Geological observations in the Patagonian Cordillera

Geological Observations in the Patagonian Cordillera.

(Preliminary Report).

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With 7 plates (I—VII) and 14 text figures.

Contents.

Introduction.

The following preliminary sketch is based on observations made on the Swiss expedition, led by the writer, from November 1939 till February 1940[1]).

The main object was to study the structure and the glaciation of the high Cordillera in the geologically unknown region of Lago Buenos Aires (lat. 46—47° S) and the vicinity of Cerro San Valentin 4058 m, the highest mountain of Pata-

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[1]) Arn. Heim: Die schweizerische Patagonien-Expedition 1939/40. Die Alpen, XVI, p. 281—289, ill., 1940.

gonia. The original idea was confirmed, viz. that this huge lake would present an outstanding possibility to study a transverse section. Indeed, it penetrates 130 kilometers from the Pampa into the glaciated high Cordillera.

First, a traverse was made along the 45th parallel from Aysen Fjord via Coyhaique to the Argentine Pampa.

Then followed the study of Lago Buenos Aires between 46 and 47° of latitude south, and its glaciated vicinity.

The first difficulty was to secure a suitable boat. There are two boats on the Chilean part of the lake making irregular connections with the few inhabitants (sheep breeders), namely the motor boat " Estrella " and the miniature steamer " Andes. " For a few days the writer had the chance to hire an outboard motor with a rowing boat, with which he could follow part of the northern shore. In several places, however, landing was impossible on account of wind and waves, which make travelling on this stormy lake most dangerous.

The literature concerning the itineraries mentioned above is extremely poor. The following papers were consulted:

(1) P. D. QUENSEL: Geologisch-petrographische Studien in der patagonischen Cordillera. Bull. Geol. Inst. Univ. of Upsala, XI, 1910.

In this dissertation, the igneous rocks of different localities from Cape Horn to Puerto Montt are described. An instructive map in colours, 1 : 3000000 presents a general view on the geology of the Patagonian Andes. The accompanying schematic section from Rio Aysen to the Pampa, however, gives an incorrect idea of the interesting and complicated region east of the great granite batholite.

(2) CARL C: ZON CALDENIUS: Las glaciaciones cuaternarias en Patagonia y Tierra del Fuego. Fr. Stockholms Högskola Geokronol. Inst., Geogr. Annaler, H. 1—2, 1932.

In this work of outstanding importance, the eastern surroundings of Lago Buenos Aires are described and mapped in the scale of 1 : 500000. In applying to the study of varves, which were found on the former bed of Rio Fénix, CALDENIUS came to the conclusion that the inner circle of moraines is chronologically equivalent to the finiglacial (late Würm) stage of northern Europe.

After his return to Switzerland, the writer thought to work out a geological monograph, together with a fellow-worker in petrology. But this proved to be impossible in this time of war. The collection of rock-samples and fossils was presented to the Geological Institute of the Federal High School of Technology, at Zurich. It is hoped that it will be worked out there later on.

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Section Aysen-Coyhaique. [2])

45° lat. S.

The writer had, unfortunately, not sufficient time at his disposal to study a detailed cross section from Aysen Fjord eastward along Rio Aisen–Simpson to Coyhaique and the Argentine Pampa. The following observations were made in a hurry on two motor drives.

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[2]) This town of about 4000 inhabitants is not marked on former maps. The development began about 1933. The people raise sheep, cattle and horses.

Structure.

It is known that the huge granite-batholith extends south to Cape Horn and northward, probably without interruption, to Lago Todos los Santos and beyond, therefore over 15 degrees of latitude. This granite-batholith was crossed over a width of nearly 100 km coming from the West. The massive rocks are not crushed, and are probably of the same age as the granodiorite of Santiago [3]). It is considered as post-triassic and pre-senonian. All high mountains with their local glaciers belong to the granite. The highest ones of 1800—2000 m are situated near the eastern boundary.

In the western part, dominating the Pacific side, high above the granite basement, rises Mount Macá 2980 m, a magnificent extinct volcanic cone, cuirassed with ice all round. Its eastern neighbour, Mount Cay, is the older one and shows intense erosion.

Nothing similar to these volcanoes was found on the eastern side of the granite-batholith. The granite is medium grained to coarse, usually whitish, but locally pink (km 20) from P. Aysen.

In the eastern part, between km 40 and 48, fine grained varieties and porphyry are found. Their intense decomposition and weathering has caused a general topographic debasement on the east side of the high granite peaks.

After the bridge, at about km 48 from Puerto Aysen, the road is blasted out of a massive wall formed of greenstone with red porphyrite and tuffaceous layers. The steep northwestern dip passes to a vertical position, then to SSE dip.

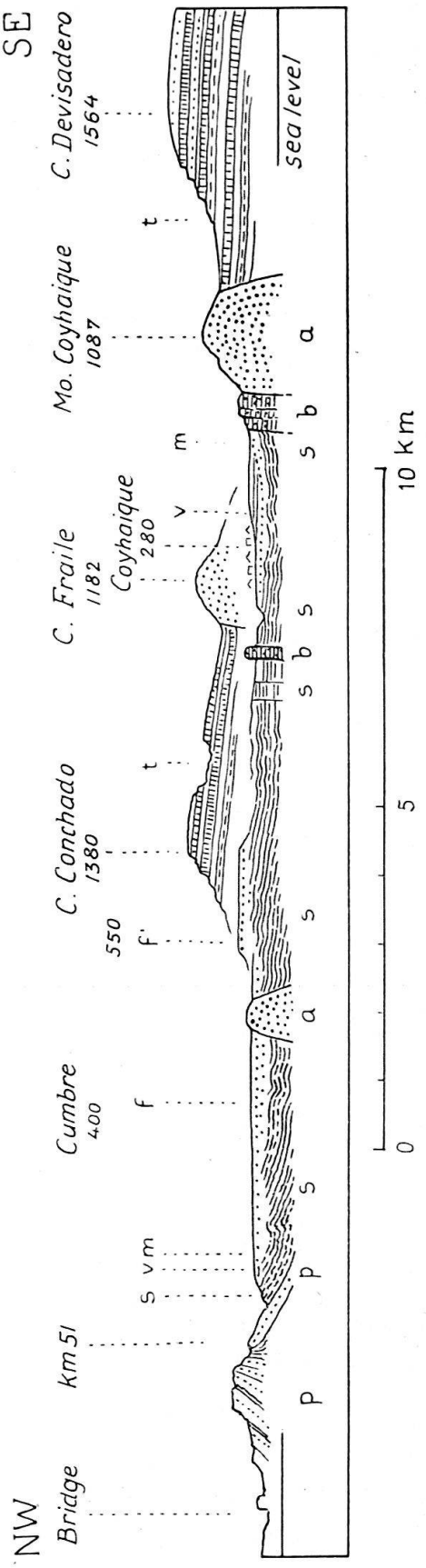

Fig. 1. *Section of Coyhaique.*

p = porphyrite with tuff, green and red; s = black clay shale; t = Devisadero formation, tuffs and lavas; a = acid intrusions of the "Morros"; b = basalt; m = ground moraine; v = varves; ff = fluvioglacial gravels, locally covered with loess.

[3]) J. Brüggen: Grundzüge der Geologie und Lagerstättenkunde Chiles. Herausgeg. v. d. Heidelberger Ak. d. Wiss., Tübingen 1934.

On the anticlinal axis, the porphyrite with red tuffaceous layers is squeezed and crumbled. The facies is similar to that of Santiago. The gray toplayer of 100—150 m dips regularly 25—30° to SSE and disappears in the gorge of Rio Simpson (figs. 1 and 2).

The region from here to Coyhaique (km 56) is the most interesting one. The porphyrite, of probably jurassic age, is normally overlain by clay shale of great thickness and extension. The bluish gray basal part excepted, it is black throughout, recalling the Spiti shales of the Himalayas. In the lower black part streaks of lustrous black coal of a few mm were observed. The stratification is locally made visible by occasional concretionary layers. They are frequently undulated, but seem to dip predominantly to SE (figs. 1 and 2).

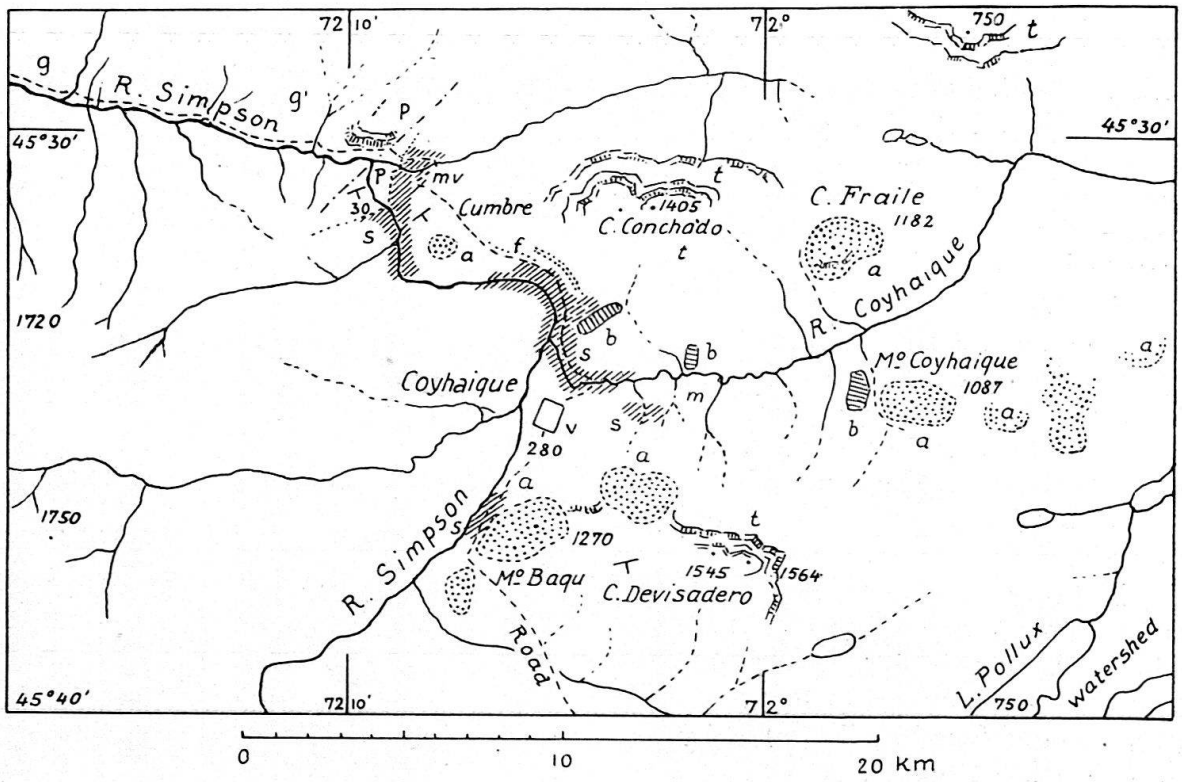

Fig. 2. *Geological sketch-map of Coyhaique.*

g = granite; g′ = porphyry; p = porphyrite with tuff; s = gray and black clay-shale; t = tuffs and lavas, Devisadero formation; a = acid intrusions of the " Morros "; b = basalt; m = ground moraine; v = varves; f = fluvioglacial gravel.

The road now passes the platform of Cumbre, at 350—400 m, which is formed of ground moraine and coarse fluvioglacial gravel, but re-enters again into the shale, which is exposed all along the gorge on the north side of Coyhaique. The last shale outcrops were found east and south-west of this town, where they are partly cut off by igneous intrusions and partly covered by stratified extrusives, which we call the Devisadero series (t). They form the flat-topped mountains called Cerro Devisadero, 1564 m, and Cerro Conchado, 1405 m. This series consists of repeated layers of yellowish tuffs and of dark lavas forming walls.

The peculiar characteristic aspect of the region of Coyhaique is due to igneous rocks, which penetrate the stratified series from below. There are two types:

(*a*) gray acid trunks or cones, some of which are called " morro " by the inhabitants.

The most prominent one is the Morro of Baquedano[4]), 1270 m. It is freely exposed, but leans with the back side on the Devisadero series, which it has pierced. The vertical jointing is seen at a distance (fig. 3). The rock is a gray, fine grained granite to porphyry with little quartz.

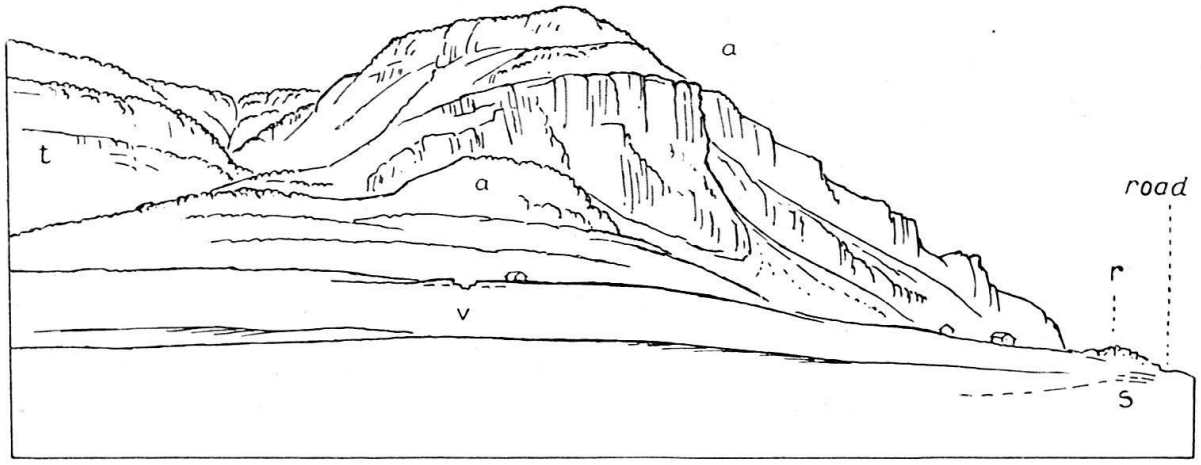

Fig. 3. *Morro Baquedano, seen from Coyhaique, towards SSW.*

a = acid intrusion; t = tuffs and lavas of C. Devisadero; s = outcrop of black clay-shale on road to Balmaceda; r = blocks of mountain slide; v = varves exposed in clay ditch.

Morro Baquedano has two brothers. The larger one is on the east side, the smaller one on the SW. The road to Balmaceda passes the gap between the southern ones.

The Morro Coyhaique, lying about 12 km east of the town Coyhaique, rises like a cone to 1087 m. On the opposite side is the still higher Cerro Fraile, 1182 m, which seems to be surrounded by the Devisadero series.

East of Morro Coyhaique follows a rough barren country with wide intrusions of granite-porphyry and less acid rocks, intersected with rhyolithic to andesitic lavas and tuffs.

(*b*) Another type of intrusives is related to basalt. The most prominent one, in the shape of a dyke-like wall, is situated on the east-side of the road, north of Coyhaique. Others, less conspicuous ones, occur farther east (fig. 1). They probably represent the roots of surface flows, which have been weathered off.

East of Morro Coyhaique, we come to an undulated rough region of the watershed between the two Oceans, which is the boundary of Chile and Argentine, at 750—800 m. Several small lakes of glacial origine are encountered in this region. Beyond km 15 of the bad road east of Coyhaique follow porphyritic and acid lavas with tuffs, partly dipping slightly eastward. They are interrupted by extended trunks (granite-porphyry at the small Lago Toro), and by moraines. Gradually, the prominent eruptive rocks disappear from the surface, and the monotonous plain of the Pampa begins. It is made of a sandy Tertiary basement with a regional cover of Pleistocene gravels. They form plateaus which increase in the height above the Mayo river in the same proportion as the latter gradually deepens its course towards east.

[4]) Former name of the town Coyhaique.

Reviewing the igneous intrusions of Coyhaique, it seems that the basaltic rocks during their activity were in connection with the surface, while the acid holocristalline trunks did not reach it. This impression is especially gained from a view on the top of Morro Baquedano towards east. The cone of the Morro southwest of Coyhaique seems to have been closed upwards before reaching the higher level of C. Devisadero. This idea is supported by the presence of the smaller trunks, like that of Cumbre, which only slightly overtops the glacial platform[5]). The trunks of Coyhaique of which we have observed seven or more, are possibly in some connection with the great granite batholith of the Cordillera, of which they may be offshoots.

Former Glaciation and Morphology.

Little is known of the former glaciation towards the Pacific, where the ice probably covered not only the inner fjords, but even the Chonos Islands, except their higher mountains, which reach 1270 m in Picos Sulliván, at 45° of latitude south.

Obviously, the ice flowed away towards west and east, parting from the high Cordillera, east of Rio Maniuales and south of Rio Simpson, where only the highest granite peaks above about 1600 m looked out of a great ice sheet, similar to the actual condition of Spitzberg.

At the confluence of Rio Maniuales and Rio Simpson, 15 km straight east of P. Aysen, a terrace of moraine passing to coarse gravel, 15—20 m high, is cut out along the road, illustrating a later phase of retreat. East of it the Simpson Valley is partly filled with the corresponding ground moraine.

Although the river runs westward, the region of Coyhaique belongs to the east-side of the former ice shed. This is proved by the numerous large granite blocks. Indeed, no such coarse granite was found in situ further east. The road-work at km 52, NW of Coyhaique, has exposed coarse ground moraine with huge granite blocks upon black shale. Above this basal moraine were found varves deposited in a glacial lake. They, in turn, are superposed by ground moraine of a later stage of glaciation, while the loess on the top may be post-glacial (fig. 4).

On the eastern side of the granite mountains the valley widens. The surface is dominated by plateaus. The higher ones are formed of the volcanic Devisadero series (Cerro Conchado 1380, and C. Devisadero 1564 m). The lower ones are those of Cumbre, 350—400 m, made of ground moraine and fluvioglacial gravel, and Coyhaique at 260—300 m[6]) of ground moraine and varves. Besides this, remnants were seen at a distance of a fluvioglacial terrace above the road north of Coyhaique at about 550 m (figs. 1 and 2).

At the confluence with the Rio Coyhaique, the Simpson River has cut its way about 60—80 m into the Pleistocene platform, down to the black shales at about 200 m above sea level.

On the south side of the town Coyhaique, forming a gentle hill, clay is excavated. A surprising series of varves is exposed, on the top of which are erratic blocks. The altitude is 280—300 m (barometric). These varves seem to be superposed upon the ground moraine of the Coyhaique platform. They prove the former existence of a vast lake, nourished by glacial streams, when the ice still existed in the vicinity.

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[5]) Also the original roof of the huge granite batholith must have been irregular.

[6]) Barometric readings.

The latest deposits of Coyhaique are small mountain slides derived from Morro Baquedano (fig. 3).

Following eastward and upstream the Coyhaique Valley, moraines with granite blocks are frequently encountered, especially so at km 30 from Coyhaique, 700 m above sea level. The flat region of the Coyhaique sheep ranch, at 35 km, shows two fluvioglacial terraces of 10 m difference, about 700 m above sea level. Upon the lower one, varves also were noticed in one place.

At 750—800 m, 50 km on the road from Coyhaique, the watershed and frontier to Argentine is made of rounded rhyolite and trachyte hills, upon which are left erratic blocks of Cordillera granite. Other hills at this altitude are formed of a terminal moraine. The eastward distance, in a straight line, from the former glacial divide, is about 60 km.

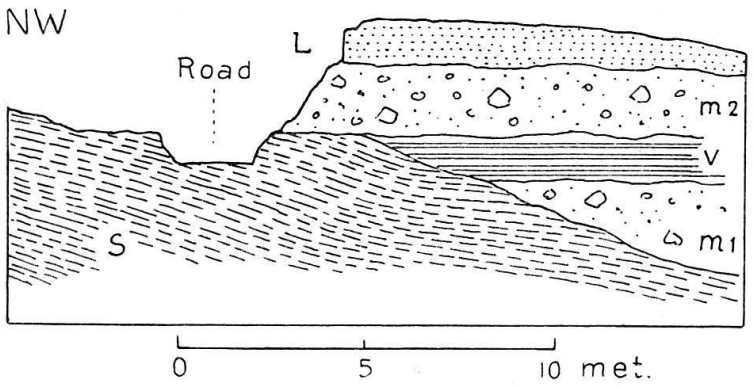

Fig. 4. *Outcrops on the new road from Puerto Aysen to Coyhaique* at about km 52 (combined).

s = black clay-shale; m1, m2 ground moraine with granite blocks; v = varves; L = loess, wind deposit.

Therefrom, the flat Pampa is dominated by fluvioglacial gravel deposits. The last erratic blocks were noticed on the Mesa, at about 650 m and 30 km east of the watershed.

Since the retreat of the ice, the rivers have changed their course to the opposite direction. The drainage of the Coyhaique glacier stream, which was eastward, turned westward. Several side streams still flow eastward until they reach the main valley, as for instance the river joining Rio Simpson east of the town of Coyhaique (fig. 2).

Such changes in the drainage excepted, the glaciation has little modified the main topography, which is older than the last glaciations. Indeed, the fjords and rivers form a complicated and irregular network, independent of the former ice-flow, and in places the crests between acted as barriers which stopped the flowage towards the Ocean. The deep seated, irregular lakes between the high peaks like L. Riesco, Portales and Caro, are probably the result of dead ice separated from the feeding glaciers, while the Cordillera has undergone a general subsidence, which caused the drowning of the main valleys and their conversion into fjords.

Section of Lago Buenos Aires.

46—47° lat. S.

Structure.

(See map, pl. I.)

1. Eastern surroundings of Lago Buenos Aires.

CALDENIUS has shown on his map that on the south side of the eastern part of Lago Buenos Aires the pre-quaternary sedimentary formations are covered by basalt. It forms the rim of an extended flat plateau, as shown on to the topographic map 1 : 500000, and rises towards west from 1250 to 1520 m on a distance of 30 km. The slopes are usually covered with glacial deposits as far as the Chilean boundary, Rio Jeinemeni. Some kms west of this river, and equally on the opposite northern shore of the lake, the landscape changes suddenly. The Pampa with its plateaus and moraine hills gives place to the Cordillera. First, on their eastern slopes, is exposed a complex variegated series of stratified rocks made of marine sediments with porphyritic lavas and tuff. The marine sediments are green, gray and purple clay-marls with sandy layers. They contain the large thick-shelled *Ostrea ingens* ZITT., a Tertiary species of the Patagonian formation, and are considered as marine warm water deposits. About 7 km south of Chile Chico the dip is 10—30° towards southeast. In other places the bedding planes are undulated.

2. Eastern part of the Cordillera, Chile Chico–Puerto Ibañez.

The sedimentary series is underlain by a large and widely distributed series of lavas which form the mountains west of Rio Jeinemeni, and of Ibañez on the north side of the lake. This relation is seen especially well at the distance looking north to Cerro Cabeza Blanca 1570 m, which is made of the green and purple sediments with interbedded lavas and tuffs.

Ten km further west, above Puerto Ibañez, is Cerro Pirámide, 1785 m. In spite of its apparent conical shape as seen from the South, it is not a volcano as was erronously stated (CALDENIUS). In place of a crater, the top is a sharp crest of S–N direction, made of dark greenish lavas and dykes. It is superposed on a basic igneous terrace at about 800 m. The basis is made of brown, more acid lavas, sculptered by ice into rounded hillocks.

A most interesting mountain of the same tectonical position, but south of the lake, 40 km south of Cerro Pirámide, was called Cerro Apidame by a native (pl. I). It seems to correspond to point 1720 of the map, 10 km SW of Chile Chico (textfig. 5 and pl. III, fig. 1).

The walls show striking columnar jointing. The mountain is a volcanic neck or trunk apparently made of two consequent andesitic intrusions. The eastern walls (c) are brown and red. The western rock, which is in sharp contact with the former, is of dark bluish weathering, and underlain by white tuff layers (t) which seems to have been erected by the intrusive action.

Around Apidame, the stratified Devisadero series of acid lavas, tuff and clay shale is traversed in all directions by dykes and sills, mostly of acid extrusive

rocks (quartz-porphyry). The top of the plateau is formed of olivine-basalt (b), which may be the prolongation of the eastern plateau basalt, or is at least an equivalent. Similar in both cases is the existence of small volcanic caps on the top of the plateau seen at a long distance (pl. I).

The surroundings of Chile Chico show some more isolated brown igneous rocks, though more in the shape of huge blocks than of volcanic necks. One of these is situated 17 km ESE of Chile Chico on the coastal plain, another one lies on the south-east side of the little town Chile Chico. It is about 100 m high, a few hundred m wide and one km long. A fourth one was observed from the boat, about 10 km north-west of Chile Chico near the coast.

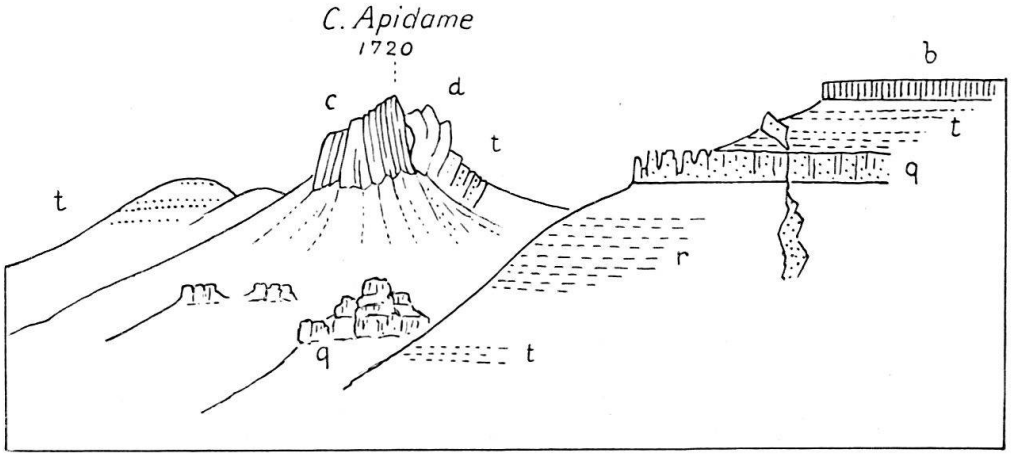

Fig. 5. *Cerro Apidame, South of Chile Chico.*

t = yellow, green and reddish tuff; q = acid intrusives, dykes and sills with quartz; c = brown and red pillars; d = dark bluish rock; b = olivine-basalt; r = red and green clay-shale.

Just behind the village, and westward from it, the mountain slopes are uniformly made of old lavas and yellowish tuffs piled upon each other, and forming high barren cliffs along the lake. We propose to call it the Ibañez series, after the name of this place on the opposite side of Lago Buenos Aires. The rocks, mainly acid, are intensely weathered. At the little harbour of Chile Chico the lowest wall is formed of white rhyolite. Numerous faults are visible towards NW and W, demonstrating vertical displacements up to about 50 m (fig. 6).

In the vicinity of Chile Chico, a striking aspect is presented by a massive basic tuff of intense blue-green colour with vesicles and angular inclusions. In places it forms rock walls of 50—100 m. The small rounded islands of verdigris colour in front of Chile Chico are formed of this tuff (pl.II, fig. 1). It is the youngest deposit of what may be called the Ibañez series of extrusives. It covers the brown acid lavas, and fills their erosive or faulted depressions. The basis of the green tuff which on the small islands is below the water, rises irregularly towards South and South-west until 500 m or more. At the little natural harbour about 2 km NW of Chile Chico, the faulted brown lava rock with its remains of green tuff dips as much as 40—45° towards NE (fig. 6).

The tuffs, being rounded by the former glacier, must be much older than the finiglacial period. Their basement, plunging towards the lake, shows plainly that the lake depression is older than the glaciation.

The green tuff, though covering the main mass of the Ibañez igneous series, is not yet the youngest rock of the region. On the road W above Chile Chico it is traversed by brown dykes of a deeply weathered rock (andesite?).

The fractured igneous series of Chile Chico is exposed again on the north side of Lago Buenos Aires around Ibañez-bay, partly in horizontal position, partly dipping up to 20° to NW. The basic lavas and dykes there are more abundant, while the green tuff was noticed only at a place S of Puerto Ibañez.

3. Middle Part of Lago Buenos Aires.

Until the solitary farm Fachinal (*F* on pl. I), 45 km in a straight line W of Chile Chico, the coastal mountains, as far as seen from the lake, are formed of monotonous old lavas with occasional tuff layers of the Ibañez series, piled upon each other, and cut by minor faults. The total thickness seems to be over 1000 m. Basalt is still seen in places on the top.

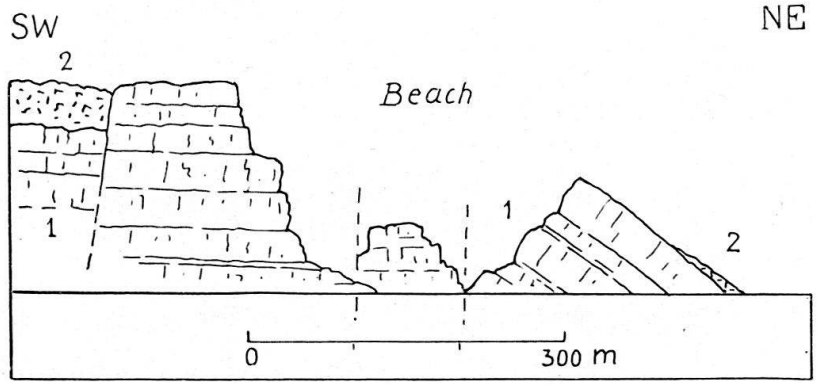

Fig. 6. *Faulted extrusives.*
Detail about 2 km NW of Chile Chico.
a = acid rocks; t = green tuff.

Some 10 km E of Fachinal beach half a circus of about 1 km in diameter, with red and yellow walls, was seen in passing on the little steam boat. It is apparently part of a crater (pl. I).

West of the farmhouse Fachinal the contact should be seen to the underlying much older phyllitic series. Unfortunately the weather was bad, and there was no chance to make another landing. Obviously, the separation is a large unconformity. Indeed, the Ibañez series shows no tectonic stress, whilst the underlying phyllite is intensely contorted.

Mina Silva.

The best place to observe the phyllite series and its contact to the granite is at Mina Silva, where three poor huts have been built. The rock consists of little sericitic hard schist minutely banded with quartzite layers, and is usually crumpled, though, at the little port, it shows a general dip of 20° to NW. It is pierced by basic sills (fig. 9). On the trail to the mine the quartz-phyllite is exposed up to 700 m, i. e. 500 m above the lake.

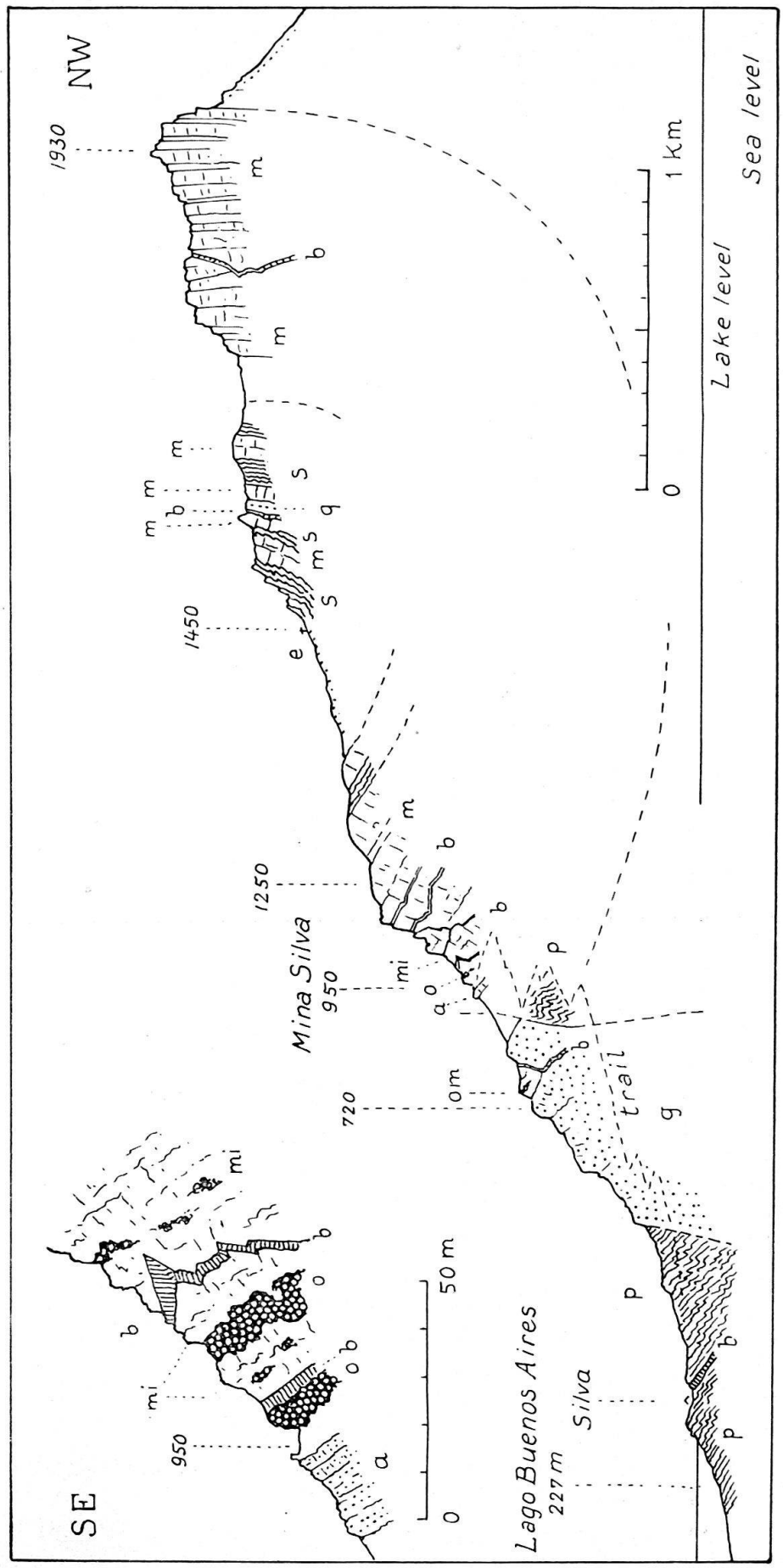

Fig. 7. *Section of Mina Silva, Lago Buenos Aires.*

p = quartz phyllite; s = calcarous phyllite; m = marble; mi = impregnated marble with siderite, diopside and ore; o = lead ore; g = granite; a = brown andesitic porphyrite; b = basic dykes, porphyrite.

The figure in the upper left corner is the section of the mine, enlarged.

Half a mile W of Silva the quartz-phyllite series is pierced by granite. The contact is well exposed (fig. 8). It is partly a primary contact with quartz impregnation, partly faulted.

The granite reaches 700 m and locally penetrates into the overlying marble as high as 950 m above sea level. It forms the coastal walls from Silva towards SW until Cabo Negro for 20 km. About 10 km SW of Silva a slightly sulphurous, possibly radioactive spring of 50 centigrades temperature emanates from the granite at the lake level. The rock is a coarse-grained granite with hornblende, usually gray to white, but frequently of pretty pink colour, and completely massive without any sign of compression.

Climbing up to the ore deposits which will be described later, the contact to the huge mass of massive marble which overlies the granite is exposed (pl. IV, fig. 1). Its thickness may be near to 1000 m. The white walls are intersected by greenish-black basic dykes and sills.

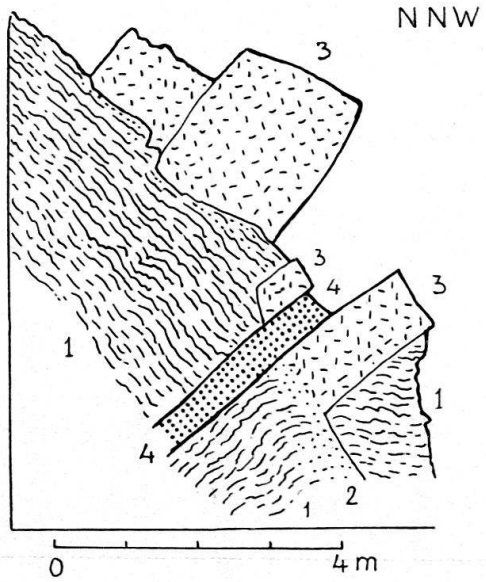

Fig. 8. *Contact of granite and phyllite at Mina Silva.*

1 = quartz-phyllite; 2 = quartz impregnation; 3 = granite; 4 = basic dyke, porphyrite with plagioclase phenocrysts.

The dip of the walls, above the mine, seems to be 20—35° towards N.

Climbing further up, the marble is partly covered by talus and moraine. At 1400 m we come to crumpled lustrous phyllite with a steep opposite dip to SE. As shown in the section fig. 7, this younger phyllite has the position of a syncline. It differs from the lower quartz-phyllite in being frequently interbedded with and passing into marble.

At about 1670 m, a tooth of white marble sticks out from phyllite on its southeastern side, while on the NW it is accompanied by dykes of dark porphyrite and quartz porphyry (fig. 9).

The highest crest of the unnamed mountain of 1930 m (barometric) above Mina Silva consists again of marble. Being away from the granite and traversed by a few basic dykes only, it is much less metamorphic than the marble at the

mine, so that even a minute stratification is conserved. On the highest crest, the strata stand vertical and strike N 30—45° E.

The view is magnificent. Towards North and Northwest, separated by a deep valley, rises to about 2400 m a gloomy mountain probably made of phyllite, with small hanging glaciers. In the southwestern continuation of the marble crest 1930 m stand the magnificent towers of about 2100 m of vertical marble which we propose to call C. Gotico (phot. pl. V, fig. 1).

In conclusion, the section of Mina Silva is characterized by a large unsymmetric syncline of marble with calcphyllite which opens towards NE, the southeastern limb sitting partly on quartz-phyllite, partly on intruded granite.

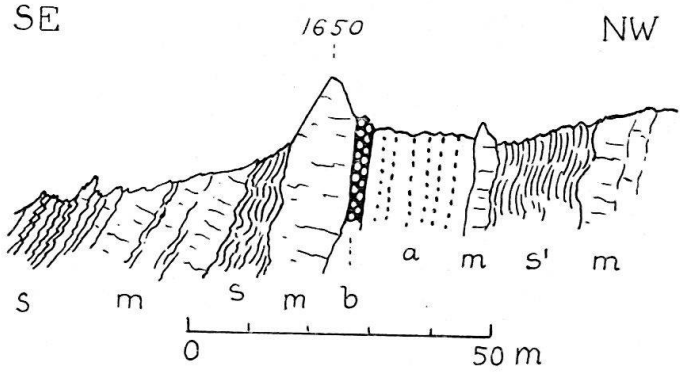

Fig. 9. *Detail above Mina Silva.*

s = crumpled sericitic phyllite, calcarous; s' = silicified phyllite; m = marble; b = porphyritic dyke 1—2 m; a = quartz-porphyry.

The opposite, southeastern side of the lake, as seen at a distance, only shows subordinate layers of marble within the phyllite, while the granite seems to form the main walls up to the highest peak of "Las Claves" which may reach about 1900 m.

Cabo Negro.

This name is used by the inhabitants for the spit of land made of granite at the eastern entrance to Murta Bay. The mountain above of about 1300 m which might be called Cerro Pintado, is anything less than black, and presents an extraordinary view: white massive walls of marble intersected by a network of dark and rusty brown rocks (phot. pl. IV, fig. 2). The same phenomena as at Mina Silva was expected. However, in climbing up, it was found that the network is not so much caused by siliceous impregnation from the underlying granite, but mainly due to basic porphyritic dykes which have little affected the metamorphism of the carbonate. From veins were found epidote, actinolite and pyrrhotite with chalcopyrite.

In the middle part, a fine-grained diorite-porphyrite, probably derived from the granite, and accompanied by quartz-phyllite, are projecting upwards into the marble which, as a whole, seems to be in a narrow synclinal position. Indeed, the marble is accompanied on both sides by steep and crumpled quartz-phyllite. The whole is underlain by granite which has forced its way through the synclinal phyllite up to 800 m above sea level. The syncline seems to be the southwestern continuation of that above Mina Silva.

4. Old Formations of the Western Part of Lago Buenos Aires.

Northwest of the granitic Cabo Negro follows again steeply erected and crushed quartz-phyllite and banded quartzite with another smaller granite intrusion. The axes of the minor folding are frequently vertical (columnar folding).

At the entrance of Murta Bay the island consists of chlorite-sericite schist, partly with biotite. This is the most metamorphic rock of the country.

The steep dip is partly towards ENE, partly towards NW. The higher walls of the island are made of marble which continues at Capilla del Marmol (*CM* on pl. I). Tectonical striation in the direction of the northeastern strike was observed. The marble possibly overlies the phyllite with an unconformity. Here the latter contains a basic greenish dyke showing the effect of compression. It is thus a much older dyke than those in the marble of Mina Silva and Cerro Pintado, which are completely massive.

The Capilla, after which the ranch is called, is an isolated rock with beautiful grottos washed out of the banded marble at the water level. Tectonically, it represents a minor anticline with a vertical southeastern limb (phot. pl. V, fig. 2). As a whole, the marble dips 45—70° to SE. There is no doubt about its regional strike of N 30—45° E.

Southwest of Capilla, the main marble retreats into the higher mountains. But 3—4 km from Capilla, smaller layers of marble of some meters thickness are exposed on the shore. They are interbedded in chlorite schist of a steep southeastern dip.

Stratified intercalations of marble in phyllite were found also in the beach of Guadal. Here, the phyllite is more or less calcarous and recalls the alpine " schistes lustrés " or " Bündnerschiefer. " It contains tiny layers of marble in the crumpled slate, each of 1—2 cm.

The surroundings of the western-most part of Lago Buenos Aires including Lago Bertrand, as far as visited, consist of monotonous phyllite, except at the small beach of the farmer Soto, 10 km S of the outlet of Lago Buenos Aires, where granite, 30 m wide only, has intruded the phyllite.

5. The Sedimentary Syncline East of Guadal.

Looking across the great lake towards SE, a high plateau was seen above Guadal beach.

The Chilean Expedition of 1938[7]) was said to have brought an ammonite from Guadal. On a consequent two days' excursion the following observations were made (phot. pl. III, fig. 2, pl. I and textfig. 10):

Instead of an overthrust, the folded phyllite was found to be stratigraphically overlain by a huge series of sediments in shape of an unconformity. The upper part of the basal 200 m is highly fossiliferous.

On the eastern slope of the ridge, the basis is exposed in one place. There it is made of violet to green quartzporphyry or rhyolite lava, about 15 m thick. Then follow with steep eastern dip gray to violet shales with beds of arkose-sandstone and conglomerate-sandstone. Where the sandstones become calcarous, numerous littoral pelecypods appear, especially moulds of *Panopaea*, joined

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[7]) Kindly mentioned, with other welcome hints, by Prof. Dr. Fr. Reichert, of Cayutue, Lago Todos los Santos.

by *Pecten* and *Bryozoa*. The greenish clay-marls contain small *Turitella* and pelecypods, while there are more calcarous layers abounding in huge oysters with shells of 5 cm thickness (*Ostrea ingens* ZITT.).

In a ravine, near the basis of the series, thin layers of flint were observed in vertically erected gray to violet clay shale.

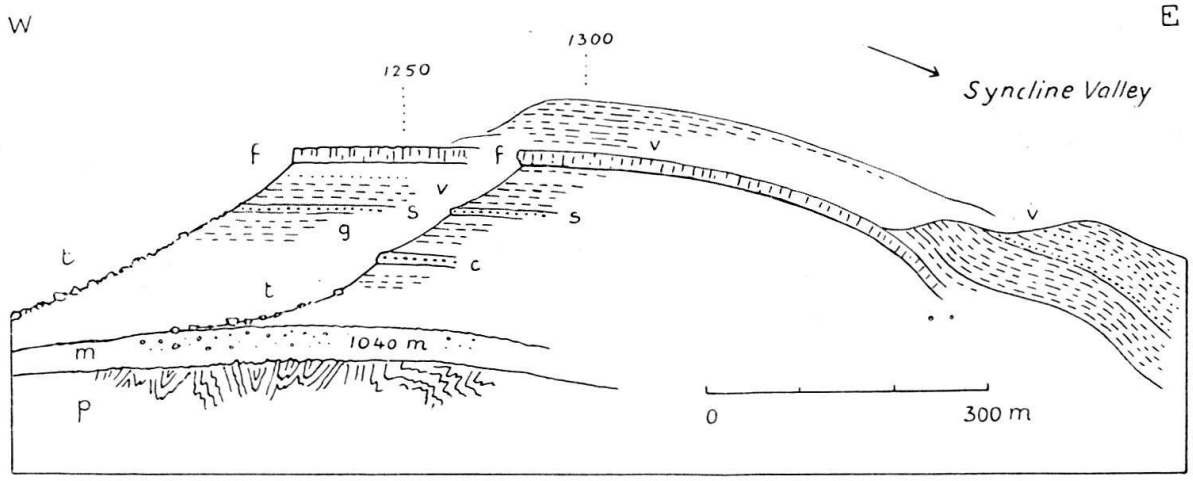

Fig. 10. *Stratigraphic section of Mesa Guadal.*

p = phyllite; c = conglomeratic arkose-sandstone, 12 m; s = sandstone with small pebbles, 2 m; g = gray clay shale; v = violet clay-shale, partly sandy; f = 12—15 m of hard glauconitic sandy limestone full of shallow-water fossils; m = local moraine; t = talus with large blocks from f.

The best fossiliferous locality is the plateau of 1250 m about 14 km in a straight line SSE of Guadal (textfig. 10). It is formed of a horizontal sandy and glauconitic hard limestone of 12—15 m filled with fossils. The slope is overstrewn with blocks from this cliff of which the fossils can be gathered. In spite of their abundance, it is difficult to obtain well preserved specimens. The fresh rock is too hard, while in the weathered part the shells are dissolved. Most abundant are:

Pelecypods:

Ostrea ingens ZITT.
Venus cf. *darwini* PHIL. or *Dosinia burmeisteri* IH.
Panopaea, different species
Pecten.

Gastropods:

Turritella breantiana D'ORB. and *T. ambulacrum* SOW.
Struthiolaria cf. *ameghinoi* IH., and others.

Brachiopods:

Terebratella dorsata GMEL. and passage to *T. patagonica* SOW.
Rhynchonella cf. *plicigera* IH.

These preliminary determinations point to the Patagonian formation which was regarded as Miocene by ORTMANN[8]), but later generally placed into the Oligocene (GERTH). Much reservation is needed regarding the question of age.[8a])

The great sedimentary series seems to be divided into two parts:

a) Lower division of about 200 m, with conglomeratic beds in the lower part, and fossiliferous horizons in the upper one.

b) Upper division, as seen from a distance, chiefly made of wellbedded soft shales of violet to gray or greenish colour, with sandy layers, probably about 1000 m thick.

Locally, the basal division is erected vertically and over, while it is horizontal at the plateau of 1250 m. The upper division is deeply eroded by the " Syncline river " which falls into the lake 10 km NE of Guadal. The dips attain as much as 50° towards E on the western slope (textfig. 10).

Passing with the boat along the north side of Lago Buenos Aires, the eastern border of the sedimentaries was seen at a distance. They seem to rise gently eastward over the phyllites. The structure thus is a wide gentle syncline. The axis seems to pitch at 2—5° towards N in its southern part. The lake shore on both sides of the syncline river is formed of level gravel terraces at about 100 and 200 m above Lago Buenos Aires. Behind them rise the gently synclinal sediments. Their bottom seems to extend to about 100 m below the water level.

On the north side of the lake, no continuation of the syncline was found.

6. Valle Leon.

The western-most beach of Lago Buenos Aires is formed of the wide delta of Rio Leon. Following it upwards, the phyllite zone is traversed for about 9 km. It consists of intensely folded slates usually of western dip. The upper part consists of chlorite schists dipping 30° W.

The next zone, probably continuous until the Pacific fjords, is made of granite with more or less hornblende and biotite. It is part of the great batholite which was mentioned from the Aysen section. The contact with the phyllite is not exposed along the trail.

Similar to the Aysen-Coyhaique section, the high glaciated peaks belong to the granite. Magnificent shapes resulted from the jointing of the massive rock and its dykes.

Besides granite, darker rocks of diorite and gabbro become frequent towards W, as already illustrated by the erratic blocks. The top of the glaciated mountain S 10° E from the lower end of Lago Leon is entirely made of basic rock. The terminal moraine of this lake is composed of the following rocks:

Hornblende-biotite granite, predominant; aplite, ordinary and spotted diorite; gabbro and amphibolite. Sporadically occur blocks of injected quartz-phyllite with biotite, which must derive from inclusions in the granite. The minerals of these igneous rocks are locally ordered in one direction, like fluidal granite. An interesting detail was observed S of the western end of Lago Leon, at 1250 m above sea level: massive granite passing within 20 m into fluidal granite, showing " stratification. "

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[8]) A. E. ORTMANN: Tertiary Invertebrates. Princeton University Exped. to Patagonia, Vol. IV, part 2. Stuttgart 1901—1906.

[8a]) B. L. CLARK: A note of warning concerning the correlation of Patagonian beds . ., Proc. Pan Pacific Sc. Congr. Melbourne, 1, 1924, p. 873.

No true gneiss or mica schist was found. The quartz-phyllite thus is the oldest formation of the country.

Some interesting details were observed at 1200 m on the eastside of the southern Leon glacier. In the midst of the bare granite is a place of about 50—100 m made of a weathered porous extrusive rock. It may be the filling of a volcanic chimney.

Glaciation and Morphology.

1. Eastern surroundings of Lago Buenos Aires.

As observed already by MORENO in 1890, Lago Buenos Aires is surrounded by enormous terminal moraines.

Approaching the lake from NE (Paso Rio Mayo), the traveller crosses first the level pleistocene gravel plateau of 500—600 m above sea level. The road then rises gently to a zone of hills, representing the outermost terminal moraines, as observed and mapped by C. CALDENIUS. These hills reach 700—750 m, or 500 m above Lago Buenos Aires. They are the oldest and widest moraines attributed to the inicioglacial period. Though partly removed by erosion, it seems that this moraine division in Deseado valley reached as far as 70 km E of the present lake. The total eastern extension from the former glacial divide at San Valentin would thus have been 240 km.

The following inner walls of the daniglacial, gotiglacial and finiglacial stage of CALDENIUS are successively better conserved and form horse-shoe shaped hills around the lake. Each moraine system has a width of 5—10 km. According to the map of 1910 and barometric readings the daniglacial moraines would reach 800 m, i. e. 570 m above the present lake[9]). This moraine system extends 47 km E of the lake. The flats between the moraines are filled with fluvioglacial gravel.

Besides the usual igneous rocks, like granite, diorite, gabbro, amphibolite, and basalt, an unusual block was found on the finiglacial wall at 750 m, namely a hard siliceous ironstone with black and zinnobar-red banding, exactly like the huronian banded ironstone of Lake Superior, U.S.A., visited by the members of the International Geological Congress in 1933.

This and other fine-grained rocks frequently show a glossy surface of " desert varnish, " as it was encountered by the writer not only in hot deserts, but also at Lake Superior, in Tibet and Greenland.

The modern little town of Nacimiento, named on the map first Pariaiken, then Rio Fenix, is situated on the flat watershed between the Pacific and Atlantic oceans, at about 400 m (barometric), immediately to the right of sketch-map pl. I.

In order to gain territory for Argentine, the Rio Fenix which formerly made a sharp knee towards W[10]), was led away towards E.

It was at the bend of Rio Fenix Chico (R. F.), 9 km E of the lake, where CALDENIUS made the excavations for his fine geochronological studies of the varves. These are formed of fine silt and clay with annual stratification, deposited in the lake after the retreat of the glacier behind the finiglacial moraines. When the place was visited again in December 1939, the former excavations were no

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[9]) CALDENIUS gives 400 m only. The level of Lago Buenos Aires is indicated as 217 m on the map 1 : 200000 of 1902, as 227 on the map 1 : 500000 of 1910, and again as 217 on the latest edition 1 : 500000 of 1938, Sheet 82, Lago Fontana, of Inst. Geogr. Militar de Argentina.

[10]) Now called Rio Fenix Chico, R.F. in pl. I.

more visible[11]). These glacilacustre sediments form a wide terrace extending up to 190 m above the present lake (CALDENIUS).

Numerous erratic blocks are found on the top which must have been transported by icebergs. This shows that the top varves were deposited while the glacier still reached the great lake. It was at this moment, when the eastward outlet to the Atlantic ceased to flow, and the epigenetic course to the Pacific through the Baker Valley was formed or reformed. We thus find the same conditions of drainage here, as we had to deduct them from the study of Coyhaique with its ground moraines, its varves and the erratic blocks on the top.

According to CALDENIUS, the deterioration of the climate which caused the finiglacial advance, commenced before the year —2040. The improvement which resulted in the retreat of the ice from the finiglacial moraine wall, commenced before —1340, or about 3300 years ago.

2. Middle and western part of Lago Buenos Aires.

The next place where varves were found is the small island about one km off Chile Chico. The thickness preserved is about 10 m; but the varves are very fine, in places about 1 mm each.

The green tuff rock is beautifully rounded according to the direction of the former ice flow.

On both sides of Rio Jeinemeni extended fluvioglacial terraces occur up to about 450 m above sea level.

Corresponding gravel terraces in successive steps are encountered at Puerto Ibañez. They fill the erosive depressions between the old lava rocks (textfig. 11). Erratic blocks are abundant at the pass of 1100 m at C. Penon 30 km NNW of Ibañez on the way to Coyhaique. Varves seem to occur on the NE-side at 850—900 m[12]).

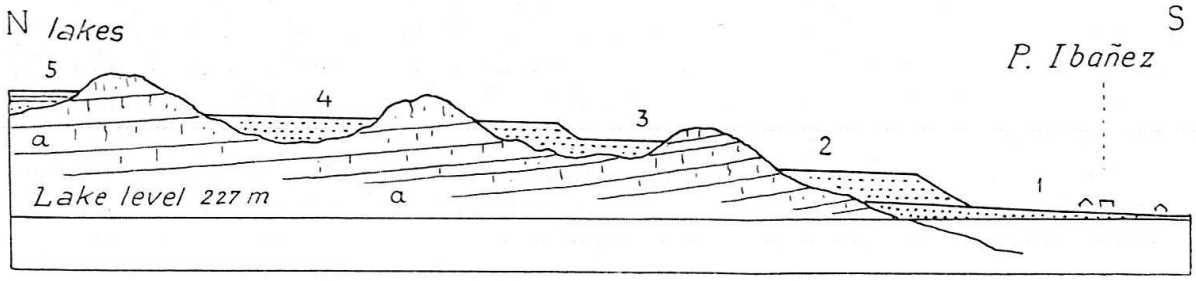

Fig. 11. *Gravel Terraces showing former Lake Levels at Puerto Ibañez, schematic.*

a = mesozoic lavas, acid to andesitic (Ibañez series) forming rounded and polished hills between the gravel terraces.

In contrast to the high valleys in the Himalaya, the rocks along Lago Buenos Aires usually are rounded, striated or polished on the side wherefrom the ice

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[11]) Prof. Dr. C. CALDENIUS of Stockholm kindly informs me that his excavations were destroyed by an earthquake in 1929.

[12]) Outside of the region described in this report, beautiful glacial varves were observed by the writer on the road at Puerto Blest on the western extremity of Lago Nahuel Huapi, 10—15 m above the Lake level which is 767 m. The thickness of the varves is about 8 m. Part of them is folded. The varves are underlain by washed moraine and overlain by sand and loess-like loam (phot. pl. II, fig. 2).

flowed. In climbing above Mina Silva, numerous erratic granite blocks were found from 1300—1400 m, and the last one at about 1500 m. This would be 700 m above the terminal moraine 115 km farther E.

Some kilometers N of Cabo Negro, a whole scale of gravel terraces is superposed to the phyllite slope, as shown in textfig. 12 (barometric readings, approximate).

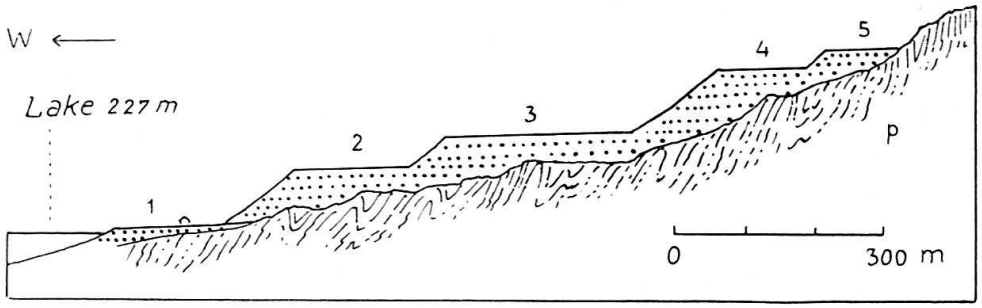

Fig. 12. *Gravel Terraces showing former Lake levels of Lago Buenos Aires, exposed N of Cabo Negro.*

1 = present delta 1—10 m; 2 = 330 m; 3 = 375 m; 4 = 475 m; 5 = 500 m (barometric, above the present lake).

In one place, at the 500 m level, the gravel shows a stratification of 35° dip towards the lake, corresponding to the delta of a former small side-valley, when the lake was at the 500 m level.

The south shore NE of Guadal would be worth while to be studied for its fluvioglacial terraces, which seem to correspond to those of R. Jeinemeni and Ibañez.

A small local moraine was found about 17 km S of Guadal at 900 m, surrounding a minute lake within the sheep pasture. The only mountain where the ice could come from, is not higher than 1500 m. The little ice-tongue must have been formed after the finiglacial stage.

3. Valle Leon and the present Glaciation.

The Rio Leon[13]), called Rio de las Deltas on the map of 1902, has formed a wide valley of one to several kilometers' width. All the way up to Lago Leon at about 350 m[14]) the valley bottom is formed of fluvioglacial gravel. The fall is thus 120 m for about 25 km. The passage of the later terminal moraine to the fluvioglacial valley deposit is clearly illustrated. Boulders of 10—25 m^3 were washed down from the moraine wall for one kilometer, and such of one cubicmeter even for several kilometers distance. Gradually, the gravel is getting finer with the distance from the moraine. The river, frequently branching, flows upon its own deposits without having cut its way into it. The depth of the preglacial valley is therefore unknown. Also the depths of Lago Buenos Aires and Lago Leon remain to be measured. At the end of December 1939, after a long dry spell, the

[13]) So called by the few sheep farmers of the valley on account of the pumas (leones) who come down from the forest for sheep.

[14]) This glacial lake and three others were discovered by the Chilean Expedition, directed by Prof. F. Reichert in 1938. The elevation was given as 600 m which is certainly too high. From 5 barometric readings we obtained 340—350 m only.

quantity of water flowing out of Lago Leon thus derived almost exclusively from the melting of ice and was estimated to be 40 m^3 per second. After a week of rainy weather, the lake rose more than 0,5 m and the flow increased to the double or more.

A few kilometers off the border of Lago Buenos Aires, typical yellow loess of wide extension is encountered. In the deforested valley-bottom it forms low, dune-like hills, but rises on the spur on the south side (at Varrocal's ranch) 100—200 m above the valley. In places big erratic blocks look out of the loess, and the basal rocks of folded phyllite appear (phot. pl. VI, fig. 1). Farther up the valley, the loess becomes coarse and seems to pass into ordinary dunes.

The formation of the loess is still going on. The dust storms from the W are almost unsupportable. Everything even inside the sheep farmers houses in December 1939 was covered with dust which is blown out of the weathering moraines and gravels of the valley. Since the horrible destruction over the whole valley of the magnificent Nothofagus timber, purposly burnt for sheep raising, the loess formerly settled is blown off again. By wind and rain the rock-bottom is rapidly denuded. Within some decades the country will be completely ruined.

Lago Leon has a length in WSW-direction of about 8 and a width of 1 to 2,5 km (phot. pl. VI, fig. 2). It is a typical glacier lake, surrounded by terminal moraine walls of two successive stages:

1. The older and larger moraine rises up to 140 m above the lake and forms a very sharp crest with the steepest slope turned toward the lake. We call it the First Leon stage. Peculiarly, no corresponding fluvioglacial terrace eastward in the Leon valley was observed.

2. The Second Leon stage has left a small horse-shoe moraine within a gap of 400 m width which was washed out by the glacial river during the retreat of the ice from the first stage. The diameter is only about 300 m and the height 25—35 m above the lake (textfig. 13 and phot. pl. VI, fig. 2).

Huge granite blocks of the second moraine at the outlet of the lake provide sufficient shelter from west-storm and rain.

The two stages of retreat are quite distinct and prove considerable climatic changes during post-finiglacial time. The absence of a rock barrier at the end of the lake shows that the glacier must have had its tongue for a very considerable time at the same place in order to heap up such a mighty wall.

In the next following period, the ice tongue must have been lowered for more than 140 m. Also it must have considerably retreated before the last advance, when the glacier gained once more a similar extension, though at a hundred meters lesser level.

In spite of dangerous storms, we crossed the lake many times in a paddle boat. This enabled me to make the following observations: The white cliff corresponding to the First Leon stage continues for several kilometers on both sides of the lake, though at a lesser level than the summit of the terminal moraine. It is partly made of gravel washed out in place from the side moraine. In the middle part of the lake where the granite forms steep walls, the glacial deposits are interrupted, but they set in again at the western end of the lake in shape of typical moraine with large granite blocks forming a terrace which rapidly rises to 350 and 500 m above the lake, until it disappears above the actual glaciers (phot. pl. VII, fig. 2). Small lakes have been formed behind the moraine on the S-side of the lake, 350—400 m above it.

The glaciers which flow down from the continental ice, join before breaking off at the lake (photos on pl. VII) and rise rapidly to the gaps between magnificent

hitherto unseen and unnamed granite peaks of 2400—3000 m. It is at these gaps where the continental ice has its end towards E, at elevations of 1600—1800 m above sea level[15]). According to F. REICHERT who had partly traversed the continental ice already in 1921[16]), its surface is smooth without cracks, and slightly drops southward and westward, where the glaciers flow out until they reach sea level. The flat continental ice sheet thus is 35 km wide on the S-side of San Valentin. It is similar to that of Greenland, though in a very much reduced scale,

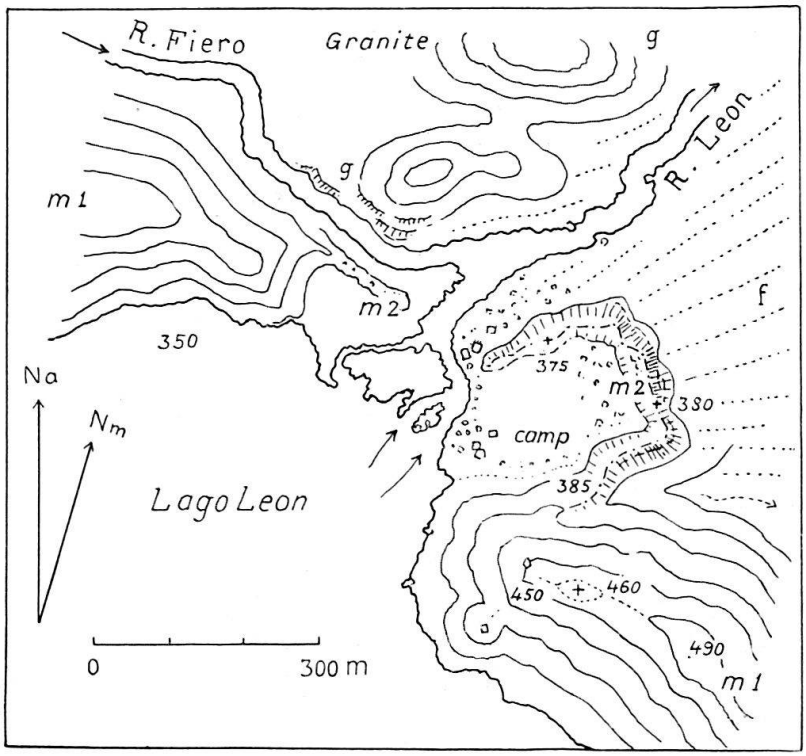

Fig. 13. *Sketch-map of the terminal moraines of Lago Leon.*

Elevations in meters above sea level, barometric.

g = granite, with glacial polish; m_1 = First Leon stage; m_2 = Second Leon stage; f = fluvio-glacial boulders and gravel.

filling a depression between two rows of mountain peaks, through the gaps of which the ice flows down in the shape of glaciers into valleys and fjords. Similar also, though small, are the icebergs which break off from the glacier tongues. On Lago Leon, during stormy weather, they took one night to drift 8 km from the ice precipice to the end of the lake.

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[15]) In February 1940, two expeditions reached the eastern border of the continental ice. The expedition REICHERT reached it from the Pacific side, starting from Ofqui, and found the elevation 1500 m (personal communication by Prof. Dr. F. REICHERT, dated March 22, 1940). Mr. HERMANN HESS, of the expedition HEIM, reached the rim of the continental ice from the East. The differences of the elevations partly derive from the unreliability of the barometric readings in this stormy country, partly from measurements taken at different gaps.

[16]) F. REICHERT: Cerro San Valentin, Vorl. Bericht über die Expedition Hicken-Reichert 1921, in " Phoenix, " Buenos Aires 1923. See also J. BRÜGGEN, Grundzüge der Geologie und Lagerstättenkunde Chiles. Tübingen 1934, p. 177.

4. The Formation of Valleys and Lakes.

In some respect, the glaciation of Lago Leon is a late repetition of that of Lago Buenos Aires, in a small scale. No moraines of retreat have been found as far as the lakes extend. The question thus arises: Why are there no intermediate moraine stages? How have the water basins been formed?

For Lago Leon and its neighbour lakes, the most satisfactory explanation as to the origine of the lake is to suppose that the glacier, after cessation of further feeding and push from the continental ice, became dead or almost dead and slowly melted, leaving the water in its place. While the glacier advanced gradually, there was no corresponding gradual retreat of the ice tongue.

This explanation is conformous to the ideas recently expressed by R. STAUB[17]) for part of the lakes of Switzerland. Lago Buenos Aires which is 60—80 times larger than Lago Leon has not been studied systematically in regard to its possible moraines of retreat.

The question of the formation of the water basins of course is different from that of the primary origin of the valleys in which they occur. Obviously, the latter have not been excavated by the glaciers, but are of interglacial and pre-glacial origine.

Regarding Lago Buenos Aires, we have seen that at Chile Chico the basis of the green pre-pleistocene tuff drops down from the mountains to a level below the lake, and that the old, probably mesozoic lavas even are inclined towards the lake (textfig. 6). In the western region, the southern shore, with its wide sedimentary syncline, is tectonically in a much lower position than the northern shore with its phyllite and marble. Faults, usually of small vertical displacement, occur in abundance along the southern shore. From the present discharge of the ice to the former outlet of Rio Deseado, the rock-bottom of the valley is hidden below the surface and at an unknown depth. Several islands in the middle of the lake and of the former ice-flow show in addition that the basin is not the work of glacial excavation. It is partly of tectonical and mainly of fluvial origine, excavated by river erosion in pre-glacial and interglacial times, in spite of the luxuriously illustrated ice polish. The same conclusion is derived from the general configuration of the valleys and fjords. Instead of troughs in the direction of the former ice-flowage, the trend of the valleys is quite irregular and angular. The Murta beach and valley of 50 km length, and Lago Bertrand — a depression of 2000 m below the peaks of its western side — are even perpendicular to the former ice drainage. As a whole, the relief of the Patagonian Cordillera is that of river action followed by general subsidence. This subsidence is still going on, as demonstrated by the drowned forest on the Pacific side (Laguna San Rafael). The main effect of the glaciation was the enormous accumulation in front of the lakes like L. Buenos Aires, and the conservation of the river valleys behind.

Mineral Deposits.

The Cordillera with its igneous intrusions was said to be rich in ore deposits. In addition petroleum was reported.

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[17]) R. STAUB: Prinzipielles zur Entstehung der alpinen Randseen. Eclogae geol. Helv., vol. 31, 1938. — R. STAUB: Zur Frage einer Schlussvereisung im Berninagebiet etc., Eclogae geol. Helv., vol. 31, 1938.

"Petroleum."

The writer, with his long experience in petroleum research, was naturally much interested to see the location where a seepage was reported by the Chilean expeditions. Although being more than skeptic, he followed a guide of Chile Chico, first with a boat, then on foot over the old lava rocks. After a few hours, the location was found about 10 km NW of Chile Chico. The "bitumen" consists of excrements of a cave-dwelling mammal (Viscacha) which were nicely deposited in a row on a rocky cornice below a roof of similar old lava. The material shown to me from the opposite side of the lake on the peninsula S of Ibañez bay is of similar odour and consistency.

Ores.

A special study was made of Mina Silva, the tectonic position of which is already described (p. 34 and textfig. 7). It is the most interesting locality because the ore is freely exposed on the high marble walls (phot. pl. IV, fig. 1), while in other mining countries similar occurrences only can be studied below the surface with artificial light.

The ore is mainly galenite PbS. Less abundant is sphalerite (zinkblende) ZnS. The galenite exists in large crystals as well as mixed with sphalerite in bands of microscopic crystallisation. Accessories are pyrite and chalcopyrite. The ore also is said to contain traces of antimony (Sb) and $0{,}9^0/_{00}$ of silver (Ag)[18]).

This lead ore is distributed in the shape of irregular inclusions in the marble. The largest lumps are about 5 m thick and can be followed for 10 to 20 m. There are numerous such occurrences. They are bound to the lower part of the great marble wall characterized already at a distance by its irregular rusty brown patches. These in turn only occur where the granite underlies the marble series (phot. pl. IV, fig. 1). The stained parts of the marble are due to limonite derived from weathering of siderite, ferrocalcite and calcsilicate (diopside) formed by impregnation during and shortly after the granite intrusion. The basic dykes, on the other hand, do not seem to have had any influence on the ore bearing.

Exceptionally, segregations of hematite Fe_2O_3 also were found in the marble.

Some hundred meters W of the initial mining place, the intrusion of the granite into the marble is directly visible. A protuberance of the granitic magma reached the height of 950 m above sea level. It stiffened with finer grain than the lower part of the granite mass. The surrounding marble, on the contrary, is very coarse grained.

Until December 1939, when Mina Silva was visited, only preparations were made for mining. The success mainly depends on the question of transportation. To the miniature Port Silva the ore can be easily brought down on a cable. The horizontal distance is about 1500 m, the vertical one 725 m. From the port the ore must be shipped in boats to a suitable place on the Argentine part of Lago Buenos Aires, if there is any, thence by motor truck over the pampa. Another possibility would be to use trucks from Puerto Ibañez to Puerto Aysen via Coyhaique, for a distance of 200 km. For this purpose the road which, at present, hardly can be used for bullock-cars, would have to be built.

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[18]) The latter figures by courtesy of Mr. ALFREDO COX, of Chillan, Chile.

Northwest of Cabo Negro, a vein of pyrrhotite (Magnetkies) in the phyllite was examined (textfig. 14). Numerous pure specimens of such ore were shown to the writer at Guadal, all of them deriving from the phyllite.

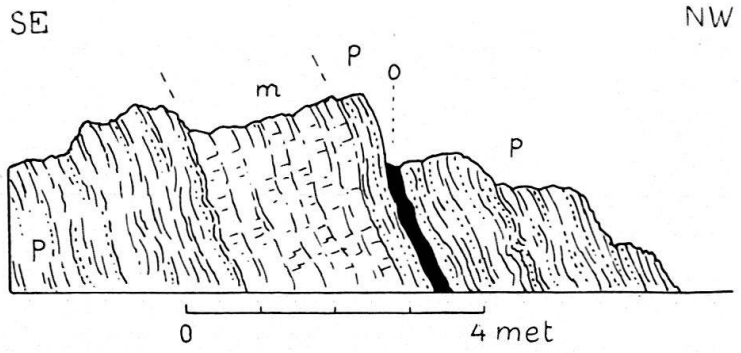

Fig. 14. *Outcrop of pyrrhotite on Lago Buenos Aires.*

p = quartz-phyllite and banded quartzite; m = banded marble; o = pyrrhotite.

On Lago Bertrand, at + of pl. I, a dyke of chalcopyrite $CuFeS_2$ mixed with quartz, of 10—20 cm was found in the northerly striking and steeply erected phyllite.

Also molybdenum is present on the S-side of Lago Buenos Aires. Characteristic samples of molybdenite (MoS_2) were shown to the writer.

Fragments of geological History.

In the regions described above, the first recognizable geological event was the deposition of clay and fine quartz sand of great thickness. Its origine is unknown. Then followed calcarous precipitation.

In a later period, these apparently marine sediments were subject to intense compression which resulted in folding and crumpling, as well as in the transformation of the clay and sand to quartz-phyllite and of the lime to marble. Although the phyllite is more or less sericitic, no true gneiss or mica schist has resulted. The depth of transformation seems to have been unsufficient for a complete mineralisation.

The fine banding of the limestone forming the crest 1930 m above Mina Silva, away from the granite and at higher level, was only little transformed and seems to indicate that the deposition was a shell-less chemical precipitate in water of rising temperature. The chlorite schists are regarded as metamorphosed marine tuffs[19]).

The primary age of the phyllite and marble series is unknown, but supposed to be Paleozoic. Their compression and folding in N to NE direction (anticline of Capilla, syncline of Silva) might have occurred in Permian time.

The section of Mina Silva (textfig. 7) shows that the granite intrusion is younger than the great marble syncline. It is older than the Tertiary series of Mesa Guadal and probably corresponds to the great Patagonian batholith

[19]) This series resembles the chlorite schists and micaceous phyllite in the coastal Cordillera of Valdivia.

which forms the culminating part of the Cordillera (San Valentin) and is regarded as middle to upper Mesozoic.

Normal granite was encountered in no place intruding the Mesa Guadal and Ibañez formations. This does not prove however its older age, since the corresponding regions are far outside the granite batholith. In Coyhaique the acid trunks are younger than the Devisadero series of extrusives which may be equivalent to the upper part of Ibañez series.

The black, unfossiliferous clay shale of Coyhaique is probably Mesozoic. It seems to belong to the porphyrite series, being underlain by porphyrite and overlain by the Devisadero series which also contains porphyritic layers. The well-known porphyrite of Santiago[20]) has been determined as Jurassic by its intercalations with ammonites, but extends in Patagonia into the Lower Cretaceous[21]).

The great mass of lavas and tuffs piled upon each other which we called the Ibañez series, in its upper part, is also in relation with the porphyrite series, and thus is regarded as mainly Mesozoic[22]).

The Mesa Guadal formation was deposited on the eroded surface of the crumpled phyllite after its subsidence below sea level. This is confirmed by the conglomeratic arkose layers in the lower part. Their stratigraphic resemblance to the Pueyrredon series, according to STANTON[23]), is so striking that the basal conglomerates might at first sight be taken as Cretaceous. However, no unconformity was seen up to the fossiliferous layers which are characterized by the Tertiary Patagonian fauna with its abundance of subtropic oysters, panopaeids, gastropods and brachiopods.

The great upper division of the Guadal series seems to be made of barren clays and sandstone proving subsequent subsidence. Obviously, the Tertiary sea must have extended far westward of Guadal and possibly all over the Cordillera. Indeed, a marine argillaceous formation of 1000 meters thickness cannot have had the abrupt end of its actual erosive border.

The folding of the Mesa Guadal series and the disturbances along the eastern front of the Cordillera from Chile Chico to Coyhaique thus are younger than the Patagonian formation, and possibly have extended into the Pliocene.

No trace was found on Lago Buenos Aires of the " main folding period " of the Andes in Chile which is of Middle Cretaceous age (GERTH, BRÜGGEN). This does not say that it was absent. Indeed, it is indicated at Lago Pueyrredon, the next lake S of Lago Buenos Aires, where HATCHER[24]) has found a slight unconformity between the Lower Cretaceous Pueyrredon series and the Upper Cretaceous.

The structure, although being contemporary to the Alpine movements, is totally different to that of the Alps. In the Cordillera the horizontal compression during the later tectogenetic periods was subordinate in relation to the vertical and magmatic movements.

The basalt flows of the mesas and the corresponding dykes and volcanic caps are younger than the last folding and are supposed to be of latest Tertiary age.

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[20]) The writer is much indebted to Professor Dr. J. BRÜGGEN of Santiago for his kind guidance into the region of Santiago.

[21]) J. BRÜGGEN: Grundzüge der Geologie und Lagerstättenkunde Chiles, 1934, p. 12.

[22]) H. GERTH: Geologie Südamerikas, 2. Teil. Berlin (Gebr. Borntträger) 1935, p. 298.

[23]) T. W. STANTON: The marine Cretaceous Invertebrates. Princeton Univ. Exped. to Patagonia, vol. IV, part 1. Stuttgart 1901—1906.

[24]) J. B. HATCHER, Am. Journal of Sc., 4th ser., vol. IX. Feb. 1900.

A new stage of general erection of the Cordillera was introduced. The main valleys were formed, after which followed a minor subsidence that still continues.

The Pleistocene depressions of temperature caused enormous glaciations. In four main periods at least, the ice advanced through the valleys far out into the foreland. In the middle part of Lago Buenos Aires the ice had a thickness of at least 1300 m. The centre of the glaciation or *divortium glaciarum* was and still is Cerro San Valentin, 4058 m, the highest mountain of Patagonia (phot. pl. VII, fig. 1). Enormous moraines were deposited E of the lake. Its shores must have reached about 500 m, 300 m above its present water level. But with the retreat of the ice from the basin, the glacial river found its way backwards to the Pacific Ocean.

The terminal moraines of Lago Leon illustrate the last " post-glacial " stages of glacial advances and retreat. They may correspond to the " Schlussvereisung " of AMPFERER and R. STAUB in the Alps, and to the ice advance of about 500 years B.C., which is generally exhibited in the Scandinavian mountains[25]). The lake was formed by the final melting of dead ice or by a very rapid retreat.

During the last decades our region shows a general retreat of the ice. It is plainly illustrated by the glaciers on the W-side of Lago Bertrand which withdrew their snouts from about 600 to 900 m above sea level. The tongue of a glacier called Helena on the S-side of Leon Valley shows a recent retreat from about 400 m (= 100 m above the valley) to 700 m. Also the Pacific side at Ofqui is under similar conditions. According to BRÜGGEN[26]), the San Rafael glacier flowing down from the continental ice sheet into the Laguna at sea level, withdrew its front about 4 km since the year 1905.

The lower termination of the glaciers on the Pacific side corresponds to the depression of the snow line. According to F. REICHERT, it is at about 1000 m on the Pacific side. There the precipitations reach their maximum. On the E-side of the continental divide the clouds and precipitations rapidly diminish. The snow-line, around the western end of Lago Leon, was estimated at 1400 to 1500 m, and it still rises further towards E. This is the effect of the prevailing western winds and storms from the Pacific which are the strongest during the summer months after new year.

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[25]) By kind information from Professor C. CALDENIUS, of Stockholm.

[26]) J. BRÜGGEN: Informe geologico sobre la region del Canal de Ofqui. Bol. 52 Dep. de Minas y Petroleo, Santiago 1935.

Manuscript received July 22, 1940.

Explanation of Plates II—VII.

Photographs taken by ARNOLD HEIM.

Plate II :

Fig. 1. The " Verdigris Island " of Chile Chico, from S. 1 = brown acid lava of Ibañez series; 2 = green amygdaloid tuff, rounded by glacier grinding; the top is about 50 meters high; 3 = glacial varves.

Fig. 2. Glacial varves on the road at Puerto Blest, west end of Lago Nahuel Huapi. The embedded white angular granite blocks must have been brought with swimming ice. The overfold may have been scratched up by an iceberg coming from S (Lago Frias).

Plate III:

Fig. 1. Cerro Apidame, S of Chile Chico, seen from N. Volcanic andesitic neck, piercing the tuff and shale. In the foreground an acid dyke or sill. On the top to the right is basalt. Compare textfig. 5.

Fig. 2. Mesa Guadal, looking from a point 1270 m towards NNE. In the foreground decayed quartz-phyllite under surface creeping (solifluction). The mesa is formed of marine sediments. The fossiliferous glauconitic limestone of 1250 m forms the black wall. Upon it, more in the distance, are violet clay shales forming the hill of 1300 m = basal part of the upper sedimentary division. In the left background is Lago Buenos Aires with the marble peaks behind. Compare textfig. 10.

Plate IV:

Fig. 1. Mina Silva, at 950 m. The white patches of the rock are marble. The dark parts are rusty brown limonite = weathered siderite and diopside. The native Chilean holds the hand on lead ore. In the background is Lago Buenos Aires seen from NE.

Fig. 2. "Cerro Pintado" above Cabo Negro on Lago Buenos Aires. The white rock is marble. The black wall + in the middle is diorite-porphyrite, probably in connection with the underlying granite. It is bordered to the left by quartzphyllite which seems to have been dragged up by the intrusive activity. The dark network in the marble is made of basic dykes.

Plate V:

Fig. 1. "Cerro Gotico," about 2100 m, made of vertically erected marble of north-eastern strike. At the left is a small hanging glacier. In the right background, due W, is C. San Valentin 4058 m.

Fig. 2. Capilla del Marmol. Banded marble forming a narrow anticline. The foot is washed out to beautiful grottos, seen from SW.

Plate VI:

Fig. 1. Quartz-phyllite, intensely tormented, traversed by a minor sliding plane. Semiplastic deformation of the quartz. Strike of folds to NNE. Location: Rancho Varrocal, Valle Leon.

Fig. 2. Lago Leon, looking towards SW from its outlet. The blocks in the foreground are what is left of the second stage terminal moraine. In the middle background is the joint Leon glacier plunging into the lake. At the left is a small iceberg. The rocks and mountains seen on the picture are made of granite. The gaps between the peaks represent the eastern border of the continental ice sheet.

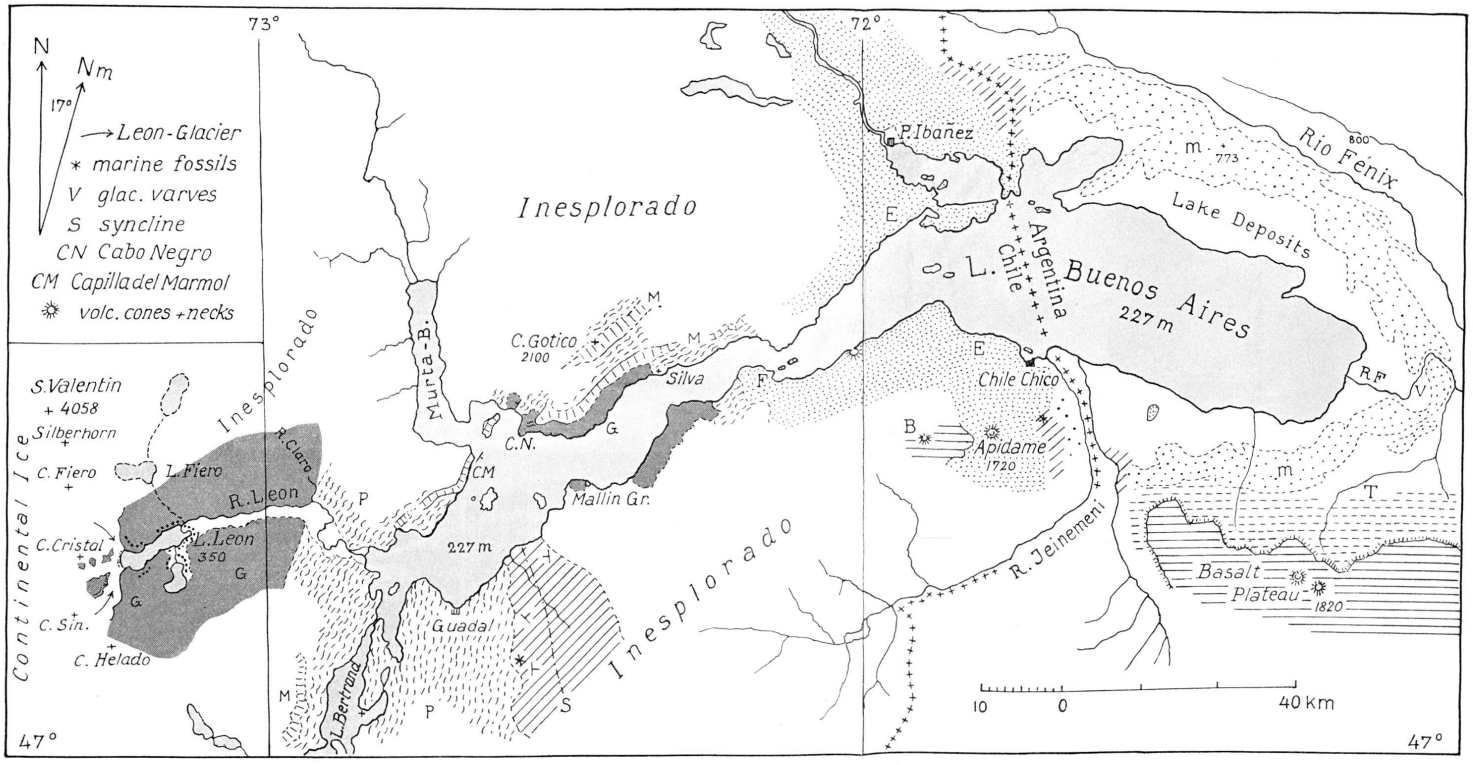
Plate VII:

Fig. 1. Cerro San Valentin, 4058 m at +, seen from SSE. Its neighbour to the right, more in front, with a snow flag is "Silverhorn." To the left and still nearer is C. Fiero.

Fig. 2. Leon Glacier. Joint lower continuation of the glaciers seen in phot. pl. VI, fig. 1, plunging into Lago Leon. At + is the left lateral moraine of the first Leon stage, 500—600 m above the lake. View taken from about 750 m. ab. s.-l. towards N.

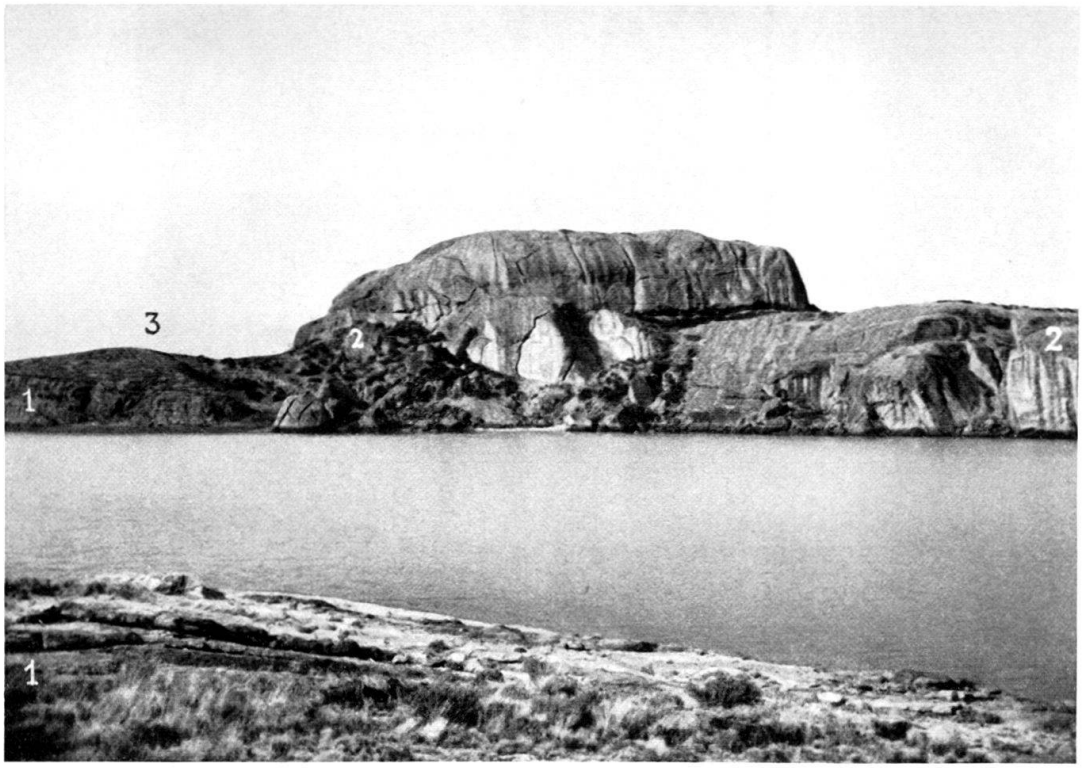
Geological Sketch-Map of Lago Buenos Aires, Patagonia

(Eastern extremity after C. Caldenius)



m	B	T		E	G	M	P
Moraines Finiglacial and retreat	Plateau-Basalt	Sandstone and Clay	Patagonian Formation	Extrusive Rocks mainly acid	Granodiorite Batholith	Marble	Quartz-Phyllite
	Tertiary			Mesozoic		Paleozoic	

Repr. Birkhäuser, Basel.



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Repr. Birkhäuser, Basel.

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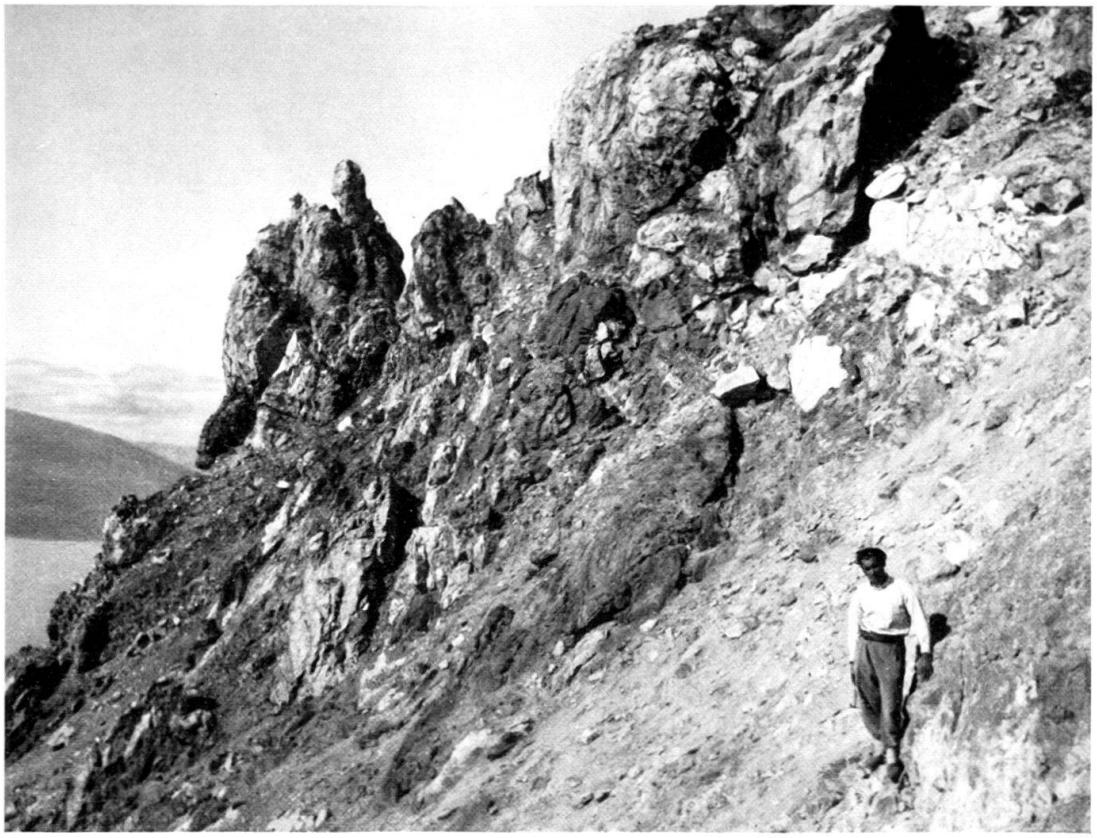

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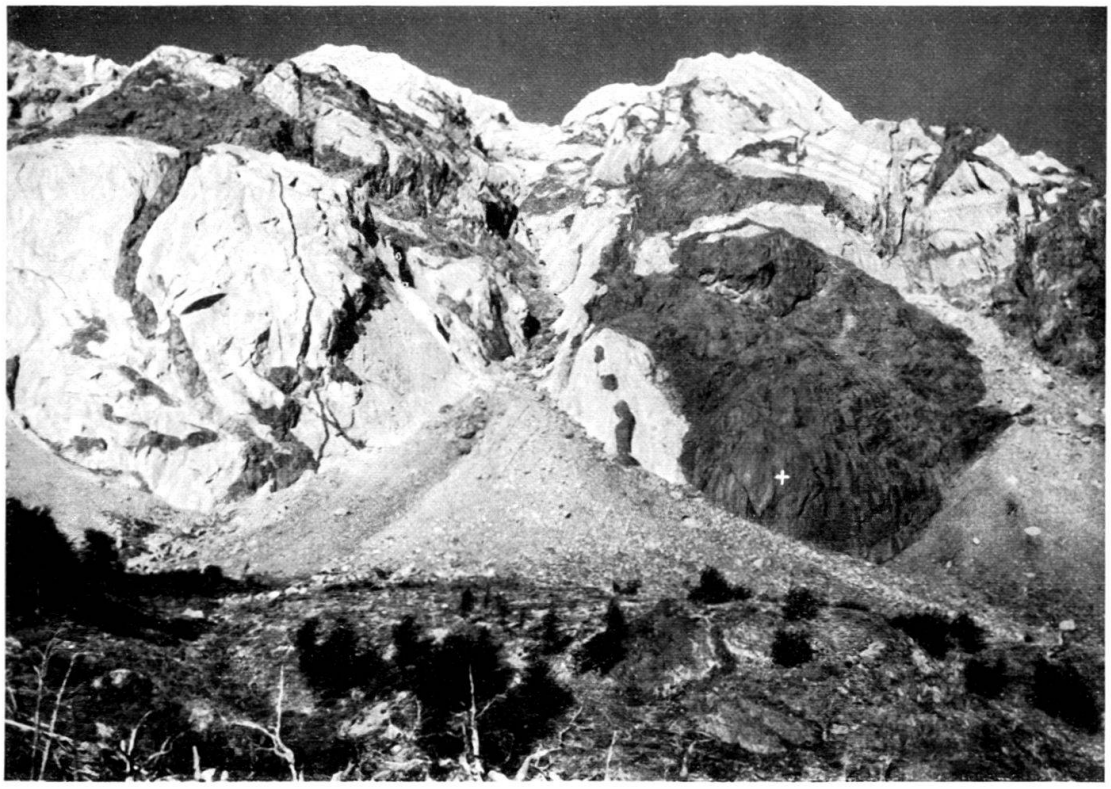

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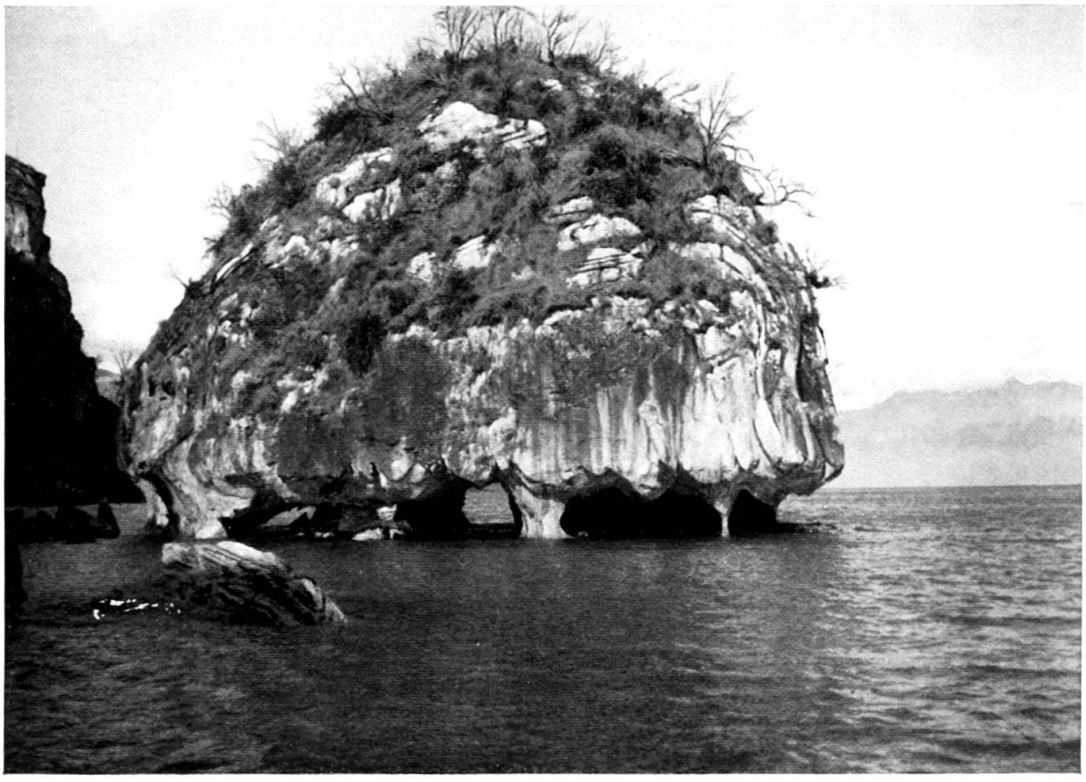

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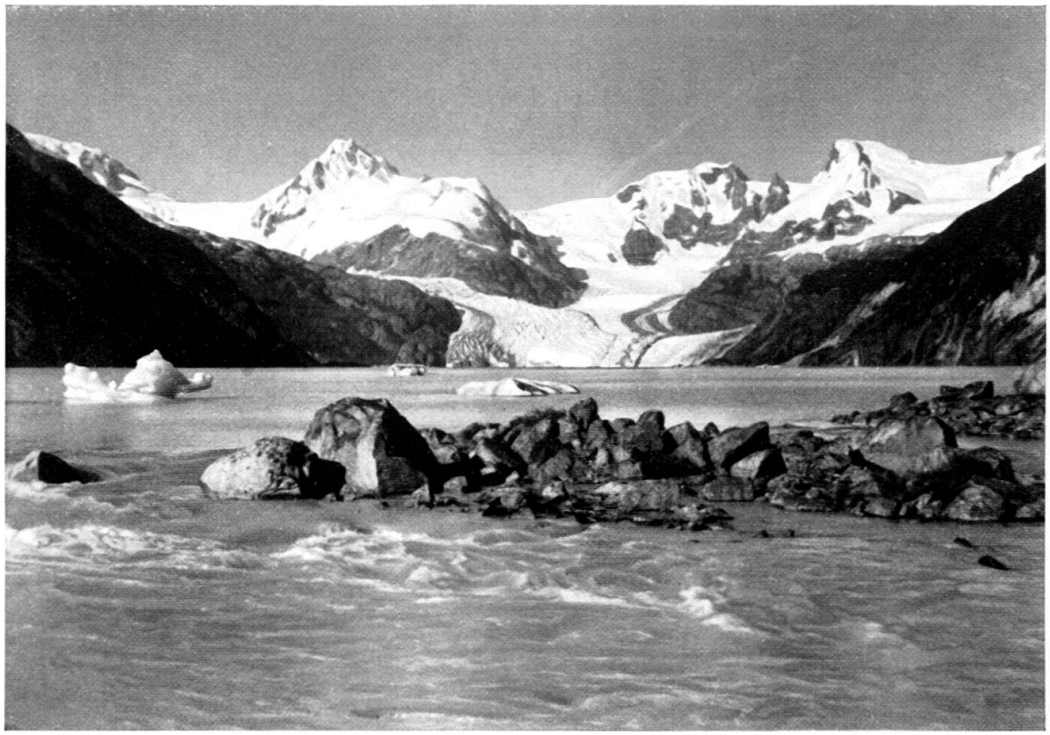

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