33. Contributions *to the* Geology *of* British East Africa.—Part I. *The* Glacial Geology *of* Mount Kenya.

By J. W. Gregory, D.Sc., F.G.S. (Read May 23rd, 1894.)

Contents.

		Page
I.	Introduction	515
II.	The former Glaciation	518
III.	The Nature and Age of the Glaciation	520
IV.	The Causes of the Glaciation	522
V.	Climatic Conditions during the Period of Maximum Glaciation	527
VI.	Summary of Conclusions	530
	Map of the S.W. slopes of Mount Kenya	517

I. Introduction.

In the discussion as to the respective merits of the rival theories concerning the causes of former glaciation, few lines of work seem likely to yield better results than the study of the originally greater extension of glaciers in tropical regions. When therefore, on emerging from the dense forests of the lower slopes of Mount Kenya, I came upon a series of old moraines, not 10 miles from the Equator and far below the level of the existing glaciers, my interest was at once aroused in the additional problems presented for solution.

Mount Kenya is situated in long. 37° 20′ E. and lat. 0° 6′ S.; it rises to the height of approximately 19,500 feet, and covers an area of about 700 square miles. It consists in its lower part of a huge pile of volcanic ash and débris, with a low gradient, rising from 7200 to 10,200 feet, densely covered with forest and bamboo-jungle. Above this frown steep craggy slopes of coarse agglomerates, ash, and lava, while the whole is surmounted by a rugged pyramidal peak which is part of the central core of the old volcano.

The central peak is of such excessive steepness that the snow is scattered irregularly over it, instead of forming a 'calotte' or snow-cap, similar to those on Kibo (the higher summit of Kilima Njaro) and Chimborazo. The snow accumulates in the hollows and on the slopes with lower gradients; from these snow-fields a series of glaciers flow down into the valleys.

The existing glaciers occur mainly on the western and south-western slopes of the mountain. The three principal classes of glaciers are represented; there are the normal valley-glaciers, of which the largest is the Lewis glacier, named after the late Prof. J. Carvell Lewis, whose premature death cut short a career of such brilliant work on glacial geology. This, and two similar valley-glaciers to the north-west of it, flow from nevé-fields to below the snow-line. Their lower courses are bordered by moraines. The glaciers are crevassed, especially in the steeper portions of their course, and are separated from the nevé-fields by fairly large *berg-schrunds*. The second type consists of the 'corrie' or 'hanging

Fig. 1.—*View of the central Peak of Mount Kenya; with the Lewis Glacier.*
(The Teleki Valley, with a grove of *Senecio kenyensis*, is seen in the foreground.)

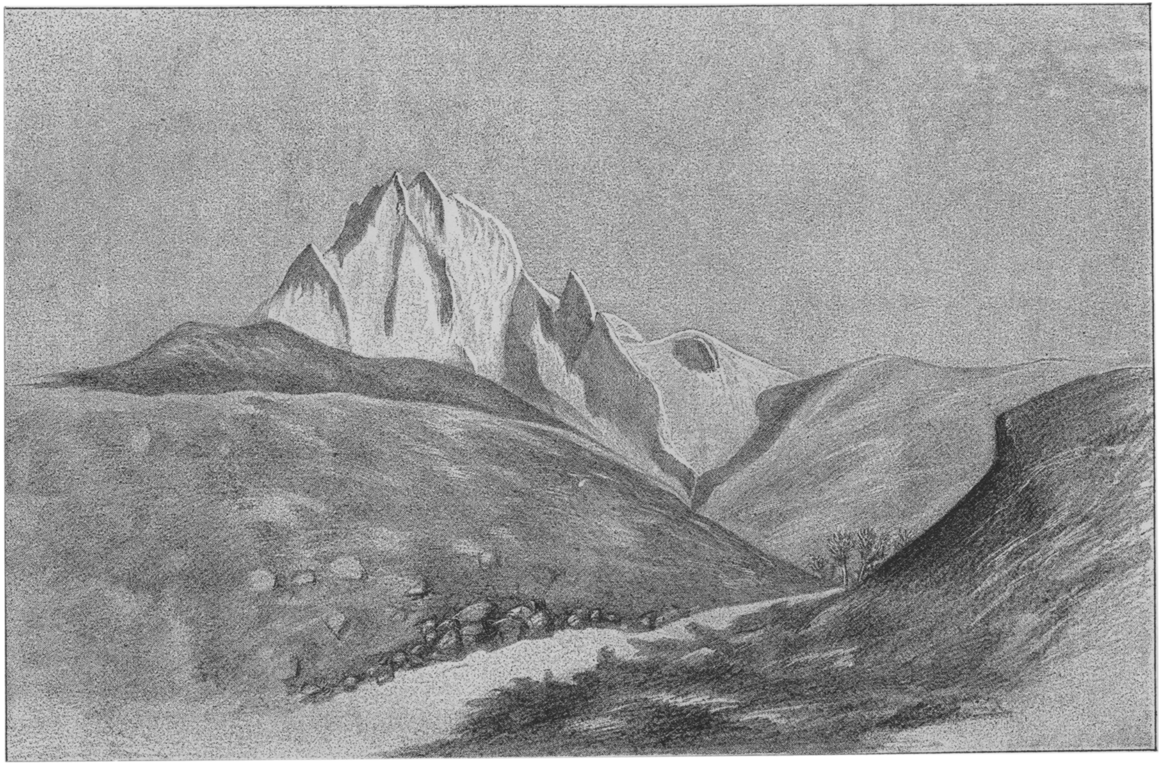
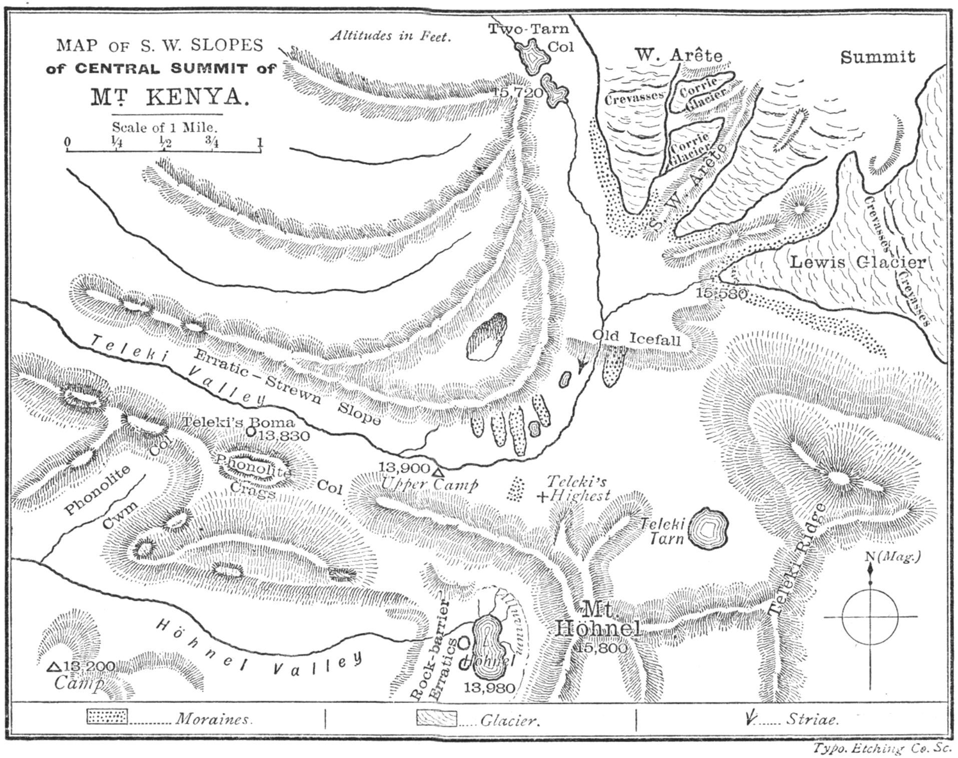


Fig. 2.


MAP OF S. W. SLOPES
of CENTRAL SUMMIT of
MT KENYA.
Scale of 1 Mile.
0 ¼ ½ ¾ 1
Altitudes in Feet.
Two-Tarn Col
15,720
W. Arête
Summit
Crevasses
Corrie Glacier
Corrie Glacier
S. W. Arête
Lewis Glacier
Crevasses
Crevasses
15,580
Old Icefall
Teleki Valley
Erratic-Strewn Slope
Teleki's Boma
13,830
Col
Phonolite Crags
Col
13,900
Upper Camp
Teleki's Highest
Teleki Tarn
Phonolite
Cwm
Teleki Ridge
N (Mag.)
Mt Höhnel
15,800
Höhnel
13,980
Alluvium
Rock-barrier
Erratics
Höhnel Valley
13,200
Camp
Moraines.
Glacier.
Striae.
Typo. Etching Co. Sc.

glaciers'; the two largest of these are situated on the south-western face, just north of the south-western arête. They end in vertical ice-cliffs 200 to 300 feet high. Below these are huge masses of fallen ice-blocks, by the consolidation of which the third type or the 're-cemented glaciers' have been formed: these are here tributary to the valley-glaciers.

The snout of the Lewis glacier ends at the height of 15,580 feet, but the two others reach a lower level, as they occur in sheltered valleys and drain larger collecting-grounds: they come down to about 15,300 feet.

II. The former Glaciation.

As has already been remarked, the lower slopes of the mountain are swathed in so dense a cloak of vegetation that it is impossible, on a hasty march through that area, to learn much regarding its geological structure. At the level of 9800 feet, however, I found some erratics of coarse andesite, some of which measured about 4×4×3 feet. They were much weathered and rounded, but their surfaces were still grooved; they were certainly not *in situ*, and did not appear to be ejected blocks. I halted the caravan, and cut my way through the neighbouring bamboo-jungle, in order to see whether I could obtain any evidence of the former existence of a parasitic cone at this point. No such evidence, however, could be found, and the irregularly undulating nature of the ground seemed to indicate that the rocks are a series of erratics overlying or weathered out of an old moraine, rather than an extra-morainic fringe.

As soon as we emerged from the forests, we came on abundant evidence of former glaciation, for we struck at once on a terminal moraine. Huge erratics lay strewn about, and I soon noted among them specimens of most of the coarser rocks which were afterwards found in the central portion of the mountain. Small sections cut by streams showed that these occurred in a stiff, greasy clay, formed of a re-deposited volcanic ash: it was of the type familiar as the matrix of a boulder-clay. The scenery also, with its irregular undulations, its numerous swampy, mossy hollows, and its scattered boulders, was highly characteristic of old moraines.

Above the moraine rises a steep, glaciated, rocky slope, over 1000 feet in height, from the summit of which the first view of the general structure of the mountain may be obtained. The base is seen to consist of a vast forest-covered declivity, rising with a gradient of about 1 in 18 to the level of 10,200 feet. Between the forests and the base of the rock-slope is the undulating tract of moraine, which I could now see was continuous as a belt all round the mountain. From the edge of the rock-slope rises a series of alpine meadows furrowed by deep valleys, the walls of which are crowned by picturesque pillars and crags of agglomerate and lava. From this last zone abruptly towers the pile of rocks that forms the great central peak.

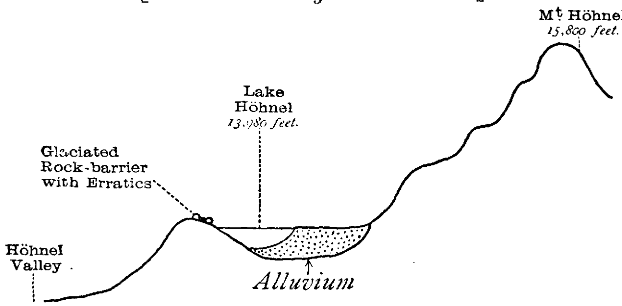
The rock-slope can be clearly seen from Laikipia, and is shown in von Höhnel's sketch from Ndoro; its nature appeared to me rather puzzling, as there were points in it which did not accord with the theory of its being a crater-wall. Its *moutonné* surface, however, showed that it had been greatly worn by glaciers, and it doubtless represents the site of the old ice-fall that once occurred here when an ice-cap covered the upper part of the mountain.

In the whole of the alpine zone of Mount Kenya there is abundant evidence of former glaciation. The rocks on the face of the rock-slope, the bosses that rise from the peat-swamp above it or are exposed on the flanks of the valleys, are all *moutonnées*. Erratics and perched blocks are numerous on the sides of the valleys and even on the summits of the ridges that separate them. Three final proofs were the discovery in the higher parts of the valleys of glaciated lake-basins, of a series of terminal moraines, and finally of well-preserved striæ. It is, I think, desirable to describe examples of each of these in detail, so that the foregoing statements may be the more readily checked by future visitors to the mountain.

(1) *Lake-Basins.*—The example of these which best shows a glacial origin is that which I have named Lake Höhnel (see fig. 3).

Fig. 3.—*Section through the cirque, on the W. side of Mount Höhnel, and its lake-basin.*

[Natural scale: $\frac{1}{3}$ inch = 1 mile.]



It is situated in a cirque on the western face of Mount Höhnel, and has its longer diameter running north and south. Between the base of the cliffs of the cirque and the lake is a swampy plain formed by the tumbling of talus from the crags above. The lake is nevertheless at its deepest near the eastern shore, and apparently shallows gradually to the west. On this side it is bounded by a bare rocky barrier, the whole of which is *moutonnée*, while some enormous andesite erratics are perched upon it, in positions which they could not possibly have held unless transported by glaciers. For the sake of avoiding unnecessarily controversial topics, it may be advisable to leave untouched the subject of the possible glacial origin of cirques, although the alternative theory of waterfall action is clearly inapplicable here. I do not think that anyone could contest the glacial origin of this lake-basin, unless he were ready to adopt the extreme position of denying the glacial erosion of any of the small Alpine tarns and lakelets; and this is admitted by many of those who are most resolutely opposed to such a theory of formation for the greater lakes of Switzerland and Scandinavia, and the lochs and fiords of North-western Europe.

(2) *Old Moraines*.—Of the numerous moraines connected with the present glaciers, a group in the upper part of the Teleki Valley serves as the best example; I have never seen any old set of moraines preserved with more diagrammatic simplicity than these. The first three stand out from the north wall of the valley as clearly as so many railway-embankments. They are composed simply of piles of andesite-boulders, with a smaller proportion of clay than is usual in Alpine moraines. They are about 30 feet in height and reach nearly across the valley. A small tarn occurs behind the uppermost one, and the drainage from this—as well as the stream that flows from the glaciers—is forced by the moraines to the south side. A little farther up, the valley bends abruptly northward, and is crossed by a steep rock-slope that doubtless marks the site of an old ice-fall. From this point a median moraine runs along the valley, and marks the line of junction of the Lewis glacier with that which flowed from the other two.

The Map which accompanies the present paper (fig. 2, p. 517) shows the general arrangement of this group of moraines.

(3) *Striæ*.—The rocks on Mount Kenya are for the greater part coarsely crystalline lavas which weather irregularly and rapidly, and would do so even if they were not subjected to such exceptionally powerful disintegrating agencies as those which operate on the summit of Kenya. I did not therefore expect to find striæ on unexposed surfaces. A few likely situations on lava-bosses on the sides of the valleys were selected and the turf removed; striæ were then found in every case; they were usually very well marked, and especially so on the rocks near the great bend of the Teleki Valley, at the point marked in the map (fig. 2, p. 517). The other localities are not marked, as the striæ were there not so well preserved and might easily be overlooked by anyone who was not prepared for a little trouble and had not had some practice in observing striæ.

The boulders in the upper moraines are seldom striated.

III. The Nature and Age of the Glaciation.

In the preceding pages evidence has been adduced to prove that the existing glaciers on Kenya were once far more extensive than they are at present. They are now merely 'stream-glaciers.' Erratics, however, occur on the crests of the ridges, as on that on the north side of the Teleki Valley; the ice must therefore at one time have completely filled up the valleys, as they were then in existence. Moreover, the great terminal moraine which probably extends all round the mountain could not have been formed by any system of mere valley-glaciers, as the moraine occurs in places at the foot of a rock-slope which is concentric with the peak and at some distance from the mouths of the radial valleys. This terminal moraine could alone have been formed by an ice-sheet which filled up the whole of the valleys then in existence and spread out over the whole surface of the mountain as a 'calotte.' The ice-cap would have been much like that which now fills up the crater of Kibo, or that which Mr. Whymper has so well described as covering the dome of Chimborazo, or again that which the Rev. Maxwell Close has invoked to explain the glacial phenomena of Iar-Connemara.[1]

It must be remembered, therefore, in studying the glacial evidence near its lowest margin, that we have to deal with an ice-sheet and not with a mere valley-glaciation.

Former Extent.—The glaciers now terminate at a height varying from 15,300–15,580 feet, or we may take the mean as 15,400 feet. The old moraine at the foot of the ice-fall occurs at the level of 10,000 feet, while the erratics can be seen down to 9800 feet. How much farther they extended it will be very difficult to determine, owing to the deneseness of the bamboo-jungle that covers this region of the mountain. The glaciers, however, unquestionably extended for at least 5400 feet below their present limit.

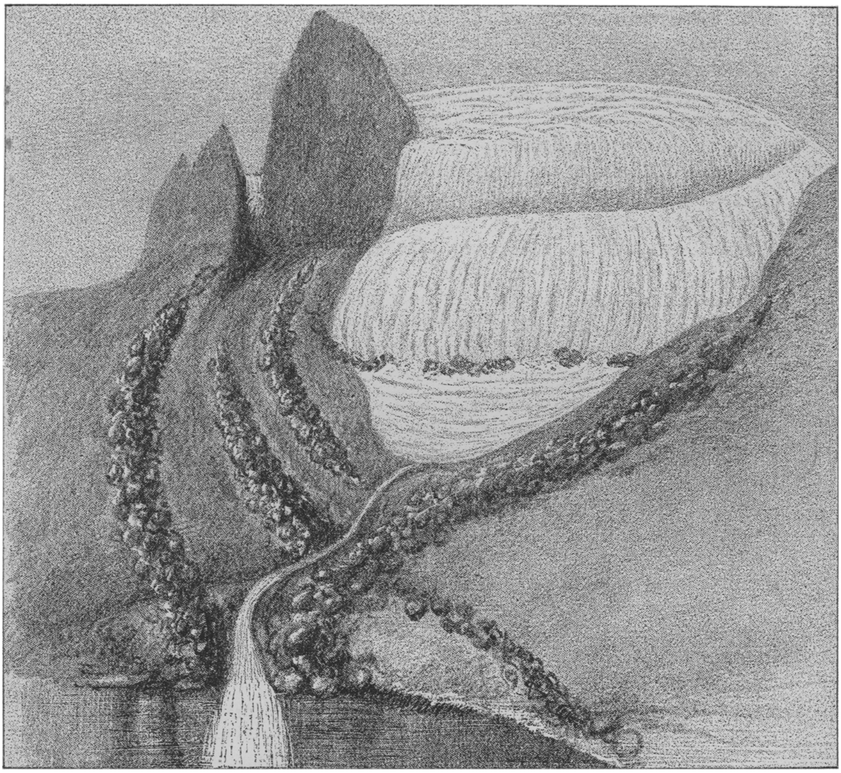
Age of the Glaciation.—This is another problem that can only be approximately determined. The upper set of moraines in the Teleki Valley are very perfectly preserved, but there are full-sized specimens of the arborescent *Lobelia gregoriana*, Baker fil., and *Senecio kenyensis*, Baker fil., growing upon them. Though the former of these may reach the height of 25–30 feet, they are probably of very rapid growth. The great terminal moraine is certainly much older; it is weathered, the slopes are rounded, gullies and valleys have been cut through it and the sides covered with turf; the boulders are covered with moss and the striæ have been erased; the *roches moutonnées* have lost their polished surfaces, and only the deeper grooves and the general form remain to attest their true origin. Great trees, whose age must be measured by centuries, grow in sheltered places on the moraine.

There can be no reasonable doubt that the glaciation took place at a date which, judging by historical standards, must have been very far distant; it was probably anterior to the introduction of the tribes who now inhabit the district, and may date back to the period of the maximum extension of the lakes of the East African lake-chain, of which the present members are the greatly diminished representatives.

In reference to the age, it may be asked whether the glaciers are now still receding. Fig. 4 (p. 522) shows the snout of the Lewis glacier encircled by a set of terminal moraines; the uppermost of these, however, has been burst through by the glacier, and therefore it has recently advanced. The advance, however, has so far been a very

[1] G. H. Kinahan and Maxwell H. Close, 'The General Glaciation of Iar-Connemara,' Dublin, 1872, p. 18.

Fig. 4.—*Terminal Moraines of the Lewis Glacier.* (Diagrammatic.)



small one, and the close proximity of the different members of this series suggests that the glacier has been for some time almost stationary, but subjected to numerous slight oscillations. These may result from irregular annual variations in the snowfall, but it is not improbable that they may have been produced by the well-known oscillation of the ice-periods [1] which results from the periodical oscillation in the temperature of the globe.

IV. The Causes of the Glaciation.

The main geological interest of the former extension of the Kenyan glaciers, at a period geologically recent, is the fact that the

[1] M. Rykatschew, 'Ueber den Auf- und Zugang der Gewässer des russischen Reiches,' IIter Suppl. Bd. zum Repert. f. Meteor. St. Petersburg, 1887, p. 53.
Ed. Brückner, 'Klimaschwankungen seit 1700, nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit,' Geogr. Abh. vol. iv. Heft 2 (1890), pp. 244–255.

mountain is situated directly on the Equator. Bearing in mind that the glaciation of Northern and Central Europe, North America, and New Zealand took place in times which are geologically *approximately* synchronous, the discovery of a great extension of the Equatorial glaciers seems at first sight to support the idea of the universal refrigeration of the globe and to necessitate some astronomical explanation of its cause.

Theories of the universality of glaciation are here ignored because of the absence not only of any traces of former more extensive glaciation from the tropics, as in the Andes and Kilima Njaro, but also from the Cape.

The absence of evidence in the first of these three is very striking. In spite of the extensive glaciers now in existence on the higher peaks of the Andes, there is practically no evidence of their former greater extension. Mr. Whymper kindly tells me that only in two cases did he see any traces of glaciation below the limits of the present glaciers; the chief of these were some decayed *roches* below his second camp on Chimborazo, but it was only a little below the level of the neighbouring Glacier de Débris.

Nor has any such evidence been recorded from Kilima Njaro, though over 100 Europeans have visited it. The majority of these, however, have been sportsmen or naturalists with no geological training, and the others have not reached the level which the glaciation attained. Both Hans Meyer[1] and L. Purtscheller are well acquainted with the appearance of recent glacial phenomena, but it is possible that they may have failed to recognize the weathered traces of old moraines. Some doubt may therefore be felt as to the negative evidence in this case.

Another negative record is that of Prof. Henry Drummond, who says, "In East Central Africa not a vestige of boulder-clay, nor moraine matter, nor striæ, nor glaciated surface nor outline is anywhere traceable;" and he adds "It has been my lot to have had exceptional opportunities of studying the phenomena of glaciation."[2]

The third case is the most instructive. The one region of Africa that one would expect to have been glaciated, if any were, is Cape Colony: but it seems almost certain that, in spite of some old records, this district cannot have been glaciated since at least Cretaceous times, for otherwise erratics of the conspicuous 'Pipe-Amygdaloids' of the Stormberg series must have been carried on to the surrounding lowlands.

It does not therefore seem necessary to consider here the theory that explains glaciation as being due to the alteration of the position of the earth's axis of rotation, notwithstanding the remarkable astronomical results recently obtained, which show that some shifting of

[1] Meyer speaks of moraine-like ridges round the snow-fields, but explains them as merely talus accumulations ('Across East African Glaciers,' pp. 312–313).

[2] 'Tropical Africa,' 4th edit. 1891, p. 198.

the pole almost certainly does take place. As this, however, is periodical and of very slight amount, its effects would be insignificant.[1]

Another favourite theory—the agency of a different distribution of land and water—cannot be applied in this case, unless one is prepared to maintain the existence of Gondwanaland to a very late Tertiary date, which probably few geologists would be prepared to do.

It seems therefore necessary to fall back on a purely local explanation, of which the natural one is elevation, owing to which a greater mass of the mountain was upreared above the snow-line. This elevation may have been effected by either or all of the three following agencies:—

(1) An elevation of the whole region.

(2) Local earth-movements of the Mount Kenya district.

(3) By the height of the volcano before it was reduced to its present level by denudation.

In regard to the first, there seems no sufficient evidence to establish the existence of any subsidence of the country for 5000 feet. The fiord-like estuaries that run up into the coastal plain, such as Port Reitz, or the harbours of Kilindini, Takaaungu, or Khilifi, indicate a submergence of only slight amount. The coral-reefs of the coastal plain show changes of level all along the coast which vary in amount from 20 to 50 feet.

There may be evidence of a greater and older submergence in the occurrence of some limestones on the Magarini Hills, though it is probable that the rocks have been carried there (for some economic purpose) by some exceptionally energetic native. But even if they be in place, they indicate a subsidence of only some 300 feet, which would be quite useless.

It may be suggested that the depression, which formed the channel of over 1000 fathoms in depth that broke the former connexion between Madagascar and the mainland, indicates a subsidence of the whole region of the required amount. But the differences in the fauna and flora show that this was probably much older than the period of maximum glaciation, while the subsidence along this line is more likely to have counterbalanced a simultaneous elevation of the

[1] The principal references to the subject of the variation of latitude are as follows:—

S. C. Chandler: six papers in Astron. Journ. Nos. 248–251, 267, 277, and Monthly Notices R. Astron. Soc. vol. liii. (1893) pp. 119–120. For subsequent discussion, see F. Folie, 'Essai sur les Variations de Latitude,' Bull. Acad. R. Sci. Brux. sér. 3, vol. xxvi. (1893) pp. 577–613; A. d'Abbadie, 'La Fluctuation des Latitudes terrestres,' Bull. Astron. vol. ix. (1892) pp. 89–102; Simon Newcomb, 'On the Dynamics of the Earth's Rotation with respect to the Periodic Variations of Latitude,' Monthly Notices R. Astron. Soc. vol. lii. (1892) pp. 336–341; H. G. van de S. Bakhuyzen, 'Variations of Latitude deduced from the Observations of Polaris made at Greenwich 1851–89,' *op. cit.* vol. li. (1891) pp. 286–306; W. G. Thackeray and H. H. Turner, 'On the Variations of Latitude as indicated by Recent Observations at the Royal Observatory, Greenwich,' *op. cit.* vol. liii. (1893) pp. 2–11; W. G. Thackeray, 'Latitude Variation and Greenwich Observations 1851–1891,' *ibid.* pp. 120–123, pls. iii.–v., and *ibid.* pp. 292–296; G. C. Comstock, 'The Secular Variation of Latitude,' Amer. Journ. Sci. ser. iii. vol. xlii. (1891) pp. 470–482.

land-masses on either side than to have been part of a widespread equal earth-movement.

There is therefore no evidence on the coast of changes of level sufficiently recent or important to account for the glaciation.

The second suggestion, namely, that it was due to local earth-movements, seems much more probable, as in the great rift-valley a few miles to the west there is evidence of very extensive faulting and earth-movements of Pleistocene age; some of these have cut through the great pile of Settima, the companion volcano that rose opposite Kenya on the western side of the Laikipia plateau. If there were no elevation on the coast or at Kilima Njaro, a differential movement of only 1 in 250 would give the required elevation on Kenya.

The third cause no doubt contributed something, as not only must the cone once have been very much higher than it is at present, but the slopes would then have been more suitable for collecting snow than the precipitous crags that now form the central summit of the mountain. It is unfortunately impossible to determine from the data at present available the exact height of the original crater, as, until it is known how much the forest-clad slopes have been lowered by denudation, one cannot estimate the height and extent of the base from which the crater rose. Kibo rises about 2000 feet higher than Mawenzi, and the parallel between these, the newer and older eruptive centres of Kilima Njaro, must be very similar to that between Kibo and Kenya. If we assume that the slopes of Kenya in its prime were at the same angle as those of Kibo, then an addition of 2000 feet to the altitude of Kenya would form a peak of almost exactly the right diameter.

We may thus account for 2000 of the 5400 feet required. But an increase in the size of the snow-fields would lead to an increase in the length of the glaciers, which would thus reach a lower level. To take an illustrative case from the Swiss glaciers. The following glaciers are arranged in pairs, and the members of each pair are closely adjacent and under apparently similar conditions; thus the two Grindelwald glaciers are parallel, adjacent, flow from the same mountain-axis, and both to the north; the Aletsch and Fiesch glaciers are also similar, but flow both to the south. The figures are taken from Heim's 'Handbuch der Gletscherkunde,' p. 73:—

Name of Glacier.	*Area of ice-field in square kilometres.*	*Alt. of snout of glacier in metres.*	*Depth of snout below the nevé-line in metres.*
Gorner	69	1840	960
Zmutt	27	2100	650
	Area of collecting-ground.		
Aletsch	99·54	1353	1400
Fiesch	33·57	1500	1300
Unteraar	22·0	1879	850
Oberaar	6·7	2243	500
Unter Grindelwald	28	1080	1650
Ober Grindelwald	12	1320	1400

This shows that in each case the glacier with the larger collecting-area goes the lower and farther below the nevé-line. The distance to which this 2000-feet addition to the height of Kenya would carry down the glaciers cannot be determined; it would depend (1) on the rate of the motion of the glaciers, which is probably high—owing to the steepness of the gradient and the enormous diurnal range of temperature: I had intended to measure this, but the refusal of my men to approach the snow-line rendered it impossible to do so; and (2) on the rate of ablation, which would probably be very great and would lessen the length of the glaciers.

The fact, moreover, that the valleys are glaciated to their bottoms and that perched blocks still surmount the crests show that there has been no very great denudation in the alpine zone since the maximum glaciation. Thus, though there may have been a considerable lowering of the central plug which now forms the summit since the time of maximum glaciation, in the later stages, as when the glaciers were depositing the terminal moraines of the Teleki Valley, the entire crater-walls had disappeared. Therefore, though the lowering of the summit by denudation has no doubt helped to restrict the downward extension of the glaciers, as these were more extensive in times later than the destruction of the crater, this factor can account for only a fraction of the balance of 3400 feet.

In spite, however, of the absence of evidence of earth-movements on the coast or of a glaciation of Kilima Njaro, there is one line of argument which shows that the elevation was not limited absolutely to the Kenya district. On the higher summits of Kilima Njaro, Ruwenzori, Elgon, the mountains of Abyssinia and the Cameroons, there is an alpine flora quite unlike anything in the lower country of Equatorial Africa. This must once have extended across the lower plateaux and retreated to the mountains as the land subsided to a warmer and lower level. In the 'Geographical Journal'[1] is a map illustrating the present and former distribution of this alpine flora, showing that a downward extension of the glaciers for a little over 5000 feet would enable this distribution to be effected without the intervention of any universal African ice age, and merely as a result of its greater elevation. The fact that the fauna extended to the Cameroons is of interest, as the submerged fiord beyond the mouth of the Congo shows that great subsidence has occurred in that region.[2]

[1] J. W. Gregory, 'Contributions to the Physical Geography of British East Africa,' 1894, vol. iv. p. 289.

[2] Enrico Stassano, 'La foce del Congo,' Atti R. Accad. Lincei, ser. 4, vol. ii. pt. 1 (1886), pp. 510–513; see also Ernst Linhardt, 'Ueber unterseeische Flussrinnen,' Jahresber. Geogr. Gesellsch. München [1890–91], 1892, pp. 26–27, 41–42. It is fair to note, however, that this case is not regarded as a proof of subsidence by J. Y. Buchanan, 'On the Land Slopes separating Continents and Ocean Basins, especially those on the West Coast of Africa,' Scottish Geogr. Mag. vol. iii. (1887) pp. 222–223.

V. Climatic Conditions during the Period of Maximum Glaciation.

The former distribution of the alpine flora of Equatorial Africa is an indication of the different climatic conditions that resulted from or were concomitant with the maximum glaciation. An attempt will be made in this part of the paper to determine the meteorological conditions of Equatorial Africa at that period.

In the first place, it will be advisable to consider the changes in the general conditions of the atmospheric circulation, that would have resulted from the elevation of Mount Kenya for over 5000 feet, and then the effects of these changes on the atmospheric pressure and thus on the winds and rains.

The first change to be noticed is that the whole of the uplifted region would be colder. The average rate of decrease is generally taken, following Herschel, at 1° F. for every 300 feet of ascent; and though in many later cases which have been more accurately observed the rate of diminution of temperature has been increased, it may be advisable to take this rate—so as not to exaggerate the amount. But it must be remembered that the rate of cooling increases both with the ascent and the seasonal descent of the isotherms. The annual mean, however, for the carefully collected data given by Hann [1] from the observations on the Théodule, when reduced to feet and Fahrenheit, also gives 1° F. for 300 feet. As these results were obtained at the height of over 10,000 feet, and well above the snow-line, the conditions of that case are probably fairly analogous to those on the higher African peaks.

The mean temperature will therefore have been 17° F. lower than at present. This would have a treble influence: (1) the air would contract in bulk; (2) the saturation-point would be lowered, and the air become drier; (3) there would therefore, owing to the increased precipitation, be more snow than under existing conditions. Now all these three factors tend in the same direction, viz. an increase of barometric pressure on the lower regions and a depression of the isobaric surfaces. Consequently, there would be at night, when the cold is greatest, an inset current at a high level toward the mountain. This further helps the depression of the isobaric surfaces, and there would thus be at night a downrush of air along the slopes, similar to that well known in the Alps, with a high-level inset current sweeping in to the mountain and carrying the damp air from the surrounding lowlands on to the snowclad summit.

In the daytime the conditions would be reversed; the sun would exercise enormous power, the surface of the mountain would be heated, ablation would be very rapid, the air would become moist, the

[1] J. Hann, 'Ueber das Klima der höchsten Alpenregionen,' Zeitschr. oesterreich. Gesellsch. Meteor. vol. v. (1870) p. 197.

See also Hann's recent memoir, 'Weitere Untersuchungen über die tägliche Oscillation des Barometers,' Denkschr. k. Akad. Wissensch. Wien, vol. lix. (1892) pp. 297–356.

isobaric surfaces would rise and air rush in from below. There would thus be a high-level radial outflow, and a low-level inflow.

The air would not, however, be free to move radially from the mountain equally in all directions, for along the Equator there is a prevailing westerly wind. This is due to two factors: as the heated air rises, if its proper easterly motion were to remain the same, its radius vector would increase; its velocity has therefore, by Newton's second law, to diminish, and it lags behind as a westerly wind. Then the air that rushes in to the Equator from north and south has a lower eastward velocity than points on the lower latitude; it therefore also drags to the west. Therefore any low-pressure area on the Equator is simply in the position of a stationary eddy on a westward-flowing stream, and is supplied mainly from the east. Thus Uganda, as it is in the neighbourhood of the low-pressure area of the Nyanza, has its prevalent winds from the east. But east winds in this part of Africa are dry ones, because they arise on the dry barren steppes or 'Nyika' between the mountains and the sea; for the monsoons blow parallel to the coast, and thus cut off any large wind-supply from the Indian Ocean. The wet winds are those from the great forest-regions of the west; thus it is that the snow-line is so much lower on the western sides of Kilima Njaro and Kenya than on the eastern; in the former, the glaciers reach the level of 13,800 feet on the western side and only 18,700 on the eastern. The different amounts of snow on the two sides of the main southern arête of Kenya show that the same condition holds there.

The points to which these observations have led up are :—

1stly. The meteorological conditions of Kenya and doubtless also of Kilima Njaro[1] are very different from those on the surrounding plains, for there is a daily reversal of the wind-direction, so that westerly winds can come in at all times of the year and not only during the changing of the monsoons. There is therefore no such sharp differentiation on these mountains into wet and dry seasons.

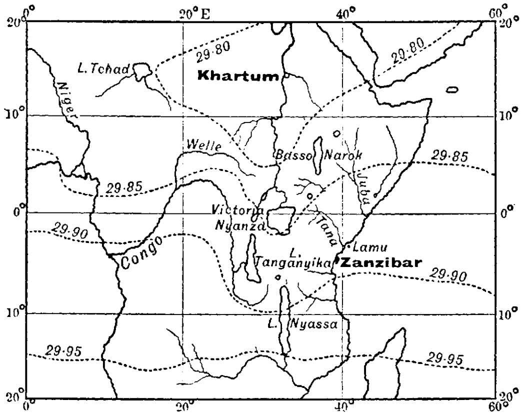
2ndly. If the whole region were raised 5400 feet, an enormous tract of country would be placed under these conditions, and not only a few isolated peaks.

Let us next consider what influence would result therefrom on the conditions of atmospheric circulation, and thus on the rains and plant-distribution.

At the present time this region of Africa appears to be one of low pressure. If we take Dr. Buchan's isobaric charts for each month and calculate from these the mean for 5 points—viz. the north end of Lake Nyassa, Zanzibar, the first point at which the Congo crosses the Equator, the Nyanza, and Khartum—we get indications that the low-pressure area of Arabia and the Sahara has a branch up the Nile Valley to the south. This is shown in fig. 5. In the time of

[1] Hans Meyer has discussed ('Across East African Glaciers,' pp. 307–310) the winds of Kilima Njaro, which are not now under the same conditions as those of Kenya, for it is over 200 miles south of the Equator, and therefore is within the region of the trade winds, and not of the Equatorial westerly drift. It is, moreover, nearer the southern line of maximum pressure.

Fig. 5.—*Isobaric Map, showing the low-pressure area in Equatorial Africa.*



The dotted lines ...... = mean isobars.

the maximum glaciation, on the other hand, a high-pressure area would have occurred over Kenya, Kilima Njaro, Elgon, and doubtless also the Ruwenzori districts; this would have resulted from the cold, dryness of the air, abundance of snow, and inset high-level current.

The influence of this on the rains would be as follows:—

(1) This high-pressure area would deflect the normal westerly drift of the air along the Equator, and therefore more air would reach this region from the damp forest-land of the west than does so at present.

(2) The whole region, moreover, would be subject to daily reversal of the direction of the wind, and thus there would be much greater local irregularities, and no sharp differentiation into wet and dry seasons. The rainy seasons are now very well defined on the lowlands. They occur:—

On the coast at Lamu, Mombasa, etc., from April to August and for parts of December and January.
In South-western Kikuyu from February to May.
In Uganda from September to November and in April.
Around Basso Narok (Lake Rudolph) in April and May.
In Southern Abyssinia in March and April.

(3) The maximum rainfall now occurs in the forest zone on Mount Kenya, between 7000 and 11,000 feet, though at some seasons it may rise higher, just as in the Alps it is in the winter at from 3000 to 4000 feet, and in the summer occurs above the highest peaks.[1] But when the ground was higher the line of maximum rainfall would not rise to the same amount, owing to the resultant lowering

[1] J. Hann, 'Die jährliche Periode des Regenfalles in Oesterreich Ungarn,' Zeitschr. oesterreich. Gesellsch. Meteor. vol. xv. (1880) p. 264.

of the temperature. At the period of maximum glaciation it would therefore occur relatively lower than at present, and there would thus be a considerable rainfall over areas that are now very sparsely watered.

The results on the rainfall of the changes that would have occurred at the time of the maximum glaciation would therefore have been :—(1) an increase in its amount; (2) a relative lowering, and therefore widening, of the surface of maximum rainfall; (3) the more even distribution of the rain throughout the year.

The results on the vegetation of the district would have been very great. Much of the scrub which now covers the country with its spine-like or narrow leaves, and succulent leafless herbs and trees, which are all specialized to secure a minimum of transpiration, would have been replaced by vegetation of a more normal and luxuriant growth, and better adapted for animal food. The forests that now occur as belts beside the rivers would have spread out as wide tracts of primeval forest, similar to those of the Congo and the Aruwimi, which are now limited to the western side of the Tanganyika rift-valley. Hence in the time of maximum glaciation the food-supply for insects and small mammals would have been distributed very differently from what it is at present, and there would have been fewer, if any, of the waterless wastes that now present barriers to animal migration.

VI. Summary of Conclusions.

1. That, by the discovery of moraines, striæ, glacial lake-basins, perched blocks, and *roches moutonnées* below the present limit of the Kenyan glaciers, it is proved that these must once have extended for at least 5400 feet below their present level.
2. That at the time of maximum glaciation Mount Kenya was covered by a great ice-cap or 'calotte,' and did not merely support a system of valley-glaciers.
3. That the glaciation was due to the former greater elevation of Mount Kenya, which has been reduced by subsidence and denudation. The theory of an universal glaciation is unnecessary, and is opposed by many facts in African geology.
4. That the glaciation affected the adjoining mountains, including Kilima Njaro, Ruwenzori, Elgon, and Abyssinia, is rendered highly probable by the facts of botanical distribution.
5. That the meteorological changes concomitant with the maximum glaciation, and also due to the elevation, would have been the formation of a high-pressure area and an increase in the amount of the rainfall, its more equable seasonal distribution, and a lowering and widening of the surface of maximum rainfall.
6. This would have led to a great change in the distribution of animal- and plant-life.