

by Mr. Owens's excavation. The disjointed stones of the upper part of the stairway (some of which have already been cleared away) had slid down bodily from above and, until the excavation was made, had completely hidden the lower part of the stairway.

It is to be hoped that the next part of the *Memoirs of the Peabody Institute* will give the details of this interesting work, and a more accurate (if less ambitious) drawing than that of the "restored" stairway published in the *Century Magazine*. If it has been possible to preserve the continuity of the inscription on the steps, Mr. Gordon's labours will have added to our store one of the longest and most valuable inscriptions yet found in Central America.

Surely it is through an unintentional error that the drawing of the Jaguar stairway, on page 409 of the *Century*, is ascribed to Henry Sandham. A. P. M.

RECENT PAPERS ON GLACIATION.

AT the Toronto meeting of the British Association the numerous papers bearing on the glaciation of the North American continent were of exceptional interest to the British student of glacial geology, inasmuch as they brought prominently to mind the methods adopted by the Canadian and American glacialists, which differ in many respects from those to which we have become accustomed on this side of the Atlantic.

In no branch of earth-lore is the influence of his environment more strongly impressed upon the worker than in stratigraphical geology, and the effect of the simple topographical forms and of the enormous extent over which the glacial deposits are distributed in North America, has been to give a broader grasp and bolder tone to the general run of its glacial literature. This was admirably illustrated by the work brought forward at the meeting. In the British Islands, from the abundance of natural and artificial sections as well as from the complexity and narrow limits of the topography, the lithological composition of the drift deposits is usually made the pivot of the studies, while in America it is rather the arrangement of the drift in regard to the general physical features which is held to be of paramount import.

The following comments on the papers read at Toronto have been written from the standpoint of a British glacialist anxious to find wherein he might profit by the adoption at home of the Transatlantic methods.

To realise the extent of the field in North America it must be remembered that the total area of the Dominion of Canada, about 3,616,000 square miles or not much less than the whole of Europe, can show, in one form or another, traces of the Great Ice Age in every part, and that the same glaciated area further extends over a region about one-fifth as large to the southward of the Canadian border. It is not surprising, then, that the study of glacial phenomena should have attracted so many able workers in Canada and the United States.

The exploratory work of Russell, Wright and others upon the existing glaciers of Alaska, and of Chamberlin, Peary, Barton and others upon the edge of the ice-sheet in Greenland has been more readily assimilated by American than by British glacialists, and its influence is perceptible throughout their researches. It is true that the Danish explorers had already made known to us the leading facts relating to the latter region, but their studies were not perhaps made so directly from the standpoint of the glacial geologist as those of the above-mentioned observers, nor were their results so accessible to the English-speaking geologists. But since Russell, by his investigation of the Malaspina Glacier, with its forested moraine-covered margin sheltering a varied fauna and flora, has shown how widely different are the conditions of Piedmont ice and Alpine glaciers, and since Chamberlin, in describing the mode of occurrence of the detrital matter in the basal layers of Greenland ice-tongues, has thrown so much new light on the whole question of drift-deposition, the British glacialist would do well to recognise, with his colleagues across the Atlantic, that the glaciers of the Alps do not afford the best introduction to the study of glacial geology. It is clear that the Alpine conditions are, in many respects, very different from those under which the ice-sheets of the Glacial period did their work.

As regards the cause of the Great Ice Age, we heard at the Toronto meeting two interesting communications. That of Prof.

T. C. Chamberlin, outlined in a former number of *NATURE* (September 16), was avowedly altogether speculative, and belonged to the domain of earth-physics rather than to geology in the ordinary sense. The other was that in which Dr. J. W. Spencer ably advocated his well-known views on the continental elevation of the Glacial epoch.

Dr. Spencer described a large number of drowned valleys, often extending from the mouths of the great modern rivers across the submarine plateaus at various depths, reaching to even 12,000 feet or more, and recognisable as far northward as Labrador. He stated that upon tracing northward the deposits occupying the great valleys, he found that glacial accumulations occur in New Jersey between the Lafayette formation, which is the latest horizon dissected by the great valleys, provisionally regarded as of late Pliocene age, and the Columbia formation, which is mid-Pleistocene. From all these considerations he concluded that the eastern portion of North America stood more than two miles above the sea during the earlier Pleistocene epoch.

On other evidence he judged that the Mexican plateau was mostly depressed to near sea level during the times of the high elevation of the eastern portion of the continent; and that, with the subsidence of the eastern region, the western side of the continent was elevated from 6000 to 10,000 feet or more. The separation of the Atlantic and Pacific Oceans he regards as only of recent date. These changes of levels and the dependent variations of currents, &c., seem, in his opinion, to be sufficient cause for the Glacial period.

As Dr. Spencer pointed out, his views are practically those which have been advocated by Lyell and many others. But while a pre-glacial elevation of the North American continent is generally acknowledged by geologists, the extent of this elevation is not usually admitted to have been even approximately as large as Dr. Spencer would claim, and the difficulties in accounting for the widespread glaciation of the Northern Hemisphere by the effects of elevation alone are so great that the defenders of this hypothesis are at present few.

There is a somewhat remarkable blank in the evidence to hand in North America as to the conditions immediately antecedent to the Glacial Period, nothing equivalent to the Forest Bed Series and associated pre-glacial deposits, of which we possess such excellent sections on our Norfolk coast, having yet been discovered. For this reason the paper of Mr. R. Chalmers, of the Geological Survey of Canada, on the pre-glacial decay of rocks in Eastern Canada, was of especial interest. Mr. Chalmers showed that in the region he described, beds of decomposed rock, of variable thickness and more or less modified, occur wherever the surface of the rocks has not been abraded by Pleistocene ice, though boulder clay may often be found overlying them.

He gave the following general section of these beds in descending order:—(1) Transported and stratified water-worn gravel with beds of fine sand and clay. (2) Coarse stratified gravels, usually yellow and oxidised, the materials wholly local. (3) Sedentary rotted rock, passing into solid rock beneath.

There seems at present to be no evidence as to the precise age of these beds in Eastern Canada; but Mr. Chalmers pointed out that somewhat similar deposits occurring at the western base of the Green Mountains in Vermont, have yielded vegetable remains by which Lequereux, many years ago, referred them to the Miocene. He concludes that the general aspect of the dry land in Eastern Canada previous to the Glacial period must have been nearly similar to that of the region south of the glaciated zone in North America.

The occurrence of similar local rubble in sheltered situations beneath the drift has often been noted in the British Islands, and the ease with which such loose-lying material would become incorporated into the basal layers of an advancing ice-sheet has been frequently discussed. On both sides of the Atlantic it seems more probable that the greater bulk of the glacial deposits was derived from this source, rather than from the direct erosive action of the ice upon the solid rocks.

With regard to the initial stages of the glaciation, while the European glacialist looks to the highest ground in the northern part of his continent and its islands—to the mountains of Scandinavia, of Scotland, England, Wales and Ireland, and of Switzerland—as the great gathering grounds, it is generally recognised that in North America, with the exception of the Cordilleran mass in the extreme west, the glaciation commenced and spread from the comparatively low ground in the north of the continent and moved southward against the slope of the land, the mountains near its south-eastern margin being

obstacles in its course rather than aids to its accumulation. It is, indeed, probable that in Eastern Europe too much stress has been laid on the importance of the hill-ranges as glacial centres, since there is much evidence to indicate that, at any rate during the maximum glaciation, the movement, and probably therefore the growth, of the great sheets was more or less independent of the orographic features. In this connection the explorations of Mr. J. B. Tyrrell, of the Canadian Survey, in that birthplace of ice-sheets the desolate region to the westward of Hudson Bay, are of the highest importance. In his paper on the glaciation of North-western Canada, Mr. Tyrrell stated that no evidence was discovered of any great elevation of this central area in Glacial, or immediately Pre-glacial times, and it would seem not improbable that the land then stood at about the same height above the sea as at present; and that the moisture giving rise to the immense precipitation of snow would probably be derived from the adjacent waters of Hudson Bay and the Arctic Ocean.

In the region immediately west of Hudson Bay, the earliest glaciation of which he could recognise any traces flowed outwards from a gathering-ground which lay north or north-west of Doobaunt Lake. Subsequently this gathering-ground moved south-eastward, until it centred over the country between Doobaunt and Yath-kyed Lakes. From one or other of these centres the ice seems to him to have flowed westward and south-westward to within a short distance of the base of the Rocky Mountains; southward, for more than 1600 miles to the States of Iowa and Illinois; eastward, into the basin of Hudson Bay; and northward, into the Arctic Ocean.

He applies the name Keewatin Glacier to this central continental ice-sheet, which in general character appears to have been somewhat similar to the great glacier of north-western Europe, with a centre lying near the sea-coast, a steep and short slope seaward, and a very much longer and more gentle slope towards the interior of the continent. But, remarked Mr. Tyrrell, there was this difference between the two, that the centre of the latter was over a high rocky country; while the centre of the former was over what is now, and was probably also then, a low-lying plain, on which the snow accumulated to such depths as to cause it to flow over country very considerably higher.

This great glacier, in the different stages of its retirement down gradually descending slopes, caused many temporary extra-Glacial lakes to be formed, which were drained one after another as it retired to still lower country. Before it had withdrawn from the Winnipeg basin, Mr. Tyrrell thinks that it was joined by an advancing glacier from the east, and in front of the two, Lake Agassiz, one of the largest of the extra-Glacial lakes, was formed. During the final stages, its general gathering-ground is believed to have moved still nearer to the coast of Hudson Bay, and to have broken into several separate centres; and Mr. Tyrrell notes that after its retirement the land in the vicinity of Hudson Bay stood from 500 to 600 feet below its present level, and gradually rose to its present height.

The shifting of the centres of glaciation at different stages of the Great Ice Age, to which Mr. Tyrrell referred, seems to be a well-recognised characteristic in North America, though it is diversely explained. Dr. G. M. Dawson, in the admirable summary of Canadian Geology in the new Handbook for Canada prepared for the Toronto meeting, notes that the western part of the Great Plains was invaded at an early stage by large glaciers issuing from the Cordilleran ice-sheet through the main valleys of the Rocky Mountains, while at a later period, when this ice had shrunk back, a newer series of glacial deposits was spread out in the same area, largely composed of Laurentian and Huronian débris transported from the north-east.

Dr. Dawson, while acknowledging that the evidence is not satisfactory, is still inclined to think that these latter deposits may be in part of marine origin, and that they indicate great relative and absolute changes of level in this region in Glacial times.

In eastern Canada also "it has been found by Mr. Chalmers that when the Laurentide Glacier invaded the lowlands to the west of Quebec, the Appalachian glacier had either greatly decreased or had vanished" (Handbook, p. 30).

In England the drift deposits of the eastern and midland counties show many similar indications of successive glaciation from different centres, and until recently the tendency has been, as in America, to ascribe the facts to the intervention of warm inter-glacial periods. But since it is now generally acknow-

ledged that, given a sufficiently low temperature, the prime factor in the accumulation of the ice-sheets has been the excessive snowfall rather than the extreme cold, may not the whole of the phenomena have been due to the gradual shifting of the areas of greatest precipitation, brought about, as a secondary effect, by the growth of the ice-sheets themselves?

It will be observed that Mr. Tyrrell, in common with all American glacialists, has recognised an up-hill movement of the ice sheet. The possibility of such movement has frequently been questioned on our side of the Atlantic, in spite of the occurrence of transported boulders in various parts of the British Islands at levels considerably higher than their source. But the extent of the uplifts in such instances is slight as compared with that described by Prof. C. H. Hitchcock in his paper on the Southern Lobe of the Laurentian Ice-sheet.

Prof. Hitchcock pointed out that one great lobe of the Laurentide Glacier went southward through the Champlain and Hudson valleys, moving from a plain near sea level, over the highest mountains in New England and New York, 6000 and 4000 feet in altitude, as shown by the transport of the boulders and by the direction of the glacial striæ. As indicative of the distinctiveness of this lobe he described how the striæ diverge from the central line "much like the barbs of a feather from the central shaft," and how the terminal moraines are looped round the area rudely at right angles to the direction of the ice movement. The initial gathering ground for this portion of the ice-sheet seems to have lain to the eastward of Hudson Bay; hence it is sometimes termed the Labradorian Glacier.

The lobate character of the southern termination of the ice and the tendency of these lobes to spread outwards from a centre is strongly insisted upon by all the American glacialists who have studied the peripheral portions of the glaciated area, and the delimitation of these lobes and the discussion of their chronological relations has been made the subject of much recent research. The matter is worthy of more attention than it has yet received with us, for as was shown by Mr. H. B. Woodward in a paper, read at Toronto, on the Chalky Boulder-clay of our West-midland counties, some at least of the characteristic phenomena can be recognised in this country also. The fact that in America these distinct lobes did not reach their maximum development at the same time, and that the overlapping of one great tongue upon the area previously occupied by another is frequently indicated, has given rise to much difference of opinion as to the length of the time-interval separating these different stages of growth and retreat. Prof. T. C. Chamberlin, who gave a lucid demonstration of his views¹ at Toronto, is of opinion that the glacial phenomena of the northern United States indicate two or more successive and distinct periods of glaciation separated by mild interglacial intervals, while other observers are inclined to agree with Dr. G. F. Wright, who though acknowledging wide oscillations of the ice-margin, regards the growth and wane of a single sheet as sufficient to account for all the facts.

In America, therefore, as in Europe, in spite of the prolonged discussion, not only is the number of the supposed warm interglacial periods still unsettled, but the evidence for even one such interval is challenged. The whole question is largely a legacy from the brilliant theorising of the late Dr. J. Croll, and with the breakdown of his captivating generalisations it has become necessary to reconsider the whole evidence which has been adduced, in support of them, on both sides of the Atlantic, before a safe conclusion can be reached. It is suggestive that while the explorers of the peripheral areas of the old ice-sheets are usually steadfast in their belief in such periods, those whose investigations lie more centrally to the regions of accumulation, both in Europe and in America, are more frequently in favour of the unity of the great glaciation. Yet even this localisation of opinion is capable of two opposite applications.

One of the strongest threads in the evidence for an inter-glacial period in North America is furnished by the sections in the vicinity of Toronto. Since Dr. G. J. Hinde described these deposits in 1877, fresh excavations in the Don Valley have revealed new facts of importance. Prof. A. P. Coleman, in his paper on the subject at the British Association meeting, stated that in the Don Valley a lowest till is seen, upon which rest 18 feet of sand and clay containing many unios and other shells, as well as leaves and pieces of wood. Some of the unios do

¹ These are ably stated by Prof. Chamberlin in the chapter on the Glacial phenomena of North America in the third edition of Prof. Jas. Geikie's "Great Ice Age."

not now live in Canadian waters, but are found in the Mississippi; and several species of trees now belonging to the States to the south occur with them, indicating a climate decidedly warmer than the present. Above this come stratified clay and sand, with a caribou horn and remains of insects and plants belonging to a colder climate than the present. This set of clays and sands is best shown in the cliff-section at Scarborough Heights a few miles to the east, where the series rises 148 feet above Lake Ontario, and contains many species of extinct beetles, as well as shell-fish, mosses, and wood of hardy trees. A complicated middle till overlies these beds which were deeply eroded before the advance of the ice. Another less important fossil-bearing bed occurs above the middle till at elevations up to 240 feet above the lake, and is followed by a third till. Prof. Coleman notes that great changes have occurred in the level of the water, the lake being much lower than at present before the first glacial advance and after the first interglacial time, and that during the deposition of the middle till, and also while the last sheet of till was being deposited, the water stood from 250 to 300 feet above the present level of the lake, which is 247 feet above the sea. In his opinion the length of time required for the first interglacial period is probably to be estimated at thousands of years; and during this time he thinks the ice-sheet of the Laurentide Glacier must have completely disappeared.

As a result of this paper a British Association Committee was appointed to investigate these deposits further by means of excavations. The palæontological evidence is held to imply that, as above stated, the climate when the Don Valley deposits were laid down was such as would be incompatible with the presence of ice anywhere in the Laurentide area, and that this warm period was followed by a later glaciation, of which the clearest evidence is contained in the section at Scarborough Heights. The identification of the warm-climate horizon in this cliff-section is especially desirable, and is one of the results which may be hoped for from the Committee's investigations.

In describing the drift phenomena of the Pacific coast around Puget Sound, which in most respects compare very closely with those of our own islands, Mr. Bayley Willis put forward the hypothesis that the channels of the Sound, which have usually been considered submerged valleys, are the hollows remaining after repeated glacial invasion of a wide and diversified depression, during which the earlier divides were built upon, and transformed into plateau-like eminences of glacial drift, whereas the occupation of the valleys by glacial ice, particularly in the stagnant stages of retreat, prevented their being permanently filled; so that with the final retreat of the ice the moulds of glaciers remained as the channels of the Sound.

This view accentuates the undoubted fact that the accumulation of glacial débris has been greater around the margins of the old ice lobes than in the more central areas, and it may be applied to some extent to our own islands, where the persistence since pre-glacial times of the shallow basins of the North Sea and the Irish Sea appears to indicate that a larger proportion of the material transported by the ice-sheets which once filled them has been deposited around their margins than within their beds.

The old lake-beaches, incidentally referred to by Prof. Coleman and Mr. Tyrrell, occupy a large place in the studies of the American glacialists, while in the British islands, in spite of the rough pioneer work of the late Prof. Carvell Lewis, the subject has scarcely been touched. The scope for these researches in our country is, of course, limited; but the classical example of the parallel roads of Glen Roy is sufficient to prove that the phenomena are not unrepresented. In America two distinct types of old lakes have been recognised—those like Lake Agassiz and Lake Warren, which were formed in front of the retreating ice-margin, and those like Lake Nipissing and Lake Iroquois, which owed their position to differential earth movements.

The literature in regard to both types is already very extensive, and is not altogether satisfactory. Especially in the case of the glacially-dammed waters, their reputed vast extent, their impersistence of level and brief duration, the later modification of their sites by earth movements, and above all the obscurity of their traces over wide tracts of uncleared forest, makes it certain that while the broad fact of their former existence may be undoubted, the delimitation and correlation of their boundaries must be regarded in most cases as more or less provisional. With gravelly deposits of all kinds spread over such an enormous extent of territory it must necessarily be difficult to pick out an individual shore-line unless this can be traced

almost continuously, which is rarely possible. In certain regions, however, the study has been carried on under more favourable conditions, with most interesting results. Thus Prof. H. Leroy Fairchild, in describing the glacial phenomena of Western New York,¹ showed how the long upland valleys of that part of the State contain the terraces of lakes which have overflowed southward across the watershed, leaving well-marked channels of glacial drainage, and how as lower passes were opened by the retreating ice the waters of these lakes sank to corresponding levels. The highest of the continuous shore-lines of this region is recognised as being that of the glacial Lake Warren, which is believed to have stretched from the western end of the basin of Lake Ontario over the whole or the greater part of the Great Lakes.²

Below this are found several less continuous terraces, probably marking different stages of the depletion of the lake, until at about 500 feet lower the Iroquois shore-line is reached, which appears to have been the immediate forerunner of the Lake Ontario of the present day. This beach is admirably developed in the vicinity of Toronto, and the main facts regarding it were demonstrated by Mr. Gilbert and Dr. Spencer during the meeting. Dr. Spencer considers that it is an old sea-beach; but in this he is at variance with most of the American glacialists, who hold that it, like the higher beaches, is of fresh-water origin.

These old beach-lines are of especial importance in that they reveal considerable differential uplift during late-glacial and post-glacial times. On this point all the students of the subject are agreed, and it is, of course, regarded therefore as a factor of prime importance in the later history of the lake basins. It was insisted upon by Mr. F. B. Taylor in an interesting communication on the relation of the Champlain submergence to the Great Lakes and to Niagara Falls. Working on the same lines as Mr. Gilbert had done, Mr. Taylor showed that an old shore-line, named the Nipissing Beach, surrounds a large portion of the Upper Great Lakes, and leads to a low col at the east end of Lake Nipissing. The formation of this beach he supposes to have been contemporaneous with the Champlain submergence by which the St. Lawrence Valley and the Champlain depression became arms of the sea, so that during this period the Upper Great Lakes had their outlet by way of the Nipissing Pass and the Ottawa River into the St. Lawrence, leaving only the discharge of Lake Erie, or one-ninth of the total volume, to occupy the Niagara River. Mr. Taylor stated that the Nipissing beach is tilted so that it falls regularly towards S. 27 W. at the rate of nearly 7 inches to the mile, being 110 to 115 feet above the present surface of the north-eastern part of Lake Superior, while not far east of Duluth it has sunk to the water level, and if its plane were projected it would pass 100 feet below the lake-level at Chicago. He gave reasons for considering that the tilting was caused by the same uplift which raised the Champlain Valley, and that one effect of this movement was to close the Nipissing outlet and to open that at Port Huron, by which the entire discharge of the lakes was sent into the Niagara. The result of these changes is to be found, according to Mr. Taylor, in the cañon below the Falls, the narrow and shallow gorge of the Whirlpool Rapids indicating the work of the comparatively feeble stream from Lake Erie, while the Upper Great Gorge has been excavated since the closing of the Nipissing outlet, which, accepting the known rate of recession of the Horse-shoe Fall as the principal datum, may have taken place from 5000 to 10,000 years ago.

These researches may well serve to illustrate the complexity of the problem whenever an attempt is made to transmute the term of geological processes into an equivalent in years. Simple multiplication and division without a steady-going chronometer can never suffice, nor is the time-unit that serves for a man's life ever likely to help us much in measuring the duration of cosmic processes.

As regards the differential movement, Spencer and Gilbert are of opinion that it is still in progress, and will eventually submerge Chicago and dry up Niagara. In a recent paper³ Gilbert has even ventured to predict in years when this may be expected.

G. W. L.

¹ This paper is printed in full in the *Geological Magazine*, and is therefore easily accessible to British geologists.

² An admirable summary of the work of Spencer, Gilbert, and others in elucidating the history of this great body of water will be found in a paper by Mr. Warren Upham on "Glacial Lakes in Canada," *Bull. Geol. Soc. of Am.*, vol. ii. (1891) pp. 243-276.

³ "Modification of the Great Lakes by Earth Movement," *U.S. Nat. Geographic Mag.*, vol. viii., September 1897, p. 231 (see *NATURE*, December 30, 1897).