On variations of climate in the course of time

By

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The following is a short abstract from various papers, viz.:

Essay on the immigration of the Norwegian flora during alternating rainy and dry periods. Chria. (A. Cammermeyer) 1876. 8. 89 pp. With a coloured map of Norway.

Die Theorie der wechselnden kontinentalen und insularen Klimate in Engler's Botanische Jahrbücher II. Leipzig 1881. 8. pp. 1—50. Nachtrag mit Kart pp. 177—184.

Ueber Wechsellagerung und deren mutmaasliche Bedeutung für die Zeitrechnung der Geologie und für die Lehre von der Veränderung der Arten in Biologisches Centralblatt III n. 14–15, pp 418—434 et 449—461. Erlangen 1883. 8.

Ueber die wahrscheinliche Ursache der periodischen Veränderungen in der Stärke der Meeresströmungen in Biologisches Centralblatt IV n. 2. pp. 33—48. Erlangen 1884. 8.

If we examine the meteorological charts of Norway we observe at once what a great influence the sea and the mountains exercise over the climate in various parts. Nearly all the climatological lines run more or less with the shape of the coast, so that we encounter far greater variations when proceeding from the centre coastwards than from south to north. In keeping with the same are the variations of the flora.

The plants of Norway may be divided into certain *groups* *of species*, the species belonging to the same group having a somewhat similar extension, whilst each of these groups of species is confined to special climatological conditions and is only found in those parts where such prevail.

The *Norwegian flora* is in the main monotonous. On the mountains large areas are covered with only a few lichens, mosses, and heather, or copses of dwarf birch, juniper and willows; lower down the forests are formed of birch, fir, and spruce, and have a monotonous flora viz., heather and lichen in the fir forests blue berries and a few kinds of moss in the spruce forests, while the west coast is covered with heather and the numerous marshes with a vegetation, poor in species, of a few mosses and Carices.

But in spite of this general monotony of the flora of the mountain wastes, with their greyish yellow lichens, greyish green and green copses of willows and dwarf birch, there are certain places, particularly on slaty ground, where a richer vegetation may be found. It consists of small perennial plants, some inches in height, and which are particularly distinguished by their copiousness of flowers, which are very large in proportion to the size of the plant, and have very pure and lovely colours. Outside Norway we also encounter these plants in arctic regions and the alpine flora of these slaty tracts is therefore of arctic character. But not all slate mountains have such a varying flora. The coast climate is, in consequence of the mild winters, when the temperature frequently changes, destructive to these plants, which shoot at a very low degree of heat. It is for this reason that when we mark those places on the map which have a rich alpine flora, they lie scattered as oases over the land with great spaces between, but always sheltered from the seawinds, i. e. on the east and north east side of the highest mountains and greatest glaciers, which act as barriers against the mild climate of the coast. In these places the botanist may fancy himself transfered to Spitzbergen or North Greenland; he finds the principal plants encountered there; and if we follow the Arctic flora to Spitzbergen we find that also here it shuns the sea and is most copious at the bottom of the fjords.

In the lower districts, sheltered from the open sea, we find in favourable spots another group of plants, which also shun the coast, and which thrive on loose slates and warm limestone cliffs or in screes of different kinds of rock, under precipitous mountains, facing the south. These screes are generally full of bare boulders at the bottom; but in the finer debris higher up grows a wreath of green underwood, formed of tender deciduous trees and shrubs, hazel, elm, lime, maple, wild apple, dogroses, Sorbus Aria, Prunus avium &c., as well as a number of highly scented Labiatæ, several Papilionaceæ, grasses and a great number of other plants, together forming that part of the Norwegian lowland flora, which shuns the open sea coast and prefers the fjords and the sunny valleys. But even this flora has a scattered extension. It is richest in the tracts around Christiania, and becomes poorer westwards along the coast, disappearing almost entirely on the coast of the province of Bergen, but at the bottom of the Sogne- and Hardanger- and along the Throndhjemsfjord we find the same flora, and that in spite of these parts being entirely separated from the eastern parts by enormous mountains.

Near the open sea the flora becomes poorer in species, most of those characteristic of the interior disappearing, whilst their number is not by far made up by those belonging to the coast. Here we shale only name a few of the coast plants, such as the holly, the ivy, the foxglove, whilst in place of the Primula veris of East of Norway, we have the P. acaulis of the West-coast. In the woodless tracts of the coast the heather predominates, and besides the ordinary common one we find two other species. This group of plants belong exclusively to the south and west coast and is hardly found north of the Throndhjemsfjord. Most of its species are not found near Christiania, but they reappear in the South of Sweden. Some, however, are in Scandinavia only found on the west coast of Norway, and we must travel to the Faroe Islands, Scotland, England, and Belgium to re-encounter them.

We have thus seen that the Norwegian flora consists of groups of species, which make different demands as to climate.

If we were to colour a map according to the places where certain groups are most copious, we should at once discover that they had a scattered distribution. We should find the same colour here and there, in smaller or larger patches, *but those of the same colour would be separated by great spaces of a different tint.*

At one time botanists were satisfied with explaining the distribution of species through soil and climate, but as the study of their appearance proceeded, it was discovered that there were great gaps in the extension of many. And the gaps were often so great that scientists were obliged to resort to explaining the same by maintaining that such species were created in places far apart. But since the doctrine of the origin of species by descent has been accepted such an explanation must be rejected. There remains, therefore, only two ways in which to explain these things. Either wind, animals, or sea currents are capable of carrying the seed of plants at once across such large areas, that the gaps in the extension can be explained by the means of transport at work at present, and there are even those, who still believe that this is the case. In certain instances this explanation is indeed the only one possible, when for instance it concerns the flora and fauna of Oceanic islands which have never been connected with the great continents, and still have species more or less related to those of the mainland. But such a sudden migration is very improbable, and must even be dispensed with altogether, as we shall presently show, when it is necessary to explain such gaps in the extension of whole groups of species as those we have pointed out above in the flora of Norway.

We have, besides, another explanation of this problem, first advanced by M. Edward Forbes, who maintained — in common with many modern botanists — that *the climatic variations of the Past are reflected in the fauna and flora of the Present.* He was, we believe, the first savant who demonstrated, that the Glacial Age has left its distinct mark on the flora of the present day. Arctic species are found on mountains in temperate climates. During the Glacial Age these species grew in the plains at lower latitudes, but as the climate became milder they receded gradually to the Far North and the high mountains. In the warm plains they had to give way to the new immigrants and this is the reason of our discovering hyperborean plants on the mountains of Europe.

If now we were to apply this explanation to the scattered extension of the species in Norway, we must bear in mind, that the distances here are smaller, although at times there are several degrees of latitude between the places, where the same species appear. We must, therefore, see if an acceptable explanation of the Norwegian flora can be made by means of geology, and if the same be supported by other circumstances.

It is not long since, geologically speaking, that the Scandinavian peninsula was covered with an *inland ice*, stretching right out to sea, above which only solitary mountain tops rose, like the „nunataks" in Greenland. It is evident that the majority of the present flora could not then exist in Norway. But the present flora is older than the Glacial Age, which is conclusively proved by specimens from the same being found in coal strata, older than that period. Thus, yew, fir, and spruce, hazel, willow etc. have been found in old peat bogs of England and Switzerland, for instance, which are covered by the bottom moraine of the inland ice. The present Norwegian flora, therefore, must have lived in other countries which were free from ice during the Glacial Age and *immigrated to Norway* as the climate became milder and the ice receded. This is the reason of Scandinavia having no peculiarly characteristic species, because the flora has immigrated from outside countries and the time is so short since it settled in the country, that it has not yet had time to produce new species.

If we may now apply the geological way of explanation to the flora, we come to the conclusion that the immigration took place during repeated changes in the climate. After several thousands of years with a severer climate which favoured the immigration and extension of northern and eastern species, other thousands of years followed with a milder climate. During this period fresh immigrants came from the south and south-west, compelling the older flora to retreat. *In this manner the climate must have changed several times since the Glacial Age* and the distribution of plants must have changed in accordance therewith. The periods of variation are reflected in the present flora, and it is the former which have led to the great gaps in the extension of coast as well as inland plants. The sunny screes, the slate districts, and the moist coast tracts are asylums where the different floras have found refuges. In the intermediary parts they have been dislodged by the new comers. But certain species being indifferent to the variations, extended constantly to the expense of others, and this is the reason of the Norwegian flora being so monotonous.

In order to test the accuracy of this assertion we shall first turn to the *peat bogs* and examine their structure. We shall for comparisons sake also examine the Danish ones, which are well known from the researches of Prof. Steenstrup.

In the forest and mountain districts of Norway there are innumerable marshes. In the forest districts most of them are now comparatively dry, the heather and wood covering parts of the bog, and on the surface of the latter tiny mossy knolls are often found in the middle of which stands the old stump of a tree. An examination of the structure of the peat layers — which is easily made with a bore — shows, that previous to the present time, when the surface is generally more or less dry, there was a period when the bog was much more watery. Under the present conditions the growth of the peat is arrested, at all events in dry places. But just below the lichen and heathercovered surface we find on boring a pure, unmixed white moss (Sphagnum). It is this moss in particular which has formed the peat in the Norwegian bogs; and in the upper layers — only one or two feet from the surface — flint implements from the Stone Age are often found. At the period this upper layer of Sphagnum was formed, the bogs were woodless, because they were too watery. We see, therefore, that peat in these bogs has not grown very much within historical times, and that the layer of stumps of trees, which are found on the surface in the knolls, indicates an arrest of the growth of the peat, the duration of which may probably be measured by many hundreds, perhaps by thousands of years. It might be argued that the present drier state of the bogs was simply due to the circumstance that the peat had grown so high that the moisture had run off. But this is not an acceptable explanation, because if we bore deeper in the peat, we find that *the oldest bogs are built of four layers of peat, and between these stand three layers of stumps*, so that these bogs are *for the fourth time covered with trees* since they began to form. *And as most of the bogs, if not all, are at present drier than they were before*, the theory of merely *local* variations of the moisture is also *insufficient* to explain the phenomena. It remains, therefore, only to assume, that periods of dry and wet have alternated during ages. The peat layers generally belong to the latter, and the stump layers speak of drier periods, when the bogs were covered with trees.

Of these four layers of peat, which in some places measure upwards of twentysix feet in thickness, only the two youngest enclose, as far the researches in Norway go to show, remains of foliferous trees sensitive to cold. And this justifies the assumption that they correspond to the four layers which Steenstrup has shown in the bogs of Danemark, and which appear like geological strata with distinct fossils, viz., the aspen, the fir, the oak, and the black alder. This comparison of the peat layers of Norway and Danemark is further supported by the circumstance that layers of stumps are also found in the Danish bogs, and here they stand between the peat layers of the different periods. They indicate long periods, during which also the Danish bogs were dry and partly covered with forests, when the peat ceased to grow. But *during these dry times the flora was changed* through the immigration of new species, and when a wet time again set in, it was other trees which grew around the bogs and which spread their boughs, leaves and fruits over the watery bog, their remains being buried by the growing layer of peat.

In this manner the structure of the peat confirms the conclusion to which the distribution of the flora pointed, and if we take the fossil plants and marine shells to our aid, we may explain the gaps in the extension of the species without assuming long transports of seeds.

In the fresh water clay of Scania and Seeland, Prof. Nathorst has discovered numerous remnants of arctic plants. This clay lies below the peat. When it was deposited in the cavities of the old bottom moraines of the inland-ice, not only the dwarf birch, but even hyperborean plants, such as Salix polaris and others flourished in the southernmost parts of Scandinavia; therefore the arctic flora was the first which immigrated into our land. It entered whilst the climate was very severe. But the climate became milder and more moist. The peat began to form; then the aspen and birch entered and, later on, under varying conditions of moisture, the fir and the spruce, with the flora of the mountain- and forest-glens, a series of species which have not yet been mentioned, viz. Mulgedium and Aconitum, many great ferns and grasses, wood Geraniums, and Lychnis &c. But the climate became warmer and warmer; and finally the foliferous trees, more sensitive to cold entered, viz. the hazel, the lime, the ash, the oak, the maple, and a number of others from warmer regions. In the province of Bohus quantities of stones of sweet cherries are found in many places, in peat, where this tree is now extinct; and in the Norwegian peat bogs hazel nuts are very frequent in a certain layer, not only in the interior of the great coniferous forests, where not a single hazel tree is found, but even in heathery woodless coast-lands. It will, therefore, be seen that the hazel and the sweet cherry were then very plentiful, and from this we may justly conclude that the trees and shrubs and herbs which thrive in their company were also once far more plentiful than at present. It is this flora which has found an asylum in the above mentioned screes.

Following the period when Southern Norway was covered with foliferous forest to a far greater extent than now, came a warm and moist one, in which the peat again began to grow. At that time the coast oak (Qvercus sessiliflora) was far more frequent in Danemark than at present, judging by the evidence of the peat bogs, and at that time, the shell deposits inform us, (as shown by Prof. M. Sars), the present marine animals of the west coast were found in the Christianiafjord. And there is every reason to assume that the present flora of the west coast immigrated thither, at that period, from the south of Sweden, along the Christianiafjord to the west coast of Norway.

New changes again set in with new immigrants, and finally came the present age with its comparatively dry climate. But all these events are prehistoric, as is shown by the stone implements lying in the uppermost peat layer close under the surface.

Thus, the remains of plants and animals in clay, peat, and shell deposits inform us that *the gaps in the extension of the species in Norway may be explained by the varying events of times long gone by.*

Since the Glacial Age *the relation between sea and land in Norway has changed.* Formerly the sea was in some places upwards of 600 feet higher than at present.[1]

The clay at that time deposited on the sea bottom, and the shell deposits formed near the shore, contain, as Prof. M. Sars and Kjerulf have taught us, remains of Arctic animals even in the southernmost parts of the country. There is a difference of opinion between savants whether this alteration of the shore line is due to a rising of the land or the sinking of the sea, or to both. There is further some dispute about the manner in which the level became altered some maintaining that it took place suddenly at intervals, whilst others believe that it is the result

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[1] The depth of the peat in the parts which were formerly below the sea, increases with the height above its surface, because the formation of the peat commenced long before the lowest lying parts had risen above the surface of the sea. From the remains of plants found in the various peat layers we may therefore learn how the Norwegian flora was composed during the various phases of the rising of the land.

of a gradual and continuous process. The marks left by the sea seem at first glance to corroborate the first of these theories. Thus, in the lower parts of our valleys we find along the river courses *terraces* of sand, pebbles, and clay, one behind and above the other right up to the highest old shore line. The terraces of which Kjerulf, preeminently amongst others, has given us particulars, have an even surface and a steep declivity outwards, against the mouth of the valley. They contain sometimes remains of sea animals. Under a higher level of the sea the river carried down sand and gravel to its mouth, just as in the present day banks and bars are formed at the estuary of our rivers. And the terraces seem to indicate that the changes in the level were broken by periods of rest. During the latter the river had time to form a bank, which rose comparatively rapidly; the next period of rest gave occasion to the formation of another terrace, an so on. But this theory has to combat many obstacles because the terraces lie often, as Prof. Sexe has shown, even in valleys situated near each other, at different elevations. This scientist is of opinion that steplike terraces may be formed even under a gradual and steady rising, if the carrying power of the river is subjected to changes. Our theory may therefore probably also be applicable for explaining the terraces because if long periods with milder climate have alternated with others whose climate was more severe, it is evident that the volume of the water and thus *the carrying power of the current must have altered.* Perhaps the rivers have at certain times carried down floating ice, at other not, and the thaw in the spring must have increased the carrying power. We can thus understand why the corresponding terraces in valleys near each other do not always lie at the same elevation. Their rivers differ in size, and when the carrying power diminishes a big river will retain the strength to form a terrace longer than a small one.

Besides these terraces, which are particularly conspicuous in the short, steep valleys of the west coast of Norway and on account of their regularity must excite the wonder of every one who se them, there are other equally striking marks of the old sea levels, viz. the so-called „*strandlinier*“ ɔ: *shore-lines*, which are known chiefly through the researches of Prof. Mohn and Dr. Karl Pettersen.

When travelling through the fjords and sounds particularly in Northern Norway, one sees here and there horizontal lines drawn along the mountain sides sometimes several hundred feet above the sea. They are not always equally marked, but appear often remarkably clear; sometimes they look like roads or railway lines. They are always horizontal, or nearly so, and must, therefore, be remains of an old sea shore. Often two parallel lines are seen running one above the other in the same place, and on closer inspection it will be discovered that they are hollowed out of the rock itself. They have a surface sometimes many feet broad, and are bounded behind by a more or less steep mountain wall, forming thus horizontal incisions in the same. The shore-lines have also been brought to prove that the rising was broken by periods of rest, during which the sea had time to hollow out the rock; but I am of opinion that they could be formed too under a gradual rising, if the climate be subjected to periodical changes. The shore-lines belong to the northern parts of the country and the deep fjords where the winter cold is more severe, and they are found in districts where there is a tide. They seem to have been blasted out by the influence of the cold. At high tide the sea water fills the holes and fissures in the rock, and when the tide recedes, it is left in the same. In severe winters the water will freeze, and thus burst the rock. *During the rising of the land, shore-lines will be broken out in this manner, as long as the erosion is able to keep pace with the rising.* When the climate becomes milder, a time will come when the erosion is unable to continue. Then the shore-lines will be lifted up above the level of the sea, and out of the reach of the blasting influence of the water. If next, after thousands of years, when the land has perhaps risen fifty or a hundred feet, a period follows with a severer climate, a new shore-line is formed below the former.

The *shell-banks*, too, (i. e. deposits of shells of marine animals living in shallow water near the shore) lie, as Kjerulf has shown, in the Christianiafjord at different levels, the older at heights from 540 to 350 feet and the youngest between 200 and 50 feet above the present level of the sea. But between 350 and 200 feet none has been found. In the neighbouring Swedish province of Bohus they are found at all elevations, even between 350 and 200 feet, and it must therefore be assumed that local causes, as, for instance the ice-formation in the more closed Christiania fjord, destroyed the shell banks when they reached the shore-line, at a period when the land lay 350 to 200 feet lower in relation to the sea than at present. According to the evidence of the peat bogs, there is reason to believe that *this part of the rising occurred under a more severe climate.*

It is, therefore, seen, that all the facts which have been advanced in order to prove that the rising was broken by periods of rest may be easily explained, if we assume that *the land rose gradually and steadily under periods alternating with milder and severer climates.*

If such a periodical variation in the climate does take place, we should be able to trace it in *the older formations*, as we cannot assume that it first began to operate in the most recent geological age. We must, therefore, try to discover if such variations can be traced in the earlier times.

During the melting of the Norwegian inland ice, it left here and there *moraines*, and on the map drawn by Kjerulf they are seen to stretch in *lines more or less continuously across large parts of Southern Norway.* On both sides of the Christiania fjord the outside lines, the so-called „Raer" stretch like gigantic ramparts from Moss and Horten south-east and south-west many miles through Smaalenene and far into Sweden and, on the other side of the fjord, through the province of Jarlsberg and Laurvig, to Jomfruland outside Kragerø. And behind this outside line of moraines others follow in more or less broken but distinct continuity, one behind the other through all Southern Norway. These lines show that the ice did not recede continually, because it would not then have left behind such great ramparts, but the sand and the gravel would have been spread more evenly. During the melting, however, its edge remained at time stationary, or advanced perhaps a little. At each such event a row of moraines was formed, and as the same row stretches across large tracts of the country, they cannot be attributed to local circumstances, but we have to assume that *periodical variations of the climate were the cause of the manner in which the ice receded.*

We found in the peat bogs alternately layers of different kinds, peat alternating with remains of forests several times, and we saw how this was easiest explained by periods of change in the climate, but these *alternating layers* are not peculiar to the peat alone, but found *in all stratified formations*, loose as well as solid, whether deposited in fresh or salt water, or on land, in all the strata from the Laurentian gneiss to the loose deposits of the present age. Take a geological structure from any age, alternating layers will be found everywhere. Sand alternates with gravel, sandstone with conglomerate, clay with sand, slate with sand or sandstone, marl with clay, chalk with marl, and so on. The layers vary in thickness from several yards to less than an inch.

The solid rock withers away by the action of air and water in heat and cold, partly it crumbles away mechanically and partly it changes chemically. The products of the erosion are carried by wind or running water as dust, in dissolved or original state, and deposited in places more or less remote from those where they were produced. The foaming mountain stream carries often great stones in its course, and the softer the wind the weaker the current the finer is the matter deposited. When the current becomes weak the gravel sinks first, then the sand, then the clay, and, finally, the chemically dissolved lime by the animal life in the water. When we, therefore, have a change of layers of different composition through all geological ages, as those mentioned above, it must be due to the circumstance that the speed of the depositing stream was always varying, now increasing, now decreasing.

The Challenger expedition has taught us, that all the stratified rocks which geologists hitherto have known even deep sea formations must have been formed comparatively near the shore. They are all of quite a different nature than the strata in the abysses of the great oceans. From this follows that the variations in the rain-fall might have had some influence on the nature of the strata in the known geological formations since they were formed comparatively near land and are the result of the erosion of the solid rock. A weak river is unable to carry debris far out to sea, but a strong one is capable of supplying the sea-currents with deposits over great areas. When, therefore, *the rivers alternately increased and decreased,* the sand, clay, and gravel was carried, now far, now short into the sea, and thereby the variations of the layers were produced.

It is, however, not the intension to assert that all alternations of layers are due to that long climatic period. When the stratification goes on quickly, and the supply of matter is plentiful, rapid local changes may produce an alternation of strata. In the Norwegian marl-clay, formed during the melting of the inland ice alternating thin layers of sand and clay are found, varying in colour, sometimes only a quarter of an inch in thickness, or even less. These variations must be ascribed to local changes during brief spaces of time, and cannot be referred to long climatic periods. But, of course, such layers are only formed in the immediate vicinity of the coast, and during the constant advance and retrogression of the latter, which may be traced through all geological ages, such shore formations were most exposed to destruction. They were frequently lifted above the sea, and more exposed to the destructive agencies air and currents than those formed in deeper waters further from the shore. For this reason these quickly formed layers have at all times been more exposed than others to destruction, and we must already from that reason conclude that *most of the layers* which constitute the geological stratified deposits were formed somewhat *further from the shore,* and that, consequently, *the time of their formation was longer.* From the thickness of the layer alone it is impossible to form an idea of the time it has taken to form, because in the time a layer in one place upwards of several yards in thickness has been forming, only an inch has formed in another, whilst in a third place in the same time the formation has ceased or older layers even carried away. But we have a means whereby we may ascertain the time it has taken to form a layer viz., the study of the remains of the flora and fauna found in the same. The most frequent species have, ceteris paribus, the most chance of being preserved. When therefore, we find that fossils, as is often the case, vary from stratum to stratum, we must assume that this proves that great changes took place in the fauna and the flora during the formation of such strata. What was stated above with regard to the variations in the peat bogs of remains of plants from layer to layer may be applied to variation of strata through all ages. *The examination of the fossils in the strata teach us respect for Time.* The fossils vary quickly even in strata of small thickness. In one stratum we find remains of distinct animals and plants, and in the one above, although perhaps only an inch atweit, we find others quite different. A thin stratum of a couple of inches is sometimes distinguished by peculiar animals and plants, so that the stratum may be recognized over large areas by the aid of the same. When two strata of different nature alternate, it is generally found that one kind of stratum contains certain fossils and that those of the other are quite different. The theory of periodical variations of the climate explains all this. Because if the sea currents varied in strength, the temperature of the water, and consequently the marine fauna and flora, must have changed too; with a higher temperature of the sea the moisture of the air and the rain-fall must have increased, and thus would *a periodical change of the sea-currents have the effect of causing variations of the strata.* It is exactly such strata of varying nature, and varying forms of fauna and flora, which would build the geological formations of the earth.

We have seen how *this theory explains a number of various puzzles to scientists* viz., the scattered extension of species of plants and animals, the formation of the terraces the shellbanks and the shore-lines, the rows in which the moraines appear, and, finally, the alternation of the peat-layers and various geological strata. It remains now only to find *a natural cause* of such a periodical variation of the climate; but before doing this it is necessary clearly to understand what the theory demands.

It does not require great changes, all the facts on which it is founded may be explained by comparatively small variations in the extremes of temperature and rainfall. No very great variation is required in order that the holly and similar coast plants should be able to grow by the Christianiafjord, as the theory assumes they once did. Because the holly, which cannot stand the winter-cold at Christiania (lat. 60 ⁰ N.), has for many years been succesfully cultivated in open air at Horten, only half a degree further south, on the same fjord. And along the coast, plants of oriental origin have during the last thousands of years spread from the Christiania and Throndhjems fjord right out to the open shores of Jæderen and Fosen, the former in lat. 58, 59 ⁰ and the latter in 63, 64 ⁰ N., and there would hardly be required a very great change to enable them to grow also in the intervening district of the province of Bergen, which would again make their extension continuous.

Whether the surface of a bog becomes covered with forest or not, whether the peat grows or not, whether during the rising the erosion is strong enough to hollow out the shore-line, or the carrying power of the river is great enough to the formation of terraces, whether the edge of the inland-ice recedes or advances, whether a deposit of clay or marl is to be formed in a certain place near the shore, or whether chalk only is to be left — may entirely depend on small variations in the climate, as the conditions will alter as soon as a certain point is reached. The periodical changes, dealt with here were, therefore, not great; but as they acted simultaneously, and in the same direction, over whole climatic areas, it must be generally-acting forces which caused the same and not variations in local conditions.

The theory advanced here proves thus that *the climate is* *at all times subjected to periodical changes, the duration of which may be measured in thousands of years, and which act in the same direction within the same climatic area, and which for one period, are not great, but which, as alternations of strata are often remarkably regular, seem to return after the lapse of a fixed cycle of years.*

It is obvious that periodical changes in the strength of the *Ocean currents* will cause corresponding changes in the climate of the adjacent continents. Thus, if, for instance, the warm North-Atlantic current, to which North Europe owes the climate which is so mild compared to its latitude, should increase in strength, the climate there would doubtless become still milder. Our shell-banks show that such changes in the temperature of the sea have accompanied the climatic variations. We are, therefore, compelled to ask, what is the force which causes this warm sea-current to flow northwards, and if we may assume that there is some natural cause effecting periodical changes in the intensity of this force? The question being one as to a climatic period, we must examine the great laws which govern the climate. We must, of course, leave all temporary disturbances of the air out of consideration, and only pay attention to the great and simple laws which are revealed by the synoptic charts of the average distribution of the aerial pressure at various seasons. These charts show us: in the summer a low pressure over the heated continents, but generally a higher one over the cool oceans, and in the winter a higher pressure over the cold continents, and a lower one over the oceans which are warmer.

In order to understand this varied distribution of pressure, we shall imagine an atmosphere, which everywhere has the same degree of heat and the same height. The warmer the air, the more it expands, so that the height of the atmosphere will change if the temperature rises or falls. If we further assume that the air cools or becomes quicker heated in some places than others, the equilibrium will be disturbed. Over cold areas the height of the atmosphere will decrease. The surface of the atmosphere should, thus, become uneven, and, consequently, in the upper strata of the atmosphere air must flow from the warm regions into the cold ones, so that equilibrium be maintained. For this reason a greater mass of air will lie over cold regions, which have therefore a higher atmospheric pressure. But at the surface of the earth, too, the equilibrium will be disturbed as a high atmospheric pressure will drive the air from the cold to the warm regions. As long as the temperature of the air varies, movements will be created by the disturbed equilibrium, during which, therefore, air will flow from the cold to the warm regions along the surface of the earth and vice versa in the upper part of the atmosphere. In winter as well as in summer the disturbances of the equilibrium of the atmosphere will proceed from the continents, because the latter are heated and cooled more intensely than the oceans. Over the ice covered interior of Greenland the sun in the summer cannot create any low pressure because all its heat is consumed in melting the snow. Even in the summer comparatively cold air and high pressure prevails over Greenland, and this is probably the cause of the atmosphere in the North Atlantic differing from the above mentioned law, inasmuch that this ocean has a low pressure even in summer. This low pressure, which lies generally near Iceland, is, however, more marked in winter.

The air, according to the law of Buys Ballot, moves against the low pressure, so that in the Northern Hemisphere one has the low pressure a little in front, to the left, when turning the back to the wind. That is a but natural consequence of the rotation of the earths axis. At lower latitudes this action is more intense. Air, flowing from lower to higher latitudes, retains for a time its original speed of rotation, and will thereby deviate in the direction of the rotation of the earths axis i. e. towards the east. And vice versa, when the air flows from higher to lower latitudes. In this manner southerly winds become southwestley, and northerly ones north-easterley. In fact, the low atmospheric pressure at Iceland draws the south-west winds up the North-Atlantic, and as the cause prevails all the year round the consequence is that south-west winds blow in this sea summer as well as winter.

The opinion held by Croll, Zöppritz etc. that *the winds are the chief cause of sea-currents* is now generally accepted by savants. The winds set the surface of the sea in motion and by frictional resistance the movement is conveyed to lower depths. It depends on the force and the duration of the wind how deep the action will have effect. The main current runs in the direction of the wind prevailing and its speed is dependent on the average one of the surface. Winds of short duration are only capable of changing the direction of the current on the surface, but through the predominance of such winds through thousands of years, great currents are created. Their strength may vary, but their direction is independent of temporary changes of the wind. For the upper net of currents which alone affects the climate and which reaches to a depth of a couple of hundred fathoms (Mohn), the average direction and force of the wind during the last great epoch are determinal.

Such a great stream is the warm North-Atlantic current. It softenes the winter even at higher latitudes. As the surface imparts heat to the air, the heat lost is replaced from lower depths, and as long as there is a store of heat below, the sea will always yield heat to the air. The mild climate of Norway is, therefore, dependent on this warm current. It runs predominantly in a north-easterly direction, and, thus, it must, in consequence of the general laws for currents and winds have run through untold ages, or, as long as sea and land have been divided as at present.

We will now see if the force which guides this current is periodically changeable. As we know, the orbit described by the earth round the sun is not circular but elliptical, so that the distance between the two bodies varies according to seasons; when there is winter in the Northern Hemisphere the earth is nearest to the sun, and the nearer the earth approaches the sun, the quicker it runs, so that the winter in the North is shorter than the summer. The difference is 5 days. In the

Southern Hemisphere on the other hand the winter is 5 days longer than the summer. But these relations change through the precession of the equinoxes, the period having a mean duration of 21,000 years. Thus, 10,500 years ago the conditions were the reverse of what they are at present, and the same will be the case 10,500 years hence. The winter at the Northern Hemisphere will then fall when the sun is furthest from the earth, and last longer than the summer, and in the Southern Hemisphere conditions will be the reverse.

But the orbit of the earth is also subjected to periodical changes, inasmuch that it differs more from the circular some times than at others. The further it deviates from it the greater becomes the difference between the length of winter and summer, and this difference may even amount to more than 30 days every year. The length of winter and summer varies, therefore, in the course of 10,500 years, and the difference increases the more the earths orbit deviates from the circular. During the 10,500 years in which the winter is longer than the summer, there will be several thousand more winter days than summer ones, and in the second half cycle there will be as many thousand less. Even at present, when the orbit deviates but little from the circular, the excess of winter or summer days for each half cycle is more than 50,000, and when the deviation is greatest it amounts to nearly 220,000 days, or some 600 years.

As the cooling of the continents contributes to preserving the low atmospherical pressure over the oceans, and this directs the prevailing winds and currents at sea, *the winds,* thus directed, as, for instance, the south-west winds of the Atlantic, *must be stronger in winter than in summer.* And this is indeed the case. The weather conditions differ in summer and winter. Of course south-westerly winds blow predominantly in the North-Atlantic and West-Europe all the year, but they predominate more in the winter. According to Prof. Mohn their force in the North-Atlantic is about three times as great in winter as in the summer, and similar conditions prevail in the Pacific Ocean. In the southern temperate seas, north-west winds, which correspond to south-west ones with us, are aqually predominant, when there is winter in that Hemisphere. It will, therefore, be seen, that the forces which promote the warm sea currents in our latitude are most active in the winter. And the same is the case in the Southern Hemisphere, so that it must be said that the winter favours these currents, whether it falls when the sun is nearest as with us or when it is most distant, as in the Southern Hemisphere. From Prof. Zöppritz's studies of the currents it appears that the wind excercises an influence over the strength of them even long after it has ceased to blow. The action of the winds is summed up through centuries and the total is recorded in the sea-currents.

As we know that the wind-conditions vary at different seasons, and that the effect of the wind does not cease as soon as it is discontinued, but leaves traces in the sea currents for a long time after, so that, in fact, the strength of the current is dependent on the average force of the wind during last great ages, it can hardly be a matter of indifference whether the thousands of days fall as a surplus to winter or summer in the 10,500 yearly half-cycle. When they fall to the winter, the south-west winds must be more predominant than else and, correspondingly, when they fall to the summer, weaker. It seems, therefore, reasonable that the currents must increase or decrease, as the equinoctial line moves round. *When the winter falls in aphelion, our warm currents will increase, and when the reverse is the case, they will decrease.* We should, therefore, now in the Northern Atlantic have a weaker current, and in North-Western Europe less rain, and a greater difference between winter and summer heat, and this is exactly what the theory demands.

In regions with different weather conditions the case will be different. In the Eastern parts of North-America, for instance, north-west-winds are more predominant in the winter and south-west ones in the summer. Winter in aphelion will here increase the north-west winds, and one might conclude, that these parts under such conditions would perhaps thereby obtain a more severe climate, so that it seems evident *that variations* *in the climate will not simultaneously move in the same direction everywhere in the Northern (or Southern) Hemisphere.*

From calculations we have, elsewhere, demonstrated that the varying length of the seasons alone during the precession of the equinoxes will cause an increase or decrease in the force of the current of several percent of the total. And these termes are doubtless below the true ones, but which space does not here permit of developing. We may, therefore, with a high amount of probability conclude that *the precession of the equinoxes causes periodical variations of the climate, which are great enough to explain all the facts on which the theory for these periodical variations is based.*

But the excentricity of the earths orbit changes so rapidly that in two consecutive half-cycles it is not accurate the same. Therefore, will variations in the strength of the sea-currents, and consequently also those in the climate, in one half-cycle not be quite balanced in the next, and it might even be possible *that greater and more lasting variations of the climate might be caused by the same agencies.*

Trykt 18 Juni 1886.