CLIMATIC FEATURES OF THE PLEISTOCENE ICE AGE.*

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UNTIL now, the climate of the Pleistocene Ice Age has been studied mostly from a very theoretic point of view. There have been discussions as to how astronomical changes would influence terrestrial climate; how far changes of the position and inclination of the Earth's axis, how far changes in the eccentricity of the Earth's orbit, would influence the distribution of warmth on the Earth's surface. Investigations have been made as to what climatic changes must be produced by changes in the actual distribution of water and land, of the present winds, of the heights of the land, of the composition of the air, and so on, but it cannot be said that any one of these theories is sufficient to account for the real climatic conditions of the Pleistocene Ice Age. In order to arrive at a solution of this important problem, another method can also be adopted: we can try to draw conclusions as to the climate of the Ice Age on the base of observations; we can try to recognize the bearing of geological facts on climatic conditions. Physio-geographical research promises, therefore, some elucidation on the problem, and already allows us to arrive at certain conclusions.

The development of the glaciers of the Great Ice Age affords no direct means to understand the climatic conditions of this period, for glaciers depend not only on climatic conditions, but also on orographic forms. We find very small glaciers sometimes in high latitudes, where the country is not mountainous; on the other side, a very considerable development of glaciers in lower latitudes—for example, in the Himalayas—is due to the existence of a mountain chain. The climatic conditions of the development of glaciers can be best recognized by the elevation of the snow-line above the sea, and in late years one prominent task of glacial geology on the continent has been to determine the elevation of the snow-line during the glacial period. There are many ways of determining this; the glaciers themselves afford them—they begin in the *névé* region, and terminate below it. The mountains, which feed glaciers, rise above the snow-line, and the tongues of the glaciers end below it. The snow-line lies always between the two ends of a glacier: it lies above the region of morainic accumulation, for this is going on only where glaciers are melting away—that is, along its tongues; it lies above those summits which have had no glaciers. By paying attention to all this, it becomes possible to determine the elevation of the glacial snow-line in pretty narrow limits—to, say, less than 300 feet.

In Central Europe most of the mountain groups had glaciers during the Ice Age; the glacial snow-line, therefore, was depressed to an elevation of 3000 feet and less. In the west it lay lower than in the east; the mountains of Wales produced a considerable glaciation in the same latitude in which the Ural mountains were not glaciated at all. The snow-line of the glacial period descended towards the ocean, and ascended towards the centre of the continent, as is the case with the present snow-line. This points to the fact that during the Great Ice Age Central Europe was in the neighbourhood of the sea. In the Alps the glacial snow-line was more elevated in the central parts than in the peripheric regions; it arched over the mountains. The same happens at present, and there is a marked parallelism between the actual and the glacial snow-line, the latter lying from 3600 to 3900 feet below the former. In Southern Europe there are conspicuous

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irregularities in the elevations of the glacial snow-line. On the west coasts of the three southern peninsulas it lies very low, in some places at an elevation of only 4000 feet, while it rises very much towards the centres of the peninsulas, where it is met with in elevations of above 6000 feet.

This arrangement of the glacial snow-line reveals to us some of the climatological circumstances of the glacial epoch. There is always a considerable depression of the snow-line in mountainous regions which stretch across the direction of the prevailing winds. The very remarkable depression of the glacial snow-line along the western flanks of the southern peninsulas of Europe therefore indicates prevailing westerly winds in the northern part of the Mediterranean sea during the Great Ice Age, in the same way as the depression of the actual snow-line on the coasts of Patagonia, New Zealand, and Alaska depends on the westerly winds there. After all, probably these westerly winds did not extend so far north as to reach the rim of the large ice-cap which covered Northern Europe; this ice-cap must have been accompanied by a barometric maximum, which caused easterly winds along the southern frontier of the ice. Thus we have to assume in the middle parts of Central Europe eastern winds, and during the Ice Age the arrangement of the winds in Central and Southern Europe must have been nearly the same as that found by the different Antarctic expeditions at the border region of the actual Antarctic ice-cap. There are also some indications that the realm of the easterly winds was subject to seasonal changes.

South of the Alps we find only indications of prevailing westerly winds; north of these mountains, however, there are traces of westerly winds as well as of easterly ones. Many of the minor features in the old glaciation of the eastern Alps are consistent with westerly winds, which caused heavy accumulations of snow on the west sides of the mountains, whilst smaller glaciers came into existence on the eastern slopes, which seem, therefore, to have been sheltered. On the other hand, we find on the north foot of the Alps a deposit which is nearly totally absent from the basin of the Mediterranean, and which is evidently deposited by easterly winds—that is, the loess.

There have been many discussions on the origin and the age of the European loess, and since it has not been sufficiently studied as a whole until now, there are still at present many diversities of opinion about it. Originally, it has been taken as a deposit of the highly swollen rivers of the Ice Age, but it can easily be shown that it reaches far above the highest waters of the Pleistocene epoch. Then Baron von Richthofen advanced his ingenious hypothesis on the origin of the loess as a continental deposit of a dry climate; but the whole arrangement of the European loess is not consistent with its deposition in interior basins. Many facts, however, make it sure that the loess is an æolian deposit, and that it is the river mud of the Pleistocene epoch blown off and redeposited by winds. There is always a certain relation between the accumulation of Pleistocene river gravels and river sands and the loess, and along the Austrian Danube the loess lies west of the former, being blown by easterly winds to its actual position. Thus, near Vienna we have the sandy plain of the Marchfeld along the Danube, and west of it the slopes of the Bohemian peneplain are covered up to a considerable height by loess, which originates in the sand-dunes of the Marchfeld.

There has never been the least doubt about the Quarternary age of the loess, and as long as there were only known traces of *one* glaciation, it was thought that the loess would be a deposit of this age. But when the traces of different glaciations in the Alps and in Northern Germany were discovered, doubts arose about the contemporanity of the loess and the glaciations, for the stratigraphical position of the loess is an interglacial one. It extends above the moraines of the older glaciations, but does not enter the region of the last glaciations except at some places, where an evidently younger loess has been found. At a few places loess is met with between the moraines of two successive glaciations. But it must be borne in mind that the loess does not form a unit deposit. In larger sections of the loess districts along the Danube we observe that there are different layers of true sandy loess separated by decomposed surfaces of decalcified loess. The highest layer of undecomposed loess never extends to the morainic districts of the Alps, and its stratigraphical position as to the glaciation cannot be settled. Its palæontological and prehistoric remains, however, point to a glacial age; its fauna is the same as that of some later glacial deposits, and the palæolithical implements in it have close resemblance with those of the Magdalenian Age, which is post-glacial in comparison with the maximum of the last glaciation. This youngest loess along the Austrian Danube is possibly contemporaneous with the maximum of the last glaciation of the Alps, and it may be regarded as the mud of the glacial rivers, carried on by eastern winds to the neighbouring western heights and deposited there. Further investigations must show how far this way of reasoning can be extended over other loess deposits. It may be mentioned only that the European loess, taken as a whole, appears as a border formation of the great northern glaciation; it follows its southern rim from Southern Russia to the Straits of Dover, and extends southward only into the basins of the Danube, the middle Rhine, and the upper Rhone, which were invaded to a certain extent by Alpine glaciers. Its occurrence close to those Alpine glaciers, which reveal the influence of westerly winds, may be due to seasonal changes of the winds. During the summer the westerly winds may have had a wider realm than during the winter, as is now the case in the Antarctic Regions, where the east winds are the strongest in winter, when the atmospheric pressure is highest on the ice-cap.

The situation of the glacial snow-line helps us also to conceive the general character of the European vegetation during the Ice Age. There is always a certain vertical distance between the tree-line and the snow-line on the Earth, and we must assume such a distance also for the glacial periods, for above the snow-line the duration of the snow-covering of the country being the whole year, there must be below it a zone in which the snow-covering lasts too long for the development of trees. We can expect them only at a certain height below the snow-line. At present this height is least at those shores where the snow-limit is very much depressed, and is reduced at Alaska and at Patagonia to 1500 feet, while in the Alps it is 2500 feet, and in Central Asia 4500 feet. It can be observed that the distance between snow-limit and tree-limit is less in moist oceanic than in dry continental climates. Its amount, therefore, during the glacial period may help us to recognize if the latter was more a period of increased moisture or of altered temperature.

Palæontological researches, carried on especially by Mr. Nathorst, have shown that during the Ice Age an Arctic-Alpine flora was spread over Central Europe, and researches in plant-geography require that once the Arctic and Alpine floras were united on the soil of Central Europe. Therefore we have full certainty that during the Ice Age this country lay above the tree-line, the distance of which from the snow-line cannot have been less than it is now—that is, 2500 feet, in round figures. From this we conclude that the Ice Age in Europe did not develop under an oceanic climate with a considerable augmentation of precipitation, but that it was due to a change of temperature.

This conclusion is in harmony with another one, at which we arrive when we study the very roots of our Alpine glaciers. There are two ways which account for the increase of a glacier: either an increase of precipitation—then it becomes at first thicker above the snow-line; or a decrease of temperature—then it thickens at first below the snow-line, the latter being depressed in both cases. If we compare the height reached by the Alpine glaciation near to its centre with the height reached by the actual glaciation, we shall find that the surface of the old glaciers did not reach above that of those of the actual glaciers in their *névé* region. Therefore, if the glaciation of the Ice Age should be derived from the actual one, the latter must get thicker below their snow-line; that is, the glaciation of the Ice Age will be arrived at if a decrease of temperature takes place.

Such a decrease of temperature need not be a very great one, for we see that under actual conditions little changes in the amount and distribution of temperature are quite sufficient to produce a rather great change in the situation of the snow-line. As we have already remarked, the present one arches over the Alps. In the northern parts of this mountain chain it is found at a height of 7200 feet; in the interior it rises to 9000 feet and more, and we find here in the Œtztal mountains, forests of the arve (*Pinus cembra*) at heights which come near to the snow-line in the Bavarian Alps.

Thus at present in the Alps one-half of that depression of the snow-line can be seen which caused the glaciation of an Ice Age, when we go from the interior chains to the border region, and the climatic changes which take place at present in the Alps at a level of 7200 feet are sufficient to account for one-half of the depression of the glacial snow-line. These changes are very slight as to temperature, the range of the latter being in the interior of the mountains more continental, at the border region more oceanic. They are larger as to precipitation, the amount of which is less in the interior than at the margin region; but a comparative study of the two factors shows that an important part of the actual depression of the Alpine snow-line is due to a slight diminution of the summer temperature.

Thus we are entitled to assume that a rather slight decrease of the annual temperature—say 2°–3° C.—if it is connected with a diminution of the summer temperature, will cause an Ice Age. Such a decrease of its side will cause also changes in the amount, and especially in the distribution of precipitation, and the glaciations themselves will influence the climatic conditions by producing changes in the distribution of air-pressure, as we have already seen, and by causing alterations in the isothermic lines. Thus the problem of the climate of the glacial period is a very intricate one. We have to deal with initial climatic changes, which produced the glaciations, and sequential ones, which were produced by the glaciations. As far as we know, the initial causes have been effective over the whole globe, for we find in all mountain chains, which have a sufficient height, a depression of the snow-line; the sequential changes, however, are only there displayed where we have to deal with very large glaciations, such as came into existence on both sides of the Atlantic, in Northern Europe and in North America, where the whole distribution of air-pressure was influenced.

It is an important field of future investigation to determine how far the initial climatic changes have influenced the distribution and air-pressure, and how far the latter are determined by sequential changes. The favourite working grounds of glacial geology do not afford good evidence in this direction, since the large ice masses which once covered Northern Europe and North America have caused such strong sequential changes. In order to solve the problem which we have mentioned, we must go to those regions which during the Ice Age were not extensively glaciated. I believe that we may expect some results in this direction from further exploration in South Africa. I believe that we may find there, besides the traces of the Permian Ice Age, also those of the Pleistocene times, corresponding to the great glaciations of Northern Europe and North America. The depression of the glacial snow-line which is known in Europe has been already recognized on the high volcanoes of tropical East Africa, in the south island of New Zealand, in the Australian Alps, and Tasmania. We shall expect, therefore, to discover also traces of it in South Africa, if we go high enough into the elevated regions, as, for example, the high Drakensberg in the frontier region of Natal and Basutoland.

There seems to be no doubt that South Africa has experienced some very important changes, which seem to be the equivalents of glacial times. In his very remarkable book on the Kalahari, Passarge points out how this desert region shows many traces of a former pluvial period, which he correlates with the Pleistocene glacial period of the northern hemisphere, and besides this, that very able and sharp observer finds also traces of former desert conditions in the same and neighbouring regions. Unfortunately, there are only a few fossils in that Botletle formation which afforded proofs of repeated desert and humid conditions to Passarge, and since the subjacent layers are formed by very old rocks, there remains, therefore, a vast range in their possible age. Passarge tries to settle this by a comparison of the events which have taken place in the Kalahari with those which he assumes to have taken place in Egypt, according to Blanckenborn's observations, and he arrives at the conclusion that the great climatic changes of the Kalahari region belonged to the Tertiary period. This conclusion seems not to be perfectly strong. It is not consistent with the fact that the few fossils which Passarge brought home from the Botletle formation belong to actually still existing species of fresh-water shells, for we generally observe that Tertiary layers contain extinct species. The organic remains of the Botletle formation point rather to the Quarternary age of the deposit than to the Tertiary, and, at all events, they are not unfavourable to a comparison of the climatic changes which Passarge proved at the Kalahari with those which are proved by the study of the Pleistocene deposits of Europe and North America. There can be no doubt that both continents have had not only one glaciation, but that there has been a succession of pluvial and interglacial epochs, forming altogether one great Ice Age; and it seems not to be improbable that the dry periods, which are proved by Passarge in the Kalahari, correspond to interglacial periods, while his limestone formations, which point to a moister climate, are equivalents of the glacial epochs of the Great Ice Age of the northern hemisphere.

Passarge's standpoint is different. He compares only his last pluvial period with the great Pleistocene Ice Age, but he assumes some interpluvial periods in it, which might be compared with interglacial epochs. But those interpluvial periods are only indicated by very slight evidence, and I should be inclined to compare them rather with the interstadial epochs, which interrupted the retreat of the last Alpine glaciation. Perhaps the peculiar form of the Victoria falls of the Zambezi is connected with those minor climatic changes which have happened since the last glacial period. We have below the fall a series of broader rents, connected by narrow gorges. Perhaps the latter were formed in times when the Zambezi had little water, while the broader rents would correspond to times when the river was as rich in water as at present.*

In a very convincing way, Passarge shows us that since the last fifty years the desiccation of the Kalahari has made considerable progress; how some lakes—as, for example, the very well-known lake Ngami—have disappeared, and many river-

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* After the visit of the British Association at the Victoria falls of the Zambezi, I had the opportunity to make a detailed study of the falls and the neighbouring regions. I convinced myself that the formation of the chasms below the falls is in no connection with climatic changes, but only due to the internal structure of the basalt-sheet, in which the river has cut.

beds have become dry. These facts have their counterparts in Europe. Since fifty years all our Alpine glaciers are retreating, and some shorter advances which have been observed now and then, have not prevented our glaciers from being now reduced to a state which they had four centuries ago. The very close parallelism of the events going on now in the northern and the southern hemispheres point to a common origin, and this seems to be, that by a very slight increase of temperature, the ablation of the Alpine glaciers and the evaporation in the interior of the continents are augmented, and that, therefore, here rivers and lakes, there glaciers, partially or totally disappear.

The actual coincidence of the recession of the glaciers which is nearly everywhere observed, and the desiccation phenomena, which are not only met with in South Africa, but also in the interior of Asia, seems to indicate that interglacial periods in the temperate regions are the equivalents of the reinforcements of desert conditions in the interior of the continents, whilst the glacial epochs correspond to the pluvial epochs, whose traces are so ably pointed out by Passarge in the Kalahari, and by others in the Sahara and the interior of Asia. There seems to have been repeated changes of all the climatic regions of the Earth during the Great Ice Age; glaciers came into existence where now there are rivers, and rivers have been at work where now deserts exist, and *vice versâ.* All these changes can be accounted for by the assumption of slight variations of the surface temperature, for temperature is a very efficient factor in the ablation of the glaciers and the evaporation of water over the land-surface of the Earth.