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The geology of the Morcote Peninsula and the petrochemistry of the porphyry magma of Lugano

by *K. P. Rode*, Benares

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FOREWORD

During the last fifteen years a very valuable series of geological and petrographical studies on the different parts of the Lugano Erup-tive District was published by the students of Prof. B. G. ESCHER in Leiden. The only part on which no detailed account was yet published in this series is the Morcote Peninsula which was investigated by Prof. ESCHER himself over 25 years ago. Since there was no likelihood of such a publication coming from him in the near future Prof. P. NIGGLI very kindly suggested my undertaking the detailed investi-gation of this peninsula afresh, to which Prof. ESCHER gave his ready consent.

In the beginning the idea was to study the inclusions in quartz-porphyries and preliminary field-work from this point of view was carried out by me in the month of April 1938; it was, however, soon realized that a fresh mapping of the whole peninsula would be highly desirable. The summer of 1938 and the spring of 1939 were, there-fore, devoted to the study of the whole region.

It was also seen that though the geology and the petrography of the rock-types of the porphyry district were very well known not much was known regarding the chemistry of the porphyry magma. The laborious analytical work of Miss C. M. KOOMANS, also a student of ESCHER, has opened the way for such investigations; this oppor-

tunity was, therefore, taken to study the available data on the lines initiated by Prof. NIGGLI.

I wish to express my sincerest gratitude to Prof. NIGGLI for entrusting to me this interesting problem as the subject of my Dissertation and for the instructive guidance he gave during the progress of these investigations. His inspiring personal contact during my stay at Zurich has instilled in me a lively interest in these studies. I am also highly thankful to Profs. BURRI, PARKER and other members of the Mineralogical Institute for the varied help and advice during these two years at Zurich. My special thanks are due to Prof. JAKOB who carried out for me chemical analyses of seven rocks from my collection. I take this opportunity of thanking Prof. ESCHER for placing his collection of thin sections at my disposal. I had a number of interesting excursions in the Alps and the Jura which were highly instructive in elucidating the structure of these mountains. For these I am very thankful to Profs. R. STAUB and A. JEANNET of the Geological Institute.

During the course of my field-work I have received constant hospitality and encouragement from Dr. FR. WEBER (Lugano) with whom I had also several excursions in the different parts of the Tessin. He also placed at my disposal the collection of rocks and minerals he had previously collected near Carona; for all this I am deeply indebted to him.

It is also with extreme pleasure that I wish to record my happy association with the fellow workers at the Institute, particularly Messrs A. STUTZ, S. CASASOPRA, J. C. DUNNE and H. HUBER.

Part I. Geology of the Morcote Peninsula

A. INTRODUCTION

The investigated area is bounded in the E, S and SW by the Lake of Lugano, in the NW by Piano Scairolo and in the N by a line joining Grancia Ciona and Alla Ferrera. The whole region constitutes an area of about 18 sq. kilometres.

The Morcote Peninsula and its surroundings owe their form and topography to the erosive action of the late Pleistocene glaciers, Tessin and Adda coming from the N and NE whose retreat is recorded in the terminal moraines of Vedo and Melide.

The most important feature of the peninsula is the ridge of Arbostora running NE-SW, and culminating in three slightly separated hill tops 839, 826 and 814 metres high respectively. The ridge

terminates to the SW in an arcuate amphitheatre with steep sides enclosing the beautiful plain of Vedo facing the lake, while in the NE it merges with a low saddle-like depression into the high craggy dolomitic hill of S. Salvatore. The Arbostora ridge on the whole has a roughly rounded hummocky top with gently sloping plains on different levels thickly covered with moraines. Some of these plains have been utilized for wine-growing.

Towards the lake the slopes become somewhat steep and bare and are covered only with hanging rock-debris. In some parts extensive rock-slides may be seen on steep faces as those above Cantine Codato in the west. These slopes are traversed by numerous small streamlets only a few of which are perennial. Among these the most prominent are Val di Fiume flowing south, Soresello, Garaverio and Grancia flowing west and north-west, and Alla Ferrera, Melide, Baslona and Colombajo flowing to the east.

The geological structure of the Morcote Peninsula has been known in its broad features since the seventies of last century when NEGRI, STOPPANI and SPREAFICO included this region in their geological map, sheet XXIV of the Swiss Dufour-Atlas 1:100 000 (1876), while a short description of this part was given by TARAMELLI in 1880 in the text accompanying this map. HARADA (1883) in his work on the petrography of the Lugano region also added many important contributions to the geology of the Morcote Peninsula. The regular geological mapping of this area, however, was undertaken in 1911 by B. G. ESCHER who published some preliminary observations on the geology and petrography of this area in 1913 though his full work never came out. This region was also left out of the detailed systematic work on the Lugano porphyry district by students of ESCHER. The geological map of this peninsula, based on ESCHER's work was, however, published in the dissertation of Miss KOOMANS and again in the latest publication of DE SITTER.

In the proper study of this region, the high degree of alteration which the eruptive rocks of the area have undergone and the extensive moraine and "Schutt" coverings which have obscured the fresh outcrops have always been a little discouraging. The recent construction of the new Carona-Vico Morcote road had opened the possibility of fresh exposures of the eruptive rocks and this prompted the undertaking of renewed geological mapping by the present author.

During the field work most of ESCHER's observations as embodied in KOOMANS' map have been corroborated, but several modifications

in detail have been found necessary while a number of altogether new observations has amply justified the present labours.

The general geological structure of the Morcote Peninsula may be described as having at its base a highly variable series of ortho- and para-gneisses and schists including what may be called the "Carbonids" folded by the Hercynian orogenics. Over this occurs a series of Permocarboniferous sediments composed of sandstones and conglomerates. These are then flooded over by a thick series of acid and basic lava flows and tuffs, the whole system being later intruded by porphyry dikes. These eruptives are succeeded along the northern border of the region near Ciona by a thin band of tuffogene material which in its highly crumpled and decomposed condition very much resembles the Servino. This is then succeeded by the Salvatore dolomite. As the last manifestation of Permian igneous activity occur the pneumatolytic-hydrothermal mineralizations.

The whole region suffered extensive block-faulting and brecciation during the Tertiary folding movements. The youngest deposits are the fluvio-glacial moraines and "Schutt" covering.

B. THE METAMORPHIC GROUND COMPLEX

In the Morcote Region the metamorphic rocks form a real base for all the later formations, being observable over long distances along the periphery of this area. There are at least three detached outcrops, the largest being in the south and south-east stretching along the lake from Val di Torre in the SW to Colombajo in the east. The other two outcrops are on the western and northern boundaries of this area.

The Morcote-Colombajo outcrop, though continuous, is partly interrupted near Morcote, by a sheet of porphyrite which, in places, is thin enough to expose the underlying schists. The upper junction of the metamorphics with the younger rocks runs from Val di Torre through Castello and Vico-Morcote to Colombajo, its nearly northward course being interrupted and shifted to the east by a series of stepfaults running east-west until the metamorphics disappear under the lake at Colombajo. The metamorphics in this outcrop are intruded by two massive porphyry dikes running for a long distance slightly obliquely to the strike of the metamorphics. Breaks and shifts in the run of these dikes have helped to locate the major step-faults in the field.

The metamorphics, here, show a sharp fold whose axis runs nearly NNE-SSW. The rocks in the San Carlo-Castello region show

a general steep dip to the ESE while those along the Morcote-Colombajo road show a similar steep dip to the WNW.

The Castello Morcote region exhibits a sort of discordance within the metamorphics (Fig. 1). The lower series is composed of compact, less plicated granite-gneisses and hornfels and dips 50° to ESE. The higher series is composed of less metamorphosed but highly folded sedimentogenous rocks — the micaschists, phyllites, quartzites and psammite-gneisses dipping 35° to $S 10^{\circ} E$. The upper series, at least in part, corresponds well with what KOENIGSBERGER (1928) described as "Prae-obercarbonische Ablagerungen" or the "Carboniden". These are also comparable to the Casanna schists of the Insubrians.

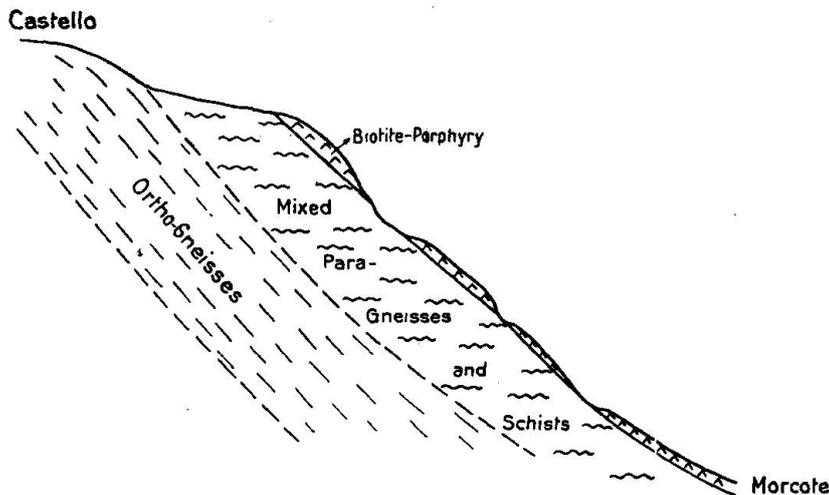


Fig. 1. Detailed profile of the Castello Morcote region

Not far away from this main outcrop, to its west, but detached from it, occur a few very small isolated patches of metamorphic rocks between Val di Torre and Val di Gaggio (the latter is a small stream flowing south from the point 609 half a km west of Vico Morcote, and referred to as such by ESCHER). These metamorphics are composed of greenish gray chlorite schists and phyllites which in some places show an apparent transition into the overlying conglomerates. The field relations of these small isolated patches especially in regard to the other metamorphic rocks are not quite clear in this highly disturbed part of the region.

The second important outcrop of the metamorphics lies on the western slopes of the Arbostora hill exposed on the Figino-Morcote road about half a km. south of Figino. Here the metamorphics, mostly belonging to the paraschist-series, strike NE-SW and dip

about 70° to the NW. (The maps given by KOOMANS (1937) and by DE SITTER (1939) based on ESCHER'S field work do not show this outcrop of the metamorphics though ESCHER has already referred to the occurrence.)

The metamorphics in this outcrop are bounded in the north by a strong faulted junction against granophyre, while in the east they are covered directly by porphyrites. The southern boundary is altogether obscured by scree.

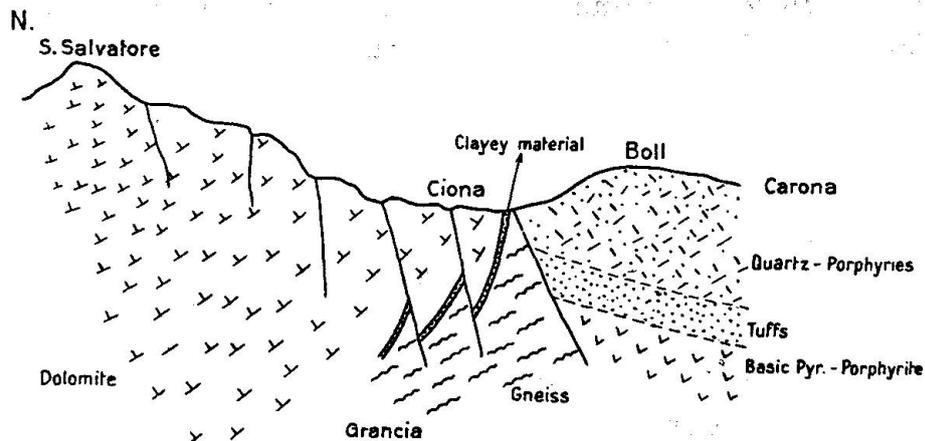


Fig. 2. Detailed profile of the region South of M. S. Salvatore

The rock-types in this outcrop correspond closely with those occurring along the Morcote-Colombajo road and are composed of micaceous gneisses, schists, quartzites and psammite-gneisses. These are traversed by a white aplitic dike running slightly obliquely to the foliation in the metamorphic rocks.

The third large outcrop of the metamorphics in this peninsula occurs between Grancia and Ciona with its continuation running to Alla Ferrera. This outcrop is of great tectonic interest inasmuch as it occurs like a wedge between the dolomites in the north and the eruptive rocks in the south. The metamorphic rocks are usually finely laminated mica-schists and quartzites and are almost identical with those occurring a little east of Castello. Though not highly folded they are very much crumpled and can often be mistaken for fine moraine-material. The rocks are best exposed on the hill-slopes near Berina south of Grancia, but the outcrop can be followed from Rampiga in the south to Ronchin (Ciona) in the east. Its southern junction with porphyry tuffs is obscured under debris. In the north it comes into contact with dolomites with a thin intervening band of reddish brown soft clayey material about 3 to 6 metres thick (Fig. 2).

One curious feature about this outcrop of metamorphic rocks is its association with two wedges of dolomite only a few metres thick, occurring almost wholly within the metamorphics and striking ENE-WSW. They appear to be a continuation of the dolomite mass south of Barbengo to the SW.

This metamorphic outcrop finds its continuation to the east beyond Ciona up to Alla Ferrera. The thickness of the outcrop is least at Ronchin where dolomite appears to come into direct contact with porphyry tuffs, but the contact is obscured. To the east of this point the outcrop gradually widens until a little west of Alla Ferrera

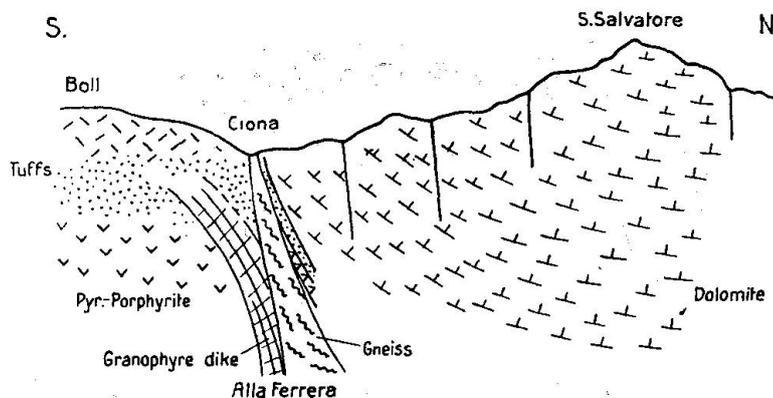


Fig. 3. Detailed profile through the region south of M. S. Salvatore (view from the East)

it is nearly 80 m. thick. This band is nicely exposed all along the stream. In the north, in contact with the metamorphics, occur a few thin strips of porphyries and porphyrites running east-west and separating the schists from the dolomites (Fig. 3). In the south the metamorphic band is for nearly its whole length in direct contact with the granophyre dike of Alla Ferrera. ESCHER (1913) and FRAUENFELDER (1916) show a thin band of "Servino Beds" below the dolomites and in direct contact with the porphyries. Several attempts on my part failed to show any trace of typical Servino rocks between the dolomites and the porphyries in this part of the tract unless they are covered by loose dolomitic blocks. It is, however, possible that the thin porphyry bands noted above have been mistaken for Servino.

The metamorphics in this outcrop like those in the Grancia outcrop belong to the upper metamorphic series. These rocks appear to be associated with a few traces of marly and sandy rocks of Permocarboniferous age.

C. THE PERMOCARBONIFEROUS CONGLOMERATES

Sandstones and conglomerates which could be assigned to Permocarboniferous age are extremely rare within the confines of the Lugano porphyry district. The only localities which were so far known to show outcrops of conglomerates lying between the porphyry series and the metamorphics are Brinzio, Bovarezzo near M. Piambello, Poncia near Porto Ceresio, Val di Nave and Val di Tresa. The outcrops of Brinzio and Poncia are very small, only a few sq. m. in extent, whereas those of Val di Nave and Val di Tresa are fairly extensive. On the Lake of Lugano, Poncia was the only locality where these rocks were known to occur (DOEGLAS 1930, p. 344).

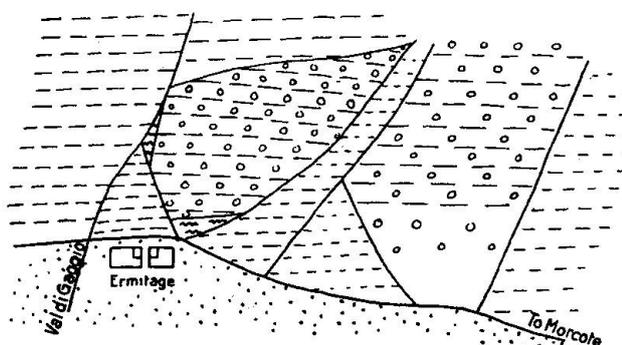


Fig. 4. Sketch Map of the neighbourhood of Val Gaggio. Explanation of signatures on the plate

The present investigations have disclosed some fairly large occurrences of the basal conglomerates within the Morcote Peninsula.

These rocks occur as a thin formation of variable thickness interposed between the metamorphics and the porphyrites and exposed interruptedly from Val di Fiume in the SW to Colombajo in the NE. These have been traced in four, altogether detached, outcrops along the upper junction of the Morcote-Colombajo metamorphic exposure. These are 1. Val di Gaggio near Ermitage, 2. Val di Torre west of Castello, 3. along the new road about half a km. NNE of Vico-Morcote and 4. the last at Colombajo.

The conglomerates are best developed in Val di Gaggio. This outcrop has been mentioned by ESCHER (1913, p. 728) who describes it as a series of sandy tuffs and conglomerates with a strike of 70° E and a dip of 30° to NNW.

The field relations of this conglomerate are highly complicated since it is associated with porphyritic basal tuffite on all sides. A closer examination of this outcrop brings to notice a clear discordant junction between the tuffite mass towards the base and the

overlying conglomerate. The junction is strongly oblique to the bedding in the conglomerate and is undoubtedly one of tectonic nature. The upper junction, however, appears quite normal. Between the conglomerate and the underlying tuffites is also traceable a very thin band of green micaceous thinly bedded schist above the faulted junction (Fig. 4). This schistose band increases in thickness towards SE, but is abruptly terminated to the south and south-east against the porphyrites. The conglomerates are thus always underlain by metamorphic rocks and not by tuffites, though the disturbed tectonics of this part show an apparent reversal of these relations.

The conglomerate band in this outcrop has a great thickness and reaches to a fair height above the footpath leading to the Ermitage. It is composed of pebbles, predominantly of quartz, of varying sizes mixed irregularly in a hard sandy matrix. Beside vein-quartz, pebbles of sandstones, quartzites, gneisses and schists also occur, while a few small pebbles of quartz-porphry-like rock have also been noted. Layers of thinly laminated clays occur within this conglomerate band at irregular intervals.

The second outcrop of the Permocarboniferous sediments is found in Val di Torre west of Castello. The footpath behind the houses in S. Carlo and leading to Ermitage takes a sharp bend where the Torre stream emerges from its rocky course into the vineyards of Arbostora. As we proceed up the stream we find on our right coarsely crystalline hard gneisses and on our left massive greenish gray basal tuffite. The valley marks a fault with a downthrow to the west. About 40 m. up in this valley we suddenly come across a grayish brown fine-grained sandstone showing a sharp discordant junction with the underlying metamorphics. This coarsely bedded calcareous sandstone dips roughly 45° to NE and can be traced for several metres up the stream. This bed, however, can be followed better on the southern slopes of the valley where a footpath runs a long distance over these sandstones. A careful search along this footpath discloses a very thin layer of conglomerate only $\frac{1}{2}$ m. thick, occurring between the sandstones and the metamorphics. The sedimentaries as exposed along this footpath show an apparent thickness of nearly 30 m. In the bed of the stream can be traced a few thin layers of micaceous gritty sandstone which in one place contained abundant coal partings and impregnations which give a clear streak on paper. Higher up was seen another band of conglomerate lying over the sandstones and containing numerous pebbles of gneisses and schists (Fig. 5). The whole of this sedimentary outcrop,

however, is thickly covered with the stream debris for most of the year which has prevented a proper study of the true field relations of this important formation.

Above these sedimentaries is seen a band of well bedded quartzitic rocks about 4 m. thick which are not quite conformable to the bedding of the sedimentaries below. They form a fairly conspicuous feature in this part of the valley. They are very fine-grained pinkish siliceous rocks resembling a porphyry dike. They can be followed from the base of the valley to the Castello.

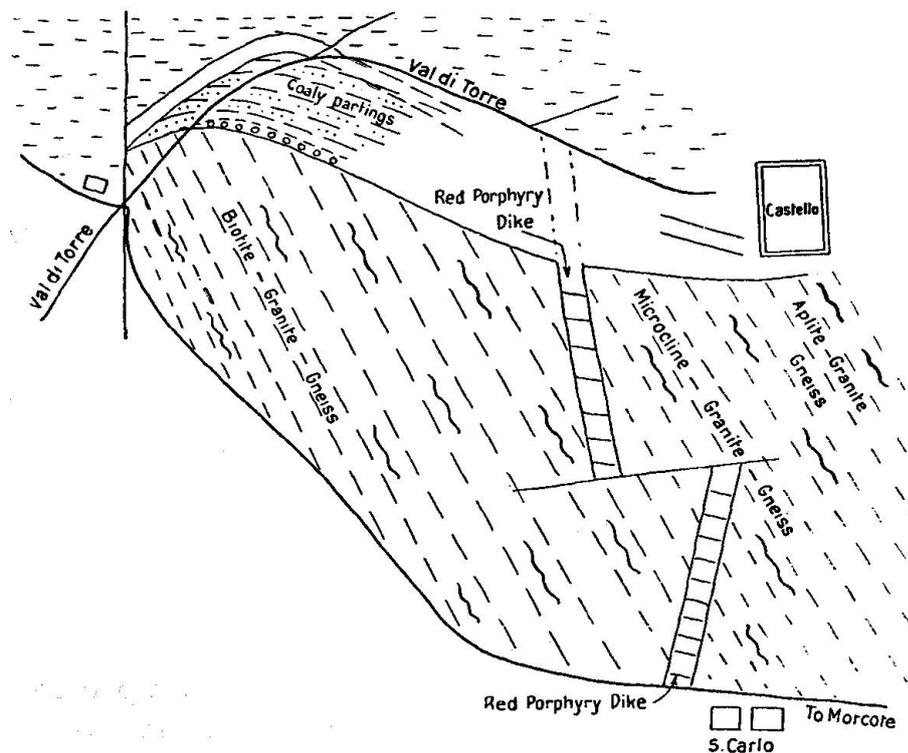


Fig. 5. Sketch Map of the area between Val di Torre and S. Carlo (W. of Morcote)

The third important outcrop and the one most easily approachable is seen on the new road about half a km. NNE of Vico-Morcote. Here the road-cutting has exposed a highly crumpled brownish mica schist and psammite-gneisses together with a thin band of grayish white quartzite forming the Hercynian base (Fig. 6). Over this occurs with a sharp unconformable junction a three metre thick band of well bedded sandstone with clayey partings along the bedding planes. These sandstones strike $N 30^{\circ} E$ and dip 70° to NW. About 16 m. higher up along the slope is found a conglomerate bed, hard and compact with quartz pebbles of the size of a nut; this

conglomerate passes in its higher parts into a grit with hardly any pebbles. This, again, is overlain by quartz porphyry and tuffs. A little to the south a small fault has thrown the conglomerate band up by about 4 m. bringing it side by side with the eruptive rocks. No trace of porphyry boulders could be found in these conglomerates. This outcrop also is thickly covered with a deposit of moraine and "Schutt" material and no direct contact between the sandstones and the conglomerates is anywhere seen. There is, however, no doubt that the sandstones are conformably overlain by the conglomerates.

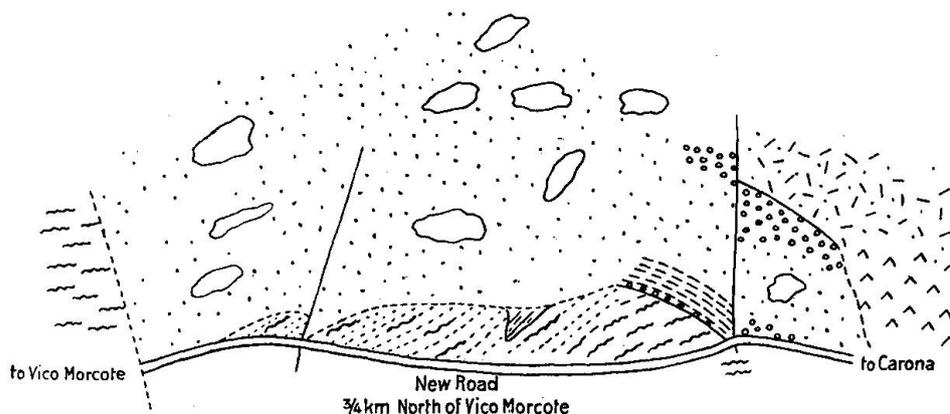


Fig. 6. Sketch Map of the exposure of Permo-Carboniferous rocks on the new road, $\frac{3}{4}$ km North of Vico Morcote. Explanation of signatures on the plate

The junction of the sandstones with the metamorphics, though sharp, is still marked by $\frac{1}{2}$ m. thickness of loose clayey material with pebbles of older rocks. Though it simulates a fault-breccia, the greater probability is that this thin layer is a normal conglomerate band comparable to that lying between the sandstones and the gneisses in Val di Torre.

The last outcrop, which is also easily accessible, is at Colombajo. Here, in the garden behind the Villa the gneisses and schists run nearly N-S with an almost vertical dip. On the upright edges of these occurs a thin pinkish band of hard fine-grained cherty rock with a dip of 40° to NNW and followed concordantly by a bed of conglomerate about 4 m. thick (Fig. 7). The cherty rock is only 1,5 m. thick and shows a nicely bedded structure. Though much reduced in thickness these rocks are quite identical in their field relations with those exposed on the new Carona-Vico-Morcote road described above.

It will thus be seen from the above description that the Permo-carboniferous conglomerate at the base of the Lugano eruptive series

is fairly well represented in the Morcote Peninsula. To all appearances the rocks of Poncia on the other side of the lake and described by SENN (1924, p. 554) as Verrucano conglomerate and those of Valle dei Molini on the Brinzio-Bedero road (KUENEN 1925, p. 145) are identical in their lithology and field relations with those of the Morcote Peninsula.

It may be useful at this stage to add a few remarks on the question of age and correlation of these sedimentaries at the base of the Lugano eruptive rocks. The question is rather a difficult one especially in the absence of any recognizable fossils.

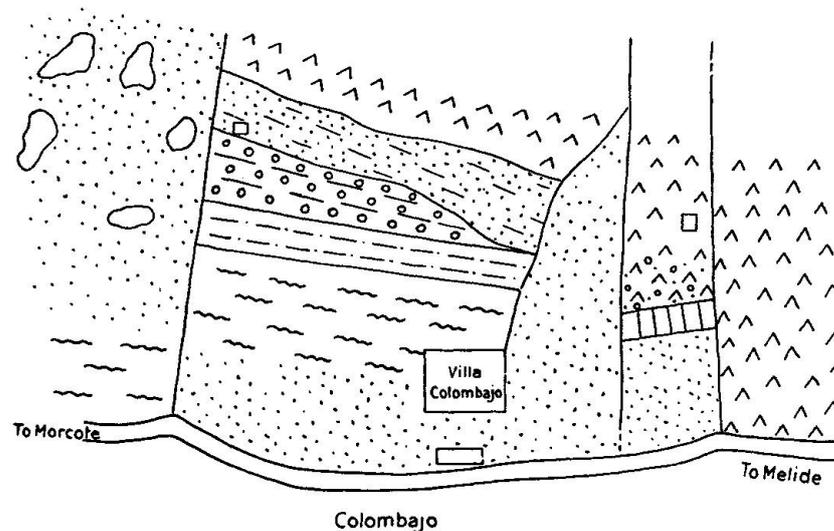


Fig. 7. Sketch Map of the neighbourhood of Colombajo. Explanation of signatures on the plate.

It has already been noted that these rocks are known from the following localities in the Lugano porphyry district: Voldomino (Val Tresa), Grantola (V. di Nave), Brinzio (V. dei Molini), Bovarezzo (Val Ganna), Morcote and Poncia (Lago di Lugano).

The occurrences of Post-Hercynian conglomerates and sandstones nearest to the Lugano region are those of:

Manno-Mugina about 6 km. NW of Lugano,

Val di Colla about 12 km. NE of Lugano and

Bergamasker Alps over 30 km. to the east, beyond Lago di Como.

The conglomerates of Manno and Mugina have been described in detail by ESCHER (1911) and KELTERBORN (1922). The age of these rocks has been definitely fixed on the basis of plant-remains as Uppermost Carboniferous (Ottweiler beds) but the controversy still remains as to whether these beds participated in the Hercynian folding or not. ESCHER thought that they were folded along with the

basal metamorphic rocks during the Hercynian movements but KELTSERBORN disagreed with this view and explained their intimate connection through later block-faulting.

If one examines the rock-formations of Manno-Mugena and those of Morcote one is impressed by the far reaching similarity between the two formations. Conglomerates, quartzites, brown marly sandstones and micaceous sandstones which are so typically developed

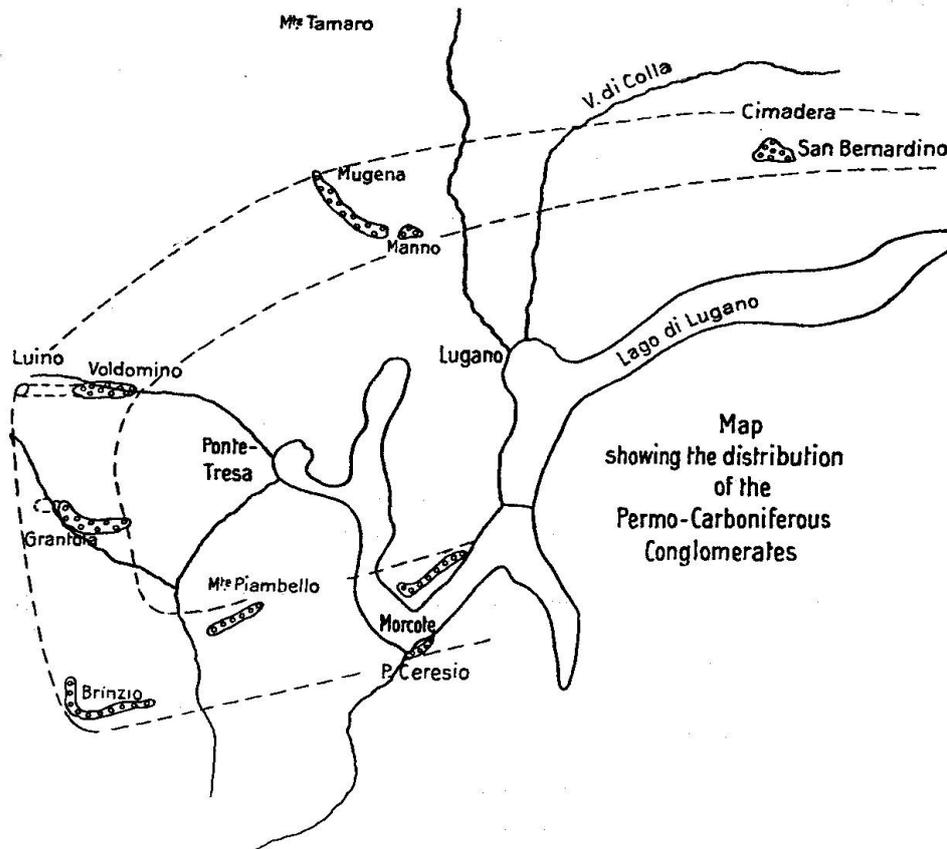


Fig. 8

in the former region are all represented in the latter though on a much smaller scale. Plant remains in the Manno rocks could be deciphered but they are too few and badly preserved in the Morcote rocks. In both areas the rock-formations lie directly on the metamorphics and are overlain by eruptive tuffs and flows. The one character which was thought sufficient to differentiate the two rock series was the seeming absence of porphyry blocks in the rocks of Manno, whereas traces of volcanic ash and pebbles have been recognized in the conglomerates of the Lugano region. As noted on previous pages no volcanic material could be found in the outcrops

of Colombajo, of the new Vico-Morcote road and of Val di Torre while with difficulty a few porphyry pebbles could be traced in the Val di Gaggio outcrop. One may, therefore, venture to suggest that the absence of volcanic material in the Manno rocks may possibly be only apparent and accidental and due to its distance from the eruptive centres. If this were accepted the Morcote conglomerates would be contemporaneous with or not much later than the Manno conglomerates; in other words they are transitional between the Uppermost Carboniferous and Lowest Permian.

Lately J. J. Dozy has discussed this question of the basal conglomerates below the Permian eruptives in detail (Dozy 1935, p. 43 and 158). He has realized that the so-called aporphyritic basal conglomerates have in many instances yielded porphyry material. He, therefore, does not take the absence of porphyry pebbles as a proof of older age but takes all such basal conglomerates as Lower Permian transgressional conglomerates.

Dozy gives certain typical occurrences of basal conglomerates from the Bergamasker Alps which may be compared to those of the Lugano Region. The succession obtains near Lago Rotondo-Pian' del Asino (Dozy 1935, p. 158):

- (above) 6. Tuffs with a few conglomerate bands.
- 5. Sandstones alternating with conglomerates; in upper layers tuff-like intercalations.
- 4. Gray to reddish conglomerates with abundant quartz pebbles, \pm 20 m.
- 3. Red sandstones \pm 10 m.
- 2. Wine-red conglomerates with white quartz pebbles. \pm 10 m.
- (below) 1. Mica, Schists.

It is clear that the Morcote conglomerates are very similar to and, therefore, comparable with the basal conglomerates of the Bergamasker Alps. In this connection the following sentence may be quoted from Dozy (1935, p. 43):

„Im Westen sind die Basalkonglomerate mit den zu Unrecht Verrucano genannten Konglomeraten zu vergleichen, die SENN (1924) von Poncia (L. di Lugano) zwischen Grundgebirge und Porphyry beschreibt, und mit den basalen Tuffiten aus dem Porphyrgbiet von Lugano (DE SITTER, DOEGLAS, u. a.).“

D. THE PERMIAN ERUPTIVE ROCKS

Above the metamorphic basal complex and its thin sedimentary cover occurs a great thickness of eruptive rocks which occupy by far the largest part of the peninsula. In their lowest horizons they are in places highly mixed up with clastic sediments and have given

Table 1 Comparative stratigraphical Table

| | Manno-Mugena | Lugano | Bergamasker Alps ¹⁾ | Cima d'Asta ²⁾ | Bolzano ²⁾ |
|--|--|---|--|--|--|
| Verrucano | | San Martino-conglomerate Granophyre | Servino Conglomerate with Sernifite | Seiser beds Grödner-sandstone | Seiser beds Grödner-sandstone |
| Lowest Permian | Silicified tuff and tuff-breccia | Porphyry-eruptives Basal-tuffs | Porphyry-eruptives Tuffs with conglomerate bands | Porphyry-eruptives Tuffs with conglomerate | Porphyry-eruptives Tuffs with conglomerate |
| Transitional | Red micaceous sandstone | Marl conglomerate | Sandstones & conglomerates | | |
| Permo-Carboniferous | Brown marly sandstone | Micaceous sand- stone with coaly impregnations Brown calcareous- sandstones | Gray to red quartz- conglomerate Red sandstone | Basal conglomerate | Basal conglomerate |
| Uppermost Carboniferous (Ottweiler Beds) | Quartzite Conglomerates with plant remains | Quartzite conglomerate | Wine-red conglomerate | | |
| Carbonides and Pre Carboniferous | Gneisses and schists of the Hercynian Basal Complex. | | | | |

¹⁾ Dozy, J. J. 1935, p. 158. ²⁾ Dozy, J. J. 1935. p. 59.

rise to what are called the basal tuffites as those seen between Val di Fiume and Val di Torre. Later on they become true lava flows and tuffs. The earliest flows in the Morcote peninsula are those of the biotite-porphyrates which are largely represented in the western half of the region. On the southern slopes of M. Arbostora they are covered by a considerable thickness of quartz-porphyrates and tuffs which are typically developed round Lauredo. Then followed thick sheets of andesitic lavas which occupy the whole region between M. Arbostora and Alla Ferrera along the eastern slopes of the peninsula; these are the basic "pyroxene"-porphyrites. These gradually pass into basic and then into acid tuffs which separate them from the overlying quartz-porphyrates. The latter types of rocks are well developed between Carona and Ciona but a pair of through faults has thrown the tuffs down to the level of Melide. During these later extrusive phases the granitic magma also poured out through long fissures running NE-SW giving rise to a thick sheet of granophyre between Figino and Carona. The main magmatic activity was coming to an end when the region was further intruded by a number of large and small dikes elongated roughly in NNE-SSW direction. After this the extrusive and intrusive activity came to an end but the magmatic effects persisted much longer, even as late as the Lower Triassic period. These post-volcanic phases produced tourmalinization, mineralization in miarolitic cavities and veins typical of the high temperature hydrothermal condition and at still lower temperatures lead to extensive hydrothermal alteration of the eruptive rocks.

E. THE TRIASSIC SEDIMENTARY ROCKS

Towards the end of the Permian the volcanic activity came to an end and a period of rapid denudation started. The sedimentation of chiefly volcanic detrital matter lead to the formation of conglomeratic rocks such as those exposed near San Martino and Mte San Giorgio which later gave place to calcareous sediments, the well known dolomites of San Salvatore. These sedimentary rocks do not occur within the boundary of the investigated area. They have been treated in detail by FRAUENFELDER (1916).

F. THE TECTONICS OF THE MORCOTE PENINSULA

In the last few pages we have seen that the principal geological units which constitute the Morcote Peninsula are the Hercynian metamorphic rocks and the Permian eruptive sheets. The Post-Permian sedimentary rocks are exposed north of the region under study.

The tectonic build of the peninsula has been shaped mainly by two orogenic movements: the Hercynian during the Carboniferous and the Alpine during the Tertiary. The effects of the former are largely hidden under the cover of Permian eruptives but have also been obliterated or modified by the effects of the Alpine orogenesis.

The Lugano district which lies to the south of the "root-zone" of the Alps running through Locarno and Bellinzona, has escaped the main phase of the Alpine folding but has suffered the later Insubrian phases, the dominant effect of which was to produce large-scale block faulting.

The tectonics of the porphyry district as a whole have recently been treated in detail, by DE SITTER (1939) who has traced a number of major systems of faults and folds running ENE-WSW. I, therefore, confine myself to a few observations regarding the Morcote Peninsula.

Not much is known about the Hercynian tectonics of these "Süd-alpine" regions. These parts of Europe form the "Rückland" in the ground plan of the Hercynian orogenesis and according to R. STAUB (1928, p. 190) have undergone an enormous degree of overthrust folding.

In the Morcote Peninsula the metamorphics are best exposed in the south-eastern part. It has been noted elsewhere that these rocks in the Castello-Morcote area show two distinct facies, namely the ortho-gneisses below and the para- or mixed-gneisses above, resting discordantly on them. There are indications that the former are intrusive into and, therefore, younger than the latter; the actual contact in this area, however, is tectonic. It appears, therefore, probable that the mixed-gneisses which in some places show extreme folding and plication have been thrust over the nonfolded granite-gneiss-massif, giving a miniature nappe structure developed during the main Hercynian folding.

The Permo-Carboniferous conglomerates which in Manno and Val di Colla were supposed to have been involved in the main Hercynian folding were shown by KELTERBORN to be Post-Hercynian in age and sunk down in the metamorphics through block-faulting. The conglomerates of the Morcote Peninsula which are not much younger than those of Manno, are distinctly discordant to the underlying gneisses and schists and therefore are later than the main Hercynian folding. They appear to have suffered tilting before they were covered by the Permian eruptives, which may be referred to the later tectonic phases of the same orogenesis.

The eruptive sheets of the Lugano district have suffered block-faulting on a large scale. Many of these faults run into the overlying sedimentary rocks of the Mesozoic age and are therefore clearly related to the Alpine orogenesis.

In the Morcote Peninsula many faults have been traced which could be classified broadly into two more or less distinct systems: one running ESE-WNW, and the other roughly NNE-SSW. The former is much more common and offers examples of horst- and trough-faults while step-faulting is quite general. The latter system though less common in this peninsula corresponds roughly with the major systems of the porphyry district viz. the Cuvio-Ardeno, the Marzio and the Piambello-Martica faults, which run nearly NE-SW (DE SITTER, 1939).

Among the numerous faults in the Morcote Peninsula the Sorello-Colombajo and the Rampiga-Ciona-Alla Ferrera faults are the most important. The former has a great throw to the north and is easily seen in the field at its two ends. Near Soresello the granophyre has a sharp E-W running junction against the metamorphics and the porphyrites. At Colombajo the metamorphics and the overlying conglomerates terminate abruptly against the porphyrites in the north and disappear under the lake. (Section Fig. 7 and Profile section A on the Plate.) The same fault has thrown down the Vico Morcote dike by over 70 m. near the sharp bend of the new road west of Colombajo. (Profile-Section B, Plate.)

There are a number of smaller faults which run parallel to this one and which have brought about the step like breaks in the two big dikes between Morcote and Villa Miramonte.

The Ciona-Alla Ferrera faults are an example of the horst-type in which the metamorphics are thrown up like a wedge between the eruptives in the south and the dolomites in the north. This fault is a continuation of the big Grantola-Barbengo fault and terminates to the east against the Lugano Fault near Campione. (Sections Figs. 2 and 3 and Profile sect. C, Plate.)

Another significant system of faults runs between Garaverio and Melide. It includes a system of trough faults which brought about the downthrow of the porphyry tuffs between the "pyroxene"-porphyrites on either side. These faults continue to the east across the lake to Bissone and Ca Nova, while in the west they terminate on the Barbengo faults.

Of the NNE-SSW running faults one pair can be located in the Vedo amphitheatre. One fault runs along Val di Fiume and has

brought the quartz-porphyrines and tuffs of Lauredo against the basal tuffites showing a downthrow to the west. The other fault runs a little to the east, partly along Val di Gaggio, and is very clearly seen along the craggy line near the pt. 609 (due west of Vico Morcote) where the quartz-porphyrines show a sharp contact against the biotite-porphyrines. The same fault is traceable in Val di Torre. These two faults cannot be properly followed further to the north but probably find their continuation in the two faults near Carona.

The Morcote peninsula is thus characterized by extensive block-faulting brought about during the late tectonic or insubrian phases of the Alpine orogenesis. The geological history of the region is also quite distinct from that of the main Alpine belt: the basal complex with its typical Hercynian build, the discordant deposition of the Permo-Carboniferous sediments, the thick cover of the Permian eruptive sheet and the dominant southern facies of the Trias all mark this as a typical "sud-alpine" region.

Part II. Petrography

A. THE CRYSTALLINE GROUND COMPLEX

The field observations in the Castello-Morcote region have shown that the rocks of the basal complex in this Peninsula can be divided into at least two very distinct groups: the ortho-gneisses below and the para-schists above. The junction of these two major groups which runs along the line joining Castello and Morcote church down to the lake is not one of concordance but is marked by a thin zone of tectonic breccia representing probably a plane of hercynian overthrust. Above the gneisses lies a thick series of biotite-schists, gneisses and quartzites which make up the bulk of the ground complex of the Morcote Peninsula. The ortho-gneisses are confined to the region between Val di Torre, Castello and Morcote and form the core of the crystalline rocks of the south-eastern outcrop.

Although no pronounced contact effects could be seen along the junction, it is not impossible that the extensive development of tourmaline, garnet and other contact minerals for which the presence of a subjacent granitic mass was invoked by ESCHER and others, has been brought about by this granitic mass. If this were true the ortho-gneiss group would be younger than the overlying zone of para-schists.

1. Ortho-Gneisses

These ortho-gneisses are almost identical with the biotite-granite-gneisses of Malcantone described by KELTERBORN (1922). It also seems quite likely that the fine-grained nonfoliated pink gneisses described by KUENEN (1925, p. 149) from east of Brinzio may belong to this group.

Within the group of ortho-gneisses as exposed west of Morcote, three more or less well defined rock-types can be recognized (see fig. 5):

- a) Biotite-granite-gneiss at the base;
- b) Microcline-granite-gneiss in the middle, and
- c) Aplitic granite-gneiss at the top.

These three rock-types are not separated by sharp dividing lines but usually grade one into the others and possibly represent the differentiates of one intrusive mass.

Within these gneisses were found a few thin bands of dark compact hornfels with an extreme development of tourmaline suns. These probably represent intercalations of older sedimentary rocks. One such band over a metre thick is exposed along the foot-path a little west of Morcote church. Another similar band was traced in Val di Torre.

a) The Biotite-Granite-Gneiss

This is the lowermost of the three types and is best exposed along the eastern slopes of Val di Torre; another small outcrop has been exposed on the main road along the lake near the steps going up to the Morcote church.

It is a nicely foliated grayish dark rock with abundant flakes of dark mica alternating with grayish white bands of quartz and feldspar.

Under the microscope the rock shows a coarse-grained granoblastic texture with quartz and orthoclase as the main components and with acid plagioclase and biotite as the subsidiary minerals. As accessories occur zircon, apatite and zoisite.

Orthoclase is generally sericitized and is often replaced by myrmekitic growths of quartz and plagioclase. Quartz is clear and usually xenomorphic; sometimes it occurs as rounded or oval drops showing a distinctly higher relief against the turbid orthoclase. It shows a strongly undulating extinction and has frequently featherlike strain lines similar to those described by KELTERBORN from biotite-granite-gneiss of Novaggio (1922, p. 163).

Plagioclase is usually in much smaller grains and is easily distinguished by its thin lamellar twinning giving an extinction angle of about 15° . Biotite has a linear development but the individual flakes are frequently bent giving

a strained extinction. It is commonly fresh and gives pleochroism in light greenish brown and deeper brown colours. It has frequent inclusions of zircon and apatite.

Among the accessories, zoisite is the most common and occurs in medium to small, rounded or elongated grains which are clear. It has a high relief and low birefringence and in these respects resembles apatite but is distinctly biaxial positive. Zircon is fairly common as inclusions in biotite, but apatite is much less frequent.

b) The Microcline-Granite-Gneiss

This is a hard compact pinkish rock with a weakly developed foliation. It occurs as a thick band above the biotite-granite-gneiss and is nicely exposed on the higher slopes W and SW of Castello; it is also observed along the foot-path west of the Morcote church. In the field it is easily distinguished from the biotite-gneiss by its pink colour and very subordinate development of biotite, so that the rock appears somewhat massive.

Under the microscope the rock is characterized by its larger content of plagioclase and microcline in fairly large individuals and by its poverty in biotite.

Quartz, orthoclase and biotite have the same habit as in the first group except that the latter two occur in much smaller quantity. Much of the alkali feldspar is of the microcline variety which is recognized by the typical cross-hatching between crossed nicols. In some individuals this grating structure is only faintly developed while in others the irregular flecky undulating extinction alone is suggestive of the microclitic nature of the alkali feldspar. It is generally clear and has distinctly lower refringence than quartz. It is always xenomorphic, occupying the interspaces between other mineral grains.

Plagioclase occurs in large xenomorphic crystals with distinct lamellar twinning giving an extinction angle of 12° — 15° . It is usually dusty with brown secondary products and is frequently replaced by myrmekitic quartz.

Biotite varies in amount in different slides and is usually altered to a dark brown ferruginous product. The rock is on the whole poor in accessories, among which zircon and zoisite can be made out. A few specks of irregularly developed bluish green tourmaline were noted in one of the slides.

c) The Aplitic Granite-Gneiss

This grayish white rock with the appearance of a graphic granite or a faintly foliated quartzite occurs along the southern slopes of Castello and constitutes the craggy part of Sasso Bissolo between Castello and Morcote church. It lies everywhere above the microcline-granite-gneiss.

Under the microscope are seen only quartz and alkali feldspar, the latter being altogether altered into sericite. Biotite is very meagre and is completely bleached to muscovite and a skeleton of iron ore.

The three types of gneisses described above form one continuous series of rocks showing gradual transitions from one to the others. They differ among themselves mainly in the content of biotite which also determines the degree of schistosity of the rock. Quartz, orthoclase and plagioclase are the common constituents but the middle type is particularly rich in microcline.

In these rocks no aluminous minerals of the andalusite group, or minerals like staurolite or garnet have so far been detected. Tourmaline, also, has been only rarely observed. On the other hand these minerals have an extraordinary development in the overlying schists. It appears, therefore, very likely that the gneisses described above, were originally intrusive rocks of granitic composition in which differentiation in situ gave rise to the three rock-types; they are also responsible for the contact metamorphism of the older para-schists. These granitic rocks originally formed a large laccolithic mass continuous with the one exposed in Malcantone to the north-west. Later these were metamorphosed during the Hercynian folding.

2. The Mixed Gneisses and Schists

Above the ortho-gneisses lies a highly heterogenous group of metamorphosed sediments which forms by far the largest part of the ground complex in the Morcote Peninsula. The rock-types included in this group are mica-gneisses and schists, quartzites, mylonite- and psammite-gneisses showing a large variation in composition and degree of metamorphism. In some places the schists are highly plicated and faulted and the brecciation has led to the formation of abundant mylonite. There is again a large scale injection whereby the rocks are in places thoroughly permeated by small veinlets of quartz. Tourmalinization is also very widespread.

Among the rock-types of this group the garnetiferous biotite-gneisses and the psammite-gneisses are the most common. There is no distinctive distribution of these rock-types in the field, all the different varieties occurring together in all the outcrops. The micaceous rocks however appear to dominate in the southern half of the Morcote-Colombajo outcrop whereas in the northern half hornfelsic psammite-gneisses are more abundant. In the Grancia-Alla Ferrera section the mica-schists are the more common while in the western outcrop south of Soresello both types are generally found.

a) *Biotite-Gneisses* (Mixed Type)

These rocks which are fairly widespread in all outcrops are easily distinguished in the field by the abundance of pinkish-dark biotite

which imparts to the rock a highly schistose appearance. In some rocks brownish silvery mica abounds, part of which is probably an altered variety of biotite.

In thin sections the rock shows a coarsely foliated texture in which thin wavy bands of quartz and feldspar are separated by thin elongated lamellae of biotite.

The main components of the rock are quartz, orthoclase, acid plagioclase, biotite and frequently muscovite. Beside the common accessories like zoisite, zircon, apatite?, rutile and iron ore, many rocks show a good development of garnet, staurolite and kyanite; tourmaline is also very widespread.

Quartz and orthoclase generally occur together in bands parallel to the foliation; they are both xenomorphic with zigzag junction lines and probably represent the crystallization of aplitic material injected into the clayey sediments. Orthoclase is always dusty or sericitized. A faint lamellar twinning frequently discloses the acid plagioclase. Biotite is very abundant and is always elongated parallel or sub-parallel to the foliation forming a sort of lattice or net within which are developed garnet, staurolite and kyanite; it shows a characteristic pleochroism in red-brown but is sometimes altered to chlorite or bleached to muscovite.

Garnet is the most commonly developed aluminous mineral inside or outside the biotite flakes; it is normally colourless with minute inclusions and has always a sieve structure. Staurolite is usually in rounded or irregularly broken fragments and rarely shows any crystallographic outline. It has the characteristic golden yellow colours with a distinct pleochroism; it has a high relief with moderate to low birefringence; frequently garnet crystals are seen developed within it. Kyanite is generally tabular or columnar, elongated parallel to the biotite flakes; it has a good pinacoidal cleavage, high refringence and moderate birefringence; a few individuals show faint pleochroism in light blues. Among the accessories zoisite is here again very common, in rounded, oval or rectangular grains, colourless with high relief. Zircon and rutile have also been frequently noted.

Tourmaline occurs fairly abundantly in short stumpy prisms as also in acicular aggregates, sometimes around biotite showing a distinct reaction zone.

Andalusite was reported from gneisses near Soresello by ESCHER and from Silva Piana (on the other side of the lake) by RIVA and ESCHER (ESCHER 1913, p. 723). On the strength of this, ESCHER regarded the metamorphic rocks of the Morcote Peninsula as andalusite-contact-gneisses. Andalusite has not come to my notice in any of the numerous slides examined by me from this region. If present at all it must be very rare in these rocks.

The abundant development of such minerals as garnet, staurolite and kyanite in these biotite-gneisses and schists, is typical of the dynamothermal or dislocation metamorphism of argillaceous sediments in the meso-zone. It therefore appears to me that the basal rocks of the Morcote Peninsula have undergone a predominantly

dynamothermal metamorphism during the main Hercynian folding. This was supplemented by injection and tourmalinization deriving from the laccolithic intrusions of the ortho-gneisses described above.

b) The Psammite-Gneisses

These are the higher members of the "Paraschiefer-Zone" and have their greatest development in the Vico Morcote-Colombajo section. They show on the whole a lower degree of metamorphism than the mixed biotite-gneisses, the principal effect being epizonal, of a cataclastic nature.

These rocks are dark gray, usually fine-grained and partly conglomeratic and are extremely heterogeneous both in texture and composition. In some cases the rock resembles a tuff-breccia; it is however a wholly detrital product formed by the breaking and crushing of the older quartzitic and gneissose rocks during the main phases of the Hercynian folding and which itself suffered folding during the later phases of that movement.

The rocks are hard and compact with only ill-developed bedding and foliation; the abundant injection in these rocks has, in some places, given them a gneissose appearance.

The usual mineral components are: abundant quartz in small interlocking grains, a variable quantity of dusty or sericitized feldspars, a few flakes of muscovite and occasional rounded grains of zircon and fragments of garnet. Pyrite in well-formed crystals is of general occurrence. Tourmaline is also very frequent in these rocks.

Besides these two dominant types a variety of other rocks with very restricted development is met with. Thin layers of more or less pure quartzite, micaceous quartzite and other intermediate types have been traced in several localities.

It is thus seen from the above description that the rocks of the crystalline ground complex in the Morcote Peninsula are in most respects identical with those of Malcantone to the north-west described by KELTSBORN (1922) except that a few types of the mixed-gneisses containing sillimanite, hornblende and actinolite and the intercalations of amphibolites described from the other region have not been found in the Morcote Peninsula.

It may also be noted here that some of the rocks rich in brownish or silvery mica as those of Grancia which show very few effects of metamorphism may be referred to what KOENIGSBERGER has called the "Carboniden" of the neighbouring regions (J. KOENIGSBERGER, 1928).

B. THE MAIN ROCK-TYPES OF THE LUGANO PORPHYRIES

1. The Diabase (Basalt), Type A *)

This is the most basic rock-type so far found in the Lugano porphyry district. It occurs as a lamprophyric dike cutting through the granophyre sheet near Borgnana on the other side of the lake, only 2 km. SW of Morcote (DE SITTER 1925, p. 241). No rocks of this type have come to notice from the Morcote Peninsula nor have they been recorded from other parts of the main Lugano outcrop, but the basaltites described by HARLOFF (1927, p. 181—185) from Mesenzana and Ponte Cremenaga in the Grantola Region and analysed by KOOMANS (Nos. 33 and 34, Tab. 16) are distinctly referable to this type.

The diabase dike is a fine-grained, dark gray rock which has assumed a deep green aspect due to intense alteration. In hand specimens abundant plagioclase crystals can be seen which make up the major part of the rock.

The microscope shows numerous plagioclase phenocrysts irregularly distributed with magnetite and other dark minerals in an ophitic groundmass. The plagioclases are largely decomposed and are replaced by calcite, while the dark minerals are totally altered to chlorite. Other minor minerals are biotite and apatite.

The basaltites of the Grantola region are also fine-grained dark gray rocks but are much less decomposed and under the microscope show clear evidence of enstatite and basic plagioclases in a glassy groundmass. In some rocks as those of Cremenaga the groundmass is holocrystalline with minute laths of plagioclase in sub-parallel orientation.

The plagioclases in these rocks have a content of 60—90 % anorthite. This observation together with the presence of undoubted enstatite has rightly lead HARLOFF to designate these rocks as basaltites.

The chemical composition of these rocks has been published by KOOMANS who gives the following NIGGLI values for them. (Refer Table 16):

| | si | al | fm | c | alk | k | mg |
|------------------|-----|------|------|----|-----|------|------|
| Diabase | 124 | 26 | 42 | 25 | 7 | 0,39 | 0,62 |
| Basaltite No. 34 | 140 | 24,5 | 38,5 | 29 | 8 | 0,30 | 0,58 |
| No. 33 | 151 | 27 | 41 | 23 | 9 | 0,39 | 0,60 |

The magma composition thus varies between the c-gabbroid and achnahaitic magma-types of NIGGLI, the values of which are:

*) The derivation and significance of types A to H is explained on page 253 See also Table 18.

| | si | al | fm | c | alk | k | mg |
|-----------------|-----|------|----|------|-----|------|------|
| c-Gabbroid | 115 | 25 | 44 | 25 | 6 | 0,20 | 0,50 |
| Achnahaitic | 119 | 27 | 40 | 29 | 4 | 0,2 | 0,60 |
| Leucomiharaitic | 140 | 26,5 | 38 | 26,5 | 9 | 0,2 | 0,50 |

All these types belong to the basic magmas of the Circum-Pacific eruptive provinces and are usually represented by gabbros, basalts and andesites.

The kata-molecular norm given below for the Lugano type A, represented by the diabase under discussion shows a very low content of calcic pyroxene molecule W_o , and a fairly high content of ferromagnesian pyroxene molecules. This shows that the rhombic pyroxenes dominate over the monoclinic variety as is clearly seen in the basalite of Mesenzana (No. 33). Lime-poor hornblende is also a possibility.

Kata-norm for type A

| | | | | | |
|-----------|-----------|-----------|----------|----------|--|
| Or = 10,2 | Ab = 15,5 | An = 37,6 | | | |
| Wo = 3,6 | En = 20,6 | Hy = 6,3 | Mt = 3,0 | Ap = 0,3 | |
| Qz = 1,8 | Ru = 1,3 | | | | |

As regards the feldspathic molecules, a part of these may go to the formation of augite, hornblende or biotite which have been noticed in the rocks, but the major part remains which gives a plagioclase very rich in anorthite, of the type of labratownite, while Or occurs in the groundmass. Thus the over 35 % of normative dark minerals, the highly basic plagioclase and an insignificant quantity of (normative) quartz definitely put this rock-type in the basalt group which according to NIGGLI contains over 37 % melanocratic constituents and a basic plagioclase containing over 62,5 % An.

The following rocks may be cited which show a closely similar composition:

Table 2

| Rock and locality | si | al | fm | c | alk | k | mg |
|--|-----|------|------|------|-----|------|------|
| Olivine-basalt, Nicaragua (BURRI, 1936) | 131 | 25,5 | 38,5 | 27 | 9 | 0,24 | 0,48 |
| Basalt-lava, Panama (BURRI, 1936) | 127 | 25 | 41 | 26 | 8 | 0,14 | 0,49 |
| Gabbro, Kittitas Co., U. S. A. (G. O. SMITH, U. S. G. S. Fol. 106, p. 6, 1904) | 138 | 25 | 39,5 | 27,5 | 8 | 0,18 | 0,51 |
| Gabbro, Elkhorn, U. S. A. (J. S. BARREL, U. S. G. S. A. R. 22, II, p. 514, 1901) | 112 | 25,5 | 41,5 | 25,5 | 7,5 | 0,24 | 0,48 |
| Tholeiite, (P. NIGGLI, Das Magma II, not yet published) | 122 | 24 | 39,5 | 27,5 | 9 | 0,29 | 0,51 |
| Biotite-augite-diorite Brocken Massif (TRÖGER, 1930) | 133 | 24,5 | 42 | 24 | 9,5 | 0,27 | 0,54 |

It is seen from this comparison that when the magma of the composition of our diabase crystallizes under deepseated conditions it commonly gives rise to gabbros while under volcanic conditions it yields basalts. It is further interesting that at least two of the above rocks, the Nicaragua basalt and the tholeiite contain a good amount of olivine beside pyroxenes. Thus the same magma under different conditions may give rise to different mineral combinations. In the above examples:

Tholeiite or Olivine basalt containing } = { Gabbro or Diorite containing
Olivine + pyroxene + plagioclase + glass } { augite + plagioclase + biotite + quartz

Olivine and pyroxenes have crystallized under drier conditions in a basalt than the biotite combination which has been developed under more hydrous conditions. This is a fine example illustrating the heteromorphism of the magmas.

It may again be noted here that relicts of olivine have been noted in the vitrophyres of the Grantola region by HARLOFF and others. According to HARLOFF olivine is an abundant constituent (1927, p. 190). I have seen a slide of vitrophyre from Grantola in the collection of rock-slides by ROSENBUSCH in Zurich and the mineral distinctly appears as a relict. This proves that the Lugano magma has during some stage of its differentiation yielded olivine, which as we have seen is quite possible from a magma like the diabase Lugano type A.

2. The Porphyrites (Types B to F)

The porphyrites in general form a very comprehensive group of rocks and include a large variety of types. In the Morcote Peninsula they cover more than half the area and particularly the higher parts of M. Arbostora and the whole of the eastern slopes between Colombajo and Alla Ferrera. They also occur on the southern, western and north-western slopes. In the Lugano porphyry district in general they are dominant in the eastern part and have important outcrops in the western. They range in composition from gabbro-dioritic to acid opdalitic magmas. Beside the pure types there are also others which through contamination by other rocks now appear as tuffs, agglomerates and also as ash-beds. Owing to the intense hydrothermal alteration these rocks have assumed an aspect which makes it hard to distinguish the various types in the field and hence to map them separately is very difficult if not impossible. The microscopic examination of the rocks, however, helps us in a certain measure to distinguish the major types and with the help of numerous rock-

slides it has been possible to fix some approximate boundary lines between these major divisions of the porphyrites.

In this direction the Leiden school of petrologists has done a great amount of work on the Lugano porphyries. They have classified the porphyrite group into the following three broad divisions:

the pyroxene-porphyrites,
the quartz-bearing biotite-porphyrites and
the porphyritic tuffs and agglomerates.

Since the rocks of the third division have a very irregular distribution and show gradual transitions into other rock-types including acid tuffs and porphyries, they have not been mapped separately as an independent group.

The first two sub-groups alone are, to a certain extent, susceptible to field mapping and this has been accomplished in the recent map published by DE SITTER (1939). I had come to similar conclusions purely on the basis of field work in the Morcote Peninsula where an almost identical succession of lava flows was recognized.

a) The Basic ("Pyroxene") Porphyrites or Andesites (Types B to E)

The first group which may preferably be called the basic porphyrites includes all the dark porphyrites in which biotite is either absent or insignificant as a dark constituent of the rock. The rocks show a strong variation in colour but the dominant types are dark to pinkish gray, whereas the alteration of the dark minerals has usually imparted a greenish tinge. All gradations to biotite-porphyrites are known and a clear distinction between these two types is not always possible even under the microscope. The name pyroxene-porphyrite, at least for the Morcote rocks, is not quite apt since no trace of original pyroxene has been detected so far. Only the octagonal or rectangular outline of the green secondary product is indicative of the original pyroxene, but hornblende or even biotite may sometimes give similar forms. The chemical composition discussed in another chapter does not give any definite indication of augite as a significant dark mineral in these rocks, whereas orthorhombic pyroxenes, pigeonites or even hornblende seem more likely to have been represented.

The group of "pyroxene"-porphyrites is in itself a fairly comprehensive one and includes rock-types of variable chemical and microscopical characters. On the basis of chemical composition three types have been recognized in this group, namely B, C and D, while a fourth type, E has also some similarity to this group (see Tab. 18).

Of these types B and C are closely allied whereas type D differs considerably from the others. Under the microscope two fairly distinct types of textures have been observed in the rocks of this group. In the less common one the groundmass has a fine-grained holocrystalline texture in which small plagioclase laths show a parallel or sub-parallel arrangement giving a type of fluidal texture. In the second, which is much more common, the groundmass is hyalopilitic containing feldspar microliths irregularly distributed in a glassy, now devitrified, base. The first type of texture with fluidal holocrystalline groundmass has been characteristically observed in the rock of type B, from Marzio, while the rocks of type D have generally shown the hyalopilitic groundmass. Though textures can never be a sure guide to the chemical nature of a rock it has been attempted to study the distribution of these two types B and D separately.

a) Basic ("Pyroxene") Porphyrites of Type B (and in part, C)

The magmatic rock-type B could, unfortunately, be based on only one modern analysis, that of the pyroxene-porphyrite of Marzio by KOOMANS (anal. no. 8 given on p. 84). However, an old analysis by A. SCHWAGER and quoted by T. HARADA (1883, p. 18) (given as anal. P) is available for a porphyrite south of Brinzio. It is very similar to that from Marzio. Moreover, the two analyses from the "Luganensee" and Arogno by J. JAKOB representing the type C are much allied to type B. Further, the analysis No. 31 from the Grantola region is also closely related to this group. Thus this group of porphyrites appears to be well represented in the porphyry district.

The porphyrite of Marzio has been described by DE SITTER (1925, p. 223). The rock is dark and decomposed and plagioclase phenocrysts and chloritized dark minerals are clearly visible in the hand-specimen; it also contains numerous cavities filled with secondary minerals like zeolites, chalcedony, chlorite etc.

Under the microscope the rock is characterized by a holocrystalline groundmass composed of small plagioclase laths and rods in sub-parallel arrangement giving a fluidal texture. Among the phenocrysts plagioclase dominates; and has an anorthite content of 45 %. The dark minerals are totally altered to chlorite but the idiomorphic outline suggests a pyroxene as the original mineral. Magnetite as a primary mineral is very abundant and is probably responsible for the high basicity of the rock; it occurs between the plagioclase laths of the groundmass.

The rocks with this type of texture are not common among the porphyrites of the Lugano district. The closest similarity to this type

is provided by the porphyrite described by D. J. DOEGLAS from Val Sovaglia (1930, p. 378—9). Under the microscope the rock appears to be wholly composed of fluidally arranged plagioclase laths with magnetite grains finely distributed in between. Phenocrysts of plagioclase are sporadic. Dark minerals occur only in the groundmass. DOEGLAS found similar rocks SE of Arogno and on the eastern side of Mte San Giorgio. It is quite possible that the analysis B by JAKOB belongs to one of these rocks from Arogno in which case they can be safely included in this group of "basic"-porphyrites.

KUENEN also mentions the occurrence of similarly textured rocks from SW of Brinzio (1925, p. 156). If SCHWAGER's analysis refers to these rocks they must also be included in this group.

In the Morcote Peninsula, however, no exactly similar textures have been found in the pyroxene-porphyrites, but a number of these rocks particularly from the northern part of the peninsula between Garaverio and Alla Ferrera do show a fluidal arrangement of extremely minute plagioclase crystallites while magnetite grains are also abundantly present. Since no definite analyses of these rocks are available no proper comparison can be made. It is however possible that the analysis No. A by JAKOB corresponds to one of these. Should this be the case the occurrence of porphyrites of this group within the Morcote Peninsula can be expected in its northern parts.

It appears to me quite probable that the Marzio porphyrite represents the youngest of the pyroxene-porphyrite flows and that its main development is along the northern margin of the porphyry district largely covered by the later eruptives, the granophyres, the quartz-porphyrines and tuff and also faulted down by later tectonic movements. The main Marzio porphyrite band would then extend through Garaverio, below the Boll hill, south of Alla Ferrera to Arogno. Another band may be along the southern boundary which includes the outcrops of Brinzio, Mte San Giorgio and Val Sovaglia.

Chemically this group is characterized by the following molecular values:

| | si | al | fm | c | alk | k | mg |
|--------------|-----|----|----|----|-----|------|------|
| Magma-type B | 155 | 26 | 44 | 15 | 15 | 0,56 | 0,56 |
| Magma-type C | 188 | 27 | 39 | 19 | 15 | 0,41 | 0,41 |

In the kata-norm of Type B the content of Wo (2,5 %) is small as compared to 24,5 % of En + Hy + Mt indicating a large content of orthorhombic pyroxenes or pigeonite or of hornblende. Quartz is also comparatively low. But the most striking feature is the extraordi-

narily high content of normative orthoclase which is probably hidden in the groundmass. If a part of the normative feldspathic molecules goes to form dark minerals the proportion of the latter would approach the lower limit for the basalts. Hence the type is either a trachydolerite or a trachyandesite and the high content of orthoclase relates it to palatinite. Type C on the other hand is a little more acidic than the above and is, therefore, a true andesite.

The following rocks may be cited as close equivalents to these basic porphyrites, those corresponding to type B are:

Table 3

| Rock and locality | si | al | fm | c | alk | k | mg |
|--|-----|------|------|------|------|------|------|
| Corresponding to Lugano Type B: | | | | | | | |
| Basalt, Yellowstone N. P., U. S. A. (IDDINGS, U.S.G.S., Mon. 32II, 1899) | 133 | 25 | 44,5 | 17,5 | 13 | 0,40 | 0,59 |
| Lamprophyre, Riesengebirge (TRÖGER, 1930) | 143 | 25,5 | 44,5 | 14,5 | 15,5 | 0,44 | 0,56 |
| Minette (TRÖGER, 1935) | 139 | 23,5 | 45,5 | 15 | 16 | 0,51 | 0,63 |
| Hornb.-porphyrite, Marysville, U. S. A. (BARREL, U.S.G.S., Pr. P. 57, 1907) | 170 | 27,5 | 41 | 16,5 | 15 | 0,31 | 0,69 |
| Magma-type lamprosyenitic | 150 | 23 | 46 | 13 | 18 | 0,6 | 0,6 |
| Magma-type lamprosommaitic | 135 | 22,5 | 46,5 | 18 | 13 | 0,5 | 0,6 |
| Corresponding to Lugano Type C: | | | | | | | |
| Diabase, Kittitas Co. Wash., U. S. A. (SMITH, U.S.G.S., Fol. 106, 1904) | 181 | 24 | 43 | 20 | 12 | 0,25 | 0,18 |
| Basalt, Denver, Colorado (CROSS, U.S.G.S., Mon. 27, 1896) | 143 | 28,5 | 39,5 | 21 | 14 | 0,46 | 0,46 |
| Enstatite-porphyrite, Elbingerode (TRÖGER, 1930) | 168 | 27 | 41 | 19 | 13 | 0,41 | 0,53 |
| Syenite, Reichenstein (TRÖGER, 1930) | 216 | 25,5 | 40 | 18,5 | 16 | 0,49 | 0,40 |
| Shoshonite (TRÖGER, 1935, No. 269) | 150 | 28,5 | 36,5 | 19,5 | 15,5 | 0,44 | 0,51 |
| Magma-type Vredefortitic | 250 | 28 | 42 | 17,5 | 12,5 | 0,5 | 0,4 |
| Magma-type lamprodioritic | 150 | 25 | 40 | 21,5 | 13,5 | 0,25 | 0,5 |

From the above comparison it is seen that this basic porphyrite group has a composition between the lamprosommaitic and vredefortitic magmatypes and with some variation in silica-content corresponds to a variety of rock-types ranging from basalts to andesites.

β) Basic Porphyrites of Type D (incl. part of C)

This group of porphyrites is more abundant and better represented than the last, not only in the Morcote Peninsula but in the porphyry district as a whole. The most typical rock of the group in the Morcote region is exposed in the cuttings of the new Carona-

Vico Morcote road above the sharp bend and the same band continues to the hill top pt. 826. To the west of this it is again nicely exposed by a rock-slide. The whole of the eastern slopes north of Colombajo are composed of rocks of this group.

These rocks are normally fine-grained porphyritic and show various shades of colour from dark gray, chocolate brown to grayish greens due mainly to weathering. In handspecimens abundant crystals of whitish plagioclase and nests of greenish dark minerals are visible, set in an aphanitic base. Inclusions of older porphyrites and even of schists are seen in many rocks; part of these with abundant foreign inclusions may be taken as tuffs rather than as true porphyrites.

Under the microscope are seen relatively large phenocrysts of twinned plagioclases and chloritized dark minerals distributed in a cryptocrystalline or glassy groundmass. The plagioclases are commonly twinned according to the Albite-Law and give an extinction angle of $16-22^\circ$ and biaxial positive figures. Measurements on the U. Stage have given an anorthite content ranging from 50 to 58 %. (See Table 39, p. 298.) These plagioclases are well zoned, the central, more basic, parts showing advanced alteration into sericite whereas the outer shells are much clearer partly on account of albitisation. A few of the feldspar phenocrysts are untwinned and some others show Carlsbad twins and give very low extinction angles and biaxial negative character. They are most probably orthoclase. Quartz is altogether rare as a primary mineral among the phenocrysts, but clusters of secondary quartz are fairly common.

Among the dark minerals no fresh mineral-grains have been observed. They are mostly altered to chlorite, often retaining the original idiomorphic outline which may suggest a pyroxenic origin.

As accessories occur apatite and magnetite. Owing to the resemblance of apatite with zoisite which is also quite common in these rocks, one may be mistaken for the other. Magnetite is also largely of secondary origin. Zircon has not been found in any appreciable quantity.

Among the secondary minerals sericite and chlorite are the most abundant, the former within the feldspar crystals and the latter associated with magnetite and quartz as an alteration-product of the dark minerals after which it is often pseudomorphic. Chlorite is usually of the penninite variety, pleochroic in light and deep greens and giving bluish polarization colours. In some of the slides secondary hornblende is seen abundantly developed within the dark minerals; it occurs as minute elongated prisms sometimes radially arranged, but more commonly irregularly distributed in clusters. It is distinctly pleochroic in greens and has moderate birefringence. Zoisite is seen developed in most rocks in short stumpy rounded or rectangular grains of varying sizes and very much resembles apatite. It is however distinctly biaxial positive and is always associated with secondary hornblende, chlorite and iron ore.

Epidote and calcite are abundantly developed in many slides. They replace both the feldspars and the dark minerals and also occur in cavities and cracks and have evidently been formed by the circulating hydrothermal solutions.

Iron ore is abundantly developed as a secondary product chiefly as magnetite but besides this is also seen a brownish alteration product which is isotropic; this is probably stilpnomelane.

Among other minerals tourmaline is occasionally seen as solitary well developed crystals with zoning and the characteristic pleochroism. It is also seen as irregular growths along cracks and cavities.

Garnet has been found in these porphyrites as individual large rounded crystals showing advanced decomposition. It is distinctly an inclusion from the underlying schists which contain this mineral in abundance. It has been found in specimens from SE and NE of Garaverio. ESCHER also found garnet in porphyrites from Miramonte and Cantine Codato and GIRARD found it in porphyrite from Melide (ESCHER, 1913, p. 730).

The groundmass of these porphyrites shows much variation in texture. It is in most cases micro- to cryptocrystalline and is partly ?glassy. It shows signs of devitrification but the texture is usually obscured by dusty ferruginous material. Under high magnification minute feldspar laths can be observed which are generally irregularly distributed, but in some cases a distinctly parallel disposition of these crystallites could be seen. Orthoclase could only be recognized with difficulty particularly owing to limonitisation. Quartz in minute clear grains occurs within the interspaces and is always allotriomorphic. Chlorite, calcite and dust of brown iron ore are distributed throughout the groundmass.

The rocks also contain inclusions in variable quantities particularly of other porphyrites but sometimes also of schists and quartzites.

Chemically this group of porphyrites is very well known through about half a dozen good analyses from different parts of the porphyry district (see Table 18). The molecular values for type D are:

| | si | al | fm | c | alk | k | mg |
|--|-----|----|----|----|-----|------|------|
| | 199 | 34 | 33 | 18 | 15 | 0,48 | 0,43 |

These values correspond to those of the opdalitic and normal quartz-dioritic magma-types whose values are:

| | | | | | | | |
|-----------------------------------|-----|----|----|----|----|------|------|
| Opdalitic magma-type | 225 | 32 | 32 | 18 | 18 | 0,45 | 0,45 |
| Normal quartz-dioritic magma-type | 225 | 32 | 31 | 19 | 18 | 0,25 | 0,45 |

The Lugano type E which is based on a single porphyrite analysis from Morcote has nearly the same values as the above type D but the field relations and the abundant occurrence of biotite relate it more closely to the group of biotite-porphyrites.

The kata-norm of type D is:

| Or | Ab | An | Wo | En | Hy | Mt | Qz | Ru | Ap |
|------|------|------|----|-----|-----|-----|------|-----|-----|
| 20,5 | 21,7 | 26,6 | — | 8,1 | 3,2 | 3,7 | 15,4 | 0,5 | 0,3 |

The total absence of normative Wo and a fair content of other femic normative minerals indicate that the dark mineral is either an ortho-

rhombic pyroxene or a biotite since both augite and hornblende necessarily call for a certain amount of Wo. The normative feldspars again show a high content of orthoclase molecules. It is possible that a good proportion of this goes to form biotite while the remainder forms a component of the groundmass either alone or as microperthite. One of the rocks of this group, however, showed the definite occurrence of hornblende which indicates that a part of the lime now in An must have originally been in Wo. But the hornblende must all the same be a lime-poor variety.

The proportion of normative anorthite is sufficiently high to give the basic plagioclase occurring in the rocks of this group. A remarkable feature, however, is the content of Qz which is much higher than in the previous groups. The rocks, therefore, appear to be quartz-bearing basic porphyrites.

The presence of labradorite, orthoclase and quartz places these rocks among the quartz-trachydolerites of CROOK'S and JOHANNSEN'S classifications (A. HOLMES, 1920).

The following rocks show a comparable composition:

Table 4

| Rock and locality | si | al | fm | c | alk | k | mg |
|---|-----|------|------|------|------|------|------|
| (Lugano Type D) | 199 | 34 | 33 | 18 | 15 | 0,48 | 0,43 |
| Hornblende-andesite, Mexico (H. LENK in FELIX u. LENK, Bd. G Mexico, II, p. 229, 1899) | 197 | 34,5 | 33 | 19,5 | 14,5 | 0,34 | 0,55 |
| Hypersthene-andesite, Montana, U. S. A., (MERRILL Proc. U. S. Nat. Mus. XVII, p. 651, 1895) | 199 | 32,5 | 33,5 | 17,5 | 16,5 | 0,36 | 0,49 |
| Hornblende-monzonite, Engadine (NIGGLI, 1923, p. 117, No. 12) | 210 | 32 | 34 | 18,5 | 15,5 | 0,39 | 0,44 |
| Quartz-monzonite, Engadine (NIGGLI, <i>ibid</i> , No. 4) | 243 | 34 | 31 | 19 | 16 | 0,50 | 0,64 |
| Qz-monzonite, Boulder Mt, Mont., U. S. A., (NIGGLI, <i>ibid</i> , No. 8) | 218 | 32,5 | 32 | 18,5 | 17 | 0,48 | 0,48 |

γ) Basic Biotite-Porphyrites of Type E

These are the rocks which in chemical composition show similarity to the previous group of basic porphyrites Type D but which in field relations and in the development of biotite as the principal dark mineral are allied to the acid biotite-porphyrites of type F.

As developed in the Morcote Peninsula they are among the earliest flows, lying directly over the metamorphic rocks. The geological field-relations suggest that these flows (see Fig. 1) are almost

contemporaneous with the biotite-porphyrite flows to the north-west from which they are altogether detached.

These rocks occur as a small thin flow close to Morcote. They are, however, best exposed east of Castello, while their isolated outliers and exposures can also be seen in the Morcote cemetery and along the Morcote-Melide road. This outcrop of porphyrite was regarded by ESCHER as a dike feeding the main porphyrite flow to the north (ESCHER 1913, section Fig. 2).

They are dark gray, very fine-grained, compact rocks in which few phenocrysts are visible to the naked eye.

Under the microscope they show a holocrystalline fine-grained porphyritic texture. The groundmass is composed of fine plagioclase laths and needles, small flakes of altered biotite with a varying amount of quartz and possibly orthoclase. The plagioclase laths commonly show a distinct fluidal arrangement curving round the phenocrysts.

Among the phenocrysts plagioclase is very abundant. It is highly zoned and gives an extinction angle between 16–23°. The crystals show abundant sericitization particularly of the central parts. A few twinned phenocrysts when measured on the U-stage gave a content of 46–50% An for the outer parts (Table 39). Orthoclase is common as a phenocryst in many slides but is absent in others. Quartz does not occur as a phenocryst but medium sized grains have been found which appear to be of metamorphic origin. So are also certain flakes of bleached biotite which are bent and broken, but primary biotite is also common. In places it shows distinct pleochroism in light and deep browns and has apatite inclusions. Usually it is extensively altered to chlorite. No other primary dark minerals are preserved but in places secondary hornblende is abundantly formed as minute needles arranged radially or irregularly distributed within the chloritized minerals as described in the last group.

Zircon and apatite are the common accessories generally included within the biotite crystals.

There is abundant development of secondary quartz and calcite while brownish ore material is distributed throughout.

Some slides show numerous inclusions of gneisses, schists and quartzites but no porphyrite inclusions have come to notice.

Rather similar looking rocks, which also show a fluidal arrangement of small plagioclase laths in a fine-grained non-porphyritic groundmass containing biotite flakes, are exposed near Buro along the western shore. These are characterized by the concave ends of the plagioclase laths apparently due to resorption.

The pyroxene-porphyrite described by DE SITTER from M. Piamello shows some resemblance to the rocks mentioned above. It belongs to the lowest flows and contains biotite and is thus related to the biotite-porphyrites to which it corresponds fairly well in chemical composition.

In the absence of more analyses from other parts it is difficult to determine the distribution of this group of intermediate porphyrites in the Lugano porphyry district, but it appears quite probable that a part of the lower biotite-porphyrite group (Piambello type of DE SITTER) belongs to this basic type E.

As already noted this type is chemically related to the previous type D. It contains, however, in its kata-norm (Tab. 21), more Ab and less An than type D which explains the presence of andesinic plagioclase (46—50 % An); the small amount of Wo (0,9 %) perhaps goes to form hornblende.

This group corresponds to the biotite-andesites of the mineralogical classifications (HOLMES, 1920).

Below are given some of the rocks which have a similar composition:

Table 5

| Rock and locality | si | al | fm | c | alk | k | mg |
|---|-----|------|------|------|------|------|------|
| (Type E Lugano) | 211 | 31,5 | 35 | 17,5 | 16 | 0,39 | 0,55 |
| Quartz-diorite, Meissen (TRÖGER, 1930, p. 44) | 211 | 30,5 | 34,5 | 18 | 17 | 0,41 | 0,52 |
| Melaphyre, Waldenburg (TRÖGER, 1930, p. 55) | 205 | 32 | 35 | 15,5 | 17,5 | 0,39 | 0,29 |
| Opdalite (TRÖGER, 1935, No. 108) | 210 | 30 | 35 | 16,5 | 18,5 | — | — |
| Diorite, Electric Peak, Mont., U.S.A. (IDDINGS, U.S.G.S., A.R., 12, 1891) | 194 | 30 | 34 | 18,5 | 17,5 | 0,22 | 0,59 |
| Hyp.-aug.-andesite, Mexico (BURRI, Z. Vulk., 13, 1930) | 197 | 30,5 | 35 | 19 | 15,5 | 0,32 | 0,58 |
| Qz.-biot.-latite, Colorado, U.S.A. (CROSS & HOWE, U.S.G.S., Fol. 153, 1907) | 213 | 33 | 32 | 16,5 | 18,5 | 0,44 | 0,46 |

b) Quartz-bearing Biotite-Porphyrites or Dacites (Type F).

These rocks together with the porphyrites of the Morcote and Buro types are almost the earliest porphyry flows in the Morcote peninsula as well as in other parts of this eruptive district. They are commonly found lying over the metamorphics with an intervening band of basal tuffites of variable thickness.

This group of porphyrites has a fairly extensive occurrence in the Morcote Peninsula but in most places is covered by later flows of quartz-porphyrines, basic porphyrites and their tuffs and partly also by granophyres. The main outcrop extends from a little south of Carona, along the western slopes of Cima a Tenza and M. Arbostora and continues SW down Cantine Codato. The northern continuation of this outcrop but separated from it by a strip of granophyre, occurs

near Cernesio, SW of Carona. The other outcrop of these rocks is to the east along the lower slopes, north of Colombajo.

These rocks in which white specks of plagioclase feldspar are abundantly seen in handspecimens are generally fine-grained and dark gray. When fresh they are hard and compact but are usually highly cleaved and decomposed. An unusual type occurs at Pt. 632 on the way from Carona to Madonna d'Ongera, where the granophyre shows an intrusive contact with the porphyrites. The rock is medium- to coarse-grained, almost dioritic in appearance, quartz, feldspar and biotite being easily seen with the unaided eye.

Under the microscope the rock shows a holocrystalline porphyritic texture with a groundmass of even-grained quartz, feldspars and biotite. Plagioclase forms the dominant phenocrysts, some of which are unusually fresh. U-Stage determinations on several individuals gave an anorthite content of 42–48 %, while in some zoned individuals values up to 52 % were found (Tab. 39). Sericite and albite are common alteration products. Orthoclase is frequent as phenocrysts but is more common in the groundmass. Quartz is rare among the phenocrysts; a few large individuals show 'resorbed' borders. It also occurs as a secondary filling of cavities. Biotite is fairly common as large individuals but very frequently occurs in irregular clusters of small flakes.

Apatite, zircon and magnetite are the common accessories, the first two being usually enclosed within biotite flakes.

As secondary minerals occur sericite, albite, zoisite, epidote, calcite, chlorite and magnetite.

In a few slides comparatively large crystals of garnet have been observed (as in a specimen from a little east of Madonna d'Ongera). It probably derives from a schist, many of which are included in these and other porphyrites.

Chemically this group is the best known among the porphyrites, 7 analyses being available (Tab. 12) of which 5 are from the Morcote Peninsula.

The type-values for this group are

| | si | al | fm | c | alk | k | mg |
|--------|-----|----|----|----|-----|------|------|
| Type F | 264 | 37 | 29 | 14 | 20 | 0,42 | 0,51 |

and correspond to the opdalitic magma-type which has the following values

| | | | | | | | |
|-------------------|-----|----|----|----|----|------|------|
| Opdalitic m.-type | 225 | 32 | 32 | 18 | 18 | 0,45 | 0,45 |
|-------------------|-----|----|----|----|----|------|------|

The mineral composition of this type F calculated as a biotite-variant is approximately as follows (see p. 261):

| | | | | |
|--------|---------------|---------------------------|---------|----------|
| quartz | microperthite | plagioclase (with 45% An) | biotite | ore etc. |
| 27,3 | 16 | 35 | 20 | 1,7 |

With its high content of quartz and andesine feldspar the rock is distinctly a Dacite.

The following rocks show a very similar composition:

Table 6

| Rock and locality | si | al | fm | c | alk | k | mg |
|--|-----|------|----|------|------|------|------|
| (Type F Lugano) | 264 | 37 | 29 | 14 | 20 | 0,42 | 0,51 |
| Andesite, Yellowstone N. P., U.S.A. (IDDINGS, U.S.G.S., A. R. I., 1891) | 264 | 37 | 28 | 15,5 | 19,5 | 0,26 | 0,53 |
| Quartz-monzonite, Montana, U. S. A. (BARREL, U.S.G.S., A. R., 21, II 1901) | 253 | 35,5 | 26 | 17,5 | 21 | 0,50 | 0,40 |
| Diorite-porphyrity, Electr. Peak, U. S. A. (NIGGLI, 1920, p. 232) | 263 | 39 | 26 | 14 | 21 | 0,37 | 0,49 |
| Biotite-granite, Lausitz (TRÖGER, 1930, p. 42) | 239 | 36,5 | 28 | 14 | 21,5 | 0,37 | 0,37 |

3. The Granophyres (Types G and H)

The granophyre is a well-known rock and occupies a comparatively small area in the Morcote Peninsula, occurring as a narrow elongated strip running SW-NE from Soresello south of Figino, to Carona, where it is cut off by an E-W fault. Its greatest development, however, occurs in the western part of the porphyry district from where it has been described in detail by KUENEN and DE SITTER. Only some principal features will, therefore, be mentioned here.

The granophyre represents the most widespread rock type occurring as a more or less continuous sheet from Cabiaglio in the west to Carona in the east and covers nearly all the older rock-formations. In spite of this great extension and thickness the rock is nearly uniform in composition. Only occasionally it passes into an aplitic type. There are no intercalated beds of tuffs or other rocks, nor are any inclusions found in these rocks.

The rock as a whole is carmine-red in colour, is medium- to coarse-grained, and the component minerals quartz, feldspars and biotite are easily seen in the handspecimen. There are also numerous cavities with miarolitic crystallization of minerals.

In thin sections the rock mostly shows a typical holocrystalline granitic texture. The grain-size is commonly medium to coarse but a few varieties show a fine aplitic or sometimes weakly porphyritic texture. A remarkable texture, frequently met with is the granophyric one in which principally quartz and orthoclase but sometimes plagioclase and biotite show a well developed graphic intergrowth. Both the granitic and granophyric textures may be found in the same rock-section.

The minerals quartz and orthoclase are commonly without any crystal outline but the latter may show faintly subhedral forms in some non-graphic textures. Orthoclase sometimes shows a perthitic appearance which is explained by its high content in albite molecules (seen in the katavariant composition). It is usually clouded by limonitic dust which serves to distinguish it readily from quartz. Plagioclase is comparatively less common and is usually subhedral. A number of measurements has indicated a uniform content of 35 % An. A few slides show the presence of microcline with its typical cross-hatching. Biotite though small in quantity is fairly common and often fresh. It is usually allotriomorphic and is penetrated by quartz and feldspar grains. It also shows inclusions of zircon with pleochroic rings. Hornblende was noted only in one rock-slide from the granophyre—biotite-porphyrite contact, on the way from Carona to Madonna d'Ongera. Apatite is rare as an accessory. Fluorite though frequently reported from these rocks from other regions was not noticed in the granophyres of the Morcote area. It is, however, very common in the miarolitic cavities.

The chemical characteristics of the rocks of this group are fairly well defined. Nearly a dozen good analyses (Tab. 13 and 14) are available which fall into two more or less distinct types differing not only in the content of silica but also in that of other constituents. The first and the more dominant type G has the following values:

| | si | al | fm | c | alk | k | mg |
|--------|-----|----|----|----|-----|------|------|
| Type G | 404 | 39 | 16 | 11 | 34 | 0,48 | 0,23 |

and thus belongs to the engadinite-granitic magmatype whose values are

| | | | | | | | |
|--|-----|----|----|---|----|-----|------|
| | 380 | 43 | 13 | 3 | 36 | 0,5 | 0,25 |
|--|-----|----|----|---|----|-----|------|

The other type though probably widespread is less common and occurs locally within the main granophyre mass as aplitic bands. The type values for this subgroup are:

| | | | | | | | |
|--------|-----|----|---|---|----|------|------|
| Type H | 480 | 47 | 8 | 3 | 42 | 0,52 | 0,05 |
|--------|-----|----|---|---|----|------|------|

and the values of the corresponding magma type are:

| | | | | | | | |
|---------------------------|-----|----|---|---|----|------|------|
| Aplite-granitic magmatype | 460 | 47 | 8 | 5 | 40 | 0,45 | 0,25 |
|---------------------------|-----|----|---|---|----|------|------|

The type H differs from the type G in the proportion of alkali- and plagioclase feldspars to the dark minerals as will be seen from the calculated mineral compositions:

| Type | quartz | micropertthite | plagioclase | biotite + ore |
|------|--------|----------------|-------------|---------------|
| G | 31 | 48 | 16 | 5 |
| H | 33 | 55 | 10 | 2 |

That these two types represent roughly the eutectic composition of the residual magmas is indicated by the frequent occurrence of graphic textures. The following rocks are closely comparable in composition to these types:

Table 7

| Rock and locality | si | al | fm | c | alk | k | mg |
|---|-----|------|------|------|------|------|------|
| (Type G Lugano) | 404 | 39 | 16 | 11 | 34 | 0,48 | 0,23 |
| Liparite, Karpathen (NIGGLI, 1922, p. 199) | 386 | 39,5 | 15 | 13,5 | 32 | 0,47 | 0,39 |
| Perthite-quartz-granite, Småland (NIGGLI, 1923, p. 112) | 388 | 39 | 14 | 12 | 35 | 0,48 | 0,25 |
| Pyterlite (TRÖGER, 1935, p. 79) | 463 | 40,5 | 16,5 | 8 | 35 | 0,62 | 0,18 |
| Beschtauite („ „ „ 95) | 374 | 43 | 12 | 12 | 33 | 0,44 | 0,28 |
| Granodiorite, Gleinalm-Kern (F. ANGEL, N. Jb. f. Min., Beil. Bd. LVI, 1928, p. 427) | 454 | 42,5 | 14,5 | 9,5 | 33,5 | 0,14 | 0,29 |
| Granite, Harz (NIGGLI, 1923, p. 110, No. 13) | 374 | 42,5 | 15 | 8,5 | 34 | 0,52 | 0,19 |
| (Type H Lugano) | 480 | 47 | 8 | 3 | 42 | 0,52 | 0,05 |
| Aplite-granite, Lausitz (TRÖGER, 1930, p. 43) | 501 | 47 | 7 | 4,5 | 41,5 | 0,48 | 0,16 |
| Granophyre, Meissen (TRÖGER, 1930, p. 44) | 452 | 46,5 | 7 | 3,5 | 43 | 0,43 | 0,29 |
| Granite-aplite, Riesengebirge (TRÖGER, 1930, p. 39) | 473 | 46,5 | 7 | 3,5 | 43 | 0,41 | 0,16 |
| Quartz-porphyrite, Victoria (NIGGLI, 1923, p. 119, No. 2) | 509 | 47 | 5 | 4 | 44 | 0,03 | 0,08 |
| Rhyolite, Colorado, U.S.A. (W. CROSS, U.S.G.S.) | 472 | 47,5 | 6,5 | 2,5 | 43,5 | 0,47 | 0,06 |
| Tordrillite, Nevada, U.S.A. (SPURR, U.S.G.S., B. 228, p. 207, 1904) | 449 | 47 | 7 | 5,5 | 40,5 | 0,45 | 0,11 |

C. OTHER ERUPTIVE ROCKS OF THE MORCOTE PENINSULA

1. The Basal Tuffites (including the Lowest Tuffs)

This group of rocks which lies at base of the porphyry-flows is not a well defined homogeneous group but is for a considerable part made up of clastic sediments which were being formed during the early phases of the Permian eruptive activity; they are consequently charged with volcanic matter. Higher up, they gradually give place to normal tuffs and lava-flows.

In the Morcote Peninsula, rocks which could be included in this group have a rather small development, being confined to the Vedo amphitheatre between Val di Fiume and Val di Torre. They cover the Permo-Carboniferous conglomerates and are overlain by biotite-porphyrites and their tuffs.

They are hard compact grayish-green rocks with a number of small biotite flakes. In their external appearance they recall the Taveyannaz Sandstone of the Alpine regions (DE QUERVAIN, 1928). The tuffites in their higher levels are associated with fine-grained

hard cherty layers of variable thickness which sometimes pass into agglomeratic rocks.

Under the microscope they show an equigranular groundmass of medium-sized interlocking grains of quartz and highly sericitized feldspars, with numerous flakes and shreds of bleached biotite. The whole groundmass is highly impregnated with calcareous matter.

These rocks cannot be sharply demarcated from the overlying lava-flows and tuffs.

Owing to the mixed nature of these rocks they cannot be referred to any particular magmatic type. One of the analyses by KOOMANS probably refers to these rocks, the values given by her are:

| | si | al | fm | c | alk | k | mg |
|--------------------|-----|----|----|---|-----|------|------|
| Tuff, anal. No. 37 | 383 | 47 | 23 | 7 | 23 | 0,47 | 0,23 |

2. The Quartz-Porphyrries

The quartz-porphyrries are normally true lava flows which are frequently characterized by well marked fluidal structure and by an abundance of xenolithic inclusions. They cannot, however, always be distinguished either in the field or under the microscope from other acid tuffaceous rocks to which they show all gradations.

These rocks occur in the Morcote Peninsula in two distinct flows which belong to two different periods of volcanic outbursts. The older one is nicely developed on the southern slopes of M. Arbostora between Cantine Codato and Vico Morcote, partly interrupted by two longitudinal faults. It lies over the biotite-porphyrries but is very likely older than the basic (pyroxene-)porphyrites. It is in places highly tuffaceous with a typical scoriaceous, agglomeratic appearance. Fluidal structure is commonly very poor or even absent.

The other outcrop which belongs to a younger flow is well seen on the Boll hill near Carona. Here the rocks are characterized by an extreme abundance of porphyritic blocks sometimes as big as one metre in diameter, enclosed in an aphanitic matrix. Fluidal structure rendered visible by light and deeper coloured limonitic bands is often excellently developed. Nearly identical rocks have been described from the adjoining parts by KUENEN, DE SITTER and DOUGLAS.

One of the most usual characteristics of these rocks in thin sections is the abundance of phenocrysts of resorbed quartz. The phenomenon has been described by workers from many localities and till lately was always regarded as due to magmatic corrosion of quartz crystals of earlier generations (ERDMANNSDÖRFFER, 1916).

G. LAEMMLEIN (1930, 1933) on the other hand has now shown that a proper magmatic corrosion of quartz crystals can take place only when the surrounding magma is chemically sharply different from that in which quartz can crystallize. Moreover, owing to the changed thermodynamic conditions of the magma, the solution of the quartz phenocrysts leads only to rounding of the outer surface and not to a corrosion of the crystals such as is commonly seen in quartz-porphyrines. The highly irregular forms of quartz phenocrysts are, according to LAEMMLEIN, the result of a regeneration of quartz by which the irregular spaces within the solidifying magma are filled up.

These quartz-porphyrines are for a large part not the normal products of magmatic differentiation but appear to be highly contaminated by the inclusion of foreign material, chiefly the older porphyrites and the schists.

The chemical composition as known from the analyses given by KOOMANS Nos. 9—12 and 15 (Table 15, p. 250) shows an enormous variation in the different rocks of this group and cannot be referred to any one magma type.

| | si | al | fm | c | alk | k | mg |
|--|-----|------|------|-----|------|------|------|
| Quartz-porphyry of Lauredo, anal. No. 9 | 446 | 49,5 | 14,5 | 6,5 | 29,5 | 0,42 | 0,13 |
| (Lugano magma interpol.) | 450 | 42 | 12 | 8 | 38 | | |
| Quartz-porphyry of Carona, anal. No. 12 | 358 | 48,5 | 21,5 | 3,5 | 26,5 | 0,51 | 0,09 |
| (Lugano magma) | 358 | 38 | 21 | 13 | 28 | | |

The Lauredo porphyry with its high si and al and low fm has affinity with the granophyres but has too low an alk-value. On the other hand the Carona porphyry with low si and alk and high fm is much nearer to biotite-porphyrites but has too high al- and too low c-values.

These quartz-porphyrines appear to derive from magmas ranging from those of acid porphyrites to those of granophyres, which before their consolidation were probably contaminated by the digestion of stoped material from the country rock which in these cases was either schist or porphyrite or both. These differences in chemical composition may also to a certain extent be brought about by the loss of alkalis as volatile compounds during the effusion of the porphyry lava flows, leaving a large excess of alumina.

3. The Dikes

a) *The Quartz-Porphyry (Aplite) Dike of Alla Ferrera*

The quartz-porphyry dike which runs nearly E-W between Ciona and Alla Ferrera on the northern boundary of our area has long been known, particularly on account of its intense tourmalinization.

The dike rock which is darkish pink in colour is fine-grained with very few phenocrysts visible to the naked eye. There are, however, numerous large inclusions of porphyrites within the dike.

The microscope reveals an even-grained nonporphyritic rock usually with an aplitic groundmass consisting mostly of quartz; in some cases, however, a typical granophyric texture is developed owing to the intergrowth of quartz and orthoclase. There are a few slightly larger individuals of orthoclase and plagioclase distributed within the groundmass. In some sections biotite is fairly common but is probably derived from the porphyrite inclusions.

The most important characteristic of this dike, however, is the abundant development of tourmaline in the cracks and cleavages of the rock. In some cases tourmaline has permeated the whole rock whereby the latter has become quite dark and has assumed the appearance of a porphyrite. Intense tourmalinization of this type, however, is only local and occurs towards the eastern extremity of the dike, but more feeble effects are fairly widespread particularly in the south-west direction. It is, however, remarkable that the schistose rocks adjoining this dike to the north show no signs of this tourmalinization. It has been shown elsewhere that the contact of the dike and the schists is not original or normal but that the rocks have been brought into juxtaposition by faulting with downthrow to the south. The absence of tourmalinization in the schists also lends support to this view.

This porphyry dike-rock resembles the granophyres both in its frequent graphic and aplitic textures and in mineral composition, but in its abundance of porphyrite and other inclusions and in chemical composition it is akin to the quartz-porphyries. One chemical analysis of this dike-rock is available from KOOMANS (anal. no. 25); the molecular values are:

| | si | al | fm | c | alk | k | mg |
|--------------------------|-----|------|----|------|-----|------|------|
| Alla Ferrera aplite dike | 373 | 45,5 | 17 | 14,5 | 23 | 0,47 | 0,15 |

As will be seen, these values do not agree with any of the type values for the Lugano region (given on p. 285). The si value lies between those of types F and G; so do also the alk and fm values but al is much higher than even that of G. The interpolated values for the Lugano magma with si = 373 are:

| | si | al | fm | c | alk |
|---------------------|-----|----|----|----|-----|
| Interpolated values | 373 | 38 | 19 | 13 | 30 |

Obviously al of the dike is too high and alk is too low. These discrepancies in the values cannot be wholly explained by alteration of any of the main rock-types; it is, however, possible that a large amount of alkalis has been lost as volatile compounds during consolidation. It may also be that the al excess is a result of contamination of the magma by foreign material as was possibly the case with the other quartz-porphyrines.

b) The Quartz-Porphyry Dike of Olivella

This quartz-porphyry dike which is frequently visible as one passes along the Morcote Melide Road has long been known owing to its striking contrast with the enclosing metamorphics. The numerous detached outcrops, however, have lead to different interpretations. HARADA for example following NEGRI and SPREAFICO writes (1883, p. 21): „Die mehr oder weniger mächtigen Gänge, von denen man auf der nur 2 km langen Strecke nicht weniger als sieben zählt, sind wahrscheinlich auf dem Porphyrgänge zwischen Vico-Morcote und Miramonte senkrechte Quergänge.“ ESCHER shows a system of about three parallel dikes running NNE-SSW within the metamorphics between Morcote and Colombajo and connects one of these with the red porphyry dike near Miramonte (ESCHER 1913, section). This is also seen in the recent map given by DE SITTER (1939). My observations, however, show that there is only one thick dike which runs almost N-S which is thrown down by a number of E-W running transverse faults with a continual throw to the north. The southernmost part of this dike can be seen in Morcote village a few metres north of the ferry station while in the north it vanishes below the lake near Villa Colombajo. The Miramonte dike is not related to this one.

The dike varies in thickness from 8—15 metres but its apparent thickness is increased by its inclination both to the vertical and to a number of local faults with small throw. The general run of the dike is $N 10^{\circ} E - S 10^{\circ} W$ but sometimes it shows appreciable deviations from this line owing to the throw of the faults.

At a number of places a border band of a grayish green fine-grained rock of variable thickness is seen between the dike and the metamorphic country-rock. This band often contains inclusions of schists but is very poor in quartz and feldspar phenocrysts. Under the microscope this border band shows the characters of a biotite-

porphyrite similar to that of Morcote. Numerous inclusions of this porphyrite and others occur in the dike.

The main dike rock is throughout characterized by an abundance of large phenocrysts of gray shining quartz and dull red or white feldspars which stand out conspicuously in a greenish gray, brown or chocolate-coloured fine-grained base. The feldspar crystals are usually euhedral and often reach a length of over 1 cm. The quartz grains rarely show crystal forms but frequently have a corroded outline.

Under the microscope the rock is holocrystalline fine-grained porphyritic with a groundmass of even-sized crystals of quartz, feldspar and a little biotite.

Among the phenocrysts orthoclase which has grown turbid owing to kaoline and limonite dust is fairly common. The plagioclase is andicase with 35 % An. The crystals are large and often show an irregular or 'resorbed' outline. Quartz is commonly corroded, the groundmass penetrating the cavities within the crystals. Some of these crystals give a faintly undulating extinction, suggesting a probable metamorphic origin. Biotite though small in amount is fairly common; it is partly altered to chlorite. Accessories are zircon and less commonly apatite which are usually associated with biotite.

The chemical composition is known through two analyses by KOOMANS, Nos. 13 and 14 (Tab. 14). The former appears to be the more fresh and has the following values which correspond to an adamellitic or yosemite-granitic composition

| | si | al | fm | c | alk | k | mg |
|------------------------------|-----|------|------|------|------|------|------|
| Olivella dike | 346 | 45 | 19 | 10 | 26 | 0,45 | 0,11 |
| Adamellitic magma type | 300 | 37,5 | 22,5 | 13,5 | 26,5 | 0,45 | 0,3 |
| Yosemite-granitic magma type | 350 | 43 | 14 | 13 | 30 | 0,45 | 0,3 |

Quartz-porphyries in general are characterized by a large excess of alumina, a feature also shown by this quartz-porphyry dike as will be seen from the following basis composition where it is shown as C:

| Kp | Ne | Cal | C | Fo | Fa | Fs | Q | Ru | Ap |
|------|------|-----|-----|-----|-----|-----|------|-----|-----|
| 13,6 | 16,4 | 5,1 | 4,1 | 0,6 | 4,4 | 0,5 | 54,6 | 0,4 | 0,3 |

Besides the feldspars there are no aluminous minerals in the rock except a very small quantity of biotite, which cannot account for this enormous al excess. Nor are the rocks so highly altered as to bring about this excess. It is difficult to explain this unless we suppose that a large amount of alkalis and lime originally in combination with alumina has escaped during the consolidation of the quartz-porphyries.

Table 8

The following rocks have a comparable composition:

| Rock and locality | si | al | fm | c | alk | k | mg |
|--|-----|------|------|-----|------|------|------|
| Biotite-porphyrite, Döberitz (Tröger, 1930, p. 57) | 290 | 43 | 23,5 | 8,5 | 25 | 0,27 | 0,35 |
| Biotite-granite, Fichtel-Gebirge | 309 | 44,5 | 21 | 8,5 | 26 | 0,34 | 0,43 |
| Dacite, Sepulchre Mts., Mont. (Iddings, U.S.G.S. A.R., 12, 1891) | 303 | 43 | 18 | 13 | 26 | 0,27 | 0,50 |
| Trachyrhyolite, Elk Creek, Mont. (Iddings, U.S.G.S., Mon. 32 II, p. 325, 1899) | 281 | 45,5 | 20,5 | 8,5 | 25,5 | 0,31 | 0,26 |

c) The Red Porphyry Dike of Vico Morcote

This is a non-porphyritic red feldspathic dike newly traced out in the field with only a few breaks from southwest of Vico Morcote, down to Villa Miramonte, south of Melide. It has twice been nicely exposed in the cuttings of the new Carona-Vico Morcote Road near the northern sharp bend and also at the water-capture $\frac{1}{2}$ km. NNE of Vico Morcote. The dike exposed near Villa Miramonte is a northern continuation of this Vico Morcote dike.

Another dike has been newly located near S. Carlo about 300 m. WNW of Morcote on the foot-path to Val di Torre. A little higher up it stands out like a huge wall 10 m. thick running NE. After a deflection through faulting it is again exposed in the Torre valley west of Castello. Both the megascopic and microscopic characters correspond closely with those of the Vico Morcote dike, and it is probably the southern continuation of that dike.

The main dike rock is a fine-grained compact feldspathic rock with an intense pink to brick-red colour. No phenocrysts are ordinarily visible to the naked eye. These characters suffice to distinguish it easily from the Olivella dike to which it runs parallel throughout its course.

Sometimes the dike rock shows a number of small solution cavities in which carbonate minerals have crystallized.

Under the microscope a few 'phenocrysts' of quartz are seen, sparsely distributed in a fine-grained feldspathic groundmass which is not easily resolved because of abundant ferruginous and secondary matter. A peculiar feature of the quartz 'phenocrysts' is the frequent occurrence of a corona which surrounds them like a reaction rim. The corona has in many cases a sharp boundary against the enclosed grain but it may also show gradual transition into it. The breadth of the corona has apparently no relation to the size of the quartz grain within it; two or more larger 'spherulites' may fuse together around a common irregularly shaped quartz grain. In others the quartz kernel may have altogether 'vanished'. The corona is generally composed of quartz

having the same optical orientation as the core as is clearly seen between crossed nicols with the help of the gypsum plate. The corona differs from the core only in the abundant inclusions of finely divided brown matter which is usually arranged in small radial bundles giving a slightly inclined extinction. There are sometimes also tiny flakes of muscovite lying irregularly within the corona, sometimes along the contact with the core, but none has ever been found within the core which is always clear and without any inclusions.

The same phenomenon was also observed by DOEGLAS in the dike-rock of Val Sovaglia (1930, p. 392).

The groundmass is usually full of small 'spherulites' without any clear core which extinguish as a single unit, the enclosed radiating needles giving a sort of star-like extinction. These 'spherulites' are probably a result of devitrification of an originally glassy base which cannot now be made out owing to the extensive alterations.

The chemical characteristics of this rock are known through a new analysis kindly made for me by Prof. J. JAKOB. It is given as No. 199 (Table 14). The molecular values are:

| | si | al | fm | c | alk | k | mg |
|-------------------|-----|----|----|----|-----|------|------|
| Red porphyry dike | 388 | 38 | 21 | 15 | 26 | 0,60 | 0,65 |

When we examine the weight % analysis of this rock, the remarkable feature that comes to notice is the abnormal content of CO₂ which is as high as 3,12. The content of CaO is also much higher than in most of the normal granophyres, while that of MgO is more than 5 times higher than in the granophyres. On the other hand the Na₂O present is less than two thirds the amount found in most of the normal granophyres.

These features must be referred more to processes of alteration than to an abnormality in the original composition. The circulating solutions appear to have introduced carbonates of lime and magnesia and have leached away soda. The other constituents appear comparatively little affected. The same features are apparent in the NIGGLI values given above. The nearest comparable type from the Lugano porphyries, particularly as regards si and al values is Type G whose values are

| | si | al | fm | c | alk | k | mg |
|--------|-----|----|----|----|-----|------|------|
| Type G | 404 | 39 | 16 | 11 | 34 | 0,48 | 0,23 |

It will be seen that alk is 8 units too low, whereas c and fm are higher by 4 and 5 units respectively. Again though alk is too low, k is abnormally high, and has a value not reached in any rock of the main Lugano region. This definitely shows that the low alk is mainly due to an excessive loss of Na. Similarly the value mg is

higher than even in the most basic rock-types. The higher values of fm are, therefore, due to an abnormal increase of Mg through addition by circulating solutions.

This extensive alteration is shown in the rock-slide by an abundance of calcite and other secondary products.

Since the values of SiO_2 , Al_2O_3 , $(\text{Fe}_2\text{O}_3 + \text{FeO})$ and K_2O of the dike rock 199 agree very closely with those of the normal granophyres and since the divergencies in the values of MgO , CaO and Na_2O are due to the action of circulating solutions, it is evident that the original composition of the red porphyry dike was quite similar to that of the normal granophyres of type G.

It may be added that though the present composition of the Vico Morcote dike is somewhat abnormal for the Lugano types, this composition is closely realized in other regions as the following comparison will show.

Table 9

| | Dike 199 | L | M | | | | |
|-------------------------|---------------|---------------|---------------|----------|------------|----------|-----------|
| SiO_2 | 70,26 | 71,48 | 72,77 | | | | |
| Al_2O_3 | 11,70 | 13,00 | 13,00 | | | | |
| Fe_2O_3 | 1,14 | 1,25 | 1,28 | | | | |
| FeO | 0,83 | 1,55 | 2,65 | | | | |
| MnO | 0,05 | 0,09 | 0,08 | | | | |
| MgO | 1,66 | 0,95 | 0,67 | | | | |
| CaO | 2,50 | 2,60 | 2,47 | | | | |
| Na_2O | 2,00 | 2,60 | 4,95 | | | | |
| K_2O | 4,45 | 4,24 | 0,34 | | | | |
| $\text{H}_2\text{O} +$ | 2,02 | 1,24 | 1,16 | | | | |
| $\text{H}_2\text{O} -$ | 0,21 | 0,20 | 0,07 | | | | |
| TiO_2 | 0,24 | 0,43 | 0,22 | | | | |
| P_2O_5 | 0,09 | 0,09 | 0,04 | | | | |
| CO_2 | 3,12 | 0,30 | 0,47 | | | | |
| | <u>100,07</u> | <u>100,02</u> | <u>100,17</u> | | | | |
| Rock | si | al | fm | c | alk | k | mg |
| 199 | 388 | 38 | 21 | 15 | 26 | 0,60 | 0,65 |
| L | 375 | 40 | 18 | 14,5 | 27,5 | 0,52 | 0,33 |
| M | 373 | 39 | 21,5 | 14 | 25,5 | 0,04 | 0,24 |

199 Red porphyry dike, Vico Morcote, Lugano

L Granite, Canyon Range, Nev. (T. E. SPURR, T. G. IX, p. 602, 1901)

M Qz.-porphyry, Greenville, Calif. (W. H. TURNER, U. S. G. S. B. 148, 1897)

d) Other Minor Dikes

Besides the three main dikes of Alla Ferrera, Olivella and Vico Morcote, there also occur a few other much smaller acid dikes which

in their megascopic and microscopic characters resemble one or the other of these three.

One such dike nearly 3 m. thick is exposed near Garaverio, within the porphyrites. It runs NE-SW and has been repeatedly faulted with downthrow to the north. It much resembles both in texture and mineral contents, the red granophyric dike of Vico Morcote and differs only in the fact that it has a number of large phenocrysts of feldspars and quartz much like those in the Olivella dike. The quartz individuals are, however, invariably rounded, the ground-mass is fine-grained and devitrified with a number of small spherulites and muscovite shreds developed in it.

Similar rocks with large rounded quartz "phenocrysts" were also found within the granophyre mass east of Figino and south of Carona.

A small dike about a metre thick running NE-SW was observed along Val di Torre foot-path, about 100 m. west of Morcote church; the rock is fine-grained and rose-red in colour and is much allied to the dike rock exposed a little to the west near S. Carlo.

The dike-like outcrop a little east of Carona is a part of the granophyre mass highly calcitized and weathered, and is separated from the main outcrop through faulting.

D. THE MIAROLITIC MINERALIZATION IN THE GRANOPHYRE OF MADONNA D'ONGERA QUARRY

The granophyres of the Lugano porphyry district in general have long been known for the crystallization of a number of minerals in cavities of the rock as a result of post-volcanic hydrothermal activity of the magma. These rocks are full of elongated cavities and cracks, which apparently favour no particular direction. KOOMANS has described these mineralizations from the quarry at Cuasso al Monte from which she mentions the following species: quartz, orthoclase, fluorite, calcite, dolomite, siderite, pyrite, limonite and chlorite; and notes the absence of biotite. (See also DE ANGELIS, 1924 and 1938.)

The mineralization at Madonna d'Ongera has recently been briefly described by PARKER in NIGGLI, KOENIGSBERGER, PARKER (1940, p. 248) who mentions the following minerals: quartz, orthoclase, albite, fluorite, biotite, tourmaline, epidote, calcite and siderite.

During my fieldwork I chanced to discover a mineral species occurring as fine hairy aggregates which much resembled amiant. The presence of the latter in a granitic rock seemed somewhat un-

usual but a closer examination has shown the material to be tourmaline — which was already known to occur in larger well developed crystals.

The amiant-like habit of tourmaline is rather rare and as such could not be suspected off hand, but the following characters have served to identify the mineral:

The mineral occurs as an aggregate of thin hairy needles of greenish, bluish, grayish or brownish colour. The needles are usually small but often reach a length of 1 cm.

Under the microscope its cross-section is seen to be triangular. It is strongly pleochroic from colourless to bluish green or brown, the greatest absorption being perpendicular to the elongation. X = colourless, Z = greenish blue.

Between crossed nicols it gives a straight extinction, a negative elongation, and bright polarization colours.

The refractive indices as determined by the liquid immersion method were found to be

$$\begin{aligned} N_e &= 1,634 \\ N_o &= 1,662 \\ N_o - N_e &= 0,028 \end{aligned}$$

The above characters correspond to those of the schorlite type of tourmaline and the refractive indices indicate, according to W. KUNITZ (1929), a composition intermediate between dravite and schorlite.

The X-Ray determinations kindly made for me by Dr. BRANDENBERGER gave diffraction patterns and lattice constants which are typical of tourmaline.

E. A NOTE ON THE TOURMALINIZATION IN THE MORCOTE PENINSULA

Tourmalinization is a very common and widespread phenomenon in the rocks of the Morcote Peninsula. It is not restricted to any particular rock-type or locality but is observed in different types over a large part of the region. It is rather rare in the ortho-gneisses but very common in the mixed gneisses and abundant in the hornfels. It is occasionally seen in the porphyrites and quartz-porphyrines along with their tuffs and is most abundant in the aplite dike of Alla Ferrera. It is also commonly met with in the miarolitic cavities in the granophyres. Though widespread in its occurrence two fairly well defined areas are especially important: the Alla Ferrera-Garavario section, and the Morcote-Colombajo section. The former cor-

responds to the zone of tourmalinization running NE-SW from Alla Ferrera to M. Piambello already noted by HARADA (1883, p. 45) and is definitely connected with the post-volcanic activity of the granophyric magma of Lugano. The other zone of tourmaline occurrences is restricted to the metamorphic rocks of the south eastern part of the peninsula. Though this region is also intruded by large acid dikes tourmaline has not been detected in them. It is also absent from the adjoining porphyrites between Vico Morcote and Melide. Its abundance in the mixed gneisses and its absence from the younger volcanics in this part suggest that this phase of tourmalinization was already over before the main eruptions of the porphyry magma took place and is, therefore, probably connected with the Hercynian gneissose granite intrusions. The extraordinary abundance of tourmaline-suns in the hornfelsic intercalations in the ortho-gneisses clearly points to this conclusion.

Tourmaline occurs in several different forms in the rocks of this peninsula. ESCHER has mentioned the three common types (ESCHER 1913, p. 723):

A. the larger, well crystallized variety in stumpy prisms or grains with zonal distribution of colours (green in the core and yellowish brown at the periphery);

B. the smaller, thin acicular variety, pleochroic in blues, the needles sometimes arranged radially giving the tourmaline suns;

C. an irregular cryptocrystalline variety grayish-brown or blue in colour.

The first variety is very widespread and occurs as individual crystals or in small groups commonly formed through replacement of original feldspathic or micaceous minerals of the rocks. The second variety is common where tourmalinization has been very intense as at Alla Ferrera. The needles are usually crowded in cracks or cleavage planes and are for a large part to be regarded as crystallizations in fissures. The third or cryptocrystalline variety is apparently much less frequent and perhaps restricted to those cracks where the supply of boron was low.

Besides the above three modes of occurrence of tourmaline within the rock mass there also occur two others in which the mineral appears as crystallizations in themiarolitic cavities of granophyre:

D. as large well-developed individual crystals; in one specimen the crystal is nearly 1 cm. long with striated prismatic faces; the end is, however, missing;

E. as "amiant"-like growths in which a crowd of thin greenish or brownish needles project from a leathery surface. Several samples of this sort were collected from the quarry at Madonna d'Ongera, south of Carona.

Part III

Chemistry of the porphyry magma of Lugano

A. DATA AND CALCULATIONS

It has already been noted that through the careful investigations of HARADA, the broad petrographic characteristics of the Lugano eruptive rocks became fairly well known. A detailed investigation of the geology and petrography of this region, part by part, was undertaken during the last twenty years by B. G. ESCHER and his students in Leiden. It was, however, only during the last four years that a systematic study of the chemistry and provincial relationship of the porphyry magma was attempted by Miss C. M. KOOMANS, also a student of ESCHER. She carried out a large number of analyses of different rock-types from the whole region including the Morcote Peninsula. With the help of NIGGLI differentiation-diagrams and the k-mg-diagrams based on all these analyses she pointed out the relationship of the Lugano porphyry magma with the calc-alkali-suites.

In the present study seven new analyses were made by J. JAKOB of the eruptive rocks of the Morcote Peninsula. Six of these rocks are porphyrites which were analysed specially with a view to study the process of alteration and one rock is a quartz-porphyry dike newly traced out in the field along the new Carona-Vico Morcote road.

One more analysis which was not taken into consideration by KOOMANS is also available. It is of the granophyre of Madonna d'Ongera south of Carona, and was published by F. DE QUERVAIN.

All these analyses which form the data for the study of the chemistry of the Lugano porphyry magma are given in the following tables with a list of analysed rock species and their localities.

1. List of Analysed Rocks with their Localities

Analyses by Miss C. M. KOOMANS (1937)

1. Biotite-porphyrite, M. Piambello at a height of 1000 m above S. L.
2. Biotite-porphyrite, Morcote.
3. Biotite-porphyrite, Villa Miramonte, South of Melide.
4. Quartz-biotite-porphyrite, between Brinzio and Bedero.
5. Pyroxene-porphyrite, on the way from Ganna to the peak of M. Piambello.

6. Pyroxene-porphyrite, Monte Martica.
7. Hornblende-pyroxene-porphyrite, above Tedesco.
8. Pyroxene-porphyrite, Marzio.
9. Quartz-porphyrity, North of Castello near Morcote.
10. Fluidal quartz-porphyr, South of Cabiaglio.
11. Fluidal quartz-porphyrity, on the way from Ganna to Poncione.
12. Fluidal quartz-porphyrity, Carona.
13. Quartz-porphyrity dike, near Olivella.
14. Quartz-porphyrity dike, on the road Olivella-Vico Morcote.
15. Fluidal quartz-porphyrity, M. Val dei Corni.
16. Granophyre, South of Brusimpiano, 1100 m. above S. L.
17. Granophyre-aplite, Cuasso al Monte Stonequarry.
18. Granophyre, near the aplite No. 17, Cuasso al Monte.
19. Granophyre, Cuasso al Monte.
20. Granophyre, on the way from Brinzio to Bedero opposite point 508.
21. Granophyre, Cuasso al Monte.
22. Granophyre, Cuasso al Monte.
23. Granophyre, Cuasso al Monte.
24. Granophyre, near Carona.
25. Quartz-porphyrity aplite dike, Alla Ferrara.
26. Diabase dike, Borgnana East of Cuasso al Monte.
27. Felsophyre, SW of Dogana Fornasette Svizzera.
28. Vitrophyre, Grantola.
29. Vitrophyre, Grantola.
30. Porphyrite, Grantola.
31. Porphyrite, South of Dogana Fornasette Svizzera.
32. Quartz-porphyrity, 2 km. NW of Cugliate.
33. Enstatite-basaltite, Mesenzana.
34. Basaltite, Casa Genestrato, 1/2 km. NW of Ponte Cremenaga.

Analyses by J. JAKOB

- | | | |
|----|-------------------------------------|--|
| A. | Basic porphyrite, „Lake of Lugano“. | } “Chemismus Schweizerischer Gesteine”. |
| B. | Basic porphyrite, Arogno. | |
- 33c. Quartz-biotite-porphyrity, near Pt. 632 on the way from Carona to Madonna d’Ongera.
 105. Basic (pyroxene)-porphyrite, on the new road Carona-Vico Morcote, east of the point 814.
 109. Basic (pyroxene)-porphyrite, on the main road, half way between Melide and Alla Ferrera.
 - 143c. Quartz-biotite-porphyrity, Villa Miramonte S. of Melide.
 199. Red quartz-porphyrity dike, on the new road 1 km. NNE of Vico Morcote.
 226. Quartz-biotite-porphyrity, on the foot-path from Torello to Morcote about 1/2 km. due west of Pt. 826.
 285. Basic Biotite-porphyrity, Morcote Cemetery.

Analysis by F. DE QUERVAIN (DE QUERVAIN und GSCHWIND, 1934)

86. Aplitic-granophyre, Madonna d’Ongera Stone-Quarry.
Analyses by A. SCHWAGER, quoted by T. HARADA, 1883, p. 18.
- P. Porphyrite, near Brinzio towards Maria del Monte.
108. Pyroxene-porphyrity, railroad near Melide.

Table 10
Diabase Dike and Basic Porphyrites

| | 26 | 8 | A | B | P |
|--------------------------------|---------------|---------------|---------------|--------------|--------------|
| SiO ₂ | 48,17 | 53,55 | 57,26 | 56,59 | 50,28 |
| Al ₂ O ₃ | 17,34 | 15,00 | 13,95 | 14,05 | 19,24 |
| Fe ₂ O ₃ | 2,75 | 4,71 | 7,54 | 4,55 | 7,92 |
| FeO | 4,69 | 3,44 | 3,48 | 3,95 | 1,98 |
| MnO | 0,10 | 0,12 | 0,17 | 0,24 | — |
| MgO | 6,94 | 5,74 | 3,51 | 3,25 | 6,09 |
| CaO | 8,97 | 4,78 | 2,92 | 5,31 | 4,21 |
| Na ₂ O | 1,59 | 2,38 | 2,58 | 2,72 | 2,81 |
| K ₂ O | 1,59 | 4,63 | 2,57 | 2,91 | 3,24 |
| TiO ₂ | 1,74 | 0,89 | 2,02 | 0,89 | — |
| P ₂ O ₅ | 0,19 | 0,12 | 0,27 | 0,32 | — |
| H ₂ O + | 3,35 | 3,82 | 2,64 | 3,25 | 3,56 |
| H ₂ O — | 0,14 | 0,69 | 0,20 | 0,25 | |
| CO ₂ | 2,28 | 0,27 | 0,38 | 1,58 | — |
| Total | 100,11 | 100,14 | 100,33 | 99,86 | 99,73 |
| si | 124 | 155 | 188 | 188 | 135 |
| al | 26 | 26 | 27 | 27 | 31 |
| fm | 42 | 44 | 45,5 | 39 | 44 |
| c | 25 | 15 | 14 | 19 | 12 |
| alk | 7 | 15 | 13,5 | 15 | 13 |
| k | 0,39 | 0,56 | 0,40 | 0,41 | 0,43 |
| mg | 0,62 | 0,56 | 0,38 | 0,42 | 0,45 |
| Analyst | KOOMANS | KOOMANS | JAKOB | JAKOB | SCHWAGER |

Table 11
Basic "Pyroxene" Porphyrites (Quartz bearing)

| | 7 | 6 | 285 | 109 | 105 | 5 | 108 |
|--------------------------------|--------------|---------------|---------------|---------------|---------------|---------------|---------------|
| SiO ₂ | 58,02 | 58,42 | 61,12 | 60,76 | 62,82 | 62,89 | 61,84 |
| Al ₂ O ₃ | 18,29 | 16,01 | 15,49 | 14,87 | 14,65 | 18,09 | 14,60 |
| Fe ₂ O ₃ | 4,32 | 2,34 | 1,64 | 3,58 | 5,42 | 1,80 | 6,60 |
| FeO | 2,25 | 4,55 | 4,34 | 1,67 | 1,59 | 3,58 | |
| MnO | 0,11 | 0,09 | 0,08 | 0,04 | 0,04 | 0,12 | — |
| MgO | 2,67 | 2,92 | 3,45 | 2,91 | 2,57 | 1,64 | 2,72 |
| CaO | 5,62 | 4,64 | 4,74 | 6,51 | 3,21 | 2,87 | 4,48 |
| Na ₂ O | 2,44 | 2,16 | 2,97 | 3,04 | 3,53 | 2,70 | 5,52 |
| K ₂ O | 3,05 | 3,53 | 2,83 | 2,02 | 3,28 | 3,62 | 2,92 |
| TiO ₂ | 0,69 | 0,64 | 0,97 | 0,85 | 0,74 | 0,40 | — |
| P ₂ O ₅ | 0,10 | 0,09 | 0,16 | 0,15 | 0,17 | 0,13 | — |
| H ₂ O + | 1,86 | 3,45 | 2,20 | 3,38 | 1,50 | 2,30 | — |
| H ₂ O — | 0,41 | 0,48 | 0,15 | 0,33 | 0,14 | 0,35 | — |
| CO ₂ | 0,13 | 1,00 | 0,00 | 0,10 | 0,52 | 0,20 | 0,36 |
| Total | 99,96 | 100,32 | 100,14 | 100,21 | 100,18 | 100,19 | 100,91 |
| si | 196 | 201,5 | 211 | 215 | 234 | 249 | 202 |
| al | 36 | 32,5 | 31,5 | 31 | 32 | 42 | 28 |
| fm | 31 | 34,5 | 35 | 30 | 35 | 26 | 32 |
| c | 18,5 | 17,5 | 17,5 | 25 | 13 | 12 | 16 |
| alk | 14,5 | 15,5 | 16 | 15 | 20 | 20 | 24 |
| k | 0,45 | 0,52 | 0,39 | 0,30 | 0,38 | 0,46 | 0,26 |
| mg | 0,43 | 0,43 | 0,55 | 0,61 | 0,66 | 0,38 | 0,43 |

Analyses: 5, 6 and 7 by KOOMANS, 285, 109 and 105 by JAKOB,
108 by A. SCHWAGER.

Table 12
Quartz bearing Biotite Porphyrites

| | 3 | 4 | 2 | 33c | 226 | 143c | 1 |
|--------------------------------|--------|--------|-------|--------|--------|--------|--------|
| SiO ₂ | 64,46 | 63,73 | 64,97 | 65,55 | 65,35 | 69,11 | 68,33 |
| Al ₂ O ₃ | 16,58 | 16,99 | 15,60 | 15,03 | 14,87 | 14,00 | 17,07 |
| Fe ₂ O ₃ | 1,11 | 1,34 | 0,94 | 1,36 | 1,57 | 0,98 | 1,76 |
| FeO | 3,34 | 3,07 | 3,46 | 3,05 | 2,84 | 2,31 | 1,42 |
| MnO | 0,09 | 0,09 | 0,07 | 0,07 | 0,03 | 0,03 | 0,09 |
| MgO | 2,40 | 2,28 | 2,60 | 2,35 | 2,11 | 1,85 | 0,66 |
| CaO | 3,40 | 4,71 | 2,82 | 3,17 | 3,42 | 0,57 | 2,07 |
| Na ₂ O | 2,21 | 2,27 | 2,75 | 3,36 | 3,15 | 4,87 | 2,55 |
| K ₂ O | 3,15 | 3,30 | 3,44 | 2,99 | 3,48 | 3,21 | 4,35 |
| TiO ₂ | 0,55 | 0,66 | 0,56 | 0,72 | 0,94 | 0,48 | 0,12 |
| P ₂ O ₅ | 0,20 | 0,13 | 0,18 | 0,19 | 0,17 | 0,18 | 0,16 |
| H ₂ O + | 2,32 | 1,50 | 2,14 | 1,90 | 2,05 | 2,39 | 1,31 |
| H ₂ O - | 0,27 | 0,16 | 0,28 | 0,28 | 0,09 | 0,13 | 0,19 |
| CO ₂ | 0,07 | 0,10 | 0,08 | 0,00 | 0,00 | 0,00 | 0,10 |
| Total | 100,15 | 100,33 | 99,89 | 100,02 | 100,06 | 100,11 | 100,18 |
| si | 259 | 241 | 264 | 266 | 268 | 330 | 324,5 |
| al | 39 | 38 | 37 | 36 | 36 | 39 | 48 |
| fm | 29 | 27 | 31 | 29 | 27,5 | 26 | 16,5 |
| c | 15 | 19 | 12 | 14 | 15 | 3 | 10,5 |
| alk | 17 | 16 | 20 | 21 | 21,5 | 32 | 25 |
| k | 0,48 | 0,49 | 0,46 | 0,37 | 0,42 | 0,32 | 0,53 |
| mg | 9,49 | 0,49 | 0,52 | 0,52 | 0,51 | 0,55 | 0,27 |

Analyses 1-4 by C. M. KOOMANS; Analyses 33c, 226 and 143c by J. JAKOB.

Table 13
Granophyres

| | 24 | 23 | 22 | 21 | 20 | 18 |
|--------------------------------|--------|--------|--------|--------|--------|--------|
| SiO ₂ | 70,17 | 72,04 | 73,49 | 73,59 | 73,65 | 74,82 |
| Al ₂ O ₃ | 16,12 | 15,60 | 11,97 | 12,22 | 12,23 | 11,06 |
| Fe ₂ O ₃ | 1,91 | 1,22 | 1,67 | 1,19 | 1,28 | 1,08 |
| FeO | 0,43 | 0,82 | 1,42 | 1,09 | 1,23 | 1,11 |
| MnO | 0,04 | 0,06 | 0,05 | 0,04 | 0,05 | 0,05 |
| MgO | 0,26 | 0,13 | 0,35 | 0,22 | 0,74 | 0,35 |
| CaO | 2,57 | 1,39 | 1,92 | 1,81 | 1,69 | 2,02 |
| Na ₂ O | 2,63 | 2,79 | 3,46 | 3,12 | 3,50 | 3,85 |
| K ₂ O | 4,14 | 2,51 | 4,27 | 5,50 | 4,64 | 4,43 |
| TiO ₂ | 0,02 | 0,04 | 0,02 | 0,02 | — | 0,02 |
| P ₂ O ₅ | 0,26 | 0,13 | 0,23 | 0,30 | 0,12 | 0,29 |
| H ₂ O + | 1,02 | 0,36 | 0,30 | 0,59 | 0,82 | 0,76 |
| H ₂ O - | 0,14 | 0,13 | 0,90 | 0,42 | 0,22 | 0,18 |
| F | 0,04 | — | — | — | — | — |
| Total | 100,11 | 100,22 | 100,05 | 100,11 | 100,17 | 100,02 |
| si | 356 | 383,5 | 403 | 410 | 398,5 | 425 |
| al | 48 | 49 | 38 | 40 | 39 | 37 |
| fm | 12 | 10 | 17 | 13 | 17 | 13,5 |
| c | 14 | 8 | 11 | 11 | 10 | 17,5 |
| alk | 26 | 33 | 34 | 36 | 34 | 37 |
| k | 0,51 | 0,57 | 0,45 | 0,54 | 0,46 | 0,43 |
| mg | 0,18 | 0,10 | 0,17 | 0,16 | 0,35 | 0,23 |

Analyses by C. M. KOOMANS.

Table 14 Aplite-Granophyres and Dikes

| | Dikes | | | | | | | |
|--------------------------------|-------|-------|--------|--------|-------|--------|-------|-------|
| | 17 | 19 | 86 | 16 | 25 | 199 | 13 | 14 |
| SiO ₂ | 75,11 | 74,01 | 75,95 | 76,72 | 70,55 | 70,26 | 68,85 | 68,82 |
| Al ₂ O ₃ | 11,77 | 13,25 | 12,78 | 13,07 | 14,55 | 11,70 | 15,24 | 15,44 |
| Fe ₂ O ₃ | 0,91 | 1,45 | 1,26 | 1,86 | 0,71 | 1,14 | 0,41 | 3,04 |
| FeO | 1,28 | 0,80 | 0,39 | 0,31 | 2,49 | 0,83 | 3,54 | 1,78 |
| MnO | 0,04 | 0,07 | 0,03 | 0,04 | 0,05 | 0,05 | 0,10 | 0,07 |
| MgO | 0,26 | 0,24 | 0,02 | 0,37 | 0,33 | 1,46 | 0,27 | 0,34 |
| CaO | 1,17 | 1,12 | 0,39 | 0,36 | 2,52 | 2,50 | 1,77 | 0,50 |
| Na ₂ O | 3,70 | 3,25 | 3,29 | 2,93 | 0,41 | 2,00 | 2,88 | 3,01 |
| K ₂ O | 4,51 | 4,14 | 5,35 | 3,64 | 3,20 | 4,45 | 3,70 | 3,75 |
| TiO ₂ | 0,02 | 0,08 | 0,20 | 0,02 | 0,44 | 0,24 | 0,49 | 0,53 |
| P ₂ O ₅ | 0,21 | 0,23 | — | 0,16 | 0,11 | 0,09 | 0,17 | 0,18 |
| H ₂ O + | 0,67 | 0,94 | 0,79 | 0,46 | 1,28 | 2,02 | 1,96 | 1,86 |
| H ₂ O — | 0,34 | 0,21 | — | 0,16 | 0,18 | 0,21 | 0,30 | 0,40 |
| CO ₂ | — | — | — | — | 0,11 | 3,12 | 0,09 | 0,03 |
| B ₂ O ₃ | — | — | — | — | 0,99 | — | — | — |
| Total | 99,99 | 99,79 | 100,45 | 100,10 | 99,92 | 100,07 | 99,77 | 99,67 |
| si | 442 | 437 | 480 | 495 | 373 | 388 | 346 | 357,5 |
| al | 41 | 46 | 47 | 49,5 | 45,5 | 38 | 45 | 47 |
| fm | 13,5 | 13 | 8 | 14,5 | 17 | 21 | 19 | 22 |
| c | 7,5 | 7 | 3 | 2,5 | 14,5 | 15 | 10 | 3 |
| alk | 38 | 34 | 42 | 33,5 | 23 | 26 | 26 | 28 |
| k | 0,44 | 0,46 | 0,52 | 0,45 | 0,47 | 0,60 | 0,45 | 0,45 |
| mg | 0,18 | 0,17 | 0,05 | 0,24 | 0,15 | 0,65 | 0,11 | 0,11 |

Analyses 13, 14, 16, 17, 19 and 25 by C. M. KOOMANS, Analysis 86 by DE QUERVAIN and Analyses 199 by J. JAKOB.

Table 15 Quartz-Porphyrries

| | 9 | 10 | 11 | 12 | 15 |
|--------------------------------|-------|--------|--------|-------|--------|
| SiO ₂ | 74,39 | 73,15 | 72,01 | 71,73 | 67,35 |
| Al ₂ O ₃ | 13,97 | 13,99 | 14,63 | 15,37 | 16,43 |
| Fe ₂ O ₃ | 0,65 | 2,28 | 2,23 | 2,49 | 2,13 |
| FeO | 1,85 | 0,53 | 0,73 | 1,96 | 1,56 |
| MnO | 0,07 | 0,03 | 0,12 | 0,09 | 0,08 |
| MgO | 0,19 | 0,13 | 1,61 | 0,22 | 1,12 |
| CaO | 1,03 | 1,19 | 1,18 | 0,62 | 0,96 |
| Na ₂ O | 2,98 | 2,78 | 1,71 | 2,45 | 3,51 |
| K ₂ O | 3,28 | 3,95 | 4,66 | 3,93 | 3,94 |
| TiO ₂ | — | — | 0,02 | — | 0,68 |
| P ₂ O ₅ | 0,09 | 0,28 | 0,13 | 0,10 | 0,37 |
| H ₂ O + | 1,01 | 1,26 | 0,89 | 0,77 | 1,82 |
| H ₂ O — | 0,28 | 0,47 | 0,22 | 0,20 | 0,41 |
| CO ₂ | 0,09 | 0,09 | 0,04 | 0,05 | — |
| Total | 99,88 | 100,13 | 100,18 | 99,98 | 100,36 |
| si | 446 | 414 | 371 | 358 | 317 |
| al | 49,5 | 46,5 | 44,5 | 48,5 | 45,5 |
| fm | 14,5 | 13,5 | 25 | 21,5 | 21,5 |
| c | 6,5 | 10,5 | 6,5 | 3,5 | 5 |
| alk | 29,5 | 29,5 | 24 | 26,5 | 28 |
| k | 0,42 | 0,48 | 0,64 | 0,51 | 0,42 |
| mg | 0,13 | 0,08 | 0,50 | 0,09 | 0,36 |

All Analyses by C. M. KOOMANS.

Table 16
Eruptive rocks of the Grantola region between
Ponte Tresa and Luino

| | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
|--------------------------------|--------------|---------------|---------------|---------------|--------------|---------------|---------------|--------------|
| SiO ₂ | 75,11 | 71,83 | 64,60 | 64,30 | 56,82 | 72,21 | 54,44 | 51,85 |
| Al ₂ O ₃ | 10,49 | 13,62 | 14,52 | 14,71 | 14,21 | 13,52 | 16,39 | 15,30 |
| Fe ₂ O ₃ | 3,22 | 2,70 | 2,81 | 3,94 | 3,69 | 1,80 | 4,42 | 4,13 |
| FeO | 0,22 | 0,58 | 1,87 | 1,78 | 3,40 | 0,16 | 2,88 | 3,06 |
| MnO | 0,06 | 0,07 | 0,05 | 0,06 | 0,15 | 0,02 | 0,15 | 0,24 |
| MgO | 0,32 | 0,95 | 1,44 | 1,33 | 3,67 | 0,17 | 5,94 | 5,55 |
| CaO | 1,28 | 1,51 | 2,90 | 2,96 | 7,46 | 1,25 | 7,81 | 9,98 |
| Na ₂ O | 1,87 | 2,08 | 3,43 | 3,02 | 2,07 | 2,81 | 2,08 | 2,19 |
| K ₂ O | 5,37 | 5,21 | 3,48 | 5,02 | 2,45 | 6,51 | 2,05 | 1,41 |
| TiO ₂ | 0,02 | 0,04 | 0,04 | 0,10 | 0,61 | 0,35 | 0,89 | 0,71 |
| P ₂ O ₅ | 0,11 | 0,16 | 0,12 | 0,12 | 0,16 | 0,12 | 0,18 | 0,22 |
| H ₂ O + | 0,79 | 0,73 | 4,47 | 1,75 | 2,85 | 0,79 | 1,73 | 2,66 |
| H ₂ O - | 0,23 | 0,33 | 0,39 | 1,04 | 0,60 | 0,57 | 0,54 | 0,47 |
| CO ₂ | 0,78 | 0,42 | — | 0,12 | 1,65 | — | 0,70 | 2,12 |
| Total | 99,87 | 100,23 | 100,12 | 100,25 | 99,79 | 100,28 | 100,20 | 99,89 |
| si | 472 | 379 | 280 | 262,5 | 183 | 403 | 151 | 140 |
| al | 39 | 42,5 | 37 | 35,5 | 27 | 44,5 | 27 | 24,5 |
| fm | 20 | 21 | 25,5 | 26,5 | 36 | 10 | 41 | 38,5 |
| c | 8,5 | 8,5 | 13,5 | 13 | 25,5 | 7,5 | 23 | 29 |
| alk | 32,5 | 28 | 24 | 25 | 11,5 | 38,0 | 9 | 8 |
| k | 0,66 | 0,62 | 0,40 | 0,52 | 0,44 | 0,61 | 0,39 | 0,30 |
| mg | 0,15 | 0,36 | 0,36 | 0,30 | 0,49 | 0,14 | 0,60 | 0,58 |

Analyses by C. M. KOOMANS.

The chemical analyses of the Lugano rocks as expressed in weight percentages have been given in the above tables. The composition of a rock expressed in this form though important as a record is not quite convenient for the purposes of petrographic classification, nor is it so for gaining a general idea of the chemical characteristics of that rock. For this purpose one must calculate the molecular proportions (or molecular values) from the weight % analysis, and after grouping allied molecules, express the composition in a smaller number of units. Several methods on these lines are in use but the one found most advantageous for expressing the rock-composition on a molecular basis is that introduced by NIGGLI. In this the molecular content of (Al₂O₃ + Cr₂O₃), (FeO (all iron as FeO) + MnO + MgO), (CaO + BaO + SrO) and (Na₂O + K₂O) are all added together and reduced to 100. On the same basis are expressed the molecular proportions of SiO₂, TiO₂, P₂O₅, CO₂, H₂O etc. These give the "molecular" (so-called "NIGGLI") values si, al, fm, c, alk, ti, p etc. and the sum (al + fm + c + alk) is always equal to 100.

Besides these are also given the values

$$k = \frac{K_2O}{K_2O + Na_2O (+ Li_2O)}, \text{ and } mg = \frac{MgO}{FeO + MnO + MgO}$$

These "molecular" values si, al, fm, c, and alk and the values k and mg for the rocks of the Lugano porphyry district have been given below each analysis in the above tables.

Table 17
Molecular Values of the rocks belonging to Main
Types of the Lugano Porphyry District

| Rock No. | | si | al | fm | c | alk | k | mg | Magma Type |
|----------|---|-------|------|------|------|------|------|------|--|
| 26 | Diabase dike | 124 | 26 | 42 | 25 | 7 | 0,39 | 0,62 | c-Gabbroid (Achnahaitic) |
| 8 | Basic (Pyroxene)- porphyrite | 155 | 26 | 44 | 15 | 15 | 0,56 | 0,56 | Lamprosommitic |
| A | Porphyrite | 188 | 27 | 45 | 14 | 14 | 0,40 | 0,38 | (Lampro-dioritic) |
| B | Porphyrite | 188 | 27 | 39 | 19 | 15 | 0,41 | 0,42 | (Lampro-dioritic to Vredefortitic) |
| 7 | Quartz bearing 'Pyroxene-' porphyrite | 196 | 36 | 31 | 18,5 | 14,5 | 0,45 | 0,43 | Opdalitic or Normal Quartz dioritic |
| 6 | id. | 201,5 | 32,5 | 34,5 | 17,5 | 15,5 | 0,52 | 0,43 | Opdalitic or Quartz dioritic |
| 109 | id. | 215 | 31 | 30 | 25 | 15 | 0,30 | 0,61 | (Cumbraitic) |
| 285 | id. | 211 | 31,5 | 35 | 17,5 | 16 | 0,39 | 0,55 | Opdalitic |
| 105 | id. | 234 | 32 | 35 | 13 | 20 | 0,38 | 0,66 | |
| 5 | id. | 249 | 42 | 26 | 12 | 20 | 0,46 | 0,38 | (Granodioritic) |
| 4 | Quartz bearing Biotite-porphyrite | 241 | 38 | 27 | 19 | 16 | 0,49 | 0,49 | Opdalitic (Leucotonalitic) |
| 3 | id. | 259 | 39 | 29 | 15 | 17 | 0,48 | 0,49 | id. |
| 2 | id. | 264 | 37 | 31 | 12 | 20 | 0,46 | 0,52 | id. |
| 33c | id. | 266 | 36 | 29 | 14 | 21 | 0,37 | 0,52 | id. |
| 226 | id. | 268 | 36 | 27,5 | 15 | 21,5 | 0,42 | 0,51 | id. |
| 143c | id. | 330 | 39 | 26 | 3 | 32 | 0,32 | 0,55 | Opdalitic (Rapakivitic) |
| 1 | id. | 324 | 48 | 16,5 | 10,5 | 25 | 0,53 | 0,27 | Opdalitic (Granodioritic) |
| 24 | Granophyre | 356 | 48 | 12 | 14 | 26 | 0,51 | 0,18 | (Adamellitic) |
| 23 | di. | 383,5 | 49 | 10 | 8 | 33 | 0,57 | 0,10 | Engadinite-granitic (Aplite-granitic) |
| 22 | id. | 403 | 38 | 17 | 11 | 34 | 0,45 | 0,17 | id. |
| 21 | id. | 410 | 40 | 13 | 11 | 36 | 0,54 | 0,16 | id. |
| 20 | id. | 398,5 | 39 | 17 | 10 | 34 | 0,46 | 0,35 | id. |
| 18 | id. | 425 | 37 | 13,5 | 12,5 | 37 | 0,43 | 0,23 | id. |
| 17 | id. | 442 | 41 | 13,5 | 7,5 | 38 | 0,44 | 0,18 | Aplite-granitic |
| 19 | id. | 437 | 46 | 13 | 7 | 34 | 0,46 | 0,17 | id. |
| 86 | id. | 480 | 47 | 8 | 3 | 42 | 0,52 | 0,05 | id. |
| 16 | id. | 495 | 49,5 | 14,5 | 2,5 | 33,5 | 0,45 | 0,24 | id. |
| 25 | Aplite dike | 373 | 45,5 | 17 | 14,5 | 23 | 0,47 | 0,15 | Granodioritic |
| 199 | Red porphyry dike | 388 | 38 | 21 | 15 | 26 | 0,60 | 0,65 | (Adamellitic) |
| 13 | Qz.- porphyry dike | 346 | 45 | 19 | 10 | 26 | 0,45 | 0,11 | id. |

2. Type-Construction

The number of rock-analyses given in these tables is fairly large and covers several well-defined groups of rocks ranging from basic through intermediate to highly acid types. It is, therefore, instructive to base on them a study of the chemical characteristics of these well defined eruptive series and also to study the trends of magmatic differentiation which lead to the formation of these various types.

As already noted, an attempt was made by Miss KOOMANS particularly to study the differentiation tendencies, on the basis of all the analyses, most of which were made by herself. It enabled her to recognize the calc-alkaline affinities of this porphyry series. It was, however, realized in the present investigations that for a detailed study of the chemical characteristics of the porphyry magma as also for its precise comparison with other magmatic series, most of the analyses given above are not quite reliable. The Lugano rocks in general have suffered intense alteration whereby both the mineralogical and chemical compositions have been largely affected. The present composition as given by many of the above analyses does not truly represent the original composition of these eruptive rocks. For a proper study of the magma and its normal products, therefore, a large number of the analyses as given above are unrepresentative and often misleading. The above material requires careful sifting to minimise the disturbing effect of alteration. This can be done by studying the alteration process and then selecting the apparently least altered rocks. These will form the basis for constructing ideal types which may be expected to approximate closely to the original (magmatic) composition of these rock-types.

In constructing ideal-types to represent the Lugano porphyries, analyses of quartz-porphyries, and those of rocks of the Grantola region (between Ponte Tresa and Luino) were excluded for reasons given later.

The ideal types given below were constructed on the following considerations:

I. When all the analyses are plotted in a differentiation diagram certain rocks are almost isolated; moreover their values for al , fm , c and alk as a whole, are also distinctive. These isolated rocks have been taken as independent types. Types A, B and E were formed in this way.

II. Some groups of rocks are represented by a number of analyses distributed in the diagram over a certain range of si . A study

of the effects of alteration in rocks of these groups has made it possible to judge which of them are least affected by such alterations; these rocks at the same time show among themselves a close agreement in all their values. These were selected and a mean of their values gave an ideal type for that whole group. Types D, F, G and H were formed in this manner. Type C was chosen from two similar analyses by rejecting the one which shows some abnormality in its values of c and alk but agrees with the other rock in values of si, al and fm.

III. A consideration of the Q L M-values of all the above rocks has shown that in some groups certain particular values appeared more common than others and appeared characteristic for that group. The rocks having these values were taken as the nearest representatives of that type. Types developed in this manner corresponded exactly with those constructed as in I and II, above.

Table 18

The Main Rock-types of the Lugano Porphyry District

| Type | Name | si | al | fm | c | alk | k | mg |
|------|--------------------------------------|-----|------|----|------|-----|------|------|
| A | Diabase | 124 | 26 | 42 | 25 | 7 | 0,39 | 0,62 |
| B | Basic porphyrite | 155 | 26 | 44 | 15 | 15 | 0,56 | 0,56 |
| C | „ „ | 188 | 27 | 39 | 19 | 15 | 0,41 | 0,41 |
| D | Quartz bearing basic porphyrite | 199 | 34 | 33 | 18 | 15 | 0,48 | 0,43 |
| E | Basic biotite-porphyrite | 211 | 31,5 | 35 | 17,5 | 16 | 0,39 | 0,55 |
| F | Quartz bearing biotite-porphyrite | 264 | 37 | 29 | 14 | 20 | 0,42 | 0,51 |
| G | Granophyre | 404 | 39 | 16 | 11 | 34 | 0,48 | 0,23 |
| H | Aplitic granophyre | 480 | 47 | 8 | 3 | 42 | 0,52 | 0,05 |

Type A is based on only one analysis, that of the diabase dike from Borgnana (anal. No. 26). The rock is highly altered but there being no better analysis available for this most basic type this one has been taken as a main type. It corresponds in composition to the c-gabbroid magma-type of NIGGLI.

Type B is also represented by one modern analysis only, No. 8 of the pyroxene-porphyrite from Marzio. An old analysis No. P of similar rocks from Brinzio is probably an altered variety of type B.

Type C corresponds to the analysis of a porphyrite from Arogno given above as anal. No. B by JAKOB. Analysis No. A also by JAKOB corresponds to the same rock-type.

Type D is represented by two fresh rocks, analyses Nos. 6 and 7 and by three more or less altered rocks, Nos. 109, 105 and 5. An old

analysis by SCHWAGER of the porphyrite from Melide corresponds to the same rock as 109 and also belongs to the same type D.

Type E is based on a single analysis No. 285 of the porphyrite of Morcote. It differs only slightly from the above type, D, and it is possible that analysis No. 5 included under type D belongs to this group.

Type F separated from the previous and the succeeding types by a large *si* interval is a fairly well-defined group and is represented by five about equally fresh rocks Nos. 2, 3, 4, 33 c and 226 and by two altered rocks Nos. 1 and 143 c. Of these seven analyses all except Nos. 1 and 4 are from the Morcote Peninsula.

Type G comprising the granophyres is the most widespread of the various rock-types, and is again separated from the previous type F by a large *si* interval. It is represented by three nearly identical analyses of apparently fresh rocks Nos. 20, 21 and 22 from the main outcrops of Cuasso al Monte and Brinzio and by three more or less altered rocks Nos. 18, 23 and 24.

The last magma-type H is also a granophyre but very aplitic in composition. The analysis of the granophyre from the quarry at Madonna d'Ongera has been taken as the representative of this type though it is not regarded as a quite fresh rock. Rocks Nos. 16, 19 and also possibly 17 are other members of this group.

It may again be noted here that of the above types, A, B and E are based on single analyses of rocks which are not quite fresh and, therefore, do not necessarily give the composition of the primary magmatic rock-types. In the absence of better data they have been taken as the nearest representatives of the respective magmatic types.

The case of the quartz-porphyrines is rather peculiar. These rocks apparently do not belong to any one magma-type. Admixture of other material and later alterations have been combined to bring about an intense heterogeneity in their present composition. They are apparently not normal products of magmatic differentiation and have, therefore, been excluded as unsuitable for the construction of magma-types.

Again the rocks of the Grantola region as a whole show some general tendencies which are rather different from those of the main Lugano outcrop. These differences cannot be referred to alteration alone but are probably connected with the conditions of consolidation of the magma. For this reason they have been treated separately.

3. The Normative Composite Mineral Content

In the above Table (18) are given the NIGGLI values si , al , fm , c and alk together with the values k and mg for the main types of the Lugano porphyries. These form the basis for our study of the chemical characteristics of the porphyry magma and also for the study of its differentiation. In utilizing these values for the discussion of relationships existing between the various members of this series the most satisfactory results are obtained when we calculate certain new values based on them. Among these the following are especially suitable for bringing out the relative basicity of the different rocks: $2 alk$, $2 (al - alk)$ and $(100 - 2 al)$.

These values for the different members of a series when plotted in a suitable diagram can also be utilized, as will be seen later, in studying the trends of differentiation within that series.

When al is less than the sum $(alk + c)$, the value $2 alk$ gives the proportion of al combined with alk to form the molecules Kp (K-nepheline) and Ne (nepheline) and hence gives the proportion of normative alkali feldspars. The value $2 (al - alk)$, on the other hand, gives that part of al which is combined with c to form Cal (calcium-aluminate) and gives the proportion of the normative anorthite. The difference $(100 - 2 al)$ represents the remaining metallic constituents, c and fm which are not combined with al and thus gives the proportion of the normative femic constituents.

In those cases, however, where $al > (alk + c)$ the expression $2 (al - alk)$ includes not only that part of al which is combined with c but also that which is combined with Mg and Fe to form Sp (spinel $MgAl_2O_4$) and H_z (hercynite $FeAl_2O_4$) and, therefore, gives no proper measure of the content of anorthite. Similarly the expression $(100 - 2 al)$ in these cases represents only the excess of fm remaining after combining fm with al and, therefore, does not give the full content of the ferromagnesian constituents.

Table 18 a

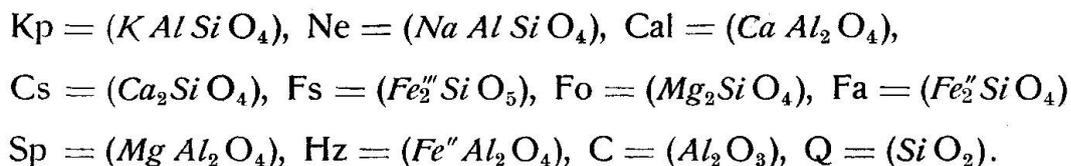
| Type | alk.-feld. 2 alk | anorthite 2 (al-alk) | dark minerals (100-2 al) |
|------|---------------------|-------------------------|-----------------------------|
| A | 14 | 38 | 48 |
| B | 30 | 22 | 48 |
| C | 30 | 24 | 46 |
| D | 30 | 38 | 32 |
| E | 32 | 32 | 36 |
| F | 40 | 34 | 26 |
| G | 68 | 10 | 22 |
| H | 84 | 10 | 6 |

In the Lugano rocks, though many analyses show an excess of al over $(alk + c)$, the main types rarely do so. Hence the above values $2 alk$, $2 (al - alk)$ and $(100 - 2 al)$ are fairly suited to give the relative proportions of normative minerals viz. alkali feldspars:anorthite:femic minerals. The following Table 18a gives the above values for the main types of the Lugano region.

4. Calculation of the Basis Composition

One of the important objects in the study of the chemistry of the magma is to compare the mineral composition as computed from the chemical analysis with the actual (modal) mineral composition. Since several mineral combinations can be developed from the same magma these different combinations must be comparable within themselves. The C. I. P. W. method of computation of the mineral composition based on percentage weights, though applicable, is not quite suitable for converting readily one mineral combination into another, as it involves laborious calculations and use of tables. In this respect, however, the method developed by NIGGLI (1936 a) and based on molecular values has been found highly satisfactory. Stated briefly, it is as follows:

The percentage analysis is converted into molecular values (with the help of tables like those of PHILLIPSBORN). These give the atomic values of oxides directly except those of Al_2O_3 , Fe_2O_3 , Na_2O , K_2O , P_2O_5 etc. which must be multiplied by 2. These atomic values are then allotted in definite proportions to form what are called basis molecules. The major basis molecules common in calc-alkali suites are:



The minor ones are:



The composition in terms of these basis molecules when recalculated to a sum of 100 gives the basis norm of the rock. The following example illustrates the method of calculation of the basis:

Table 19

Basis Norm of Analysis No. 285 (Pyroxene-Porphyrite Morcote)

| | Weight % | Atomic values | Kp | Ne | Cal | Cs | Fo | Fa | Fs | Q | Ru | Cp |
|--------------------------------|----------|---------------|------|------|-----|-----|-----|-----|------|-----|-----|----|
| SiO ₂ | 61,12 | 1018 | 60 | 96 | — | 4 | 43 | 30 | 10 | 775 | — | — |
| Al ₂ O ₃ | 15,59 | 304 | 60 | 96 | 148 | — | — | — | — | — | — | — |
| Fe ₂ O ₃ | 1,64 | 20 | — | — | — | — | — | — | 20 | — | — | — |
| FeO | 4,34 | 61 | — | — | — | — | — | 61 | — | — | — | — |
| MnO | 0,08 | | — | — | — | — | — | — | — | — | — | — |
| MgO | 3,45 | 86 | — | — | — | — | 86 | — | — | — | — | — |
| CaO | 4,74 | 85 | — | — | 74 | 8 | — | — | — | — | — | 3 |
| Na ₂ O | 2,97 | 96 | — | 96 | — | — | — | — | — | — | — | — |
| K ₂ O | 2,83 | 60 | 60 | — | — | — | — | — | — | — | — | — |
| TiO ₂ | 0,97 | 12 | — | — | — | — | — | — | — | — | 12 | — |
| P ₂ O ₅ | 0,16 | 2 | — | — | — | — | — | — | — | — | — | 2 |
| | | 1744 | 180 | 288 | 222 | 12 | 129 | 91 | 30 | 775 | 12 | 5 |
| Basis : | | 100 = 10,3 | 16,5 | 12,6 | 0,7 | 7,4 | 5,2 | 1,7 | 44,6 | 0,7 | 0,3 | |
| Kala-molecular-norm | | 100 = 17,2 | 27,5 | 21,0 | 0,9 | 9,9 | 5,9 | 1,7 | 14,9 | 0,7 | 0,3 | |
| | | | Or | Ab | An | Wo | En | Hy | Mt | Qz | Ru | Ap |

The following Table 20 gives the basis of the main types of the Lugano eruptive rocks calculated by the above method. In types D, F and H, Al is greater than $(K + Na + 2Ca)$, and so remains in excess after the formation of Kp, Ne and Cal. In normal course this excess would take up Mg and Fe" to form Sp and Hz and in some cases may even form C after using up all Mg and Fe". However, since we know that this excess of Al in Lugano rocks is not a normal magmatic condition but has been chiefly brought about by alteration through the leaching of Ca, it has been found advisable to give two sets of basis values for these types D, F and H. In one (a) this excess of Al is shown separately as C and in the other (b) it is distributed between Cal and Q.

Table 20

Basis of the Main Lugano Types

| Type | Kp | Ne | Cal | C | Cs | Fo | Fa | Fs | Q | Ru | Cp |
|------|------|------|------|-----|-----|------|-----|-----|------|-----|-----|
| A | 6,1 | 9,3 | 22,6 | — | 2,7 | 15,3 | 6,2 | 3,0 | 33,2 | 1,3 | 0,3 |
| B | 17,2 | 13,3 | 10,5 | — | 1,9 | 12,6 | 4,4 | 5,3 | 34,0 | 0,6 | 0,3 |
| C | 11,1 | 15,8 | 11,3 | — | 2,3 | 7,3 | 5,2 | 5,2 | 40,6 | 0,6 | 0,6 |
| D a | 12,3 | 13,0 | 15,6 | 0,8 | — | 6,1 | 4,2 | 3,7 | 43,5 | 0,5 | 0,3 |
| b | 12,3 | 13,0 | 16,0 | — | — | 6,1 | 4,2 | 3,7 | 43,9 | 0,5 | 0,3 |
| E | 10,3 | 16,5 | 12,6 | — | 0,7 | 7,4 | 5,2 | 1,7 | 44,6 | 0,7 | 0,3 |
| F a | 12,1 | 16,0 | 9,3 | 1,9 | — | 5,1 | 3,9 | 1,5 | 49,3 | 0,6 | 0,3 |
| b | 12,1 | 16,0 | 10,3 | — | — | 5,1 | 3,9 | 1,5 | 50,3 | 0,6 | 0,3 |
| G | 17,3 | 18,6 | 2,4 | — | 1,1 | 1,0 | 1,5 | 1,5 | 56,1 | — | 0,5 |
| H a | 19,4 | 18,0 | 1,2 | 0,9 | — | — | 0,5 | 1,4 | 58,4 | 0,2 | — |
| b | 19,4 | 18,0 | 1,6 | — | — | — | 0,5 | 1,4 | 58,9 | 0,2 | — |

Table 21

Kata-Molecular Norms of the Main Lugano Types

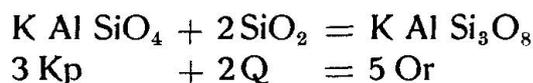
| Type | Or | Ab | An | Wo | En | Hy | Mt | Qz | Ru | Ap |
|------|------|------|------|-----|------|-----|-----|------|-----|-----|
| A | 10,2 | 15,5 | 37,6 | 3,6 | 20,6 | 6,3 | 3,0 | 1,8 | 1,3 | 0,3 |
| B | 28,6 | 22,1 | 17,5 | 2,5 | 16,8 | 2,4 | 5,3 | 4,0 | 0,6 | 0,3 |
| C | 18,5 | 26,3 | 18,0 | 3,1 | 9,7 | 3,5 | 5,2 | 13,6 | 0,6 | 0,3 |
| D | 20,5 | 21,7 | 26,6 | — | 8,1 | 3,2 | 3,7 | 15,4 | 0,5 | 0,3 |
| E | 17,2 | 27,5 | 21,0 | 0,9 | 9,9 | 5,9 | 1,7 | 14,9 | 0,7 | 0,3 |
| F | 20,2 | 26,6 | 17,1 | — | 6,8 | 4,3 | 1,5 | 22,6 | 0,6 | 0,3 |
| G | 28,8 | 31,0 | 4,0 | 1,5 | 1,3 | 1,1 | 1,5 | 30,3 | — | 0,5 |
| H | 32,4 | 30,0 | 2,7 | — | — | — | 1,4 | 33,4 | 0,2 | — |

5. Calculation of the Kata-Molecular Norms and Kata-Variants

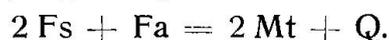
With the basis for the various types of Lugano rocks at our disposal, we are now in a position to calculate the mineral composition of the above rock-types. As is well known a magma can give rise to different sets of mineral combinations under different cooling conditions and we can, therefore, have more than one normative mineral composition for a given rock. The most generalized one, in which the minerals show the highest silicified condition possible for a given silica content and are in keeping with the mineral paragenesis of the kata-zone, is termed the kata-molecular norm. This ideal mineral composition when calculated for different rock-types gives a good basis for comparison.

For the Lugano rocks which are all over-saturated with respect to silica we can build the following normative minerals:

With $\frac{2}{3}$ of its amount of Q, Kp forms Or (orthoclase) according to the equation:



Similarly Ne forms Ab (albite) and Cal, An (anorthite). Fs combines with Fa to form Mt (magnetite).



With $\frac{1}{3}$ of its amount of Q, Cs forms Wo (wollastonite), Fo forms En (enstatite) and remaining Fa forms Hy (hypersthene). The remaining Q forms Qz (quartz). Ru gives rutile and Cp gives Ap (apatite).

The kata-molecular norms for the main Lugano types as calculated on the above scheme are given in Table 21.

The kata-molecular norm given above does not represent the composition of the rock in terms of the actual (modal) minerals

present in the rock but in terms of simple mineral molecules. The modal minerals are often highly complex mixtures of two or more norm-minerals. Thus wollastonite (Wo) rarely occurs as an independent mineral species in igneous rocks but is usually combined with other norm-minerals e. g. En, Hy, An etc. to form common augite or hornblende or may combine with Ru to form titanite. The mineral composition calculated in terms of modal minerals of the kata-zone gives what is called the kata-variant.

The calculation of these kata-variants requires a very intimate knowledge of the nature of the modal minerals in the rock. Since some of these minerals show a wide range of composition, the kata-variant will depend on the particular composition of the minerals chosen for calculation and hence several alternative kata-variants may be obtained for the same rock.

When we attempt to calculate k a t a - v a r i a n t s for the Lugano types we are faced with the initial difficulty about the nature of the original minerals crystallized from the magma. These minerals have been highly altered and replaced by secondary products leaving no trace of the original minerals. In the basic porphyrites of the Morcote Peninsula no trace of original augite or hornblende has been detected while feldspars have been extensively replaced by albite and sericite. Under these circumstances it is not possible to calculate any appropriate kata-variants particularly for types A to E. Some approximate idea of the possible mineral composition can, however, be obtained from the proportion of the various basis or norm molecules. For example, if we suppose that all Cs, Fo, Fa and the greater part of Fs in types A to E were originally constituents of augite or hornblende, it is seen that the amount of Cs as compared to that of (Fo + Fa + Fs) is too low to build any normal augite in which the proportion of Cs to (Fo + Fa + Fs) is always more than $\frac{1}{3}$. Common augite has normally the following composition:

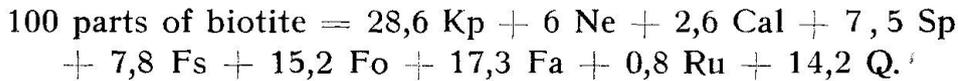
$$100 \text{ parts of augite} = 1 \text{ Kp} + 7 \text{ Ne} + 2,9 \text{ Cal} + 26,5 \text{ Cs} + \\ 5 (\text{Fs} + \text{Fa}) + 25,9 \text{ Fo} + 22,8 \text{ Q} + 0,2 \text{ Ru.}$$

In normal hornblendes this proportion is somewhat lower. In the Lugano types A to E the proportion actually observed in the basis is less than even $\frac{1}{8}$. This low proportion is possible only in some pigeonite pyroxenes which are not uncommon in the groundmass of basic rocks. Some of these pigeonites have the following composition:

$$100 \text{ parts of pigeonite} = 7,5 \text{ Cs} + 22,5 \text{ Fo} + 45 \text{ Fa} + 25 \text{ Q.}$$

Some types of hornblende are poor in lime and may also show this low proportion of Cs. If the amount of Cs in the Lugano types represents their original content we may suppose that the original femic minerals were of pigeonitic or of hornblendic nature. There is still another possibility: Cs with the necessary part of Fo may form diopside and the rest of Fo with Fa may form a hypersthene, these two minerals then forming together the main dark minerals. These are the possibilities but in the absence of definite indications under the microscope not one cannot be preferred to the others.

With respect to the other types, F, G and H we are in a somewhat better position. In rocks of type F biotite has been commonly observed. This mineral requires some alumina-excess for its formation as will be seen from the following equation in which al excess is shown as sp.:



In type F (Table 20, basis a) some alumina-excess C is actually present, a part of which at least may be referred to biotite. If we build a biotite of the above or a slightly more aluminous variety and a plagioclase with 45 % An we get the following kata-variant for the rock-type F:

| Quartz | Microperthite (30 % Ab) | Plagioclase (45 % An) | Biotite | Ore | Rutile | Apatite |
|--------|----------------------------|--------------------------|---------|-----|--------|---------|
| 27 | 16 | 35 | 20 | 1 | 0,4 | 0,3 |

Thus owing to the formation of biotite we have a little more quartz in the variant than is seen in the norm (Table 21). In type G the biotite variant with plagioclase containing 35 % An roughly comes to

| Quartz | Microperthite | Plagioclase | Biotite + Ore + Hornblende |
|--------|---------------|-------------|-------------------------------|
| 31 | 48 | 16 | 5 |

This corresponds very well with the following modal composition of granophyre as given by KOOMANS (1937, p. 33):

| | | | |
|----|----|----|---|
| 35 | 42 | 20 | 3 |
|----|----|----|---|

In type H with a more acid plagioclase the kata-variant is:

| | | | |
|----|----|----|---|
| 33 | 55 | 10 | 2 |
|----|----|----|---|

6. The QLM-values and $\pi\gamma$ -values

For the purposes of comparative petrography it would be most helpful if we could represent the composition of rocks graphically by means of single points. This can in fact be accomplished by

combining the various related components of the rocks into a small number of new values which then can be plotted in a plane diagram. The character of an igneous rock is determined principally by the relative proportions of the three important components, quartz, feldspars and ferromagnesian minerals. When one considers the basis molecules given in tab. 20 it is seen that Kp, Ne and Cal are the unsaturated feldspathic molecules which can therefore be grouped together as one value under L (leucocratic), the molecules Cs, Fo, Fa and Fs are lower silicates of the ferromagnesian minerals and can be combined as M (melanocratic), whereas Q is the basis molecule for quartz. Now if these three quantities Q, L and M be plotted in a triangular diagram as done by NIGGLI (1936 a, p. 306), the rock is represented by a single point as desired.

The following table gives the Q L M-values for the main Lugano types:

Table 22

| Type | Q | L | M |
|------|------|------|----|
| A | 33,5 | 38,5 | 28 |
| B | 34 | 42 | 24 |
| C | 41,5 | 37,5 | 21 |
| D | 44 | 41 | 15 |
| E | 45 | 40 | 15 |
| F | 50 | 39 | 11 |
| G | 56 | 38 | 6 |
| H | 58,5 | 39,5 | 2 |

The above values of Q L M as obtained from the base composition are highly important in the discussion of magmatic differentiation and in tracing the magmatic affinities with some of the well known petrographic suites. Similar characteristic tendencies are also exhibited by some other values which can also be obtained from the base composition. These values are:

$$\pi = \frac{\text{Cal}}{\text{Kp} + \text{Ne} + \text{Cal}}; \quad \text{and} \quad \gamma = \frac{\text{Cs}}{\text{Cs} + \text{Fo} + \text{Fa} + \text{Fs}}$$

Here π gives that proportion of Ca which is combined with Al to the total sum $\text{K} + \text{Ne} + \text{Ca}$ which are also combined with Al; in other words roughly the proportion of normative anorthite to the total normative feldspars. On the other hand γ gives that proportion of Ca which is not combined with Al to the amount of $\text{Ca} + \text{Fe} + \text{Mg}$ which is also not combined with Al; in other words roughly the proportion of normative wollastonite to the total normative dark minerals.

The following Table 23 gives the values of π and γ together with the values of k and mg for the main types of Lugano porphyry rocks:

Table 23

| Type | k | π | mg | γ |
|------|------|-------|------|----------|
| A | 0,39 | 0,60 | 0,62 | 0,10 |
| B | 0,56 | 0,26 | 0,56 | 0,08 |
| C | 0,41 | 0,30 | 0,41 | 0,11 |
| D | 0,48 | 0,38 | 0,43 | 0,00 |
| E | 0,39 | 0,32 | 0,55 | 0,05 |
| F | 0,42 | 0,24 | 0,51 | 0,00 |
| G | 0,48 | 0,06 | 0,23 | 0,18 |
| H | 0,52 | 0,03 | 0,07 | 0,00 |

7. Problems under Discussion

In the foregoing pages we have assembled the data regarding the composition of the leading rock types in a form which is suitable for the study of the problems connected with the chemistry of the porphyry magma. The first and the more important problem is to trace the course of the differentiation of the magma leading to the development of the various more or less distinct rock types and to see if a similar course of differentiation was followed by magmas in other petrographic provinces. The second problem is to understand the process of alteration which the eruptive rocks of Lugano have undergone after their consolidation in a measure sufficient to obscure the original nature of the rocks.

The above would also be the natural sequence in the treatment of the above problems; practical considerations, however, compel us to tackle them in the inverse order; for it was soon found that the composition of the original magmatic products could only be understood after a full study of later alterations. We shall, therefore, examine these first and afterwards make an attempt to reconstruct as nearly as possible, the original composition of the rock-types essential to the discussion of the main problem of magmatic differentiation and provincial relationships.

B. STUDY OF ALTERATION

The eruptive rocks of the Lugano porphyry district have undergone extensive alteration during the long geological period since their formation in Permian times. The rock outcrops are much softened, cleaved and broken up, often making it difficult to get a hand-specimen of normal size. Under the microscope, too, the pri-

many minerals are intensely altered and in many cases it is not easy to ascertain which of the ferromagnesian minerals occurred as original constituents of the rock. Feldspars also have suffered intense sericitization and albitization.

The effects of this alteration are, without doubt, reflected in the chemical composition of the analysed rock-specimens. The majority of the analyses show an excess of alumina and to a certain extent also of silica which must be attributed in a large measure to such effects.

In order to find out the original composition of the rocks, the trends of the chemical changes and their extent must be investigated. Two methods have been commonly employed for this purpose:

- A. The quantitative study of the mineral composition of the fresh and altered rocks; and
- B. The study of chemical analyses of such rocks.

In the volcanic rocks with aphanitic ground-mass the quantitative estimation of the mineral composition is attended with extreme difficulties and uncertainties. With such rocks, therefore, recourse can be taken to the second method only, which in recent times has been the method most commonly used in the investigation of alteration processes.

Numerous methods of calculation have been adopted to determine quantitatively the exact amount of loss or gain suffered by any particular chemical constituent during the alteration of the rock and several different methods of representation have been employed to illustrate the alteration effects. As these methods are based on different assumptions they do not give identical results, nor do the results admit a common interpretation. The common assumption used in many methods is the constancy of Al_2O_3 or SiO_2 . Some methods are based on the constancy of that oxide which shows the maximum enrichment in the alteration product, whereas some others calculate the changes which each constituent in the altered rock shows with respect to its amount in the fresh rock.

In the present investigations methods developed by NIGGLI, GSCHWIND, TRÖGER and GROSSER have been employed to follow the trends of chemical changes and these results were qualitatively compared with the mineralogical changes actually observed in the thin-sections of the analysed rocks. These results have helped in a certain measure to reconstruct the probable composition of the rock-types in their unaltered condition.

In the following comparisons, it has been assumed that the various rocks under comparison had originally the same composition and that the present chemical differences are solely due to their later alterations. It must be admitted that this is not always strictly true since the composition of the rocks varies from place to place and slight chemical differences, which are supposed to distinguish the "fresh" from the "altered" rocks, may in fact have already been present in their primary condition. In the following studies only such rocks have been brought under comparison which from their field relations could be safely taken as originally having a similar composition and without further introducing unproved hypotheses it will be taken for granted that all the differences in the composition of the allied rocks are mainly of secondary origin. Even though this is not absolutely correct it should still be possible to get a reasonably correct picture of the process involved, especially if the results obtained for various rocks are compared and only the really significant tendencies are considered.

1. The Method of NIGGLI Differentiation Diagrams

Among the numerous methods of studying the alteration process one very simple plan is to utilize the differentiation diagram based on molecular values as suggested by NIGGLI (GSCHWIND 1931). The values of *al*, *fm*, *c* and *alk* for the fresh and altered rocks are plotted on vertical lines with *si* as abscissa and the points indicating the same constituent in the various rocks are joined by straight lines; the inclination of each line to the horizontal then indicates gain or loss for that constituent.

In applying this method, however, we must introduce a few new values in order to study the behaviour not only of the composite units *fm* and *alk* but also of their individual components Fe, Mg, Na and K separately. The new values to be introduced in the diagram are: $K = k \cdot \text{alk}$; $\text{Na} = (1 - k) \text{alk}$; $\text{Mg} = \text{mg} \cdot \text{fm}$ and $\text{Fe} = (1 - \text{mg}) \text{fm}$.

If we now construct a partial differentiation diagram for a group of allied rocks and compare the changes with reference to the main type characteristic of this group it will be easy to follow the changes in each of the altered rocks.

The following example illustrates the alteration in the pyroxeneporphyrite group, type D.

Table 24

| | fresh | altered | | |
|-----|-------|---------|-----|------|
| | D | 105 | 5 | 109 |
| si | 199 | 234 | 249 | 215 |
| al | 34 | 32 | 42 | 31 |
| fm | 33 | 35 | 26 | 30 |
| c | 18 | 13 | 12 | 25 |
| alk | 15 | 20 | 20 | 15 |
| K | 7 | 8 | 9 | 4,5 |
| Na | 7 | 12 | 11 | 11,5 |
| Mg | 14 | 14 | 10 | 18,5 |
| Fe | 19 | 21 | 16 | 11,5 |

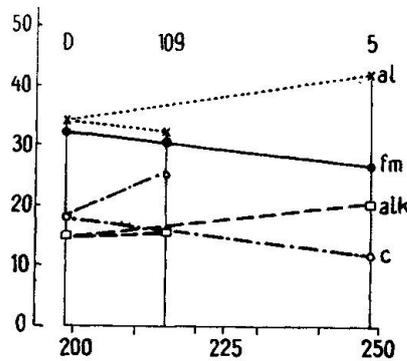


Fig. 9a

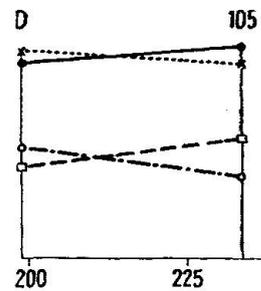


Fig. 9b

Fig. 9. Differentiation Diagrams showing the Alteration of Rocks of Type D

It will be seen from the above example that for the main type D and the altered rock No. 105, an increase of si by 35 units is accompanied by a very slight change in the content of al and fm, but alk has increased by 5 units whereas c has decreased by 5 units. Again, in the alkalis the increase has been almost wholly due to increase of Na since the change of the value K is insignificant. In fm the slight increase is due to Fe, Mg remaining unchanged. Expressed proportionately, the gradation of constituents according to changes is

relative enrichment relatively const. relative loss
 ← Na K Si Fe Mg Al Ca →

In rock No. 5, increase is shown by si, al, alk, Na and K and decrease by fm, Fe, Mg and c. The gradation based on proportionate change is

relative enrichment relative loss
 ← Na K Al Si Fe Mg Ca →

This is the same as in No. 105 except that more Al has been retained in No. 5 than in No. 105.

The case of No. 109 is peculiar. The changes in si, al, fm and alk are very small but c shows an enormous increase. Among the alkalis, too, while Na shows the normal increase as in other rocks, K has suffered a great loss. Fe and Mg also show a reversal of the normal relations: the former decreasing and the latter actually increasing. The gradation in this case is then

| | | |
|---------------------|-------------------|---------------|
| relative enrichment | relatively const. | relative loss |
| ← Ca Na Mg | Si Al | K Fe → |

Here apparently there has been an actual addition of Ca, Na and Mg through the circulating solutions which leached away K and Fe.

The chemical changes in other groups of rocks correspond as a rule with those observed in rocks Nos. 5 and 105. The general trend of alteration as given by this method and expressed as gradation is:

| | | |
|---------------------|-------------------|---------------|
| relative enrichment | relatively const. | relative loss |
| ← Na K | Si Al Fe | Mg Ca → |

It seems that owing to the activity of the circulating solutions alkalis (Na or K or both) are very commonly introduced at the expense of lime and magnesia which are usually leached away in solution.

2. The Method of NIGGLI and GSCHWIND

GSCHWIND and NIGGLI (1931) have also used a different method of calculation in the study of relative losses of rock-components during alteration. In this method the constituent which shows maximum apparent enrichment in the altered product is taken as having remained constant and as furnishing, therefore, a basis for the calculation of the comparative loss of all other components. This choice of the basis is restricted to one of the seven main components: SiO₂, Al₂O₃, Fe₂O₃ (all iron calculated as Fe₂O₃), MgO, CaO, Na₂O and K₂O since all other components e. g. H₂O, CO₂, TiO₂, P₂O₅ etc. are either quite insignificant or are liable to addition in large quantities from extraneous sources.

Owing to the possibility of some loss of the component taken as basis or of its addition through circulating solutions the figures giving the losses of other oxides do not give these in absolute terms but only in relative and approximate values. Their main utility, however, is that a sequence is established for the loss of the various

oxides which is not affected even if the original oxide taken as basis has itself actually suffered some loss.

In this method the proportion of apparent increase of the component showing maximum enrichment is first ascertained and the values of the other components correspondingly reduced. The difference between the values in the original unaltered rock and the reduced values gives the absolute loss and this when compared with the original values in the unaltered rock, gives the percentage loss. The various components when arranged according to their % losses give the gradation series which can be well illustrated in a loss-diagram. On the right-hand side of a rectangle are marked to scale the various components according to their % loss and these points are then joined individually to the lower left corner. The sequence of the radiating lines gives the gradation of the components while their inclination to the horizontal gives a measure of their absolute loss.

In the following Tables (25—27) are given the absolute and percentage loss-values for the basic (pyroxene-)porphyrites, biotite-porphyrites and granophyres and these have been illustrated in the loss-diagrams Figs. 10—12.

It will be noticed from these diagrams that in most cases alkalis appear to show maximum enrichment and have been taken as the basis for calculating the loss of other constituents. It is well known that alkalis are the most important constituents of circulating waters and are, therefore, most liable to be added to the rocks from outside. They do not, therefore, correspond to the original composition of those rocks and consequently do not give a satisfactory basis for loss calculation. It is also seen from these diagrams that a certain number of the rock-constituents appear crowded in the middle of the field. If we suppose that these constituents have in reality suffered only very slight changes during alteration, we can easily estimate the actual gains and losses suffered by the other constituents. This is best illustrated in the loss-diagrams for biotite-porphyrites. In the diagram 33 c/3 all the constituents except Na show a loss of between 32—40 % and in diagram 4/3 all except Ca show a loss of between 24—32 %. It may from the above be assumed that in rocks Nos. 33 c and 4 there has been no substantial alteration except that Na in the former and Ca in the latter have been actually introduced from outside. By reading the diagrams in this way, it is seen that among the basic (pyroxene-)porphyrites and taking rock No. 7 as fresh, the changes can be interpreted as follows:

| Rock No. | Relative gains | Relatively unchanged | Losses |
|----------|----------------|----------------------|------------|
| 6 | K, Fe | Mg, Si, Na, Al | Ca |
| 109 | Na, Ca | Mg, Si | Al, Fe |
| 105 | Na | K, Fe, Si, Mg, Al | Ca |
| 5 | K | Na, Si, Al | Fe, Mg, Ca |

Among the biotite-porphyrites (rock No.3 taken as fresh) the changes are:

| Rock No. | Relative gains | Relatively unchanged | Losses |
|----------|----------------|----------------------|------------|
| 4 | Ca | Ka, Na, Al, Fe, Si | Mg |
| 33c | Na | Si, Fe, Mg, K, Ca | Al |
| 1 | K | Na, Si, Al | Fe, Ca, Mg |
| 143c | Na | Si, K, Al, Fe, Mg | Ca |

Table 25a
Alteration of Pyroxene-Porphyrites

| | Orig. comp. | Altered product | Reduced values |
|--------------------------------|-------------|-----------------|----------------|-----------------|----------------|-----------------|----------------|-----------------|----------------|
| | 7 | 6 | 6/7 | 109 | 109/7 | 105 | 105,7 | 5 | 5/7 |
| SiO ₂ | 58,02 | 58,42 | 50,50 | 60,76 | 48,8 | 62,82 | 43,5 | 62,89 | 53,0 |
| Al ₂ O ₃ | 18,29 | 16,01 | 13,85 | 14,87 | 11,9 | 14,65 | 10,1 | 18,09 | 15,25 |
| Fe ₂ O ₃ | 6,82 | 7,40 | 6,80 | 5,40 | 4,34 | 7,20 | 5,0 | 5,22 | 4,40 |
| MgO | 2,67 | 2,92 | 2,52 | 2,91 | 2,34 | 2,57 | 1,78 | 1,64 | 1,38 |
| CaO | 5,62 | 4,64 | 4,02 | 6,51 | 5,22 | 3,21 | 2,22 | 2,87 | 2,42 |
| Na ₂ O | 2,44 | 2,16 | 1,87 | 3,04 | 2,44 | 3,53 | 2,44 | 2,70 | 2,28 |
| K ₂ O | 3,05 | 3,53 | 3,05 | 2,02 | 1,62 | 3,28 | 2,27 | 3,62 | 3,05 |

Table 25b

| | — | 6/7 | | 109/7 | | 105/7 | | 5/7 | |
|--------------------------------|---|--------|------|--------|------|--------|------|--------|------|
| | | Ab. L. | % L. |
| SiO ₂ | — | 7,5 | 13 | 9,2 | 16 | 14,5 | 25 | 5,0 | 9 |
| Al ₂ O ₃ | — | 4,44 | 24 | 6,39 | 35 | 8,18 | 45 | 3,04 | 16,5 |
| Fe ₂ O ₃ | — | 0 | 0 | 3,48 | 36 | 1,82 | 27 | 2,42 | 35 |
| MgO | — | 0,15 | 6 | 0,33 | 13 | 0,89 | 34 | 1,30 | 50 |
| CaO | — | 1,6 | 29 | 0,40 | 7 | 3,40 | 61 | 3,20 | 57 |
| Na ₂ O | — | 0,57 | 23 | 0 | 0 | 0 | 0 | 0,16 | 7 |
| K ₂ O | — | 0 | 0 | 1,43 | 47 | 0,78 | 25 | 0 | 0 |

Ab. L. = Absolute Loss, % L. = Percentage Loss.

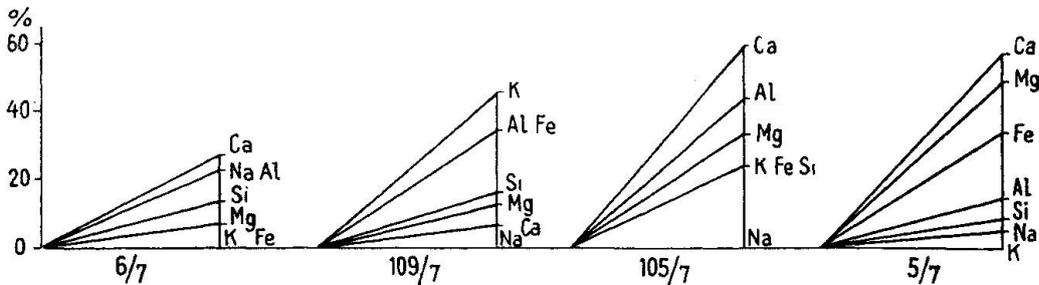


Fig. 10. Loss Diagrams illustrating the Alteration of Pyroxene-Porphyrites

Table 26a
Alteration of Biotite-Porphyrites

| | Orig. comp. | Altered product | Reduced values |
|--------------------------------|-------------|-----------------|----------------|-----------------|----------------|-----------------|----------------|-----------------|----------------|
| | 3 | 4 | 4/3 | 1 | 1/3 | 33c | 33c/3 | 143c | 143c/3 |
| SiO ₂ | 64,46 | 63,73 | 46,0 | 68,33 | 49,5 | 65,55 | 43,2 | 69,11 | 31,4 |
| Al ₂ O ₃ | 16,58 | 16,99 | 12,28 | 17,07 | 12,4 | 15,03 | 9,9 | 14,00 | 6,35 |
| Fe ₂ O ₃ | 4,82 | 4,75 | 3,44 | 3,34 | 2,24 | 4,75 | 3,13 | 3,54 | 1,61 |
| MgO | 2,40 | 2,28 | 1,64 | 0,66 | 0,48 | 2,35 | 1,55 | 1,85 | 0,84 |
| CaO | 3,40 | 4,71 | 3,40 | 2,07 | 1,50 | 3,17 | 2,08 | 0,57 | 0,26 |
| Na ₂ O | 2,21 | 2,27 | 1,64 | 2,55 | 1,85 | 3,36 | 2,21 | 4,87 | 2,21 |
| K ₂ O | 3,15 | 3,30 | 2,38 | 4,35 | 3,15 | 2,99 | 1,97 | 3,21 | 1,46 |

Table 26b

| | | 4/3 | | 1/3 | | 33/3 | | 143c/3 | |
|--------------------------------|---|--------|------|--------|------|--------|------|--------|------|
| | | Ab. L. | % L. |
| SiO ₂ | — | 18,46 | 28,6 | 15,0 | 23,2 | 21,3 | 32,0 | 33,06 | 51,0 |
| Al ₂ O ₃ | — | 4,30 | 26 | 4,2 | 25 | 6,7 | 40 | 10,20 | 62 |
| Fe ₂ O ₃ | — | 1,38 | 29 | 2,40 | 50 | 1,7 | 35 | 3,21 | 67 |
| MgO | — | 0,76 | 32 | 2,9 | 80 | 0,85 | 35 | 1,56 | 65 |
| CaO | — | 0 | 0 | 1,9 | 56 | 1,32 | 39 | 3,14 | 92 |
| Na ₂ O | — | 0,57 | 26 | 0,36 | 16 | 0 | 0 | 0 | 0 |
| K ₂ O | — | 0,77 | 24 | 0 | 0 | 1,18 | 37 | 1,69 | 54 |

Ab. L. = Absolute Loss, % L. = Percentage Loss.

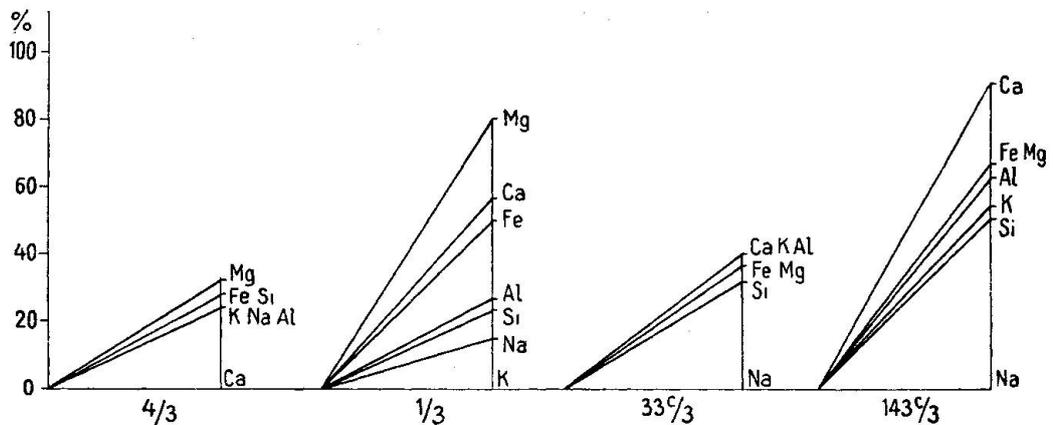


Fig. 11. Loss Diagrams illustrating the Alteration of Biotite-Porphyrite

Among the granophyres with rock no. 20 as fresh the changes are:

| Rock No. | Relative gains | Relatively unchanged | Losses |
|----------|----------------|----------------------|--------|
| 18 | Ca | Na, Si, K, Al, Fe | Mg |
| 23 | Al, K | Si, Ca, Na Fe | Mg |
| 24 | Ca Al | Si, Fe, K, Na | Mg |

It is difficult to estimate how far the original differences in the rock composition have influenced the course of the alterations but

Table 27a
Alteration of Granophyres

| | Orig. comp. | Altered product | Reduced values | Altered product | Reduced values | Altered product | Reduced values |
|--------------------------------|-------------|-----------------|----------------|-----------------|----------------|-----------------|----------------|
| | 20 | 18 | 18/20 | 23 | 23/20 | 24 | 24/20 |
| SiO ₂ | 73,65 | 74,82 | 62,60 | 72,04 | 56,50 | 70,17 | 46,25 |
| Al ₂ O ₃ | 12,23 | 11,06 | 9,33 | 15,60 | 12,23 | 16,12 | 10,60 |
| Fe ₂ O ₃ | 2,70 | 2,37 | 1,99 | 2,20 | 1,72 | 2,43 | 1,60 |
| MgO | 0,74 | 0,35 | 0,29 | 0,13 | 0,10 | 0,26 | 0,17 |
| CaO | 1,69 | 2,02 | 1,69 | 1,39 | 1,09 | 2,57 | 1,69 |
| Na ₂ O | 3,50 | 3,85 | 3,23 | 2,79 | 2,20 | 2,63 | 1,73 |
| K ₂ O | 4,64 | 4,43 | 3,72 | 5,51 | 4,32 | 4,14 | 2,72 |
| Alk ₂ O | 8,14 | 8,28 | 6,94 | 8,30 | 6,50 | 6,77 | 4,45 |

Table 27b

| | 18/20 | | 23/20 | | 24/20 | | |
|--------------------------------|--------|-------|--------|-------|--------|-------|----|
| | Ab. L. | % L. | Ab. L. | % L. | Ab. L. | % L. | |
| SiO ₂ | — | 11,00 | 15 | 17,15 | 23 | 27,40 | 37 |
| Al ₂ O ₃ | — | 2,9 | 24 | 0 | 0 | 1,63 | 13 |
| Fe ₂ O ₃ | — | 0,71 | 26 | 1,0 | 37 | 1,10 | 41 |
| MgO | — | 0,45 | 61 | 0,64 | 86 | 0,54 | 73 |
| CaO | — | 0 | 0 | 0,60 | 35 | 0 | 0 |
| Na ₂ O | — | 0,27 | 8 | 1,30 | 37 | 1,77 | 50 |
| K ₂ O | — | 0,92 | 20 | 0,32 | 7 | 1,92 | 41 |
| Alk ₂ O | — | 1,20 | 15 | 1,64 | 20 | 3,69 | 45 |

Ab. L. = Absolute Loss, % L. = Percentage Loss.

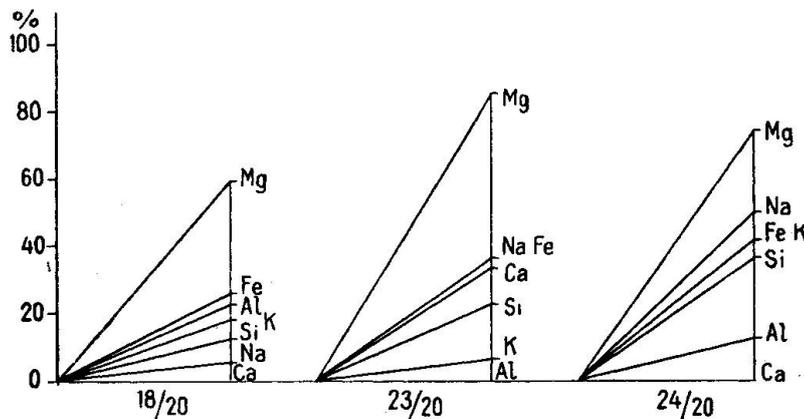


Fig. 12. Loss Diagrams illustrating the Alteration of Granophyres

even so the resultant effects are the same as seen before. Thus the general trend of the chemical changes during the alteration of the Lugano porphyries may be summarized as: Gain of Na or K or Ca and Net Loss of Ca or Mg, Fe. The gain of Ca is only occasional and is easily seen in the thin sections as development of epidote in cracks and cavities.

It is further seen from the above treatment that in contrast to the porphyrites, the granophyres retain more Al. This is largely due to the fact that in porphyrites a large proportion of Al is bound to Ca in the anorthite molecule which is easily broken up and lost. Granophyres, on the other hand, are poor in anorthite and Al is in more stable combination with the alkalis. Ca, again, tends to migrate and is often added to the rock from outside. Among the alkalis Na has lost its privileged place and is susceptible to heavy losses; K, on the contrary, is retained in much larger proportions. This may imply dominance of sericitization and much reduced albitization. It is remarkable that in granophyres Mg has consistently suffered great loss which is to be referred to alteration of small biotite flakes.

3. TRÖGER'S Modification of the above Method

Almost identical results are obtained when NIGGLI-molecular values are used in the calculations in place of weight percentage values. E. TRÖGER (1930) has calculated the absolute and % loss by the same method as NIGGLI and GSCHWIND but uses the NIGGLI-molecular-values. In addition to the changes in si, al, fm, c, alk and those in K_2O , Na_2O , m and f, he also calculates the absolute and % loss in m e (the sum of metallic constituents — (al + fm + c + alk) which in the unaltered rock is 100) and plots the % loss of individual components as ordinates against the % loss of m e as abscissa.

On these lines a gradation series in terms of % loss is obtained which according to TRÖGER corresponds to the particular type of chemical alteration. He has, for example, in his studies on the chemistry of the Variscan igneous rocks of Central Germany, cited above, shown that the gradation alk, si, al, fm, c is characteristic of epizonal metamorphism under the influence of slightly higher temperatures and pressures than obtained near the surface.

This method of calculation of the % losses was tried on rocks of the biotite-porphyrine group, from the Lugano eruptives. The results were identical with those obtained by the NIGGLI-GSCHWIND method.

4. GROSSER'S Method

In recent years G. GROSSER (1937) has revived the method of calculation of chemical changes previously introduced by STRENG (1860). In this the % weight a' of a particular oxide in the altered rock is divided by the % weight a of that oxide in the fresh rock

and the quotient $\frac{a'}{a}$ is called the gradation number. These numbers when calculated for all the oxides, for total alkalis and for total iron and arranged in serial order give the gradation series. This gradation series simply gives, without making any assumptions, the direction and the approximate change suffered by each oxide during alteration. To get a clear picture of the changes, the gradation numbers are plotted to scale on a straight horizontal line and each point is marked by a small vertical line with the name of the oxide which it represents. This gives the gradation-diagram. The marks between 1 and 0 indicate the losses and those beyond 1 show the gains. The degree of alteration is directly proportional to the distance from the point 1. The point 1 itself represents the unaltered condition of a rock-constituent. A crowding of the various oxide-lines in the vicinity of point 1 indicates almost no change whereas greater spreading stands for advanced alteration. By comparing the various rock-analyses belonging to the same type in this way, one can easily determine the grades of alteration in each rock. The different groups of Lugano rocks when studied on these lines yielded results which agreed very well with those given by the other methods described above.

The following Table (28) gives the gradation numbers of the various constituents in different rocks of the pyroxene-porphyrite group, type D.

A preliminary examination of the thin sections and the chemical data had indicated that the rock 7 has suffered least alteration; it was, therefore, found advisable to take this analysis as that of a fresh rock and to study the changes in the other rocks in comparison to it.

Table 28
Pyroxene-Porphyrites

| | | 7 | 6 | 6/7 | 5 | 5/7 | 105 | 105/7 | 109 | 109/7 |
|-------------|--------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Si | SiO ₂ | 58,02 | 58,42 | 1,007 | 62,89 | 1,085 | 62,82 | 1,083 | 60,76 | 1,04 |
| Al | Al ₂ O ₃ | 18,29 | 16,01 | 0,866 | 18,09 | 0,989 | 14,65 | 0,800 | 14,87 | 0,813 |
| Fe''' | Fe ₂ O ₃ | 4,32 | 2,43 | 0,542 | 1,80 | 0,416 | 5,42 | 1,252 | 3,58 | 0,826 |
| Fe'' | FeO | 2,25 | 4,55 | 2,020 | 3,08 | 1,367 | 1,59 | 0,706 | 1,63 | 0,725 |
| Fe Σ | Fe ₂ O ₃ | 6,82 | 7,40 | 1,08 | 5,22 | 0,76 | 7,20 | 1,05 | 5,40 | 0,79 |
| Mg | MgO | 2,67 | 2,92 | 1,092 | 1,64 | 0,614 | 2,57 | 0,961 | 2,91 | 1,090 |
| Ca | CaO | 5,62 | 4,64 | 0,826 | 2,87 | 0,511 | 3,21 | 0,572 | 6,51 | 1,150 |
| Na | Na ₂ O | 2,44 | 2,16 | 0,885 | 2,70 | 1,107 | 3,53 | 1,450 | 3,04 | 1,246 |
| K | K ₂ O | 3,05 | 3,53 | 1,157 | 3,62 | 1,189 | 3,28 | 1,075 | 2,02 | 0,663 |
| Alk | Alk ₂ O | 5,49 | 5,69 | 1,036 | 6,32 | 1,151 | 6,81 | 1,242 | 5,06 | 0,922 |
| | H ₂ O | 1,86 | 3,45 | 1,855 | 2,30 | 1,235 | 1,50 | 0,805 | 3,38 | 1,815 |

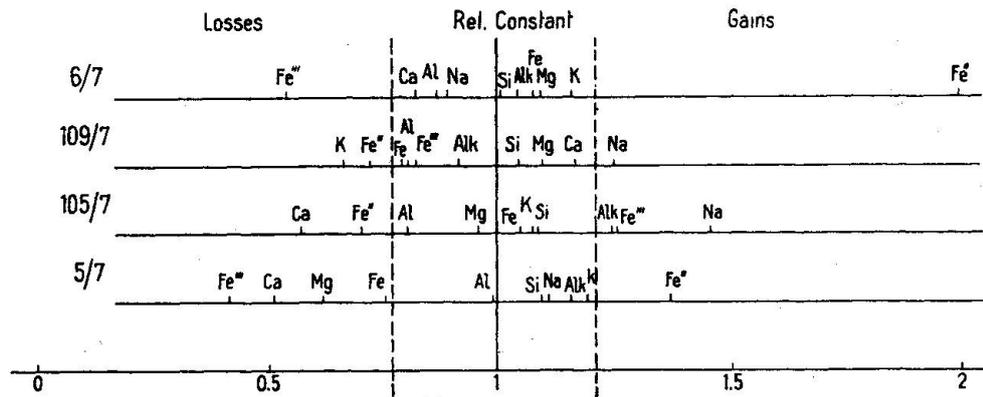


Fig. 13. Gradation Diagram illustrating the Alteration of Pyroxene-Porphyrites

It will be seen from these diagrams (Fig. 13) that of the four rocks compared with rock 7, 6 shows the least developed diagram while 109, 105, and 5. show an increasing dispersion of points indicating the advancing degree of alteration.

Table 29

| | 6 | 109 | 105 | 5 | Changes with progressive alteration |
|----------------------------------|-------|-------|-------|-------|-------------------------------------|
| SiO ₂ | 1,007 | 1,048 | 1,083 | 1,085 | → slight increase |
| Al ₂ O ₃ | 0,876 | 0,813 | 0,800 | | ← slight decrease |
| Fe ₂ O ₃ | 0,524 | 0,826 | 1,252 | | → considerable increase, variable |
| Σ Fe ₂ O ₃ | 1,08 | 0,79 | 1,05 | 0,76 | ← decrease, variable |
| MgO | 1,092 | 1,090 | 0,961 | 0,614 | ← large decrease variable |
| CaO | 0,826 | | 0,572 | 0,511 | ← large decrease variable |
| Na ₂ O | 0,885 | 1,246 | 1,450 | | → large increase |
| K ₂ O | — | — | — | | → irregular increase |

It is seen that though irregularities occur, the various oxides do show some general tendencies of loss or gain with the progress of alteration. The increase of CaO in 109 is rather abnormal and is apparently due to circulating solutions; this excess of CaO is made evident in the rock slide by the unusual abundance of Epidote. K₂O usually shows an increase but is sometimes liable to be lost; moreover it is also susceptible to wrong determinations.

The general tendency of alteration as given by the gradation series in the pyroxene-porphyrites is Na, K, Si, Al, Fe, Mg, Ca identical with that obtained by the NIGGLI-GSCHWIND method.

5. The General Results of the Chemical Alteration

The various methods employed above in the study of the chemical changes during the alteration of the porphyry rocks of Lugano,

give the same results regarding the general trends which may be summarized as follows:

- a) Alkalis show the largest relative gains; Na more in the basic rocks and K more in the acid rocks. They are most frequently introduced into the rock by extraneous circulating solutions. K occasionally also suffers losses.
- b) Silica, alumina and iron oxides suffer comparatively small changes.
- c) Lime and magnesia generally show maximum losses, but in some cases lime has actually increased owing to additions from circulating solutions.

Another point which comes out from the above treatment is that during the progressive alteration the chemical changes do not always progress continuously at the same speed. The circulating solutions also disturb the normal trends through addition of foreign material.

Taking the above tendencies of alteration as the ones truly operative in the case of the Lugano rocks it is evident that the rocks taken in the various groups as fresh are actually the least altered of the available analysed rocks. They are, therefore, the closest representatives of the primary magmatic products and as such are suitable for selection in the building of magma-types.

6. Chemical Changes during Hydrothermal Alteration

The tendencies of alteration outlined above are in many respects similar to those obtained under hydrothermal conditions. Recently G. M. SCHWARTZ (1939) has summarized the results of investigations mostly carried out in America on the hydrothermal alterations of igneous rocks. According to him the dominant tendencies of chemical changes under these conditions are:

- a) A small net loss in silica and alumina.
- b) A somewhat greater loss of ferric and ferrous iron and a relatively larger loss of magnesia, lime and soda.
- c) A net gain in potash and water.

In individual cases, however, there may be some typical variations from the above general tendencies owing to the local dominance of one or other of the many different processes working under hydrothermal conditions. Thus in place of a net gain, potash may

actually show a loss during silicification or carbonation; soda may, on the other hand, show a relative gain owing to albitization etc. It is, again, not always necessary that the mineralogical and chemical changes during alterations run parallel with the same speed. Great mineralogical transformations may take place in a closed system without the loss of any chemical constituent, so that the bulk composition remains the same; on the other hand, in fissured rocks, for example, there may be abundant loss of material unaccompanied by any considerable mineralogical changes in the rock.

In the case of the Lugano eruptives the considerable chemical changes discussed above are also accompanied by abundant formation of new minerals which are also typical of hydrothermal alterations, as has been shown elsewhere.

7. The Alumina Excess

One of the important results of alteration discussed above is the apparent increase in the content of silica and alumina. The increase in silica becomes conspicuous when one examines the katalmolecular norms for the Lugano rocks as given in Table 21. Here even the most basic rocks show an over-saturated condition giving a certain amount of free silica as quartz which increases rapidly with the acidity of the rock. Though there is no means of determining, what proportion of this quartz is of primary magmatic origin, there is no doubt that an appreciable proportion is of secondary origin and has been deposited in cavities and cracks as can easily be seen under the microscope.

The effect of alumina-excess is vividly brought out in the calculation of the base composition of the rocks given in Table 20. There, all the excess of alumina which remains after the formation of molecules Kp, Ne and Cal, is shown as C. Since no such aluminous minerals as spinel, cordierite or corundum are known to occur in these rocks this alumina must originally have been combined with alkalis and lime, largely as a constituent of feldspars but partly also of dark minerals.

The same effect is also to be seen in Table 30 where beside the three main values Q L M, are also shown the values of C representing the excess of alumina. When we study the Q L M-values for rocks of a particular group, say pyroxene-porphyrates of type D, it is seen that the values for the different rocks of the group show some variation among themselves.

Table 30

| No. | Calculated values | | | | Part of C added to | | Interpolated values | | | Rocktype |
|------|-------------------|-----|------|------|--------------------|------|---------------------|------|------|--|
| | L | C | M | Q | L | M | L | M | Q | |
| 26 | 38,5 | — | 28 | 33,5 | 0 | 0 | 38,5 | 28 | 33,5 | Diabase. Type A |
| 8 | 42 | 2 | 22 | 34 | 0 | 2 | 42 | 24 | 34 | Basic (pyroxene)- porphyrite type B |
| B | 38 | — | 21 | 41 | — | — | 37,5 | 21 | 41,5 | id. type C |
| A | 37 | — | 21 | 42 | — | — | 37,5 | 21 | 41,5 | id. type C |
| 7 | 41 | 1,5 | 13,5 | 44 | 0 | 1,5 | 41 | 15 | 44 | id. type D |
| 6 | 41 | — | 15 | 44 | — | — | 41 | 15 | 44 | — |
| 109 | 38,5 | — | 16,5 | 45,5 | — | — | — | — | — | — |
| 5 | 38 | 5 | 9,5 | 47,5 | 1,5 | 3,5 | 39,5 | 13 | 47,5 | id. |
| 105 | 40,5 | — | 14 | 45,5 | — | — | — | — | — | — |
| 285 | 39,5 | — | 15,5 | 45 | +1 | -1 | 40,5 | 14,5 | 45 | id. |
| 4 | 39 | 1 | 10 | 50 | 0 | 1 | 39 | 11 | 50 | Quartz bearing biotite-porphyrite type F |
| 2 | 37 | 2 | 11 | 50 | 2 | 0 | 39 | 11 | 50 | id. |
| 3 | 35 | 3 | 11 | 51 | 3,5 | -0,5 | 38,5 | 10,5 | 51 | id. |
| 33 | 40 | 0,5 | 10 | 49,5 | -1 | +0,5 | 39 | 11 | 50 | id. |
| 226 | 40,5 | — | 10 | 49,5 | -1,5 | +1 | 39 | 11 | 50 | id. |
| 143c | 40 | 1,5 | 8 | 50,5 | -1 | +1,5 | 39 | 11 | 50 | id. |
| 1 | 36 | 5 | 5 | 54 | 1 | 4 | 37 | 9 | 54 | id. |
| 24 | 37,5 | 3 | 3,5 | 56 | 0,5 | 2,5 | 38 | 6 | 56 | Granophyre, type G |
| 23 | 39 | 3 | 3 | 55 | -0,5 | 3,5 | 38,5 | 6,5 | 55 | id. |
| 22 | 38 | — | 7 | 55 | 0,5 | -0,5 | 38,5 | 6,5 | 55 | id. |
| 21 | 39 | — | 5 | 56 | -1 | +1 | 38 | 5 | 56 | id. |
| 20 | 38 | — | 6 | 56 | — | — | 38 | 6 | 56 | id. |
| 18 | 37 | — | 7 | 56 | +1 | -1 | 38 | 6 | 56 | id. |
| 25 | 33 | 3 | 5 | 59 | 4,5 | -1,5 | 37,5 | 3,5 | 59 | — |
| 19 | 36 | 2 | 3 | 59 | 1,5 | 0,5 | 37,5 | 3,5 | 59 | — |
| 17 | 38 | — | 4 | 88 | — | — | 38 | 4 | 58 | Aplitic grano- phyre, type H |
| 86 | 39 | 0,5 | 2,5 | 58 | -1 | +1,5 | 38 | 4 | 58 | id. |
| 16 | 31 | 4 | 3 | 62 | 4 | 0 | 35 | 3 | 62 | id. |

These variations are particularly large in rocks in which there is a large alumina excess, whereas they are least where this excess is nil. Rocks Nos. 5, 1, 24, 25 and 16 are good examples. These have large values of C and their values of Q L M differ remarkably from those commonly observed in other rocks of their particular group. Knowing the general tendencies of these values in the various groups an attempt was made to find out the probable values of L and M, if C were equal to zero, by taking the value of Q as correct. This interpolation of values of L and M was done by graphical methods and the results thus obtained for all the rocks are included in table 30.

A study of these probable values shows that certain values of Q L M recur in a number of rocks belonging to a particular group. Each group of rocks thus appears to be characterized by certain values which are appreciably different from those of other groups. Thus the values $Q = 50$, $L = 39$ and $M = 11$ are observed in five out of seven rocks belonging to the group of quartz bearing biotite-porphyrites and appear to be characteristic for that group. On the strength of such dominant values all the analysed rocks can be classified into the following groups (Table 31) which will be seen to be identical with those deduced from a consideration of the differentiation diagram given in Table 32.

Table 31

| Group | Q | L | M | Represented by Anal. No. | Corresponding Magma Type | Rock-Group |
|-------|------|------|----|-----------------------------|-----------------------------|------------------------------------|
| I | 33,5 | 38,5 | 28 | 26 | A | Diabase |
| II | 34 | 42 | 24 | 8 | B | Basic porphyrite |
| III | 41,5 | 37,5 | 21 | B | C | Quartz bearing basic porphyrite |
| IV | 44 | 41 | 15 | 6, 7, 285 | D & E | id. |
| V | 50 | 39 | 11 | 2 & 4 | F | Quartz-biotite porphyrite |
| VI | 56 | 38 | 6 | 20 | G | Granophyre |
| VII | 58 | 38 | 4 | 17 | H | Aplite-granophyre |

8. The Mineralogical Changes during Alteration

The chemical changes typical of the hydrothermal processes are reflected in the mineralogical changes, abundantly exhibited by the Lugano porphyries.

The most typical minerals developed during the alteration of the Lugano eruptive rocks are:

Sericite, chlorite, green fibrous hornblende, zoisite, epidote, calcite, quartz, chalcedony, albite, kaolin and to a smaller extent hematite, limonite, tourmaline and fluorite.

In the basic rocks, the ferromagnesian minerals have been altered beyond recognition into aggregates of chlorite, zoisite and iron ore. Fibrous amphibole in some cases is still recognizable but has more commonly also changed to chlorite. In many cases chlorite has been replaced by epidote in small grains. In the pyroxene-porphyrite of Melide there is an extreme development of epidote, usually as slender rods in cavities. This mineral has also been abundantly formed along cracks and fissures and is not restricted to the vicinity of dikes. These features suggest the formation of epidote from circulating

hot solutions. Carbonation is also a common feature in these rocks. Calcite is seen to replace not only the chloritized dark minerals but is seen developed within the feldspar phenocrysts as well. The more common type of alteration of the plagioclases, however, is the formation of sericite especially in the central basic core. Albitization of feldspar is a common feature which gives a clear unaltered rim to the plagioclase phenocrysts and a fresh appearance to the whole rock.

The process of sericitization is often seen to be selective in that the calcic plagioclases are first attacked and the sodic parts later, while orthoclase may be left fairly fresh. In advanced stages, however, orthoclase may also be wholly replaced. Quartz largely resists alteration but in extreme cases it is also replaced by sericite, especially along fractures.

Next to sericitization and chloritization, formation of secondary quartz is a common phenomenon in the Lugano rocks, particularly in the quartz-porphyrines. Large quantities of silica are liberated during the decomposition of other silicates and may be deposited either as chalcedony or directly as quartz, especially in cavities. The abundant occurrence of spherulites in fluidal quartz-porphyrines, in tuffs and in some of the acid dike-rocks is referable to the process of silicification.

The remarkable development of tourmaline in the quartz porphyry dike of Alla Ferrera north of Melide is well known. Here tourmaline has crystallized as minute prisms along joints and cracks and has thoroughly permeated the rock, bringing about extensive replacement chiefly of the feldspars. Though typically developed here, tourmalinization is not restricted to this place. Small amounts of the mineral, often in well developed crystals, have been found over a large part of the Morcote Peninsula. Formation of tourmaline is a typical pneumatolytic process but appears in some cases to be intimately connected with high temperature hydrothermal action.

Tourmaline has been newly found as a miarolitic mineral in the granophyre of Madonna d'Ongera quarry south of Carona. Here it has an amiant-like habit, occurring as bundles of extremely thin needles and associated with nicely developed crystals of quartz, orthoclase, albite and fluorite beside such other minerals as calcite, dolomite, pyrite, biotite, sericite, hyalite etc. The whole association is typically high-temperature hydrothermal in nature.

Most of these autometamorphic processes leading to the formation of secondary minerals like hornblende (uralite), epidote,

zoisite (saussurite), chlorite etc. are typical of hydrothermal alterations during the post-volcanic stages of magmatic activity. These changes were followed by further alterations mostly due to weathering, whereby the original effects were either magnified or modified to a variable extent.

9. Epi-Mineral Composition of Lugano Porphyries

The above studies have shown that during the alterations of the Lugano rocks the chemical constituents have suffered relative (in some cases, actual,) gains and losses while at the same time extensive mineral transformations have also taken place. It may be instructive to enquire at this stage if the present mineral composition of the rocks can be deduced by calculation from their chemical composition. In other words we have to see whether the epi-mineral modal composition corresponds even roughly with the epi-norm variants.

In a previous chapter the kata-norm variants of the main types were discussed and it was found that in the absence of positive indications of some of the primary minerals it was not possible to calculate any appropriate kata-variants for the Lugano rocks. In the calculations of the epi-variants, however, we are not faced with this difficulty to the same extent. The calculations can be made either from the basis composition or more conveniently from the atomic contents of the chemical constituents directly. For this purpose a method evolved by NIGGLI, and first published by DIEHL (1938) may be employed. The procedure of calculation as given by DIEHL is briefly as follows:

- I. Change $Ti \rightarrow Ru$; $P \rightarrow Ap$ ($P:Ca = 2:3$); $(CO_2) + 1 Ca = 1 Cc$
- II. $Na \rightarrow Ab$ ($Na:Al:Si = 1:1:3$)
 $K \rightarrow Sc$ ($K:Al:Si = 1:3:3$); if $Al < (Na + 3K)$ then change
 $K \rightarrow Sc + Or$
- III. If $Al > (Na + 3K)$ then
 $Ca \rightarrow Zo$ ($Ca:Al:Si = 4:6:6$); if Al still remains in excess
 $Mg \rightarrow At$ ($Mg:Al:Si = 2:2:1$)
 $Fe'' \rightarrow At$ ($Fe'':Al:Si = 2:2:1$)
- IV. If $Al < (Na + 3K + 3/2 Ca)$
 $Ca \rightarrow Ho$ ($Ca:Mg:Si = 2:5:8$) Grammatite
 $\rightarrow Ho$ ($Ca:Fe'':Si = 2:5:8$) Actinolite
- V. The remaining $Mg \rightarrow Mg-Serp$ ($Mg:Si = 3:2$)
 $Fe'' \rightarrow Fe-Serp$ ($Fe'':Si = 3:2$)
- VI. $Fe''' Hm$
 $Si Qz.$

On calculating the epi-norms by this method it was found that after building Ab and Sc very little alumina was left for Ca to form Zo and, therefore, a large part of Ca combined with Mg and Fe went to form Ho. When this was done little Mg or Fe was left to form Serp. Thus by this method very large amounts of Ho and practically no Zo or Serp were obtained. In many rocks, however, no Ho was seen but Serp (chloritic) was abundant. Zo was also fairly common. To obtain this result a slight modification of the above method was necessary, whereby a certain amount of Al was made available by changing part or whole of Sc to Or and this Al was combined with Ca to form Zo. Thereby also Mg and Fe were made available to form Serp. Calculating the epi-norms by this modified method we get the following results (Table 32).

Table 32. Epi-norms A
for the Main Types of the Lugano Porphyries

| Type | Ab | Or | Sc | Zo | Ho | Serp | Hm | Qz | Ru | Ap |
|------|------|------|------|------|------|------|-----|------|-----|-----|
| A | 15,4 | — | 14,1 | 29,4 | 14,7 | 15,7 | 2,0 | 7,1 | 1,3 | 0,3 |
| B | 22,0 | 28,7 | — | 18,7 | 0,9 | 18,3 | 3,5 | 6,9 | 0,6 | 0,3 |
| C | 26,2 | 18,5 | — | 20,0 | 3,0 | 12,6 | 3,5 | 14,9 | 0,7 | 0,6 |
| D | 21,6 | 12,0 | 11,9 | 20,8 | — | 11,4 | 2,5 | 19,0 | 0,5 | 0,3 |
| E | 27,5 | 13,8 | 4,9 | 18,8 | — | 14,1 | 1,1 | 18,8 | 0,7 | 0,3 |
| F | 26,7 | 11,5 | 12,1 | 12,4 | — | 10,0 | 0,9 | 25,5 | 0,6 | 0,3 |
| G | 31,0 | 28,8 | — | 4,3 | 3,4 | 0,9 | 1,0 | 30,1 | — | 0,5 |
| H | 30,0 | 29,4 | 4,0 | 1,6 | — | 0,6 | 0,9 | 33,4 | 0,2 | — |

This corresponds fairly well with what we actually see in many slides, but for a large number of rocks the calculated amount of Zo is rather too high and that of Sc a little too low. Moreover a number of rocks show a good development of epidote and Ho is also seen in a few cases, while Zo was quite subordinate or absent. For such rocks the method suggested by A. STUTZ (personal communication) is partly applicable. His modification is as follows:

If after the formation of Ab and Sc (and/or Or), Al is greater than $(Na + 3K)$, form Ho. If Ca remains over, then form epidote, or when Mg, Fe are in excess, form chlorite (At). If Al still remains, change Ho to Ep and At. On the other hand if Ca (or MgFe) remain over then change a part of Sc to Or and utilize this Al to form Ep or At. Calculating on these lines we get the following epi-norms for the main types (Table 33).

Owing to the complex nature of the hydrothermal alterations which the rocks of the Lugano region have undergone, no one particular combination of epi-minerals is common to all the rocks or even

to those which belong to the same magma type. It is, therefore, evident that no one scheme of calculation of epi-norms would cover the diversity of combinations found in the Lugano rocks. The schemes given above cover the major tendencies at least qualitatively. Thus for rocks showing abundant epidote-formation the second type of epi-norm is more applicable while for the great majority of others the first type is more correct.

Table 33
Epi-norms B

| Type | Ab | Or | Sc | Ho | | Ep | At | | Hm | Qz | Tn | Ap | Cc |
|------|------|------|------|------|------|------|------|-----|-----|------|-----|-----|-----|
| | | | | Mg | Fe | | Mg | Fe | | | | | |
| A | 15,4 | — | 14,2 | 17,2 | 7,1 | 18,6 | 11,2 | 4,4 | — | 7,7 | 3,9 | 0,3 | — |
| B | 22,2 | 13,2 | 21,7 | 24,2 | 7,0 | — | 2,0 | — | — | 4,0 | 1,9 | 0,3 | — |
| C | 26,3 | 3,3 | 21,4 | 14,4 | 10,3 | 5,6 | — | — | 2,7 | 13,4 | 2,0 | 0,6 | — |
| D | 21,6 | — | 28,6 | 9,6 | 7,6 | 6,8 | 2,2 | 1,2 | 1,6 | 18,7 | 1,6 | 0,3 | 0,8 |
| E | 27,6 | — | 24,1 | 13,7 | 9,5 | 4,0 | 0,9 | 0,7 | 0,6 | 16,6 | 2,0 | 0,3 | — |
| F | 26,7 | — | 28,1 | 10,3 | 7,8 | 0,4 | — | — | 0,9 | 23,8 | 1,7 | 0,3 | — |
| G | 31,0 | 27,1 | 2,4 | 1,5 | 3,1 | 3,6 | — | — | 0,6 | 30,2 | — | 0,5 | — |
| H | 30,0 | 28,3 | 5,5 | — | 0,9 | 0,5 | — | — | 0,8 | 33,5 | 0,5 | — | — |

C. DIFFERENTIATION OF THE LUGANO PORPHYRY MAGMA

When we construct a differentiation diagram in which are plotted the NIGGLI values of all the rocks so far analysed of the Lugano porphyry district, including the quartz-porphyrines, it is interesting to study the resulting distribution of the material. The Lugano rocks encompass a large range of si in the diagram (Fig. 14), but they are particularly well represented in the acid part of the field. At the basic end, no rock is represented with si below 120. The most acid rock in the Lugano region, on the other hand, reaches nearly 500 in its si value. Within this si range are represented over 40 analysed rocks from the porphyry district. When we examine the distribution of the rocks it is seen that the whole range is more or less uniformly beset with points and apparently shows no concentration of rocks in any one part more than in others. The largest gap where no rock is represented, comprises less than 40 units of si between si = 280 and si = 317; the other two smaller gaps are between 155 and 183 and between 446 and 472. From this it is clear that the distribution of rocks is fairly uniform over the whole range.

When, however, we take into consideration that a very large number of these rocks are altered, whereby particularly their si content has undergone enormous changes, it becomes clear that their

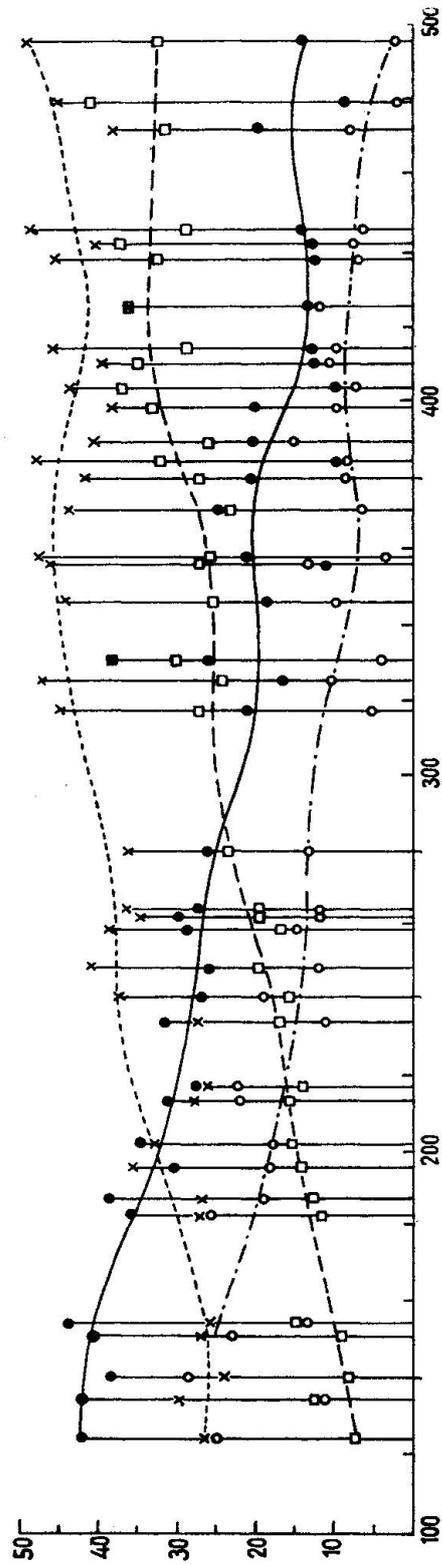


Fig. 14. General Differentiation-Diagram of the Lugano Porphyry District

present values give no real indication of their original magmatic composition and that their si values cannot be depended on to give the true distribution of the magmatic products. For similar reasons we must also exclude all the analyses of quartz-porphyrines and naturally of tuffs from any consideration of the process of magmatic differentiation. We have thus to restrict ourselves, so far as possible, only to fresh rocks of which we have a comparatively small number; but these are quite representative of the whole series.

When we examine the distribution of these selected "fresh" rocks in the differentiation diagram we come to quite different conclusions; these rocks are not uniformly distributed but leave gaps which are often large and irregular. The si values which are represented by these selected rocks are:

*124, 155, 188, 196, 201, 211, 241, 259, 264, 266,
268, 398, 403, 410, 480.*

These figures clearly show that the eruptive rocks of the porphyry magma are most frequent in certain definite regions of si , separated by irregular intervals. Moreover these groups of si values are also characterized by certain definite values of the metallic constituents, which mark them out as distinct types. These types, which are the same as those given in Table 18, represent the principal products of crystallization separated during the different stages of differentiation of the Lugano porphyry magma. The differentiation diagram based on these types (A—H) gives a much truer picture of the course taken by the porphyry magma in its differentiation (Fig. 15 a).

The first important feature of the diagram is the simultaneous increase of al and alk with the increase of si and a corresponding decrease of fm and c . The al curve runs more or less horizontally from $si = 124$ to 188 but from this point to 211 it is highly irregular showing sudden rises and falls. On the other hand the alk curve first rises steeply from $si = 124$ to $si = 155$ but later becomes quite horizontal till 211. From here on alk rises gently and continuously till 480, while al rises similarly but irregularly. Thus the difference ($al-alk$) which is greatest (reaching 19 units) in the diabase and biotite-porphyrines decreases to a minimum (4 units) in the aplite-granophyre. The curve fm first rises slightly from $si = 124$ to $si = 155$ where it shows its maximum value 44, but from this point on it shows a continuous and fairly regular decrease to its minimum value 8 at $si = 480$. The c curve, on the other hand, which starts with a maximum value 25, first falls abruptly by 10 units till $si = 155$, then recovers a little till $si = 211$, but afterwards shows a

continuous and irregular fall until it reaches a minimum of 3 at the acid end. Thus the two curves *fm* and *c* which are widest apart at $si = 155$ come gradually nearer together till $si = 400$ where they are a minimum distance apart (5 units). From here they run quite parallel up to the acid end. The curves *al* and *c* which are together ($al = c$) at the basic end show a maximum divergence ($al - c = 44$ units) at the acid end. The curves *fm* and *alk*, on the other hand, which start with a difference of 35 units meet in the middle of the diagram at $si = 315$ but again diverge in the reverse direction, again giving a difference of 34 units at the acid end.

The other instructive features of the diagram are given by the points of intersection of the various curves. The most significant among them, which is often quite typical of a rock-series, is where the curves *fm* and *al* intersect. This, the isofalic point, is in our diagram characterized by the following values:

$$si = 215, \quad al = fm = 32, \quad c = 17, \quad alk = 16.$$

The other points where the curves *c* and *alk*, on the one hand, and *fm* and *alk*, on the other, intersect, are in this diagram at $si = 230$ and $si = 315$ respectively.

Thus all the three main points of intersection lie between the *si* range 200–315, a feature which clearly demonstrates the affinity of the Lugano rocks with the calc-alkali suites of igneous rocks.

The differentiation diagram, constructed on the basis of certain definite rock-types, also serves to give by interpolation the values of *al*, *fm*, *c* and *alk* for any particular value of *si*. For the purposes of comparison of different rock-series, it is often convenient to have these values of the metallic constituents for certain suitably distributed intervals of *si*. The following Table 34 gives the interpolated values for the Lugano porphyry magma.

Table 34
The Interpolated Values for the Porphyry Magma
of Lugano

| <i>si</i> | <i>al</i> | <i>fm</i> | <i>c</i> | <i>alk</i> |
|-----------|-----------|-----------|----------|------------|
| 120 | 26 | 42 | 25 | 7 |
| 150 | 26 | 44 | 18 | 12 |
| 200 | 30 | 37 | 18 | 15 |
| 250 | 35 | 30 | 16 | 19 |
| 300 | 37 | 26 | 14 | 23 |
| 350 | 38 | 21 | 13 | 28 |
| 400 | 39 | 16 | 11 | 34 |
| 450 | 42 | 12 | 8 | 38 |
| 480 | 47 | 8 | 3 | 42 |

Slightly detached from the main outcrop of the Lugano porphyries is another exposure of the same eruptives which lies between Luino and Ponte Tresa. This has been referred to here as the Grantola outcrop. The detailed work on the petrography of these rocks by HARLOFF (1927) has brought out characteristics which are in certain respects distinct from those of the main porphyry region. The rocks are fairly fresh and frequently show the presence of minerals like olivine, enstatite, hypersthene, which have not been recorded, so far, from the main outcrop.

The rocks show a fairly large range of variation from basaltite to felsophyres. Eight analyses are available for the various rock-types of this area and are given in Table 16. The distinctive characteristics of this group make it desirable to treat them separately.

The differentiation diagram based on these eight analyses has been shown in Fig. 15 b while the interpolated values as read from this diagram are given in Table 35.

Table 35
Interpolated Values for the Grantola Porphyries

| si | al | fm | c | alk | (al-alk) | c-(al-alk) |
|-----|----|----|-----|------|----------|------------|
| 120 | 22 | 42 | 28 | 8 | 14 | 14 |
| 150 | 25 | 40 | 26 | 9 | 16 | 10 |
| 200 | 30 | 34 | 21 | 15 | 15 | 6 |
| 250 | 34 | 28 | 15 | 23 | 11 | 4 |
| 300 | 38 | 24 | 12 | 26 | 12 | 0 |
| 350 | 40 | 22 | 10 | 28 | 12 | - 2 |
| 400 | 42 | 21 | 8 | 29 | 13 | - 5 |
| 450 | 42 | 20 | 6,5 | 31,5 | 10,5 | - 4 |
| 480 | 42 | 20 | 6 | 32 | 10 | - 4 |

It will be seen from the differentiation diagram of the Grantola types that the general tendencies of the various curves though similar to those of the main diagram show some differences in detail. Thus the curves al and alk run almost parallel throughout their course and so do the curves fm and c. The differences (al-alk) and (fm-c) thus maintain uniform values through the whole range. The difference (al-fm) which at the acid end of the main diagram was 30 units is only 12,5 units in the corresponding part of the Grantola diagram. Further, the points of intersection of the curves fm-al (isofalic point), and c-alk are shifted slightly towards higher values of si, whereas the one for the fm-alk curves corresponds to a slightly lower value of si. The curves c and al which, in the main diagram cut at si = 124, do so in the Grantola diagram near si = 165.

These differences will be better appreciated if we compare the interpolated values for the two regions, arranged side by side as given in the table below.

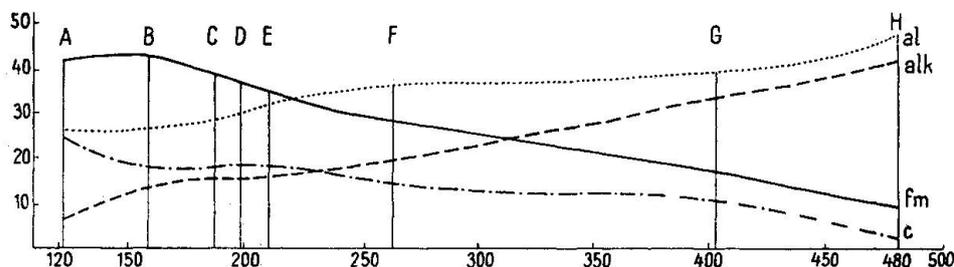


Fig. 15a Differentiation Diagram for the Main Region of the Lugano Porphyry District

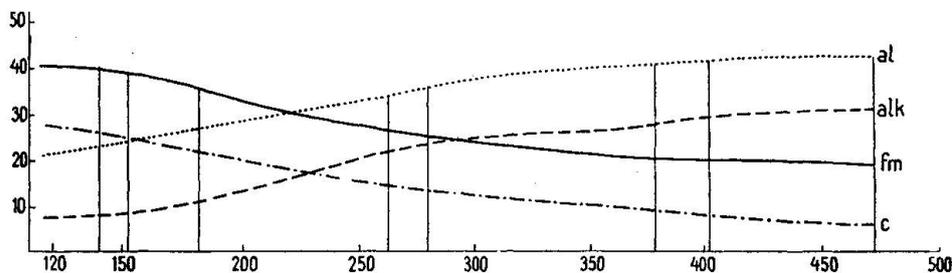


Fig. 15b Differentiation Diagram for the Grantola Region

Table 36

| si | al | | fm | | c | | alk | | al-alk | | c-(al-alk) | | alk (al-alk) | |
|-----|-----|----|----|----|----|-----|-----|------|--------|------|------------|-----|-----------------|-----|
| | L | G | L | G | L | G | L | G | L | G | L | G | L | G |
| | 120 | 26 | 22 | 42 | 42 | 25 | 28 | 7 | 8 | 19 | 14 | +6 | +14 | 1,2 |
| 150 | 26 | 25 | 44 | 40 | 18 | 26 | 12 | 9 | 14 | 16 | +4 | +10 | 0,9 | 0,6 |
| 200 | 30 | 30 | 37 | 34 | 18 | 21 | 15 | 15 | 15 | 15 | +3 | +6 | 1 | 1 |
| 250 | 35 | 34 | 30 | 28 | 16 | 15 | 19 | 23 | 16 | 11 | 0 | +4 | 1,2 | 2,1 |
| 300 | 37 | 38 | 26 | 24 | 14 | 12 | 23 | 26 | 14 | 12 | 0 | 0 | 1,6 | 2,2 |
| 350 | 38 | 40 | 21 | 22 | 13 | 10 | 28 | 28 | 10 | 12 | +3 | -2 | 2,8 | 2,3 |
| 400 | 39 | 42 | 16 | 21 | 11 | 8 | 34 | 29 | 5 | 13 | +6 | -5 | 6,8 | 2,2 |
| 450 | 42 | 42 | 12 | 20 | 8 | 6,5 | 38 | 31,5 | 4 | 10,5 | +4 | -4 | 9,5 | 3,0 |
| 480 | 47 | 42 | 8 | 20 | 3 | 6 | 42 | 32 | 5 | 10 | -2 | -4 | 8,4 | 3,2 |

L = Main type of the Lugano district; G = Sub-type of Grantola area.

In the above table, beside the usual values al, fm, c and alk put side by side for the two areas, are also tabulated the values (al-alk), c-(al-alk) and alk/(al-alk) which give information on the comparative normative mineral composition of the various types of the two regions. The value (al-alk) which normally gives a measure of the anorthite content is about the same for the basic

types of the two series, but its values are lower in the intermediate and higher in the acid types of the Grantola region than those in the corresponding rocks of the main region. The value $c - (al - alk)$ gives that proportion of c which is not bound to the anorthite molecule and is available for the formation of the diopside-type of femic minerals. In the basic rocks of Grantola it has a much higher positive value than in those of the main types, but whereas the acid rocks of the main region still show positive values those of the Grantola region are negative. These negative values may also be a result of alteration of the Grantola rocks. The ratio $alk / (al - alk)$ gives an idea of the proportion of normative alkali feldspars to the normative anorthite feldspar molecules and normally increases with the higher values of si . In the two types there is not much difference for the basic and for intermediate rocks, but for the acid rocks they show a pronounced difference in this respect as will be realized from the following diagram (Fig. 16):

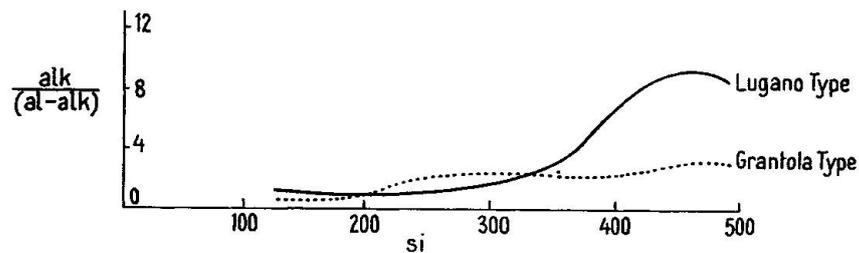


Fig. 16. Diagram showing the Proportions of Normative Feldspars Molecules in Rocks of the Lugano and Grantola Types

The value of free silica which is available to form quartz is given by the expression $si - (100 + alk)$. Except the most basic types with si less than 140, all rocks in both regions show rapidly increasing positive values for this normative quartz.

The $k - mg$ Diagram. The differentiation diagram has indicated the behaviour of the main rock-components in the various products of the porphyry magma. In order, however, to examine the behaviour of the individual components K, Na, Fe and Mg which in the NIGGLI values are combined in the units alk and fm , we can calculate the values of these individual components from the values of k and mg . For our present purpose, however, we can utilize the k and mg values as such. When these values, as given in Table 18 for the various type-rocks, are plotted with k as abscissa and mg as ordinate we can follow the tendencies of the four components during differentiation (Fig. 17).

In this diagram are also plotted the k — mg values for the Grantola rocks (Table 16). It is clear that the higher values of mg are combined with the lower ones of k and vice-versa. The k values vary comparatively little, the maximum variation in the Lugano rocks being only 0,17, whereas the mg values vary as much as 0,55. As a result, the projection-points are located in a narrow elongated zone which if not quite vertical is only slightly inclined and indicates a tendency somewhat allied to potash suites. In the Grantola rocks, on the other hand, the k values also show a fairly large variation (to the extent of 0,36). The reciprocal relation between k and mg thereby becomes more pronounced and the zone of projected points is distinctly inclined to the vertical. This is the condition which is found to be normal in the calc-alkali suites.

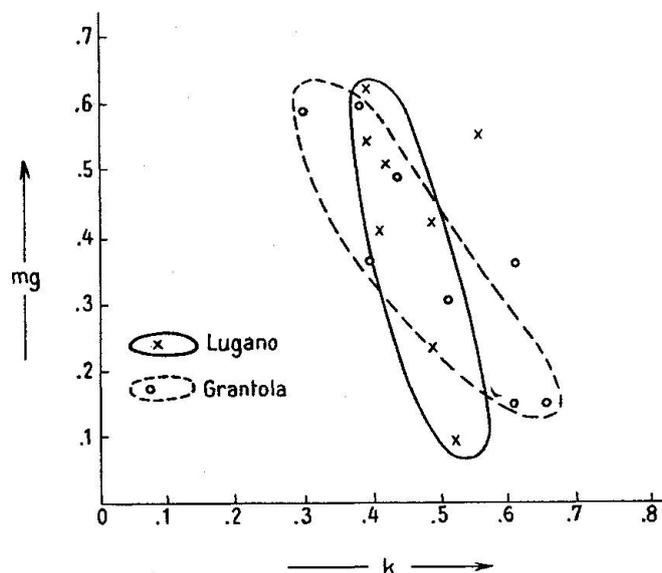


Fig. 17. k - mg -Diagram for the Lugano and Grantola Rocks

It has already been seen that a fair estimate of the normative mineral composition of a rock can be made from the NIGGLI molecular values of the metallic constituents. Thus when enough silica is available and when al is less than the sum ($alk + c$), the value $2alk$ gives the proportion of alkali-feldspars, orthoclase and albite; $2(al - alk)$ that of anorthite, and $(100 - 2al)$ that of the dark minerals. Since the sum of these three values is always 100, they can be projected by a single point in an equilateral triangle of which the three corners represent 100 % alkali-feldspars, 100 % anorthite and 100 % dark minerals.

The above three values as calculated for the main types of the Lugano porphyry series are given in Table 19 and have been projected in the diagram Fig. 18. It gives a clear insight into the relative proportions of these three main mineral groups which determine the basicity of those rocks. A careful examination of their distribution also reveals a general sequence, according to which the various types have separated during the consolidation of the magma. This trend conforms to the present theories of crystallization-differentiation of basic magmas.

Two dominant tendencies can be easily recognized as operative throughout the process of differentiation:

1. The decrease of femic constituents with a constant anorthite content, and
2. the decrease of anorthite with a constant content of femic constituents.

Both these tendencies always lead to the enrichment of alkali-feldspars.

Thus starting with the type A which has the highest content of anorthite as well as of dark constituents, we see both the above tendencies working side by side and leading to the development of two distinct rock-types. The first tendency has given rise to types D and E, the quartz-bearing basic porphyrites rich in anorthite but poor in dark minerals; the other tendency separated fractions (types B and C) distinctly richer in femic minerals but poorer in normative anorthite. From the magmatic fractions of types D and E now separate portions which mainly through the dominance of tendency 1, give rise to type F, the biotite-porphyrites, with nearly the same content of anorthite as in types D and E but appreciably poorer in dark constituents. This type F has a very extensive development and was among the first to be thrown out as a lava-flow.

The types B and C, on the other hand, being richer in heavy dark mineral-constituents are by the action of gravity restricted mainly to the deeper levels and apparently do not take any further active part in the development of the later types poured out on the surface.

The magma-type F markedly poor in heavy dark constituents is dominant in the higher levels and now undergoes renewed differentiation. The second tendency, mainly, is at work and fractions poor in anorthite separate out. From these develop the granophyres, type G, almost the most extensive among the erupted rocks. They are very poor in anorthite but still contain some biotite. The residual

magma already poor in anorthite now separates portions still poorer in dark constituents, which give rise to the aplitic type H composed almost wholly of alkali-feldspars and residual quartz.

The QLM-Diagram. From a consideration of diagram 18 based on the values 2 alk , $2 (\text{al} - \text{alk})$ and $(100 - 2 \text{ al})$ we have been able to trace the course of differentiation followed by the Lugano porphyry magma. For the same purpose one can also utilize the triangular diagram based on the values QLM. There is, however,

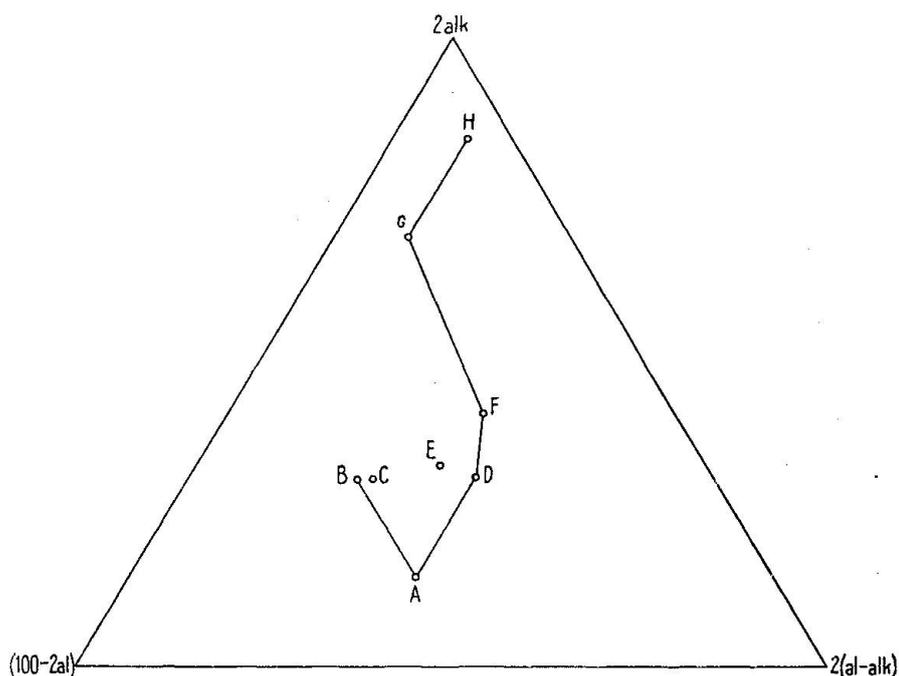


Fig. 18. Diagram showing the Proportions of Feldspars to Dark Minerals in the Lugano Porphyries

one important difference between these two apparently similar diagrams: In the former the feldspars are separated into two divisions, the alkali- and the lime-feldspars whose behaviour during the differentiation process can be studied separately, whereas in the latter they are treated together under one value L. The opposing tendencies exhibited by these two classes of feldspars which are of great importance in petrogenesis are better demonstrated in diagram 18; but it has one important shortcoming, namely the total omission of quartz. The consideration of the differentiation process based on this diagram presupposed that enough silica was always available to saturate all products of crystallization. That quartz plays an important and in some cases decisive part in the development of certain

typical rock-suites is well known. It is, therefore, necessary to study the behaviour of this important component individually during differentiation. For this purpose, the other diagram based on the values Q L M is particularly suitable. Such a diagram for the Lugano porphyries is given in Fig. 19 and is based on the values for the main types given in Table 22.

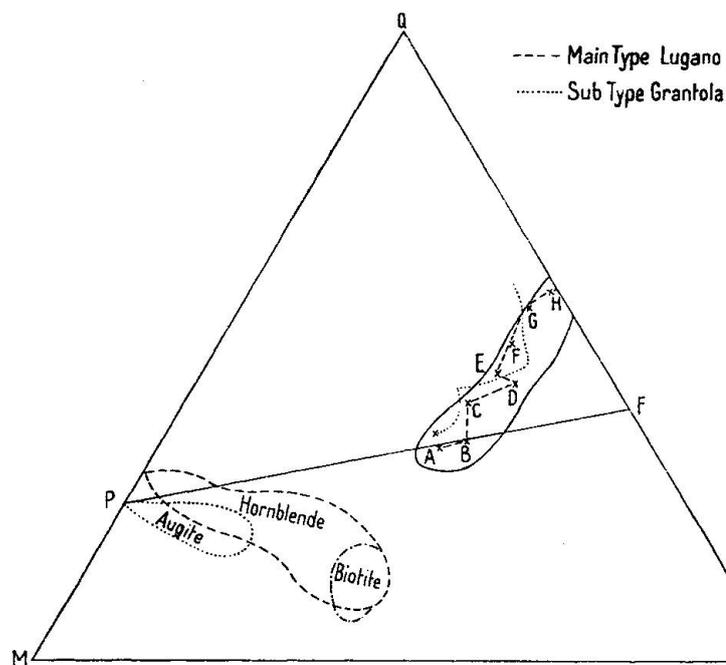
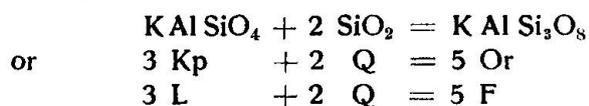


Fig. 19. Q-L-M-Diagram for the Lugano and Grantola Rocks

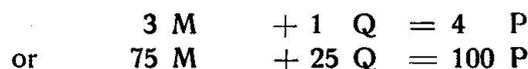
In this diagram the three corners represent 100% of the three components Q, L and M respectively. The point F on the side QL represents the feldspar molecule whose position in the full saturated condition is given by the equation:



Or expressed in 100 parts of F:

$$60 \text{ L} \quad + 40 \text{ Q} = 100 \text{ F}$$

Similarly the point P on the side QM represents the pyroxene molecule whose position is given by the equation:



The feldspars and the pyroxenes represent the fully saturated condition of the feldspathoidal and olivine molecules L and M respectively. The line PF, therefore, represents the silica-saturation line

which divides the whole triangle into two parts, the area Q P F (over-saturated) and the area P M L F (under-saturated).

When the Q L M-values of the Lugano type-rocks are projected in this diagram it is seen that all the points lie above the line P F within the triangle Q P F and that only the most basic end-types A and B touch the line P F. The whole eruptive rock-series of Lugano is thus typically over-saturated in its silica content.

When we trace in this diagram the generalized field of the calc-alkali suites as constructed by NIGGLI (1938) from a large mass of data, it is remarkable that nearly all the projection points of the type-rocks of Lugano fall within it. This clearly testifies to the strong calc-alkaline nature of the Lugano suite and also serves to emphasize the contrast between this suite and the alkaline suites whose fields are mainly confined to the area below the line P F.

The diagram shows that all the rock-types of the Lugano district arrange themselves fairly regularly in a narrow linear zone and in such a manner as to indicate a definite sequence in the development of the various rock-types. In attempting to trace the sequence of crystallization it is necessary to start with a magma of a composition which through differentiation would be capable of yielding the other types. Here we are faced with a problem which is not quite easy to solve. As is well known a great difference of opinion exists as to the type or types of the "primary" magmas. Two or even more fairly distinct primary magmas have been invoked to account for the derivation of the several well-defined petrographic suites. Olivine-basalt, for example, has been regarded as the parental magma for the alkaline suites while the calc-alkaline suites have been ascribed to an independent tholeiitic magma-type (W. Q. KENNEDY, 1933). There is, however, a greater agreement among petrologists on the general trend of differentiation, it being generally accepted that the basaltic magmas through successive fractionation give rise to the formation of increasingly acidic rocks.

Among the Lugano rocks the basic types are not well represented, the most basic type available being the Borgnana dike, type A, of leucogabbroid composition. It is, however, not impossible that rocks more basic than the above type and more representative of the parental magma lie in deeper levels and have never been extruded to the surface. When we compare the composition of type A with the primary composition (*Ausgangszusammensetzung*) of other rock-suites it shows a fairly close resemblance to these as will be seen from the following Table 37 (NIGGLI 1938, p. 655—57).

Table 37

| | L | M | Q | k | π_1 | mg | γ | Magmatype |
|-----------------------------------|------|------|------|------|---------|------|----------|--------------------------------|
| Tholeiite | 34,1 | 31,5 | 32,3 | 0,3 | 0,35 | 0,38 | 0,24 | Gabbro-dioritic c-gabbroid |
| and in part Ophiolites | 33,3 | 33,3 | 33,3 | 0,2 | 0,35 | 0,5 | 0,24 | |
| Norite | 36 | 28,8 | 35,2 | 0,05 | 0,37 | 0,55 | 0,10 | to Miharaitic c-gabbroid |
| | 33,3 | 33,3 | 33,3 | 0,1 | 0,66 | 0,66 | 0,15 | |
| <i>Lugano diabase</i> (Type A) | 38,5 | 28 | 33,5 | 0,4 | 0,6 | 0,6 | 0,1 | |
| Plateau-basalt | 33,3 | 40 | 26,7 | 0,15 | 0,5 | 0,5 | 0,15 | Normal gabbroid |
| Alkali-basalts | 40 | 40 | 20 | 0,23 | 0,35 | 0,6 | 0,22 | Essexite-gabbroid |
| Tephrite | 50 | 30 | 20 | 0,23 | 0,2 | 0,4 | 0,25 | Normal-theralitic |

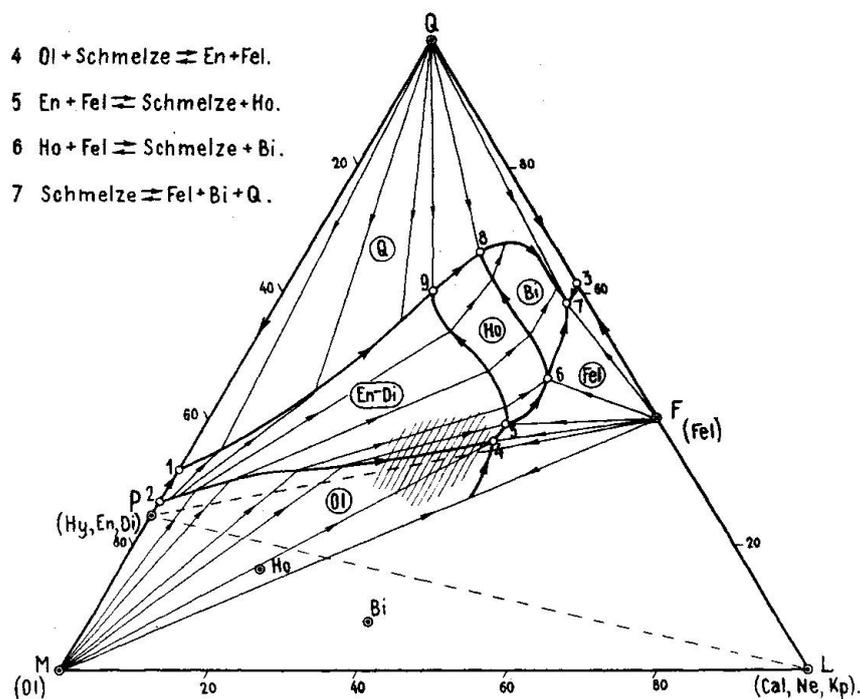


Fig. 20. Q-L-M-Diagram (Explanation see Text)

The similarity to the tholeiites and norites given above is particularly marked. The projection-point of our diabase falls within the main basalt field in the QLM-diagram as suggested by NIGOLI.

In order to follow the course of differentiation in the Lugano porphyry magma more precisely it will be instructive to combine in the same diagram, the fields of crystallization of the various important minerals observed in the Lugano rocks. Such a diagram can only be schematic and approximate as the magma from which the minerals crystallize is a highly complex polycomponent system which cannot be expressed accurately as a three component system. Only certain possible tendencies of crystallization can be indicated by using the data on artificial ternary systems published by N. L. BOWEN

and others of the Geophysical Laboratory. P. NIGGLI has attempted such a theoretical diagram (Fig. 20) in which he has drawn the fields of crystallization of the principal minerals and has also indicated the trends of differentiation common in Pacific rock provinces (P. NIGGLI 1937, p. 348).

A comparison of the Lugano diagram with this theoretical diagram will show that the trends of differentiation indicated by NIGGLI are realized to a remarkable extent in the case of the Lugano rocks.

In order to trace the course of crystallization in the porphyry magma we start with an original magma of type A. The point of projection of this type falls into the field allotted to olivine whose composition is represented by the corner M. Here accessory minerals like magnetite and apatite and olivine itself begin to crystallize and the composition of the liquid magma changes so that its point of projection moves away from M until it reaches the line 2—4 (Fig. 20). Since the early-formed crystals are not removed from the liquid magma olivine is resorbed and in its place the pyroxenes (diopside or enstatite) now crystallize.

Owing to the complete resorption of olivine no rocks containing this mineral are known from the Lugano region, but that the magma has gone through this stage of olivine formation is shown by the fact that this mineral is reported in a vitrophyre of Grantola where probably it occurs as a relict (HARLOFF 1927, p. 189 and KOOMANS 1937, p. 38).

In the Lugano rocks, again, the magma was apparently fairly rich in lime and diopsidic pyroxenes crystallized in preference to orthorhombic types. The latter, however, have also been reported in the basaltite of the Grantola region (HARLOFF 1927, pp. 181 and 197 and KOOMANS 1937, p. 39).

The composition of the pyroxenes is represented by the point P, but the normal augites always contain a certain proportion of L (lime and alkalis) and hence are represented by a small area to the right of P along the line PL. As these pyroxenes crystallize, the composition of the liquid magma moves in the opposite direction until it reaches the point 4. This may be a peritectic point where in addition to pyroxenes the basic plagioclases also crystallize. These minerals sink through gravity and lead to the formation of pyroxene-porphyrates of types B and C, while the upper portions richer in anorthite form the quartz-bearing basic porphyrites of types D and E. The feldspars are represented at the point F and their crystallization

changes the composition of the liquid magma along the curve 4—5. At the point 5, hornblende also begins to crystallize at the expense of augite. This mineral shows a much more variable composition, particularly in the content of lime and alkalis, its L values thus varying between 0—40. Its formation is promoted at lower temperatures by the presence of abundant volatile constituents, conditions which are not fully realized during eruptions. Moreover, augite-rich portions of the magma are removed before that mineral is resorbed and replaced by hornblende. For these reasons the latter mineral is much less common in the Lugano eruptive rocks. In some of these rocks, however, hornblende may be of secondary origin and due to later uralitization.

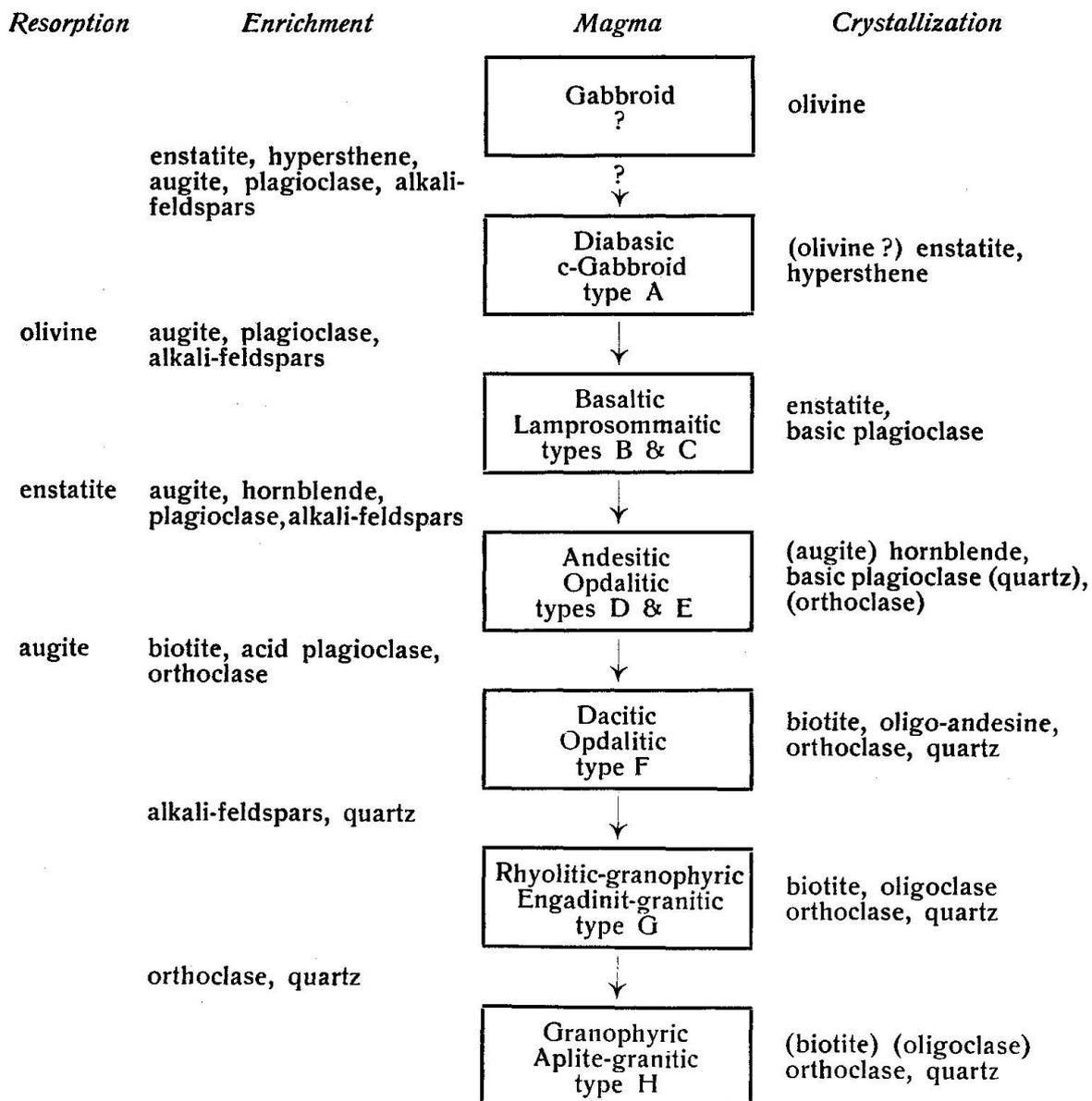
The main portion of the magma continued to differentiate and the crystallization proceeded along the peritectic curves 4—5—6. At the point 6 hornblende becomes subordinate and in its place biotite now crystallizes. The composition of biotite varies within much smaller limits than that of hornblende and is represented in the diagram by a small area near the middle of the line ML but shifted a little towards Q. Thus during the passage of the magma along the curve from 6 to 7, a large proportion of the femic and feldspathic constituents combine with comparatively small amounts of silica to form biotite and leave a very large proportion of free silica. The crystallization of biotite, therefore, tends to develop quartz-rich rocks and the curve takes a decisive turn towards Q. During this stage are formed the quartz-bearing biotite-porphyrites type F. The residual magma now reaches a composition represented by point 7 and crystallization takes place under more or less eutectic conditions; biotite, feldspars and quartz all crystallize simultaneously, giving rise to the types G and H, the granophyres with pronounced graphic structures. Type H represents the last residual portion of the magma almost devoid of all ferromagnesian minerals.

The crystallization of feldspars during the various stages of the magma proceeded side by side with that of the femic minerals, in such a way that while the early-formed crystals are rich in anorthite the later-formed ones are increasingly poor in that component (compare Table 39, p. 298).

Thus the basic-porphyrites of types B, C and D consolidated during the stages represented by the curves 2—4 and 4—5 in the above diagram have plagioclases containing more than 52 % An. The porphyrites of type E which often contain hornblende and biotite and thus are a connecting link between the above type D and the

next type F correspond to the curve 5—6; these rocks have plagioclases with 46—53 % An. The biotite-porphyrates, type F, corresponding to the curve 6—7 show an anorthite content of 38—48 % in their plagioclase phenocrysts, while the granophyres corresponding to the eutectic crystallization at point 7 have a residual, soda-rich plagioclase with 35% An (compare An % values in various rock-types in Table 39).

Table 38
Scheme of the Crystallization Differentiation of the Lugano Porphyry Magma



This sequence in the crystallization of plagioclases is also supported by the abundant zoning exhibited by the plagioclases, particularly in the biotite-porphyrites. The early-formed plagioclase forming the core has a high content of An, and this is surrounded by shells of later-formed parts showing a decreasing content of An.

Table 39
Universal-Stage Determinations of Plagioclases
from different rock-types from the Morcote Peninsula

| Rock-Type | Rock No. | Twinning Law | Anorthite % |
|--|--|-----------------|-------------|
| Basic porphyrites types C? and D | 138 | Carlsbad | 53 |
| | 190 | Albite-Carlsbad | 56 |
| | 105 | Albite | 50—52 |
| | | Albite-Carlsbad | 50 |
| | | Carlsbad | 48 |
| | 211 | Albite | 50—52 |
| Basic biotite-porphyrites type E | 166 | Albite | 52 |
| | 223 | Albite | 50—52 |
| | | Carlsbad | 48—52 |
| 285 | Carlsbad | 46—50 | |
| | Quartz-bearing biotite-porphyrite type F | 33 c | Albite |
| Carlsbad | | | 45—52 |
| Albite-Ala | | | 42—45 |
| 226 | | Albite | 42—46 |
| 35 | | Albite-Carlsbad | 45—50 |
| | | Albite | 45—50 |
| Granophyre types G & H | 79 | Albite | 45—52 |
| | 143 c | Albite | 35 |
| | 86 | Albite-Ala | 35 |
| | | Albite | 35 |
| | 88 | Albite-Ala | 35 |
| | | Albite | 35 |
| 212 | Albite | 35 | |
| Quartz-porphyrity, Aplite dike, Alla Ferrera | 142 | Albite-Ala | 30—35 |
| | 240 | Albite | 35 |
| Quartz-porphyrity dike, Olivella | 264 | Albite | 35 |
| Red porphyry dike, Vico Morcote | 225 | Albite-Ala | 35 |
| | | Albite | 35 |
| | 277 D | Albite | 35 |

Thus the above diagram enables us to follow the trend of magmatic differentiation more or less in detail. It has also shown conclusively that the course followed by the magma is throughout in conformity with the stipulations of NIGGLI's theoretical diagram based on the process of differentiation through fractional crystallization aided by gravity and modified by the reaction principle as conceived

by N. L. BOWEN. The process obtaining in the Lugano Magma has been summarized in the following scheme (Table 38).

The $k-\pi$ -Diagram. We have already referred above to the strong affinities of the Lugano porphyries to the calc-alkaline suites as shown by the distribution of their types in the QLM diagram. The same diagram also indicated the strong contrast to the other alkaline suites. Similar indications are obtained when we study the inter-relations of the three feldspathic base molecules Kp, Ne and Cal as observed in the various members of these series.

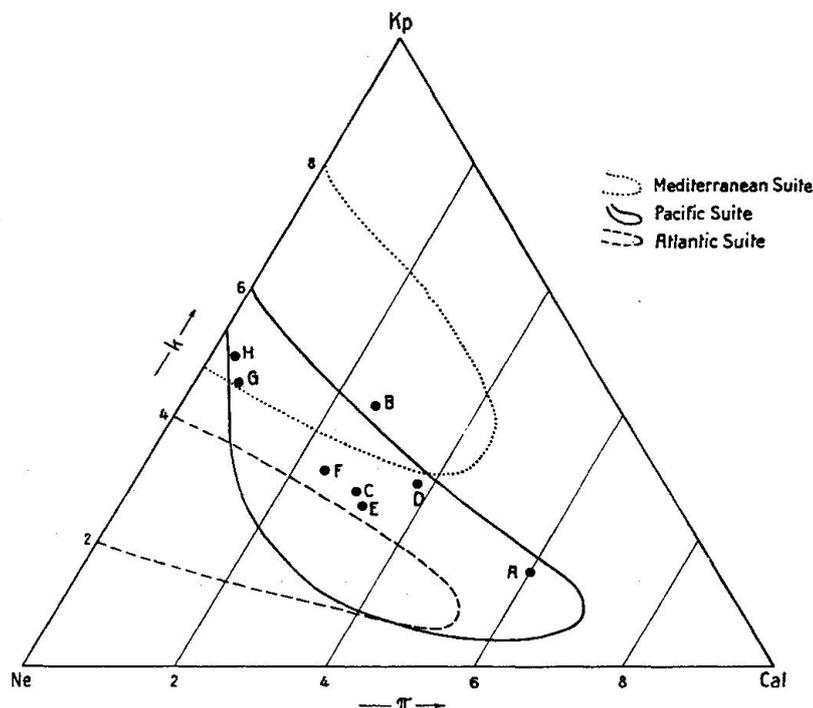


Fig. 21. $k-\pi$ -Diagram for the Lugano Types

These inter-relations are easily given by the two values k and π already referred to on p. 108, which may be plotted in an equilateral triangle with Kp, Ne and Cal at the three corners. Each side is equivalent to one unit and is divided into 10 equal parts of 0,1 each. The value k giving the relation between Kp and Ne is read along the side Ne—Kp and the line joining each such point on this side with the corner Cal represents one particular value of k . The value π gives the relation which Cal bears to the other two and is read along the side Ne—Cal (or Kp—Cal). Each value of π is indicated by a line running parallel to the side Ne—Kp.

The values of k and π for the Lugano types as given in Table 23 are plotted in the diagram Fig. 21.

For the sake of comparison the three generalized theoretical diagrams as constructed by NIGGLI (1938, figs. 2 b, 3 b and 4 b) for the three main petrographic suites, are also included in a simplified manner in the same diagram.

It will be seen that the Mediterranean suite with constantly higher values of k dominates in the upper part, whereas the Atlantic with constantly lower values of k is more or less restricted to the lower part. The Pacific suite has the intermediate position, with certain areas in common with the other two suites.

When we consider the distribution of the Lugano types it is noticeable that the points fall almost exclusively within the field of the Pacific suites; only one point (type B) falls a little outside this area, in the field of the Mediterranean suites. This type B is a highly basic rock and the high value of k is abnormal for such members of the Pacific suites. This may either suggest a branching of the Lugano magma toward a lamprosommitic magma of distinct Mediterranean affinities, or, as is more probable, be merely the effect of an addition of potash from outside as is seen in many other rocks of this region.

It is thus evident from this diagram that the Lugano rocks bear an undoubted relationship with the Pacific suites.

It may be remarked here, by the way, that the Lugano types arrange themselves in this diagram more or less in the same sequence as is observed in the crystallization differentiation of a basaltic magma, k increasing and π decreasing with the progress of crystallization.

D. MAGMATIC RELATIONSHIPS OF THE LUGANO PORPHYRY SERIES

It is interesting at this stage to enquire whether the typical tendencies of chemical variation during the progress of differentiation of the Lugano porphyry magma are reproduced to any extent in other suites of calc-alkaline affinities. Miss KOOMANS (1937) has made a reference to the general similarities of the differentiation diagrams of the Aar- and Gotthard-massif eruptives and of the eruptives of the "Unterostalpine" Nappes to those of the Lugano series.

It may be noted here that the magmatic activity particularly in the first two regions is regarded as largely of Carboniferous age, the eruptives having actively participated in the Hercynian folding. These eruptives may thus be regarded as immediate precursors (representing the main Hercynian tectonic activity) of the eruptives of Lugano, Valsesia, Bozen and a part of the "Unterostalpine"

Nappes which followed in the Permian and represent the late Hercynian tectonic activity. It is thus possible that all these eruptives are genetically connected, and represent two phases of the same magmatic activity.

The three petrographic regions of the Aar- and Gotthard-massifs and of the "Unterostalpine" Nappes show, as has already been noted above, undoubted Pacific affinities. In their tendencies, however, the first two show appreciable differences from those of the Lugano type. These differences are brought out clearly when we compare the interpolated values of these eruptive series. The interpolated values for the Aar- and Gotthard-massifs as deduced from the differentiation diagrams given by NIGGLI and others (1930, pp. 330 and 338) are given in Tables 40 and 41 (Figs. 22 and 23).

Table 40
Interpolated molecular values of the Hercynian Eruptive rocks of the Aar-Massif

| si | al | fm | c | alk | (al-alk) | c-(al-alk) |
|-----|----|----|----|-----|----------|------------|
| 120 | 23 | 45 | 20 | 12 | 11 | 9 |
| 150 | 26 | 40 | 18 | 16 | 10 | 8 |
| 200 | 32 | 32 | 15 | 21 | 11 | 4 |
| 250 | 37 | 27 | 11 | 25 | 12 | -1 |
| 300 | 40 | 20 | 11 | 29 | 11 | 0 |
| 350 | 42 | 16 | 10 | 32 | 10 | 0 |
| 400 | 44 | 11 | 8 | 37 | 7 | 1 |
| 450 | 46 | 9 | 5 | 40 | 6 | -1 |
| 500 | 46 | 9 | 5 | 40 | 6 | -1 |

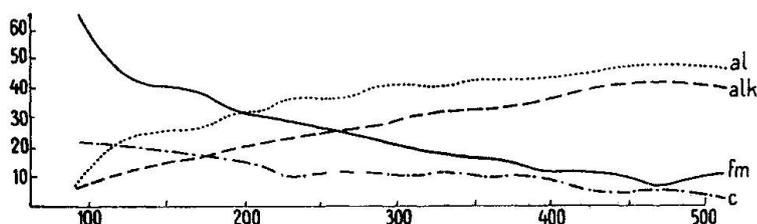


Fig. 22. Differentiation Diagram of the Aar-Massif Eruptives

Among the "Unterostalpine" nappes, granites and the intermediate rocks of the unusual types banatite and quartz-monzonite are fairly common, but the more basic rocks — diorites and gabbros — are represented both as the plutonic and volcanic varieties in the Bernina nappe only. These numerous types of rocks are divisible into two more or less distinct series: 1. the granite-banatite-quartz-monzonite-diorite-gabbrodiorite series and 2. the alkali-granite-alkali-

syenite series. The former forms a typical calc-alkaline suite whereas the latter has a strong tendency towards atlantic suites, a feature which is somewhat unusual in the region of the Alps.

Table 41
Interpolated molecular values of the Eruptive
rocks of the Gotthard-Massif

| si | al | fm | c | alk | (al-alk) | c-(al-alk) |
|-----|----|----|----|-----|----------|------------|
| 120 | 23 | 43 | 23 | 11 | 12 | 11 |
| 150 | 29 | 36 | 21 | 14 | 15 | 6 |
| 200 | 34 | 28 | 20 | 18 | 16 | 4 |
| 250 | 38 | 25 | 16 | 21 | 17 | -1 |
| 300 | 40 | 18 | 15 | 27 | 13 | 2 |
| 350 | 42 | 15 | 11 | 32 | 10 | 1 |
| 400 | 43 | 12 | 8 | 37 | 6 | 2 |

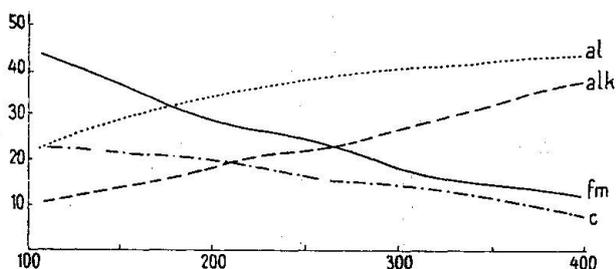


Fig. 23. Differentiation Diagram of the Gotthard-Massif Eruptives

In Table 42 are given some of the chief representative types with calc-alkaline affinities from the analysed rocks of the Bernina-nappe only. The differentiation diagram based on these types has been given in Fig. 24 while the interpolated values as read from this diagram are shown in Table 43.

When we compare the interpolated values for the Lugano and the Aar-massif eruptives (AME) it is seen that the latter, for a large range of si, show appreciably higher values of al and alk and appreciably lower values of fm and c than the corresponding Lugano rocks. The maximum difference in al is seen in the si range 300–500 where it reaches 4–5 units, while that in alk, in the range 200–300, reaches even 6 units. The difference in fm values is over 5 units for the intermediate range 200–400 while the c values are almost uniformly 3 units lower. Though al and alk both have higher values in the AME, alk shows a comparatively higher positive difference than does al. This has resulted in a decrease of alumina available for c to form anorthite as is shown by the value (al-alk) for the two regions. Thus for a large part, the Lugano types show a higher con-

tent of normative anorthite and a lower content of alkali feldspars than the corresponding types of the Aar-massif. On the other hand the content of normative diopside as given by the value $c - (al - alk)$ is appreciably lower in the basic types of Lugano than in the corresponding rocks of the Aar-massif.

Table 42
Eruptive Rocks of the Bernina-Nappe (Group I)
("Unterostalpine Decke")

| Rock-type | si | al | fm | c | alk | k | mg |
|----------------------------|-----|------|------|------|------|------|------|
| Diorite | 108 | 22,5 | 44,5 | 23,5 | 9,5 | 0,21 | 0,63 |
| Gabbro | 118 | 23,5 | 45 | 23,5 | 8 | 0,09 | 0,61 |
| Diorite | 117 | 25 | 43 | 20,5 | 11,5 | 0,40 | 0,63 |
| Gabbro-diorite | 137 | 26,5 | 39,5 | 24 | 10 | 0,30 | 0,48 |
| Gabbro-diorite | 140 | 25 | 39 | 27 | 9 | 0,32 | 0,58 |
| Vogesite | 148 | 27 | 42,5 | 17,5 | 13 | 0,48 | 0,44 |
| Diorite-porphyrity | 160 | 27,5 | 37 | 19,5 | 16 | 0,20 | 0,40 |
| Augite-diorite-porphyrity | 162 | 27,5 | 36,5 | 20,5 | 15,5 | 0,31 | 0,52 |
| Lamprophyre | 162 | 27,5 | 34,5 | 21 | 17 | 0,50 | 0,54 |
| Diabase-porphyrity | 173 | 27,5 | 41,5 | 13 | 18 | 0,41 | 0,55 |
| Biotite-diorite-porphyrity | 184 | 31,5 | 34 | 17 | 17,5 | 0,54 | 0,54 |
| Quartz-diorite | 223 | 36 | 30 | 17 | 17 | 0,34 | 0,42 |
| Banatite | 251 | 36 | 25 | 17,5 | 21,5 | 0,50 | 0,40 |
| Banatite | 277 | 32,5 | 28,5 | 15 | 24 | 0,49 | 0,39 |
| Banatite | 387 | 41 | 10 | 18,5 | 30,5 | 0,38 | 0,13 |
| Granite | 292 | 35 | 28,5 | 10,5 | 26 | 0,72 | 0,35 |
| Granite | 410 | 43 | 14 | 9,5 | 33,5 | 0,58 | 0,20 |
| Quartz-porphyrity | 476 | 50 | 7,5 | 4 | 38,5 | 0,44 | 0,00 |

The eruptives of the Gotthard-massif have in composition several features in common with those of the Aar-massif. Thus in both, the al and alk values are higher and the fm and c values lower than in the Lugano types. In the Gotthard eruptives, however, the difference in al rarely exceeds 3 units while that in alk is less than 4 units. The difference in c is smaller and varies between +3 and -3, whereas that in fm is constantly high, reaching as much as -9. In this case, however, owing to a nearly equal increase in the al and alk values, the difference $(al - alk)$ is about equal in both types. Thus the Gotthard types though a little richer in normative alkali-feldspar content have the same normative anorthite content as the Lugano types. There is again not much difference in the normative diopside content of the two series. It is thus seen that in spite of certain differences in detail the Gotthard-massif eruptives show somewhat closer relationship to the Lugano types than do the Aar-massif erup-

tives. A further indication of this relationship is to be found in the fact that some of the important rock-types of the Gotthard-massif have nearly the same composition as that of the Lugano rock-types. For example: a large number of amphibolites are gabbrodioritic in composition with the following values:

| si | al | fm | c | alk | k | mg |
|-----|----|----|----|-----|-----|-----|
| 114 | 24 | 44 | 23 | 9 | 0,2 | 0,5 |

clearly showing a correspondence to type A of Lugano. Similarly some lamprophyres have the following values:

| | | | | | | | corresponding to |
|-----|----|----|----|----|------|------|------------------|
| 122 | 22 | 45 | 24 | 9 | 0,25 | 0,58 | Lugano type A |
| 150 | 28 | 40 | 17 | 15 | 0,5 | 0,55 | „ „ C |
| 160 | 30 | 35 | 19 | 16 | 0,4 | 0,55 | „ „ E |

Table 43
Interpolated Molecular Values of the Bernina
Eruptives, Group I ("Unterostalpine" Nappe)

| si | al | fm | c | alk | (al-alk) | c-(al-alk) |
|-----|----|----|----|-----|----------|------------|
| 120 | 24 | 43 | 23 | 10 | 14 | 0 |
| 150 | 27 | 40 | 20 | 13 | 14 | 6 |
| 200 | 32 | 33 | 17 | 18 | 14 | 3 |
| 250 | 34 | 29 | 16 | 21 | 13 | 3 |
| 300 | 35 | 25 | 15 | 25 | 10 | 5 |
| 350 | 38 | 21 | 12 | 29 | 9 | 3 |
| 300 | 42 | 15 | 10 | 33 | 9 | -1 |
| 450 | 47 | 10 | 6 | 37 | 10 | -4 |
| 500 | 51 | 7 | 3 | 39 | 12 | -9 |

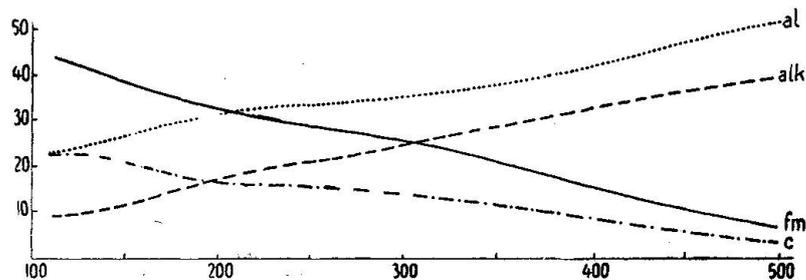


Fig. 24. Differentiation Diagram of the Bernina Eruptives

The third series — the eruptives of the "Unterostalpine"-nappe, represented by the calc-alkaline types of the Bernina-nappe (Bernina-group I) offers a still closer agreement with the Lugano series (Fig. 24). A closer examination of Table 42 shows that, except the unusual banatites, all other rock-types have their equivalents in rocks of the Lugano series with only small differences in the si values. The differentiation diagram shows the same general trends of the

various curves as in the Lugano diagram. The isofalic point, characterized by the values $si = 210$, $al = fm = 32,5$, $c = 17$ and $alk = 18$, is almost identical with that of the Lugano diagram. The interpolated values given in Table 43 also offer a very close correspondence. The al values vary only ± 2 units except above $si = 400$, while the values fm , c and alk show still smaller variations. The normative anorthite content ($al - alk$) is identical except at the acid end and the values for the normative diopside are also of the same order for the basic types of both series.

It is thus seen that of the three Hercynian eruptive provinces within the Alpine region the closest approach to the Lugano series, both in the nature of rocks as well as in differentiation tendencies, is offered by the Bernina group I, of the "Unterostalpine" nappes. The minor differences shown by the other two are such as could be accounted for by the dislocation and epizonal metamorphism suffered to a large extent by these two massifs. Moreover the igneous activities in the Aar- and Gotthard-massifs belong to the main tectonic phase whereas those of the "Unterostalps" (at least in part) and of Lugano belong to the late tectonic phase of the Hercynian magmatic activity. This tectonic phase difference may also have brought about certain variations in the original composition of these eruptive series.

Table 44
Eruptive Rocks of the "Brocken"-Massif,
Central Germany

| Type | si | al | fm | c | alk | k | mg |
|-------------------------------|-----|------|------|------|------|------|------|
| Mica-peridotite | 60 | 11 | 82 | 1 | 6 | 0,95 | 0,61 |
| Olivine-norite | 90 | 20,5 | 53 | 23 | 3,5 | 0,27 | 0,75 |
| Augite-norite | 113 | 25 | 39,5 | 30 | 5,6 | 0,24 | 0,69 |
| Biotite-augite-gabbro | 136 | 24,5 | 41,5 | 25,5 | 8,5 | 0,38 | 0,21 |
| Biotite-augite-gabbro | 140 | 24,5 | 42,5 | 23,5 | 9,5 | 0,32 | 0,59 |
| Quartz-biotite-augite-diorite | 168 | 30 | 39 | 16 | 15 | 0,24 | 0,14 |
| " | 190 | 31 | 37,5 | 21 | 10,5 | 0,39 | 0,45 |
| Quartz-diorite | 212 | 31 | 37,5 | 16 | 15,5 | 0,27 | 0,36 |
| Augite-granite | 250 | 31 | 37 | 12,5 | 19,5 | 0,43 | 0,22 |
| Hornblende-granite | 276 | 36,5 | 31 | 8,5 | 24 | 0,45 | 0,30 |
| Augite-granite | 318 | 39 | 21,5 | 11 | 28,5 | 0,52 | 0,21 |
| Biotite-granite | 342 | 40 | 19 | 9,5 | 31,5 | 0,47 | 0,23 |
| " | 374 | 42,5 | 15 | 8,5 | 34 | 0,52 | 0,19 |
| " | 399 | 43 | 13,5 | 7 | 36,5 | 0,55 | 0,15 |
| Biotite-muscovite-granite | 434 | 46,5 | 11,5 | 5,5 | 36,5 | 0,50 | 0,10 |
| Augite bearing granite | 460 | 46 | 9 | 6 | 39 | 0,58 | 0,06 |
| Biotite-aplite-granite | 496 | 46 | 9 | 3,5 | 38,5 | 0,81 | 0,15 |

We have studied above the magmatic relationship of the Lugano porphyries with other Hercynian eruptive series within the Alpine region. There is another magmatic province of Hercynian age which is also not far away from the Alps. This is the Variscan eruptive province of Central Germany. The region is fairly large and has both plutonic and volcanic rocks developed within it. They are, on the whole, typically calc-alkaline in nature and TRÖGER (1930) in a detailed study has classified the whole suite of rocks into several series differing from one another only in the details of differentiation tendencies.

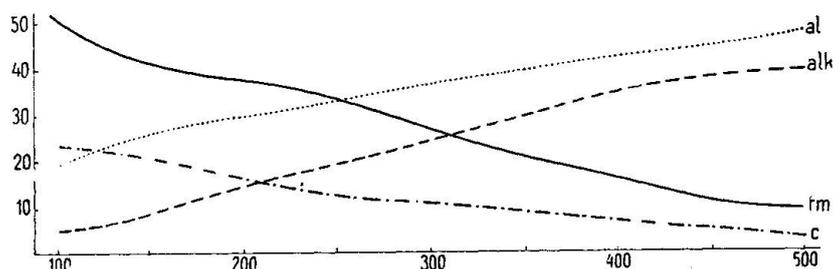


Fig. 25. Differentiation Diagram of the 'Brocken'-Massif Eruptives

An examination of the data given by TRÖGER has shown that close equivalents of the individual rock-types of Lugano occur in several series of the Variscan Province. Taken as a whole, the Lugano porphyries find their nearest equivalent in the "Brocken Massif" series. Since the magmatic activity in this massif is deep-seated, slow differentiation has given rise to a very large number of rock-types ranging from peridotites, gabbros through all the intermediate types to granitic aplites. Some of the representative rock-types have been given in Table 44 and the interpolated values as deduced by TRÖGER are included in Table 45. The differentiation diagram for this series is shown in Fig. 25.

Table 45 a

| si | al | | | | fm | | | | c | | | | alk | | | |
|-----|----|------|------|----|----|------|----|----|----|------|------|----|-----|------|------|----|
| | Lu | Br | EP | Ni | Lu | Br | EP | Ni | Lu | Br | EP | Ni | Lu | Br | EP | Ni |
| 120 | 26 | 23,5 | 26 | 25 | 42 | 46 | 42 | 41 | 25 | 23,5 | 25 | 28 | 7 | 7 | 7 | 6 |
| 150 | 26 | 26,5 | 29 | 29 | 44 | 42 | 37 | 34 | 18 | 22 | 23 | 26 | 12 | 9,5 | 11 | 11 |
| 200 | 30 | 30,5 | 31 | 35 | 37 | 38 | 32 | 26 | 18 | 16,5 | 19,5 | 21 | 15 | 15 | 17,7 | 18 |
| 250 | 35 | 33,5 | 36 | 36 | 30 | 34 | 26 | 26 | 16 | 12,5 | 17 | 18 | 19 | 20 | 21 | 20 |
| 300 | 37 | 37,5 | 42,5 | 37 | 26 | 26,5 | 18 | 23 | 14 | 11 | 15 | 17 | 23 | 25 | 25 | 23 |
| 350 | 38 | 40 | 45,5 | 38 | 21 | 20,5 | 13 | 20 | 13 | 9 | 11 | 16 | 28 | 30,5 | 29 | 26 |
| 400 | 39 | 42,5 | 47,5 | 40 | 16 | 15,5 | 11 | 17 | 11 | 7 | 8 | 13 | 34 | 35 | 34 | 30 |
| 450 | 42 | 45,5 | 48 | 42 | 12 | 11 | 9 | 13 | 8 | 5 | 6 | 12 | 38 | 38,5 | 37 | 33 |
| 500 | 48 | 48 | 48 | 46 | 8 | 9 | 8 | 7 | 3 | 3 | 4 | 9 | 42 | 39,5 | 40 | 38 |

Table 45b

| si | al-alk | | | | c' = c-(al-alk) | | | |
|-----|--------|------|------|----|-----------------|------|------|----|
| | Lu | Br | EP | Ni | Lu | Br | EP | Ni |
| 120 | 19 | 16,5 | 19 | 19 | 6 | 7 | 6 | 9 |
| 150 | 14 | 17 | 18 | 18 | 4 | 5 | 5 | 8 |
| 200 | 15 | 15,5 | 13,5 | 17 | 3 | 1 | 6 | 4 |
| 250 | 16 | 13,5 | 15 | 16 | 0 | -1 | 2 | 2 |
| 300 | 14 | 12,5 | 17,5 | 14 | 0 | -1,5 | -2,5 | 3 |
| 350 | 10 | 9,5 | 16,5 | 12 | 3 | -0,5 | -5,5 | 4 |
| 400 | 5 | 7 | 13,5 | 10 | 6 | 0 | -5,5 | 3 |
| 450 | 4 | 7 | 11 | 9 | 4 | -2 | -5 | 3 |
| 500 | 6 | 8,5 | 8 | 8 | -3 | -5 | -4 | 1 |

Lu = Lugano; Br = Brocken Massif; EP = Electric Peak; Ni = Nicaragua.

From a comparison of these interpolated values with those of Lugano it is seen that they agree fairly closely. The al values are nearly the same, with a small variation in the acid part; the fm values are the same throughout, but the c values are lower by a maximum of 4 units while the alk values agree very well. The normative anorthite value (al-alk) is throughout similar but the diopside value, $c-(al-alk)$, is negative for the acid types in the Brocken series, indicating a tendency to form lime-poor pyroxenes (like hypersthene), hornblende or biotite. It is thus apparent that the Lugano type finds a close equivalent in the Variscan activity of the Brocken massif, which belongs to the Late tectonic phase.

The above comparison with four of the Permo-Carboniferous rock-suites has proved that the tendencies exhibited by the Lugano magma are quite common during the later phases of the Hercynian magmatic activity.

It will now be instructive to enquire whether these differentiation tendencies are also realized in the magmatic activities of other ages.

It is well known that the Pacific trends of differentiation are typically exhibited by the igneous rocks of the younger mountain chains surrounding the Pacific ocean. BURRI (1927) has made an extensive study of the data on the eruptives of the Circum-Pacific regions and has shown that most of these suites fall into one or other of the principal types of the North American Cordillera. BURRI classifies these types into three main groups:

- Group I. including the types Pelee-Lassen Peak and Electric Peak.
- „ II. including the types Sierra Nevada (effusives) and San Francisco Mts.
- „ III. including the type Yellowstone Park with its sub-type Rosita.

By comparing the interpolated values of these different types, it was found that the Lugano series shows closest relationship with the first group and particularly with the Electric Peak type. This type is characterized by the *c* values being a little higher and *alk* values lower than the mean values for the N. Am. Cordillera, and it is further distinguished from the Lassen Peak type by higher *fm* values particularly for the *si* range 120—350. The interpolated values for the Electric Peak (E.P.) type are included in Table 45. Fig. 26 gives the type diagram for the same.

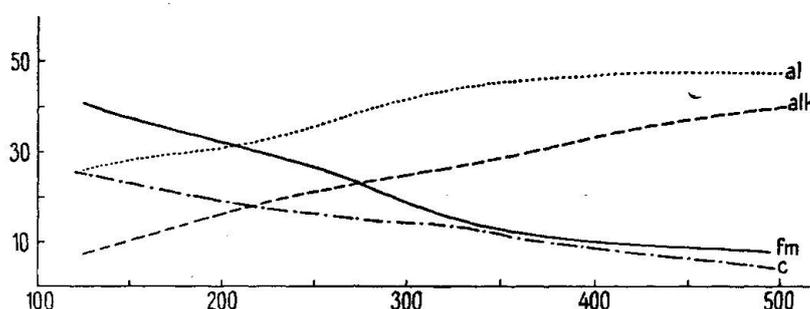


Fig. 26. Differentiation Diagram of the Electric Peak Eruptives

Comparing these with the Lugano values it is seen that the *al* values correspond quite well for *si* less than 250 but for *si* between 300—450 the E.P. values of *al* are much higher (5—8,5 units). Among the types of N. Am. Cord. E.P. has the highest values of *fm*; but even as such these *fm* values of E.P. are lower by 4—8 units than the Lugano type. The *c* and *alk* values are approximately the same for both types, the difference rarely exceeding 2 units. The higher values of *al* between *si* = 300—450, have also increased the difference (*al*—*alk*) by 6—8,5 units for the E.P. type. This alumina excess is far too great to be used up by *c* in anorthite building and has thereby lead to high negative values for normative diopside; the Lugano type, on the contrary, shows high positive values for this region (*si* = 300—450). Except for these differences the E.P. type shows a fairly close correspondence.

Among the Circum-Pacific suites which correspond to the E.P. type the following have lower values for *al* and higher for *fm* than the E.P. type and thus show a greater approach to the Lugano series:

- a) Elkhorn Mts. Mo., U. S. A.
- b) Marysville Batholith Mo., U. S. A.
- c) Mt. Stuart Quadrangle, Kittitas Co. Wash., U. S. A.

Beside these, mainly early Tertiary, igneous rocks of the N. American Cordillera, eruptive rocks of late Tertiary and Quaternary age with the same trends of differentiation as those of Lugano are also found within the Circum-Pacific Belt. C. BURRI and R. A. SONDER (1936) have described the geology and petrography of the volcanic rocks of Nicaragua (Central America) and have shown that these rocks are related in their differentiation tendencies to the Electric Peak type. The values of the main types are given in Table 46 and the interpolated values deduced by BURRI are included in Table 45 and Fig. 27.

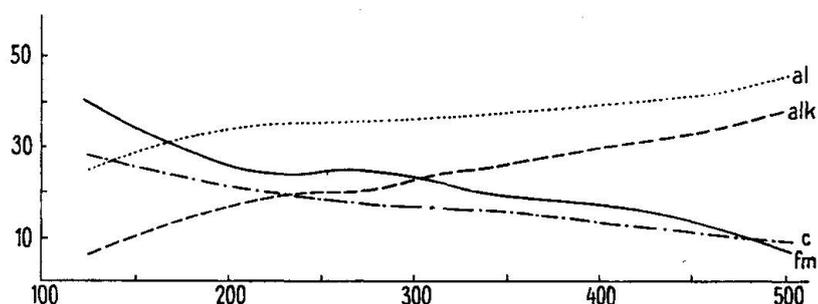


Fig. 27. Differentiation Diagram of the Volcanic Rocks of Nicaragua

Table 46
Characteristic Types of Eruptive Rocks of
Nicaragua

| Type | si | al | fm | c | alk | k | mg | Magma-type |
|--------------------------|-----|------|------|------|------|------|------|----------------------------------|
| Olivine-anorthite-gabbro | 76 | 13 | 52,5 | 31,5 | 3 | 0,11 | 0,52 | Issitic |
| Olivine-basalt Type I | 112 | 24 | 41 | 29 | 6 | 0,20 | 0,50 | Pyroxenite-Hornblendite-gabbroid |
| Olivine-basalt Type II | 113 | 29 | 32 | 31,5 | 7,5 | 0,26 | 0,44 | Ossipit-gabbroid |
| Olivine-basalt Type III | 135 | 26 | 39 | 26 | 9 | 0,26 | 0,48 | Gabbroid-dioritic |
| Andesite Type I | 156 | 24,5 | 42 | 25 | 8,5 | 0,20 | 0,49 | Normal-dioritic / Peelitic |
| „ „ II | 165 | 32 | 29 | 26 | 13 | 0,30 | 0,40 | Peelitic / Normal-dioritic |
| „ „ III | 200 | 35 | 25,5 | 21,5 | 18 | 0,41 | 0,25 | Quartz-dioritic |
| „ „ IV | 259 | 35,5 | 26,5 | 18 | 20 | 0,32 | 0,35 | Quartz-dioritic |
| „ „ V | 272 | 39 | 18 | 15 | 28 | 0,43 | 0,36 | Granodioritic |
| Biotite-rhyolite Type I | 416 | 43,5 | 10 | 6 | 40,5 | 0,58 | 0,30 | Engadinitic |
| Rhyolite Type II | 462 | 42 | 12 | 12 | 34 | 0,41 | 0,06 | Trondhjemitic |
| Rhyolite Type III | 521 | 48 | 5 | 6,5 | 40,5 | 0,53 | 0,05 | Aplite-granitic |

From an examination of the rock-types it is seen that several have nearly the same composition as the Lugano types. For example:

| Nicaragua Types | Lugano Types |
|--|----------------------------------|
| Olivine-basalt Type III corresponds to | Type A Diabase |
| Andesite Type I also approximates | Type A Diabase |
| Andesite Type IV also approximates | Type F Quartz-biotite-porphyrite |
| Rhyolite Type I approximates | Type G Granophyre |
| Rhyolite Type III approximates | Type H Granophyre-aplite |

Types B to E find no equivalents in the Nicaragua series as the magma shows great variation in the isofalic region. This is reflected in the interpolated values which show the maximum differences in the values of al, fm and c between the si values 150—200. For other values of si the values of al, fm, c as well as alk are identical. The anorthite values and the diopside values are also identical for most values of si.

Thus these post-tectonic Andean-Alpine igneous series of Central and North America give evidence of similar trends of differentiation as shown by the Lugano porphyry magma.

The above comparisons of the eruptive series of the Aar- and Gotthard -massifs, "Unterostalpine" -nappes, Variscan province of Central Germany, all belonging to Carboniferous and Permian igneous activity, and of the eruptives of the North American Cordillera and Nicaragua ranging in age from Cretaceous to Recent, have clearly shown that the magmatic differentiation on the lines followed by the Lugano magma is by no means unusual but quite common and widespread both in time and space, and that the process is intimately connected with the major tectonic earth-movements.

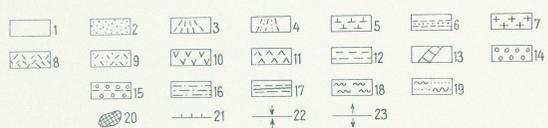
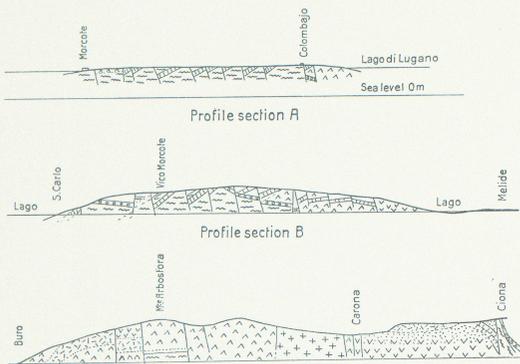
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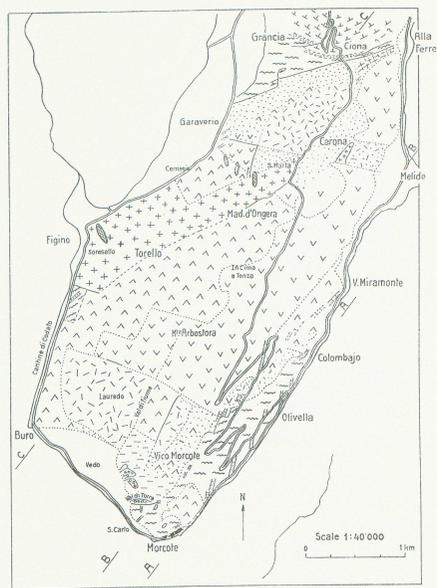
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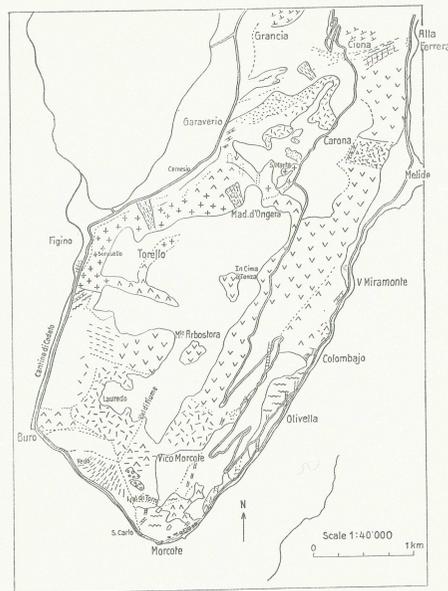


Legend to Sketch-Maps and Profiles on Plate and to Text-Figures 2-7.

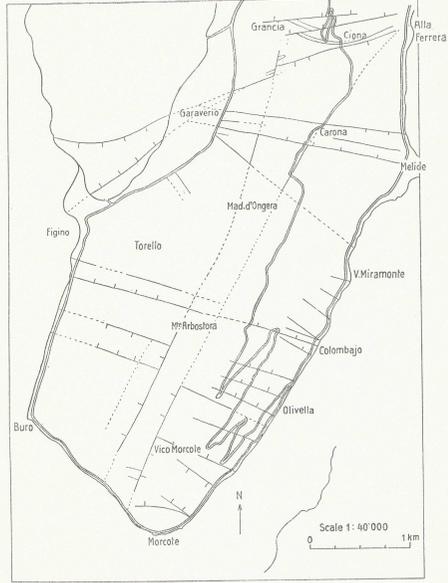
- 1 Moraine (only Sketch-Map B)
- 2 Debris (only Text-Figs 4, 6, 7)
- 3 Basic and Acid Tuffs (All Figures on Plate)
- 4 Alluvial fans (only Sketch-Map B)
- 5 Dolomite
- 6 Servino Beds
- 7 Granophyre
- 8 Quartz-Porphyrines and Tuffs
- 9 Bolt Quartz-Porphyrines (only Profile Section C)
- 10 Basic „Pyroxene“-Porphyrites
- 11 Biotite-Porphyrines
- 12 Basal Tuffites — Sandstones with clayey partings (only Text-Figure 6)
- 13 Quartz-Porphyry Dikes
- 14 Permocarboiferous Conglomerates and Sandstones
- 15 Do. in Text-Figure 4
- 16 Cherty Rock (only Text-Figure 7)
- 17 Quartzite (only Text-Figure 6)
- 18 Gneisses and Schists
- 19 Crumpled Gneisses and Schists
- 20 Barite Veins
- 21 Faults with Downthrow
- 22 Syncline
- 23 Anticline



Sketch-Map A.
Geology of the Morcote Peninsula



Sketch-Map B.
Geo-Morphology of the Morcote Peninsula



Sketch-Map C.
Tectonics of the Morcote Peninsula

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