and pleasant. The resources of the country include minerals (gold, iron, copper, coal, etc.), agricultural products (which could be made to include tea, coffee, cotton, indigo, cacao, tobacco, vanilla, etc.), and those derived from cattle-rearing.

Colonel Arnold found the chieftaincy of the country in dispute between two rival claimants, each of whom called himself the Makombe. He considers, however, that Shupatora, the lawful successor, according to the customs of the country, though not the son, of the late king, is decidedly the more influential, his rival Nkanga (son of the late chief) having lost ground during the past five years. The disturbances which have prevailed within recent years in the Barue country seem to have caused an efflux of population, which is now estimated at 20,000 only.

THE MEAN TEMPERATURE OF THE ATMOSPHERE AND THE CAUSES OF GLACIAL PERIODS.*

By H. N. DICKSON, B.Sc.

It is not proposed, in this paper, to add another to the ever-lengthening list of theories which attempt to account for the occurrence of glacial periods. My object is rather to point out some consequences which must follow if we adopt certain of the theories still on trial, in the belief that some meteorological considerations, which I believe to have been insufficiently noticed, although hinted at by Howorth, Davis, and others, may help us in making a selection amongst the suggested theories, and thereby at least reducing their number. My attention has recently been drawn to this subject by Mr. F. W. Harmer, who has attempted to account for some features of the glaciation of the northern hemisphere by suggested changes in the normal distribution of barometric pressure.

It will be conceded that theories assuming an arrangement of climatic belts precisely similar to those existing at present, but symmetrically displaced through a given angle, must be abandoned. For example, the position which must have been occupied by a pole of cold, if we are by its means to explain the distribution of the permo-carboniferous glacial deposits in the southern hemisphere, so far as it has been ascertained, is unintelligible alike to the geologist and the physicist. It involves an antipodal area of cold and an antipodal ice-sheet, with intermediate areas of warmth, the existence of which is unrecognized; and it does not even account for many features observed in the deposits themselves. Again, it is almost impossible to conceive any physical cause which can have so displaced the climatic zones of the globe without producing effects which would leave behind them more formidable traces than those due to glaciation.

Leaving such hypotheses out of account, there remain two sources from which a possible explanation of glacial periods may be derived—

1. Tectonic changes, which may have either raised the region to be covered by an ice-sheet—or at least part of it—above the snow-line, or may have so altered

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the distribution of land and sea that the prevailing winds have changed their direction, and thereby caused lowering of temperature over certain areas sufficient to greatly lower the snow-line.

2. General lowering of the mean temperature of the atmosphere.

Firstly, tectonic changes.

It is difficult to suppose that the necessary lowering of temperature can have been produced by elevation alone. A great elevation and extension of the land area no doubt occurred during the Pliocene period, but its culmination was reached before the Pleistocene period, and J. Geikie states emphatically that glacial periods are characterized by submergence, and inter-glacial periods by emergence. Conceivably, the discrepancy in time may have been due to a species of lagging; the elevation of the land caused an ice-sheet to form gradually over it until the surface was depressed, isostatically, by the weight of accumulated ice and the cooling of the crust itself; then the increased temperature at the lower level caused melting of ice, relief from part of the weight, and consequent springing back to higher levels, when the weight of ice increased again; and so on, till the primary tectonic cause of elevation disappeared. But this seems more likely to assist in accounting for the smaller variations occurring during a great glacial period than for the main fact of the glacial period itself. The first elevation to the snow-line, even in fairly high latitudes, seems to involve vertical movements which in geographical relation and in scale are difficult to admit, and we must conclude that the effect of such movements as did occur cannot, in the first instance at least, have been direct.

The effect of elevation in extending the land areas must also be rejected as an efficient primary cause. It is true that if the land areas are extended continental conditions prevail over wider fields, and the winter temperatures are greatly reduced. But summer temperatures are correspondingly increased, and at the same time the precipitation in the form of snow is diminished by the anticyclonic conditions induced during winter. Hence we get nearly the same mean temperature, with less snowfall, and the occurrence of ice-sheets over such regions is contrary to experience: witness Siberia. Note here that these conditions are not to be confounded with the conditions of high pressure induced as the *effect* of an ice-sheet, as in Greenland, or, as seems probable, on the antarctic continent.

It has been argued that the extension of land surfaces might so alter the positions of the centres of high and low barometric pressure that glacial conditions might be induced by the change of direction of prevailing winds. We have already seen that the establishment of an ice-sheet within continental anticyclonic areas is unlikely. But if the land area is increased the sea area is diminished, and the ascending vortices or cyclones during the winter seasons must increase correspondingly in number and intensity in order to feed the increased volume of the descending currents over the land. The tendency would therefore be to increase the amount of condensation taking place within the cyclones, while their opportunity of penetrating into the land would be diminished rather than increased. Thus the proportion of cyclonic precipitation received on the land in the form of snow would be less, the total snowfall would probably not be increased, and, in any case, it would tend to be deposited on the eastern sides of the land areas rather than on the western. Finally, the ascending currents over the continental areas during summer would induce strong descending compensating currents over what was left of the oceans, which would then be occupied by enormously exaggerated systems analogous to our "Atlantic anticyclone," greatly raising the summer temperature of the maritime regions.

We are therefore led to inquire, secondly, whether the nature and distribution of glacial phenomena, as they are at present known to us, can be more adequately accounted for by supposing a lowering of the mean temperature of the atmosphere as a whole to have taken place, and whether an adequate cause can be found which may have produced the necessary change of temperature.

The mean temperature of the air is determined by the ratio between the heat received by radiation from the sun, and that lost by radiation into space. Now, a change of mean temperature may be supposed to take place in two ways: every part of the atmosphere may undergo the same change, *i.e.* the atmosphere may be equally heated or cooled in all latitudes, the polar regions may be cooled or warmed more than the equatorial, or conversely. The effects of any change, direct or indirect, must evidently be very different according as it takes place in one or other of these ways. For if it occurs in the first, a genial climate in high latitudes must coincide with intense heat in the tropics, and a temperature climate in the tropics with intense cold in polar regions; but the temperature *gradient* from equator to pole must remain the same. The whole atmospheric circulation, and the consequent arrangement of the climatic belts, is, however, caused and determined by the difference of temperature between the equator and the poles, and there is no reason to suppose that a change in the absolute temperature would seriously modify either the form or intensity of the circulation, unless that change was very large. We should expect to find that evidences of climatic change in the past would adhere to parallels of latitude; traces of genial climate in high latitudes would go right round the parallels, and would correspond to an equatorial belt of intense heat, which, it may be supposed, would leave some record in the forms of animal or plant life; and traces of great cold in the higher latitudes (not necessarily in the form of ice-sheets) would correspond with belts of temperate climate in the tropics. It will be conceded that this does not satisfactorily agree with known facts.

Coming, then, to the case where the cooling is unequal, it seems scarcely worth while to seriously consider the case where the equatorial belt is cooled more than the polar. Such a change would explain no known fact, and imagination would be hard put to it to find even a possible explanation.

Suppose the lowering of the mean temperature to be due chiefly to cooling in the higher latitudes, the change at the equator being relatively slight. A comparatively small change in the total heat received and lost will then enable us to account for great cooling at the poles. A fall of 5° near the pole would mean a reduction of the mean temperature of, approximately, a little over 1°.

But a change of this kind involves other variations. The fall of temperature near the poles being greater than that near the equator, the equator-poleward temperature-gradient is increased. Now, according to the theory of Ferrel, if the whole atmosphere were at rest relatively to the Earth's surface, and if it were of uniform temperature, it would *remain* at rest. But if the equatorial regions have a higher temperature than the polar, a disturbing force arises which acts in the planes of the meridian, and causes an interchanging motion of the air-particles along those planes. On account of the Earth's rotation, a torsional force comes into play which causes a very great easterly velocity of the air in the higher latitudes, and a large, but considerably smaller westerly velocity in the lower latitudes, and the easterly velocity increases in proportion to the height above the surface of the Earth. The greater the temperature-gradient between the pole and the equator, the greater is the velocity of interchanging motion between the equatorial and polar regions, and the greater the torsional force which causes an easterly motion at the surface in the higher latitudes, and westerly motion in the lower; for the greater the velocity of interchanging motion, the faster a particle of air settles down in the higher latitudes from a stratum where the velocity is greater to one where it is less, or the faster it rises up in the lower latitudes from a stratum where it is less to one where it is greater. Thus the acceleration of easterly velocity, positive or negative, is greater the greater the temperature-gradient, and consequently the greater is the force which overcomes the resistances, due to friction and inertia, to the east-and-west motions at the Earth's surface.

But, further, when the friction of the air moving over the Earth's surface is taken into account, we have the condition imposed that the moments of gyration of the air moving eastward must be equal to those of the air moving westward, otherwise there would be a tendency to change the velocity of the Earth's rotation. Any increase in the force causing the motions is likely to cause a displacement of the boundary between east-and-west motions at the surface, *i.e.* of the tropical belts of calms.

The net result is, then, that if we increase the difference of temperature between the equator and the poles, we increase the velocities of both the trade winds and the westerly winds of higher latitudes, and we displace the tropical high-pressure belts to positions nearer the equator.

Illustrations of changes of this kind may be derived from known conditions on the Earth's surface. During winter, the difference between the temperature at the equator and the north pole is nearly double what it is in summer, and the velocities are greater, although in a less ratio. Again, the mean velocities for the year, both of the trades and of the west winds, are greater in the southern hemisphere than in the northern, and the axes of the high-pressure belts lie in 30° S. and 35° N. respectively, more than can be accounted for by the displacement of the meteorological equator (due to other causes) to about 2° N.

Applying these results (which, it must be understood, are entirely qualitative, since our ignorance of the coefficients of friction depending on the distribution of land and sea, the nature of the land surfaces, etc., prevents definite numerical calculation) to the particular case of the northern hemisphere, we find that a lowering of the polar temperature has the effect of increasing the strength of the west wind circulation, and at the same time extending its influence at the surface to lower latitudes than is the case at present. The easterly currents, having necessarily a poleward component, *against* the temperature gradient, constantly tend to develop vortices or eddies—the familiar cyclones or depressions of these islands; and the stronger the current the more violent and frequent these cyclones are likely to be; under present conditions we find this in winter, contrary to what ought to happen if these systems were, as was once supposed, of purely convectional origin. But with the increased strength of the easterly current the relative influence of the continental land masses is diminished, and since at the same time the tropical belt of calms is displaced equatorward, the normal cyclone track will be displaced to lower latitudes, and will run more west to east instead of south-west to north-east, as at present.

With a general lowering of temperature, we might therefore have, in western Europe, a main cyclone track whose central axis would probably run from near the mouth of the English Channel eastward and only slightly northwards, to a point somewhere in the region of the Kara sea. North and west of this line, on the polar side of the depressions, an increased snowfall would be deposited during winter, and the cloudy conditions prevailing during summer would depress the temperature sufficiently to reduce the melting almost to vanishing point, even near sea-level. It is to be observed that in this region the prevailing cyclonic winds would then be from the east, a fact which may serve to explain some peculiarities of the glaciation of the Scandinavian peninsula, and which accounts incidentally for the shell deposits of the Upper Crag on the east coast of England, at that time a lee shore.

Again, the north-easterly drift of surface water in the Atlantic would be greatly modified. This drift is at present most marked during the winter season, and its climatic effect is comparatively slight. During summer the Atlantic winds, although weaker in the higher latitudes, are more nearly west, and water is banked up against the European coast, escaping northwards and southwards in stream currents of very considerable volume. The northern branch of this stream current, which I have proposed to call the European stream, penetrates far northward, and melts large quantities of ice in the region north of Iceland and round Jan Mayen, the water flowing southward and westward as a surface current during autumn, covering over the warm waters of the European stream, and keeping up atmospheric pressure during early winter. The effect of this distribution, if strongly developed, as during the past winter, is to make the winter cyclones move more directly eastward into the heart of the continent. The modified movement of the cyclones suggested during the cold period would greatly increase this action, the whole of the Norwegian sea would be permanently flooded with cold water, and the surface movement along the European coast would be southward all the year round, a result predicted by J. Geikie.

As the cyclones penetrated eastwards, many of them no doubt following the line of the Mediterranean, the precipitation would diminish as the supply of vapour gave out, and sufficient snowfall to produce an ice-sheet would only be found at proportionally higher levels—following the results recently obtained in the Alps, the Carpathians, and the Balkans, by Penck, Cvijić, de Martonne, and others.

On the southern side of the cyclonic axis we should find a region of strong westerly wind and abundant rainfall, which would give a cool rainy climate to the whole of the Mediterranean region, extending into northern Africa, probably over a considerable part of the Sahara.

Thus for Eurasia generally, the difference from present conditions would be, more snow in north-western Europe, and rain in the south, the fall diminishing eastward until in the Asiatic regions the climate would be simply cooler, with smaller extremes of temperature, and more snow at greater elevations, as in the Himalaya.

Turning to North America, the cyclonic area would run more north-west to south-east, many of the depressions from the Pacific failing, as they do now, to cross the Rockies. In this case the western and south-western sides of the cyclones would afford more snow in proportion than in the cyclones of the Atlantic, and we should therefore expect to find the edge of the ice-sheet further south, at least near the eastern side. This is precisely the outline represented by Chamberlin and others, and it would be very difficult to account for it by an atmospheric circulation of any other type, unless, indeed, we suppose the glacial periods of Europe and North America not to have been simultaneous, a view which seems to raise more difficulties than it explains. Such cyclonic movements would also account for Gilbert's "moist periods," coinciding with the glacial period, in the region of Lake Bonneville and Lake Lahontan.

In the case of the southern hemisphere, the field of observation is of course much more limited, and it has not been so fully explored. A summary of what is known about permo-carboniferous glaciation in southern latitudes, published recently by Penck, is interesting in this connection. It appears that glacial action during that period has left traces in Victoria and New South Wales, Natal and the Transvaal, and possibly also in the Argentine, all in lat. 30° to 40° S., and on the east sides of the land masses. The actual evidence of ice-action seems somewhat obscure, and the Gondwana Land question has relations to this part of the subject which I confess are far from clear to me. But if we suppose climatic changes to have taken place in the southern hemisphere in a manner analogous to those described in the northern, the Roaring Forties, which must then have attained a violence truly appalling, many have extended to within 20° of the equator, and the latitudes named would have come within the polar half of cyclones, which would deposit abundant snowfall on the eastern coasts.

Greater interest, perhaps, attaches to Penck's investigation, in the same paper, of the relative positions of the snow-line in South Australia and New Zealand during the quaternary glacial epoch and at the present time, which he shows to be almost precisely the same as those in the Pyrenees. This result, if extended by further research, goes a long way to show that the cold periods were of planetary and probably simultaneous origin, and that they were not primarily due to changes in the land or sea surfaces.

It is impossible here to go into the subject with more detail, but if the meteorological conclusions are correct, or even in the right direction, it seems that the assumption of a lowering of mean temperature, taking place chiefly by cooling in the polar regions, enables us to account for a glacial period by changes of temperature and of the distribution and amount of precipitation, considerably smaller than has been supposed. The increased strength of the planetary circulation is almost a necessary consequence of increased temperature gradient: the displacement of the tropical high-pressure belts is a matter of more uncertainty, for their position on the Earth's surface is dependent on friction to an extent which cannot at present be definitely ascertained by calculation. But if, from the analogy of the two hemispheres, we admit the occurrence of this displacement, it seems that the snowfall will be distributed in a way which will go far to account for the supposed positions of the ice-sheets.

The climatic changes accompanying a *rise* of temperature in the polar regions present some points of interest. The temperature-gradient becomes less steep, and the atmospheric circulation consequently less active, while the tropical high-pressure belt moves further from the equator. Hence the arid belts extend into somewhat higher latitudes; we may suppose the Mediterranean region to become one of intense drought like the Sahara. The geological evidence indicates that in Miocene times Spain had the present climate of Morocco. In the west wind region, the general movement is slower, and, the land and sea influences being relatively stronger, the contrast of oceanic and continental types of climate is increased. Thus on the whole the variation in latitude is diminished, and climate becomes more uniform over large areas. Over the Atlantic the stream currents would be weakened, and the surface movement would be of the drift type, northward along the European coast, with little melting of ice, and consequently warm surface water, a result again agreeing with Geikie's account of the inter-glacial periods. Over Europe the oceanic influence would be much more restricted to the western coast, and the continental climate would probably extend over the greater part of Germany and France, and perhaps also Sweden, a result again agreeing with Geikie, who remarks that during inter-glacial periods the climate of western Europe was that of a steppe. We might expect, from the direction of the main cyclone tracks, that during such a period the climate would in the higher latitudes be milder to north-east of the oceans, especially the Atlantic, than to north-west. I am not aware whether there is evidence of any such difference between, *e.g.*, eastern Greenland and Labrador, but it would suggest that the glaciation of north-eastern America would be more intense and protracted than elsewhere.

Until the question has been subjected to mathematical analysis, it is perhaps premature to attempt to apply the suggestions made to the surviving theories of the causes of glacial and genial periods. The chief point to which I would draw attention is the very small change of mean temperature necessary on the conditions assumed, and therefore the relatively small cause required to produce the desired effect. The occurrence of changes in the intensity of insolation, due to a change in the Earth's mean distance or the eccentricity of its orbit, or to a change in the value of the solar constant, seems very unlikely. It is difficult to say precisely what would be the effect of such a change on the temperature-gradient between the equator and the poles; but it seems probable that this would not alter much except for a large change of mean temperature, which, as we have seen, does not fit well with the facts.

Of the possible causes likely to give rise to large proportional changes in the gradient for a small change of mean temperature, two only need be mentioned: change of the obliquity of the ecliptic, and change of the transmission coefficients of the atmosphere for bright or dark rays. According to Stockwell's calculations, the mean value of the obliquity is nearly 23°·3, with a maximum of 24°·6, a minimum of 22°·0, and a period of about forty thousand years. At a period of maximum obliquity the pole gains about 5 per cent. on its present insolation, and the equator loses about one half per cent., corresponding to a warming of about 1°·6 C., and cooling of 0°·2 (or increase in the gradient 1°·8). An epoch of minimum obliquity corresponds to a cooling of 2°·7 C. at the pole, and warming of 0°·4 at the equator, or an increase of 3°·1 compared to present conditions. But it is impossible to say how far those changes represent the actual variation of gradient at the Earth's surface; the change would probably be greatly increased by the lowering of summer temperature due to increased cloudiness. In any case, however, it seems, from what has gone before, that the range of temperature-variation, although small, is at least of the order of magnitude required.

The effect of a slight change in the transmissive coefficient of the atmosphere, in altering the equator-poleward temperature-gradient, is very great. Assuming the present value to be about 0·6, the Earth receives (in arbitrary units) 170·2 at the equator, and 28·4, or less than one-sixth, at the pole. If the value is increased to 0·7, the equator receives 209·2 and the pole 45·0, or nearly one-quarter as much. L. de Marchi has worked out the temperature-change produced by a reduction of value from 0·6 to 0·54 for oceanic and continental climates, and finds an increase or gradient of 4°·7 C. for continental regions, and 1°·8 for oceanic. These again seem to be of the order of magnitude required.

The question remains as to how far such a change in the coefficient is likely to have taken place, and what cause or causes can be assigned for it. Any alteration in the transmissive power of the atmosphere for bright solar rays is very unlikely, but a change in the amount of water-vapour or carbonic acid would produce marked variation in the transmission of dark rays, these substances being nearly opaque to long-wave radiations. Thus, if the quantity of carbonic acid in the atmosphere increases, the temperature of the ground and of the lower atmospheric strata will be raised, till the increase of radiation into space has restored equilibrium between gain and loss of heat. Aqueous vapour, although it possesses similar properties, is unable itself to produce any radical change of temperature, for the quantity of aqueous vapour in the atmosphere depends on the temperature of the air; if the temperature be lowered by some other cause, as by radiation, the vapour is partly condensed and its protecting powers diminished—then the increased radiation again causes further condensation, and so on.

Arrhenius has calculated the probable departures from present atmospheric temperatures which would be caused by multiple changes in the present amount of carbonic acid. If the amount of carbonic acid were reduced to two-thirds, this would represent a fall of temperature of about 3°·1 C. in all latitudes from the equator to at least 65°. If the amount were trebled, temperature would rise about 7°·3 at the equator, and 9°·3 in lat. 65°. Thus we have, with a rise of temperature, a marked diminution of the temperature-gradient, but with a fall of the order required the gradient remains much the same. But if we take into account the corresponding changes in aqueous vapour, and especially the changes which would be induced in the amount of cloud, there are many reasons to suppose that not only would the total effect of a given variation in the amount of carbonic acid be much greater than that represented, but the effect of a diminution would be to considerably increase the temperature gradient.

The amount of carbonic acid in the atmosphere at the present time is represented by about 45 parts in 100,000 (by weight), and Hogbom finds that agencies now at work on the Earth's surface are capable of producing or absorbing, in a single year, quantities which form a not unimportant fraction of this amount. But a serious increase in the total carbonic acid necessary to produce a given change in the atmosphere results from the fact that of all carbonic acid set free, the ocean absorbs nearly five-sixths. Chamberlin, and more recently Ekholm, have discussed the question from a geological point of view, and believe that liberation and absorption of carbonic acid may actually have taken place on the scale required; and Ekholm has even formulated a scheme showing alternate liberation and absorption, and consequent succession of warm and cold periods.

REVIEWS.

ASIA.

Khurasan and Sistan.*

In 'Northern Afghanistan' Colonel Yate gave an account of Afghan-Turkestan from Kabul to Herat. In this volume he carries the narrative further west into Persia, and describes the north-eastern provinces of that country from the Kurd and Turkoman country along the Russian frontier to the north down to the confines of Baluchistan on the Indian frontier to the south. He also gives an account of a stay among the Goklan and Yamut Turkomans, "hitherto comparatively unknown," as well as of a trip to the source of the river Gurgan, "never before visited by any European traveller." Colonel Yate also has a good deal to tell of the Afghan and Persian soldiery, of the official and commercial sides of Persian life, of the recent changes in Persian society, and of certain of the notable sights of the country of the Lion and Sun, especially the shrine of Imam Raza at Mashhad, the tomb of Omar Khaiyam, and the turquoise-mines at Madan. The Russo-Afghan frontier is also described in chapter ii., the Russo-Persian frontier in chapter iii., the Persian-Afghan border in chapter ix., Astarabad and the Caspian in chapter xvi. Three years' experience as British Consul-General at Mashhad gave the author his opportunity, and he has used it with great industry and patience, as well as with admirable temper and good sense. It might have made the volume more interesting to its general reader if a stricter selection had been observed in the narratives of social functions and of excursions to the more obscure Persian localities; but Colonel Yate professes to write with the special object of helping brother officers in the

* 'Khurasan and Sistan.' By Lieut.-Colonel Yate. Blackwood. 1901.