10. Petrology of Interglacial Volcanics from the Andes of Northern Patagonia.[1]

By

Walter Larsson.

(With Pl. III—IV.)

Contents.

[1] Report No. 7 of the Swedish Expedition to Patagonia 1932—1934.

Preface.

This thesis constitutes the result of an adaptation of part of the material which was collected by Docent E. LJUNGNER during his two last expeditions to Northern Patagonia in 1930 and 1932—34. The journeys in 1930 were made in his capacity of State Geologist in Argentina and by order of Dr. JOSÉ M. SOBRAL, at that time Director General of Dirección General de Minas, Geología e Hidrología. With kind permission of the present Director Ingeniero T. EZCURRA part of the material from these travels has been included in this treatise. The laboratory research was carried out at the Mineralogical-Geological Institution, Upsala, mainly during the winters of 1937—38 and 1938—39, and the final arranging of the collected data during the past winter. Apart from a number of duplicates the investigated collection comprised nearly 200 rock samples, about 120 from the first expedition, the rest — chiefly from the northern parts of the district investigated by the expeditions — from the second one. At the request of E. LJUNGNER, Mr OTTO MEILING, San Carlos de Bariloche, Argentina, kindly collected some valuable rock samples during an ascent of the Tronador summit in 1938. One of his excellent photographs, taken on that occasion, is included in this work (Fig. 8). — About 140 thin sections of the rocks in question have been thoroughly examined.

In publishing the results of my investigations I would like to thank all those who have, in various ways, helped to bring about the completion of this work. In the first place, I wish to express my deep gratitude to my teacher Professor H. G. BACKLUND, Principal of the Geological Institution, Upsala. In connection with this and previous work of mine he has always shown the greatest interest, and in many ways actively contributed to — and made possible — the fulfilment of my academic studies. The instrumental equipment at his Institution has constantly been at my disposal, and I am particularly obliged to him for permission to publish this thesis in the Institution's Bulletin.

I am extremely pleased to avail myself of this opportunity to thank Docent E. LJUNGNER for his collaboration during the time I was occupied on the adaptation of the material collected during his expeditions. At all times he has been willing to place at my disposal those observations which were of importance to my work. And with his aid a good amount of literature, particularly Spanish, has been made accessible to me. Most of the reproduced photographs illustrating the geological appearance of the Tronador series have been taken by him. He has also placed at my disposal an unpublished manuscript (see the bibliography), in which full evidence is given of the interglacial age of the rocks.

The eight new, chemical analyses published here have been executed with great skill and care by Dr. NAIMA SAHLBOM. The thin sections of the rocks — from the viewpoint of preparation partly less desirable types — have in a very satisfactory manner been prepared by Mr W. PLAN, Preparator at the Geological Institution. The microphotographs have been taken with the Busch-citophot of the Upsala Institute in collaboration with Mr A. G. SAGERHOLM. The author has drawn the diagrams and maps, and also translated the manuscript in English. The English has later been revised by Dr. F. A. L. CHARLESWORTH, Lector in English at the Upsala University. To all those persons who have in one way and another given me their assistance I wish to express my sincere thanks.

Financial aid for the execution of this work has been received from funds provided for the adaptation of the material of the Patagonia Expeditions, chiefly from the LARS HIERTA Memorial Fund, and to some extent from lottery proceeds.

I. **Introduction.**

The area, the youngest geological formation of which is the object of this treatise, is situated in the western central part of the Argentine »Parque Nacional del Sur» and comprises the most northwesterly corner of the North-Patagonian province Rio Negro (Dept° Bariloche) and the most southwesterly part of the province Neuquen (Dept° Los Lagos). Consequently the area lies in the western border-districts of the republic towards the Chilean province Llanquihue (Fig. 1). The greater part of the rock material studied has been collected in the Argentine territory, only a few samples being available from the Chilean side of the boundary. The localities of the rock samples collected *in situ* are situated within a roughly triangular area fixed by the points: 41°1′ S—71°28′ W, 40°59′ S—71°49′ W and 41°16′ S—71°52′ W. The northernmost border of the area running approximately east-west is consequently cut by the 41st parallel, whereas the 72nd longitude falls some ten kilometres west of the approximately north-south running western limit of the region. The sides of the triangular district are about 30, 33 and 48 kilometres, respectively.

The area lies topographically as well as geologically within the Andean zone of mountain folding. Omitting the relatively young, volcanic Cerro

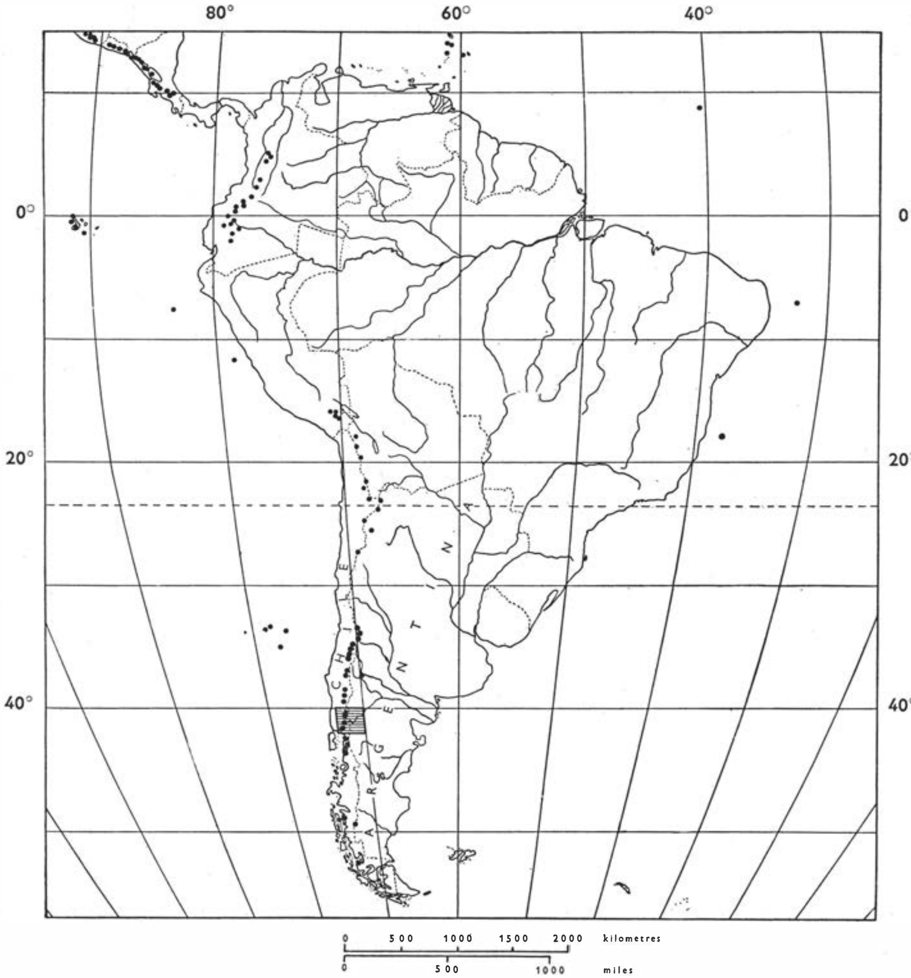


Fig. 1. Outline map of South America showing the distribution of volcanoes and submarine centres of eruption active in historical time (dots), according to SAPPER (1927) and v. WOLFF (1929). Shaded area indicates the location of Fig. 2. Scale 1 : 65 000 000.

Tronador with its 3473 metres high summit, the loftiest mountain of northern Patagonia, the axis of highest elevation of the Cordillera, as has been shown by LJUNGNER, is situated considerably more to the east than was formerly assumed namely at about longitude 71°30′ W (Fig. 2). The summit plane, the central parts of which are slightly arched in east-westerly direction, exceeds 2300 metres in certain areas. The area of volcanic rocks dealt with in this paper is consequently located mainly on the western slope of the Cordillera. That it is nevertheless more easily accessible from the eastern, Argentine side is due to the great Andean lake Nahuel Huapí, which with an approximate length in east-west of little short of 60 kilometres reaches far into the heart of the Cordillera. As a matter of fact the general axis of

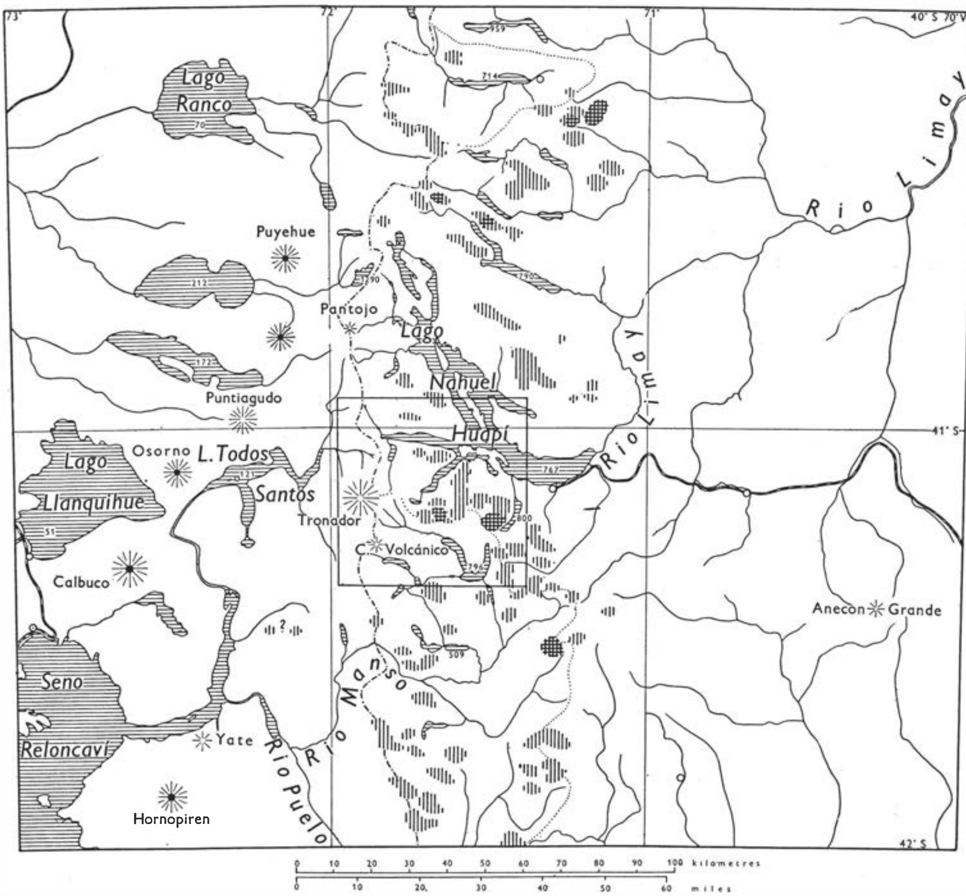


Fig. 2. Sketch map showing the orographical conditions of Sheet 72 Nahuel Huapí (1928) of the map of the Argentine Ordnance Survey, with corrections by LJUNGNER. Scale 1 : 2 000 000.

Areas surpassing 2000 metres a. s. vertically ruled.
» » 2300 » » » cross-ruled.
»Suns» with open centres — Extinct volcanoes.
» » black » — Active » .
Stippled line — The inter-oceanic watershed.
Broken line with stipples — The Chilean-Argentine boundary.
The »sun» south of Puyehue refers to a cone of typical recent volcanic form photogrammetrically localized. It is visible on the panorama (Pl. IV) 4.8 cm from the right margin at the horizon.
Numbers refer to the altitude above the sea of the levels of the lakes. The area of the rectangle in the central part of the map is covered by Fig. 3.

highest elevation of the mountain-range mentioned before cuts the central part of the lake (Fig. 2).

The course of the inter-oceanic watershed in this region is particularly interesting and is marked as a stippled line in Fig. 2. North of Cerro Tronador it runs mainly in a north-southerly direction on an average about

35 kilometres west of the general axis of elevation and coincides with the frontier line between Chile and Argentina. South of Tronador this frontier continues in the same southerly direction, whereas the watershed from the northeast side of Tronador turns abruptly to the east, through Paso de las Nubes, and from the pass between the lakes Gutiérrez and Mascardi makes a wide curve of some twenty kilometres east of the axis of elevation. Not until about 75 kilometres south of Tronador does it coincide again with the frontier in its general north-southerly course. The northeast and greater part of our area is consequently drained to Lago Nahuel Huapí, which by Rio Limay and Rio Negro runs off to the Atlantic, whereas the southwest and minor part belongs to the basin of Rio Manso, which by Rio Puelo discharges its waters into the Pacific. The northern and western slopes of Tronador are drained to the west by Rio Peulla and Rio Blanco to Lago Todos los Santos, which by Rio Petrohue flows off at the present day to the same gulf of the Pacific, Seno Reloncaví, as Rio Manso.

An idea of the order of magnitude of the relief energy of the area will be given by the surface heights of the great lakes above sea level. The following are in the area draining to the Atlantic: Lago Nahuel Huapí 767 metres, Lago Frio 790 metres, Lago Gutiérrez 800 metres; in the drainage area of Rio Manso: Lago Mascardi 796 metres, Lago Guillelmo 820 metres, Lago Fonck 740 metres, Lago Hess 730 metres, Lago Vidal Gormaz 725 metres. All these lakes lie in the zone where the summit plane partly in many areas considerably exceeds the level of 2000 metres. Differences of 1200—1300 metres between the surface levels of the lakes and the summit plane frequently occur in this district. Also taking into consideration the deep shelving of the lakes together with the steep sides of the greater valleys as well as the considerable depth of the lakes (Brazo del Viento of Lago Nahuel Huapí according to LJUNGNER's soundings in maximum 350 metres) and the solitary peaks of young volcanoes covered with glaciers (particularly towards the west) towering high over the general »Gipfelflur», the denomination »Suiza Sud-Americana» for this part of the North-Patagonian Andes cannot from a general orographical point of view be looked upon as either unjustified or inadequate.

II. **Summary of the pre-Quaternary geology of the Nahuel Huapí region.**

Before entering into a more detailed description of the late formations which are the subject of study in this paper it is necessary to sketch in broad outlines the earlier geological history of the district. It is not only essential to take into consideration the relatively restricted area, from which the rock material described in this treatise derives, but to extend this general survey to the Nahuel Huapí region in its entirety to the extent of the territory investigated by LJUNGNER's expeditions.

According to LJUNGNER (1931 and later modifications) the rock formations appearing in the Nahuel Huapí region are the following in descending chronological order:

Glaciation	Younger Pleistocene
The Tronador series	Interglacial
Glaciation (or glaciations)	Older Pleistocene
Talus breccias	Pliocene
Folding	Miocene
The Alto Limay series The Nahuel Huapí series	Oligocene—Lower Miocene
The Tristeza granite series	Eocene
The granodiorite series	Malm (or Cretaceous)
Folding	Malm
The Milleaqueo formation	Probably Lias
The quartz porphyry—porphyrite formation	Rhaetian
Folding (or foldings)	?
The high-metamorphic basement	Palaeozoic or pre-Cambrian

East of Nahuel Huapí, in Cerro Catedral and at Lago Gutiérrez occur gneisses, highly metamorphic, regarded by LJUNGNER as belonging to the basement of the Andean geosyncline. If this conception holds good, one must reckon with the possibility that these gneissose rocks have undergone one or several foldings before the deposition of the Mesozoic formations. Whether, if such be the case, we have to see in these gneisses metamorphic derivatives of pre-Cambrian or Palaeozoic rocks is, however, an open question.

The oldest formation of the Andean geosyncline in this region is the quartz porphyry—porphyrite formation. This complex appears on Peninsula Huemul and farther to the northwest on the northeastern side of Nahuel Huapí and is composed of porphyrites, dacites, quartz porphyries, and their tuffs. The thickness is several hundreds of metres. This effusive series shows great similarity with and forms an almost immediate continuation of the great porphyrite zone developed in the East-Cordillera of Patagonia, where its age has been determined as upper Triassic (Rhaetian).

The Milleaqueo formation so named by LJUNGNER (1931) with regard to age as well as genesis is intimately connected with the porphyrite series. Its greatest area of distribution is somewhat west of the middle part of Brazo del Viento. Here it deals with a sedimentary formation, composed of slates, sandstones and conglomerates in rapid interstratification. The close connection with the porphyrite series appears *inter alia* from the fact that the sediments — and this applies particularly to the sandstones and the conglomerates — consist almost entirely of detrital material of the volcanic rocks of the porphyrite series, especially the relatively younger dacites and quartz porphyries. Granitic rocks of deep-seated character do not seem to have yielded material to the sediments. The rocks of the porphyrite series have been found in the basal parts of the sedimentary zone mentioned, whereas, on the other hand, sediments of the nature of the Milleaqueo formation occur in close connection with the porphyrite series on Peninsula Huemul. Also taking into consideration the fact that the conglomerates of the Milleaqueo formation do not possess the character of basal conglomerates, but appear at various levels in the sedimentary series, and further, that some of the sediments are penetrated by porphyrite dikes, apparently identical with effusives of the porphyrite series, the question arises, whether the two formations in part are not of the same age. Certain of the facts stated above seem to favour the belief that the lower part of the Milleaqueo series and the upper part of the porphyrite series may be equivalent formations. With a Rhaetian age for the latter series the former may be referred with some plausibility concerning its principal development to the Lias. Certain analogies between the Milleaqueo formation and Liassic sediments in more northerly parts of Argentina, in Neuquen and Mendoza, are in favour of this interpretation.

The two formations now mentioned are highly folded, and this process probably occurred during the Upper-Jurassic epoch of folding (Malm). This determination of the age of the folding is based upon the central situation in the Andes of the formations in question and upon the northwesterly strike of the folds, which may easily be combined with the north-southerly strike of the Upper-Jurassic folds not far to the north in the Chilean-Argentine Andes. Cretaceous folding is known only from the eastern border, though it also occurs outside the Cordillera, and its arcs of folded sediments have mainly a northeasterly strike.

To the epoch of the Upper-Jurassic folding or in any case in close connection to it we have to refer the origin of the so-called granodiorite series. This series has a great distribution in the region and is probably to be parallelled with the great areas of granitic rocks, which may be followed in an almost unbroken zone from the Nahuel Huapí region towards the south in the West-Cordillera extending almost as far as Cape Horn. The granodiorite series in the Nahuel Huapí region seems to comprise two consecutive subseries. The older of these, the Huemul granite, has a predominantly eastern distribution and is partly gneissose, and varies from diorite to hornblende granite. Farther to the west portions of this Huemul granite are enclosed in and sharply separated from the younger Viento granite, which has its principal distribution in the neighbourhood of Brazo del Viento. The Viento granite shows, on the other hand, transitions from quartz dioritic, via granodioritic to plagioclase granitic members. These two granites, the Huemul and the Viento granites, have metamorphosed and gneissified to a marked extent as well as formed migmatites with the older porphyrite and Milleaqueo formations. As a matter of fact inclusions of the rocks of these formations, more or less altered, are very common in great parts of the area of the granodiorite series, particularly in the higher parts of the mountains.

The Tristeza granite series is younger than the Huemul and the Viento granites. The greatest occurrence of this series is on both sides of the inner and greater part of Brazo Tristeza of Lago Nahuel Huapí. It also occurs on the northern shore of Brazo del Viento and on the island of Centinela. The types of rocks belonging to this series are coarse-grained granite, porphyry granite, aplite granite, and quartz porphyry. The porphyritic and more acid dikes which penetrate in great numbers the older series of rocks — especially the granodiorite series — are probably to be referred to the Tristeza granite complex. The Tristeza rocks differ in their varying texture from the rocks of the granodiorite series and in their generally more intense, red colour (the granodiorites are gray or pale reddish) and the absence of primary hornblende, which has been mainly substituted by pyroxene. In connection with the large massive round Brazo Tristeza a laccolithic appearance of the rocks of the Tristeza granite series has been demonstrated. To the north and northeast the granodiorite series forms the bottom, to the south and southeast the top of the almost horizontally lying intrusive body. South of Lago Frey the upper as well as the lower contact of the laccolith have been cut by erosion processes. Here the thickness is about 500 metres. Finally, attention may be drawn to the fact that the laccolith is composed of petrographically differing rock members layered one upon the other.

As to the age of the Tristeza granite it has been established that the texture of the rocks indicates that their *mise-en-place* has taken place in a higher level than that of the granodiorite series. For this reason a period of erosion between the two series must be presumed. LJUNGNER (1931, p. 215) believed that he had found evidence of this erosion period in what he called the »Llancamil formation». This formation has, however, later (LJUNGNER 1933, p. 644) proved to be a considerably younger, pseudo-conglomeratic breccia, formed by tectonic movements in Tertiary time. The Tristeza granite shows geologically as well as petrographically certain similarities with some granitoid laccoliths in the more southerly parts of the Patagonian East-Cordillera (QUENSEL 1911). These laccoliths are closely connected to some extent with alkaline rocks of basic character. Such rocks have only rarely been found outcropping in the Nahuel Huapí region. Finds of boulders of gabbroic dolerite and monzonitic dolerite with partly essexitic affinities in the moraine material of Ventisquero Grande, Tronador, show that such rocks probably occur in the basal parts of this mountain, in close geographical connection with the Tristeza laccolith. If this laccolith is comparable with the more southerly East-Cordilleran examples, which appears probable from the evidence stated above, they may be localized between rather narrow age limits. Three of these laccoliths, namely those of Cerros Balmaceda, Donoso, and Payne, are younger than the regional Cretaceous folding, as they have partly arched and contact-metamorphosed intensely folded Senonian sediments. The Tristeza granite, on the other hand, is decidedly older than the Oligocene sedimentation in the Nahuel Huapí region. An Eocene age of the laccolithic intrusions in question seems therefore to be the most probable one.

The mountain-range developed by the Upper-Jurassic (and Cretaceous?) folding was to a large extent eroded and levelled, when the Tertiary sedimentation began in the Nahuel Huapí region. This sedimentation is here represented by the Nahuel Huapí series forming a broad continuous zone with northwesterly strike through the central part of the lake together with two minor synclines situated more to the west, one striking across the peninsula Llau-Llau to the northern shore of Brazo del Viento, northwest of the island of Centinela, the other located to the northeastern precipice of Cerro Lopez. A porphyrite dike of the type indicating a genetical connection with the Tristeza series has been found cut by the erosion surface below the formation and in the basal conglomerate occur boulders of the Tristeza quartz porphyry. Volcanic material plays an important rôle in the Nahuel Huapí series. Tuffs of varying appearance are most abundant though mainly andesitic. Interfering with the tuffs there occur lava flows of dacitic, andesitic or basaltic composition. Also sills and dikes of basaltic character (dolerites) appear in the lower parts of the series. In the middle part of the principal zone, *e.g.* on the Victoria island, fossilized trunks of trees have been found embedded in the pyroclastic sediments, several in intact natural positions. This proves the terrestrial formation of these beds. In, apparently, stratigraphically lower levels, in tuffaceous sandstones and slates, at some localities — Otto's Höhe, Puerto Pañuelo, Brazo del Viento, Cerro Lopez — a littoral fauna has been met with, preserved in casts, and these comprise bivalves, spiral univalves, anthozoans, crustaceans, echinids etc., the components of which indicate an intermediate position between the faunas of the Argentine Patagonico and the Chilean Navidad beds, both of which are looked upon as Oligocene.

In 1931 LJUNGNER distinguished a volcanic formation, the Alto Limay series, at that time considered to be younger than the folding, which the Nahuel Huapí series has undergone. This first-mentioned series lies at the eastern extremity of the lake and is chiefly composed of basaltic lava flows and tuffs as well as possibly subordinate liparitic effusives with obsidian.

This Alto Limay series, however, upon closer investigation has proved not to be sharply separable from the Nahuel Huapí series. Both are folded, the Alto Limay series, however, in a minor degree. This might be due to its eastern, peripherical position in relation to the central zone of folding. Yet it obviously occupies a stratigraphically higher level than the lowest parts of the Nahuel Huapí series. As the Tertiary folding is not strictly confined to a relatively restricted period, but had already started during the Pliocene, for which the frequently occurring intra-formational conglomerates (also with granite fragments) bear evidence, the comparatively slight orogenic deformation of the younger members (the Alto Limay series) is also explained upon these grounds. The age of the youngest effusions of the Alto Limay series therefore ought to be at most Lower Miocene, during which period the principal part of the Andean folding is considered to have taken place.

The Tertiary folding, which as to its strike coincides with the earlier, Upper-Jurassic one, may here be described most adequately as an intense block-folding, the orogenic pressure also having been released along great faults. These faults strike in northwest—southeast as the folds, and the northeast border of the blocks has been lowered and partly overridden by the southwest border of the adjacent block. Breccias occur along these faults, which also appear in the more westerly, predominantly crystalline area. Such breccias injected by liparite, in which sometimes fossiliferous portions of the Nahuel Huapí series enter (the »Llancamil pseudo-conglomerate» mentioned before) are found in the southwest part of Lago Nahuel Huapí.

In reconstructing the geological history of the region from the Miocene folding up to the Glacial period the study of the hydrographic relations, and in particular the character of the valley sections, has given important results. Thus the existence of three generations of valleys has been demonstrated, which involve two different phases of elevation of the Andes after the principal folding. The oldest, overripe, fossil, and very flat valley fragments at high elevation, situated at approximately 200 metres below the highest summits, probably derive from the period (Late-Miocene), when following the Miocene folding a tendency to the development of a peneplain evidently existed. This peneplain is now present in the »Gipfelflur», a highly developed feature of the area which also cuts off the zones of folded Tertiary rocks. After the first elevation of the Cordillera a revived formation of valleys ensued, in which the hydrographic system was partly shifted and some portions of the older valleys were dried and fossilified. The valleys of this second stage (the [n + 1] stage according to B. WILLIS 1914 c) are to be traced at the present day in the upper flatter portions of the sides of the younger valleys and in the hanging tributary valleys to these latter ones. The deeper, precipitous, canyonlike portions of these valleys (the [n + 2] stage, B. WILLIS) owe their origin to a second elevation of the Cordillera. Both these latter generations of valleys and, therefore, also the two phases of elevation are pre-glacial, probably Pliocene. In favour of the correctness of this age determination is the occurrence on some localities in these youngest valleys of talus breccias consolidated to rocks and composed of local material — the northern shore of Brazo del Viento, the northeastern shore of Lago Moreno Este, and the northeastern precipice of Cerro Lopez. On account of the degree of diagenetic consolidation these breccias and, therefore, also the valleys, in which they occur, ought to be pre-glacial.

The relief conditions of the region at the end of the Pliocene period were, therefore, in their leading features the same as those of the present time. The modifications which subsequently ensued are to be ascribed to a large extent to the partly eroding, partly depositing activity of the Pleistocene glaciations. Of certainly still greater importance for the morphology and hydrography of the region was the volcanicity recommencing in interglacial time. We have thus arrived in our survey of the geological history of the Nahuel Huapí region at the youngest formation, which in the following chapters will be the object for a closer study, *viz.* the Tronador series.

III. Previous knowledge of the rocks of the Tronador series.

Cerro Tronador, the dominant mountain of the area here treated, is already mentioned in an account of journeys made across the Cordillera since the year 1703 by pater DE OLIVARES and other Jesuits from the island of Chiloë to the lake Nahuel Huapí. Mention is made of a great volcano, visible from the lake, called Anon by the Indians (BARROS ARANA 1874; STEFFEN 1893 a, p. 312). The conception of the volcanic nature of the mountain was, however, obviously based only upon observations of its general morphology. In addition it is probable that the rumble caused at short intervals by the numerous glaciers of the mountain, which later inspired its present name, may have led a traveller making his observations at some distance to believe in a faint but recurrent volcanic activity.

These districts were visited during the years 1791—94 by pater MENENDEZ. In his diary (FONCK 1900, p. 220) for the 25th February 1791 we find the first reference to Cerro Tronador of petrographical interest. A piece of rock is mentioned, which had probably fallen from the lower extremity of the glacier (Ventisquero Blanco), which gives birth to Rio Blanco, *i.e.* at the southern base of Tronador. This stone contained sulphur, which is said to have been so extremely hard, that it was necessary to strike with great vigour to divide it. This description accords well with the opal-altered volcanic rocks impregnated with sulphur described later in this treatise.

During his journey in Patagonia 1862—63 G. E. COX on the 25th December 1862 made an ascent of the glacier of Rio Peulla. In the account of his travels (COX 1863, p. 48 a. f.) and in a letter to FR. FONCK (FONCK 1900, p. 473 a. f.), dated »Nahuelhuapi» the 4th January 1863, he gives an interesting description of the morainic material on this glacier. From the upper regions of the glacier mention is made of large boulders of conglomerate (further on they are called agglomerate) among the granites in the moraine, which differed in general character from those boulders, which occurred at the base of the precipices surrounding the glacier. These latter boulders are said to have consisted of yellow earth with embedded stones, »some are a compact conglomerate of different rocks, but generally they are syenites».[1] The former ones, on the other hand, are dark. The black mass is »very compact and very old». These boulders appeared to him as being »sedimentary formations broken down from the peaks by the snow». Boulders of the same characters are still met with one legua (5 $^1/_2$ kilometres) below the glacier, where the remaining loose material is said to consist of »red, yellow and lead-coloured clay or earth with stones». On account of this occurrence of the same boulders as on the glacier COX propounds the question, whether or not this glacier had reached this point at an earlier date. His supposition, that the dark boulders derive from the higher parts of Tronador, is surely correct. Probably, however, it deals with a volcanic agglomerate or a lava and not with any sedimentary formation. Also the yellow moraine material might largely come from the summit portions of the mountain and chiefly consist of more or less altered tuffs.

In »Nouvelle Géographie Universelle» E. RECLUS (1893, p. 724) referring to Tronador states that this mountain does not owe its name, which means »The Thunderer», to its volcanic explosions, but to its »avalanches, neiges et glaces, s'écroulant avec fracas dans les vallées». (See also M. V. DE SAINT-MARTIN and L. ROUSSELET 1894).

In the beginning of the year 1893 J. STEFFEN and O. DE FISCHER led an expedition to the districts between Golfo de Reloncaví and Lago Nahuel Huapí, from which some observations of interest in this connection are reported from the areas north and east of Tronador. On the 31st January 1893 FISCHER made an ascent of Cerro Doce de Febrero (STEFFEN 1893 b, p. 1198 a. f.). The bottom of a north-southerly gorge dividing the mountain into two parts was filled by huge pieces of rocks apparently of volcanic origin. A petrographical investigation proved them to be basaltic lavas. The rocks on the sides of the gorge are said to show

[1] The quotations from Spanish literature have been translated into English by the author.

»indications of influence of the subterranean heat». In the highest part of the same gorge immense quantities of volcanic ash were found, which »completed the illusion that we were on the scene of an old and gigantic eruption, which has completely cut the mountain in half and thrown its lava towards both sides through the gorge mentioned before». According to FISCHER this gorge owed its origin to a fissuring consequent upon the basalt eruption. The possibility that the volcanic rocks in part fill a pre-existing valley in the older rocks (amphibole granite, STEFFEN 1893) is, however, also worthy of consideration. Of interest are also the statements as to the morphology of the two peaks of Cerro Doce de Febrero. The somewhat higher eastern top is described as being dome-like in shape and is probably composed of granite. The western peak, on the other hand, forms a meseta bounded by vertical cliffs, a morphological feature, which is highly characteristic of the rocks of the Tronador series. A similar interpretation was given by STEFFEN in 1919, when on a geological section (p. 137) the eastern summit is stated to consist of granite, the western one of basalt.

STEFFEN also makes other statements of interest in this connection. The strip of shore at the southwest part of Lago Frio is said to consist of »black sand», obviously to a large extent detrital material of the basalts of the Tronador series. The ground of the extensive heathy swamps (ñadis) in the valley of Rio Frio is also stated to be composed of a deep silt of red colour indicating the existence of ferriferous soils and rocks in the area. On the return to Chile an excursion was made on the 9th February towards the upper part of Rio Peulla. From this place a terminal moraine is mentioned, composed of »very fine yellow clay containing enclosed large fragments of rocks derived from the Tronador massive». Great masses of very finely triturated particles of this yellow material, already noticed by COX, coloured the water in one of the four river-arms originating from the glacier.

The rock samples collected during STEFFEN's journeys were microscopically investigated by R. PÖHLMANN (1893). Among these a small number of rocks from the Tronador series was also included. From a lateral moraine of the Rio Frio glacier and from the eastern slope of Tronador in the neighbourhood of Portezuelo Barros Arana (Paso de las Nubes) are described two rough, somewhat porous, gray specimens of augite andesites looking like trachytes. In a groundmass consisting of feldspar, augite, magnetite, and a little apatite there occur porphyritic crystals of augite and feldspar in one sample, only feldspar in the other. According to optical analysis the feldspar is said to be a plagioclase of oligoclase or andesine composition. A sample of blackish brown augite andesite from a moraine at the uppermost part of Rio Peulla, on the northern slope of Tronador, showed phenocrysts of plagioclase, augite and magnetite in a groundmass of augite, feldspar, magnetite and ferric oxide. From the lateral moraine of the Rio Frio glacier a somewhat porous, ash-coloured hypersthene andesite is also mentioned. In a groundmass of plagioclase, augite, magnetite, apatite, and probably a little glass are lying porphyritic crystals of plagioclase with many vitreous inclusions, pyroxene, mostly hypersthene with pleochroism in greenish and reddish, magnetite, and finally »very little biotite mica with black rims formed by the heat of the melted mass». From only one locality, namely Cerro Doce de Febrero, basaltic lavas are described. He makes a distinction between plagioclase basalts and ordinary basalts. The former ones are rocks of black—dark gray colour and somewhat porous texture and contain porphyritic crystals of feldspar, olivine, and augite in a groundmass of plagioclase, olivine, augite, magnetite, somewhat apatite, and a small quantity of glass. The proper basalt lavas contain the same minerals but only solitary small phenocrysts of plagioclase.

From these petrographical investigations by PÖHLMANN of the boulder material of the moraines on the northern as well as the eastern side of Tronador STEFFEN concluded that andesites occur outcropping in the highest parts of the Tronador massive (STEFFEN 1894, p. 154). The rocks in the lower parts of the mountain, west of Rio Frio, between Cerro Doce de Febrero and Portezuelo Barros Arana, proved, in 1893, to be for the greater part of mica-schist.

At the end of the year 1897 and in the beginning of 1898 L. WEHRLI travelled in this region. *Inter alia* from the study of samples of rocks brought home this geologist arrived at the conception that Tronador is »a great old volcano of basalt resting upon a massive base of granite» (WEHRLI 1899, p. 227; see also »Esposición Chilena» 1902, p. 1136). The Peulla glacier, from which he made his observations, is up towards the mountain terminated in an immense glacial circus with rocky walls 500—600 metres high. WEHRLI there observed a distinct contact between the basalts and the subjacent granite at some distance in the circus. The rainy weather and the continuous ice-avalanches down the steep sides rendered a close examination impossible. From a later part of the journey an interesting observation is dated the 10th February 1898. On the southern shore of Nahuel Huapí, not far east of Puerto Blest, a »not very thick outcrop of basalt in the form of well developed columns» was observed. Three alternatives are propounded for the interpretation of this occurrence of basalt, namely that it forms a minor local eruption, that it is a lava from Tronador or, thirdly, that it has come from the east. WEHRLI seems to consider the first-mentioned alternative the most probable one, but defers the decision of this question to the microscopical and chemical examination, which, however, has not as yet been published. The eruption is said to be pre-glacial, as the basalt shows glacial sculpture with horizontal striae. This basalt occurrence is obviously the same as that described later in this paper as the lava neck at Peña de Columnas.

In »XVII. Jahresbericht der Geographischen Gesellschaft von Bern 1898/99» WEHRLI (1900 a, p. 165) writes concerning Tronador, that this mountain is an extinct volcano resting upon a granite basement (see also WEHRLI 1900 b, p. 157). »Elegantly the black basalt walls penetrated by coloured dikes rise precipitously from the round-knobby, white basement of granite. Along the whole gigantic mountain the boundary line between the two rocks is clearly visible from a great distance» (in the Peulla valley), »only interrupted by the gazing, yawning tongues of ice, until it disappears to the right and left, to the east and west, in impenetrable primeval forest on the steep valley-slopes.» The Peulla glacier is upwards terminated by basalt walls 600 metres in height.

Determinations of the magnetic declination at Puerto Blest, at the northern base of Tronador and at Lago Todos los Santos showed the appearance of disturbances at Tronador. This magnetic anomaly is interpreted by WEHRLI (1919, p. 495) as being due to the »magnetite-bearing basalt masses» in the upper parts of the mountain.

S. ROTH, who made geological investigations at and south of Lago Nahuel Huapí in the years 1897—1899, speaking of Tronador states (1922, p. 343) that all mountains, the older ones as well as the still active volcanoes, of the eruptive zone, of which Tronador forms an integral part, consist at the base of granitic rocks. »In the upper part rocks of porphyritic and basaltic texture prevail, accompanied by breccias and detrital material.»

L. GALLOIS (1901) certainly gives no information as to the geology of Tronador, but on a photographic panorama (Plate 18) of the mountain, obviously taken from one of the headwaters of Rio Manso, immediately northeast of Ventisquero Grande, appears as plainly as any one could wish the layered, stratovolcanic structure of the southeast part of Tronador.

R. HAUTHAL registers in his list of the volcanic centres of Argentina and Chile (1904, p. 187) Cerro Tronador as volcano No. 154. This volcano according to his subdivision is the southernmost one of the Argentine-Chilean area, south of which the Patagonian area begins.

In »Landeskunde von Chile» (MARTIN 1909, p. 62) Tronador is said, according to STEFFEN, to consist of »mica-schist with superposed young-plutonic rocks». Also PÖHLMANN's petrographical notes of rocks from Tronador and its environs are reviewed in a few words. Further on (1909, p. 86) HAUTHAL's list of extinct and active volcanoes in the Chilean-Argentine Andes is quoted. »Some volcanoes mentioned by him have later proved to be mountains of another nature. Thus Tronador southwest of Lago Nahuel Huapí to a large extent consists of mica-schist.»

P. D. QUENSEL, who participated in an expedition to Patagonia and

Tierra del Fuego in 1907—1909 and in this connection also visited the region between Puerto Montt and Nahuel Huapí, had no material at his disposal for petrographical examination from Tronador (QUENSEL 1911, p. 109). On the general map appended to his paper Tronador has, however, in accordance with WEHRLI, got the same colour as the young volcanoes Osorno, Calbuco aud others. (See also the map of E. MORTOLA 1923).

In January 1911 F. REICHERT attempted an ascent of Tronador from Casa Pangue via the Peulla glacier and reached a point rather close to the summit (REICHERT 1917). He says he has neither in the basal nor in the summit parts found rocks of young-volcanic origin, for which reason he believes that Tronador must not be regarded as a volcanic mountain, »just as little as Aconcagua». He considers the Tronador to be a massive of crystalline rocks in conformity with the central massives of the Alps. This statement as to the non-volcanic nature of the mountain is, however, in part contradicted by his own report. Certainly granites and crystalline schists are asserted to be the principal rocks, but in the highest parts »a breccia with apparently trachytic rock fragments» was observed. Most probably this observation refers to a volcanic breccia or an agglomerate, very likely with andesite as the predominant constituent. In his abstract of REICHERT's paper STEFFEN (1921, p. 92) calls attention to his finds of andesite boulders in the moraine material of the Peulla and Frio glaciers as well as to WEHRLI's statements as to the occurrence of effusive lavas on the northern side of the mountain.

According to BAILEY WILLIS (1914 c, p. 740), who was mainly responsible for the investigations conducted in the years 1911—1913 by »La Comisión de estudios hidrológicos», »Mount Tronador is a volcanic peak composed of flows of andesite which rest upon a granite basement». The granite surface is lying on an altitude of 1600—2000 metres above the sea-level and the height of the mountain is given as 3460 metres (1914 b, p. 727; in 1914 c stands by a shifting of the figures 3640 metres). The actual height of the volcanic portion of the mountain should then be about 1500 metres. The lava is said to fill old valleys in the granite, of the (n + 1) stage according to WILLIS. He had, however, failed to observe that the rocks of the Tronador series fill up valleys of his canyon-stage, the (n + 2) cycle, too, on account of which his conclusion cannot be accepted at the present day, that the granite basement, on which the volcano was built, has been elevated about 2000 metres, since the eruptions ceased. Lava flows from Tronador, according to B. WILLIS (1914 a, p. 234), partly cover the Cordillera and its easterly offsets, west of the depression, in which Lagos Hess and Vidal Gormaz are situated. Southeast of the lakes mentioned the mountains consist of slate, quartzite, and granite.

In H. STEFFEN's great work on the Patagonian Cordilleras and the bordering areas (1919) Cerro Tronador is mentioned as »a three-pointed, andesitic, gigantic cone on a basement of metamorphic schists». About Cerro Doce de Febrero it is said that this double-topped mountain »is characterized by a great penetration of basaltic lavas through the granitic base of the massive». Any new observations of the formation here concerned are not published.

In the second edition of C. MARTIN's »Landeskunde von Chile» (1923) the data of the first edition (1909) as to the geology of Tronador are reproduced unmodified. A new picture (1923, Table 6, Fig. 8) of an »ice cave in the Tronador mountain» is of interest. This figure may be identified as representing the lower end of the Frio glacier. The photograph is of interest not only from a glaciological point of view demonstrating the farther extension of this glacier a decade or two ago compared with the present conditions, but also in the respect that it illustrates to a remarkable degree the contact between the lighter granodiorite and the superposed series of darker, partly stratified rocks.

As to the geological constitution of Tronador L. RISO PATRON (1924, p. 905) only states that the basement consists of granite and that the mountain »shows cliffs of hornblende granites in almost the whole western side, in no parts rocks being exposed, the origin of which derives from a volcanic activity».

In 1924 H. HAFERS DE MAGALHÃES gives an account of an ascent of Tronador from Rigi performed in the summer of 1923. He says about the upper part of the principal peak that it consists of »loose, red granite» (1924, p. 218). As this observation obviously was made from a certain distance — the expedition had to turn 80 metres below the summit — and as the author is not a geologist, too great an importance must not be attached to the word »granite». The epithet »loose» makes it probable that the rock in question is of a volcanic nature, perhaps an altered pyroclastic rock. The red colour does not argue against such an interpretation. As to the mountain ridge, evidently Pico Meridional, along which the climbing towards the highest peak was undertaken, it is said (1924, p. 220) that it gleams splendidly of various rocks and is corroded, decayed and crumbled. He then speaks about these rocks as »a hard silt of volcanic origin». As a matter of fact the description given above accords exactly with the physical character of some of the hydrothermally altered tuffs in the moraine material of Ventisquero Grande.

In »Die Alpen» for the year 1925 H. HAFERS DE MAGALHÃES also gives an account of a number of ascents of chiefly the northern and northwest slopes of Tronador, made in the autumn of 1923. Only the statement (1925, p. 327), that the moraine material of the Peulla glacier has a reddish colour is of any geological-petrographical interest. As a general opinion of Tronador it is stated that this mountain »is no volcano, though it also, as the whole South- and Middle-American Cordillera, shows a somewhat volcanic character». It is said to be »fundamentally different» from the adjacent, real, though in part extinct volcanoes Puntiagudo, Osorno, Calbuco, and Puyehue.

ROTH quotes in 1925 (p. 155) REICHERT's views as to the non-volcanic nature of Tronador. He says in this connection that the mountain certainly is not a volcano in activity, but that it »has been formed by volcanic activity similar to that of the volcano Calbuco and not by folding as the Alps». Then he refers to REICHERT's own statements as to the nature of the rocks of the highest portions of Tronador, concluding that these statements may be interpreted only as being applicable to a volcanic breccia. During a visit to Rigi in 1922 ROTH was able to establish that the top of this foothill to Tronador consists of granodiorite, »which ends in a breccia composed of fragments of volcanic rocks lying in a mass of granitic magma». This breccia is said to be covered by a layer of »effusive rocks and porous lava». Near the path from the pass by the boundary cairn (Paso and Hito Perez Rosales respectively; Locality No. 28 on Fig. 3) a completely crystalline volcanic rock occurs with platy cleavage, »which has been mistaken for a crystalline schist». Sedimentary layers have never been observed in the whole Tronador massive. Nor have sedimentary rocks been found in the morainic material of the glaciers. This material consists predominantly of granodioritic rocks and volcanic breccias.

A. WINDHAUSEN states in 1926 (p. 280) speaking of the Tertiary and Quaternary volcanicity in the neighbourhood of Nahuel Huapí that »Tronador, the remainder of an Oligocene andesite eruption having penetrated the broad granitic basement», may be looked upon as the veteran of all the volcanic cones of this area. Any evidence for the assumption of an Oligocene age is not given. Obviously his statement is, however, based on the opinions of B. WILLIS cited above concerning the relation of the Tronador eruptions to the different generations of valleys. On a sketch-map (p. 277) neo-volcanic rocks are indicated as occurring in Tronador within a circular area with a diameter of about 17 kilometres and with the highest summit of the mountain as centre.

WINDHAUSEN in 1929 (p. 104) calls Tronador an andesitic cone and he mentions further that just as Aconcagua it has more than once been looked upon as a volcano by different authors, and this opinion has as many times been combated by others. He believes that the truth lies in the interpretation of the mountain as a monogene volcano, formed by a single gigantic effusion without participation of gases, an interpretation, which, however, is by no means confirmed by the real facts. In 1931 (WINDHAUSEN 1931, p. 359) a Lower Tertiary age is still ascribed to

Tronador, its andesite being referred to the »Serie Andesítica», which is paralleled by this author with Eocene or Oligocene (Eogene).

P. DENIS mentions in Géographie Universelle (1927, p. 392) Tronador as a »massif volcanique».

Further it is cited by VON WOLFF (1929, p. 335) after STEFFEN as an extinct volcano.

According to F. REICHERT (1927, p. 389) it has not been possible on the western, Chilean side of Tronador to observe lavas and young eruptive rocks. The basement consists of hornblende granites, to the north partly crystalline schists. Further on, however, he speaks about »torres sombrias» and »torres negras», cropping out from the névé field on the western side of the summit portions of the mountain. Nothing is said about the petrographical character of these pinnacles, only that »abundant volleys of stones» fall down during the warm part of the day. Probably these crags consist of basaltic lava or perhaps rather pyroclastic material. The rock of the mountain ridge running in southerly direction from Pico Chileno »is formed by gypsum in such a loose condition that it is impossible to climb it». At the highest point reached by REICHERT in 1911, about 80 metres below Pico Principal towards the depression between this peak and Pico Chileno, the rocks consist of »apparently trachytic breccias». No gypsum could be established at this place.

At an ascent of Tronador in the summer of 1922 REICHERT also made some observations of petrographical interest (1927, p. 394). Rigi, a northern foothill to Tronador, east of the Peulla glacier, about half-way between Pico Principal and Lago Frio, »chiefly consists of granitic rocks». In the southern part of this foothill REICHERT observed »a sudden change in the composition of the rocks in the direction that there are here met with typical volcanic elements, apparently trachytic, even though it is sure that the presence of modern lavas may not be established». By this observation he was obliged to modify his opinion expressed in 1917 as to the formation of Cerro Tronador. The ridges proceeding from Pico Meridional in easterly and southerly direction »in their higher parts consist almost exclusively of gypsum in such a decomposition that it is very difficult to climb them». Towards the summit of Pico Meridional the gypsum ceases and the rocks consist of the same »apparently trachytic» breccias as had earlier been found in the northwest steep of Pico Principal. Recent lavas are absent, »as also all other genuine volcanic products». The only indication of volcanic activity in Tronador according to REICHERT should be his find below Pico Meridional of a piece of gypsum with particles of sulphur. For this sulphur he certainly assumes a volcanic origin, but obviously believes that it derives its origin in some way or other from one of the minor centres of eruption, which, as he has shown, occur in the district south of the Tronador massive. He especially mentions Cerro Volcánico as a typical volcano. He does not, however, believe that a centre of eruption was situated in the summits of Tronador neither »that the existence of the massive is due to real volcanic processes». As a matter of fact, however, one must state that the petrographical data given by REICHERT clearly indicate the volcanic nature of the mountain and that further a centre of eruption has been located in the summit of Tronador is fully shown by the petrographical investigation, the results of which are published in the following chapters.

In February 1931 F. REICHERT and others made an ascent of Tronador from La Cantera at Rio Peulla. From the description given by ILSE VON RENTZELL (1931) the observations may be cited, which are of geological and petrographical interest. The base of the mountain consists here, too, of granite, but in the upper part of the Cantera valley »a distinct change of the geological structure reveals itself». The cliffs, which enclose the upper end of the valley, consist of »conglomerate of tuffs, which according to REICHERT is quite identical with that of the upper Tupungato valley in the Cordillera of Mendoza. In the same manner in our conglomerates and 'breccias' fragments of stones of porphyry with large feldspars and incrustations of calcite are met with, which likewise occur in the high Cordillera of Mendoza and must be looked upon as extraneous material.» The last remark must be seen in connection with a somewhat later statement, »that the Tronador massive in no way may be spoken about as a volcano in the general sense of the word». It seems to me beyond doubt that we in the »tuff-conglomerate» have to see pyroclastic products of eruption derived from the volcanic centre, which must have been situated in the highest parts of Tronador. The »tuff-conglomerate» reaches the glacier plateau. At the base of the glacier the dark »tuff-conglomerates» are cut by wide dikes of black basalt. At an altitude of 2200 metres a wall of black basalt projects from the snow. This wall is a part of the ridge separating the Peulla glacier from the La Cantera glacier. It is »composed exclusively of black basalt and smooth, light phonolite», just as in the higher parts of Tupungato. »The ridges leading to the peaks and sometimes emerging from the snow are formed by eruptive rocks.» About 100 metres below the principal peak it was established that the eruptive rock is »almost completely replaced by gypsum, which also forms the whole summit and its slopes». The gypsum is interpreted as sedimentary and is paralleled with Oxfordian-Kimmeridgian of the Aconcagua-Tolosa group. Of special interest is that an intense odour of »ácidos sulfurosos» was noticed, which was ascribed to emanations from the fissures. This observation may be cited as an indication that the late-volcanic manifestations of Tronador have not quite ceased.

E. DE LA MOTTE in the summer of 1932 made a reconnaissance of the northwest base of Tronador with starting-point from La Cantera at

Rio Peulla. The highest point reached was only 4600 ft (1400 metres), on the mountain-ridge between the uppermost ends of the valleys of Rio Tronador and Rio Peulla. The valley of Rio Tronador was found to be shut off towards Tronador by a wall of »conglomerate», 2500 ft (about 760 metres) in height. The bottom of the valley has a height of about 1800 ft (550 metres) at this place. The situation of this wall of agglomerate is diagrammatically indicated on a sketch-map (DE LA MOTTE 1933, p. 332).

The first ascent of the highest peak of Tronador was achieved by G. CLAUSSEN on the 29th of January 1934. In his account of it (CLAUSSEN 1934), however, only one statement of greater geological interest is to be found. From a fissure in the depression between Pico Argentino and Pico Principal a gas with very disagreeable smell escaped. CLAUSSEN seems to think the gas is sulphuretted hydrogen and that it has formed through the influence of water on sulphurous rocks. Either it deals with sulphuretted hydrogen or sulphur dioxide, it would, however, be probable that in this case, too, we have to do with volcanic exhalations, which, therefore, by different observers have been established on opposite sides of the principal peak.

The results of two geological expeditions in the Nahuel Huapí region in 1928 and 1930 were given by E. LJUNGNER in a preliminary report of the year 1931. Here the term Tronador series is introduced for the occurrence of predominantly volcanic rocks in the area genetically related to the rocks of Cerro Tronador. As to details it may be referred to the descriptions of localities in Chapter IV of this treatise. The specimens of the rocks of the Tronador series collected during the expedition of the year 1930 have been included in the material investigated by the present author. Here only the most important of LJUNGNER's results may therefore be mentioned. As to Tronador itself there is established its stratovolcanic structure consisting of pyroclastic as well as effusive components, the latter ones include basalts as well as andesites. REICHERT's discovery of gypsum in the higher parts of the mountain is discussed and LJUNGNER interprets this gypsum as volcanic deposit in vertical fissures. It may be noticed that LJUNGNER had no opportunity of making an ascent of the upper parts of the mountain. Of great importance for the question of the age of the series are the finds of minor, solitary occurrences of Tronador rocks. These are to a large extent remnants of fillings of valleys and fjords (Brazo del Viento) of canyon-type. Glacial striae and »roches moutonnées» on the surface of these valley fillings as well as finds of boulders of rocks of the Tronador series in the moraines so far towards the east as longitude 70° 30′ west fix an upper limit of the age of the series. It is older than the last glacial period. The decision of its pre- or interglacial age could not, however, be made, even if some circumstances (striated surface of granodiorite under the Tronador rocks in Cerro Tronador, though the direction of the striae coincides with that of tectonic striae on slickensides in the granodiorite; the fresh condition of the latter rock under the contact; the topographically dominating position of Tronador in spite of its being composed of easily eroded material) seemed to argue in favour of the latter alternative. On the other hand similarities are noted between certain basal layers of the Tronador series and the so-called Araucanian sandstone from the lower course of Rio Negro considered as Pliocene.

From LJUNGNER's expedition to the North-Patagonian Andes in 1932—34 as yet only two short geological reports have been published. In the first of these (LJUNGNER 1933, p. 646; see also LÜTGENS 1933, p. 203) evidences could be given for the interglacial age of the Tronador series. The glacially sculptured and striated valley fillings of Tronador rocks are namely resting upon a surface of rocks also showing typical glacial striae and »roches moutonnées». In the second report (LJUNGNER 1935, p. 111) the occurrence is mentioned of »loose sandstone of stream-laid basalt tuff», between an upper and a lower moraine deposit at an altitude of 2089 metres on Sierra (or Cerro) Lopez. From this occurrence important conclusions have been drawn relating to the thickness of the interglacial volcanic material and to the glaciological conditions during the two glacial periods now established in South America.

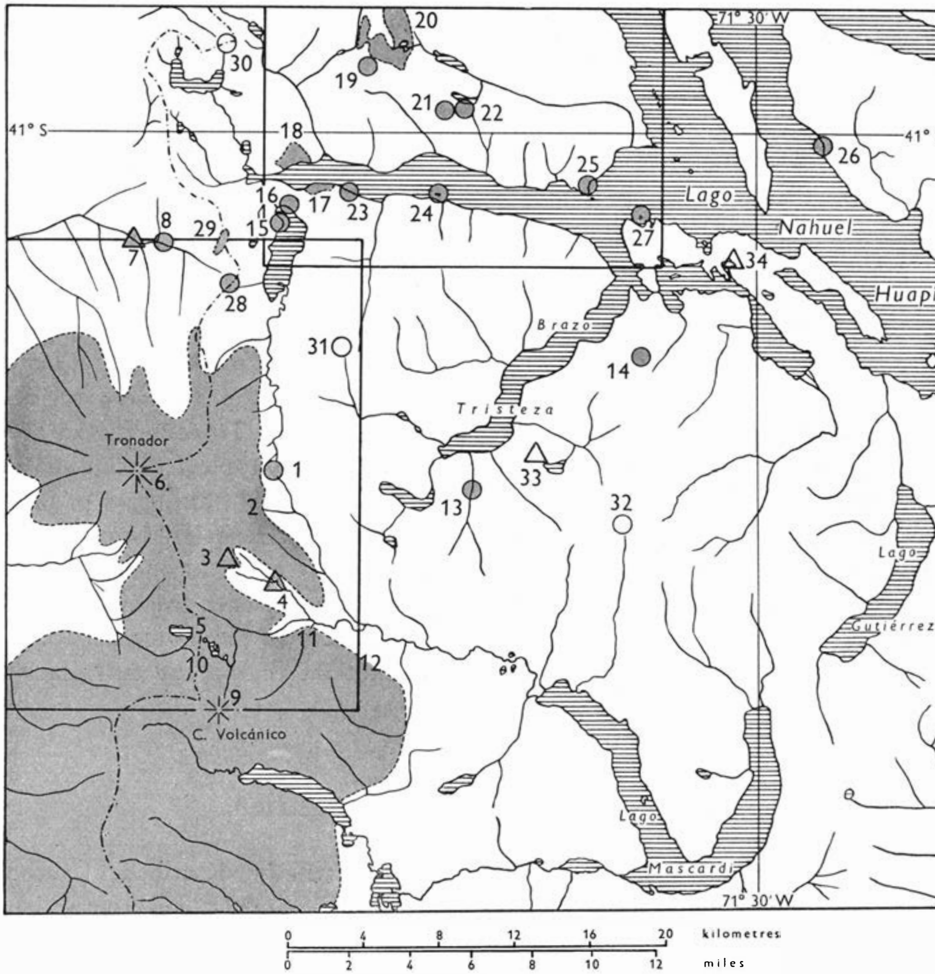
IV. **Descriptions of localities.**

In this chapter the geological conditions will be described of those localities in which the rocks of the Tronador series appear, and from which specimens have been collected and petrographically, or chemically analysed. The detailed petrographical descriptions will follow in the Chapter V. The field-geological observations and interpretations here stated refer only to a small extent to earlier literature (see Chapter III). The details are primarily based upon LJUNGNER's observations made during his journeys in the years 1930 and 1932—34 (*cf.* Report No. 6 of the expedition). All localities dealt with are indicated on the index map Fig. 3, the most ones also on the special maps Fig. 15 and Plate III.

a. **Cerro Tronador.** (Loc. 1—8).

(Plates III—IV.)

For several reasons it is appropriate to open this description with Tronador. This mountain possesses the largest series of interglacial rocks in the region with reference to its area as well as its thickness. It is obvious that Tronador has been the most important volcanic centre of the region



Greater areas of interglacial volcanics.

Minor outcrops (including dikes).

Probable outcrops, seen from a distance.

Deposits of boulders, closely examined.

Single boulder of glaciological interest.

Fig. 3. Index map showing areas of distribution of rocks of the Tronador series of the southwest part of the Nahuel Huapí region. Scale 1 : 400 000. Topography according to maps prepared by LJUNGNER's expeditions, Sheet 40^b (S^n Carlos de Bariloche) of Dirección General de Minas, Geología e Hidrología (1925), the map of the Nahuel Huapí region by C. C. HOSSEUS (1914), Sheet 1 of the map of the region between the latitudes 41° and 49° 50′ south (Frontera Argentino-Chilena. 1902, Mapa XVIII), and a sketch-map of an area between Brazo Machete and Puerto Blest (Club Andino Bariloche. Memoria 1936, p. 16). The rectangles inserted are covered by the detailed maps Fig. 15 and Plate III. The locality No. 29 has been marked somewhat too far to the west (*cf.* Plate III).

in interglacial time, and it is to this activity that it still owes its topographically dominating position in the North-Patagonian Cordillera. Another reason for placing Tronador first in this description is the fact that from this area the relatively greatest number of rock specimens has been collected for investigation, though LJUNGNER visited only the lower, eastern and southern parts of the mountain.

As appeared from the previous chapter the opinions as to the geological position and composition of Tronador have varied in a rather high degree according to different authors. The same also holds good of the statements in the literature as to the absolute height of the mountain. To throw light upon this fact the statements met with in the literature available have been put together in Table I without claims on completeness. By way of greater perspicuousness they have been inserted in a diagram with the height of the mountain as ordinate and the year of publication as abscissa (Fig. 4). The value determined by LJUNGNER, 3473 metres, has been indicated by a horizontal dash line. The difference between the greatest (3600 metres) and the lowest value (2880 metres) amounts to at least 720 metres. As will appear from the diagram the height-values stated are divided into two principal groups. In the literature from the four last decades of the 19th century values of the height of Tronador averaging about 3000 metres (from 2880 to 3110 metres) are given. A few years before the turn of the century statements suddenly appear indicating generally a much greater height for the mountain by some 500 metres. From the year 1902 the statements as to the lower height have completely disappeared and only the higher values are stated. These may on the other hand be subdivided into three groups. The majority of the statements from the literature of this century are in the neighbourhood of 3460 metres. The earliest determination of this order of magnitude has been found on the maps of the Chilean boundary commission 1894—1900 (3463

List of localities:

1. Paso de las Nubes.
2. Ventisquero Alerce.
3. Ventisquero Grande.
4. The bed of Rio Manso.
5. Paso Vuriloche.
6. Pico Argentino.
7. The bed of Rio Peulla.
8. Casa Pangue.
9. Cerro Volcánico.
10. Hito Paso Cauquenes.
11. El Salto.
12. Casa Piedra.
13. Victoria valley.
14. Cerro Lopez.
15. Lago Frio, western shore.
16. » » , northern shore.
17. Peña de Columnas (with Cueva Bloque and Punta de Bloques).
18. Arroyo de las Cuevas.
19. East of »Kr».
20. Calderón de Lavas.
21. Fraile.
22. East of Fraile.
23. West of Arroyo sin Pava.
24. Las Mellizas.
25. Puerto Sobral.
26. Peninsula Huemul, western shore.
27. Isla Llau-Llau.
28. Paso Perez Rosales.
29. Cerro Doce de Febrero.
30. Northeast of Lago Media Luna.
31. Southeast of Lago Frio.
32. Planicie Navidad.
33. Cerro Laguna.
34. Laguna Vasquez.

metres). A group of statements, rather unanimously indicating the height of the mountain to 3400 metres, can be traced back to the map elaborated by Museo de La Plata and published in 1898 by Fr. MORENO. A third group finally comprises values of 3550 metres and upwards. Leaving out of consideration the statement of WEHRLI in 1900 (1900 a) with »about 3600 metres» these higher values have appeared only during the two last decades. The determination of the height of Tronador performed by LJUNGNER's expedition, 3473 metres, consequently falls at the top of the first-mentioned sub-group.

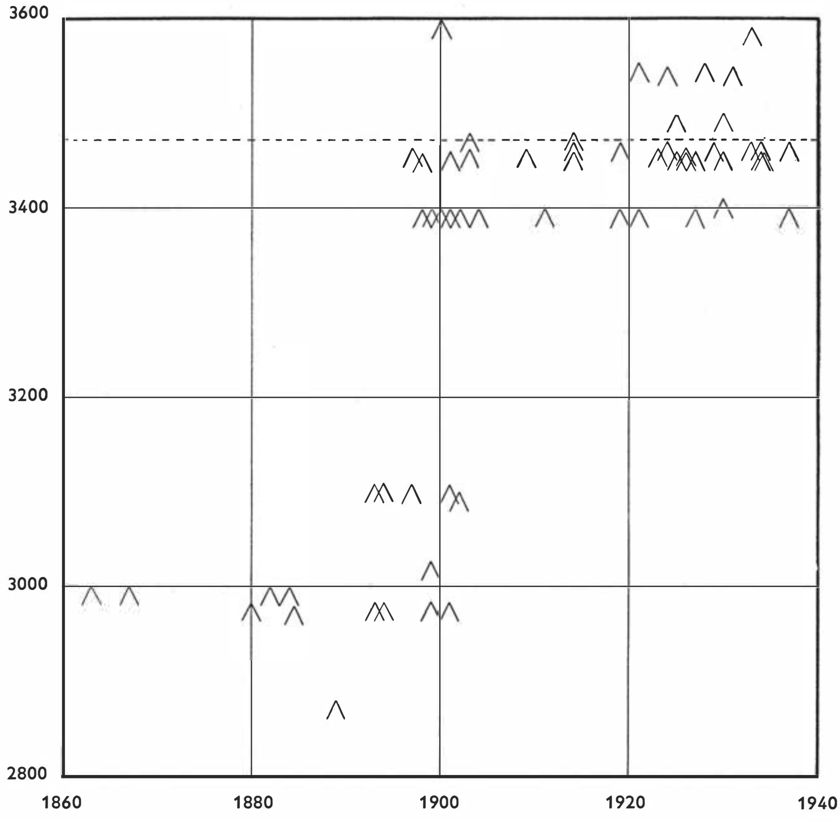


Fig. 4. Diagram showing the height of Cerro Tronador according to different authors (Table I). Height in metres as ordinate, year of publication as abscissa.

The detailed knowledge of the geological composition of Tronador is still far from satisfactory. This statement applies particularly to the western and southwestern slopes. In spite of this an attempt has been made in Plate III at a cartographic compilation of statements which occur concerning the geology of Tronador. For the summit portions and the northern slopes the data have been chiefly collected from the literature (noted in Chapter

Table 1.

The height of Cerro Tronador.

Author	Year	Height in metres	Author	Year	Height in metres
Amer. Geogr. Soc. . . .	1930	3410	LJUNGNER	1931	3550
ANASAGASTI	1926	3460	LJUNGNER's triangulation	1933—34	3473
ASTA-BURUAGA	1867	3000	MARTIN	1880	2984
»	1899	2984	»	1909	3463
BONACOSSA	1934	3460	»	1923	3463
CLAUSSEN	1934	3471	MORENO	1898	3400
Club Andino Bariloche .	1933	3470	»	1899	3027 (10860 pies)
Com. Chil. de Límites .	1898	3458	MORALES	1929	3470
»	1894—1900	3463	Nordisk Världsatlas . . .	1926	3463
COX	1863	3000	RECLUS	1893	2984
CRAWFORD	1884	3000 (9840 ft)	REGEL	1914	3480
DE LA MOTTE	1933	3591 (11780 ft)	REICHERT	1927	3460
			RISO PATRON	1924	3470
DENIS	1927	3400	ROHMEDER	1937	3400
Dir. Gen. de Min. etc. .	1920—22	3554	ROTH	1925	3460
» .	1930	3460	ROVERETO	1911	3400
Esposición Argentina . .	1902	3400, 3460	DE SAINT-MARTIN-ROUS-		
» Chilena . . .	1902	3100	SELET	1894	2984
FESTER	1937	3470	SANJUAN	1933	3460
FISCHER	1893	3108	SIEVERS	1903	3463
»	1894	3110	STANGE	1903	3480
FONCK	1900	3400	STEFFEN	1897	3108
GALLOIS	1901	3400	»	1919	3470
HAFERS DE MAGALHÃES	1924	3550	STIELER	1881—88	2980
»	1925	3500	STIELER's Handatlas . .	1921	3400
HAUTHAL	1904	3400	TOBAL	1934	3460
HOSSEUS	1914	3470	VICUÑA	1901	3108
Inst. Geogr. Arg. Atlas .	1889	2880	WEHRLI	1899	3400
Inst. Geogr. Mil.	1928	3554	»	1900	Ab. 3600
KEANE	1901	2984 (9790 ft)	»	1919	3400
KNOCHE	1930	3500	WILLIS	1914	3460
KOFFMAHN	1882	3000			

III); for the eastern and southern slopes the reconnaissances of LJUNGNER have predominantly formed basis of the representation.

Tronador may be said, from a geological point of view, to consist of two principal parts, *viz.* the older, predominantly Mesozoic basement and the younger, volcanic overlying structure formed in interglacial time (Fig. 5). The rocks of the crystalline basement have not been more closely studied in this connection, but would appear, at least in the area represented on the map, to belong predominantly to the granodiorite series. The petrographical character is certainly somewhat varying as already indicated by the different rock names, such as granite, hornblende granite, quartz diorite,

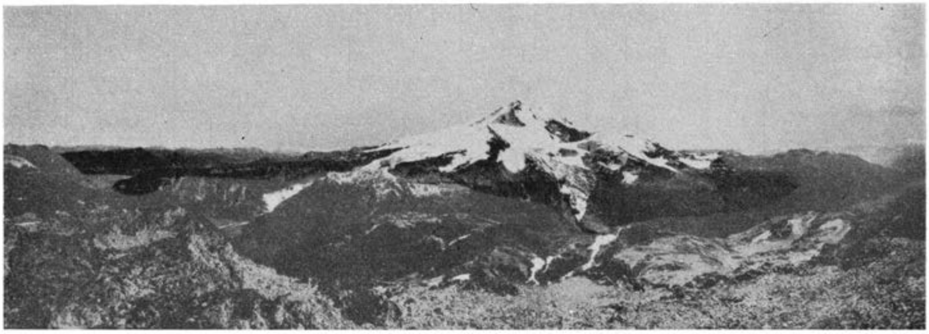


Photo E. LJUNGNER's expedition (O. RING). 16.4. 1934.

Fig. 5. Panorama of Tronador from Cerro Constitución (= Plate IV). Looking west. The rocks of the Tronador series dark, the prevolcanic basement light.

diorite, and also syenite, which are to be found in the literature referring to the rocks in question. From the western side of the valley of Rio Frio the occurrence of metamorphic rocks has been specially emphasized by STEFFEN (1893 b) and called mica schists. Also at Paso de las Nubes and farther to the south in the valley of Rio Manso inclusions are common and have in part been identified as sandstones of the Milleaqueo formation. It is probable, however, that remnants of still older formations may be represented, particularly in the northern parts rich in mica schists. But younger crystalline rocks also enter into the preglacial country rocks in the area seen on the map. Thus in the eastern margin of the map, southeast of Paso de las Nubes, there occurs the westernmost part of the great Tristeza granite laccolith round Brazo Tristeza and judging from the boulder material in the moraine below Ventisquero Grande, an essexitic rock, equated by LJUNGNER as to its age and genesis with the Tristeza granite series. It appears, as mentioned before, in the bed of this glacier, probably in its lowest part.

The limit between the crystalline basement and the superimposed interglacial volcanic rocks as given in Plate III certainly is almost wholly a limit of erosion. Various facts favour the belief that the area now occupied by Tronador and its spurs before the commencement of the eruptions had a relief quite comparable with the present one for instance in the districts north and east of the mountain. The area of the later volcano then formed an integrating part of the westerly inclined plateau surface, which was closely furrowed by deep canyon valleys. By the volcanic activity of Tronador and other minor centres of eruption the earlier relief of an extensive area particularly west of the axis of highest elevation of the Cordillera was levelled and even partly inverted, at the same time as the volcanic cone of Tronador was built up. On account of the probably rather great share of pyroclastic products, in contrast to the basement rocks more easily eroded, the earlier relief system was reverted to after the decline and ceasing of the volcanicity by the glacial and fluvial erosion. The old topography was once more dominant in a relatively short time geologically speaking, though of course some changes in the hydrographic conditions, compared with the pre-volcanic ones, were persistent. That Tronador has resisted to a marked degree the breaking down processes of erosion may be chiefly ascribed to two factors. First of all the accumulation of volcanic products has here reached its maximum around the principal centre of eruption, secondly the relative quantitative share of compact lavas, more resistent to the erosion, ought to be much greater than in the peripheral areas.

The development briefly sketched above gives an explanation of the rather irregular course of the exterior limit of the volcanic rocks of Tronador. That in the great principal valleys on the different sides of Tronador, *e.g.* the valleys of Rio Peulla, Rio Tronador and Rio Manso, this limit runs nearer the centre of the mountain is a natural consequence of a headward erosion. The fact that this limit in the upper ends of the valleys often lies on a lower level than in the ridges between the valleys can only be explained by the assumption that these valleys existed before the formation of the volcano and that the volcanic products therefore partly had the character of valley fills. The contact surface of the volcanic series towards the crystalline basement is then by no means an approximately even plain, but shows highly varying heights. On an average, however, it would have a westerly dip, as Tronador is situated on the western slope of the Andes (see FONCK 1900, p. 224, Vista).

The available data as to the geology of Tronador certainly do not admit any detailed petrographical subdivision and cartographic representation of the geological structure of the volcanic series. The great features are, however, clear. In spite of the great morphological modifications, which the mountain has undergone, the volcanic character has not been quite lost. On the other hand, by the work of the post-eruptive erosion huge natural sections through the volcanic series of strata have partly been produced (Fig. 6). These show that the mountain has a typical bedded

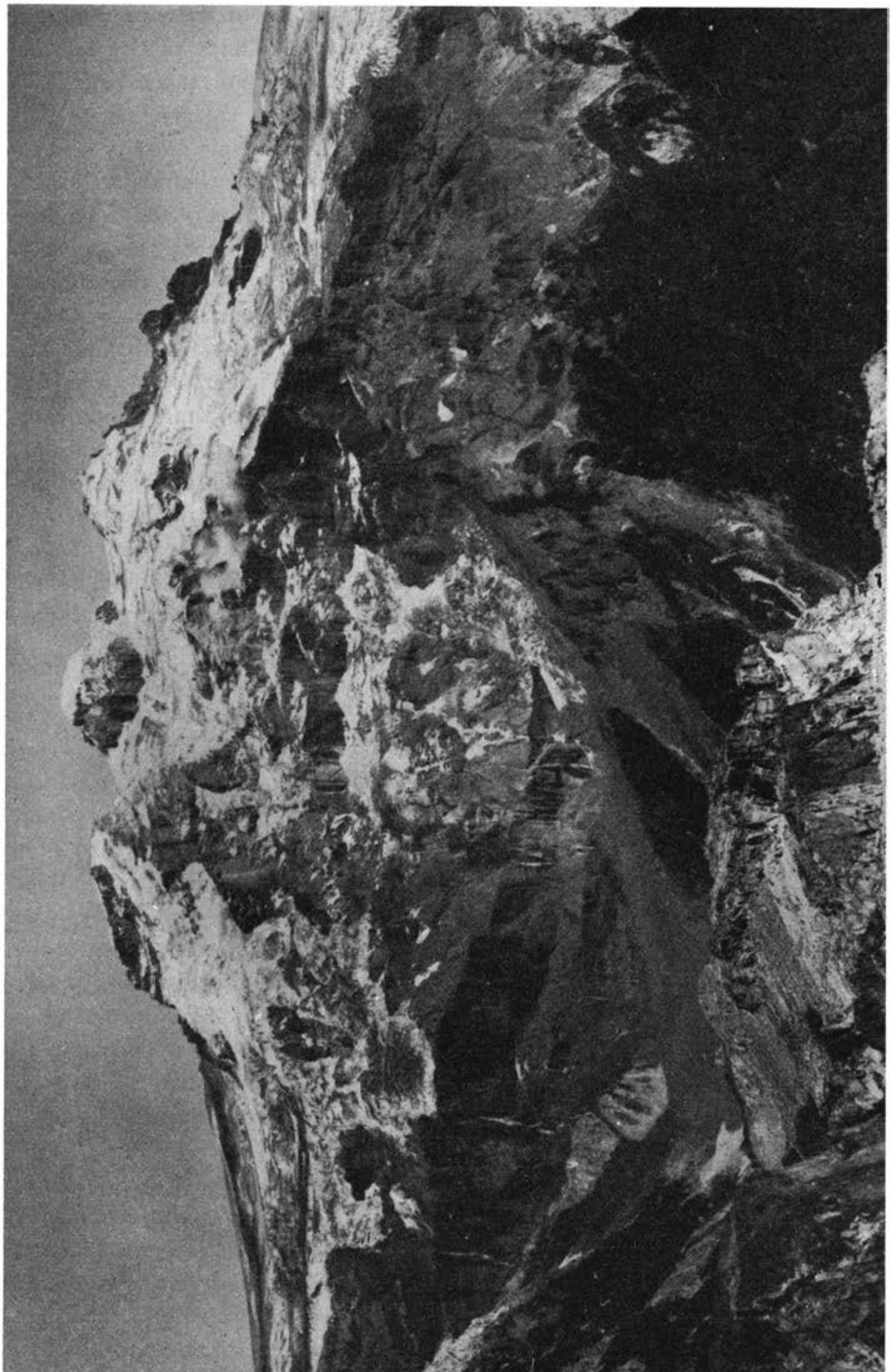


Photo Hahn.

Fig. 6. Tronador from Rigi. Looking S.SW.

structure with a repeated alternation of lava flows and beds of pyroclastic material. Photographs taken from different directions distinctly reveal conical stratification dipping outwards at a relatively low angle from the summit. Only in minor parts a parallelism between this volcanic stratification and the present slope of the mountain may be noticed. Generally the latter one, as indicated before, is considerably steeper.

As to the sequence of strata it may be established that immediately upon the basement, in those cases when more or less reliable statements are available, pyroclastics are mainly resting. The lava flows in the basal parts of the volcanic series, so far as investigations show, seem to consist exclusively of basalts. On higher levels, however, the basaltic lavas seem to be wholly or partially substituted by andesitic rocks. Samples of these andesitic lavas taken *in situ* in an unaltered condition have not yet been available to petrographical investigation. Their existence is, however, proved by their occurrence in the moraine material being carried down by the glaciers of the mountain. Already PÖHLMANN (1893) describes andesites from the recent moraines of the Peulla and Frio glaciers, and in the following descriptions are given of similar rocks collected below the Alerce glacier and Ventisquero Grande. The »trachytic» breccias and lavas observed by REICHERT (1917, 1927) and the »fonolita llana y clara» mentioned by I. VON RENTZELL (1931) from the northern, higher parts of Tronador in all probability refer to outcrops of these andesitic volcanics.

The crater of the ancient Tronador volcano seems to have been situated somewhat south of the present highest summit of the mountain (Pico Principal). This view is supported by the distribution of the altered rocks and the mineral deposits, which for their alteration and formation, respectively, require an influence of volcanic gases and hot vapours of long duration. Of these rocks, the distribution of which is given on the map (Plate III) relying mainly upon statements in literature, samples have been examined derived from Pico Argentino (collected by O. MEILING) and from the moraine material of Ventisquero Grande. In addition there are statements as to finds of sulphur probably below the Rio Blanco glacier (MENENDEZ. See above p. 204), whereas from the terminal moraines of the glaciers radiating to the north and northeast no positive statements as to similar rocks are available. These facts go to prove the correctness of the situation of the outcrops of these rocks as indicated on the map, according to which they mainly belong to the feeding areas of the southern glaciers. The altered rocks, where determinable, have proved predominantly to be earlier andesitic lavas and tuffs. This fact supports the conception that the highest parts of the mountain mainly consist of andesites and that, therefore, the volcanicity has, broadly speaking, developed from a basic to a more acid character. The last manifestations of the volcanic activity of Tronador are to be seen in the emanations of sulphurous gases from the highest parts of the mountain (VON RENTZELL 1931, CLAUSSEN 1934) and the occurrence of hot springs in the valley of Rio Blanco (Baño Vuriloche) at the southwest base of the ancient volcano.

From Tronador specimens of rocks are described in the next chapter from the following localities:

Loc. 1. Paso de las Nubes. Over this pass, also called Portezuelo Barros Arana, runs the divide line between the water systems of Rio Frio and Rio Manso and, therefore, also the interoceanic *divortium aquarum.* The height of the pass would amount to somewhat more than 1300 metres At some distance upon the western side of the valley runs the wavy contact towards the Tronador rocks, whereas in the pass and the eastern valley side the country rocks consist of granodiorite with inclusions of crystalline schists, which have been partly recognized as metamorphosed Milleaqueo sandstones. From this pass a sample of a basaltic dike rock has been examined, which is probably related to the Tronador volcanicity. The dike cuts through the granodiorite, but further details as to its strike, dip, and width are lacking.

Loc. 2. Ventisquero Alerce. This name was given by LJUNGNER's expedition to the glacier coming down from Tronador not far south-southwest of Paso de las Nubes (Plate III). Its melt waters run off through a hanging valley to Cañadón Alerce, the tributary valley to Rio Manso coming from the pass mentioned. Towards the glacier crystalline schists and higher up granodiorite outcrop in the valley side. A dike, about one metre in width, a sample of which is described in the following chapter, penetrates the granodiorite with west-southwesterly strike and steep northern dip. The superimposed Tronador series (Fig. 7) begins at the base with a loose tuff agglomerate, in which are included fragments of lavas as well as of diorite. Only higher up do interstratified effusive lava flows occur at intervals. From this locality a number of samples of coarser and finer pyroclastic rocks as well as effusive, basaltic lavas and a scoriaceous andesite have been examined.

The granodiorite is quite fresh at the contact towards the Tronador series. The former is intersected by two systems of vertical joints, striking west-northwest and southwest. Further there occur slickensides with southeastern dip striated parallel with the dip of the planes of movement. The same strike (northwest—southeast) also appears in the recent glacial striae. When a part of the contact surface under the tuff was uncovered (about one dm^2), this also proved to be striated in northwest—southeast. As it could not be finally determined, whether these striae were of glacial or tectonic origin, *i. e.* if the uncovered surface showed glacial erosion or formed a casually exposed plane of movement in the granodiorite, the

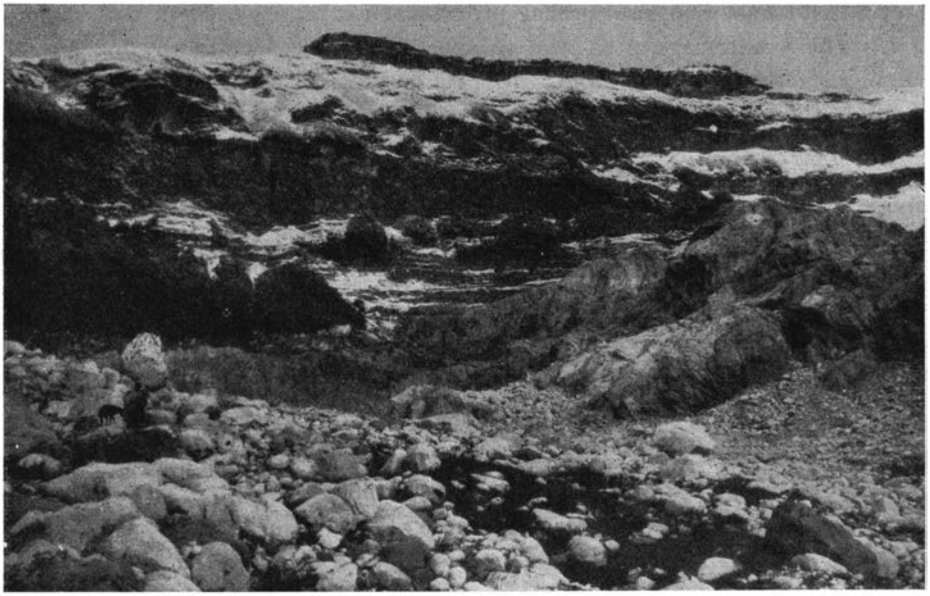


Photo E. LJUNGNER. 6.5. 1930.

Fig. 7. Contact between crystalline basement and Tronador volcanics below Ventisquero Alerce, Tronador. Looking southwest. The stratification of the volcanic rocks is emphasized by the distribution pattern of the snow. In the foreground the recently abandoned bed of the glacier now ending immediately to the right of the figure.

question of a pre-Tronador glaciation could not be decided by this observation.

Loc. 3. Ventisquero Grande. This glacier, also called Ventisquero Tronador, extends from the highest slopes of the mountain in a south-southeastern to southeastern direction to a level of about 1000 metres in one of the valleys of the head-waters of Rio Manso, and proceeds over a petrographically rather varying bed. The varied nature of the ground which it has traversed appears most clearly from the character of the boulder material of the terminal moraine below the glacier. In addition to granodiorite, cropping out at the lower end of the glacier and at a short distance upwards on the sides of the valley though superimposed by the interglacial volcanics, there occurs an essexitic dolerite, which, as mentioned before, though not exposed, must occur in the bed of the glacier some distance higher up, together with a representative assembly of the rocks of the Tronador series. Of these a collection of specimens has been petrographically examined. Among these basalts, basaltic andesites, pyroxene and hornblende andesites, different types of pyroclastics, as well as pneumatolytically and hydrothermally altered lavas (predominantly andesites) and pyroclastics occur and finally mineral aggregates formed by pneumatolytic and hydrothermal processes are represented in this collection. These latter types as well as the altered rocks certainly come from the highest parts of the mountain. With reference to the conception expressed above as to the structure of the volcano the unaltered basaltic lavas would chiefly derive from lower, the unaltered andesites from intermediate und higher parts of the volcanic series.

Loc. 4. The bed of Rio Manso. This locality refers to a point in the valley of Rio Manso about half-way between the lower end of Ventisquero Grande and the junction of the stream coming from Valle Vuriloche with Rio Manso. The place is thus orographically located somewhat outside the proper Tronador. The two rock samples investigated, which were collected among the rolled pebbles of the river bed, show, however, by their petrographic character (a basaltic andesite and an altered hornblende andesite) that they probably derive from Tronador. In the bottom of the valley granodiorite occurs, but in both sides the volcanic rocks of the Tronador series are outcropping.

Loc. 5. Paso Vuriloche. This pass, over which the boundary between Chile and Argentina runs at the present day and which during earlier centuries was regularly employed for the maintenance of communications between the coast of Chile and the Nahuel Huapí district, joins the valleys of Rio Manso and Rio Blanco on the southern side of Tronador. The height of the pass would appear to exceed 1300 metres. It is wholly excavated in the rocks of the Tronador series. From a hill north of the pass two samples of rocks have been investigated, *viz.* a basaltic lava and a pyroclastic rock.

Loc. 6. Pico Argentino. The collection of rock specimens in the moraine of Ventisquero Grande was undertaken by LJUNGNER chiefly with the intention of trying to find boulders of the gypsum rock, which according to REICHERT (1927) should occur in the highest parts of Tronador and has been considered to be of sedimentary origin (VON RENTZELL 1931). No gypsum was found, instead however sulphur of distinctly volcanic nature occurred. LJUNGNER (1931) therefore interpreted also the gypsum as a volcanic product, *viz.* as a deposition in vertical fissures.

For that reason it was of great value to be able to examine microscopically samples of the gypsum rock in question. Such samples were received from OTTO MEILING, which in October 1938 made an ascent of Pico Argentino, the eastern principal peak of Tronador. Fig. 8 shows a general view of the peak. The samples were taken from the outcrops in the western margin of the névé field near the left border of the photograph. A study of the specimens sent by MEILING (see the petrogra-

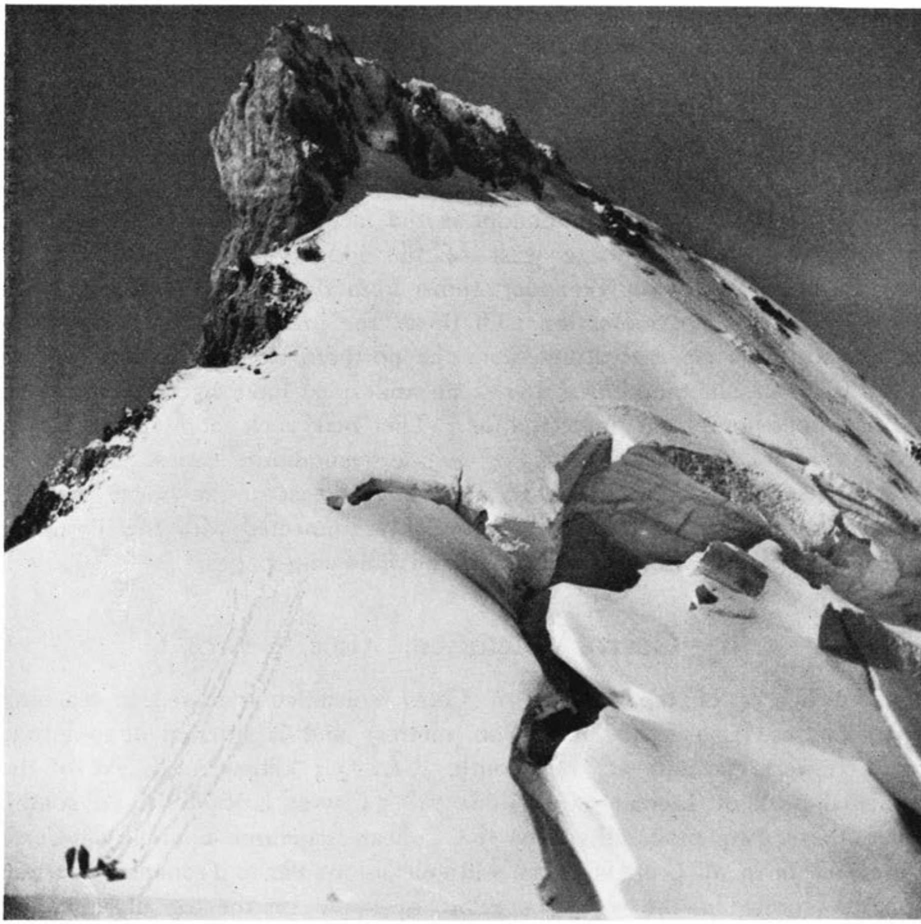


Photo O. MEILING. 10.10. 1938.

Fig. 8. Pico Argentino, Tronador, from the south.

phical description) revealed that the gypsum was obviously a volcanic product. It do not, however, occur, at least on this locality, as fissure filling but as impregnation, though partly as large, rather well developed crystals, in opalized, highly scoriaceous lavas or porous tuffs. A sample of a tuff breccia free from gypsum was also sent, but this rock, too, was highly altered. If it is thus proved that altered volcanic rocks are exposed in Pico Argentino, the horizontal and vertical distribution of this alteration is, however, unknown.

Loc. 7—8. Rio Peulla and Casa Pangue. Casa Pangue is a lodging-house at the route, which nowadays is used when crossing the Cordillera in this district and leads from Lago Todos los Santos (121 metres) through the valley of Rio Peulla and Paso Perez Rosales (1010 metres) over to Lago Frio (790 metres) and Puerto Blest, in the westernmost part of Lago Nahuel Huapí (767 metres). Casa Pangue lies somewhat east of Rio Peulla about at the point, where the river after having run in a northerly direction from the Peulla glacier on Tronador turns in a westerly direction towards Todos los Santos. The reason why this locality (No. 7) is mentioned in connection with Tronador is the fact that from the bed of Rio Peulla, about one kilometre west of the lodging-house, a collection of samples of rocks of the Tronador series from the river pebbles has been made available for examination. Of these, the greater part of which may be looked upon as derivatives from the northern slope of Tronador, five types (two basalts and three pyroxene andesites) have been subjected to a closer petrographical investigation. The bed rock consists here of a coarse granite, probably belonging to the granodiorite series. A sample of a vertical dike, taken a few hundred metres east of the house (Loc. 8), cutting through this granite and probably connected with the Tronador volcanism has also been described in the following pages.

b. **Cerro Volcánico.** (Loc. 9—10).

The height of the summit of Cerro Volcánico is stated as reaching 1930 metres (also 1900 and 1800 metres) and is situated at longitude 71° 51′ west, latitude 41° 17′ south, *i. e.* 13.5 kilometres S.SW of the principal peak of Tronador (longitude 71° 54′ west, latitude 41° 10′ south). Over these two mountains runs the Chilean-Argentine boundary. Cerro Volcánico is in all probability an old volcano similar to Tronador. Certain ablation forms in the deep covering of snow on the top observed by LJUNGNER (1931, p. 225) might indicate that up to the present time hot exhalations are still escaping at intervals. That the effusive stage of the activity of the volcano has ceased long ago, is shown by the morphology of the mountain. Certainly the conical form is noticeable in broad outline (Fig. 9), though it is highly modified by erosion. The slopes have in part considerably greater inclination than the dip of the volcanic stratification. As on Tronador, no crater is preserved. Highly scoriaceous lavas seem to play an important rôle in this mountain. Judging from the material of specimens examined, among which a few volcanic bombs of different types are present, Cerro Volcánico (Loc. 9) has yielded exclusively basaltic products of eruption.

As distinct from *e. g.* WINDHAUSEN's (1926, p. 277) geological sketch-map of the Nahuel Huapí district, where on both sides of the frontier south of Tronador an area has been marked of granitic rocks, LJUNGNER in this region and east of the same boundary could only find neovolcanic rocks. Two samples of basaltic lavas from a hill southeast of

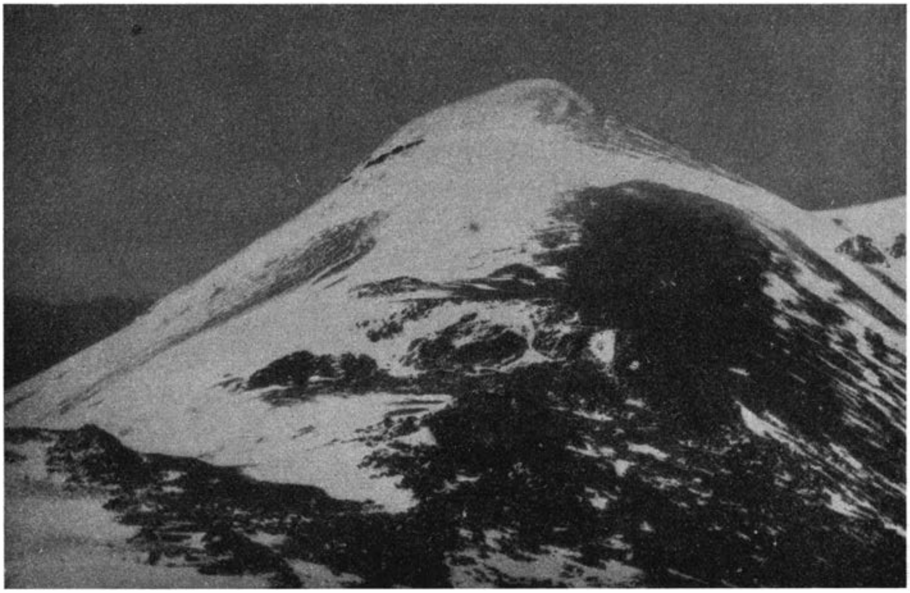


Photo E. LJUNGNER. 12.5. 1930.
Fig. 9. The summit of Cerro Volcánico. Looking southwest.

Loc. 10. Paso Hito Cauquenes have been examined. This pass, 1350 metres in height, is the southern one of the two passes between Cerro Tronador and Cerro Volcánico. The northern one, Paso Vuriloche, has been mentioned before. In neither of these passes has the erosion reached the substratum of the Tronador series, for which reason an immediate connection exists between the volcanic areas of Cerros Tronador and Volcánico.

c. The valley of Rio Manso. (Loc. 11—12).

Loc. 11. El Salto. This name refers to the place on the southern side of the Manso valley at Pampa Linda, where a rivulet from the northeast slope of Cerro Volcánico with a waterfall comes down the valley side towards Rio Manso. In the bottom of the valley, lying here on a level of somewhat less than 900 metres, the granodiorite series outcrops. In some hillocks at El Corral, in the valley a short distance downwards from El Salto, a somewhat problematic brecciated rock occurs. Probably it is an igneous breccia of sediments of the Milleaqueo formation in the granodiorite. The precipitous southern side of the valley at El Salto forms a section through the rocks of the Tronador series (Fig. 10). Here may be seen a suite of chiefly horizontal lava flows interstratified between beds of pyroclastics: tuffs and agglomerates. It seems as if the lava in part should show intrusive relations to the tuff. In the precipice 50—100 me-

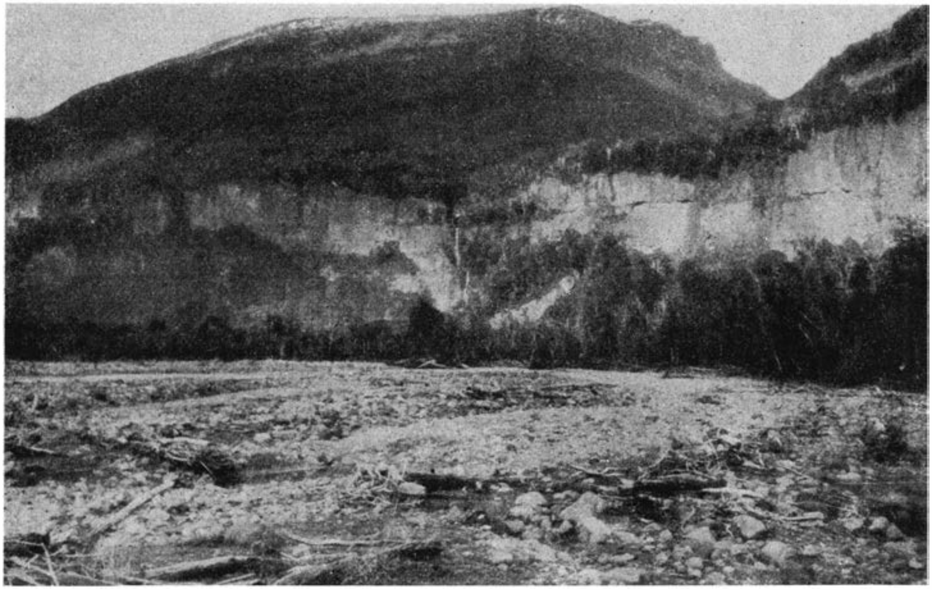


Photo E. LJUNGNER. 16.5. 1930.
Fig. 10. Cliffs of Tronador volcanics. El Salto, valley of Rio Manso. Looking S.SE.

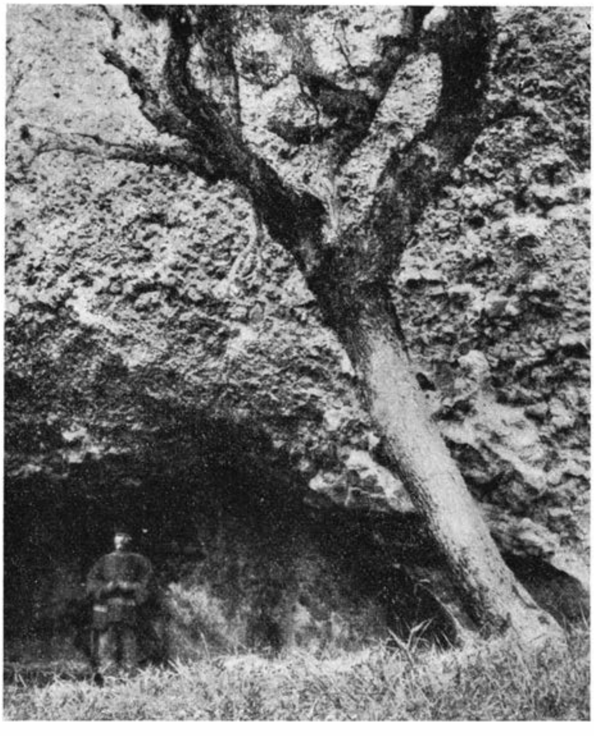


Photo E. LJUNGNER. 16.5. 1930.
Fig. 11. Cave in Tronador agglomerate. Casa Piedra, southern side of the valley of Rio Manso.

tres above the level of the valley there was observed in the somewhat violet tuff a thin horizon with fragments of white pumice together with indeterminable plant remains (wood). The same pumice horizon could also be identified in the cliff south of El Corral. The tuffs are there partly red, partly dark. From the section at El Salto three samples of rocks have been petrographically examined, *viz.* two basaltic lavas and a tuffaceous sediment with one of the pumice fragments just mentioned. These all but horizontally layered Tronador rocks seem to occupy rather wide areas between the upper course of Rio Manso and Cerro Volcánico and from thence extend farther to the south (see Fig. 3). Except from El Salto only one rock sample has been available from this area, *viz.* from

Loc. 12. Casa Piedra. This locality is also situated on the southern side of the valley of Rio Manso, at Mallin Grande, about nine kilometres W.NW of the most northwesterly end of Lago Mascardi. The name (Casa Piedra = the stone house) refers to a cave in a coarse Tronador agglomerate (Fig. 11). The specimen examined was taken from a basaltic boulder in this agglomerate. The agglomerate is superimposed by a basalt flow with columnar jointing.

d. **Solitary occurrences.** (Loc. 13—26).

Loc. 13. The Victoria valley. In the inner region of Brazo Tristeza, about 1.5 kilometres east of the outlet of the streamlet from Lago Frey, a valley opens from the south, called the Victoria valley. In relation to Brazo Tristeza it is a typical hanging valley and the stream flowing through it forms at the mouth of the valley a high waterfall over wide naked outcrops of coarse, younger Tristeza granite with subhorizontal structures (Fig. 12). Not far south of this waterfall the valley is compressed by a ridge projecting from the western side of the valley. This ridge, about 50 metres in width, consists of young volcanic rocks, which as the petrographical investigation proved comprise labradorite and hornblende andesites. To the south, towards the upper part of the valley, the rock is bounded by an overhanging precipice. This valley threshold strikes chiefly in N 25° W. The fluidal structure, emphasized by drawn out vesicles, dips 70° to the east. The rock shows a pronounced columnar jointing (Fig. 13). The columns dip 20° towards about S 50° W. Angular and more rounded boulders of Tristeza granite occur enclosed in the volcanic rock, a number measuring several decimetres in diameter, as well as more fine-grained granite gravel. This material enclosed in the andesite might possibly have been moraine. The ridge is covered by a moraine-like, closely packed mixture of gravel and stones. These latter ones are angular or rounded and

Photo LJUNGNER's expedition (H. CLAUSSEN). 24.9.1933.

Fig. 12. The Victoria valley with Tronador volcanics (×). Looking south. Brazo Tristeza in the foreground. From △ Wort, alt. 1559 metres.

consist of granite as well as the subjacent volcanic rock. Striae were, however, not observed on the surface of the andesite.

LJUNGNER considers this occurrence as representing a dike, which (in interglacial time) penetrated a valley fill of moraine and perhaps also other deposits. The observations cited do not, however, seem to me to preclude the possibility that we are dealing here with an erosional remnant of quite effusive rocks with the point of eruption located at Tronador, where similar types of rocks are recorded. The dissimilar nature of the specimens examined (seven in number), of which from a mineralogical-petrographical point of view two types could be distinguished, the decidedly »effusive» appearance particularly of the highly scoriaceous rocks as well as the fact that LJUNGNER in spite of seeking on both sides of the valley did not succeed in finding any continuation of the presumptive dike but only Tristeza granite, — all these facts might be advanced in favour of the second of the alternative interpretations cited above. But even on the assumption that the occurrence represents a dike (or perhaps a neck) the rock must have solidified at a very slight depth under the surface. On account of these reasons the rocks from the Victoria valley have been treated in the petrographical description in connection with the effusive lavas.

Photo E. LJUNGNER. 2.7.1933.

Fig. 13. Columnar jointing in andesite. The Victoria valley. Looking about northeast.

Loc. 14. Cerro Lopez. Cerro Lopez is the name of the mountain ridge running in north-southerly direction immediately east of the outer part of Brazo Tristeza. The middle portion of the ridge, with which we are chiefly concerned in this connection, is located at about latitude 41°7′ south and longitude 71°34′ west. The ridge form is pronounced only in the northern and southern parts. The highest point lies in the southern part, where some high pinnacles rise steeply and inaccessibly to about 2100 metres. These northern and southern parts of the mountain ridge consist entirely of rocks of the Tristeza granite series, of a character indicating consolidation at a relatively inconsiderable depth under the earth's surface (liparite, quartz porphyry, granite porphyry). At lower levels in the eastern slope of Cerro Lopez gneissose rocks, however, outcrop.

Of differing morphological and geological character is the middle part of the mountain (Fig. 14). The ridge is there widened to a plateau and shows a softly rounded arching, the highest part of which lies at 2090 metres a. s. This point is the highest ascendable one in Cerro Lopez. In this hillock the following series of strata could be established:

Moraine	about	5 metres.
Tuff	»	12 » .
Moraine (tillitic)	»	<1 metre.
Granite (substratum).		

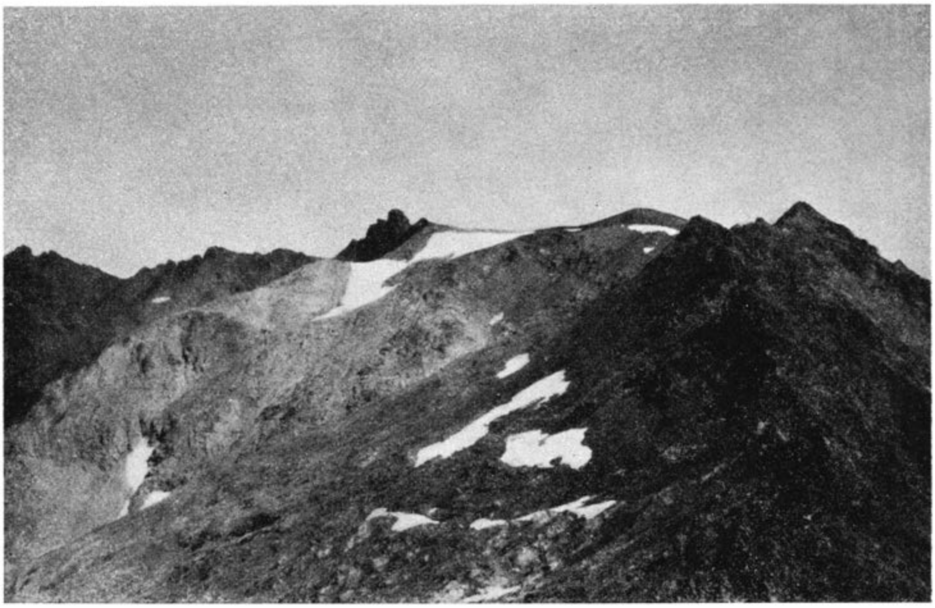


Photo E. LJUNGNER. 4.3.1933.

Fig. 14. Cerro Lopez, from △ Lj., alt. 2012 metres. Looking south.

The upper moraine, petrographically in the main consisting of porphyritic Tristeza granite and, in small quantity, metamorphic rocks, forms a loose mixture of gravel with embedded boulders. The boulders have partly rounded edges, though the majority are sharply angular, and this may be due to frost-shattering. This morainic cover seems to be thickest on the top of the hillock mentioned and on its western slope, whereas on the eastern side it is quite lacking in places. This fact favours the belief that the moraine in question has been deposited by an ice coming from the west and only just reaching the level of the summit plateau.

The series of strata belonging to the rocks of the Tronador series, about 12 metres thick, occurring under the upper moraine consists of a fine-grained, porous tuff or rather tuffaceous sandstone, as it is nicely and regularly layered, indicating a deposition in water. It crops out from the gravel or may be exposed easily by digging on the northeast, eastern and southern sides of the hillock mentioned. The strata are either horizontal or dip slightly (5°) to the west or southwest. In one case a folding was observed on a small scale with the axis of folding striking in north-south. In another case current bedding could be established in the tuff of such a character that the current ought to have come from the south or S.SE. On account of later displacements this part of the series of strata has acquired a westerly dip. On the whole the secondary displacements may be accounted for by a pressure acting from the west. Such a pressure ought to have been exercised by the ice, which deposited the upper moraine.

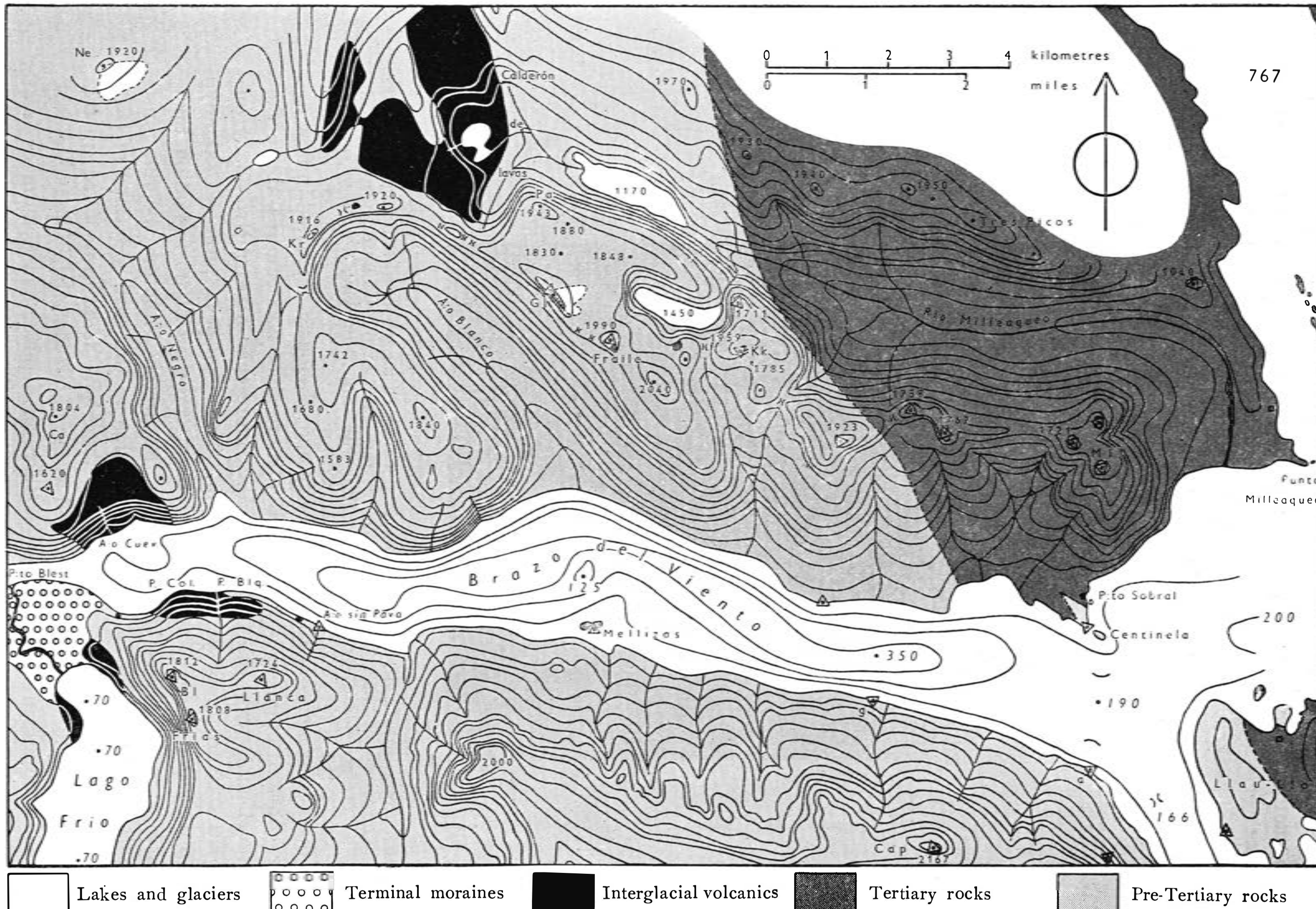


Fig. 15. Preliminary map of the Brazo del Viento area constructed by E. LJUNGNER and O. RING chiefly from material collected by the expeditions. Redrawn by the author. Scale 1 : 110 000. Contour interval 100 metres. Upright figures indicate heights above the sea in metres, inclined figures depths of the lakes.

(A:o Cuev. = Arroyo de las Cuevas, P. Col. = Peña de Columnas, P. Blq. = Punta de Bloques, P:to = Puerto.)

An important locality occurred on the eastern slope of the peak of 2090 metres. Here the bedded tuffaceous sandstone is underlain by a moraine of varying thickness, which contrary to the younger moraine is very hard-packed or tillitic. This lower moraine is, on the other hand, resting upon a glacially sculptured granite surface with well-defined glacial striae from the west.

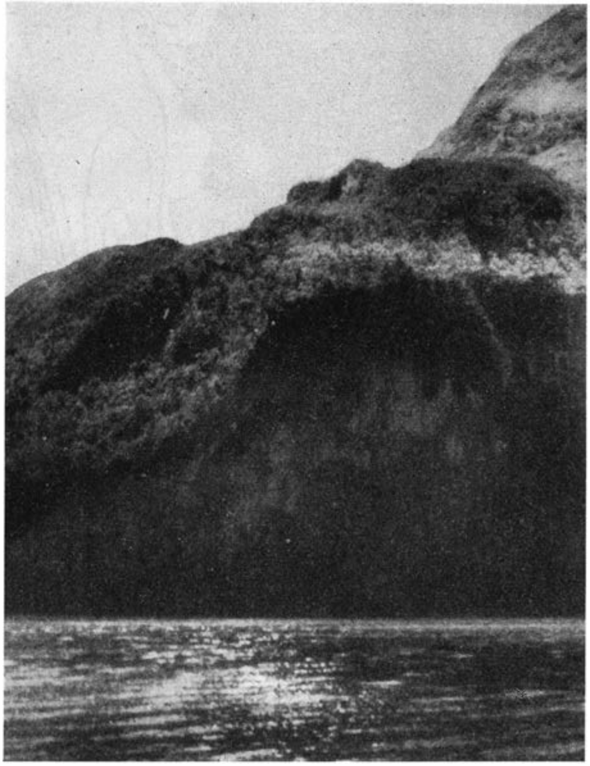


Photo E. LJUNGNER. 13.7. 1930.

Fig. 16. Remnant of valley fill of interglacial volcanics on the northern shore of Lago Frio. The volcanics show steep cliffs towards the lake. In the background to the right valley side of granodiorite, covered with snow. Looking north.

This occurrence of a tuffaceous sandstone, obviously deposited in flowing water, on an exposed mountain ridge more than 2000 metres above the sea level and with valleys considerably more than 1000 metres deep on both sides is no doubt very interesting. The deposit in question evidently requires very different relief conditions at the time of its formation than the present ones. Exactly contrary to the present situation the tuff must have been deposited in a relative depression in the earth's surface of that time. The adjacent deep valleys must then have been quite filled up by material. Ice must first be considered as the filling material. The tuffaceous sediment should in such a case have been deposited in a more or less ephemeral nunatak lake. Other occurrences of the rocks of the Tronador series — to which the occurrence on Cerro Lopez on account of its petrographical character undoubtedly belongs — show, however, that they were formed in interglacial time with hardly much greater glaciation than at the present day. Moreover several of these occurrences prove that the great valleys of canyon-type existed already in pre-interglacial time. Thence it follows that the material which levelled the relief in interglacial time

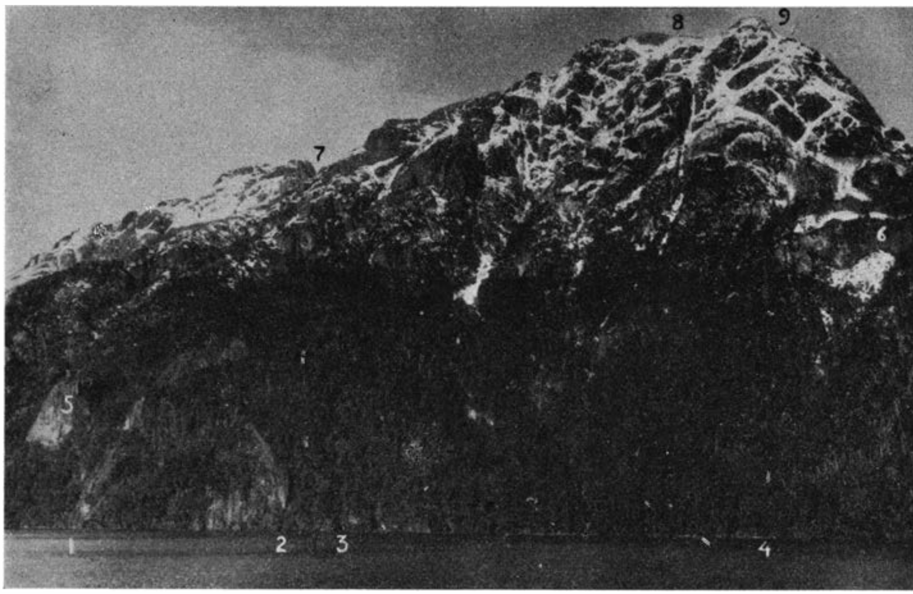


Photo E. LJUNGNER's expedition (O. RING). 5.7.1934.

Fig. 17. Interglacial volcanics on the southern shore of the western part of Brazo del Viento. Looking southeast from △ at A:o de las Cuevas, alt. 771 metres. 1—2 = Peña de Columnas. 2—4 = Mainly pyroclastics with caves (3 = The great cave). 5, 6 = Other remnants of the same volcanics. 7 = △ »Llanca». 8, 9 = △ »Bl».

must have been these very volcanic products of the Tronador series, *viz.* probably to a large extent loose pyroclastic deposits, which should account for the relatively rapid and rather complete restoration of the leading features of the pre-interglacial relief.

Loc. 15—16. Lago Frio. At the northern part of Lago Frio (Fig. 15), on the western (Loc. 15) as well as the northern shore (Loc. 16) of the lake, there appear lavas and tuffs belonging to the Tronador series. They occur from the level of the lake to a fair height upon the steep walls of the valley (Fig. 16), which otherwise consist of granodiorite. This occurrence obviously represents remains of a valley fill which, according to what has just been stated, probably in interglacial time wholly filled up the valley of Rio Frio. From here, more specifically from the western side of Lago Frio, only one specimen has been available for examination, namely a lapilli tuff.

Loc. 17. Peña de Columnas (with Cueva Bloque and Punta de Bloques). As early as in the year 1899 WEHRLI (p. 228) had noticed an occurrence of basalt with columnar jointing on the southern shore of Brazo del Viento about three kilometres east of Puerto Blest, close to the outlet of

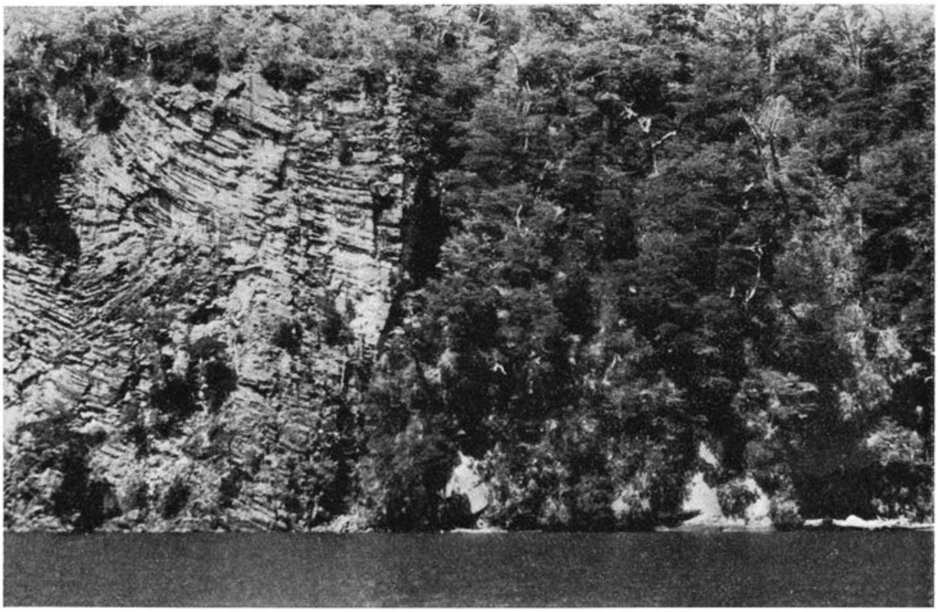


Photo E. LJUNGNER. 13.2.1933.

Fig. 18. Peña de Columnas from the northwest. To the right at the shore caves in pyroclastics (Cueva Bloque).

Rio Frio in Nahuel Huapí. He proposes three alternative interpretations of the genesis of this basalt (see Chapter III above). According to the information given by LJUNGNER and photographs taken by him the most plausible interpretation seems to be that it forms part of a local eruption, a neck. This neck has obviously penetrated a series of tuffs and interbedded lava flows, which possibly completely filled (the western part of) the fjord valley of Brazo del Viento. The later erosion has not only selectively uncovered the more resistive neck from the loose volcanic products, but also, owing to the highly pronounced columnar jointing of the intrusive basalt, been able to remove great parts of the intrusion in question (Fig. 17). As a matter of fact only the southern half of the probably rounded neck is preserved above the level of the lake. By this natural section a certain idea of its interior structure may be gained. A comparison between the two photos 18 and 19, one (Fig. 18) taken from the northwest, the

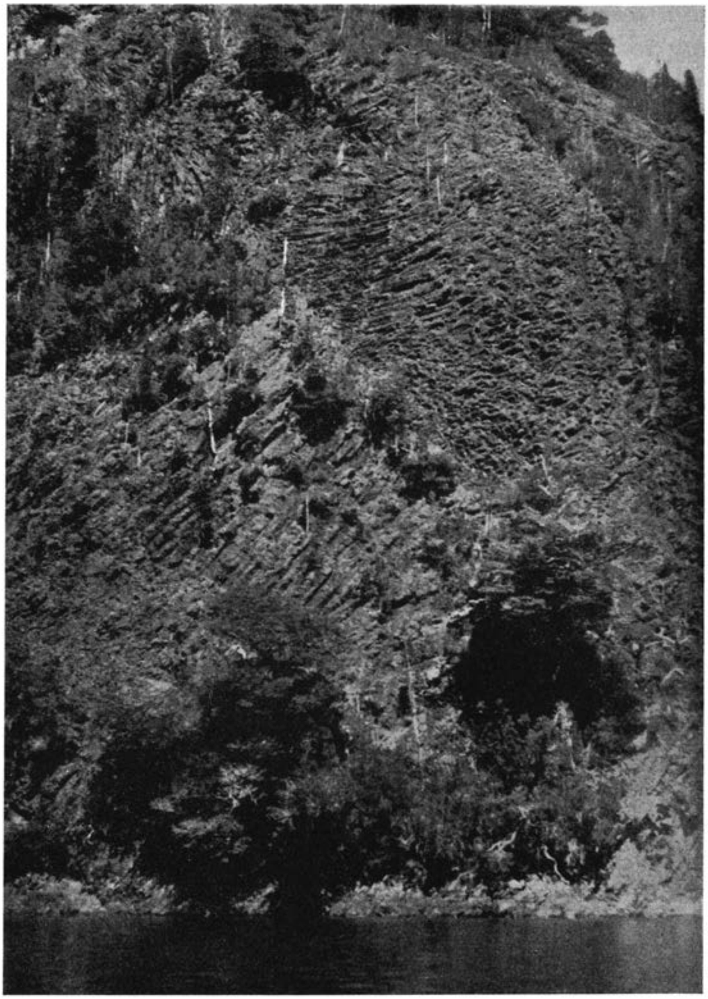


Photo E. LJUNGNER. 13.2. 1933.

Fig. 19. Peña de Columnas from the northeast.

other (Fig. 19) from the northeast, shows, apart from minor irregularities, a certain system in the arrangement of the columns. On the whole the arrangement seems to be such that peripherically the basalt columns are lying radially and horizontally or with a slight dip outwards. Towards the centre of the intrusion the out- and downward directed dip of the columns increases continuously in such a manner that in the upper parts of the remaining portion of the neck the columns from diametrically opposite points of the periphery, curved with the concavity up- and outwards, in the central axis meet at a (downwards open) angle of about 100°. In this arrangement and form of the columns it is possible to see the result of cooling processes proceeding simultaneously from above, from the earth's surface, and from the sides, in centripetal direction, from the relatively cool country rocks. The curved form of the columns might perhaps also be accounted for by an intrusion pressure acting from below, which had persisted to an advanced stage in the consolidation of the rock. In support of this the fact may be stated that in the lower parts of the neck now visible the curvature of the columns seems to be considerably less pronounced. In the higher parts having been located nearer to the earth's surface the consolidation and the development of the columnar jointing ought to have taken place somewhat earlier and thereby also the degree

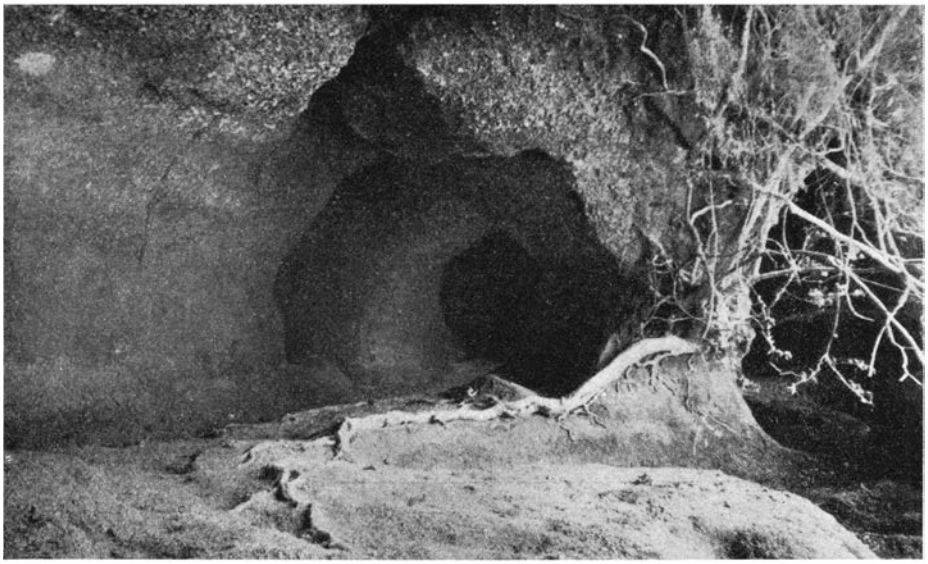


Photo E. LJUNGNER. 31.5.1933.

Fig. 20. Caves in interglacial pyroclastics. About 200 metres southwest of Peña de Columnas. Looking south.

The tree *Caldcluvia paniculata* (Cav.) Don, visible on the figure, has here its upper limit of distribution.

of deformation should be greater than in a part of the intrusive body lying on a lower level. It is questionable, however, whether at such a far advanced stage of consolidation, as the formation of columnar structure implies, such a plastic deformation of the columns is at all possible. For that reason I should suppose the interpretation first stated of the structures observed as the most probable one. The generally slightly inclined position and the less curved form of the columns in the lower parts of the neck is, then, a natural consequence of the fact that here the cooling from above has been relatively unimportant as against the effect of the cool adjacent rocks. Not far southeast of this neck a short distance up the precipitous slope there occurs a conical hill (see Fig. 17 near the left margin at 5), which is probably an analogous formation. It has not been

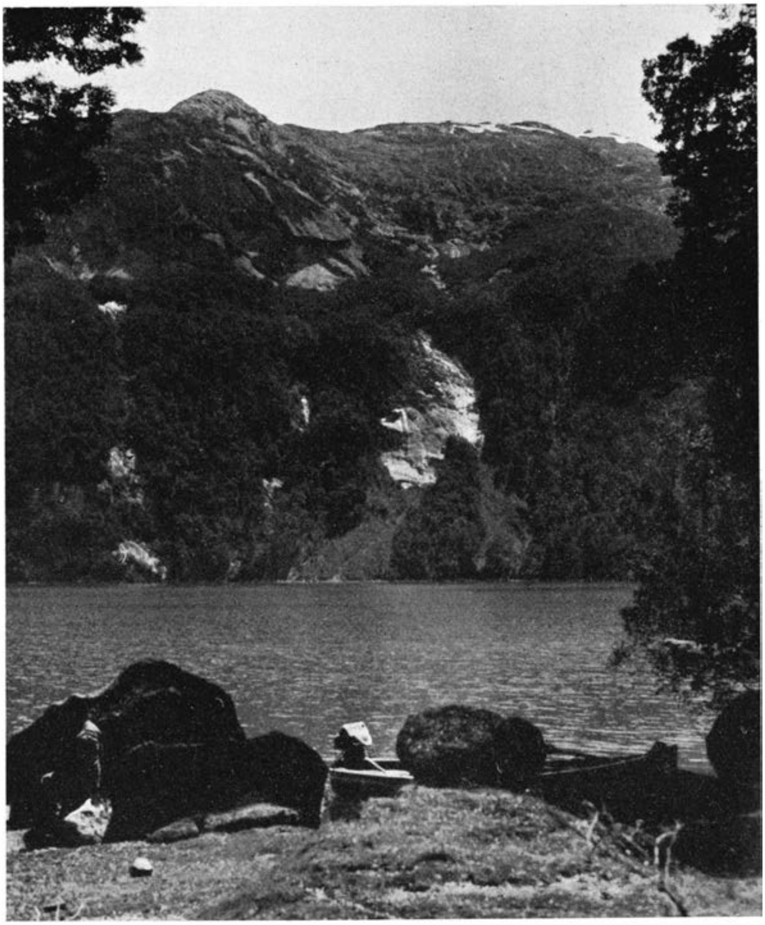


Photo E. LJUNGNER. 13.2. 1933.

Fig. 21. Arroyo de las Cuevas from the southeast. The dense forest indicates the approximate distribution of the volcanic valley fill. The large white spot in the forest above the talus fan is the granite wall uncovered by the erosion of the brook. The local boulders of agglomerate in the foreground are lying in front of the greatest cave southwest of Peña de Columnas (3 in Fig. 17).

visited by LJUNGNER, for which reason no sample of the rock could be examined. It seems, however, to be light gray in colour as the lavas, of which samples have been collected from adjacent localities. The neck on the shore of the lake, described above, consists, on the other hand, of a dark gray — black basalt.

Rocks of the effusive series are preserved west as well as east of the last-mentioned neck. In the western part the interglacial rocks occur still at the level of the lake, where rather large caves have been carved out in the relatively loose tuffs (Fig. 20). Towards the east the outcrops seem to recede a distance up the precipice, because here (at Punta des Bloques)

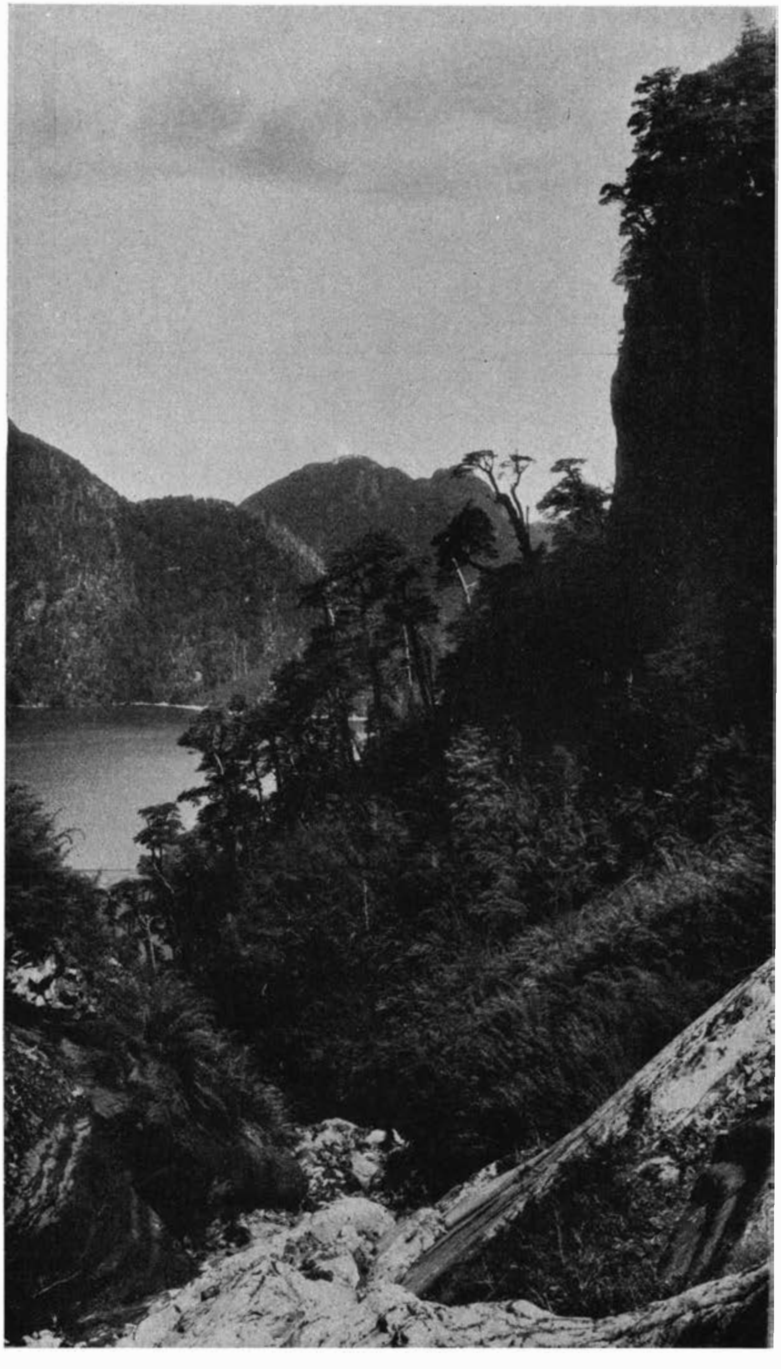


Photo E. LJUNGNER. 26.1.1933.

Fig. 22. From Arroyo de las Cuevas. Looking S.SW. In the foreground contact between light granite (to the right) and dark bedded tuffs. In the upper part to the right vertical cliffs in interglacial volcanics. The mountain in the background with two peaks is Cerro Doce de Febrero west of Lago Frio (*cf.* p. 206).

only lava-boulders of the Tronador series are met with on the shore. The older country rocks in the western part consist of granodiorite, to the east predominantly of the rocks of the Milleaqueo series.

From this locality several samples of rocks have been microscopically examined, *viz.* in addition to the intrusive neck and a sample of a tuff breccia exclusively effusive lavas. About ten of the latter are porphyritic, a few indistinctly or non-porphyritic basalts.

Loc. 18. Arroyo de las Cuevas. Rocks of the Tronador series also occur on the northern shore of Brazo del Viento, northwest of the preceding locality. Remnants of a series of strata, 500—600 metres thick, are here preserved. Lowest finely layered ashes and tuffs are preponderating. Higher up scoriaceous and compact lava flows appear in addition. The nature of valley fill of this series of strata is here quite obvious by the fact that a minor brook, by LJUNGNER called Arroyo de las Cuevas, has cut through the volcanic series and uncovered the valley wall behind (white in Fig. 21). This here consists of granite of the younger series with well marked platy jointing. Farther to the east, towards Arroyo Negro, quartzitic sediments of the Milleaqueo formation outcrop on the steep slope of the shore. The quartzite, striking in N 10° E and dipping about 60° to the east, is intersected by a vertical dike with the same strike as the sediments, which dike possibly belongs to the Tronador series.

The tuffs of the Tronador series in the cutting of Arroyo de las Cuevas mainly prove to be horizontally layered, though often with a certain undulation, probably due to secondary slides caused by the load of the superposed volcanic masses. The brook mentioned is preferably flowing in the contact between the granite and the volcanic rocks (Fig. 22) and has at intervals cut out caves in the superposed, relatively loose tuffs. In such a cave, located 90 metres above the level of the lake, the granite surface was observed to be glacially eroded and showed striae indicating a movement of the ice from the west. By digging away further tuff material LJUNGNER was able to prove that the glacially sculptured granite surface really was of the same character under the tuff. As the basalt on the southern shore of Brazo del Viento is also glacially ground, already mentioned by WEHRLI (1899), and the genetical connection between the two occurrences on both sides of the fjord cannot be called into question, *inter alia* on account of far-reaching petrographical analogies, these observations indicate the same relation of the volcanic series to the Pleistocene glaciations as was established for the tuffitic rocks on Cerro Lopez, *viz.* an interglacial age.

From Arroyo de las Cuevas five rock specimens have been examined, namely one lapilli tuff, one porphyritic and three non-porphyritic basalt lavas.

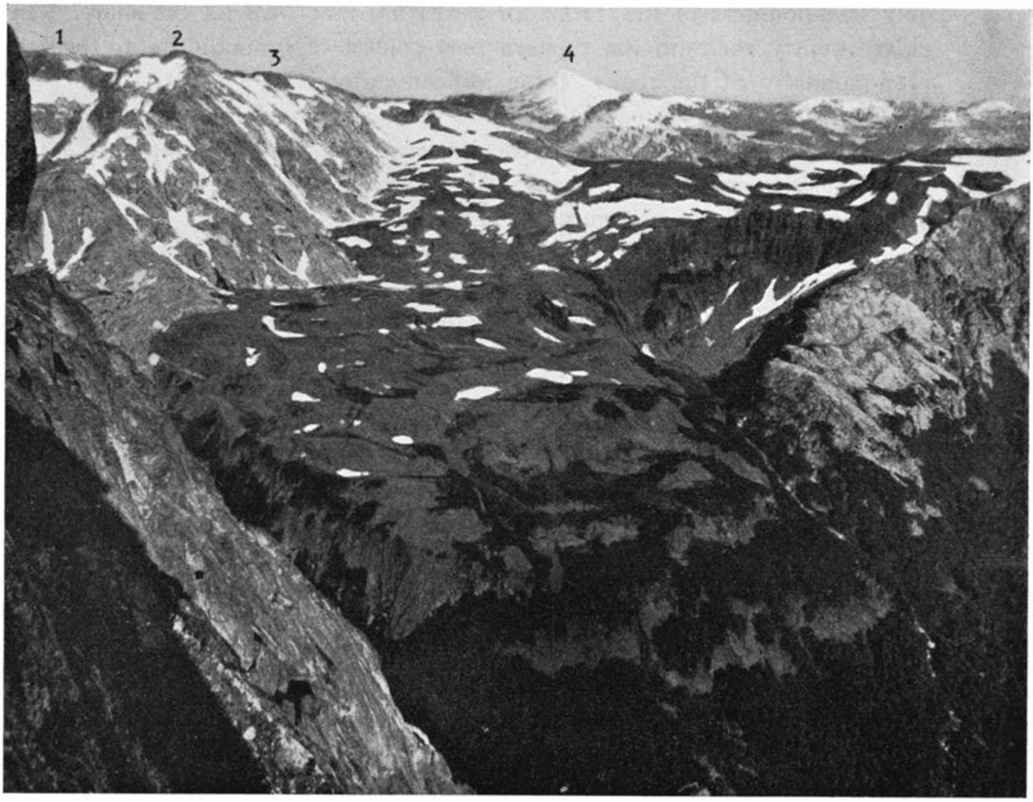


Photo E. LJUNGNER. 24.2. 1934.

Fig. 23 a. Calderón de Lavas, SW part. From »Pa», alt. 1943 metres. Looking W.NW. Valley fill of interglacial volcanics dark. 1 = »Kr», 1916 metres. 2 = Peak 1920, which hides the locality 19. 3 = A small erosion remnant of volcanics not examined. 4 = The glaciated peak »Ne» (1920 metres) recently called Cerro Cox.

Loc. 19. East of »Kr». This locality lies at an altitude of about 1900 metres a short distance northeast of the pass in the upper northwest end of the valley of Arroyo Blanco, *i.e.* about 6 kilometres northwest of the mouth of the brook in Brazo del Viento. The older country rocks of this district consist of granite, here and there with great inclusions of schistose porphyrite. The lava occurrence here consists of a cylindrical, in plan therefore rounded body, about 15 metres in diameter, rising 5 metres above the granite. LJUNGNER has not recorded in his diary the orientation of the joints of the rock, but says he has a recollection of a concentric structure, for which reason he interprets the lava as representing the erosion remnant of a volcanic pipe. A similar formation might conceivably have been brought about in the manner that a lava flow fills out a rounded depression in the bed, on which it is advancing. The thickening of the lava bed formed in such a way ought to be more resistent

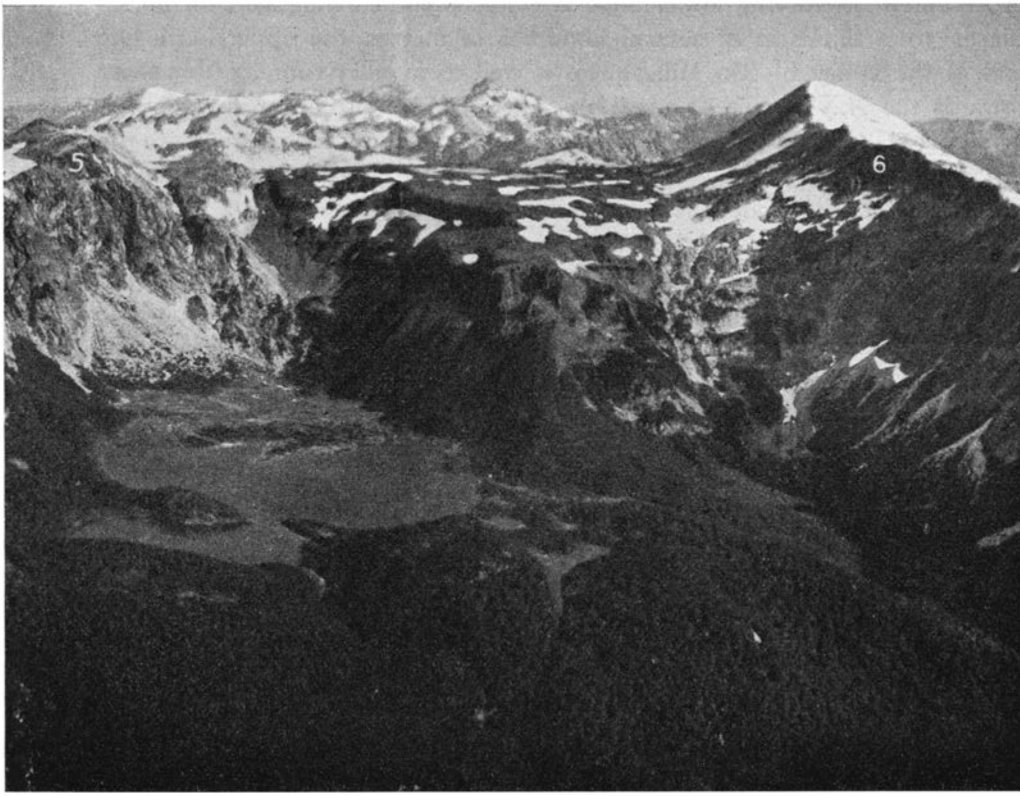


Photo E. LJUNGNER. 24.2. 1934.

Fig. 23 b. Calderón de Lavas, NE part. From »Pa», alt. 1943 metres. Looking N.NW. The volcanics occur in the foreground round the lake and fill the valley between 5 and 6. The northern margin of the map Fig. 15 runs immediately behind 6. This figure forms a panorama with Fig. 23 a. Clouds removed.

towards the erosion than adjacent parts of it and by another type of arrangement of the joints readily give an impression of representing a local centre of eruption. In addition to the rock in question, a compact basalt of a type common among the effusive lavas of the Tronador series in this northern part of the area, another type of rock occurs on this locality, too, *viz.* a highly scoriaceous lava being preserved at the base all round the lava cylinder. Of the relations between these rocks, *i.e.* whether the scoriaceous basalt is penetrated by or underlies the compact basalt, observations are lacking. On account of this uncertainty and as the latter rock in any case must have solidified quite near the earth's surface, both rocks have been described in connection with the effusive lavas.

Loc. 20. Calderón de Lavas. Not far northeast of the last-mentioned locality there exists a relatively large area of Tronador rocks. Lava flows of a somewhat varying appearance are here predominating and fill up, in places to a thickness of several hundreds of metres, the upper kettle-like end of the valley of Rio Milleaqueo as well as a valley running from there towards the N.NW (Fig. 23 a and b). Agglomerates also occur, but subordinately. On the lava of the valley-basin glacial striae were measured with the directions S 60° W and S 70° W. Whether also the basement of the volcanic series is glacially eroded, is difficult to decide, as compact lava flows are generally lying immediately on the older granite without interbedded tuffs. Not far northwest of Calderón de Lavas, on the eastern side of the upper course of what is probably one of the head-waters of Rio Colorado, where the pyroclastic component plays a more important quantitative rôle, it has been established that the tuffs are resting upon glacially sculptured granite surfaces.

From Calderón de Lavas seven samples of rocks have been more closely examined, all porphyritic basalts.

Loc. 21. Fraile. Fraile is a mountain top, 1990 metres high, located on the northeast side of the valley of Arroyo Blanco, 2.5 kilometres N.NE of the outlet of this streamlet in Brazo del Viento. Immediately southeast of the summit, on a level of 1925 metres, there exists a little area of interglacial volcanics preserved from erosion. It is a thin covering of a basaltic lava, according to a sample examined, which by the action of the frost has been highly shattered on the surface and is underlain by a tuff bed. The tuff, on the other hand, is resting upon a glacially striated granite surface. The striae strike in N.NE—S.SW and a roundness of the southern edges of the granite rocks indicates a direction of the ice-movement from S.SW.

The high position of this occurrence on a mountain top, surrounded by deep valleys, involves for the dispersal of the lava flow from an early centre of eruption quite a different topography than the present one in this district. Together with the sequence on Cerro Lopez this locality also gives evidence of the considerable thickness of the volcanic products, which were deposited in interglacial time in the zone of maximum altitude in this region of the Cordillera.

Loc. 22. East of Fraile. The presence of a rock belonging to the interglacial series is recorded about one kilometre east of Fraile. It is located in the slope about 500 metres south of the middle part of Lago Escondido, a lake discovered and named by LJUNGNER's expedition, which is drained to Rio Milleaqueo. The occurrence lies on a level of about 1760 metres, *i. e.* about 310 metres above the lake (1450 metres) and about 165 metres lower than the lava on Fraile. Here, however, it deals with an agglomerate. According to a small sample of an agglomerate pebble, which has been available for the examination, the rock shows a great similarity with the lava on Fraile. Microscopical investigation also reveals an unmistakeable affinity between this agglomerate and the lavas of Calderón de Lavas.

Loc. 23. West of Arroyo sin Pava. A minor occurrence of the basal parts of the Tronador series is found at the shore in a little bay not far west of Arroyo sin Pava, a small brook which falls into Brazo del Viento on the southern shore, 5 kilometres east of Puerto Blest. It deals with a tuff of quite an insignificant thickness. The tuff rests upon a slate of the Milleaqueo formation, which shows excellent glacial striae from N 70° W. The striae continue also under the tuff. In the tuff are embedded greater and smaller fragments of slate and granite probably of local origin. On account of the difference in hardness these non-volcanic rock fragments stand out in relief over the friable tuff and are planed off and striated by an ice with the same direction of movement as that which wore the substratum of the tuff. This interglacial »basal breccia» of the Tronador series may be seen to continue outwards from the shore below the level of the lake. Similar formations have been observed at several other places within the area of the lake, often never reaching above the surface of the water. Such a locality is

Loc. 24. Las Mellizas. Las Mellizas (»the twins») are two small islands, joined by a narrow isthmus and located in the middle part of Brazo del Viento, near the southern shore. The country rocks consist of porphyritic Viento granite, cut by porphyritic dikes. In the small coves in the western and eastern ends of the island as well as on its southern side there occurs at a depth of 0.5—2 metres a slightly consolidated, partly argillaceous, partly conglomeratic sediment, into which a considerable percentage of volcanic, tuffitic material enters. The tuffitic conglomerate is in part highly corroded, often undermined, forming subaqueous, sharply projecting points. In those parts consisting of more homogeneous, finegrained material, which has a remarkably light colour, sometimes a certain stratification appears. In addition to a sample of this light, tuffitic clay a specimen of a darker, almost purely pyroclastic tuff rock has been examined appearing as a dike-like filling of a flat-lying fissure in the granodiorite in the westernmost part of the island.

Loc. 25. Puerto Sobral. This name is applied by LJUNGNER to the little bay lying inside a small islet (Isla Sobral) not far to the north of the island Centinela, *i.e.* beyond the mouth of Brazo del Viento on the northern shore. The country rocks round this bay consist of rather varying sediments and volcanics of Tertiary age. On the floor of the inner part

Photo E. LJUNGNER. 2.10.1933.

Fig. 24. Folded interglacial tuffaceous sediments with shore caves. Puerto Sobral. Looking south.

of the bay there occurs a light gray, very slightly consolidated deposit, which also appears on the shore to the south and proves to be a striped tuff probably belonging to the interglacial volcanism. The tuff is in part so highly folded that the structure holds a vertical position (Fig. 24), and this folding can only be ascribed to the ice thrust during the last glaciation.

Loc. 26. Peninsula Huemul. This easternmost locality here mentioned lies on the eastern shore of Lago Nahuel Huapí, *viz.* on the southwest part of Peninsula Huemul, east of the southernmost part of Isla Victoria, or more specifically at the shore inside a little rocky islet connected at low water with the shore. The sample from this locality consists of a hard, light gray, tuffitic clay. As the country rocks in the neighbourhood are composed of Tertiary volcanics of porphyritic, andesitic, and basaltic character it might be reasonably supposed that the volcanic components of the clay were to be regarded as mainly a detrital product of the local Tertiary rocks. The petrographical examination shows, however, that nothing contradicts the conception that a quantitatively essential part of the tuffitic clay really is derived from the interglacial volcanism of the Tronador series.[1]

[1] In addition to the occurrences described in this chapter further eight localities are shown on Fig. 3. As from most of these no samples of rocks have been available for

V. **Petrographic description.**

In the following detailed description of the petrographical characters of the different rocks of the Tronador series it has been found most appropriate to make a subdivision into two minor districts from a geographical point of view. To the Tronador area in a restricted sense I refer the southern part of the region represented in the collection of specimens studied, with Cerro Tronador as the main locality, whereas the northern part, to the north and south of the westernmost arm of Lago Nahuel Huapí, will be a subject for a separate study under the heading of the Brazo del Viento area. Such a subdivision is quite natural even on account of the fact that the two areas, as is obvious from the map Fig. 3, are separated by a strip of land more than 10 kilometres broad, from which no rock specimens of the interglacial series are to be found in the collection investigated. This geographical subdivision corresponds, however, also to a petrographical difference between the areas. Types of rocks in common are certainly represented in great numbers. Types however occur which are only known from one or other of the two areas. The description begins with the Tronador area, which is represented by the greatest number of specimens in the collection which show in petrographical respect the greatest range of variation.

A. **The Tronador area.**

(Plate III.)

In the Tronador area those localities are included, which are situated on the eastern and southern slopes of Cerro Tronador, and also the northern part of Cerro Volcánico as well as the upper course of Rio Manso. Further the volcanic rocks occurring in the Victoria valley, which opens into the

examination (excepting No. 33 and 35) they may here be mentioned with only a few words. No. 27 (Isla Llau-Llau) represents a tuff with intermingled extraneous boulder material of the same type as the occurrence at Las Mellizas (No. 24). As to the localities 28 and 29 (Paso Perez Rosales and Cerro Doce de Febrero) it may be referred to the historical survey of Chapter III. No. 30 (northeast of Lago Media Luna), 31 (southeast of Lago Frio), and 32 (Planicie Navidad) refer to localities not visited but only observed from a greater or minor distance, for which reason some uncertainty is attached to these occurrences as to the nature and extension of the rocks. No. 33 and 34 finally represent two occurrences of ice-transported boulders of Tronador rocks of predominantly glaciological interest. In one case (No. 33, Cerro Laguna) it deals with a boulder of a scoriaceous Tronador lava on a relatively high level (1800 metres) and rather easterly position (71°38′ W), in the other (No. 34, Laguna Vasquez) the most easterly found boulder of tuff of the rather friable type with scoriaceous lava fragments being exposed for instance at Cueva Bloque in the inner end of Brazo del Viento.

inner part of Brazo Tristeza, the southwestern fjord arm of Nahuel Huapí, will be included in this study. For petrographical reasons the pyroclastic deposit on Cerro Lopez has also been described together with the corresponding rocks of the Tronador area. Finally those Tronador rocks are taken into consideration, which are represented in the collection of pebbles made in the bed of Rio Peulla at Casa Pangue on the Chilean side of the frontier. These rocks, as stated before, have most probably once formed a part of the higher summits of Cerro Tronador and by means of glacial and fluviatile action been brought down the valley of Rio Peulla.

In the following petrographical description those rocks are first dealt with, which have their original mineralogical and structural characters well preserved. Then an account of those types of rocks will be given, which by late volcanic processes have suffered a more or less thorough alteration. As a third group will follow a description of mainly hydrothermal mineral deposits represented in the material examined.

a. **Unaltered rocks.**

The unaltered rocks may naturally be divided into three groups, *viz.* effusive lavas, dikes and volcanic ejectamenta. Of these groups the dikes have not been positively proved to be of interglacial age. As they penetrate dynamometamorphically affected rocks without themselves showing any traces of tectonic deformation and as their petrographic characters are not inconsistent with a genetic connection with the interglacial series, they have been included in this description, which will be opened by the most varying and quantitatively dominating group of rocks, the effusive lavas.

α. Lavas.

The lava rocks of the Tronador area are all, at least under the microscope, porphyritic. In the great majority of cases the phenocrysts also appear before the naked eye. In the following description I have found it appropriate to use as a principle of classification the occurring types of phenocrysts. Not less than thirteen combinations of phenocryst minerals have been recorded. These may suitably be divided into four groups according to the character of the dark silicate minerals. The first group (1—7) comprises all olivine-bearing lavas. The second group (8—10) is characterized by the absence of olivine but the presence of pyroxenes as phenocrysts. For the third group (11—12) the appearance of amphibole as phenocrysts is characteristic, whereas the rocks of the last group (13) are lacking phenocrysts of mafic silicate minerals. This classification corresponds first of all to a decreasing frequency of the number of types as well as the total number of samples of rocks, being included in the collection, from group I to group IV, secondly a decreasing average basicity from basalts (I) via basaltic andesites and normal andesites to dacites (III), the last group (IV), however, in this respect falling to a certain extent beyond the series.

Group I. Olivine-bearing basalts.

The seven types belonging to this group are distinguished by phenocrysts of olivine and (as the lavas of the Tronador area in general) plagioclase. The different types will be described in order of decreasing average percentage of anorthite of the phenocryst plagioclase. This order has the advantage of being equally applicable also to the other groups of lavas here described.

1. With phenocrysts of plagioclase, olivine and diopside.

Five rocks are to be referred to this group, two of which derive their origin from Tronador without any further statement as to the locality, whereas the other three are collected at Casa Piedra on the southern side of the valley of Rio Manso (Loc. 12 in Fig. 3), at a rocky hill southeast of Paso Hito Cauquenes (Loc. 10) and on Cerro Volcánico (Loc. 9), respectively. The specimen from Casa Piedra is a fragment of a pebble of an agglomerate underlying a lava with columnar jointing, whereas the other samples are obviously taken from outcropping lava flows.

Macroscopically the rocks are nearly aphanitic and massive, *i.e.* not vesicular. The colour varies from black to dark gray, with exceptional light gray. The phenocrysts are comparatively inconspicuous partly owing to their small dimensions, partly to their colour only slightly differing from that of the groundmass of the rock. In the black type the phenocrysts are also black and lustrous, whereas in the grayish types the colour of the phenocrysts is somewhat lighter gray than that of the groundmass. Their lustre is also less marked. The maximum length of the plagioclase phenocrysts of the different specimens varies between 1 and 2 mm. In the lightest types brownish yellow phenocrysts of olivine appear sparsely.

In the microscope the phenocrysts of plagioclase prove to have a rather varying magnitude and sometimes a fairly different degree of ideal development. A stout prismatic shape is characteristic, however, which may be exemplified by the dimensions 0.9×0.35 mm. The crystals are usually perfectly clear and free from inclusions. Only the rock from Casa Piedra displays a slight formation of sericite along some cleavages of the plagioclase. Abundant inclusions of the groundmass of irregular shape are to be observed occasionally. For the most part they consist of dark brown glass. Further attention may be called to the fact that the inclusions are sometimes confined to the larger phenocrysts and that phenocrysts studded with inclusions often occur side by side with those totally devoid of them. The phenocrysts bearing inclusions have usually an outer shell free from them. This zoned structure with regard to the distribution of the inclusions also corresponds to a zoning in the chemical composition of the plagioclase substance. The latter is, however, applicable to all phenocrysts of the rock. This zoning is characterized by the fact that the relatively homogeneous, quantitatively dominating core of the crystal is surrounded by a thin shell of more acid composition. The transition from one zone to the other is very rapid and sometimes seems to mark a *hiatus* in the composition of the plagioclase.

The composition of the plagioclase phenocrysts is evident from Table II, where all determinations on phenocryst minerals in the group of rocks now in question are put together. Here some remarks may be made, which refer not only to this table but also to the analogous ones given in the following pages. For each rock specimen two values of the anorthite percentage of the plagioclase are given. These values refer to two twin individuals of the same crystal. In those cases where the axial angle has been determinable, this is given immediately beneath the corresponding anorthite percentage. In the third horizontal line the twinning law is indicated (A = Albite, C = Carlsbad, AC = Albite-Carlsbad, P = Pericline, AA = Albite-Ala). At the plagioclase determination the FEDOROW method has if possible, *i. e.* in most cases, been applied. The fixation of the anorthite percentage has been made by means of NIKITIN's (1933, Table 2; 1936, Table VI) corrected curves. Further it is to be noted that the anorthite percentages given in the tables are often averages of values obtained by means of two reference surfaces, generally (010) and (001) or the rhombic section. On the other hand the axial angle has not been made use of for determining the composition. The determination of the twinning law has been made with the assistance of REINHARD's stereograms (1931, Table 1 and 3).

The composition of the plagioclase phenocrysts of the lava type now in question is the most basic one met with in the material examined. It varies from an almost pure anorthite to a basic bytownite with 85 % An. The average of the determinations performed gives an anorthite with 92.2 % An. These statements refer to the central, homogeneous principal parts of the phenocrysts. The thin outer shell has a composition more rich in albite; in one case (Table II. 2. Ind. I) the extinction angle $\perp$ M and P = $37^\circ.5$ was measured, according to DUPARC-REINHARD's (1924, Fig. 10) curve corrected by GORANSON (1926, Fig. 2) giving 72 % An. In a second case (Table II. 3. Ind. I) the corresponding extinction was determined to be $38^\circ.5$, answering to 74 % An, and in a third one (Table II. 4. Ind. II) to 39°, corresponding to 75.5 % An.

Table II.

Optical data on phenocrysts.

		1	2	3	4	5
Plagioclase	% An	100, 93.5	96, 93	93, 91	93, 89	88, 85
	2 V	— —	−86°, 90°	−81°, −85°	— —	−78°, —
	Tw. law	C	C	C	P	AC
Olivine	2 V	—	−88°	−85°	−89°	−80°
Diopside	2 V	—	+54°	+58°	+57°.5	—
	c : γ	—	40°.5	37°.5	39°.5	—

1. Cerro Volcánico.
2. Southeast of Paso Hito Cauquenes.
3. Tronador.
4. Casa Piedra.
5. Tronador.

The olivine phenocrysts, as appears from Table III, form mainly from 1—2 per cent of the volume of the rock. They are generally roundish idiomorphic, sometimes quite rounded, more rarely with digitated outlines. The maximum dimensions vary in different thin sections from 0.4 to 1.6 mm. Only in two of the specimens (No. 3 and 4) is the mineral practically unaltered, in No. 3, however, along fissures with a thin coating of iddingsite, pleochroic in fainter and deeper reddish brown. In the rocks No. 1 and 2 the olivines are surrounded with a thinner or thicker opaque border of ore. This opacitic margin makes its appearance only on the boundary towards the groundmass, not towards immediately adjoining plagioclase phenocrysts, which indicates, that the alteration has proceeded from the groundmass. The minor olivine crystals have often been com-

Table III.

Volumetric analyses.

		1	2	3	4	5
Phenocrysts	Plagioclase	7.3	7.0	9.7	13.5	11.4
	Olivine	0.6	1.5	5.8	1.9	1.8[1]
	Diopside	0.1	0.3	0.2	0.3	0.03
	Groundmass	92.0	91.2	84.4	84.3	86.7
	Total	100.0	100.0	100.1	100.0	99.93
	Vesicles	—	—	—	—	0.3

[1] Including 0.2 % serpentine pseudomorphous after olivine. 1—5=Table II.

pletely transformed into a highly ore-pigmented mass which at a hasty glance resembles primary magnetite phenocrysts. The granular nature of the ore masses and eventual remnants of unaltered olivine, however, unveil their character of pseudomorphs. In the rock No. 5 a third kind of alteration may be observed. Some crystals, and this seems to be the case especially with the greater ones, are not infrequently entirely altered into a greenish yellow serpentine. This alteration occurs without any segregation of ore. The determinations of the axial angle of the olivine, which have been made, are put together in Table II. These give according to WINCHELL's

Fig. 25. Photomicrograph of basalt lava with phenocrysts of plagioclase, olivine and diopside (No. 3 in Table II and III). Tronador. Ord. light. Magnif. × 68.

diagram (1933, Fig. 109) a variation of the composition between 16 and 37 %, on an average 24 % Fe_2SiO_4.

In quite small quantities also phenocrysts of monoclinic pyroxene occur in these rocks. They form rounded, equidimensional individuals without decided crystal boundaries, which frequently border upon olivine phenocrysts (Fig. 25). Greatest diameter measured was only 0.4 mm. The pyroxene has a faint, but distinct greenish colour and is devoid of pleochroism. Only exceptionally (No. 3) some solitary twinning lamellae on (100) are to be seen, determined by means of their relation to the generally very distinct cleavages. The crystals are often not optically homogeneous, but show an irregular undulatory extinction. The monoclinic pyroxene has not met with any chemical alteration. The determinations of axial angle and extinction (Table II) performed on the universal stage show that we are dealing with a diopsidic augite. In those cases, when because of the position of the sections a more intimate study was rendered impossible

(No. 1 and 5), there are other circumstances which prove that members of the diopside-hedenbergite-series rich in lime are also here present.

Without forming real phenocrysts two lumps of ore were finally observed in one thin section (No. 4), one smaller and one greater, the latter of which contained two inclusions of a brownish green, completely isotropic mineral with indistinct cleavages and irregular shape. Probably it deals with a spinel mineral, perhaps chrome-bearing.

The groundmass is distinguished by the plagioclase laths with the average dimensions 0.2 mm, and these are extraordinarily plentiful and display a fluidal arrangement, partly rather distinctive and partly more vague. By fluidal movements of differential nature the plagioclase phenocrysts have occasionally (No. 5) been broken and the pieces separated by groundmass. Further there are to be observed in the groundmass equidimensional grains of ore, pyroxene and (in the rocks No. 3, 4 and 5) olivine, too, together with a comparatively insignificant quantity of brown glass. The ore partly appears as small, idiomorphic, octahedral crystals. In specimen No. 5 the glass is more abundant and is rather uniformly distributed in irregular shaped patches, whereas the pyroxene and olivine minerals are more or less masked through a heavy, but stripe-variegated ore pigmentation. Especially in certain parts of the thin section there are rounded or more irregularly elongated patches of yellowish green chlorite, often immediately surrounded by relatively pure glass, and these formations possibly represent pre-existing vesicles. Their magnitude is about 0.2 mm.

2. **With phenocrysts of plagioclase and olivine.**

To this group, numerically the best represented one, ten rock specimens are to be referred. Of these three come from Ventisquero Alerce, Tronador, two from El Salto and two from Cerro Volcánico, whereas the following localities are each represented by only one specimen: a hill north of Paso Vuriloche, Hito Paso Cauquenes and Casa Pangue. Megascopically these rocks are somewhat varying. Most of them are compact lavas, but also more or less vesicular (Vent. Alerce, Tronador) or highly scoriaceous types (C. Volcánico) appear, these last ones with partly typical flow structures. The colour varies from black via grayish black and dark gray to bluish gray. An exception forms one of the scoriaceous lavas from Cerro Volcánico, which is reddish brown of colour. In the highly scoriaceous, but also in some of the compact lavas no distinct phenocrysts appear to the naked eye. In the other cases the maximum magnitude of the plagioclase phenocrysts of different rock specimens generally varies within the limits 1 and 5 mm. In the scoriaceous lava from Vent. Alerce there occur, however, feldspar phenocrysts spotted in brownish gray and as much as 2 cm in length. As to the colour of the phenocrysts also in this group of rocks the rule is valid, that the phenocrysts are lighter gray than the groundmass, in the darkest types, however, the difference in colour between phenocrysts and groundmass decreasing to a minimum. Olivine phenocrysts are macroscopically plainly distinguishable only in one of the specimens from Tronador as solitary mineral grains at most 1 mm in size and of a yellowish green, metallic lustre.

The chemical composition of the plagioclase phenocrysts of this group of rocks (Table IV) extends over a range of almost 30 % An, from an acid anorthite to a basic labradorite. The rocks with the more acid phenocryst plagioclases, however, being comparatively insignificant in number an average of the determinations performed gives as result a bytownite with 80.5 % An. As to the shape of the phenocrysts a certain relation to their composition may be noted in so far that the plagioclases rich in anorthite generally follow a broadly prismatical development, whereas the phenocrysts of the types higher in albite content appear as comparatively thin laths with length : width *e.g.* 1.1 : 0.1 mm. In the latter case they sometimes display a beautiful fluidal parallel arrangement. In all rocks now in question the plagioclase is unaltered without even traces of pro-

Table IV.

Optical data on phenocrysts.

		1	2	3	4	5
Plagioclase . . .	% An 2 V Tw. law	90, 88.5 —, —79° Ala	91, 85.5 —86°, — A	88, 86 —, — AC	85, 85 —, —88° AC	84, 82 —83°, —79° AC
Olivine	2 V	—86°	—88°	—88°	—85°	—85°

		6	7	8	9	10
Plagioclase . . .	% An 2 V Tw. law	84.5, 80.5 —87°, — A	76.5, 69 +82°, — A	70, 68 —, — C	71, 62 +83°, — C	—, — —, — —
Olivine	2 V	+88°	—88°	—83°	90°	+88°

1. El Salto, lowest lava flow.
2. » » » » »
3. Casa Pangue.
4. Ventisquero Alerce, Tronador.
5. Hito Paso Cauquenes.
6. Cerro Volcánico.
7. Ventisquero Alerce, Tronador.
8. Hill north of Paso Vuriloche.
9. Ventisquero Alerce, lowest basalt flow.
10. Cerro Volcánico.

ducts of alteration. The most common type of zonal structure closely agrees with that of the first group of rocks. Round a fairly homogeneous core, which occupies all but the whole of the crystal, there is a thin shell of a composition less high in anorthite with a rather well-defined limit against the former. In one rock (Table IV, No. 8) this limit is accentuated by a zone of small inclusions of the groundmass. Also in the specimen No. 7 the phenocrysts bear similar inclusions, which are often quite opaque and appear in a greater number but without such a distinct zonal arrangement. Peripherically some solitary basic recurrence may be established. The structure of the plagioclase phenocrysts of the specimens 2 and 9 is somewhat more deviating. The first one forms to a certain extent a transitional type to No. 9. The zonal structure of No. 2 is such that round a homogeneous core, forming about half the crystal, there appears a shell of a composition on an average more rich in albite, being made up of a greater or smaller number of zones with basic recurrences. The transition from core to shell and more distinct zones of the latter are often marked by vitreous inclusions. The plagioclase phenocrysts of the rock No. 9 have an extraordinarily fine, oscillatory zonal structure with a great number of zones. Small olivine crystals are enclosed even in the centre of the large phenocrysts. One phenocryst shows in the central part, another near the periphery a zone of small, opaque inclusions. For the rest the plagioclase substance is free from extraneous particles. The following determinations of the anorthite percentage of core and shell, respectively, (the latter from the extinction) will give an idea of the range of variation of the composition of different parts of the same plagioclase crystal:

$$\begin{array}{lll} 88.5 & \longrightarrow & 67 \\ 85.5 & \longrightarrow & 67 \\ 88 & \longrightarrow & 73 \text{ \% An.} \end{array}$$

In addition to plagioclase the olivine in this group of rocks is the only mineral appearing as phenocrysts. It is generally met with as idiomorphic crystals, sometimes, however, showing more rounded forms. When olivine phenocrysts of essentially different magnitude are present, it may be established, that the larger crystals have the highest degree of idiomorphism. The maximum length of the phenocrysts varies in different rocks from 0.5 to 1.5 mm. Generally the olivine is free from primary inclusions. Sometimes (No. 1) it encloses small plagioclase crystals. In four of the rocks in question (No. 5, 7, 9 and 10) no alteration phenomena at all are to be observed in the olivine. The same holds true of No. 6, too, though along certain fissures a ferrioxidic substance of an intense, reddish brown colour has been deposited. In the rocks No. 1 and 8 (Fig. 26) a slight alteration of the olivine into a grayish green — yellowish green, more or less distinctly pleochroic, fibrous serpentine has

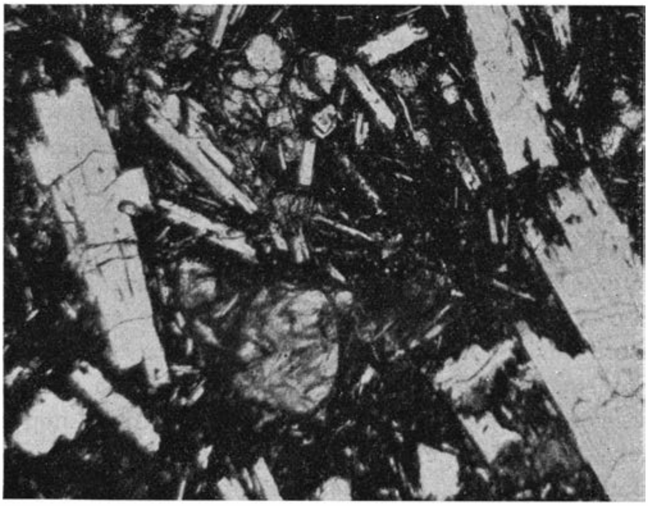


Fig. 26. Photomicrograph of basalt lava with phenocrysts of plagioclase and olivine (partly serpentinized; No. 8 in Table IV and V). Hill north of Paso Vuriloche. Ord. light. Magnif. × 67.

taken place. In No. 2 and 3 this alteration is more advanced. It is remarkable, that the alteration often begins in the central parts of the crystal, so that at a certain stage a central mass of serpentine is surrounded by a more or less thin shell of unaltered olivine. In some cases the olivine substance has been entirely consumed. The alteration of the olivine is most advanced in No. 4 (see Table V), where the mineral secondarily formed is an olive brown, iddingsitic serpentine.

The character of the groundmass rather varies in this group of rocks. The specimens 4 and 7 from Tronador have a practically completely holocrys-

Table V.

Volumetric analyses.

		1	2	3	4	5	6	7	8	9	10
Phenocrysts	Plagioclase	13.6	48.8	19.5	17.5	3.3	15.6	35.1	29.3	49.0	1.7
	Olivine . .	2.7	3.5	3.8	1.0	0.4	6.0	3.2	5.1	1.0	3.8
	Serpentine[1]	—	1.5	1.4	5.3	—	—	—	—	—	—
Groundmass		83.7	46.2	75.4	76.3	96.3	78.4	61.7	65.6	50.0	94.5
Total		100.0	100.0	100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0
Vesicles %		—	1.3	0.2	—	—	34.9	—	—	4.5	53.8

1—10 = Table IV.

[1] Pseudomorphous after olivine.

talline groundmass, composed of plagioclase laths, equidimensional grains of monoclinic pyroxene, rounded individuals of olivine, more or less altered into serpentine, and small, evenly distributed, often sharply idiomorphic crystals of magnetite. In the other cases a generally very dark pigmented, exceptionally brownish yellow glass plays a more or less important rôle in the groundmass. Olivine is found in the groundmass of the glass-bearing rocks only in two cases (No. 1 and 3), in the former together with orthorhombic as well as monoclinic pyroxene, the last-mentioned mineral, however, predominant. In some rocks the groundmass is so highly reddish brown (No. 6), brown (No. 10) or black (No. 8 and 9) pigmented, that its mineralogical composition is largely masked. At most the small plagioclase laths may under such circumstances be distinctly discerned. Their length amounts on an average to about 0.1 mm. Of other groundmass minerals appearing more sporadically may be mentioned a yellowish green serpentine in partly spherulitic segregations (No. 3), and calcite in radiated aggregates.

The occurrence and quantitative importance of the vesicles will appear from Table V. There are compact as well as moderately vesicular and highly scoriaceous types represented. The vesicles are not mineralized. An exception forms No. 2, the sparse and irregular vesicles of which are filled up by a yellow, isotropic substance, most frequently in the centre with a very fine-grained, scaly, serpentine-like mineral aggregate. Occasionally beautiful calcite spherulites occur in the vesicles. In the rock No. 9 there occur firstly larger, rounded vesicles, secondly minor, more irregularly shaped cavities. The latter are partly filled up with minerals, particularly plagioclase crystals drusily projecting from the groundmass, whereas the walls of the larger vesicles are smooth and the plagioclase laths of the groundmass immediately adjoining most commonly tangentially arranged in relation to the boundary surface.

One of the lavas from El Salto, namely No. 2 in the tables IV and V, has been the object of a complete chemical analysis, as the other new analyses published here made by Phil. Dr. NAIMA SAHLBOM. The figures together with the normative composition and the NIGGLI values calculated are cited in Table VI. A close discussion of the results of the analysis with regard to the connection between the chemistry of the rock and its mineralogical composition is deferred to a later chapter. It may be noted that the conformity of this analysis to the average values of 198 analyses of basalts calculated by DALY (1933, p. 17) is rather great. The analysis of our rock, however, shows a greater percentage of Al_2O_3 and CaO together with a correspondingly smaller total iron percentage as compared with the average mentioned. In these respects the conformity with the average of gabbro analyses, excluding olivine gabbros, given by the same author, is very close. In the system of magma types proposed by NIGGLI

Table VI.

Analysis I. Olivine basalt, El Salto, the Tronador area.

	Weight-%	Mol. Prop.	Norm			NIGGLI values		
SiO_2	49.86	8302	or	7.30	64.57	si	120	
TiO_2	1.20	150	ab	24.28		al		25.5
Al_2O_3	18.14	1780	an	32.99		fm		41
Fe_2O_3	2.71	170	ol Mg_2SiO_4	0.98	35.55	c		25
FeO	6.93	965	ol Fe_2SiO_4	0.63		alk		8.5
MnO	0.16	23	di $CaSiO_3$	4.66				100.0
MgO	6.12	1518	di $MgSiO_3$	2.78		ti	2.15	
CaO	9.61	1714	di $FeSiO_3$	1.62		h	4.49	
Na_2O	2.87	463	hy $MgSiO_3$	11.00		p	0.55	
K_2O	1.23	131	hy $FeSiO_3$	6.38		o	0.12	
H_2O+	0.56	311	mt	3.94		mg	0.53	
H_2O-	(0.70)	—	il	2.28		k	0.22	
P_2O_5	0.54	38	ap	1.28				
			H_2O+		0.40	qz		−14
Total	99.93				100.68			

II. 5. 4. 4—5. Hessose. — Or : Ab : An = 11.31 : 37.60 : 51.09.

Spec. gr. $\frac{19^\circ}{4^\circ} = 2.80$.

in 1923 and further completed in detail in 1936 the rock in question holds, in a certain degree, an intermediate position between the normal gabbrodioritic and the c-gabbroidic magma type. This ossipitic tendency in the chemistry of the rock finds its mineralogical expression in the abundance of phenocrysts of basic plagioclase.

3. **With phenocrysts of plagioclase, olivine and magnetite.**

This combination of phenocryst minerals was met with in only two rocks. One specimen is taken from an outcrop of the lowest basalt flow at Ventisquero Alerce, the other, however, being collected among the pebbles in the bed of Rio Peulla, Chile. The two rocks show considerable differences macro- as well as microscopically.

Whereas the specimen from Ventisquero Alerce is a black, massive and aphanitic rock with sparse, somewhat lighter coloured phenocrysts, at most 1 mm in length, the rock sample from Casa Pangue consists of a blackish gray lava, bearing occasional vesicles and closely lying phenocrysts, being on the weathered surface a pale gray, on the fresh fracture planes blackish gray of colour and at most 5 mm in size.

The plagioclase phenocrysts of the first-mentioned rock have a comparatively broad prismatic form, are unaltered, and generally devoid of inclusions. The zoning is rather distinct, for the most part with a more remarkable basic recurrence. As will appear from Table VII the composition of the central and greater part of the phenocrysts corresponds to an average bytownite. The phenocrysts of the Casa Pangue rock are

Table VII.

Optical data on phenocrysts.

		1	2
Plagioclase	% An	81, 79	55, 62.5
	2 V	—, —	+77°, —
	Tw. law	C	A
Olivine	2 V	—	−80°

1. Ventisquero Alerce, lowest basalt flow.
2. Casa Pangue, Chile.

relatively thinly tabular and show generally round a central, homogeneous part a shell, outwards more rich in albite, with a greater or smaller number of basic recurrences. Often occurring in the outer part of the shell is one zone, rarely several, of groundmass inclusions. The plagioclase phenocrysts are not so high in anorthite as in the former rock. According to the optical determinations a labradorite of average basicity is present.

With regard to the olivine phenocrysts the two rocks also differ. In the lava from Ventisquero Alerce there occur only a few individuals of olivine (see Table VIII), about 0.1 mm in size. No alteration products

Table VIII.

Volumetric analyses.

		1	2
Phenocrysts	Plagioclase	1.1	37.6
	Olivine	0.1	3.8
	Serpentine[1]	—	1.9
	Magnetite	0.2	0.3
	Groundmass	98.6	56.4
	Total	100.0	100.0

1—2 = Table VII.

[1] Pseudomorphous after olivine.

are to be observed. Because of the orientations of the sections of the mineral no determination of the axial angle could be performed. In the lava specimen from Casa Pangue the olivine phenocrysts occur rather frequently. They appear as roundedly idiomorphic crystals, to 1 mm in size, having been more or less thoroughly subjected to an alteration into a deep brown, iddingsitic substance. Judging from the size of the axial angle the olivine is comparatively rich in iron silicate.

The octahedral crystals of magnetite appearing as phenocrysts are in both rocks very sparse. In the Alerce lava they reach the size of at most 0.2 mm.

In the groundmass of the lava from Ventisquero Alerce, in spite of heavy pigmentation, plagioclase laths, about 0.06 mm in length, showing a beautiful sub-parallel orientation, and grains of pyroxene and ore may be identified. The intensity of the pigmentation varies in a streaky manner. In the heavier pigmented parts the glass seems to be present in greater quantity, too. The groundmass of the Casa Pangue rock is also very darkly pigmented and contains small, rather broad tabular crystals together with pyroxene in frequent fan-shaped radiating aggregates. In places there occur irregular vesicles, filled up by a limonitic substance, often with calcite in the centre.

4. **With phenocrysts of plagioclase, olivine and orthorhombic pyroxene.**

This combination of phenocryst minerals is represented by only one specimen. This is taken from a boulder at Ventisquero Alerce, Tronador.

Macroscopically the rock may be described as a non-vesicular lava with closely lying, light gray feldspar phenocrysts, up to 1 cm of size, in a blackish gray, aphanitic groundmass. Only a slight tendency to parallel orientation of the phenocrysts may be traced.

The microscopic picture of this rock is wholly dominated by the large plagioclase phenocrysts or, more correctly, aggregates of them. In appropriate sections an extraordinarily fine oscillatory zoning appears. The differences in extinction between the successive zones as well as between the central and peripheric parts amount to only a few degrees. In certain zones sometimes appear small, rounded, all but opaque inclusions. Moreover there occur now and then larger, semi-opaque interpositions without any distinct relation to the zoning. With the FEDOROW method a phenocryst twinned according to the Albite law was determined to basic labradorite with 70 and 67.5 % An, respectively. The axial angle of the latter partial individual was $2\,V_\gamma = 80^\circ$.

The mafic phenocrysts consist for the greater part of olivine. It forms sharply idiomorphic, partly more rounded crystals of perfect freshness. The greatest dimensions observed were 1.2×0.8 mm. This individual enclosed a little plagioclase crystal, whereas on the other hand the large plagioclase phenocrysts frequently bear small olivine crystals as inclusions. It is worthy of remark, too, that no chemical reaction at all has taken place between the two minerals at their contact surface. The axial angle of the olivine was determined to $2V_{\alpha} = 88°$, corresponding to 16 % Fe_2SiO_4.

Only one solitary phenocryst, 0.3 mm in length, of orthorhombic pyroxene was found. It differs through lower refraction and birefringence, more distinct cleavages, the appearance of the characteristic brown inclusions and the magnitude of the axial angle, from the olivine. The axial angle was measured to $2V_{\alpha} = 80°$, corresponding to 22 % $FeSiO_3$.

In the groundmass may be discerned plagioclase laths, about 0.1 mm of length, small grains of pyroxene not further determined (and probably olivine, too) together with rather evenly distributed ore grains in a residuum of relatively dark brown coloured glass.

A ROSIWAL analysis of the rock gave the following result (in percentage by volume):

Phenocrysts	Plagioclase	31.8
	Olivine	1.3
	Orthorhombic pyroxene (Not touched by the indicatrix line)	—
	Groundmass	66.9
	Total	100.0

5. With phenocrysts of plagioclase, olivine, clinopyroxene and magnetite.

Five rock specimens belong to this group. Of these three specimens have been collected at Ventisquero Alerce on the eastern side of Tronador and one sample on each of the two localities Cerro Volcánico and Ventisquero Grande.

If, at first, the rock from Cerro Volcánico, being in many respects of a different character, is not taken into consideration, the rocks in question are macroscopically dense, dark gray, blackish gray or grayish black lavas, in one case (No. 4) with somewhat brownish hue, in another case (No. 5) with dark reddish brown spots. The phenocrysts are generally rather sparse, in No. 2, however, more abundant, and usually somewhat lighter gray than the bulk of the rock. In the darkest types the difference is, however, very small. The maximum length of the phenocrysts is in the different specimens varying from 3 mm (No. 3) to 6 mm (No. 2). The different degree of vesicularity will appear from Table X. The vesicles are sometimes lined by a brown substance, very rarely quite filled up with minerals. The specimen from Ventisquero Grande (No. 2) is to a certain extent banded, layers of more numerous and larger vesicles,

Table IX.

Optical data on phenocrysts.

		1	2	3	4	5
Plagioclase	% An	88, 87	65.5, 59	53, 56.5	52.5, 52	50.5, 52
	2 V	—, −88°	+80°, +76°	—, +73°	+74°, —	+72°, —
	Tw. law	A	A	C	AC	AC
Olivine	2 V	−78°	−89°	−83°	−78°	−79°
Clinopyroxene	2 V	+51°	—	+44°	+51°	+46°
	$c:\gamma$	39°.5	41°	43°.5	43°.5	42°

1. Cerro Volcánico.
2. Ventisquero Grande, Tronador.
3. Ventisquero Alerce, lowest basalt flow.
4. Ventisquero Alerce, Tronador, boulder.
5. Ventisquero Alerce, lowest basalt flow.

partly more than 1 cm of width, alternating with those, bearing fewer and smaller vesicles, rarely 1/2 cm in diameter. The latter layers have a minor thickness (about 1 cm) than the former ones. The shape of the individual vesicles does not show any distinct relation to this banding. The specimen from Cerro Volcánico (No. 1), being different from the other rocks in question, is a somewhat bluish, rather light gray, compact lava with faintly appearing, sparse, lighter gray plagioclase phenocrysts, little more than 1 mm of length, and still less numerous, olive brown olivine crystals of about the same magnitude.

Table X.

Volumetric analyses.

	1	2	3	4	5
Plagioclase	5.6	27.9	7.7	9.2	8.3
Olivine	0.2	4.0	0.7	1.0	0.6
Serpentine[1]	—	—	0.3	—	0.9
Clinopyroxene	0.3	1.3	1.3	0.6	0.3
Magnetite	0.3	0.5	0.4	0.5	0.1
Groundmass	93.6	66.3	89.8	88.8	89.9
Total	100.0	100.0	100.2	100.1	100.1
Vesicles	—	20.6	1.2	0.1	3.3

1—5 = Table IX.

[1] Pseudomorphous after olivine.

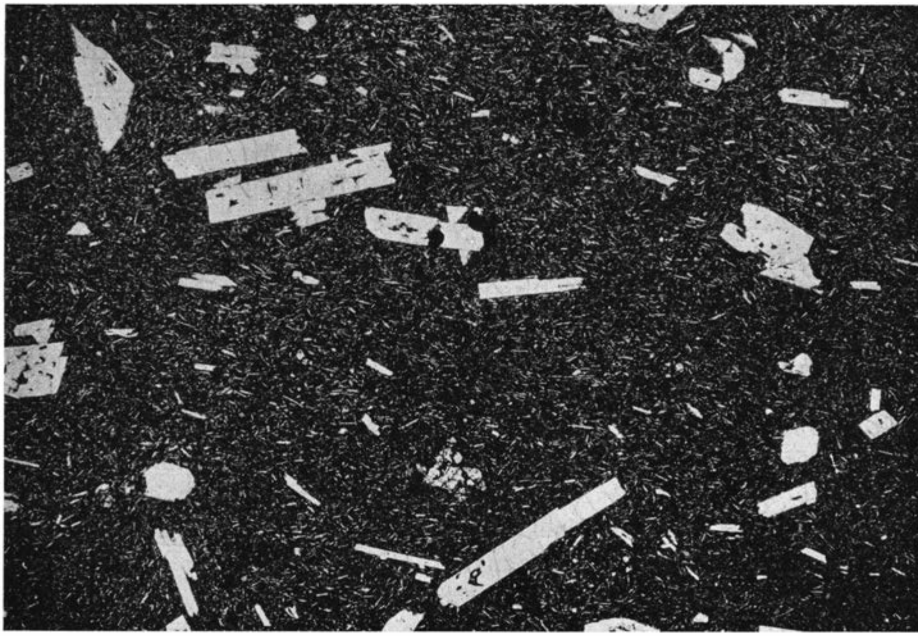


Fig. 27. Photomicrograph of basalt lava with phenocrysts of plagioclase, olivine, clinopyroxene and magnetite (No. 4 in Table IX and X). Tronador. Ord. light. Magnif. × 10.

The plagioclase phenocrysts form in thin sections relatively slender laths (Fig. 27). The ratio length : width is often about 7 : 1. They are unaltered and often quite free from interpositions. Sometimes inclusions are sparsely present, but seldom in distinctly zonal arrangement. The phenocrysts of rock No. 5 partly bear numerous, comparatively large groundmass inclusions of irregular shape. The zonal structure in the different rocks is of somewhat different type. In No. 4 it is very slightly pronounced. Nevertheless a distinctly more acid, outmost margin is clearly discernable. In No. 5 the plagioclase phenocrysts show a rather coarse zonal structure with only a few zones respectively basic recurrences, whereas No. 2 and 3 are characterized by a great number of fine recurrent zones, closely succeeding each other. Without considering No. 1 the phenocrysts show a chemical composition (see Table IX) entirely falling within the generally accepted limits of labradorite, and on an average tend to the more albite-rich side. The phenocrysts of the lava from Cerro Volcánico (No. 1) have a comparatively broadly prismatic shape and sometimes bear some inclusions of the groundmass as well as pure, brown glass. The zoning is such that round a quantitatively dominating core of basic bytownite with an albite percentage slightly decreasing outwards follows a thin margin of a distinctly more acid composition, in Ind. II, Table IX, according to the extinction ⊥ M and P (39°.5) 76 % An.

As will appear from Table X the olivine phenocrysts are generally rather sparse. The crystals, in maximum 0.2—0.6 mm of size, have in general an irregularly rounded shape; more rarely sharply idiomorphic individuals are observed. In general it may be stated that the degree of idiomorphism increases with the dimensions of the crystal. Only in specimen No. 2 the olivine is, as a matter of fact, unaltered. In No. 3 it has peripherically and sometimes along fissures, too, suffered an alteration into a lighter or darker green serpentine, whereas in No. 4 a rather inconsiderable, originating from fissures, and in No. 5 a farther advanced, often complete alteration into a typical, deep yellowish brown iddingsite has taken place. In the latter case the alteration is particularly thorough in the olivines lying in the vicinity of the vesicles. In the Cerro Volcánico lava No. 1, finally, especially the smaller crystals have been transferred peripherically, sometimes almost completely, into a fine crystalline aggregate of clinopyroxene, heavily impregnated with small ore grains. The composition of the olivine within this group of rocks varies, judging from the magnitude of the axial angle (Table IX). Members comparatively rich in fayalite however seem to prevail.

The phenocrysts of monoclinic pyroxene are larger, on an average, than the olivine phenocrysts. The maximum size in the different rocks was measured to 0.4, 4, 1.1, 0.8 and 0.6 mm. They generally show isometric, rounded, at most hypidiomorphic crystal forms. Sometimes (No. 3) the crystals may be accumulated in clusters, in one case also together with plagioclase, forming a gabbroidic body, as the groundmass here has as a matter of fact been quite squeezed out between the crystals. The pyroxene is usually faintly, but distinctly greenish coloured, non-pleochroic, and often shows simple twins or solitary twinning lamellae on (100). Only in the rock No. 2 inclusions of small olivine and ore crystals are present in any quantity worth mentioning. No secondary alteration has affected the pyroxene phenocrysts. The optical determinations (Table IX) hint at a composition fairly rich in lime, not, however, pure diopsidic.

Finally phenocrysts of magnetite are only to be found sporadically. The octahedral form is often developed. The crystals, in general 0.25—0.50 mm, sometimes fully 1 mm of size, are occasionally irregularly accumulated. In specimen No. 4 an agglomeration of a number of magnetite individuals was observed, measuring 1.5 mm in diameter.

The groundmass may be so heavily ore-pigmented (No. 3 and 5) that of crystallized minerals only the plagioclase laths, about 0.08 mm of length, are distinctly outlined. In rock No. 3 they are in beautiful fluidal arrangement parallel to the surfaces of the phenocrysts and round the small vesicles. At a more moderate pigmentation grains of pyroxene and magnetite, generally 0.02—0.03 mm of size, also make their appearance.

In No. 2 the pyroxene grains are, however, of about the same length as the plagioclase laths, 0.1 mm, and the magnetite crystals of idiomorphic development. The quantity of glass in the groundmass varies. Whereas No. 4 is as a matter of fact holocrystalline and No. 1 shows a quite unimportant uncrystallized remnant of relatively light brown glass, in No. 2 the glass is rather abundant and dark brown—black of colour.

The vesicles are mostly lined, more seldom wholly filled up, by an olive brown or commonly a deep yellowish brown, isotropic substance, partly with concentrically arranged fissures, obviously a limonitic product, which often penetrates into the groundmass immediately surrounding the vesicles. In some cases (No. 2) also a few radiating spherocrystals of a grayish green, chloritic mineral were noticed in the vesicles.

6. **With phenocrysts of plagioclase, olivine, orthorhombic pyroxene and pigeonite.**

Only one specimen with the combination of phenocryst minerals mentioned in the heading above was found in the collection examined. It derives its origin from Ventisquero Grande, Tronador. It is a spotted, lighter or darker, partly bluish gray, very scoriaceous rock with lighter feldspar phenocrysts, up to 8 mm in length, and rather well rounded vesicles, generally about 1—3 mm in diameter.

The plagioclase phenocrysts are fresh and either wholly lacking inclusions or have a zone of them near the periphery. Only exceptionally do larger groundmass inclusions occur with irregular size and orientation. The zoning is little pronounced and is of the finely recurrent type with only slight differences in the extinction of the zones. On an Albite-Carlsbad twin the anorthite percentage was determined to 62 and 56 %, respectively. The axial angle of the first one of the twin individuals was $2V_\gamma = 70°$.

Olivine is present as idiomorphic, wholly fresh crystals with a greatest length of about 0.6 mm. A determination of the axial angle gave the result $2V_\alpha = 85°$, corresponding to 22 % Fe_2SiO_4.

Orthorhombic as well as monoclinic pyroxene are met with in this rock as phenocrysts, too. The former was observed only in a few, broadly prismatic individuals (the largest one measuring 1.3×0.55 mm) with distinct pleochroism. The axial angle, $2V_\alpha = 62°.5$, measured on the universal stage, corresponds to a composition of 40 % $FeSiO_3$. The orthorhombic pyroxene contains small enclosed crystals of monoclinic pyroxene and plagioclase.

The phenocrysts of monoclinic pyroxene have commonly rounded outlines, often with embayments filled with the groundmass. The largest individual measured 1×0.4 mm. A slight pleochroism is sometimes discernable, not so strong as that of the orthorhombic pyroxene, but in about the same colours. Twinning is occasionally found. On the universal stage the axial angle was determined to $2\,V_\gamma = 12^\circ.5$ and the extinction in section $\perp \beta$ to $c : \gamma = 37^\circ.5$.

The groundmass is composed in the greater part of a brown, heavily pigmented glass, in which are lying solitary microliths of chiefly plagioclase and pyroxene. The abundant, rounded vesicles are partly without mineral filling, partly filled with either a black, opaque or brownish yellow, isotropic substance.

The volumetric composition of this lava will appear from the following ROSIWAL analysis:

Phenocrysts	Plagioclase	27.4
	Olivine	2.2
	Orthorhombic pyroxene	0.8
	Pigeonite	1.5
Groundmass		68.2
	Total	100.1

The vesicles form not quite half the volume of the rock, or 42.5 %.

7. **With phenocrysts of plagioclase, olivine and pigeonite.**

Three specimens belong to this last group of the olivine-bearing lavas of the Tronador area. Two of them come from Ventisquero Grande, Tronador, whereas the third one was collected from the bed of Rio Manso, in the same valley, into which the glacier mentioned opens, but about 4 kilometres southeast of its lower end (Loc. 4, Fig. 3). As the three specimens have all been taken from loose pebbles, the two first-mentioned from the terminal moraine of the glacier (*cf.* LJUNGNER 1931, p. 226) and the third one among the river pebbles, for which a fluviatile (and glacial) transport from the same place of origin as that of the moraine material seems highly probable, it is possible to infer that rocks of this group occur, or in any case have occurred, in primary position in higher parts of Cerro Tronador. As the lava described in the preceding section (p. 267) was collected in the moraine material below Ventisquero Grande, too, it is very likely that on the whole the interesting rock types characterized by phenocrysts of pigeonite within the whole area covered by this investigation are to be found *in situ* only within a relatively restricted part of the feeding grounds of the glacier mentioned.

Megascopically the three rocks show great similarities. They are porphyritic lavas with dark, lustrous phenocrysts of feldspar, sometimes of more than 1 cm in length. The larger phenocrysts in particular have partly a brownish gray hue. Phenocrysts of mafic minerals do not appear distinctly with the naked eye. The groundmass is aphanitic and dark steel-coloured or black. Only in the lava No. 3 (Table XI and XII) solitary, small vesicles may be observed.

Table XI.

Optical data on phenocrysts.

		1	2	3
Plagioclase	% An	60, 62	61.5, 55	57.5, 54
	2 V	—, +74°	+76°, +72°	—, +71°
	Tw. law	C	A	AC
Olivine	2 V	−80°	−88°	−83°
Pigeonite	2 V	0°	0°	+ 5°
	$c:\gamma$	40°	41°	40°

1, 2. Ventisquero Grande, Tronador.
3. The bed of Rio Manso.

Microscopically the phenocrysts of plagioclase prove to be extraordinarily fresh and generally quite free from inclusions of every kind. Sometimes, and especially in the larger individuals, there occur well-defined rows of minute, semi-opaque grains parallel to the limiting faces of the crystals. In appropriate sections of the larger crystals in particular a beautiful zoning makes its appearance, characterized by a repeated sequence of fine, closely lying, recurrent zones, being in extinction and, therefore, in percentage of anorthite, too, only slightly different. The range of variation in the chemical composition of the phenocrysts is relatively unimportant. As will appear from Table XI it deals with a tolerably albite-rich labradorite, on an average with 58.5 % An.

Pyroxene and olivine, respectively pseudomorphs after the latter mineral, appear as phenocrysts, too. Whereas the olivine in the rock No. 3 is met with as quite fresh and often perfectly idiomorphic crystals, up to 0.8 mm in length, it is found in the two other rocks only in a few unaltered remnants (see Table XII). It is in fact in these rocks generally quite altered into a dark, partly somewhat brownish, green serpentine, forming rounded pseudomorphs of fibrous structure of an average size of about 0.4 mm. Judging from the magnitude of the axial angle the chemical composition of the olivine varies somewhat. On an average, however, a rather fayalite-rich member seems to prevail.

The phenocrysts of monoclinic pyroxene, in maximum reaching the length of 1.5 mm, are not of a perfectly idiomorphic form, but show in general a rough, as it were corroded outline against the groundmass (Fig. 28). The mineral is free from inclusions and alteration products and is in thin sections either all but colourless or shows a rather distinct pleochroism in pale brownish and pale reddish. Twinning is frequent. This

Table XII.

Volumetric analyses.

		1	2	3
Phenocrysts	Plagioclase . . .	24.0	24.7	25.9
	Olivine	0.1	0.2	3.2
	Serpentine[1] . . .	1.0	2.3	—
	Pigeonite	1.1	0.8	1.0
Groundmass		73.9	71.8	69.9
	Total	100.1	99.8	100.0
Vesicles		—	—	1.1

1—3 = Table XI.

especially holds good for No. 1, where in particular the larger phenocrysts show an abundant polysynthetic twinning lamellation. Thus on an individual 0.9 mm in breadth there were counted not less than 54 twinning lamellae on (100). These facts together with the optical determinations in Table XI prove that pigeonitic pyroxenes poor in lime are here present.

Corresponding to a different rate of cooling the groundmass of the lavas 1 and 2 is of a deviating development as compared with that of No. 3. In the two first-mentioned rocks it is composed of an all but holocrystalline, relatively homogeneous mineral mixture, in which may be discerned twinned plagioclase laths with an average length of about 0.12 mm, between these occur rather isometric grains of pyroxene and irregular, but evenly distributed ore lumps, both of the order of magnitude 0.02 mm. Solitary lumps of ore are larger, then showing a tendency to the development of crystal faces. The quantitative proportion between the two last-mentioned minerals could be estimated by eye to pyroxene : ore = about 5 : 1, and the proportion plagioclase : dark minerals in the groundmass to about 2 : 3. The proportion between the different phenocryst minerals mutually and to the groundmass will appear from the ROSIWAL analyses compiled in Table XII. Characteristic of the groundmass of No. 1 and 2 is the appearance of winding, rather diffusely bounded, somewhat coarser streaks, in which the dark minerals, except of ore, are represented by a green or brown, fibrous serpentine, obviously representing a local enrichment in volatile constituents, mainly water. The groundmass of the lava No. 3, being more rapidly congealed, is composed for the greater part of a dark brown, almost opaque glass, in which are lying scattered microliths of plagioclase, pyroxene and olivine. Here and there rounded vesicles of somewhat varying size are noticed, being lined by serpentine.

[1] Pseudomorphous after olivine.

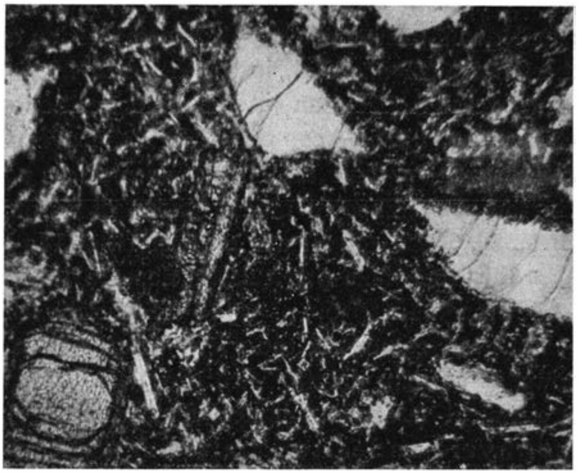


Fig. 28. Photomicrograph of basaltic lava with phenocrysts of plagioclase, olivine and pigeonite (No. 1 in Table XI and XII). Ventisquero Grande, Tronador. Ord. Light. Magnif. × 67.

Table XIII.

Analysis II. Andesitic olivine basalt with pigeonite phenocrysts. Ventisquero Grande, Tronador.

	Weight-%	Mol. Prop.	Norm				Niggli values		
SiO_2	53.21	8860	Q		3.47	65.25	si	141	
TiO_2	1.61	202	or		10.35		al		26
Al_2O_3	16.66	1634	ab		23.75		fm		40.5
Fe_2O_3	1.16	73	an		27.68		c		23.5
FeO	8.93	1243	di	$CaSiO_3$	4.17	34.40	alk		10
MnO	0.21	30		$MgSiO_3$	1.89				100.0
MgO	4.44	1101		$FeSiO_3$	2.25		ti	3.22	
CaO	8.28	1477	hy	$MgSiO_3$	9.17		h	1.95	
Na_2O	2.81	453		$FeSiO_3$	10.91		p	0.59	
K_2O	1.75	186	mt		1.69		o	0.06	
H_2O+	0.22	122	il		3.07		mg	0.44	
H_2O-	(0.59)	—	ap		1.25		k	0.29	
P_2O_5	0.53	37	H_2O+			0.22	qz		+1
Total	99.81					99.87			

II. 5. 3. 4. Andose. — Or : Ab : An = 16.75 : 38.44 : 44.80.

Spec. gr. $\frac{17^{\circ}.5}{4^{\circ}}$ = 2.81.

A chemical analysis of the lava from Ventisquero Grande, Tronador, the qualitative and quantitative mineralogical composition of which is given as No. 2 in the Tables XI and XII, is to be found in Table XIII. This analysis holds in several respects an intermediate position between quartz-free and quartz-bearing basalts, compared with the average compositions given by DALY (1933, p. 17 and 18). This intermediate position also finds its expression in the appearance of modal olivine at normative quartz and positive, though small, NIGGLIan quartz number (+1). In NIGGLI's system of magma types this rock falls particularly close to the type of the normal gabbrodioritic magma (1936, p. 352). Especially the *si* number of our analysis is, however, somewhat too great. In this as well as some other respects it shows a certain affinity with the orbitic magma type. Considering these chemical and mineralogical facts andesitic olivine basalt or chrysophyric andesitobasalt with plagioclase and pigeonite phenocrysts seem to be adequate denominations.

Group II. **Olivine-free basalts and pyroxene andesites.**

In this group those rocks are brought together which lack phenocrysts of olivine but, on the other hand, have phenocrysts of pyroxene. According to the mineral paragenesis of the phenocrysts three types may here be distinguished.

8. **With phenocrysts of plagioclase, orthorhombic and monoclinic pyroxene.**

The rock type, characterized by this combination of phenocrysts originates from the collection of boulders made in the moraine material at Ventisquero Grande, Tronador. Only one specimen is present, namely a dark gray, fine-grained, non-vesicular rock with rather abundant, dark, lustrous phenocrysts, at most 2 mm in size.

The plagioclase phenocrysts are relatively thick tabular to prismatic. They are fresh, but bear generally abundant inclusions of the minerals of the groundmass, which are most commonly arranged in such a way that an outmost, more acid border is entirely free from them. The plagioclase substance of the basic core is either homogeneous or shows an insignificant zonal structure with basic recurrences. The chief central part of a Carlsbad twin showed a composition of 83 and 90 % An, respectively, whereas in the outmost thin marginal zone of the twin individual I an extinction $\perp$ P and M indicates a percentage of anorthite of only 59 %.

Olivine is lacking. Orthorhombic pyroxene is, on the other hand, present in a few, relatively slender, prismatic phenocrysts, up to 0.9 mm of length, with faint, but quite distinct pleochroism and, peripherically and along fissures, a slight alteration into serpentine. The axial angle was measured to $2\ V_\alpha = 72°$, corresponding to a hypersthene with 29.5 % $FeSiO_3$.

Phenocrysts of monoclinic pyroxene also occur. They form pale greenish, rather equant, often twinned individuals with a maximum diameter of 1.1 mm and fairly irregular outlines. On the universal stage were determined $2\ V_\gamma = 49°$ and $c:\gamma = 44°.5$.

The quantitative importance of the different phenocryst minerals will appear from the following ROSIWAL analysis:

Phenocrysts	Plagioclase	21.2
	Orthorhombic pyroxene	0.3
	Monoclinic pyroxene	0.6
Groundmass		77.9
	Total	100.0

The groundmass of this rock is holocrystalline and comparatively coarse. The plagioclase laths are rather broad. Orthorhombic as well as monoclinic pyroxene appear, the former in hypidiomorphic, prismatic crystals, the latter in more irregularly rounded, generally rather equant grains. Magnetite is present in moderate quantity evenly distributed in partly idiomorphic crystals. Finally mention must be made of a dirty brownish green, fibrous serpentine mineral, in places filling up the interstices between the plagioclase laths. The same mineral also forms larger aggregates, possibly representing altered olivine phenocrysts.

From this description it appears that the rock in question must be described as a basalt. The absence, or instability, of the olivine indicates a type relatively rich in silica.

9. **With phenocrysts of plagioclase, orthorhombic pyroxene, monoclinic pyroxene and magnetite.**

This type is represented by six rock specimens. Three of them were collected amongst the boulders at the lower end of Ventisquero Grande, one below the Alerce glacier and two in the bed of Rio Peulla at Casa Pangue. All samples are taken from loose boulders, obviously in secondary location. On account of the position of the localities in relation to Cerro Tronador it may be stated with good reason that the rocks in question by means of glacial and perhaps partly fluviatile transportation, too, have been brought to their present positions from one or more primary occurrences in the more elevated parts of Cerro Tronador, areas not visited by LJUNGNER's expeditions.

The macroscopic appearance of these effusive rocks shows some variations. The colour ranges from grayish black through darker or lighter, partly bluish gray to reddish brown. Compact or somewhat vesicular as well as highly scoriaceous types are represented. A lava of the last-mentioned character (No. 3 in the Tables XIV and XV) has fluidally very much elongated vesicles. In cross section they have a flattened oblong size of a magnitude up to 2×5 mm, whereas their length may reach several cm. The vesicles have a lighter gray, partly brownish violet coating. In this rock, obviously coming from a very superficially congealed part of a lava flow, the phenocrysts hardly appear to the naked eye. In the other five rock types feldspar phenocrysts occur abundantly. They are lighter gray than the groundmass, in No. 2 and 4 partly almost quite white. An exception occurs in the reddish brown lava No. 5, which has dark, partly gree-

Table XIV.

Optical data on phenocrysts.

		1	2	3	4	5	6
Plagioclase	% An	56.5, 59	57.5, 57.5	53.5, 58	51, 57.5	53, 55	43, 44
	2 V	–, + 78°	+76°, +84°	+70°, +71°	+81°, +77°	+78°, –	+87°, +85°
	Tw. law.	AC	C	A	AC	C	A
Orthopyroxene	2 V	−72°	−58°	−60°.5	−66°	−59°	−65°
Clinopyroxene	2 V	+55°	+57°	+50°	+53°	+52°	+53°
	c : γ	42°.5	42°	42°	43°.5	41°.5	44°.5

1. Ventisquero Grande, Tronador.
2. » » » .
3. Ventisquero Alerce, » .
4. Ventisquero Grande, Tronador.
5. Casa Pangue, Chile.
6. » » » .

nish phenocrysts. The greatest lengths of the phenocrysts of the different rock specimens were measured to 2, 4, 2.5, 4, 6 and 2 mm, enumerated in the same order as in the Tables XIV and XV.

The plagioclase phenocrysts have generally a rather broad tabular or prismatic form, in cross sections often with all but quadratic outlines. In No. 1 they are, however, relatively thin platy and in No. 3 rather slender, lath-shaped, for instance with the dimensions 2.4×0.35 mm. The zoning shows some variations. In No. 1 a fine oscillatory zonal structure is observed, the zones, however, differing quite slightly in extinction. The plagioclase phenocrysts of the rocks No. 2, 4 and 5 show less numerous and broader zones with greater differences in extinction and therefore in An-percentage, whereas in No. 3 and 6 the zonal structure is slightly pronounced and of most simple type without basic recurrences. Whereas the phenocrysts of No. 1 and 3 are quite lacking inclusions and those of No. 4 only exceptionally have large ones of irregular size consisting of pure, pale brown glass, those of No. 2 and 5 are bearing primary groundmass inclusions abundantly, which especially holds good of the larger phenocrysts. In No. 6 occur, side by side, phenocrysts closely studded with inclusions and others having only a few or no interpositions, the latter type of the two kinds of phenocrysts being predominant. Sometimes the inclusions are confined to a more or less broad, intermediate zone in the plagioclase (No. 2). The outmost margin highest in albite is almost completely free from the inclusions. No secondary alteration at all of the plagioclase may be noticed in the rocks here described. As will appear from Table XIV the phenocryst plagioclase of this group of rocks shows a rather inconsiderable range of variation with regard to its chemical composition, namely from average labradorite (No. 1) to basic andesine (No. 6). The mean value of the determinations performed gives an acid labradorite with about 53 3/4 % An.

Table XV.

Volumetric analyses.

		1	2	3	4	5	6
Phenocrysts	Plagioclase	13.1	21.4	1.9	9.3	23.6	19.8
	Orthopyroxene . .	1.2	2.6	0.1	1.1	3.9	2.1
	Clinopyroxene . .	0.2	1.9	0.4	0.6	2.3	4.8
	Magnetite	0.9	2.2	0.3	1.0	2.5	2.4
Groundmass		84.6	71.9	97.4	88.0	67.7	70.9
	Total	100.0	100.0	100.1	100.0	100.0	100.0
Vesicles		—	—	15.0	1.7	—	4.9

1—6 = Table XIV.

As will be seen from Table XV of the pyroxene phenocrysts the orthorhombic is in most cases quantitatively predominant (Fig. 29). The crystals are long, prismatic to the c axis. The ratio length : width is often about 10 : 1. The crystals are sometimes sharply idiomorphic, sometimes they have softly rounded ends. The greatest length measured in the different sections was 1.75, 2.1, 1.0, 0.5, 0.8 and 0.6 mm, respectively. Pleochroism in green and brownish red colours is generally quite distinct. Only in No. 3 the pleochroism is remarkably faint. The chemical composition deduced from the magnitude of the axial angle shows a percentage of the $FeSiO_3$ component varying between 29.5 and 46.5 % with an average of 39.5 %. In most cases the hypersthene has suffered no secondary alteration worth mentioning. In rock No. 1, however, in some phenocrysts

Fig. 29. Photomicrograph of pyroxene andesite with phenocrysts of plagioclase, orthopyroxene, clinopyroxene and magnetite (No. 1 in Table XIV and XV). Ventisquero Grande, Tronador. Ord. light. Magnif. × 11.

an alteration along fissures into a relatively dark yellowish brown bastite has started, whereas in No. 5 the alteration product, occurring peripherically, especially in the ends, and along solitary cross-cutting fissures in the hypersthene phenocrysts, is a green bastitic serpentine.

The monoclinic pyroxene forms phenocrysts of a more rounded equidimensional shape than those of the orthorhombic pyroxene. Sometimes a sharp idiomorphic form prevails. The crystals on an average are somewhat smaller than the hypersthene phenocrysts. The greatest dimensions measured in the different rocks are in order from No. 1 to No. 6: 0.5, 0.5, 0.3, 0.6, 0.6 and 1.0 mm. In thin sections they have a pale greenish colour, but are lacking distinct pleochroism. Simple twinning or solitary twinning lamellae on (100) often occur. The rather closely agreeing optical properties (Table XIV) hint at a not too great variation in the chemical composition. Also in those types, where the hypersthene shows an incipient alteration, the monoclinic pyroxene is quite fresh.

Finally phenocrysts of magnetite occur in these rocks more or less abundantly, too. It forms crystals of often sharp octahedral form with following maximum dimensions measured, from No. 1 to 6: 0.3, 0.125, 0.25, 0.4, 0.5 and 0.4 mm. In rock No. 5 the crystals are throughout relatively rounded. The magnetite phenocrysts are sometimes included in the pyroxene phenocrysts, also the orthorhombic ones, less often in the plagioclases.

The groundmass is holocrystalline only in No. 1. The length of the plagioclase laths amounts to about 0.08 mm. By their arrangement they give rise to a distinct, though not especially remarkable fluidal structure. The dark silicate minerals can scarcely be characterized more precisely. Small magnetite octahedrons, about 0.02 mm in size, are dispersed rather evenly and abundantly in the groundmass. The other rocks are characterized by the fact that the groundmass largely consists of glass. When this is deep reddish brown (No. 5) or black (No. 3) pigmented, only the plagioclase laths, about 0.075 mm of length, appear distinctly. In the latter rock these are lying fluidally arranged parallel with the elongation of the large vesicles. These are surrounded by a lighter zone almost one mm broad, only differing microscopically from the remaining part of the groundmass by its reduced pigmentation. In the groundmass of the rocks No. 2, 4 and 6 the pale brown glass is not, or only slightly, pigmented. The scattered plagioclase and pyroxene microliths show a beautiful fluidal arrangement, especially in the immediate neighbourhood of the phenocrysts and the sparse vesicles. Small crystals of pleochroic apatite are of rare occurrence in No. 2. In No. 6 the small, sparse, and irregular vesicles are lined with a chloritic substance.

The chemical analysis No. III (Table XVI) refers to a loose boulder from Ventisquero Grande, Tronador. Its modal qualitative and quantitative composition is to be found under No. 4 in the Tables XIV and XV. If this analysis is compared with the mean values of augite and hypersthene andesites calculated by DALY (1933, p. 16), our analysis shows the following essential divergences: higher SiO_2, higher total of alkalies, and especially higher K_2O, together with smaller percentage of iron, as well as smaller MgO and CaO. On the other hand the agreement with the average of quartz latites is particularly great. The divergences (the oxidation degree of the iron, the slightly lower SiO_2 and somewhat smaller ratio $K_2O : Na_2O$) point in the direction of andesite. Taking into consideration the chemical, as well as the mineralogical composition, this rock could be characterized as quartz-latitic pyroxene andesite. An attempt at fitting our rock into the NIGGLIan system of magma types gives the result that it holds an intermediate position between the normal granodioritic and the opdalitic respectively the farsunditic magma types (NIGGLI 1936, p. 347—348). Finally from a chemical point of view it remains to call attention to the relatively high percentages of water and phosphorus of this rock, which, as minerals bearing essential quantities of H_2O and P_2O_5 are lacking, obviously enter into the quantitatively abundant glass.

Table XVI.

Analysis III. Quartz-latitic pyroxene andesite. Ventisquero Grande, Tronador.

	Weight-%	Mol. Prop.	Norm				NIGGLI values		
SiO_2	62.11	10341	Q		16.62	83.87	si	233	
TiO_2	0.92	115	or		19.03		al		34.5
Al_2O_3	15.66	1536	ab		31.98		fm		25.5
Fe_2O_3	1.99	125	an		16.24		c		18.5
FeO	3.31	461	di	$CaSiO_3$	0.48	14.32	alk		21.5
MnO	0.06	9		$MgSiO_3$	0.27				100.0
MgO	1.70	422		$FeSiO_3$	0.18		ti	2.59	
CaO	4.57	815	hy	$MgSiO_3$	3.97		h	25.74	
Na_2O	3.78	610		$FeSiO_3$	2.85		p	1.28	
K_2O	3.22	342	mt		2.90		o	0.22	
H_2O+	2.06	1144	il		1.75		mg	0.37	
H_2O-	(0.23)	—	ap		1.92		k	0.36	
P_2O_5	0.81	57	H_2O+			2.06	qz		+47
Total	100.19	—				100.25			

II. 4. 3. 4. Tonalose. — Or : Ab : An = 28.30 : 47.55 : 24.15.

Spec. gr. $\frac{17^\circ.5}{4^\circ} = 2.53$.

10. **With phenocrysts of plagioclase, orthorhombic pyroxene, monoclinic pyroxene, magnetite and apatite.**

One single specimen of unaltered lava with the phenocryst combination cited above originates from the collection of boulders made in the bed of Rio Peulla at Casa Pangue on the Chilean side of the boundary. Together with the rocks of the preceding group its primary occurrence is most probably to be found in the higher parts of Cerro Tronador.

Macroscopically it is a dark, somewhat bluish gray, compact lava with closely lying, light gray (feldspar) phenocrysts, only exceptionally up to 2 mm of length.

The plagioclase phenocrysts are broadly tabular and have, especially in the centre, generally abundant groundmass inclusions in irregular arrangement. The zoning is usually such that round a large, tolerably homogeneous, central part follows a margin more rich in albite with a small number of basic recurrences. An Albite-Ala twin gave a percentage of anorthite of 41.5 and 42 %, respectively, *i. e.* an andesine of average composition. The axial angle of the two partial individuals was determined to $2\,V = -89^\circ$ and $+88^\circ$, respectively.

Orthorhombic pyroxene occurs as phenocrysts rather scantily. It is thickly prismatic and devoid of inclusions, shows distinct pleochroism and has partly been altered into fibrous bastite. The crystals attain at most the length of 0.7 mm. The axial angle $2\ V_\alpha = 69^\circ$ corresponds to a composition of 33 % $FeSiO_3$.

The phenocrysts of monoclinic pyroxene are predominant over the orthorhombic. They are, in thin sections, colourless or pale greenish in colour, have no inclusions or alteration products and form relatively equant, generally twinned crystals of about the same order of magnitude as those of the orthorhombic pyroxene. The determinations on the universal stage of axial angle and extinction, $2\ V_\gamma = 53^\circ$, $c:\gamma = 40^\circ$, suggest a chemical composition closely related to that of the monoclinic pyroxene of the immediately preceding group of rocks.

Magnetite and apatite also appear as phenocrysts. The former is rather abundant in somewhat rounded, idiomorphic octahedrons, at most 0.3 mm in size. The apatite forms hexagonal prisms of the order of magnitude 0.2 × 0.06 mm. These have a quite distinct pleochroism in

ω — reddish brown
ε — greenish brown-gray.

This pleochroism seems to be due to the occurrence of extremely thin rods arranged parallel to the c axis of the apatite. When these rods are lacking, as is often the case in the terminal parts, no pleochroism may be observed. Sometimes a central groundmass inclusion occurs in the apatite prisms.

The volumetric proportions between the phenocrysts mentioned will appear from the following ROSIWAL analysis:

Phenocrysts	Plagioclase	26.3
	Orthorhombic pyroxene	1.1
	Monoclinic pyroxene	3.3
	Magnetite	1.7
	Apatite	0.1
Groundmass		67.5
	Total	100.0

The groundmass is composed of a faint brownish glass with abundant, extremely small, not further definable microliths.

Group III. **Hornblende andesites and dacites.**

Lavas with hornblende as primary phenocrysts in the Tronador area are obviously of a rather limited occurrence, as only four specimens from two localities fall under this heading. With regard to the nature of the other phenocrysts these rocks may be divided into two groups.

11. **With phenocrysts of plagioclase, hornblende and magnetite.**

All the three specimens belonging to this group originate from the lava occurrence in the Victoria valley, southeast of the inner part of Brazo Tristeza. Macroscopically it is dense, rather light gray (No. 1), blackish gray (No. 2) or bluish brown-gray (No. 3) rocks, in the latter case partly vesicular and with highly ferruginous weathered crust. The two other rocks are compact. The phenocrysts hardly appear to the naked eye. In No. 2 there occur, however, irregularly distributed light gray to white mineral grains of varying size (to 4 mm), which, on account of their appearance, might be presumed to be of exogeneous origin.

The plagioclase phenocrysts are often fluidally arranged. They are fresh and mostly free from inclusions. In maximum the slender prismatic crystals reach a length of 0.5, 0.35 and 0.4 mm, respectively. The ratio between length and width generally exceeds 10 : 1. The minor individuals show skeletal, pointed ends. A slight zoning with a thin, more acid, outer zone can generally be observed. As appears from Table XVII the composition of the plagioclase phenocrysts varies between 56 and 62.5 % An, on an average corresponding to a mean labradorite with 59.5 % An.

Table XVII.

Optical data on phenocrysts.

		1	2	3	3 a
Plagioclase	% An	59.5, 62.5	60, 60	59.5, 56	68, 61
	2 V	+78°, +72°	—, +67°	+77°, —	+77°, —
	Tw. law	C	A	C	A

1—3. The Victoria valley.
3 a. Fragment from detritus of 3.

The magnetite phenocrysts generally form solitary octahedrons, partly with sharply idiomorphic shape, partly with somewhat irregular surfaces. Sometimes (in No. 1) small groups of crystals appear grown together. In maximum the magnetite crystals may reach the magnitude of 0.2 mm. The average size falls between 0.05 and 0.07 mm.

The sparse hornblende phenocrysts (see Table XVIII) are mostly altered into a granular, opaque mass rich in ore. The remnants, sometimes preserved in the centre show pleochroism in yellow and brown (No. 1), yellowish brown and dark brown (No. 2) or yellowish brown and greenish brown (No. 3). The extinction is small and twinning is observed. The hornblende has been of a long prismatic form. One of the largest pseudomorphs in the rock No. 1 had the dimensions 0.57 × 0.05 mm. One

Table XVIII.

Volumetric analyses.

		1	2	3
Pheno-crysts	Plagioclase	3.9	3.7	5.5
	Hornblende[1]	0.1	0.2	—[2]
	Magnetite	0.8	0.8	0.7
Groundmass		95.2	95.3	93.9
	Total	100.0	100.0	100.1
Vesicles		—	—	21.5
Xenoliths		—	2.5	—

1—3 = Table XVII.

indistinctly bounded crystal of the rock No. 3, in fact the only one found in this section, measured 0.3 × 0.06 mm.

The groundmass consists of plagioclase laths (about 0.05 mm of length), a felted aggregate of extremely minute, probably pyroxene microliths, and small magnetite grains. Whereas in No. 1 the existence of glass residuum cannot be definitely ascertained, the mentioned microliths of No. 2 and 3 are lying in an abundant, pale brownish coloured glassy base. The close lying vesicles, on an average under 1/2 mm in size, appearing in the last-mentioned rock, partly reveal rather irregular forms, but are not elongated in any certain direction.

A supposition was expressed above that the macroscopically visible, phenocryst-like mineral grains of rock No. 2 were of extraneous origin. This surmise is verified by microscopic examination. The xenocrysts, consisting of plagioclase, potash feldspar and quartz, are easily recognized by their accidental, fragmentary form, and concerning the plagioclase by the fact that the thin polysynthetic twinning lamellae do not show any definite relation to the external shape. The potash feldspar crystals are further dustpigmented. The latter, through the influence of the hot lava, have acquired a peculiar zoning in the manner that peripherically and with continuously decreasing intensity towards the centre of the xenocrysts a pale brownish tint has appeared. This colour, at the highest magnification, proves to be due to a partial fusion of the feldspar, by means of which exceedingly small, but close lying, pale brownish coloured drops of glass have been formed. In the plagioclase and quartz fragments no phenomena of fusion are to be observed. On the other hand close to the fragments mentioned there occur larger or smaller portions of pale brownish glass free from microliths. These glassy patches might be interpreted in

[1] Including pseudomorphs.

[2] Not touched by the indicatrix.

two ways, either in such a way that the relatively cool, extraneous mineral fragments enclosed by the lava have been wrapped in a partial or complete covering of quickly congealed glass, which during the continued movements of the magma has been partially torn off, or secondly and with more probability, in such a way that the comparatively hot magma has reacted on, and to some extent dissolved, the fragments being in relation to the equilibrium crystals — melt too acid and therefore instable. Round these were formed aureoles in this manner of a more acid composition than the average lava. The increased viscosity and decreased power of crystallization explain why these small glassy portions have congealed without crystallization of microliths, whereas in the relatively uncontaminated parts of the groundmass of the lava these latter are decidedly dominating. That this latter interpretation is the proper one is shown by the plainly corroding manner, in which these glassy patches enter into the foreign fragments. That the plagioclase xenocrysts have not been in equilibrium with the magma is shown by their composition. An individual twinned to the Albite law gave 37 and 34 % An, respectively (axial angle $2\ V_\alpha = 75^\circ$ and $74^\circ.5$, respectively), *i. e.* an average andesine, whereas the real plagioclase phenocrysts, as has been shown above, are labradorites.

An approximate idea about the temperature of the lava at the time for, and after, the incorporation of the xenocryst material may be obtained by the observation that only the potash feldspar shows indications of incipient fusion, whereas the plagioclase and the quartz have only undergone a partial chemical dissolution. The (incongruent) melting of potash feldspar, according to MOREY and BOWEN (1922, p. 21), begins at 1170° C. The lower limit of the melting interval of a plagioclase of the composition determined, according to BOWEN (1913, p. 289) lies at about 1235° C, whereas the fusion point of silica is $1685 \pm 10^\circ$ (ENDELL and RIEKE 1912, p. 252). The maximum temperature of the lava at and after the incorporation of the extraneous mineral fragments would consequently have been between 1170 and 1235° C, a value in good harmony with the direct estimations of temperatures, which have been made on active volcanoes in historical time (see the compilation made by DALY 1933, p. 68).

In this connection there may be mentioned a sample of a rusty brown, only slightly cemented disintegration product, collected close by the ledge from which the rock No. 3 above originates. This product, in the microscope, proves to be mainly composed of fragments of scoriaceous lava of a similar character as that of the subjacent rock. Hornblende phenocrysts were, however, not observed, which is not surprising, as in the whole thin section of the lava *in situ* only one phenocryst of that kind was observed. The interstices between the lava pieces are filled up chiefly with small fragments of quartz and feldspar, obviously deriving their origin from the granite of the vicinity. The results of a determination of a plagioclase phenocryst of one of the lava fragments are given as No. 3 a of Table XVII.

12. **With phenocrysts of plagioclase, hornblende, magnetite and apatite.**

This combination of phenocryst minerals has been met with in only one rock, *viz.* in the collection from the moraine at the lower end of Ventisquero Grande, Tronador. Macroscopically it is a dense, bluish gray rock with rather abundant, but small, partly whitish gray, partly more

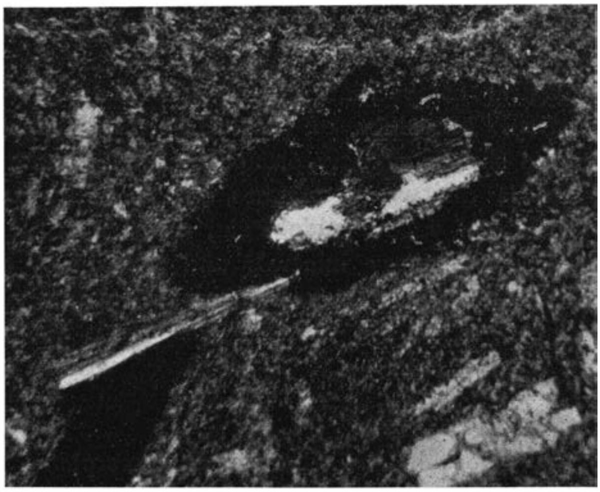


Fig. 30. Photomicrograph of hornblende dacite with phenocrysts of plagioclase, hornblende (largely resorbed), magnetite and apatite. Ventisquero Grande, Tronador. Ord. light. Magnif. × 68.

sparse, dark phenocrysts, at most 2.5 and 1 mm in size, respectively. A slight indication of parallel structure caused by stripes of somewhat different colour may be observed.

The plagioclase phenocrysts have a rather broad prismatic form and are partly aggregated in clusters. In part they are fairly rich in groundmass inclusions and have a rather faintly developed zoning. Small enclosed apatite crystals are not infrequent, more exceptionally some secondarily formed epidote crystal is observed, or a veinlet, filled by chlorite, cuts through the plagioclase phenocrysts. A crystal without products of decomposition, twinned to the Albite-Carlsbad law, proved to be a basic andesine with 49 respectively 50 % An in the two twin individuals. The axial angles were determined to $2\,V_\gamma = 78^\circ$ and 80°, respectively.

Phenocrysts of hornblende (and their pseudomorphs) occur sparingly. The hornblende substance only in a few cases is preserved to some extent in the central parts of the phenocrysts. A thinner or broader zone being altered into a granular, opaque, black matter (Fig. 30) always occurs peripherically. This alteration often proceeds to a complete disappearance of the hornblende substance. The hornblende, showing pleochroism in brownish yellow and greenish brown colours, has a small extinction angle, but because of the orientation of the sections could not be determined more thoroughly.

From the hornblende pseudomorphs the magnetite phenocrysts are easily distinguished being developed as separate octahedral crystals. Phenocrysts of apatite must also be mentioned. This mineral forms slender prismatic crystals of similar properties as in the apatite-bearing pyroxene andesites (p. 279). Apatite also occurs as inclusions in all other kinds of phenocrysts.

The mineralogical composition of the groundmass is veiled by a heavy pigmentation. Microliths of plagioclase feldspar however play an important rôle and show a slightly pronounced fluidal arrangement. The quantity of glass is difficult to estimate, but might be rather moderate. Here and there spots of yellow epidote and pale bluish green chlorite are to be seen. These secondary minerals and particularly the epidote increase highly in closest proximity to a thin ore — calcite vein intersecting the slice with somewhat winding course. This one is not included in the following ROSIWAL analysis:

Phenocrysts	Plagioclase	6.5
	Hornblende (including pseudomorphs)	0.8
	Magnetite	0.6
	Apatite	0.1
Groundmass		92.0
	Total	100.0

This rock specimen has been the object for a chemical analysis. The results of it will appear from Table XIX. If the average values of the chemical composition of different rock types calculated by DALY (1933) are brought forward for comparison once more, it appears that the analysis in question holds a position considerably nearer the average of dacites than that of hornblende andesites. As a matter of fact the divergences of our analysis IV from the dacite average, *viz.* a minor MgO, CaO and total iron percentage, as well as greater total percentage of alkalies, point in a more salic direction, whereas the SiO_2, TiO_2 and Al_2O_3 percentages show rather coinciding values. The relatively high percentage of P_2O_5 is remarkable for this analysis as well as for the preceding one (No. III). This finds its mineralogical expression in the appearance of apatite phenocrysts. Consequently the rock in question is most adequately described as a hornblende dacite with a certain tendency to rhyodacitic che-

Table XIX.

Analysis IV. Rhyodacitic hornblende dacite. Ventisquero Grande, Tronador.

	Weight-%	Mol. Prop.	Norm				NIGGLI values		
SiO_2	65.56	10916	Q		17.63	89.23	si	270	
TiO_2	0.52	65	or		13.91		al		40.5
Al_2O_3	16.63	1631	ab		46.45		fm		19
Fe_2O_3	1.30	81	an		9.77		c		12.5
FeO	2.50	348	C		1.47		alk		28
MnO	0.15	21	hy	$MgSiO_3$	2.37	9.97			100.0
MgO	0.95	236		$FeSiO_3$	2.94		ti	1.61	
CaO	2.88	514	mt		1.87		h	11.51	
K_2O	2.35	250	il		1.14		p	1.21	
Na_2O	5.49	886	ap		1.65		o	0.21	
H_2O+	0.84	466					mg	0.31	
H_2O-	(0.20)						k	0.22	
P_2O_5	0.70	49	H_2O+			0.84	qz		+58
Total	99.87					100.04			

I. 4. 2. 4. Lassenose. — Or : Ab : An = 19.84 : 66.24 : 13.93.

Spec. gr. $\frac{18°.5}{4°}$ = 2.55.

mistry. — For a final illustration of the chemical position of the rock in question it may be stated that in NIGGLI's system (1936) it is most naturally described as a rather basic representative for the leucoquartzdioritic magmas.

Group IV. Labradorite andesites.

This last group of lavas represented in the Tronador area is characterized by the absence of dark silicate minerals as phenocrysts and includes with regard to the combination of phenocryst minerals only one type of rock.

13. With phenocrysts of plagioclase and magnetite.

This type of rock is represented by three specimens, all from the lava occurrence in the Victoria valley. Macroscopically they are fine-grained to aphanitic, rather light gray or deep slate gray (No. 2) lavas, sometimes with a faint yellowish brown tint (No. 1). Vesicles are lacking in No. 1, whereas No. 2 has close lying vesicles, about 2 mm in length, uniformly elongated in the same direction. In No. 3 they are without distinct orientation and of varying size, exceptionally up to 2—3 mm in diameter, and partly lined with a white mineral. No phenocrysts appear before the naked eye.

Under the microscope, however, (micro)phenocrysts of plagioclase and magnetite are noticed. The former have an average size of 0.6 × 0.1 mm and are therefore thinly lath-shaped, sometimes showing skeletally pointed ends. They are unaltered and poor in, if not quite free from, inclusions. The zoning is generally slightly prominent. In rock No. 2 the plagioclase phenocrysts by means of their parallel orientation contribute to the accentuation of its pronounced fluidal structure. From Table XX it appears that the composition of the plagioclase varies from an acid bytownite with 72 % An to a basic andesine with 49.5 % An. An average of the determinations made gives a mean labradorite with 58 % An.

Table XX.

Optical data on phenocrysts.

		1	2	3
Plagioclase	% An	72, 60	56, 57	52.5, 49.5
	2 V	+76°, —	—, +78°	—, +
	Tw. law	C	AC	AC

1—3. The Victoria valley.

The magnetite phenocrysts appear as sharply limited octahedrons, partly with more irregularly curving limitation, though with roughly octahedral outlines also in this case. They are about 0.2 mm in size. In rock No. 2 some pseudomorphs after phenocrysts of a mafic mineral were noted with elongated, prismatic form now consisting of an opaque, fine-grained mass of ore. Most probably we are dealing here with magmatically quite altered phenocrysts of hornblende. Not only the shape and nature of the pseudomorphs are in favour of this but also the appearance at the same locality of lavas with partly preserved hornblende phenocrysts as described above.

The quantitative importance of the phenocrysts appears from the volumetric analyses in Table XXI.

The groundmass contains abundant plagioclase laths, 0.075—0.2 mm in length, and pyroxene microliths being in No. 2 very small, in No. 3 about 0.04 mm in size and not closer definable, whereas the groundmass of No. 1, being of somewhat coarser grain, contains, by far the most predominant, an orthorhombic pyroxene in prismatic crystals, 0.1 mm in length, partly sparse and considerably smaller, isometric grains of monoclinic pyroxene. Pleochroism is not distinctly noticeable in either of the pyroxenes. Of crystallized groundmass minerals, ore in octahedral grains, 0.02—0.04 mm

Table XXI.

Volumetric analyses.

	1	2	3
Phenocrysts: Plagioclase	10.2	5.0	4.0
Phenocrysts: Magnetite	0.8	0.7	0.7
Groundmass	89.0	94.3	95.3
Total	100.0	100.0	100.0
Vesicles	—	6.3	11.8

1—3 = Table XX.

in size, remains to be mentioned. Further a not inconsiderable, rather pale brown glassy residuum is present, being gray pigmented in No. 1. The plagioclase laths of the lava No. 2 show a nice trachytoidal arrangement coinciding with that of the elongation of the phenocrysts and vesicles.

The white mineral, which in certain parts of the lava No. 3 lines the vesicles, proves to consist under the microscope of a limpid, isotropic substance, probably opal.

Table XXII.

Analysis V. Labradorite andesite. The Victoria valley.

	Weight-%	Mol. Prop.	Norm			Niggli values		
SiO_2	56.52	9411	Q	9.35	78.48	si	173	
TiO_2	1.16	145	or	8.57		al		31
Al_2O_3	17.27	1694	ab	38.66		fm		31.5
Fe_2O_3	3.35	210	an	21.64		c		21
FeO	5.06	704	C	0.26		alk		16.5
MnO	0.23	32	hy $MgSiO_3$	5.72	21.38			100.0
MgO	2.30	570	hy $FeSiO_3$	5.03		ti	2.65	
CaO	6.34	1131	mt	4.86		h	1.03	
K_2O	1.45	154	il	2.21		p	1.95	
Na_2O	4.57	737	ap	3.56		o	0.24	
H_2O+	0.10	56				mg	0.33	
H_2O-	(0.20)					k	0.17	
P_2O_5	1.50	106	H_2O+	0.10		qz		+7
Total	99.85			99.96				

II. 5. 3. 4. Andose. — Or : Ab : An = 12.44 : 56.14 : 31.42.

Spec. gr. $\frac{18^\circ.5}{4^\circ}$ = 2.59.

Analysis V (Table XXII) has been made of the rock specimen, the qualitative and quantitative composition of which is stated in column 1 of the tables XX and XXI. A comparison with the analysis averages computed by DALY (1933) shows that the rock is most closely related to the andesite average. It has, however, lower SiO_2 and K_2O as well as higher total iron, CaO and Na_2O than the average mentioned. Also noticeable is the low H_2O and the high P_2O_5 percentage. From the type of the normal dioritic magma according to NIGGLI (1936) the rock in question differs by higher *si*, *al*, and *alk* as well as lower *fm*, *k* and *mg*. Whereas the higher *alk* value points to the normal quartzdioritic magma type, the low *mg* and the exceptionally low *k* number by relatively high *alk* show a distinct peléeitic affinity. Considering these chemical facts and the appearance of only labradoritic plagioclase as phenocrysts in addition to magnetite labradorite andesites seems to be the most adequate denomination for this group of rocks.

β. Dike rocks.

In the rock collection examined from the Tronador area *s. str.* there are only two occurrences of dike rocks represented, the petrographical characters of which are such that a genetic connection with the interglacial volcanicity seems to be probable. As the two dikes cut through the probably late-Mesozoic granodiorite but do not appear in contact with the lavas and pyroclastics of the interglacial series, the geological relations give no positive evidence for the estimation of their age. The geographical situation of the occurrences, at Ventisquero Alerce and Paso de las Nubes, respectively, on the eastern side of Tronador, might, on the other hand, be advanced in support of their inclusion in the interglacial series already based upon petrographical evidence. As the two rocks from a petrographical point of view present some divergences, they are each described separately.

1. The dike from Paso de las Nubes.

The rock from this dike is somewhat brownish dark gray, fine-grained, compact and macroscopically without distinct phenocrysts. Under the microscope, however, the rock exhibits a porphyritic picture, as monoclinic pyroxene appears in two generations and in addition pseudomorphs are present of obviously olivine phenocrysts.

The plagioclase, too, shows a dual tendency dividing into two dominating size groups. The larger magnitudes (about 1.1 × 0.1 mm) are so abundantly represented and transitionary sizes to the minor ones (about 0.07 × 0.01 mm) are present in so great a number that no typical porphyritic texture results with regard to the plagioclase. As will appear from the dimensions stated the feldspar is of a decidedly prismatic form. Inclusions occur very sparsely and secondary alteration products are quite lacking. The zoning is not specially pronounced and is generally of the simplest, normal type. A determination of a relatively large individual twinned according to the Albite-Carlsbad law gave 78.5 and 79 % An, respectively. The axial angle in both cases was 90°.

Olivine is nowhere preserved. But pseudomorphs occur, which by their shape and other characters prove to derive from earlier existing, porphyritic olivines. These pseudomorphs consist of a somewhat brownish green, scaly serpentine in the outer parts, whereas in the central portions colourless calcite predominates. The cleavages of the olivine are still conspicuous in the pseudomorphs through preserved ferritic coatings.

Monoclinic pyroxene is present, as already mentioned, in two generations. The larger crystals, in maximum about 0.6 × 0.3 mm, are rounded idiomorphic and rather equidimensional. They have a faint green colour without distinct pleochroism in thin sections of ordinary thickness. The boundary towards the surrounding groundmass is not sharply defined, as in the periphery enclosed groundmass minerals occur abundantly. A rather distinct hourglass structure is to be seen. Twins are, on the other hand, relatively scanty. The groundmass pyroxene appears in grains of the order of magnitude 0.03 mm, the optical characteristics of which cannot be more closely determined on account of the minor size. A porphyritic pyroxene crystal gave the following values on the universal stage: $2\ V_\gamma = 48^\circ$, $c:\gamma = 40^\circ.5$.

Magnetite occurs rather abundantly in octahedral crystals, generally 0.04 mm, only exceptionally 0.2 mm in size.

Except as indubitable olivine pseudomorphs serpentine of the same character also appears here and there in the interstices between the other minerals. Further there is found in a similar position a relatively unimportant, brown pigmented glassy residuum.

The quantitative proportions between the minerals mentioned will appear from the following volumetric analysis:

Plagioclase	49.7	
Olivine pseudomorphs	3.8	
Monoclinic pyroxene	34.6	(including 6.3 % phenocrysts)
Magnetite	5.9	
Serpentine (not pseudomorphous after olivine)	3.7	
Glass	2.3	
Total	100.0	

2. The dike from Ventisquero Alerce.

The rock from this 1 metre wide dike is somewhat brownish gray and fine-grained with scattered vesicles, up to 4 mm in size.

The texture of the rock may be described as doleritic. This applies to the bulk. There are also to be found larger or smaller, irregular, but rather sharply bounded portions of another texture, to which the vesicles seem to be tied.

Firstly the coarser bulk of the rock may be described. The plagioclase forming relatively thin, lath-shaped individuals of the dimensions 0.5×0.7 mm is quantitatively predominating. The zoning is of a simple type and not specially conspicuous. Inclusions are extraordinarily few in number. Secondary alteration products are quite lacking. A Carlsbad twin was determined to 69 and 73 % An, respectively. The axial angle of the two twin individuals was $2\ V_\gamma = 76°$ and $78°.5$, respectively.

Olivine or orthorhombic pyroxene are not observed. Fibrous aggregates of serpentine might possibly represent pseudomorphs of the latter mineral partly influenced in shape by the plagioclase laths.

Monoclinic pyroxene appears, on the other hand, in abundant, anhedral to subhedral grains of the order of magnitude 0.1 mm. They show a faint greenish colour. The axial angle was measured directly in one individual to $2\ V_\gamma = 46°$, in another it was obtained by means of graphical construction to $2\ V_\gamma = 47°$. The extinction $\perp \beta$ was measured to $44°.5$.

Magnetite is present rather abundantly and fairly uniformly scattered in octahedral crystals, about 0.07 mm in size, often joined into groups.

Finally there also occurs a glassy residuum of some importance. This is pigmented brownish gray and contains often rod- or hair-shaped microliths of pyroxene and ore.

The vesicles, generally quite or almost entirely filled by nicely spherulitic, yellowish brown coloured calcite and/or brownish green iron hydroxide gel, mostly of a concentric structure, are surrounded, as already mentioned, by an aureole of deviating character as compared with the bulk of the rock. Where the vesicles are lying close together, these aureoles join. In these the glass plays quantitatively a considerably more important rôle than in the remainder of the rock. In this glass thin plagioclase laths (order of magnitude 0.18×0.01 mm) are lying together with pyroxene crystals in the form of long, slender hair-like rods (one individual 0.46×0.007 mm). These pyroxene rods are generally sprinkled with small ore grains along a greater or smaller part of their length. Also smaller, obviously compact ore rods occur. Finally minute, irregular spots of all but isotropic, yellowish green chlorite may be observed.

ROSIWAL analysis:

Plagioclase	53.2
Monoclinic pyroxene	11.5
Serpentinous products	12.5
Magnetite	5.0
Glass	17.9
Total	100.1
Vesicles	13.5 %.

From the petrographical descriptions of the two dike rocks given above it is apparent, that they are both to be described as basaltic. The dike first described, *i.e.* that from Paso de las Nubes, has obviously a more basic composition (primarily olivine-bearing, plagioclase average bytownite, femic minerals : feldspar + glass = 48.0 : 52.0) than that from Ventisquero Alerce (no olivine, plagioclase basic labradorite, femic minerals : feldspar + glass = 29.0 : 71.0). The last-mentioned dike possibly represents a more superficial section than the former because of its greater percentage of glass and the appearance of vesicles, even though the more acid composition and the presumably greater percentage of volatile constituents, especially water, in the dike from Ventisquero Alerce may have contributed to the textural differences between the two dikes.

γ. Pyroclastic rocks.

In the description of the pyroclastic rocks the classification proposed by WENTWORTH and WILLIAMS (1932, p. 51—53) has been applied. These authors have adopted the size of the particles as the main principle of classification. Further subdivision has been made on the basis of shape and origin, structure and crystallinity of the particles as well as the occurrence of the material as individual fragments, detrital aggregates of fragments or indurated rocks.

1. Bombs.

Two volcanic bombs occur in the material examined, both being collected on Cerro Volcánico. One type is rusty brown and highly scoriaceous, revealing in cross section different concentric stripes of a somewhat varying texture. About two thirds of the bomb are preserved. Primarily it might have had a length of about 30 cm and a maximum thickness of somewhat more than 10 cm. Very prominent surface markings on the bomb indicate that it has undergone a spiral twisting of between 90° and 180° during its flight through the air. Megascopically no phenocrysts appear. The second bomb, of which two fragments are preserved together amounting to about the half of the original, has obviously been rounded with a diameter of about 8 cm. Surface markings are few and little prominent. The rock is black, in the outer parts (1—2 cm) dense, massive, in the centre finely scoriaceous. The phenocrysts are small and indistinctly visible.

Microscopically phenocrysts of plagioclase as well as olivine appear. The plagioclase phenocrysts are relatively few (Table XXIV) and minute (length about 0.25—0.3 mm) as well as thinly lath-shaped. In a thin section of the larger bomb only one solitary larger, platy crystal was observed, near the margin with a zone abundant in inclusions. For the rest the phenocrysts are not sharply differentiated in size from the groundmass plagioclase. On account of the diminutiveness of the crystals zoning is only slightly conspicuous. From Table XXIII it appears, that the plagioclase phenocrysts have a bytownitic composition.

Table XXIII.
Optical data on phenocrysts.

		1	2
Plagioclase	% An	90 , —	75, 79
	2 V	−86°, —	—, —
	Tw. law	—	C
Olivine	2 V	+89°	+89°

1. Cerro Volcánico, reddish brown bomb.
2. » » , black bomb.

Olivine is met with rather abundantly as phenocrysts, being considerably larger than the plagioclase phenocrysts, and measuring up to 0.75 mm in the larger and 1.75 mm in the minor bomb. The idiomorphic crystals sometimes contain larger groundmass inclusions and generally ore grains in fine regular lines, but are completely devoid of secondary alteration products. The positive axial angles measured correspond to a composition of 8—9 % Fe_2SiO_4.

The nature of the groundmass is highly disguised by an intense, reddish brown and respectively black pigmentation. Plagioclase together with pyroxene crystals may be discerned in the larger bomb. The small vesicles are devoid of mineral filling. As to the ROSIWAL analyses (Table XXIV) it is noteworthy that No. 2 represents a rather peripherical part of the bomb with relatively sparse vesicles.

From the preceding description it appears that the two volcanic bombs consist petrographically of olivine basalt, *viz.* of the quantitatively well represented type of lavas (No. 2, p. 255) characterized by phenocryst minerals plagioclase and olivine.

Table XXIV.

Volumetric analyses.

	1	2
Phenocrysts { Plagioclase . .	10.1	6.3
Phenocrysts { Olivine	5.8	4.5
Groundmass	84.1	89.2
Total	100.0	100.0
Vesicles	30.8	4.1

1—2 = Table XXIII.

2. Tuff breccias.

From Ventisquero Grande, Tronador, comes a sample of a rock, which is best described as a tuff breccia. Megascopically it consists of a yellowish brown-gray, unstratified tuff with interspersed subangular, partly amygdaloidal fragments of lava rocks, up to 3.5 cm in diameter.

Microscopically the rock fragments predominate over the more fine-grained ash particles. Among these latter, crystal fragments of plagioclase, olivine, and orthorhombic as well as monoclinic pyroxene are recorded. The ash particles are cemented by a brownish green, ferruginous substance.

The lava fragments are mainly basaltic, though slightly olivine-bearing. But andesitic types also occur. Special mention may be made of an olivine-free, vesicular type represented by a larger fragment, which has the vesicles almost entirely filled by two zeolite minerals, one in smaller, slightly brownish, beautifully developed, radiating aggregates with positive interference cross, whereas the other, later formed mineral constitutes bunches of more lengthened crystal needles without the strictly regular radial arrangement of the former. These also have positive elongation, but very weak birefringence.

A specimen of somewhat dubious origin has been collected as a loose boulder in the bed of Rio Manso, about 4 kilometres below the lower end of Ventisquero Grande. It is megascopically a fragmental rock with angular or more rounded fragments, almost 4 cm in size, and of composite character: light gray, grayish white, greenish gray, rarely grayish black, generally aphanitic, with some porphyritic. The rather sparse matrix is here and there deep yellowish green in colour.

It has been determined microscopically that the lava fragments as a matter of fact consist wholly of andesitic types, a number being extraneous to the lavas in Tronador. One such type is composed of slender plagioclase laths closely dispersed in a mass of bluish green, almost isotropic chlorite with or without small magnetite grains. Into other types a tolerably deep yellow epidote enters, which also appears abundantly in spots in the matrix, occasionally with calcite. Of the crystal fragments in the matrix plagioclase predominates. Olivine and pyroxene are lacking. A pale greenish, dark pigmented, chloritic impregnation forms the cementing matter.

Probably this tuff breccia, if it belongs to the Tronador series, represents an accidental component deriving its origin from the older country rocks penetrated by the explosion. The tuff breccia first described, on the other hand, obviously consists of essential and accessory material in the sense of WENTWORTH and WILLIAMS (1932, p. 45).

3. Lapilli tuffs.

Three rock specimens from three different localities are to be referred to this group of pyroclastic rocks. As they reveal rather great differences, they will be described separately.

From a hillock north of Paso Vuriloche, on the southern side of Cerro Tronador, there occurs a lapilli tuff of a rather dark bluish gray colour with darker lava fragments, up to 2 cm in size, and without any trace of stratification.

In this rock the lava fragments predominate to a marked extent over particles consisting of separate crystal or glass fragments. The tuff is therefore essentially lithic.

Among the crystal fragments the plagioclase is most abundant. Further orthorhombic and monoclinic pyroxene appear, the latter one, however, quite subordinately. Olivine is, on the other hand, entirely lacking. A plagioclase crystal (Carlsbad twin) proved to contain 63 and 58 % An, respectively. The axial angle of both twin individuals was $2\,V_{\gamma} = 73°$. A fragment of an orthorhombic pyroxene was determined to hypersthene with 49.5 % $FeSiO_3$ ($2\,V_{\alpha} = 56°$).

Nor is olivine present as phenocrysts among the lava fragments. Only andesitic types are represented:

1. Type with phenocrysts of plagioclase and monoclinic pyroxene in a black, practically opaque groundmass without microliths.

2. Type as 1, but highly scoriaceous with the vesicles partly filled by brown iron hydroxide gel.

3. As 1, but with plagioclase microliths in the groundmass.

4. Phenocrysts of plagioclase and orthorhombic pyroxene in a fine-grained groundmass with plagioclase, pyroxene and ore microliths as well as glass (darker or lighter brown).

5. Phenocrysts of plagioclase, monoclinic and orthorhombic pyroxene in a light yellowish brown glass with scattered microliths.

6. Phenocrysts of plagioclase and orthorhombic pyroxene in a colourless glass with abundant microliths.

A relatively slightly cemented, dark bluish black-gray tuff rock with fragments up to 2 cm in size occurred as a loose boulder at Ventisquero Grande. No stratification could be observed.

The dark colour under the microscope proves to be due to the abundance of dark, generally almost quite opaque basalt glass without crystallized minerals or with some solitary plagioclase, or olivine crystal, together with larger lava fragments with more abundant phenocrysts of plagioclase and, to a minor extent, olivine and/or orthorhombic and monoclinic pyroxene in an abundant, dark brown — black, more or less microlith-bearing glassy base. Pronounced vesicularity seldom occurs. But lighter, andesitic types appear with phenocrysts of plagioclase, pyroxene and sometimes magnetite as well, in a light brownish yellow glassy base with microliths of the same minerals. These types occur only in subordinate quantity.

Crystal fragments are comparatively sparse in this tuff. Of these plagioclase is highly predominant, whereas olivine and pyroxene are represented only in small quantities. Some fragments of quartz with undulatory extinction have a definitely accidental origin. — A plagioclase crystal (Carlsbad twin) had 57 and 55 % An, respectively, in the two twin individuals. The axial angles $2\,V_\gamma$ were 76° and 83°, respectively.

The third lapilli tuff, from Ventisquero Alerce at the eastern foot of Cerro Tronador, is slightly cemented and rather dark, somewhat bluish gray with lighter and darker fragments up to 6 mm in size. No distinct stratification was noticed.

It is evident microscopically that crystal fragments form a rather high percentage of the matrix between the rock fragments. Plagioclase, quartz, olivine, orthorhombic and monoclinic pyroxene, muscovite, biotite and chlorite occur and are cited according to decreasing frequency. Of these minerals quartz, muscovite, biotite, chlorite and part of the plagioclase, recognizable by means of its turbid, sericitized state, are obviously of accidental nature, originating from the penetrated granodiorite. In the matrix glassy fragments occur, of which the dark brown to black examples are decidedly predominating. On a fragment of a plagioclase phenocryst of essential (or accessory) origin the An percentage was determined to 62 and 65.5 %, respectively. It was an Albite twin with $2\,V_\gamma = 73^\circ$ and 72°, respectively. An olivine had $2\,V_\alpha = 86^\circ$, corresponding to 20 % Fe_2SiO_4, a hypersthene $2\,V_\alpha = 62^\circ$, corresponding to 41 % $FeSiO_3$.

Of the rock fragments the following types may be mentioned:

1. *Granite*. Abundant quartz with faint undulatory extinction. Plagioclase, in the centre highly sericitized. Chlorite, pleochroic in yellow and bluish green. Muscovite, sparse. Magnetite, zircon, and apatite, accessories.

2. *Basalt.* a. Doleritic, indistinctly porphyritic with solitary larger olivines, partly serpentinized. Practically holocrystalline rock.

b. Porphyritic with phenocrysts of plagioclase and olivine in a hemicrystalline, heavily pigmented groundmass.

c. As b, but with quite or almost quite vitreous, black groundmass.

d. As c, but with scattered vesicles.

3. *Basaltic andesite.* Phenocrysts of plagioclase and clinopyroxene in a heavily pigmented, hemicrystalline groundmass.

4. *Andesite.* a. Phenocrysts of plagioclase, orthorhombic and monoclinic pyroxene as well as magnetite in a hyalopilitic groundmass with brown glass.

b. Phenocrysts of plagioclase, monoclinic pyroxene and magnetite in a sparse groundmass, prevailingly of brownish yellow glass.

c. As b, but without magnetite and with lighter glass.

d. Sparse plagioclase phenocrysts in a hyalopilitic groundmass with all but colourless glass.

Summing up the descriptions of these three lapilli tuffs it can be said that apart from the varying percentages of accidental components (none in the tuff from Paso Vuriloche, greatest in the Alerce tuff) several petrographical types of lava rocks occur intermingled in each tuff sample amongst the fragments. When various types are represented quantitatively in approximately the same degree, it may, of course, be difficult to decide, whether a particular type is to be regarded as essential in the sense of WENTWORTH and WILLIAMS (1932). If, however, as in the tuff from Ventisquero Grande, one type is decidedly predominant over the others, this type being highly vitreous and the crystal and glass fragments prove to belong chiefly and genetically to the same type, such a tuff may be described with a high degree of probability as a predominantly essential (lapilli) tuff. As the primary lava, which gave rise more or less directly to an explosion, as well as all the lavas earlier extruded and blown up at the eruption have contained in some degree crystallized minerals in the form of phenocrysts, the consequence is that the pyroclastic rocks of this area are generally mixtures of vitric, lithic and crystal components, though their mutual quantitative proportions vary as a matter of course.

4. Coarse tuffs.

Those pyroclastic rocks, the grains of which are from 4 to $^1/_4$ mm in diameter, are called coarse tuffs by WENTWORTH and WILLIAMS (1932, p. 52). In our material from the Tronador area five samples occur, which must be included in this group.

The first rock to be described forms a layer in the predominantly coarser pyroclastics at Ventisquero Alerce on the eastern side of Tronador. Megascopically it is a faint yellowish gray, fine-grained tuff, towards one side of the specimen somewhat coarser. These portions of different grade are separated by a rusty brown, probably limonitic layer, 3 mm thick. In the coarser part from which the thin section was taken, the lava fragments reach a size of 3 mm.

Microscopically the fragments prove to consist of crystals, glass and rock particles.

The crystals consist of predominant plagioclase, sparse olivine and solitary pyroxenes, orthorhombic as well as monoclinic, the latter, however, are very sparse. All mineral fragments are unaltered. As will appear from Table XXV, where determinations of two plagioclase fragments are

Table XXV.

Optical data on plagioclase fragments.

		1	2
Plagioclase	% An	96, 93	54, 53
	2 V	$-84°, -83°$	$-, +69°$
	Tw. law	AC	A

given, anorthitic as well as labradoritic plagioclases are represented. An olivine crystal had the axial angle $2\ V_\alpha = 86°$, corresponding to 20 % Fe_2SiO_4, whereas the determination of a hypersthene crystal gave $2\ V_\alpha = 66°$ with 36 % $FeSiO_3$.

The glass fragments are predominantly dark brown to black and opaque.

The rock fragments mainly consist of basalts with plagioclase and olivine, plagioclase and clinopyroxene or merely plagioclase as phenocrysts in a quite vitreous or hyalopilitic groundmass. Several smaller and most of the larger fragments are highly scoriaceous. A few andesitic fragments are also present.

A fainter or deeper greenish brown coloured, colloidal substance serves as cementing matter.

In the vicinity of the same locality as that of the tuff just described, Ventisquero Alerce, still another sample has been collected. These two rocks represent the basal parts of the Tronador series. The last-mentioned rock is a faint yellowish brown-gray, comparatively slightly cemented tuff. The ash particles have varying colours from light gray to almost black. Traces of stratification may be established, one part of the specimen being more fine-grained than the other with a gradual transition between them. Even in the coarsest part, however, the size of the particles, seldom exceeds 2 mm.

Microscopically the fragments prove to consist on the one hand of solitary crystals or pieces of them with or without attached vitreous groundmass, and on the other of rock particles.

The crystals or crystal fragments consist of plagioclase, olivine and monoclinic as well as orthorhombic pyroxene, arranged according to decreasing frequency. The freshness of all these minerals is a remarkable feature. As a matter of fact no secondary disintegration has occurred. In order to ascertain the genesis of these crystals some optical determinations were made. Three completely determined plagioclase crystals all proved to be labradorites (Table XXVI). A quite preserved, idiomorphic,

Table XXVI.

Optical data on plagioclase fragments.

		1	2	3
Plagioclase	% An 2 V Tw. law	68, 67 +82°, +75° C	67.5, 67.5 +77°, — C	58, 57.5 +72°, — AC

completely fresh olivine crystal had the axial angle 2 $V_\alpha = 88°$, corresponding to 15.5 % Fe_2SiO_4. Crystals of monoclinic pyroxene are relatively sparse. On an individual of appropriate orientation were determined 2 $V_\gamma = 44°$ and $c:\gamma = 39°$. The few hypersthenes observed did not permit any closer optical examination. The optical determinations made together with the development in other respects prove that the crystal fragments of the tuff originate from phenocrysts of lavas of essential or accessory character.

The rock fragments included in the tuff are predominantly basaltic. The most common type consists of porphyritic plagioclase, olivine and/or monoclinic pyroxene in a dark brown — black, semiopaque — opaque glass. This glass without phenocrysts, but often with single plagioclase microliths also forms independent, generally smaller fragments. The basaltic fragments are sometimes scoriaceous with the vesicles filled by a yellowish brown, limonitic substance. Next to the basalt in frequency comes a type containing phenocrysts of plagioclase in a groundmass of plagioclase laths, pyroxene grains and magnetite crystals. The term basaltic andesite seems to be most adequate for this type. But real andesites are also represented, though of rare occurrence. They are distinguished by their light groundmass, consisting of light brown glass, a denser or more scattered aggregate of plagioclase microliths and extremely small magnetite octahedrons, and in this groundmass rather sparse phenocrysts of plagioclase, clinopyroxene, and magnetite are found lying.

A yellowish brown isotropic gel substance, obviously rich in iron appears as a cement between the fragments. Calcite also occurs though only in spots with the same function, but not to such an extent that the tuff does more than effervesce slightly for acid. The open pore volume is not inconsiderable.

Below El Salto, in the valley of Rio Manso, a tuff rock has been sampled from a local boulder, consisting of alternating, irregular layers, at most 1 cm thick, of dense, brownish gray respectively fine-grained (grains at most 1 mm), bluish gray character. In one of the dense layers lies a solitary, rounded, light grayish white fragment, about 2 cm in length, of scoriaceous texture.

Microscopically the dense layers consist of an extremely fine-grained, brownish mass, composed of small glass fragments and of colloidal substances, probably of nonvolcanic, sedimentary origin. In this mass are scattered small fragments of plagioclase crystals.

The coarser layers are, for the greater part, composed of plagioclase, glass, and a lava rock with phenocrysts of this plagioclase and some rare minute olivine in a quite vitreous, light brown groundmass of the same character as the pure glass fragments. Some solitary greenish pyroxene microliths are sometimes distinguishable in the glass. Only exceptionally a small fragment with black, opaque groundmass and plagioclase as well as olivine phenocrysts is met with. A generally limpid and to a minor extent turbid calcite appears as the cementing matter. Judging from its extraordinarily limpid and fresh appearance no decalcification of the plagioclase of the lava fragments seems to have occurred. A phenocryst of plagioclase from a fragment of the predominant type was determined on the universal stage to 60 % An (the same percentage in the two partial individuals, twinned according to the Albite-Carlsbad law). The optic angle was $2\ V_{\gamma}=71°$.

The pumiceous rock fragment mentioned above consists of colourless glass of a fine reticulated structure, the pores of which are mainly filled by a limpid or more or less yellowish brown pigmented calcite, partly forming radiating aggregates.

From the border moraine of Ventisquero Grande comes a sample of a brownish gray, rather slightly cemented tuff with partly dark gray-black fragments, up to 1 mm in diameter. No distinct stratification could be observed.

Under the microscope the crystal fragments turn out to be predominantly plagioclase and olivine. Pyroxene is, on the other hand, rare. On a plagioclase fragment the An percentage was determined to 85 and 88 %, respectively (Albite-Carlsbad twin). The axial angle of the latter partial individual was 2 $V_\alpha = 82°$. An olivine crystal had 2 $V_\alpha = 84°$, corresponding to 24 % Fe_2SiO_4.

Among the rock fragments the following types are noted:

1. *Basalt* with phenocrysts of plagioclase and olivine in a dark brown groundmass with plagioclase microliths and generally highly scoriaceous. The vesicles filled with calcite, radiating zeolites or ferric hydroxide. This type is extremely common.

2. *Basalt* with phenocrysts as above in a quite or almost quite black, vitreous groundmass, sometimes with vesicles. This type is rather sparse.

3. *Basalt* with large, closely spaced olivine phenocrysts in a groundmass deep reddish brown coloured by iron oxide and containing feldspar microliths. Only one fragment of this type was observed.

4. *Andesitic basalt* with phenocrysts of plagioclase, pyroxene (orthorhombic and monoclinic) as well as some olivines in a light brownish glass with scattered microliths. Vesicles are either lacking or sparse (not mineralized or filled with calcite). This type is abundant.

The matrix between the fragments mainly consists of a brownish gray, turbid substance impregnated by iron hydroxide. In spots, however, they are cemented by large, clear calcite masses.

Though originating from a locality situated somewhat outside the Tronador area in the restricted sense, a tuff sample from the summit 2090 of Cerro Lopez, not far south of the central part of Lago Nahuel Huapí (Loc. 14, Fig. 3) will finally be described in this connection. It is well stratified, consisting of plane layers, two or three mm thick, of alternating lighter, more fine-grained respectively darker brown and somewhat coarser material. Even in the coarser layers the size of the fragments, however, only exceptionally reaches 1 mm.

In this tuff there also occur crystal as well as glass and rock fragments. Of the former plagioclase and olivine as well as sparse hypersthene and monoclinic pyroxene may be identified. A small plagioclase fragment twinned according to the Carlsbad law was determined to 75 and 78 % An, respectively. The dark mineral fragments were too small or had such an orientation that a closer establishment of their optical characters appeared impracticable.

The small rock (respectively glass) fragments are predominantly basaltic with phenocrysts of plagioclase and, less abundantly, olivine in a generally black, opaque, vitreous groundmass. The fragments are frequently so diminutive that the phenocrysts are only rarely quite surrounded by the glass. Only quite subordinately lighter, andesitic types occur. The whole rock is impregnated by a brownish yellow substance, probably iron hydroxide.

The composition of the rock (nature and degree of freshness of the fragments) agrees so extensively with certain tuffs from the nearer environs of Tronador that a genetical connection seems to be highly probable. The smaller grain coupled with the more regular stratification might possibly be considered as indicating sedimentation in water of windtransported volcanic ashes (distance from Tronador about 30 kilometres).

The general statements as to the lapilli tuffs (p. 296) may also be applied to these coarse tuffs. A natural consequence of the smaller grain is the fact that the volumetric share of the lava rock fragments has changed in favour of the crystal and glass fragments. This also applies to an even greater extent in regard to the following group of pyroclastic rocks.

5. Fine tuffs.

The most fine-grained pyroclastic deposits, the grain of which is below $^1/_4$ mm, are described by WENTWORTH and WILLIAMS as fine tuffs. From the Tronador area only two specimens are contained in the material studied.

The first one of these forming a bed in coarser pyroclastics at Ventisquero Alerce is megascopically a slightly cemented, evenly fine-grained, somewhat bluish gray, not distinctly stratified rock. No individual fragments may be discerned with the naked eye.

Microscopically the rock proves to consist of approximately equal parts of crystal chips and rock (respectively glass) fragments.

The crystal fragments consist predominantly of plagioclase. The degree af assortment according to the size of the grains is rather high. On an average the diameter of the particles is about 0.12 mm. On a fragment (an Albite twin) the composition 58 and 59 % An, respectively, was determined. The axial angle of the firstmentioned partial individual was $2\ V_\gamma = 75°$. Olivine and monoclinic pyroxene play a comparatively inconspicuous rôle. The olivine seems to preponderate over the pyroxene. A single pleochroic hypersthene was also observed. Attached to it was an idiomorphic magnetite crystal. An olivine grain had $2\ V_\alpha = 87°$, giving 18 % Fe_2SiO_4.

There are chiefly two types of rock (and glass) fragments occurring with about the same mutual frequency and being of about the same size as the plagioclase fragments. One type consists of a dark brown — black, all but opaque glass, in which often small plagioclase laths and sometimes small olivine crystals, too, may be observed. This type obviously has a basaltic composition. The second type of fragments consists of a light greenish brown glass either with or without minute, scarcely determinable crystallites, rarely with larger crystals of plagioclase or pyroxene, probably monoclinic. These fragments probably correspond to a shattered lava of andesitic chemistry.

The second specimen of fine tuff, from Cerro Lopez, shows, as to colour and degree of cementation, great similarity with that described immediately before. It has, however, a certain stratification through layers of different grain. Yet the stratification is somewhat disturbed after the sedimentation (according to LJUNGNER through glacial thrust).

A thin section through one of the more fine-grained parts shows a maximum size of the fragments of about 0.11 mm. Among the crystal fragments plagioclase predominates, whereas the heavy, dark minerals through the eolian differentiation (LARSSON 1936) of the ash material during wind transportation are represented only by a few small olivine and pyroxene fragments. On a plagioclase fragment twinned according to the Albite law the An percentage could be determined to 70 and 60 %, respectively.

Because of the fine-grained character of the rock the lava fragments mainly consist of groundmass chips without enclosed phenocrysts. Dark brown, highly pigmented glass fragments with single microliths are predominant. — This tuff specimen from Cerro Lopez does not show any characters incompatible with the conception of its genetical connection with the Tronador tuffs.

6. Redeposited tuff.

A sample of a rather dark sand with single, lighter and larger (1/2—1 cm) granitic pebbles comes from »Lagos» on the slope of Cerro Lopez.

A powder preparation of the finer part of the sand is seen microscopically to consist predominantly of volcanic rock fragments as well as fragments of phenocryst minerals of lavas agreeing essentially with those of the tuff from the ridge of Cerro Lopez. Compared with the specimens of the latter one, which have been described above (p. 300, 301), the sand here in question shows a considerably larger average size of the crystal and rock fragments as well as a greater proportion of dark mineral fragments (chiefly olivine and hypersthene). This fact may be interpreted either in the manner that the sand in question forms a product of redeposition of a coarser, eolically less differentiated tuff bed transported by means of a more powerful wind or during another wind direction, or alternatively that its composition is to be ascribed to a redeposition (probably by means of water) which effected the enrichment of the larger and specifically heavier particles primarily dispersed in a larger tuff mass and the selective removing of the finer material. Probably these two alternative interpretations are both applicable to a certain degree.

b. Altered rocks.

Rocks of the Tronador series altered through late-volcanic processes may be described as of local importance judging from the material placed at my disposal. Only from three localities, in fact, have samples been collected of such rocks, namely on the summit of Tronador (Pico Argentino), Ventisquero Grande and the bed of Rio Manso, about 4 kilometres southeast of the glacier mentioned. Of these localities the end moraine of Ventisquero Grande has yielded by far the greatest number of the rock samples in question. In the following petrographical description the same principle of subdivision as applied to the unaltered rocks has been employed. By this means two groups of rocks are obtained: altered effusive lavas and altered pyroclastics. In the few cases where the pre-existing material has been changed to such a degree that its original nature can no longer be safely deduced, the description of these specimens has been given in connection with the third chief group of volcanic products from the Tronador area comprised predominantly of primary, late-volcanic mineral deposits.

α. Altered lavas.

A strict application of the same principle of subdivision as that practised on the unaltered lavas meets here for natural reasons with certain difficulties. Thus a subdivision in only a limited number of groups has been possible, and it must be remembered that the total of altered lavas is only a fraction of the number of the unaltered ones. In this connection it must also be noted that basalts, as will appear from the following description, are almost entirely lacking among the lavas having suffered late-volcanic alterations, whereas among the fresh lava rocks, on the contrary, basalts quantitatively predominate over the andesitic types.

1. Basalt.

Only one specimen of hydrothermally altered lava, from Ventisquero Grande, Tronador, is present, of which it can be said with a certain degree of probability that it has developed from a lava of originally basaltic composition. Megascopically it is a light gray, in spots almost quite white, on weathered surface yellowish gray — rusty brown, somewhat irregularly scoriaceous rock without distinct phenocrysts.

Microscopically the rock proves to consist in the greater part of more or less intensely brown pigmented opal. Nevertheless the texture of the rock, especially in ordinary light, is well preserved. Phenocrysts of plagioclase have been rather abundant. In the opal pseudomorphs after these phenocrysts small scales of a colourless, rather slightly refracting mineral, probably alunite, occur either rather uniformly dispersed or concentrated to certain streaks or spots, particularly to a thin zone immediately inside the outer surface of the pseudomorphs and conformably following their outlines. Mafic minerals seem to have occurred only sparsely as phenocrysts, now being represented by opaque, brownish black pseudomorphs.

The vesicles, at most 1—2 mm in size, are in certain parts wholly unmineralized, in others filled with opal or exceedingly fine-crystalline chalcedony. Sometimes, on the other hand, they have a lining of minute crystals, probably tridymite.

The reference of this rock to basalt as primary material is founded to some extent on negative indications, *viz.* the absence of characters distinguishing fresh as well as altered andesitic lavas of different types. On the other hand the frequency and development of the plagioclase pseudomorphs as well as the shape of the dark pseudomorphs being suggestive of that of olivine are characters arguing positively in favour of a basaltic provenance. It seems most probable that the rock has been originally a rather highly scoriaceous representative of the quantitatively well represented group of lavas described above (p. 255 a. f.) as type 2, characterized by phenocrysts of plagioclase and olivine.

2. Pyroxene andesites.

As derivatives of pyroxene andesites four samples of altered lava rocks could be interpreted, all from Ventisquero Grande, Tronador. Because of difficulties sometimes arising with regard to the determination of the original nature of the pyroxene minerals the absence or appearance of apatite phenocrysts was chosen as a basis for the further subdivision of this group of rocks.

2 a. Pyroxene andesite without porphyritic apatite.

The only rock falling in this group is macroscopically a dull, light bluish gray, in spots darker and somewhat lustrous lava with abundant, light gray — white phenocrysts, up to 5 mm in size, and irregularly dispersed vesicles, confined to the dull portions and at most 2 mm in size.

The rock, megascopically having a rather fresh appearance, appears under the microscope to be a hydrothermally very much altered andesite. In ordinary light the outlines of the plagioclase phenocrysts are to be seen distinctly. Between crossed Nicols the plagioclase substance, however, proves to be quite altered to opal with larger or smaller spots of fine-crystalline tridymite together with some kaolin. The scarce pyroxene phenocrysts have at the same time been altered into opaque ore masses. A few primary magnetite phenocrysts do not appear to have undergone any alteration.

The groundmass has undergone in spots, *viz.* mostly in aureoles round the altered phenocrysts, a similar alteration. Otherwise it is fresh consisting of a light brownish glass with abundant feldspar microliths often showing a distinct fluidal arrangement. Smaller, semiopaque globulites appear more sparsely.

The vesicles being of an irregularly sinuous form are lined next to the groundmass by a thin coating of fine-grained ore. After this follows a layer of minute tridymite crystals quite filling the smallest vesicles, whereas the larger ones are open in the centre.

This rock must probably be regarded as an altered representative of the pyroxene andesites of type 9 (p. 273 a. f.). As a matter of fact it shows, apart from the somewhat bleached colour in connection with the opal alteration, a great similarity with the andesite from the same locality, which has yielded material for analysis No. III (p. 278).

2 b. Pyroxene andesites with porphyritic apatite.

Another type of alteration is shown by the three specimens falling under the above heading. The first of these is megascopically a rather dark bluish gray, porphyritic rock with partly faint reddish, light gray phenocrysts, 2—4 mm in size, partly darker or lighter greenish gray, rather diffuse spots, at most $^1/_2$ cm in diameter.

The plagioclase phenocrysts having a broadly tabular to prismatic development are only exceptionally tolerably free from secondary alteration products. In these cases a fine, oscillatory zonal structure appears distinctly. A well preserved individual twinned according to the Albite-Carlsbad law was determined to 45 and 47 % An, respectively. The axial angle of the first twin individual was $2\ V_\gamma = 87°$. A decalcification has generally taken place followed by the formation in the feldspar of rather large individuals of epidote, pleochroic from colourless to yellowish green. Together with this mineral, though in somewhat less quantity, calcite appears replacing the plagioclase substance.

The alteration of the pyroxene phenocrysts has advanced considerably farther, no pyroxene substance being preserved. The pseudomorphs, which on account of their shape, might be supposed to have originated from monoclinic pyroxene, wholly consist of amphibole with the fibres in subparallel arrangement and pleochroism in dirty yellowish green (α) and somewhat bluish green (β and γ). The twinning on (100) characteristic of the monoclinic pyroxene of these lava rocks is sharply reproduced in the pseudomorphs.

Another type of pseudomorph appearing in smaller number and of minor dimensions consists of a faint yellowish green chlorite, often with a thin, sometimes interrupted zone of fibrous amphibole peripherically towards the groundmass of about the same character as in the indubitable pseudomorphs after pyroxene. This mineralogical constitution, the rather elongated, prismatic form and the absence of traces of twinning indicate that these pseudomorphs represent altered phenocrysts of orthorhombic pyroxene.

Further there occur phenocrysts of magnetite often in idiomorphic crystals, up to 0.5 mm in size, and of apatite in hexagonal prisms of the same character as those described on p. 279.

Finally, concerning the groundmass, it forms an extremely fine-grained, aggregate-polarizing mass, the constituents of which cannot be more closely defined. Obviously it is composed in the main of a devitrified glass.

The second specimen referable to this group shows before the naked eye partly light gray — white plagioclase phenocrysts, 2—3 mm in size, partly less numerous and smaller as well as more indistinct spots of dark green colour in a blackish gray, dense matrix.

Microscopically the rock proves to have undergone an incipient alteration of a similar kind as in the immediately preceding case. The plagioclase phenocrysts have distinct twinning lamellae only exceptionally preserved. Generally the plagioclase substance is replaced in an irregular, reticular manner by fine-scaly sericite. The calcium percentage of the altered plagioclase is now represented in irregular areas of calcite and by small, partly idiomorphic crystals of pistacitic epidote appearing, though in no greater quantities, in most plagioclase pseudomorphs. The epidote is highly pleochroic in colourless and greenish yellow.

Another type of pseudomorph consists of a yellowish green, fibrous, optically anomalous chlorite. As these are generally smaller and more rounded than the indubitable plagioclase pseudomorphs, they may represent in most cases altered phenocrysts of pyroxene.

In this rock crystals of magnetite appear as phenocrysts, generally with rather sinuous outlines, sometimes, however, with clear crystal boundaries. The size reaches 0.5 mm. Apatite also occurs, partly enclosed in the magnetite crystals, partly as larger, solitary microphenocrysts, about 0.12 mm thick.

The texture of the groundmass can be characterized as hyalopilitic, rather closely lying slender, lath-formed plagioclase crystals of the order of magnitude 0.05 mm with partly quite a nice fluidal arrangement round the phenocrysts occur in a dark, brown pigmented glass. In addition to the plagioclase magnetite appears in small (about 0.03 mm), rather scattered, rounded grains the only determinable mineral in the groundmass.

The following volumetric analysis:

Phenocrysts	Plagioclase pseudomorphs	24.2
	Chloritic pseudomorphs	1.8
	Magnetite	1.3
	Apatite	0.3
Groundmass		72.5
	Total	100.1

gives an idea of the ratio between the phenocryst minerals mutually and to the groundmass in the original lava.

The third and last specimen has macroscopically an appearance differing from the other ones, but shows phenomena of alteration of a similar type. It is a dense, compact, grayish violet, slightly banded rock with scattered, whitish gray phenocrysts, up to 5 mm in size, and, parallel to the banding, joints with a grayish green coating.

The phenocrysts prove to be of plagioclase, which but for remnants optically hardly determinable is altered to aggregates of predominant calcite, besides which appear a few crystals of a generally deep greenish yellow epidote.

In a considerably smaller number than these pseudomorphs after plagioclase there occur those after mafic phenocrysts. They are often heavily pigmented. When the pigmental matter is somewhat thinning, one can distinguish a fine-grained aggregate of chlorite and epidote, with which calcite is associated. Possibly the heavily and the less heavily pigmented pseudomorphs represent products of alteration of orthorhombic and monoclinic pyroxene, respectively. In favour of this interpretation argues the more elongated, thin form of the former as against the more isometric outlines of the latter.

The sparse octahedral phenocrysts of magnetite and the still more solitary, thinly prismatic apatite crystals pigmented in the usual way for these rocks, remain unaltered.

Formerly the groundmass has probably been in part vitreous. Its present nature is, however, difficult to ascertain on account of a heavy, grayish brown pigmentation. Epidote, however, occurs in small crystals rather evenly dispersed with high birefringence and, here and there, diffuse spots of chlorite, often surrounding the epidote crystals.

From the descriptions above it appears that these rocks represent andesites of the type previously described as No. 10 (p. 278), characterized by the phenocryst combination plagioclase, orthorhombic and monoclinic pyroxene, magnetite and apatite.

3. Hornblende andesites.

As altered hornblende andesites (and dacites) three rock specimens have been classified. A subdivision analogous to that in the immediately preceding group has also been made here.

3 a. Hornblende andesites without porphyritic apatite.

The two rocks belonging to this type are sampled at Ventisquero Grande, Tronador. Macroscopically one specimen is slightly, but distinctly banded with alternating light bluish gray and more purely whitish gray bands, about $^1/_2$ cm thick, and with solitary, white as well as, less prominent, dark phenocrysts, at most 3 and 1 mm in size, respectively, all with coarse parallel orientation.

Microscopically a highly altered, obviously primarily andesitic lava rock is apparent. In a rather light, slightly ore-pigmented, aggregate-polarizing, not closer definable groundmass larger and smaller crystals of plagioclase lie rather close together or, more properly expressed, pseudomorphs after this mineral, as plagioclase substance with twinning lamellae preserved is only exceptionally observed. The plagioclase is replaced to a large extent by calcite, and this particularly applies to the larger, megascopically visible crystals. The rock reacts with hydrochloric acid forming an appreciable amount of carbonic acid.

Another type of pseudomorph consists of a very much ore-pigmented substance, in part consisting of almost quite compact ore; the other constituents are scarcely determinable on account of the fine-grained state and the heavy pigmentation. The exterior form of the pseudomorphs, however, gives an indication of their provenance. In a few cases the prismatic angle characteristic of hornblende could be measured.

Plagioclase as well as hornblende pseudomorphs show a subparallel arrangement, obviously indicating a primary fluidal structure. The rock is evidently a hydrothermally altered hornblende andesite.

The second rock referred to this group is megascopically whitish gray and fine-grained with yellowish gray weathered surfaces showing rusty brown spots. A rather distinct parallel structure appears by interchanging bands of somewhat darker and lighter colour.

Microscopically the rock presents a moderate kaolinization, which, however, has been so strong that the different mineral components appear only indistinctly. This is especially the case in ordinary light. Between crossed Nicols it can be established that the rock is rich in plagioclase crystals of varying size, but with so smooth transitions that no typical porphyritic texture results. The crystals are arranged coarsely subparallel with the megascopically noticeable banding, which depends upon the varying intensity of pigmentation by reddish brown ferric hydroxide, as well as different percentage of small, somewhat roundish magnetite crystals. A sure determination of the anorthite percentage of the plagioclase is on account of the strong turbidity rather unrealizable. Here and there occur small aggregates of irregularly bounded quartz grains in the feldspar mass involved in kaolinization. Very sparsely rather sharply bounded masses of a yellowish brown or pale yellow, serpentinous mineral are present, which possibly represent pseudomorphs after mafic phenocrysts. It has not been proved that these have been hornblende in this case. The rather great similarities of the rock with the preceding one in spite of its somewhat deviating type of alteration have, however, seemed to be sufficient motives of mentioning it in this connection.

3 b Hornblende andesite with porphyritic apatite.

Only one specimen belongs to this group, taken as loose boulder in the bed of Rio Manso. It is a dense, light gray, all but white, compact rock with sparsely appearing, thin phenocrysts, up to 5 mm in length, and darker gray in colour, in part with metallic lustre. The phenocrysts have a subparallel arrangement.

Microscopically it appears that the sparse feldspar phenocrysts (probably plagioclase) are almost entirely altered to aggregates of comparatively large individuals of calcite. Pseudomorphs, which on good reasons may be presumed to have been originally mafic phenocrysts (probably hornblende), now consist of partly a chlorite, in thin sections almost colourless and of irregularly twisted texture, with dark dirty olive browngreen colours, partly a sulphide mineral, in reflected light pale yellow, probably pyrite, in compact masses well segregated from the chlorite. This sulphide mineral also occurs scattered in small grains in the groundmass. Sometimes a quartz grain or two enter into the pseudomorphs, too. Further pseudomorphs appear sparsely of granular leucoxene after titanomagnetite judging from the form. The solitary apatite phenocrysts have remained unaltered with the exception that the characteristic pigment inclusions have apparently been concentrated, as it were, to a smaller number of particles.

The groundmass has undergone secondary alterations, too. The small feldspar laths lying close together and showing a slight fluidal arrangement appear rather indistinctly on account of an impregnation of the rock with small individuals of calcite as well as scattered, somewhat larger spots of quartz and smaller grains of brownish black, opaque pigmental matter. Pre-existing glass seems to have been quite devitrified.

The rock obviously represents a hydrothermally whitened and altered andesite of type 12 (p. 283), characterized by the phenocryst combination plagioclase, hornblende, magnetite and apatite.

β. Altered pyroclastics.

On account of their commonly porous character the pyroclastic deposits have offered an easy passage and a large total surface for the action of the altering agencies, by means of which the alteration in this case has taken place much more completely than in the more compact lavas. In spite of this however the primary textures are generally so well preserved that without greater difficulties the same principle of subdivision has been applied to these rocks as to the pyroclastics unaffected by late volcanic processes. A comparison with the latter shows that among the altered rocks the coarsely pyroclastic types are decidedly predominant. This is due less to a selective decrease of the quantity of the identifiable, more fine-grained volcanic ejecta caused by their more easily effected complete alteration than to the fact that the alteration has obviously been localized to the immediate neighbourhood of the central place of eruption with the pyroclastic rocks in primarily coarse, proximal facies.

1. Tuff breccias.

To this group belong three rock specimens. They originate, as all other altered pyroclastics, from the moraine of Ventisquero Grande, Tronador. The first one of these is megascopically a light gray, in spots pure white and mealy, in other places yellow — rusty brown, distinctly altered fragmental rock with some porphyritic fragments, up to 5 cm in size.

Under the microscope the rock proves to be very much altered by hydrothermal processes. Two elements may be discerned, *viz.* a homogeneous mass, in thin section colourless, and, lying in it, fragments of pigmented material, which probably correspond to the fragments of the original tuff breccia. In these fragments the original phenocrysts of plagioclase are distinctly observable on account of a lesser degree of pigmentation as well as a different texture. Between crossed Nicols, however, they prove to consist of isotropic opal as does the main part of the groundmass. Here and there, however, occur small groups of minute, colourless, doubly refracting scales with negative elongation, probably alunite. The mafic phenocrysts have been altered to opal, too. The pseudomorphs are in this case more heavily pigmented than the groundmass.

The matrix, between the fragments mentioned above, consists of a homogeneous, extremely fine-crystalline aggregate. The somewhat elongated individuals have negative elongation, suggestive of chalcedony. One gets the impression that this chalcedony mass has »eaten» its way into the fragments consisting essentially of opal. Solitary spots of chalcedony also occur in the fragments themselves.

Idiomorphic crystals of a regular sulphide mineral, probably pyrite, are to be found somewhat unevenly dispersed in the rock. These crystals occur in the opal fragments as well as in the chalcedony matrix.

A similar type of alteration is represented by the second specimen, which is a light gray, in spots greenish or bluish gray, fragmental rock with slight parallel structure and fragments, up to 4 cm in diameter. These are uniformly porphyritic with light gray or greenish phenocrysts, 2—3 mm in length. The rock has megascopically a hydrothermally altered appearance.

This alteration is verified by the microscopical examination. Over 90 % of the rock consists of a more or less brown coloured and pigmented, isotropic opal. The pseudomorphs after the plagioclase phenocrysts are composed of a colourless and clear opal being irregularly veined by a second generation of brownish coloured, slightly pigmented opal, which quantitatively almost equals the former. Sometimes small remnants of plagioclase substance occur in the clear opal portions.

The sparse mafic silicate phenocrysts have been altered into granular, brownish black, opaque aggregates, with opal as an essential component. The magnetite crystals, few in number, have not undergone any visible alteration. Whether the magnetite occurring in small, irregular aggregates rather abundantly in certain parts of the rock has been formed in connection with its opalization is difficult to decide. In any case it may be established that this ore is sometimes accompanied by small, diffusely bounded areas of a clearer cryptocrystalline, chalcedony-like substance. The most probable conclusion is that the ore grains were formed by recrystallization of the pigment dispersed in the opal, at its alteration to chalcedony.

The third rock belonging to this group shows a deviating character as against the two specimens described immediately before. It is megascopically a greenish blue-gray, well cemented fragmental rock. Among the fragments a piece of a porphyritic lava was noted, at least 4 cm in size, with close lying feldspar phenocrysts, up to one or two mm in length.

Microscopically the rock proves to be of heterogeneous origin. On the other hand the components included in the rock are rather highly altered. Among the fragments there occur supercrustal as well as deep-seated rocks.

Among the lava fragments are certainly included basalt as well as andesite, probably the latter preponderating. The original character is not easy to determine, as the phenocrysts have been wholly or almost entirely altered. The plagioclase phenocrysts now consist of calcite, together with kaolin and plagioclase remnants too insignificant to be examined more closely. The mafic phenocrysts have been altered into ore and/or chlorite. In the groundmass an extensive formation of chlorite and calcite has also taken place. In some fragments, however, the groundmass is quite black and opaque by ore impregnation. The outlines of the plagioclase microliths are nevertheless preserved so that the original fluidal structure of the groundmass still persists.

Among the fragments a number of albite granite occur with abundant quartz and chlorite and the finely twinned feldspar highly altered into epidote (in the centre), sericite and chlorite.

Quartz grains, for the most part with strain shadows, are also distributed here and there between the other fragments.

Finally a fragment was found of a tectonite, a quartz sericite chlorite schist, with alternating layers of quartz and sericite-chlorite-ore.

This rock, with regard to the interglacial volcanicity, is mainly of accidental origin. The composition of the fragmental material, its partly rounded character, and its cementation exceptionally firm in such a comparatively young pyroclastic product are reasons why this rock may be regarded with some plausibility as an »enclave allothigène» possibly originating from a conglomerate or agglomerate of Tertiary (or older) age. Such being the case the secondary alteration of the fragments should be in all probability only partly attributable to the influence of the Tronador volcanicity.

2. Lapilli tuffs.

From the moraine material below Ventisquero Grande, Tronador, come four specimens of altered pyroclastic rocks with such a size of the grains as corresponds to the group lapilli tuffs (32—4 mm). In the exterior appearance as well as in the degree of alteration these rocks present notable differences. This section must also include a specimen collected (by O. MEILING) on Pico Argentino, the eastern summit of Tronador.

The slightest alteration has overtaken a tuffaceous rock with partly porphyritic, dark gray lava fragments, up to 1 cm in size, in a sparse, light gray matrix.

Microscopically the fragments prove to be predominantly of the same type as the altered pyroxene andesite lava described on page 306 a. f. The frequency of phenocrysts, however, is considerably lower as to the plagioclase and the chloritic pseudomorphs. A feature in common is the appearance of comparatively large, idiomorphic apatite phenocrysts. *Inter alia* there occur apatite crystals in cross section consisting of a thin shell of apatite substance, with sharply prismatic development towards the groundmass, round a central inclusion of the same character as the surrounding groundmass.

The matrix between the lava fragments contains larger and smaller, extensively decomposed fragments of plagioclase crystals, together with chloritic masses, often associated with relatively idiomorphic crystals of apatite and irregular lumps of ore. In the cementing matter, which gives to the rock a remarkably solid consistency, quartz plays an important rôle. Here and there thin quartz veins are cutting through the lava fragments. Quartz is in some cases also filling vesicles in scoriaceous fragments. A direct connection and an almost identical development of the quartz in the vesicles (interlocking individuals) and in the cementing matrix may often be noted.

Another specimen is composed megascopically of a fine-grained, grayish white in part mealy stained mass, somewhat inclining to greenish colour, in which are lying solitary, rounded or angular, darker gray, aphanitic or porphyritic fragments of lava rocks, up to 2.5 cm in diameter.

A thin section of the grayish white matrix proves to consist mainly of very fine-grained kaolin, intermingled with a very fine-crystalline substance, probably chalcedony. Here and there occur sharply bounded, homogeneous crystals as well as diffuse impregnations of calcite. Further small clear quartz grains are met with and highly disintegrated remnants of chlorite or muscovite in parallel intergrowth with the chlorite. A few small, practically unaltered fragments of aplite granitic composition were observed, too, as well as blurred, indistinct remnants of the character of effusive rocks.

The rock probably represents a lapilli tuff altered by means of volcanic gases or thermal water, and also containing accidental granite fragments.

The third specimen referable to this group consists megascopically of larger or smaller, dark, partly brownish gray-black fragments lying in a partly yellowish gray-white matrix.

Microscopically the rock proves to be a pneumatolytically-hydrothermally highly altered andesitic lapilli tuff. The dark fragments consist of andesite altered into opal, in which the original plagioclase phenocrysts and also the feldspar microliths of the groundmass may still be discerned in ordinary light, but between crossed Nicols prove to be quite isotropic. The sparse mafic phenocrysts have been opaque and partly altered into a highly reddish brown, goethitic substance. A very fine-grained impregnation of sulphur occurs as unevenly diffuse spots as well as along fissures.

The megascopically lighter portions of the rock consist of a highly fine-crystalline, colourless, unpigmented chalcedony. As the youngest formation present there occurs a colourless mineral in lengthy scales with negative elongation, sometimes in parallel arrangement, more often with a rosette-like or irregularly spherulitic texture, possibly a zeolite. It appears partly in larger, diffusely bounded aggregates, usually at the boundary between the opalized fragments and the lighter chalcedony matrix, partly in clean-cut, thin veinlets.

The description of the previously mentioned specimen collected on Pico Argentino may be inserted here. It is composed megascopically of a brownish yellow, porous, incompact mass with diffuse, more compact and somewhat lighter yellowish gray portions.

Microscopical examination shows that we have here a hydrothermally altered, pyroclastic rock, the fragment size of which places it in the group of lapilli tuffs. The original components of the rock have been almost completely altered to opal with a well preserved texture. The mafic phenocrysts are represented by brownish black, opaque masses. The groundmass of the fragments and also the matrix between the fragments are rather heavily pigmented a brownish gray, by means of which the more clear pseudomorphs after the plagioclase phenocrysts and after the groundmass plagioclase, too, are sharply outlined. Many fragments of the former have obviously been rather rich in groundmass inclusions. The small, rounded or more irregularly formed spots of yellowish brown colour and optically of isotropic character, occurring between as well as inside the fragments and also within the phenocrysts, are better interpreted as secondary ferruginous gel products than as remnants of unaltered volcanic glass. In close connection with these brownish yellow substances, but appearing more distinctly as filling of pore spaces in the tuff, an exceedingly fine-crystalline substance, probably consisting of chalcedony, is present in comparatively small quantity. Minute grains of a sulphur-like mineral are here and there sparsely distributed. A finely fibrous, slightly refractive, colourless zeolite mineral appears in solitary rounded cavities as well as predominantly in irregular fissures in the tuff.

Finally mention must be made of a megascopically light gray to rather deep reddish rock, obviously altered by means of volcanic gases and hydrothermal solutions, with still preserved pyroclastic texture, porous, scoriaceous and more compact, porphyritic portions being discernable.

The interpretation of the specimen as a hydrothermally altered rock of tuffaceous origin is verified by the microscopical investigation. Whether the lava fragments have consisted predominantly of basalt or andesite is difficult to decide with any certainty. The broadly prismatic form of the primary plagioclase phenocrysts, still observable in ordinary light, cannot be said to argue positively in favour of the basic, basaltic character of the original material. The nature of the eventual mafic phenocrysts remains problematical on account of the abundant ferrioxidic impregnation, which the plagioclase phenocrysts have also undergone to a minor extent. In any case the lava fragments have been richly vesicular. The vesicles are now either open or, more often, quite or partly filled by opal. Apart from the colouring substance and in spite of the comparatively well preserved textures the whole rock consists of an isotropic opal between crossed Nicols dark.

5. Coarse tuffs.

Only two samples of altered coarse tuffs (size of the grains 4—$^1/_4$ mm; WENTWORTH and WILLIAMS 1932) have been at my disposal, one originating from LJUNGNER's collection of moraine boulders from Ventisquero Grande, the other taken by O. MEILING from rocks outcropping on Pico Argentino, the eastern summit of Cerro Tronador.

The first-mentioned rock is macroscopically a rather slightly cemented tuff with dark gray, partly porphyritic fragments, up to 4 mm in size, in a yellowish gray, mealy matrix.

Microscopically the lava fragments prove to be predominantly andesitic, only exceptionally basaltic. Whereas the groundmass with its thin plagioclase microliths in a lighter or darker brown pigmented glass is often comparatively well preserved, the phenocrysts, plagioclase and mafic minerals, have undergone a partial or complete alteration to opal. This has penetrated the primary minerals as a net-work. In the plagioclase, being most easily altered, this net-work is often more fine-meshy than in the hypersthene, which is the predominant mafic mineral. Whereas the alteration of the dark minerals universally begins peripherically, the margins of the plagioclase crystals higher in albite often resist the alteration longer than the central parts.

The facts mentioned immediately above are also true of the crystal fragments of the matrix, where, however, on account of farther advanced alteration the ratio between plagioclase and mafic minerals is scarcely determinable. The matrix is highly impregnated by sulphur.

The specimen from the summit of Tronador is megascopically a lighter or darker, grayish violet rock with scattered, light gray-white, phenocryst-like mineral grains, exceptionally up to 3 mm in size, and in spots an impregnation by a greenish yellow-gray substance.

A microscopical investigation shows that it deals with a coarse tuff, which has undergone alteration into opal with extensive preservation of the primary texture of the fragments. Especial mention may be made of the excellent preservation of such delicate textures as the zoning of the plagioclase phenocrysts and the fluidal arrangement of the groundmass microliths in spite of the fact that the rock between crossed Nicols is for the most part isotropic. Rounded or, more commonly, in an ameboid manner irregularly formed portions of an extremely fine-crystalline chalcedony occur fairly evenly dispersed. Sometimes part of the zones of the plagioclase phenocrysts have been converted preferably into chalcedony, by means of which a certain reminiscence of the earlier zoning between crossed Nicols persists. To some extent the appearance of small, yellowish grains of sulphur, preferably in the more central parts of some opal pseudomorphs after plagioclase, has a similar effect. The dark phenocrysts are made opaque in the usual manner. The rock is further penetrated by irregularly veinlike pore spaces, which are lined towards the surrounding rock with a thin layer of a blackish brown, ferrihydroxidic substance and as youngest formation a more or less continuous coating of small crystals of tridymite.

c. **Hydrothermal mineral deposits.**

In this section such late-volcanic products are described, which could not suitably be referred to the preceding main group. Certainly in some of the specimens referable to the group now in question an important pyroclastic component enters, originating from earlier stages of the activity of the volcano, but now altered. The bulk, however, is composed of primary mineral formations deposited during the final stages of the life of the volcano, as opal, chalcedony, sulphur, gypsum and aragonite. Five specimens will be described, three from Ventisquero Grande and two from Pico Argentino of Cerro Tronador.

First may be mentioned a megascopically brecciated rock with angular fragments of a pale yellowish gray — white, aphanitic substance with

Fig. 31. Photomicrograph of agate breccia. Ventisquero Grande, Tronador. Ord. light. Magnif. × 67.

conchoidal fracture in a fine-grained, in part brownish yellow — light gray matrix.

The fragments under the microscope prove to consist of either homogeneous, brown pigmented opal or an utmost fine-crystalline, striped chalcedony (Fig. 31). The agate-like striping is due to a different degree of pigmentation together with a difference in the degree of alteration of the opal to chalcedony. The brecciating matrix also consists of chalcedony, but this one is homogeneous and coarser crystalline than that forming part of the agaty fragments.

In another part of the thin section it becomes evident that the agate-like chalcedony-opal mass has obviously filled up open vesicles in a volcanic rock. Its original texture is yet noticeable in spite of complete alteration to opal. The secondary chalcedony, which in this part of the slice is clear and colourless, appears as cross-cutting veins and is further especially localized to the peripheric portions of the plagioclase pseudomorphs. In the interior of the same pseudomorphs there often occur aggregates of sulphur crystals with considerably coarser dimensions than the sulphur particles impregnating the opalized groundmass.

In the collection of boulders from the terminal moraine below Ventisquero Grande, from which the immediately preceding specimen was taken, there also occurred a piece of a macroscopically aphanitic, rather homogeneously yellowish white mass.

Under the microscope this specimen proved to consist of a chalcedony-like, exceedingly fine-grained substance of somewhat varying grain, being heavily impregnated by extremely finely dispersed sulphur. The great percentage of sulphur was also revealed by the fact that pieces of the specimen when placed in the Bunsen flame burned with a blue colour and with the formation of sulphur dioxide. Especially in the peripheric parts of the thin slice, where the sulphur during the preparatory treatment and the grinding of the slide had been dissolved to a large extent by the Canada balsam, there appeared in the porous chalcedony mass irregular remnants of varying size of a more or less heavily pigmented, isotropic opal.

From Pico Argentino comes a druse of scarcely transparent, yellowish gray-white crystals of silky lustre, rounded form, of relative softness and with a maximum magnitude of about 1 cm, attached to a substratum of an earthy, porous, pale rosy, grayish white mass. On a spot between the crystals a coating of a yellow, pulverous sulphur was observed.

The microscope verified the supposition that the drusily developed mineral consisted of gypsum. Qualitative chemical tests have further confirmed this determination. A measuring of the axial angle, giving $2\ V_{\gamma} = 54^{\circ}$, shows a somewhat lower value than that generally stated. The different crystals usually form mutual intergrowths, where they meet, of such a type that in the boundary zone one individual bears enclosed portions with the same orientation as the other one. These inclusions tend to have straight-lined boundaries, forming in thin sections parallelograms of uniform orientation. The common boundary between the main individuals is also generally composed of smaller straight-lined elements, parallel with the sides of the enclosed parallelograms mentioned. In spots, but on the whole sparsely, a fine-grained, alabastrine texture may be observed. The gypseous substance is rather heavily studded with extraneous particles. These consist partly of extremely small, dark pigment grains, partly of larger scales of a sericite-like character. These latter have often a distinct parallel orientation, which is probably a contributing cause for the megascopically silky lustre of the gypsum crystals.

The substratum for the gypsum crystals is probably an andesitic lava (or tuff), now quite altered into opal with smaller portions of chalcedony and the primary, porphyritic texture preserved, as has been described in preceding chapters. This opalized rock is also intersected in a breccia-like manner by thin veins of gypsum.

Still another specimen derives its origin from Pico Argentino, showing an aggregate of partly pale yellowish gray-white crystals, about 1 cm in size, in part with cleavages of a silky lustre, cemented by a porous, earthy, yellowish gray mass. This specimen microscopically proves to coincide in essentials with that just described. In this case, however, the gypsum has crystallized in the abundant and spacious vesicles of a highly scoriaceous or perhaps even pumiceous, obviously pyroclastic rock, now altered to opal. It is these opalized portions, which form the quantitatively insignificant, cementing material for the gypsum crystals. The »cement» is then here the older component of the complex.

Finally in this connection a description of a crystal druse (4.5 × 3.5 × 3 cm) composed of closely united prisms with slightly divergent arrangement must be given, which has been found in the moraine material below Ventisquero Grande, Tronador. The exterior surface of the mineral aggregate, worn off during the glacial transport, shows well rounded outlines, the crystal forms being almost quite effaced. The lustre of the worn surface is weak; on fresh fractures parallel with the elongation of the crystals the mineral has a strong vitreous lustre.

Microscopically the mineral proves to have rather high refringence and very high birefringence with straight extinction and negative elongation of the crystals. Thin, opaque rods enclosed parallel with the same direction may be observed. It is scratched by a knife and effervesces slightly for hydrochloric acid. A determination of the specific gravity of the crystal aggregate with the balance of WALKER—LA TOUCHE gave 2.9. These observations favour the belief that the mineral is aragonite.

B. The Brazo del Viento area.

This denomination refers to the northern part of the area represented by the specimens of interglacial volcanic rocks examined. The occurrences are mainly situated to the north as well as south of the western half of Brazo del Viento, the western arm of Lago Nahuel Huapí (Fig. 15). Here the occurrences are separated from each other by erosion to a greater extent than in the southern Tronador area.

In this area rocks altered by means of late-volcanic processes have not been found. All are fresh. As in the former area a tripartition of the material may be suitably introduced here, too, *i. e.* in effusive lavas, in rocks appearing as dikes and necks and finally in pyroclastic products.

a. Lavas.

In the Tronador area all lavas had, at least under the microscope, a porphyritic texture. This also applies to the majority of specimens from the Brazo del Viento area. Here, however, a group of rocks of comparatively coarse texture also occurs further distinguished by the character that minerals developed as phenocrysts are either lacking or only appear indistinctly. By this means we naturally attain a subdivision of the lavas into two groups, which cannot, however, be very sharply delimited from each other.

α. Distinctly porphyritic lavas.

Applying the same principle of subdivision as for the lavas in the Tronador area it is found that in the area now in question only five combinations of phenocryst minerals occur. Two of these are not represented in the former area, for which reason not less than 15 different parageneses of phenocryst minerals have been established in the rocks of this interglacial series, and form the subject of this investigation. All lavas in the Brazo del Viento area belonging to this group possess olivine as phenocrysts. In this respect they all fall in the first group of the lavas of the Tronador area, the olivine-bearing basalts.

1. With phenocrysts of olivine.

There are four rock samples with only olivine phenocrysts, which have all been collected in the same locality, *viz.* the point on the southern shore of the Viento fjord, which has been called Punta de Bloques by LJUNGNER. They were taken from loose boulders, which had fallen down from an outcrop of lava upon the steep side of the fjord.

Megascopically they are rather light gray, in one case (No. 3) darker bluish gray, fine-grained to aphanitic, compact rocks, rarely (No. 2) with single vesicles of rounded or irregular form. They are characterized by rather abundant and evenly dispersed, yellowish green or olive-coloured olivine phenocrysts, in maximum from 2 up to 3—4 mm in size.

Also microscopically olivine is generally the only mineral appearing in the form of phenocrysts. Only in No. 4 was a solitary plagioclase crystal observed. The position of the section did not, however, make a closer determination of it possible. The olivine crystals show a varying degree of idiomorphic development. The boundaries are often rather uneven with corrosion sinuosities. The crystal form however can usually be traced. Sometimes the sinuosities filled by the groundmass become so large that the olivine crystals are subdivided into several portions separated from each other by groundmass, still possessing however the same optical orientation. Especially towards the periphery there occur some partly octahedral grains of magnetite enclosed in the olivine substance. No secondary alteration, not even peripherically, has taken place at all. Judging from the magnitude of the axial angle (Table XXVII) the

Table XXVII.

Volumetric analyses and optical data on olivine phenocrysts.

	1	2	3	4
Olivine phenocrysts	6.1	5.6	5.5	3.9
Groundmass	93.9	94.4	94.5	96.1[1]
Total	100.0	100.0	100.0	100.0
Vesicles	—	—	2.0	—
Axial angle of the olivine	+89°	90°	−85°	−83°

1—4. Punta de Bloques.

chemical composition of the olivine varies, from 8 % Fe_2SiO_4 in the lava richest in olivine to 26.5 % in the specimen containing the smallest number of phenocrysts.

The g r o u n d m a s s is of a somewhat different nature in the various specimens. In No. 3 somewhat more than half of it is composed of glass. In the groundmass, heavily pigmented in dark gray—black, might further be discerned sparse, in spots more abundant plagioclase laths of the approximate order of magnitude 0.1 × 0.01 mm as well as sparse pyroxene grains (about 0.04 mm) together with ore dust. — The groundmass of No. 4 is relatively coarsely developed. The thin, lathy plagioclase crystals have in some portions a pronounced, parallel fluidal arrangement. An Albite-Carlsbad twin was determined to 67 and 73 % An, respectively. The axial angle of the latter partial individual was $2\ V_\gamma = 85°$. In the groundmass are also found small, rounded olivine grains and in addition sparse, larger, distinctly pleochroic individuals of orthorhombic pyroxene, ophitically enclosing small plagioclase laths. The bulk of the dark groundmass minerals is, however, monoclinic pyroxene in small, isometric or somewhat more irregular grains. An individual showed a very little (at most 10°), positive axial angle. The extinction $\perp \beta$ was measured to 39°. Finally there occur scattered, relatively large, rather idiomorphic magnetite octahedrons and a sparse, brown pigmented, glassy basis. — Specimens No. 1 and 2 have an almost holocrystalline groundmass, brownish yellow glass forming an exceedingly small part of it. The plagioclase laths have an

[1] Including 2.2 % magnetite.

average magnitude of 0.2×0.02 mm. An individual being large enough to be measured on the universal stage was determined to 50 % An. The pyroxene is of two kinds, orthorhombic and monoclinic. The former, appearing as larger, but decidedly less numerous grains, seems preferably to be more abundant in the vicinity of the magmatically corroded olivines. The axial angle of a grain was measured to $2\ V_\alpha = 73^\circ$, corresponding to 28 % $FeSiO_3$. The monoclinic pyroxene because of its diminutiveness optically could not be more closely characterized. Finally ore occurring in generally not sharply idiomorphic grains of varying size must be mentioned.

2. With phenocrysts of olivine and diopside.

This phenocryst combination has been found in one case only. It deals with a boulder from an agglomerate at the locality not far east of Fraile, to the north of the middle part of Brazo del Viento. The rock is macroscopically grayish black, aphanitic and compact with yellowish green phenocrysts, up to 2 mm in size.

Plagioclase does not occur as phenocrysts. Olivine, however, is present in the form of large, idiomorphic crystals. They bear sparsely small magnetite octahedrons and sometimes dark glass as inclusions. Not even traces of alteration have been established. The axial angle $2\ V_\alpha = 89^\circ$ corresponds to a composition of 13.5 % Fe_2SiO_4.

Also monoclinic pyroxene occurs as phenocrysts. It forms pale greenish, single or glomeroporphyritically accumulated crystals, sometimes occurring together with small olivine crystals. Generally inclusions are lacking. The pyroxene like the olivine is quite devoid of alteration products. The crystals are smaller than the olivine phenocrysts and more rounded, subidiomorphic. A few solitary twinning lamellae sometimes occur. The following optical data were determined on the same individual: $2\ V_\gamma = 57^\circ$, $c : \gamma = 43^\circ$, representing a member of the diopside-hedenbergite-series relatively rich in lime.

The volumetric ratio between the different phenocrysts and the groundmass will appear from the following ROSIWAL analysis:

Phenocrysts	Olivine	5.1
	Diopside	1.5
Groundmass		93.4
	Total	100.0

The groundmass is characterized by the abundant plagioclase laths, about 0.1 mm in length, with a fine, fluidal arrangement (Fig. 32). Besides rounded crystals of monoclinic pyroxene olivine crystals in smaller number may be discerned in a rather abundant, dark pigmented vitreous basis.

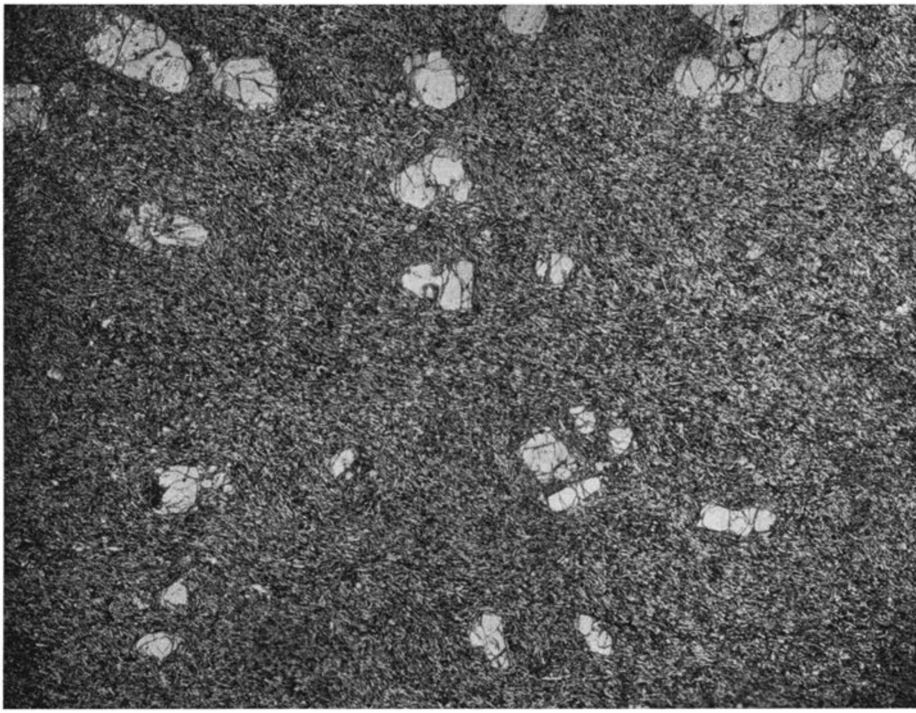


Fig. 32. Photomicrograph of olivine basalt with phenocrysts of olivine and diopside. East of Fraile. Ord. light. Magnif. × 10.

3. With phenocrysts of plagioclase, olivine and diopside.

Five specimens of lavas with the combination of phenocryst minerals stated in the heading above have been studied, all from Calderón de Lavas.

Megascopically these rocks are compact except No. 1 in the Tables XXVIII and XXIX, which displays coarse, irregular, somewhat unevenly dispersed vesicles. A characteristic feature for all specimens is a more or less pronounced, reddish gray — brownish violet tint. In some cases the lava is spotted or flamy in bluish gray and violet reddish brown. Two kinds of phenocrysts appear: light gray — white, occasionally somewhat irregularly dispersed, in maximum 2 or 3 mm in size, and, more sparsely, dark, olive brownish green or black, the latter ones generally being somewhat smaller than the former, though an exception occasionally occurs (No. 5: 3 and 2 mm, respectively).

The first-mentioned phenocrysts, consisting of plagioclase, are sometimes united to glomeroporphyritic groups and exhibit a rather broadly tabular to prismatic development. They are fresh and free from inclusions except a thin zone quite close to the exterior boundary of the crystals.

Table XXVIII.

Optical data on phenocrysts.

		1	2	3	4	5
Plagioclase	% An	95.5, 88	90, 88	87, 90	84, 89	90, 81
	2 V	—, —82°	−86°, −80°	—, —	—, −80°	—, —
	Tw. law	AC	C	C	C	C
Olivine	2 V	+87°	+87°	−88°	−86°	90°
Diopside	2 V	—	+62°	+57°	+55°	+56°
	$c:\gamma$	—	43°.5	41°.5	41°.5	43°

1—5. Calderón de Lavas.

This zone of inclusions marks the boundary between the central basic core of the crystal with homogeneous composition and a thin, exterior margin somewhat richer in albite. The chemical composition of the former will appear from Table XXVIII. It will be seen that it varies between 81 and 95.5 % An or, on an average, a basic bytownite with 88.5 % An. For the more acid marginal zone of No. 4, Ind. I a basic labradorite composition was determined with 65 % An (extinction ⊥ M and P=34°.5); No. 5, Ind. I showed 67.5 % (corresponding extinction 35°.5). A comparison with lavas of the same phenocryst paragenesis from the Tronador area shows, that the plagioclase phenocrysts of the latter as to range of variation as well as average composition are about 5 % richer in An, which is true of central as well as marginal parts of the phenocrysts.

The olivine phenocrysts behave somewhat differently in the various specimens. In No. 4 the olivine crystals are generally rather sharply idiomorphic, often, however, with corrosion sinuosities filled by groundmass. The olivine substance is extremely fresh. Only along some fissures a reddish brown colouring appears. Small groups of magnetite grains occur as the only inclusions. The olivine of No. 3 and 5, which has formed sharply idiomorphic phenocrysts, is bounded towards the groundmass by a compact opacitic margin. In the interior of the crystals also there generally occur compact agglomerations of ore grains, often exceeding in quantity the olivine substance preserved (Fig. 33). In a few cases, when the olivine phenocrysts partly border directly on plagioclase phenocrysts without intervening groundmass, the opacitic margin at the contact olivine—plagioclase is lacking or very slightly developed. The formation of ore in the central parts of the olivine has in these cases been highly reduced. In the specimens No. 2 and especially No. 1 the olivine phenocrysts are also peripherically as well as in the centre generally highly

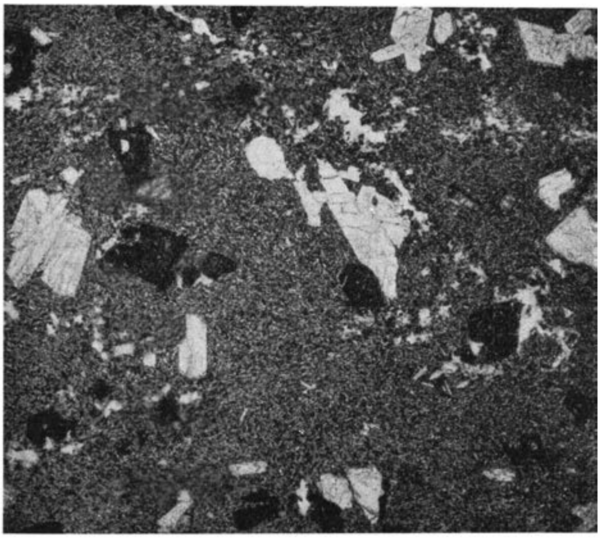


Fig. 33. Photomicrograph of olivine basalt with phenocrysts of plagioclase, olivine (opacitized) and diopside (No. 3 in Table XXVIII and XXIX). Calderón de Lavas. Ord. light. Magnif. × 9.

altered to ore. According to the magnitude of the axial angle the composition of the olivine varies between 5 and 20 % Fe_2SiO_4, giving an average of 11.5 %. The lavas of the corresponding group from the Tronador area have olivines appreciably higher in iron.

Table XXIX.

Volumetric analyses.

		1	2	3	4	5
Pheno-crysts	Plagioclase	12.7	7.2	6.4	8.8	7.8
	Olivine	5.9	5.2	5.9	6.7	5.6
	Diopside	0.6	0.8	0.3	0.8	0.4
	Groundmass	80.9	86.8	87.5	83.7	86.2
	Total	100.1	100.0	100.1	100.0	100.0

1—5 = Table XXVIII.

As will appear from the ROSIWAL analyses of Table XXIX monoclinic pyroxene occurs only sparsely as phenocrysts. The individuals are also smaller than the olivines, have a rather equidimensional form, but show little pronounced tendency to idiomorphic outlines. The colour is often very pale, generally, however, distinctly greenish, without pleochroism. In one slide (No. 2) a certain zoning appears, the centre showing a paler colour than the periphery, indicating an increased iron percentage in the later deposited parts of the crystal. Solitary twins are occasionally to be seen. The monoclinic pyroxene has only rarely suffered a similar alteration into ore as the olivine to a small extent. Generally it has remained quite unaffected by all secondary actions. The optical data correspond to a diopsidic pyroxene. Only in rock No. 4 a pigeonitic character of the pyroxene phenocrysts begins to appear.

The groundmass is characterized by its being rich in thin plagioclase laths in nice fluidal arrangement. Further occur well individualized monoclinic pyroxene in forms determined by the feldspar laths, and scattered, relatively large, mostly idiomorphic magnetite crystals and a larger or smaller, pale brownish coloured glassy residuum. In the more intensely reddish brown coloured specimens the groundmass is so highly pigmented that often only the plagioclase laths may be identified with any certainty.

One specimen, the qualitative and quantitative mineralogical composition of which is stated as No. 2 in the tables XXVIII and XXIX, has been chemically analysed (Table XXX). Immediately conspicuous is the high Fe_2O_3 and the correspondingly low FeO percentage. Otherwise the analysis values are such as might be expected for a normal, unaltered olivine-bearing basalt. The only essential alteration, which the lava has undergone, obviously involved an oxidation, by which a great part of the bi-

Table XXX.

Analysis VI. Oxidized olivine basalt. Calderón de Lavas.

	Weight-%	Mol. Prop.	Norm			Niggli values	
SiO_2	50.28	8372	Q	2.12	65.93	si 118	
TiO_2	0.78	98	or	5.01		al	25
Al_2O_3	18.08	1774	ab	25.48		fm	41
Fe_2O_3	8.29	519	an	33.32		c	26
FeO	0.98	136	di $CaSiO_3$	6.40	34.53	alk	8
MnO	0.14	20	di $MgSiO_3$	5.53			100.0
MgO	6.92	1716	hy $MgSiO_3$	11.70		ti 1.38	
CaO	10.20	1819	mt	1.34		h 2.67	
Na_2O	3.01	486	il	1.49		p 0.30	
K_2O	0.85	90	hm	7.37		o 0.36	
H_2O+	0.34	189	ap	0.70		mg 0.59	
H_2O-	(0.12)	—				k 0.16	
P_2O_5	0.30	21	H_2O+	0.34		qz	−14
Total	99.81			100.80			

II. 5. 4. 4—5. Hessose. — Or : Ab : An = 7.85 : 39.93 : 52.22. Spec. gr. $\frac{19^\circ}{4^\circ}$ = 2.72.

valent iron has been transferred to trivalent. From the petrographical description given above this oxidation does not appear to have been accompanied by the formation of any secondary hydrated minerals at all. The low water percentage of the rock corroborates this statement.

By the strong secondary oxidation the norm calculated in the usual manner gives a picture of the rock which differs essentially from its actual, primary mineralogical composition. Of the NIGGLI values it is probable that only *o* and *mg*, however, have been affected materially by the alteration and this has actually caused a great increase in both cases. The other NIGGLI values characterize the rock as belonging to the miharaitic type of the gabbroidal magmas (NIGGLI 1936), *i. e.* a type rather rich in lime, with which the appearance of basic plagioclase and diopsidic pyroxene (together with olivine) as phenocrysts is in good accord.

4. With phenocrysts of plagioclase and olivine.

As in the Tronador area this group has the greatest number of representatives, ten specimens belonging to it. Of these rock samples five originate from the southern shore of Brazo del Viento, the rest from the northern side of the fjord, *viz.* two from Calderón de Lavas and one from each of the following three localities: Arroyo de las Cuevas, east of »Kr» and Fraile.

As to their exterior appearance these lavas present rather great differences. The rocks from the southern shore of Brazo del Viento are fine-grained to aphanitic, lighter or darker gray, in one case with a greenish tint (No. 5), in another case (No. 3) violet gray. They are predominantly compact, non-vesicular, partly with platy cleavage (especially No. 6). No. 1 bears solitary, small and No. 8 abundant, well rounded vesicles, generally 1 mm, exceptionally up to 9 mm in diameter. In the last-mentioned lava distinct plagioclase phenocrysts are lacking. The other specimens have abundant, lighter or darker gray, partly white phenocrysts with the maximum magnitude varying from 1 mm (No. 5) to 4 mm (No. 1). Olivine phenocrysts appear macroscopically in all specimens, but with varying colours: yellowish green-gray, olive brownish green, brownish red, brownish black, in the last-mentioned case (No. 3) partly with metallic lustre. — The two lavas from Calderón de Lavas are compact, fine-grained and evenly violet gray (No. 9), respectively dense, in bluish gray and reddish brown flamy rocks (No. 2). The dark gray to black olivine phenocrysts, in maximum 1.5 and 3 mm in size, respectively, are more abundant in No. 9, in No. 2 of about the same frequency as the light gray plagioclase phenocrysts, at most 1.5 and 2 mm in length, respectively. — Whereas the lava from Arroyo de las Cuevas is dark gray and compact with relatively scattered, light gray phenocrysts of plagioclase, up to 2.5 mm in size, and the specimen from Fraile has a similar appearance differing in that the yellowish green phenocrysts, exceptionally 3—4 mm in size, consist of olivine, the lava east of »Kr» is reddish brown and highly scoriaceous also lacking macroscopically discernable minerals.

The form of the plagioclase phenocrysts shows a certain relation to their magnitude. The larger ones are rather broadly prismatic or tabular, the microphenocrysts (0.4—0.8 mm in length), on the other hand, thinly lathy. What appear megascopically as solitary plagioclase phenocrysts prove under the microscope to be compact lying groups of idiomorphic crystals. Sometimes about ten individuals may be joined in this manner. These glomeroporphyritic aggregates of plagioclase phenocrysts occur in all lavas belonging to this group of rocks from the southern shore of Brazo del Viento as well as in the specimen from Arroyo de las Cuevas on its northern shore. The plagioclase phenocrysts are either free from, or have sparse, inclusions of the same nature as the groundmass. Only in the scoriaceous lava east of »Kr» (No. 7) do the phenocrysts in part bear abundant vitreous inclusions. The feldspar substance is in all cases quite fresh. The zoning is most commonly of simplest type with a thin exterior margin more rich in albite round a relatively homogeneous core. Sometimes (No. 1) this more acid border is almost entirely absent. In a few cases (No. 3 and 5) a slightly oscillatory zoning with exceedingly small differences in extinction appears in the outer part of the core, whereas in the lava from Arroyo de las Cuevas in the margin rich in albite sometimes more basic recurrences may be observed. Finally the lava east of »Kr» has phenocrysts with a more pronounced zoning and a number of more accentuated peripherical recurrences.

The chemical composition of the quantitatively predominant central portions of the plagioclase phenocrysts according to Table XXXI varies between an average bytownite and a basic anorthite. Compared with the corresponding group of rocks in the Tronador area the limits of variation in the Viento area are somewhat displaced towards the basic side. The same is also true of the average of the determinations made, 88 % An, as against 80.5 % An for the corresponding rocks in the Tronador area. The outermost zone richer in albite was determined in two cases (No. 4 and 9, Ind. I) to 70 and 71.5 % An, respectively (extinction $\perp$ M and $P = 36^\circ.5$ and $39^\circ.5$, respectively).

The quantitative importance of the olivine phenocrysts will appear from Table XXXII. Their form is generally rounded idiomorphic, here and there with sinuosities filled by groundmass; frequently, however, the olivine has a sharply ideal development. In those cases when olivine enters into the glomeroporphyritic crystal aggregates, its form is in the main determined by the plagioclase. Further there also occur (in the lava east of »Kr») plagioclase crystals quite enclosed in olivine phenocrysts. Whether those ore grains appearing in the olivines of the Fraile lava are to be regarded

Table XXXI.

Optical data on phenocrysts.

		1	2	3		4	5
Plagioclase .	% An	96.5, 92	92, 90	92, 90	87.5, 87.5	88.5, 89	90, 87
	2 V	—, —	—, —	—, —	−81°, −83°	—, —	−80°, −84°
	Tw. law	C	C	C	AC	AC	C
Olivine . . .	2 V	90°	90°	−85°		+87°	−87°

		6	7	8	9	10
Plagioclase . .	% An	86, 89	84, 90	88, 84	83.5, 86.5	81, 79
	2 V	—, −78°	—, —	−84°, —	−88°, —	—, —
	Tw. law	C	A	C	A	AC
Olivine	2 V	+87°→−88°	+85°	−84°	−89°	90°

1. Punta de Bloques.
2. Calderón de Lavas.
3. Punta de Bloques.
4. Arroyo de las Cuevas.
5. Punta de Bloques.
6. Punta de Bloques.
7. East of »Kr».
8. Punta de Bloques.
9. Calderón de Lavas.
10. Fraile.

Table XXXII.

Volumetric analyses.

	1	2	3	4	5	6	7	8	9	10
Pheno-crysts Plagioclase	21.4	4.8	7.2	7.1	11.8	12.3	12.9	10.6	2.5	0.4
Pheno-crysts Olivine .	3.6	3.8	3.3	1.3	1.4	2.4	3.3	0.6	6.9	5.2
Groundmass .	75.0	91.4	89.6	91.6	86.9	85.4	83.9	88.8	90.6	94.4
Total	100.0	100.0	100.1	100.0	100.1	100.1	100.1	100.0	100.0	100.0
Vesicles . . .	2.9	—	—	—	—	—	43.8	13.5	—	—

1—10 = Table XXXI.

as inclusions of primary magnetite crystals formed before the olivine, or as secondary alteration products of the olivine substance, is difficult to decide. As to the lavas from Calderón de Lavas and east of »Kr» the last-mentioned alternative is obviously the correct one. As an initial stage in the alteration of the olivine (No. 9) the formation of small ore grains

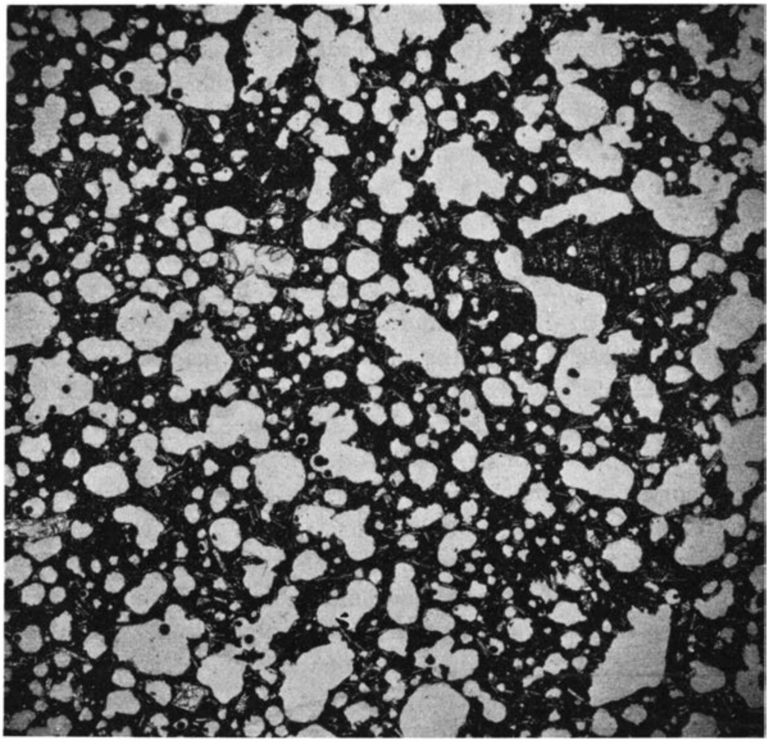


Fig. 34. Photomicrograph of scoriaceous olivine basalt lava with phenocrysts of plagioclase and olivine (partly opacitized; No. 7 in Table XXXI and XXXII). East of »Kr». Ord. light. Magnif. × 12.

appears in spots. A more advanced stage is represented by No. 2, where the olivines at least in the peripherical parts and often almost throughout their whole mass have been altered into an aggregate of closely lying ore grains. In No. 7 the opacity has developed so far that only exceptionally a net-work of seemingly unaltered olivine substance remains (Fig. 34). The lavas from the northern and southern shores of the Viento fjord have usually quite fresh olivine phenocrysts. In No. 6, however, a slight formation of serpentine occurs along fissures. The macroscopically reddish brown colour of the olivine phenocrysts of specimen No. 5 is due to an alteration beginning peripherically and along fissures into a ferrihydroxidic substance, whereas the metallic lustre of some olivine phenocrysts of No. 3 is obviously due to a similarly appearing, thin, but intensely red, ferritic coating. The olivine of this rock, in slices of common thickness, has a distinctly greenish colour in spots.

According to the axial angle the chemical composition of the olivine varies in the limits 1—24 % Fe_2SiO_4. The mean value calculated from the determinations made, 12.5 % Fe_2SiO_4, indicates an olivine on an average lower in iron than in the corresponding group of rocks from the Tronador area (16.5 % Fe_2SiO_4). The limits of the chemical variation also show a corresponding displacement (in the Tronador area 7 and 26 % Fe_2SiO_4, respectively). In the great majority of cases each olivine individual has throughout the same uniform axial angle. An olivine crystal from the lava No. 6 showed, however, zoning, the central portions having $2\ V_\gamma = 87°$, whereas in the marginal parts the axial angle continuously changed into $2\ V_\alpha = 88°$, corresponding to 5 and 15 % Fe_2SiO_4, respectively.

The groundmass in lavas from different localities varies somewhat in nature. As a representative example for the rather closely agreeing rocks from Punta de Bloques and Arroyo de las Cuevas No. 5 may be described. Plagioclase forms laths of the order of magnitude 0.2×0.02 mm. Monoclinic pyroxene occurs in crystals reaching dimensions sometimes amounting to the length of the plagioclase laths. They show a pale grayish green colour in thin sections of common thickness and are often twinned. The axial angle is comparatively large. Magnetite occurs rather evenly scattered in octahedral crystals, up to 0.15 mm in size. Finally a small residuum of dark pigmented, brown glass is recorded. In some specimens olivine is also present in the groundmass. In No. 3 the pyroxene grains are in spots slightly brown pigmented by ironhydroxide, which contributes to the macroscopically violet gray tint of the rock. Sometimes (No. 1) the pyroxene and ore grains are exceedingly small, of considerably smaller dimensions than the plagioclase laths. The quantity of glass varies somewhat. — Of the two specimens from Calderón de Lavas the groundmass is in one (No. 9) practically holocrystalline, consisting of plagioclase laths as well as grains of olivine, pyroxene and ore, whereas the other one (No. 2) is so heavily studded with ore grains and a reddish brown, limonitic pigment that only the plagioclase laths, having moreover a fine fluidal arrangement and being about 0.2 mm in length, appear distinctly, whereas the mafic silicate mineral grains are highly masked. — The groundmass of the Fraile lava also is almost entirely free from glass. The plagioclase laths are here of the order of magnitude 0.1 mm. Further there occur rounded olivine grains with an average diameter of about 0.04 mm and abundant smaller grains of pyroxene as well as ore rather scarcely. — In the groundmass of the highly scoriaceous lava east of »Kr» the only mineral to be observed is developed in greenish yellow-brown grains with a diameter of only 0.035 mm approximately. For the rest it consists of a very pigmented, opaque glass.

The vesicles are in all cases unmineralized. In No. 8 they are generally globular and in the immediately surrounding groundmass the plagioclase laths show a nice tangential orientation. In one of the larger vesicles there was observed locally a darker coating on its wall with a sharply defined limit towards the surrounding rock. This coating consists of plagioclase laths, decidedly larger than those of the groundmass in general, and magnetite octahedrons, also somewhat larger than the average in the rock, set in an abundant, brownish black glassy mass, in which rather large rod-formed pyroxene crystals just appear. The clean-cut contact towards the adjacent lava and the deviating textural development show that this partial filling has entered into the vesicle when the surrounding rock had been mainly consolidated. On account of the moderately scoriaceous nature of the lava probably only quite short material transports *en masse* must be taken into consideration. For that reason the course of events seems to me to have been such that in a lava flow, the movement of which had mainly ceased (the vesicles not elongated), when the superficial portions had solidified, from a somewhat lower level by rather far advanced crystallization and concomitant enrichment in volatiles a mobile fluid fraction of the character of residual liquor was carried upwards by departing gases. The larger vesicles being in more or less direct communication could thereby do service as ways of transfer.

5. With phenocrysts of plagioclase, olivine and orthorhombic pyroxene.

This last group of porphyritic lavas from the Brazo del Viento area is represented by only one specimen, collected on the southern shore of the Viento fjord, at Punta de Bloques.

Megascopically the rock is rather light gray with small phenocryst-like crystals of light gray plagioclase (to 1 mm) and yellowish brown olivine.

The plagioclase phenocrysts are rather broadly prismatic and often accumulated in groups, in part together with olivine crystals. They are fresh, free from inclusions and with simple zoning. An Albite-Carlsbad twin of average size had in the centre an anorthitic composition with 90 and 95 % An, respectively. The axial angles of the two twin individuals examined were $2\ V_\alpha = 81^\circ$ and 82°, respectively. In the margin of Ind. II the extinction $\perp$ M and P was 36°, corresponding to 69 % An.

Olivine forms in part rather large phenocrysts, which, however, have a comparatively rounded shape and often large corrosion sinuosities. Plagioclase crystals occur as inclusions. In the coarse plagioclase—olivine crystal groups the olivine is often influenced as to its exterior form by the plagioclase prisms. The olivine is fresh but for a thin coating of yellowish brown colour along some fissures. The axial angle $2\ V_\alpha = 89^\circ$ corresponds to 13.5 % Fe_2SiO_4.

Orthorhombic pyroxene occurs more rarely as independent phenocrysts. The axial angle of such an individual was determined to $2\ V_\alpha = 64^\circ$, corresponding to 38.5 % $FeSiO_3$. Generally it forms a reaction rim round olivine. Sometimes the optical orientation is the same in the two minerals, but mostly differs. This corona hypersthene (one or a few individuals round the same olivine) often stands in immediate connection with lobate groundmass individuals of the same mineral with ophitically enclosed plagioclase crystals. These latter are rather thinly lath-shaped. The groundmass is further characterized by small, rounded grains of monoclinic pyroxene and ore. The latter are preferably enclosed in the hypersthene. A very sparse vitreous residuum occurs interstitially.

ROSIWAL analysis:

Phenocrysts	Plagioclase	12.5
	Olivine	2.2
	Orthorhombic pyroxene	1.5
Groundmass		83.8
	Total	100.0

β. Indistinctly porphyritic and even-grained lavas.

Characteristic of this group of lavas is the rather coarse-grained texture for volcanic rocks of the groundmass, on account of which the contrast in magnitude between phenocrysts and groundmass individuals has been quite or almost entirely levelled. As in the case of the lavas from the Brazo del Viento area described above the rocks belonging to this group are olivine basalts. Two types, however, may be distinguished, *viz.* those bearing orthorhombic pyroxene and those lacking this mineral. Parallel with this mineralogical difference generally runs a certain difference in microscopic texture.

1. Hypersthene-bearing lavas.

This group comprises four specimens. Three of them come from the southern shore of Brazo del Viento (Punta de Bloques), whereas the fourth is taken at the lava occurrence east of »Kr».

Megascopically these rocks are fine-grained, compact, rather light, occasionally brownish gray lavas. In one case (No. 1) every trace of porphyritic development is lacking, in the others there appear sparsely and rather vaguely larger, lighter gray to white crystals of plagioclase, in maximum 1—3 mm in length, and, more distinctly, dark, in part brown or reddish brown-green olivines, 1—2, exceptionally 5 mm in size. In No. 3 solitary, larger or smaller accumulations of such plagioclase and olivine crystals were observed lying close together.

Microscopically the porphyritic texture becomes less prominent yet, as no sharp *hiatus* in size appears between the larger plagioclase crystals and the coarse groundmass individuals. From the larger, rather broadly tabular to the smaller, relatively thin lath-formed crystals all transitions are generally represented. The substance is fresh and free from inclusions or they are only few in number. The zoning is mostly of the simplest, normal type. A slightly prominent fluidal structure may sometimes be observed. The composition of the plagioclase stated in Table XXXIII refers to the central portions of the larger individuals. Conse-

Table XXXIII.

Optical data.

		1	2	3	4
Plagioclase . .	% An	95, 100	93.5, 94.5	91.5, 89	88, 89
	2 V	−81°, —	−81°, —	−78°, —	−86°, −87°
	Tw. law	AC	P	A	AC
Olivine . . .	2 V	−81°	−83°	−88°	−83°
Orthopyroxene	2 V	−62°	−61°	−74° → −63°.5	−68°
Clinopyroxene	2 V	+10°	—	—	+47°.5
	c : γ	42°.5	—	—	43°.5

1—3. Punta de Bloques.
4. East of »Kr».

quently it varies between pure anorthite and basic bytownite, being on an average an acid anorthite containing 92.5 % An. In the outermost margin of two individuals, *viz.* No. 1, Ind. I and No. 3, Ind. II, the extinction ⊥ M and P = 37° and 35° was measured, respectively, corresponding to a composition of 70.5 and 66 % An, respectively.

Olivine occurs comparatively sparsely in larger or smaller, generally irregularly rounded crystals. The smaller ones are sometimes quite enclosed by orthorhombic pyroxene. Secondary alteration is generally lacking. At most there appears along some fissures a thin coating of more or less highly reddish brown, ferrioxidic substance. In the rock No. 1, however, the olivine has suffered an alteration into yellowish brown serpentine both peripherically and along fissures. The percentage of fayalite silicate in the olivine derived from the magnitude of the axial angle varies in the different specimens from 15.5 to 30.5 %, being on an average 24.5 %.

Orthorhombic pyroxene occurs in these rocks rather abundantly in tolerably large individuals, which have ophitic relation to the smaller plagioclase crystals (Fig. 35). At the same time a distinct tendency is occasionally observed to a general development of idiomorphic outlines. Also small ore grains appear in the same manner as the plagioclase enclosed in the orthorhombic pyroxene. It shows most frequently a distinct pleochroism according to the common scheme. No alteration has been observed. The determinations of the axial angle performed correspond to

Fig. 35. Photomicrograph of non-porphyritic, doleritic basalt lava with ophitic hypersthene (No. 3 in Table XXXIII and XXXIV). Punta de Bloques. Ord. light. Magnif. × 66.

a hypersthene composition with values varying from 28.5 to 42 %, on an average 37 % $FeSiO_3$. The lowest value was obtained in the centre of a zoned individual from rock No. 3, the peripherical portions of which gave the composition 41 % $FeSiO_3$.

Magnetite appears more or less abundantly in larger or smaller crystals, often showing a rather sharp octahedral form. In the lava No. 1 they are more scattered and larger, often enclosing abundant plagioclase and pyroxene crystals, having, however, a distinct tendency to the development of crystal faces.

Table XXXIV.

Volumetric analyses.

	1	2	3	4
Plagioclase	61.2	59.9	56.2	60.1
Olivine	1.2	1.7	1.2	0.5
Orthopyroxene	3.7	14.7	19.1	15.2
Clinopyroxene	24.1	19.6	14.9	19.1
Magnetite	2.5	4.1	3.8	5.2
Glass	7.4	—	4.8	—
Total	100.1	100.0	100.0	100.1

1—4 = Table XXXIII.

In two of the rocks in question (*cf.* Table XXXIV) glassy matrix is almost entirely lacking. In the two others a sparse, dark pigmented residuum of brown glass occurs, filling the interstices between the other minerals.

2. Lavas free from hypersthene.

To this group of indistinctly porphyritic lavas belong five rock specimens, two from the southern shore of Brazo del Viento (Punta de Bloques) and three from Arroyo de las Cuevas on its northern shore.

Megascopically three of these (No. 1, 3 and 4) are light gray, fine-grained, compact rocks with indistinctly phenocryst-like appearing, whitish gray plagioclase crystals, up to 2—3 mm in size, and yellowish brown-green (No. 1) or blackish gray (No. 4) olivines, at most 2 mm in size. In No. 3 only scattered, brownish yellow, phenocryst-like olivines, 1 mm in size, appear. The lavas No. 2 and 5 are rather dark violet gray and scoriaceous with single larger, light gray plagioclase crystals, up to 2 and 3 mm in length, respectively, and rounded or somewhat lengthened vesicles, $^1/_2$ and partly more than 1 cm in length, respectively, in No. 5 with a reddish brown or yellowish brown coating.

Microscopically a sharp difference between phenocrysts and groundmass individuals of plagioclase is difficult to determine, as in the immediately preceding rock group, on account of the occurrence of all transitions in magnitude as well as form, from the larger, rather broadly tabular to the smaller, thinly lath-formed crystals. The zoning is generally distinct, though only the outmost part has a materially more acid composition. In the more acid, marginal portions of the larger crystals there sometimes occur (No. 1—3) more or less numerous basic recurrences, which in the smaller individuals are mostly lacking. The plagioclase is fresh and usually practically free from inclusions. In No. 5 the crystals are penetrated by some veins filled with glass. The composition of the plagioclase varies from acid anorthite to acid bytownite with an average of 85.5 % An. It is then somewhat higher in albite than in the immediately preceding group. These statements refer to the majority of the medium-sized or larger crystals. The chemical composition of the margin higher in albite was determined in some cases with the following results:

No. 1, Ind. I: Core 91 % An → Margin 78.5 % An (Extinct. $\perp$M and P: 40°.5)
» 2 » » » 90 » » → » 77.5 » » (» » » »: 40°)
» 4 » » » 86.5 » » → » 68.5 » » (» » » »: 36°).

Also the olivine generally forms larger as well as smaller crystals, which, however, only rarely show any certain tendency to the development of crystal form. In rock No. 5 olivine and plagioclase sometimes compose glomeroporphyritic accumulations with only little intermingling of other

Table XXXV.

Optical data.

		1	2	3	4	5
Plagioclase . .	% An 2 V Tw. law	91, 88 —, — C	90, 89 —, — C	87, 88 $-83°, +85°$ C	86.5, 88 —, — C	77, 72 $+88°$, 90° AC
Olivine . . .	2 V	$-88°$	90°	$-85°$	$-85°$	$-88°$
Clinopyroxene	2 V $c:\gamma$	$+49°$ 40°	— —	$+20°$ 39°.5	— —	— —

1. Arroyo de las Cuevas.
2, 3. Punta de Bloques.
4, 5. Arroyo de las Cuevas.

components. Inclusions and alteration products are generally completely lacking. In No. 2 a peripheric brown colour may, however, be established and in No. 5 also along fissures an incipient, slight alteration into a reddish brown substance. The chemical composition derived from the axial angle shows a variation from 13 to 26, or on an average 20.5 % Fe_2SiO_4. The olivine in this group of rocks is therefore not quite as high in iron as in the immediately preceding one.

Monoclinic pyroxene occurs quite predominantly as small, rounded, pale greenish grains with doleritic relation to the plagioclase. Sometimes thin twinning lamellae may be established. Only in one rock (No. 3) there also appear larger individuals of monoclinic pyroxene ophitically enclosing small plagioclase laths. In this case it is somewhat pleochroic. Also in this group of rocks the pyroxene is pigeonitic.

The two highly vitreous rocks No. 2 and 5 lack individualized ore. The others, on the other hand, bear scattered to rather abundant, partly octahedral ore grains of about the same magnitude as the pyroxene grains. In No. 3 the ore partly encloses plagioclase and pyroxene crystals in an ophitic manner. The same phenomenon occurred in a hypersthene-bearing rock of the preceding group (p. 333) from the same locality, the southern shore of Brazo del Viento. It is also remarkable that these two specimens are the only ones in which part of the monoclinic pyroxene shows a similar ophitic relation to the plagioclase.

Glass appears in highly varying quantity (*cf.* Table XXXVI) interstitially. In the compact types with a comparatively small quantity of glass it is brown and rather slightly pigmented, whereas the scoriaceous and more vitreous rocks show a brownish black to black glass made opaque by ferruginous pigment.

Table XXXVI.

Volumetric analyses.

	1	2	3	4	5
Plagioclase	60.0	42.1	58.6	51.3	39.9
Olivine	2.5	3.5	2.8	1.3	5.0
Clinopyroxene	29.5	20.4	33.9	31.9	9.0
Magnetite	2.1	—	2.9	3.4	—
Glass	5.9	34.0	1.8	12.2	46.2
Total	100.0	100.0	100.0	100.1	100.1
Vesicles	—	12.0	—	—	12.3

1—5 = Table XXXV.

In No. 5 the large vesicles are generally lined with small crystals of a deep coloured, brownish yellowgreen mineral, probably epidote. Its relation to the rock immediately surrounding the vesicles indicates that it has been formed in part at the cost of its plagioclase (and pyroxene). The vesicles of specimen No. 2 are unmineralized. The immediately adjacent rock shows here a different character in some cases with very thin plagioclase laths and also slender radiating pyroxene crystals in an abundant, heavily pigmented vitreous matrix. The boundary towards the normal rock is very sharp. The same explanation might be applicable to this formation as has been given above (p. 331) to an analogous phenomenon.

On one of the specimens from Arroyo de las Cuevas, more specifically No. 1 (Tables XXXV and XXXVI) a chemical analysis has been performed, given in Table XXXVII. Apart from the degree of oxidation of the iron and a somewhat higher percentage of SiO_2 this rock agrees rather closely with analysis VI (Table XXX). Comparing our analysis VII with the averages of analyses of different types of rocks as compiled by DALY (1933) it is found that in several respects it is intermediate between the average of quartz basalt and that of other basalts. This intermediate position finds expression in the appearance of quartz (Q) in the norm as well as in the negative NIGGLIan quartz number (qz) and the occurrence of 2.5 % by volume of modal olivine. From such an intermediate position our analysis differs essentially only by higher Al_2O_3 and CaO as well as correspondingly lower Na_2O and K_2O, depending on the relative abundance of plagioclase high in anorthite. In the classification according to NIGGLI (1936) it forms an even more typical representative for the miharaitic magma type than the analysis No. VI given above.

Table XXXVII.

Analysis VII. Doleritic olivine basalt. Arroyo de las Cuevas.

	Weight-%	Mol. Prop.	Norm			NIGGLI values		
SiO_2	52.06	8668	Q	0.53	62.36	si	125	
TiO_2	1.06	133	or	5.34		al		25
Al_2O_3	17.60	1727	ab	23.70		fm		40.5
Fe_2O_3	1.86	117	an	32.79		c		26.5
FeO	7.00	974	di $CaSiO_3$	7.03	37.91	alk		8
MnO	0.13	18	di $MgSiO_3$	4.14				100.0
MgO	6.40	1587	di $FeSiO_3$	2.55		ti	1.92	
CaO	10.23	1824	hy $MgSiO_3$	11.80		h	0.25	
Na_2O	2.80	452	hy $FeSiO_3$	7.25		p	0.17	
K_2O	0.90	96	mt	2.71		o	0.08	
H_2O+	0.03	17	il	2.02		mg	0.57	
H_2O-	(0.12)	—	ap	0.41		k	0.18	
P_2O_5	0.17	12	H_2O		0.03	qz		−14
Total	100.24				100.30			

III. 5. 4. 4—5. Auvergnose. — Or : Ab : An = 8.64 : 38.33 : 53.03.

Spec. gr. $\frac{18^\circ.5}{4^\circ} = 2.77$.

b. **Neck and dike rocks.**

Under this heading three occurrences of rocks are brought together of a cross-cutting character when viewed in relation to their immediate surroundings. The interglacial age of one of these, the lava neck on the southern shore of Brazo del Viento at Peña de Columnas, is proved by the fact that it is glacially sculptured and striated, whereas on the other hand it cuts through agglomerates, which in their turn are resting upon a pre-volcanic substratum with glacial sculpture as has been established on the opposite shore of the fjord. The other occurrences, a vertical dike in coarse granite at Casa Pangue, on the Chilean side of the frontier, and another dike intersecting Milleaqueo sediments east of Arroyo de las Cuevas, are less easily determined with regard to their age position. Their petrographical development is not, however, incompatible with a genetical connection with the interglacial volcanicity.

α. The lava neck at Peña de Columnas.

Macroscopically the rock, of which this neck is composed, is aphanitic, compact and blackish gray in colour with evenly dispersed, blackish green phenocrysts, up to 2 mm in size.

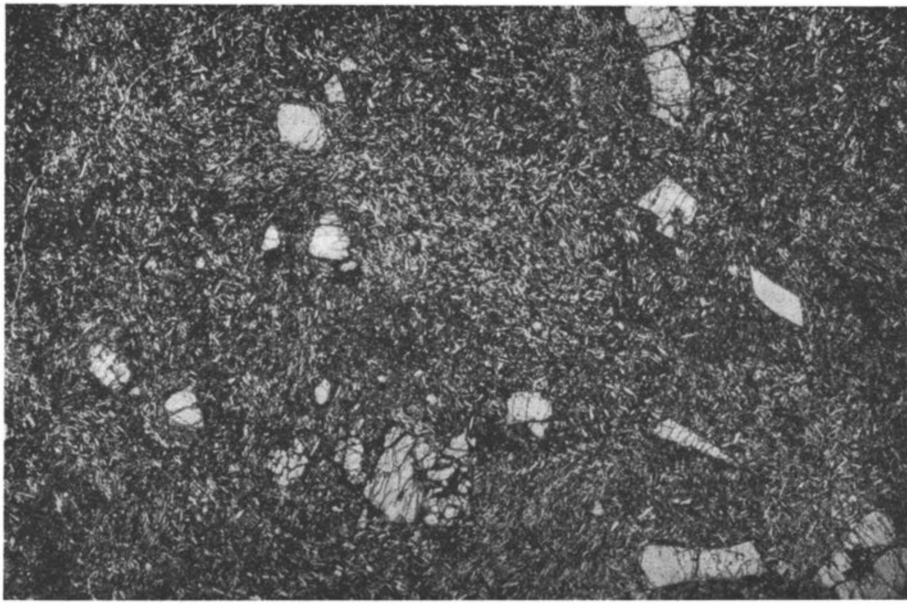


Fig. 36. Photomicrograph of intrusive olivine basalt with phenocrysts of olivine and plagioclase (very sparse). Peña de Columnas. Ord. light. Magnif. × 11.

Olivine is by far the most predominant phenocryst mineral present. It has partly suffered a rather intense resorption, as not only corrosion sinuosities appear but also the olivine crystals by dissolution preferably acting from fissures have been subdivided into a smaller number of separate portions, which have generally been displaced, though only slightly, in relation to each other (Fig. 36). The groundmass between these olivine remnants has a somewhat different structure and composition as against the normal one. It is more fine-grained and lower in plagioclase laths and also contains in proportion more glass and mafic microliths. The change in composition of the melt round the phenocrysts arising from resorption of olivine substance has therefore not been levelled, which goes to prove that the resorption has also been in progress after the magma has come to rest on its definite place. The mutual orientation of the resorption remnants just described points in the same direction. The olivine usually contains a few small magnetite octahedrons as inclusions. As a later formation sparsely yellowish green serpentine in narrow fissures may be observed. The axial angle of the olivine 2 V was determined to 90°, which gives 11.5 % Fe_2SiO_4.

Phenocrysts of plagioclase occur only in very small number. They are relatively broadly prismatic, fresh and with a thin border higher in albite round the homogeneous core. An Albite-Ala twin had 87.5 and

78 % An, respectively. In both twin individuals the axial angle $2\ V_{\alpha} = 88^{\circ}$ was determined.

The groundmass consists of abundant plagioclase laths, sparser grains of monoclinic pyroxene as well as spots of brownish green serpentine and gray pigmented glass substance. On the other hand individualized ore in small octahedral crystals is remarkably sparse.

Volumetric analysis:

Phenocrysts	Plagioclase	0.6
	Olivine	7.2
Groundmass		92.2
	Total	100.0

A chemical analysis has been made of this rock (Table XXXVIII). It shows in part a very great conformity to the analysis of the olivine basalt

Table XXXVIII.

Analysis VIII. Olivine basalt, intrusive. Peña de Columnas.

	Weight-%	Mol. Prop.	Norm			NIGGLI values		
SiO_2	52.05	8666	Q	0.35	55.57	si	120	
TiO_2	0.90	113	or	5.12		al		21
Al_2O_3	15.55	1525	ab	21.81		fm		48.5
Fe_2O_3	2.16	135	an	28.29		c		23.5
FeO	7.00	974	di $CaSiO_3$	6.62	44.50	alk		7
MnO	0.17	24	di $MgSiO_3$	4.25				100.0
MgO	8.89	2205	di $FeSiO_3$	1.91		ti	1.56	
CaO	9.50	1694	hy $MgSiO_3$	17.80		h	0.78	
Na_2O	2.58	416	hy $FeSiO_3$	7.99		p	0.45	
K_2O	0.87	92	mt	3.13		o	0.08	
H_2O+	0.10	56	il	1.72		mg	0.64	
H_2O-	(0.50)	—	ap	1.08		k	0.18	
P_2O_5	0.45	32	H_2O+		0.10	qz		−8
Total	100.22				100.17			

III. 5. 4. 4—5. Auvergnose. — Or : Ab : An = 9.27 : 39.50 : 51.23.

Spec. gr. $\frac{18^{\circ}.5}{4^{\circ}} = 2.87$.

from Arroyo de las Cuevas (Anal. VII). A lower percentage of Al_2O_3, CaO and Na_2O together with correspondingly higher values of MgO and total iron at practically identical percentages of SiO_2 indicate the somewhat more melanocratic character of the neck rock. Upon the pronounced difference in colour between the two rocks (dark blackish gray and grayish white) one would expect a greater chemical difference than that actually existing. Obviously the degree of crystallinity and the coarseness of the grains are of the greatest importance for the total colour of the rock by the present percentage of coloured minerals. With increasing magnitude of the mineral components the rock makes, *ceteris paribus*, megascopically a still lighter impression within certain limits. The increased percentage of mafic oxides in relation to the analysis VII places the analysis VIII among the normal gabbroidic magmas according to NIGGLI (1936). The rather high percentage of lime indicates, however, a tendency in the chemistry to the c-gabbroidic magma type.

β. The dike at Casa Pangue.

Macroscopically this dike rock is rather light, somewhat greenish gray and fine-grained with solitary, larger, blackish green crystals, not exceeding 1 mm in size, and scattered vesicles, at most 1 mm in diameter.

Under the microscope the rock proves to have a doleritic texture. The plagioclase laths are relatively thin and do not show any distinct fluidal arrangement. Alteration products are lacking. Inclusions are few in number and the zoning of simplest type. The common magnitude is about 0.3×0.04 mm. An Albite twin had 80.5 and 74.5 % An, respectively. The axial angle of the first-mentioned individual was determined to $2\ V_\gamma = 88^\circ$.

Pyroxene occurs in two different modes of development, *viz.* in scattered agglomerations of large crystals as well as in smaller individuals evenly dispersed in the rock. The former are composed of hypidiomorphic, pale greenish crystals without pleochroism and likewise without inclusions and alteration products. These crystals, often up to ten in number, border immediately on each other and therefore form glomeroporphyritic aggregates. Twinning occurs exceptionally. The maximum size of a pyroxene crystal was measured to 0.6 mm, the crystal aggregates in general only slightly exceeding this magnitude. A determination on the universal stage gave the result: $2\ V_\gamma = 58^\circ$, $c : \gamma = 42^\circ$, *i. e.* a pyroxene relatively rich in lime. The smaller groundmass pyroxenes have a more decidedly prismatic development (about 0.1×0.04 mm). Penetration twins on (101) are rather common. As to the optical characters they seem to agree closely with the glomeroporphyritic pyroxenes.

Magnetite occurs rather abundantly and evenly dispersed in the rock in idiomorphic octahedrons of the order of magnitude 0.03 mm.

A not inconsiderable portion of the rock mass is finally composed of serpentine. It forms greenish yellow-brown, fibrous aggregates with γ in the direction of the elongation of the fibres. When it occupies the interstices between the other minerals and when fresh plagioclase and unaltered pyroxene individuals border upon it, it is highly probable that it should not be regarded as a pseudomorphous alteration product after a pre-existing mineral, but should be regarded as a mineral directly crystallized, though late, from the magmatic melt.

Serpentine of the same character also appears in the vesicles, either wholly filling them or as a peripheric coating, in the latter case the remaining part of the vesicle being occupied by a pale greenish, almost isotropic, chloritic substance.

Volumetric analysis:

Plagioclase	54.5	
Monoclinic pyroxene	18.8	(including phenocrysts 0.6 %)
Ore	5.2	
Serpentine	21.6	
Total	100.1	
Vesicles	1.3 %	

γ. The dike east of Arroyo de las Cuevas.

The rock of this dike is fine-grained and dark gray without distinct phenocrysts but with small, evenly dispersed vesicles, at most 1 mm in diameter.

Microscopically scattered phenocrysts of plagioclase appear forming rather broad, prismatic crystals, about 0.5 mm in length. They are perfectly fresh and show a simple zoning with a thin border, richer in albite, sharply delimited from the large homogeneous core. The marginal zone sometimes contains inclusions of pyroxene grains. A phenocryst twinned according to the Carlsbad law gave in the main part of the crystal a composition of 94 and 90 % An, respectively.

The groundmass is almost completely crystallized and shows in the main a doleritic texture. Plagioclase is predominant and forms thin laths, partly with the same length, approximately, as the phenocrysts. Two kinds of pyroxenes occur, ortho- and clinopyroxene. The former is to be found in somewhat greater quantity and in larger crystals than the monoclinic type. They are partly of an almost idiomorphic form, frequently however the outlines are highly dependent on the adjacent plagioclase laths. The absence of pleochroism and an axial angle near 90° indicate a composition relatively high in magnesia. The clinopyroxene crystals are smaller and isometric. They have a distinct yellowish green colour without pleochroism. A more or less regular hourglass structure is very common. The axial angle seems to be relatively large. Finally, mention must be made of magnetite in sparse, very small octahedrons and a brown, somewhat turbid, noncrystalline vitreous residuum. The vesicles are unmineralized.

This rock differs from the lavas of the Viento area by the absence of olivine or its pseudomorphs. On the other hand it shows microscopically a great similarity with certain representatives of the indistinctly porphyritic lavas from both sides of the Viento fjord. As only the hypersthene-bearing types of these lavas have a remarkably low percentage of olivine, the present dike rock may be said to represent a more advanced stage of this series of evolution, where the crystallization of olivine has quite failed to take place. Thus no argument can be advanced from a petrographical point of view against the inclusion of this dike in the Tronador series.

c. **Pyroclastic rocks.**

Only a comparatively small number of pyroclastic rocks are present from the Brazo del Viento area, *viz.* eight specimens, including two samples of ashy clays. In the following description the same classification and terminology are applied as for the corresponding rocks in the Tronador area, *viz.* those proposed by WENTWORTH and WILLIAMS (1932).

α. **Tuff breccia.**

A local boulder from the southern shore of Brazo del Viento (at Punta de Bloques) is of an indistinctly stratified tuff breccia with predominant fragments of dark gray to black and solitary brownish red, mostly scoriaceous lavas together with a few gray quartzite-like pebbles in a brownish gray, fine-grained matrix. The lava fragments reach in maximum a size of about 3.5 cm.

In the fine-grained matrix between the larger rock fragments chips of plagioclase occur, with olivine and pyroxene crystals as well as glass in a brown pigmented mass. A plagioclase crystal with light brown glass attached to it was determined to an Albite twin with 76 and 88 % An, respectively. On an olivine was determined $2\ V_\alpha = 84°$, corresponding to 24 % Fe_2SiO_4.

Interglacial lavas as well as some pieces of older rocks occur among the rock fragments. The pre-Tronador rocks are represented by

1) an amphibolite with close lying, divergently radiating bundles of a pale greenish, actinolitic amphibole in an exceedingly fine-grained feldspar—amphibole mass. The amphibole bundles are partly formed in close connection with small irregular ore grains. Scattered apatite prisms, some titanite crystals and a few small quartz spots complete the mineral composition.

2) Aplitic plagioclase granite consisting of predominant quartz together with plagioclase as well as scales of muscovite and accessory scales of chlorite, grains of ore and a group of small tourmaline crystals

pleochroic in colourless (ε, direction of elongation) and greenish blue (ω). Small spots of greenish brown hornblende individuals indicate the genetical connection with the granodiorite.

The most important types of lava rocks have the following characters:

1. Phenocrysts of plagioclase, olivine and monoclinic pyroxene in a light brown or greenish to almost colourless glass free from ore.

2. As 1, but with a greater or smaller number of vesicles. 1 and 2 are predominant.

3. Phenocrysts of plagioclase and olivine (in part somewhat altered into serpentine) in a dark pigmented, vitreous groundmass with solitary microliths and vesicles.

4. Almost holocrystalline type with plagioclase, orthorhombic and monoclinic pyroxene as well as scattered ore octahedrons together with an insignificant, somewhat pigmented glassy residuum.

5. A larger olivine crystal with partial alteration into ore of the type which is common in some lavas from the localities to the north of Brazo del Viento. The groundmass attached to the olivine contains plagioclase crystals and is dark pigmented to a high degree. Fragments of this groundmass without phenocrysts are met with rarely.

β. Lapilli tuffs.

In this group two specimens are included. One is taken from Arroyo de las Cuevas on the northern shore of Brazo del Viento, whereas the other has been collected on the western side of Lago Frio.

The first-mentioned rock is an only slightly cemented, fine-grained, pale, on weathered surface deeper brown to yellowish gray, tuff with fragments only exceptionally exceeding a few mm in size. Yet one fragment of light gray granodiorite was observed of medium coarseness, measuring 14 mm in diameter.

As crystal fragments plagioclase and olivine appear as well as sparse quartz and sericitized feldspar, the two last-mentioned minerals obviously derived from the older country rocks. A plagioclase fragment (basalt phenocryst, Albite-Carlsbad twin) had 89 and 84 % An, respectively. A determination of the axial angle of an olivine gave $2\ V = 90°$, corresponding to 11.5 % Fe_2SiO_4.

The following types of rock fragments were observed:

I. *Accidental.*

1. *Granite*, some solitary fragments, with quartz, sericitized feldspar and sparse biotite.
2. *Sandstone*, consisting of rounded quartz grains, about 0.2 mm in size, cemented by a turbid dust mass rich in ore.

II. *Accessory and essential* (lava fragments).

1. Type with phenocryst of plagioclase and sparse olivine in a light brownish, vitreous groundmass with sparse microliths and solitary vesicles. This type is predominant.
2. Phenocrysts of plagioclase and single small olivines in a dark to opaque groundmass. Rather common.
3. As 2 but scoriaceous.
4. Phenocrysts of plagioclase and abundant olivine in large crystals in an opaque, partly scoriaceous groundmass, poor in microliths. Rare.
5. Holocrystalline, doleritic type with plagioclase and pyroxene. Rare.

The rock from the western side of Lago Frio is megascopically a dark, somewhat blue-brownish gray lapilli tuff with darker lava fragments, up to 12 mm in size. No stratification is discernable in the specimen.

Under the microscope the practically complete absence of larger fragments of plagioclase phenocrysts is characteristic. On the other hand olivine is exceptionally abundant. Further sparse crystal fragments of partly undulatory quartz together with sericitized and saussuritized plagioclase occur, obviously derived from the older country rocks. A determination of the axial angle of an olivine crystal gave $2\ V = 90^{\circ}$, corresponding to 11.5 % Fe_2SiO_4.

The lava fragments are characterized by the comparatively important rôle which olivine phenocrysts play, whereas plagioclase phenocrysts numerically as well as to magnitude are little prominent. The following types may be mentioned:

1. Phenocrysts of olivine in a well crystallized groundmass of plagioclase, pyroxene and dark brown glass. Scattered vesicles.
2. Phenocrysts of olivine and small, lath-formed plagioclases in a vesicular, dark brown, vitreous groundmass.
3. As 2, but with gray glass, ore-pigmented and non-vesicular.
4. As 2, but with more abundant plagioclase laths and the glass a light yellowish brown colour.
5. Non-porphyritic, fine-grained dolerite with sparse, dark brown glass.

γ. Coarse tuffs.

Three specimens of coarse tuffs are present from the Brazo del Viento area, *viz.* from the southern shore of the fjord, west of Arroyo sin Pava, from Puerto Sobral beyond the outer part of the same fjord though on the northern shore and finally from Isla Mellizas, an island in the middle portion of the fjord near the southern shore.

The first-mentioned tuff is macroscopically ashgray, slightly cemented and unstratified with rock fragments, up to 4 mm in size.

Under the microscope fragments of minerals and rocks prove to predominate to a marked extent over the finer argillaceous material. Among the mineral fragments from the older rocks the following occur: quartz, plagioclase and potash feldspar (sericitized) as well as green hornblende; from rocks of primary volcanic origin: plagioclase, olivine and orthorhombic pyroxene together with glass. A clear plagioclase fragment, obviously derived from a lava phenocryst, was determined on the universal stage. It was a Carlsbad twin with 61 and 60 % An, respectively. The axial angle of Ind. I was determined to $2\ V_{\gamma} = 82°$. The olivines show no secondary alteration at all. A fragment had $2\ V_{\gamma} = 88°$, corresponding to 7 % Fe_2SiO_4. The orthorhombic pyroxene is sparse and distinctly pleochroic. An individual had $2\ V_{\alpha} = 74°$, corresponding to 27 % $FeSiO_3$.

The rock fragments consist of non-volcanic as well as volcanic rocks. The former fall short of the latter as to their number, but, on the other hand, the largest fragments consist of non-volcanic material. In this the following rocks are represented: granodiorite, quartzite, graphic granite, chlorite sericite schist, biotite phyllite and epidote amphibolite.

Among the fragments of effusive rocks the following types are the most important:

1. Type with phenocrysts of plagioclase and olivine in a dark brown to black, opaque, vitreous groundmass, partly vesicular.

2. Phenocrysts of plagioclase and olivine in an abundant, very pale brownish glassy mass.

3. Phenocrysts of plagioclase, olivine and monoclinic pyroxene in a holocrystalline groundmass of plagioclase, pyroxene and ore.

4. Phenocrysts of plagioclase and ore in a pale brown, vitreous groundmass with plagioclase and pyroxene microliths.

5. Phenocrysts of plagioclase in a groundmass of plagioclase, olivine and ore-dotted glass.

6. Non-porphyritic, doleritic basalt with varying percentage of glass.

7. As 6 but with porphyritic olivine.

In Puerto Sobral a specimen was collected of a fine-grained, ash-gray, very slightly cemented, stratified and folded (according to LJUNGNER by ice thrust during the last glacial period) tuff. The stratification is made distinct by the occasional appearance of somewhat coarser, greenish brown ash layers, at most some mm in thickness.

The crystal fragments, reaching in maximum a magnitude of 0.65 mm, consist predominantly of plagioclase and olivine, to a minor extent of quartz and green hornblende, the two last-mentioned minerals obviously derived from older rocks. A plagioclase crystal was determined to 88 and 82 % An, respectively (Albite-Carlsbad twin, axial angle of Ind. II: $2\ V_{\alpha} = 84°$). On a small olivine fragment an axial angle $2\ V_{\alpha} = 85°$ was obtained, corresponding to 22 % Fe_2SiO_4.

On account of the fine grain of the tuff accidents play a certain rôle in the determination of the type of the lava fragments with regard to the nature of the phenocrysts. The following types seem, however, to predominate quantitatively:

1. Small phenocrysts of plagioclase and, rarely, olivine in a pale brownish to almost colourless vitreous basis, in part highly scoriaceous.

2. Larger phenocrysts of plagioclase and, sparsely, olivine in a dark brown to black groundmass. This type occurs relatively more abundantly in the coarser layers and produces their darker colour.

These two types also form part of the other tuffs from the Brazo del Viento area.

The third tuff sample belonging to this group, from Isla Mellizas, forms a fissure filling in light greenish gray granodiorite of medium coarseness. The pyroclastic rock is dark, somewhat greenish gray with fragments for the most part up to 1 mm in size. Only one solitary black, scoriaceous lava fragment, almost 1 cm in size, was observed.

As crystal fragments there appear plagioclase, olivine, quartz and hornblende. The two latter minerals and part of the plagioclase (turbid by sericitization, sometimes also altered into epidote) obviously derive from the granodiorite. A determination of the anorthite percentage of a basalt plagioclase gave 77 and 78.5 % An, respectively (Albite twin with the axial angles 2 $V_\gamma = 86^\circ$ and 89°, respectively). An olivine crystal had 2 $V_\alpha = 82^\circ$, corresponding to 28 % Fe_2SiO_4.

Among the rock fragments sparse fragments of the immediately adjacent granodiorite were noted. These consist essentially of quartz and plagioclase — the latter generally being rather highly saussuritized — together with larger or smaller grains of common green hornblende.

The bulk of the lava fragments consist of a type with phenocrysts of plagioclase and sparse olivine in an abundant, pale olive brownish, partly scoriaceous, vitreous groundmass with scattered crystallites. Another type has phenocrysts of plagioclase and olivine in a black, opaque groundmass, a third one only olivine in large crystals and highly pigmented groundmass, bearing microliths of plagioclase. The latter type is scarce. Finally mention may be made of a solitary fragment of an andesitic type with small phenocrysts of plagioclase and magnetite in a brown glass (somewhat more brown than that of the first-mentioned type) with close lying microliths.

δ. Ashy clays.

Under this heading two samples are finally described, one from Isla Mellizas in the Brazo del Viento fjord, the other from the western shore of Peninsula Huemul in the central part of Lago Nahuel Huapí. Normal sediments containing a quantitatively more or less important component of pyroclastic material are dealt with here.

The first-mentioned sample shows megascopically a light gray, unstratified clay with interspersed, larger and smaller stones of different nature and at most 2 cm in size.

Microscopically a sample free from stones contains a predominant brownish gray, fine clay substance. Among the mineral and rock fragments present the former partly consist of material derived from the older country rocks, *viz.* plagioclase and green hornblende. This plagioclase is generally very finely polysynthetically twinned and made highly turbid by alteration products. In contrast to this, fragments of clear plagioclase occur with more simple twinning. This latter plagioclase as well as solitary fragments of pleochroic hypersthene definitely derive in part from the ashes of the interglacial volcanoes, possibly also partly from younger ash material transported from more distant volcanoes.

Among the rock fragments there occur those of granodioritic composition and more abundantly, but of minor magnitude, those of effusive rocks. Of these latter a type with phenocrysts of plagioclase in an opaque groundmass, sometimes containing abundant microliths, predominates.

Finally the sample from Peninsula Huemul is composed of a very slightly cemented, light gray, fine-grained, argillaceous mass with a faint vestige of stratification.

Under the microscope there appear in an extremely fine-grained, brownish gray, clayey matrix abundant mineral as well as rock fragments, predominantly of volcanic origin. The mineral fragments consist of plagioclase, quartz and olivine as well as pyroxene, hornblende and epidote. The plagioclase, which in part is highly turbid by sericite and thus obviously derived from the pre-volcanic rocks together with the quartz, the green hornblende and the epidote, is predominantly of the fresh type characteristic of the phenocryst plagioclases of the interglacial volcanic rocks. A fragment of the latter type was determined to an Albite-Carlsbad twin with 86.5 and 84 % An, respectively (axial angle $2\ V_\alpha = 89°$ and $85°$, respectively). The olivine occurring rather sparsely (by far eolian, and fluvial, transport well graded ash material) resembles the young volcanic plagioclase in being quite unaltered. A little chip had the axial angle $2\ V_\gamma = 89°$, which corresponds to 9.5 % Fe_2SiO_4. A solitary fragment of monoclinic pyroxene, twinned on (100), had such an orientation that axial angle and extinction could be determined. The result was $2\ V_\gamma = 63°$, $c:\gamma = 43°.5$, *i.e.* a diopsidic augite rather high in lime.

The rock fragments at most reaching a magnitude of 0.7 mm (the crystal fragments of plagioclase in maximum 0.4 mm) are composed predominantly of volcanic types. The most abundantly represented type consists of

1. Phenocrysts of plagioclase, with or without olivine, in an opaque, black or dark brown, probably vitreous, in part vesicular groundmass. In comparison with this the other types are subordinate.

2. Phenocrysts of plagioclase and olivine in a pale brownish, usually highly vesicular groundmass free from microliths and often with fluidally elongated vesicles.

3. As 2, but the glass more or less microlith-bearing. Sometimes also with phenocrysts of monoclinic pyroxene.

4. Phenocrysts of plagioclase, monoclinic pyroxene and magnetite in an abundant, microlith-bearing, light glass.

VI. General survey of the mineralogy of the volcanic rocks.

In this chapter a comprehensive account will be given of the minerals entering into the rocks described above. These minerals may be conveniently subdivided into three groups, *viz.* 1) primary magmatic minerals, 2) alteration products of the former as well as hydrothermal minerals and 3) minerals of nonvolcanic, exogenous origin. For obvious reasons the limit between the two first groups is in some degree fluent.

A. Primary magmatic minerals.

In this group the following minerals are dealt with: plagioclase, olivine, orthorhombic pyroxene, monoclinic pyroxene, hornblende, apatite, spinel and ore. Characteristic of this series of volcanic rocks as represented in the collection studied is the complete absence of biotite as a primary magmatic mineral.

1. Plagioclase.

Of feldspar minerals only plagioclase has been definitely identified. Potash feldspar, on the contrary, nowhere appears as primary magmatic mineral, in any case does not occur as phenocrysts. The potash percentage, in the more acid rock members showing comparatively high values (in the quartz-latitic pyroxene andesite, Analysis III, 3.22 % K_2O), is obviously, as biotite is quite lacking, bound to the plagioclase and above all to the glass in the groundmass. This glass in the more acid rocks higher in potash content plays a decidedly more prominent rôle than in the more basic rocks.

The plagioclase in the rocks in question is the most important and most characteristic mineral. All rocks, except those most intensely hydrothermally altered, contain plagioclase. This mineral occurs not only in the non-porphyritic lavas and in the groundmasses of the porphyritic lavas but is also the predominating phenocryst mineral. Thus all lavas examined from the Tronador area bear phenocrysts of plagioclase, whereas from the Brazo del Viento area only a small number of porphyritic lava rocks without plagioclase phenocrysts are represented. In no case does plagioclase occur alone as phenocryst mineral but always in combination with mafic minerals. In the preceding description no less than 13 different combinations of phenocryst minerals have been recorded.

The range of variation in the composition of the phenocryst plagioclase of the rocks of the Tronador series will appear from the diagram

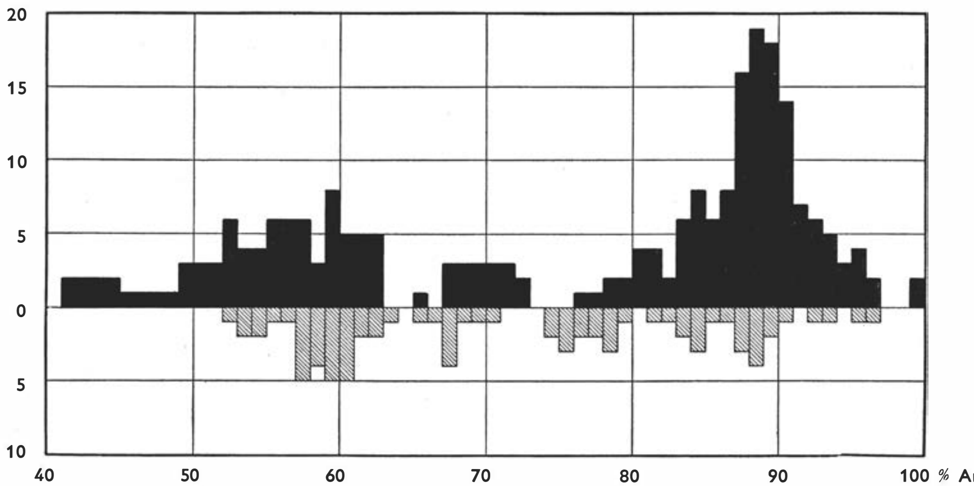


Fig. 37. Frequency diagram of the composition of plagioclase phenocrysts of effusive lavas (black) and pyroclastics (ruled) of the Tronador series.

Fig. 37. The determinations, on which this diagram is based, refer to the central, homogeneously composed portions of the plagioclase crystals. The upper part of the diagram represents the conditions in the effusive lavas, the lower one corresponds to determinations made on plagioclase fragments in the pyroclastic rocks. The composition in the former case varies between 41 and 100 % An, in the latter case between 52 and 97 % An. The somewhat smaller range of variation for the pyroclastic rocks is in all probability only an accident due to the smaller number of determinations in this case.

As will appear from Fig. 37 the frequency curve for the phenocryst plagioclases of the effusive lavas shows two distinct maxima. The more pronounced one lies at a composition of about 88—89 % An, the second one, less sharply developed, at 59—60 % An. Also in the frequency distribution maxima of the pyroclastic rocks the same approximate position may be established, though not so sharply developed. Attention must also be drawn to the fact that here as it were the rôles are changed, the maximum at the lower anorthite percentage in this case being most strongly developed. This circumstance is surely not mere chance. Upon the whole a connection exists between the acidity of a rock and the anorthite percentage of its plagioclase. As, *ceteris paribus,* also the viscosity of a melt increases with its acidity and with the viscosity, on the other hand, the probability of an explosive eruption, the consequence of this will be that

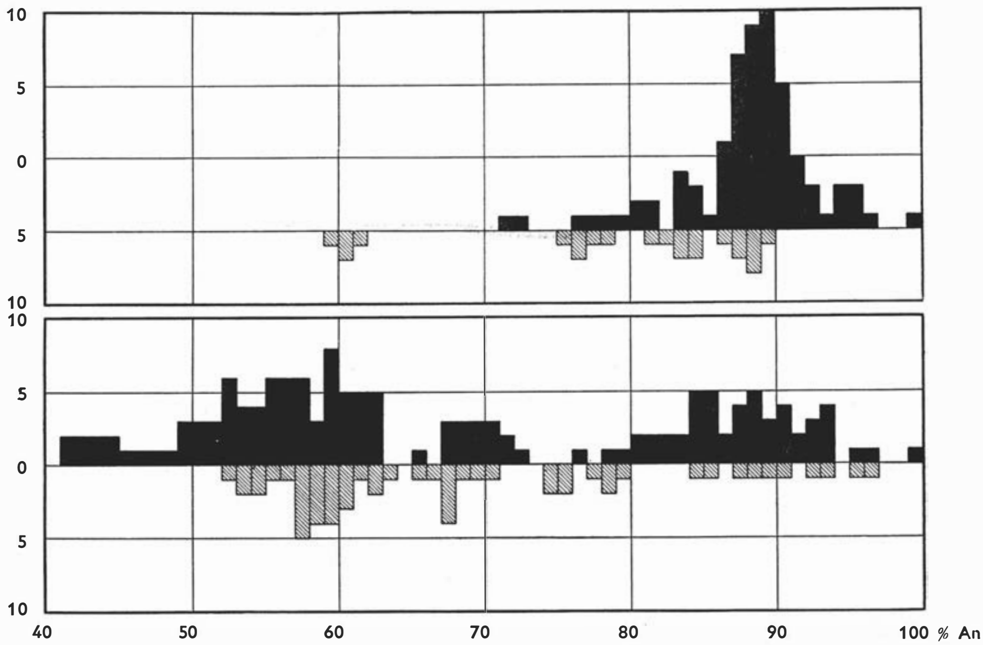


Fig. 38. Frequency diagrams of the composition of plagioclase phenocrysts of Tronador rocks from the Brazo del Viento (upper diagram) and the Tronador areas (lower diagram). Lavas black, pyroclastics ruled.

the difference in the frequency distribution of the phenocryst plagioclase of the lavas and that of the plagioclase fragments of the tuff rocks, appearing from Fig. 37, is just that which theoretically might be expected.

Whereas Fig. 37 represents the whole material examined, in Fig. 38 a subdivision of it has been made upon the Tronador and the Brazo del Viento areas, respectively. As will be seen a characteristic difference between the two areas appears. First taking the lavas into consideration the two maxima of frequency indicated above are both represented in the Tronador area, though with a certain predominance for that situated at the lower anorthite percentage. The lavas of the Viento area, on the other hand, only show the bytownite-anorthite maximum, this however, being greatly developed. This difference between the two areas is due to the fact that in the Viento area, at least in the material examined, only olivine-bearing, basaltic rocks appear, whereas in the Tronador area, especially on the higher parts of Cerro Tronador, effusive rocks of andesitic composition play an important rôle.

Turning to the pyroclastic rocks of the Tronador area we find for the same reason as was stated concerning Fig. 37 the maximum corresponding to the andesites more pronounced, when compared with the effusive rocks from the same area, as the basic plagioclases are certainly well represented but without forming any maximum. The pyroclastic rocks of the Viento area are, as will appear from Fig. 37 and the petrographic descriptions above, predominantly basaltic in conformity with the fact that from this area only basaltic lavas are represented in the material examined. The relatively inconsiderable andesitic components in the tuffs of the area are quite naturally to be explained as derived from eruptions of Tronador.

In Fig. 39 the frequency distribution of the composition of the phenocryst plagioclase has been presented diagrammatically in relation to the phenocryst parageneses of the lavas. The subdivision of the latter is the same as that applied to the detailed petrographical description above. The thirteen types are thus divided into four groups: 1) With olivine phenocrysts, 2) Without olivine, but with pyroxene phenocrysts, 3) With hornblende phenocrysts and 4) In addition to plagioclase only magnetite phenocrysts. These groups comprise 7, 3, 2 and 1 types, respectively.

A certain connection undoubtedly exists between the anorthite percentage of the plagioclase phenocrysts and the nature of the other phenocrysts. A more detailed investigation of this connection in relation to the chemical composition and genetical relationships of the rocks will be given in a later chapter. The most important facts, however, appearing from Fig. 39 may be pointed out at this stage.

The plagioclase phenocrysts highest in anorthite are met with in the lavas which in addition to plagioclase bear olivine and diopsidic augite as phenocrysts. All plagioclase determinations in this group of lavas have given values higher than 80 % An. The same is true of lavas with the mineral combination plagioclase—hypersthene—diopsidic augite as phenocrysts. The number of determinations is, however, rather small in this case. Anorthitic plagioclases (90—100 % An) also occur in lavas which in addition to plagioclase are characterized by phenocrysts of olivine, and of olivine and hypersthene respectively. Here the lower limit of variation lies already at a basic labradorite. With the addition of magnetite as phenocrysts a general displacement takes place towards compositions of the phenocryst plagioclase higher in albite. This displacement is slightest between the types 2 (phenocryst paragenesis: plagioclase, olivine) and 4 (plagioclase, olivine, magnetite), *viz.* on an average 14.8 (84.2—69.4) % An, greatest between the types 8 (plagioclase, diopsidic augite, hypersthene) and 9 (plagioclase, diopsidic augite, hypersthene, magnetite), *viz.* 32.7

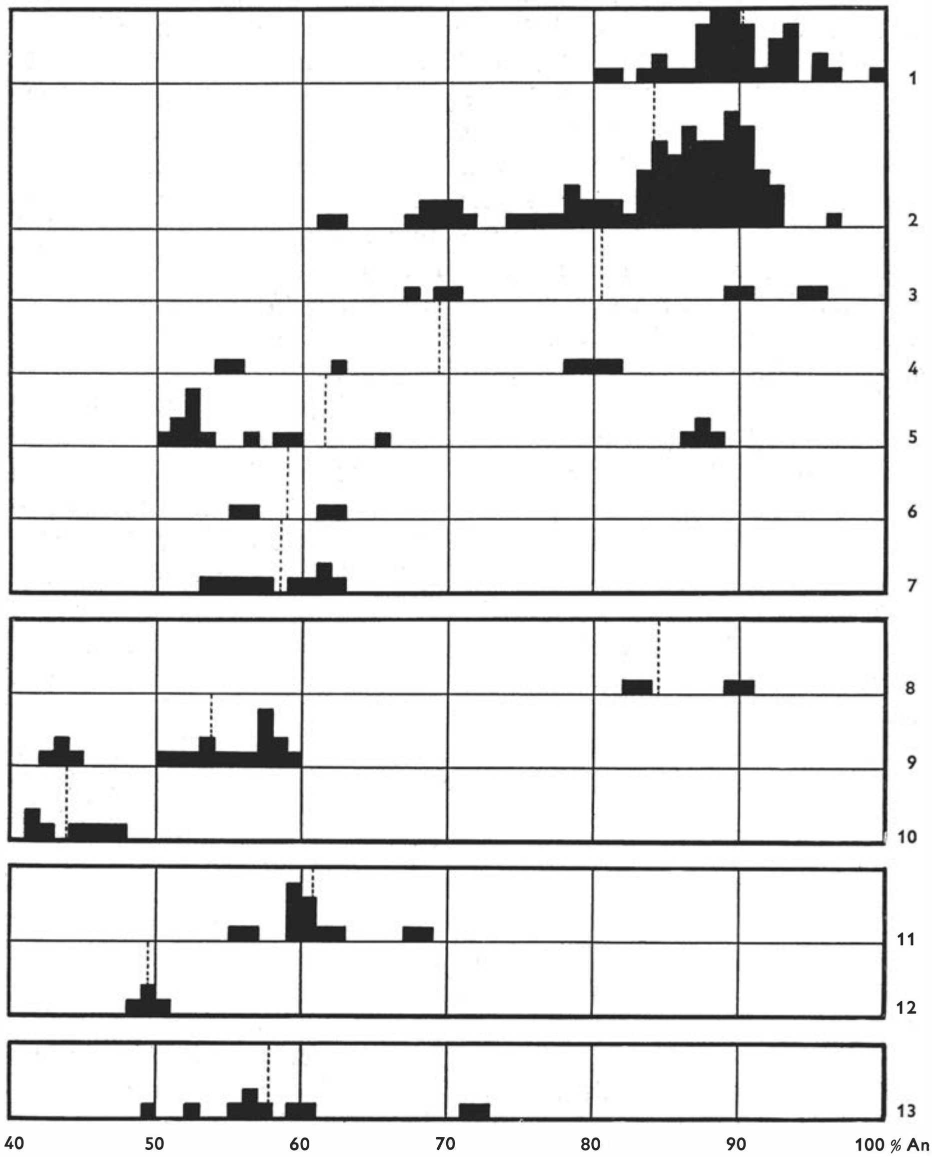


Fig. 39. Frequency diagrams of the composition of plagioclase phenocrysts of lavas in relation to their phenocryst parageneses. One determination = a square. The average composition of each type of rock is indicated by a dash line.

Phenocryst parageneses (in addition to plagioclase): 1. Olivine, diopside. — 2. Olivine. — 3. Olivine, orthopyroxene. — 4. Olivine, magnetite. — 5. Olivine, clinopyroxene, magnetite. — 6. Olivine, orthopyroxene, pigeonite. — 7. Olivine, pigeonite. — 8. Orthopyroxene, clinopyroxene. — 9. Orthopyroxene, clinopyroxene, magnetite. — 10. Orthopyroxene, clinopyroxene, magnetite, apatite. — 11. Hornblende, magnetite. — 12. Hornblende, magnetite, apatite. — 13. Magnetite.

(86.5—53.8) % An, whereas the types 1 (plagioclase, olivine, diopsidic augite) and 5 (plagioclase, olivine, diopsidic augite, magnetite) with 28.6 (90.2—61.6) % An hold an intermediate position in the features now in question. Still higher in albite is the plagioclase which appears associated with phenocrysts of apatite in addition to those of magnetite. In reality those types of lavas bearing apatite phenocrysts have the plagioclase phenocrysts lowest in anorthite in the series of the Tronador rocks, *viz.* exclusively andesines. Compared with the lavas which are devoid of porphyritic apatite but for the rest have the same phenocryst paragenesis, the apatite-bearing lavas have on an average about 10 % lower percentage of anorthite in the plagioclase phenocrysts. Thus the average difference in the composition of the plagioclase phenocrysts between the type 9 (phenocryst paragenesis: plagioclase, diopsidic augite, hypersthene, magnetite) and type 10 (plagioclase, diopsidic augite, hypersthene, magnetite, apatite) is 9.9 (53.8—43.9) % An, between the types 11 (plagioclase, hornblende, magnetite) and 12 (plagioclase, hornblende, magnetite, apatite) 11.3 (60.8—49.5) % An. Finally attention is called to the fact that the two interesting types of lavas, 6 and 7, being characterized by phenocrysts of a monoclinic, pigeonitic pyroxene, low in lime, also have phenocryst plagioclases, relatively high in albite, *viz.* average labradorites. Compared with those types of lavas which apart from the pigeonite have the same set of phenocrysts, a pronounced difference appears in the mean composition of the plagioclase, *viz.* between type 2 (phenocryst paragenesis: plagioclase, olivine) and type 7 (plagioclase, olivine, pigeonite) 25.7 (84.2—58.5) % An and between type 3 (plagioclase, olivine, hypersthene) and type 6 (plagioclase, olivine, hypersthene, pigeonite) 21.6 (80.6—59.0) % An.

The magnitude of the plagioclase phenocrysts in the effusive rocks of the Tronador series is rather varying. The maximum length in all rock specimens has been measured and proved to vary between 0.4 and 20 mm. In the former case the lavas are of course microporphyritic. How the maximum magnitudes are distributed will appear from Fig. 40. More than half of the lavas studied have phenocrysts, the maximum length of which reaches 2 mm. Not less than 80 % of the specimens fall below the maximum limit of 4 mm, whereas only a relatively small number, 10 %, have phenocrysts exceeding 5 mm in length. From the same diagram a general survey is also obtained of the quantitative importance of the plagioclase phenocrysts. In the majority of cases, *viz.* 65 %, the plagioclase phenocrysts constitute less than 15 % by volume of the rock, whereas those lavas consisting to more than 1/4 of their volume of plagioclase phenocrysts amount to only 17.5 %. The extreme limits of the variation are 0.4 and 49.0 % by volume. It is these specimens which also show the smallest and the greatest maximum lengths of the plagioclase phenocrysts, respectively. As will appear from the diagram (Fig. 40) there exists, as was to be expected, a certain connection between the maximum length of the plagioclase phenocrysts and their share in percentage by volume in the composition of the rocks, even if the same maximum length is correlative to a rather broad range in the volumetric percentage. On an average, however, a tolerably regular increase may be ascertained in the relative proportion of the plagioclase phenocrysts with increase in their maximum length.

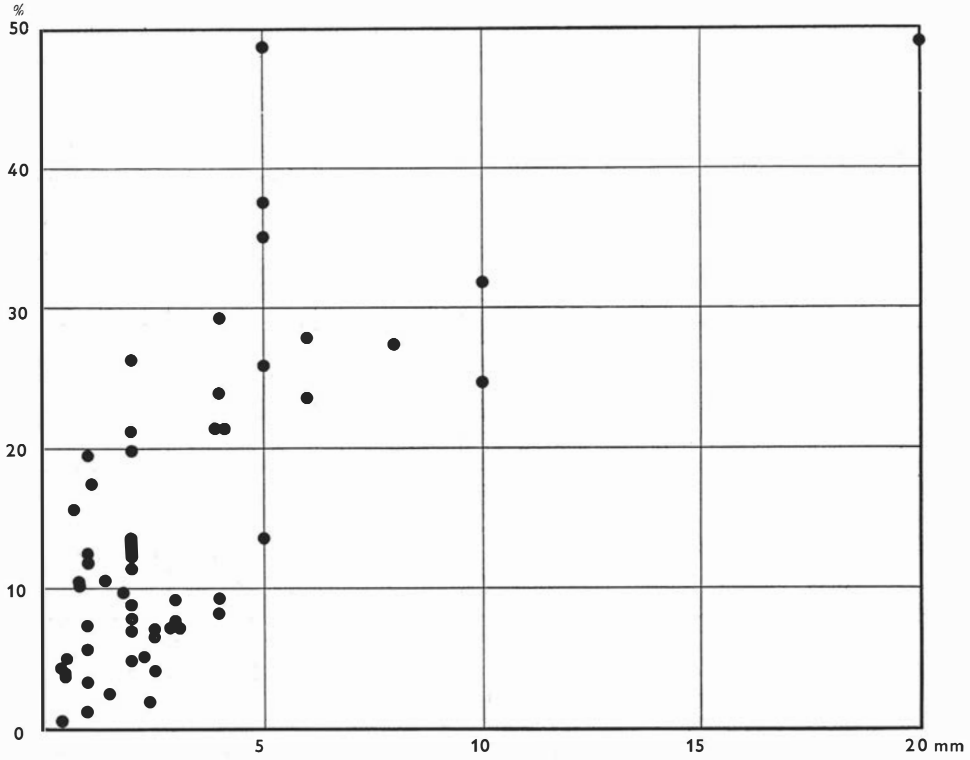


Fig. 40. Diagram showing the relation between the maximum length of the plagioclase phenocrysts and their volume in per cent of the rocks (excluding vesicles).

An idea of the magnitude of the plagioclase phenocrysts in different types of rocks is given in diagram Fig. 41, where the maximum length of the phenocrysts in question has been plotted against their anorthite percentage. The upper limit of variation of the magnitude forms, as will be seen, a rather regular curve with a pronounced maximum at basic labradorite, whereas anorthite and bytownite as well as andesine give lower values and less variation in size. Particularly striking are the differences which appear between rocks with anorthitic — bytownitic and labradoritic plagioclase phenocrysts, respectively, — these groups are numerically almost equally represented. In the first-mentioned group 77.5 % of the lavas have phenocrysts, the maximum length of which falls below or just reaches

2 mm, whereas no phenocrysts larger than 5 mm have been met with. In the other group, with labradoritic phenocrysts, in spite of somewhat smaller number of representatives, the variation in maximum magnitude is decidedly much greater. Only 29 % of the lavas belonging to this group fall at and below the 2 mm limit, whereas 37.5 % have phenocrysts, the greatest length of which is 5 mm and more. These differences are certainly not mere fortuitous phenomena, but due to genetic causes.

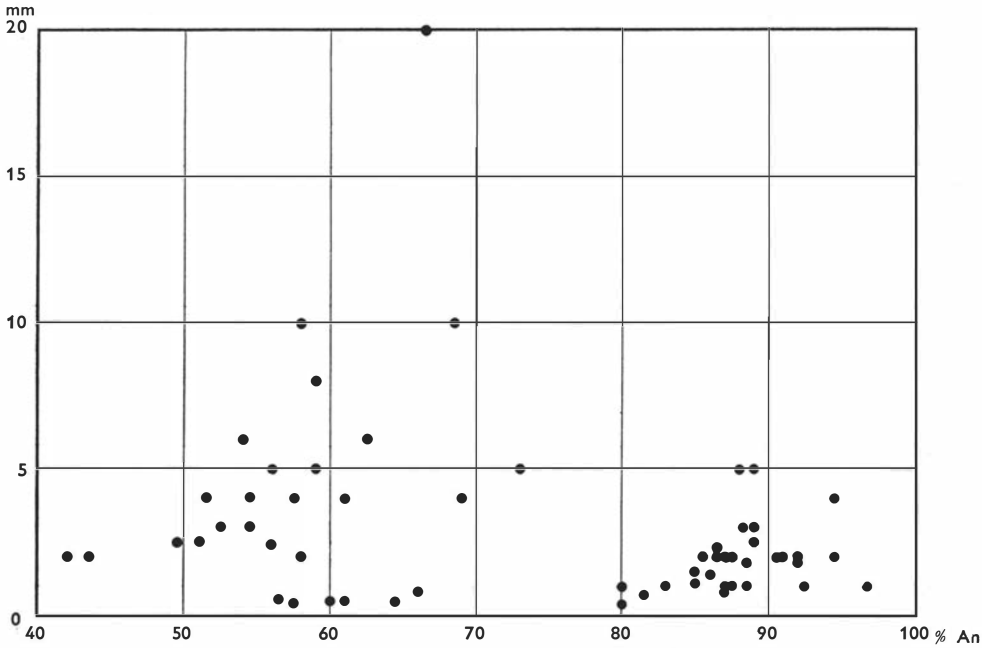


Fig. 41. Diagram showing the relation between the maximum length of the plagioclase phenocrysts and their composition.

Not only the magnitude but to a certain extent still more the shape of the plagioclase phenocrysts, more specifically the ratio between the largest and smallest dimensions, proves to be dependent on their chemical composition. This fact will appear from Fig. 42, where the ratio mentioned is plotted with black dots against the anorthite percentage of the phenocrysts. As this ratio obviously gives a numerical expression for the degree of deviation from the equidimensional form, a greater value corresponding to a more pronounced tabular or lathy shape, it may be immediately concluded from the diagram (Fig. 42) that for this series of rocks the rule is applicable that phenocrysts of anorthitic plagioclase show the most pronouncedly equidimensional development. With decreasing percentage of anorthite the ratio in question increases in a very regular manner and reaches a maximum at about 65 % An. On the more albite-rich side of this maximum the values fall again with about the same rate in relation to the composition as on the anorthitic side, the most albitic phenocrysts here represented, *viz.* the andesines, having the same relative dimensions as the most basic bytownites, at or immediately below 90 % An.

As the maximum in Fig. 42 coincides almost exactly with the maximum shown by the upper limit of variation of the maximum length of the plagioclase phenocrysts (Fig. 41), it might be surmised that the absolute magnitude of the crystals rather than their chemical composition is decisive

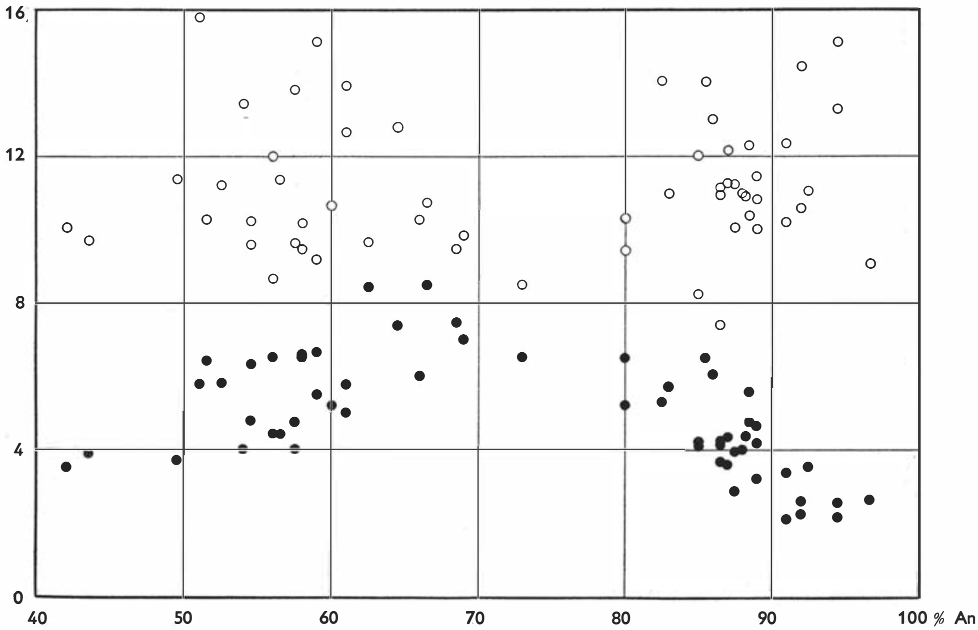


Fig. 42. Diagram of the ratio length : width of plagioclase phenocrysts (filled circles) and groundmass crystals (open circles) in relation to the chemical composition of the phenocrysts.

for their development in this respect. That it is not so will, however, appear from a comparison of the diagram Fig. 42 with the diagrams Fig. 43 and 44. In Fig. 43 the lengths of the phenocrysts in Fig. 42 have been plotted against their percentage of anorthite. Certainly the greatest value of the length of the phenocrysts, 17 mm, falls in the same composition range as the maximum in Fig. 42, but also at this composition, 60—70 % An, the minor magnitudes, less than 2 mm, are predominant. Even one of the two smallest phenocrysts measured in this connection, $^1/_4$ mm in length, falls in the same range of composition. In spite of this great variation in magnitude all phenocrysts of this composition show a relatively small range round a high value of the ratio length : width. The absolute magnitude of the plagioclase phenocrysts has thus no decisive importance for their development with regard to the ratio between the greatest and smallest dimensions. The same thing will also appear immediately from Fig. 44, where this ratio with filled circles has been plotted against the length of the phenocrysts measured. The largest phenocryst, 17 mm in length and with the ratio length: width = 8.5, has been omitted from the diagram for want of space. Certainly the lower limit of variation of the ratio length: width lies somewhat higher for the larger crystals than for the smaller ones, which with respect to the small number of observations on phenocrysts more than 3 mm in length may be expected

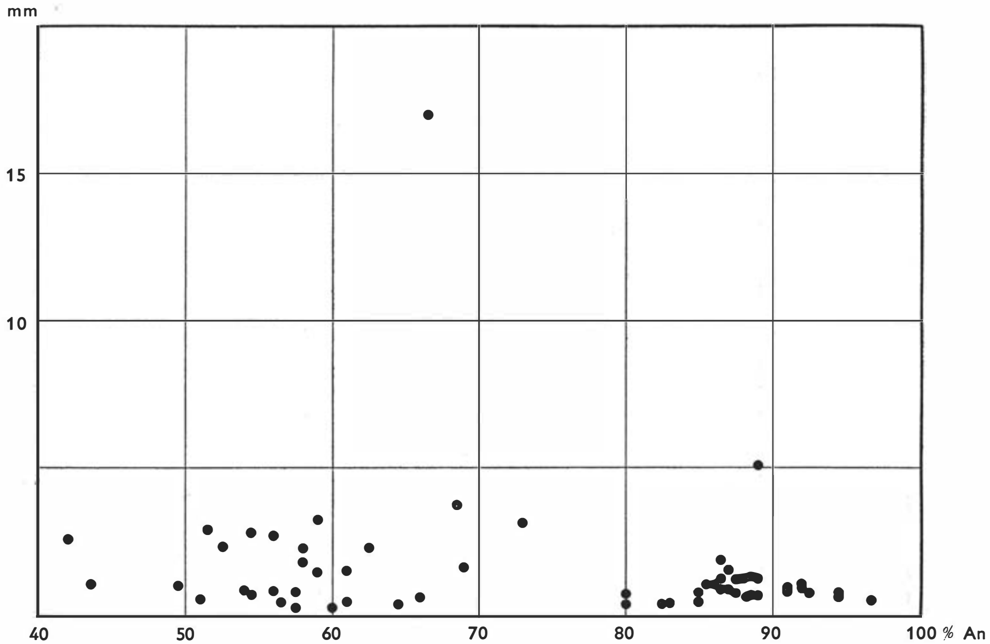


Fig. 43. Diagram showing the relation between the length of the plagioclase phenocrysts represented in Fig. 42 and their anorthite percentage.

to be due largely to mere chance. The horizontal course, broadly speaking, of the upper limit of variation and particularly the distribution of the dots in the well occupied range of magnitude < 1 mm show that no distinct relation between the magnitude of the phenocrysts and the ratio length: width can be said to exist.

With still greater reason the latter statement may be applied to the plagioclase crystals of the groundmass. These are inserted in Fig. 44 as open dots and occupy a narrow zone parallel with the ordinate, which implies that the variation in length is small (0.084—0.374 mm), whereas the range in the ratio length: width is important (7.37—15.83). As will appear from the diagram the distribution areas of the dots representing phenocrysts and groundmass crystals, respectively, do not cover each other even in part, though, on the other hand, they are not particularly sharply separated. It is also true that phenocrysts and groundmass crystals occur of the same length. The latter have throughout, however, in these cases a considerably greater value of the ratio length : width, *i. e.* a more pronounced lathy development. On the other hand, some groundmass plagioclases have been measured, the (exceptionally low) values of the ratio length : width of which coincide with the corresponding relation of some phenocrysts. The absolute magnitude of the groundmass plagioclase is, however, considerably smaller than that of the phenocrysts.

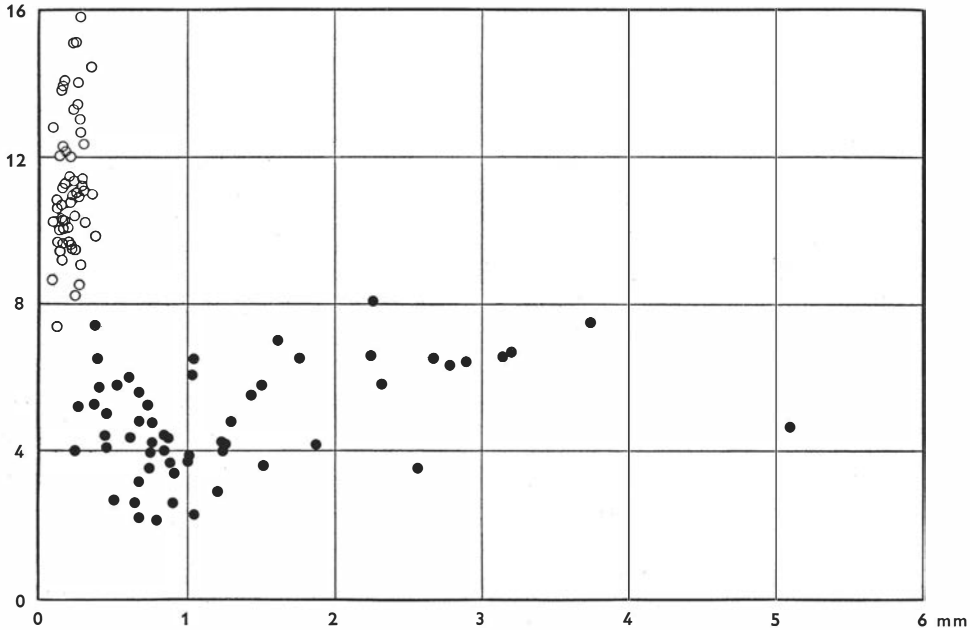


Fig. 44. Diagram of the ratio length : width (ordinate) of plagioclase phenocrysts (filled circles) and groundmass crystals (open circles) in relation to the length (in mm) of the same crystals.

To trace an eventual connection between the crystal development of the groundmass plagioclase and its composition the ratio length : width of for the different rock specimens typical groundmass crystals has been plotted in the diagram Fig. 42 with open circles against the composition of the plagioclase phenocrysts of the same rocks. Each rock specimen is thus represented in the diagram by two dots, one lower, black and one upper, open, corresponding to phenocrysts and groundmass crystals, respectively, both with the same abscissa, the anorthite percentage of the principle part of the phenocryst. The spreading of the dots of the groundmass crystals is considerably greater than that of the phenocrysts. It may, however, be said that upon the whole two maxima may be discerned, at 90—95 % and at 50—60 % An as well as an intervening minimum at 70—75 % An of the corresponding plagioclase phenocrysts. Because of the only slight zoning of the plagioclase phenocrysts indicating a far advanced equalization of the composition of the crystalline phase to equilibrium with that of the melt during the intratelluric stage of the crystallization, and upon the assumption that the phenocrysts have really crystallized from the melt, as groundmass immediately surrounding them, the anorthite percentage of the phenocrysts determined may be considered to indicate approximately the composition of the solid phase, and the groundmass plagioclase to represent the feldspar composition of the liquid, at the close of the intratelluric stage and upon the eruption of the lava — at least this is true by a small percentage of glass in the groundmass. Allowing for a difference in composition between solid and liquid of the order of magnitude 25—30 % An on an average, probably less for the parts of the diagram high in anorthite and greater for those lower in anorthite, a corresponding displacement of the open dots to the left in the diagram should be required to get the determinations of the dimensions of the groundmass plagioclase put in direct relation to its (average) composition. By such an operation the relative maximum at 90 % An in Fig. 42 will, as is easily seen, fall between about 60 and 70 % An, whereas the minimum between 70 and 80 % will be displaced to 40—50 %. The maximum at 50—60 % will fall outside the left margin of the diagram. In the range of composition represented among the phenocrysts as well as in the groundmass plagioclase, namely about 40—70 % An, the same rule seems to be valid in regard to the variation of the ratio length : width to the composition. The different order of magnitude of the ratio in question for phenocrysts and groundmass crystals, respectively, is obviously the result of the different conditions of formation of the plagioclase crystals in the intratelluric and the effusive stage, respectively, of the crystallization of the magma.

As already emphasized the zoning of the plagioclase phenocrysts is rarely pronounced and mostly of a simple type, but more complicated types also appear, though subordinately. Seven leading types of zoning have been distinguished. These are illustrated diagrammatically in Fig. 45, where the general tendency of the variation of the anorthite percentage from the core (left) towards the margin (to the right in the diagram) of the phenocrysts is indicated by the several curves.

As will appear from Fig. 45, the principal types of zoning observed may be subdivided into two groups, which in accordance with the terminology of Homma (1936) may be described as non-oscillatory (A—C) and oscillatory structures (D—G). Of these groups the first-mentioned one is quantitatively predominant, as almost 3/4 of the porphyritic lavas have phenocrysts of mainly non-oscillatory types. In the following a descriptive account of the different types is given together with statements as to their occurrence with regard to the rock type as well as the appearance of inclusions and their relation to the zoning.

Type A. Normal non-oscillatory structure. This simplest type, with a continuously decreasing anorthite percentage from core to margin and with relatively slight difference in composition between the extremes, is chiefly confined to the hornblende and labradorite andesites. The generally slight magnitude of the phenocrysts of these rocks is worthy of remark. Inclusions are sparse or mostly quite absent. Sometimes they are more abundant, without, however, showing any regular arrangement.

Type B. Combination of even and normal non-oscillatory structure. This type, characterized by a thin, gradually more acid margin round a homogeneous core occupying the bulk of the crystal, is most common in these rocks. Almost 50 % of the rock specimens studied have phenocrysts with zoning of this type. Particularly in olivine basalts with the phenocryst combinations plagioclase-olivine-diopside and plagioclase-olivine, *i. e.* those types of rocks having plagioclase phenocrysts on an average highest in anorthite, this type of zoning is most commonly represented. But in other types of basalts and in some pyroxene andesites the same type of zoning also occurs. In most cases inclusions are absent or quite rare. In those cases, when they occur abundantly, a certain difference may be noticed in their distribution according to the rock type. In the olivine-basaltic lavas the inclusions are often restricted to the less basic margin or, still more commonly, to the transitional zone between this and the homogeneous core. In the pyroxene andesites, on the other hand, the core preferably contains the inclusions, the outmost zone being free from them.

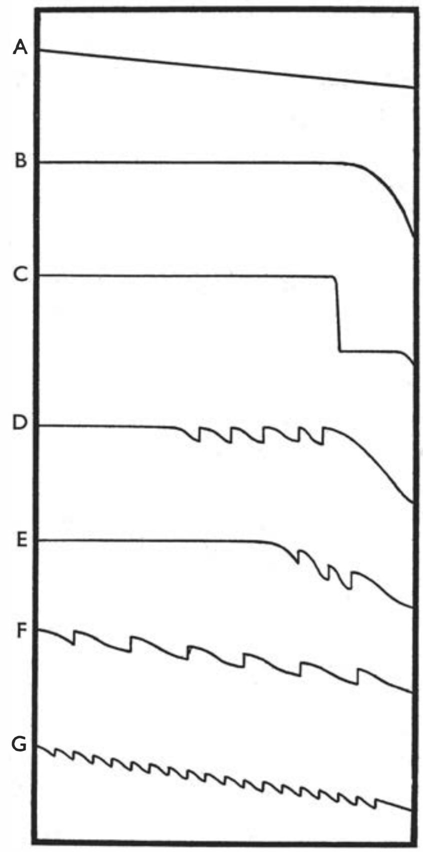


Fig. 45. Different types of zonal structure of plagioclase phenocrysts. Centre of crystals to the left, margin to the right.

Type C. Promoted multiple structure of non-oscillatory even. This structure differs from type B by the fact that the border higher in albite, except for a still more acid, very thin outer margin, has a homogeneous composition and is separated by a sharp limit from the more basic, likewise homogeneous core. This zoning is characteristic of the phenocrysts of some olivine-basaltic lavas with the phenocryst combinations olivine-plagioclase-diopside and olivine-plagioclase. Inclusions occur only sparsely.

Type D. Ordinary complex structure of non-oscillatory even, normal-oscillatory even, and non-oscillatory normal. This zoning may be said to correspond with type B with the exception that in the outer part of the otherwise homogeneous core there appears a larger or smaller number of oscillatory descents of the composition with low amplitude. Each oscillation brings the composition back to the approximate value characteristic of the central chief part of the crystal. The type of structure in question appears sparsely, partly in olivine basalt with the phenocryst combination plagioclase-olivine, partly in basaltic andesite, characterized by the phenocryst minerals plagioclase-orthorhombic pyroxene-clinopyroxene. In the former case inclusions are almost or entirely absent, in the latter they are abundant. The outmost zone is, however, free from them.

Type E. Ordinary complex structure of non-oscillatory even, normal-oscillatory normal, and non-oscillatory normal. The difference between this type and the immediately preceding one may be said to lie in the fact that here the oscillatory zoning is located to the interior part of the marginal portion, compared with the core higher in albite. Each zone has further on an average a composition somewhat lower in anorthite than that deposited immediately before. This type of zoning is observed firstly in olivine basalts with the phenocryst combinations olivine-plagioclase and olivine-plagioclase-magnetite, secondly in pyroxene andesites with the phenocryst parageneses plagioclase-orthorhombic pyroxene-clinopyroxene-magnetite and plagioclase-orthorhombic pyroxene-clinopyroxene-magnetite-apatite. When inclusions appear in quantities worth mentioning, they are preferably confined in the basaltic lavas to well delimited zones in the oscillatory zoned portions of the crystal, whereas in the andesitic types the inclusions are most abundant in the centre of the phenocrysts.

Type F. Normal-oscillatory, normal structure. This type is characterized by a restricted number of rather evenly dispersed recurrent zones with relatively low amplitude and by a general decreasing tendency of the anorthite percentage from centre to periphery. Zoning of this nature has been recorded chiefly in some pyroxene andesites with plagioclase, orthorhombic pyroxene, clinopyroxene and magnetite as phenocrysts but also in an olivine basalt with the phenocryst combination olivine-plagioclase-clinopyroxene-magnetite. Inclusions sometimes occur abundantly, usually in zonal arrangement.

Type G. Normal-oscillatory, normal structure. This type agrees fundamentally with the preceding one. The frequency of the oscillatory zones is, however, very much greater, whereas their amplitude is on an average somewhat smaller. This kind of zoning is particularly characteristic of the andesitic basalts which have pigeonite as phenocrysts. But it is also found in more basic basalts as well as in pyroxene andesites. These phenocrysts are either devoid or have only one or a few zones of inclusions.

From the summary given above and upon a closer inspection a certain connection may be inferred between the type of zoning and the composition of the plagioclase phenocrysts and the rocks. Thus the structures of predominantly even type (B—E) are to be found mainly in lavas of basic, olivine-basaltic composition with plagioclase phenocrysts highest in anorthite. This is particularly true of the types B and C. The types D and E, in which oscillatory zoning in part also occurs, hold an intermediate position with regard to their occurrence. Finally the normal types, non-oscillatory as well as oscillatory (A, F, G), are characteristic of the more acid types of rocks represented in this series. Upon the whole it may be said that those types of zoning which indicate a rather complete reaction of equalization of the crystals to equilibrium with the composition of the liquid during the crystallization, preferably appear in the more basic lavas, whereas those types showing such an equalization in only an incomplete degree are to be found particularly in the more acid types of rocks. This indicates the greater or minor degree of viscosity of the magma as a controlling factor for the development of the different types of zonal structure and possibly supersaturation phenomena connected with decreased rate of molecular diffusion (*cf.* HILLS 1936) as a probable explanation of the oscillatory zoning present of greater or minor frequency, but throughout of low amplitude. The difference between the two main types of zonal structure of the plagioclase phenocrysts of the basic and the more acid lavas, respectively, might also perhaps be partly explained by the former having been mainly formed at slower cooling, *e. g.* at a greater depth, than those of the more acid rocks, and in addition to the minor viscosity the time factor has also favoured a complete reaction between crystals and liquid in the former case. The slight oscillatory zoning towards the outer parts of the phenocrysts of the types D and E might then be explained by the increased viscosity with advanced crystallization due to the increased acidity of the liquid, or alternatively as well by the rising of the magma into higher levels resulting in more rapid cooling and by the incipient loss of volatile constituents further increasing the viscosity. In any case the outermost zone definitely higher in albite in the types B—E might be considered as representing the commencement of the purely effusive stage.

The extreme range in composition between core and margin of the same zoned plagioclase phenocryst has been measured to 11 (minimum) and 26 % (maximum), with an average value of about 20 %. These statements illustrate the relatively slight zoning of the plagioclase of this series of effusive rocks.

The positions of the poles of (010) in relation to the optical indicatrix of the plagioclases of the rocks of the Tronador series are plotted in the diagram Fig. 46 a. The curve entered in the diagram corresponds to the migration curve for the poles of (010) corrected by W. W. NIKITIN (1933, Plate 2). The scattering of the dots at right angles to the migration curve is certainly rather considerable, though a distinct gathering of the dots to a central axis in the area of distribution may be discerned. The great concentration of dots between 85 and 90 % An falls rather sym-

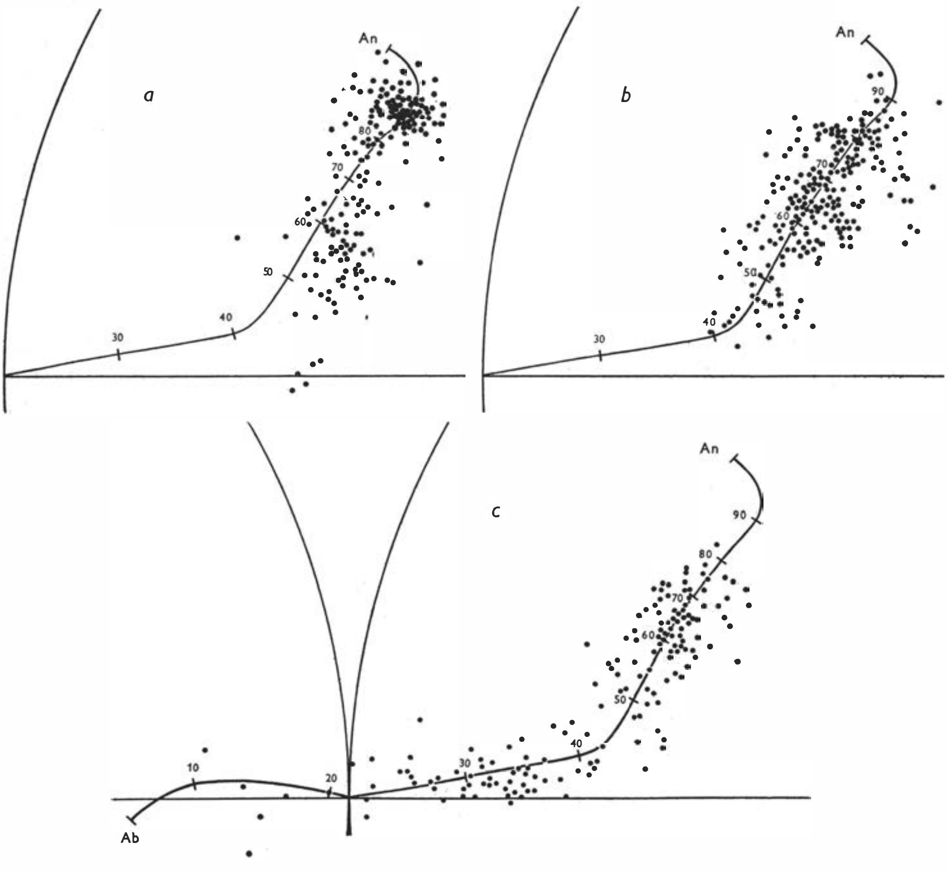


Fig. 46. Position of the poles of (010) of plagioclase from Tronador rocks (a), from rocks of the Nygård plutone, LARSSON 1935, (b) and from hyperites of Western Sweden (c) in relation to the migration curve of NIKITIN.

metrically on NIKITIN's curve. The earlier curves of BEREK (1924) and REINHARD (1931) both run more to the left (Fig. 47) in this portion. Being rather symmetrically dispersed in relation to the NIKITIN curve down to an anorthite percentage of about 70 % the dots here begin to fall predominantly to the right of the curve, with decreasing percentage of anorthite in a still more pronounced degree. For this range of composition (about 40—70 % An) BEREK's curve for these rocks would correspond better to the conditions statistically found, whereas REINHARD's curve,

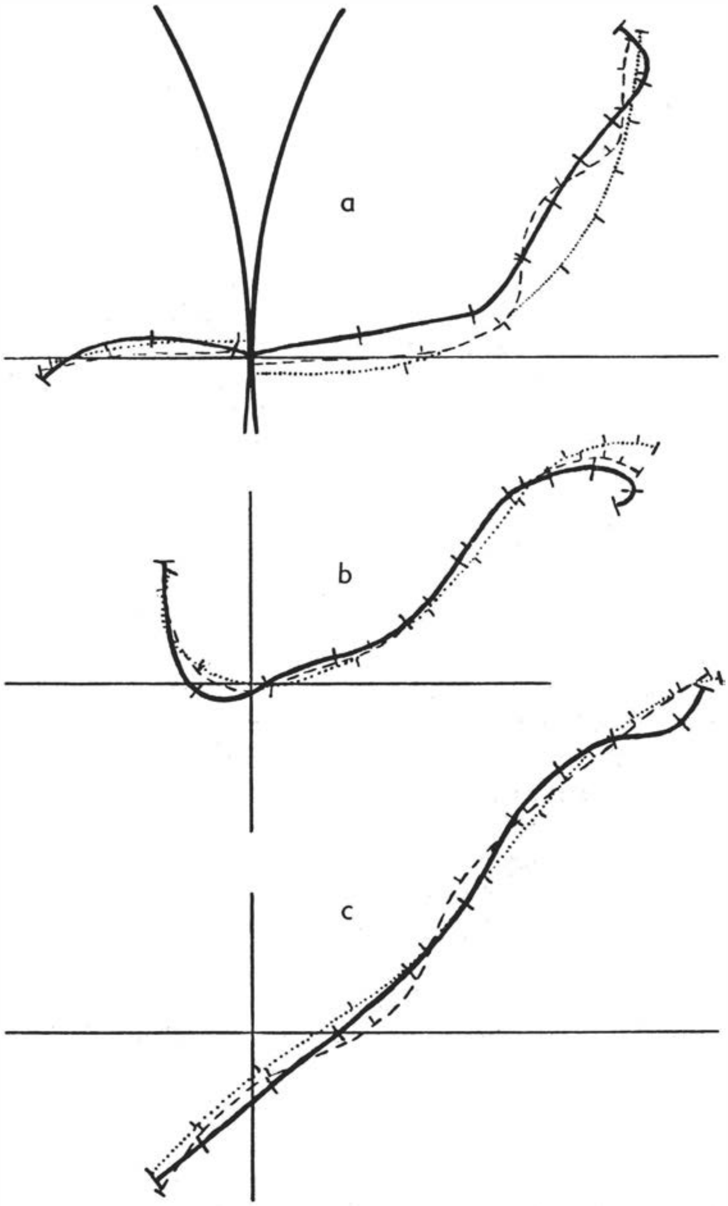


Fig. 47. The migration curves of the poles of (010) (a), (001) (c) and the rhombic section (b) according to BEREK (stippled), REINHARD (dashed) and NIKITIN (full-drawn).

which here makes a bend to the left, falls far outside the area occupied by the dots. The same discrepancy between REINHARD's curve, and the average positions of the face poles (010) in the range of composition mentioned has earlier been shown to exist for plagioclase phenocrysts of an enstatite porphyrite from Kongsberg, Norway (SCHUMANN 1931) and of Tertiary andesites from Rumania (PALIUC 1932; WENK 1933) and British North-Borneo (HOMMA 1932).

By way of comparison determinations have been included in Fig. 46 b and c made by the author on plagioclases of two groups of rocks of another character. Fig. 46 b refers to the gabbroic and noritic rocks of the small Nygård plutone in Central Sweden, described by the author (LARSSON 1935), Fig. 46 c to the hyperites appearing mainly as folded sills from two provinces of Western Sweden (investigation by the author not yet published). Both groups of rocks are of pre-Cambrian age.

Taking first the Nygård plagioclases into consideration these show in contrast to those of the Tronador rocks a range of composition on an average displaced some ten per cent towards the albite side. The scattering at right angles to the migration curve is here perhaps a little greater. The projection points are, on the other hand, from the basic to the acid end throughout rather symmetrically dispersed in relation to the migration curve of NIKITIN.

The plagioclases of the hyperites (and the hyperite amphibolites) occupy a range of composition between about 10 and 80 % An. Of the three groups of rocks here dealt with the projection points of the hyperite plagioclases are restricted to the narrowest band. As in the immediately preceding case NIKITIN's curve here, too, cuts through the area occupied by the dots practically in a symmetrical manner. Attention is drawn particularly to the close agreement in the range 20—50 % An. REINHARD's curve here runs in the lower margin of this area of distribution, and that of BEREK to a large extent quite below it.

Summing up the experiences acquired by this statistical investigation as to the applicability of the three determination curves for (010) here cited (BEREK, REINHARD, NIKITIN) it is obvious from the three examples given above of plagioclase from different types of rocks that the great scattering of the projection points and the varying position of the symmetry line of the area occupied by the dots show that it is impossible to construct a general average migration curve valid in the same degree for the plagioclase of different types of rocks. As will appear from the diagrams given above (Fig. 46 a—c) compared with the curves for (010) compiled in Fig. 47 a, NIKITIN's curve in the majority of cases seems to answer most closely to the conditions and is, therefore, to be given preference. Also the calibration of the curve by NIKITIN is likely to be the most reliable one, as it is based upon more abundant and modern sources of measurements and analyses. That determinations of the anorthite percentage according to this curve in the range of composition represented by the Tronador plagioclases are on an average a few per cent higher than those according to REINHARD's curve, appears from Fig. 48. The average difference is greatest (5 %) at about 70 % An. The greatest absolute difference was 9 % (at 88 % An). On account of the different curvature of the curves and the scattering of the projection points the determinations, however, give in certain cases (in the ranges 50—60 and 80—90 % An) somewhat higher values according to REINHARD than assessed by the NIKITIN curve.

If the diagrams Fig. 46 a—c are compared with regard to the range of composition, 40—80 % An, represented in all three cases, it may therefore be noted that the Nygård rocks (b) and the hyperites (c) show fundamental agreement, the dots being symmetrically scattered in relation to the NIKITIN curve, whereas the plagioclase phenocrysts of the Tronador rocks give projection points lying for the greater part to the right side of the curve. As the diagrams b and c represent rocks consolidated in-

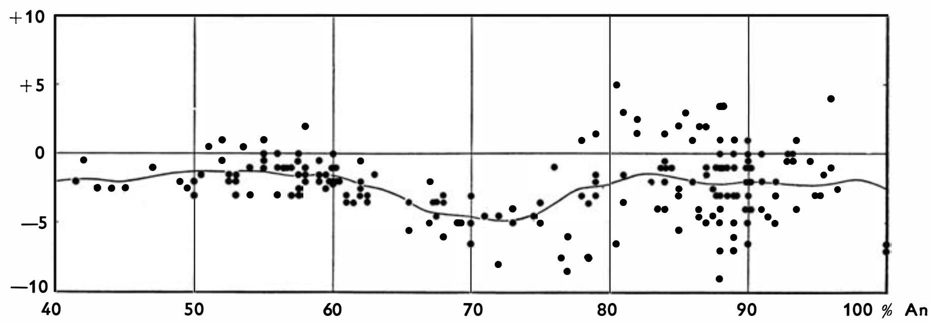


Fig. 48. Diagram showing the differences between the anorthite percentages as determined according to REINHARD's and NIKITIN's curves. Ordinate: % An (REINHARD) — % An (NIKITIN). Abscissa: % An according to NIKITIN.

trusively though probably at a relatively inconsiderable depth, and as the statistical investigations of plagioclase phenocrysts of different andesites made by HOMMA (1932), PALIUC (1932) and WENK (1933) give the same picture of the distribution of the projection points as the Tronador rocks, one is inclined to see in this behaviour a property characteristic of the plagioclase phenocrysts of intermediate effusive rocks. Such being the case it is probable that the rapid fall of temperature from the intratelluric to the effusive stage is to be held responsible for the differences as against the plagioclases of the rocks crystallized during slow and tolerably continuous cooling. Whether it is the potash percentage or the manner of its appearance in the plagioclase lattice, which is here decisive, or still another factor is a problem, the solution of which would require special investigations. Certainly the range of variation of the potash percentage of plagioclase phenocrysts seems to be greater than that of the plagioclase of evengrained intrusive rocks at the same An : Ab ratio (MÄKINEN 1917, p. 132). The plagioclases extremely high in potash are, however, very few in number in the material of analyses used by MÄKINEN. The bulk of analyses of plagioclase phenocrysts hardly show any decidedly greater

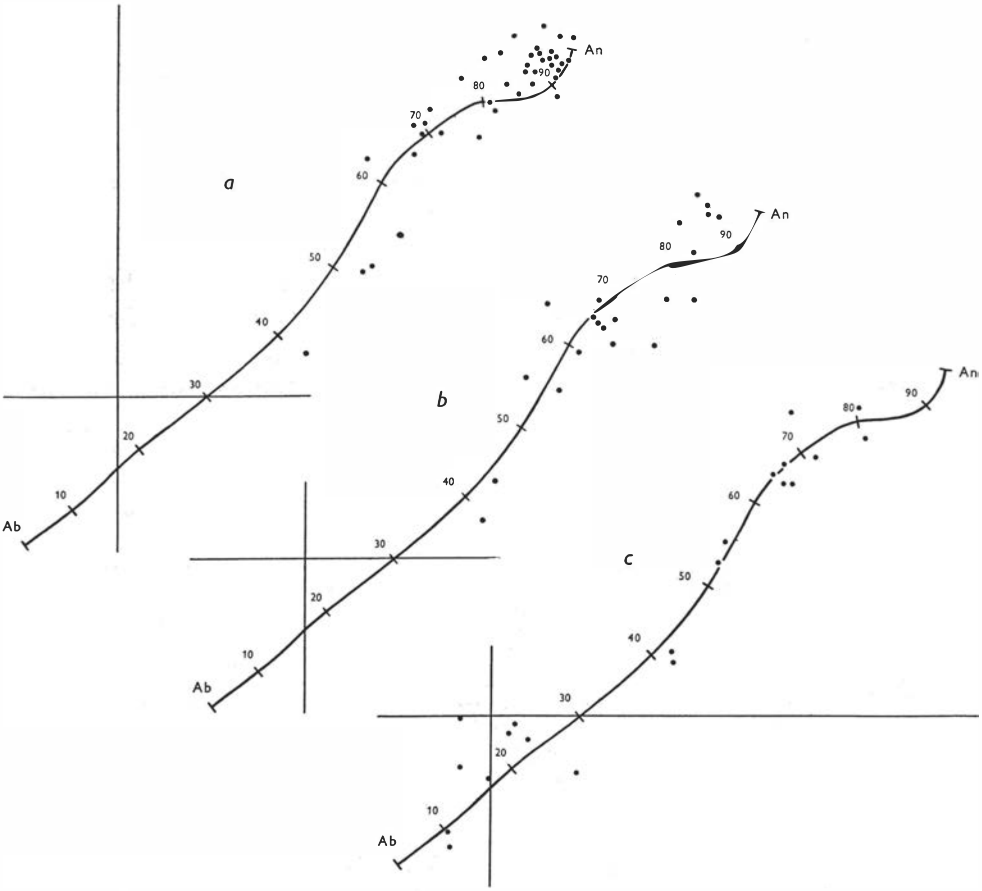


Fig. 49. Position of the poles of (001) of plagioclase from Tronador rocks (a), from rocks of the Nygård plutone, LARSSON 1935, (b) and from hyperites of Western Sweden (c) in relation to the migration curve of NIKITIN.

potash percentage than the bulk of the »plutonic» plagioclases. For this reason differences in the potash percentage do not seem *a priori* to be sufficient to explain the differences in optical conditions stated above.

The positions of the poles of cleavages (and twin planes) after (001) are represented in Fig. 49a, according to determinations on plagioclase phenocrysts of rocks of the Tronador series. The number of dots is here considerably smaller than in the preceding diagrams, but sufficient to illustrate certain fundamental features. The curve traced here is also that of NIKITIN. The most basic plagioclases (>80 % An) fall with few exceptions above (to the left of) the curve. Within this part BEREK's and REINHARD's curves, on the other hand, run rather centrally through the area of dots (*cf.* Fig. 47 c). Also in the respect that these curves extend a small distance beyond the anorthite point of NIKITIN, they agree more closely with the conditions found in connection with the plagioclases of the Tronador rocks. In the range 60—80 % An the NIKITIN curve runs centrally through the band of dots, whereas the two other curves here lie more to the right. Between 40 and 60 % An all dots, few in number, are situated to the right of the migration curve of NIKITIN. BEREK's curve here falls partly closer to the dots, whereas that of REINHARD in this range is the least compatible of the three curves to the pole positions of the Tronador plagioclases.

The diagram of plagioclases from the rocks of the Nygård plutone (Fig. 49 b) shows similarities as well as differences compared with the former diagram. Between 80 and 90 % An most dots lie, here too, above (to the left of) the curve, between 70 and 80 % An, on the other hand, all dots lie below (to the right of) it. From 70 % and downwards the NIKITIN curve coincides rather accurately with the central line of the sparsely occupied band of dots, except in the most acid plagioclases represented (about 40 % An), the dots of which fall to the right of the curve, yet not so decidedly in view of their small number.

The poles of (001) of plagioclases from hyperites finally show in the whole range of composition (10—80 % An) a remarkably small scattering on both sides of the NIKITIN curve. Only in the acid part (about 20 % An) the scattering is greater. Particular attention may be called to the close agreement between curve and positions of the dots in the middle part of the diagram (40—60 % An), in conformity with the Nygård rocks but as distinct from the Tronador lavas.

We are thus able to establish, also with reference to (001), a certain difference -- though on account of the relatively sparse material of observations not so remarkably sharp — in the average positions of the poles between the phenocrysts of the Tronador rocks on the one hand and the plagioclase feldspar of the Nygård rocks and the hyperites on the other. In a comparison with similar diagrams published earlier, which all refer to effusive rocks, a striking agreement appears between these and the diagram of the plagioclases of the Tronador rocks (Fig. 49 a). Thus the dots lie in the most basic parts (80—100 % An) mostly symmetrical in relation to REINHARD's curve (PALIUC 1932; WENK 1933). Only HOMMA (1932) has obtained positions of the dots corresponding most closely to the course of NIKITIN's curve in this part. A common feature in these diagrams referring to effusive rocks is the arrangement of the dots in the range of about 40—60 % An. They there lie in a band displaced to the right of REINHARD's as well as NIKITIN's curves.

After all it is quite natural that an »abnormal» position of the face poles of (010) involves a corresponding displacement of (001). At the same time these facts afford a security that the deviating positions of (010) being mainly measured as twin planes really refer to (010) and not to

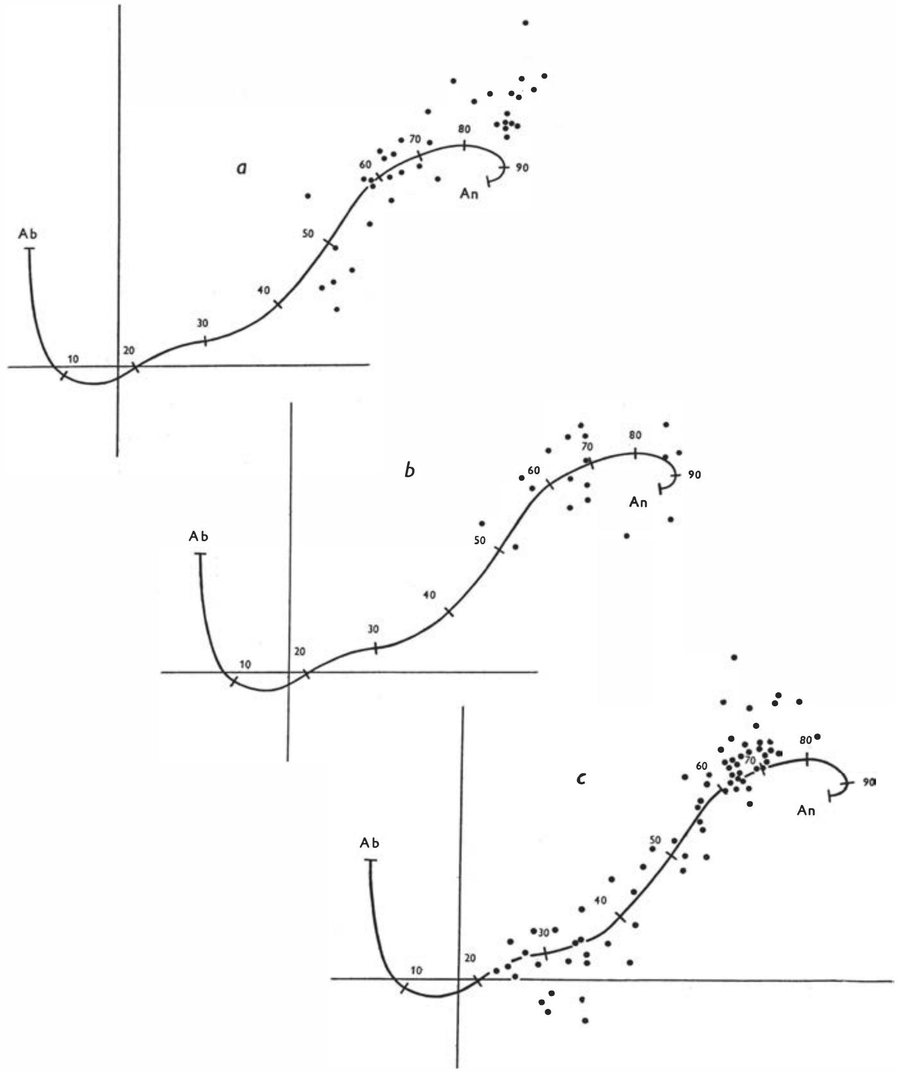


Fig. 50. Position of the poles of the Pericline twinning lamellae of plagioclase from Tronador rocks (a), from rocks of the Nygård plutone, LARSSON 1935, (b) and from hyperites of Western Sweden (c) in relation to the migration curve of NIKITIN.

any vicinal faces. As to (001) this eventuality need not be taken into consideration as here cleavages have been measured almost entirely.

Finally in Fig. 50 a—c the orientation of the Pericline twinning lamellae of the plagioclases of the same three groups of rocks has been presented. On account of the occasional difficulty of accurately measuring the orientation of the often short and thin twinning lamellae the scattering of the dots is rather considerable. In the part of the diagrams high in anorthite only the Nygård rocks (b) show a rather close approximation in the position of the dots to NIKITIN's curve. The two other diagrams, and especially that of the Tronador rocks (a), have the dots lying almost entirely, and partly rather far, above this curve, in closer agreement with the course of BEREK's curve. At about 60 % An the dots lie in all three cases in approximately equal distribution on each side of the NIKITIN curve. This condition also applies to the remaining part of the diagrams of the Nygård rocks and the hyperites, in the latter case disregarding a few aberrant dots in the most acid part represented, which lie rather far below the curve. As against these two diagrams that of the plagioclases of the Tronador rocks shows in the range 40—60 % An a decidedly favoured position of the projection points to the right of the curve. Also in this respect the plagioclase phenocrysts of the Tronador rocks show agreement with the results attained by SCHUMANN, HOMMA, PALIUC and WENK on phenocrysts of effusive rocks. Only in the anorthitic part of the diagrams the agreement is not quite so close, as the majority of the dots fall nearer to the curve (HOMMA, PALIUC) than in our case. The diagram given by WENK (1933) of plagioclases from Rumanian effusive rocks shows, however, also in this part a close correspondence in the position of the dots with the diagram of the plagioclase phenocrysts of the Tronador volcanics.

Summarizing the material stated above relating to the optical characters of the plagioclases examined it may be established that the plagioclase phenocrysts of the volcanic Tronador rocks of intermediate composition (andesine—labradorite) show on an average an orientation differing distinctly from that of the plagioclases of the noritic and hyperitic rocks cited as examples of intrusively consolidated rocks. These latter give statistically a distribution of the poles of the different morphological cleavage and twin planes examined in this respect, which corresponds upon the whole to the current migration curves; these curves in the intermediate range of composition seem to be chiefly based upon measurements and analyses of plagioclases, comparable in their formation with the plagioclase of these igneous rocks consolidated at relatively slow cooling. On the other hand, the fact that earlier investigations, cited above, of plagioclase phenocrysts of effusive rocks (statistical investigations of plagioclases of deep-seated rocks do not seem to have been published before) from different parts of the world and of different ages show the same characteristics as the phenocrysts of the Tronador rocks, provide ample reason for believing that we have to deal here with a rule of general application.

The magnitude of the axial angle has not been used in the determination of the anorthite percentage of the plagioclase. When possible the axial angle of the plagioclase individuals examined on the universal stage has, however, been determined. The 96 values thus obtained of the axial angle of the phenocrysts of the rocks of the Tronador series are plotted in the diagram Fig. 51 against the anorthite percentage determined according to the curves of NIKITIN. The following curves are inserted in the diagram: the average curve of the axial angles according to DUPARC—REINHARD (1924; stippled) and NIKITIN (1933; dash curve with stipples), curves indicating the extreme variations of the axial angle according to NIKITIN (dash lines with stipples) and, finally, an average curve computed for the axial angles of the Tronador plagioclases (solid curve). As will be seen from the diagram all determinations fall between the limits of variation

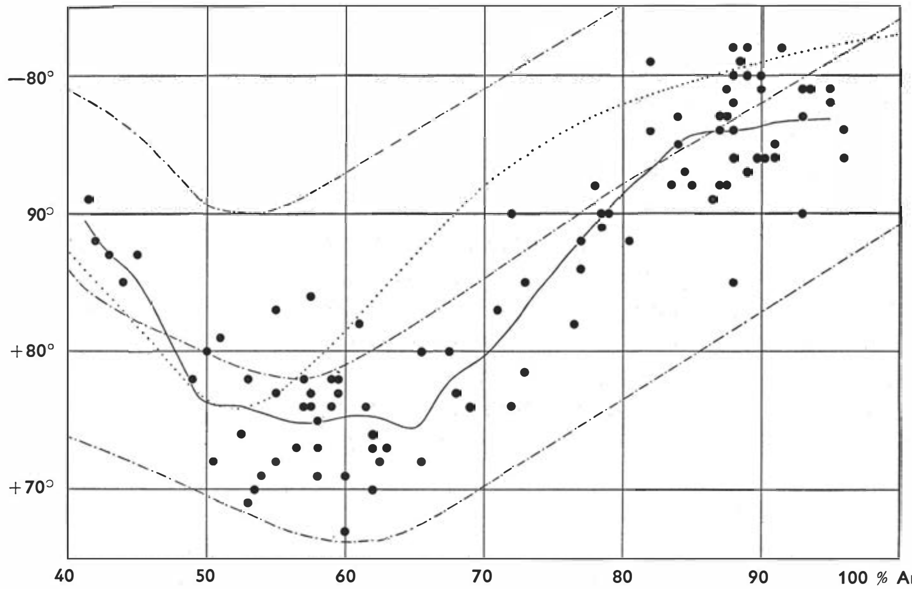


Fig. 51. Diagram showing the relation between axial angle and chemical composition of the plagioclase of the Tronador rocks. As to the curves see text.

given by NIKITIN. Of the two average curves cited that of DUPARC—REINHARD tallies rather badly with that computed by the author. Also NIKITIN's curve only agrees tolerably well in the most basic portion (> 80 % An). Between 50 and 80 % An the Tronador plagioclases show considerably smaller, positive axial angles than might be expected from the average curves mentioned, whereas the few determinations between 40 and 45 % An all show greater axial angles than indicated by these curves.

The 95 plagioclase twins determined during the course of the work are distributed on the different twinning laws in the manner apparent from Table XXXIX. A subdivision into three groups with regard to the chemical composition has here been undertaken. The three laws Carlsbad, Albite-Carlsbad and Albite are predominant in this order (together 95 %). In addition it must be noted that only those cases have been entered as Pericline twins where this twinning is predominant, and not the numerous

Table XXXIX.

Frequency of twinning laws in the plagioclase phenocrysts of the Tronador rocks.

% An	Albite	Carlsbad	Pericline	Ala	Albite-Ala	Albite-Carlsbad
35— 60	7	5	—	—	1	11
60— 80	9	12	—	—	—	4
80—100	7	19	2	1	1	16
Total	23 (24 %)	36 (38.5 %)	2 (2 %)	1 (1 %)	2 (2 %)	31 (32.5 %)

cases where thin lamellae according to the Pericline law appear subordinately together with other laws.

In Table XXXIX a certain tendency may be traced to a connection between the anorthite percentage of the plagioclase and the frequency of the twinning laws. In the most basic plagioclases Carlsbad and Albite-Carlsbad twins are predominant, whereas in the groups higher in albite the number of Albite twins relatively increases. This tendency is corroborated to a certain extent by statements in the literature on volcanic rocks. Thus PALIUC (1932) and WENK (1933) found that in phenocrysts of andesites and andesitic basalts, with compositions down to 40 % An, Albite twins were most abundantly represented (49.5 and 45 %, respectively, of all twins). SPAENHAUER (1933), on the other hand, found on synthetic plagioclase crystals of a composition mainly between 80 and 100 % An a ratio between the number of twins according to the Albite, Carlsbad and Albite-Carlsbad laws (19 : 29 : 20), which does not differ too greatly from that found by the author (7 : 19 : 16) for the same range of composition.

Finally a few words may be said about the alteration of the plagioclase. A characteristic of the predominant part of the Tronador rocks is the extremely fresh state of preservation of their plagioclase. Thus in the lavas of the Brazo del Viento area no alteration worth mentioning of the plagioclase phenocrysts has been observed. The fragments of these phenocrysts entering into the pyroclastic products also show the same clear plagioclase substance. This circumstance makes it possible to distinguish at first sight plagioclase fragments of essential character from those of accidentally intermingled material, mostly granodiorite, the feldspar of which always seems to be more or less turbid.

A more far-reaching alteration of the plagioclase has taken place exclusively by the influence of volcanic gases and solutions on the rocks of the immediate neighbourhood of the once existing crater of Tronador. Due to differences in the temperature and chemical character of the altering agents the result of the alteration has been of a rather varied character. The following different combinations of minerals and types of alteration have been observed: 1) Sparse epidote crystals. 2) Formation of sericite along fissures. 3) Reticular sericitization + somewhat calcite and epidote. 4) Epidote + a little calcite. 5) Calcite + a little epidote. 6) Calcite. 7) Calcite + kaolin. 8) Kaolin. 9) Opal (sometimes two types of different age). 10) Opal + probably alunite. 11) Opal + somewhat tridymite and kaolin. 12) Opal + chalcedony and sulphur. Of these types those containing opal seem to predominate quantitatively.

2. Olivine.

Next to the plagioclase olivine is the most abundantly occurring phenocryst mineral in the rocks of the Tronador series. Of the fifteen different

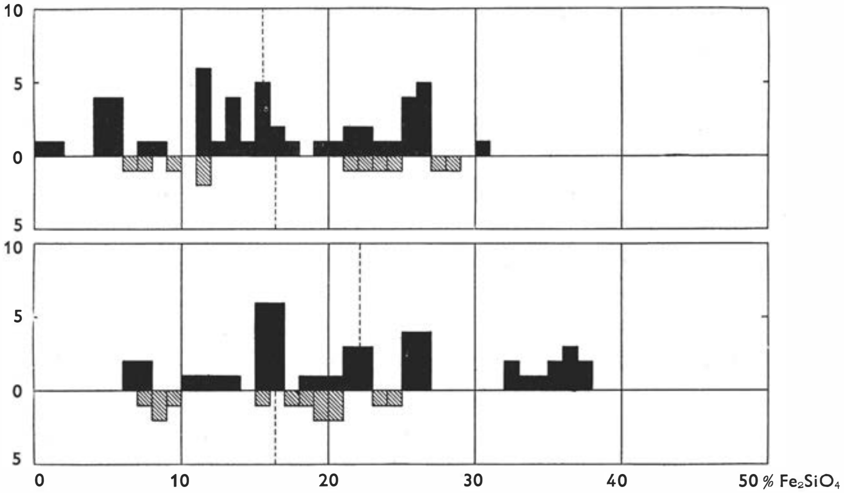


Fig. 52. Frequency diagrams of the composition of olivine phenocrysts of effusive lavas (black) and pyroclastics (ruled) of the Brazo del Viento (upper diagram) and the Tronador areas (lower diagram). Dash lines indicate the average compositions of the different groups.

combinations of phenocrysts recorded in its lavas olivine enters into nine. In the Brazo del Viento area all lavas are olivine-bearing, also the non- or indistinctly porphyritic ones. Lavas free from olivine outcrop only in Tronador and in the Victoria valley, according to the specimens examined. On account of the abundant occurrence of the olivine it is quite natural that most pyroclastic products also contain fragments of this mineral.

The range of variation of the composition of the olivine, derived from the axial angle, appears in Fig. 52. It varies from almost pure magnesium silicate to a member containing 37 % Fe_2SiO_4. The composition of the olivine fragments of the pyroclastic products (ruled in fig. 52) varies, on account of a smaller number of determinations, within more restricted limits (7—28 % Fe_2SiO_4). From the figure it also appears that the olivine phenocrysts of the lavas of the Viento area (upper part of the diagram, black) are higher in magnesia (1—30.5, on an average 15.5 % Fe_2SiO_4) than those of the Tronador area (lower part of the diagram; 7—37, on an average 22.1 % Fe_2SiO_4). For the pyroclastic products such a difference between the two areas does not appear. These relations are to a large extent analogous to those which the plagioclase phenocrysts tended to show and the same fundamental explanation is also applicable here.

A distinct zoning of the olivine was found in only one case (*cf.* p. 330). The axial angle changed from the core to the margin with an amount corresponding to an increase of Fe_2SiO_4 from 5 to 15 %.

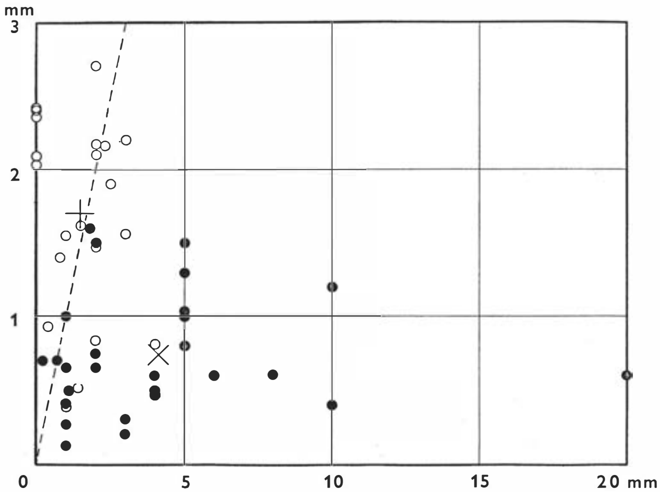


Fig. 53. Diagram showing the relation between the maximum length of the olivine phenocrysts (ordinate) and that of the plagioclase phenocrysts of the same rocks (abscissa). Rocks of the Brazo del Viento area are indicated by open circles, those of the Tronador area by filled circles, the centres of gravity of the two areas by crosses.

The degree of idiomorphism varies somewhat. A relation in this respect to the rock type can scarcely be traced. In the same thin section the larger crystals are often more sharply developed than the smaller ones, which may be connected with the partly strong magmatic corrosion, which the olivine has undergone.

As to the dimensions of the olivine phenocrysts a certain dependence on the phenocryst paragenesis of the rock may be established. The maximum largest olivine phenocrysts are to be found in the basalts with the phenocryst combinations 1) olivine, 2) olivine + diopside and 3) olivine + diopside + plagioclase, whereas only small magnitudes are represented in such types of rocks, which in addition to olivine and plagioclase bear phenocrysts of 1) pigeonite, 2) pigeonite + orthorhombic pyroxene and 3) clinopyroxene + ore. The great group of lavas distinguished by only olivine and plagioclase as phenocrysts holds an intermediate position in this respect.

In Fig. 53 the maximum length of the olivine phenocrysts of the different slides examined has been plotted against the maximum length of the plagioclase phenocrysts of the same rock specimens. As to lavas without plagioclase phenocrysts their length has been put equal to zero. It appears from the figure that the largest olivine phenocrysts (up to 2.7 mm) are found in lavas, which are either devoid of or have small plagioclase phenocrysts. The larger plagioclase phenocrysts, on the other hand, occur together with relatively small olivine crystals. In the diagram different symbols have been used for the lavas of the Viento and Tronador areas, respectively. By this means a distinct difference appears between the two areas in this respect. The lavas of the Viento area have on an average larger olivine phenocrysts and smaller plagioclase phenocrysts than those of the Tronador area. For the lavas bearing plagioclase phenocrysts the rule is valid in the former area that olivine and plagioclase phenocrysts have mainly the same maximum dimensions in the same specimen irrespective of the absolute magnitude. This finds expression in the diagram in the manner that the dots preferably lie in the vicinity of the (dash) line indicating equal maximum lengths; it is to be noted that the scale of the ordinate has been chosen five times that of the abscissa. The majority of the dots of the Tronador area fall far to the right of the same line. The lavas of this area are therefore characterized by the fact that the olivine phenocrysts are predominantly associated with plagioclase phenocrysts of considerably greater maximum dimensions than the olivine phenocrysts.

A similar result is obtained from diagram Fig. 54, where the volumetric share of the olivine phenocrysts of the rocks has been put in relation to that of the plagioclase phenocrysts. According to what has been stated above it is to be expected that the rocks of the two areas shown in this diagram will behave differently. As will appear from the average values inserted the difference is to be seen in the greater quantity of olivine phenocrysts present in the rocks of the Viento area compared with those from the Tronador area, whereas the plagioclase phenocrysts occur in exactly reverse proportions. There are, however, lavas in the Tronador area with high percentage of plagioclase phenocrysts and at the same time a comparatively high percentage of olivine phenocrysts. Apart from some intermediate cases the difference between the rocks of the two areas appears most pregnantly in the range 0—10 volume per cent plagioclase phenocrysts. With decreasing percentage of intratellurically crystallized plagioclase in the lavas of the Tronador area the quantity of porphyritic olivine also tends to approach zero, whereas in the Viento lavas the olivine phenocrysts are most abundant when plagioclase phenocrysts are lacking. These facts seem to be explicable only by differences in chemical composition and, in consequence of this, in order of crystallization between the main types of rocks in the two areas. We shall refer to these relations in a later connection.

The olivine is perfectly fresh in many rocks, particularly in the Viento area. Alteration of a deuteric character is, however, very common. Apart from the inconsiderable, thin coatings of reddish brown or intensely red colour sometimes occurring along fissures, which mainly represent late infiltrations and not real alteration products of the olivine substance, three different types of alteration may be distinguished. One type of alteration consists in a replacement of the olivine substance by a granular aggregate

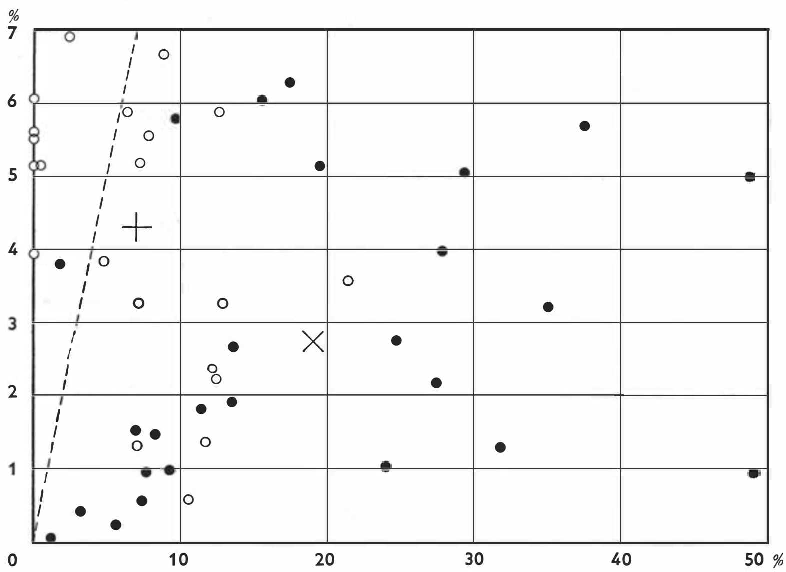


Fig. 54. Diagram showing the relation between the volumetric percentage of olivine phenocrysts (ordinate) and that of plagioclase phenocrysts of the same rocks (abscissa). The same signs as in Fig. 53.

of opaque ore grains. No other products than ore are generally to be observed in these pseudomorphs. This alteration, therefore, implies a not inconsiderable interchange of substance between phenocryst and groundmass. The most striking feature is, however, an oxidation of the iron. This type of alteration is characteristic of the lavas in the neighbourhood of Calderón de Lavas and Cerro Volcánico. In the other lavas of the Tronador area the alteration of the olivine phenocrysts has chiefly involved a hydration, the alteration products being mainly a lighter or darker grayish to yellowish green, partly pale brownish green, fibrous serpentine, less often a deep yellowish brown, brown or reddish brown iddingsite. These three types of alteration differ not only by different final products but also in the different manner in which the alteration proceeds. Whereas the opacite alteration starts from the periphery of the crystals and the iddingsite alteration preferably from fissures, the olivine substance is more irregularly affected at the formation of the green serpentine, the central parts of the olivine crystals often being altered first.

Finally in addition to these alterations it must be mentioned that the olivine, which has been subjected to the influence of the late volcanic processes in Tronador, in those cases, where it has been identified with some probability, has been altered into a dark brown, opaque, granular aggregate, probably consisting in the greater part of opal impregnated with ferric hydroxide.

3. Orthorhombic pyroxene.

As phenocrysts orthorhombic pyroxene plays a considerably more modest rôle than the olivine. As groundmass mineral, however, it is found somewhat more abundantly than this mineral. Orthorhombic pyroxene

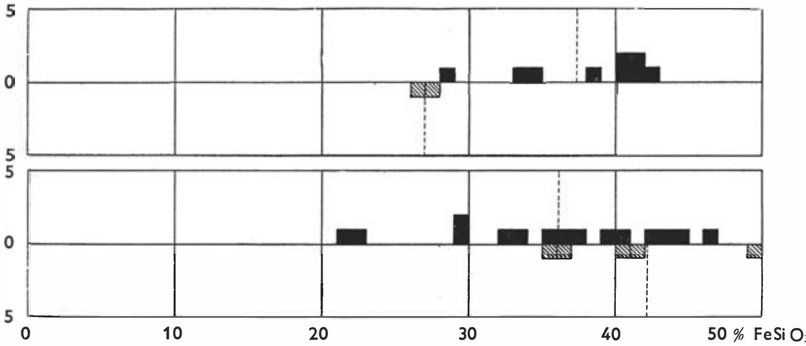


Fig. 55. Frequency diagrams of the composition of orthorhombic pyroxenes of lavas (black) and pyroclastics (ruled) of the Brazo del Viento (upper diagram) and the Tronador areas (lower diagram). Dash lines indicate the average compositions of the different groups.

enters into five different combinations of phenocryst minerals. Two of these correspond to predominantly (olivine-bearing) basaltic lavas, three to rocks of an andesitic character. With regard to the number of specimens examined with phenocrysts of orthorhombic pyroxene the andesitic lavas also predominate over the basalts. Of eleven specimens only three proved to be olivine-bearing. In this connection it may be added that in the Viento area, where only basaltic lavas have been met with, orthorhombic pyroxene phenocrysts are found only in one case. On the other hand, some of the non-porphyritic, doleritic lavas of this area bear abundantly orthorhombic pyroxene in relatively large individuals, generally in ophitic relation to the plagioclase.

The range of variation of the chemical composition of the orthorhombic pyroxene appears from Fig. 55. The percentage of $FeSiO_3$ lies between 22 and little short of 50 %. The pyroxene is thus to be described as hypersthene. A comparison between the diagrams Fig. 52 and 55 shows that the hypersthenes are on an average between 15 and 20 % higher in iron silicate than the olivines. A distinct difference in the composition of the hypersthene in the lavas of the Viento and the Tronador area, respectively, may scarcely be deduced on account of the small number af determinations. The range of variation is, however, in the latter area greater than in the Viento area, in spite of the fact that in addition to phenocrysts the hypersthenes of the non-porphyritic lavas have also been inserted in the diagram. As to the fragments of hypersthene in the pyroclastic products the determinations indicate a composition decidedly higher in iron in the Tronador than in the Viento area. On account of the small number of determinations no conclusions of wider scope may however be drawn from this fact, as accidental circumstances may be decisive. In any case the diagram reveals the sparse occurrence of orthopyroxene in the lavas as well as the pyroclastics of the northern area as compared with the southern one.

The hypersthene generally shows a distinct pleochroism in the normal tints. The idiomorphism of the phenocrysts is relatively good, particularly in the andesites. The crystals here seem to be more prismatically elongated than in the olivine-bearing lavas. In the latter the hypersthene appears partly in a corona-like manner round the olivine. The hypersthene crystals reach on an average smaller dimensions in the basalts than in the andesites. The maximum lengths measured are 0.3—1.3 mm and 0.6—2.1 mm, respectively. In connection with this the fact occurs that the quantitative share of the hypersthene phenocrysts is also greater in the pyroxene andesites (at most 3.9 % by volume) than in the olivine-bearing lavas (at most 1.5 %). From these figures it appears that the hypersthene phenocrysts never have as great a quantitative importance as the olivine phenocrysts in some of the basaltic lavas.

The hypersthene shows in the fresh lavas a considerably slighter alteration as compared with the olivine. Only along fissures and sometimes peripherically, especially in the ends of the crystals, a minor alteration into green, fibrous serpentine is to be found. Only in one case an incipient alteration to dark yellowish brown bastite was observed.

In the hydrothermally affected rocks from the higher parts of Tronador the hypersthene has met with extensive decomposition, different products having resulted under different conditions. The following types of pseudomorphs have been observed: 1) Chlorite. 2) Pale yellowish green chlorite, in part with a marginal zone of fibrous amphibole towards the groundmass. 3) Chlorite with more or less ore. 4) Fine-grained aggregate of chlorite, epidote and sometimes calcite, more or less heavily ore-pigmented. 5) A deep reddish brown goethitic substance. 6) Brownish black — black, opaque masses. 7) Opal, more or less pigmented. Of these the opal pseudomorphs obviously involve the most profound modification of the original chemical composition of the hypersthene.

4. Monoclinic pyroxene.

Monoclinic pyroxene is an important constituent of these rocks, above all as groundmass mineral. It is also common as phenocrysts, particularly in the more acid types. It enters into eight different combinations of phenocrysts.

In Fig. 56 an attempt has been made to visualize the composition of the clinopyroxene on the basis of the determinations of axial angle and

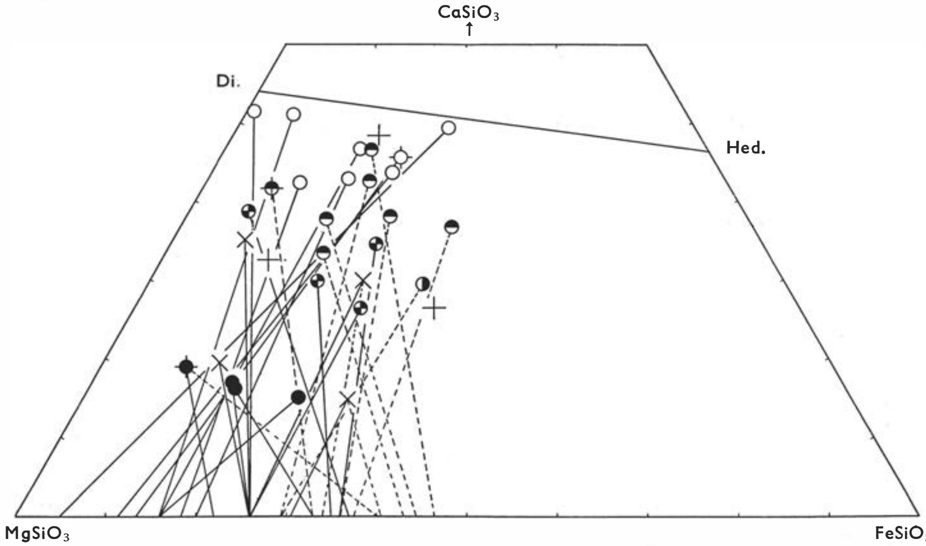


Fig. 56. Diagram showing the chemical composition of clinopyroxenes as well as of olivines and orthopyroxenes associated with the clinopyroxene.

- Lavas with phenocrysts of diopside and olivine.
- Dito of plagioclase, olivine and diopside.
- » » plagioclase, olivine, clinopyroxene and magnetite.
- » » plagioclase, olivine, orthopyroxene and pigeonite.
- » » plagioclase, olivine and pigeonite.
- » » plagioclase, ortho- and clinopyroxene.
- » » plagioclase, orthopyroxene, clinopyroxene and magnetite.
- » » plagioclase, orthopyroxene, clinopyroxene, magnetite and apatite.
- Dikes.
- Non-porphyritic lavas.

extinction on (010), making use of the diagram compiled by TOMITA (1934, p. 46) for pyroxenes of the system clinoenstatite-clinohypersthene-diopside-hedenbergite, to which the pyroxenes of these rocks predominantly belong. Even if this diagram cannot be expected to give an exact expression for the chemical composition, it will, however, give in the main a correct idea of the chemical variation of the mineral in question. In the diagram different signs have been used for pyroxenes of different phenocryst parageneses. As will appear these different dots do not lie irregularly dispersed, but each group of dots occupies in the main small, though somewhat overlapping areas. This fact shows that the composition of the pyroxenes is a function of the phenocryst paragenesis, into which they enter.

Further the composition of the olivine and hypersthene phenocrysts, which appear together with the clinopyroxene phenocrysts has been traced in the diagram. These compositions are plotted on the side $MgSiO_3$—$FeSiO_3$ of the triangle (as to the olivine the terminal points are Mg_2SiO_4 and Fe_2SiO_4), and dots belonging together (clinopyroxene-olivine and clinopyroxene-hypersthene) are joined by lines (full-drawn for the olivine, dash lines for the hypersthene). From the diagram it appears that the hypersthene is not only higher in iron than the olivine, as stated before, but also that, broadly speaking, the hypersthenes predominantly occur together with clinopyroxenes of compositions higher in iron and intermediate percentage of lime, whereas the pyroxenes appearing with olivine have a somewhat lower average percentage of iron but highly varying percentage of lime. Further it may be noted that the diopsidic pyroxenes high in lime are predominantly associated with olivines high in magnesia, the pigeonitic pyroxenes low in lime with olivines high in iron.

Also other physical characters and the habitus of the monoclinic pyroxene to a certain extent prove to be dependent on its composition and paragenesis. From this point of view we may divide the clinopyroxene phenocrysts into three main groups: 1) Pyroxenes in olivine-bearing basalts, high in lime, partly diopsidic; 2) Pyroxenes in olivine-free andesites, relatively high in lime; 3) Pigeonites in olivine-bearing (andesitic) basalts, low in lime.

The first group of pyroxenes appears in isometric, rarely idiomorphic, generally rounded crystals of pale greenish colour without pleochroism. Twinning is either lacking or of a simple type. The crystals are generally small, under 1 mm, and exceed only exceptionally 1 % of the volume of the rock.

The pyroxene phenocrysts of the andesitic lavas, on an average higher in iron and lower in lime than those of the first group, are mostly larger and more abundant, forming almost 5 % of the volume of the lava. The crystals show here a more pronounced tendency to idiomorphism and sometimes a distinct prismatic elongation, though not so pronounced as that of the orthopyroxene. As to colour, pleochroism and twinning the same is applicable as was stated for the preceding group.

The pigeonites, or clinopyroxenes low in lime with an axial angle less than 40°, form a group with characteristic properties. The phenocrysts are certainly corroded, but have a distinct tendency to elongated, prismatic form. The maximum size generally somewhat exeeds 1 mm, and the mineral forms between $^3/_4$ and $1\,^1/_2$ per cent by volume of the rock. The pigeonite is almost colourless with a faint pleochroism suggestive of that in the hypersthene. The abundant, often polysynthetic twinning is also characteristic.

The clinopyroxenes have escaped secondary alteration even more than the hypersthene. Apart from the hydrothermally affected lavas an alteration of any importance has only been noticed in one case, *viz.* a partial opacitization in a lava, the olivine phenocrysts of which have been almost entirely altered in this manner. In the altered rocks from the summit parts of Tronador on the other hand the alteration is complete. Concerning the products formed reference may be made to those under orthopyroxene. The pseudomorphs after the two kinds of pyroxenes differ in general only with regard to their form. Only exceptionally a mineralogical difference may be noticed. Thus in the rock, where the hypersthene pseudomorphs are composed of chlorite with a partial peripheric zone of hornblende, the pseudomorphs after clinopyroxene consist exclusively of amphibole fibres, pleochroic in yellowish and bluish green and with the twinning of the pyroxene palimpsest-like appearing.

5. **Hornblende.**

Primary hornblende plays a rather subordinate rôle in the series of rocks in question. It appears as phenocrysts in lavas of andesitic to dacitic character of two types with regard to associated phenocryst minerals. It is always the only mafic silicate phenocryst mineral.

On account of far-reaching alteration a closer investigation of the optical characters of the hornblende has not been possible. From pleochroism and extinction, however, it is possible that we are dealing here with a basaltic hornblende. The crystals have been prismatically rather elongated. Their length is generally below 1 mm, and the volumetric share of the rocks does not reach 1 %.

In all hornblende-bearing lavas, also those which in other respects do not show any mineralogical changes, an extensive alteration has affected the hornblende phenocrysts. Into the opaque, ore-impregnated mass thus formed pyroxene also enters. These opacitic pseudomorphs highly agree with resorbed hornblende phenocrysts, recently described by LARSEN and IRVING (1937, p. 889) from andesites and latites of the San Juan area in Colorado. These authors conclude that most of the alteration has taken place after the eruption of the lavas, as lavas high in glass show an almost imperceptible resorption of the hornblende. In accordance with this opinion is the fact that in our lavas with their rather well crystallized groundmasses and therefore probably rather slow cooling the opacitization of the hornblende phenocrysts has often taken place completely.

In addition to pseudomorphs of the type just mentioned in the hydrothermally altered rocks in Tronador others consisting of chlorite and a sulphide mineral together with a little quartz have been identified as derived from hornblende.

6. **Apatite.**

The apatite has a characteristic manner of occurrence in these rocks. As groundmass mineral it has only seldom been positively identified. As phenocrysts, however, it appears in two types of rocks, *viz.* in pyroxene andesite together with phenocrysts of plagioclase, ortho- and clinopyroxene as well as magnetite and in hornblende dacite with plagioclase, hornblende and magnetite as associated phenocrysts. Phenocrysts of apatite have, on the other hand, never been met with in olivine-bearing, basaltic lavas.

As to the crystallographical and optical characters of the apatite reference should be made to the petrographical descriptions above. It may be added here that the crystals generally have a length less than 1 mm and that they only form even at their maximum development a few tenths per cent of the volume of the rock.

In correspondence with its great chemical resistance the apatite apparently has not been affected even by the strong hydrothermal alteration processes in Tronador. Only the fibrous inclusions, probably consisting of hematite or manganite (*cf.* GROVES and MOURANT 1929, p. 99), have been changed.

7. **Ore.**

In only a few of the rocks of the Tronador series is ore lacking. The groundmasses of the porphyritic lavas always contain ore grains in varying quantities. But the ore, more specifically the magnetite, is rather common also as phenocrysts. It enters into no less than seven combinations of phenocryst minerals. The magnetite phenocrysts are particularly characteristic of the more acid types of rocks. Thus of the nine olivine-bearing types of lavas only two bear magnetite phenocrysts, whereas of the lavas free from olivine, in all six types, only one type, represented by one specimen, is lacking such phenocrysts. It is significant in this respect that in the exclusively basaltic lavas in the Viento area not a single magnetite phenocryst has been observed.

The magnetite phenocrysts are by no means always sharply idiomorphic. Generally, however, the tendency towards octahedral outlines is distinct. Sometimes several octahedrons are grown together. As to magnitude and frequency a certain connection with the type of the rock may be established. Thus the hornblende and labradorite andesites have the smallest magnetite phenocrysts (in maximum 0.07—0.2 mm), the basalts the largest ones (0.2—1 mm), whereas the pyroxene andesites hold an intermediate position (0.125—0.5 mm). Volumetrically however the magnetite phenocrysts play the most important rôle in the last-mentioned rocks (up to 2.5 %). The hornblende and labradorite andesites have 0.6—0.8 % and the basalts at most 0.5 % by volume of magnetite phenocrysts. This means that the number of such phenocrysts in the same volume is greatest in the pyroxene andesites, smallest in the basalts.

Both the magnetite and the apatite have firmly resisted strong hydrothermal alterations of the rocks. Only in one case an alteration into leucoxene could be established, indicating a not inconsiderable percentage of TiO_2 in the magnetite.

8. Spinel.

Quantitatively of no importance but of great theoretical interest is the appearance of spinel in an olivine-basaltic lava. BOWEN has (1928, p. 277) theoretically explained the formation of spinel in basic rocks by sinking of crystals of olivine and basic plagioclase down into uncooled parts of the magma and the reaction between crystals and liquid. The occurrence of spinel in a lava with phenocrysts of olivine, rather high in forsterite, and anorthitic plagioclase (with diopside) is in harmony with such an interpretation. Its character of instable relic, enclosed in magnetite, which possibly represents an opacitic reaction product between spinel and liquid, formed during the later stages of the consolidation of the rock, does not contradict BOWEN's theory either.

B. Deuteric and secondary minerals.

The limit between primary magmatic and deuteric minerals is naturally rather vague. Thus for instance serpentine (and to some extent also calcite) sometimes appears in such a manner in the groundmasses of the lavas that a direct crystallization from the magmatic liquid is extremely probable. Also several of the mineralogical changes, which have occurred in early crystallized minerals, may be referred to late though not particularly late stages in the crystallization of the rock.

The alteration of the main rock minerals has been dealt with in the preceding general survey of these minerals, for which reason a mere enumeration of late- and postmagmatically formed minerals is here given. It is thus appropriate to make a distinction between rocks apparently not struck by stronger hydrothermal alterations and those which in the earlier crater region of Tronador have been more or less intensely changed by such processes.

In rocks of the first group the following minerals have been recorded as alteration products of phenocrysts: bastite, calcite, ferrite, iddingsite, opacite, sericite and serpentine. In the groundmasses of these rocks the following minerals have been met with, some at least being of a secondary nature: calcite, chlorite, epidote, limonite and serpentine. In most cases the vesicles are unmineralized. In the unaltered lavas and pyroclastics of the Tronador area the following minerals have, however, been observed as more or less complete filling of vesicles, partly also as fissure fillings: calcite, chlorite, epidote, limonite, opaque minerals, opal, serpentine and zeolite (two species).

In the altered rocks from the higher parts of Tronador the following minerals of a secondary nature have been recorded: agate, alunite, amphibole, aragonite, calcite, chalcedony, chlorite, epidote, goethite, gypsum, kaolin, leucoxene, opacite, opal, pyrite, quartz, sericite, serpentine, sulphur, tridymite and zeolite. Chalcedony, opaque minerals, opal, quartz and tridymite have also been noted in these rocks as filling of vesicles. Apart from a few minerals, which obviously require higher temperatures for their formation, all these are minerals, which frequently appear as alteration products and deposits in connection with fumaroles and hot springs (*cf. e. g.* ANDERSON 1935). The quantitative predominance of opal as an alteration product is evidence of a high concentration of sulphuric acid in the volcanic gases and steams. A temporarily low acid concentration is however indicated by such minerals as alunite and kaolin. The appearance of gypsum is easily accounted for in a milieu so high in lime as that represented by the Tronador volcanics.

C. Accidental minerals.

In the lavas of the Tronador series minerals of accidental, extraneous origin have only been recorded in one case. It deals with fragments of plagioclase, potash feldspar and quartz in a hornblende andesite. In the pyroclastic rocks non-volcanic material is often met with. The following minerals of this nature have been found as fragments in the pyroclastics of the area: quartz, plagioclase, potash feldspar, sericitized and saussuritized feldspar, green hornblende, biotite, chlorite and muscovite. Among the rock fragments granite, albite granite, granodiorite, plagioclase granite aplite, graphic granite, amphibolite, epidote amphibolite, sandstone, quartzite, biotite phyllite, chlorite sericite schist and quartz sericite chlorite schist have been identified. A certain regional difference may be traced, as in the pyroclastics of the Tronador area granitic and granodioritic material predominates among the extraneous fragments, whereas in the Viento area sedimentary material plays a more important rôle. The petrographical character of the older subjacent rocks in the northern area is also more varied than in the southern one, where granitic and granodioritic rocks prevail. The nature of the accidental component of the pyroclastics of the Tronador series thus varies as a whole in conformity to the petrographical composition of the substratum of the formation.

VII. Petrochemical discussion.

A complete investigation of the chemical variations and genetic relations of the rocks of the Tronador series would require not only a considerably greater number of chemical analyses than those now at my disposal but also an increased knowledge of the field-geological interrelations of the different types of rocks. It would thus have been desirable that representatives for all the fifteen different types of porphyritic lavas recorded above should have been chemically analysed. Among the eight analyses only six of these types are represented. In spite of this these analyses seem to give the most important features of the chemistry of the Tronador rocks, especially in connection with the numerous optical mineral determinations also on types not analysed.

A. On the relation between the mineralogical and chemical composition of the rocks.

In the interest of comparative study the eight chemical analyses have been brought together in Table XL. The normative compositions of the feldspar (or : ab : an) and the femic silicates, mainly pyroxene (wo : en : fs), calculated from the analyses, are also included, each referred to a total of 100. In the triangle diagrams Fig. 57 and 58 these normative compositions have been plotted, each analysis with its due number. The white sector of the circles in Fig. 57 indicates the normative percentage of salic minerals, the black one in Fig. 58 that of femic minerals. Further in the diagram Fig. 57 the modal composition of the plagioclase (mainly phenocrysts) is shown on the An : Ab side by the terminal point of the line starting from the normative feldspar composition. In Fig. 58 the optical determinations of mafic minerals are entered with small circles (black — olivine, white — pyroxene). The circles referring to the same rock are also here joined by lines with the dot indicating its normative pyroxene composition.

In the following discussion it is first presumed that no essential change in the total composition of the rock has taken place from the moment of the incipient crystallization of the melt. Crystal sorting and assimilation are thus supposed not to have been active to any extent worth mentioning during the final consolidation of the rocks.

Table XL.

Chemical analyses of Tronador rocks.

	I	II	III	IV	V	VI	VII	VIII
SiO_2	49.86	53.21	62.11	65.56	56.52	50.28	52.06	52.05
TiO_2	1.20	1.61	0.92	0.52	1.16	0.78	1.06	0.90
Al_2O_3	18.14	16.66	15.66	16.63	17.27	18.08	17.60	15.55
Fe_2O_3	2.71	1.16	1.99	1.30	3.35	8.29	1.86	2.16
FeO	6.93	8.93	3.31	2.50	5.06	0.98	7.00	7.00
MnO	0.16	0.21	0.06	0.15	0.23	0.14	0.13	0.17
MgO	6.12	4.44	1.70	0.95	2.30	6.92	6.40	8.89
CaO	9.61	8.28	4.57	2.88	6.34	10.20	10.23	9.50
Na_2O	2.87	2.81	3.78	5.49	4.57	3.01	2.80	2.58
K_2O	1.23	1.75	3.22	2.35	1.45	0.85	0.90	0.87
H_2O+	0.56	0.22	2.06	0.84	0.10	0.34	0,03	0.10
P_2O_5	0.54	0.53	0.81	0.70	1.50	0.30	0.17	0.45
Total	99.93	99.81	100.19	99.87	99.85	100.17	100.24	100.22
or	11.31	16.75	28.30	19.84	12.44	7.85	8.64	9.27
ab	37.60	38.44	47.55	66.24	56.14	39.93	38.33	39.50
an	51.09	44.80	24.15	13.93	31.42	52.22	53.03	51.23
wo	16.61	14.69	6.19	—	—	20.65	21.45	17.16
en	52.62	38.96	54.71	44.63	53.21	55.58	48.64	57.17
fs	30.77	46.36	39.10	55.37	46.79	23.78	29.91	25.67

I. Olivine basalt, El Salto (p. 260).
II. Andesitic olivine basalt with pigeonite phenocrysts, Ventisquero Grande (p. 271).
III. Quartz-latitic pyroxene andesite, Ventisquero Grande (p. 278).
IV. Rhyodacitic hornblende dacite, Ventisquero Grande (p. 285).
V. Labradorite andesite, the Victoria valley (p. 287).
VI. Oxidized olivine basalt, Calderón de Lavas (p. 325).
VII. Doleritic olivine basalt, Arroyo de las Cuevas (p. 338).
VIII. Intrusive olivine basalt, Peña de Columnas (p. 340).

First we may draw attention to some facts which apply to all analyses. The normative feldspar compositions all lie on the plagioclase side of the two-feldspar boundary (inserted in Fig. 57) as deduced by R. DOGGETT (1929, p. 715). Plagioclase therefore in all the rocks ought to be the first crystallized feldspar mineral. As a matter of fact individualized potash feldspar has not been identified. From Fig. 57 it appears in a perspicuous manner the greater anorthite percentage of the first crystallized plagioclase as well as a distinct relation between the composition of the phenocrysts

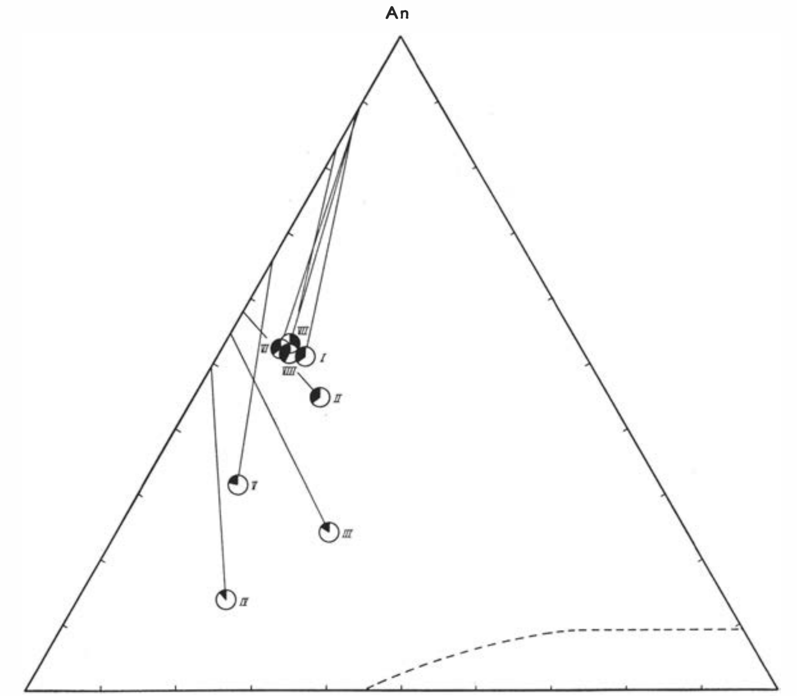


Fig. 57. Triangle diagram of the normative feldspar compositions of the Tronador rocks. For details see text.

and the normative feldspar composition. A rather regular decrease in the anorthite percentage of the normative feldspar with increasing percentage of salic minerals also appears distinctly. As to the femic minerals a decrease of femic lime with decreasing percentage of normative femic minerals may be established. At the same time the iron percentage of the normative silicate minerals increases. As to the composition of the mafic phenocrysts in relation to the normative one it appears from Fig. 58 that the former throughout have a lower iron percentage.

We now proceed to examine the different analyses more closely. These may be subdivided naturally into two groups, one comprising the analyses I and VI—VIII, the other the analyses II—V. The first group is characterized by a closely agreeing normative feldspar composition and by normative pyroxene compositions lying on the clinopyroxene side of the two-pyroxene boundary according to TSUBOI (1932).

The rock No. I, the only one analysed with normative olivine, ought to show early separation of plagioclase according to calculation by the method devised by BARTH (1936, p. 334; $f(\text{norm}) = ab' + 2\,di' + 2.3\,hy' = 99$). This rock in reality contains almost 49 % plagioclase phenocrysts with 88 % An in the centre, in the periphery 67 % An, and 5 % olivine with 16 % Fe_2SiO_4, partly serpentinized. As the normative olivine percentage is only

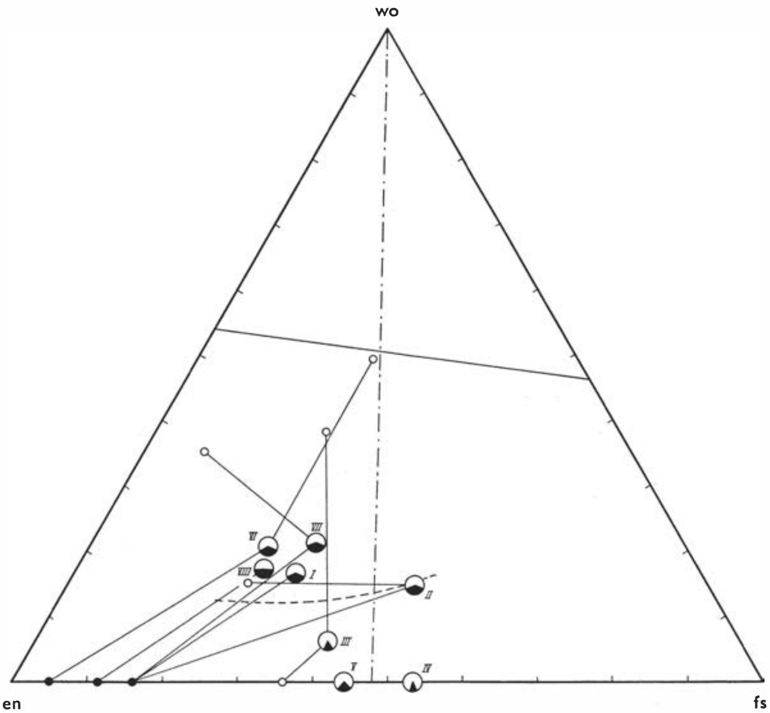


Fig. 58. Triangle diagram of the normative composition of femic silicate minerals of the Tronador rocks. For details see text.

1 %, $^4/_5$ of this olivine should be transformed to pyroxene on complete crystallization during equilibrium conditions. Pyroxene has not crystallized in the intratelluric stage. The groundmass pyroxene seems to be only of one type, namely monoclinic and probably pigeonitic.

The rock No. VI shows normative quartz, but in spite of this it contains approximately the same percentage of olivine phenocrysts as the former. The total quantity of phenocrysts here is, however, essentially smaller (13 volume per cent). With this the fact is partly connected that the olivine is richer in magnesia (5 % Fe_2SiO_4) and the plagioclase phenocrysts somewhat higher in anorthite than in the preceding rock. In addition the normative composition indicates a plagioclase somewhat higher in anorthite and femic minerals lower in iron in spite of the fact that the hematite of the norm, represented in the rock by the secondary opacite in the olivine, has been included in the normative pyroxene. F(norm) according to BARTH ($= ab' + 2\ di' + 2.3\ hy'$) is here computed to 103. The rock thus lies on the plagioclase side of the two-phase boundary surface plagioclase-pyroxene, but closer to this surface than the preceding rock. In agreement with this is the fact that to the same quantity of mafic phenocrysts an essentially smaller quantity of plagioclase phenocrysts is correlative. The appearance in this rock of pyroxene phenocrysts is connected with the greater acidity. In harmony with the position of the normative composition in the two-pyroxene field on the clinopyroxene side of the two-pyroxene boundary this first crystallized pyroxene is diopsidic, though rather high in iron. The nature of the groundmass pyroxene could not be determined, but may be pigeonitic.

The rock No. VII has been definitely referred to the group of indistinctly porphyritic lavas, as a sharp subdivision into phenocrysts and groundmass cannot be made microscopically on account of the relatively great coarseness of the latter. It is, however, probable that the larger plagioclase and olivine crystals were separated early, in the intratelluric stage. In spite of the relatively slow cooling in the effusive stage, of which the coarse texture of the groundmass bears evidence, only a very incomplete equilibrium was effected between these crystals and the liquid. This is shown by the great anorthite percentage of these plagioclases compared with the normative feldspar composition of the rock and by the appearance of 2.5 % olivine at a, certainly small, normative quartz percentage and only 5—6 % glass. Plagioclase should have been the first mineral to crystallize also in this rock, as f (norm) in the sense of BARTH is 106. The pyroxene, which began to separate only in the effusive stage, shows a tendency to a pigeonitic character, but is relatively high in lime in conformity with the normative composition.

A magma of the chemical composition of analysis VIII ought to show plagioclase as first crystallized silicate mineral or rather a simultaneous precipitation of both plagioclase and ferromagnesian minerals, as f (norm) is 120 or very close to the value 123, which is characteristic of the two-phase boundary surface. The modal mineral composition seems, however, to show another course of crystallization. Of 7.8 % phenocrysts 7.2 % consist of olivine with 11.5 % Fe_2SiO_4 and only 0.6 % of plagioclase with 83 % An. In spite of this great percentage of olivine high in magnesia the normative magnesia percentage is only slightly greater than in the rocks mentioned before, and the rock is oversaturated ($Q = 0.52$). The percentage of normative femic minerals in this case is the greatest of the eight analyses, whereas the normative feldspar composition is almost the same as in the preceding rocks. All these facts together seem to support the conception that at least part of the olivine phenocrysts have not crystallized in the milieu, where they are now to be found (see next chapter).

The analysis No. II is somewhat more acid than the group dealt with above. The normative feldspar composition shows a smaller An and a greater Or percentage. Corresponding to this the plagioclase phenocrysts contain only 58 % An. If BARTH's method of calculation is also applicable to these more acid rocks, ferromagnesian minerals should be the first to crystallize, as f(norm) = 157. The phenocrysts of plagioclase form almost

25 % of the volume of the rock. Olivine has been present to the extent of 2 3/4 % in volume, but is now transformed for the most part into serpentine. Of further interest is the appearance of 3/4 % phenocrysts of uniaxial pigeonite.

In connection with the description (1936 a) of some pyroxene andesites with pigeonite phenocrysts from the Hakone volcano, Japan, H. KUNO has recently statistically examined the conditions for the appearance of intratelluric pigeonites. He arrived at the conclusion (1936 b, p. 148) that the chemical composition of the crystallized pyroxene (and the magma) is decisive for the character of the porphyritic pyroxene. If the composition of the pyroxene lies to the right of the line marked with dashes and stipples in Fig. 58, *i. e.* in the »pigeonite field», only one, monoclinic, pigeonitic pyroxene will crystallize. When the pyroxenic components have compositions to the left of this line, *i. e.* in the »two-pyroxene field», two pyroxenes, hypersthene and augite, appear in conformity with the interpretation given by TSUBOI (1932). The normative pyroxene composition of our rock No. II certainly falls in the pigeonite field according to KUNO. The composition of the pyroxene present falls, however, in his two-pyroxene field. On the assumption that the chemical composition of the pigeonite is approximately correctly determined, these facts are not strictly compatible with the results of KUNO. That the appearance of pigeonite phenocrysts is, nevertheless, connected with the chemical composition of the rock will appear from the fact that all specimens with such pyroxene phenocrysts have plagioclase relatively poor in lime, and the rocks are probably also comparatively high in iron. An explanation that these pigeonite crystals were metastable formed by rapid cooling during and after the eruption of the magma is contradicted by their tendency of being restricted to a certain chemical milieu and of their distinct development as phenocrysts. Thus the conclusion must be that also in the plutonic stage under certain conditions pigeonite of a composition lying in the »two-pyroxene field» according to KUNO is able to crystallize. Probably the temperature was so high at the pyroxene crystallization and the immiscibility gap (see ASKLUND 1925, p. 85) so reduced that pigeonite of the composition determined could be formed as stable crystals (*cf.* BOWEN and SCHAIRER 1935, p. 203). The eruption with rapid crystallization of the groundmass of the rock then obviously took place before the temperature during the plutonic stage had fallen below the stability range of the pigeonite in question.

The rock No. III has the greatest potash percentage of the analyzed types. The plagioclase phenocrysts are, however, still of labradorite composition. F (norm) is in this rock 88.5. If this manner of calculation is applicable to such an acid rock, plagioclase should here begin to crystallize before pyroxene. Probably this was also the case, as 9.3 %

plagioclase phenocrysts correspond to only 1.7 % pyroxene phenocrysts. Olivine obviously never crystallized (Q = 16.62). Whereas the normative pyroxene composition of the preceding rock falls on the two-pyroxene boundary of TSUBOI, the rock now in question has a composition corresponding to a position on the orthopyroxene side of the boundary mentioned. The nature and relative quantity of the pyroxene phenocrysts (1.1 % hypersthene and 0.6 % diopsidic augite) indicate that the pyroxene crystallization was initiated by the hypersthene and that at the moment of the eruption of the lava both pyroxenes were separating simultaneously, a course of crystallization agreeing with that sketched by TSUBOI (1932) for Japanese rocks of corresponding composition. In this rock phenocrysts of magnetite also appear, which phenocrysts are lacking in the more basic rocks dealt with above. The oxidation degree of the iron of the rocks is obviously the dominant factor favouring the appearance of this kind of phenocrysts, which is shown by the magnitude of the NIGGLI value *o*. In those lavas lacking magnetite phenocrysts (the secondarily oxidized lava No. VI not included) this value varies between 0.06 and 0.12, in lavas bearing such phenocrysts between 0.21 and 0.24. The magnetite phenocrysts probably began to crystallize before the plagioclase (and pyroxene) phenocrysts.

The labradorite andesite (Analysis V) has a greater normative anorthite percentage and also plagioclase phenocrysts higher in lime than the preceding rock. F (norm) gives almost the same value, 88, but in spite of the somewhat greater quantity of plagioclase phenocrysts as compared with this rock no pyroxene minerals have here crystallized as phenocrysts, only magnetite. The normative pyroxene is non-calcareous. The groundmass pyroxene consists of two kinds, one orthorhombic and one monoclinic. As is to be expected from the normative composition the former is by far predominant. The monoclinic pyroxene only occurs in few and small, not closer determinable grains, but would appear to be relatively high in lime. The rather high crystallinity of the groundmass indicates slow cooling as the cause of the crystallization of a stable paragenesis of two pyroxenes instead of one metastable, clinoenstatitic — pigeonitic phase.

The hornblende dacite (Analysis IV) is, in several respects, the most extreme type of the analyzed rocks. It is the most acid and at the same time the richest in salic minerals. Further it has the normative feldspar composition highest in alkalies (though not highest in potash) and the normative pyroxene composition highest in iron. In conformity to the low normative anorthite percentage the plagioclase phenocrysts consist of andesine. In addition to magnetite and apatite, phenocrysts of hornblende appear in this rock. The question as to the factors determining the formation of hornblende instead of pyroxene can scarcely be settled without knowing the chemical composition of the hornblende. KENNEDY (1935) has particularly laid stress upon the fact that all igneous hornblendes have compositions lying in the immiscibility gap in the pyroxene diagram as inferred by ASKLUND (1925), but he does not seem to ascribe any controlling rôle to the water percentage of the magma. LARSEN and IRVING (1937), on the other hand, consider the abundance of mineralizers as the dominant factor determining the formation of hornblende. Probably both conditions must be fulfilled, *i. e.* firstly a MgO-FeO-CaO ratio within a certain range of variation and secondly a certain minimum concentration of volatiles. The pressure has probably no great importance. The resorption of the hornblende after the eruption of the magma is probably to be ascribed to changed equilibrium conditions caused chiefly by the partial escape of volatile constituents. The importance of water for the crystallization of hornblende appears from the comparatively great percentage of water in the rock, 0.84 %. That it is not alone sufficient is obvious from the fact that the pyroxene andesite (Analysis III) with 2.06 % shows the greatest water percentage of the analyzed rocks. Probably the MgO-FeO-CaO ratio was not such as to favour the crystallization of hornblende.

Finally, some remarks may be made on the paragenetic relations of the phenocryst minerals in those types of lavas which have not been chemically analyzed. The main factors determinative of the nature and the mutual quantitative relations of the phenocrysts are obvious: namely the chemical composition of the magma, and the stage of the crystallization at which the eruption of the lava took place. This implies that lavas of the same chemical composition may show, to a certain extent, different phenocryst parageneses. On the other hand, a qualitative conformity between the phenocryst minerals of two lavas must not simply be taken as indicating identity in chemical composition.

The lavas with phenocrysts of olivine only are for the most part definitely more basic and have a greater normative proportion of femic minerals than those characterized by the phenocryst paragenesis olivine and plagioclase. The same relation probably exists between the lavas with olivine + diopside and those with olivine + diopside + plagioclase as phenocrysts. On the other hand, it is obvious that these diopside-bearing lavas are higher in lime than the corresponding diopside-free types. The appearance of diopside phenocrysts may be taken as an indication that the normative pyroxene compositions of these rocks lie on the clinopyroxene side of the two-pyroxene boundary (see Fig. 58). The phenocryst paragenesis plagioclase + olivine + orthopyroxene means a position on the opposite side of the same boundary. An increased percentage of ferric iron at constantly relatively low percentage of silica makes possible the appearance of the phenocryst combinations plagioclase + olivine + magnetite and plagioclase + olivine + clinopyroxene + magnetite.

Of special interest in this connection is the rock characterized by the phenocrysts plagioclase, olivine, orthopyroxene and pigeonite. According to what has been stated with reference to Analysis II of a lava with pigeonite phenocrysts the pyroxene crystallization of the rock now in question might be interpreted in the following way. In the first stage of the crystallization of the pyroxene the conditions were such as making the separation of a stable pigeonite possible. Later the physical and chemical state of the magma changed in such a manner that the stability range of the pigeonite was no longer reached, and hypersthene (possibly together with a small quantity of clinopyroxene high in lime) began to crystallize. This course of crystallization in the intratelluric stage is proved by the fact that the hypersthene phenocrysts contain enclosed crystals of pigeonite (and plagioclase) and thus are crystallized relatively late. Further the pigeonite phenocrysts show the most distinct indications of corrosion. The groundmass pyroxene also seems to be pigeonitic, for which reason we have in this rock an example of the following, certainly rather exceptional, course of crystallization of the pyroxene: stable pigeonite → stable hypersthene → metastable pigeonite.

In the group of pyroxene andesites, the absence or presence of phenocrysts of magnetite and/or apatite, in the hornblende dacite group that of apatite, *i. e.* chemically the relative proportions of Fe_2O_3 and P_2O_5, have been determinative of the subdivision. As a matter of course the different types of the same group also differ with reference to other oxides. The labradorite andesites, finally, form chemically an intermediate group between the olivine-bearing rocks on the one hand and the pyroxene and hornblende andesites on the other. The absence of mafic silicate phenocrysts obviously depends on the fact that the eruption took place already at a comparatively early stage of the crystallization.

B. On the genetical relations of the rocks.

From the preceding geological and petrographical descriptions it is sufficiently obvious that the rocks of the Tronador series are in some way or other genetically connected. For reasons stated before an exhaustive analysis of this connection may hardly be effected on the basis of the material available. Some main features, however, may be elucidated in the following.

Direct field-geological observations on the age relations of the different types of rocks are very sparse. From the petrographical investigation as well as from the position and character of the localities represented in the material studied, however, a general idea of the course of development has been attained.

Of the analyzed types of rocks, which in spite of the small number have been chosen in such a way as to cover the greatest possible chemical range of variation and at the same time to give a certain idea of the

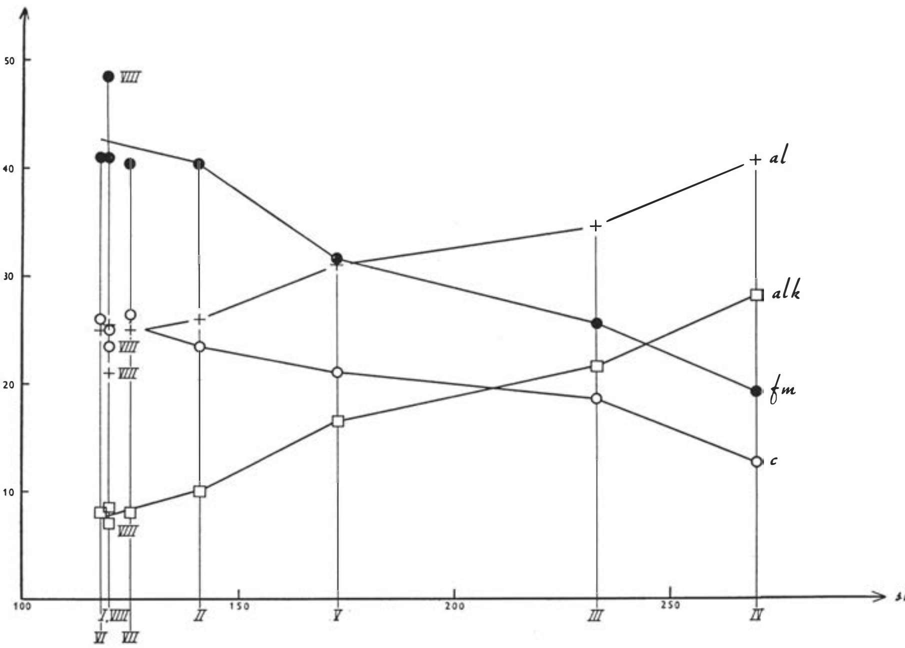


Fig. 59. NIGGLI diagram of the analyzed rocks of the Tronador series. Roman figures refer to the analyses of Table XL. The analyses I and VIII have the same *si*.

relative quantitative importance of the main groups of rocks, the basalts No. I, VI and VII certainly belong to the more basal parts of the Tronador series. The analyses No. II, III and IV represent rocks undoubtedly belonging to higher levels of the series and therefore later erupted than the former. The position of the rock No. V is doubtful in this respect. The rock No. VIII finally penetrates intrusively lavas (and pyroclastics) of basaltic character. Its relation to the intermediate and more acid lavas in Tronador is unknown. It might, however, also be younger than these rocks. Such being the case we have in the Tronador series another example within a restricted area of the old experience that a volcanic period is opened by the eruption of basic lavas and that the evolution of the volcanicity leads to the formation of progressively more acid types, the magmatic manifestations being terminated by a pronouncedly basic phase. This course of evolution for the Tronador series is to be regarded as valid only in broad outlines. The appearance of an acid, andesitic, in part rhyolitic, component also in the basal pyroclastic deposits shows that the eruption of more acid products occurred at intervals also in the first stages of the volcanic activity, though highly subordinate in relation to the bulk of the basic rocks.

For further illustration of the chemical relations of the analyzed rocks a NIGGLI diagram has been given in Fig. 59. The analyses are distributed

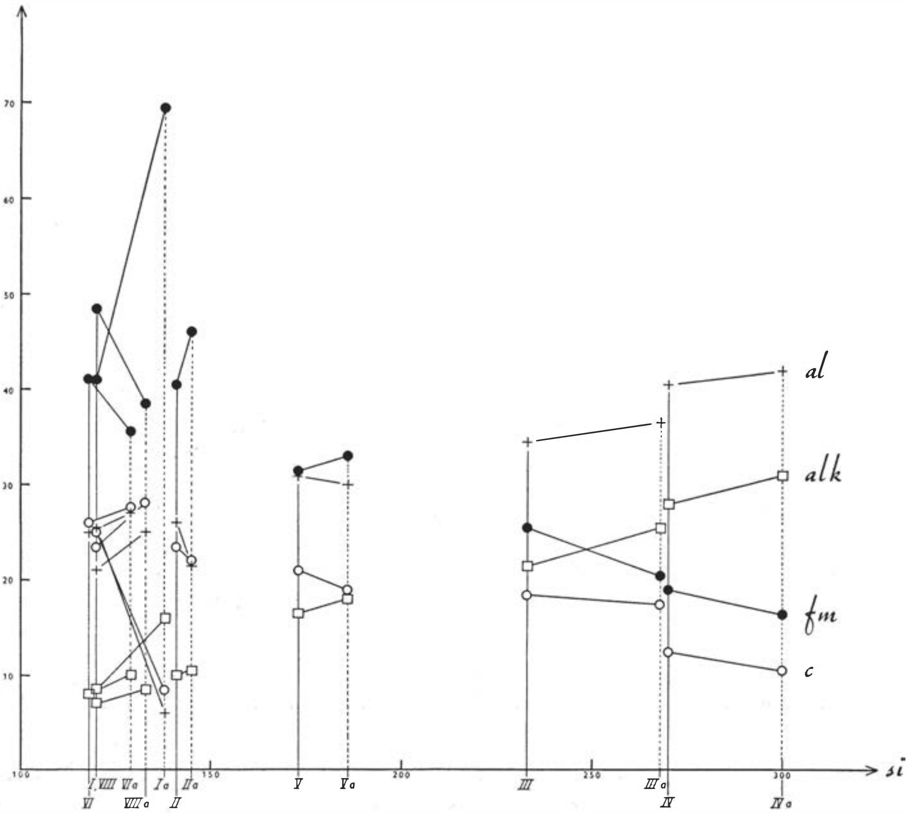


Fig. 60. Diagram showing the relations between the compositions (in NIGGLI values) of the groundmasses (Ia, IIa, *etc.*; dash lines) and the total compositions of the rocks (I, II, *etc.*).

on a *si* range between 118 and 270 with a distinct accumulation in the basic part. The curves of the different oxides and oxide groups run in an even, regular manner; with increasing *si al* and *alk* rise, *fm* and *c* fall. One analysis differs from the general course of the curves, *viz.* No. VIII. It shows greater *fm* and smaller *c, al* and *alk* than the other rocks of the same acidity. In the previous chapter some facts were emphasized relating to this rock indicating that it has been gravitatively enriched in olivine. In close harmony with such an interpretation is the fact that a subtraction of the phenocrysts (mainly olivine) from the rock brings it back to a composition (with *si* = 133; see VIII a in Fig. 60) which in the main fits into the curves. One also obtains a vivid impression in the microscope that the olivine was not in equilibrium with the liquid on account of its exceptionally intense magmatic corrosion and the inhomogeneous character of the groundmass.

It is, then, very probable that this rock has been enriched in olivine by gravitative sinking of olivine crystals (such crystal settling has been recorded even towards the basal parts of lava flows after their eruption; see *e. g.* FULLER 1939). The question then proposes itself as to the extent to which the diversification of the Tronador rocks is due to crystallization differentiation, or to other processes present. To some extent Fig. 60 throws light upon this question. In addition to the total compositions of the analyzed porphyritic lavas, the calculated compositions of their groundmasses (Ia, IIa, *etc.*) have also been entered. At this calculation the volumetric analyses, the determinations of the specific gravity of the rocks, and the density of the minerals according to v. PHILIPSBORN (1932) and WINCHELL (1933) have been employed. In the plagioclases a percentage of orthoclase substituting part of the albite according to the figures statistically deduced by ALLING (1921) was included. As representing the composition of the hornblende of the rock No. IV a brown hornblende of an andesite from the Daiton volcanoes, Formosa (ICHIMURA 1931, p. 564) was chosen.

If the different types of rocks had developed from a common parent magma by crystallization differentiation, the groundmasses — at least when the quantity of phenocrysts is relatively great — ought to show tendencies towards compositions approaching those of later members of the series of differentiation. A glance at Fig. 60 shows that only in two cases, the most acid rocks, such a relation exists between groundmass and total composition. In the other cases the groundmasses throughout show higher *si* and higher *alk* than the total composition of the rocks, the other oxide groups, however, *c*, *al* and *fm*, behave differently. In some rocks (I, II, V) *fm* rises and *al* falls, in the others (VI, VIII) *c* rises with increasing *si*. Analysis I deviates most from the »normal» course of differentiation. This is all the more remarkable as in this rock the phenocrysts play the most important rôle (more than half the volume), and further several reasons go to prove that this type of rock is to be regarded as corresponding most closely to the primary or parent magma of the Tronador series. This type of rock, with phenocrysts of plagioclase and olivine, is thus quantitatively dominant in the material studied and shows chemically a rather normal basaltic composition. Further the first erupted, basal lava flows of the series are composed of this basalt. By the high predominance of plagioclase among the phenocrysts the groundmass is much enriched in pyroxene (low in lime) and also in alkali feldspar. The same tendency, though less pronounced, also appears in the rocks No. II and V. The analysis VI shows a distinct similarity with No. VIII concerning the relation between groundmass and total composition. As in the latter case an enrichment in olivine has most probably taken place, for good reasons the same may be surmised as to the analysis VI. On account of the relatively high *c* we have here in addition to reckon with a slight enrichment in plagioclase (*cf.* the rare appearance of spinel in this type of rock).

From that stated above it appears that crystal settling, at least to some extent, may be held responsible for the diversification of the basic rocks of the series. On the other hand, the facts presented in Fig. 60 may hardly be said to argue in favour of gravitative differentiation as the controlling factor for the development of the more acid types. I should therefore be inclined to explain the appearance of these types in the following way, partly in analogy with the interpretation of HOLMES (1931) of the association of acid and basic rocks in central complexes. The basaltic magma effected at its rising in the earth's crust such a great supply of heat to the pre-existing crustal material that a partial, selective refusion ensued. As pre-existing material in this region we have to take into consideration rocks of mainly granodioritic composition. An incipient refusion of this material would probably give a liquid of anchi-eutectic quartz-feldspar composition. As an indication of this process may be regarded those sparse fragments of rhyolitic pumice, which have been found in pyroclastics on rather low levels in the series. As time passes and the heat supply increases, the composition of the newly formed, acid magma approaches that of the material from which it originates. This stage in our case may be said to be represented by the hornblende dacite, which shows a composition which does not essentially differ from that of many granodiorites. Still later, increased possibilities also arise for assimilation and for mutual contamination of the two magmas, the primary, basaltic and the secondary, acid formed by refusion of mainly granodioritic rocks. The rocks II and V might thus be interpreted as basalts more or less intermingled with acid magma and the rock III as dacite mixed with some basaltic material. The *hiatus* between the analyses V and III (Fig. 59) is probably only fortuitous. The sparse occurrence of these intermediate types, however, appears in a distinct manner *e. g.* from the plagioclase diagram Fig. 37.

With this interpretation of the genetical connection between the rock types of the Tronador series the diagram Fig. 59 cannot be characterized as a differentiation diagram, if with differentiation is meant a progressive development from a common parent magma. Crystallization differentiation seems mainly to have caused some irregularities in the basic part of the diagram.

C. Concluding remarks.

With the interpretation given above of the diversification of the rocks the conceptions of petrographic provinces and comagmatic regions do not lose their meaning. The consanguinity only does not become quite as immediate as on the assumption of a direct differentiation of all the different types of rocks from a common parent magma. As to the Tronador series the petrographical, mineralogical and chemical data given above show that upon the whole it is a rather typical representative for the Pacific region. The abundance of plagioclase, the rare occurrence of potash feldspar in particular and the absence of soda pyroxenes and amphiboles as well as the almost complete absence of micas are distinctive characters of these Pacific rocks and, more specifically, of those of the Circum-Pacific zone. The conformity of the rocks of the Tronador series to those of this zone as distinct from the Intra-Pacific lavas appears strikingly in a comparison between our Fig. 58 of the normative pyroxene compositions and BARTH's Fig. 5 (1936, p. 337).

Of the Pacific types of differentiation proposed by BURRI (1926, p. 140) the Tronador series, to the extent in which analytical material is available, shows the greatest conformity to the Sierra Nevada type (effusive rocks). Special attention is called to the almost complete identity as to the position, and the NIGGLI values, of the isofaly ($fm = al$) which is accurately fixed for the Tronador series by the analysis V being almost exactly isofalic. BURRI found that the effusive rocks of the Argentine-Chilean Andes formed a transition between his types Sierra Nevada (effusive rocks) and Yellowstone National Park. In the Tronador series, however, no tendency towards the latter type can be traced in the range of variation represented by the chemical analyses.

VIII. **Summary.**

The volcanism in Northern Patagonia, at present represented by a line of volcanoes at the western base of the Andean range, was localized during the last interglacial period to a more easterly zone in the high Cordillera, though still west of the axis of maximum heights. (Concerning the tendency to displacement of the volcanism to the west, see GROEBER 1928.) The volcanic activity at that time was obviously very intense, as evidence has been found that the pre-existing relief in great areas of this section of the Cordillera was wholly drowned under the eruptive masses. After the ceasing of the interglacial volcanism these products were removed to a large extent by fluvial and glacial erosion. In the district treated in this investigation, the Nahuel Huapí region, a greater area of these rocks is preserved with Cerro Tronador, the highest mountain of this district, as the most important volcanic centre. To the north and northeast of this area a great number of minor occurrences appear possessing the character of erosional remnants.

Pyroclastics seem to play quantitatively a comparatively important rôle, which is probably connected with the fact that the magma had begun to crystallize already in the intratelluric stage. Practically all lavas are porphyritic. A few dike rocks and a volcanic neck have been included in the investigation. Lavas and pyroclastics in the higher parts of Cerro Tronador have been greatly altered through the influence of volcanic gases and steams.

The effusive rocks in particular have been thoroughly examined. Petrographically they vary from basalts of different types with regard to the relations of the phenocrysts via pyroxene andesites to hornblende dacites. In broad outlines this series also corresponds to the order of extrusion, possibly with a last basaltic phase.

In the lavas plagioclase, olivine, orthopyroxene, clinopyroxene, hornblende, magnetite and apatite appear as phenocrysts in 15 different combinations. The complete absence of quartz, potash feldspar and biotite as phenocrysts is characteristic. The plagioclase phenocrysts have been subjected to a special statistical investigation from different points of view. Of the current determination curves preference is given to those of NIKITIN.

Chemically the rocks are typical representatives of the calc-alkali series, and correspond most closely to the Sierra Nevada type (effusive rocks) as defined by BURRI for the Circum-Pacific igneous rocks. Crystallization differentiation is held responsible for part of the diversification of the basic lavas. The acid types are considered to develop by refusion of pre-existing crustal material caused by the heat supplied by the rising basaltic magmas. The intermediate types, comparatively few in number, are interpreted as having been formed preferably by assimilation and mutual contamination of the two contrasted magmas.

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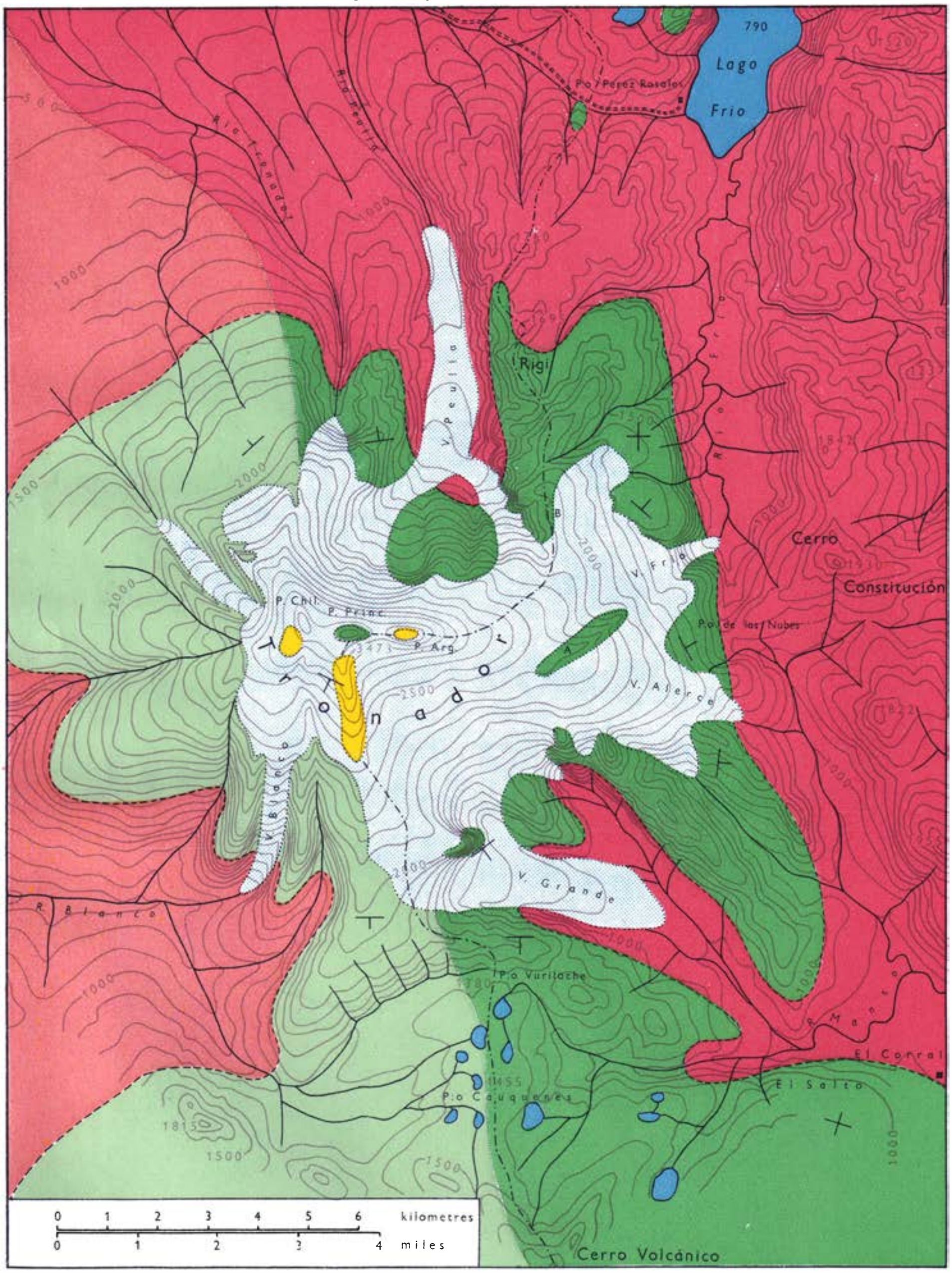
Printed 3/5 1940.

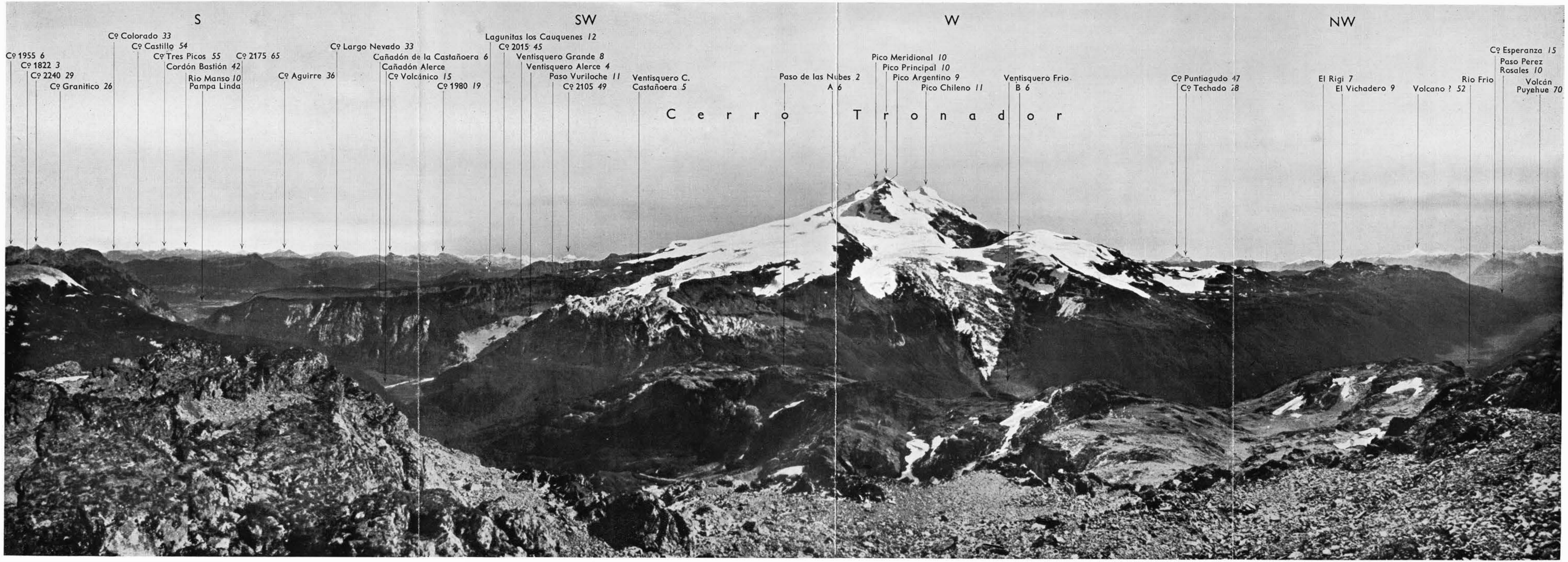
GEOLOGICAL MAP OF CERRO TRONADOR

compiled by WALTER LARSSON



Glaciers	Interglacial volcanics
Crystalline basement	» » , unexplored
» » , unexplored	» » , altered

Topography mainly according to a map compiled by F. SANJUAN (Club Andino Bariloche. Memoria. 1933, p. 20). Contour interval 100 metres. Strike and dip from stereographs of the expedition. (P. Arg. = Pico Argentino, P. Chil. = Pico Chileno, P. Princ. = Pico Principal, V. = Ventisquero, P:o = Paso, R. = Rio.) — Scale: 1 : 150 000.



Panorama from Cerro Constitución (△ Const. Stereo W, alt. 1 907 metres) showing the Argentine frontier districts towards Chile with the eastern slopes of Cerro Tronador in the centre. Numbers in italics refer to the distance in kilometres from the spectator. The arrow-heads indicate the position of the objects. Where arrow-heads are lacking the objects are hidden. Concerning the distribution of the interglacial volcanics see Fig. 5. The localizations are made by E. Ljungner with the aid of his stereophotogrammetric material. The panorama consists of ten photogrammetric pictures combined and retouched by the »Kartografiska Institutet», Stockholm.

Photo Ljungner's expedition (O. Ring). 16.4.1934.

A.B. Kartografiska Institutet
Esselte ab. Stockholm 1940