THE STRUCTURE OF THE BERGAMO ALPS COMPARED WITH THAT OF THE NORTH-WEST HIGHLANDS OF SCOTLAND

BY

Dr. J. H. L. WENNEKERS.

(With Plates 9 and 10).

CONTENTS.

INTRODUCTION.

Some time ago I drew a blockdiagram to illustrate the structure of part of the Bergamo Alps which, moreover, I believe to be representative of the whole of this region. During a discussion of this tectonogram with Prof. Dr. B. G. ESCHER, he pointed out the great resemblance between the structure of these Alps and that of the North-West Highlands of Scotland. He advised me to attempt a more detailed study of this comparison. I wish to express my sincere thanks to Professor ESCHER for the generous manner in which he allowed me to make use of his suggestion in the following paper.

Leiden, June 18th 1930.

SECTION I.

STRUCTURE OF THE BERGAMO ALPS.

Before proceeding to a general review of the tectonic structure of the Bergamo Alps, it is desirable to give a rough sketch of the **stratigraphy.**

The basis of the sedimentary series is formed by various crystalline schists, of which a large portion is probably of Upper Palaeozoic age. These are covered by the nonporphyric conglomerate, that, however, is by no means always present. In its turn this series is followed by the porphyric series. Going from west to east counting from Lake Como, the thickness of the porphyry rapidly declines, apart from local conditions (porphyry culmination by Trabuchello (see bibl. 1, map)). The Collio series, on the other hand, steadily increases in thickness from west to east. The Collio series began to form in the east, while in the west the submarine porphyric lavas were still pouring out. Gradually the volcanic activity declined. The lavas were more and more confined to the western part of the Lower Permian Sea, which drew away steadily eastwards. In the west lavas still flowed out after the formation of the Collio strata in the east had come to an end, whence in the neighbourhood of lake Como the Verrucano conglomerate and the Sernifites are found immediately above the porphyric series. It is even probable that the thickness of the Verrucano deposits has been influenced by the porphyry series. In that case we must suppose that after the retreat of the sea volcanic activity still continued. Where the porphyric deposits came above sea level the psammitic and conglomerate tuffites were formed. They are chiefly found at the base of the Collio series, generally speaking directly above the porphyry series. The Verrucano is conformably covered by the Servino (Lower Triassic). It is desirable to deal more in detail with the strata, which belong to the Servino, as they played an important part in the tectonics.

The following general remarks may be made:

Servino. The basis consists of sandstones and fine conglomerate deposits, in which limestone beds (consisting of calcium carbonate and quartz) are found. Locally these beds of limestone are absent. These are followed by yellow to grey-brown sandy marls, in which many beds of limestone are found, especially towards the bottom (general habitude of the Lower Servino).

Middle Servino. In the normal sequence the sandy marls of the Lower Servino merge into a thick series of bright coloured marls and marly shales, in which beds of sandstone occur now and then. In the younger parts limestone dolomites are found. Higher up still these beds become more numerous and the calcium carbonate contents of the marls and shales increases, the latter becoming much less conspicuous. The bright colours disappear. (General habitude of the Middle Servino). The rocks now become greyish yellow. Where this portion is exposed, we find the very porous, cavernous dolomite and limestone rocks, in which the carbonate is concentrated, sometimes in large quantities, forming opaque crystals.

Upper Servino. The upper part of this zone is the typical Upper Servino, which can usually be recognized by a brownish yellow sand, with here and there dolomite and limestone layers, which merges upwards almost imperceptably into the black or bluish black veined dolomitic limestones which belong to the Muschelkalk (general habitude of the Upper Servino).

The thickness of the whole Servino is about 200 meters. That of the Lower, Middle and Upper Servino may vary greatly.

The limestone and dolomite deposits that follow upon the Servino belong to the Muschelkalk and Esino. They may reach a considerable thickness (more than 1100 m).

The Raibler will also be treated more in detail, as, like the Servino, it has played an important part in the tectonics.

COSIJN (bibl. 2, p. 292—293) describes it about as follows: Above the dark Upper Esino limestone, often well stratified and sometimes rich in ore, occur dark, very finely crystalline limestone beds with marl layers interstratified.

Lower Raibler. These are the so called „Plattenkalken''. They occur almost everywhere between the Raibler series and the Esino limestone. Sometimes they appear to be absent or to be very much reduced.

Middle Raibler. The red and green strata of the Middle Raibler then follow immediately above the Upper Esino. Normally, however, the Plattenkalk (about 5 to 35 m in thickness) is immediately followed by a series of red and green sandstones in which limestone beds have been found. In the higher parts of this zone volcanic tuffs are found which can be distinguished more especially from the sandstone by their coarser grain. Then follow blue limestone and marls which form the fossiliferous beds of the Raibler.

Upper Raibler. The Upper Raibler consists of marls and cavernous rocks of calcite and bits of marl. In the same manner as the Muschelkalk is, as it were, born from the Upper Servino the Hauptdolomit is born from the Raibler.

The Hauptdolomit is a very thick deposit of about 1000 to 1100 m. It is covered by the Rhät to which I ascribe a similar part in the tectonic movements as to the Raibler and Servino. But the necessary data are still wanting. Younger deposits than the Rhät are not dealt with in this article, partly because they are found far to the south of the territory which I have studied.

Regarding the **structure** the following may be said:

In the sediments found south of the Orobic line [1]) there are certain strata that allowed of horizontal thrusts from north to south. The deposits found in between such strata show thrust planes that have been formed by one and the same cause. They are not all of the same character.

The difference in character of the thrusts is the consequence of the difference in composition of the deposits between. Thus a series of thrusts was generated in the Permian-Lower Triassic deposits that show an im-

[1]) The Orobic line runs where crystalline schists have been thrust over the sediments of the foreland in the rootzone of the Upper East Alpine nappes.

bricate structure. In the area investigated by COSIJN (see bibl. 2) a number of spoon-shaped thrusts were formed in the Muschelkalk-Esino (drainage area of the Valli di Olmo al Brembo between Lenna and Caprile) and a few overthrusts in the limestone-dolomite masses of the Mte. Pegherolo and the Pizzo del Vescovo (see bibl. 3, p. 320).

The pressure from the north, formed by the folding over backwards of the roots, was the primary origin of this structure of the Bergamo Alps. The structure described above was generated through the medium of the strata in the Servino and in the Raibler (possibly another slide occurs in the Rhät) that played the role of lubricating material. The imbricate structure of the Permian-Lower Triassic mass, the thrusts in the Muschelkalk-Esino and the Raibler „Plattenkalk'', were formed in consequence of the existence of culminations and depressions in the schists that form the basis of the Bergamo Alps. The same holds for the horizontal transverse faults and the thrusts that may be compared with them. In consequence of the sediments following the culminations and depressions already existing in the substratum, when they were forced over them by the pressure from the north, the thrust planes were necessarily formed. These resulted amongst others in the formation of an imbricate structure in the Permian-Lower Triassic deposits, as we have seen.

The pressure from the north manifested itself in two ways in the sedimentary series of the Bergamo Alps. In the first place we find the great overthrusts between sedimentary rocks that were thus relatively displaced in an approximately horizontal sense. Certain sediments acted as lubricating material. In the second place a series of upthrusts was formed in the strata lying between those lubricating masses.

By the lowest overthrust the Permian-Lower Triassic sediments were moved over the crystalline schists. The basis of the porphyric series, in so far as it is present, does not form a continuous thrustplane. The younger sediments are again displaced separately relative to the porphyries in each wedge of the series of slices in the Permian-Lower Triassic mass, in which the tuffites that nearly always occur over the porphyric series have acted as lubricant. The next overthrust brought forward the Muschelkalk-Esino mass relative to the Permian-Lower Triassic series. The Servino was partly left intact as upper member of the lower series (the Lower Servino) and partly it acted as lubricating mass (chiefly the Middle and Upper Servino). Finally the Hauptdolomit is in turn thrust over the Muschelkalk-Esino, by means of part of the Raibler series. There are strong indications that the Rhät is the basis of another thrust.

In part of the Servino, the Raibler and possibly in the Rhät, there are therefore continuous thrustplanes. Movements also occurred at the basis of the Collio and the porphyry series. The small plasticity of the material and the structure of the Permian-Lower Triassic series of slices together precluded the formation of larger continuous thrusts. In the north (in the region of the Orobic watershed) the crystalline series has been thrust over the sediments of the Bergamo Alps and two further thrusts have been found in the crystalline series itself. Sometimes these thrusts overlap. We are not always dealing with the same overthrust when we see crystalline schists superimposed upon sediments.

The crystalline mass occurring to the north of the Bergamo Alps is to be looked upon as the rootzone of the East Alpine nappes. We can understand the development of thrusts in this rootzone if we assume that the underthrusting movement of the hinterland continued after the formation of the East Alpine nappes. The roots were compressed. First upthrusts were formed, that later developed into overthrusts from north to south. As a consequence of the continuation of the underthrusting of the hinterland the connection was broken between the southern part of the upper East Alpine nappes and the parts further to the north. Slides must have occurred and the sedimentary series that had slid off were further transported passively southwards in the rootzone by the overthrusts. Sediments are now found, for instance north of the Baite Fontanini and at the Laghi di Porcile etc., along the exposure of an overthrust in the rootzone. Together with the thrust that transported them on its back they have been moved by an overthrust that was generated further to the north (see map, bibl. 3).

The problem of the boundary between the Alps and the Dinarides now appears in a new light. Bearing in mind what has been said concerning the overlapping thrusts occurring in the rootzone we need not look for the Alpino-Dinaric boundary line always where cristalline schists cover the sediments. This conception of the problem thus explains the occurrence of abnormal contacts on the one hand between the remains of sediments, that were transported passively by the thrusts in the rootzone and on the other hand the sediments of the series of slices. There the orobic line runs through the sediments.

It is noteworthy that the Alpino-Dinaric boundary line that is the exposure of the Orobic overthrust (primary boundary between the crystalline schists and the sediments towards the south) is hardly anywhere to be found, as far as I am aware. Nearly everywhere it is covered by the overthrusts in the rootzone of the upper East Alpine nappes. Only in the region examined by Th. Klompé and south of the Corno Stella it may be directly observed (see the maps bibl. 3 and 4).

This sketch of the structure is illustrated by the diagram of the movements (Plate 9) and the idealized section (Plate 10). The diagram was constructed with the aid of the sections contained in the bibliography numbers 2, 3, 4 and 5. First a structural map was constructed of the substratum (fig. 1) from the sections. Afterwards the maps and sections were used to ascertain as accurately as possible the positions of the upthrusts in the wedges of Permian-Lower Triassic.

1. culmination of Salmurano .... (S.) +
2. „ „ the Val Sassina (E. part) ...... (V.S.) +
3. „ „ Caprile .... (C.) +
4. „ „ Segado .... +
5. „ „ Mezzoldo .... (M.) +
6. depression of the Pegherolo-Secco.
7—10. culminations and depressions on the great culmination of Foppolo (F.).

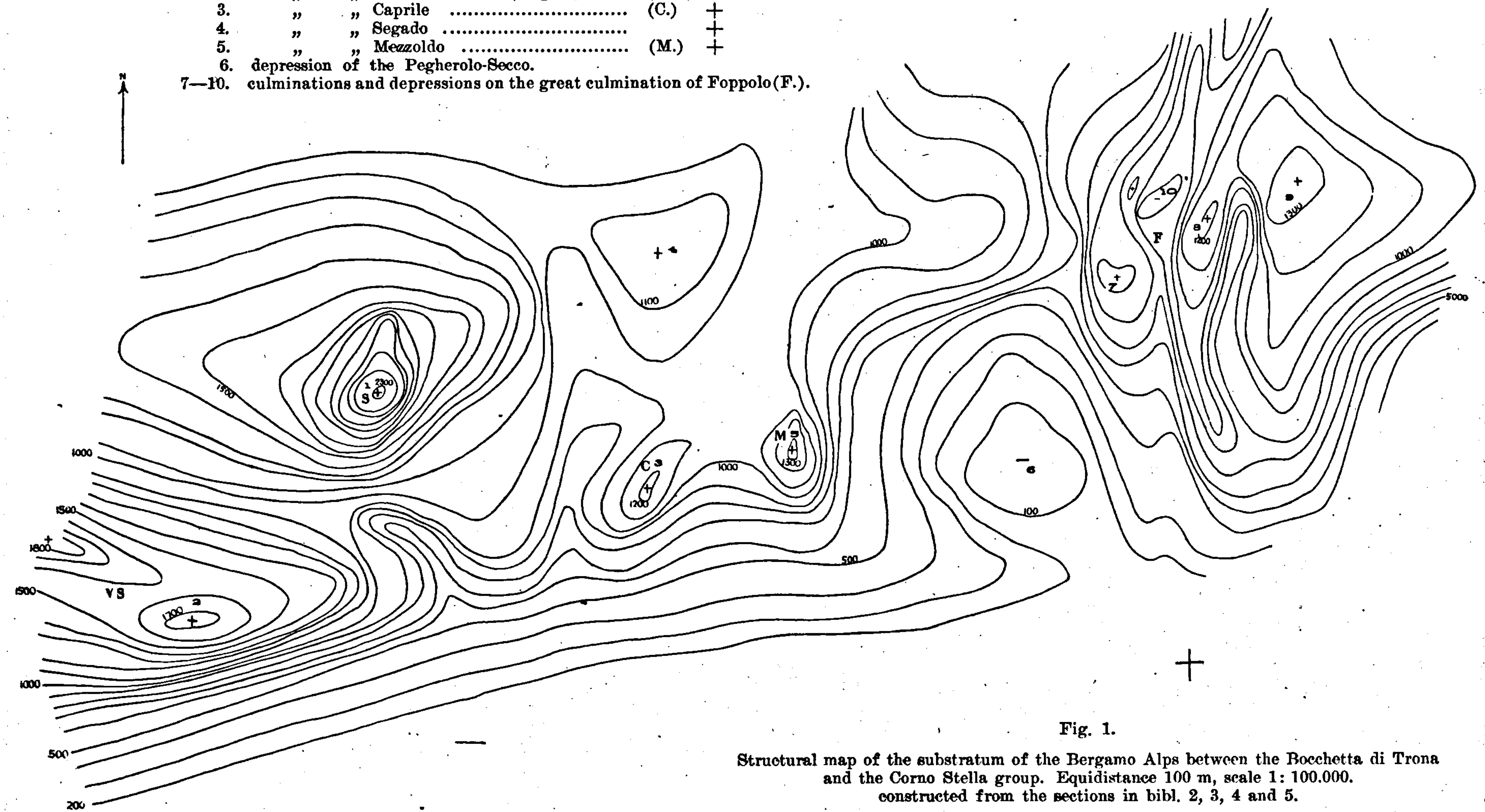

Fig. 1.

Structural map of the substratum of the Bergamo Alps between the Bocchetta di Trona and the Corno Stella group. Equidistance 100 m, scale 1: 100.000. constructed from the sections in bibl. 2, 3, 4 and 5.

SECTION II.

COMPARISON BETWEEN THE BERGAMO ALPS AND THE NORTH-WEST HIGHLANDS OF SCOTLAND.

A. General character of the structure of the North-West Highlands of Scotland.

In 1907 under the auspices of Sir Archibald Geikie a large volume of the Memoirs of the Geological Survey of Great Britain (bibl. 6) was published under the title: „The Geological Structure of the North-West Highlands of Scotland''. The chief contributors were Peach and Horn. In 1930 „Chapters on the geology of Scotland'' were published (bibl. 7). Before describing the structure of the North-West Highlands we will first deal shortly with the stratigraphy.

The basis of the sedimentary series is formed by the Lewisian gneiss series (after the island Lewis). As in the substratum of the Bergamo Alps culminations and depressions also occur here (see section on page 544, bibl. 6). On these gneisses the Torridon sandstones were deposited. Three groups are distinguished: The Diabaig-, the Applecross- and the Aultbea-group. From Cape Wrath to Skye these groups show fairly large differences in development. The oldest group, the Diabaiggroup, is absent in the district of Cape Wrath. In Rossshire the thickness varies from 250 to 700 feet, while in Skye the thickness is sometimes more than 7000 feet. The same holds for the Applecrossgroup of which the thickness in the Cape Wrath district is 1000 feet, while in Rossshire the thickness varies from 6000 to 8000 feet. The Aultbeagroup is 250 feet in the Cape Wrath district, and 4000 in Rossshire, but in Skye it is absent. The irregularities of the thickness of the Aultbeagroup are ascribed to denudation to which the Torridon sandstone was subjected before the Cambrian strata were deposited. The difference in thickness of the other two groups (Applecross and Diabaig) are the consequence of the irregular surface on which they were deposited (see fig. 8, p. 84, bibl. 7).

In bibl. 7 on page 73 occurs the following description:

3. Aultbea[1] Group with Cailleach Head beds at top. Sandstone, flags, dark and black shales, and calcareous bands, passing down into chocolate and red sandstones, and grey, micaceous flags with partings of grey and green shale. Thickness 3,000 to 4,000 feet.

2. Applecross[2] Group. Chocolate and red arkoses with pebbles of quartzite, felsite, jasper, &c. Occasional chocolate and red shales. Thickness 6,000 to 8,000 feet.

1. Diabaig[3] Group. Hard, fine, red sandstones at top, mixed with red mudstones and dark grey sandy shales with calcareous lenticles. The basal conglomerates and braccias are derived from Lewisian Gneiss. In Skye grey and buff arkoses have a great development with bands of shale.

Epidotic grits and conglomerates at the base. Thickness, 500 feet in Gairloch; 7,200 feet in parts of Skye.

On the Torridon sandstone Cambrian sediments were laid down. On p. 94, bibl. 7 and on p. 366, bibl. 6 a vertical section may be found. The following groups are distinguished: *a.* Arenaceous (Quarzite) series; *b.* Middle series — partly calcareous and partly arenaceous — and *c.* calcareous series. Attention must be drawn to the Lower zone, to the so called Fucoidbeds of *b.* and to the Eileen Dubh Group (II) of *c.* The „Fucoid beds'' are dolomitic shales and mudstones in which thin beds of dolomite occur and locally lenticular beds of flaggy dolomite grit and quartzite are developed. Above the Fucoid beds Serpulite grit occurs.

The group II of the calcareous series, the Eileen Dubh group consists of fine-grained, white, flaggy, argillaceous dolomites and limestones with chert bands.

Apart from Alluvium the youngest sediments that occur are the group VII of the calcareous series of the Cambrian strata, the Durine group.

Concerning the structure the following may be said:

In the sedimentary series of the North-West Highlands of Scotland several great overthrusts have been detected, generally situated the one above the other. In the sedimentary series between the various thrusts there occurs a series of thrusts (major and minor thrusts). The series of thrusts (minor thrusts) are of a different character, occasioned by the varying composition of the deposits between the major thrusts.

Thus the Cambrian strata are traversed by major thrusts that are principally found in the Fucoid beds and in the lower parts of the calcareous series (probably in the Eileen Dubh group), and by a series of minor thrusts that called forth imbricated structures between the major thrusts.

It was further possible to show that the Lewisian gneiss with the overlying Torridon sandstone and Cambrian strata have been thrust over the sediments of the foreland in a westerly direction (if we assume that the structure was produced by an underthrusting from the west it is the hinterland).

Other overthrusts of the crystalline schists with the overlying sediments sometimes brought about major thrusts and minor thrusts in the sediments that had themselves already been brought forward. They had been carried forward on the backs of thrusts by which crystalline schists had been shoved on to sediments of the foreland (or hinterland). But there is one great overthrust, the „Moine thrust'' of the Eastern schists that probably did not transport sediments corresponding with the Torridon sandstone and the Cambrian strata of Sutherland and Ross.

The Moine thrust must be considered as a thrust that carried crystalline schists of a different composition to the Lewisian gneiss forward on to the sediments of the foreland (or hinterland). The exposure of the Moine thrust is the dividing line between two structural units.

Fig. 2 (= fig. 39, p. 524, bibl. 6) illustrates the structural style of the North-West Highlands of Scotland.

B. Correspondence between the structure of the Bergamo Alps and the North-West Highlands of Scotland.

In the discussion of the structure of the Bergamo Alps it was clearly shewn that the overthrust planes, the major thrust planes, had been developed in the sediments that are capable of becoming lubricating material.

Concerning the major thrust planes of the North-West Highlands we may probably assume the same. They occur principally in the Fucoid beds and in the Eileen Dubh group. The description of the rocks that these contain has shewn that they also contain material that is apt to form lubricating matter (section 39, p. 524, bibl. 6 clearly shows that the Fucoid beds and the Eileen Dubh group have acted as sliding material, see fig. 2).

The great thrusts that moved Lewisian gneiss with the overlying sediments (Torridon and Cambrian) on to the Cambrian strata may be compared to the imposing imbricate structure of the Dinarides to the south of the rootzone of the upper East Alpine nappes.

The exposure of the Moine Thrust may be compared to the exposure of the Orobic thrust = Alpine Dinaric boundary line.

The many sections included in the text of bibl. 6 and 7 show a striking resemblance to those published by Cosijn, Jong, Klompé and myself in the: „Bijdragen tot de geologie der Bergamasker Alpen'' (Contributions to the geology of the Bergamo Alps) (bibl. 2, 5, 3 and 4). The Torridon-sandstone, as far as it was not transported on to sediments together with Lewisian gneiss by thrusts, played the same part as the porphyry series in the Bergamo Alps. In many cases this formation accentuated the culminations of the substratum, thus adding to the resistance against the thrusts in the Cambrian strata.

In consequence of the culminations and depressions in the Lewisian gneiss and of thick strata of Torridon sandstone in localities where depressions in the Lewisian gneiss are suspected, the shape and the dip of the thrust planes of the wedges were influenced (compare the influence of the porphyry culminations of

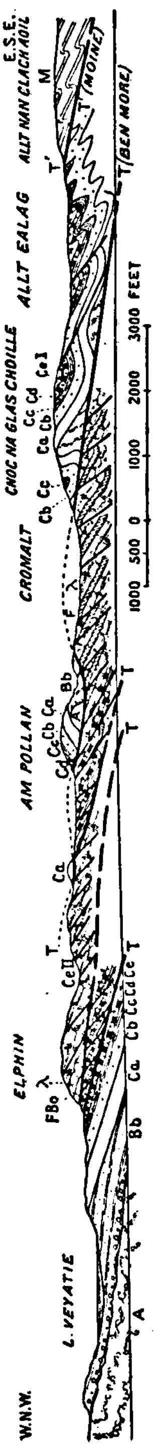

Fig. 2—Section from Elphin by Cnoc na Glas Choille to Allt Ealag. [After Mem. Geol. Survey 1907 Fig 39]

A. Lewisian Gneiss. Bb. Applecross group (Torridonian). Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit. Ce. Limestone. Ce I. Limestone (Ghrudaidh group). Ce II. Limestone (Eilean Dubh group). λ. Marble (Cambrian). FBo. Borolanite. F. Porphyrite Sills. M. Eastern Schists. T. Thrusts. T'. Moine thrust.

Porta in the valley of Carona bibl. 3; in the sections). I am of opinion, moreover, that the imbricate structures in the sedimentary series are the direct consequence of the presense of culminations in the substratum. In section 27, page 497, bibl. 7 the influence of a culmination in the substratum on the dip of a thrust plane in the Cambrian strata is clearly shown. Section 48, page 544, bibl. 6 shows the part played by the Torridon sandstone. This series of deposits partly acts as culmination of the substratum, thus increasing the resistance offered to the thrusts in the Cambrian strata and partly it has taken part in the imbricate structure (compare what Dr. Jong and I wrote in bibl. 5 and 3 concerning the part played by the porphyry series in the Bergamo Alps; see the series of sections).

A comparison of the figures 45, page 536 bibl. 6 with the sections N.—S. nos. IV and V of bibl. 3 shows that both in the North-West Highlands of Scotland and in the Bergamo Alps disharmonious folding occurs.

When considering the great resemblance of both structures it seems reasonable to suppose that they were formed in the same manner. The structure of the Bergamo Alps was formed by underthrusting. I venture to suppose the same for the structure of the North-West Highlands.

The Eastern schists are rocks from a root zone. They were pressed together from west to east after the formation of the nappes because the underthrusting of the Lewisian gneiss with the overlying sediments continued after the overthrust sheets had already been formed. In the underthrust mass an imposing imbricate structure was generated comparable to that of the Dinarides, the hinterland of the upper East Alpine nappes.

In the Bergamo Alps the great wedges in which the substratum takes part are not exposed. Perhaps detailed examination of the region between Valtorta and Bajedo will bring to light overthrusts in the substratum.

In the North-West Highlands, on the other hand, the thrusting planes that form the boundary of the substratum, the Lewisian gneiss can often be observed. This is shown in the map and sections of bibl. 6. See for instance section 39, page 524; 24, page 489; 25, page 491; 28, p. 500; 31, p. 510; 37, p. 521 and our Fig. 2.

The facts mentioned above teach us the following:

During and after the Alpine folding a structure was formed in the Bergamo Alps as described shortly in section I. During the Post Cambrian a similar structure was formed in the North-West Highlands of Scotland. In both regions we are dealing with a structure that was formed at the margin of an orogene.

BIBLIOGRAPHY.

1. C. PORRO, Alpi Bergamasche, Note illustrative della Carta Geologica e delle Sezione. Milano, 1903.
2. J. COSIJN, De Geologie van de Valli di Olmo al Brembo, avec résumé en français. Leidsche Geol. Mededeelingen II, p. 251—324. Leiden, 1928.
3. J. H. L. WENNEKERS, ' De Geologie van het Val Brembo di Foppolo en de Valle di Carisole, avec résumé en français. Leidsche Geol. Mededeelingen III, p. 265—334. Leiden, 1930.
4. TH. H. F. KLOMPÉ, Die Geologie des Val Mora und des Val Brembo di Mezzoldo. Dissertatie. Leiden, 1929.
5. W. J. JONG, Zur Geologie der Bergamasker Alpen nördlich des Val Stabina. Leidsche Geol. Mededeelingen III, p. 49—104. Leiden, 1928.
6. B. N. PEACH, J. HORNE, the late W. GUNN, C. T. CLOUGH, L. W. HINXMAN with petrological chapters and notes by J. J. H. TEALL edited by Sir ARCHIBALD GEIKIE in the „Memoirs of the Geological Survey of Great Britain'', «The Geological Structure of the North-West Highlands of Scotland». Glasgow, 1907.
7. B. N. PEACH and J. HORNE, Chapters on the Geology of Scotland. Oxford University Press. London, Humphrey Milford, 1930.