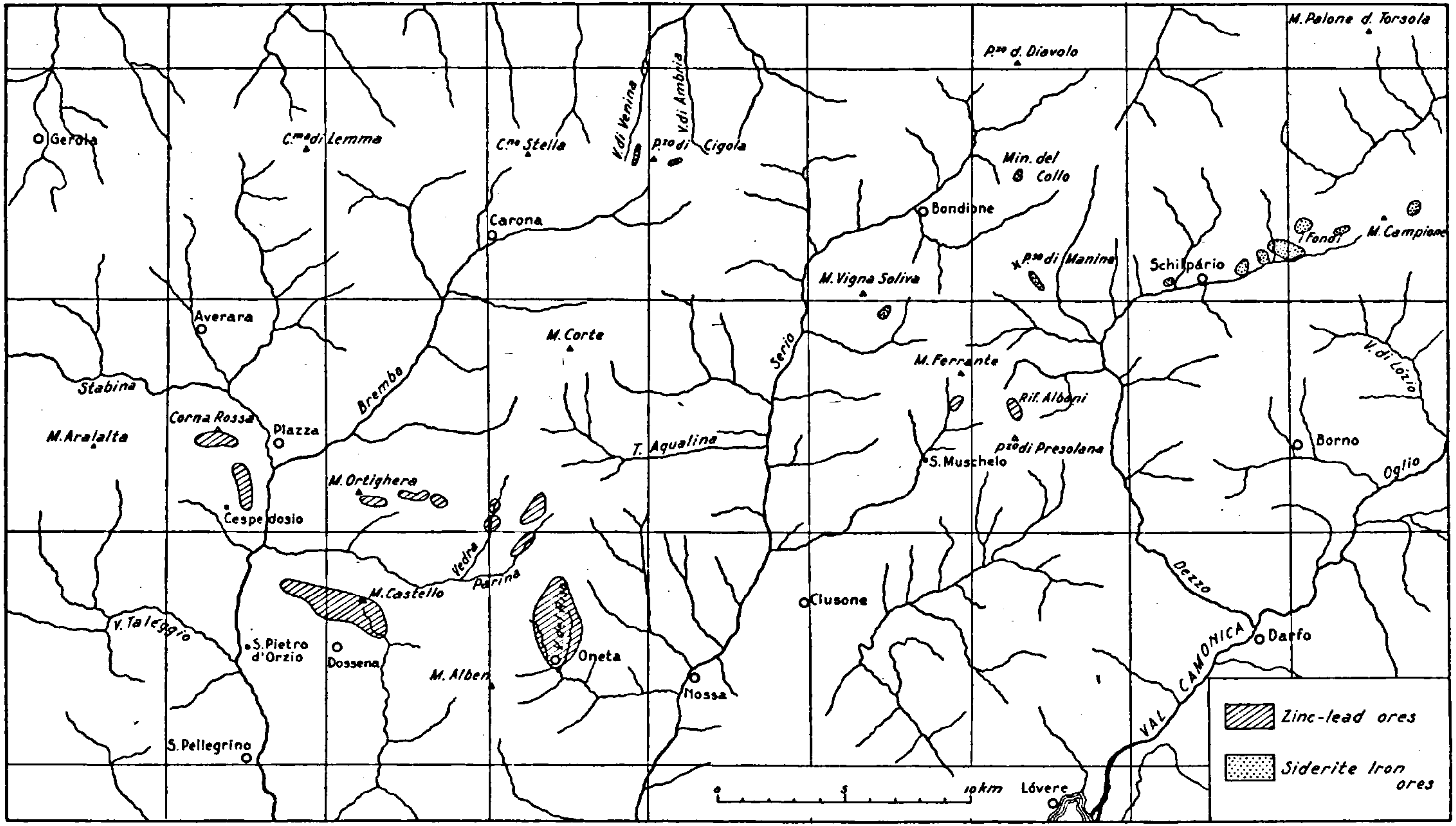


Fig. 13.
Map of main ore deposits in the Bergamasc Alps.

CHAPTER VI.

ORE DEPOSITS.

Although the Bergamasc Alps have never yielded a large production of metal ores, the ore deposits are widespread and of considerable scientific interest.

We must distinguish between two kinds of ore infiltration viz.:

1st zinc-lead ores in Lower Raibler (Upper Esino) limestones and 2nd iron-ores limited to alpine faultzones in Permian or lower Triassic schists.

The zinc-lead ores are widespread and many mines have been worked on these deposits since Roman times. HOFSTEENGE investigated the zinc-lead ores to a greater extent than any of the other surveyors (9), and we shall follow his mineragraphic description of the ores, amplified by observations of other surveyors.

The zinc-lead ores are bound to one distinct stratigraphical horizon which is reckoned by older authors (HOFSTEENGE) to the Upper Esino, by others, principally KROL (18 and 26), to the Lower Raibler. This horizon is well known and PORRO (1903) gave the formation known as „calcare metallifero" a special colouring on his map. In our stratigraphical part we shall study the stratigraphical position in more detail. The impregnated rock consists of limestone with some dolomite and has a thickness of some 50—60 m. It is situated above the „calcare rosso" a red and green irregular coloured limestone, indicating the top of the Esino limestone. The impregnated limestones have a dark grey colour. The top is formed by thin shales and cherts. The ores occur as irregular lenses in the limestone or have been accumulated in bituminous shale-intercalations between the limestones.

The ores are accompanied by calcite, baryte and fluorspar mostly. Sometimes the metal ores lack alltogether and nothing but baryte or fluorspar accumulations indicate the ore horizon. As the zinc-lead ores are bound to one horizon their distribution is naturally limited to the outcrops of this formation. However, even within this formation the occurrence is restricted mainly to a zone between Piazza Brembana on the Brembo river in the west and Nossa on the Serio in the east. Smaller occurrences are found just north of the Pzo della Presolana.

The most important ores are: Sphalerite (ZnS) with its substitute Smithsonite (Calamine) ($ZnCO_3$) Galena PbS, and Pyrite (FeS_2) together with the minerals baryte, fluorspar, quartz and calcite.

Sphalerite occurs, according to HOFSTEENGE in two types:

a. with inclusions of chalcopyrite, and
b. without chalcopyrite inclusions.

The ore body of Dossena-San Pietro d'Orzio carries only sphalerite of the first type. The chalcopyrite inclusions are arranged according to straight lines, and are either drop-shaped or lath-shaped, in the latter case orientated in three directions.

The second type is found in the mines of Valle del Riso (Oneta). Zonal structure of the sphalerite is very scarce, an example of this structure has been photographed (fig. 1, plate XV).

Sphalerite has been replaced by smithsonite in the higher layers. The metamorphosis attacks the sphalerite along irregular cracks and fissures in the sphalerite, it then proceeds along the cleavage planes (fig. 2, plate XV). In the mine of Rifugio Albani, north of the Pzo. della Presolana the zinc ore has been oxidized to pure zinc oxide and is used locally as a white point (KROL, 18).

Galena sometimes occurs in great quantities, notably in the Valle del Riso and the Mt. Vaccaregio region (eastern part of the Dossena ore body), sometimes lacking altogether. The most common occurrence is as a replacement of sphalerite by galena along cracks in the rock and then proceeding along the grain surfaces. Metasomatosis of the limestone by galena is also often observed. Galena oxidizes much less than sphalerite, this is probably due to the formation of concentric layers of oxidation ores (anglesite and cerussite) round the galena crystals (fig. 4, plate XV). The silver content of the ores is due to a small content of silver ores in the galena. Specially the mines of Valle del Riso and Pzo. Arera are relatively rich in silver.

Argentite is certainly present, probably also polybasite.

Pyrite is very common in all the ores, but mostly in small quantities. Some of the ores of Valle del Riso showed beautiful idiomorphic pyrite crystals of some 2 mm diameter.

A very common inclusion in galena are fahlores, mostly Tennantite (Cu-As fahlore) and perhaps freibergite (Cu-Sb fahlore). Larger crystals occur in the Valle Vedra mines, up to 1.5 mm diameter (fig. 3, plate V). Covelline (CuS) probably replaces tennantite.

Bournonite is very rare and has only be found in some polished samples of Dossena and Valle del Riso.

Baryte and fluorspar accompany, together with calcite, the ore impregnation.

Baryte is the only mineral exploited north of the Pzo della Presolana (VISSER, 14). This occurrence is a metasomatic replacement of the limestones by baryte. The mineral is broken out the rock in shallow pits and transported to Stalle Muschelo and is of inferior quality.

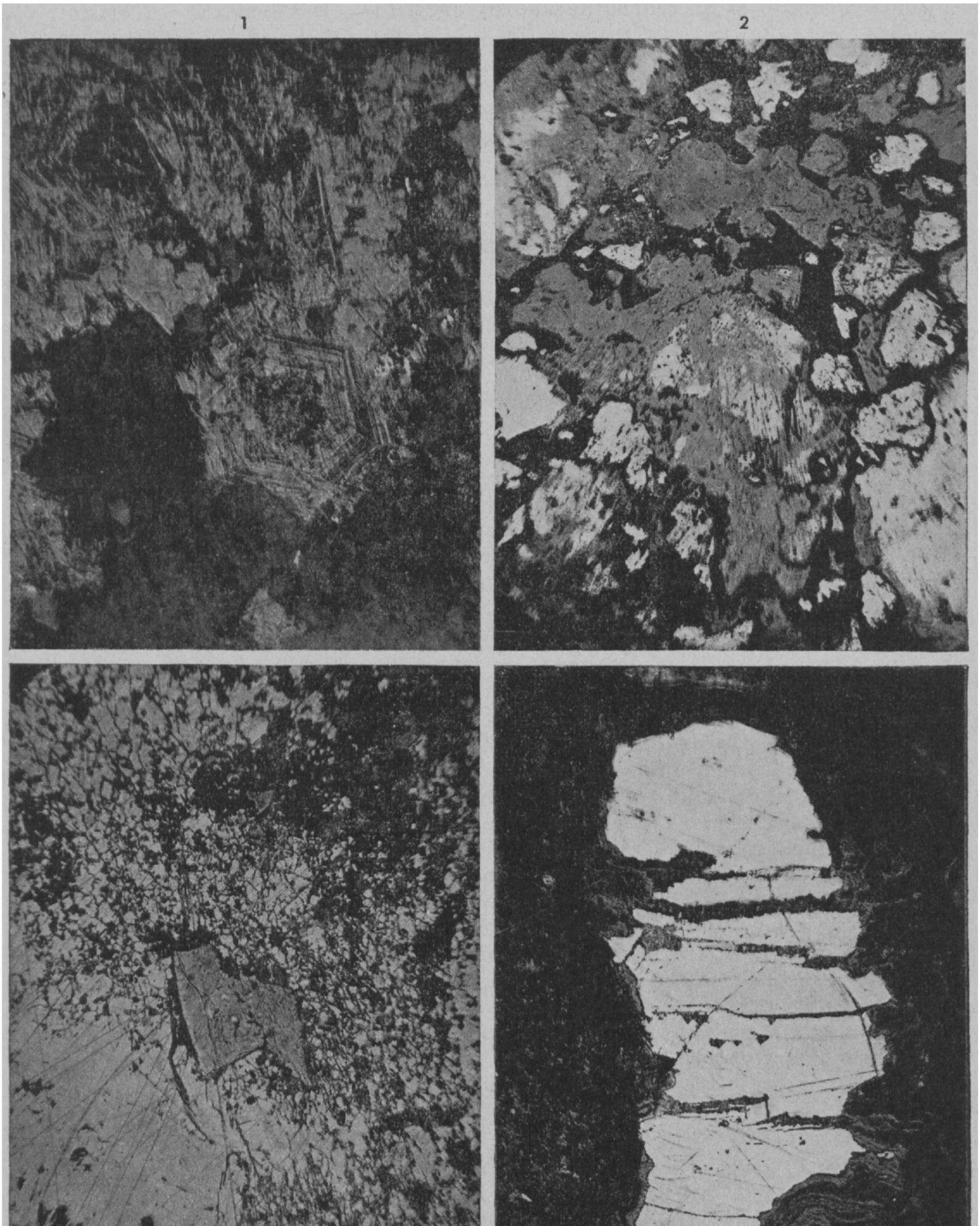
Fluorspar ccurs in great quantities in the mines of Dossena, as a metasomatic replacement of limestone. In the mines of Valle Vedra and Valle del Riso it is also a common mineral. Fluorspar is probably somewhat older than the galena, but younger than the sphalerite, which latter mineral has sometimes been replaced by fluorspar.

The general sequence of phases of impregnation is probably:

Plate XV. Lead and Zinc ores.

1. Zonal sphalerite crystal. The dark constituent is fluorine. Etched with $KMnO_4$ + H_2SO_4 during 18 sec. enl. ± 100 ×.
2. Large sphalerite crystal partially altered in smithsonite. The alteration has followed cleavage planes. Sphalerite is white, pyrite is white with much relief, smithsonite is gray and quartz is black. enl.: 25 ×.
3. In a partially oxidated galena mass appear two intergrown tennantite crystals. enl.: 25 ×.
4. Galena crystal surrounded by rythmic grown oxydation ores. The hexaedron cleavage is clearly visible. enl.: 25 ×.

PLATE XV



1 Sphalerite → 2 Quartz → 3 Fluorspar → 4 Calcite, galena + silver ores and tennantite → 5 Tennantite and pyrargyrite → 6 Calcite.

The determination of the age of the lead-zinc ore impregnation meats with great difficulties. KROL (18) observed that the ore-bearing zone of the Rif. Albani north of the Pzo. della Presolana has been cut off by a horizontal thrustplane, therefore the ore-impregnation must be older than this particular thrustplane and probably older than the Alpine orogenesis. However we know of tertiary dykes, most of them later than the alpine orogeny, which have also been cut off by faults. The above mentioned argument is therefore not conclusive. Another important feature is the fact that *all* the lead-zinc ores are rigorously restricted to the Upper Ladinien, whatever in lithological development may be and little reason can be detected why these limestones or bitumineus shales offered more favorable circumstances to metasomatism than any other of the Triassic limestones.

With these facts in mind TROMP (6) ascribes a Carnien (or an Upper Ladinien) age to the ore impregnation, whilst HOFSTEENGE (9) prefers to suppose a Tertiary age as this latter formation shows more intrusive and volcanic activities.

To my mind the evidence of the restricted occurrence of the ores in one horizon over great distances and its dependence of tectonical lines must be accepted as final as long as no other explanation of these facts has been brought forward. Moreover some volcanic activity has taken place in the Carnien, as part of this formation consists of volcanic tufs.

The Siderite iron ores occur in the north west of the Bergamasc Alps. They have been described by DOZY (10), WEEDA (13), KROL (18), ZIJLSTRA (23).

The ore consists of siderite mostly with a varying amount of haematite and often accompanied by pyrite, always together with quartz. Next to siderite the younger minerals pyrite, chalcopyrite, arsenopyrite, pyrrhotine and calcite, and perhaps marcasite were observed by HOFSTEENGE in samples from the „Vena del Ferro" in the upper Valle di Venina (10). These veins have a thickness of several metres, in general the siderite veins are much thinner. All the iron ores occur in rocks older than the Anisian, either in the Lower Triassic Servino (i Fondi, Nona) or in Permian schists (min. del Collo, Mt. Vigna Soliva, Pso della Manina) or in the basement rock (Vena del Ferro in gneiss chiaro). They are bound to tectonic zones, faults or thrustplane of tertiary age. The Upper Val di Scalve from Nona up to I Fondi is especially rich in these iron ores. Everywhere deserted or still working galleries are encountered. Probably the time of the hydrothermal impregnation is therefore also younger tertiary and may be brought in connection with the large intrusion of the Adamello tonalite.

Most of the mines have been shut down long ago, but in each period when the country had been shut off more or less from the international market as in the war of 1914—'18, or under the autarchic reign of present times a new impetus has been given to this local mining industry. The mines of i Fondi, Pso della Manina, Oneta, Dossena have all been brought to new life in later years. Production quantities and statistics of individual mines or of the whole district are not available to the writer.

Barite is mined at two localities in the Valsassina, viz. in the Vle Cagnaletto and then some 800 m to the NW. The largest barite vein is 5 m thick and lies between the Verrucano and the Werfenien. They can be compared to similar veins in the Lugano district[1]) and belong to the last manifestations of the Permian volcanic activity reaching into the Triassic.

[1]) L. U. DE SITTER. Les porphyres luganais entre le Lac de Lugano et le Valganna. Leidsche Geol. Med. I, 1925.

PH. H. KUENEN. The porphyry district of Lugano west of the Valganna. Leidsche Geol. Med. I, 1925.

CHAPTER VII.

AGE OF THE METAMORPHIC AND INTRUSIVE ROCKS.

In the preceeding pages we have described a highly metamorphic series of para- and ortho-schists, which have been intruded by rocks of a younger age. To the highly metamorphic series belong all the para-schists, the Valsassina granulite, some smaller occurrences of ortho-metamorphic rocks and the amphibolites. To the younger intrusive rocks belong the gneiss chiaro, the Val Biandino granodiorite and the Fioraro granite-gneiss.

A third group, of Triassic intrusives, is restricted to the Val Dezzo porphyrite and the Mt. Guglielmo porphyrite. The Tertiary dykes together with the large Adamello tonalite intrusive constitute the fourth and youngest group of intrusives.

The oldest ortho-metamorphic rock, the Valsassina granulite, differs from the younger intrusives of the second group, the gneiss chiaro, Val Biandino granodiorite and Mt. Fioraro gneiss, mainly in its metamorphic state. The granulite is highly metamorphic of the mesozone or biotite-zone, the same as all the para-schists, whilst the second group of intrusive rocks has acquired nothing but a cataclastic habitus and some recrystallization of chlorite, sericite and such minerals, all features pointing to the highest part of the epizone.

The Permian volcanic rocks, the Collio schists and even the Lower Triassic Servino rocks show a similar state of metamorphism. Cataclastic structures in the coarser-grained variaties, and chlorite and sericite metamorphism in the tufs and fine-grained rocks of the Servino, are typical. Even the Tertiary dykes when situated in epi-metamorphic Collio schists have acquired a certain schistosity. There can be little doubt that this metamorphism is wholly due to the alpine orogeny. The Adamello tonalite mass shows very little dynamo-metamorphism, as it has been intruded in the latest phase of the alpine orogeny. Its „mise en place" leaves no doubt that the main tectonic structures had been formed before its intrusion. This fact is corroborated by a hornblende porphyrite dyke of the Pzo della Presolana which follows a crushed zone of a nearly vertical thrustzone, but is cut off and shifted some 50 m to the south by the horizontal thrustplane of the Ardesio thrust, which in itself has a much larger dimension, measured in hundreds of meters (VISSER 14, 1937, p. 140). Therefore the intrusion of Tertiary rocks occurred at a very late stage of the alpine orogeny and these rocks suffered accordingly very little metamorphism. Without doubt older rocks like the gneiss chiaro, suffered considerably more strain and at greater depth, during the alpine orogenetic period, accordingly their alpine metamorphism will be much more intense than that of the Tertiary rocks.

The second group of intrusives, however, may have suffered more dynamo-metamorphism in some more remote period. They belong to the basement rock i. e. they are of at least Prae-Permian age, and therefore must have undergone at least a part of the orogenetic phase which separates, in the whole alpine system, the basement rock from its Permian-Mesozoïc mantle.

In the central massives of the Swiss Alps one of the main variscean orogenesis must be one of Upper-Carboniferous age, as the Upper-Carboniferous itself is folded in the basement rock and overlain unconformibly by Triassic sediments [1]). The folding phase is supposed to be the Asturian and/or the Saalic phase, as it must be post Upper-Westphalian. The intrusive granites, Gotthard and Aare granite, are supposed to be also of Upper-Carboniferous age, mainly because in the Carboniferous conglomerates no pebbles or boulders of these granites where ever found [2]). We have seen already that petrographically our gneiss chiaro is almost identical with the Gotthard granite, moreover, its state of metamorphism is very similar. Therefore there can not be many arguments against the assumption that the gneiss chiaro, and with it, the Fioraro granite and the Val Biandino granodiorite which belong undoubtly to the same group, are also of Upper-Carboniferous age.

However, in the central Alps, by lack of determinable sedimentary strata of palaeozoïc age, except the Upper-Carboniferous, the age determinations of palaeozoïc incidents are not very satisfactory. We have to turn our attention to Kärnten, much further east before we encounter a good Palaeozoïc rock sequence. Here a rather complete series is developed and a conception of the geological history has been given by HERITSCH [3]). On the crystalline basement rock, consisting of highly metamorphic para-schists mostly, Upper-Ordovician sediments are deposited followed by Silurian and Devonian. The Caledonic orogenetic phase is very slight and only represented by the Taconic phase discernable as a slight unconformity between Ordovician and Silurian.

Of the Variscean orogeny the Bretonnic phase causes the transgression of the Lower-Carboniferous Hochwipfel schists over older sediments of Devonian and sometimes Upper-Silurian age, but is in itself not a major orogenetic phase, with nothing but slight folding. According to GAERTNER [4]) the denudation never went deeper than 200 m. The major Caledonic phase of the Karnian Alps is the Sudetian phase because the unconformable Naszfeld schists are of Upper-Carboniferous age. According to JONGMANS [5]) however the Auernig horizon, together with other occurrences in Tirol belonging to the Naszfeld schists, is of Westphalian D and E age, and the preceding orogenetic phase could be of Asturian age as well. This orogenetic phase is very important, it has created the large scale palaeozoïc nappes of the Karnian Alps, but has failed to produce a pronounced metamorphism in the older sedimentary rocks except in the phyllites of the Plenge faciës.

Therefore the conclusion at which both HERITSCH and SCHWINNER [6]) arrive,

[1]) B. G. ESCHER. „Ueber die praetriassische Faltung in der Westalpen". Amsterdam 1911.

[2]) ALB. HEIM. „Geologie der Schweiz", Vol. II/1, Leipzig 1921. The argument is perhaps not very conclusive as the outcrops of carboniferous conglomerates are very rare and of no great volume.

[3]) FR. HERITSCH. „Die karnische Alpen". Graz 1936.

[4]) H. R. VON GAERTNER. „Geologie der zentralkarnischen Alpen". Denkschr. Ak. Wiss. Wien Math. nat. Kl., Bd. 102, 1931.

[5]) W. J. JONGMANS. „Die Flora des Stangalps Gebietes in Steiermark". 2e Congr. Stratigr. Carb. t. III, Heerlen 1938.

W. J. JONGMANS. „Palaeobotanische Untersuchungen im Oestreichischen Karbon". Berg- u. Hüttenmännische Monatshefte, Bd. 86, 1938.

[6]) R. SCHWINNER. „Das Karbongebiet der Stangalpe". 2e Congr. Stratigr. Carb. Heerlen III, 1938.

is that the basement rock has been metamorphosed neither during the Variscean orogeny nor in the Caledonian orogenetic phase, but in a prae-palaeozoïc orogeny. There is no reason why this age of the basement rock of the Karnian Alps should not be applied also to our para-schists of the basement rock.

Summarizing we may say that in analogy with Kärnten the para-schist basement rock with the Valsassina granulite is probably of prae-Ordovician age, and in analogy with the geology of the central massives of the Swiss Alps the ortho-rocks of prae-Tertiary age are probably of Upper-Carboniferous age, but could be much older as no major orogeny causing severe metamorphism is known either in the Caledonian or in the Variscean orogenetic phases.

TROMP (6) considered the Fioraro gneiss a Tertiary intrusive. His arguments, however, are very feeble and often based on tectonic reasoning. It is true that the Fioraro granite differs somewhat in chemical composition and mostly by the large zone of injection gneisses surrounding it, from the gneiss chiaro, but there is no reason why this difference should be ascribed to an age difference. On the contrary, the mineralogical and chemical compositions of gneiss chiaro and Fioraro gneiss are sufficiently alike to assume a common origin of the magmas. The differences of contact-metamorphic zones and formation of injection gneisses and tectonics are due in any case to differences of depth of intrusion and other external circumstances and cannot be used as arguments in an age determination.

In the chapter on the granodiorites a comparison between the differentiation diagram of these rocks with those of the Permian porphyries of Lugano and of the Err-Bernina thrust sheet was made. The great similarity suggests a common origin or at least close relationship. PORRO [1]) in his work on the Valsassina granodiorite assumed already the rélationship of the intrusive rocks with the extrusive rocks and suggests a Permian age for a porphyric granite, which CROMMELIN (8) regards as a marginal facies of the granodiorite and therefore of Upper-Carboniferous age. BUNING (7) and CROMMELIN (8) agree with PORRO that the granodiorite must be older than the Permian because of its geological position. Both arguments are conclusive, but are not altogether irreconcilable. Undoubtedly the intrusion of the granodiorite is older than most or all the extrusive lavas as the granodiorite is an integral part of the basement rock and the porphyries are the oldest rocks of the unconformable overlying strata. But on the other hand we know from the Lugano district [2]) that the porphyries were deposited immediately on the young erosion landscape of mica-schists, and that considerable erosion took place in between the extrusive periods.

In an earlier paper [3]) the author like DOZY (10a) and ZIJLSTRA (23) pointed out that the Collio schists, to which the porphyries belong, were deposited in a period in which the variscean orogenic phase had not yet been closed.

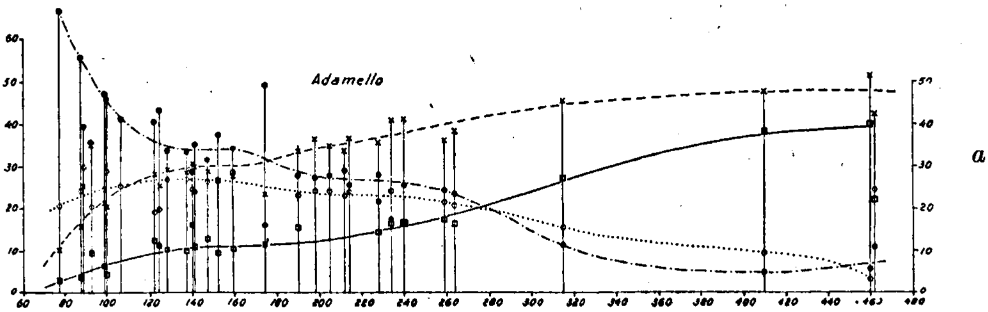
These considerations all point to one conclusion viz. that the intrusion of large magmatic bodies, the extrusions of lavas, the raising of variscean mountain chains, and the last manifestations of this orogeny happened in

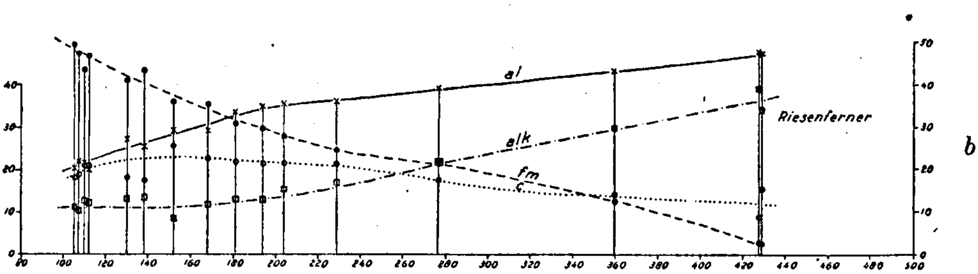
[1]) C. PORRO. Cenni preliminari ad un rilievo nelle Alpe Orobie. Rend. R. Ist. Lomb., Vol. 30, 1897.

C. PORRO. Rocce granitiche della Valsassina. Rend. R. Ist. Lomb., Vol. 31, 1898.

[2]) L. U. DE SITTER. Les porphyres luganois et leurs enveloppes. L. G. M. XI, 1939.

[3]) L. U. DE SITTER. La géologie des Alpes meridionales etc. Geol. & Mijnb. 1939.





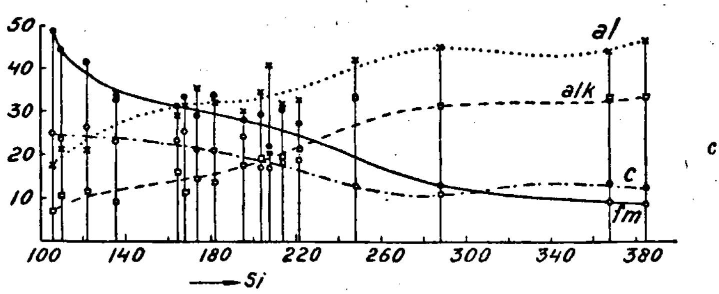


Fig. 14.

Differentiation diagrams of Tertiary intrusive rocks.
a. Adamello intrusive mass. *b*. Riesenferner intrusive mass. *c*. Combination of the Traversella, Biella and Bregaglia intrusive masses.

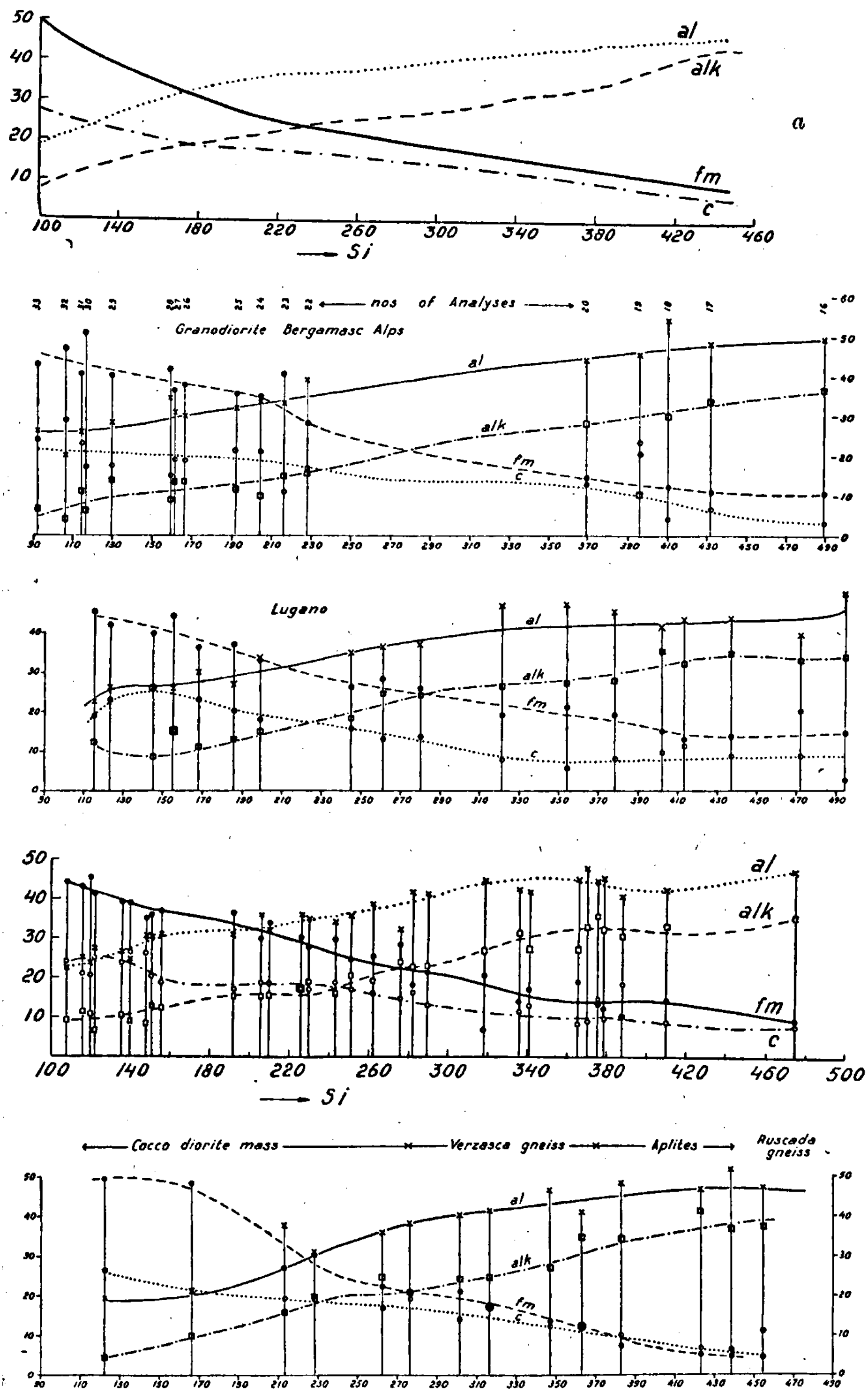


Fig. 15.

Differentiation diagrams of Permo-Carboniferous igneous rocks.
a. Gotthard mass. *b.* Granodiorite of Val Biandino. *c.* Porphyries of Lugano. *d.* Err-Bernina intrusives. *e.* Coccodiorite.

a period which occurred at the end of the Carboniferous and extended into the Lower-Permian.

The sequence of the magmatic cycle, was a continuous process, first the intrusion of the ordinary granodiorite, perhaps preceded by the noritic basic differentiates, then the more granitic intrusion, which intruded the existing granodiorite rock, then porphyric dykes, either of quartzporphyries or of porphyrites and finally extrusions, which continued for a long time into the Permian. A boundary between Carboniferous and Permian is impossible to trace in this continuous process.

NIGGLI [1]) compared already the Variscean (Hercynean) intrusives with the Permian rocks. His comparison can be extended now with our newer analyses of more Permo-Carboniferous rocks of which the isofaly values are assembled in the following table.

	Isofaly points			
	si	al = fm	c	alk
Schwarzwald	220	31.5	16	21
Aare granites	200	32	15	21
Gotthard granites	185	31.5	20.5	16.5
Selva Nera merid.	220	31.5	16	21
Zillertal	190	32	20	16
Lower east-Alpine nappes	200	32	18	16
Lugano porphyries	210	31	18	15
Granodiorite Valsassina	210	33	19	14
Verzasca gneiss	220	29	19	18

The Tertiary intrusives have quite a different character, which difference has been mentioned already by C. DE SITTER—KOOMANS [2]), who compared the Lugano porphyries with the Tertiary differentiation diagram of Biella, Traversella and Bregaglia. This comparison can now be extended with the differentiation diagrams of the Adamello intrusives [3]) and those of the Riesenferner [4]) and the Cocco mass [5]).

In figs. 14 and 15 the Tertiary diagrams are assembled and compared to some of Permo-Carboniferous age. The different position of some of the intersection points of the different lines is very striking:

[1]) P. NIGGLI. Petrographische Provinzen der Schweiz. Viertelj. Schw. Naturf. Ges. 1919.

[2]) C. M. KOOMANS. Der Chemismus des luganer Porphyrgebietes. L. G. M. IX, 1937.

[3]) A. BIANCHI, Gb. DAL PIAZ, Il settore meridionale dell Massiccio dell'Adamello. Boll. R. Uff. geol. d'Italia. LXII, 1937.

M. FENOGLIO. Studi geologico-petrografici sulla Val Nambrone (Massiccio dell'Adamello). Mem. dell Ist. Geol. Univ. Padova. XIII, 1939.

C. GOTTFRIED. Die basischen Einschlüsse im Tonalit des Adamello. Chem. d. Erde, VII, 1932.

[4]) A. BIANCHI, Gb. DAL PIAZ, La Monographia geologico-petrografica sull'Alto Adige orientale e Regioni limitrofe. Relazione dei risultati. Periodico di Mineralogia. Anno X, n. 2, 1939.

[5]) H. PREISWERK. Der Quartzdiorit des Coccomassivs (zentr. Tessiner Alpen). Schweiz. Min. Mitt., Bd. XI, 1931.

	Granodiorite	Cocco	Bregaglia	Adamello	Riesenferner
al. = fm at si =	210	220	170	170	175
c = alk at si =	230	230	205	275	260
fm = alk at si =	280	275	230	275	275

The lower si value of the al/fm intersection, the isofaly point, of the Tertiary intrusives, is conspicuous. The Adamello and Riesenferner diagrams are very similar but differ somewhat from the Bregaglia diagram, mostly due to a totally different c line, which in the Adamello-Riesenferner diagrams has an exceptionally high position between si = 120 and si = 240 (25 in Adamello, 22 in Riesenferner). With higher si values the c line drops to a lower level, but remains constantly higher than the fm line, whereas in normal kalkalkali or alkali diagrams, even as in the Permo-Carboniferous diagrams the c line always drops below the fm line. In the Bregaglia diagram the c line is much more normal but intersects the fm line at a rather high si value and in this way rises above the fm line.

The very high c value of the Adamello may be ascribed to limestone assimilation, as the „mise en place" of this intrusive mass necessitated a large volume of Triassic limestones to be absorbed.

The Cocco diorite and Verzasca gneiss diagram of Preiswerk shows the same feature of c line rising above the fm line as the Tertiary diagrams, but is in other respects much more like the Permo-Carboniferous diagrams.

APPENDIX.

List of rock analyses of the Bergamasc Alps.

All analyses have been made by C. M. DE SITTER—KOOMANS, if not stated otherwise.

Specimen and slide numbers refer to the official nos of the Rijks Museum voor Geologie en Mineralogie at Leiden.

Literature numbers refer to the list of „Contributions to the Geology of the Bergamasc Alps" printed opposite the index map p. 7.

The localities of the analysed rock specimen are indicated on the map Plate XXXVII by the number of the analysis.

	1	2	3	4	5	6	7
SiO_2	78.56	43.80	71.98	76.31	75.05	73.95	74.89
TiO_2	0.04	1.45	1.36	—	—	—	—
P_2O_5	—	0.15	0.16	0.10	0.10	0.14	0.12
Al_2O_3	8.63	29.92	12.10	13.06	13.43	13.81	12.84
Fe_2O_3	5.65	4.45	0.61	1.24	0.97	1.07	1.14
FeO		4.35	3.73	0.34	0.33	0.59	0.68
MnO	0.04	0.11	0.05	0.02	0.04	0.04	0.03
MgO	1.05	2.93	1.65	0.48	0.78	0.58	0.63
CaO	1.44	2.47	0.72	0.95	0.77	1.23	1.09
Na_2O	1.28	2.55	1.35	3.47	3.48	2.86	3.51
K_2O	1.61	4.41	2.27	3.27	3.75	3.90	4.26
$+H_2O$	1.26	3.04	2.84	0.70	0.63	1.05	0.73
$-H_2O$	0.23	0.12	0.21	0.11	0.10	0.10	0.11
CO_2	—	0.30	0.94	0.08	0.38	0.71	0.22
	99.79	100.05	99.97	100.21	99.81	100.03	100.25
si	532	118	429	472	466	436.5	436
al	34.1	48	42.5	47.5	49	48	44
fm	40.2	31	36	12	10	13	13.5
c	10.6	7	5	6.5	5	8	6.5
alk	15.0	14	16.5	34	36	31	36
k	0.43	0.53	0.52	0.38	0.42	0.47	0.44
mg	0.26	0.38	0.41	0.36	0.35	0.40	0.41
c/fm	0.26	0.23	0.13	0.52	0.54	0.59	0.49
ti	—	2.9	6.1	—	—	—	—
p	—	0.16	0.36	0.36	0.37	0.35	0.35
h	—	28.4	64.2	18.19	14.88	24.50	16.13
co_2	—	1.14	7.5	—	—	—	—

No.	Kind of rock	Specimen no.	Slide no.	Locality, references
1	Quartzite	—	—	Prati della Brusada, lit. 6
2	Sericite-garnet-phyllite	32507	1840	South of Corno Stella
3	Granulite	—	3111	Cima d'Agrella
4	Gneiss chiaro	32513	1810	Path from Forno to Baita Salinoni
5	Gneiss chiaro	41490	3235	Val Muggiasca between Bellano and Taceno
6	Gneiss chiaro	32458	3018	Top of Pizzo Cornagiera
7	Gneiss chiaro	32504	1812	Baita dell'Arete, Cima di Lemma

	8	9	10	11	12	13	14
SiO_2	74.99	72.46	70.67	65.60	53.91	65.49	64.60
TiO_2	0.05	0.42	0.73	1.02	1.06	1.17	1.04
P_2O_5	—	0.11	0.14	0.27	0.17	0.15	0.11
Al_2O_3	11.64	13.64	15.06	15.23	17.28	14.60	15.61
Fe_2O_3	3.96	1.10	0.25	1.52	2.08	1.78	0.99
FeO		1.33	1.63	3.47	7.14	4.30	4.55
MnO	0.04	0.04	0.06	0.06	0.11	0.06	0.04
MgO	1.18	0.47	1.05	1.66	3.99	2.01	2.20
CaO	2.17	1.39	2.05	2.21	4.07	2.81	4.01
Na_2O	2.10	3.65	4.01	2.02	2.71	2.67	2.30
K_2O	2.27	4.73	1.99	4.54	3.29	3.74	3.43
$+H_2O$	1.23	0.75	0.98	2.12	3.29	1.26	1.12
$-H_2O$	0.19	0.05	0.02	0.08	0.13	0.08	0.19
CO_2	—	—	1.20	—	0.82	0.16	0.13
	99.82	100.14	99.94	99.80	100.05	100.28	100.32
si	431	385	360	290	163	267	251
al	39.26	43	45.5	39.5	31	35	35.5
fm	27.43	14	16.5	28.5	41	32.5	30.5
c	13.35	8	11.5	10.5	13.5	12	17
alk	19.96	35	26.5	21.5	14.5	20.5	17
k	0.42	0.46	0 24	0.59	0.44	0.48	0.49
mg	0.37	0.37	0.50	0.38	0.44	0.38	0.43
c/fm	0.49	0.55	0.68	0.36	0.32	0.38	0.55
ti	0.21	1.60	2.82	3.45	2.4	3.70	3.03
p	—	0.32	0.31	0.54	0.18	0.24	0.23
h	—	14.10	17.18	32.37	34.7	18.12	17.01
co_2	—	—	—	—	—	—	—

No.	Kind of rock	Specimen no.	Slide no.	Locality, references
8	Gneiss chiaro	—	—	Cma della Rosetta
9	Granite	41479	4918	Mt. Fioraro, lit. 6
10	Granite gneiss	32476	1674	Between Pzo delle Segade and Mt. Fioraro
11	Injection gneiss	41487	1655	Psso di Pedena
12	Injection gneiss	32495	—	Psso San Marco
13	Injection gneiss	32508	4922	Laghi di Porcile, Plate VI fig. 5
14	Injection gneiss	32500	1839	Laghi di Porcile

	15	16	17	18	19	20	21
SiO_2	63.70	76.05	74.00	71.66	72.28	69.83	66.90
TiO_2	1.03	—	0.10	0.10	0.07	0.17	0.54
P_2O_5	0.12	0.18	0.22	0.19	0.16	0.18	0.13
Al_2O_3	15.93	13.10	14.06	16.03	14.12	14.12	15.67
Fe_2O_3	0.72	1.43	0.62	1.26	1.31	0.55	1.24
FeO	5.13	0.25	0.63	0.59	1.51	1.12	2.83
MnO	0.05	0.02	0.04	0.03	0.08	0.09	0.04
MgO	2.39	0.29	0.62	0.49	0.97	0.92	1.51
CaO	3.08	0.43	1.01	0.63	1.78	2.31	2.69
Na_2O	3.01	3.11	2.72	1.44	2.75	2.68	3.50
K_2O	3.59	4.17	5.01	6.01	2.54	4.37	3.04
$+ H_2O$	0.95	1.09	0.98	1.38	1.34	1.60	1.23
$- H_2O$	0.20	0.07	0.05	0.17	0.11	0.26	0.20
CO_2	0.11	—	—	—	0.74	1.66	0.36
	100.01	100.19	100.06	99.98	99.76	99.86	99.88
si	242	489	432	410	396	369	292
al	35.5	49.5	48.5	54	45.5	44	40
fm	32	11	11	12	20.5	14.5	24.5
c	12.5	3	6.5	4	10.5	13	12.5
alk	20	36.5	34	30	23.5	28.5	23
k	0.49	0.47	0.55	0.74	0.38	0.52	0.37
mg	0.43	0.24	0.47	0.33	0.39	0.50	0.41
c/fm	0.39	0.28	0.56	0.33	0.52	0.89	0.52
ti	2.87	—	0.70	0.69	—	0.64	1.81
p	0.23	0.38	0.35	0.34	0.33	0.32	0.26
h	10.02	24.70	20.00	29.55	26.65	32.69	20.62
co_2	—	—	—	—	—	—	—

No.	Kind of rock	Specimen no.	Slide no.	Locality, references
15	Injection gneiss	41489	4920	Laghi di Porcile
16	Aplite	27135	3027	Vle Rossiga, Plate VIII, fig. 3
17	Granite	27292	2938	Stalle di Mt. Spina, Val Troggia, Plate VIII, fig. 1
18	Granite	27165	3028	Vle Rossiga
19	Granite	41478	3035	Vle Rossiga, Plate VII, fig. 1, 2
20	Granite	41480	—	Cortabbio, leucocrate part of „panther skin''
21	Granite and biotite-diorite	41481	3273	Vle Rossiga

	22	23	24	25	26	27	28
SiO_2	61.43	60.82	58.64	55.75	55.62	59.06	53.47
TiO_2	0.85	1.08	0.65	0.89	1.36	0.91	1.23
P_2O_5	0.15	0.32	0.21	0.36	0.19	—	0.16
Al_2O_3	18.09	15.62	16.64	17.25	18.18	16.71	19.67
Fe_2O_3	1.00	0.90	0.58	0.26	1.47	0.82	0.36
FeO	4.56	6.13	5.34	5.80	6.39	6.07	6.61
MnO	0.07	0.26	0.16	0.19	0.13	0.04	0.08
MgO	1.94	3.70	4.31	5.03	3.99	3.61	5.41
CaO	4.23	2.89	5.73	5.82	6.07	6.07	4.75
Na_2O	2.97	3.02	1.81	3.35	3.20	2.73	2.24
K_2O	2.09	1.94	1.62	1.89	2.42	1.37	1.41
$+ H_2O$	1.35	2.94	2.36	1.42	0.95	1.69	4.06
$- H_2O$	0.19	0.05	0.15	0.14	0.07	0.09	0.09
CO_2	1.12	0.43	1.68	1.92	0.09	—	0.49
	100.04	100.10	99.88	100.07	100.13	99.17	100.03
si	228	216	204.5	166	161	192	159
al	39.5	33	34	30	31	32	34.5
fm	28	41	35	38	36.5	35.5	41.5
c	17	11	21	18.5	19	21	15
alk	15.5	15	10	13.5	13.5	11.5	9
k	0.31	0.36	0.37	0.27	0.33	0.25	0.29
mg	0.40	0.48	0.49	0.59	0.49	0.49	0.59
c/fm	0.59	0.27	0.61	0.49	0.51	0.60	0.37
ti	2.23	2.78	1.68	1.96	2.88	2.15	2.68
p	0.22	0.43	0.42	0.54	0.17	—	0.18
h	18.91	35.48	29.14	15.53	9.72	19.34	41.00
co_2	—	—	—	—	—	—	—

No.	Kind of rock	Specimen no.	Slide no.	Locality, references
22	Biotite-granodiorite	41482	3253	Val Marcia
23	Biotite-granodiorite	27496	3267	Val Marcia
24	Hornblende granodiorite	41483	2942	South of Cma Pianca, Plate VII, fig. 4
25	Kersantite	32442	3299	Vle Rossiga
26	Quartz-diorite	41484	4919	Mt. Fioraro, Plate IX, fig. 1, 2
27	Quartz-diorite	—	—	Cortabbio, Valsassina, an.: Giammarino
28	Quartz-diorite	41485	1679	Scallugio, Val Brembo, Plate IX, fig. 3

	29	30	31	32	33	34	35
SiO_2	50.10	48.30	46.32	47.11	42.25	54.26	48.36
TiO_2	1.05	0.53	4.05	1.36	0.66	1.90	2.22
P_2O_5	0.29	0.26	0.36	0.18	0.31	0.34	—
Al_2O_3	18.71	18.51	17.67	15.10	20.93	15.87	16.90
Fe_2O_3	1.09	3.08	0.88	1.36	1.70	3.40	1.14
FeO	7.58	7.31	9.76	7.56	4.92	7.83	6.77
MnO	0.36	0.36	0.21	0.12	0.38	0.22	—
MgO	5.40	8.39	4.88	10.53	9.45	3.59	9.80
CaO	6.29	6.71	8.80	11.98	10.31	4.75	7.75
Na_2O	3.86	1.38	3.58	0.97	1.90	3.96	0.66
K_2O	2.69	1.81	1.45	1.48	1.68	1.93	5.08
$+ H_2O$	1.72	3.03	1.65	1.57	1.61	2.07	1.40
$- H_2O$	0.10	0.08	0.15	0.14	0.12	0.04	0.05
CO_2	0.65	0.41	—	0.68	0.69	—	—
	99.89	100.16	99.76	100.14	99.91	100.16	100.11
si	129	115.5	114	106	92	159	108
al	28.5	26	25.5	20	26.5	27.5	22.5
fm	40	51	40.5	47	43	42.5	47
c	17.5	17	23	29	24	15	18.5
alk	14	6	11	4	6.5	15	12
k	0.32	0.46	0.21	0.51	0.37	0.24	0.08
mg	0.52	0.59	0.44	0.76	0.71	0.37	0.69
c/fm	0.43	0.34	0.58	0.61	0.56	0.35	0.39
ti	2.01	1.01	9.33	2.29	1.04	4.22	3.7
p	0.31	0.29	0.44	0.13	0.26	0.35	—
h	15.64	24.85	14.82	12.77	34.24	20.6	10.9
co_2	—	—	—	—	—	—	—

No.	Kind of rock	Specimen no.	Slide no.	Locality, references
29	Biotite-diorite	41480	4921	Cortabbio, Melanocrate xenolith in „panther skin" Plate VIII, fig. 5
30	Hornbl.-granodiorite	41486	2976	NE of Alpe Piarola
31	Kersantite	32479	1680	Pso di Pedena, Plate IX, fig. 5
32	Hornbl.-diorite	41491	1677	Mt. Fioraro
33	Norite	41488	2972	NE of Casa Gore, Plate VII, fig. 3
34	Biotite-amphibolite	—	3703	Lago della Malgina, lit. 12
35	Amphibolite	36051	—	Valle del Goglio, an.: HEERTJES, Pl. X, fig. 5 Mt. della Croce, lit. 17

	36	37	38	39	40	41	42
SiO_2	77.70	73.71	55.60	65.70	56.81	58.41	56.03
TiO_2	—	—	—	0.73	1.39	0.64	0.92
P_2O_5	0.10	0.18	—	0.19	0.26	0.30	0.34
Al_2O_3	10.09	13.77	22.30	16.07	18.00	18.27	19.57
Fe_2O_3	1.00	2.02	3.50	2.23	0.29	1.89	0.80
FeO	0.59	0.50	4.50	1.81	3.82	2.71	3.98
MnO	0.05	0.04	—	0.10	0.13	0.13	0.18
MgO	0.96	0.49	1.65	2.06	2.96	4.22	5.37
CaO	0.86	1.07	1.75	1.92	7.62	6.73	6.05
Na_2O	3.20	1.72	1.56	2.89	2.40	2.99	2.83
K_2O	3.45	5.22	3.42	3.25	1.65	1.20	1.42
$+ H_2O$	1.40	0.88	2.42	2.37	3.84	1.68	2.21
$- H_2O$	0.18	0.22	—	0.44	0.50	0.28	0.12
CO_2	0.57	—	2.52	—	0.24	0.36	0.28
	100.15	99.82	99.22	99.76	99.91	99.81	100.10
si	520	433	202	289.1	190.1	184	166
al	40	47.7	48	41.6	35.5	34	34
fm	18	16.1	32	27.9	26.2	32	36
c	6	6.8	7	9.1	27.3	22.5	19
alk	36	29.4	13	21.4	11	11.5	11
k	0.42	0.27	0.59	0.43	0.32	0.21	0.25
mg	0.53	0.67	0.28	0.49	0.57	0.62	0.66
c/fm	0.33	0.42	0.21	0.33	1.04	0.71	0.54
ti	—	—	—	—	—	1.5	2.1
p	0.40	—	—	—	—	0.38	0.36
h	35.5	—	28.5	—	—	20.6	23.0
co_2	5.2	—	12.4	—	—	1.5	1.1

No.	Kind of rock	Specimen no.	Slide no.	Locality, references
36	Quartz-porphyry	—	—	Lago di Val dei Frati, lit. 10
37	Quartz-porphyry	—	—	Fraine, Val Camonica, lit. 22
38	Porphyrite	—	—	Val. Dezzo, Pl. XII, fig. 1, an.: Gümbel
39	Pyroxene porphyrite	—	—	Mt. Guglielmo, lit. 22
40	Hornbl.-diorite-porphyrite	—	—	Val d'Agra, Pl. XIII, fig. 5 lit. 21
41	Spessartite	35519	3665	Vle Sambuzza
42	Vintlite	35520	3662	Mt. Masoni South flank

	43	44	45	46	47	48	49
SiO_2	56.12	52.98	45.93	45.47	44.86	57.48	75.30
TiO_2	0.97	0.71	1.63	0.95	—	0.37	0.05
P_2O_5	0.33	0.29	0.38	0.31	—	0.10	—
Al_2O_3	17.13	18.03	22.27	13.86	12.00	22.04	3.27
Fe_2O_3	1.69	2.76	0.26	2.42	3.05	5.02	8.30
FeO	4.67	4.19	6.65	5.99	8.22	3.54	—
MnO	0.16	0.16	0.23	0.23	—	0.02	0.04
MgO	5.70	4.81	4.79	11.36	16.34	3.30	1.21
CaO	6.34	7.52	8.75	9.23	10.00	0.74	1.79
Na_2O	2.06	2.63	1.98	1.15	3.69	2.64	5.09
K_2O	2.41	1.31	1.52	1.33	1.84	2.28	3.33
$+ H_2O$	1.92	3.70	4.33	4.59	—	2.19	1.32
$- H_2O$	0.07	0.89	0.15	0.10	—	0.06	0.21
CO_2	0.22	—	0.81	2.68	—	—	—
	99.79	99.98	99.68	99.67	100.00	99.78	99.91
si	164	151.5	119	103	80	196	397
al	29.5	30.3	34	18.5	12.5	44.2	10.13
fm	40.5	36.9	34	54.5	60	39.5	42.72
c	19.5	23.1	24.5	22.5	19	2.6	10.13
alk	10.5	9.7	7.5	4.5	8.5	13.7	37.0
k	0.44	0.25	0.25	0.42	0.27	0.36	0.30
mg	0.61	0.56	0.54	0.71	0.73	0.42	0.22
c/fm	0.49	0.63	0.71	0.41	0.32	0.07	0.24
ti	2.1	—	3.12	1.6	—	—	—
p	0.35	—	0.47	0.27	—	—	—
h	19.3	—	38.85	35.5	—	—	—
co_2	0.88	—	—	8.3	—	—	—

No.	Kind of rock	Specimen no.	Slide no.	Locality, references
43	Spessartite	—	—	Valle di Venina South of L. di Venina
44	Hornblende-diorite-porphyrite	—	—	Val d'Agra, lit. 21
45	Porphyrite	27134	3006	Val Marcia
46	Augite-diorite	(154)	4846	Mt. Campione, Plate XIII, fig. 3
47	Augite-porphyrite	—	—	Val Flesch, Clusone; anal.: ARTINI
48	Mylonite	—	—	Monte Masoni, lit. 10
49	Mylonite	—	—	Prati della Brussada, lit. 6

PART II.

STRATIGRAPHY OF THE SEDIMENTARY ROCKS.

INTRODUCTION.

The stratigraphy of the sedimentary rocks of the Bergamasc Alps offers a very interesting object of study from several points of view. In the first place the slow development of a portion of the great Alpine geosyncline can be followed in great detail by studying facies and thickness of the different strata. The Bergamasc Alps show a very complete development of the Alpine facies of the Triassic with its peculiar lateral alternations of heteropic facies. Together with the Venetian Alps and Tirol the stratigraphy of Lombardia forms the basis from which the study of the East-Alpine thrustsheets should start, because in this southern part of the Alpine geosyncline the mutual positions of the different formations in their variable facies can be determined with great accuracy. Since the classic work of Heim and his son on the Säntis thrustsheets, we know that the imbricated structure of piled-up thrustsheets can never be unravelled satisfactorily unless the situation of the different parts in the original basin has been determined according to their facies. It is my firm conviction that unless this southern basin development is properly understood the origin of the great East-Alpine thrustsheets and their relative position in the original basin will remain uncertain.

The group of surveys which are represented on our maps are mainly concerned with the basement rock, treated in Part. I, the Permian and the Triassic. The Rhetic is present on the southern border of the map, younger formations only on the south west corner. These latter formations will be treated here only in a very summary way as no new points of view can be offered.

The Quaternary of the Bergamasc Alps is still unsufficiently investigated as no comprehensive field survey has yet been undertaken.

The *Permian* of the Bergamasc Alps is a non marine mostly psammitic volcanic formation resting locally with a basal conglomerate unconformibly on the basement rock. The age of the rocks belonging to this series is still somewhat uncertain as no fauna and only very scarce plant remains are at our disposal.

The *Triassic*, conformable following the Permian with a very thin transition has in general a marine limestone shelf facies with many heteropic developments. It ends, however, in the uniform Norian dolomite of great thickness. The *Rhetic* is complete everywhere in the Bergamasc Alps and does not differ much in facies from the older Triassic. With the *Liassic*, however, a deep sea facies sets in, which continues throughout this formation and the *Lower-Cretaceous.* In the *Upper-Cretaceous* the depth of the sea diminishes again and the large sedimentation cycle closes with the insufficiently exposed *Eocene.*

Thus the stratigraphic sequence of the Bergamasc Alps comprises the whole period between the Variscean and younger Alpine orogenetic periods. It moves on from a continental facies to a shelf facies and to deep sea facies, to return to a neritic facies.

CHAPTER I.

THE PERMIAN.

Between the basement rock and the Lower Triassic Servino (Werfenian or Buntsandstein) an important series of rocks occur throughout the Bergamasc Alps. The series is essentially very coarse grained and volcanic, and with these characteristics certainly represents a stratigraphical unit in contrast with all higher formations, which none have this predominating coarse and volcanic character. Its lower and upper limits are moreover sharp and very well defined. It is uncorformable overlying the basement rock and there is never any doubt about this boundary. The upper limit also is sharp and lies always between strongly contrasting rocks, allthough thin zones of transition do occur.

Insofar as the Bergamasc Alps are concerned this petrographical characterisation would suffice, but in order to compare this small part of the Alps with the rest of the world an age determination is necessary. Here we are met, however, with great difficulties as fossils are extremely rare and then only consist of badly preserved plant remains in the middle subdivision of this series. Therefore we have to proceed mostly by comparison with neighbouring regions where more about the age can be ascertained. As will be seen much evidence indicates that this series belongs to the Permian, but need not represent the whole of this formation.

The development of this series in the Bergamasc Alps has been assembled in the next table:

Permian	C. *Verrucano.*	30—800 m red and green conglomerates, micaceous sandstones, shaly intercalations. The components of the conglomerates are: porphyries, tufs, basement rock.
	B. *Collio.*	*Volcanic facies:* volcanic sandstones, tufs, porphyries, conglomerates, etc. 0—500 m. *Non volcanic facies:* „Carona schists'' shales and sandy shales, well stratified. 0—2000 m.
	A. *Basal conglomerate.*	0—50 m. Conglomerats of basements rock pebbles, sometimes with porphyries, sandstones etc.

A. The Basal Conglomerate.

A conglomerate, mainly or exclusively containing components of the basement rock, at the basis of the Permian series, occurs rather continuously east of the Val Brembana. West of this river it is unknown. DOZY (lit. 10 and 12) describes three types of basal conglomerate: one with quartz as main component, one with basement rock as principal component and one where porphyry pebbles form an important component of the conglomerates. The first and second types are by far the most common and can better be regarded as one type, as the quartz pebbles are also derived from the basement rock. The occurence of porphyries in the basal conglomerate is rare. PORRO gave even the name of „aporphyric conglomerate" to this basal formation, but in view of later surveys this name can not be maintained as it has been found in several instances that the volcanic activity had been started already when the basal conglomerate was deposited.

The sequence of strata of the basal conglomerates varies greatly from point to point. A typical section is given by DOZY (lit. 10) NE of Mt. Cabianca (second type):

a b o v e tufs with a few conglomerates
sandstones alternating with conglomerates, at the top tufs are intercalated
20 m grey to reddish conglomerates, mainly of quartz-pebbles
10 m red sandstone
10 m whine-red conglomerate with quartz pebbles
b e l o w micaschists.

ZIJLSTRA (lit. 23) observed frequently that a few decimeters thick layer of eluvium separated the micaschists from the overlying Collio or basal conglomerates. From the Upper Val di Vo this author reports the following section:

a b o v e 1 m conglomerate free of volcanic material
± 2 m conglomeratic tuf
15 cm glass lava
10 m tuffaceous material with basement rock pebbles
b e l o w micaschists.

From the Mt Aga DOZY (lit. 10) reports the following section:

a b o v e Conglomerate with mainly basement rock components (first type):
3 m red sandstone with layers of quartz or basement rock pebbles intercalated
± 4 m greenish marl with pebbles, traversed by numerous ultra-mylonite veins
2.5 m light grey-green coarse sandstone
b e l o w gneiss chiaro.

Obviously no regularity in the sequence of conglomerates, sandstones and other components can be expected. The thickness varies greatly from 0 to some 200 m, which maximum thickness is reached near the Pizzo Strinato in the east.. It is often impossible to determine the upper limit of the basal

[1]) PORRO, C. — Alpi Bergamasche Note illustrative Milano 1903.

conglomerate because the overlying Collio may have an equally conglomeratic facies without basement rock components. In the region of the upper Val Seriana some 50 m of the normal non porphyric conglomerate type is generally found. East of the upper Val Paisco and west of the Laghi Gemelli the formation is lacking altogether.

B. The Collio.

To the Collio formation are ascribed those strata which are found between the basement rock or basal conglomerate and the Verrucano. Although it is not always easy to distinguish between Collio and Verrucano rocks locally, there is generally no doubt that two distinct formations must be discerned.

The Collio period was one of very frequent volcanic activity in the Bergamasc Alps and of large scale vertical movements of the earth crust resulting in great variation of thickness. Nevertheless the facies is either continental or of very shallow water. The formation as a whole is composed of three elements, viz.: 1. lava's, 2. tufs and 3. shallow water shales. On the map each of these three elements are distinguished, but as not all the surveyors did make this distinction on their maps, the present representation has a somewhat conjectural character.

In general the lower half of the formation has a more volcanic habit than the upper half, but in the great central trough three large porphyric bodies are floating at different height in the very thick shale complex which fills up this trough.

In fig. 16 the development of the Collio has been represented by an isopach map. The principal feature of this map is the *central trough* in which a thickness of more than 2000 m is reached. The trough has a N 65° E trend, a flat bottom and steep flanks. Its south-western end is taken up by the great Trabuchello porphyric mass, but the rest of it is filled up by the Collio- or Carona-shales, in which the Cabianca and Corna Rossa porphyric masses occur.

By a narrow strait the central trough is connected via Mezzoldo with the basin of the Pzo dei tre Signori, in which thicknesses up to 500 m are found. Further west the thickness of the Collio decreases rapidly, and west of Introbio the formation is absent. East of the Central trough a large area is found where Collio is again lacking. It gradually wedges out in eastern direction along the Val di Scalve and finally disappears altogether in the upper Val Paisco. Neither can it be found east of the Val Camonica near Darfo or Pisogne. An unpublished and yet unfinished survey by P. A. Hacquébard in the Val Trompia—Mt. Colombine area shows that the well known Collio schists locality of this mountain wedges out rapidly towards the west and exactly 4 km due west of the top of the Mt. Colombine, just beyond the Passo delle Sette Crocette, the Collio has disappeared altogether. From there onwards to Pisogne the Verrucano rests directly on the basement rock. East of the Mt. Colombine a very great thickness of the Permian is reached near Bagolina (Salomon) [1]). The great central Permian through of the Bergamasc Alps appears therefore to be flanked in the SE by a large regional uplift, the *Camonica uplift.*

[1]) Salomon, W. — Die Adamellogruppe, Abh. d. k. k. geol. Reichsanst. XXI, 1908.

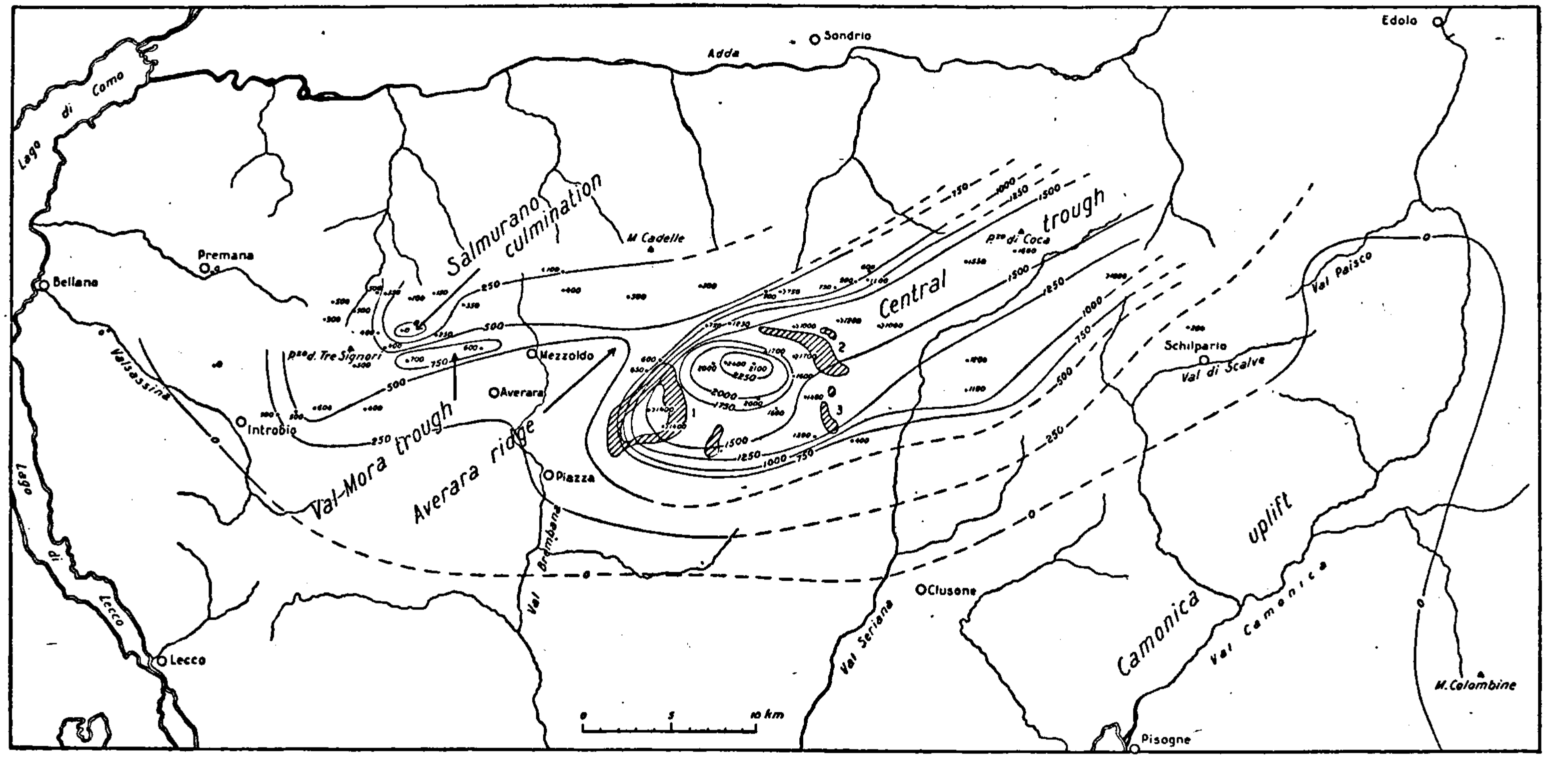


Fig. 16.

Isopach map of the Collio formation (Lower Permian) in the Bergamasc Alps.

Besides these two main structural features, the central trough and the Camonica uplift, many irregularities in thickness of the Collio formation occur. The *Salmurano culmination* is the most striking topographical irregularity of the pre-Collio surface. On both sides of this basement rock outcrop Verrucano rests on Collio tufs and sandstones of considerable thickness, but when one follows the mountain ridge from the Passo Salmurano eastwards, toward the Mt. Valletta first a small patch of Verrucano lying directly on the basement rock is encountered and further east one can see the wedging out of the Collio north and south of the Mt. Valletta. The whole outcrop of basement rock, called the Salmurano culmination, is an old mountain ridge rising high above the surrounding country when Collio sediments were accumulating (ZIJLSTRA, lit. 23). In several other instances, similar evidence, but on a smaller scale, of the irregular surface topography can be found. In the Val di Vo for instance the irregular thickness of the Collio is not only due to tectonical causes but is partly of primary origin (ZIJLSTRA, lit. 25).

The narrow strait between the Salmurano culmination and Mezzoldo, the *Val Mora trough,* where the thickness increases from 0 to 700 m and then decreases again to 400 m and less may be due to an original deep channel, filled up by Collio sediments.

However, in this instance I believe that structural influences as in the case of the formation of the central trough and the Camonica uplift are more important. The ridge between the central trough and the Val Mora deep, the *Averara ridge,* is not very pronounced in the isopach map of the Collio, but plays an important role in later Triassic sedimentation and it is therefore more logical to see the ridge as a structural feature already in Collio time.

As mentioned before the shallow water shale facies of the Collio, which has been called Carona shales, is restricted to the central trough and to the narrow channel of Mezzoldo. These shales and sandy shales are dark coloured black to grey, massive to finely stratified shales with a phyllitic habitus. Cleavage is more or less pronounced. In plate XVII, fig. 1 a large slab of these shales from the quarry of Carona, where they are exploited, is represented. The cleavage is perpendicular to the bedding, giving us a good cross section through the formation. DOZY (lit. 10) reported many beautiful examples of ripple marks (plate XVII, fig. 2), mud cracks and raindrop impressions, and even tracks of Reptiles [1]), all found near the Pzo del Diavolo and the Pzo Poris.

The shales are throughout deposits of very shallow water condition. Volcanic eruptions of mostly acid lava's, quarzporphyries, occured in the western end of the trough, Trabuchello, Mt. Cabianca, Corna Rossa. These large bodies of porphyry and associated tuf agglomerates are not restricted to any definite horizon. The Trabuchello porphyry lies directly beneath the Verrucano blanket, those of Mt. Cabianca and Corna Rossa are somewhat older. They represent large volumes of volcanic rocks, RAASVELDT (lit. 17) estimated the Trabuchello mass at 10 km^3, the Mt. Cabianca mass 1 km^3 and the Corna Rossa at 0.1 km^3. The porphyry is accompanied by conglomerates and tufs.

Towards the border of the trough the grain size of the Carona shales

1) *Anhomoiichnium orobicum,* Dozy and *Onychichnium escheri,* Dozy.
DOZY, J. — Einige Tierfährten aus dem unteren Perm der Bergamasker Alpen. Pal. Zschr. B. 17, 1935.

PLATE XVII.

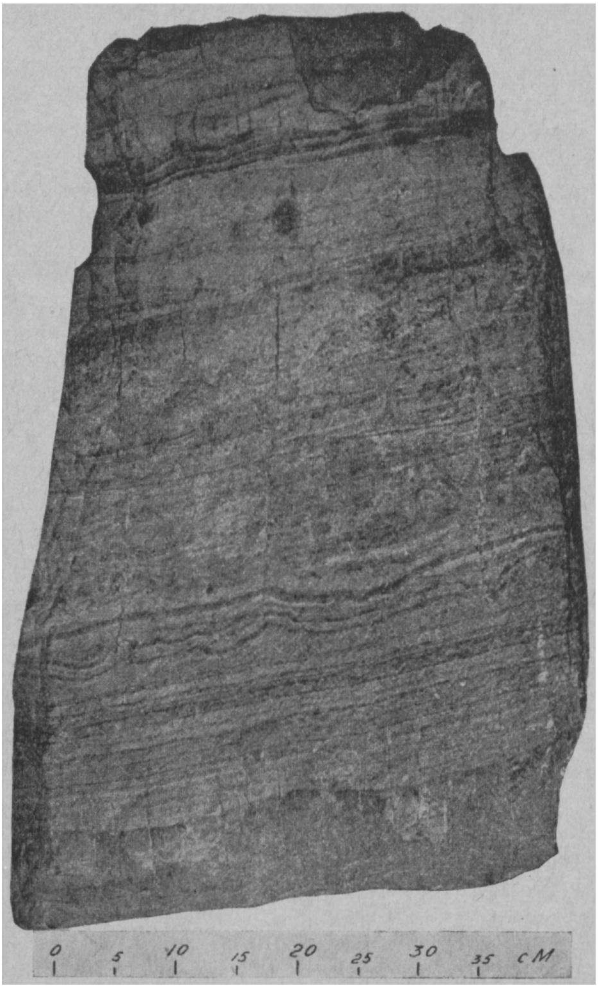


Fig. 1.

Carona shales of the Collio formation. The cleavage is perpendicular to the stratification. Loc.: Carona near Branzi, Val Brembana.

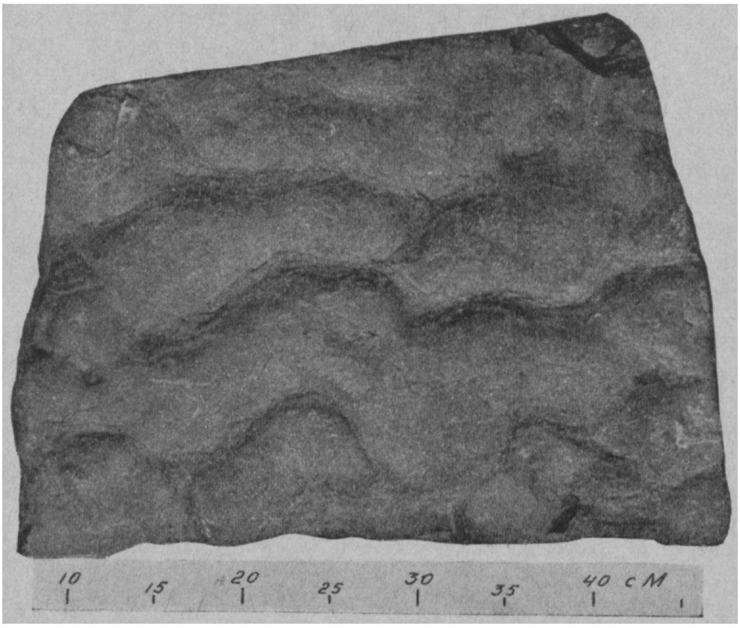


Fig. 2.

Collio sandstone with ripplemarks.

increases, and alternating banks of sandstone become frequent (plate XVIII, fig. 1). Once the 500 m isopach has been passed, no Carona schists can be found anymore east of the central trough. Then the whole formation consists of volcanic sandstones and various tufs, lithic-, crystall- and vitric-tufs, mixtures of these various components, transported or not transported in all possible varieties. SWOLFS (lit. 16) made a special study of this tuf facies problem. The volcanic facies of the Collio becomes very schistose when it has been subjected to strong tectonical forces and most of the tufs, porphyries and associated rocks can no longer be distinguished macroscopically, only the microscope can decide. The metamorphism never comes beyond the epizone, however, sericite, chlorite are common minerals but garnets or such higher metamorphic minerals are lacking altogether plate XVIII, fig. 2 gives a good impression of the metamorphic facies of the Collio schists.

On both sides of the central trough the lower part of the Collio schists is much more truly porphyric than the upper part, and the surveyors of these regions distinguished an Upper- and a Lower-Collio, which subdivision in view of the occurence of large porphyry bodies high up in the Carona shales of the central trough could not be maintained. In the west the purely porphyric habitus of the Collio reaches far down the Valsassina, whereas the more tuffaceous habitus is not found west of the Pzo Varrone.

In the north east of the central trough, north of the Pizzo di Coca, a peculiar quartzporphyry flow, situated just above the basal conglomerate, has been mapped by DOZY and TIMMERMANS (lit. 12). This conspicuous quartz porphyry can be followed a long way to the east, and ZIJLSTRA (lit. 23) reports it from the Collio round the Passo del Demignone as a light orange-yellow coloured band of some 20 m thickness easily recognisable from great distances.

Round the large basement outcrop of the Val Sassina-Val Biandino, the surveyors reported at the base of the porphyric series a curious rock, which was interpreted varyingly as a glass lava, a basal tuffoid and later as an ultra mylonite. In view of the great similarity of the microscopial image of this rock with true ultra-mylonites it must be recognised as such (see Part I, Chapter V, Mylonites and plate XIV, p. 83). With DOZY (lit. 10) we presume that the boundary between the Permian in tuffaceous facies and the basement rock represented a horizon specially suitable as a receptive of fused rock material of the basement rock. I do not think that the presence of this ultra-mylonite indicates large scale movements along this boundary plane.

The detailed sections vary so greatly from one locality to another, that it is useless to quote such sections, we may refer the reader to the publications by COSIJN (1), JONG (2) and KLOMPÉ (3). Shales are reported from different positions in these sections, and this fact again warns us that the Carona shale formation is not younger than the volcanic facies, but a time equivalent.

In fig. 17, a schematic section from west to east, crossing obliquely the Permian structures, the facies and the development of the Collio has been represented.

C. The Verrucano.

The Verrucano is the formation overlying the Collio or the basement rock and underlying the lower Triassic Werfenian. It consists of mostly

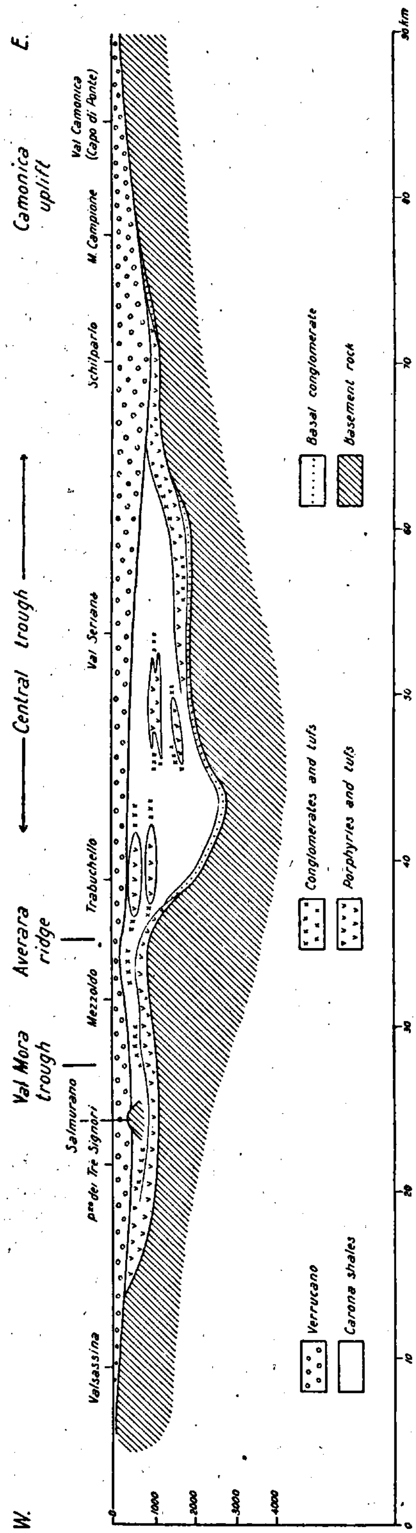


Fig. 17.

red coloured conglomerates and micaceous, mostly coarse grained sandstones increasing regularly in thickness from west to east. It is never absent in the Bergamasc Alps allthough its thickness decreased to less than 30 m on the Como lake, but further west in the Luganese region it is generally absent. The components of the conglomerates are a little rounded but still rather angular pebbles of porphyries and crystalline schists (plate XVIII, fig. 3), the content of crystalline schists pebbles increases everywhere when the formation rests directly on the basement rock and decreases when the Collio is found between the Verrucano and the basement. For instance KLOMPÉ (lit. 3) reports that north of the Passo di S. Simone that is south of the Cma di Lemma, the Verrucano carries no porphyry pebbles at all, and CROMMELIN (lit. 8) points out that near the Casa Pio XI, north of the Pzo Varrone near the Orobic thrustplane, the basement rock pebbles are very predominating. The same feature is found round the Salmorano culmination according to ZIJLSTRA (lit. 25). The basement rock components of the Verrucano conglomerates are: phyllites, micaschists, alkali felspar gneisses, gneiss chiaro, quarzites and much quartz. When in a certain region the basement rock comprises some typical rock as the granodiorite of the Valsassina, or the tonalite of the Adamello, the Verrucano does *not* contain pebbles of this special rock. This point is emphasized by several surveyors (CROMMELIN, SALOMON, PORRO). PORRO points out that this is quite naturel as we observe in general that the Collio separates the Verrucano from the basement rock and therefore the latter can hardly derive pebbles from a rock which at that time and that locality was covered by some other sediment.

PLATE XVIII.

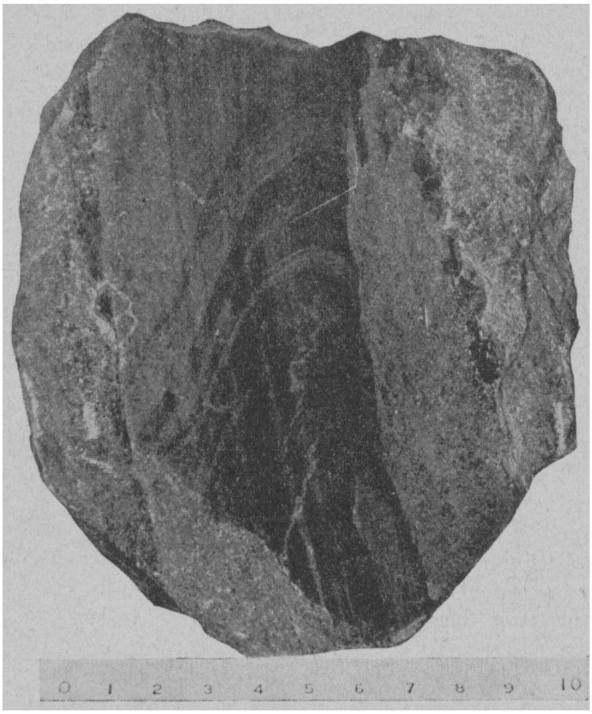


Fig. 1.

Collio schist from Laghi Gemelli. Well stratified by alternation of volcanic sand and more pelitic material. This facies is typical of the border of the great Permian trough. The curious S shaped stripes are apparently the result of bending of original vertical lines, the bending being due to internal movements along bedding planes, during folding processes.

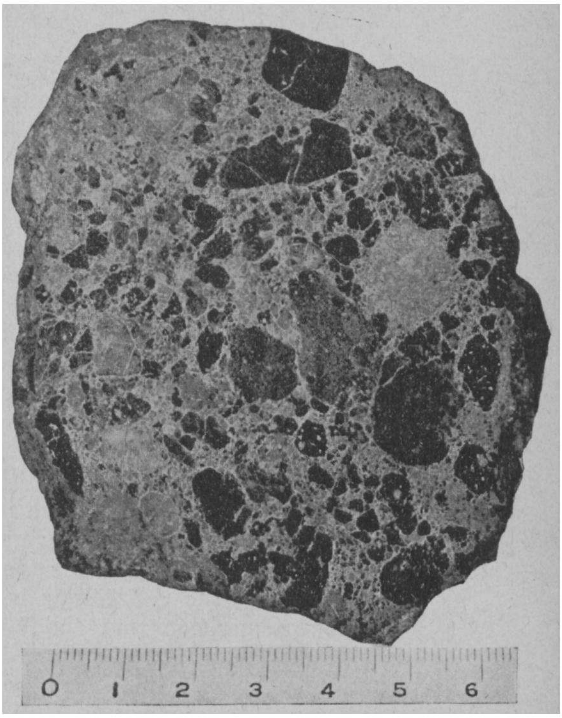


Fig. 3.

Verrucano conglomerate from Valtorta. (Mus. no. 31957).

Zijlstra

Fig. 2.

Collio schists in metamorphic facies. Loc.: West of Baita Venano di Mezzo, Upper Val di Vo North of Schilpario, Val di Scalve.

The porphyry pebbles all belong to types well known in the Bergamasc or Luganese Alps. They are characterized by phenocrysts of quartz and felspar and a glass groundmass, more or less devitrified. Porphyrites and all sorts of tuf are represented as well. The most typical quartz phorphyry is a dark red coloured rock with glass basis and a few quartz grains as phenocrysts. Allthough several authors claim that their special porphyries of the Collio are not represented as pebbles in their Verrucano, the general assemblage of the pebbles is very much analogous to the volcanic facies of the Collio. Very coarse conglomerates with a size up to 50 cm diam. have been found, then the rock becomes more a breccia than a conglomerate. as near the Lago di Sassa between the Pzo dei Tre Signori and the Pzo Varrone (CROMMELIN lit. 8).

The matrix of the conglomerate is coarse, consisting of sharp edged quartz grains. sometimes felspar grains and much undefinable, probably largely tuffaceous, material.

The dark red colour which is peculiar of the whole Verrucano is perhaps nowhere and certainly not everywhere its original colour. When very deep and fresh artificial outcrops were made the rock appeared to have mostly green colours, the red colour is then a superficial weathering phenomenon.

The assumption that the Verucano is a desert formation, based chiefly on this red colour, is therefore not warranted. As ZIJLSTRA (lit. 23) pointed out the pebbles, which are somewhat rounded but often quite angular still, point to deposition by mountain streams on a plain adjoining rugged mountains.

Besides the conglomerates, the Verrucano consists of coarse sandstones, greywacke and arkoses. These psammitic rocks all have the same red colouring and are characterized by the same angular quartz grains and mostly are very micaceous. The red micaceous sandstones are called sernifites, after the occurence in the Glarner Alps.

The Pietra Simone of the Camonica valley is a special kind of these micaceous sandstones. rather fine grained, hard and very micaceous and characterized by „röhrigen Wülsten'' (Salomon), widely used for ornamental purposes. The sandstones predominate in the Val Camonica, where conglomerates are restricted mostly to the higher horizons of the formation.

The Verrucano increases in thickness rather regularly from west to east (fig. 17). Near Bellano on the Como lake the thickness is but ± 30 m near Introbio it has increased to 150 m and more. Over the Averara ridge the thickness diminishes again to increase steadily to 800 m over the Central Permian trough and its eastern border. Over the Camonica uplift it appears to be much thinner again but increases in thickness again at the other side.

The ridges and the basins, very pronounced in Collio time are thus recognisable in the Verrucano, but less pronounced, and the greatest thickness is not in the central trough but further east.

D. The age determination of the Permian rocks.

The age of the strata described above, lying below the lower Triassic Servino and above the basement rock offers great difficulties as fossils are extremely scarce. The upper limit is well defined and puts the whole series into the Permian or older, but to quote SALOMON from „Die Adamellogruppe'', p. 369:

„Geradezu unlösbar ist bis zum heutigen Tage di Frage ob nicht „eventuell stellenweise die untersten Schichten der auf meiner Karte „zum Perm gestellten Bildungen noch dem Karbon entsprechen können".

This is quite as much true for the Bergamasc Alps as for the Adamello region and in 1943 as it was in 1908. Fossil plant remains from the Mt. Colombine, have been described by GEINITZ[1]) and the Collio schists containing them have been placed in the Permian. DOZY[2]) visited the same locality and reports that JONGMANS, in accordance with GEINITZ found the genus W a l ch i a, indicating a Permian age.

The aporfyric conglomerate was placed by preference by PORRO and others in the Upper Carboniferous, DOZY preferred to reckon it to the Permian as it does often contains porphyry pebbles.

Our petrographic analysis of the younger intrusive rocks of the basement rock, granodiorites, granites (gneiss chiaro) and of the porphyries belonging to the volcanic facies of the Collio, indicates that as far as the chemical differentiation is concerned a continuous series of intrusions and extrusions must be accepted, and we preferred to indicate the active intrusive-volcanic period as Permo-Carboniferous.

As mentioned before in Part I, chapter VII, the basement rock is better regarded as of prae-Cambrium age instead of Hercynian age, exept the younger ortho-rocks, because the largest variscean orogeny observed in Kärnten is the Asturian phase, which produced large scale overthrusting, but failed to metamorphise the palaeozoic sediments to any great degree. Caledonian orogeny is present there but is not of great importance. On the other hand the metamorphic status of the Collio schists is greater than that of any of the younger sediments and therefore it would not be unreasonable to suppose that they derived this metamorphism form the Asturian or perhaps a Salic folding phase. As mentioned above a certain discrepancy between the tectonical structure of the Collio and the Verrucano can be observed locally and these two facts would indicate that perhaps the whole Collio formation ought to be placed in the Westphalian before the Asturian phase. The few plant determinations are contradictory to this assumption, but the poor state of preservation and the fact that more modern determinations are not available, combined with the fact that the genus W a l ch i a alone is not enough for a final argument, are not conclusive at present. However, in anology with the German facies of the lower Permian the typical volcanic facies is regarded as Permian. It is obvious that we are very much in need of new palaeontological evidence as to the age of the Collio.

A comparison with other regions of the southern Alps has been assembled in the next tabel.

The Lugano region has been described by DE SITTER[3]). The San Martino conglomerate was then placed in the Werfenian, but the complete similarity of this conglomerate with the Verrucano of the Bergamasc Alps induces us to prefer to regard it at present as a representative of this latter stage.

[1])published in: SUESS, E.: Ueber das Rotliegende im Val Trompia. Sitz. ber. Math. Naturw. Kl. der Ak. d. W. zu Wien, Bd. LIX, I, 1869.

[2]) DOZY, J. J. Ueber das Perm der Süd-Alpen, L. G. M. D. VII, 1935.

[3]) SITTER, L. U. DE, Les porphyres Luganais et leurs enveloppes. Historie géologique des Alpes tessinoises entre Lugano et Varese, L. G. M. XI, 1939.

		Lugano, DE SITTER	Bergamasc Alps	Daone-Val Rendena SALOMON—TREVISAN
Permian	Upper	Verrucano conglomerate of San Martino?	Verrucano conglomerates with porphyric and base- ment rock components Arkoses Greywackes mic. sandstones Pietra Simone Sernifite red colour dominating thickness increases from 30 to 800 m from W to E.	Praso list. öolitic and cavernous list. of Costa di Nambi 0—5 m. Grödener sandst. Greywacke sandstone, Arkose, Conglomerate 200 m and more
	Lower	Granophyr extrusion erosion strato-volcanoes quartz porphyry porphyrites tufs	**Collio** 0—2000 m. (1) Carona shales, 1500— 2000 m. in central trough, with large porph. bodies of Trabuchello, Cabianca, Corna Rossa. (2) Volcanic facies: quartz porphyries porphyrites tufs volcanic sst.	thin breccia horizon, with black marl (V. Rendena) thick porphyries of Val Rendena 1500 m.
		Congl. of Germignago basal tufs of Mt. Piambello and of Poncia 0—20 m	Basal Conglomerate mostly only basement rock components occasionally porphyric components 0—50 m	Basal Conglomerate (often absent)
Carboniferous		Conglomerate, sandstone with plant remains of Manno		
		ASTURIAN TECTONICAL PHASE		
		intrusions of granodiorite and granite in Basement rock, phyllites, mica schists, Alk. felspar gneisses, ortho gneiss, Quartzites etc. etc. prob.: Pre-Cambr.		

Fassa-Grödener-Enneberg OGILVIE—GORDON Pale S. Martino, CASTIGLIONI	Cortino-d'Ampezzo OGILVIE—GORDON	Kärnten HERITSCH		
Bellorophon Horizon 140 m.: 3. dolom. fossilifer. list. 36 m. 2. dolom. + rauhwacke 42 m. 1. gypsiferous marl and dolomite 65 m.	Bellorophon Horizon 210 m.: 3. black fossiliferous list. 25 m. 2. sdy marl, dolomite, rauhwacke 45 m. 1. gypsiferous marl 140 m.	Bellerophon Horizon: dolomite, cavernous dolom., gypsum and limestone 500 m.	Thuringian	Permian
Grödener sst. 85 m. sandst. and schists 3. gypsiferous dolom. 2. coloured schists 1. red and green sst.	Grödener sst. brown and red Conglomerate of limestone and basement rock components	Grödener sst. and conglomerate 600 m.		
Bozener quartzporphyry 5. porphyry 4. Upp. Conglomer. 3. porphyries 2. tuf and congl. 1. porphyries **In the Pale S. Martino:** 150—500 m. quartz porphyry, with tufs, congl. etc. ± 80 m porphyrites, tufs etc. Basal Conglomerate The „Verrucano" of Tirol. 0.200 m thick. Preponderance of basement rock components	absent absent	Red schists with lavas, spilites and tufs of Dimon thrustsheet Traviser breccia Trogkofel list. marine. 300—400 m. Rattendorfer series: 3. Upp. Schwagerina 70 m. list. 2. Grenzland bank 70 m. 1. Low Schwagerina 135 m. list.	Artinskian	
		Auernig series 860 m Schist, sandst. Asturian tect. phase Hochwipfel list. Low. Westphalian	Carboniferous	

As to the Carboniferous of Manno we refer to KELTERBORN [1]). The Adamello stratigraphy has been taken after Salomon and TREVISAN [2]). Of the many surveys of the Dolomites of Tirol we have selected those nearest to our region, two by OGILVIE-GORDON [3]) [4]) completed by a study of the Pale S. Martino by CASTIGLIONI [5]) Kärnten has been the object of a monographic study by HERITSCH [6]). As to the Bergamasc Alps the present study is of coarse based on all the different surveys, but an article by DOZY (10a) on the Permian and the chapters on the Permian by ZIJLSTRA (23, 25) have been followed to a great extent.

Little need be added to the tabel. It is certain that the Verrucano of the Bergamasc Alps, which merges into the Lower Triassic Werfenian is of Upper Permian age and therefore a time aequivalent of the Bellerophon horizon further east. The Paso limestone and the oölitic limestone of Costa di Nambi, respectively described by SALOMON [2]) and TREVISAN [2]) are regarded by these authors as the last vestiges of the Bellerophon horizon.

The comparison with Kärnten becomes very uncertain in the lower regions of the Permian. Tentatively we have put the volcanic formation of the Dimon thrustsheet in the period of the Collio, but representatives of the Trogkofel limestone and Rattendorfer series are lacking further west.

The Manno Carboniferous is placed above the Asturian orogenetic phase in accordance with KELTERBORN, both its tectonical position and the palaeontological evidence of the flora indicate this position.

The very thick porphyries of the east bank of the Val Rendena are without doubt to be parallelisized with our Collio porphyries. A thin, very local zone of breccia and marls are compared to the Collio by TREVISAN. The Grödener sandstone is very thin above this thick porphyries, indicating again that the Verrucano basins did not coïncide exactly with those of the Collio but had wandered somewhat to the east.

Summarizing we can characterize the first period of preserved post basement rock sedimentation in the Bergamasc Alps as follows: A long period of denudation had removed all the palaeozoïc rocks. The last Variscean, the Asturian, orogeny had lifted up the whole region again and had activated the erosion. Large intrusions of granodiorite and granite (Malcantone granite, granodiorite of Val Biandino, gneiss chiaro etc.) had intruded already or were still active in long anticlinal zones. The uplift after the Asturian phase was not equal over the whole region but ridges and troughs were formed. The invasion by the in the lower parts deposited a basal conglomerate. Volcanic extrusions on a large scale followed the intrusions of a former period. In the west the land remained dry and volcanic products were not transported (Lugano volcanoes), further east most of the volcanic products were either submarine effusions or transported by water action.

[1]) KELTERBORN, P., Geologische und Petrographische Untersuchungen im Malcantone. Verh. Naturf. Ges. Basel, XXXIV, 1923.

[2]) SALOMON, W., Die Adamello Gruppe. Abh. K. K. Geol. R. Anst. XXI, Wien 1908.
TREVISAN, L., Il gruppo di Brenta. Mem. Ist. Geol. R. Univ. Padova XIII, 1939.

[3]) OGILVIE—GORDON, M. M., Das Grödoner-Fassa und Enneberggebiet in den Südtiroler Dolomiten. Abh. Geol. Gundesanst. XXIV, H. 1, Wien 1927.

[4]) OGILVIE—GORDON, M. M., Geologie von Cortina d'Ampezzo und Cadore. Jb. Geol. R. anst. 84, 1934.

[5]) CASTIGLIONI, B., Il Gruppo delle Pale di San Martino e le Valle limitrofe. Mem. Ist. Geol. R. Univ. di Padova, Vol. XIII, 1939.

[6]) HERITSCH, FR., Die Karnische Alpen, Graz 1936.

The accidentated topography of the partly subsided land surface is the cause of the irregular thickness of the Collio, combined with the formation tectonical „highs'' and troughs. In the largest and central trough very shallow water deposits were formed. In the west erosion continued and the last volcanic action was the pressing out of a viscous and acid magma, the granophyr dome of the Lugano region. Renewed upheavel in the North caused an extensive denudation of this region and deposition of large masses of conglomerates and sandstones of the whole sumberged Bergamasc Alps. In the west the land was dry and the Verrucano is absent exept in the San Martino conglomerate which represents perhaps a river bed apporting the Verrucano material. Far in the east in normal marine conditions the Bellerophon horizon was deposited. The tectonical movements of the Collio continued much less pronounced in the Upper Permian, but the basins were then slightly shifted.

Between the two extreme points, Lugano and Kärnten, the former continuously dry land, the latter continuously marine, the Bergamasc Alps and Tirol have an intermediate position, and reflect the important geological accidents and evolution more completely than in either of the extremes, but can only be understood with the help of these extremes.

Introduction to the Triassic.

The Triassic is the most interesting formation of the investigated part of the Bergamasc Alps. It follows conformably on the Verrucano with thin transition beds and develops from the partly neritic facies of the Werfenian to a pure limestone shelf facies with shale, sand and marl intercalations. The development of local but very extensive reef limestones, due mostly to algae and only very subordinately to corals, as heteropic facies is prominent.

The Triassic is divided as follows.

Upper Triassic	*Norian*		thick dolomite „*Hauptdolomite*"
	Carnian		limestones, marls, sandstone and tuf. local name „*Raibler*"
Middle Triassic	*Ladinian*	Heteropic facies	4. *Esino* limestone and dolomite, reef facies reaching down into the Anisian often occupying the whole Ladinian.
			3. *Perledo-Varenna* lifestone, local facies of well stratified limestone.
			2. *Wengener* limestone, sandstone or shales, sometimes absent.
			1. *Buchensteiner,* chert limestones often absent.
	Anisian	Lower	2. *Trinodosus schists,* often fossiliferous nodulous limestones with black shales, absent in northern part. Locally *Recoara limestone.*
		Upper	1. *Gracilis schists,* nodulous limestones sometimes sandstones, shales and marls. *Mendola dolomite* as reef facies.
Lower Triassic.	*Werfenian*		2. *Cavernous dolomite* or *Elto dolomite.*
			1. *Servino,* sandstones and marls, some limestone.

The whole Triassic is rather poor in fossils exept parts of the Raibler and the Trinodosus schists of the Upper Anisian. As result most of the mapping has been performed on the lithological characteristics, and therefore the above mentioned names assemble mostly similar facies of similar position between two other well defined facies. For instance the Wengener substage has been applied to all formations between the overlying Esino limestone (dolomite) or, when this is absent, Carnian and the underlying Buchensteiner, or when this is absent, Anisian. As such it can either have a pure shale or a sandy or a limestone facies. The name Buchensteiner has been applied only to limestones carrying chert nodules or layers. A certain confusion arrises out of such unequal weighing of stratigraphical terms, but this can not be avoided. Purely lithological names as „the splinter shale" used for the shale facies of the Wengener have been introduced by the surveyors and will be used here when no further confusion can arise.

The terms „Raibler" and „Carnian" are used as synonyms, but the use of the term „Servino" as a synonym for Werfenian is not in accordance with the original use of this term and must only be applied to the lower, neritic, facies of this stage.

CHAPTER II.

THE LOWER TRIASSIC, THE WERFENIAN.

The next stratigraphical unit, following the Verrucano is a marine series of sandstones, shales and dolomites, belonging to the Lower Triassic. The Werfenian is generally subdivided in accordance with LEPSIUS [1]) in a Lower shale and sandstone member, locally known by the name of „Servino" and an Upper member consisting of a cavernous, gypsiferous dolomite, the „Cellendolomit" or „Dolomia cariata". In the Bergamasc Alps the name of „Servino" has often been applied to the whole of the Werfenian, which is, however, contrary to the original use of the term.

The Werfenian is everywhere present in the normal sequence of the Bergamasc Alps between the Verrucano and the Anisian.

When a good stratigraphical section can be obtained, and this is not often, the sequence is in general like this:

above	3.	dolomites, cavernous dolomite, gypsum.
	2.	shales, marls, micaceous and mostly multi-coloured.
below	1.	brown and red micaceous sandstones.

The basal sandstones form a direct transition from the Verrucano. The transition zone is restricted to a few metres however, and the much softer habitus of the Servino in general, due to its many shaly and marly constituents, results in a totally different aspect in the scenery. Whereas the Verrucano is exceptionally barren and forms steep escarpments and stony plateaus, the Servino forms gently undulating slopes mostly covered with succulent pastures. The photograph of Plate XIX, fig. 1, shows this totally different character very well. The Upper Servino is characterized by its multi-coloured shales, which often are quite phyllitic in habitus, due to epimetamorphism. The Upper Werfenian in its dolomitic or cavernous facies is very characteristic. There is no marked increase in thickness from west to east or vice versa.

The Werfenian has a peculiar tectonical role almost everywhere in the Bergamasc Alps. By virtue of its ductile and soft strata it has acted very often as gliding horizon. Large complexes of the overlying massive limestones have been sheared from their substratum, and the shearing plane has followed by preference the Werfenian strata. This phenomenon naturally leads to the result that an unbroken sequence of the Werfenian is difficult to obtain. For instance in the southern slope of the Valsassina a band of Werfenian is cropping out from Bellano to Introbio, apparently in the normal sequence between Verrucano and Anisian. Still we have conclusive evidence that several thrustsheets, the two Grigna thrustsheets and the Coltignone thrust-

1) LEPSIUS, R. Das westliche Süd-Tirol. Berlin 1878.

sheet, have glided from the north to the south using some part of the Werfenian as thrustplane. The lower part of the Werfenian band, therefore, belongs to the autochthonous south flank of the northern uplift, and the upper part to one or more of the thrustsheets. Thus we can not expect a normal sequence in the Werfenian. It is not to be wondered at, in view of the facts that a brecciated horizon will be found in this sequence sometimes at the top of the Servino (Primaluna for instance) and sometimes right in the middle of the complex (Parlasco). TRÜMPY's conclusion [1]) that the brecciated horizon, which in every respect is very much like and probably often identical with the upper Werfenian cavernous dolomite, is *not* a stratigraphically fixed horizon is *not* warranted and erronous insofar as the cavernous dolomite *is* the top part of the Werfenian, but has been used as thrustplane, and that at Parlasco the strata above the brecciated horizon are a repetition and belong to the overthrusted masses.

BUNING (7) reports from the section near Bellano:

above	5.	transition to the Anisian by the intercalation of dark grey limestones in 4
	4.	5 m. marly and quartzitic sandstone and rauhwacke
	3.	20 m. hard massive congl. Components to 10 cm. diam. mostly quartz, some porphyry
	2.	marls and sandstones alternating, multi-coloured, a few dolomite banks.
below	1.	light coloured sandstone with thin congl. banks.

The sequence is quite abnormal from no. 3 upwards. The assumption that the 20 m. conglomerates are a repetition of Verrucano due to the tectonical structure seems quite logical. The rest of the overthrusted Werfenian is all squeezed out and only some of the upper Werfenian rauhwacke remains.

In the Valsassina the Servino is very sandy and the marls and shales are almost absent. TRÜMPY gives the following general section for the Valsassina:

above	3.	30—50 m. dolomite with micaceous sandstone to which we add the cavernous dolomite always brecciated by tectonical causes and overlying the dolomites and sandstones.
	2.	50—100 m. red and green micaceous sandstone.
below	1.	200 m. red micaceous quartz sandstone. (Verrucano?)

The Werfenian of the upper Valle Varrone has already the facies common to the rest of the Bergamasc Alps. CROMMELIN (lit 8) reports:

above	3.	± 40 m dark yellow cavernous dolomite and limestone.
	2.	± 110 m green marls, blue and red-brown shales all micaceous, alternating with sandstone.
below	1.	± 50 m yellow and white micaceous sandstone with peculiar weathered surface.

The peculiar weathered surface of lower Servino sandstone is typical

[1]) TRÜMPY, E. Beitrag zur Geologie der Grignagruppe am Comosee. Ecl. Geol. Helv. vol. 23, 1930.

of this formation and consists of a pitted, cavernous habitus probably due to solution of calcareous inclusions.

Further to the east the Werfenian increases in thickness to 450 m. according to COSIJN (lit 1), the facies of green marls alternating with sandstones occupies the mayor part of his section. The cavernous dolomite is apparently lacking.

In the Val di Scalve much the same sequence is still observed. According to KROL (lit 18):

above 3. 75—120 m. gypsiferous, yellow, cavernous dolomite.
2. 200 m. green and red fossiliferous micaceous shales.

below 1. 75 m. light coloured limestone, green marls and red to grey-brown micaceous sandstones (iron ore).

The whole series is less sandy, but the lithological aspect and sequence is unchanged. Also in the Val Camonica DORSMAN (lit 19) observed:

above 3. 100 m cavernous dolomite
18 m grey phyllitic shale
3 m light red-brown sandstone
10 m grey-green marly shales.
2. 15 m brown-grey siliciferous limestone in banks of 50 cm. alternating with shales
5 m light-grey calcareous sandstone
10 m multi-coloured micaceous shale
20 m red micaceous shale.

below 1. 30 m red-brown sandstone alternating with marly shales.
total thickness some 210 m.

According to these sections a division in an Upper- Middle- and Lower-Werfenian could be made, and has been made by several authors. An occasional find of *Naticella costata, Pecten venetianus* or *Myophoria costata* is not enough for a subdivision however. From the region of the upper Trobiolo east of Pisogne MAASKANT (lit. 22) gives the following section:

above 3. 70 m cavernous dolomite „Rauhwacke"
15 m yellow marl with intercalated white compact dolomite (Eltodolomite type)
2. 80 m red calcareous micaceous sandstone with a few intercalations of red limestones.
5 m red limestone with nummerous small gastropodes the so called „gastropodenoölith", intercalations of sandstone.

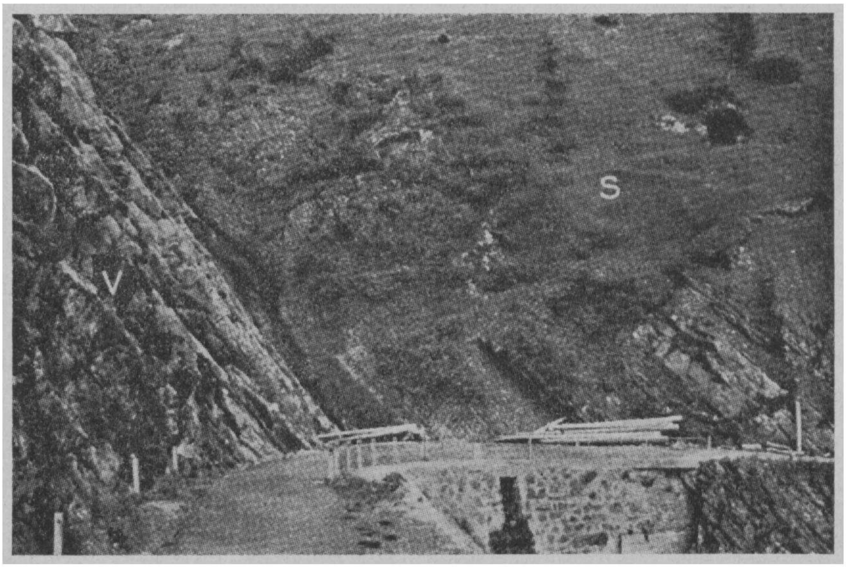
below 1. 90 m red micaceous calcareous sandstone, often with ripple marks. The lowest section often impregnated with iron ore (siderite).

This section is almost identical with that of LEPSIUS[1]) from the Val Rendena (Prasso-Daone).

Further north on the mountain ridge from Mt. Campione to Mt. Elto,

[1]) LEPSIUS, R. Das westliche Südtirol 1878.

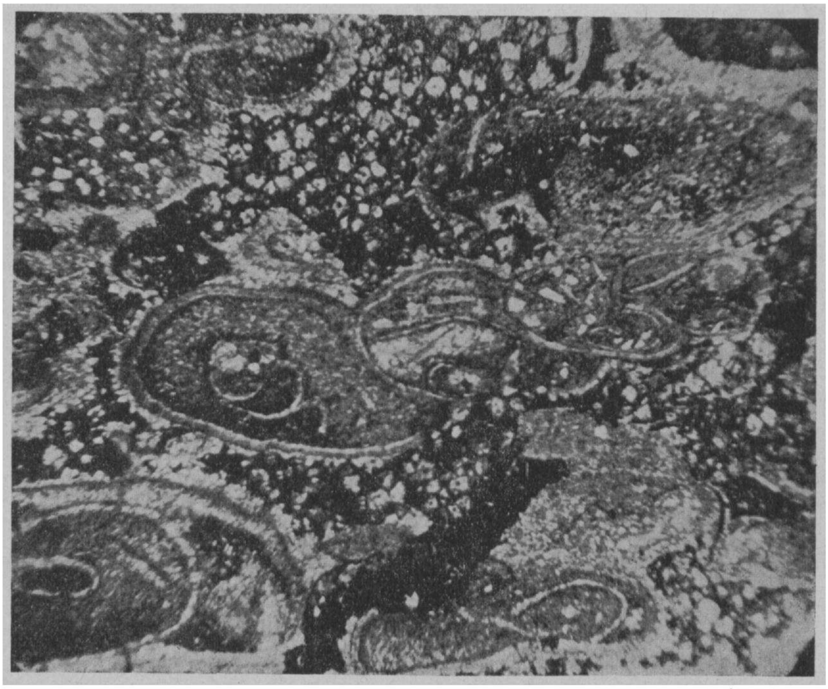
PLATE XIX.



Zijlstra

Fig. 1.

Servino shales (right) on Verrucano sandstone and conglomerate (left). Loc.: Road between i Fondi and Passo del Vivione, Upper Val di Scalve.



Maaskant

Fig. 2.

The so-called „Gastropoden oölith'' of the Lower Werfenian, a limestone full of small gastropodes. Loc.: Vle del Trobiolo, East of Pisogne on the Lago d'Iseo.

south of the Val Paisco we find a gradual transition from the upper cavernous dolomite into the Eltodolomite facies, a white, hard, compact dolomite (FABER lit. 21 and SALOMON [1])).

The oölithic limestone with gastropodes, Plate XIX, fig. 2, according to LEPSIUS [2]) containing *Chemnitza, Pleurotoma, Natica,* etc. divides the Servino in an upper and lower member: the Campiler- and Seiser series of VON RICHTHOFEN [3]), which occurs over a wide area in Tirol. The oölitic gastropod bank is, however, not a single horizon but often occurs in several banks in the Campiler series. In any case the subdivision of this Servino can not be parallelised with the sandy Lower- and shaly Upper Servino which can be discerned in the Bergamasc Alps.

The Werfenian has a shallow marine litoral facies. It starts with a transgression of marine sands over fresh water sands and conglomerates of the Verrucano. The Lower Servino is still very shallow; ripple marks, the occasional abundance of fossils, indicate pure litoral conditions.

The more shaly facies of the Upper Servino is perhaps somewhat deeper water, but elsewhere the litoral facies is maintained. The Upper dolomitic horizon is regressive in its character, but as the water never has attained any great depth, the change of facies is probably due to other factors viz: less terrestrial material, clearer water conditions. Reef-limestones and gypsiferous limestones and dolomites were formed, the former, by later solution of the gypsum, transformed in cavernous dolomite and limestone.

1) SALOMON, W. Die Adamello gruppe loc. cit.
2) LEPSIUS, R. Das westliche Südtirol 1878.
3) v. RICHTHOFEN. Geognostische Beschreibung der Umgebung von Predazzo. Gotha 1860.

CHAPTER III.

THE MIDDLE TRIASSIC.

With the Middle Triassie, the Anisian and the Ladinian, starts the thick series of shelf limestones alternating with shales and marls, which are characteristic for the whole Alpine Trias. The shelf conditions cause a great variety of facies and heteropic formations are numerous. Again and again large and thick reef limestones occupy the place of series elsewhere developed as well stratified limestones alternating with shales and marls. Obviously this phenomenon has been and still is a great handicap for every surveyor and has caused many misunderstandings as to the age and sequence of the members of the series.

MOJSISOVICS [1]) had been the first to recognise the fact that reef limestones are here the lateral equivalent of other formations and from that moment it became possible to construct the true stratigraphical sequence. Nevertheless the lithological similarity of reef limestones and dolomites of different age, the paucity of fossils and the complicated tectonical conditions often puts the surveyor to problems which can not be solved with any certainty.

When several stages, which can be distinguished by their lithological characteristics and faunal content are locally replaced by one continuous reef facies the fauna of the latter facies often contains elements of several of the replaced stages at the same time. From this fact we must conclude that the sequence of fauna's of the different stages is largely due to changes of facies, and that the restriction of a certain species to one zone is more or less accidental [2]). The reef facies picks up certain faunal elements and they survive as long as this facies subsists, long after they have already disappeared in the other facies sequence. Thus the reef facies forms a local link between the fauna of the different zones.

The Middle Triassic is generally divided as follows [3])

Ladinian	St. Cassian schists
	Wengener schists zone of *Daonella lommeli*
	Buchensteiner schists zone of *Protoachyceras Reitzi*
Upper An	Trinodosus schists zone of *Ceratites trinodosus*
Anisian	Recoaro limestone zone of *Rhynchonella decustata*
Lower An.	Gracilis schists zone of *Dadocrinus gracilis*

1) MOJSISOVICS, E. VON. Ueber heteropische Verhältnisse im Triasgebiete der lombardischen Alpen. Jahrb. Geol. Reischsonst. Bd. 30, 1880.

2) TRÜMPY, E. Beitrag zur Geologie der Grignagruppe am Comosee. Ecl. Helv. Vol 23, 1930.

3) ARTHABER, G. VON und F. FRECH. Die Alpine Trias des Mediterrangebietes. Lethaea geognostica II Teil, Bd. 1, Stuttgart 1905.

The St. Cassian schists of Tirol are lacking as a lithological stage in the Bergamasc Alps and are therefore not distinguished as a separate unit.

But in Lombardia as in Tirol reef limestones often occupy large parts of this sequence. In the Lugano region the Salvatore dolomite occupies probably all of the Middle-Triassic. The Esino limestone of the Bergamasc Alps may reach down to the Lower Triassic and up into the overlying Carnian, but most often is restricted to the Ladinian. The Mendola dolomite occupies the Lower- and part of the Upper-Anisian in Tirol. The Marmolata limestone and Schlerndolomite is a Tirolean equivalent of the Lombardic Esino limestone and dolomite. In the Bergamasc Alps a division in two parts has been proposed by SWOLFS [1]), an Upper part: the Esino limestone, and a Lower part the Valsecca formation. This proposal had the advantage that two lithological units, the reef facies and the complex of dolomite-shale-sandstone facies became clearly separated. It showed, however, the great disadvantage that the stratigraphical boundary between Ladinian and Anisian disappeared from the map altogether. DORSMAN (lit. 19) succeeded to reestablish this boundary throughout the Bergamasc Alps with considerable succes and we followed his investigations. We want to emphasize the fact, however, that even now the Esino limestone is not a stratigraphical unit but a lithological unit, and the same is true for the Buchensteiner and Wengener schists. The division in Anisian and Ladinian on the contrary is a stratigraphical division as long as the Upper Anisian Trinodosus schists are developed. When this sub-stage fails the limit Anisian-Ladinan becomes uncertain.

A. The Anisian.

The Anisian can be divided most conveniently in two sub-stages, the Gracilis schists (*Dadocrinus gracilis*) and the Trinodosus schists (*Ceratatites trinodosus*), of which the lower division, the Gracilis schists (Plate XX), is much thicker tran the upper division. Generally the Gracilis schists consist of dark coloured nodulous limestones often with white calcite veins, somewhat sandy, reaching great thickness in the eastern part of the Bergamasc Alps (650 m in Val d'Angolo). They carry little fossils, except frequent crinoïd stem joints, and can hardly be distinguished from similar nodulous limestones of higher stages. Fortunately the series are normally overlain by the typical fossiliferous Trinodosus schists, a thin zone mostly of some 30 m thickness but also increasing in thickness to some 200 m, in the upper Val di Scalve. The Trinodosus schists are much more shaly than the Lower Anisian and are very dark coloured.

A typical section for the Central Bergamasc Alps has been given by COSIJN (lit. 1) from the neighbourhood of Lenna in the Val Brembana:

above

25 m. lower Esino limestone, transition beds. Blue coarse limestone

[1]) SWOLFS, H. C. A. Verslag bij de Geol. kaart van der bergkam Mt. Secco-Pzo Arera. L. G. M. D. X, 1938.

25 m. Upper Anisian.

c. grey blue limestones well stratified
b. blue limestones with undulated surface, many small gastropods (*Omphaloptycha*).
a. dark blue to black nodulous limestones, with black shale intercalations rich in ammonites and brachiopods (Brachiopod bank).

225 m. Lower Anisian.

15 m. thin banks of nodulous limestone
200 m. thickly banked limestone
10 m. slightly nodulous limestones, transition to the Servino marls.
below

The fossiliferous horizon (a) of the Upper Anisian is cropping out here in two localities viz: in the village of Lenna and near Sosseni north of Piazza Brembana. Fossils from this horizon have been described by TOMMASSI [1]) and COSIJN (lit. 1) and contain many *Ceratites* (*C. trinodosus* v. Mojs., *C. binodosus* v. Mojs. etc.), many *Ptychites* (*P. flexuosus* v. Mojs., *P. evolsens* v. Mojs.) and the generae *Meckoceras, Balatonites, Longobardites.* Brachiopods are also frequent, specially *Rhynchonella trinodus* Bittn., *R. decurtata* Gir., *Spirigera trigonella* Schl. and many others. Lamellibranchs were also found even as stem joints of crinoïds. Another wellknown fossil locality is found near Gegna, east of Lenna, wherefrom most of the material of TOMMASSI [1]) was derived. The fossils are found only in the scree as the outcropping rock is to a large degree covered by debris from the overlying Esino limestones.

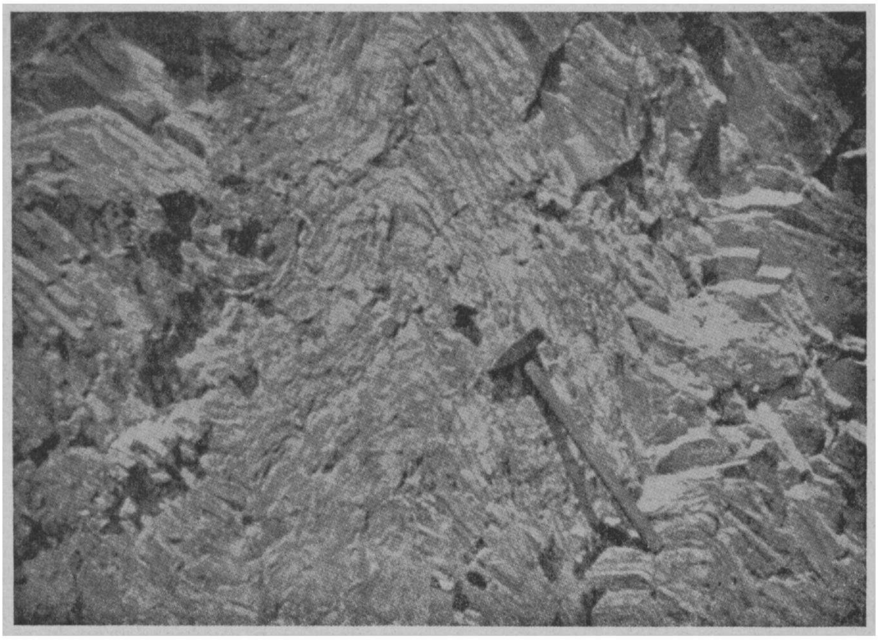
Towards the west, along the Valsecca and the Valcanale the development of the Anisian changes somewhat. The Upper Anisian becomes somewhat thinner, 5—10 m., on the Passo della Marogella and further east, but the Lower-Anisian reaches a thickness of some 400 m. (SWOLFS, lit. 15) but such great thickness looks very doubtful with a view to the section construction. According to DORSMAN the 2nd nodulous limestone, which SWOLFS placed in the Ladinian is actually the Upper-Anisian Trinodosus schists. The limestones of the Lower-Anisian remain dark coloured and in the lower part true nodulous limestones are developed, with shale intercalations, in the upper part the shale is lacking and the limestones become lighter coloured.

Crossing the Serio river the Anisian is again found in the Timogno thrustsheet (see Part III p. ??). The Lower Anisian Gracilis schists consists again of some 200 m. nodulous limestones, now overlain by a much thicker Upper Anisian of some 140 m. thickness, consisting of limestones with black shales and marls, the latter sometimes weathering into violet and green colours. The upper 30 m. of the Upper-Anisian is again a nodulous limestone. Not unlikely the black shale facies has extended into the Lower Anisian.

Still further east, along the Val Camonica the Anisian is cropping out

[1]) TOMMASSI, A. I fossili della lumachella triasica di Gegna in Valsecco presso Roncobello. Paleontographica Italica 1911.
La faunetta anisica di Valsecca in Val Brembana. Rendic. R. Ist. Lomb. di. Sc. e. Lett. Ser. 2, Vol. 44, 1913.

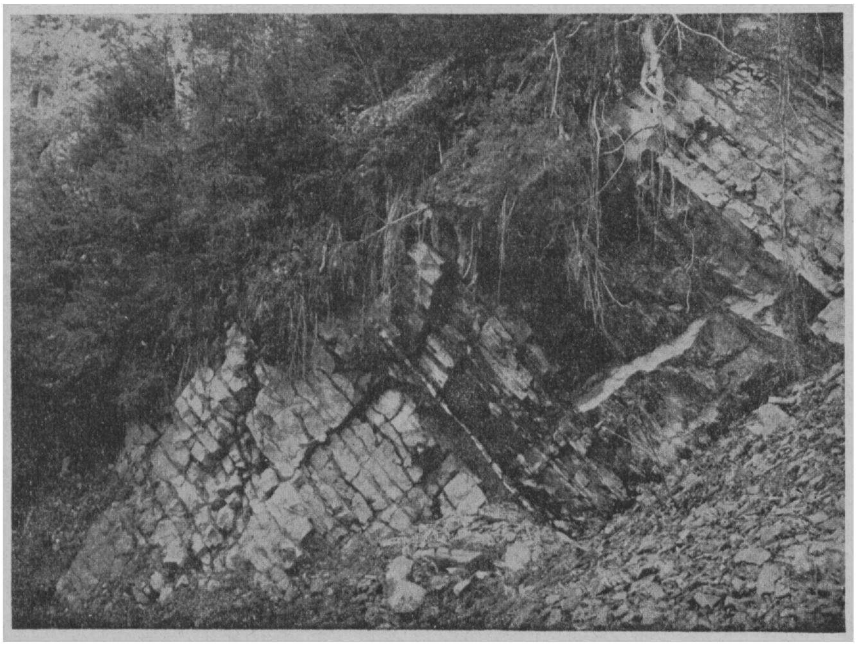
PLATE XX.



Erdmann

Fig. 1.

Lower Anisian (Gracilis horizon) intensely folded limestones. Locality: Val torrente Lanico between Lozio and Cividate, Val Camonica.



Krol

Fig. 2.

Nodulous limestone of the Lower Anisian (Gracilis horizon). Locality: below Malga Epolo, Val di Scalve.

to a large extent. DORSMAN (lit. 19) reports 650 m. of Lower Anisian thinly banked dark blue limestones alternating with micaceous shales. This thickness is somewhat exaggerated, 500 m seems to be a better estimate. The limestone surfaces are either undulating or plane, sometimes the undulations become so pronounced that a nodulous limestone consisting of separate nodules is formed (Italian: „Bernocolutto"). Fossils are very scarce, only crinoïd stem-joints were found. The Upper Anisian reaches a thickness of some 100 m, and consists of nearly black limestones alternating with black micaceous shales and marls. They are rich in fossils [1]) of which *Daonella Sturi* Ben. is most frequent. The fossil content of the Upper Anisian of Judicaria has been described by LEPSIUS and BITTNER [2]). These surveyors and SALOMON [3]) divide the Upper Anisian in two horizons, the lower Brachiopod limestone or zone of *Rynchonella decurtata* and the upper Trinodosus zone (Prezzo limestone) or zone of *Ceratites trinodosus*. As we will see làter on, a similar development of the Upper Anisian has been found far in the west in the Val Sassina. However, in the Bergamasc Alps the two facies, a brachiopod and a ammonite facies can not be separated, as has already been shown by the two localities quoted by COSIJN near Lenna in Val Brembana which both carried ammonites and brachiopods, and where the faunae had been mixed to some extent.

At the other side of the Lago d'Iseo, below the Mt. Guglielmo the Anisian has the same thickness and development as in the Val Camonica (MAASKANT lit. 22), but is poor in fossils.

The Anisian of the Upper Val Dezzo has been folded to such extent that no reliable stratigraphical section can be obtained. Moreover they have been folded together with younger strata, Wengener and Buchensteiner schists, which are developed in a similar limestone-shale facies, with the result that the different formations can hardly be separated. A good section could be obtained, however, between the Pizzo di Petto and Nona in the upper Valle Nembo by KROL (lit. 18). The Lower-Anisian has a thickness of 250 m. of which the lower half consists of nodulous limestones, poor in fossils (one *Daonella Sturi* Ben. reported by WEEDA (lit. 13)).

Further up the Val Camonica the Anisian diminishes in thickness and ERDMAN (lit. 20) reports 325 m. of Lower-Anisian, limestones alternating with marls, and 125 m. of Upper-Anisian. The most northern outcrop of Anisian in this region is found near the Passo di Campelli wherefrom a total thickness of only 300 m. of Anisian is reported by FABER (lit. 21). The Trinodosus schists have lost their most characteristic property, the abundancy of fossils, and a division in Upper and Lower Anisian is no longer possible.

We have seen that the development of the Anisian from the Val Brembana eastwards is rather unvariable but that a considerable increase of thickness occurs from the Val Seriana to the Val Camonica and towards the Val Trompia. The most characteristic properties of the formation are the dark coloured limestones and shales and their undulated surfaces, which result

[1]) TOMMASSI, A. Contribuzione alla Paleontologia della Valle del Dezzo. Mem. R. Ist. Lomb. Sc. e. Lett. Ser. 3, 1901.

[2]) LEPSIUS, R. Das westliche Südtirol. Berlin 1878.

BITTNER, A. Ueber die geologischen Aufnahmen im Judikarien und Val Sabbia. Jahrb. K. K. Geol. R. Anst. 1881.

[3]) SALOMON, W. Die Adamello Gruppe, Abh. K. K. R. Anst. Bd. XXI, 1908.

in a nodulous limestone. The fossiliferous Upper-Anisian is apt to loose this character locally.

When we proceed from Lenna in the Val Brembana northwards we meet in the north bank of the Val Bindo a much thinner series (COSIJN lit. 1) where the Lower Anisian is only some 30 m. thick and the Upper Anisian some 5—10 m, with *Spirigera trigonella* Schl., *Spiriferina Köveskalliensis* Boeckn. and crinoïd stemjoints.

The upper half of the Lower-Anisian carries brown micaceous sandstones. Along the east bank of the upper Val Brembo of Mezzoldo the total thickness of the Anisian has increased somewhat to some 100 m. (KLOMPÉ lit. 3). The abundance of fossils in the upper horizon has disappeared and the Trinodosus schists can no longer be distinguished from the Gracilis schists.

The Anisian north of the Mt. Pegherolo and east of Valleve has a similar development viz. dark coloured limestones, brown sandstones and nodulous limestones. The Upper-Anisian is not developed as a fossiliferous horizon.

This facies of the Anisian, which COSIJN called „the northern facies", is restricted to this zone along the upper reaches of the Brembo valleys. It is much thinner than the normal facies and much sandier, while the Upper Anisian fossiliferous zone is lacking.

Further west along the Val Sassina, on its southern bank the Anisian is again cropping out. In this stretch of Anisian belonging to the Grigna settentrionale mass the facies changes from some 150 m. thick calcareous sandstones, the Gracilis schists in the east to the dolomitic facies, the 200 m. thick Mendola dolomite, of TRÜMPY [1]).

This western facies is described near the Alpe di Era as follows:

Upper Anisian	20 m	Trinodosus schists thinly bedded limestones alternating with marls, brachiopods and ammonites.
	10 m.	Recoara limestone max. 20 m. nodulous limestone many brachiopods.
Lower Anisian	0.5 m.	compact yellow dolomite.
	2.5 m.	compact grained, dark grey dolomite with quartz grains.
	30 m.	blue, when weathered yellow, medium grained thickly banked limestone.
	80 m.	blue black micaceous sandy fine grained limestone, often nodulous, with black shale partings.
	40 m.	sandy micaceous thinly banked dolomites alternating with some marls.
		Werfénian

The sandy facies is a transition from the Mendola dolomite to the facies of the Upper Brembo valley, described above.

The Mendola dolomite, from Pasturo to Lake Como is, a grey white, when weathered, yellow, well bedded dolomite with many diplopores (*Diplopora plilosophi*, Pia.).

The typical Recoara limestone and Trinodosus schists are lacking

[1]) TRÜMPY, E. Beitrag zur Geologie der Grignagruppe, loc. cit.

between the Mendola dolomite and the overlying Ladinian Esino limestone, but are present between the Gracilis schists and the overlying Ladinian between Pasturo and Alpe di Era. The Recoara limestone is a nodulous limestone with partings of micaceous shale or sandstone, carrying many brachiopods (*Spirigera trigonella* Schl., *Terebratula vulgaris* Schl., *Rynchonella decurtata* Gir.).

The Trinodosus schists are well bedded limestones alternating with black marls. Brachiopods (*Rynchonella trinodosus* Bittn.) are found in the marls, ammonites in the limestones. The Upper Anisian in the Grigna meridionale and the Coltignone thrustsheets can no longer be divided into the two above mentioned horizons. The Lower Anisian has a western Mendola facies in the middle thrustsheet but everywhere else is developed as rather sandy Gracilis schists.

The Mendola dolomite facies, together with the Perledo-Varenna limestones of Ladinian age which occur also only in this most western part of the Bergamasc Alps, form a transition of the Bergamasc facies to the Lugano facies of Salvatore dolomite where Anisian and Ladinian are united in one continuous dolomite complex. The bituminous horizon of Senn [1]), separating the Anisian from the Ladinian Meride limestone on the Mt. San Giorgio, between the two southern arms of the Lugano lake, is very similar to the black Trinodosus schists horizon, both are rich in fossils and both have a black shale and limestone habitus.

The isopach map fig. 18, with additions and corrections after

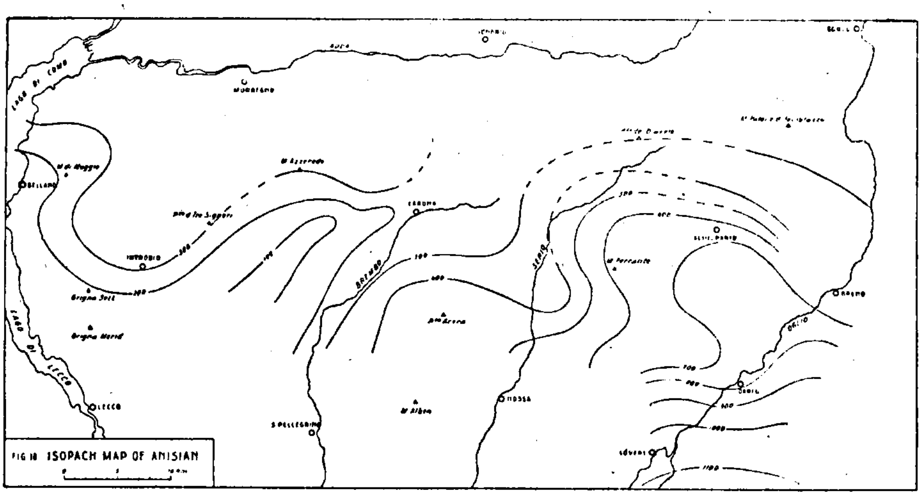


Fig. 18.

Dorsman (lit. 19) shows the general thickening of the Anisian in a S W direction. The thrustsheets have been put in their supposed original position in order to arrive at a better picture of the original basin. A special feature is the much thinner Anisian on the Averara spur a tectonical feature, which

[1]) Senn, A. Beiträge zur Geologie des Alpensüdrandes zwischen Mendresio and Varese. Ecl. geol. Helv. Vol. 18, 1924.

we encountered already in the development of the Permian. Apparently the positive movement of this spur persisted through the Anisian. East of the Brembo valley we perceive a general thinning towards the north, west of this valley a slight thinning towards the south probably due to the S W extension of the Averara spur.

B. Ladinian.

The Ladinian of the Bergamasc Alps shows by far the greatest variety of facies. Its most characteristic member is the Esino limestone (dolomite) a very light coloured massive algae reef facies which can reach great thickness and often occupies the whole Ladinian. The Esino forms all the great mountainous complexes south of the northern Permian basement rock zone which are not of Norian age and is therefore very conspicuous in the landscape. It is very similar to the Schlern dolomite and Marmolata limestone of Tirol and is of the same age. The name is derived from the village of Esino near the Como Lake N W of the Grigna settentrionale.

The Esino limestone (dolomite) is always the highest member of this stage when it is present at all and when other facies have been developed also. Older, or synchronous with the Esino are the Wengener schists, a very variable series of which the development as sandstones and sandy limestones is most typical. In the east, however, we find a limestone facies and a shale facies of the Wengener restricted to small areas. In general one can say that the thicker the Esino the thinner the Wengener.

The lower member of the group is the Buchensteiner limestone, dark coloured well stratified limestones with chert bands and nodules. They are often absent. The Perledo-Varenna limestones famous for their fish fauna occur only in the N W corner of the map, and there occupy nearly all the Ladinian.

The lower limit of this stage is clearly determined when the Upper Anisian black limestone-shale is well developed, but when this is lacking and the Esino limestone follows immediately on the Mendola dolomite, or the Perledo-Varenna facies of the Lower Anisian, the limit it rather arbitrary. The upper limit is often much more difficult to ascertain as the transition from Esino limestone in Raibler limestone is often very slow. In such case the limit has been taken on purely lithological grounds and becomes very arbitrary. Nevertheless I am convinced that no great mistakes have been made. The metalliferous facies of limestones, the „Metallifero'', overlying the Esino, was formerly reckoned to this latter formation, but there are good reasons to regard it as Lower Carnian. The whole problem of the upper limit of the Ladinian has been treated separately by Krol (lit. 26).

The most typical development of the Ladinian can be observed in the Val Seriana, specially in the Ardesio and Timogno thrustsheet east of the Serio river.

Ladinian. 835 m. Val Seriana.	**Esino** ± 700 m	3. white, coarse grained dolomite 2. white or light grey limestones with evinospongiae 1. brown or pale rosa coloured limestones with dark patches.
	Wengener 70 m	10 m blue well stratified limestones 60 m sandstones, sandy marls and tuffaceous sandstone, with plant remains, a few limestone banks.
	Buchensteiner 65 m	25 m blue siliciferous limestones alternating with tuffaceous marls 30 m well stratified blue sometimes siliciferous limestones alternating with shales a few chert nodules. 10 m blue fine grained somewhat noduleus limestones and thin shales intercalations.

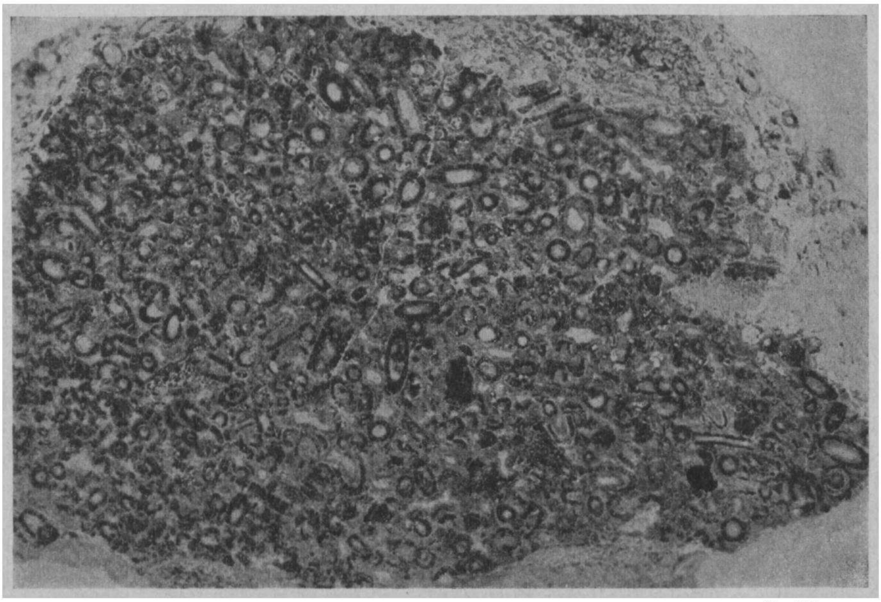
The Esino limestone (dolomite) facies of the Ladinian of the Lombardia consists of massive, mostly unstratified or badly stratified limestones (dolomites) weathering in very light colours. The original colour is also predominant very light, white, grey and pale rosa, but even darker coloured limestones which occur locally weather in grey and white colours.

The stratification is not always absent, in particular towards the top and the bottom better stratified parts are developed. Breccia horizons are often observed, more frequently at the bottom or top, but also occasionaly anywhere else in the massive rock. In the west the stratification is much more pronounced than in the east, the transition is observed in the area west of the Val Seriana as SWOLFS (lit. 15, fig. 2, p. 120) showed.

Fossils are generally scarce although internal moulds of large gastropods (*Chemnitzia*) are reported often from everywhere. The original algae structure is seldom preserved over larger distances but diplopores (*Diplopora annulata*) have been frequently observed (Plate XXI, fig. 1). Localities rich in fossils have been described by TRÜMPY (loc. cit.) and by HOFSTEENGE (lit. 5), which publications contain fossil lists. A special feature are the evinospongiae, probably a anorganic structure of concentric build (Plate XXI, fig. 2), which in the weathered rock often appears as petals round a centre. This rock has been exploited near Mazzunno opposite Angolo in the lower Val Dezzo as an ornamental stone known as „Occhiadino''. Oölitic textures have often been observed but are not frequent.

The large masses of Esino limestone and dolomite by offering great resistance to the erosive forces, now often form the top of mountains and offer an imposing view of great beauty (Plate XXII, fig. 1). The lower reaches of these mountainous masses are covered by talud fans of great dimensions. But besides these recent debris accumulations older ones of the same source and origin but thoroughly cemented into a hard, though very

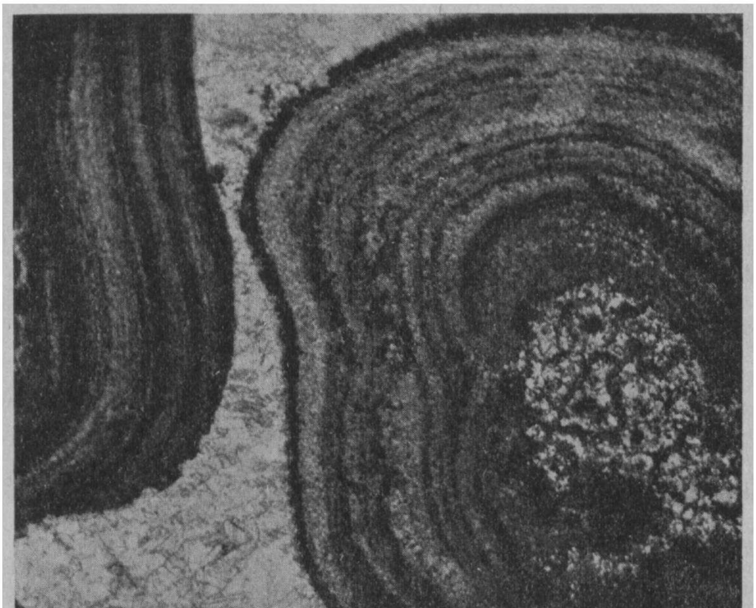
PLATE XXI.



De Wit

Fig. 1.

Esino limestone build up by Algae (Diplopora annulata).
Locality: Zucco Orscellera, South-East of Introbio.



Visser

Fig. 2.

Microscopic image of Esino spongiae showing the concentric structure.

porous, rock are frequent. They are much more numerous than the map indicates as many surveyors failed to register them separately.

Detailed sections of the Esino facies from different parts of the Bergamasc Alps have been given by KROL (lit. 26).

The Wengener of the Val Seriana is characterized by the olive green tuffaceous sandstones, often with numerous plant remains (Plate XXII, fig. 2). SWOLFS (lit. 16) found a crystal tuf with orthoclase, perthite, plagioclase, quartz and biotite deposited in water as shown by the high calcite content. Fossils again are scarce but *Daonella Lommeli* Wism is a type fossil of this age, and has often been found in this facies.

The Buchensteiner is characterized by the chert content of the limestones, either as black bands or as nodules. The limestone itself, mostly of a dark blue colour is often siliciferous. Fossils are very scarce, older finds of MOJSISOVICS and others of for instance *Trachyceras Curionii* have not been repeated and are very difficult to trace as no exact localities are known.

The facies of the Ladinian changes but little in the whole complex between the Valle Nembo, tributary of the Dezzo river and the Val Seriana. In the north of this complex the Buchensteiner are some 175—200 m. thick and consist of siliciferous limestones with cherts. WEEDA (lit. 13) showed that radiolaria and sponge spicules account for the siliciferous habit of the rock. The Wengener of some 50—100 m. thickness consists of dark coloured well stratified limestones with some black sandstones at the top. The sandy facies has disappeared nearly altogether.

From the section between Pizzo di Petto and Nona in the Valle Nembo KROL (lit. 18) reports:

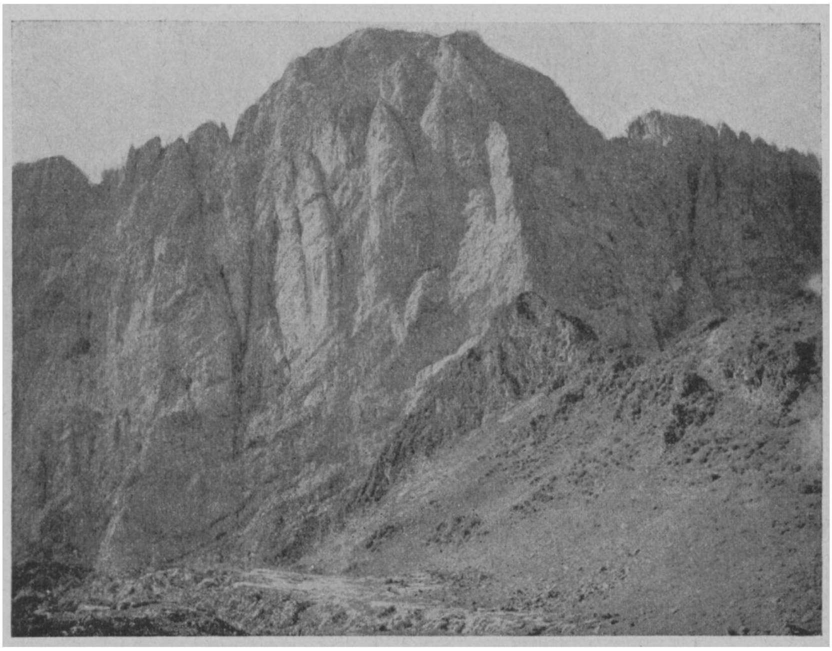
Esino 700—800 m	massive light grey limestones at the bottom dark grey and pale rosa limestones.
Wengener 350 m	2. 150 m. well stratified limestones with a few blue sandstones. 1. 200 m green sandstones, marls and dark limestones, plant remains.
Buchensteiner 150 m	Dark or black nodulous limestone with rare chert bands, a few blue sandstones.

The sequence is very similar to that of the Val Seriana, only the Wengener limestones have become much thicker and the sandstones which were lacking in the north and west are again present.

Along the Val di Scalve we meet quite another facies of the Ladinian; there we find below the Raibler limestones:

Wengener ± 300 m	black shales, weathering in brown colours, desintegrating in small chips and splinters, the so called „splinter shale".
Buchensteiner 150 m	sandy limestones, marls and sandstones, nodulous limestones with chert nodules (Plate XXIII, fig. 2).

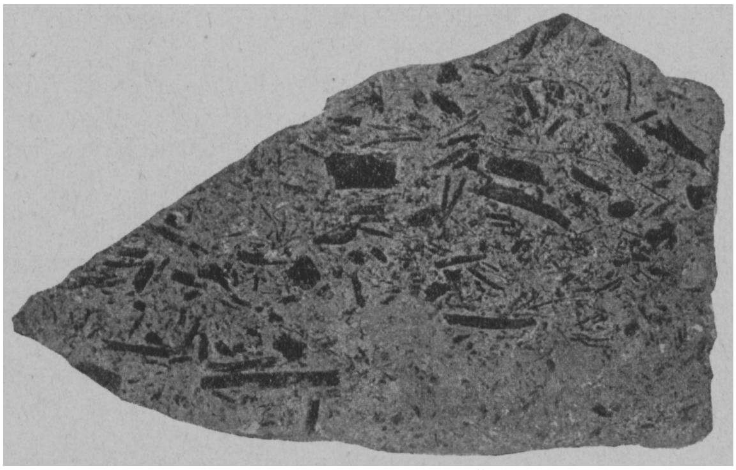
PLATE XXII.



Krol

Fig. 1.

The Esino Mass of the Presolana seen from the north. The dark rock at the bottom of the high cliff is Wengener sandstone.



Krol

Fig. 2.

Wengener sandstone with plant fragments.

No Esino limestones are present and the splinter shales have taken their place. This facies is found in the whole of the Lozio region wherefrom ERDMAN (lit. 20) reports:

	no Esino limestone
Wengener 400 m	350 m. splinter shale 50 m. marly schistose limestone with calcareous sandstones with plant remains.
Buchensteiner 250 m	100 m. fine grained blue limestone with a very few and thin marl intercalations. 100 m. blue sandstones alternating with blue limestones with chert. 50 m. limestones alternating with yellow and green tuffaceous sands and marls.

The limit between Buchensteiner and Wengener is purely arbitrary and the sandstone facies of the Wengener and the siliciferous limestone facies of the Buchensteiner have become thoroughly mixed.

The same facies with thin Esino limestones at the top of the Ladinian is found in the Palline-Borno overthrust according to DORSMAN (lit. 19):

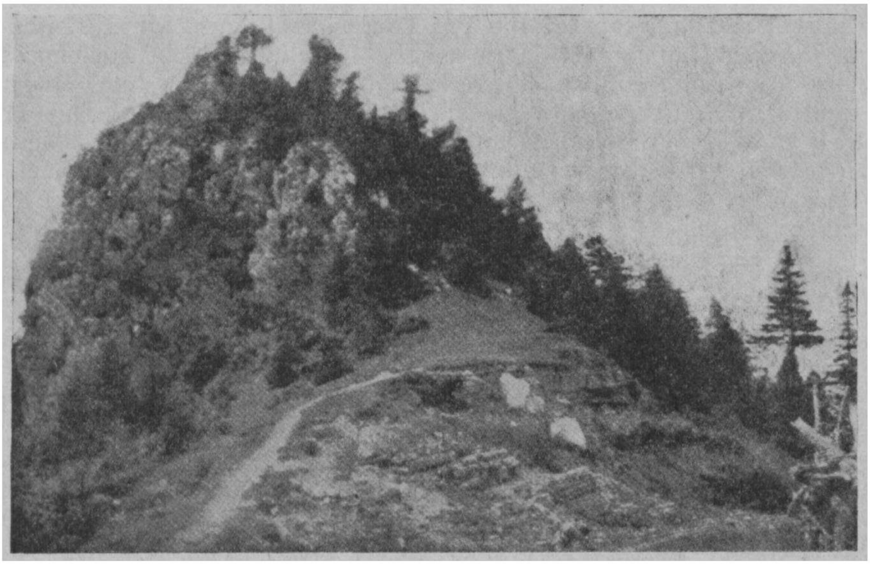
Esino 20—30 m.	limestone alternating with marls (perhaps this thin series would better be included in the overlying Raibler).
Wengener	300 m. splinter shale.
Buchensteiner	150 m. limestone with chert banks, nodulous limestones, marls and sandstones.

Along the Val Camonica and the Val d'Angolo a gradual change of the Ladinian facies from south to north occurs (DORSMAN lit. 19).

	Val d'Angolo.		Above Pian di Borno, Val Camonica.
Esino	350—500 m. massive Esino limestone 10 m. stratified Esino limestone	Esino	50 m. Esino limestone
Buchensteiner	20 m. nodulous limestone with chert, alternating with blue sandstones 15 m. blue limestones alternating with thin marls	Wengener	65 m. blue fine grained li. st. shaly and weathering in chips 145 m. sandstones, splinter shales blue li. st. plant remains
		Buchensteiner	85 m. black siliciferous nodulous li. st. tuffaceous marls.

PLATE XXIII.

ESINO

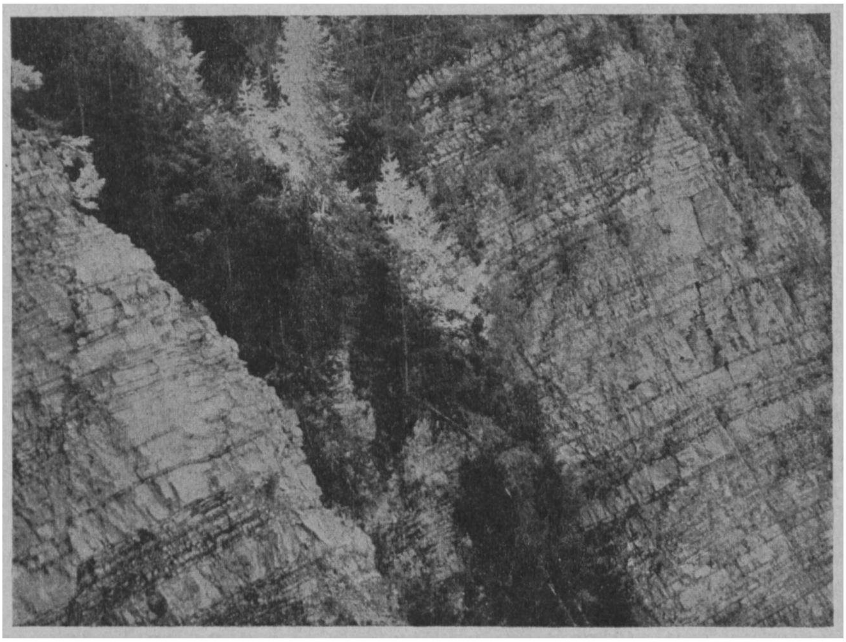


Maaskant

Fig. 1.

Esino limestone on Wengener horizon. Locality: Near Pt 1254 east of Bluzena, Mt. Guglielmo, East of Lago d'Iseo.

BUCHENSTEINER



Krol

Fig. 2.

The well stratified Buchensteiner Horizon on the left bank of the Upper Val di Scalve below the Bta Ezendola.

In the south we find comparatively thick Esino limestone and no Wengener sandstone or shale facies, and towards the north this latter facies gradually displaces the Esino reef limestones.

On the mountain tops of the Pzo Camino and Corna di S. Fermo we encounter again the normal facies of the Ladinian. Buchensteiner which is rich in chert bands and lenses, overlain by Wengener shales and sandstone and some 500 m. Esino limestone at the top (KROL, lit. 18). This facies which we know from the Valle Nembo, and find back in the Camino mountains is also present in the large mass of Esino limestone of the Concarena and from this mass to the Passo di Campelli. From this latter locality FABER (lit. 21) reports:

1100 m	*Esino limestone* and dolomite, probably an exagerated thickness due to tectonical doubling (ERDMAN lit. 20).
175 m	*Wengener* limestones, tuffaceous sandstones with plant remains, shales.
100 m	*Buchensteiner* dark shales, black to blue limestones with chert bands.

Summarizing the development of the Ladinian in this eastern section of the Bergamasc Alps we recognize a northern facies with a normal sequence of Buchensteiner-Wengener-Esino, to which belong the Valle Nembo, the Camino thrusted mass which we derived from the North, and the Concarena mass. In sharp contrast with this development we find a central basin where the Esino is lacking altogether and the Wengener has developed in a thick splinter shale facies instead. The Palline-Borno, Costone and Lozio overthrusted masses belong to this section.

The southern and western section are again normal as in the Val d'Angolo.

Transition from one facies type to the next are occasionally observed. In the Camino thrustmass the replacement of Esino limestone by Wengener proceeds from north to south (see section XXIII), and the replacement by the splinter shale facies proceeds from west to east. A similar gradual transition has been observed from S W to N E along the Val Camonica.

The present position of the different tectonical-stratigraphical units is not their original position. From the above mentioned distribution of the different facies types it becomes clear that the Lozio splinter shales and those of the Palline Borno and Costone overthrusts belong to one and the same basin or stratigraphical unit. In the same way the Camino thrustmass is stratigraphically closely linked to the Concarena mass, whilst the Val di Scalve facies of splinter shales without Esino limestone again belongs to the splinter shale basin.

It is impossible as we will see in the tectonical description of Part III that the Palline-Borno thrustmass has been derived from north of the Val di Scalve, its overthrusted position on the Raibler and Norian East of the Val Dezzo must have its origin between the Val di Scalve and this Raibler zone. The close similarity of facies of the Lozio mass, which also rests on the same Raibler zone, forces us to accept a similar origin for this tectonical unit, which was regarded as a thrustsheet derived from north of the Concarena by ERDMAN (lit. 20).

The Camino thrustsheet, now resting on the Palline-Borno overthrust with its quite different facies must belong to a zone originally situated north of the Val di Scalve, and was in this its original position also in direct contact with Concarena mass of similar facies. The original position of the units, therefore was as presented by fig. 19.

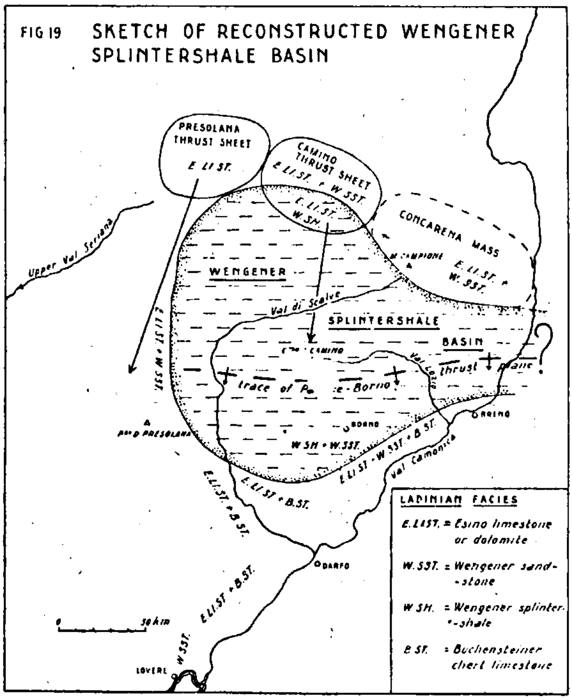


Fig. 19.

This conception is different from that of Dorsman and Erdman, and has important tectonical consequences which will be treated extensively in Part III, but we want to point out here that this is the only way to unite the splinter shale facies occurrences in one basin which does not separate the Camino and Concarena facies units from one another.

The splinter shale basin is an elongated basin with a West-East axis, and closed towards the west.

Towards the east it is open towards the Val Camonica, the other side of this valley is occupied by tonalite or metamorphic rocks which have not been mapped with sufficient detail to be able to advance any ideas about the continuation of the splinter shale basin.

Along the northern border of the shale basin the facies transition is affected in a very narrow zone. This is partly exposed in the front of the Camino thrustsheet south of the Corna di S. Fermo, but between the southern limit of the Concarena mass and the Lozio shale basin only a fault and a hypothetical narrow fold occur. The whole transition must have taken place in this wharped up narrow zone now absent due to erosion. But south of the Passo di Lifretto where thin Esino limestone rests on splinter shales we notice already the quick increase of thickness of the shale mass.

The western end of the shale basin is not exposed but here also the facies change must have taken place in the limited space available across the Val Dezzo.

Along the southern border of the shale basin the facies transition may have been much slower as shown by the gradual transition between Pian di Borno towards Angolo, but here we cut the border of the basin very obliquely.

Such quick facies changes need not surprise us. The growth of reefs is bound to clear water conditions. When a river charged with a clay suspension debouches in the sea, the algae and corals will grow freely at both sides of its channel, but in the channel all growth will be impossible. Here a slow occumulation of clay and sand will take place. Further away from the coast the reefs will grow more sparsely, due to the deeper water and closer to the coast the pollution of the water will prohibit reef formation. This latter condition is illustrated by the development of the Ladinian further south.

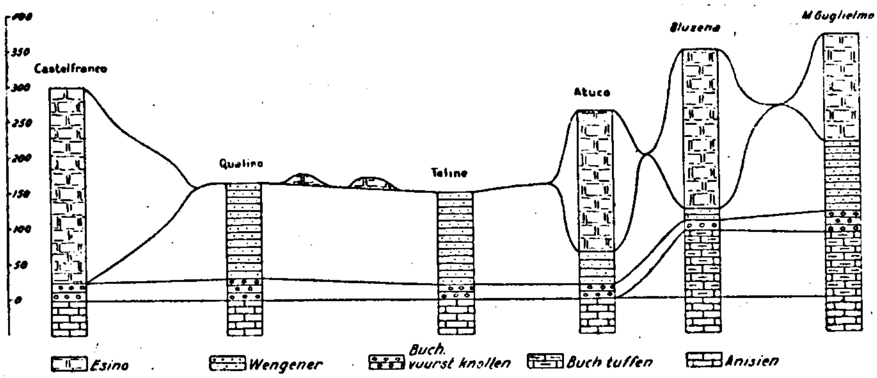
When we proceed from Angolo southwards towards Lovere the facies again changes quickly once we have crossed the Valle dell'Ogna.

The situation is here somewhat complicated by the presence of the Camorelli thrust which has acted from west to east with regard to the upper tectonical unit.

Below the thrustplane the Esino limestone of unknown thickness, because its upper limit is the above mentioned thrustplane, rests directly on the Anisian without any Buchensteiner or Wengener intercalation. This is in accordance with the tendency observed along the Val Camonica of decreasing thickness of these members in South-Western direction. Above the thrustplane the Esino limestone is underlain by Wengener and Buchensteiner, the former increasing in thickness when the Esino decreases. From the Torrente Supine to Lovere the Esino is absent altogether and we find the following sequence (MAASKANT lit. 22).

Wengener 150 m	75 m	tuffaceous sandstone with plant remains, black limestone and shales.
	75 m	blue slightly siliciferous limestones.
Buchensteiner 27 m	12 m	grey or yellow hard marls alternating with marly shales with chert nodules.
	8 m	grey limestones with black chert nodules and bands, some shale and sandstone.
	7 m	blue-black limestones with black shales (perhaps better regarded as Trinodosus schists!).

Still further south, south of the Lago d'Iseo the Esino limestones or dolomite forms real reefs of great thickness but limited extension. MAASKANT (lit. 22) mapped three reefs, that of the Mt. Aguina, of Bluzena and of the Mt. Guglielmo (Fig. 20). Two sections are given below:



after Maaskant

Fig. 20.

Schematic section of the development of the Esino reefs N. and S. of the Lago d'Iseo.

	Bluzena	Mt. Guglielmo
Esino	± 300 m Esino limestone	± 300 m Esino limestone
Wengener	10 m yellow fossiliferous li. st. (*Daonella lommeli* Wissm.) marls and tuffaceous sandstone.	30 m fossiliferous black li. st. with tuffaceous sandstone.
Buchensteiner	15 m nodulous limestone with chert 60 m green porphyrite („Pietre verde").	40 m blue li. st. abundant chert nodules 60 m green porphyrites and tufs.

When the Esino is lacking the Wengener reaches a thickness of 150 m in the above mentioned section north of the Lago d'Iseo and 160 m near Toline south of this lake.

For the first time we encounter here the porphyrites of the Buchensteiner horizon, which are very common in Tirol. There can be no doubt that in this continuously marine series the extrusions are subaquatic. The chert content of the horizon may be due to this volcanic activity.

In fig. 21, the development of the Middle-Triassic in this eastern part of the Bergamasc Alps has been represented schematically. The quiet and unvariable development of the Anisian is in strong contrast with that of the Ladinian, where heteropic facies are frequent. The swelling and disappearance of the Esino facies combined with the different developments of the Wengener horizon is most striking. The position of the splinter shale basin between two large masses of Esino limestone explains why by subsequent compression these shales were pressed up and thrusted over its foreland. A very similar section could be constructed somewhat further east, where the sequence of strata of the Camino thrustsheet has been replaced by that of the Concarena, the Lozio overthrust instead of the Palline-Borno overthrust and the Val Camonica instead of the Val d'Angolo.

As we will see further on similar complete N. S. sections can not be

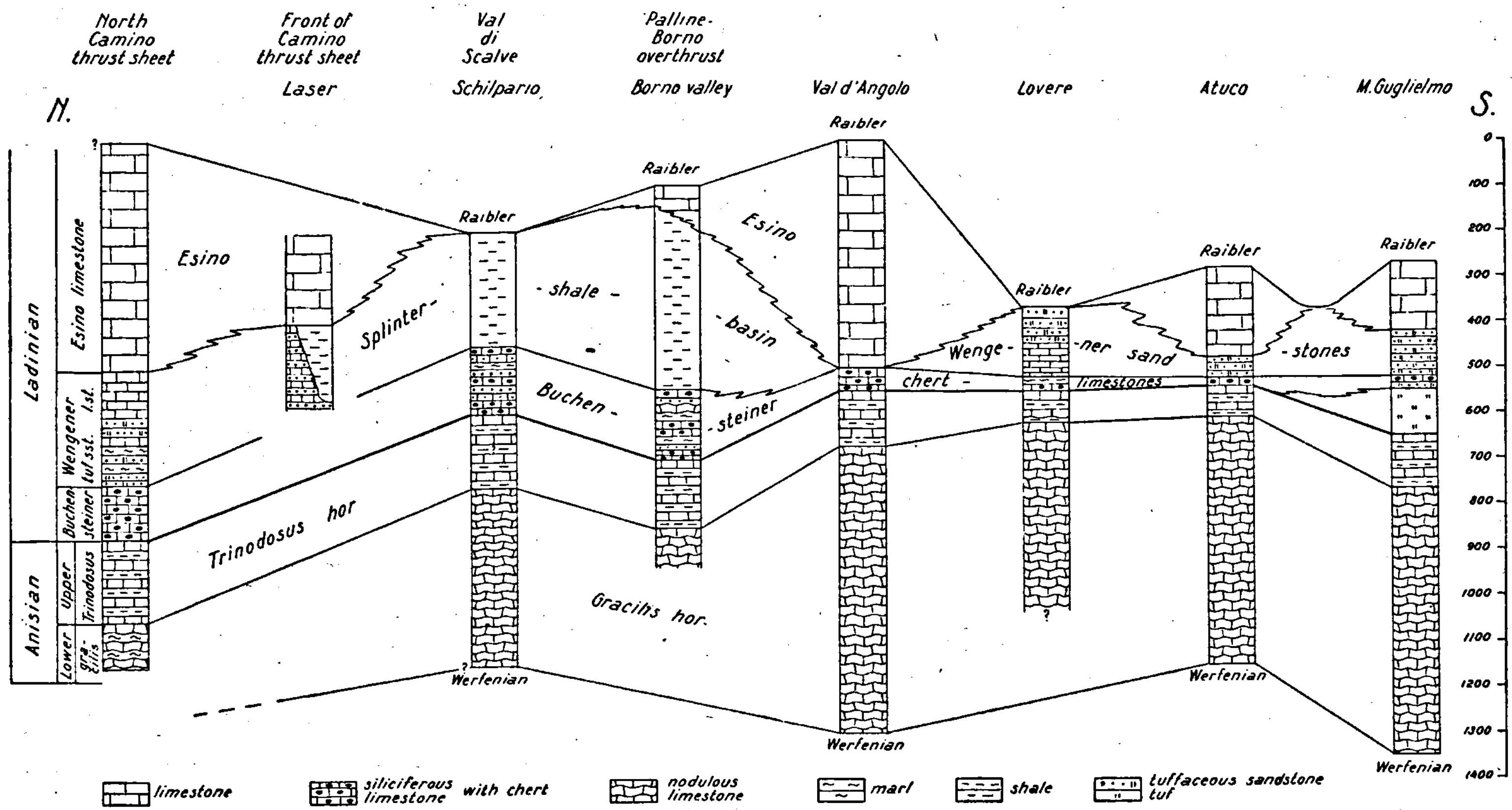


Fig. 21.

Stratigraphic development of the Middle Triassic in the Eastern Bergamasc Alps.

drawn for any other regions of the Bergamasc Alps, because the outcropping zone of the Middle-Triassic is much narrower anywhere else.

Between the Val Seriana and the Val Brembana the Ladinian occupies the large mountainous masses of the Mt. Secco, Pzo Arera, Cma di Grem, Cma di Menna and Mt. Ortighera. The facies changes but little and the whole of the Ladinian is developed in Esino facies, which along the Valcanale and the Valsecca rests directly on the Anisian. The replacement of the Wengener and Buchensteiner horizons by Esino limestones can be observed in the Timogno thrustsheet and across the Val Seriana just south of Gromo. The lower boundary of the Esino, which rests directly on the Anisian in the Timogno thrustsheet where it crosses the Serio near Valle dell'Ogna, is characterized by a primary breccia of considerable interest, described by SWOLFS (lit. 16). North and N W of Dosso, Vle. dell'Ogna, a black bituminous limestone of 45 m. thickness, equivalent to the Buchensteiner is intercalated between the Esino limestone and the Anisian. Here the Esino begins with a 40 m. thick brecciated horizon, followed by the normal massive Esino limestone. Further north the same breccia is observed to rest directly on the Anisian, the bituminous limestones being absent. The components of the breccia consist of white Esino limestone and a dark component probably derived from the dark limestones. As shows fig. 22 SWOLFS considered this breccia horizon as a primary breccia due to wave action near the coast. In the region between the Val Seriana and the Valle Vedra the lithological aspect of the Esino changes from east to west from unstratified limestones and dolomites to a much better stratified sequence. Along the western border of the Serio river the Esino can be divided, according to Swolfs in three badly distinguishable parts:

Esino 800 m.:
1. Lower Esino, dark grey coarse unstratified dolomite.
2. Middle Esino, white unstratified limestone.
3. Upper Esino, white coarse well stratified dolomite.

The upper limit of the Esino is taken below the metalliferous Lower Raibler limestones, but when these limestones are not, or very little, ore bearing it is difficult to trace the boundary. We will come back to this point when the Raibler is discussed.

In the west of this area along the Valle Vedra the total thickness has increased to 840 m. and a stratification of the Middle Esino has set in.

Still further west little changes occur, except the curious development near the Baita dei Muffi in the Val Secca, and the thickness remains in general some 800—900 m but increases to some 1200 m in the Val Parina. Along the Val Brembana and in the Mt. Ortighera the Esino is rich in fossil mollusca, the best known locality being the talud fans opposite Scalvino on the Brembo river. (Fossil lists in HOFSTEENGE lit. 5). Gastropods (*Chemnitzia*) and diplopores (*Diplopora annulata* Schafh.) are most frequent, but lammellibranchs and cephalopods occur occasionally. Another good fossil locality is the Val dei Lacci near Lenna. Breccia horizons are reported by COSIJN (lit. 1) and HOFSTEENGE (lit. 5); they are due to local raising of the algae reefs above the sea surface.

South of Roncobello in the Valsecca occurs a small patch of well stratified blue limestones in banks of some 10 cm thickness, alternating with thin marls, on which are situated the Baita di Bordogna and the Baita dei Muffi. DORSMAN (lit. 19) mapped this region in detail and concluded that

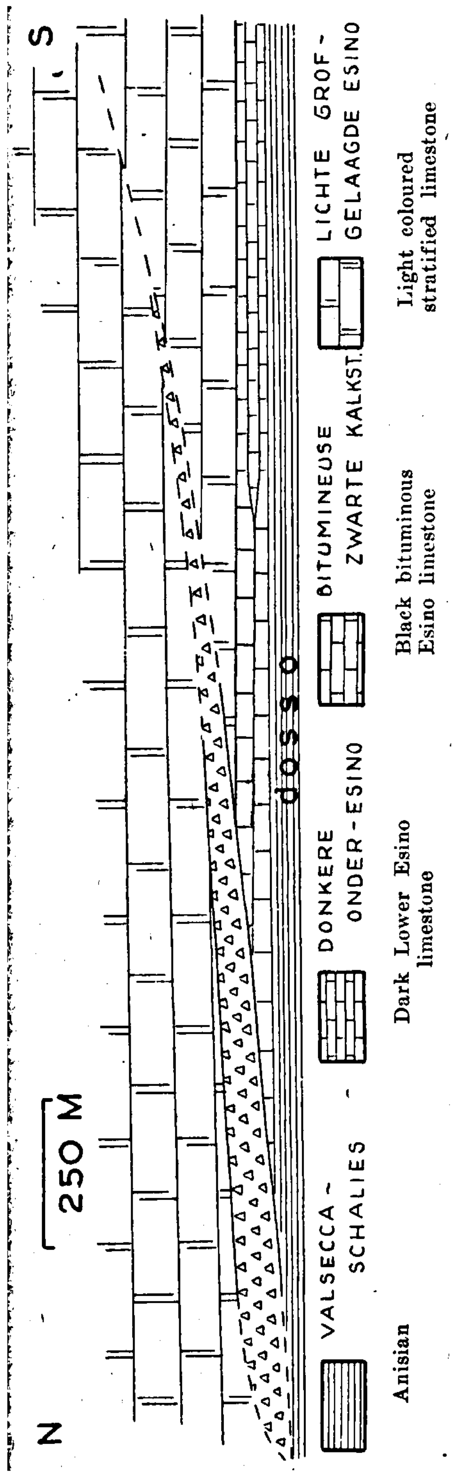


Fig. 22.

Brecciated horizon in Lower Esino, rising in N—S direction in the stratigraphical sequence. Vle dell'Ogna after Swolfs.

it represents a small region of a different facies of the Ladinian. The numerous fossils collected near La Gegna and described by TOMASSI[1]) are derived from the scree of this facies and indicate a Lower-Ladinian age. The limestones are siliciferous, with chert bands and nodules and ressemble both the Buchensteiner and the Perledo-Varenna facies of the Ladinian. Banks very rich in fossils, real shell limestones, with many diplopores, occur at 1300 and 1400 m height. Below the Passo del Menna the transition towards the Esino facies is cropping out, and the lateral facies change can be observed west of Baito di Bordogna.

When we follow the Brembo river upwards the Esino facies persists throughout the Ladinian but its thickness decreases to about 600 m near Olmo. North and NW of this village the thickness probably further decreases, but as Raibler is no longer present on the Esino its true thickness can not be ascertained.

In the Mt. Pegherolo the Esino has a thickness of 600—700 m in the west flank of this mountain. In the east flank towards the Valleve valley both the Wengener and the Buchensteiner are again developed. DORSMAN (lit. 19) reports:

[1]) TOMASSI, A. I fossile della lumachella triasica du Ghegna in Valsecca presso Roncobello. Parte 1, 2. Paleontographica Italica 1911.

Esino		Esino limestones
Wengener: 390 m.	180 m.	blue black shales, green to brown sandstones with plant remains, siliciferous limestones with chert nodules and chert banks.
	130 m.	blue, well stratified coarse limestones, often brecciated, alternating with shales.
	80 m.	well stratified blue limestones and calcareous marls. somewhat siliciferous.
Buchensteiner: 110 m.	30 m.	light coloured dolomite without marls.
	10 m.	siliciferous dark blue limestones with chert bands.
	70 m.	grey quartzites and sandstones alternating with red marls.

It is not very apparent why Dorsman puts a limit between the two Lower Ladinian horizons as the development is very similar. The upper green sandstones with plant remains are typical for the Wengener horizon though (on the map the distinction has not been followed). The development is very similar to the northern facies of the eastern Bergamasc Alps as we have described before. Across the Brembo di Valleve on the Mt. Valgussera we find a similar development of the Lower Ladinian.

Along the northern flank of the Mt. Pegherolo mass the Lower Ladinian facies disappears gradually. On the Passo di San Simone are exposed, according to Dorsman, some 325 m of siliciferous limestones with chert and thickly banked blue limestones on shaly thinly stratified limestones with chert, the whole series in vertical position. The Anisian has here a thickness of only 150 m. Further west along the east bank of the Mezzoldo valley this Wengener facies of the Lower Ladinian has again disappeared. In the Mt. Pegherolo has been observed a similar transition from east to west from Wengener facies to pure Esino facies of the Ladinian as we observed already on the east bank of the Serio river.

The Grigna overthrusted masses (Trümpy, loc. cit.), which again consist mostly of Ladinian limestones are separated from the Ladinian of the Brembo river by the large Norian area of the Val Tallegio, on which are preserved only small patches of an once large thrustsheet, the Salzana thrustsheet, which again consists of mostly Ladinian.

The Grigna thrustsheets have been pushed from North to South and are piled one upon the other in their present position. In order to visualize the original development of the Ladinian we have to replace them one behind the other towards the north. In the lowest and southern thrusted mass, the Coltignone thrustsheet, the Ladinian consist wholly of Esino limestone and dolomite of some 1000—1200 m thickness, comparable to that of the Val Parina. In the middle thrustsheet, the Grigna meridionale, the thickness and development remains the same, except in the western part of this thrustsheet where the Perledo Varenna facies occupies a large part of the Ladinian. This facies will be described further on. The Esino limestone (dolomite) of all three thrustsheets is still rather well stratified white to light grey reef limestone, rich in fossils in the Grigna settentrionale, poor in the southern part.

In the northern unit, the Grigna settentrionale, three facies have been developed. From West to East, the Perledo Varenna limestone, in the centre Esino limestone and dolomite, and above Pasturo: Buchensteiner, Wengener and Esino limestone.

Trümpy (loc. cit.) described the whole sequence of the Ladinian above Pasturo as follows:

Esino		Esino limestone
Wengener: 420 m.	30 m.	dark dolomitic well stratified limestones, transition to the light coloured Esino.
	300 m.	grey-brown sandy and marly tuffogenous thinly banked limestones and sandstones with plant remains, alternating with green marls.
	30 m.	thinly banked blue limestones alternating with green sandy marls.
	60 m.	well stratified sandy light blue limestones.
Calimero limestone	80 m.	max. crinoïdal and coralline reef limestone.
Buchensteiner: 145 m.	4 m.	grey, thinly banked dolomitic limestone.
	3 m.	dark dolomite, brecciated.
	15 m.	light coloured sandy dolomite.
	5 m.	grey blue limestone with 1—3 cm. thick chert bands.
	10 m.	sandstone alternating with blue limestone.
	2 m.	„Pietra verde'' dolomitic tuf.
	10 m.	grey brown sandy tuffogenous marl.
	25 m.	blue limestone with chert.
	40 m.	tuffogenous dolomitic limestone „Pietra Verde''.
	10 m.	blue limestones with chert nodules.
	0.5 m.	green calcareous sandstone, very conspicuous.
	20 m.	black marls alternating with thinly banked limestone transition to the Anisian Trinodosus horizon.

The whole Lower Ladinian series is replaced by Esino dolomite in the centre of the thrustsheet and the lateral transition is remarkably quick. The more than 400 m. thick Wengener series disappears within one kilometer both in southern and in northern direction, the Buchensteiner disappears more slowly as shows the map. Both the Buchensteiner horizon, characterized by blue siliciferous limestones with chert bands and nodules, and the Wengener horizon, characterized by green tuffogenous sandstones and limestones ressemble in every respect the Buchensteiner and Wengener of the eastern Bergamasc Alps described before. As the tectonic unit of the Grigna settentrionale has its origin from some 10 km further north than its present position a direct connection between the two facies may be assumed.

The Esino facies of the Grigna area can be divided generally in a lower dolomitic and an upper limestone series, only in the Grigna meridionale the whole series is dolomitic. The Upper limestone facies is rich in fossils in the Grigna settentrionale near the village of Esino, on the Sasso Mattolino and the Cima dei Cic. The rich fauna has been tabulated by Trümpy (loc.

cit.) and has been described by MOJSISOVICS [1]), AIRAGHI [2]), STOPPANI [3]), PIA [4]), MARIANI [5]) and KITTL [6]).

The general stratigraphical conclusion to be derived from the rich upper Esino fauna is that the reef facies, which extends from the Anisian to the Carnian, unites fossils which are elsewhere characteristic for the Buchensteiner, the Wengener, the Cassianer and other distinct Ladinian substages.

The gasteropods are predominant in the fauna together with diplopores, but bivalves and cephalopods are to be found in restricted areas. Doubtless the gasteropods thrived exceptionally well on the rich diplopore meadows growing at a depth of the sea of not more than maximum 400 m., probably in general much less.

Further west, along the border of Lake Como, both in the Grigna settentrionale and in the Grigna meridionale thrustsheets the lower Esino dolomite has been laterally replaced by the well known Perledo-Varenna limestones. They consist of a max. 500 m. thick series of blue-black well banked limestones and shaly limestones. Chert nodules are frequent in the lower part, higher up they are lacking. Often thin bituminous shales separate the limestone banks, they weather in yellow colours, thus accentuating the stratification. Primary brecciated zones are frequent and white calcite veins across the limestones give the rock a very characteristic habit. Towards the east the whole complex is replaced along a N—E transition zone by the Esino dolomite. First the limestones become more dolomitic, the colour becomes lighter and the stratification disappears. The Perledo-Varenna limestones follow directly on the Anisian Mendola dolomite and the upper boundary is not very distinct, a transition zone occurs towards the overlying Esino dolomite.

The fossil content of the Perledo-Varenna limestone is very poor (an occasional find of *Daonella Moussoni* Mer) except the rich fish fauna derived from the neighbourhood of Perledo. This fauna has been described by ALESSANDRI [7]).

The Esino limestone S E of Introbio in the Valle di Bobbio and on the Zucco Orscellera is the normal Esino dolomite and limestone of the Grigna, with many diplopores. This Esino complex is probably underlain by Buchensteiner siliciferous limestones but the mapping of this region was never completed (DE WIT, lit. 24).

1) MOJSISOVICS, E. VON. Die Cephalopoden der mediterranen Triasprovinz. Abh. d. k. k. geol. Reichsanst. Bd. 1, H. 1, 1882.

2) AIRAGHI, C. Nuovi Cefalopodi del Calcare di Esino. Palaeont.. Italica, Vol. VIII, 1902.

3) STOPPANI, A. Risultati paleontologici e geologici dedotti dallo studio dei petrefatti di Esino. Atti Soc. Ital. d. Sc. Nat. Vol. II, 1860.

4) PIA, J. V. Die Gliederung der alpinen Mitteltrias auf Grund der Diploporen. Akad. Anzeiger, Wien, 1925.

5) MARIANI, E. Note geologiche sul gruppo delle Grigne. Rendic. R. Ist. Lomb. Vol. 34, 1901.

Contributo allo studio delle bivalvi del „calcare di Esino'' nelle Lombardia. Atti Soc. Ital. di Sc. Nat. Vol. 46, 1908.

Su una nuova forma di Temnocheilus della dolomia ladinica della Grigna di Campione. Atti Soc. Ital. di Sc. Nat. Vol. 53, 1914.

6) KITTL, E. Die Gastropoden der Esinokalke. Ann. d. k. k. Naturhist. Mus. Bd. XIV, 1899.

7) ALESSANDRI, G. DE. Studi sui pesci triasici della Lombardia. Mem. Soc. Ital. di Sc. Nat. Vol. VII, 1910.

The remnants of the large Salzana thrustsheet north of Val Taleggio consist of Esino limestone, often very much brecciated by tectonical influences. DESIO [1]) found some fossils in the Bruco mass of which *Undularia* is typical for the Ladinian.

[1]) DESIO, A. Sull esistenza di falde tectoniche in Val Taleggio. Publ. d. Ist. di Geol. etc. della Universita di Milano Serie G., 1934.

CHAPTER IV.

THE UPPER-TRIASSIC.

The Upper-Triassic of the Bergamasc Alps is clearly divided in two major stages:

B. The Norian or „Hauptdolomit''

A. the Carnian or „Raibler''.

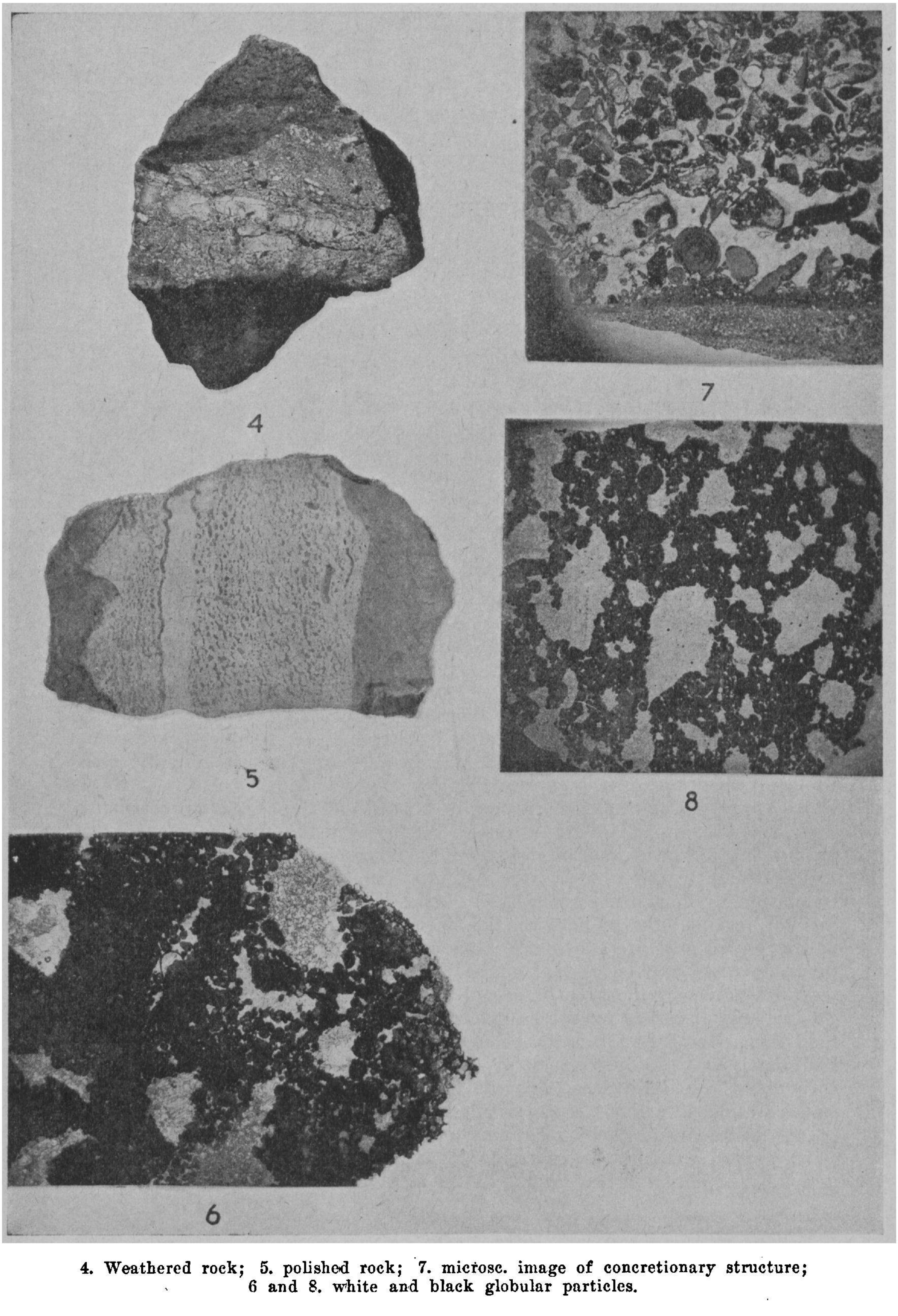
The two stages are lithologically very distinct and specially the lower one, the Carnian, well defined by a rich fauna.

A. *The Carnian or „Raibler''.*

The Carnian is generally a series of limestones, marls, shales, sandstones and tufs of 600—750 m. thickness. Its lower limit with the Esino limestone is not easy to determine and considerable controverseries have arisen in the course of the survey. Finally KROL (lit. 26) made a special study of this problem throughout the Bergamasc Alps, which has been completed since then by the eastern surveys of DORSMAN, ERDMAN and MAASKANT (lit. 19, 20, 22). The difficulties arise out of the fact that nearly everywhere the transition from the typical Esino limestone or dolomite to the typical Lower-Raibler well stratified dark limestones alternating with marls is very slow and moreover varies considerably in character. A peculiar ore bearing limestone horizon, known as the „Metallifero'', carrying mestasomatic zinc, lead and sometimes iron ores (see Part I) was reckoned to the Upper Esino by all surveyors of the Western part up to the Val Brembana in accordance with PORRO (map of 1903). SWOLFS (lit. 15) was the first to regard this ore bearing formation as Lower-Raibler, a view which has been substantiated and extended to the whole region by KROL (lit. 26). SWOLFS arrived at his conclusion by comparing his section of the limestones, marls and shales of the Val Seriana situated between the typical Esino limestone and the typical multicoloured fossiliferous marls, tufs and limestones of the Raibler with the same stratigraphic interval of the Val Brembana. In the Seriana section several bivalves of the type of *Myophora* could be recognised. Although not good enough preserved for species determination they offer sufficient indication that this „Metallifero'' series belongs to the Carnian rather than to the Ladinian. KROL, in his survey of the Esino-Raibler boundary, found that throughout the Bergamasc Alps the best field property of the lower limit of the Raibler (Carnian) is the occurence of the so called „Raibler texture'' of the white or dark coloured limestone rock. This „Raibler texture'' of which typical examples an represented Plate XXIV and fig. 1, Plate XXV, is a kind of oölitic texture arranged in streaks and bands. The weathered

PLATE XXIV.

Lower Raibler characteristics „Raibler texture''.



4. Weathered rock; 5. polished rock; 7. microsc. image of concretionary structure; 6 and 8. white and black globular particles.

rock (Plate XXV, fig. 1) is easy to recognise as the dark calcite veins stand out in relief. Under the microscope it is found that part of the rock consists of very minute opaque calcite globules which show mostly no concentric texture. Real oölitic textures do occur though (7 on Plate XXIV) and sometimes a brecciated habit of the rock has been observed. The origin of this texture is obscure.

Other features of the Lower-Raibler are the red colouring of the Esino type of limestone, the so called „calcare rosso'', the ore content, bands of black chert, fluorine bands, tuffaceous breccia's etc., which will be described in due course when the different sections are discussed.

In the western and central Bergamasc Alps the Raibler can be divided in three parts:

Carnian or Raibler 700 m. thick	Upper: fossiliferous limestones with marls etc.
	Middle: fossiliferous multicoloured shales, marls etc.
	Lower: non-fossiliferous limestones, marls etc. (ore).

The division is arbitrary and of no great importance, but is convenient for the description of such thick series. In the Eastern part it is the Upper Raibler which consists of the typical marl-shale facies with vivid colours and the middle and lower parts are either tuffaceous, calcareous or dolomitic. Obviously therefore a division in three subdivisions is only of very local value and is only introduced as such.

The abbundancy of fossils of the Carnian is very striking as compared to that of the Ladinian and the Norian. It consists principally of bivalves of the generae *Myophoria, Myoconcha, Gervillia* and several others (*Pecten Lingula, Nucula* etc.) (Plate XXVI, fig. 1).

HOFSTEENGE (lit. 5) investigated in great detail the particularly fossiliferous lower 100 m. of the Upper Raibler of the Val Brembana and gives a complete fossil list of this locality. DORSMAN (lit. 19) also reports a fossil list of the Lower-Raibler of the Val Camonica and PARODI [1]) one from Vle. Fontagnone (Val Seriana). Hofsteenge's list contains 27 forms, Dorsman's 37 forms, Parodi's list 27 forms of which all three lists have only 4! species in common viz: *Myophoria Whateleya, M. Kefersteini, Lima inaequicostata* and *Gervillia Meriani.*

An extensive study of the Raibler fauna was made by PARONA [2]), who described some 50 species, from the best fossil locality, the small valley of Rogno (the first affluent of the T. Riso reckoned from the Serio river) to which PARODI added some 6 new ones.

Plant remains of the genera *Equisetes* are found in the green sandstones of the Upper-Raibler at different localities.

On fig. 23 the different sections mentioned below are tabulated and can be compared.

In the Val Brembana the following sequence is developed.

[1]) PARODI, A. Notizie geologiche della regione compresa fra la Valle Canale e la Valle del Riso, Vale Seriana. Boll. Soc. geol. Ital. Vol. IV, 1936.

[2]) PARONA, C. F. Studio monografico della fauna Raibliana di Lombardia. Mem. premiata dal R. Ist. Lomb. di Sc. e. Lett. Pavia, 1889.

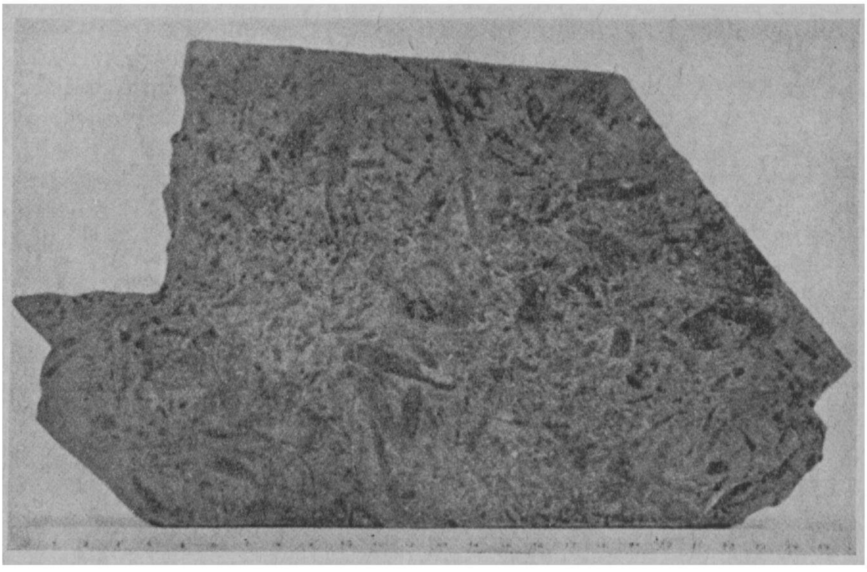
PLATE XXV.

Krol

Fig. 1.

Lower Raibler limestone, with alternating white and grey bands. This typical structure has been accentuated by the weathering of the rock surface.

RAIBLER



Maaskant

Fig. 2.

Raibler sandstone with plant remains, locality 2 km north of Zone, east of the Lago d'Iseo.

Carnian or Raibler ± 600 m.	Upper 240 m.	140 m.	gypsiferous marls, cavernous limestone, tufs, at the top brown sandstone.
		100 m.	fossiliferous dark blue limestone alternating with blue-grey marls.
	Middle 235 m.		multicoloured marls, sandstones and tufs, shales and nodulous limestone, non-fossiliferous.
	Lower 125 m.	100 m.	light grey or pale rosa limestone (Esino habitus) alternating with shale and marly limestone, Raibler texture, ore impregnation, fluorine bands.
		10 m.	sandy and marly limestone with Raibler texture.
		14 m.	yellowweathered grey-blue limestone with Raibler texture.
		1 m.	red brecciated limestone („calcare rosso”).

The lowest member of this series is the „calcare rosso”, in this section a brecciated rock, which elsewhere often reaches larger thickness (Hofsteenge reports 30 m.). Further east in the Val Seriana the red brecciated horizon is accompanied by tufs as will be described later on. Evidently the vertical facies change, leading from the Esino limestone to the Raibler, sets in by a raising of the bottom of the sea and subaquatic erosion by wave action. Tuffaceous material was apported from far off. The limestone deposition, however, went on, now characterized by the curious „Raibler texture”. Some 25 m. higher up in the section the ore impregnation sets in, and well stratified limestone alternating with shales, marls and marly limestone constitute a 100 m. thick series. The limestones are still of rather light colour, elsewhere they are much darker. The upper part of this limestone carries chert bands, fluorine and shales, of which Hofsteenge (lit. 5) gave a detailed section from the fluorine mine of Nember near Capo Paglio. The fluorine occurs here in a bank of 3 m thickness overlain by an alternation of chert and shale in bands of some 10—30 cm. thickness. In the chert, cropping out above the church of Bosco San Rocco, Hofsteenge found numerous small gasteropods which could not be determined, however. They were filled with secundary quartz. Similar chert bands without fossils though, are reported from the Grigna region by Trümpy (Plate XXVI, fig. 2).

The multicoloured shales, marls, tufs and sandstones of the Middle Raibler of this region represent the most conspicuous member of the Carnian, throughout Lombardia. The same series is reported from the Lugano region and from Tirol. The green, red and violet colours of the marls and tufs are very typical.

In the Upper Raibler are assembled a similar series of limestones and marls, but here the limestones, often fossiliferous, are predominating. In the lower 100 m. Hofsteenge (lit. 5) distinguished 7 fossiliferous horizons, which we assemble here in a somewhat simplified form.

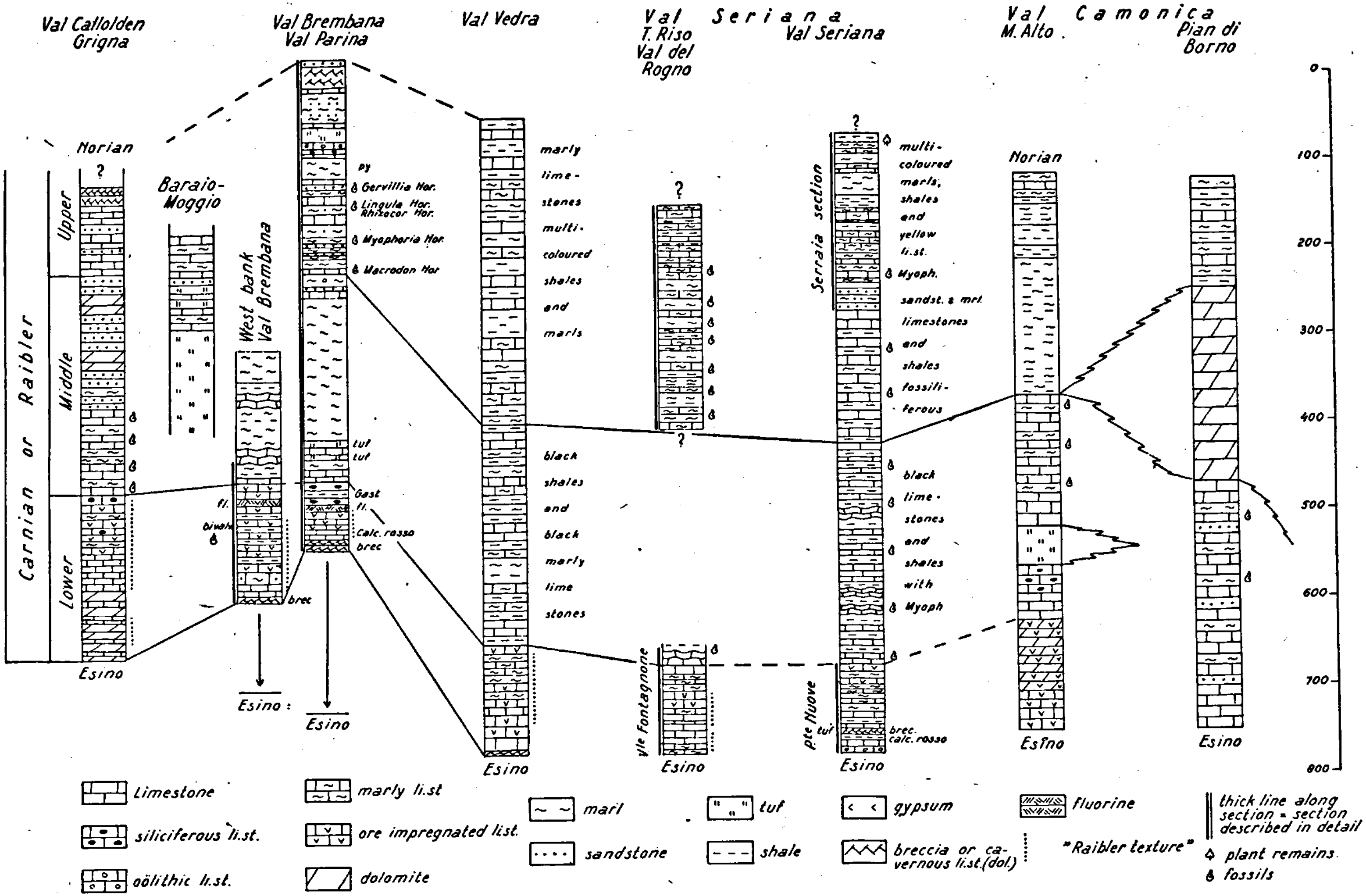


Fig. 23.

Stratigraphic development of the Carnian in the Bergamasc Alps.

PLATE XXVI.

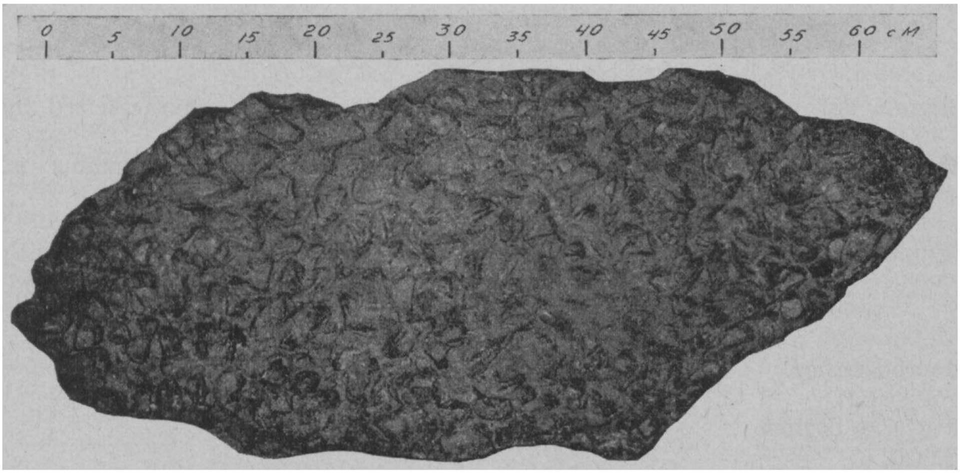
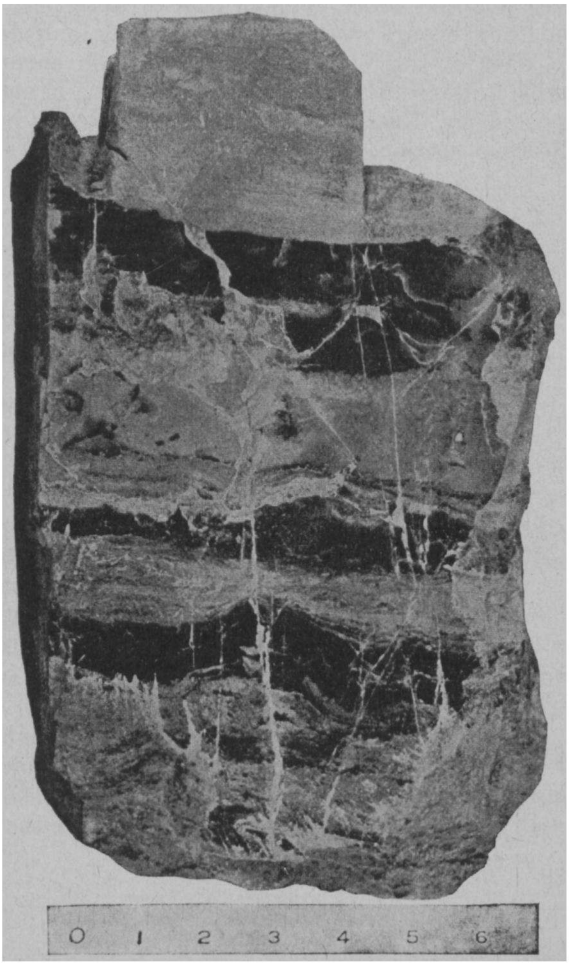


Fig. 1.

Upper Raibler sandy limestone. Surface covered with Myophoria Kefersteini and Myoconcha Curioni. Chiappa.

Fig. 2.

Lower Raibler white compact limestone with black chert bands. Loc. 350 m above road from Lecco to Abbadia, above Casa alla Fontana.



	top	Upper Raibler limestone etc.
Gervillia hor.	? **30 m.**	limestones, marls and sandstone characterized by the genus *Gervillia* besides *Myoconcha curionii, Myophoria Kefersteini.* One bank contains *Nautilus brembanus.*
Lingula hor.	? **10 m.**	Green marl with thin sandstones, characterized by *Lingula gornensis* and *L. tenuissima.*
Rhizocorallum hor.	**10 m.**	dark blue limestone with doubtful remains of *Rhizocorallum* on the bedding planes.
	15 m.	marls and sandstone poor in fossils.
Myophoria hor.	**25 m.**	grey marl alternating with green sandstone with plant remains. The marls contain numerous *Myoconcha* and *Myophoria Whateleya.*
	15 m.	non fossiliferous marls.
Macrodon hor.	**3 m.**	dark limestone with internal moulds of *Macrodon subalpinum?* and *M. Taramelli?*
	bottom	Middle Raibler shales and marls.

In view of the quick lateral changes occuring in the sequence of marls, sandstones and limestones it is not to be wondered at that other surveyors have never succeeded in identifying these horizons elsewhere.

In the upper 150 m. fossils are lacking again, the limestones become cavernous and large gypsum masses have been formed. At the top a brown sandstone occurs with marl fragments and lenses.

West of the Val Brembana we again encounter a complete development of the Raibler in the Grigna mountains. From the section of Val Callolden reported by Krol (lit. 26) and completed by the survey of Trümpy the following section is known.

Upper > 100 m.	brecciated grey-blue well bedded limestone crossed by calcite veins, some tuffaceous sandstones. The breccias are in part of tectonical origin.
Middle 250 m.	150 m. red and green sandstone with a few yellow dolomite banks. 100 m. fossiliferous limestones alternating with marls, weathering yellow (*Myophoria Whateleya, M. Kefersteini* etc.
Lower 190 m.	70 m. dark limestone and thin marls with chert and ore impregnation and Raibler texture. 40 m. thinly banked limestone with Raibler texture. 25 m. thinly banked limestones and dolomites. 55 m. limestone and dolomite with Raibler texture.

This section is in every respect very similar to that of the Val Brembana, but much less marly. The typical multicoloured marls and shales of the Middle-Raibler have disappeared.

In the region of Barzio-Moggio, east of the Val Sassina, the development of the Lower-Raibler and the lower half of the Middle Raibler is identical with that of the Callolden section, at the base dark limestone and higher up yellow fossiliferous limestones and marls. But in the Middle Raibler a series of red and green tufs, very fine grained with a few dolomite banks have been reported by DE WIT (lit. 24) sometimes coarser tuf sandstones can be observed.

Some 8 km N W of Moggio DE WIT (lit. 24) found a coarse sand with clay lenses and fragments and numerous plant remains of the genus *Equisetum*. Further on we will find these same tufs and sandstones again in the region south of the Lago d'Iseo.

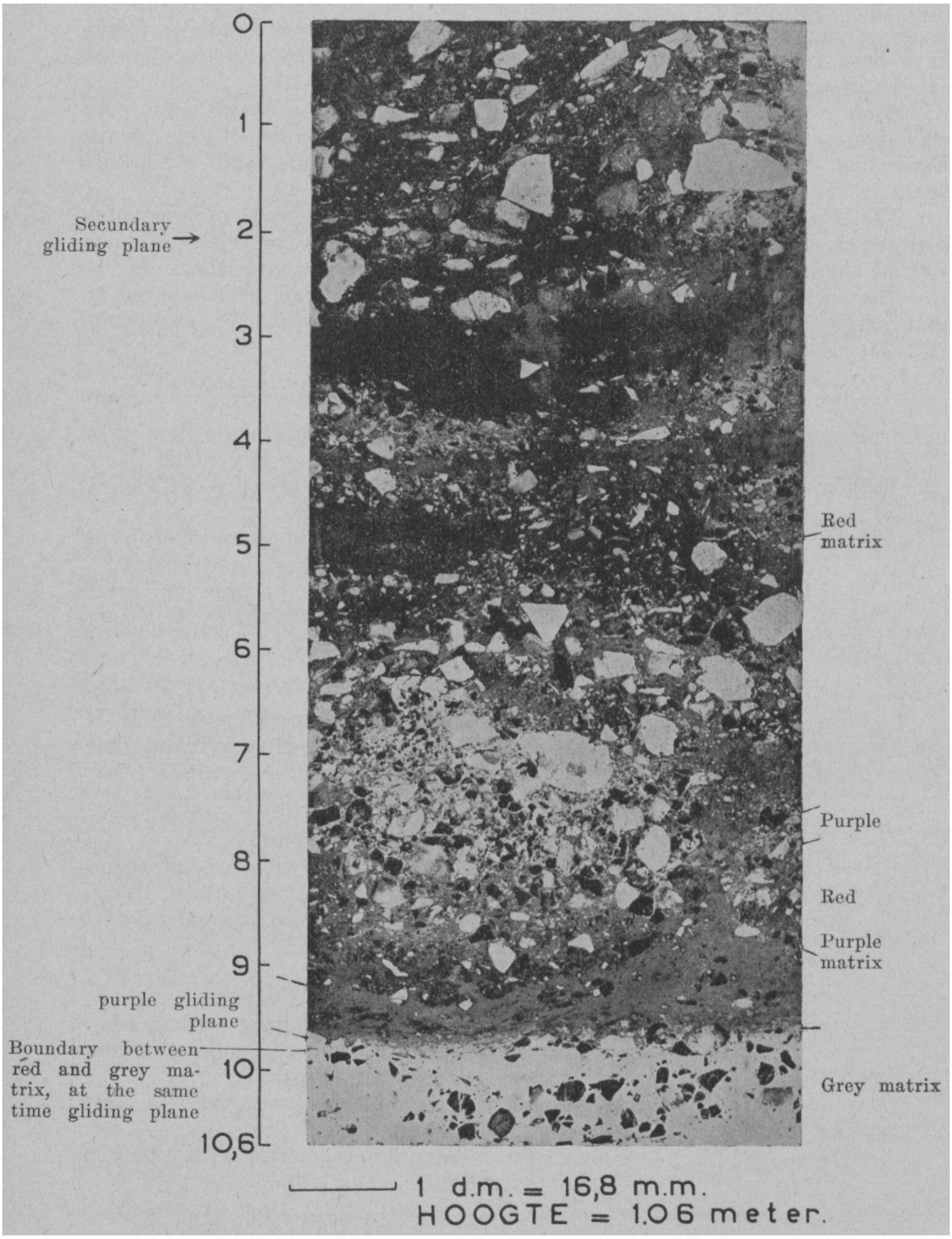
The Upper Raibler is not well exposed but a series of grey-blue limestones, oölitic limestones and marly limestones, marls and shales of some 100 m. thickness is exposed in the upper T. Pioverna above Mezzacca.

The section of the Val Brembana can also very well be compared to that of the Val Seriana, quoted below after SWOLFS (lit. 16) and KROL (lit. 26).

Carnian or Raibler 700 m.	Upper 350 m.	175 m.	multicoloured marls and shale light grey limestone, dark grey sandy marl.
		25 m.	black marly shales alternating with hard, dark brown sandstone.
		150 m.	blue, grey and white limestone alternating with multicoloured marls and shales. light coloured limestones, blue and green shales. (*Myophoria Kefersteini, M. Whateleya, Gervillia Bouei*).
	Middle 250 m.		shales and multicoloured marls with *M. Kefersteini*, and dark blue nodulous limestones.
	Lower 100 m.	6 m.	well stratified limestone.
		5 m.	light grey limestone with ore impregnation.
		50 m.	well stratified limestone alternating with marl.
		20 m.	dark blue limestone.
		3 m.	grey and blue marly shale.
		2 m.	dark limestone alternating with marl.
		1.70 m.	red and green marl, tuf, shale and limestone, brecciated in part.
		7 m.	red or red mottled limestone and deep red claystone.
		6 m.	white Esinolike limestone with „Raibler texture".

Again we find at the bottom of the series a brecciated horizon together with typical „calcare rosso". Near the Ponte delle Seghe in the vicinity

PLATE XXVII.



Lower Raibler breccia.

Polished slab of 10.6 m height, Geological Museum, Leiden.

of Ardesio a peculiar brecciated horizon has been described in great detail by SWOLFS (lit. 16).

The rock consists of a red or gray fine grained tuffaceous marl matrix with angular limestone fragments (Plate XXVII). Several gliding planes in the original mud can still be observed and the whole rock is undoubtedly a subaquaceous talud fan indicating erosion by wave action in the neighbourhood. Limestone conglomerates with rounded limestone fragments occur both below and above the breccia horizon.

The breccia or calcare rosso horizon is followed by well bedded generally dark coloured limestones alternating with thin marls, often showing zinc-ore impregnation. The ore occurs in lenses or in thick (max. 4) banks of impregnated limestone or is generally dispersed through the limestone. The upper part of the Lower Raibler is known as „Plattenkalk''.

The Middle-Raibler consists of black shales and black nodulous limestones. When the shaly development is not very pronounced the series resembles to a high degree the Lower-Anisian limestones. Fossils are sometimes abundant.

The Upper Raibler with its soft multicolouréd shales is very conspicuous SWOLFS (lit. 16) distinguished a lower limestone section of some 150 m thickness, a middle sandstone section of 25 m, and an upper marly section of at least 175 m thickness. *Myophorias* and *Gervillias* are sometimes abundant.

Still further east along the Val Camonica and at both sides of the Lago d'Iseo we meet a very different development of the Carnian, which we have represented in fig. 24, a series of representative sections.

The Lower-Raibler „Metallifero'' is only present between the Valle dell' Ogna and Lovere, as a series of ore impregnated limestones or dolomites of dark blue colour. The ore is here siderite and not the usual zinc-lead ore. This „Metallifero'' facies is followed by a tuffaceous series which across the Lago d'Iseo occupies the whole Lower-Raibler. The tufs are very well stratified and have green and red colours and are very fine grained. South of the Lago d'Iseo this tuffaceous series, which resembles in every respect the Raibler tufs from Moggio-Barzio of the Val Sassina far in the west (see p. 169), is followed by a series of sandstones with plant remains (Plate XXV, fig. 2) alternating with shales and marls. The sandstones have a olive green colour and are very much similar to the Wengener sandstones. Similar sandstones were reported by HOFSTEENGE from the Upper Raibler. Higher up in the sequence fossiliferous limestones are intercalated between the sandstones. The Upper-Raibler is the only normal sequence and is uniform in the whole region. It again consists of multicoloured marls alternating with shales, sandstones, yellow limestones but carries occasionally thick gypsum beds, which are exploited above Lovere. We recall the fact that in the Upper Raibler of the Val Brembana similar gypsum beds are present. (DORSMAN lit. 19, MAASKANT lit. 22).

Further to the north the sandstones of the Middle-Raibler, the tufs and the „Metallifero'' make place for a thick series (500 m.) of dark blue fossiliferous limestones alternating with marl, shale and occasional sandstones (Vle. dell'Ogna). But here the lower part of the Upper-Raibler is occupied by grey-blue fine grained well bedded dolomites. This dolomitic facies invades further north the whole Lower- and Middle-Raibler and rest near Cogno directly on the Esino dolomite from which they are difficult to distinguish. The „Raibler texture'', however, indicate where the boundary

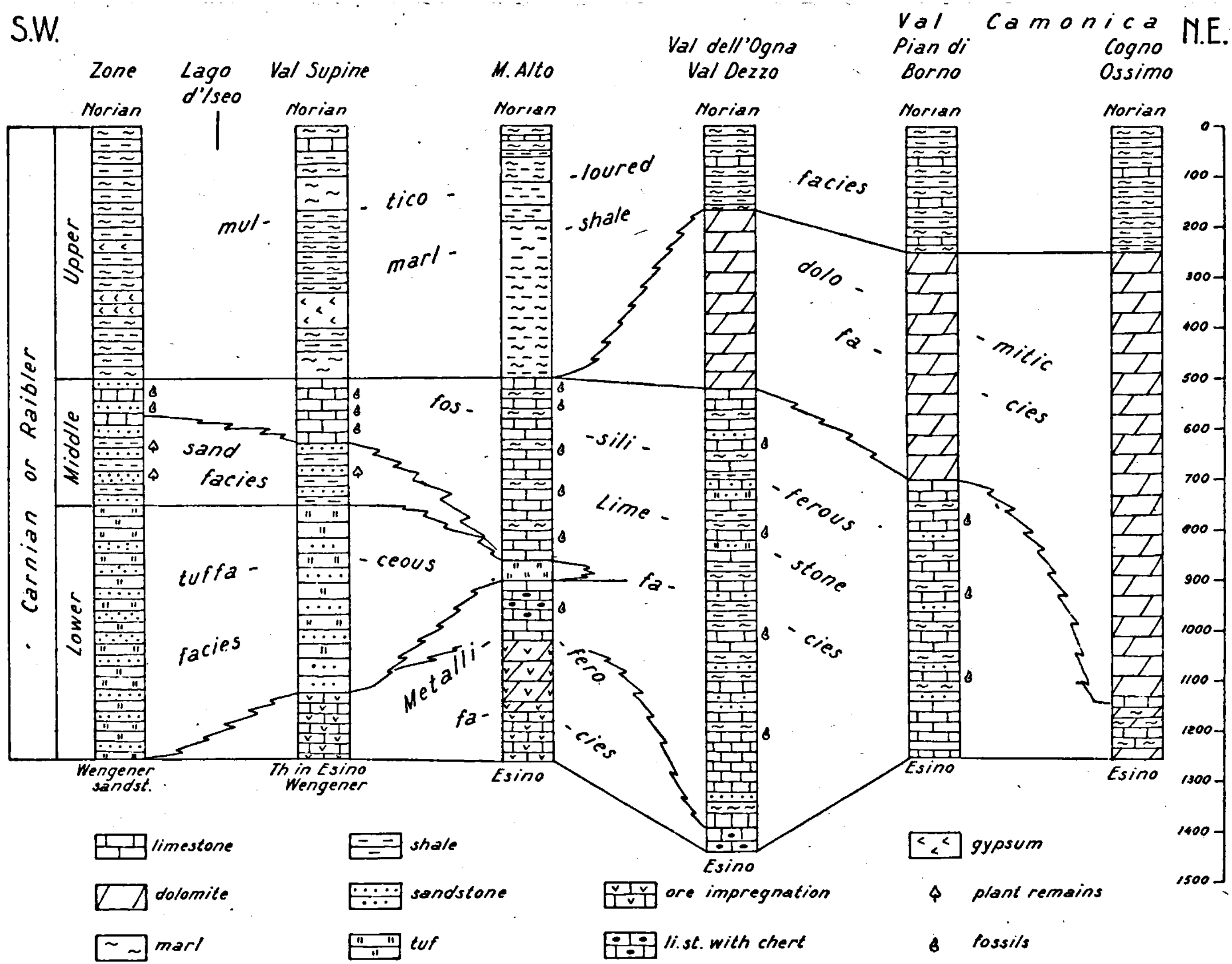


Fig. 24.
Stratigraphic development of the Carnia in the Val Camonica.

must be drawn. MAASKANT (lit. 22) pointed out that the development of the Lower- and Middle-Raibler shows a more litoral facies in the south compared with the shelf facies of the north. Apparently we approach the coast when we proceed from north to south (fig. 25). The thickening of the Upper Raibler facies in the same direction, and its gypsum content in the south, indicate the same tendency. We must be careful, however, to generalize this idea, and to assume a continent in the present Po plain, to few data are known at present to allow such far reaching conclusions.

When we consider with the help of fig. 22, the general development of the Carnian in the Bergamasc Alps we notice in the first place the rather uniform thickness increasing from 550 m in the West to 700 m in the East. While the general lithological character is also rather uniform except along the Val Camonica, the detailed sections show considerable divergencies. The whole series is characterized by an increase of detrital matter and a decrease of the calcareous sediments. Apparently the continental region which furnished the detritus must be sought in the central Alpine region where the scanty triassic sediments (Quartenschiefer and Rötidolomite) give ample evidence of erosive periods. Accordingly we suppose that the facies change of the Middle-Triassic to the Upper-Triassic as shown by the Raibler sediments is due more to the elevation of continental masses elsewhere than to the gradual upheaval of the sea bottom resulting in shallower water on the spot.

B. *The Norian or „Hauptdolomite".*

The Norian is represented by a thick uniform series of grey sugary dolomite, with scarce fossils and frequent primary breccias, mostly only very roughly banked.

The fossils most frequently encountered are diplopores of the kind of *Gyroperella vesiculifera* GÜMB. This form and *Griphoporella curvata* are considered by PIA [1]) as key fossils of the Norian. As a key fossil of the Norian is further considered *Gervillia (Avicula) exilis* STOPP., whereas *Turbo (Trochus) solitarius* and *Megalodon Gümbeli* STOPP. and *M. triqueter* WULF are often mentioned.

All fossils are scarce, however, and it is often difficult to distinguish between Esino dolomite and Norian dolomite when the tectonical situation is complicated.

In the west the Norian „Hauptdolomite" occupies a large area between the Grigna Mountains and the Val Brembana (Plate XXVIII, fig. 1). This region has been surveyed by DE WIT (lit. 24) and DESIO [2]).

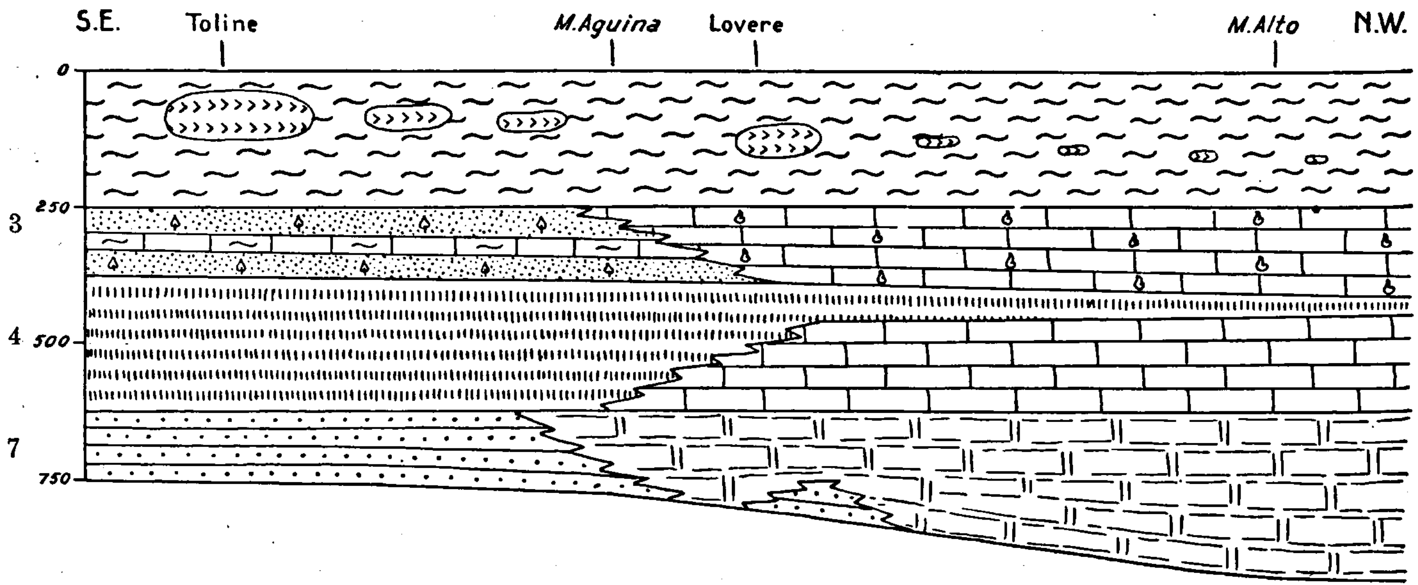
The thickness of the Norian reaches at least some 1200 m in the autochtonous portion. The remnants of thrustsheets, the Mt Muschiada, Zuc di Maesimo and the Corno Zuccone are regarded by DESIO as Norian dolomite on the force of *Turbo solitarius (Worthenia solitaria* BEN!) and rests of *Megalodon sp.* DE WIT did not succeed to find any fossils and is somewhat

[1]) PIA, J. Neue Studien ueber die triadischen Siphoneae verticillatae. Beitr. Pal. Geol. Oestr. Ung. Or. Vol. 25, 1912.

— Die Siphonae verticillatae vom Karbon bis zur Kreide Abh. Zoöl. Botan. Ges. Wien. Bd. XI, H. 2, 1930.

[2]) DESIO, A. Sull esistenza di falde tettoniche in Val Taleggio. Publ. d. Ist. di Geol. etc. della Univ. di Milano, Serie G, 1934.

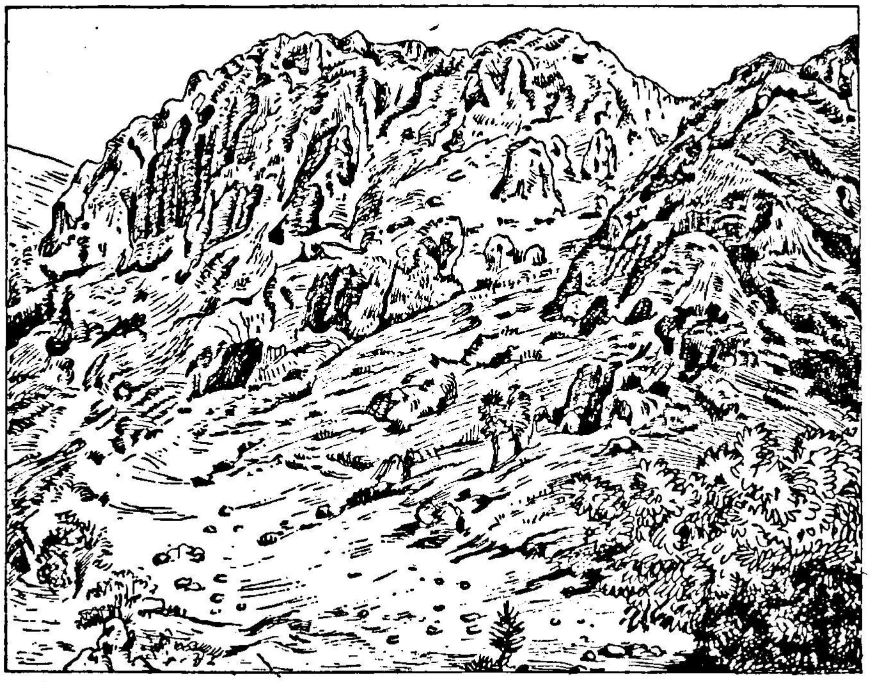
— Studie Geologici sulla regione dell'Albenza. Mem. Soc. It. Sc. Nat. Vol. X, 1929.



1. Marl with gypsum inclusions; 2. Fossiliferous limestone; 3. Sandstone with plant fragments and limestone intercalations; 4. Tuf; 5. Limestone with ore impregnation; 6. Esino limestone; 7. Wengener sandstone.

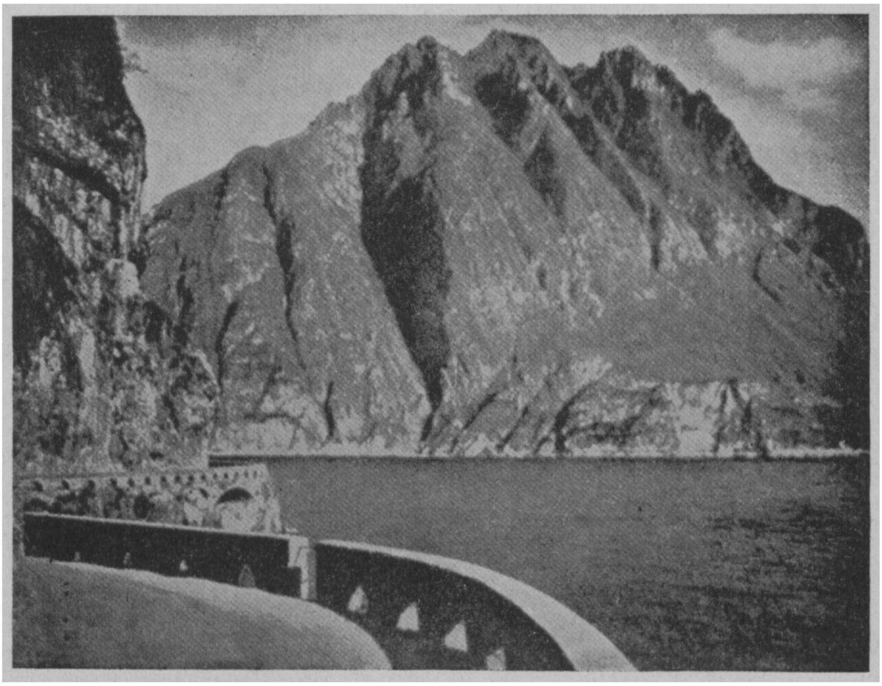
Fig. 25.

Heteropic facies of the Raibler and Ladinian round Lago d'Iseo, after Maaskant. In the S E near coast deposits, in the N W more marine facies.



De Wit

Fig. 1.
Hauptdolomite landscape of Rifugio Castelli, South-East of Introbio.



Maaskant

Fig. 2.
Steep dipping „Hauptdolomite'' of the Corna Trentapassi, east shore of the Lago d'Iseo.

doubtful of the age of these overthrusted masses as the lithological character is sometimes more like Esino dolomite.

Right in the centre of the large extension of Norian dolomite lies a complex of platey dolomites with a maximum thickness of 500—600 m., which DE WIT regards as a heteropic facies of the Norian dolomite. The rock is a well stratified dolomite with banks of an average thickness of 15 cm. weathering in brown and red colours, alternating with dark blue limestones. The thinly banked dolomites are very similar to thinly banked dolomites occurring everywhere between the normal 10 m. thick dolomite banks of the Hauptdolomite and there seems to be little doubt as to the age of this complex although no fossils have been found.

Along the Val Brembana the Norian starts with a 20 m. thick grey cavernous dolomite which is followed by a 25 m. thick primary brecciated horizon. (HOFSTEENGE lit. 5, COSIJN lit. 1). On this basal series follows the at least 1000 m thick uniform dolomite complex.

Further east the Hauptdolomite forms everywhere the southern limit of the surveyed area. From the Mt. Alben to the Val Seriana the same 1200 m. thick complex of uniform grey dolomite with some limestones is developed.

The Hauptdolomite between Clusone on the Serio and the Giogo della Presolana has been divided by VISSER (lit. 14) in a lower brecciated horizon and an upper uniform dolomitic limestone complex. From the Mt. Scanapà he reports:

above

30 m dolomite breccia
85 m rather well stratified grey coarse grained dolomite
15 m coarse dolomite breccia.

below

Similar brecciated horizons, cavernous dolomites and some clay and marl intercalations are found in the same horizon elsewhere in this region. This division in two members of the Hauptdolomite has not been taken over by any of the later surveyors.

MAASKANT (lit. 22) gives a thickness of 1500 m for the Norian dolomite, in which he found many diplopores and sometimes banks with *Gervillia (Avicula) exilis*. On the Lago d'Iseo the thickly banked Hauptdolomite forms the picturesque Corna Trenta passi (Plate XXVIII, fig. 2). Along the shore of this lake a primary breccia of the Hauptdolomite is exploited in a quarry (Plate XXI, fig. 1). It is often difficult to distinguish between such primary breccias and consolidated, cemented scree which also is common below the steep scarps of the Hauptdolomite masses.

CHAPTER V.

THE JURASSIC AND CRETACEOUS.

Introduction.

The Jurassic of the Bergamasc Alps follows concordantly on the Triassic, and slowly develops from the bathyal shelf conditions of this latter period to a real abyssal facies in the Dogger and Malm. In the Cretaceous the facies develops again from a bathyal facies to a neritic facies.

The Middle and Upper Mesozoic has been divided into several stages:

Cretaceous	Upper: Scaglia	flyish facies.	
	Lower: Majolica	white or rosa coloured fine grained slightly siliciferous limestone	
Dogger-Malm	Aptici schists.	thinly bedded marls	Abyssal facies of Jurassic.
	Radiolarite	red chert	
Lias	Upper —	Ammonitico rosso — red marls Toarcian	
	Middle —	Domerian — light brown siliciferous limestone	Siliciferous limestone.
	Lower —	thinly bedded siliciferous limestone Hettangian-Sinemurian.	
Rhetic.	Upper —	Dolomitic zone	Conchodon dolomite.
	Middle —	Coralline limestone, oölitic limestone	Coralline limestone.
	Lower —	black shales zone of *Avicula contorta*	Scisti neri.

On our maps the subdivision of the Rhetic could not be introduced except in the region of Val Taleggio and Alta Brianza, where DESIO introduced the three subdivisions and RASSMUSS distinguished a lower subdivision comprising the Lower and Middle Rhetic of DESIO, and an Upper division, the Conchodon dolomite. The Lower Liassic has not been subdivided on our maps. The Upper Liassic together with the Dogger and Malm has been assembled in one subdivision of the Jurassic, the abyssal facies, as the scale of the maps did not allow to represent the very thin bands separately.

The Jurassic has been mapped in detail only in the southwest corner of the map, in the Alta Brianza and in the Albenza and Val Taleggio, the rest of the southerly Bergamasc and Bresciane Alps is still very much in need of a modern survey.

A. *The Rhetic.*

A controversy as to the position of the Rhetic, whether it belongs to the Jurassic or the Triassic is still apparent. The old school of Italian paleontologists, regard the Rhetic as the lowest Liassic formation. STOPPANI [1]) distinguishes the „Infralias'', of which the lower division is the zone à *Avicula Contorta* (our Lower- and Middle Rhetic) and the upper division is the Conchodon dolomite and the Hettangian.

The French school (HAUG a. o.) includes the Rhetic in the Jurassic. English and German authors prefer to reckon it to the Triassic. This attitude has been taken over by modern Italians, for instance PARONA [2]), mostly on the evidence of the ammonites, described by POMPECKJS [3]), which undoubtedly are closely related to the Triassic ones.

The controversy is of no great consequence, and in our region the Rhetic has a similar intermediate position between the Lower- and Middle Mesozoïc. It is related to the Triassic facies in the west as a continuation of the prevalent shelf facies but merges into the Liassic in South Tirol. On the other hand the limit between the Norian and the Rhetic is very sharp in the Bergamasc Alps and that between the Rhetic and the Hettangian only a gradual transitian. Moreover in the Lugano region the first real interruption of the sedimentation occurs at the top of the Norian. Due to this fact the field surveyor will be inclined to include the Rhetic in the Jurassic as has been done in this monograph.

DESIO [4]) refers again to the original division of STOPPANI and is followed by many others, for instance TREVISAN [5]) in his study on the Brenta Mountains east of the Adamello. They divide the Rhetic in three subdivisions:

Upper.

3. Conchodon dolomite. Dachstein facies characterized by dolomites and limestones with large bivalves of the group of *Megalodonti.*

Middle.

2. Calcareous facies. The Karpathian facies of SUESS [6]). Coralline limestone with *Terebratula gregaria.* (Kössener schichten.)

Lower.

1. black shale and limestone facies. „Scisti Neri'', The Swabic facies of SUESS [6]). Shallow sea facies with *Avicula contorta* and many lamelli branchs.

In the Alta Brianza (RASSMUSS [7]) the black shales and limestones of the Lower Rhetic contain many shell limestones build up by small lamellibranchs as *Nucula, Leda* and *Cyprina* in the lower portion. Higher up the dark coloured marls, shales and limestones are much less fossiliferous. The Middle Rhetic consists of marly limestone, limestones and shaly limestones. Fossils are rare

[1]) STOPPANI, A. Studi geologici e paleontologici sulla Lombardia Milano 1857.
[2]) PARONA, C. F. Trattato di Geologia. Milano 1903.
[3]) POMPECKJS, J. F. Die Ammoniten des Rhäts. N. Jahrb. f. Min. usw.
[4]) DESIO, A. Studi geologici sulla region dell'Albenza. loc. lit.
[5]) TREVISAN, L. Il gruppo di Brenta. Mem. It. Geol. R. Univ. Padova XIII, 1938.
[6]) SUESS, E. Das Anlitz der Erde II Bd. p. 337, Vienna 1888.
[7]) RASSMUSS, H. loc. cit.

in general except on the Mt. Azzarola described by STOPPANI. The upper member of the Middle Rhetic is a coralline limestone (Madreporenkalk), a hard well stratified grey-brown limestone.

The corals, mainly *Thecosmilia clathrata* EMMR, are accompanied by gastropods and lamellibranchs. Lower and Middle Rhetic reach a thickness of some 30 m in the Alta-Brianza. The coralline limestone is overlain by a reef dolomite or limestone of variable thickness (15—300 m), the so called Conchodon dolomite. In this horizon fossils are mostly very scarce, and it reaches its greatest thickness in the picturesque Corni di Canzo. On the Mt. Barro the horizon is developed as an oölitic limestone which elsewhere often occupies only the bottom of this member.

In the Albenza [3]) and the Val Taleggio (DE WIT lit. 24) the Rhetic has very much the same character, although somewhat thicker and better developed. The lower black shales and limestones reach a thickness of 220 m and are rich in fossils in the lower portion, of which DESIO gives a complete list. The transition of the Lower to the more calcarous Middle Rhetic is very gradual. Its maximum thickness is some 300 m. It consists of coralline limestones (with *Thecosmilia clathrata* EMMR), oölitic limestones, brown marly limestones and marly fossiliferous shales.

The Upper Rhetic, the Conchodon dolomite, is developed as a limestone-dolomite complex, poor in fossils of some 80 m thickness.

The limit with the Lower-Liassic is difficult to determine as only a gradual transition from the yellow-brown reeflimestones and dolomites to the siliciferous limestones of the Sinemurian exists. Therefore the Hettangian can only be ascertained by fossils which sometimes are scarce enough.

North and west of the Lago d'Iseo only the Lower Rhetic, black limestones with little black shales, have been mapped, and no particulars are mentioned by MAASKANT (lit. 22). Later on we will see that east of the Adamello in the Brenta Mountains the Rhetic has still a very similar development to that of the Albenza (TREVISAN, loc. cit.) and we may assume therefore that little variation will occur between the Val Brembana and the Val Trompia.

B. *The Jurassic.*

The Jurassic occurring only in the Val Taleggio, and along the southerly border of the foothills in the S W corner of the map can be divided into two parts:

Upper Jurassic, abyssal facies radiolarite, red marls	Aptici schists, red and green marl. Radiolarite, red chert. Ammonitico rosso, red marl.
Lower Jurassic, Liassic, bathyal facies, siliciferous limestone	Domerian, grey, brown, white list. Sinemurian, black list. Hettangian, light coloured list.

DESIO distinguishes on his map of the Albenza region three divisions of the Liassic, but on the small corner of our map the Hettangian is much reduced and can hardly be separated from the Sinemurian. The Domerian, also a siliciferous limestone is of much lighter colour than the mostly black Sinemurian siliciferous limestones but is hardly thick enough to be represented on a 1:50.000 map.

The *Sinemurian* is a black or dark blue limestone rich in chert nodules and chert bands and is well stratified in thin layers. In the Val d'Erve the Sinemurian is rather poor in chert and contains many shale and marl intercalations. Further west, at the other side of the Adda, the Liassic increases enormously in thickness, to some 800 m in the Alta Brianza. Generally a lower horizon the „Grenzbivalvenbank'' belonging to the Hettangian can be distinguished, a yellow shaly limestone with many remnants of *Pinna, Ostrea* and *Pecten.* On the Mt. Cornizzolo the lamellibranchs have been replaced by cephalopods and crinoid stem joints. These faunae are certainly of a Hettangian age. The Sinemurian is everywhere very poor in fossils and consists west of the Lago di Lecco also of grey- and black siliciferous limestone with chert bands and nodules. The chert of the Liassic limestones is derived from spongiae. RASSMUSS succeeded in determining different horizons in the homogenous black limestone facies of the Lower- and Middle Liassic by occasional finds of very restricted ammonite faunae. These determinations do not allow a subdivision of this formation in different stages on the map as the petrographical habit of the rock is unvariable.

The *Domerian,* has been mapped as a distinct horizon both by DESIO and RASSMUSS, but has been included in the Lower-Jurassic on our map as it is only a thin horizon. It consists of lighter coloured, grey, white, rosa, siliciferous limestones, never more than 30 m thick, with a rapid transition to the overlying red marly limestone of the Upper Liassic Ammonitico rosso. The lithology of this thin band is rather variable over short distances. The limestones sometimes carry much chert, at other points they are marly; the colour varies mostly between yellow and red, and most limestones are micaceous. Both above mentioned authors give fossil lists which contain mainly cephalopods and a few brachiopods.

The abyssal facies of the Jurassic has been assembled on our map under the name of *Upper Jurassic,* although it comprises the whole series from Toarcian to the Kimmeridgian, or the Upper-Liassic, Dogger and Malm.

Two distinct facies can be distinguished. The Lower portion consists of the well known „*Ammonitico rosso*'', a red nodulous limestone and marl with numerous ammonite internal moulds, and the overlying *Radiolarite* together with „*Aptici schists*'' red chert and red marls.

The „*Ammonitico rosso*'' comprises the upper Liassic (Toarcian and Aalenian) and Lower Dogger in the Alta Brianza. It consists of a maximum 30 m thick, very conspicuous band, of red soft marls with numerous limestone nodules which probably are all of them badly preserved ammonite internal moulds. The series gains considerably in thickness towards the east, and in the Albenza region reaches as much as a 100 m thickness. Fossil lists of the ammonites are cited by RASSMUSS and DESIO.

The *Radiolarite* and the *Aptici schists* (Rosso ad Aptici) consist in the Alta Brianza of red radiolarian chert in 20—30 cm thick banks, together of some 20 m thickness, sometimes alternating with red shales, marls and marly limestones. Upwards the radiolarian chert changes rapidly in red marls and limestones of some 25 m thickness. This formation also increases considerably in thickness in an eastern direction to 85 m in the Albenza region. In the upper portion badly preserved Belemnites and Aptici can be found.

C. The *Cretaceous* appears on our map in the Ravella Syncline and along the steep rand zone north of the L. di Annone and between this lake and the L. di Garlate, and east of this lake in the Val d'Erve.

The Lower Cretaceous is represented by the *Majolica* facies, a very compact, fine grained white foraminiferal limestone with black radiolarian chert The fracture is conchoidal. The rock is traversed by numerous dark clay films in all directions, which give it a very peculiar habitus. The thickness of this formation is some 100 m. The boundary with the underlying Aptici schists is sharp, but it is certain that this boundary does not coincide exactly with the boundary Jurassic-Cretaceous, and not even with the boundary between the Kimmeridgian and Tithonian stages.

The white limestones are nearly wholy devoid of fossils. In the upper portion of the formation a few grey marl banks are intercalated, forming the transition to the overlying Upper Cretaceous. The scarce fossils indicate that the Barremian is still included in the Majolica.

The Majolica is followed upwards by red, grey and greenish marly limestones and marls, thinly stratified.

These variegated marls are overlain by a thick complex of flysch facies, marls, sandstones shales etc. Fossils have never been found in this series except badly preserved plant remains, and the name of *Scaglia* has been given to this neritic facies of the Upper-Cretaceous.

CHAPTER VI.

QUATERNARY AND PHYSIOGRAPHY.

The flysch facies of the Upper Cretaceous announced the great Alpine folding phase of the Tertiary. In the Bergamasc Alps no remains of Tertiary sedimentary formations are preserved if they ever have been present, except some small remains of local Pliocene basins outside our map, estuaries or fjords extending from the Po plain between the foothills [1]. The only Tertiary rocks present in our region are the Tertiary dykes which are closely connected with the great Adamello intrusion. They have been fully treated in the first Part of this paper.

In the Younger Tertiary the orography of our region was begun to be moulded out of the strongly folded earth crust. The great valleys of the Bergamasc Alps were formed, the Val Tellina, the Lake Como-Adda valley, the Brembo valley with its many tributaries, the Serio Valley, the Val di Scalve-Val d'Angolo, and the great Oglio valley or Val Camonica.

That the erosion of the Val Tellina is closely related to one of the most important tectonical lines of the Alps, the Insubric line is obvious. The strongly shattered and brecciated rocks along this line were more easily eroded than any other formation, and the high and massif chain of mountains along the south flank of the Val Tellina, the Orobic Mountains, are the result. Apparently the erosion in the Younger Tertiary had sufficient time to model a landscape of mature aspect in the southern slopes descending from the central chain.

Particular attention to these older denudation surfaces has been paid by NANGERONI [2]. This author distinguishes a Miocene surface, a Pliocene and two Quaternary surfaces. The physiography of these high terraces is most interesting. The excavations of the younger glaciers in the hard rock, now visible mostly as a multitude of small lakes gives an otherwise rather monotonous undulated landscape its particular charm.

A. *The glaciation.*

During the glaciation of the Alps tremendous glaciers descended from the nearly unbroken ice surface which blanketed the central Alps, over the southern Alps, which were largely below the permanent snow level. The Orobic mountain chain, however, acted as a buttress, against which the large glaciers abutted, and which protected the whole region south of the Orobic Mountains from being overrun by these glaciers. There were two alpine glaciers, i. g. the Adda glacier, following the Val Tellina and

[1]) See on list p. 16: GUAITANI and MALANCHINI.

[2]) NANGERONI, L. G. Morfologia del gruppo di Sella e della regione Barbellino. Publ. Univ. catt. sacro Cuore Milano. Sc. geogr. Vol. II, 1938.

the Como lake valley, and the Oglio glacier following the Val Camonica. These two glaciers embracing the Bergamasc Alps from three sides sent out branches entering this region from east and west [1]).

Thus a branch of the Oglio glacier entered the valley of Borno-Palline and others the Val d'Angolo, the valley of the Torrente Borlezza as far as San Lorenzo and the Val Cavallina. A diffluent glacier of the Adda glacier descended into the Valsassina, covered the basin of Pasturo-Barzio and formed the lateral and terminal moraines from Barzio — Cremeno — Moggio — Mezzacca — Maggio — to Balisio. The glacier did not extend further south into the narrow Norian gorge.

Besides the two large Alpine glaciers, glaciers originating in the high mountains of the Orobic chain were formed. These Orobic glaciers were much smaller than the Alpine glaciers and descended not very far southwards. The Serio glacier for instance never reached much further down than the Selva-Parre moraine near Clusone, and the Remboglacier did not descend further south than Scalvina just south of Lenna.

Therefore a large area was never touched by glacial erosion or covered by morainic material. Only the high region of the central Orobic chain has been permanently covered by ice, while the high Triassic limestone peaks of the Grigna, Zuccone Campelli-Mt Venturosa, Cima di Menna, Pzo Arera-Mt Secco, Mt Ferrante - Pzo della Presolana, Pzo Camino - Concarena formed independent mostly small „névés'', firn fields.

The glacial erosion scooped corries in the flanks of these limestone peaks, and the glaciers eroded the existing valleys to a great extent. Outside the glaciated area and the post glacial erosion of the main valleys the country still preserves its mature physiographic character. As soon as one has ascended the steep slopes of one of the main valleys, a landscape of grass covered slopes sometimes covered by pinewoods is discovered. The contrast with the rocky cliffs of the riverbed is very striking. It would be a very interesting study to analyse the pre-glacial erosive system in the Bergamasc Alps, the same as has been done by Annaheim [2]) in the Luganese Alps. No doubt the 1st. and 2nd system of this region could be found back here, probably better preserved.

B. *Glacial deposits.*

As glacial deposits we shall distinguish

1. moraines
2. fluvio-glacial gravels and bench gravels
3. cemented screes
4. lacustrine deposits

1. *Moraines.*

Moraine material has been deposited to a great extent in the river valleys formerly filled by the glaciers and the ice cap. The ground moraines

[1]) The glaciation of the Bergamasc Alps has been the subject of one modern comprehensive study:

HAUPT, H. O. Die eiszeitliche Vergletscherung der Bergamasker Alpen, Berlin 1938, which has been followed here to a great extent. For more detail and literature we refer the reader to this work and to two publications by DESIO on the Val Seriana and Val Brembana, mentioned on p. 15.

[2]) ANNAHEIM.

in the river valleys are only exposed in deep gullies of the present rivers were they have cut through the later gravels.

Terminal moraines of larger dimensions are only found in the Barzio basin, belonging to the Valsassina glacier, and below Clusone in the Val Seriana, where the Selva moraine and the Parre moraine are remnants of the terminal moraine of the Serio glacier. Small terminal moraines of the T. Borlezza glacier, a diffluence glacier of the large Oglio glacier, can be observed near San Lorenzo. Small moraines are frequent in the higher mountain plateaux of the Orobic chain. They belong naturally to a later period of melting of the glaciers.

Of the terminal moraines of the Brembo glaciers little has been preserved. Small remnants occur near Valnegra and Bordogna. but our map is very inaccurate here as to the quaternary deposits.

2. *Fluvio-glacial gravels.*

Of much greater importance than the moraines are the extensive bench gravels which often form the banks of the larger rivers. The pleistocene gravels are either of glacial or interglacial time, or formed in late glacial time during the melting of the ice in dammed up portions of different valleys.

The terraces of Lecco, south of the Mt Coltignone - Mt Melma were formed in a time when the Adda glacier still occupied the valley of the L. di Lecco, and accumulated against this glacier. Several terraces can be distinguished but all appear to belong to the late glacial period.

Similar late-glacial gravel accumulations are found in the Brembo di Mezzoldo valley upstream of Olmo till as far north as the mouth of the Pegherolo valley. Piazzolo is build on this terrace. The bench gravels of the Vle Piazzotorre are somewhat older, they accumulated when this valley was dammed up by the Brembo valley glacier. The terraces which are connected with the Po valley do not reach so far up into the Brembo valley that they enter into our map.

The glacial terraces in the Serio valley can be found along the river from Nossa to Pte delle Seghe. Piario and Ardesio are build on these terraces. Above Gromo no fluvio-glacial gravels can be found any longer, the glacial valley is filled by morainic material.

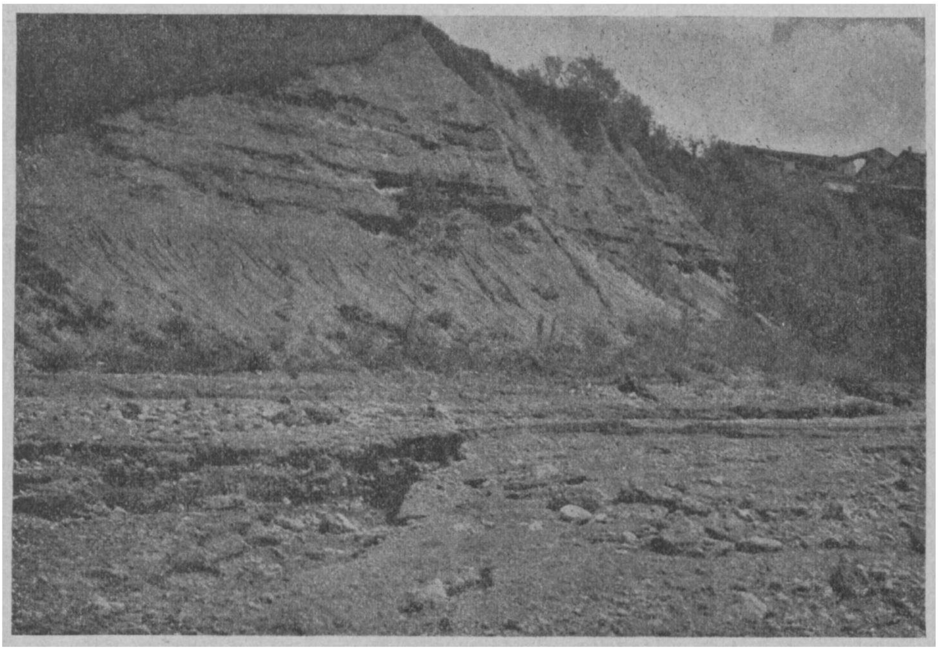
A special problem are the fluvio-glacial bench gravels of the valley between Clusone and Bratto (Plate XXIX, fig. 1). Visser (lit. 14) distinguished four different levels. The basin was dammed up by the Borlezza glacier, a diffluent of the Oglio glacier, and by the terminal moraine of la Selva, and the sedimentation is probably older than the bench gravels of Ardesio and Piario. We refer the reader, however, for a description to Haupts study, as a definite conclusion as to the complex problem can not be reached yet.

In the Upper Val di Scalve and in the Valle Nembo similar late-glacial gravel benches are described by Krol (lit. 18).

In the Valle Nembo this author found two terraces with a height difference of 75 to 100 m.

The fluvio-glacial bench gravels are particularly well developed in the valley of Zone (Plate XXX). Two diffluent glaciers of the Oglio glacier penetrated into this region, one from the north, by way of Toline and the Pso Croce, the other from the south by way of Marone on the lake border and Cislano. Apparently the southern glacier dammed up the Zone valley

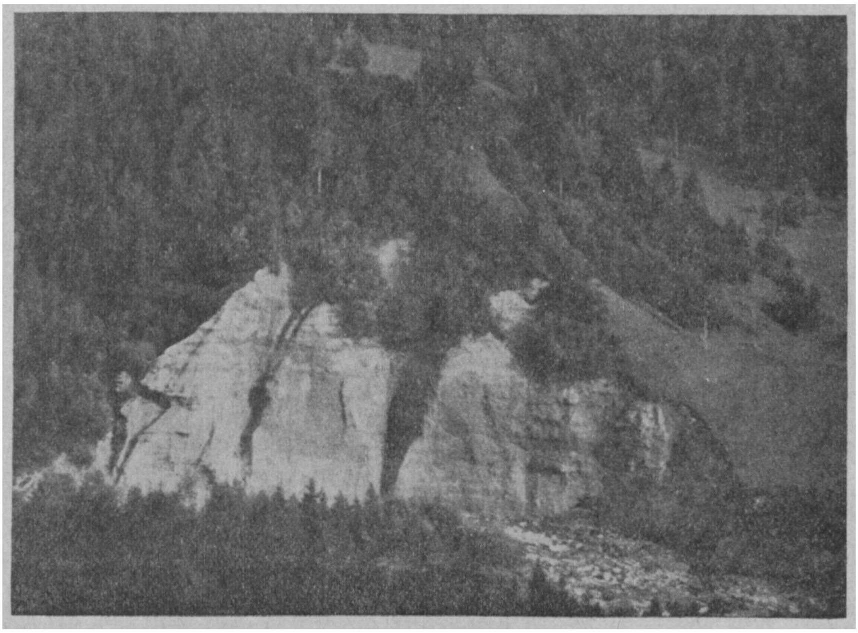
PLATE XXIX.



Swolfs

Fig. 1.

Fluvio-glacial bench gravels of Rovetta, Torente Vallegio, East of Clusone, Val Seriana.



Krol

Fig. 2.

Lacustrine deposits in the Val di Scalve opposite S. Andrea.

during some time, allowing the accumulating of a fine grained sediment in this basin. Later this was covered again by morainic material, and finally during the melting of the glaciers at least three distinct river benches were modulated. The large moraine blocks of Verrucano covering the finer grained fluvio-glacial sediment were the origin of beautiful earth pillars, where these blocks are precariously balanced on a slender pillar of soft sediment.

Val di Lozio also has been filled to a great extent by fluvio-glacial gravels. The whole of this region has been covered by the Oglio glacier, augmented by tributaries from the Concarena and the Mt. S. Fermo. Probably a damming up of the Lozio valley occurred in late glacial time, against the flank of the Oglio glacier, the resulting sedimentary accumulation being modulated into riverbenches.

The valley of Palline-Borno was also entered by a diffluent of the Oglio glacier and filled by fluvio-glacial gravels which merge into the moraine west of Palline. The Bacino di Lova is also dammed up by a moraine in the valley of the T. Fiorina (DORSMAN lit. 19).

In the Val Camonica little has been mapped of fluvio-glacial or moraine deposits. Below the rock barrier of Breno most of the broad valley is a recent alluvial plain. A narrow terrace has been preserved between Casino Boario and Pian di Borno. Above Breno the Val Camonica is filled with ground moraines and fluvio-glacial gravels [1]).

3. *Cemented scree.*

A special mention should be made of the rather numerous cemented screes which we find distributed over the whole Bergamasc Alps. They form coherent masses, already deeply cut up by the more recent erosion, and must be of Quaternary or perhaps partly of Younger Tertiary age. The debris consists mostly of Triassic limestones, Esino and Anisian, strongly cemented and often showing considerable dip (20°) (Plate XXXI, fig. 2). Of special interest is the small elongated mass on the Corna Busa, described by KROL (lit. 18). This peculiar mass is situated on the crest of the hill and Krol supposes that it was originally deposited as a talud fan from the Pzo Camino mass in a valley running from east to west from this mountain. After it was soundly cemented this rock was much harder than the surrounding Anisian and Ladinian shales and limestones and thus protected its substratum from further erosion. Similar cemented Esino debris is reported south from the Presolana and from many other places.

Along the border of the Lago d'Iseo strongly cemented breccias consisting of Hauptdolomite debris are often difficult to dinstinguish from primary Hauptdolomite breccias (Plate XXX, fig. 1).

In general these cemented screes may supposed to represent the remnants of the scree cones of the Pliocene landscape, while some of them will be of Quaternary age.

4. *Lacustrine deposits.*

The damming up of parts of Pliocene valleys by glaciers naturally led sometimes to the formation of lakes.

The best example of such dammed up lakes can be found in the Upper

[1]) NANGERONI, L. G. Geomorfologia della Valle del T. Dezzo. Natura XXII, 1931.

PLATE XXX.

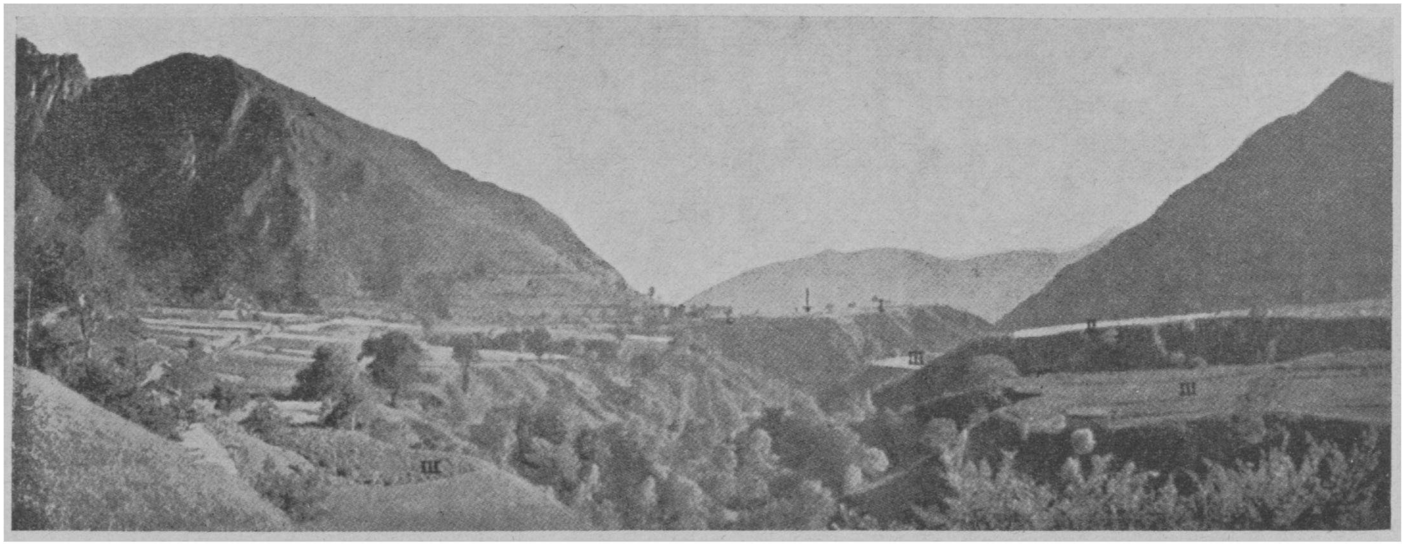


Photo Schiess

Quaternary river terraces of Val Marse just below Zone, East of Lago d'Iseo. Three terraces can be distinguished (I, II and III). The arrow indicates the position of earth pillars. (After MAASKANT).

PLATE XXXI.

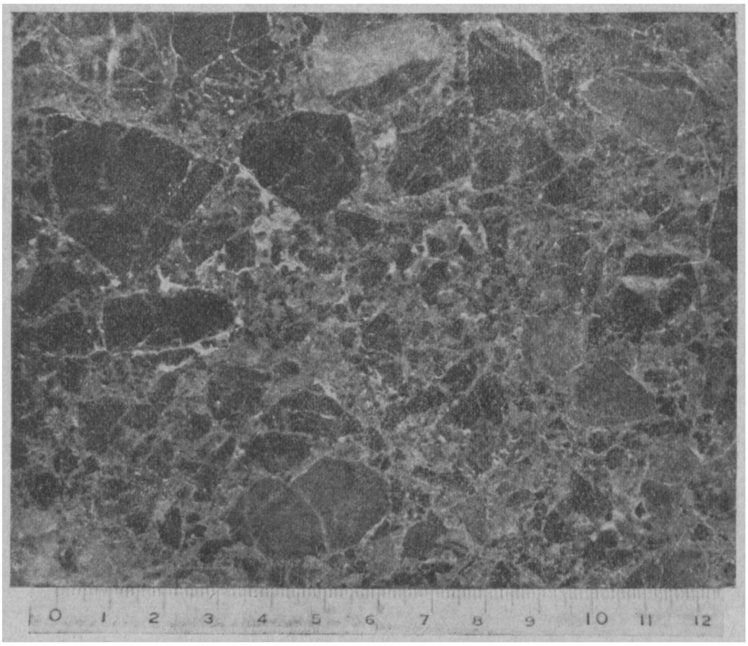


Fig. 1.

Brecciated, Hauptdolomite North-West shore of Lago d'Iseo, south of Lovere.

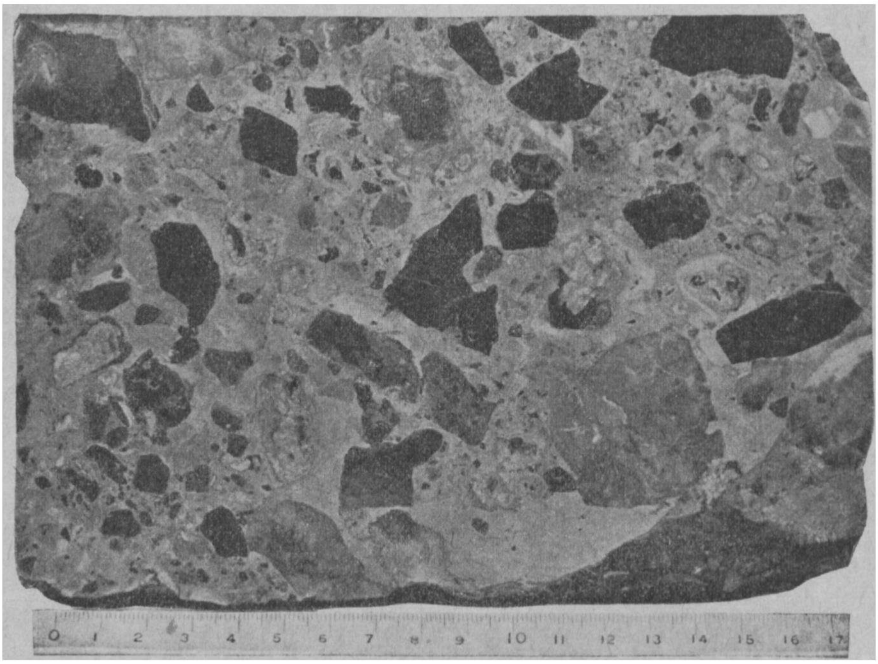


Fig. 2.

Polymict scree breccia, containing fragments of Esino, and Anisian limestone and Verrucano, firmly cemented. Val Camonica.

Val Sassina between Balisio and Mt. Melma. It was comprised between the terminal of the Val Sassina glacier and of the Lecco diffluent of the Adda glacier which entered the valley from the south, both terminal moraines shutting off this dead piece of valley.

Another lacustrine development can be found in the Val di Scalve above the narrow gorge starting below Dosso where the river leaves the soft Anisian limestone and enters the very hard Raibler zone across a complicated fault zone. According to KROL (lit. 18) the overdeeping of the upper Val di Scalve and the rock bar of Dosso, is due to glacial erosian in the soft Anisian, and a lake was formed in interglacial and late glacial time when the melting of glacier advanced beyond Dezzo di Scalve. The lake deposits consist of fine loam, silt, and sand and are covered again by moraines[1]) (plate XXIX, fig. 2).

Further down the same valley a similar overdeeping by glacial erosion occurred in the soft Servino strata of Angolo behind the Verrucano rock bar, covered with „roches moutonnées''.

Twice a lake was formed in this basin, as shown by fine sand and loam layers between morainic and fluvio-glacial material.

The most important lacustrine formation is without doubt that of Pianico-Sellere described by many authors, as it contains a interglacial flora, some fishes, a reptile and *Rhinoceros Mercki* and *Bos primigenius*[1]). The barrier of Hauptdolomite of the Rocca of Castro must have been higher than at present, probably heightened by a morainic wall of the Riss glacier. The lacustrine marls are covered again by moraine of the Würm glaciers.

The very cursory description of the quaternary period is only meant as an explanation to the map. Unfortunately the different surveyors very seldom mapped the quaternary deposits with much detail, and the work of HAUPT does not contain any maps, therefore our map is not accurate in this respect. The physiography of the Bergamasc Alps has not been described or studied comprehensivily at all and only sparse and incomplete mentions scattered in all sort of geological literature is available.

Hence the study of the physiography should offer a very interesting object for any student, particularly as the glacial history has been outlined already by HAUPT in his admirable work.

[1]) SALMOJRAGHI. Formazioni interglaciali allo sbocca di Val Borlezza nel Lago d'Iseo. Rend. R. Ist. Lomb. XXX, 1897.

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PART III.

THE TECTONICAL STRUCTURE OF THE BERGAMASC ALPS.

CHAPTER I.

GENERAL FEATURES.

The Bergamasc Alps form topographically the southern slopes of the central Alps with their intricate pattern of thrustsheets. The boundary between the two units is the Insubric fault-line running east-west and following the Valtellina. This major tectonical line separates the roots of penninic and east alpine thrustsheets from the southern Alps [1]).

Compared with the extreme folding phenomena of the central Alps, the Bergamasc Alps are of simple structure. The structure is mainly characterized by the fact that the Lombardic zone forms the steps by which we descend from the enormous heights, to which the central Alps have been uplifted, to the depth of the Po plain. The descent is by no means a gradual slope but ressembles much more the steps of a staircase. There are three steps viz.: with the first step from the Po plain we ascend from the Upper-Cretaceous, Eocene, Oligocene and younger formations of this plain, on a broad platform consisting of older-Mesozoïc strata. The second step brings us up to a much narrower stepping zone formed by Permian strata, overlying the basement rocks. The third step carries us from this Permian plateau up to the heights of the central Orobic chain, which has been deeply eroded into the basement rock. A fourth step would cross the insubric line and would bring us into the highest uplift of the central Alps.

Naturally this simplified structural scheme can not be applied throughout the Bergamasc Alps, but it remains everywhere the basic structure.

The boundaries between the steps are generally very steep zones. With the first step, for instance, we cross the steep zone, which runs north of the lakes of Pusiano and Annone in the west, crosses the lake of Garlate, the southern extension of the Como lake, and then curves with a very large convex arc towards Bergamo. In this steep zone are exposed Upper-Cretaceous Scaglia, Lower-Cretaceous Majolica and Jurassic strata; the higher platform consists of Liassic, Rhaetic and Norian strata. The continuation of the steep zone eastwards has not yet been mapped accurately.

The first platform, west of the Val Seriana, consists of Norian dolomite

[1]) On Plate XLIII the main tectonical features have been traced.

and Rhaetic strata, very slightly folded. It has a breadth of 20—25 km and ends abruptly against the next steepzone, here developed as a major fault, the Valtorta fault. Crossing this fault we arrive on a domed platform of some 6 km breadth, in the flanks of which Permian strata are exposed while the apex consists of basement rock. It has been called the *Orobic anticline.*

Crossing this domed platform we reach the next boundary, here developed as a rather flat dipping overthrust, the *Orobic thrust,* and reach the *Orobic zone* of exclusively basement rock.

In this western part of the Bergamasc Alps, west of the Val Seriana, we thus find three boundaries, from north to south: the *Orobic thrust,* the *Valtorta fault* and the *steep rand-zone,* and four platforms: the Orobic zone of basement rock, the *Orobic anticline* of Permian strata, the large Norian-Rhaetic platform and the Po Plain.

This main structural feature has been partially obliterated by strong compressional forces acting mostly in a direction parallel to the meridian. These forces have folded the sedimentary strata along the steep rand in the sharp and overthrusted folds of the *Ravella syncline* and the *Rai anticline* and the *Albenza anticline.* The same compressional force has sheared of the Triassic limestone blanket from the basement rock in the north and has deposited them in a series of partially piled up thrustsheets on the central platform.

We find there the two *Grigna thrustsheets* and the *Coltignone thrustsheet* all three consisting of Esino limestone and dolomite, the large overthrusted Norian dolomite mass of the *Resegone* and *Muschiada-Zuccone thrustsheets* and the remnants of a large thrustsheet consisting of Ladinian limestones viz. the *Salzana thrustsheet.* In connection with this great thrusting movement the Orobic thrustplane hades very flatly towards the north, and several upthrusts of less formidable dimensions have been developed in the Permian strata of the Orobic anticline along the *Trona fault,* the *Pzo Giacomo fault* and the *Mt. Foppa fault.*

East of the Val Seriana the pattern changes somewhat allthough the same fundamental principles are valable.

The Valtorta fault peters out and in its place the *Val Canale fault* gradually developes some 5 km further south. The Permian zone thus becomes larger. The Norian platform shows a strong regional dip westwards, as a consequence the platform consists east of the Val Seriana of Carnian and Ladinian limestones. Moreover a new step in this platforms is formed by the *Clusone fault.*

South of the Clusone fault we now find as a foreland to the main uplift an undulated platform of Norian and Rhaetic strata (Fig. 26). Enclosed between the Clusone and the Val Canale faults we find a strongly compressed zone of Carnian and Ladinian strata whereas north of the Val Canale fault the Permian zone consists of a large dome with a series of anticlines viz. the *Trabuchello anticline,* the *Cabianca anticline* etc. with many up -and overthrusts and a large syncline, the *Masoni syncline* with many upthrusts. Again a part of the Triassic sedimentary cover of the northern higher step has been sheared of and has been pushed over on the strongly compressed central zone. Only rather small remnants of these thrustsheets, which are of much smaller dimension than those in the west are found and have been called the *Arera-Mt. Secco thrustsheet* and the somewhat larger *Presolana thrustsheet.* The strong compression of the central zone between the Val Canale and Clusone fault has resulted in upthrusts of large dimensions, in which the southern

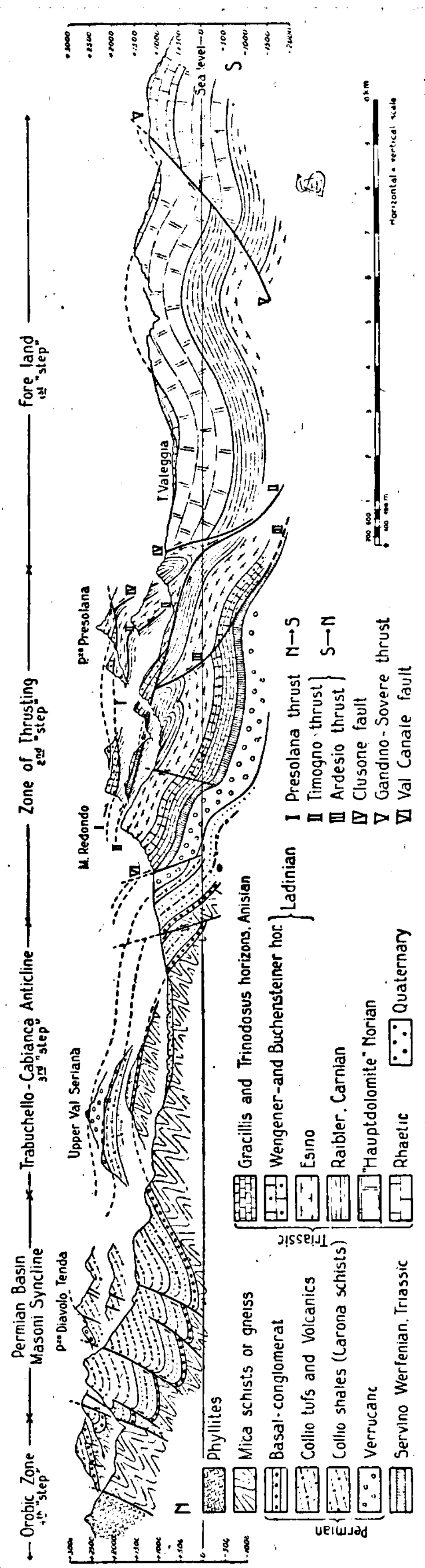


Fig. 26.

N—S cross section through the Central Bergamasc Alps.

limb has been pushed over its northern foreland a contradictory movement to the generally observed north to south movement. The *Ardesio-* and *Timogno upthrusts* are the largest, the latter the most conspicuous one. In fig. 26, perhaps the most typical section through the Bergamasc Alps, these features have been compiled.

Still further eastwards the general features again change somewhat. The thrustsheets, sheared of the northern range again reach larger dimensions, and are piled upon some local overthrusted anticlines. From west to east we find the *Presolana*, the *Camino-thrustsheet,* resting on the *Pallino-Borno thrust* and the *Lozio thrust.* These thrustmasses cover the whole central zone and even have been pushed over the eastern extension of the Clusone fault, which probably perseveres below this tectonical blanket.

The northern Permian zone is no longer limited in the south by a fault comparable to the Valcanale fault but the boundary has more the character of a flexure, the *Val di Scalve flexure,* which flattens out in eastern direction. This Permian zone has been developed again as a broad anticline, dipping eastwards, called the *Cedegolo anticline,* limited in the north by a series of thrusts viz.: the *Sellero-* and *Gallinera-thrust* and several more in the basement rock of the Orobic zone. South of the large thrustsheets the general structure changes rather abruptly. From Lecco in the west untill Lovere on the Lago d'Iseo, in the east, the southern zone consist of Norian and Rhaetic limestone, but further eastwards a large uplift developes, which brings the whole series of Triassic and Permian strata to the surface and causes the exposure of the basement rock east of the Val Camonica. Of this large tectonical feature, the *Camonica uplift* wharped up some 4000 m in the course of 10 km horizontal distance, only the western part has been mapped. The uplift is accompanied by some faulting, the *San Vigilio* and *Val Trompia faults* and a latter compression has caused some thrusting movements against the rising mass viz.: the *Camorelli thrust* and to a certain extent the *Gandino-Sovere thrust*. Almost every major tectonical line reviewed above has a general strike of ENE—WSW. An older feature, partially rejuvenated in the major folding process, is a faulting system with a N—S strike. The best example is the *Val Vedra fault-trough*, halfway between the Val Seriana and the Val Brembana, with which the *Val Vedra-*, the *Pessel-*, the *Oneta-* and probably also the *Gemelli faults* are connected. Another example of this faulting is the Anisian trough dividing the Val Canale fault from the Val di Scalve flexure. The fact that the small *Toazzo thrustsheet* has been pushed over Anisian limestone, compressed between the *Bondione fault* and the *Fles fault* convinces us that the N—S fault system is older than the main thrusting movement. The San Vigilio- and the Val Trompia-faults mentioned above, belong also to this fault system.

This fault system has been obliterated to some extent by the later uplifting in E—W orientated zones and the subsequent N—S compression.

Let us summarize the rapid review of the tectonical structure outlined above. We found a series of stepping stones divided by faults, steep zones or flexures each northern step being higher than its southern neighbour, leading up to the height of the Central Alps. The blocks are tilted, dipping slightly sometimes strongly towards the west. Three regions can be distinguished, a western, a central and an eastern one. In the western region large sheets of the Triassic blanket sheared off from the northern, highest block have been pushed on the flat central block, partially piled upon one another in the Grigna region. In the central region the central block has been strongly compressed, large flat dipping upthrusts with S — N movement of the upper limb have been formed. The eastern region again is characterized by piled up thrustsheets sheared off from the high northern block, but a new feature the considerable uplift of the southern block changes the whole situation. The northern block is everywhere characterized by numerous thrustfaults but more so in the eastern region than in the west. An old system of N — S faults can be discerned but has been largely obliterated by the later folding movements which created E — W structures.

We will now proceed to describe in detail the different regions which we have learned to distinghuish. The 1: 100.000 structural map, of the Bergamasc Alps, Plate XLII the two sheets with N—E cross-sections. Plates XL and XLI, and the 1:200.000 structural map of the Lombardic Alps Plate XLII will assist the reader in his perusion of the next chapters.

CHAPTER II.

THE WESTERN BERGAMASC ALPS BETWEEN LAKE COMO AND VAL SERIANA.

The western region again can be divided into several tectonical units (Plate XLII).

A. In the south west corner of the map we find the strongly compressed folds of the Alta Brianza.

B. East of Lake Como we find the piled up Grigna thrustsheets.

C. The Resegone thrustsheet, together with the Muschiada thrustsheet and the Barzio region can be regarded as a separate unit.

D. North of the Valsassina the basement rock has been pushed over the gentle saddle of the Orobic anticline along the Orobic thrustplane.

E. Finally the extensive Norian and Rhaetic region of which the Val Talegio is the main drainage system, with the Muschiada-Zuccone thrustsheet and the Salzana thrustsheet posesses its own tectonical features.

A. *The Alta Brianza.*

The Alta Brianza is limited in the south by the steep rand zone, the boundary between the Po plain and the foothills of the Alps. The vertical or almost vertical zone runs just north of the Lago di Annone and crosses the Lago di Garlate. The steep zone is the south flank of the E — W striking Rai anticline.

The north flank of this anticline is the south flank of the Ravella syncline, which is bordered in the north by the Morigallo anticline. These two anticlines and the dividing syncline are steep and overthrusted structures, but are followed in the north by a series of gentle synclines and anticlines, the Valbrona syncline, the Magreglio anticline and the Civenna syncline. Still further north, but no longer on the map, a fourth anticline is developed. The three anticlines, viz.: Rai-, Morigallo- and Magreglio-anticlines have Norian limestone exposed in their core and all three show a strong axial dip towards the west. In consequence the Norian is followed on the apex of the anticlines by Rhaetic and finally by Liassic limestones. The Ravella syncline also shows a very pronounced western axial dip and in its center cretaceous strata are exposed. The gentle Valbrona syncline only shows Liassic limestone.

However, we are principally concerned with the two southern anticlines and with the Ravella syncline. The six cross sections of fig. 27 [1]) illustrate

[1]) The large N—S sections of Plate XLI and XLII, have roman numbers, the small sections of the text figures have been numbered from 1—23 with arabic numbers, their situation is indicated on the maps Plate XXXVIII and XXXIX.

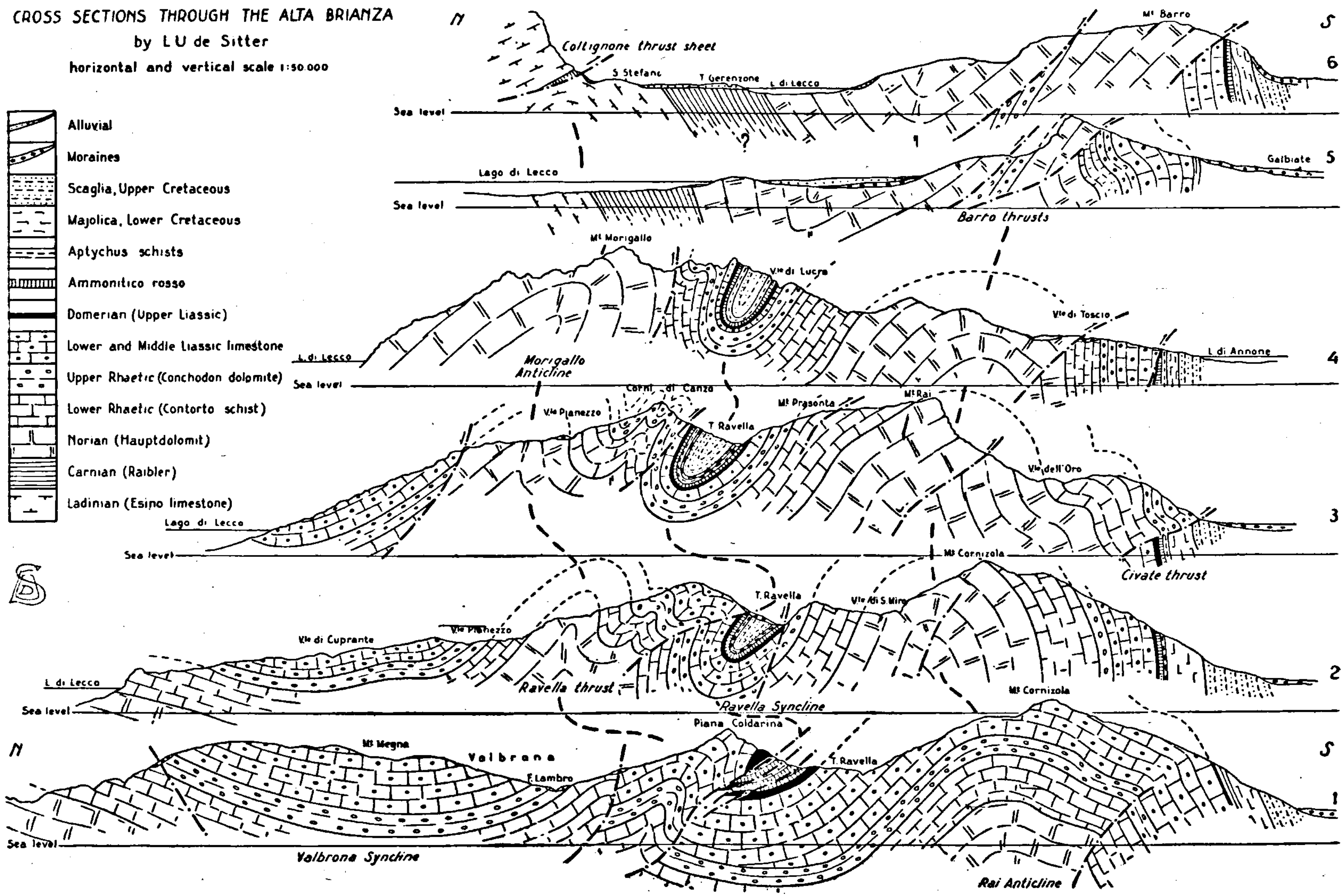


Fig. 27.

N—S cross sections through the Alta Brianza, redrawn after Rassmuss.

the development of these structures. They differ somewhat, but nowhere essentially and mostly in drawing technique from the sections given by RASSMUSS. To the very carefull survey of this geologist and his minute description of the tectonical structure the reader may turn when desirous of a very detailed description. In the west the Rai anticline is a simple arc with a 70°—80° dipping south flank and a 45° dipping north flank. The north flank keeps this general dip in its eastern extension, the south flank however soon becomes vertical. This steepening of the south flank is due to the strong axial rise towards the east, which locally reaches some 40°, between section 1 and 2. Due to the increasing folding intensity the north flank of the anticline has been pushed over the vertical zone, a feature which has caused on the map the thinning out of the Liassic limestone and the disappearance of the Domerian, Ammonitico rosso, Aptychus schists and partially even of the Majolica below this thrust. The disappearance of these strata was explained by RASSMUSS by hypothetical cross faults. However, RASSMUSS did not observe these cross faults in the field and a simple overthrust of small dimensions is much more in accordance with the observed facts of his map and explains them much better. This thrustplane, which may be called the Civate thrust can be followed along the northern border of the Lago di Annone untill beyond Sala and is found in sections 3 and 4 of fig. 27.

Once risen to the height of the Mt Rai the axial dip disappears, but gradually the increase of compression continues shown by the development of a new thrust in the south flank. North of Civate the Norian limestone has been pushed over the Rhaetic of the south flank. Across the Valmadrera the thrust recedes again towards the north, but in the western slope of the Mt Barro the thrustmovement increases again and south of this mountain the Norian limestone rests directly on the vertical Domerian, then it again recedes and can perhaps be traced back in the Maggianico fault east of the L. di Garlate. This thrust is joined in the Mt Barro by a second one, a little higher up, exposing a strip of Lower Rhaetic reaching up to the top of the Mt. Barro. These two thrusts have been named the Barro thrusts, and show once more that the higher an anticline has been folded up, and the deeper the erosion cuts into its core, the more complicated becomes the structure.

The Ravella syncline, which lies between the Rai and Morigallo anticlines, is a very steep fold, slightly overturned towards the south. In the upper reaches of the Torrente Ravella and of the Val del Gatton the syncline is rather symmetric. In its centre is exposed Upper Cretaceous Scaglia, in the flanks can be found the whole series of the Mesozoïc abyssal facies up to the Liassic limestone. Specially in the south flank, however, many of these thin formations are squeezed out. In the western extension, however, the north flank of the syncline, being at the same time the south flank of the Morigallo anticline has been pushed over the syncline and conceals the synclinal structure alltogether. At the same time the south flank has been severely broken up in four minor thrusts, demonstrated by the reoccurring of the Ammonitico rosso in four limbs. The place where this Ravella thrust swings over the syncline is almost wholly covered by moraines, but the detailed description of RASSMUSS of the brecciated and crushed zone in the north flank, where the overthrust starts, allows us to draw the overthrust plane in the way we have done, allthough this author again presumes a system of cross faults. A real cross fault, with a downthrown eastern limb crosses the syncline from the Corni di Canzo in a SSE direction.

Further eastwards the synclinal axis rises abruptly and near Valmadrera nothing but Norian limestone is exposed. Allthough no longer expressed by the outcropping formations, it probably continues below the alluvial terraces of Lecco at the other side of the lake, and as we will see further on, probably continues for a long way. The Morigallo anticline is very similar to the Rai anticline; it has a steep and complicated south flank, a much gentler north flank and has a pronounced axial dip towards the west. Along the Ravella overthrust (section 1, 2 and 3) its south flank shows some intricate secondary folding, which is best exposed in the Corni di Canzo and described in great detail by RASSMUSS and well illustrated by photographs.

Towards the east the anticline rises to great heights. Locally the Norian limestone has been pushed up against the Contorta schists (section 4). Taking into account the small outcrop of Esino limestone at the other side of the lake near Cna San Stefano just north of Lecco we presume that this axial rise continues and that the soft Raibler schists between this Esino outcrop and the Norian limestones of the western lake border are outcropping in the lake bottom. The Esino of San Stefano is then the core of the anticline.

In the south flank of the Morigallo anticline the Liassic limestone has been wharped down along a normal fault, cutting out the outcropping Rhaetic strata (section 3).

The Valbrona syncline has flat dipping flanks and again shows a pronounced axial rise towards the east. The Norian limestone outcrop of Abbadia at the other side of the lake belongs to this syncline and probably lies on the axis.

B. *The Grigna thrustsheets.*

The country between the Valsassina and Lecco has been studied in great detail by PHILIPPI and TRÜMPY, and their tectonical conception of three piled up thrustsheets has been thoroughly ascertained. Nevertheless the 1:100.000 Italian geological map sheet Como, surveyed by REDINI recognizes but one overthrust, that of the Grigna meridionale. The Ladinian Esino dolomite of this latter mountain is regarded by this latter author as Anisian limestone and dolomite normally underlying the Esino limestone of the Grigna settentrionale. In Part II „Stratigraphy'' we have already expressed our confidence in the work of TRÜMPY and PHILIPPI, and rejected the views of REDINI.

On section II, Plate XLI, the structure of the three Grigna thrustsheets, appears to its best advantage. The Grigna settentrionale thrustsheet has a synclinal shape, the thrustplane probably following the plastic Servino schists. It has an axial dip of 10—20° towards the N W, the Ladinian reaching the lake level in the west and the Anisian rising above the level of the T. Pioverna in the East. Near Pasturo the axial dip changes apparently to a slight dip eastwards.

Carnian strata have been preserved in the axis of this syncline in the vicinity of Esino. A small normal longitudinal fault can be discerned here, with a downthrow of the northern limb.

In the Grigna meridionale thrustsheet the strata dip flatly northwards and the whole thrustsheet lies as a wedge between the Grigna sett. sheet and the Coltignone thrustsheet. The thrustplane again follows the Servino horizon. The whole thrustsheet is domed with a N — S axis, whose apex is situated on the Mt Grigna meridionale, and with a 20° westward dip and a 10° eastward dip from this mountain.

The Coltignone thrustsheet is also domed with a N — S axis, which lies approximatively on the Mt. Coltignone. The general dip of this sheet is 10—15° northwards. Very little of the Anisian strata have been preserved at the bottom of the thrustsheet, but we can safely assume that the thrustplane is again mainly situated in the Servino-horizon.

We have seen that a slight doming effect can be discerned in all three thrustsheets, running from the Mt Coltignone over the Mt Grigna meridionale and east of the Mt Grigna settentrionale. It is the result of a slight E — W compression, which we shall find also in other regions.

The thrustplane of the Grigna settentrionale shows two complications viz: the Lierna wedge above Lierna on Lake Como consisting of Servino strata and the Riale wedge north of Balisio. The position of the Lierna wedge is not quite clear. An E — W section of TRÜMPY (section 15 of his publication) indentifies the thrustplane below the Servino horizon as the Grigna meridionale thrustplane and the thrustplane below the Anisian of the Grigna settentrionale as the thrustplane of this latter thrustsheet. But this conception can never be conciliated with his N — S section no. 6. Also on the schematic map, fig. 1, p. 420, the thrustplane of the Grigna settentrionale is drawn with a curve round the Servino outcrop, identifying the thrustplane below the Servino with that of the Grigna settentrionale. The latter conception is much more probable than the former one, as the Servino then would normally underlie the Anisian of the northern thrustsheet. However the structure is not as simple as that, because the eastern boundary of the Servino, against the Esino limestone of Zuc di Miseole must be a fault contact. Therefore we presume that the Lierna wedge belongs essentially to the upper thrustsheet but is a small tectonical unit of its own separated from the two Grigna thrustsheets by an upper and a lower thrustplane.

The Riale wedge has a similar position between the two thrustsheets, but this wedge, build up mainly by Raibler strata, belongs probably more to the Grigna meridionale thrustsheet, than to the upper thrustsheet.

The Grigna meridionale thrustsheet broadens very much in western direction. North of the Valle di Monastero a large slab of Esino limestone with some Anisian limestone has slided down the slope of the Zuc Pertuso. As this slab is partially covered by morainic sediments the phenomenon can not be very recent. As mentioned above, the thrustsheet narrows down to a small strip between Balisio and Valle dei Grassi Lunghi, but is apparently directly connected by this strip to the supposed autochtonous Raibler-Esino of the Barzio region.

The Coltignone thrustsheet is less clearly developed as the higher thrustsheets. Its thrustplane is seldom exposed, most everywhere it is covered by morainic or younger deposits. The Mt. Melma, east of the Valle del Gerenzone, and the Esino mass from Valle Boazzo to Pizzo d'Erna belong both to this same tectonical unit. The frontal part of the thrustplane can thus be followed rather well at the foot of these mountains, but the boundaries of the thrustsheet to the west and to the east is less characteristic:

In the west we find the Norian dolomite outcrop of Borbino, which without doubt belong to the Alta Brianza folds, in casu the Valbrona syncline. The steep fault crossing the Valle di Monastero is therefore the western limit of the Coltignone thrustsheet, and may be regarded as the direct continuation of the thrustplane.

In the east another steep fault running from Ballabio inf. northwards forms its eastern limit. The Coltignone thrustsheet thus rises up between two faults, which both bring the Norian dolomite in lateral contact with Esino limestone. The Norian dolomite of Ballabio, however, belongs to the Resegone thrustsheet, which north of the Valle Boazzo and east of the Pizzo d'Erna overrides the Coltignone thrustsheet.

In both instances an almost horizontal thrustplane becomes a very steep fault, the thrustsheet has scooped out its bed in the underlying strata, as has been represented in fig. 28, a west-east section through the Coltignone- and Resegone thrustsheets. Neither the Borbino nor the Ballabio faults are therefore normal faults, they are vertical border sections of otherwise almost horizontal thrustplanes. The feature will be found back in many instances and for instance has given rise to many controversies in the case of the Lugano fault („Luganer Hauptverwerfung"). This latter fault was originally regarded as a normal fault only, with a downthrow of the eastern limb, bringing the Liassic limestones of the Mt. Generoso in lateral contact with the Permian porphyries (FRAUENFELDER)[1]. Later DOEGLAS[2]) recognized ist thrustplane characteristics and DE SITTER[3]) showed that the whole Generoso mass has been thrusted southwards along a thrustplane which joins the Lugano fault. VONDERSCHMIDT[4]) again postulated the vertical habit of the fault.

1) FRAUENFELDER, A. Beiträge zur Geologie der Tessiner Kalkalpen. Ecl. geol. Helv. vol. 14, 1916.

2) DOEGLAS, D. J. Die Geologie des Monte San Giorgio und des Val Mara. L. G. M. III, 1930.

3) DE SITTER, L. U. Les porphyres Luganois et leurs enveloppes. L. G. M. XI, 1939.

4) VONDERSCHMIDT, L. Die Luganer Hauptverwerfung bei Melano etc. Ecl. geol. Helv. 30, 1937.

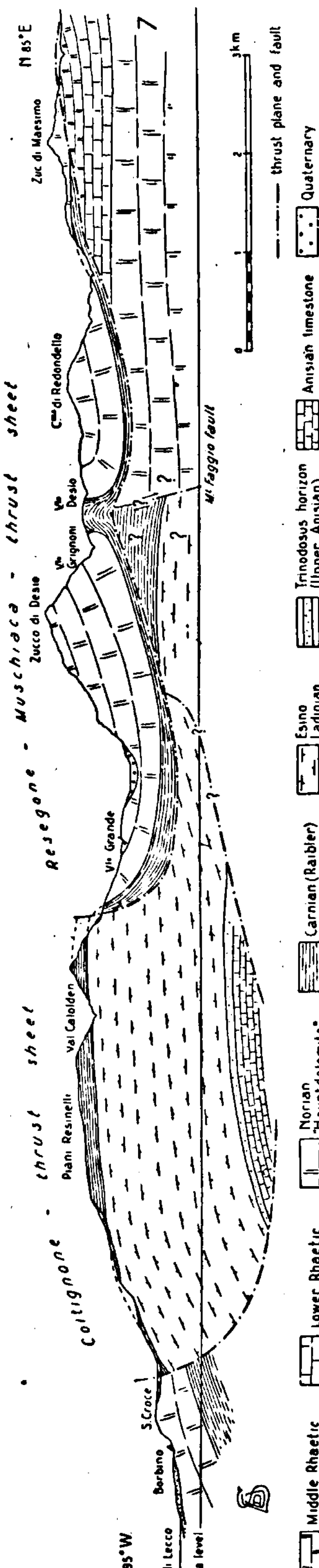


Fig. 28.

W—E section through the Coltignone- and Resegone-Muschiada thrustsheets.

Comparing the structure of the Generoso thrust with those found in the Bergamasc Alps, I believe that the southern part of this „Luganer Haupt verwerfung'' is a similar vertical section of a thrustplane, and that the Generoso thrustsheets has scooped out its bed in the same way as the Coltignone and Resegone thrust. It is of considerable interest to note that in the Lombardic Alps it is always the western limit of a thrustplane which has this shape.

In section II we have drawn the three main thrustplanes as following the Servino, below the Anisian limestone. This Servino has thus acted as a gliding horizon. We will see that everywhere in the Bergamasc Alps this function is taken up either by the Servino or by the Raibler shales. However, whereas the frontal parts of the thrustsheets are easy to designate, the back part is more difficult to indicate. In the Val Sassina the whole series of Esino limestone or dolomite, Anisian strata, Servino, Verrucano, Permian porphyries and basement rock is represented in a normal sequence. If nothing were known about the imbricate structure of the Grigna mountains, nobody would suspect a major thrustplane in this sequence. Still the thrustplanes must enter the rock sequence somewhere and than the most probable location is the top part of the Servino formation. Here we find in the Vle di Baredo and in the Vle Cagnaletto, south of Primaluna the „Rauhwacken'' horizon, which near Parlasco is situated in the lower part of the Werfenien (Servino). According to Buning a Rauhwacke also occurs in the Werfenien between Bellano and Varenna. Philippi pointed out that the „Rauhwacken'' horizon of the Werfenien is a very unreliable stratigraphic layer, and that its character can be defined much better as a tectonical breccia. The position of the Servino, consisting of ductile, friable and soft strata, between the large and compact masses of the basement rock together with the Verrucano at one side and the Anisian-Ladinian limestone dolomite at the other, predisposes it as a gliding horizon. Therefore it can not be wondered at that the „Rauhwacke'' horizon as tectonic breccia is specially developed in this formation. In the Raibler shales and tufs a similar breccia horizon has been developed wherever this formation has acted as gliding horizon between the masses of the Norian dolomite and the Esino limestone. We find these Raibler tectonical breccias north of Esino and just below the Grigna settentrionale thrustplane on the Riale wedge and in the Raibler formation of the Coltignone thrustsheet in the locality called Piani di Resinelli; furthermore everywhere when exposed below the Resegone-Muschiada thrustsheet.

As the combined thrustplanes of the Grigna-Coltignone thrustsheets must enter the stratigraphic sequence of the southern slope of the Valsassina somewhere it is logical to designate this breccia horizon of the Servino as the thrustplane.

When we put together the three thrustsheets behind one another instead of upon one another, allowing for some erosion of the frontal part, and allowing for about 3 km forward movement of the Coltignone thrustsheet, we find that the Grigna meridionale thrustsheet reached with its back part into the Valsassina and that the Grigna settentrionale sheet must have formed the sedimentary cover of the Permian strata north of the Valsassina. The total movement of the upper thrustsheet perhaps attained some 10 km.

C. *The Resegone-Muschiada thrustsheet and the region round Barzio.*

The question then arises, where to the Norian dolomite of the three thrustsheets together has disappeared. Nowhere, except in a very small patch on the Coltignone thrustsheet, any of this large and solid mass has been preserved on the thrustsheets themselves. Everywhere the thrustplane of the higher thrustsheet rests on Raibler schists or directly on the Esino limestone. We must assume therefore that the Norian dolomite had been removed beforehand either by erosion or by some tectonical feature. It is much more probable that the Norian dolomite has been sheared off than that it should have been eroded away equally over the whole region just so far as to leave the Raibler schists untouched. This assumption becomes the more acceptable when we notice the frequent occurence of tectonical breccias in the Raibler schists of all three thrustsheets. Bearing in mind this conclusion, hypothetical as it may be, it is obvious that the large Norian dolomite masses of the Resegone-Muschiada-Zuc di Maesimo-Corno Zuccone thrustsheets are the remnants of the removed masses of the Grigna thrustsheets. The largest breadth of this combination of thrustsheets, which certainly once formed a coherent mass is about 11 km, the same breadth as the largest breadth of the Grigna settentrionale thrustsheet. The total length of the present Resegone mass is some 10 km, much less than the original length of the three Grigna thrustsheets put together. Apparently much of the Norian mass has been carried away by erosion.

Let us regard the Norian dolomite thrust-masses to some more detail. The Resegone thrustsheet is one continuous mass of Norian dolomite comprising the mountains Zuc Campei, the Monte Due Mani and the Resegone crest with the Monte Serrada. Its western boundary against the Coltignone mass is a steep „scooping'' fault but further south the thrustplane becomes very flat and essentially horizontal after it has risen above the level of the Mt. Melma. On its western border the thrustplane is accompanied almost everywhere by Raibler breccias either belonging to the Resegone mass itself or to the underlying Coltignone mass as is the case in the Valle Boazzo-Pzo d'Erna region (Sections III and IV).

In its northern end it has been overridden by the Muschiada thrustsheet, which formerly formed one unit with the Zuc di Maesimo and Corno Zuccome units. The Muschiada sheet also floats on strongly brecciated Raibler schists, the Zuc di Maesimo and the Corno Zuccone masses also consisting of Norian dolomite rest directly on the Rhaetic schists.

The seam between the Muschiada mass and that of the Resegone is indicated by a very narrow zone of Raibler strata developed as a tectonical breccia.

The Resegone thrustplane plunges rather abruptly into the topographical surface from above, along the Valle del Geron and Valle del Lupo, and rises again to a higher level further south, when the thrustmass has to pass over the Mt. Melma and the Pzo d'Erna. As stated before the thrustplane is accompanied by a Raibler breccia in the North and in the West but no more on its eastern border. Also the thrustplanes of the Zuc di Maesimo and Corno Zuccone masses are free of this peculiar breccia. A movement of the thrustsheet in a NW—SE direction seems to be in accordance with these facts.

The Raibler strata on which the Norian masses are floating are in direct connection with the Raibler of the Barzio region. From south to north we find here Raibler-Esino limestone — Buchensteiner horizon — Anisian limestone, folded in an arc limited in the North by a steep fault, the Valtorta fault. This very important fault, striking N 70° E appears for the first time on the west bank of the Valsassina just above Introbio, below the Grigna settentrional thrustsheet. It separates here Permian Verrucano and Ladinian Esino limestone. A little further to the East, on the east bank of the river, it cuts off a NW—SE striking fault, along which the Esino limestone of the Zucco Angelone has been warped down, with the result that east of this fault and south of the Valtorta fault Anisian limestone appears. The vertical Valtorta fault cuts in a straight line across the country, crossing the Valle della Snella, on one side Permian porphyries and on the other side strongly contorted Anisian limestone. On the Passo di Cedrino, between the Valle della Snella and the Valtorta, the Valtorta fault is met from the south by the Vle del Faggio fault running roughly from North to South. This fault is also cut straight off, and no such feature can be found back north of the Valtorta fault. Along the also vertical Faggio fault the Norian dolomite of the Corna Grande and the Zuccone Campelli has been warped down, with Raibler strata just cropping out beneath the dolomite in the Valtorta. The Valtorta fault continues its course unaltered for some distance, now dividing the basement rock in the north from the Raibler in the south. Its further adventures will be described later on.

The triangle enclosed by the Faggio fault, the Valtorta fault and the morainic blanket of Barzio has been strongly compressed against the solid mass of basement rock and its Permian mantle. It is obvious that the Valtorta fault is older than both the Faggio fault and the other tectonical features, faults and folds, of this triangle. It is true that the N—S and NW—SE faults are cut off by the Valtorta fault, but of neither of them any trace can be found back north of the Valtorta fault. Also the strongly compressed nature of both the Anisian limestones and of the Raibler strata south of the Valtorta fault and the comparatively unbroken nature of the strata north of this fault, indicate that the severe folding in the south is younger than the main fault. With these considerations in mind we must conclude that the Valtorta fault is a very old feature compared to the general tectonical lines. It has been overridden by the Grigna thrustsheets and in the Barzio region the older Triassic strata have been pressed up against it, whereas the Norian mass east of the Faggio fault remained more or less stationary.

In this domed triangle of Barzio several faults have been formed. We mentioned already one fault striking NW—SE, which in its northern part is developed as a normal fault with downthrown limb in the East. Further south, however, the Esino limestone of Barzio has been pressed up along this fault, thus revealing below it a patch of Lower Raibler tufs, which lie normally on the Esino limestone of Corna di Robbio.

The Esino limestone of the Zucco Orscellera has been pressed further northwards along the vertical fault running NE from Barzio.

The Raibler tufs and marls of Cremeno are very much contorted and no definite tectonical lines can be discerned. This can hardly be wondered at, as at least the Muschiada thrustsheet must have passed over it.

D. *The Orobic anticline and the Orobic thrust.*

North of the Valsassina and the Valtorta from west to east a zone of basement rock stretches with a mantle of Permian rocks, limited in the north by the great Orobic thrust. This elongated zone is principally of anticlinal build with several longitudinal thrust- or reverse faults in its northern flank. The sections I to VIII represent a series of cross sections through this structure.

The Orobic anticline (Porro, 1903) has a direction of N 70° E thus exactly parallel to the Valtorta fault, which we have met in the preceding chapter. It has an axial culmination near the Mt. Foppabona, east of the T. Troggia and a rather sharp axial dip in western direction. Towards the east the axial dip is less pronounced, and the axis is lost between the northern reverse faults (see tectonical map Plate XLII). As the Orobic thrustplane, which limits the Orobic anticline to the north, has a roughly E—W direction the Orobic anticline approaches this thrustplane more and more in the east, and only the rather flat south flank of this anticline remains. In the west the anticline broadens and becomes a flat west-dipping plateau, cut off by the Orobic thrust.

Just east of the culmination the anticline is transversed by a normal fault striking NW—SE with a slight horizontal displacement, the eastern limb being thrown down and having moved in a SE direction. This oblique fault is certainly due to the thrusting movement along the main longitudinal reverse or thrust fault, the Pzo Giacomo fault. The Giacomo fault is a reverse fault of considerable length, characterized by a narrow zone of Servino along almost its entire length of 20 km. It can be most clearly discerned where it constitutes the southern limit of the Salmurano culmination, where the basement rock of this culmination has been pushed up against the Verrucano of the south flank of the Orobic anticline. At this location the seam of Servino schist is lacking, but further east it reappears when Collio schists rest on Verrucano conglomerate with Servino pressed between these two formations. The Giacomo fault has here been doubled along some 3 km length, and at one place even a very small outcrop of Anisian limestone peeps out between the faultplane and the Servino schists. Opposite this Anisian outcrop a very small outcrop of basement rock, belonging to the overthrusted limb appears. Southeast of this doubling on of the Giacomo fault appears another normal fault, the Foppa fault, along which the southern limb has been thrown down, thus causing the reappearance of Servino schist on Verrucano conglomerates. This Foppa fault has only a limited extension and from its original N 65° direction soon turns eastwards and crosses the Val Mora and crosses even the ridge between this valley and the Brembo valley, but than disappears in the Collio schists. From the Salmurano culmination eastwards the Giacomo fault has a N 65° E direction, and therefore eventually appears to join up with the Orobic thrust. It is not impossible though, that it can be followed further on eastwards but now north of the Orobic thrust, and that the Giacomo fault and the Laghi di Porcile fault can be identified. We will come back to this feature later on.

West of the Salmurano culmination the Giacomo thrustplane, still hading steeply to the north, is again discernable by a narrow strip of Servino schists between Collio and Verrucano strata. It soon splits in two, the southern end petering out in the Verrucano. The other end continues westwards, but with diminishing throw and joins up with the Pzo Trona fault south of the Pzo del Dente. This Trona fault is an exact replica of the Giacomo fault, only generally with a smaller throw. Along the steeply northwards hading Trona fault the Collio schists have been thrusted up against the Verrucano conglomerates, and it is not accompanied by a seam of Servino schists as is the Giacomo fault. It runs parallel to the Giacomo fault about 1 km to the north, crosses the Salmurano culmination and joins up with the Orobic thrustplane south-east of the Mt. Verrobbio. The Giacomo fault, after having absorbed the Trona fault continues its course westward in between the Servino schists, occasionally marked by smaller or larger Verrucano outcrops.

It finally disappears below the gneiss chiaro mass of the Pzo Cornagiera, which has been thrusted over its foreland along the Orobic thrust. However, we find the Giacomo fault back in the tectonical window of the Val Marcia, between the two large gneiss chiaro lobes of the Orobic thrustsheets, the Pzo Cornagiera lobe and the Cimone di Margno lobe. The two narrow strips of Verrucano conglomerate exposed in the stream, in between Servino schists, probably again represent the Giacomo fault. The fault then disappears below the gneiss chiaro mass of the Cimone di Margno, but probably reappears in one or several of the many thrustplanes of the imbricate structure between Casargo and the Torrente Pioverna below Taceno. Here we find two main zones of thrusting parallel to one another and striking N 65° E. Each of these zones is often doubled or even tripled and consists of narrow strips of Verrucano and Servino strata wedged in between gneiss chiaro and paraschists of the basement rock. Part of this imbricate structure may represent the Giacomo thrustfault, but part of it is certainly the beginning of the great Orobic thrust. North of the Servino-Verrucano strips more thrust movements occur, discernable by narrow zones of orthogneiss or amphibolite in the paraschists. Together, the faults of this thrustzone disappear below the Grigna settentrionale thrustsheet.

As mentioned above, we presume that the great Orobic thrust originates also in this imbricate structure between Casargo and Taceno. BUNING, however, draws another thrustplane from Bellano to Indovero, assuming that the paraschists of the Mt. Muggio west flank are pushed along a flat hading thrustplane over the gneiss chiaro of the T. Pioverna stream bed. If this is true, but this author advances very scanty actual observed information about the thrustplane, this thrust might be identified with the thrust of the Cimone di Margno gneiss chiaro mass. From map or description little further information can be gained, but it looks quite possible to join the two major thrustplanes across the imbricate structure of Casargo-Margno. However, the paraschist thrustplane need not be one of great importance, the original boundary between ortho- and para gneiss might have been a flat dipping plane since the intrusion and a little movement along such plane would give exactly the same result.

We presume therefore that the northernmost thrustplane of the imbricate structure may be identified with the Orobic thrust, either disappearing below the Grigna mass or continuing as the thrustplane between Bellano and Indovero.

East of Margno the Orobic thrust is developed as a flat dipping thrustplane (some 17° N) very clearly exposed on the two opposite banks of the Val Marcia. Further east it runs just below the summit of the Pzo Cornagiera but already with a much steeper hade of some 45° N. Due to this hade its outcrop then runs down to the Valle Varrone, and increasing its dip continues its course in a pure eastern direction. It is often accompanied by mylonites and breccia zones and secondary thrusts, viz. below the Pzo del Dente and the Boccheta di Trona. Untill it reaches the southern slope of the Mt. Azzaredo it retains the same character, beyond that region it changes its character as we will see later on. Along its entire course the paraschists or orthogneisses of the basement rock have been pushed over or thrusted up against the Permian rocks of the north flank of Orobic anticline, and thus forms one of the most striking features of tectonical build of the Bergamasc Alps. Its E—W strike, which causes it to cut off N 70° E striking structures, indicates that this E—W direction is of younger date.

E. *The Val Taleggio region.*

The Val Taleggio region, thus called after the Val Taleggio with the Torrente Enna, its main drainage system, is a large flat structure with gentle undulations, crossed by sections V, VI and VII (Plate XLII). Its main structural features are the very flat and broad syncline running SW—NE, a very unusual direction in the Lombardic Alps, and the remnants of two large thrustsheets dispersed in its centre.

The whole plateau has in general a south-western dip, as the Raibler strata crop out beneath the Norian dolomite, in the North and in the East, which latter formation is the main superficial formation exposed, whereas Rhaetic limestones and shales cover its southern part. In the syncline, in the south-west corner of the plateau, Liassic limestones are preserved. In the south the plateau is bordered by the A l b e n z a a n t i c l i n e, another broad structure which accompanies and runs parallel to the sharp flexure, which marks the final border of the Lombardic foothills, the steep rand zone. In this flexure, which is wholly identical with that which we observed bordering the Alta Brianza structures to the south, all the younger Mesozoïc strata are exposed from the Norian dolomite of the core of the Albenza anticline to the Upper-Cretaceous Scaglia.

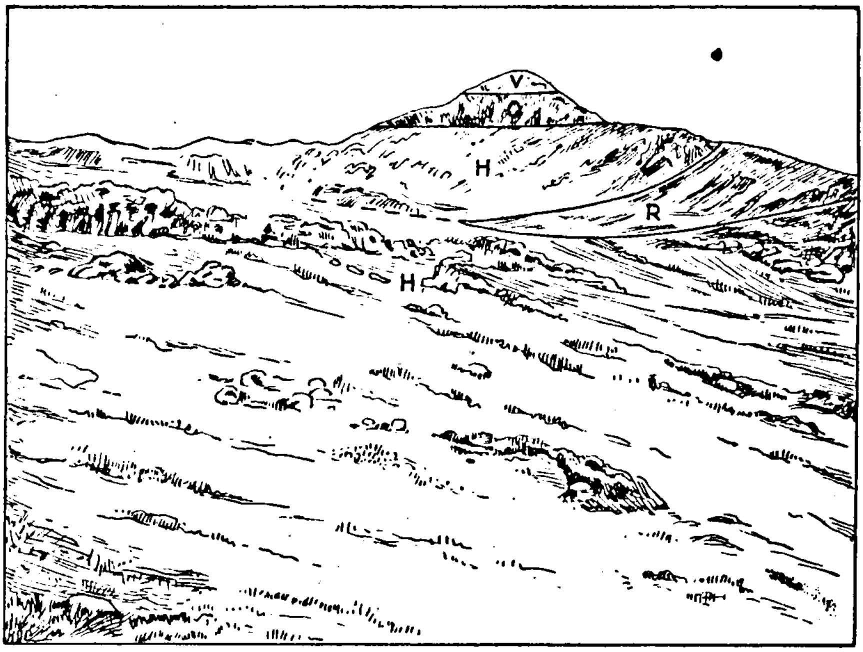
In the Albenza anticline small overthrusts of the same kind as the Civate thrust of the Alta Brianza were observed by DESIO. The Albenza anticline can be regarded as the direct continuation of the Rai anticline. Whether the Val Taleggio syncline can be regarded as the eastern continuation of the Ravella syncline is very doubtful.

Remnants of two thrustsheets are preserved in the central part of the syncline on the northern slopes of the Val Taleggio. Here we find the Z u c d i M a e s i m o and the C o r n o - Z u c c o n e consisting of Norian dolomite slabs, and the C o r n o d e l B r u c o, the C a n t o l d o and the R e g g e t o s l a b s which consist of Esino limestone with some Anisian strata at their base. The top of the Mt. Sodadura, consisting of Anisian strata resting on Norian dolomite, which in its turn has been pushed on Lower Rhaetic strata, belongs to the same unit (Plate XXXII). We have seen already that the Zuc di Maesimo and the Corno del Bruco, together with another small remnant situated between them, are regarded as belonging to the Resegone-Muschiada thrustsheet.

The other slabs, all build up by Esino limestone with some Lower Ladininian or Anisian at its base belong to another thrustsheet, which we call the S a l z a n a t h r u s t s h e e t after the stream which separates the three main slabs from one another. Stratigraphical considerations indicate that the Esino limestone of the Salzana thrustsheet in its Perledo-Varenna facies belongs to a northern zone of deposition comparable to the western part of the Grigna settentrionale thrustsheet. This conclusion is in accordance with the tectonical data, as the Salzana thrustsheet must originate anyhow from north of the Valtorta fault beyond the unbroken stretch of Norian dolomite reaching up to this fault.

The thrustplane of the Salzana thrustsheet hades with 10°—15° to the south. How far south the original thrustsheet mass reached southwards can in no way be ascertained. The small outcrops of Anisian strata, however,

PLATE XXXII.



De Wit

The Mt. Sodadura, whose top is formed by a remnant of the Salzana thrustsheet. V = Anisian. O = scree and tectonic breccia. H = Norian dolomite. R = Rhaetic.

all occur on the present northern boundaries of the Salzana thrustsheet remnants, whereas the small remnant of this thrustsheet on the top of the Mt. Sodadura is only represented by this formation. At the southern limit of the present thrustsheet remnants no Anisian has been found. Perhaps this difference between the southern and northern limits may indicate that the frontal part of the thrustsheet is not far removed.

Below the Anisian of the Mt. Sodadura we find a wedge of Norian dolomite thrusted over the Rhaetic strata, a secondary phenomenon, the Norian dolomite being derived directly from the great mass of the formation in the North.

When we traverse the Val Taleggio plateau in an eastern direction and cross the high crests of mountains of the Mt. Venturosa, Mt. Cancervo and Mt. Sornadello, all consisting of the massive Norian dolomite, and descend into the Val Brembo, we descend stratigraphically because the plateau rises considerably in this direction. This is due to the general upheaval of the whole central region with regard to the western region.

CHAPTER III.

THE CENTRAL REGION OF THE BERGAMASC ALPS.

As the central region of the Bergamasc Alps we shall describe the area comprised roughly between the Val Brembana in the west and a N—S line running from the Lago Barbellino in the north to the Lago d'Iseo in the south. The western half of the central region falls on sheet I of our geological map, the eastern half on sheet II.

With a view to the detailed description we can divide this region to our advantage in 6 subregions, viz.:

a. The upper Val Brembo north of Olmo and Branzi.
b. The great central uplift of Trabuchello-Mt. Cabianca.
c. The upper Val Seriana, north of the Val Canale fault.
d. The region comprised between Val Brembana and Val Seriana, south of the Val Canale fault.
e. The region comprised between the Clusone fault and the Val Canale fault east of the Val Seriana.
f. The Norian dolomites between the Clusone fault and the Lago d'Iseo.

A. *The Upper Val Brembana region, north of Olmo and Branzi.*

In the foregoing chapter we have described already how the Orobic thrustplane and the Giacomo fault seem to be united in the upper reaches of the Val Brembo. In section VIII we notice the small throw which has been left to the Giacomo fault. One section further eastwards, section IX, the whole situation along the boundary of the cristalline schists in the north and the Permian-Triassic complex in the south has changed. Instead of the very flatly northwards dipping Verrucano and Servino, cut off by the Orobic thrust, along which phyllites have been pushed up, we find a sharp flexure in which the Ladinian and Anisian limestones have been folded, now rising vertically in the air, together with the Verrucano, which is followed in its turn by orthogneisses. Less than 1 km further north we find the same phyllites of the Mt. Azzaredo thrusted up against the orthogneiss along the Porcile thrustfault.

There is no gradual change from one kind of structure into the other, but the boundary is a sharp and short N—S fault with horizontal movement the Vle Terzera fault. West of this fault we find the flat Verrucano and Servino, overlying the Collio schists, east of it the vertical zone of limestone, Verrucano and gneiss chiaro. The abscence of the Collio schists between the Verrucano and the gneiss chiaro can hardly be primary, but must be ascribed to a thrustfault between these two formations.

The striking difference in structure left and right of the transversal Terzera fault probably is due to the fact that the Orobic anticline has been crossed by the Orobic thrustfault. As long as the Orobic thrust was situated in the north flank of this broad anticline it had been developed as a thrust-fault, along which one part of the flank has been pushed over the other, the fault becoming steeper the more it approached the anticlinal axis. Once it crossed the anticline the situation changed and in the south flank of the anticline a steep flexure developed by the same N—S directed compressive forces.

A curious feature in this tectonic pattern is the Porcile thrust-fault, along which in the neighbourhood of the Laghi di Porcile three much squeezed patches of Verrucano and Servino schists have been preserved. As the Porcile thrustfault continues its course in a N 70° E direction, a direction which we have recognized as one of the older features of the tectonic pattern, we may assume that it represents an old longitudinal fault belonging to the original Orobic anticline and we may identifie it with the Giacomo fault, a fault which along its whole previous course further west accompanies the crest of the Orobic anticline. The three Servino-Verrucano patches near the Laghi di Porcile substantiate this view because they also indicate that the axis of the anticline is situated a little further south.

These considerations lead us to further speculations on the tectonic build of the basement rock. We have seen already that the great mass of the granodiorite of Val Biandino has been intruded into the core of the Orobic anticline. Now we find that the anticlinal crest south of the Porcile fault is formed by another orthogneiss, the gneiss chiaro. In Part I we reasoned on petrological grounds that the gneiss chiaro, the granodiorite and the Fioraro granite gneiss belong to the same intrusive period. Now we assume on purely tectonical grounds that the gneiss chiaro zone of Corno Stella- Mt Cadelle and the Orobic anticline with its granodiorite intrusions form one and the same tectonical unit. It is significant to note that in the southernmost corner of the basement rock exposure of the Salmurano culmination a small oblong outcrop of gneiss chiaro occurs, quite near the axis of the anticline, thus constituting a link between the Mt. Cadelle intrusion and the Val Biandino intrusion. From the Mezzoldo and Caprile basement rock outcrops, which are situated far on the south flank of the Orobic anticline according to sections VII and VIII no such ortho-rocks have been reported, except the small diorite stock of Scaluggio in the northernmost corner of the Mezzoldo outcrop.

The petrological connection between the younger orthorocks of the basement series, inferred from their chemical compositions and state of metamorphism has been established much more firmly now by purely tectonical reasons. On the other hand the original structural feature of the Orobic anticline must now be dated back to the Permo-Carboniferous period. This result naturally leads us to point out the parallelism between the great Permian basin described in Part II and the now established Permo-Carboniferous Orobic anticline.

The whole complex of questions in connection with the Permo-Carboniferous orogeny will be treated in full in the last part of this monograph. However, we will not leave this problem alone before having drawn the attention to another structure of the same age situated a little further north, the Mt. Fioraro anticline. Here we notice a granite intrusion of very elongated shape surrounded by phyllites, which in their turn are followed by ordinary mica-schists in the north flank. The true intrusive character of the Fioraro granite has been described in Part I, and their can be little doubt that here also we must distinguish an anticlinal structure with a granite intrusion in its core.

The phyllites are separated by the Porcile fault from the gneiss chiaro zone and further on in the east from the mica-schists. We assume that the continuation of this fault must be sought in the fault which in the Vle di Venina again separates phyllites from mica schists. On the map of CORNELIUS [1]) the Porcile fault is drawn with a great northwards curve towards the Val Tellina. No definite answer to this controversy can be given before this area has been mapped in detail.

In fig. 29 six cross sections (sections 8—13) represent the detailed tectonics of the region left and right from the Brembo di Valleve valley. The sections have been drawn in order to rectifie the sections of WENNEKERS (lit 4 and 8a), who constructed large scale overthrusts of Triassic limestones and long drawn out wedges of Permian strata below the cristalline basement rock. PORRO (1933) rightly protested against such constructions, which in no way are confirmed by the map. In reading the text of WENNEKERS it becomes evident that this surveyor has been led mainly by theoretical considerations in his out-of-scale constructions, and much less by the observed facts. The well exposed curvature of the main flexure, for instance, becomes in his sections a long drawn out wedge and each gliding surface of the Servino a major thrustplane. Also the careful survey of DOZY (lit. 10), in the neighbouring region of the gneiss chiaro outcrops necessitated a reconsidering of the sections of WENNEKERS.

In the northern half of the sections we can study the development of the Orobic thrust and the flexure accompanying it from the Cma di Lemma onwards.

We notice in the first place the Porcile fault along which phyllites have been pushed up against the gneiss chiaro anticline of Mt. Cadelle. In section 8 and 9 the Servino-Verrucano wedge south of this fault has been drawn. The gneiss chiaro zone is limited in the south by the Orobic thrust, to be found in each section. The Orobic thrust fault is accompanied by one or two minor thrusts and some secondary folding, but in the main there is one syncline along the thrustfault followed by a small anticline, in whose core Collio schists crop out in the valley. At its turn this faintly expressed anticline is followed by a very flat syncline in which the Esino limestone masses of the Mt. Pegherolo and the Pzo del Vescovo are preserved. On the Mt. Pegherolo we find the complete series of Raibler, Esino, Wengener, Anisian, Servino. Both masses have probably been pushed some distance southwards, but there is no reason whatsoever to assume large scale shrustsheets as does WENNEKERS, the surveyor of this region. A similar small scale thrusting has occured south of the Mt. Valgussera, section 13.

Between Branzi and Valleve the river crosses another series of thrustfaults of not very great importance, but forming a typical region of imbrication. These thrustfaults disappear below the limestone masses of the Mt. Pegherole — Mt. Secco, and have clearly been overridden by this mass. Thus the horizontal shortening of the Permian strata due to the general compression and expressed in thrustfaults, has not been taken over by the Triassic limestone masses, they in their turn have moved southwards over the small distance of perhaps a few hundred meters, eventually forming

[1]) CORNELIUS, H. P. and CORNELIUS FURLANI, M., Die insubrische Linie vom Tessin bis zum Tonale pass. Denkschr. Ak. Wiss. Wien, Math. Kl. 102, 1930.

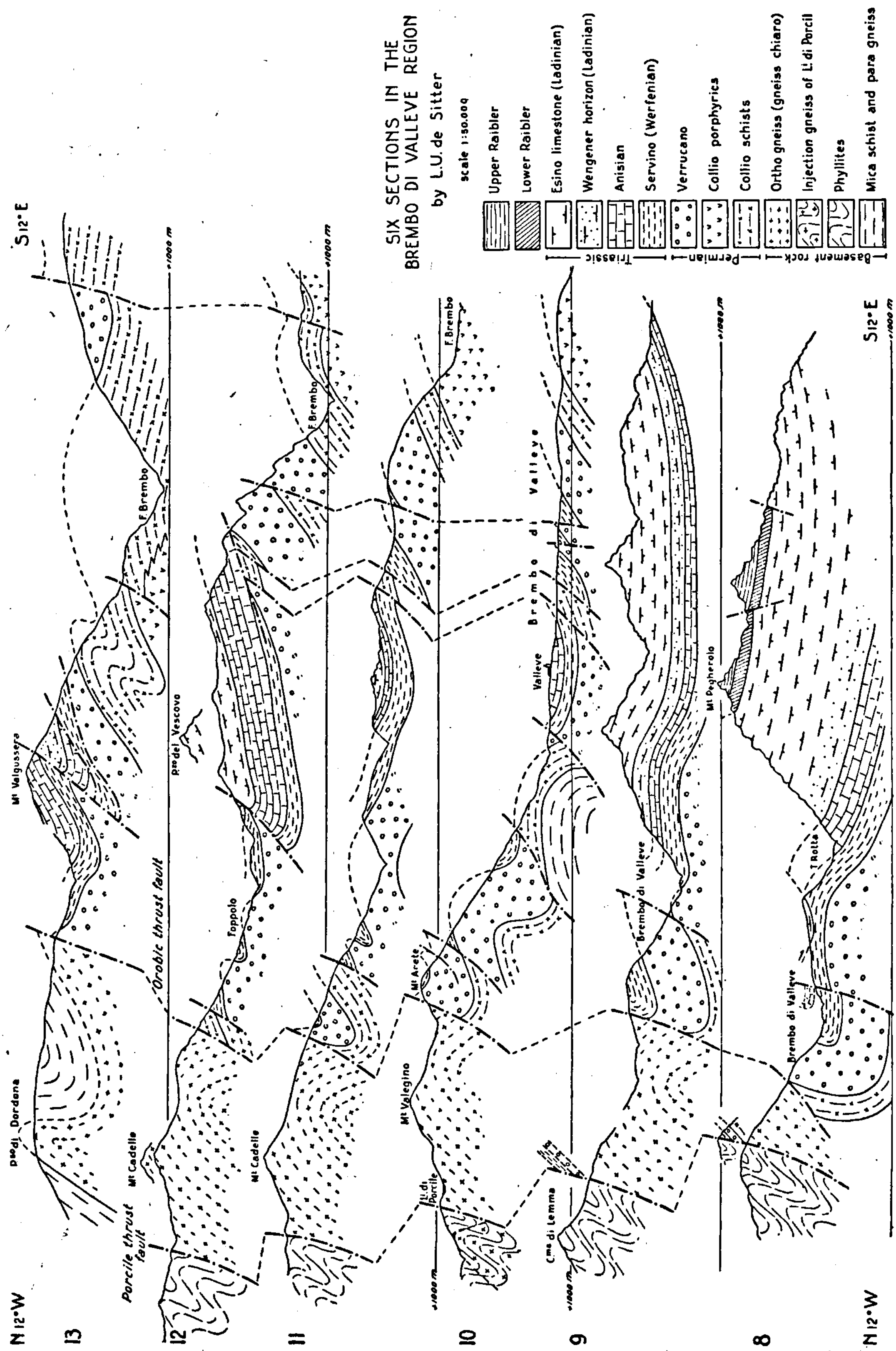

SIX SECTIONS IN THE BREMBO DI VALLEVE REGION
by L.U. de Sitter
scale 1:50.000
Upper Raibler
Lower Raibler
Esino limestone (Ladinian)
Wengener horizon (Ladinian)
Anisian
Servino (Werfenian)
Verrucano
Collio porphyrics
Collio schists
Ortho gneiss (gneiss chiaro)
Injection gneiss of L.t di Porcil
Phyllites
Mica schist and para gneiss
Triassic
Permian
Basement rock
N 12° W
S 12° E
13
12
11
10
9
8
Porcile thrust fault
Orobic thrust fault
Brembo di Valleve
F. Brembo
Mt Valgussera
Mt Cadelle
Mt Valegino
Mt Arete
Mt Pegherolo
Valleve
Toppolo
T. Rotta
Cme di Lemma
1000 m

Fig. 29.

thrusts elsewhere further south. These Valleve thrustfaults reappear at the other side of the Triassic limestone mass, where the other Brembo river has eroded into the basement rock near Mezzoldo, in the west. The southern point of this basement rock outcrop has been revisited by Dozy after the survey of Klompé. Dozy did not map his observations and therefore we are not in the position to change the map of Klompé, but this former surveyor did put his data in a sketch section which we here reproduce in fig. 30 (fig. 1, p. 67 „Beitrag zur Tektonik der Bergamasker Alpen" L. G. M.

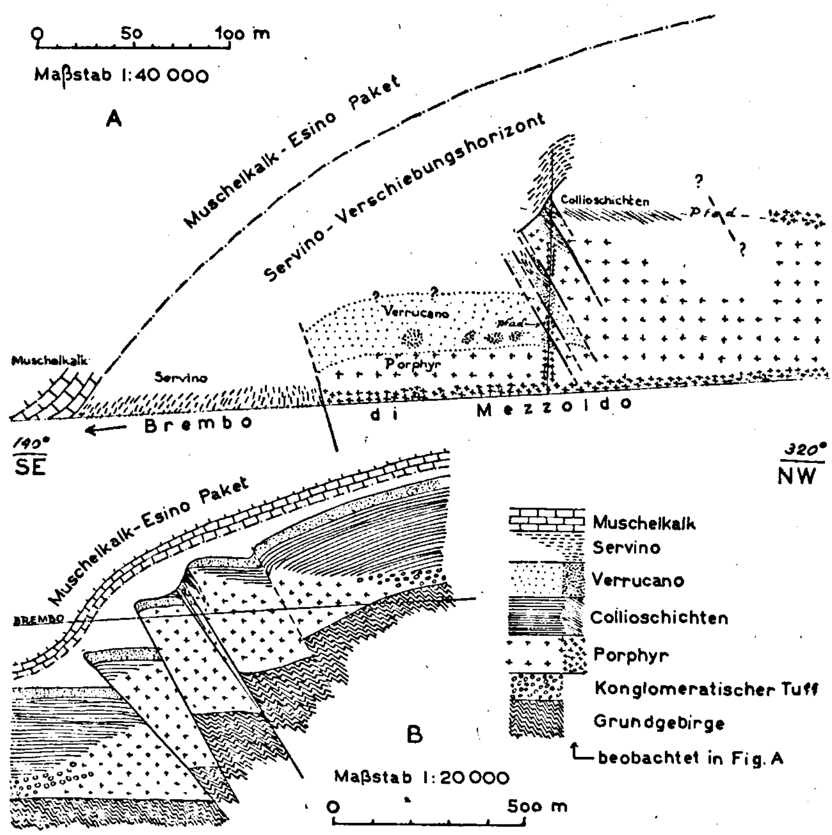


Fig. 30.

The southern limit of the basement rock outcrop of Mezzoldo after Dozy.
A. projection in one vertical plane of all data observed.
B. completed hypothetical section.

Deel VII afl. 1, 1935). The similarity of this section and the Valleve thrust-faults is striking.

Further west the faulted region again disappears below the small unbroken, but slightly southwards pushed, Triassic limestone mass of La Corna, and then joins up with the Valtorta fault. In Chapter II we followed the Valtorta fault from Valsassina, where it disappeared below the Grigna settentrionale thrustsheet, eastwards towards the region of Cusio. In the village of Cusio it disappears again below the small slab of Triassic limestone situated between this village and Averara. South of the main fault we find

Raibler cropping out beneath the Norian dolomite, and north of it we find a narrow strip of Servino, together with Verrucano and Collio schists. Near Bindo the Valtorta' fault reappears, still dividing Servino from Raibler, accompanied by a secondary fault of the same movement, resulting in the small E—W strip of Norian dolomite on which the village of Bindo is situated. The main Valtorta fault crosses the Val Mora just above Averara and then disappears for the third time now below the Triassic limestone of Mt. Faino. The above mentioned communication of Dozy gives us the missing link to join up this major faulting zone with that of Valleve. Everywhere this shows the same character, viz.: downthrown southern limb, thrusting against the fault, and larger or smaller slabs and thrustsheets of Triassic limestone masses covering it.

The careful survey of Cosijn (1) shows us the mechanism of the smaller thrusts of these limestone masses. Facing the Brembo river of Piazzolo and the Val Mora several small thrusts have been mapped. Without affecting seriously the general strike of the Esino limestone curving round the large central uplift of the Trabuchello anticline, and thus proving the local character and small dimensions of thrusting, we find a series of thrusts, represented in section VIII. We find the following sequence from North to South descending the southern slope of the Mt. Faino: Esino limestone — 1st thrust-plane — Raibler, thin band of Esino — 2nd thrustplane — Anisian, small strip of Servino — 3rd thrustplane — Anisian — 4th thrustplane — Raibler, Esino. The longest of these four thrustplanes is the fourth thrustplane, which reaches from below Averara to il Culmine striking some N 135° E when we take into account the fact that the outcrop rises from 700 m to 1200 m height. This 4th thrustplane has this peculiar strike in connection with the axial dip of the Trabuchello uplift.

B. *The Trabuchello-Mt. Cabianca uplift.*

The great central uplift of the Bergamasc Alps, consisting of Permian strata and basement rock cropping out in the culminations and in the overthrusted north flank is the second of the ENE—WSW striking anticlines which to a great extent determine the tectonical build of the Lombardic Alps.

The present anticline coïncides roughly with the former Permian trough filled up with enormously thick lower Permian strata, the Carona schists. The region has been resurveyed after the general survey of Porro 1903, by Dozy (10), Dozy—Timmermans (12), Raasveldt (17) and Weeda (13), and is crossed by the sections IX to XX. This central uplift has the same main axial dip westwards as the Orobic anticline, but shows a well pronounced culmination near Mt. Cabianca. The general structure of this uplift is difficult to read from the geological map because the two main features, viz: the Permian trough and the latter anticlinal arc do not coïncide exactly with the result that the basal conglomerate for instance shows a northern dip in the south flank of the anticline. The construction of the structure map, Plate XLII, on the Servino horizon, however, leaves no doubt about the direction and strike of the younger structure. It is true that the construction of this contour map is to a large degree conjectural as no Servino strata are cropping out north of the Val Canale, and as it had to be based mainly on the outcropping base of the Verrucano, but as the thickness of this latter formation is variable only over large distances, the main picture derived from these data will not be misleading.

The axis of the central uplift with an approximately N 70° E strike, has been cut into several sections by younger E—W striking faults and subsequent thrusting. This younger compression has resulted in a splitting up of the main axis into several anticlines running E—W, viz: from south to north: the Trabuchello anticline, the Cabianca anticline and the Sasso anticline. The Trabuchello anticline is separated by the normal Lago Marcio fault, with downthrown northern limb, from the Cabianca anticline. This latter anticline by the normal Lago Rotondo fault with the same movement from the Sasso anticline and this latter anticline by the Diavolo (or Orobic) thrustfault from the Masoni syncline. The L. Marcio fault and the L. Rotondo fault were originally normal faults with considerable vertical movement, but the later compression has resulted in a renewed thrust along these faults producing all the phenomena of a thrusting movement but not obliterating the original throw.

In sections IX to XII we see how the Trabuchello anticline rises up mostly by the steepening of its southern flank, where the Verrucano covered by Servino dips with some 80° into the Valsecca. A number of crossfaults, typical for a normal anticline are to be found in this steep flank, resulting in a reoccurrence of Servino schists. In the sections and on the map we notice that the steepening of this flank has been accompanied by a normal longitudinal fault, along which the southern region has been further warped down. Often the fault is situated in the almost vertical Servino strata, and then the normal stratigraphical sequence Verrucano-Servino-Anisian has not been interrupted. Elsewhere, however, the fault separates Verrucano from Anisian, near the Passo della Marogella even Collio from Esino limestone. This major faultline can be followed over a long distance and has been called the Val Canale fault after the valley of this name between the Passo della Marogella and the Val Seriana.

The above mentioned crossfaults are older than the Val Canale fault, as they are cut off by this latter fault and often can be traced back south of it. Such is the case with the Gemelli fault and a fault west of Roncobello. Again the E—W fault is younger than the main folding process.

In the north flank of the Trabuchello anticline another E—W fault, now with a downthrown of the northern limb has been developed, the Lago Marcio fault. The large Verrucano masses of the Pizzo Vacca and of the Pizzo del Becco are due to the presence of this fault, which has a throw of some 800 m in section XII and some 450 m in section XIII.

The block between this fault and the next one, the L. Rotondo fault, has been compressed and the Cabianca anticline has been formed, which reaches its culmination in the basement rock outcrop of Lago Rotondo and Passo di Portula. The western pitch of this anticline is a secundary feature due to the compression after the faulting movements of the L. Marcio and L. Rotondo faults, its culmination, however, and its eastern pitch are part of the original N 70° E striking main uplift.

The Lago Rotondo fault disappears rapidly eastwards and westwards of the basement rock outcrop. In section XIII it has a throw of some 1000 m, when measured on the basement rock surface, in section XIV probably much less, whereas in section XV it has disappeared altogether in the thick Collio schists. The Lago Rotondo fault is certainly not the continuation of the Valleve thrusts and thus of the Valtorta fault, because it has a downthrown block on the other side as this latter fault.

The block north of the L. Rotondo fault has a complicated structure. The main feature is the basement rock outcrop of the Valle del Mt. Sasso. due to a strongly compressed anticlinal structure. This Sasso anticline again is not everywhere as simple as it has been represented by section XIII, further east it has a more complicated shape, with a sharply compressed anticlinal structure and thrusts, as the detailed sections of DOZY, fig. 31, indicate.

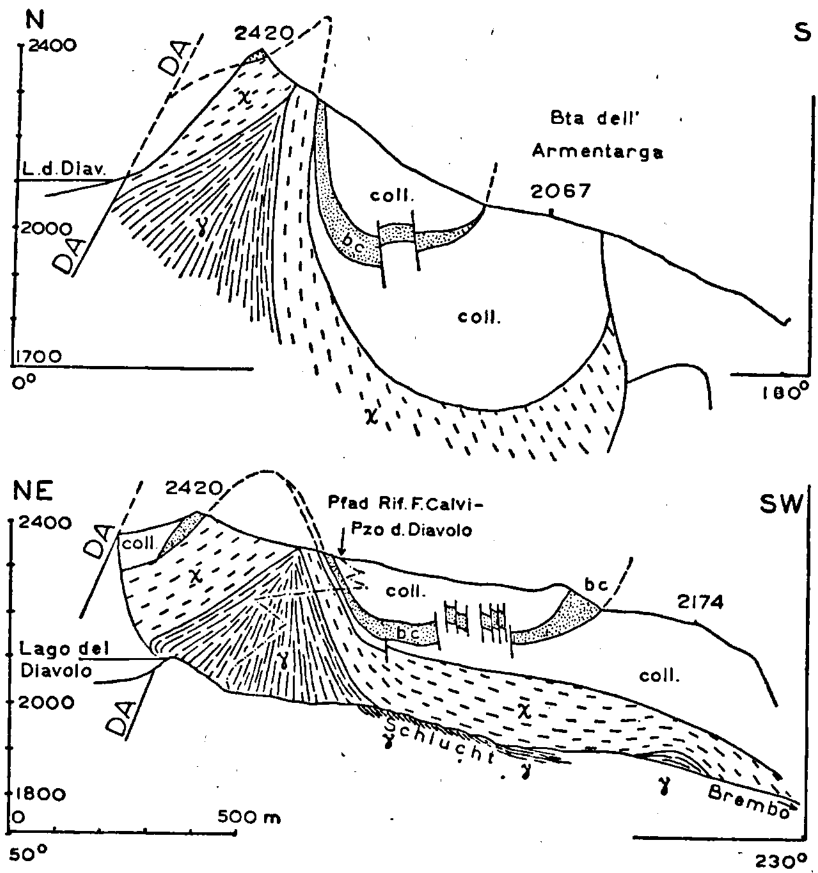


Fig. 31.

Two sections through the Mt. Sasso anticline (after DOZY).
Coll. = Collio schists. b c = basal conglomerate.
χ = gneiss chiaro. γ = mica-schists. DA = Diavolo thrustfault.

The Sasso anticline is limited in the north by the **Diavolo thrustfault**, which is the continuation of the Orobic thrustfault. The throw of this fault has diminished considerably and its trace is soon lost in the Collio schists east of the Lago del Diavolo.

The next block, north of the Diavolo thrustfault has a pronounced synclinal structure, the Collio schists with the basal conglomerate at its base have been bent into a sharp syncline with a vertical north flank. The structure can be compared to that of the flexure of the Cima di Lemma but probably may not be regarded as its direct continuation. The structure is limited in the north by another E—W striking thrustfault, the Publino fault of not very large dimensions. This thrustfault which runs north of the Corno Stella to north of the Pizzo di Cigola can be found in the field by the narrow strip of mica schists between two gneiss chiaro masses. The vertical north flank of the above mentioned Mt. Masoni syncline, having a strike of N 75° E approaches the Publino fault in eastern direction and is crossed by this fault in the upper Valle di Ambria.

In this synclinal block two curious sharp V shaped faults occur, on the Pzo Zerna and on the Pzo di Cigola, of which the sketch, fig. 32, of Dozy gives an idea.

We presume that older N—S striking cross faults, belonging to the original anticline, and the subsequent thrusting have together called forth these complications.

All these faults and thrustfaults and many more of which Dozy has

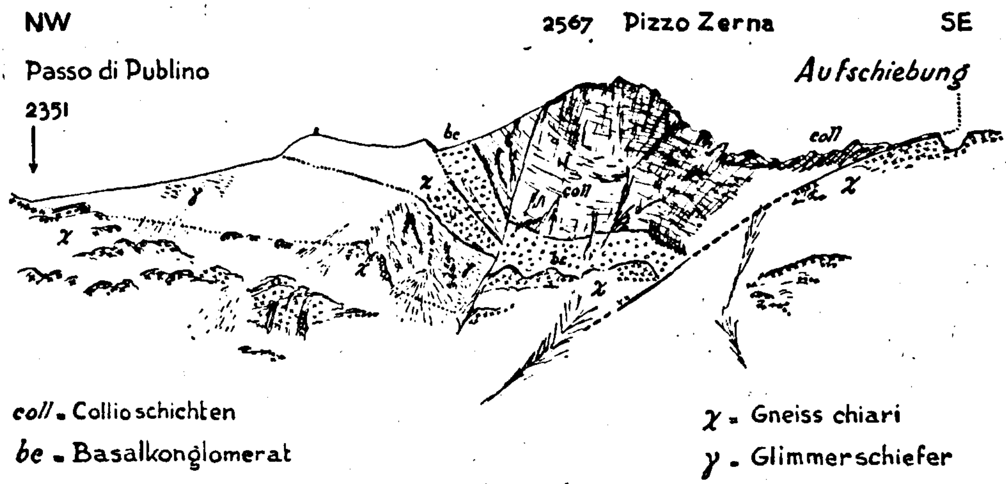


Fig. 32.

The Pizzo Zerna seen from the south (after Dozy).

found traces as mylonitic zones in the basement rock of Valle di Venina and Valle di Ambria, and in the slab consisting of basal conglomerate with Collio of Pzo Ceric, strike into the enormously thick Collio schists mass of the Pzo di Redorta and Pzo di Coca, and can not be traced back there.

The flat northwards dipping outcrop of basal conglomerate on the Pizzo Ceric north of the steep north flank of the syncline, together with similar outcrops further east, prove conclusively that the Permian blanket of the basement rock has been present at least on the southern limit of the Orobic zone at a height of approximately 2300 m. A similar, but very small outcrop occurs just north of the Pizzo Biolco, and the outcrops further east on the Pizzo del Diavolo on the Mt. Demignone etc., all point to the same conclusion that the Orobic zone of basement rock is definitely not a totally new tectonical unit but just another stepping stone towards the central Alps, warped up still higher and therefore only seldom showing any sedimentary cover. This conclusion is incompatible with the views of

R. STAUB [1]), who regards the Orobic zone of basement rock as the vertical root of the upper east Alpine thrustsheets.

The vertical north flank of the Masoni syncline can be followed in a E N E direction from the Pizzo di Cigola, cut by numerous small faults and finally cut off by a larger thrustfault, the Val Caronno thrustfault, which also limits the Pizzo Ceric basal conglomerate outcrop to the north. This fault eventually curves towards the north, round the Pizzo Biolco and the vertical north flank reappears and can be followed further east untill it runs into the complicated fault pattern of the Pizzo del Diavolo and the Passo della Malgina. In this neighbourhood the north flank of the syncline has been cut up by numerous faults in a complicated pattern of small blocks which have been compressed to a high degree. The syncline has risen to such height that its floor of basement rock is exposed, otherwise the imbricate structure could never have been mapped. The N 55° W striking Malgina cross fault puts definitely an end to this structure, and from here to the Mt. Torena only phyllite zones in the mica schists indicate the continuance of the usual imbricate structure.

C. *The Upper Val Seriana north of the Val Canale fault.*

We have left the Valcanale fault, the southern limit of the Trabuchello anticline at the Passo della Marogella. Further east, along the Valcanale it maintains the same character as it had west of this pass. In section XIII it runs between the Servino strata and the Anisian limestone and one would be inclined to deny its existence in this normal sequence of strata if it did not reappear a little further east (section XIV) as separating the Verrucano from the Anisian and further on from the Ladinian. The sudden disappearance of Servino north of the Valcanale fault is due to a cross fault of the same character as we observed several already west of the Passo della Marogella.

Approaching the Val Seriana the Valcanale fault changes its E—W direction somewhat and starts to swing to the north, and another cross fault, butting against it, is observed. Between the Val Seriana and the Val Sedornia the same structure prevails, two cross faults butt here against the main fault. Crossing this latter streamlet, however, the Valcanale fault swings further to the north and, from thereon is better called by the name of Bondione fault as we will see later on.

The Cabianca anticline can only be followed eastwards in a very conjectural way. The Collio schists mass gives little tectonical information and the basement rock outcrops of the upper Val Seriana are much less due to the folding in anticlinal and synclinal structures than to the much older Permian trough. Most of the basement rock exposures lie on the flat south flank of the large anticlinal upheaval and are the original southern border of the Permian trough. In section XVII, for instance, the northwards dip of the basement rock surface from the Mt. Calvera to the Val Seriana is a feature of the Permian trough, because the base of the Verrucano must rise some 500 m from the top of this mountain to a height of ± 2500 m at the other side of the Val Seriana, in this same direction, a rise instead of a fall.

The unbroken south flank of the anticline is beautifully exposed in the

[1]) R. STAUB. Zur tektonischen Deutung des Catena Orobica Ecl. geol. Helv. Bd. 16, p. 28, 1920.
„Der Bau der Alpen''. Beitr. z. geol. Karte der Schweiz. N. F. LII, 1924.

right bank of the upper Val Seriana between Valle del Goglio and Val Grabiasca. Cross faults appear only still further in the flank, butting against the Val Canale fault. Near Gromo, on the Serio, two of these faults cross one another.

Further eastwards, however, larger cross faults have been developed. The first of these is the M o l a f a u l t, limiting the Verrucano mass of the Mt. Vigna Soliva to the west. This fault is at the same time the boundary of the basement rock exposure. To the west the Mt. Vigna Soliva is also bordered by a large cross fault, the V i g n a S o l i v a f a u l t thus presenting this mountain as a "graben" in wich the Verrucano covered by Servino has been preserved between the Seriana and Bondione basement outcrops. The Vigna Soliva fault joins up with the S e r i a n a f a u l t, the latter being the abnormal contact between the Collio schists and the basement rock on the right bank of the Serio river above Bondione. This Seriana fault, however, coïncides rather closely with the old flank of the Permian trough, and is probably only a gliding plane along which the Collio schists have been slightly thrusted upwards along an older inclined stratigraphical plane.

In the beautiful circus of the upper Val Bondione, surrounded by high and lofty mountains, the basement rock outcrop continues. The basement rock exposure is limited in the south by the Vle. d. C a s c i n a t h r u s t, and has an anticlinal build. We may presume that the Cabianca anticline is found back in this overthrusted anticlinal structure. Two elements cross another at this moment, one the Cabianca anticline, the other the south flank of the Permian trough. Towards the east this last basement rock outcrop of the Val Seriana is limited by another cross fault, the L. B a r b e l l i n o f a u l t, which joins up further northwards with the Pso d. M a l g i n a f a u l t, but has a contrary movement. The Cascina thrustfault itself probably continues eastwards in the Collio schists and we will find it back as the limit between basement rock and Collio NE of Mt. Gleno.

Only about 1 km further south runs another thrustfault, the Pzo T r e C o n f i n i f a u l t, forming the contact line between the large Verrucano shield of the Mt. Tornello-Torrente Gleno-Mt. Sasna and the Collio schists of Mt. Gleno - Mt. Cimone. The Verrucano strata have a regular southward dip (see section XX) but suddenly curve upwards in the same way as the north flank of the Masoni syncline. Again the northern block has been pushed up against this synclinal flexure, a feature which we have encoutered already in several instances.

The synclinal flexure, accompanying the Tre Confini thrustfault follows the westward plunge of the Cedegolo anticline, which we will describe in greater detail in the next chapter. This anticlinal structure is revealed for the last time on the two banks of the Torrente Bondione, where the Verrucano forms an arc over the exposed Collio schists. This pitch of Cedegolo anticline can be compared very well to that of the Trabuchello anticline further west and described above. The plunge is marked by the Servino and Anisian strata curving round the nose of the anticline.

However, many complications of this simple structure have arisen, partly obliterating the orginal structure. In a former paper (DE SITTER 1939) on the Bergamasc Alps I misunderstood the position of the Anisian limestone reaching as far north as the Upper Val Seriana and ascribed this protuberance to thrusting, in accordance with the conception of WEEDA (lit. 13). With the assistance of the five sections of fig. 33 the structural features of this region can be understood.

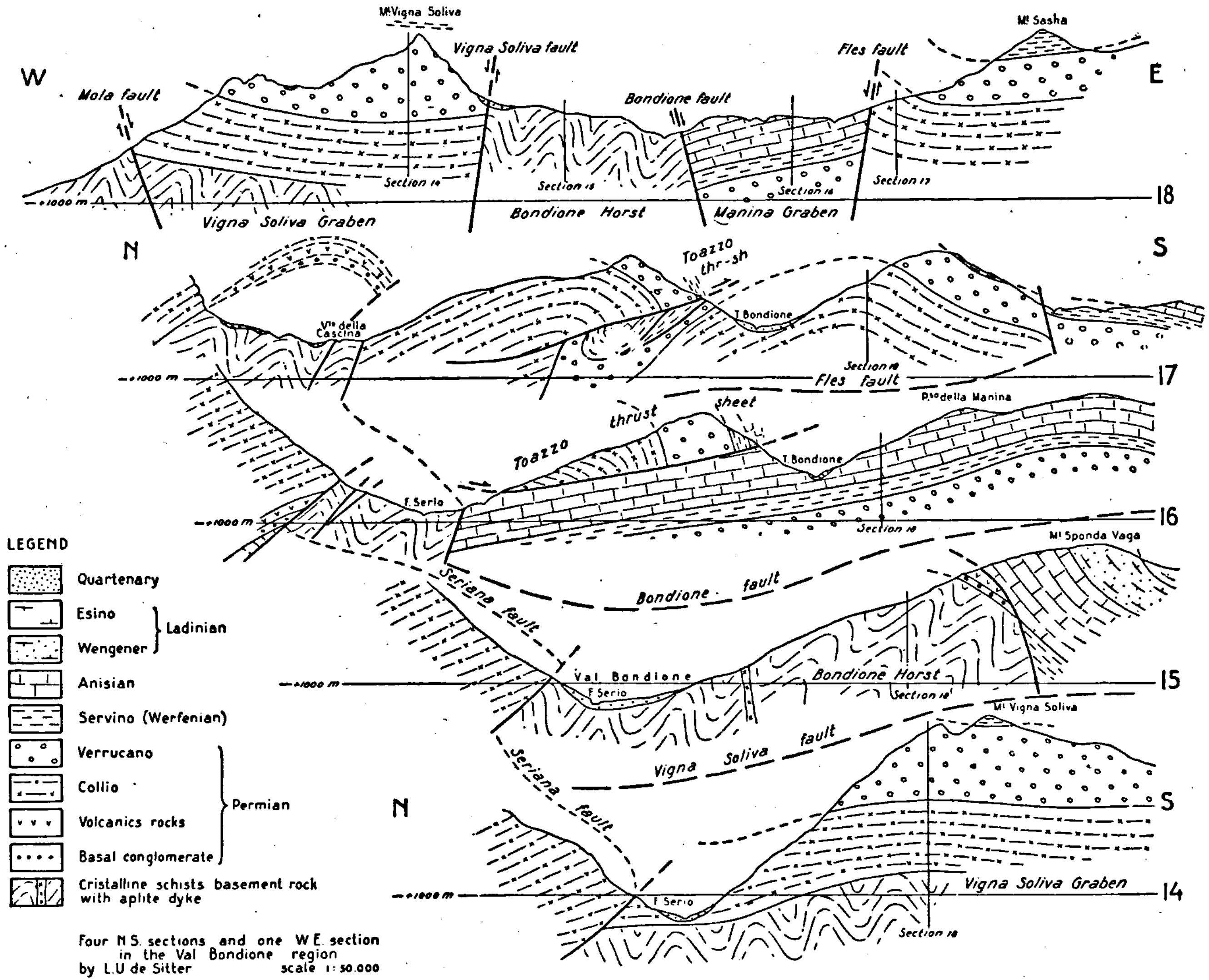


Fig. 33.

Four N—S sections, 14—17, through the Val Bondione region and section 18, a W—E section.

In the first place the plunge of the Cedegolo anticline has been cut by three major diagonal faults, the Vigna Soliva fault the Bondione fault and Vle Fles fault. (section 18). The block between the Vigna Soliva and Bondione faults has been wharped up, and we call the resulting horst the Bondione horst. The block between the Bondione and Fles faults has been wharped down and we call this the Manina Graben. A fourth fault, west of the Mt. Vigna Soliva, the Mola fault belongs also to this system and the block between this fault and the Vigna Soliva fault has been called the Vigna Soliva Graben. The four faults are not strictly parallel, allthough their main direction is N—S.

The Bondione fault, the most important one of the system, especially, has a NNE—SSW direction and can be followed over a distance of 13 km. Later compression has obliterated the faulting to some extent by two thrusting movements. In the first place the Anisian limestone curving round the nose of Cedegolo anticline has been pushed over the Mt. Sponda Vaga. North and South of this small-scale thrust the Bondione fault is clearly visible and the Bondione horst between the Vigna Soliva fault and the Bondione fault continues south of the Anisian thrust for some 3 km.

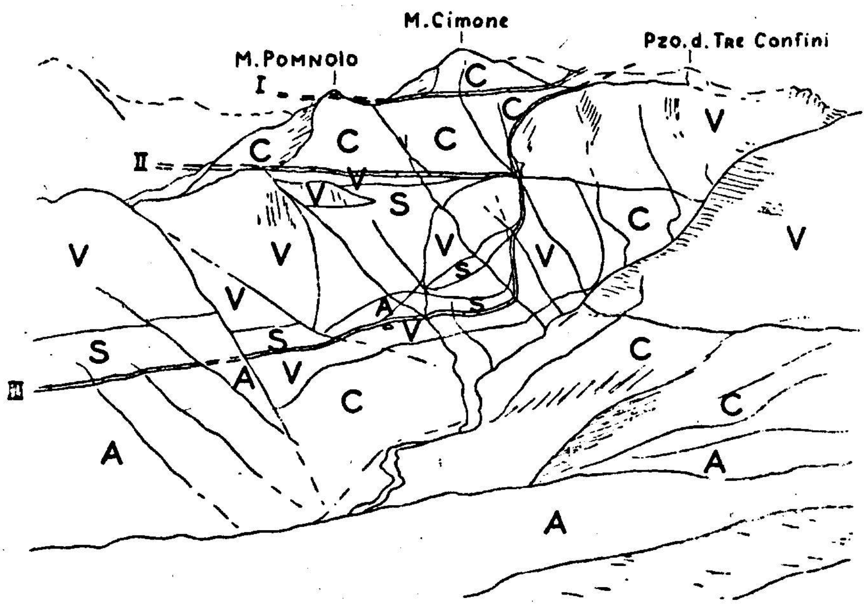
Of greater importance are the thrusts which have come from the NE, from the region of the large Collio highland of the Mt. Cimone-Pzo Recastello-Mt. Gleno. In three thrusts, one above the other the Collio has been pushed over, and into the gap formed by the Manina Graben. The upper thrust, the Mt. Cimone thrust is composed wholly of Collio schists and rests altogether on Collio schists, the next, the Mt. Pomnolo thrust consists of Collio schists but has been pushed over the Verrucano and Collio of the marginal syncline of the Tre Confini fault. The lowest thrustsheet, the Mt Toazzo thrustsheet is the most important of the three, and has advanced a considerable distance into the Manina Graben. It consists of Collio-Verrucano-Servino and Anisian limestone and represents a true anticlinal front of a thrustsheet with vertical strata. It has been pushed over the Anisian strata of the Cedegolo plunge, which can be followed beneath the thrustsheet up to the Val Bondione (upper Serio valley). The Toazzo thrustsheet covers the northern extension of the Fles fault altogether.

In Plate XXXIII, a photo and drawing by WEEDA a special view of these thrustsheets has been given. On this drawing the complicated imbricate structure of a small triangle situated north of the Torrente Bondione appears. The structure of this triangle is due to the fact that a small part of the marginal syncline of the Tre Confini thrust has been compressed and quenched by the thrustsheets pressing over it. Is consists of wedges of Verrucano, Servino and Anisian.

The Fles fault, which originates at the height of the Passo della Manina has a N—S strike and soon after it has crossed the Torrente Bondione it disappears below the Toazzo thrustsheet. Its throw increases rapidly in a northern direction, as it already brings Anisian limestone in contact with Collio schists in this stream.

The Bondione fault can be followed from the Valle della Cascina southwards. In this valley it has been cut off by the Cascina thrustfault (with E—W strike) and can be parallelised perhaps with the Barbellino fault, which has the same movement. The Bondione fault follows the SE bank of the Val Bondione crosses the Torrente Bondione and disappears below the Anisian just below and north of the Mt. Sponda Vaga. The Bondione horst consists of basement rock only in its northern portion, but north of the Mt. Sponda

PLATE XXXIII.



The valley of the Torrente Bondione seen from the Passo della Manina, after WEEDA.

I. thrustplane of the Cimone thrust.
II. thrustplane of the Pomnolo thrust.
III. thrustplane of the Toazzo thrust.

C = Collio. V = Verrucano. S = Servino. A = Anisian.

Vaga it shows a strong south dip (section 14). When it reappears below the Anisian limestone it consists of Collio and basal conglomerate overlying the basement rock. In its southern extremity the Bondione horst becomes very narrow because the Vigna Soliva fault, with its N—S strike, approaches the Bondione fault to a distance of less than 500 m. The Bondione fault joins up with the Valcanale fault, which we have followed to this point, and the Vigna Soliva fault butts previously against a short cross fault which definitively puts an end to the Bondione horst.

The Mola fault, also with a pure N—S direction somewhere north of the Val Sedornia, slowly increases in throw northwards, crosses the Serio river and disappears in the thick Collio on the north bank of this river, probably below the Seriana thrust.

Except the Bondione fault, all these faults have the characteristic of increasing their throw in a northern direction and all four are overrun by later thrust.

The sequence of events can thus be clearly followed in this instance. In fig. 34 the stages in the development are represented in three successive sketches. First the formation of NNE—SSW striking large anticlines, then the formation of a diagonal fault running from the plunge of one anticline to the crest of the next, the Bondione fault, possibly with a horizontal movement, accompanied by other N—S cross faults all of them with considerable vertical throw, finally strong compression and overthrusting partly obliterating the older elements resulting mainly in E—W directed structures but locally diverted of this general strike by these older elements.

In the second phase, the phase of cross faulting, the Bondione fault is probably the eldest one. It joins up with the Valcanale fault, which in its turn cuts off several cross faults, which partly can be traced back on both sides, north and south of the main fault partly only occur north of this fault. The divergent direction of the Bondione fault puts it already in a class of its own and its position, diagonally crossing from the plunge of one anticline to that of the next, already lends it a somewhat different character as if it still belonged to the foregoing folding process.

D. *The region comprised between the Val Brembana and Val Seriana, south of the Val Canale fault.*

The region south of the Valcanale fault has a totally different character from the region north of this fault. In the first place the outcropping strata all belong to the Triassic and secondly the structure of the southern region shows many features altogether unknown in the north.

Along the Val Brembana a monocline, flatly dipping southwards has been developed (sections VIII and IX), which represents the flat and unbroken south flank of the Trabuchello anticlinal uplift. Small undulations occur in this monocline, of which the T. Parina anticline is the best developed one. In section X the Valcanale fault appears for the first time, and further south between sections IX and X several cross faults cut the Raibler-Esino boundary. A little further east a small outcrop of the Trinodosus horizon appears below the Esino limestone in the gorge of the Torrente Parina, constituting the core of the Parina anticline.

East of section X and just south of the Valcanale fault and parallel to the latter fault, a new feature appears, a thrustfault along which the southern mass of Triassic strata has been pushed up, over and against the

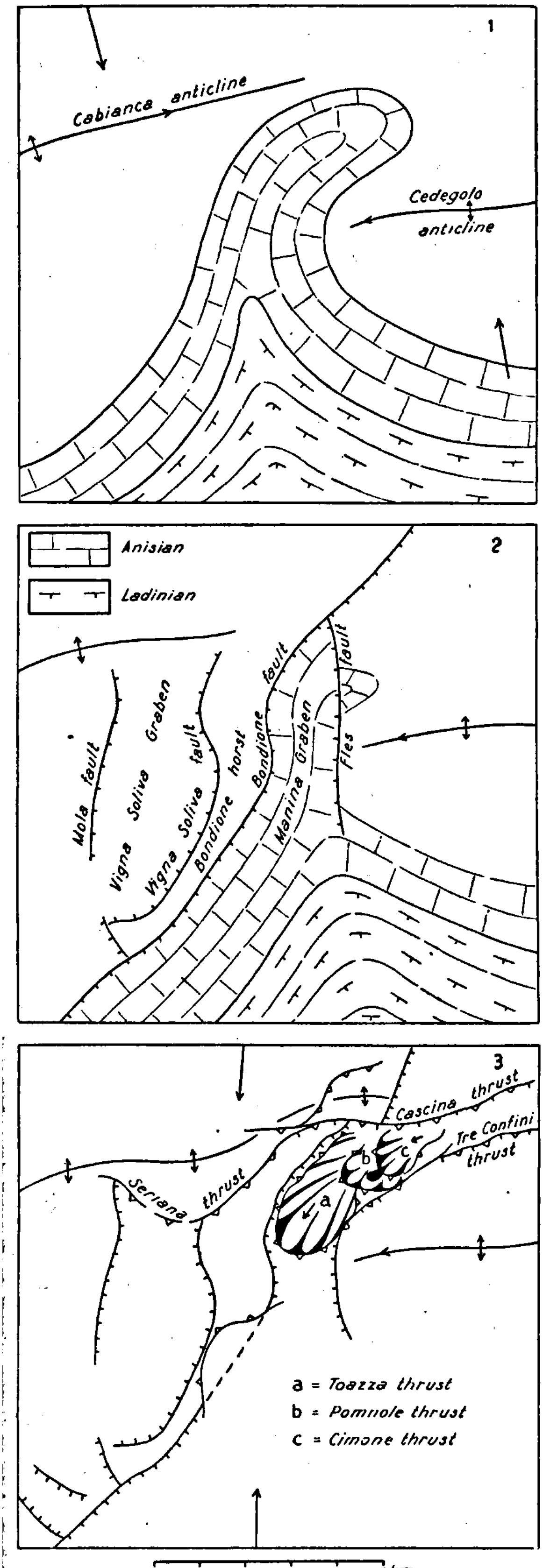


Fig. 34.

The development of the faulted region of Val Bondione.

1. Anisian limestones curve round the plunge of the Cedegolo anticline into the syncline between the Cabianca and Cedegolo anticlines.

2. First the Bondione fault, then the Mola, Vigna Soliva and Fles cross faults are developed.

3. Subsequent thrusting results in the Cascina thrust-fault, the Tre Confini thrust-fault and the three small thrust-sheets penetrating into the Manina fault trough:
(a) The Toazza-, (b) Pomnolo- and (c) Cimone thrustsheets.

northern Permian mass. This thrustfault can be followed over a large distance and has been called the Ardesio upthrust, after the village of this name in the Val Seriana, where the movement has reached its maximum throw. The narrow strip of strata comprised between the Valcanale fault and the Ardesio upthrust, varying in width from 300 to 800 m untill it widens near the Val Seriana, has everywhere been strongly compressed and squeezed as may be expected in such tectonical situation. The movement along the Ardesio thrust is not very large west of the Val Seriana and the thrustplane lies unvariably at the bottom of the Anisian limestone or in the Servino strata. The strip between the two faults consists of Anisian limestone, sometimes accompanied by the underlying Servino or by the overlying Esino.

The gentle undulating plateau of Esino limestone and dolomite of the

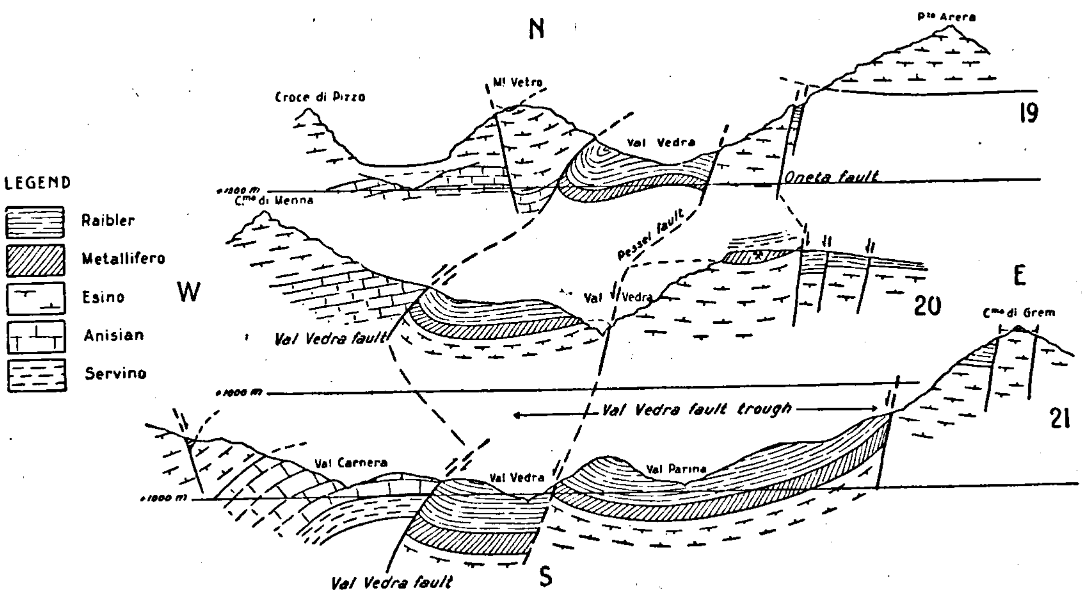


Fig. 35.

Three W—E sections through the Val Vedra fault trough.

Mt. Ortighera - Cma di Menna, has been interrupted by the Val Vedra fault trough, but continues east of this fault-trough in the similar monoclinal structure of the Valle Nossana and the Valle Fontagnone.

In the Val Vedra fault trough Raibler strata are exposed reaching northwards up to the Ardesio thrustplane. The western boundary is formed by one fault, the Val Vedra fault, along which the Raibler of the trough has been brought in lateral contact with the Anisian of the western plateau. Later compression has had two results; in the first place the heavy mass of Esino limestone has been pushed some small distance over the trough boundary fault, and in the second place the Parina anticline has been compressed into a sharp fold, with a flexurelike south flank, as represented on section XI. Fig. 35, with sections 19, 20 and 21 give the structure of the Val Vedra fault-trough in more detail. In the north the Val Vedra fault is cut by a curved fault, which runs round the Mt. Vetro, by whose action the Anisian outcrop along the fault-trough disappears. It seems probable that the Val Vedra fault may even be followed across the Ardesion upthrust and the Valcanale fault, northwards into the flank of the Trabuchello anticline, as the Gemelli fault lies in the direct continuation of the Val Vedra fault, and has the same movement. Already we noticed that the fault trough must be older than the latest compression, as the Anisian has been pushed over the trough; now we find that it is probably also older than the Ardesio thrust, which belongs to the same latest compressive phase and also older than the Valcanale fault, which also is one of the younger features. The Val Vedra fault-trough is therefore of the same age as the N—S fault system of Val Bondione, described above.

The eastern limit of the Val Vedra fault trough is more complicated, and several N—S faults are concerned in its formation. The most important one is the fault closely following the Val Vedra, the Pessel fault, called after the Baita Pessel. Its throw decreases northwards and southwards, and it has a NNE direction. The next fault towards the East is the Oneta fault, which reaches from the Corna Piana to Oneta. At the height of the Corna Piana it is a double fault with a very narrow strip of Raibler strata between the two faults, flanked at both sides by Esino. The Oneta fault can be followed northwards across the Ardesio thrust plane and the Val Canale fault into the Verrucano of the Trabuchello anticline, in the same way as the Val Vedra fault. Several faults of lesser throw can be discerned further to the east.

East of the Val Vedra fault trough the same monoclinal plateau with a flat southern dip, as found west of the trough, has been developed. A peculiar structural feature has been added, however, viz: the Baita del Fop syncline (Plate XXXIV, fig. 1). This syncline is a recumbent isoclinal fold and appears on sections XIII and XIV. Its direction is WNW—ESE, from the Cima di Leten, passing south of the Cima Vaccaro and then disappearing above the topographical surface. It will be found back at the other side of the Serio as the M. Pare syncline. The syncline has been cut off by the Pzo Arera thrustsheet, passes below this structure and can be discerned again in the Val Vedra fault trough where the steep north flank is cropping out in the Cno Brànchino and along the Ardesio thrust. (sections XII and XIII). The recumbent north flank of this syncline has been broken off in the region of the Pzo Arera, and has been pushed over the synclinal core, forming a minor thrust mass, the Arera thrustsheet (sections XII and XIII), forming the top of this mountain and the Cma Valmora and the Cma del Fop (Plate XXXIV, fig. 2). The whole structure is due to a kind of disharmonic folding, where the Triassic strata have been sheared of their Permian substratum and the northern mass has been pushed over the southern limb. Fig. 36 illustrates the tectonical history of this structural detail.

Allthough the strong compression and overthrusting in this syncline is certainly due to the latest compressive phase, its origin must be older, because it has been cut off by the Valcanale fault and as we will see later on by the Clusone fault. Apparently its origin must be sought in the first phase of folding, allthough its strike is not in accordance with this assumption.

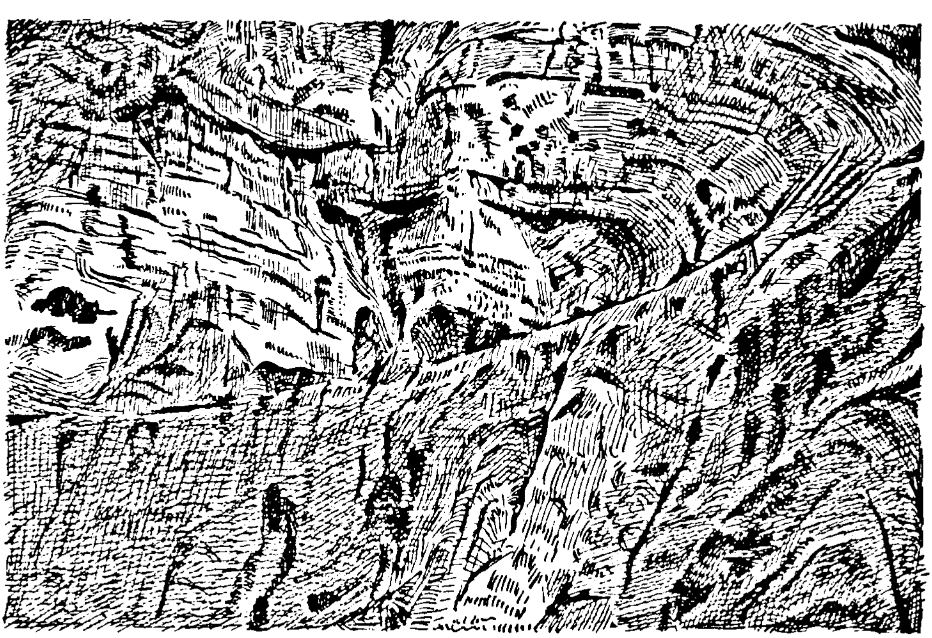
The large Raibler plateau of Oneta-Parre is limited in the south by the N 60° E striking Clusone fault, along which the southern limb has been thrown down. This very long and important fault constitutes one of the limits between two steps and is therefore of major importance in the

PLATE XXXIV.

Swolfs

Fig. 1.

The recumbent syncline of Baita del Fop to the N W of this Baita. In the core of the syncline the softer middle Raibler marls are exposed.



Swolfs

Fig. 2.

The thrustplane of the Arera thrust in the Cima del Fop. Below the thrustplane is unstratified Esino limestone, above it Anisian limestone.

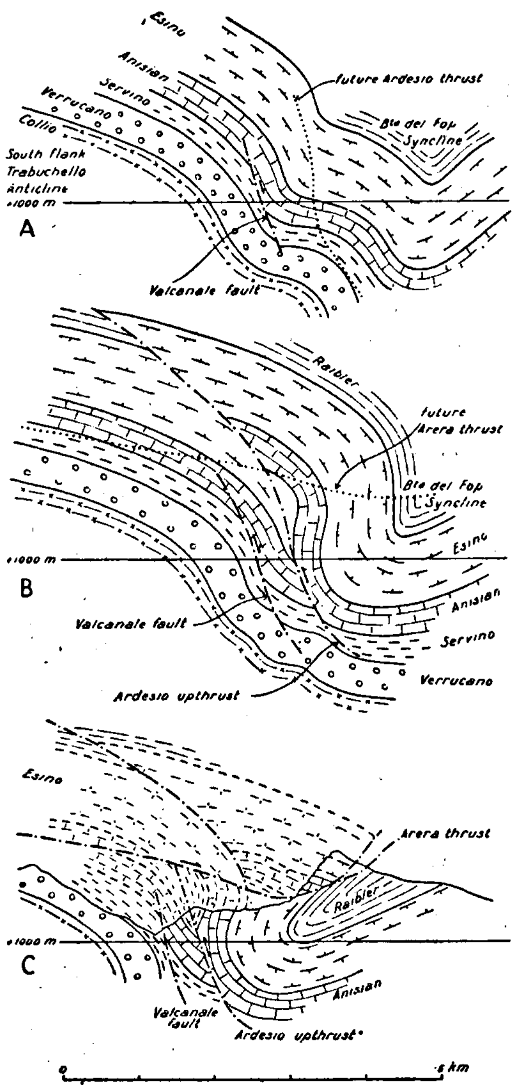


Fig. 36.

The development of the Arera thrust.

1. The Bta del Fop syncline flanking the large uplift of the Trabuchello anticline.

2. By subsequent compression the Ardesio thrustfault develops and the Bta del Fop syncline has been accentuated.

3. Present situation. Further compression has folded the syncline into a recumbent structure, its upper flank has been broken and thrusted over the syncline.

tectonical structure of the Bergamasc Alps. South of it extends a large slightly undulated surface consisting altogether of Norian dolomite with Rhaetic strata preserved in the synclinal regions, whilst north of the Clusone fault the strongly compressed zone of Ladinian and Anisian age has a totally different structural character. The Clusone fault has a length of more than 20 km from its origin, south of the Mt. Alben to the spot where it almost disappears below younger thrust-sheets, south of the Presolana.

E. *The region comprised between the Clusone fault and the Valcanale fault east of the Val Seriana.*

The Clusone fault crosses the Val Seriana between Parre and Clusone and can be followed on the southern slopes of the long ridge of Mt. Parè, always separating Raibler from Norian dolomite. North of Clusone it makes a curve northwards but soon comes back to its original track. The P a r è s y n c l i n e, the continuation of the Bta del Fop syncline is cut off by the Clusone fault northeast of Rovetta, where the Clusone fault takes a more northern direction. South of the Mt. Parè some upper Raibler strata are pressed between the Clusone fault and a narrow strip of Esino limestone, the latter belonging to the south flank of the Parè syncline. The throw of the fault increases in eastern direction and probably is generally more than 1000 m.

The zone comprised between the Clusone fault and the Valcanale fault, which latter fault also assumes a N 60° E strike since Albareti in the T. Aqualina, and between the Val Seriana and the mountain ridge of Mt. Ferrante-Pzo della Presolana has an exceptionally complicated structure.

When we study the map we notice in the first place that in the centre of this region Servino and Anisian occupy the highest mountains, overlying Raibler and Esino. This abnormal situation is due to the Cma di T i m o g n o t h r u s t s h e e t, to which belong these older Triassic strata, an upthrusting movement of southern elements over the northern block. The latter shows a similar upthrust, the A r d e s i o u p t h r u s t, which we have encountered already in the foregoing paragraph. The Ardesio upthrust is older than the Timogno thrustsheet, because the later passes over and covers the former.

Both thrusting movements have the same character, a south to north movement of the upper limb, and are due to strong compression in a monocline thus deformed to an imbricate structure.

In descending the Serio river from Gromo, we pass first the Valcanale fault, and then some 1.5 km downstreams of this fault the Cno R o n d i n i n o f a u l t, a normal fault with downthrown southern limb of no large throw (section XV). Some 2.5 km further downstream we pass the Ardesio upthrust, along which Esino has been pushed over Raibler strata. The thrustplane hades with some 35° southwards, and on the west bank of the river Anisian strata soon appear below the Esino of the overthrusted block. On the east bank of the river the thrustplane is soon cut off by the Timogna thrustplane, which we pass in the Serio river some 3 km further downstream. Again Esino limestone has been thrusted up and rests now on the Raibler strata of the Ardesio thrust mass. The thrustplane of the Timogno thrustsheet has also a hade of some 30° south near the Serio river but becomes much flatter further north- eastwards (section XVI and XVII). On the west bank of the Serio river its thrusting movement decreases rapidly and the thrust is lost in the thick Esino mass of the western slopes of the Mt. Secco. On the east bank of the Serio river, however, a strong increase of throw can be noticed. Soon Anisian limestone, underlying the Esino normally, appears and in the Torrente Rino Servino appears below the Anisian. The thrustplane has now a horizontal position and has cut off the Ardesio thrustplane. From the Mt. Corru to the Cma di Timogno, and even further east a horizontal slab of Anisian limestone and shales on a Servino base occupies the highest regions, covering the underlying structural features. The straight boundary line of Raibler-Esino, which strikes southwestwards from the Mt. Vigna Vaga, for instance, is blanketed by the thrustsheet and reappears again in the west below the Servino. Part of the thrustsheet descends as low as to 1300—1500 m in the small fault-trough of the Val di Fuga, north of the Mt. Corru. Other small faults are found here and there in this horizontal part of the thrustsheet, the mapping of which has been done with great care by SWOLFS, to whose publication (no. 16) we refer the reader who is anxious for more detail. The total thrust movement of the Timogno thrust is considerable and must be estimated at some 8 km.

As mentioned before the narrow zone between Valcanale fault and Ardesio thrust, which descends the Valcanale from the Passo della Marogella, widens from Albareti onwards, there the Valcanale fault makes a curve to the north, and the deep erosion of the Serio causes the Ardesio thrustplane to recede to the south. However, the Rondinino fault, which we met already in descending the Serio from Gromo, cuts this wedgeshaped territory between the two main faults in two parts, of which the southern one has been wharped down and consists of strongly contorted Raibler strata.

Against the Valcanale fault, Anisian strata are cropping out below the Esino on the left and right bank of the Serio, and even small outcrops of Servino occur below the Anisian, due to several faults southeast of Gromo, below the Mt. Redondo. This mountain itself is separated from these outcrops by a fault curving round it.

Further to the NE along the Valcanale fault the structure becomes more simple and we find a regular sequence of Anisian-Wegener-Esino-Raibler striking NE towards the Mt. Vigna Vaga. Near this mountain this regular complex of strata suddenly curves round to a NW—SE direction, partly due to their topographic situation, partly, however, due to the fact that the strike itself changes. Along the Valcanale fault the strata form part of the south flank of the Trabuchello-Cabianca anticline, but east of the Mt. Vigna Vaga they curve round the nose of the Cedegole anticline and soon belong to the south flank of this anticline. The regular sequence of Anisian-Wengener-Esino-Raibler is maintained but the dip has increased rapidly to vertical and even

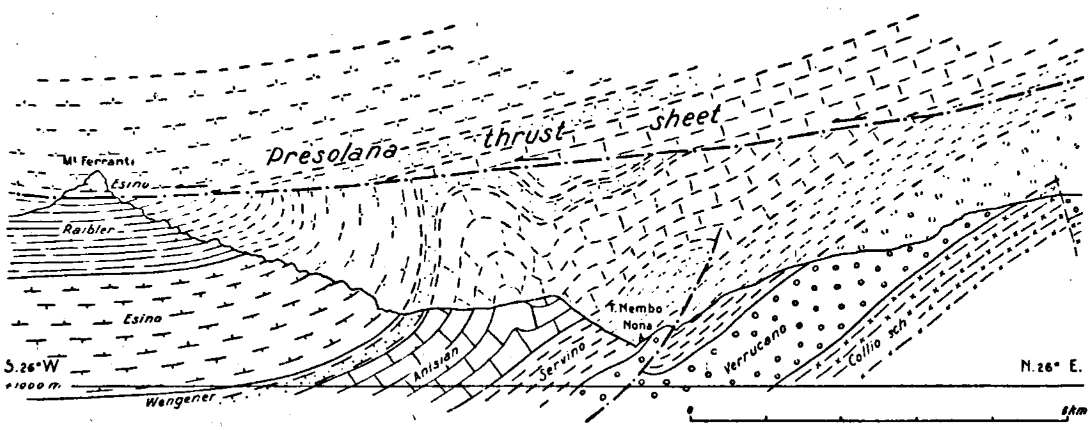


Fig. 37.

Development of the Presolana - Mt. Ferrante thrustsheet.

to an overturned position. The Anisian limestones are strongly contorted, pressed between the Esino-Raibler mass below the top of the Mt. Ferrante and the rising Cedegolo anticline. But the visible contortion of the well stratified Anisian is not the only manifestation of this strong compression. The overlying Esino of the south flank of the Cedegolo anticline has not joined in this minute folding process. This unwieldy mass has been sheared off and has been pushed over as a single thrustsheet over the contorted Anisian, and over the Wengener-Esino-Raibler of the deeper south flank. This thrust mass with a NE—SW direction of movement, has been called the P r e s o l a n a t h r u s t s h e e t after the Pzo della Presolana, which is wholly build up by this Esino mass. But numerous other vestiges of this thrustsheet have been preserved, of which the elongated outcrop of Wengener and Esino of the top of the Mt. Ferrante surrounded by three small islands of Wengener sandstone, is the longest. Another remnant is the small Anisian limestone outcrop of il Cavallo halfway between the Mt. Ferrante and the Vle Nembo. Figure 37 illustrates our conception of this rather small thrust-sheet in the Mt. Ferrante region.

The Esino-Wengener outcrop, below the thrustsheet continues its course south-eastwards, and is traversed by a cross fault with horizontal movement mainly, the SE limb receding to the NW, and then a 1½ to 2 km further to the south-east it is wholly covered by the imposing mass of the Pizzo della Presolana itself.

This triangular shaped mass of Esino limestone, with Wengener strata at its base in the north, and Raibler limestones covering it in the south, has not been pushed over a very large distance. Originally it probably covered the much contorted Anisian strata exposed on both sides of the Val Dezzo round the village of Dezzo di Scalve, but now it covers the autochtonous outcrop of Esino along the T. Nembo, the continuation of the Timogno thrustsheet and the Ardesio upthrust and even the Clusone fault and therefore must be ascribed logically to the latest compressive phase. In the top of the Pzo della Presolana another horizontal thrustplane in the Esino limestone can be discerned from a distance.

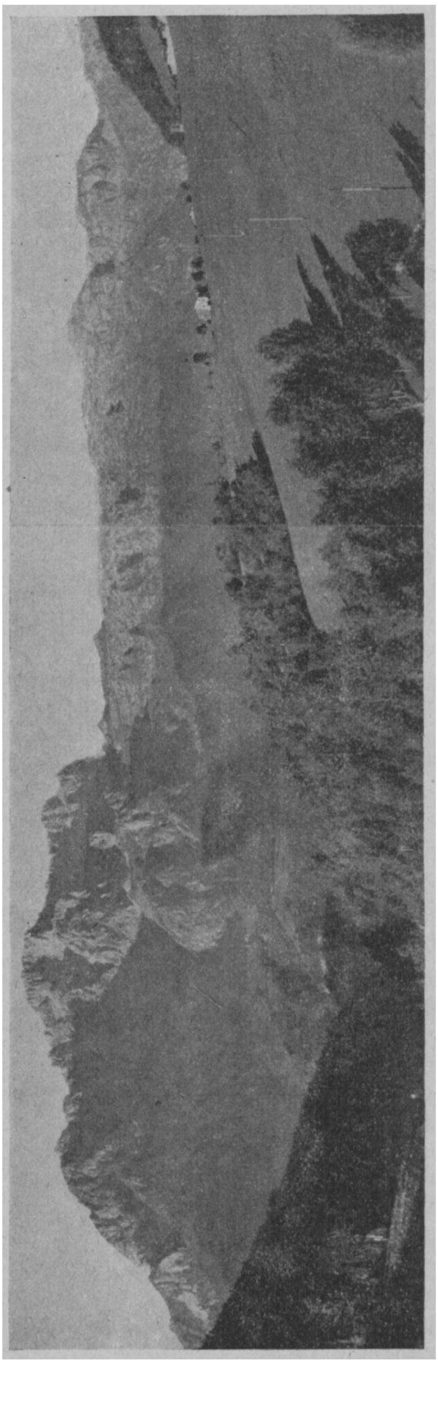
As mentioned above both the Timogno thrustplane and the Ardesio thrustplane, the latter appearing again below the former in the upper Valzurio, are cut off by the Presolana thrustplane. In the Raibler limestones below the Ardesio thrust appears another thrustplane, the R. A l b a n i t h r u s t, also covered eventually by the Presolana thrustsheet. On section XIX and XX this imbricate structure has been represented. These sections, however, do not run parallel to the direction of movement; the Presolana thrustsheet has been moved from NE to SW and the best view of the thrustsheet may be got from the Vilminore or Barzesto villages (Plate XXXV), but then one does look in the direction of movement and sees the whole breadth of the thrustsheet, not its length.

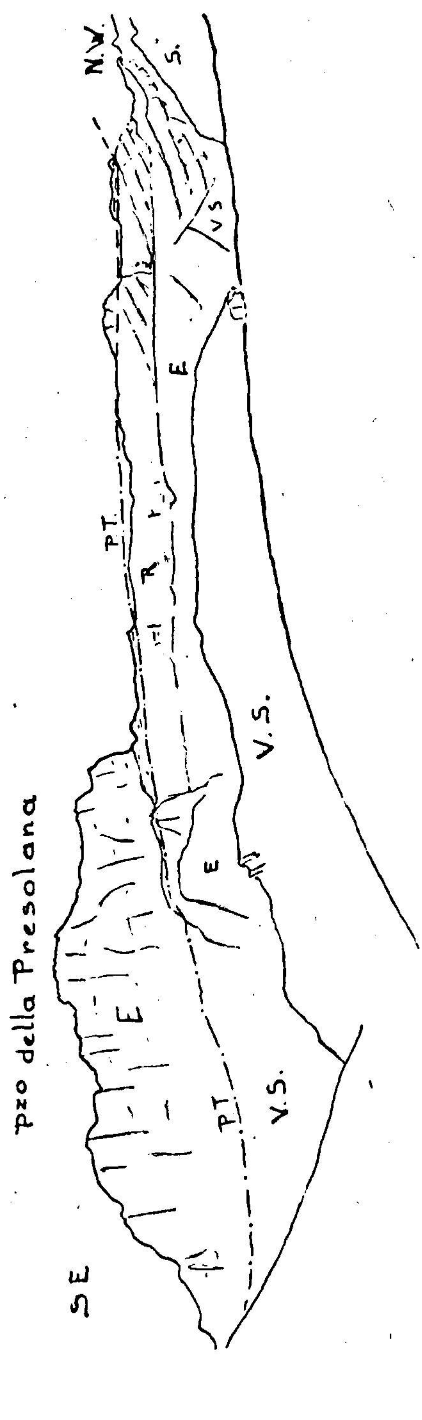
Across the Val Dezzo, opposite the Presolana, we find the last remnant of the Presolana thrustsheet, in the small Esino island of the Corna Mozza, resting on Raibler. Between this mountain and the Presolana, in the deep gorge of the Dezzo, a very complicated imbricate structure, is exposed described in detail by Krol (no. 18). It is not to be wondered at that serious complications will arise at this point below the Presolana thrustsheet, because here the Clusone fault and the Timogno-Ardesio thrusts intersect and even the Albani thrust might be represented. In the Dezzo valley Raibler butts against the Anisian, this boundary may be mostly due to the Clusone fault, which, allthough the main movement has been covered by the Presolana thrustsheet, can be followed across this overthrusted mass because a small movement along the same faultline has occurred afterwards, cutting through the overlying thrustsheet.

F. *The Norian Dolomites south of the Clusone fault between the Lago d'Iseo and the Mt. Alben.*

This great extension of Norian dolomite, here and there covered by Rhaetic strata is represented in sections XI to XX. The structure of this plateau can be studied best by means of the contour map Plate XVII. A central depression near S. Lorenzo and Cerete on the T. Borlezza is the main structural feature. The depression is flanked in the south by a shallow rise of almost W—E strike, followed in its turn by a steady fall towards Casnigo on the Serio river. Here a few normal faults, disclosed by the presence of Rhaetic on the Norian, cross the Serio and one even displaces the Clusone fault.

PLATE XXXV.





The mountain ridge of the Pizzo della Presolana - Mt Ferrante seen from Barzesto village.
E = Esino. V. S. = Anisian. R = Raibler. S = Servino.
P. T. = Presolana thrustplane. (After KROL).

Towards the east the plateau rises rather abruptly with the result that Raibler limestones cropping out below the Norian dolomite face the valley of the Dezzo river.

The Gandino-Sovere thrust appears as a quite unexpected feature in this gentle undulating structure. Along this thrustplane the Norian dolomite has been pushed over the Rhaetic, which everywhere dips down towards the curving outcrop of the thrustplane, with some 30°—40° in the south and with some 20°—30° on the N—S striking branch of the thrustplane directed towards the Borlezza river. The amount of thrusting increases south- and westwards.

The Rhaetic is overlying the Norian dolomite from Sovere - Mt. Clemo to the Punta delle Croci on the Lago d'Iseo. On the banks of this lake both the Norian and the Raibler plunge steeply down with a 80°—90° dip. On the north bank of the Borlezza river the Gandino-Sovere thrustplane disappears into the Norian dolomite of the Mt. Valtero, its throw diminishing.

The western continuation of the Gandino-Sovere thrust has not been mapped and therefore nothing can be said about its development in this direction. Still the fact that the thrust peters out in a NE direction is sufficient proof that the thrustplane is of local importance only and is not part of a major thrustsheet to be compared for instance with the Helvetian thrustsheet, as has been assumed by CACCIAMALI [1]).

1) G. B. CACCIAMALI. Morfogenesi delle Prealpe Lombarde ed in pardicolare di quelle della provincia di Brescia. Brescia 1930.

CHAPTER IV.

THE EASTERN BERGAMASC ALPS.

The Eastern region again can be subdivided into several tectonical units:

A. In the south the great uplift of the Val Camonica.
B. The central region with large overthrustsheets.
C. The northern Permian uplift or Cedegolo anticline.

A. *The Val Camonica uplift.*

The large Norian plateau south of the Clusone fault between the Val Seriana and the Val Dezzo showed a abrupt rise on its eastern limit. On both sides of the Lago d'Iseo the Rhaetic limestone and Norian dolomite rise nearly vertically, followed by the Carnian, Ladinian and Anisian. These strata curve round the plunge of an anticlinal uplift of similar character as the Orobic anticline, the Trabuchello-Cabianca anticline, and the Cedegolo anticline, but is of larger dimensions than any of these former structural units. Within 7 km we pass from the Rhaetic limestones into the basement rock, a rise of some 5 km height. That this sudden plunge has not been affected without some faulting is not be to wondered at. North of the Oglio we find the San Vigilio fault, with downthrown western limb, branching of here and there in smaller faults. It crosses the aluvial plain of the Oglio river, and probably can be traced back in the rather intricate pattern of faults east of Pisogne, which finally is collected again in the wellknown Val Trompia fault, which latter fault separates the basement rock from the Verrucano and overlying strata. This N—S fault system is of the same tectonical phase as the general uplift, and accentuates the warping up of the eastern region. The later compressive phases have altered the aspect of the faults, specially in the Pisogne area. The oblong outcrop of Verrucano in the surrounding Servino near the village of Siniga, is probably only a thrusting movement along an older fault. The Fraine fault, which abutts against the Val Trompia fault is of greater importance. The northern extension of this fault has not been mapped, but it can hardly be joined up with the San Vigilio fault, although it has a similar movement and character.

North of the Lago d'Iseo the later compressive phase has resulted in a curious thrust movement in the west plunging strata. This Cse Camorelli thrust is closely connected with the wedging out of the Esino limestone in this region as has been demonstrated by MAASKANT. The thrust does not cross the San Vigilio fault and is certainly younger than this fault. Along the thrustplane the Anisian and Wengener have been pushed over the Esino.

The two sections 22 and 23, fig. 38 illustrate the structure of the plunge of the Camonica anticlinal uplift, north and south of the Lago d'Iseo.

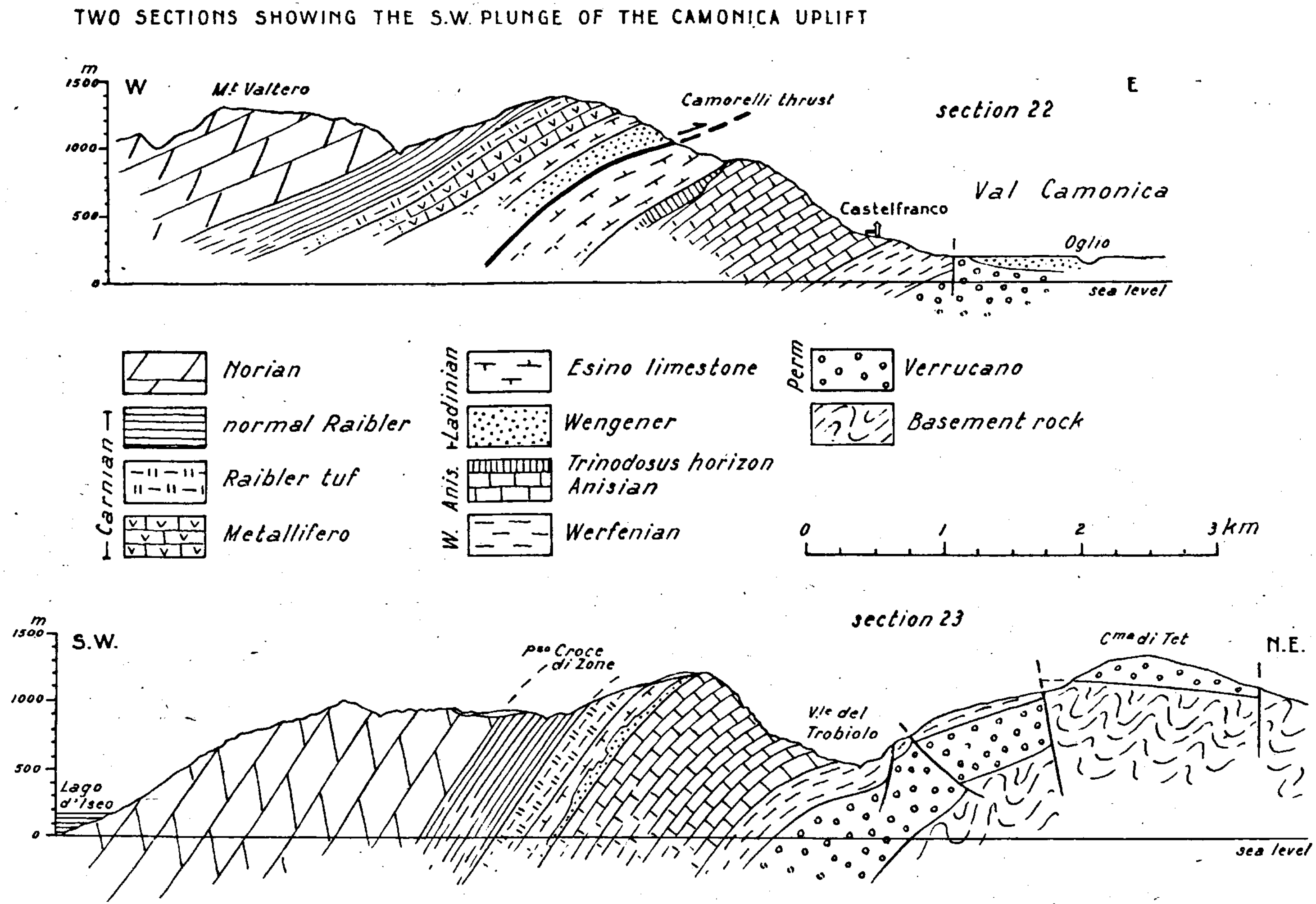

TWO SECTIONS SHOWING THE S.W. PLUNGE OF THE CAMONICA UPLIFT
m
1500
1000
500
0
W
Mt. Valtero
Camorelli thrust
section 22
E
Val Camonica
Castelfranco
Oglio
sea level
Norian
normal Raibler
Raibler tuf
Metallifero
Carnian
Esino limestone
Wengener
Ladinian
Trinodosus horizon
Anisian
Anis.
Werfenian
W.
Verrucano
Basement rock
Perm
0
1
2
3 km
section 23
S.W.
Lago d'Iseo
pso Croce di Zone
V.le del Trobiolo
Cma di Tet
N.E.
sea level

Fig. 38.

The north-west flank of the Camonica uplift can be followed along the north bank of the Oglio river. It is an almost unbroken stretch of strata from Verrucano to Raibler. Only one fault traverses this flank near Casino Boario. The Dezzo river has cut deeply into this flank, causing the formation boundary lines to recede considerably towards the NW, but everywhere the normal sequence of strata can be observed. The Esino limestone forms an escarpment parallel the river course and in the Mt Scanapa and the Mt Chigozzo the Norian dolomite forms a similar morphological feature above the Raibler limestones.

Because the Oglio river is not strictly parallel to the strike, but cuts upstreams further into the flank, it gradually climbs up in the stratigraphic sequence, and finally has cut its bed in a winding and steep gorge through the hard Esino limestone near Breno.

B. *The central region of thrustsheets.*

Here, near Breno, the Oglio almost makes contact with one of the great thrustplanes, along which large masses of Ladinian and Anisian have been pushed over, coming from the North of the synclinal region between the Cedegolo and Camonica uplifts.

These thrustmasses occupy almost the whole region between the Val Dezzo-Val di Scalve and the Val Camonica and the Trobiolo valley. The only larger autochthonous mass is the Concarena Esino-limestone mass in the North-East.

The overthrusted complex does not belong to one single thrustsheet but must be divided into two main structural units of different origin and mode of formation.

The lower unit consists of two fold-faults, overthrusted anticlines, which both find their origin in the contorted Anisian in the upper Dezzo valley. They are called the Palline-Borno overthrust further east the Lozio overthrust and the M. Costone overthrust, of which the former is the largest and most conspicuous one.

Over these strongly compressed structures large masses of Anisian-Ladinian limestones have passed, sheared off from their original position north of the Val di Scalve. These masses belong to the Pzo Camino thrustsheet.

The autochthonous is exposed beneath these thrustsheets on the southern slope of the Val di Scalve and in the Concarena mass.

A certain analogy with the Grigna thrustsheets exists, although in the western region a piling up of thrustmasses, each a true thrustsheet coming from the north, shows a larger and greater thrust movement than the single Camino thrustsheet of the eastern region.

The Palline-Borno and Costone thrusts are a new feature, not encountered anywhere else in the Bergamasc Alps. Our present structural analysis of this region deviates from the conceptions of former surveyors KROL, DORSMAN and ERDMAN.

The origin of this controversery lies in the fact that none of these surveryors had all the facts before them at the time of their publication. Formerly the Palline-Borno overthrust was thought by DORSMAN to be a large thrustsheet of the same kind as the Camino thrustsheet using the same thrustsheet in its northern extension as outcropping in the south bank of the Val di Scalve, and derived also from the Permian plateau in the north.

The thrustplane in the southern slope of the upper Val di Scalve, dividing Raibler strata belonging to the autochthonous from Servino of the thrustsheet, however, could nowhere be traced back further eastwards in the stratigraphic sequence between the Concarena and the upper Val Paisco. If we follow the assumption of KROL—ERDMAN we are obliged to assume a gradual but still rather rapid decrease in thrustmovement along this plane from the last outcrop in the southern slope of the Val di Scalve, where it disappears below the large screes of the Concarena, and the mountain ridge between the Passo di Campelli, the Mt. Campione and the Mt Giovo, where a normal sequence of strata is already established.

Such decrease of thrusting movement would be perfectly impossible if two large thrustsheets had glided over this thrustplane, but can quite well be imagined if only one thrustsheet has passed along it. In the latter case the total maximum movement is reduced by the whole length of the original Palline Borno thrustsheet.

The origin of the Palline-Borno and Costone thrustplanes must be sought elsewhere and when we turn to the survey of KROL, which author did not know the extend of either of these thrustmasses having surveyed only their western extremities, we find sufficient evidence on his map and in his tectonical description to be able to draw the thrustplanes with some accuracy. We are confronted, however, with the difficulty that KROL did not recognise the true stratigraphical position of the Wengener shales and regarded this formation as part of the Anisian. A great advantage of our new conception of the structure of these thrustsheets is, that by the resulting rearrangement of the original position of the now superposed tectonical units, the stratigraphical development becomes more logical and simpler.

The Palline-Borno thrustplane rises steeply out of the Val Dezzo just north of Dosso. The thrustplane cuts off the Clusone fault, which has just reappeared below the Presolana thrustsheet, and puts an end to the outcropping Raibler. When it has risen some 500 m, from 700 to 1200 m, it very suddenly curves round to a flat position, and the real thrusting takes place along a nearly horizontal plane. According to Krol's description it is the shale horizon of the Wengener which abutts against the Raibler in the Dezzo valley, and we may assume, as has been done in section XXII that the Esino of the Lower Dezzo gorge has been replaced already in the neighbourhood of Dosso by Wengener shales. The amount of thrusting need then not be very large. Further east the Wengener shales rest everywhere on the Raibler. West of Borno the thrust advances over the Torrente Trobiolo and the crown of the overthrust is exposed in the northern slope of the Corna Rossa. The small outcrop of Raibler at the confluence of the T. Caidone with the Trobiolo is a tectonical window, through which the autochthonous Raibler peeps out below the thrustsheet. The thrustplane disappears east of Borno beneath the Lozio thrustmass. The Costone overthrust has a similar shape. It rises steeply from the Dezzo valley to a height of 1800 m, then curves round to a flat position. The thrustplane can be followed in the Wengener shales because small and much contorted remnants of Raibler limestones are preserved just beneath the thrustplane. The Raibler belongs to the Palline-Borno overthrusted flank and most probably overlies normally the Wengener shales of this tectonical unit. The thrustplane of the Costone overthrust is soon cut off by the Camino thrustplane.

The Camino thrustsheet has quite another character, and can be compared to the Grigna thrustsheets or the Arera thrustsheet. The Anisian-Ladinian mass, which build up the whole thrustsheets, originally covered the great Permian uplift, described hereafter as the Cedegolo anticline. The Triassic mantle of this anticline has been sheared off, and has been pushed southwards over the much lower situated platform to the south of the Cedegolo uplift. Climbing up the southern slope of the Val di Scalve we pass the Anisian limestone, the Buchensteiner horizon and the Wengener shales of the normal south flank, normally overlain by Raibler.

Then we find a highly brecciated zone of probably Raibler and Servino material mixed together with remnants of porphyric intrusions. Along this brecciated horizon the Camino thrustplane enters the surface. Along the western flanks of the Camino - San Fermo mountains, the thrustplane can be followed, first at the bottom of Anisian limestone, then passing into Wengener sandstone and Esino limestone. Here we are arrived in the crown of the thrustsheet, its anticlinal front (see section XXIII). The thrustplane then curves round to the N E and the Wengener shales lie on Raibler. From the moment, however, that the Camino and the Lozio thrustsheets meet, just north of the artificial Bacina di Lova, the trace of the Camino thrustplane becomes indistinct. The Camino thrustsheet originates from the region north of the Val di Scalve, the Lozio thrustmass is only an over thrusted anticline and the reason that they are regarded as separate units is the tectonical evidence that in the north their thrustplanes have a quite different situation. The facies of the Ladinian is in both thrustsheets quite different, the Camino mass has much more Esino limestone and the Lozio mass almost only Wengener strata..

The boundary between the two thrusted masses is a rather steep, eastwards hading fault, which runs from the Passo di Lifretto to the upper Valle S. Fiorino.

The throw of this Lifretto fault increases from south to north. Passing the Passo di Lifretto we lose its trace in the scree of Esino debris, but it is reasonable to assume that it cuts off the Camino thrustplane somewhere in this neighbourhood. This latter thrustplane has still the same character as described above, viz.: Wengener normally overlain by Raibler of the autochthonous series, followed by the highly brecciated zone in the Servino. It disappears below the large screes of the Cimone della Bagozza. The assumption that it is cut off here by the Lifretto fault can not be proved otherwise, than that nowhere further east any trace of this important thrustplane can be found back. The whole stratigraphical sequence from the Cim. della Bagozzo to the Mt. Campione and further north is perfectly normal, and the thrustplane must have been wharped up. The Lozio overthrust has been developed in the splinter shale basin, between the thick Concarena mass, and the Camino uplift. The presence of the Concarena mass in a much lower position than its original continuation to the west, the Camino mass, is due to the oblique strike of the Val di Scalve flexure. In these highly incompetent shales a similar overthrusted anticline as the Paline-Borno thrust has been formed, but in the Lozio region even the northern limit of the splinter shales has been strongly thrusted up against the Concarena mass. This thrustplane separates Wengener limestones of the overthrusted mass from Esino limestone. South-east of the Passo di Lifretto the Wengener limestone is followed by Wengener shales, Esino limestones and even some Raibler limestones, all hading steeply towards the south. Plate XXXVI gives a photograph of these strata.

This northern Lozio thrustplane can easily by followed towards the east, the hade becomes less steep and at its eastern extremity the Wengener limestones lie on the Esino with a SW dip of only 30°.

The thrustplane is then traversed by a later normal fault, the Laveno fault, which throws down the thrustplane some 500 m. The continuation of the thrustplane becomes less distinct its throw diminishes and it peters out in the Anisian limestones.

Near Breno the autochthonous Anisian is suddenly replaced by Raibler, a fault of large throw, the il Pilo-fault forming the boundary. This Pilo fault emerges from beneath the Lozio thrustsheet, although some posthumous movement along the Pilo fault allows us to follow it some way into the thrustsheet with a NW—SE strike. The Pilo fault curves round to a more W—E strike on the other side of the Oglio, where it has been mapped by SALOMON. The Pilo fault can be compared in every respect to the Clusone fault and it may be its direct continuation as ERDMAN suggested already.

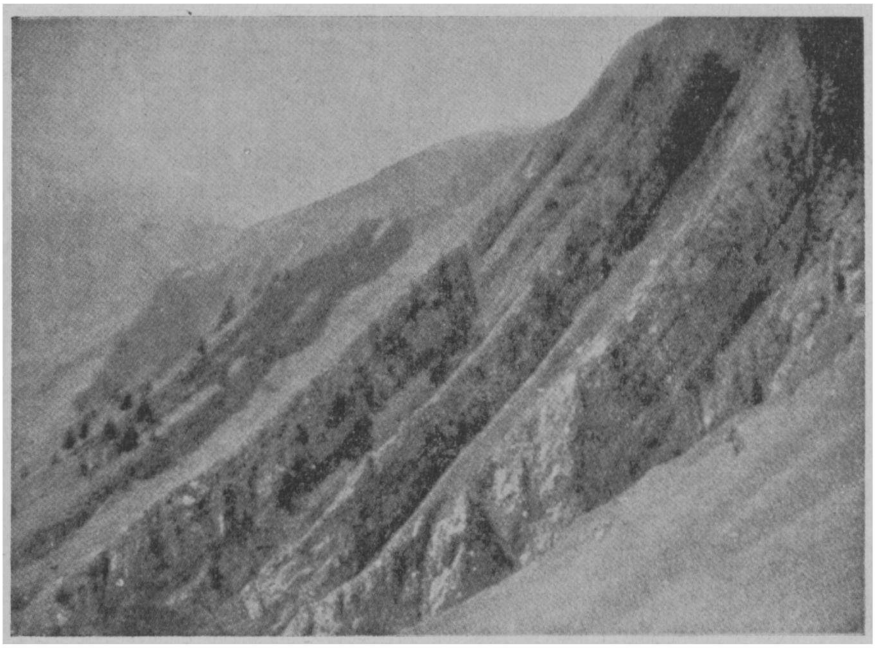
West of the Pilo fault the Lozio thrustplane rests on Raibler strata and continues to do so untill it reaches the Palline Borno overthrust west of Ossimo. Here the two overthrust planes almost join. A small E—W fault of the same kind as the Laveno fault intervenes, however, but there can be little doubt that Lozio and Paline-Borno thrustplanes are essentially identical, although the movement of the Lozio sheet has been somewhat different. In the Lozio thrustsheet we find a sharp steep zone, which separates the Lozio frontal zone with synclinal shape, from the rest of the thrustsheet. This steep zone is a squeezed anticline, in whose core the underlying Raibler has been pressed up in several elongated patches (sections XXV—XXVII). It may be presumed that this secondary anticline is the continuation of the Costone overthrust further west, developed in another shape. The rest of the thrustsheet is developed in a synclinal structure, the youngest formation, the Ladinian Wengener shales, in the centre.

The Concarena mass, with the Cimone della Bagozza and the Cima della Bacchetta, is build up entirely of unstratified Esino limestone of some 1100 m thickness at least. ERDMAN supposes that perhaps several thrusts are present, causing this abnormal high figure for the thickness of the Esino in this part of the Bergamasc Alps. Nothing definite is known about such structure, and considering the reef-like nature of these limestones a local rapid increase of thickness is not improbable.

C. *The Cedegolo anticline.*

As can be seen on sections XXIII—XXVII the autochthonous substratum north of the thrustsheets along the Val di Scalve and the Torrente Clegna, constitutes the south flank of a large anticlinal structure, of which we have already encountered the plunge in the valley of the Bondione river. Here the Anisian limestones and Servino schists curve round the plunge, although this original structure is largely obliterated by later block faulting and subsequent thrusting. In this plunging of the uplift the anticlinal structure itself has largely disappeared by the fact that the north flank has been uplifted and overthrusted along two longitudinal faults, the Cascina and Tre Confine thrustfaults. The large Verrucano flank of the Torrente Gleno and the Mt. Tornone is limited in the north by the Tre Confine thrustfault, along which Collio shales have been pushed up. This thrustfault is interrupted further east by a NW—SE fault, the Venano fault of ZIJLSTRA,

PLATE XXXVI.



Raibler and Esino limestones plunging steeply southwards, S E of Pso di Lifretto.

a normal fault with wharped down western limb, but with probably also considerable horizontal movement. In the outcropping basement rock east of this fault several minor thrustfaults are discernable, each one represented by a narrow zone of basal conglomerate and Collio in the cristalline schists. The southernmost of these thrustfaults has been called the Sellero thrustfault, a thrustfault of large dimensions. It can be followed across the Val di Vo, with basement rock thrusted over Collio schists. In the narrow gorge between the Pzo Tornello and the Pzo dell'Aquila the thrustfault can be followed by means of a narrow strip of cristalline schists, climbing up to 2000 m height. The Verrucano blanket seems altogether, or almost unaffected by this thrusting movement and one gets the impression thât a major part of the movement has taken place before the deposition of the Verrucano conglomerate. This impression, however, with its far reaching consequences, is probably erroneous and disharmonic folding must be responsible for the unbroken condition of the massive Permian conglomerate in contrast with the imbricate structure of the underlying Collio and basement rock. In the Val di Vo a small outcrop of gneiss chiaro can be observed and a normal E—W striking fault limits the basement rock outcrop of this valley to the south.

The Sellero thrust can be followed in N E direction, always with cristalline schists thrusted up against the Verrucano. It passes the Passo del Sellerino, the upper Sellero valley, and then curves round the Mt. Gaviera. East of this mountain it is lost in the basement rock but probably appears again, after crossing the Val Largone and the Valle di Scala, just east of the latter valley, again limiting the Verrucano-Collio of Paisco to the north. The Sellero thrustfault is often a double fault, and from the Passo del Sellerino it is often accompanied by small strips of Servino, which are iron-ore bearing on the Mt. Gaviera. In the upper Val Paisco the anticlinal arc of the Cedegolo anticline becomes much better developed than further west.

The Val Gallinera thrustfault, mapped by SALOMON east of the Val Camonica and followed by PORRO [1]) west of this valley, was connected with the Sellero thrust by the latter author. FABER(21), by following the actual outcrop of the Gallinera thrust further west, along the Mt. dei Matti, showed that it represents a separate structure, situated much higher than the Sellero thrust. The Gallinera thrust is also lost in the cristalline schists west of this mountain but by proceeding in the same direction we may assume that either the Tre Confini thrust or the Cascina thrust, probably the latter, is the direct continuation of the Gallinera thrust.

Still higher up, on the Passo del Torso and the Pizzo Svolt, FABER again found narrow strips of Collio and basal conglomerate, indicating that further thrusting is present in the basement rock. Comparing these facts with the structure of the Pizzo Strinato and the Lago della Malgina region, a far reaching analogy is apparent. Also, it is important to note, that allthough everywhere longitudinal thrusts, all with a WSW—ENE strike are present, the general level of the base of the Permian is not changed very much, everywhere the same basal conglomerate, Collio or Verrucano is preserved in narrow zones along these thrustfaults. Neither is the position of the blocks between the thrustfaults very much broken up, as is proved by the Collio of the Mt. Demignone and of the Mt. Venerocolo. Here the Collio with the basal conglomerate has a almost horizontal position between the Sellero and Cascina thrustfaults, curving up against faults but otherwise not seriously affected.

These facts are in direct contradiction with the assumption of R. STAUB, who regards the Orobic zone, north of the largescale thrustfaults, as the vertical root of the Upper-East Alpine thrustsheets.

[1]) C. PORRO. Note Geologiche sulle Alpe Bergamasche e Bresciane. Rend. R. Ist. Lomb. di Sc. e lett. serie II, Vol. XLIV, 1911.

SUMMARY.

In the Bergamasc Alps we have observed one major unconformity between the Basement rock and the overlying Permian.

The total absence of any recognisable Palaeozoïc sedimentary rocks accentuates this unconformity, and moreover this enormous hiatus makes the dating of any Palaeozoïc event impossible. However, by comparison with the Central Alps and Kärnten, we learned that the Asturian orogenitic phase precedes the deposition of the first volcanic sediments. In analogy with the Aar and Gotthard masses we presumed the intrusion of the less metamorphic ortho rocks of the Basement, the granodiorite and the gneiss chiaro, to be of Upper Carboniferous age. The close resemblance of the chemical composition and differentiation of the Permian volcanic rocks and the Upper Carboniferous intrusive rocks induces us to assemble this period of magmatic activity into one period of Permo-Carboniferous age. In long NE—SW striking anticlinal zones these intrusives have penetrated into the old paraschists, causing some contact metamorphism. In the Lugano region where the volcanoes are better preserved and the differentiation of the lavas is more complete, we have seen [1]) that the last feature of magmatic activity had been the pressing out of the granophyr, an acid igneous rock, in a very large dome-like structure. The chemical composition of this granophyr is so much like that of the gneiss chiaro or the granites of the Val Rossiga that there can be little doubt that they all belong to the same magmatic source. Also, the intrusive rocks of the Err-Bernina, Lower East-Alpine thrustsheets and their Permian porphyries have a similar chemical composition and must be closely related to our intrusive and volcanic rocks.

Hence the whole region of what later became the Alpine geosyncline was in Permo-Carboniferous time the scene of extensive intrusion and extrusion of igneous rocks. In Permian time the topographical surface was above sea level in the Lugano region where erosion was active and the volcanoes were formed in a mountainous country, but it was mostly covered by shallow water further east. In the later stages of this period considerable tangential forces shaped long anticlines, pressed out the granophyr magma to the surface and formed the very deep central Permian trough and the Camonica uplift of the Bergamasc Alps (see Plate XLIII). Other structural features are indicated, but only these two latter structures, the Camonica uplift and the Permian trough, are clearly visible, and they may be the result of faulting instead of folding. The shape of the Permian trough with its steep flanks and flat bottom would indicate perhaps a fault trough rather than a syncline. This trough is flanked in the NW by the Averara ridge, which, however, is a more pronounced uplift in the Middle Triassic than in the Permian. Whether the Brinzio-Maroggio anticline of the Lugano

[1]) de Sitter, L. U. Les prophyres Luganois et leurs enveloppes. Leidsche Geol. Med. XI, 1939.

district, along which the volcanoes are arranged, must also be regarded as a Permo-Carboniferous structure can not be ascertained.

Both the Lower Permian (Collio) and the Upper Permian (Verrucano) increase in thickness in eastern direction (compare fig. 16 and 17). In the Lugano region the Verrucano is only preserved in the small outcrops of the San Martino conglomerate at both sides of the Lugano lake. East of the Como lake it has a thickness of less than 50 m, but increases gradually to some 800 m in the eastern Bergamasc Alps. The Collio has a similar development of its thickness but is in the west a pure volcanic formation and is first observed round the Valsassina core as a sedimentary rock, further west only irregular patches of volcanic rocks have been deposited.

In the East Alpine thrustsheets the Verrucano is generally present but not in great thicknesses, except in the Campo sheet. The Permian in the Lower East Alpine sheets (Bernina sheet) consists of porphyries only. The western limit of the Permian is again observed in the Helvetian thrustsheets, where the most western Axen sheet does not contain any Permian, whilst the more eastern Glarner and Mürtschen sheets contain thick Verrucano masses.

The same wedging out of the Permian towards the west is observed along the Tavetscher zone between the Gotthard and Aar massives.

The Triassic of the Lombardic Alps is its most interesting and best developped formation. The Werfenian of Lugano consists of a simple coarse sandstone, and the upper dolomitic member is encountered for the first time in the Valsassina. Through the whole Bergamasc Alps the Werfenian is rather sandy but becomes more and more shaly and calcareous towards the east, apparently we pass from a purely continental region in the west to a marine facies in the east. The same tendency was found in the Upper Permian where the Bellerophon horizon of South Tirol sets in above the Verrucano from the Brenta group eastwards. The development of the Middle Triassic as Anisian and Ladinian in distinct facies, in the Bergamasc Alps increasing in thickness in eastern direction, connects with the development of these stages on the Mt. Giorgio, where the Salvatore dolomite is already split in two by the Bituminous Horizon on the boundary between the two stages.

The Middle Triassic from Lugano, with its Salvatore dolomite where Anisian and Ladinian can hardly be distinguished, slowly develops in the Bergamasc facies of Ladinian Esino dolomite-limestone and Anisian Gracilis-schists and Trinodosus horizon. We have seen that the northerly facies of the Ladinian contains mostly Buchensteiner and Wengener, in the southerly facies the Esino occupies the whole Ladinian. Over the Averara ridge both stages are much thinner and incomplete, and the Anisian increases in thickness towards the Val Camonica, whereas the Ladinian decreases. Here we find also the distinct Wengener splinter shale basin.

On the westerly border of the Camonica ridge many facies changes take place. Faber (lit. 21) pointed out that the wedging out of the Collio, the facies change from cavernous dolomite to Elto dolomite of the Upper Werfenian, and the rapid transition from Wengener shales to Esino dolomite all occur on approximately the same line, the one above the other.

In Southern Tirol the Middle Triassic has much the same development, the total thickness depending mostly on the presence of thick reef limestone (dolomite), e.g. the Schlern dolomite or Marmolata limestone.

One pecularity is, however, very striking in the region between the Pale

San Martino and the Adamello, and that is the disappearance of the Raibler as a distinct lithological horizon. The merging of Carnian and Ladinian dolomites sets in in the Val Camonica, in the Brenta group only occasionally some Upper Raibler mals are observed and the Raibler appears again north of the Pale San Martino. At the same time the Lower Ladinian facies of Buchensteiner and Wengener is also absent.

Elsewhere the Raibler, although very variable, has very much the same shallow water facies, with occasional tuffogenous intercalations. Is is much thinner in the Lugano region.

The Upper Triassic and Rhaetic are very different in the regions of Tirol, Bergamasc Alps and Lugano. In the east the two formations are developped as one dolomitic mass, the Dachstein dolomite; in the Bergamasc Alps we find a thick Norian Hauptdolomite and a complete series of well developped Rhaetic series, whereas in the Lugano region the Rhaetic is either absent or represented by the Upper member, the Conchodon dolomite. At the same time the Liassic rests here uncomformably on the Rhaetic or Norian with the typical transgressive Hierlatz facies.

The Liassic siliciferous limestones are very much the same from west to east, somewhat thicker in the west, specially in the large complex from the Mt. Generoso to the Como Lake.

The comparison of the three regions, Lugano, Bergamasc Alps and South Tirol has been summarized in a tabel. The boundaries between these geographical units are not constant though. The boundary between Tirol and Bergamasc Alps lies during the Norian-Rhetic in the Brenta group and in the Carnian-Ladinian and in the Permian west of Val Camonica. The Collio reappears even in a thick complex east of the Camonica ridge in the Val Trompia.

The boundary between the Lugano region and the Bergamasc Alps is even less fixed, it lies somewhere between the Generoso and the Alta Brianza Lecco region, but can not be determined much further as the Liassic limestones cover all the older formations between these two points.

The Averara ridge, altough very pronounced in the Permian, Lower and Middle Triassic is not a facies boundary, at both sides the facies is very similar.

It has always been known that the Lombardic Trias facies is very much alike that of the East Alpine thrustsheets. Both in the Helvetian and in the Pennine zones of the Alpine sedimentation basin the Triassic is very poorly developped, and can in no way be compared to that of the Southern and Eastern Alps. When we consider the conformity between the Lombardic and eastern Alps facies somewhat closer, we observe a great similarity between the Lugano region and the Lower East Alpine unit. Both have porphyries in the Permian and no Verrucano, in both the boundary between Ladinian and Anisian is very vague. The whole Triassic in the Err-Bernina sheets is much reduced as compared to the Triassic of Campo- and Silvretta thrustsheets. The Rhetic is much completer in the Err-Bernina than in the Lugano region, but both are again characterized by thick siliciferous Lias limestones, which is transgressive with a Hierlatz limestone facies on the Rhetic and Norian in both tectonical units.

The Middle East-Alpine thrustsheet, the Camposheet and its accessory units, is characterized in the Münster valley by a thick Verrucano series of some 600 m. with pebbles of quartzporphyry and granite. Porphyry sheets are lacking in this serie. The Triassic of the Camposheet as a whole

<table>
<tr><th></th><th colspan="2">Lugano</th><th colspan="2">Bergamasc Alps</th><th colspan="3">South Tirol</th></tr>
<tr><td>Liassic</td><td colspan="2">Siliciferous limestone
100—1000 m.
Transgressive Hierlatz facies</td><td colspan="2">Siliciferous limestone
500—1000 m.</td><td colspan="3">Limestone 300—400 m.</td></tr>
<tr><td>Rhetic.</td><td colspan="2">Absent, or only Upper member Conchodon dolomite</td><td colspan="2">Complete from Alta Brianza to Brenta group
550—800 m.</td><td colspan="3" rowspan="2">Dachstein dolomite
1000—1400 m</td></tr>
<tr><td>Norian</td><td colspan="2">Hauptdolomite
250 m.</td><td colspan="2">1200 m. Hauptdolomite</td></tr>
<tr><td rowspan="2">Carnian</td><td colspan="2" rowspan="2">Series of shales, marl, dolomite
100—350 m.</td><td colspan="2" rowspan="2">Thick series of shales, marl, dolom. and sandstones 250—700 m.</td><td>Western facies</td><td colspan="2">Eastern facies</td></tr>
<tr><td></td><td colspan="2">150 m shale
Sst. dolomite</td></tr>
<tr><td rowspan="2">Ladinian</td><td>Northern facies</td><td>Southern facies</td><td>Northern facies</td><td>Southern facies</td><td rowspan="2">Schlern dolomite

porphyries, tufs etc. from Pale S. Martino</td><td>Marmolata limestone</td><td>St. Cassian Wengener</td></tr>
<tr><td rowspan="2">Salvatore dolomite

300—600 m</td><td>Salvatore dol.

Bituminous horizon</td><td>Esino limestone Wengener sst. and sh.

Buchensteiner chert. limestone</td><td>600—1200 Esino dolomite, limestone Wengener, splinter shale facies</td><td colspan="2">Buchensteiner or Reitzi sch.</td></tr>
<tr><td>Anisian</td><td>Mendola dolomite</td><td colspan="2">Trinodosus hor. 50—150 m.
Gracilis Schists from W—E
150—450 m., Nodulous limest.</td><td colspan="3">Mendola dolomite

Gracilis schists marls, dolom.</td></tr>
<tr><td>Werfenian</td><td colspan="2">50 m. sandstone</td><td colspan="2">Cavernous dolomite
200—450 m. shale, marl, sst. Servino</td><td colspan="3">Campiler sch. 250 m.
Gastropod. list.
Seiser sch. 80 m.</td></tr>
<tr><td>Permian</td><td colspan="2">absent or porphyries, tufs etc. basal congl.</td><td colspan="2">Verrucano from WE 50—800 m.
Collio, porph. volc. sst. tufs etc.
central Collio shale basin 0—2000 m.
Basal conglomerate</td><td colspan="3">Bellerophon hor. 0—250 m.
Gardena Sst. 100—200 m. (Verrucano)
Bozener porphyries (Collio)
Basal conglomerate</td></tr>
</table>

is much thicker than that of the Lower East-Alpine sheets, but the Anisian is not very thick yet, much less than in the Upper East-Alpine sheets, and the Werfenian is hardly represented.

The Ladinian is present as Wettersteindolomite (250—600m) without the typical Partnach facies of the Upper East-Alpine thrustsheets. The Raibler is some 400 m thick, dolomites, shales, shaly limestones, rauhwacke and gypsum, porphyrites etc. The Norian is very thick, 500—2000m, and developed as typical Hauptdolomite, whereas the Rhetic is present in the facies of the Kössener schists, black and reddish shaly limestones and shales, which can be compared to the Lombardic facies of the Scisti neri.

The agreement with our western Bergamasc Alps is striking. Exceptionally thick Norian, Esinodolomite, thin Anisian, and thick Verrucano are the characteristics of the region between the Valsassina and the Val Seriana. The Werfenian is much completer in Lombardia, and the Collio of the central trough is absent in the Camposheet but in general the similarity is not less striking than that of the Err-Bernina sheet with the Lugano-Grigna region. The Averara ridge although not the boundary between the two facies, can possibly be correlated with the geoanticlinal ridge between the Lower and Upper East-Alpine sheets.

The Upper East-Alpine thrustsheets, (Lechtal, Silvretta) show a great similarity with the eastern Bergamasc Triassic. The Werfenian has an Upper Rauhwacke member, the Anisian shows the nodulous limestone (Reiflinger Knollenkalk), the Gracilis limestone, the brachiopod limestone etc. in exactly the same facies. The Ladinian is not identical to such a degree as the lower members of the Triassic, but the Arlberg Limestone and dolomite can be very well compared to the Esino limestone and the Partnachschichten to the Wengener shales (splinter-shales!). The Carnian again is very similar, rauhwacke, marls, gypsum, shales and sandstones, black limestones are present in both units.

In the Lechtal sheet the Norian Dachstein limestone and the Rhetic Dachstein corraline limestone are only separated by the „Kössenerschichten", corraline limestone and shales of the Lower Rhetic. The Norian is reduced in comparison with that of the Camposheet.

The Carnian of the Ducan region is exceptionally thick, some 900 m, with an upper 300 m of Upper-Carnian dolomites [1]). Such development of the southerly part of the Upper East Alpine thrustsheet can already be regarded as a transition to the Camonica facies where nearly the whole 700m thick Raibler is developped as dolomites.

Striking as the agreement of the development of the sedimentary sequence in Lombardia and in the east Alpine thrustsheets may be, great differences can also be noted. First of all the Permian of the Bergamasc Alps with its central Permian trough with 1500—2000 m of Lower Permian Carona shales and volcanic rocks can not be found back in the Eastern Alpine thrustsheets. In the second place the typical development of the Lower Ladinian in Buchensteiner and Wengener facies is restricted to the Southern Alps and Tirol. Finally the „Flecken mergel", (mottled marls), and Allgäuschiefer of the Liassic of the eastern Alpine facies are not represented in Lombardia. On the other hand the abyssal facies of Upper Liassic, Dogger and Malm in Radiolarite and Aptici limestone and marl is present in both stratigraphical units.

[1]) Eugster, H. Geologie der Ducangruppe, Beitr. G. K. S., N. F. 49, III, 1923.

That great differences exist between two regions, which in their original position in the geosyncline are widely separated although in the same basin, is quite logical. Lombardia is the southwesterly extension of a large basin, of which the East-Alpine thrustsheets occupy the centre and the north easterly end. Moreover the basin must have widened out considerably in NE direction. That the troughs and ridges opened fan-like in this direction from Lombardia follows from the fact that the E—W distance from L. Maggiore to the Val Camonica is less than the combined breadth of the East Alpine thrustsheets. Moreover we must not forget that even in the small width of the Bergamasc Alps already considerable facies change from North to South could be demonstrated, both in the Ladinian and in the Anisian. The main differences are found, as mentioned above, in the Permian and in the Lower Liassic, particularly in the Middle and Upper East-Alpine sheets. The development of the Permian in the Bergamasc Alps is due to late Variscian movements which apparently are not parallel to the Alpine geosyncline, and therefore need not continue in similar facies in the direction of the Alpine geosyncline.

The Liassic Allgäuschiefer of the East-Alpine facies can be regarded as a transition between the penninic Bündnerschiefer facies and the Lombardic siliciferous limestone facies.

The Cretaceous of the East Alpine basins can in no way be compared to the Lombardic Majolica and Scaglia. This is due to the fact that in Upper Cretaceous time the Alpine orogeny attacked this northern part of the Alpine geosyncline, whereas Lombardia remained mostly undisturbed. The dividing line between the southern and eastern Alps originated with the folding of the East-Alpine sheets, and became accentuated when the Pennine sheets were folded in the Oligocene, and became still more pronounced when the uplift of the central folded system occurred in the post Oligocene Insubric phase.

In the tectonical part we have shown that the youngest Tertiary tectonical direction is purely W—E. The Orobic thrustfault and its accessories cut off obliquely the older ENE—WSW structures as for instance the Orobic anticline. This latter direction is mainly pronounced in the anticlinal structures, e.g. the Brinzio-Marroggio anticline, the Orobic anticline, the Cabianca-Trabuchello anticline, and the Cedegolo anticline, but also in some faults as the Clusone and Bondione faults. The great thrustmovements, the Grigna thrustsheets, the thrusting against the Valtorta and the Valcanale faults, further the Timogno and Ardesio thrusts, and the eastern thrusts of the Pzo Camino and the Palline Borno-Lozzio masses is all bound to the E—W strike or the N—S compression. The Insubric line, the boundary between the Southern Alps and the Central Alps, i.e. the division line between Pennine root zone and the Orobic zone, has also a W—E strike from the Lago Maggiore to Dinaro. Therefore also this major tectonical line probably originated only in a later period of the folding process. This conclusion is in complete accordance with the views of the general conception of the Alpine orogeny, which places the origin of the Insubric line in the post Oligocene, older Insubric phase. In this phase the roots of the Pennine thrustsheets were tilted in a vertical position.

The Insubric phase, the tilting of the root zones is naturally a time of uplift, the Central Alps rose above their fore- and hinterland. This is also the origin of the several fault steps we could discern in the Bergamasc Alps. In the Younger Insubric phase (Pliocene) when the final compression took place, all the Bergamasc thrustsheets were formed, they were sheared of their substratum from a higher step and pushed over the lower step.

The N—S faulting has a intermediate position, it is younger than the old anticlinal folding and older than the final thrust, and is probably connected with the older Insubric phase when the uplifting of the steps occurred.

The stratigraphic comparison has made it clear that the southern, the central and the eastern Alpine basins were portions of one geosyncline, separated from another probably by ridges, geanticlines, but still forming together one continuous unit. This connection was ruptured by the first severe Upper-Cretaceous Alpine orogenesis, the origin of the east-Alpine thrustsheets. At that moment an oblique line cut a southern minor portion from the rest. This rupture line later became the Insubric line. By its present position we can still follow its course in the original basin, because the southern Alps are only little changed in aspect compared to the more central parts. West of the Lago Maggiore it followed the ridge dividing the southern basins from the central Pennine ones, then, north of this lake it curves round to an E—W strike thus cutting obliquely through the basin structures. It retains this diagonal coarse untill it had crossed or just reached the very important Camonica geanticline, it then swung back to its original direction parallel to this ridge along the so called Judicaria line. Finally it resumes its E—W strike as the Pusteria line and limites southern Tirol to the North, separating this region from the East Alpine thrustsheets.

This early boundary line is not quite identical with the Insubric line, because the latter cuts occasionally with a very sharp angle through the root zones of the Pennine thrustsheets, but the two lines are sufficiently alike to identifie them for our purpose.

The remarkable wavy course of the Pusteria-Insubric line is thus due to the fact that the N—S compressional direction necessitated an E—W strike but the existing inhomogenities of the region indicated a NE—SW strike, between those two influences the result alternated.

The ENE—WSW anticlinal structures being older than the original Insubric line, belong therefore to a prae-Cretaceous or Cretaceous phase, a phase which also accounts for the totally different facies of the Cretaceous in East-Alpine and Lombardic sedimentary-basins. If this is true some erosion on the crests of the Cretaceous structures may have taken place before the much later, probably Pliocene, finial compression took place.

Rassmuss [1]) has thoroughly treated the Cretaceous folding phase of the Lombardic Alps. The Scaglia of the foothills, in which unfortunately no fossils of stratigraphic value have been found, belongs probably to the Cenomanian-Turonian and is a typical regressive facies with which the Alpine sedimentary cycle closes. In the thick Santonian gravels, which were deposited in the Po plain, the material is derived from Liassic and Jurassic rocks, but also of Triassic rocks and even of Permian porphyrites. This conglomerate can be regarded as a equivalent of the Gosau Schists of the northern Alps. The folding phase preceding the erosion can be put therefore in one of the subhercynic phases of Stille.

Undoubtedly the final thrusting has therefore been preceded by erosion, and we may presume that some of the thrusting has the character of „reliefüberschiebungen" as advocated by Ampferer [2]). In general, however, our

[1]) Rassmuss, H. Beiträge zur Stratigraphie und Tektonik der Südöstlichen Alta Brianza, Geol. u. pal. Abh. N. F. X 1912.

[2]) Ampferer, O. Beiträge zur Auflösung der Mechanik der Alpen (6 Teile), Jb. geol. Reichsanst. Wien, 1923, 1924, 1926, 1928, 1930, 1931.

thrustsheets are of too small dimensions to allow the determination of the characteristics of this particular way of thrusting.

This phenomenon may to a certain extent account for the fact that the Grigna thrustsheets pass over the faulted and folded underground with plane thrustplanes without being affected in the least by these structures. I can not find much evidence in favour of such theory, though, because most of the structural features of the underground are of equally recent datum as the thrusting movement, or only very slightly older.

The Valtorta fault for instance is certainly older than the thrusting, both because the thrustplanes pass over the fault and because the Norian and Raibler of the southern limb have been pressed against it. But it is not as old as the Orobic anticline, although it is fairly parallel to this structure, because it certainly belongs to the phase of uplifting of the central Alps, the older Insubric phase, and therefore not to the Cretaceous phase of folding. Still, even between the Older and Younger Insubric phases some erosion may have taken place, that is between the Miocene and the Lower Pliocene, and the height differences along this fault may have been removed to some extent. The same is true for the Clusone fault in connection with the Presolana sheet and the Pilo fault in connection with the Lozio overthrust.

Let us summarize the results of our deductions in a short tabel.

Extensive denudation removing all palaeozoic sedimentary rocks.

Asturian folding
followed by extensive intrusion of acid magmas in long stretched NE—SW zones.

Permian. Erosion continues in the west. Magmatic intrusion is followed by widespread volcanic action. In the east deposition of large subaquatic volcanic sediments.

Saalic compression, origin of central Permian Collio trough, Camonica uplift and extrusion of granophyr, Erosion in the western region continues, in the east deposition of Verrucano conglomerates.

Triassic. Continuous sedimentation in the south-east Alpine basin of Triassic rocks.

Older Kimmeric phase uplift of the Arzo anticline followed by erosion and transgressive Hierlatz facies in the Lugano - Lower East Alpine region. In the Lugano region the movement started already in the Rhaetic.

Sedimentation of Liassic and of abyssal Dogger and Malm and bathyal Lower Cretaceous.

Austrian or Subhercynic folding („Juvavische phase" of R. Staub) origin of long ENE—WSW anticlines. Only the first beginnings of the strong Cretaceous orogenesis of the East-Alpine sheets has effected Lombardia, later in this phase the eastern Alps were cut off along a diagonal line partly following the anticlinal ridges and were severely compressed in thrustsheets.

The major Pennine (Oligocene) phase of the folding of the Pennine sheets and further compression of the east Alpine sheets did not reach the southern alps.

Insubric phases, 1ste phase. The central Alps were raised to considerable height, the roots were tilted in vertical position and the „steps'' of the Lombardic Alps were formed. Origin of ENE—WSW faults (Valtorta, Clusone, Valcanale faults). N—S striking fault systems (Val Vedra fault trough, Manina fault troughs). Intrusion of Adamello tonalite.

2nd. phase. N to S compression, the lower limbs of the ENE—WSW faults were pressed against the fault, origin of Timogno and Ardesio thrusts. Origin of Tertiary dikes.

3rd. phase. Possibly some erosion. Strong N to S compression. Origin of Orobic thrust and accessory thrusts, Grigna thrustsheets, Arera thrust, Palline-Borno and Lozzio overthrusts and the Presolana and Camino thrustsheets. Often renewed activity along existing faults (Clusone fault).

The age of these Insubric phases can be judged by the fact that the Miocene molasse has been folded, and that the horizontal Pliocene has been deposited in fjords eroded in a strongly dissected landscape.

INDEX OF TOPOGRAPHIC NAMES.

Behind the name is mentioned the square in which the locality occurs on the geological map and then the page(s) of the text in which the locality is (are) mentioned. If no square is indicated the locality is either a very large unit (x) or it is situated outside the region covered by the maps (•). When the name of the locality has been omitted on the maps the square is between ( ).

Considerable confusion exists on italian maps in the denomination and spelling of mountains and valleys; whether a certain valley is called Valle, Val, Val di (or del), a mountain Pizzo, Monte or Cima is often uncertain; we have tried to establish an uniform nomenclature after the latest 1:25.000 top. sheets, but as the original authors differ considerably in their nomenclature some discrepancies may have survived.

Moreover the stream and the valley often have different names, for instance: the Torrente Aqualina in the Valcanale (or Val Canale); or the T. Ogna in the Valle di Valzurio (Valzurio being the principal village in the valley, Ogna the one at its mouth, the original name of Torrente Zurio (?) has been lost altogether), but some writers refer to this valley as Val d'Ogna!

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L. U. DE SITTER and C. M. DE SITTER-KOOMANS.

THE GEOLOGY OF THE BERGAMASC ALPS LOMBARDIA, ITALY.

A. BROUWER.

POLLENANALYTISCH EN GEOLOGISCH ONDERZOEK VAN HET ONDER- EN MIDDEN-PLEISTOCEEN VAN NOORD-NEDERLAND.

MAPS AND SECTIONS

Reference to each enclosure should read:

LEIDSE GEOLOGISCHE MEDEDELINGEN XIV B, 1949.