

ART. XII.—*The Glacial Land-Forms of the Margins of the Alps*; by HUGH ROBERT MILL.

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AT the close of the sixth meeting of the International Geological Congress, which was held at Zurich during August and September, an excursion occupying a week was arranged in order to afford an opportunity of examining the remains of ancient ice-action far beyond the reach of actual glaciers on both the southern and northern slopes of the Alps. This trip was planned and directed by Professors Penck and Brückner and Dr. Du Pasquier, who, from their previous knowledge of the localities to be visited, had drawn up a guide in the form of a pamphlet of 86 pages, entitled "*Le Système glaciaire des Alpes*," which is published in vol. xxii of the Bulletin of the Neuchâtel Society of Natural Sciences.

The special object was to exhibit the part played in the formation of the land surfaces at the base of the Alps by the moraines or glacial formations, strictly so called, of the great Ice Ages, and also of the intermediate fluvio-glacial deposits of moraine material which had been rearranged by water on the retreat of the ice. To these was added involuntarily, rather too much experience of the "pluvio-glacial" conditions which several days of steady rain at the beginning and at the end of the excursion induced on the steep surfaces of the clay slopes over which Professor Penck led his followers.

The main point of interest to the glacial geologist was the proof afforded by the sections of the occurrence of at least three successive periods of great glaciation separated by relatively long intervals, during which the vast volumes of water liberated by the melting ice dispersed and rearranged the moraine material. To a geographer the interest centered rather in seeing how the scenery and structure of great stretches of country were determined by the heaping up upon the plains of extensive systems of low hills—low, that is, when compared with the Alps, for some of them exceed a thousand feet in height—differing entirely from the mountains of elevation lying beyond them. These hills and fluvio-glacial plateaus represent the amount of glacial erosion and transport; they are the rubbish heaps of the mountain sculpture. Their effect on the broad geographical features of the alpine border is very clear in determining the lines of communication. The amount of weathering they have undergone, according to the different ages of the deposits, decides the character of the soil, which in turn reacts on the vegetation and appeals directly to the eye, the general aspect of the landscapes of the first glaciation dif-

fering in a marked degree from those of the last. Unfortunately, the weather was throughout unsatisfactory for photography, and the attempts made to take comprehensive views were failures, as had been expected. Some fair results were, however, obtained in detailed sections, which are of geological rather than geographical interest.

The excursionists met at Lugano on Monday, September 17, when thirty-seven members assembled, including representatives of Austria-Hungary, Germany, France, Russia, Norway, Holland, Switzerland, Italy, the United States, England, and Scotland. The weather was hopelessly wet, the one interesting result of which was to throw into the shade the distinguishing peculiarities of the Italian lakes, and reveal the essential similarity of their scenery to that of the English lakes and Scottish lochs. Professor Penck explained, and in some cases subsequently demonstrated, that the lower ends of the North Italian lakes were dammed by glacial accumulations, thus raising their level far above the rim of the rock-basins which contain their deeper water, and accounting for such peculiarities as the "recurved hook" of Lugano.

A somewhat exciting boat-trip down the rapid Ticino landed the geologists at a fine section where the river had cut deeply through its moraine bar. Here, so far as sky or soil or vegetation were concerned, one might have been in Scotland instead of Italy. The steep boulder-clay slope, grown in part with the common coltsfoot, when ascended, led to a level moorland, the poor soil of which was covered with heather, not shrubby as in more northern latitude, but composed of long separate flower-stems with exceptionally large heads of blossom. In the distance sombre pine woods crowned the hillocks, but at a turn of the path maize and sorghum were found as common field-crops, and the similarity to northern lands disappeared.

On Monday evening the party reached Ivrea by steam tramway from Santhia, and the whole of Tuesday was occupied in seeing, as well as the mist would allow, the vast glacial amphitheater which surrounds the town, and in crossing the steep ridge of the Serra and the ferretto-covered slopes of moorland which succeed it to Biella, whence Milan was reached not long before midnight.

The morainic amphitheater is both the largest and most typical of the southern slopes of the Alps. Two ramparts of moraine material diverge nearly at right angles from the mouth of the narrow valley of the Dora Baltea, gradually diminishing in height, and these are finally united by an arc of moraines convex to the south, so that the whole completely surrounds a central plain, the two little lakes occupying the center of which overflow by the Doire, which cuts across the

southern barrier. The eastern side of the amphitheater includes the largest moraine hill of the system, so large that it by no means belies its name of the *Serra*. It is a ridge more than 12 miles long, and in its highest part more than 1300 feet above the bottom of the depression, towards which the sides slope at an angle of 20° . The accumulation is the result of several glaciations, the *moraine externe*, or early boulder-clay, being covered with a red weathered crust of *ferretto*, the intercalation of which between the older and newer moraines is one of the proofs of the occurrence of an interglacial period.

A railway journey next morning allowed a fine forenoon to be spent in driving from Lonato to Salo, on the Garda Lake, through moraines and fluvio-glacial formations—some of them compact conglomerates. Here the successive glaciations were very clearly shown in several sections, the lower moraine of the earlier Ice Age having its pebbles much weathered; in some cases even the granites had crumbled into clay, retaining only their original form. Above this came a layer of conglomerate formed of ice-scratched pebbles stratified by running water, and on the top a fresher boulder-clay much less weathered than that below.

Coming up the Garda Lake at night, the contrast between physical and political geography was finely shown by the uniform cliff walls and continuous water-surface broken by the long beam of the electric search-light at the Italian frontier station, which swept the lake all night for the prevention of smuggling.

On Thursday, September 20, the excursion left Riva by rail at 6.20, and had an excellent opportunity, on the journey to the Brenner line at Mori, of seeing that ice is not the only agent which is capable of producing scenery by the accumulation of detritus. The landslip-covered plateau of Loppo, with its lake formed in a hollow of the dolomitic detritus, and the still more extensive piles of landslip material about Mori, contrasted and compared in many ways with the glacial phenomena seen farther south. The Austrian Railway Company had provided, free of charge, an observation car at the end of the train, from which a good view was obtained of the deltaic wilderness through which the lateral tributaries entered the Adige, and of the extraordinary fertility of the alluvial flats, where maize and vines in alternate narrow strips covered almost all the available land. Later the porphyrite gorges marked the passage across the center of the range, and beyond the Brenner saddle carriages were provided at Matrei to allow of a more detailed examination of the terraces of the Sill valley than would be possible from the train. The vastness of this accumulation of moraine, fluvio-glacial deposit, and moraine

again, may be judged from the fact that it fills the ancient valley of the Sill, and that the modern river had to cut down through more than 300 feet of it before coming to the underlying rock, into which the river bed has now worn its way to some depth. As the road winds along the face of the steep slope of the clay gorge, it affords a view of the railway on the opposite side far below, cut in the hard rocks close to the river, while the slope above is so unstable that it remains in many places bare of vegetation, and wattled fences have been run along in zigzags to bind the clay and reduce the risk of damage to the roadway by sudden falls. In the moraine material the action of sub-aërial denudation has produced a number of "fairy chimneys," the *Erdpyramiden*, or earth-pillars, with which the name of Tyrol is usually associated in elementary text-books of geology; but they are neither so large nor so picturesque as those of the Finsterbach, the view of which so well repays the labor of the arduous climb from Botzen to the Ritten plateau.

Two nights were spent at Innsbruck, and the whole of Friday the 21st was devoted to the study of the sections along the mountain slope of the left side of the Inn. Here the interglacial deposits were seen in their most impressive form. A steep climb along a clay slope of unquestionable moraine, crowded with highly polished and striated pebbles, showed an overhanging cornice of compact breccia resting on the moraine, and itself a hardened water-bedded deposit. Mayr's great quarry in this reddish breccia is a prominent object as seen from Innsbruck, and has supplied a great part of the stone which, from its hardness and durability, causes the newer streets of that town to recall the clear-cut buildings of Aberdeen. Above Mayr's quarry comes a nearly level plateau—the top of the terrace of accumulation—1000 feet above the flat floor of the valley, and similar in its features to the terrace of the Wipptal, through which the Sill cuts its way, as seen from Schönberg. As the quarry is carried farther back the loose material above the hard breccia is cleared away in advance, and so a series of excellent sections of the upper moraine is exposed. The intercalation of this mass of breccia, several hundred feet thick, is a proof of the comparatively long duration of the interglacial period in which, according to Penck, it was formed as a talus or scree on the shores of the ancient Inn lake.

The remarkable terrace which breaks the steep slope of the mountains on both sides of the Inn valley is only found between the Oetzthal and the Zillerthal, from each of which glacial accumulations had blocked the main valley, thus giving origin to a lake which, invading the lower Wipptal also,

allowed the interglacial deposits to form on its margins, which are now represented by the top of the lateral terrace.

From Innsbruck the excursion proceeded by rail along the Inn valley into Bavaria, then by a branch line across the glacial amphitheater of the Inn, and the monotonous plain south of Munich to Deisenhofen, whence the Isar was reached on foot. The contrast of the uniform levels and low moraine hills of this northern slope, with their ranges of rather dwarfish pines in monotonous plantations, was sharp when compared with the more abrupt slopes and richer vegetation of the southern side. The true plateau character of this country appeared when, after a walk of several miles along a straight and absolutely level road, a break in the line of trees in front showed the swift Isar flowing almost at our feet, and a steep path descending the gorge to its shore. Crossing the river we reached Höllriegelskreut, and saw a succession of sections demonstrating the triple glaciation and intermediate genial periods. Next day a trip was made from Munich to the Würmsee, or Lake of Starnberg; but the weather proved so unfavorable that, for the first time on the excursion, the full programme for the day as planned by the leaders could not be carried out. It was possible, however, to visit a remarkable surface of interglacial conglomerate at Berg, which has been enclosed and placed under cover by the German and Austrian Alpine Club, a body which has rendered inestimable services to the scientific visitor, as well as the tourist and climber, along the whole line of the Eastern Alps. This surface is so strongly glaciated that the rock is polished as if by a lapidary, and the internal structure of every constituent pebble is clearly seen. The characteristic striae are there, showing how the glacier, long since shrunk back to the obscurity of the central Alpine ridge, had advanced over the hardened mass of cemented pebbles sorted out by water from an earlier moraine, and cut by its intense erosive power through pebbles and matrix alike. The Würmsee is deeper below the general level of the plain than the surrounding hills are high above the surface, and it is entirely surrounded by the interglacial deposits known as *Deckenschotter*, in which it seems probable that the whole basin was eroded beneath the pressure of the last great ice-sheet.

In concluding this short account of a delightful and memorable excursion, it may be of advantage to define the nomenclature and summarize the general theoretical conclusions arrived at by Drs. Penck, Brückner, and Du Pasquier.

Glacial deposits, so far as they occur in the Alps, are divided into two classes—the *glacial*, or moraines properly so called; and the *fluvio-glacial*, or alluvia formed by the action of running water on moraines. The latter are usually clearly strati-

fied, but contain many pebbles marked by glacial striæ. Fluvio-glacial deposits are always being formed on the outer slopes of moraines, forming a gentle slope leading from the edge of the morainic amphitheater to the plain of the enclosed depression. A complex of glacial and fluvio-glacial deposits of contemporaneous origin corresponds to each phase of the cessation of glaciation. Thus in a single glacial series there may be a succession of complexes, one partially superimposed on another, and each corresponding to a definite stage of retreat or advance of the ice. The fluvio-glacial deposits in a single glaciation are spoken of as inter-stadiary.

Under the deposits of relatively recent glacial accumulation which are characterized by trifling superficial alteration due to weathering, two other glacial series are found distinguished from each other and from the most recent series by highly weathered layers or by evidence of great erosion, showing the existence of a long sub-aërial period between each epoch of glaciation. These periods are termed interglacial in distinction to the brief interstadiary periods which occur in the course of a single glaciation. Amongst the interglacial deposits of the neighborhood of the Alps, at least on the north of the chain, *loess* must be included. *Lehm* is a product of alteration of loess, mainly distinguished by the absence of carbonate of lime.

The more ancient moraines are often weathered externally into a brick-red crust, termed *ferretto* by the Italian geologists. The moraines so coated always occupy the outer side of morainic amphitheaters, and are therefore called *external moraines* in distinction to the more *internal moraines*, which form the inner slopes and in part rest upon the more ancient. This is not a mere case of superposition, but of actual enclosure, the external moraine extending around as well as partially under the internal. The alluvia of the most ancient glaciation are termed *plateau alluvia* (Deckenschotter), those of the intermediate glaciation *high-terrace alluvia* (Hochterrassenschotter), and those of the most recent stage *low-terrace alluvia* (Niederterrassenschotter).

I cannot conclude without an expression of gratitude to Professor Penck, for his great kindness and tireless patience in not only showing, but making sure that every member of the excursion saw and understood, the various features which he explained.