6. On the influence of the ice age on the continental watershed of Patagonia

by

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(With two maps.)

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Introduction.

As a member of the Swedish Magellanian Expedition of 1907—1909 I spent the greater part of two summers on the eastern slopes of the Patagonian and Fugian Cordillera, principally occupied with petrological studies. My notes dealing with the glacial geology are of a very incomplete character, as neither time nor equipment gave us the opportunity of making a detailed survey of the many interesting questions relating

there to. Only a scanty supply of facts has therefore been at my disposal, and my main object in publishing this paper is more to draw attention to the wide and interesting field of work still open in these regions, than to attempt to give a full description even of those parts, to which, in the following paper, I have restricted myself.

Topography.

The general orography of the Pagatonian Cordillera is already, in its leading features, so well known and the eastern slopes, thanks to the careful survey of the Argentine Boundary Comission, so well mapped out,

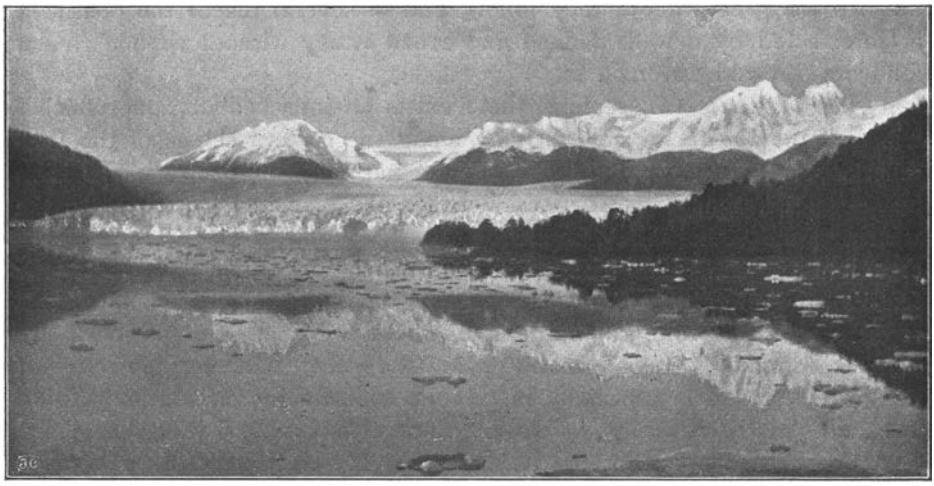

Fig. 1. Peel Inlet, a fiord of the Pacific with glaciers descending to the waters edge.

that a detailed geographical introduction would be wholly superfluous. As, however, many of the questions relating to the glacial period, which I here propose to deal with, are intimately connected with the general topography of the country, I will commence this paper by giving a brief description of those features, which stand in a near relation to the glacial deposits in question.

It is well known how the Patagonian Cordillera divides the southermost part of the South American Continent into two parts, which in their general geological, as well as orographical, features are the most absolute contrasts to each-other. The western slopes of the Cordillera are bordered by a highly developed fiord-landscape, with its characteristic inlets and islands, narrow channels and perpendicular cliffs. Geologically, this part is formed of a uniform eruptive mass which stretches without interruption over ten degrees of latitude. There prevails in this region almost perpetual

mists and rain. The land eastward of the great mountain range presents a very different appearance, consisting of the great plain, generally known by the name of the Patagonian Pampas and formed of late mezozoic and tertiary deposits in mostly undisturbed positions. The even plateau rises gently from the Atlantic up to the Cordillera, where it reaches a height of 1000—1400 m. This great plain is intersected by a number of broad valleys, which run in a direction west to east, having cut themselves deep down through the loose deposits of the Pampas formation. In consequence of the extremely dry, nearly desert-like, climate of the Pampas the rivers diminish rapidly towards the east; many of the torrents, which drain the western part of the great high-plateau never reach the Atlantic at all, but lose themselves in the sand or end in salt-lakes, lacking any outlets. On the whole, most of the rivers are out of proportion to the great valleys they follow, and in several places the continent is intersected by a well defined and broad valley without even a rivulet following the old watercourse.

Besides these two regions, there exists an intermediate zone which I will call the *sub-andine region*, lying along the eastern slopes of the Cordillera. Here the climatic conditions are naturally more normal, as is to be expected, lying, as it does, between the glaciated Cordillera to the west and the dessert-like pampas to the east. Within this sub-andine region are situated the great mountain lakes which form such a characteristic feature of the eastern Cordillera. It may be said that the whole of this region lies on a geological border-line, where the younger deposits of the Pampas formation unconformably meet the older metamorphic rocks of the Cordillera. It is especially in this sub-andine zone, that our expedition has had the opportunity of working, and it is principally to the glacial phenomena of this region that I will confine myself in the following pages.

It has long been a known fact, that Patagonia has once been the seat of a widespread glaciation, in many cases distinctly resembling the alpine glaciation of the northern hemisphere. On the other hand, different views have prevailed as to the exact geological age thereof, some geologists accepting a more or less complete synchrony between the ice ages of the northern and southern hemispheres, others ascribing the Patagonian glaciation to a late pliocene or even miocene age. Also, regarding the greatest extension of the ice as well as the question of distinguishing two or more glacial advances from interglacial epochs, opinions are still divided. On the other hand the limit of the last advance of the ice or, if full proofs of a sure advance are still lacking, the limit of the greatest extension of the ice-covering during the marked standstill, which preceeded the final regression of the ice, is well defined and just situated within the sub-andine region. Not having had any opportunity myself of visiting the eastern coasts of Patagonia and there studying the questions relating to the age and greatest extension of the ice age, I will not touch upon these subjects in this paper, but, instead, restrict myself to the late glacial formations, as found along the eastern slopes of the Cordillera

It is necessary, rightly to understand the glacial phenomena within the sub-andine region, to give a short description of the orography of the country, which borders it on both sides. As I have already mentioned, the great Pampas plain is intersected by a number of broad valleys. Following up one of these you are surprised, when nearing the Cordillera, to find that the main river is, as it were, suddenly cut off by a series of low morainic ridges. The principal stream is divided up into a number of tributaries, which reach the main valley from the »Mezetas» or high plateaus at both sides. The morains, which here stretch across the valley constitute, in many cases, the continental watershed of the present day, the whole drainage system of the great transversal valley therefore being confined to the western parts of the Pampas itself, whereas the drainage of the eastern slopes of the Cordillera seeks its way westward. To the west of the watershed you encounter either a broad valley, the direct continuation of the transversal valley, but draining off to the west, or else one of the great sub-andine lakes, which stretches away far into the snow-clad mountains, through which it seeks its outlet by one of those narrow gorges, which at intervals pierce the Cordillera range. The eastern end of these lakes, of which I will give a more detailed description later on, still lies within the Pampas formation, the depression which it fills being a direct continuation of the transversal valley. We have then to deal with the perhaps unique circumstance that the continental watershed consists of some low morainic hills; even such a paradox is met with as that a river bed or rather the bank of a river, is the water divide between two oceans, so that at high water the overflowing river sometimes issues partly by the Pampas valleys to the Atlantic and partly through a trans-andine gorge to the Pacific. The explanation of these strange freaks of nature is to be sought in the fact that the glacial ice divide and the watershed of to-day follow two very different topographical lines, the former having chiefly been situated along the central Cordillera range, while the latter, to a great extent consisting of loose glacial deposits, often lies far beyond the mountains, out on the Pampas. I base this statement on the distribution of erratic blocks. Whilst among the glacial deposits of the Pampas I found the greatest part of the erratics to consist of the crystalline rocks of the Cordillera, I have never in the Andes found anything indicating an east to west transport by the ice. And, the petrological formations of the two areas being so very different, it is particularly easy to note the origin of the erratic blocks. Comparing the general features with those in Scandinavia during the latter glacial period, you might expect to find things reversed, as there are many marked analogies. In fact, the main orographical features are very similar; to the west the fiord landscape, bordered by the ocean and with an abnormal high fall of rain, then the mountain range with the wide plateau landscape stretching away eastward. (As most of my readers are aware, the late glacial ice divide in Sweden did not follow the mountain range but lay a good deal

eastward thereof, this in many places giving rise to great ice-dammed lakes, which sought their outlet through the lowest mountain pass westward). Notwithstanding the many striking resemblances, there is nothing indicating an analogy in the situation of the ice divide; on the contrary, everything points to the fact that the late glacial ice divide of Patagonia has been situated on the Central Cordillera range. Also the distribution of the ice of the present day indicates the same, the whole of the Cordillera between lat. 48—52° S. being covered by a *continuous sheet of ice,* to the west

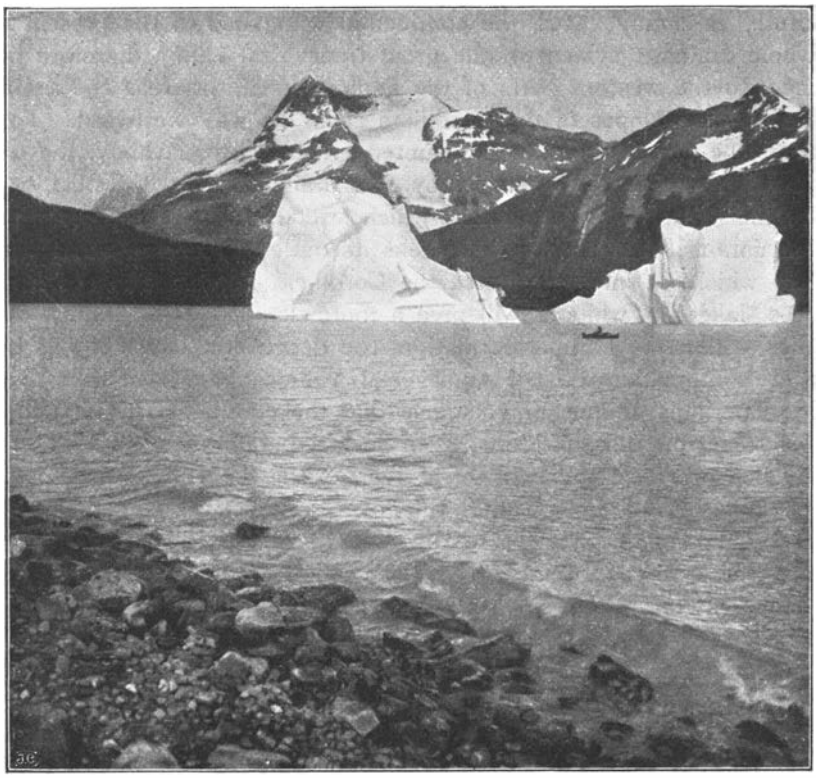

Fig. 2. Icebergs in Lago Argentino.

reaching the ocean in numerous glaciers, to the east extending to the low plains of the Rio Serrano, or else forming mighty streams of ice filling the western parts of many of the sub-andine lakes. (See map, Plate IV.)

We are now forced to presume, that most of the trans-andine valleys up to a very recent period have been filled by masses of ice, particularly as mighty glaciers, to this very day, all but reach down to several of the valleys, especially in the south. The consequence must have been, that the whole drainage system of the eastern Cordillera, which now seeks its outlet westwards, has in that direction found its passage blocked by ice

and has had to seek its outlet over the lowest passes eastward. In many places ice-dammed lakes have thus been formed. To the east, the lowest pass has inevitably been over the glacial deposits in the depressions of the great transversal valleys, which mark the older course of the drainage system of the eastern Cordillera. Here again mighty glacial moraines have in many places caused the formation of lakes by damming up the old valleys, and towards the end of the ice age there must therefore have occurred the very singular phenomena of great lakes, *to the west* dammed by ice from their outlet through a trans-andine gorge, and *to the east* still further dammed by glacial deposits formed by the mighty glaciers, which once filled the deep depression now occupied by the sub-andine lakes and valleys.

Previous surveys.

Before entering on a more detailed description of some points of special interest, I will give a short account of the views of some former explorers of these regions. The glacial phenomena here are much too conspicuous long to elude attention, and all the scientists, who have visited these parts have given more or less summary reports on the subject. Especially the formation and age of the transverse valleys of the Pampas, as also the nature of the sub-andine lakes have given rise to different views.

FRANCISCO MORENO, the principal leader of the work of the Argentine Boundary Commission, has himself visited most parts of the Patagonian sub-andine region between lat. 41° and the Straits of Magellan. In the Geographical Journal[1] of 1899 he gives a graphic and detailed description of the physical geography of these regions. He has there recognised that the lakes and rivers of the eastern Cordillera, now draining west, have formerly flowed through the transverse valleys eastward. In his explanation of why the greater part of the drainage system of the Cordillera has been reversed, he principally builds on two geological causes — in the first place a very recent upheaval of the land, secondly a rapid water erosion in the Cordillera passes. In another paper[2] he accounts for the same phenomena by »the accumulation of glacial deposits, the decrease of waters through decrease of rains and the increase of evaporation as well as to the uplifting phenomena». It is difficult to see how a decrease of rain could in any essential degree have the effect of lowering the lake level, if an outlet existed westward corresponding with the present level of the water. Many of the transversal valleys have, according to MORENO, up to very recent times, been narrow inlets of the Atlantic, reaching to

[1] Geographical Journ. 1899, p. 253.
[2] Ibid., p. 356.

the very foot of the Cordillera and have only by recent upheaval been transformed into valleys. The lakes of the eastern Cordillera would consequently have had their outlets eastward until the erosion opened a lower pass to the west. In MORENO'S paper no mention is made of the influence of the ice age, excepting in the glacial deposits forming the present watershed. But he evidently considers the erosion, which has opened up the trans-andine valleys, to be postglacial. As I have already mentioned, we must consider, that many of these trans-andine valleys have been ice-dammed up to a very late date, so that the postglacial erosion could never have been very deep. Besides that, the glaciers, which have once filled these valleys, have left very decided marks of their existence in the form of moraines and glacial striation down to the very river bed, which positively proves, that postglacial erosion has played but an insignificant part in their formation. As an exemple of how very recent MORENO considers the reversal of the drainage of many of the lakes, he quotes several Indian legends, telling how certain rivers, for instance the Shehuen, formerly came from a large lake. Except for these legends there are, however, no proofs that the present drainage has been reversed in such recent times. The only agency, which has been able to reverse the whole drainage system in postglacial time is, as far as I can judge, the ice itself, or rather *the last disappearance of the ice* from the Cordillera passes. As to the nature of the transversal valleys, MORENO seems to consider them of tectonic origin, putting them in direct connection with the depressions af the sub-andine lakes. Referring to LAGO VIEDMA he says:[1] »This lake also occupies a tectonic depression, which stretches to the Atlantic», the continuation of the lake depression, according to MORENO, consequently being the Shehuen and Chico valleys.

FLORENTINO AMEGHINO tries in a few words to prove the transverse valleys' *tectonic nature in very recent times*. He writes as follows:[2] »Having dispelled the ignorance as to the origin of the boulder formation, this leads us naturally to determine the age of the formation of the transverse valleys of Patagonia», and comes to the *inevitable* conclusion, »that the formation of the great transverse valleys of Patagonia was brought about by great dislocations and gigantic faults at a comparently recent geological period, posterior to the boulder formation, and at the last emergence of the land». Owing to the find of his brother CARLOS AMEGHINO of an *Ostrea* in the boulder formation, AMEGHINO is at once ready, without even a nearer description of the places of discovery, to draw such startling conclusions as that the valleys of Patagonia, which intersect the almost unmoved stratas of the Pampas, are formed by great dislocations and gigantic faults. The author does not even consider it necessary to give a single example of these phenomena, but, in his eagerness to avail himself of the *Ostrea* find in the Teuelche formation for ascribing to

[1] Geographical Journal, 1899, p. 262.

[2] Geological Magasine, 1897, p. 18.

it a miocene marine formation, he does not hesitate, to try to explain all relating circumstances in favour of his new idea.

OTTO NORDENSKJÖLD in discussing the Boulder formation, to which I will refer at the end of this paper, comes to the conclusion that the transversal valleys are valleys of erosion of interglacial age.[1]

HATCHER comments, in his description of Patagonias physical geography, on the transversal valleys.[2] He interprets them as old river beds, and places their formation *before* the last great Patagonian trangression (when the Fair Weather beds were deposited), that is to say of the pliocen age. During the postpliocene elevation many of these valleys would still have existed as inlets, like the Magellan Straits of the present day, cutting right through the Continent to the foot of the Cordillera, and only by degrees have been transformed into valleys. To this explanation SCRIVENOR[3] seems in general to agree. Further on in his paper HATCHER refers to the nature of the great sub-andine lakes, which he simply classifies as tectonic depressions, not mentioning their near correspondence to the transversal valleys. The eastern parts of most of these lakes are only separated from the valleys by glacial deposits and must, as far as I can judge, be considered as a direct continuation of these, whereas the western fiord-like inlets of many of them, stretching far into the mountain range, are of a very different nature. HAUTHAL, who has visited many of these lakes, is of the opinion,[4] that the eastern parts must be regarded as valleys of erosion, whereas he ascribes a purely tectonic origin to the western parts.

Special description.

I now pass on to give a more detailed description of the phenomena relating to the last stages of the ice age within the sub-andine region.

Lago San Martin.

One of the most typical examples in the postglacial evolution of a sub-andine lake is that of *Lago San Martin.* The lake itself is some 60 km. in length from east to west, but at its western end great fiord-like arms stretch away in all directions, the longest one, to the north, being over 50 km. At the northern end of this fiord, its present outlet, the Rio Pascua, is situated; a torrent river zigzagging between the steep mountains, until

[1] Wissenschaftliche Ergebnisse der Schwedischen Expedition nach den Magellansländern. 1895—97, I: 1, p. 50.

[2] Reports of the Princeton Univ. exp. to Patagonia 1896—99. Vol. I.

[3] Quart. Journal, n:o 59, 1903 p. 160.

[4] Petermanns Mitt. 1906, p. 186.

the gorge which it follows opens into the innermost fiord of the Calen Inlet. The eastern end of the lake presents a very different aspect. A great plain about 15 m. above the level of the lake stretches away to the east, intersected by a small rivulet coming from the Laguna Tar, a lake of some 10 km. in length. The level of this lake is 18 m. above San Martin. The monotony of the plain is only broken by low morainal ridges, which here and there rise above the even plateau. Just to the east of the Laguna Tar the present watershed is situated at a height of 224 m. above the sea, i. e. 24 m. above the level of San Martin. A small rivulet, the Arroyo de la Meseta, which flows into the Laguna Tar, at one point actually follows the watershed itself, which consists, as usual, of morainal deposits, an example therefore of a river bank being the conti-

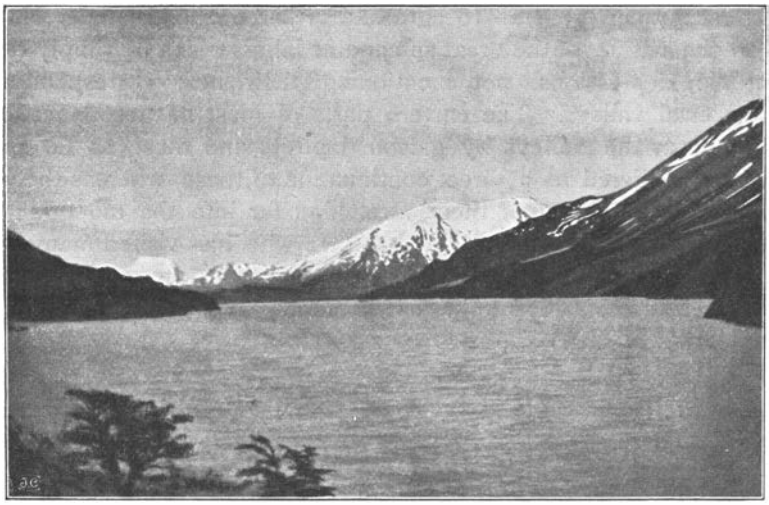

Fig. 3. Northwestern fiord of Lago San Martin.

nental water divide. At high water in the spring this rivulet would overflow and partly drain *towards* the Atlantic, following the great valley of Shehuen, which commences here, and to which, as is distinctly seen by the maps, the whole depression of the eastern part of S. Martin belongs. This valley which transverses the whole continent joins the valley of the Rio Chico only some 60 km. from the Atlantic. — These circumstances permit of some interesting conclusions being drawn. In the first place it is evident that the great lake of San Martin has once had its outlet through the marked valley, which is the direct continuation of the eastern part of the lake itself. A rise of 24 m. would suffice to give the lake once more an easterly outlet. The great plain east of San Martin undoubtedly represents lake deposits from the time, when the level of the lake was higher than it now is. Great erratic boulders of western origin,

strewed here and there, denote a transport by icebergs, and this is no farfetched explanation, as even to the present day several mighty glaciers flow far out into the western end of the lake, and moraine-covered icebergs are still to be seen drifting about. The trans-andine gorge has evidently long remained ice-dammed, blocking the western outlet, as on each side of the narrow gorge of the Pascua river mighty icefields remain, sending down glaciers towards the main valley. The ice-dammed lake must then have reached some 20 km. further eastward, and had its outlet over the low watershed of the present day down the Shehuen valley. As the last barrier of ice gave way to the west, the level of the lake would suddenly sink more or less to its level of today, the postglacial

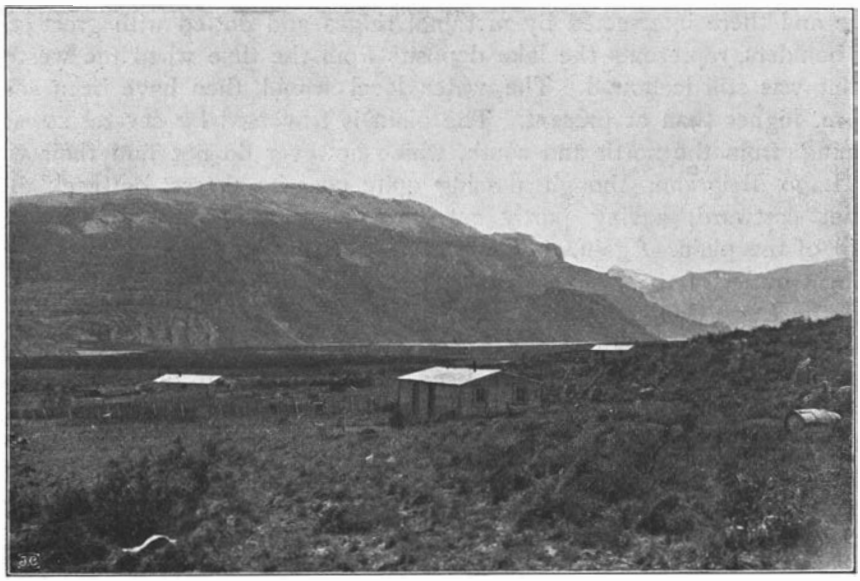

Fig. 4. Plain, consisting of gravel deposits and morainal detritus bordering the eastern shore of San Martin.

erosion in the trans-andine valley not having had time to lower the lake to any essential degree -– Taking a profile across the whole continent from the Atlantic to the Pacific, following the depressions of the Shehuen valley, the San Martin lake and the gorge of the Rio Pascua, the highest point met with, would lie 224 m. above the sea, while a profile taken only a few km. north or south would rise to upwards of 2000 m., perhaps a unique circumstance which is, with small variation and a somewhat greater minimum height, repeated time after time, parallel depressions intersecting the Patagonian continent, thus forming one of the most characteristic features of the physical geography of the country. It is as interesting as instructive to consider what the results be, were the Pascua gorge once

more to become icebound. The lake would only rise some 24 m., spread over the low terraces at its east end and seek its outlet over the watershed, following its former well defined course along the Shehuen valley.

A typical example of how complicated the drainage of the eastern Cordillera has been made by the damming up of the eastern outlets by glacial detritus, is the small alpine lake of *Belgrano* on lat. 47° 50′ long. 72° 10′ W. and at a height of 780 m. The eastern end of the lake forms the direct continuation of the broad Rio Belgrano valley, a tributary to Rio Chico, and belonging to the category of the transversal Pampean valleys. Blocking up the valley and forming the present watershed, a wide plain of lacustrine deposits stretches from the shore of the lake several km. inland. Its height is about 70 m. above the lake level. This low land, here and there intersected by morainal ridges and dotted with great erratic boulders, represents the lake deposits from the time when the western outlet was still icebound. The water level would then have been some 70 m. higher than at present. The plain is traversed by several streams coming from the north and south, which however do not find their way to Lago Belgrano, though passing quite near its shores, but seek their outlet eastward, having partly cut down deep cañons through the loose sand of the plain. Again, therefore, a river following the watershed! The present outlet of the lake presents a very different aspect. At its western end the Lago Belgrano communicates, by a short river, forming a waterfall, with another lake, Lago Azara, which in its turn drains into Lago Nansen. The outlet of this lake becomes a tributary to the River Meyer, which, after many bends and circuits, flows into a fiord of the S. Martin lake. The ultimate outlet of the Belgrano is therefore to the Pacific, through the Pascua river by a series of lakes, valleys and gorges, while the natural outlet to the east is only blocked by a low terrace of lake sediments from the time Lago Belgrano was still ice-dammed westward.

Lago Buenos Aires.

Having given a description of the San Martin — Belgrano system as one of the most typical examples of the evolution of the sub-andine lakes, I will only draw some short parallels regarding the other lakes. *Lago Buenos Aires*, is very much more regularly shaped and more typical of the sub-andine lakes in general than San Martin. Its height is 217 m. above the sea. To the east it is bordered by a wide and typical moraine landscape. Close to the lake well marked terraces mark the old shores. The watershed lies 116 m. above the present level of the lake, and is situated at the well known Paraiken, where the river Fenix makes its sharp bend toward Lago Bueonos Aires. A short canal dug through a swamp would suffice to turn its water toward the east, proving the very unstable position of the watershed of the present day. The

transverse valley, which corresponds to the depression of the eastern part of the lake, is that of the Rio Deseado, forming a broad valley, now almost destitute of water.

The present outlet of the lake is through the river Las Heras, which after receiving the waters of Lago Pueyrredon, another of the sub-andine lakes, opens into the Calen Inlet. It is noteworthy that two trans-andine gorges end in the inner part of the Calen Inlet, the whole of the Cordillera range between the Rio Pascua and Rio de las Heras being essentially lower and more free of ice than either to the north or south.

Valle Frias-Rio Pico.

The valley of the Rio Frias lat. 44° 40, gives an example of how no lake has been formed, the trans-andine pass having been low enough to drain off the whole valley. But numerous traces of a former lake are met with, from the period when the outlet westward was still ice-dammed. The watershed is at its lowest point 880 m. About 10 km. westward the bottom of the valley is about 780 m. Following up the Arroyo de los Patos southward, I came across some very well defined terraces as well as an interesting profile in the river bed. The terraces are 890 and 1005 m.,[1] the deposits consisting of loose sand and gravel. The profile shows a cutting through the narrow valley of the stream. On the one side the whole bank, 60 m. high, is built up of only loose stratified sand, on the other 50 m. is composed of a moraine, and only 10 m. of sand. The summit corresponds with the 1005 m. terrace. Numerous erratics of significant size are found strewn about on the terrace, evidently brought there by icedrift, and as usual denoting a westerly origin. The moraine of this profile is of a very typical structure and is evidently part of a terminal moraine crossing the head valley, but parallel with the smaller valley of the tributary. The lower terrace of 890 m. seems to correspond with the watershed of the present day. What connection the higher terrace has had to the present waterdivide, or whether it represents the height of an older watershed further east, now eroded away, I dare not say, only having this one observation to build upon. Detailed investigations of these parts, as of so many others is sadly needed and would without doubt lead to interesting results. The terraces must in some way be formed by deposits of the once ice-dammed lake. — At the bottom of the head valley a fine banded clay is visible in several places.

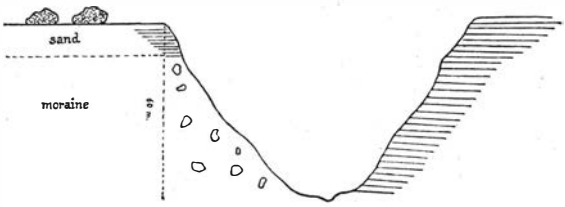

Fig. 5. Cutting through the Arroyo de los Patos valley.

[1] Aneroid measure.

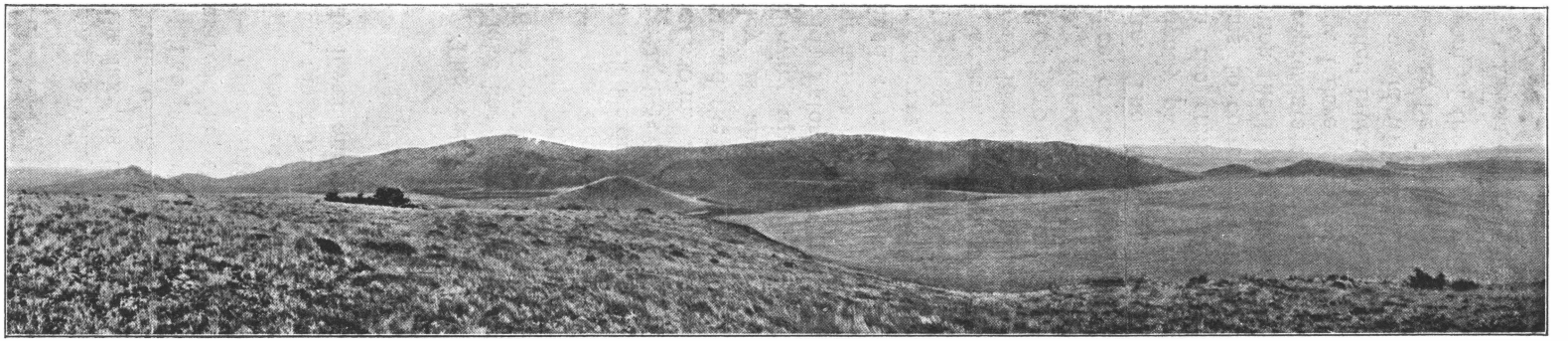

Fig. 6. The watershed, consisting of morainal deposits, to the east of Rio Frias, showing former outlet of the ice-dammed lake.

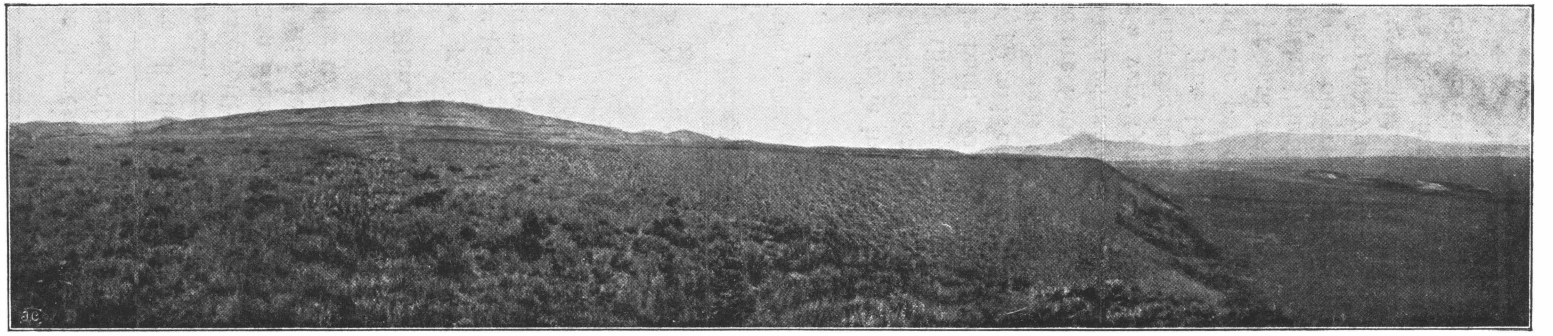

Fig. 7. Terrace in the Rio Frias valley.

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Somewhat further north the valley of the *Rio Pico* shows traces of the same evolution. The watershed lies 770 m. above the sea level and is situated in a typical morainal landscape. To the west the broad valley of the Rio Pico stretches away towards the Cordillera, where its waters enter a norrow gorge, eventually joining the Palena river. The valley near the watershed slopes very gradually, great swamps and numerous small lakes and ponds being the last remains of a former great lake. Well defined terraces right up to the present watershed indicate the former level of a lake, in all probability caused by the present western outlet still being filled by ice. The corresponding transversal valley, the outlet of the former ice-dammed lake, is that of the *Rio Senguerr* and its tributary *Arroyo Ñirehuao*, now separated from the Rio Pico valley only by a series of morainal ridges.

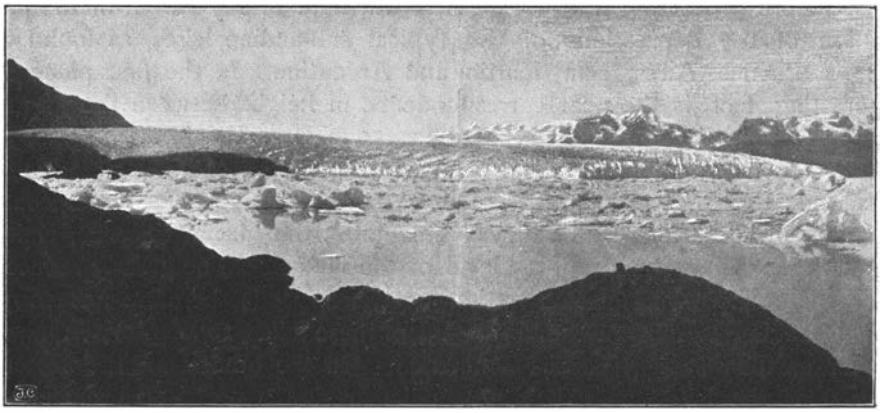


Fig. 8. The Upsa'a glacier in the northwest arm of Lago Argentino.

Lago Argentino.

We will now turn south of Lago San Martin. *Lago Argentino* differs in some respects from the other lakes. Its form is typical, the contrasts between its broad eastern end, bordered by the Pampeans ediments and the narrow fiords with precipitous cliffs over 1000 m. high, which form its western parts, is striking enough. But Lago Argentino has still its outlet eastward to the Atlantic ocean by the *Santa Cruz* river, which would find its natural explanation in a corresponding trans-andine pass not existing to the west. But even did such a pass exist, it would have no influence on the drainage of Lago Argentino, as it would still to this day be icebound. To the west of Lago Argentino the great inland ice of south Patagonia still holds its grip, sending down mighty glaciers into the fiords of the lake. What is hidden beneath its icy cover can of course not be discerned, but it is a fact, that behind the great Upsala glacier

of the north arm of the lake there exists a very marked depression in the Cordillera, as may be seen in the photo. Possibly there exists an ice-dammed passage westward, which would show us an interesting picture of the evolution of the sub-andine lakes. To the east Lago Argentino is bordered by glacial and fluvial deposits, through which the S. Cruz has cut its way. Great erratic boulders lie scattered on the top of the sand and gravel terrace some 25 m. over the level of the lake, indicating that the postglacial erosion of the S. Cruz has sunk the lake considerably. What part the great lava eruptions, which have crossed the river bed have played I cannot say, not having had the opportunity of visiting these regions.

Formation of sub-andine lakes.

Before proceeding further south, I will here briefly dwell on the formation of the depressions of the typical sub-andine lakes, as found in Lagos Buenos Aires, San Martin and Argentino. In the first place an interesting fact is the near correspondence in height between the largest lakes: Lago Argentino 200 m., Viedma 250 m., San Martin 200 m., Pueyrredon 199 m., and Buenos Aires 217 m. I have several times already emphazised, that the eastern parts of those lakes seem to be a direct continuation of the transversal valleys. Imagining the glacial deposits, which head these valleys, removed, the level of the lake would be greatly reduced and the valley would stretch further westward. It is therefore necessary, when seeking to explain the formation of these lakes, to keep this in mind, as far as their eastern part is concerned. On the other hand the western fiords of the lakes with their perpendicular shores present an aspect so totally different as to claim another explanation. They have every resemblance to the Alpine lakes of other mountain landscapes and without doubt ice has played a principal part in moulding their present form. Descending the steep mountain sides, the glaciers reach their maximum of erosive power. But further eastward the glacier, which had once filled the whole depression, has not had the same power to erode, the fall there being insignificant, if any, and in this case the ice would spread out more as in a piedmont-glacier. Of course a series of soundings in these lakes would be most interesting and doubtless give a definite answer as to the mode of formation of these depressions. There is however every reason to suppose, that the deeper part of the lakes is to the west, the whole topography of the country indicating this to be the case, especially by analogy with the very simular inlets further south, where the depths are known. I will return to this question later on after having dealt with the general formation of the southern inlets. In trying to solve the formation of the sub-andine lakes it is therefore necessary not simply to classify them, as AMEGHINO and HATCHER do, as tectonic depressions, but assume, that in their eastern parts they represent the continuation of the erosion valleys

of the Pampas, whereas their western parts have without doubt to a great extent been moulded by glacial erosion. In pre-glacial time the watershed would then have lain along the eastern slopes of the Cordillera.

As to the trans-andine passes, there can be no doubt that they are old preglacial depressions, and that therefore in pre-glacial time low passes have existed at intervals, transversing the whole Cordillera. Glacial erosion may have done much to deepen them, whereas, from reasons already mentioned, postglacial erosion can not have played any significant part.

In continuing south of Lago Argentino several breaks through the Cordillera are again met with, but differing from the trans-andine valleys I have described by being submarine, that is to say consisting of narrow fiords or channels transversing the Cordillera range, and at its eastern side widening out to considerable inlets. The analogies with the trans-andine

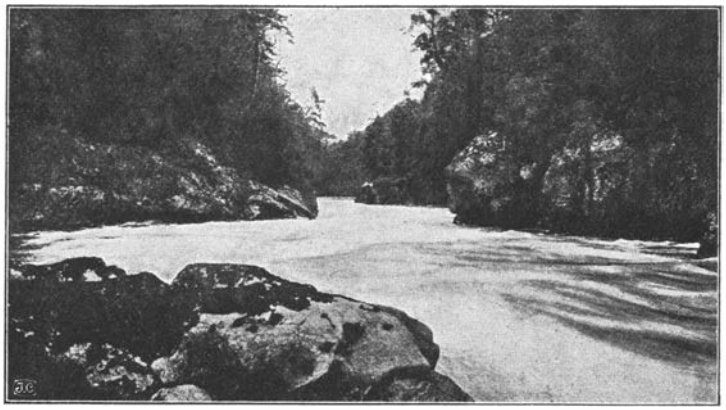


Fig. 9. Trans-andine valley of the Rio Ftaleufu.

valleys and the sub-andine lakes are however so numerous and so remarcable, that it seems as if on the whole their existence were caused by the same geological powers, the only difference being that the land to the south lies essentially lower, the valleys therefore being represented by fiords, the lakes by inlets of the ocean.

Otway and Skyring Water.

The two great inlets, *Otway* and *Skyring* Water together form an equally interesting as singular drainage system. Through the narrow Jerôme channel you enter from the Straits of Magellan into an 80 km. long, 25—30 km. broad inlet, known by the name of Otway Water. In its north-eastern corner it in its turn communicates with Skyring Water through the Fitz-Roy Channel.

Both inlets stretch far outside the mountainous Cordillera range. The eastern shore of Otway is bordered by low land, which divides it from Cabeza del Mar, an inlet of the Magellan Straits, cutting deep into the country. The breadth of the intervening land is only about *10 km.*, and at its lowest level it may be safely said, its height does not exeed 30 m. The eastern part of Skyring and the Fitz-Roy Channel are bordered by the *Palomares* range, consisting of tertiary sandstones. To the N. E. of Skyring there is another depression towards the Laguna Blanca, which lies 140 m. above the sea. Westward the topographical features rapidly change, the mezozoic and tertiary formations, which towards the east form an only slightly tilted monoclinal, become more violently disturbed, till

Fig. 10. Fiord in western Skyring, looking eastward.

in the western fiords of Skyring you find yourself surrounded by the meta morphic crystalline rocks of the Central Cordillera. Here Skyring Water communicates with the gulf of Xantegua by the narrow Cajardo Channel.

It was especially near *Los Amigos* at the north end of the Fitz-Roy Channel, that I had a good opportunity of studying the glacial formations. Skyring Water is to the east bordered by a considerable, perfectly even plain, stretching from Los Amigos to beyond Rio Verde. It divides into two well-marked terraces, the lower 13 m., the upper 24 m. high. The whole of the lower terrace consists of fine sand, inter-layered by more or less coarse gravel. Numerous erratic blocks of every description are deposited, without any sign of order, at different heights. They are all of a westerly origin, belonging to the rocks forming the main Cordillera range. Underlying this sand deposit we found, about 400 m. north

of the Los Amigos Stores, a cutting down by the shore, showing a well stratified clay. with all the characteristic features of the banded clay of our hemisphere. There exists the same variation of colour in the deposits, and the same difference in the grain between different years. The contact between two yearly deposits is as a rule very sandy, samples easily falling to pieces. In 270 cm. I counted 58 layers, increasing in thickness downward, without reaching the bottom. There can be no doubt, that these sediments are of glacial origin.

Before discussing the formation of these deposits, I will again call attention to the relation between the glacial *ice divide* and the postglacial *water divide;* whereas the former, judging by all transport of erratic blocks, has here also followed the main Cordillera range, the latter is situated far to the east and consists of low morainic ridges or glacial deposits. During the time of glaciation the ice has therefore in the same way as it dammed up every outlet through the trans-andine valleys in the north, here barred the fiords, cutting through the Cordillera, transforming them to ice-dammed lakes or, in the case of Otway Water, to inlets barred in the west by ice, for there is every reason to believe, that the low land, which now divides Otway from Cabeza del Mar, has still been submerged at the end of the glacial period. — Otway and Skyring as well as the fiords of Ultima Esperanza, have thus for a period had their communication with the Pacific channels cut off by a wall of ice.

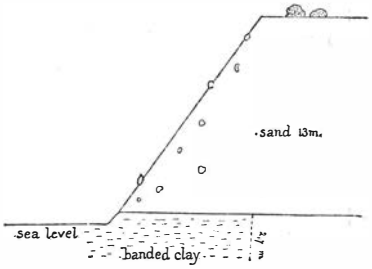


Fig. 11. Profile of terrace to the east of Skyring water.

From the Magellan Straits a deep bay has probably, towards the end of the glacial epoch, cut into the country over Cabeza del Mar and Otway. At the western end of Otway large glaciers have discharged themselves, just as to-day the western fiords of Lago Argentino and Viedma are filled by ice. The Brunswick Peninsula has at this time been an island.

In Skyring Water conditions have been somewhat different. That its narrow outlet to the west has been ice-dammed, is still more obvious than in the case of Otway. Here the glaciers even to this day reach the water's edge, and just at the Gajardo Channel a glacier terminates in a perpendicular wall of some 30 m. out in the water, where numerous small icebergs break loose and are driven by the strong tidal current either into Skying or into the Xantegua Gulf. It needs but a very small advance of the glacier, again to bar the communication in this direction, especially as the channel is so shallow, that great boulders, without doubt from an old washed-out moraine, are laid bare at low water, making it difficult to pass even in a rowing-boat. Another break in the Cordillera exists between Exelcior Sound and Obstruction Sound, but this pass is

now-a-days super-marine though the highest point does not exeed 20 m. Both these passes having been filled with ice, Skyring has had to find its outlet eastward and the lowest pass in that direction has without doubt been the low land, which divides Otway from Skyring, now transversed by the Fitz Roy Channel, which has cut its way through large moraines and fluvioglacial deposits. Beautifully modelled terminal moraines to a height of 60 m above the sea level are cut through by the channel, which in reality more resembles a river than anything else. And it may be presumed, that its original formation has been connected with Skyring emptying itself into Otway, although the broad break, measuring about 10 km., through the tertiary strates between the Palomares range in the

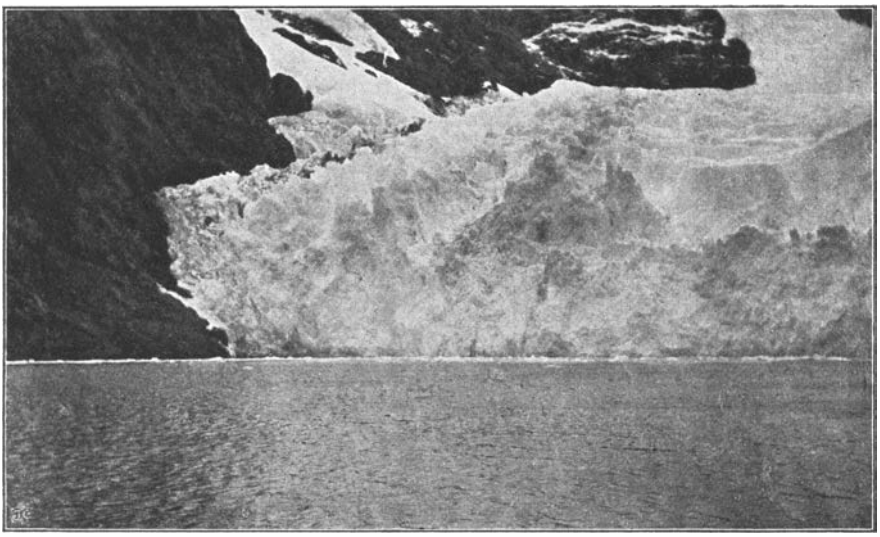


Fig. 12. Glacier still partly barring the Gajardo Channel.

east, and the Cordon Riesco in the west, is of older origin. This broad break has been filled up with glacial deposits by the receding ice. The water in these glacial lakes or rather inlets has been essentially higher than now. A whole series of terraces at varying heights both in Otway and Skyring, some of which MR HALLE has measured, give a positive proof of this. As the land rose, the channel has cut its way deeper and deeper through the loose material, and several well marked terraces on each side up to a height of about 50 m., mark the different steps. During this period the glaciers have receded to the western part of the lake, and the deposits of glacial clay and sand have taken place. On the sand terrace, described above, which is a typical ice lake deposit, occur on a small area a quantity of large erratic boulders, derived from the Cordillera formation in the west, the existence of which can hardly be explained otherwise than through icedrift. Their having collected in one place may

depend upon large icebergs having principally run aground there. Smaller erratics are, as before mentioned, strewed through the whole sand deposit.

It is not likely, that the ice-barrier disappeared exactly simultaneously in both Otway and Skyring; to judge from the distribution of the ice of the present time it would seem most probable, that Otway Water first regained its communication westward through the Jerôme Channel. If this took place while the land to the east was still submerged, or if the elevation had already transformed the former inlet into a lake, cannot as yet be decided though the former alternative seems the most probable. As the land has subsequentially risen, Skyring Water, still ice-dammed to the west, has erodated its channel deeper and deeper through the loose deposits of the Fitz Roy Channel, till its waters have gained the same level as Otway. The cessation of the ice barrier in Skyring has under these circumstances had no other effect, than that of converting the lake of sweet, or at most insignifically brackish, water into an inlet, with communication outwards at its two ends.

Just south of Los Amigos there exists a good profile of the deposits, which have filled the old depression between Otway and Skyring. At the bottom there are good-sized moraines of typical development and with erratics denoting transport from the west. Above this comes finely stratified clay, and then sand with beautiful current bedding, indicating a fluviatile formation. The whole of the Fitz Roy Channel, which is 20 km. long, and only 5—800 m. broad, is therefore to be interpreted as a post-glacial river, which rapidly has eroded itself down to its »base level», through the loose deposits, which during the latter glacial age have filled up the older depression. In its present aspect it has not the slightest resemblance either in formation or structure to the fiord-like inlets, which generally go under the name of channels.

Lastly, a few words on the depths of Otway and Skyring. The soundings confirm, what the general topography of the country would lead one to suppose, namely an increasing depth to the west. Whereas at about 10 km. from the eastern shore the depth scarcely exceeds 50 m. and at 25 km. scarcely 100 m., the western parts of both inlets show over 600 m. In the fiords furthest westward the depth decreases again to 100—200 m. — There being so many other striking resemblences between these inlets and the sub-andine lakes further north, one may venture to presume, that the relative depths of those depressions are also similar, a supposition, which is supported by the nearly corresponding topography of the country. In how great a degree the shallowness of the eastern parts is due to the deposits of glacial detritus, can, of course, not be positively decided, though, as before mentioned, the glacial deposits often reach a very great thickness.

The Ultima Esperanza district.

About the same evolution in postglacial time, as has been traced respecting Otway and Skyring, must have taken place in the Ultima Esperanza territory. The narrow Union Sound is at present the only waterroad between the Pacific and the labyrinth of inlets and fiords, which form the waters of Ultima Esperanza. Another pass, though not at present submarine, I have already mentioned between Obstruction Sound and Skyring Water, which however only reaches a height of about 20 m. But as in the case of Otway and Skyring it is probable that these passages have been blocked by ice till late in the glacial age, and that a large lake has been formed, which has had its outlet eastward to the Atlantic. The land to the east of Disappointment Bay consists of alluvial deposits forming the low land known by the name of the plains of Diana. Here and there a well-marked morainal ridge rises above the even terraces. The watershed, which parts the tributaries of the river Turbio from the Pacific drainage, is only 82 m. high[1] and consists of morainal deposits. Therefore no high land separates the waters of Ultima Esperanza from the Turbio valley, and without doubt the oulet of the lake has been situated here, the Turbio and Gallegos valleys having drained the whole fiord system into the Atlantic, this presuming that the low land has not still been submeged, which was possibly the case in an early stage of the post-glacial period. As the land rose however, the river has flowed this way till the moment, when the passage westward became free of ice. Even here many well defined terraces mark the height of the old water level.

MORENO, who during the mapping of the country visited these parts, also recognized in the low land east of Obstruction Sound an old glacial river bed. But, as well here as in discussing the corresponding questions further north, he hardly mentions the ice as having played any prominent part, but ascribes the changes in the drainage to a very recent elevation. On the Ult. Esperanza district he writes: «The broad valley, which extends between Obstruction Sound and the Atlantic Ocean, is an ancient channel, filled with glacial detritus, which gives it a characteristic appearence, with extensive lateral moraines and frontings, cut by the great glacial river, the gradual decline of which is shown by the terraces left by its distinct levels», — and a few pages further on he continues:[3] «The present Pacific Channel (Ult. Esperanza) formed another (lake), which also emptied into the Atlantic by way of the river Gallegos, before the erosion wearing away the rocks in Kirk Straits connected the ancient lake with the Pacific, converting the fresh water into salt». As we have seen the southern

[1] Zeitschr. für Erdkunde, 1903, p. 171.
[2] Geographical Journal, 1899 p. 253.
[3] Ibid. p. 256.

Patagonian Cordillera, only reckoning north of the Magellan Straits is intersected in three different places by narrow inlets, the Jerôme Channel, the Gajardo Channel and Union Sound. To the north of the latter the inland ice commences and stretches without interruption to the gorge of the Rio Pascua on lat. 48, a distance of over 450 km. The valley of the Pascua is the first of the series of trans-andine valleys, which cut through the mighty mountain range, gathering the water of the eastern slopes into the Pacific. As I have already mentioned, there seems to exist no essential genetical difference between the northern trans-andine valleys and the channels of the south. I do not intend here to enter into a detailed discussion of the different theories concerning the formation of the trans-andine valleys. It is sufficient for the question before us, that postglacial erosion has had very little to do with their formation. As already mentioned, many of these valleys have only recently been freed from ice, and quantities of morainal ditritus is deposited all over the slopes. At two different places, in the inner part of Estero Resi, a westerly inlet of Wolsley Channel, where a pass only about 25 m. high divides the Ult. Esperanza fiord from the Canal de las Montanas, as well as in the valley of Ftaleufu, I have seen glacial striation close to the river bed, which distinctly shows, that the erosion in postglacial time has had but little influence. In studying the interesting geology of these valleys I think one must keep in mind the near relation between the northern and southern representatives.

The general geology of the district north of Ult. Esperanza is comparativly well known from the papers written by NORDENSKJÖLD in 1898 and HAUTHAL 1907,[1] the latter paper accompanied by a geological map of the country between Ult. Esperanza and Lago Argentino. I will therefore confine myself to some few and brief remarks on these parts.

The district from Ult. Esperanza to the Baguales range in the north is known under the name of the Payne District. Numerous larger and smaller lakes abound in this typically morainal landscape. The eastern shores of the Lago Toro as well as of Lago Sarmiento are bordered by the finest landscape of terminal moraines imaginable. They are well illustrated on Hauthal's sketch, lying in a four-double row, gently curved to the east, and reaching a height of up to 100 m. These perfectly built terminal moraines have been formed by the large glaciers which once have filled the depressions now occupied by the lakes, barring the western outlet of the present day. The whole district has at that time formed one great sheet of water, probably seeking its outlet over the Vizcachas pass. The watershed there lies 315 m. above the sea level. Just eastward of the Vizcachas river the tributaries to the Coile originate, the watershed, according to Moreno, being a ledge of shingle and sand,

[1] O. WILCKENS, Erläuterung zu R. Hauthals Geologischer Skizze des Gebietes zwischen dem Lago Argentino und dem Seno de la Ult. Esperanza. Berichte d. Naturf. Gesellsch. zu Freiburg Band XV p. 75.

scarcely three feet in height. It is even said, that at high water the Vizcachas river overflows, discharging some water eastward to the Atlantic by the Coile valley. The analogy with the conditions in the north is therefore complete.

The Cami depression.

Passing over to Tierra del Fuego the same general features in the physical geography are met with as all along the eastern Cordillera of Patagonia.

During the 4 weeks we spent on the western shores of Lago Cami (Lago Fagnano), I devoted some time to the study of the glacial and alluvial formations of this neighbourhood. The probability has already several times been discussed, as to whether the Admiralty Sound and the valley of the Cami together form a direct continuation of the great longitudinal valley of Chile, to which a tectonic nature is ascribed. Its close resemblance to the Beagle Channel has also been pointed out. Before touching on these questions I will give some detailed observations of the parts we visited, which in some degree may contribute to solve the true nature of the Cami valley.

The Lake Cami, (which is the original Indian name and therefore preferable to the more recent Lago Fagnano) lies some 80 m. above the sea level and finds its outlet through the 13 km. long Azopardo river into Admiralty Sound. The length of the lake is 90 km., stretching in a more or less east to west direction, its mean breadth is some 6—8 km., though its western parts are narrower. On the whole the valley shows a widening out towards the east, reaching its greatest breadth of 12 km. towards its eastern end.

The valley of the Azopardo river corresponds with the mean direction of the lake and constitutes the shortest way of communication with the Admiralty Sound. The north side of the narrow valley is bounded by the isolated heights of M:t Hope, and at the other side of these, there is again another valley, in its orographical features as well as in its morphology, in every way resembling the Azopardo valley. This valley seems also to be a part of the Admiralty-Cami depression, though a low ridge, some 20 m. high, now constitutes a local watershed midway between Cami and the Admiralty inlet. The combined width of these two parallel valleys corresponds with the breadth of the adjacent parts of the Admiralty-Cami depression, and the mean direction also coincides. It seems probable therefore, that in these two combined valleys the continuation of the Admiralty depression is to be found, and the isolated heights of M:t Hope must be considered as a horst, now occupying the middle of the valley. The geological structure of this mountain, which I will treat more fully in another paper, points towards the same explanation.

The Cami lake has, as mentioned, its outlet towards the west into Admiralty Sound. But during the later glacial period as well as in preglacial times this feature seems to have differed essentially. During the glacial period, the ice-movement in the Admiralty Sound has had a westerly direction. A quantity of small islets show a marked »Stoss- und Leeseite», with full evidence marking the flow of the ice from east to west. In the Cami valley, on the other hand, the ice has moved in the opposite direction, here also the islets show a marked »Stoss-seite», but indicating a movement from west to east. On a boat excursion, which Dr SKOTTSBERG undertook some 20 km. down the lake, he observed several fine morainal hills, which I, from his description and sketches, take to represent without doubt the last remains of large terminal moraines. They consist of well marked ridges, the one end resting against the southern shore, the other in a gentle curve stretching out into the lake. Stones out of these moraines consist to a large extent of the characteristic rocks of M:t Hope, which to my knowledge do not exist further to the east, and therefore distinctly indicate a glacial movement from west to east.

During the ice age the ice in the Admiralty-Cami valley has therefore, at least during some period, moved in two opposite directions, and the contemporary local ice divide must be sought in the present Azopardo valley. The greatest masses of ice have in all probability come from the broad Betbeder valley and from there followed the Cami depression eastward.

A more detailed investigation of the Azopardo valley gives some interesting details on these questions. Where the river flows out of the Cami it cuts through a morainal ridge, which in a NE—SW direction crosses the valley. After that the river flows along the steep slopes of M:t Hope, the northern shore consisting of bare rocks, the southern, on the other hand, of morainal and especially of gravel deposits. About 400 m. east of the Mascarello river's outlet, bare rocks begin to show even on the southern shore, and the river soon after flows into about a 2 km. long, narrow cañon with steep sides. The whole of this rock chasm has a very recent character, the rocks showing no signs of glacial striation which leads me to ascribe to it a postglacial age. Before its formation there must, then, have existed a low rock ridge, at about the same point as is still to be found in the parallel valley close by. Somewhere about here, therefore, the ice divide must be sought, and the small glaciers, which from here flowed westward into the valley, would follow the natural incline of the ground towards Admiralty Sound.

OTTO NORDENSKIÖLD, who in 1895—96 visited these parts, writes on the Azopardo valley as follows:[1] »Letztere Stelle (the Azopardo valley) ist intressant, weil das ganze Thal hier oberseeisch liegt. In Osten liegt der grosse Fagnanosee, dessen Tiefe 300 m. betragen soll. Durch den

[1] Ueber die posttertiären Ablagerungen der Magellanländer. Wissensch. Ergebn. der schw. Exp. 1895—97. Sthlm. 1899. p. 54.

Azopardofluss wird es mit dem Almirantazgobucht verbunden. Der Fluss läuft an mehreren Stellen zwischen steilen Felsenwänden hin, ohne dass jedoch für die Annahme ein *sicherer* Beweis vorhanden wäre, dass die Thalsole dort höher liege als der Seegrund.» I fail to see, that there is any possible or probably reason to assume, that the narrow chasm, lying some 40 m. above the sea, should be filled up by loose material, and that therefore the bottom of the valley should lie lower than the sea level. A rock cañon of only some 20 m. in breadth, but with an original depth of over 60 m., which later has been filled by loose material, certainly would be an unusual form of erosion, especially as the fall of the river just here is uncommonly strong. NORDENSKIÖLD continues as follows: »Ausser diesen Felsen, die schon durch ihre Form wenig an die abgerundeten *Roches moutonnées* anderer Gletscherthäler errinnern, besteht der Thalriegel aus lockeren Schuttmassen, die aber nie Moränen ähnlich sind und nie westliche Blöcke enthalten. Wenn überhaupt dieses Thal einst in nicht allzu weit zurückliegender Zeit das Bett eines Gletschers ausmachte, so kann das nur eine kurze Zeit der Fall gewesen, und die Eismassen müssen ziemlich unbedeutend gewesen sein. Dagegen tragen die an den Seiten mündenden Querthäler deutliche Spuren einer früheren Eisausfüllung an sich.» As already mentioned, the fact, that the rocky shores of the cañon do not show any traces of glacial erosion, I explain by its formation in postglacial time. NORDENSKIÖLD mentions the absence of »westliche Blöcke»; what the author means by this is not quite clear; the formation westward in Admiralty Sound consists of phyllite slates, and they are naturally not represented, the ice never having flowed in that direction. At the same time I fully agree, that the glaciation of the Azopardo valley has been of quite a local nature, as the ice, which has once filled it, has only been fed by the glaciers from the small by-valleys on the south side and from the comparatively small ice covering of M:t Hope. To the question of the absence of moraines I will return later on.

Venturing to calculate how the topographical features of the Cami have presented themselves in glacial times, I first assume that the glacial pass in the Azopardo valley has been some 20 m. higher than at present. At the ultimate regression of the ice, the water in the Cami would therefore have reached the same height and one would expect to find some signs of raised beaches along the shores. I have however found no traces of any such formations. But another circumstance must now be reckoned with. After the distribution of the glaciers in present times, it is presumable, that the ice has remained longest in the western part of the lake. In the upper part of the Mascarello valley as well as on the heights to the south thereof there still exist fairly considerable glaciers, while mountains of the same height further to the east are all but free of ice. If therefore the great Cami glacier which once has filled the whole valley, has towards the end of the glacial period retreated to the western end of the lake, this would bar an outlet in that direction, the lake would be ice-

dammed, and would have to seek its drainage eastward towards the Atlantic ocean.

Having come to this conclusion, we have now to turn to the eastern part of the lake, to find what evidence can be gained there relating to the glacial period. I much regret not having had the opportunity of visiting these parts myself, but Prof. J. G. ANDERSSON has given some valuable dates, gathered from an excursion from Harberton on the Beagle Channel to the east end of Cami during the Swedish Antarctic Exp. 1901—03. ANDERSSON writes:[1] »The east end of lake Fagnano (Cami) is bordered by low land, which separates the lake from the mountains rising in the S. and N. In an easterly direction this low land joins the vast plain of northern Tierra del Fuego. In some places the shore of the lake is low and bordered by small lagoons, but in general there rises above the beach a low barrier, (about 10 m. high).» In the following description the author asserts, that the eastern end of the lake is barred by glacial deposits, in which the erratic blocks signify a western origin. Interlayered with these deposits of indisputable glacial origin he mentions sand with current bedding, coarse gravel and stratified clay. — As may therefore be seen, not only is the eastern end of the lake blocked by glacial detritus, but these also are intermixed with clearly stratified layers, which may be interpreted as fluvioglacial deposits. As in the western parts of the lake traces of a great ice stream have been met with, moving in an easterly direction, the conclusion can safely be drawn, that the moraines at the eastern end of the lake have been deposited by the same large glacier.

There are as yet too few positive dates regarding the secular rising of the land in these parts to enable us to say with certainty, whether the receeding Cami-glacier towards the end of the glacial period discharged itself into a lake of more or less the same dimensions as today, or if the low land between Cami and the Atlantic was then submerged and the greater part of the Cami valley in consequence formed a narrow inlet of the ocean reaching far into the centre of the Fuegian island. The notes that exist on raised beaches in the south of S. America are scarce and sporadical and date from several different sources. DARWIN gives as the maximum height of the sea in alluvial time 125 m.[2] in the S. Cruz valley 140 miles inland. But as this date is grounded on the find of one single much worn sea shell, it is not as reliable as his more defined terraces of 93 m. on the latitude of Gallegos. NORDENSKIÖLD[3] recounts a well marked terrace of over 10 km:s breadth at Useless Bay in the Straits of Magellan at a height of 55 m., with a quantity of erratic boulders on its surface and considers this as the maximum of the elevation in postglacial time. J. G. ANDERSSON[4] describes a raised beach of 3,5 m. height at

[1] Bull. Geol. Inst. of Upsala N:o 8 (1906) p. 180.

[2] DARWIN, Geol. Observtion on S. America, London 1846, p. 9.

[3] NORDENSKIÖLD, Post tertiäre Ablagerungen s. 59.

[4] J. G. ANDERSSON, Geol. Fragments. Bull. Geol. Inst. of Upsala N:o 8, p. 182.

Harberton in the Beagle Channel as the highest traces there of moraine action, but later observations by T. HALLE, to be published in this Bulletin, show that the elevation is, at least in parts, greater. But still our knowledge is much too limited to give a complete or continuous impression of the postglacial elevation. On the whole it seems, as J. G. ANDERSSON has already remarked, as if an unequal upheaval of land occurs here with a probably greater elevation in the north than in the south. I have here recounted these observations so as to gather from them an approximate maximum height of the postglacial elevation, which I will calculate to be 100 m., leaving it an open question if land of lesser height than this, where as yet there are no actual measurements of the postglacial upheaval, *was or was not* submerged at the close of the glacial period. It must therefore, for the present, be left undecided, whether the Cami lake towards the end of the glacial period directly communicated with the ocean in the east, or if there existed intervening land at that time. In the former case there would have been a long narrow inlet of the Atlantic, the innermost or western part of which would still be filled by a mighty glacier; in the other case there would be a lake corresponding with the Cami of today but of somewhat greater dimensions, and, as in the former case, barred by ice towards the west and seeking its outlet eastward over the low land to the Atlantic Ocean. To be able to decide which of these alternatives have taken place, we must await detailed measurements of the littoral terraces and raised beaches on the Atlantic coast. In both cases the last disappearance of the ice in the inner parts of the Cami will have opened a new way of communication, either in the form of a narrow strait or in the form of an outlet towards the Admiralty Sound. The Azopardo river has then begun to cut its way first through the loose deposits, thereby washing out and stratifying the morainal detritus in the Azopardo valley, then eroding its way deeper and deeper through the rock, cutting out for its bed the narrow cañon above described. The reason why so few traces of true moraines are found in the Azopardo valley, would be, that the mighty river which after the last disappearance of the ice barrier sought its way through the valley, rearranged and reformed the morainal material into the large gravel deposits of today.

Some dates relating to the depths of the Cami are of interest in seeking to solve the original formation of the valley. During the above mentioned boat excursion Dr SKOTTSBERG took a series of measurements. A few km. from the western shore gave a depth of 74 m., at about 10 km. distance 85 m. and at 24 km. from the west a depth f 130 m. was reached. The Chilean Boundary Commission found in 1906, in about the middle of the lake, a depth of over 300 m. These dates seem to point to an increasing depth towards the east. Prof. J. G. ANDERSSON refers in his above mentioned paper to the depths of Cami and draws a parallel to the depths of the Beagle Channel. He writes: »At any rate there is a noteworthy analogy between the Beagle Channel and Lago Fagnano. The former we have found to be deep in

its western parts, but shallow and to a large extent filled with glacial and fluvio-glacial deposits near its eastern mouth. The western part of Fagnano is narrow, with the mountains rising steeply on both sides. Here the depth of the lake is said to be 300 m. The eastern part, on the other hand, is bordered by a low-land, built up by quarternary deposits. Here the lake itself is comparativly shallow, at a considerable distance from the shore I found a depth of only 30 m. Probably the features here described are partly due to the prequarternary orography of the two longitudinal valleys. At least it seems likely, that Fagnano was originally shallow in its eastern part, where it approaches the Tertiary plains. But on the other hand it cannot be doubted, that the deposition of glacial and fluvio-glacial beds has largely contributed to make the eastern parts of the two valleys shallow.» — From analogies with the sub-andine lakes of Patagonia I am inclined to attribute the shallowness of eastern Cami as well as that of the Beagle Channel entirely to glacial and alluvial deposits. It seems, especially in analogy with the transversal valleys of Patagonia, as if the eastern parts of the lake might be considered a valley of erosion of preglacial age, cutting through the tertiary formation, having been formed as the land rose after the last transgression of the ocean.

I have dealt rather in detail with the inlets of South Patagonia as well as with the Cami valley. But my reason has been, that many striking analogies seem to exist between these parts and the subandine lakes and valleys further north, and it is especially these resemblances, I have wanted to point out, as they are of interest in solving the formation of these singular inlets, breaking right through the South Patagonian Cordillera.

The boulder formation.

Every description of the ice age of Patagonia would be incomplete if it did not touch on the great shingle or boulder formation. But having in this paper restricted myself to the late glacial deposits of the sub-andine region, I will only dwell on those formations, which are to be found nearest the Cordillera or rather within the region of the last advance of the ice. At the same time I wish to point out, that I am in no way convinced, that the boulder-like formations found near the Cordillera are identical with what has been described as the great Patagonian shingle formation. In general I think a mistake has been made in trying under this one term to classify deposits of often very different character, and especially in seeking the same origin for the gravel deposits of the whole of Patagonia, which has given rise to as many different views as works written on the subject.

The typical boulder formation is briefly described as a more or less stratified deposit of shingle of, in general, some 10—20 m. uniformly covering the great Pampas. The stones are rounded, increasing in size towards the west and inbedded in loose sand or finer shingle. For a more detailed description I refer to the works of DARWIN[1], HATCHER[2] and NORDENSKIÖLD[3]. According to their acounts the shingle formation is evenly spread over the great Pampas plateau from the Atlantic up towards the Cordillera. In the valleys, however, it only occurs sporadically, lodged in secluded nooks and angles. Concerning its extension nearer the Cordillera the reports are vaguer. On the Latorre hills the boulder formation has been found at the height of 800 m., and even in the immediate vicinity of the Cordillera remains of a more or less typical boulder formation are reported. Without entering into a general discussion on the formation of these deposits, I will here only shortly describe one or two occurrences near the Cordillera, which may be of special interest.

On the Meseta between *Rio Mayo* and *Valle Koslowski* an interesting profile is visible. The two valleys are situated at a height of between 5—600 m., while the Meseta or plateau mountain which divides them rises almost perpendicularly to a height of 1500 m. in its western parts. The Meseta being built up of relatively loose tertiary sandstones and conglomerates, the rivers which drain it have cut down deep cañons and it is a profile in the bluff of one of these, the Rio Chalia, I wish to describe. The whole lower part of the barranca, which forms the bank of the river, consists of slates and loose sandstone to a height of several hundred meters. Above these follows a layer of loose sand, well stratified and locally with fine current bedding. This deposit lies at a height of about 1050 m., quite 500 m. over the bottom of the transverse valleys. Above the sand follows some twenty meters of coarse gravel or shingle, with well rounded stones, varying in size from some few inches to half a foot in diameter, inbedded in finer material but without any visible bedding. This deposit is, in all probability spread over the whole plateau. On the north side of the same Meseta, towards the Koslowski valley I have noticed the same profile. The question is whether this gravel deposit, which in its consistency much remsembles the shingle formation, is also genetically to be explained in the same way. At this height any other mode of formation than by fluvioglacial agency seems out of the question, as there is no proof that the whole land has been submerged in such recent times. Even if Hatcher's find of marine pliocene deposits at the height of 800 m. at Lago Pueyrredon should prove to be correct, and therefore a great pliocene transgression have taken place it would not suffice to explain the boulder formation here, at nearly double the height above the sea level, as a more or less marine deposit. The underlying sand

[1] DARWIN, Geology of S. America.

[2] Reports of the Princeton Univ. Exp. to Patagonia 1896—99. Vol. I.

[3] Wissenschaftl. Erg. der Schwed. Exp. nach den Magellanländern 1895—97. I: 1.

with current bedding also indicates a fluvial or fluvioglacial formation. It is of interest to note an analogue formation near PUERTO MADRYN, where ROTH[1] describes typical Teuelche (boulder formation) lying on a fluvial sand deposit, though here a marine deposit is also found. The analogy is, however, interesting as the points are so far apart, the one on the Atlantic coast, the other on the border of the Cordillera.

On several of the other Mesetas I have noticed very similar deposits so that as a rule it may be said, that a gravel formation covers the high Mesetas right up to the foot of the Cordillera. NORDENSKIÖLD has compared the boulder formation with the Nagelfluh of the Alps, and certainly its general occurrence and distribution in many ways resembles the Nagelfluh of the Bavarian plateau. Its near relationship to the glaciation of Patagonia seems in any case obvious. The Baguales Range, which has not been glaciated, bears no trace of any gravel deposits. On the other hand, the valleys and low land within the sub-andine zone contain a gravel deposit of essentially different appearance and without doubt of recent fluvial origin. In the Vizcachas valley a well has been sunk 12 m. through a coarse gravel interlayered with sand. These fluvial deposits are without doubt of a much later formation, bound to the valleys and probably formed by the rivers which once flowed this way.

Concluding remarks.

I will now in a few sentences try to combine the principal conclusions which may be drawn relating to the postglacial evolution of the districts dealt with.

Firstly, the ice-divide during the ice age has in general followed the central Cordillera range, whereas the watershed of the present day, often consisting of glacial deposits, is principally situated considerably to the east of the mountains indicating the limits of *the latest Cordilleran glaciation.* The transverse valleys of the Pampas and the eastern parts of most of the sub-andine lakes, which orographically belong together, are nearly separated by glacial deposits. They are to be considered as valleys of erosion of preglacial age, probably formed, as the land rose after the last mighty pliocene transgression.

Until towards the end of the ice age the trans-andine valleys must have been filled with ice, barring any outlet in that direction. The drainage of the eastern Cordillera must at that period have followed the preglacial Pampean valleys to the Atlantic. High morainal ridges and quantities of glacial detritus have been deposited in the upper parts of the valleys by the receding ice, in many cases barring the rivers and thus

[1] ROTH, Beitrag zur Gliederung der Sedimentablagenung in Patagonien und der Pampasregion. Neues Jahrbuch für Mineralogie etc. B. B. 26 p. 147.

forming extensive ice-dammed lakes. Through the very inconsiderable fall of the transversal valleys, the rivers have had but a small erosive power, and have therefore not been able to cut through the extensive glacial deposits and drain off the lakes, which, hollowed out by powerful glacial erosion, without doubt contain depths far below the level of the ocean. The passage of these former outlets through the morainal landscape is in most cases recognisable. As the last ice in the trans-andine gorges disappeared, a lower pass has thus been opened in this direction, the whole drainage system has suddenly been reversed, and the level of the lakes more or less lowered; in some cases it is possible, that the pass to the west has been low enough to completly drain off the former ice-dammed lake.

In preglacial time low passes of erosion must have existed in many places in the Cordillera. Through the accumulation of ice in these depressions, the passes may have been essentially lowered by glacial erosion, mighty streams of ice from the central parts of the mountains following these depressions both east and west. The western parts of the sub-andine lakes in every way resemble the fiords of mountain regions, which once have been the seat of glaciation and have doubtless to a great extent been formed by glacial erosion. A very marked tendency which many of the fiords of the sub-andine lakes have of stretching in a north-southern direction is in all probability due to tectonic depressions or faults caused by the forming of the Cordillera range, to which they are parallel. In dealing with the Cami depression, I mentioned that the Admiralty Sound and Cami valley often have been referred to as the continuation of the western longitudinal valley of Chile. In my opinion it lies nearer to compare the Admiralty-Azopardo depression with the many longitudinal valleys and fiords of the eastern Cordillera, to which it perfectly corresponds, as well in its geographical position as in its general morphology. The continuation of the western longitudinal valley is rather to be sought in the Beagle Channel, which in its relation to the Cordillera much better corresponds to the main longitudinal valley. Typical examples of fiords running parallel to the eastern Cordillera are found in the lakes of San Martin and Argentino, as also in the fiords of Ultima Esperanza and Skyring water. A continuous longitudinal valley to the east of the Cordillera, such as Moreno has sought to establish, can, on the other hand, hardly be said to exist. How farfetched Moreno's construction of this longitudinal depression in reality is, is obvious by the way in which it has to wind in and out; at times, as to the west of Payne, it is to be sought under the inland ice, whereas in Skyring its only representative would be the Fitz Roy Channel far outside the Cordillera range. Many of the sections which have been classified as tectonic depressions belonging to the eastern longitudinal valley are often to be reduced to low passes of erosion along the great disconformability between the central Cordillera and the sedimentary formations of the Pampas, which naturally have been a favourable place for the erosive forces to work.

There is a very decided resemblance in the general features of the physical geography of the sub-andine region and of the inlets of Ultima Esperanza, Otway and Skyring as well as in the Cami valley. The principal difference consists in the whole region in the south lying essentially lower. The geological forces which explain the general formation of the sub-andine zone are the same as those which seem to have taken the principal part in the formation of the southern inlets.

Lastly, I would draw attention to the relation between the principal sub-andine lakes and the present inland ice of Patagonia. From the Kirk Narrows in the Ultima Esperanza district the inland ice stretches without break to the trans-andine valley of the Rio Pascua, where a visible depression in the Cordillera commences, stretching to the Las Heras valley, a distance of some 60 kilometers. Here another stretch of inland ice commences and reaches up towards the pass of the Aisen river, more or less 200 km. in length. With only a break of 60 km. a continuous field of ice therefore covers the central Cordillera for more than 6 degrees of latitude. Further north the general appearance of the mountain range changes. Though mighty glaciers are still to be found, the glaciation is of a more local character and confined to the highest mountains. All the large sub-andine lakes are, as can be seen by the general map, to be found within the region of the inland ice. Also, all the trans-andine passes of the southern regions have their source from sub-andine lakes, whereas further north, though the general drainage system is the same, the lakes have been drained off. Whether this depends upon the passes having been longer free of ice, and therefore having been eroded deeper, or whether they have originally been essentially lower, is difficult to say, though the former conjecture may be a likely explanation. Even during the greatest extension of the ice it has not reached the western shores of Chiloë, though in the Estero de Riñihue on the eastern side of the Corcovado gulf. I still found rounded and striated rocks down to the sea level, and numerous erratics on the western coast of Chiloë, consisting of the Cordillera rocks, denote an ice drift in the gulf of Corcovado. I mention this to show, that even during the glacial period there has evidently been a much more limited glaciation in the Cordillera between Nahuel Huapi and Aisen, than further to the south, which has led to the orography of the present day differing in many ways.

Addendum.

Since this paper was concluded, a treatise has been published by D:r P. Krüger,[1] dealing with the physical geography of the Patagonian Andes between lat. 42° and 44° S. Though not able to deal extensively with the many interesting facts he touches upon, I just wish to draw attention

[1] P. Krüger: Die Patagonischen Anden etc. Peterm. Mitt. Ergänzungsheft n:o 164 (1909).

to one or two points which have special interrest in reference to the questions I have previously dealt with.

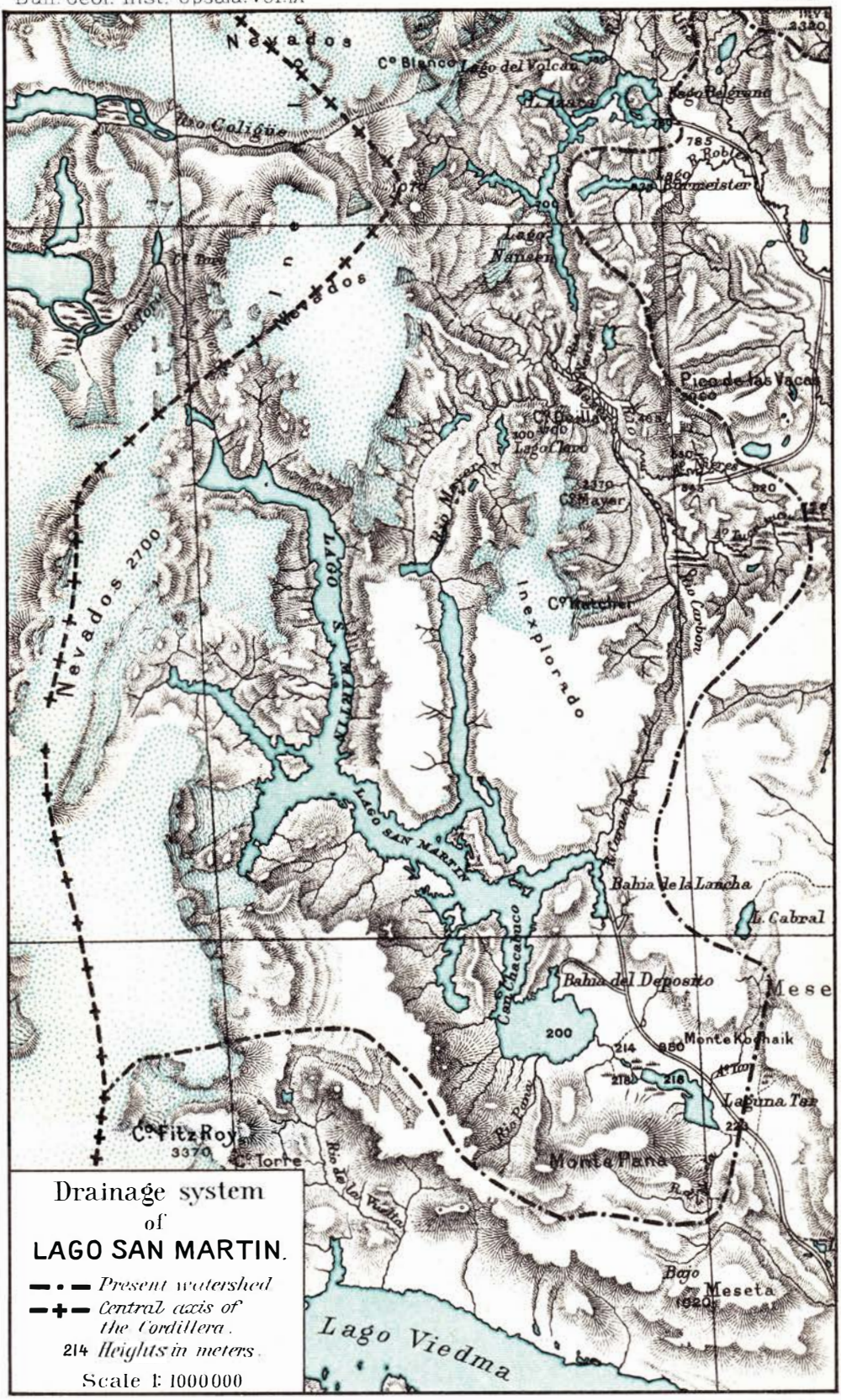
On page 107 the auther describes a series of terraces, consisting of gravel or sand, situated in the valley of the Rio Yelcho, where it widens near the tributary Rio Quilaseca. Also from several other places analogous formations are described. In discussing the formation of these terraces, (terraplenes) in the trans-andine valleys of the Central Cordillera, the author points to the fact, that they are principally formed where the valleys open towards a side valley, and mentions that in the inner parts of these valleys small glaciers still exist. D:r KRÜGER'S explanation of the formation of the terraces is, that they are not only formed by the accumulation of fluvial deposits but also by detritus from the glaciers in the side valleys. From Dr Krüger's description I think it probable, that we here see the result of an interresting process of icedamming. From the side valleys glaciers have reached down to and across the head valley, thus barring the main river and giving rise to a series of ice dammed lakes. The terraces he describes, mark the former shores of these. It is difficult to see, how glacial detritus could have been deposited as a bar across the head valley, if the glaciers of the side valleys did not also reach equally far down. It seems therefore probable that it has been the ice itself, and not accumulation of fluvial or glacial deposits, which has checked the flow of the main river. As the ice receded, the river would easily erode its way through the loose deposits, and the terraces alone would remain as evidences of the former lakes.

In many other questions the paper of Dr KRÜGER gives interesting details, in many cases showing the marked analogies in the postglacial evolution between the regions, he visited and the district I have dealt with in this paper on the question of the drainage of the eastern Cordillera. D:r Krüger builds mainly on the backward erosion in the transandine passes, which he considers to have been accelerated through the climatic contrasts east and west of the mountains. Very little mention is made of the part, the extensive glaciation of the Cordillera has played, though marks of the former glaciation are often described. As the trans-andine valleys can not have been formed in postglacial time, the ice must in every case for a longer or shorter period have blocked the outlet through these and deserves in discussing these questions at least to be taken into consideration.

Plates.

Plate 3. Drainage system of Lago San Martin.

Plate 4. General map of Patagonia, showing previous and present drainage system of the eastern Cordillera.



Gen. Stab. Lit Anst. Stockh.

GENERAL MAP
of
PATAGONIA
showing previous and present drainage system of the eastern Cordillera.
Scale 1:3,000,000
0 50 100 200 km.
74° 72° 70° 68° 66°
44° 46° 48° 50° 52° 54°
PACIFIC OCEAN
ATLANTIC OCEAN
Golfo del Chonos
Islas Chonos
Canal Moraleda
La Magdalena
Peninsula de Taytao
Golfo de Sn Jorge
Colonia Gal Sarmiento
Rio Senguerr
Rio Mayo
Rio Chico
Rio Seco
Rio Salado
Rio Deseado
Rio Gallegos
Rio Santa Cruz
Rio Shehuen
Lago Viedma
Lago Argentino
Lago Buenos Aires
Lago Pueyrredon
Lago Strobel
Lago Cardiel
Santa Cruz
Puerto Sta Cruz
Bahia Grande
Caleta Coile
Gallegos
Puerto Gallegos
Estrecho de Magallanes
Punta Arenas
Porvenir
Ushuaia
Isla Riesco
Isla Hanover
Isla Contreras
Isla Chatham
Isla Clarence
Isla Santa Inez
Isla Navarino
Isla Hoste
Isla Wellington
Canal Trinidad
Canal Fallos
Canal Smyth
Canal Wakefield
Canal Beagle
Canal Ballenero
Canal Cockburn
Canal Pitt
Canal Concepcion
Canal Stosch
Canal Mitchell
Canal Tamar
Canal Sarmiento
Canal Ladrillero
Canal Messier
Canal Fitzroy
Canal Smyth
Canal Trinidad
Canal Wakefield
Canal Beagle
Canal Cockburn
Canal Pitt
Canal Concepcion
Canal Stosch
Canal Mitchell
Canal Tamar
Canal Sarmiento
Canal Ladrillero
Canal Messier
Canal Fitzroy
Canal Smyth
Canal Trinidad
Canal Wakefield
Canal Beagle
Canal Ballenero