selection require very different mathematical treatment; it is not at all clear, that they have always been sufficiently distinguished by writers on the theory of evolution. The above paper covers only the ground of the first kind of selection, random selection, but the memoir on epidemic selection is already completed, and the theory of the other cases advanced. The importance of random selection not only arises from the differentiation of species by isolation of small groups from a general population, but also from the fact that every measurement on a population is really a measurement on a more or less extensive random selection or sample. Hence the theory of random selection is also the theory of the probable errors of the frequency constants for any race. It enables us to determine the accuracy with which we have measured the chief racial constants.

Let the frequency-surface giving the distribution of a population with regard to n-organs be

$$z = f(x_1\, x_2, x_3 \ldots x_n, c_1, c_2\, c_3 \ldots c_q)$$

where $c_1\, c_2 \ldots c_q$ are the q constants which determine the characters of the population. Then the surfaces for the distribution of the errors in $c_1, c_2 \ldots c_q$ is given approximately by

$$z = z_0 e^{-\frac{1}{2}(a_{11}\, e_1{}^2 + 2a_{12}e_1e_2 + \ldots)}$$

where

$$a_{vu} = -\int\!\!\int\!\!\int \ldots z\, \frac{d^2 \log z}{dc_v dc_u}\, dx_1 dx_2 \ldots dx_n$$

Higher terms can be evaluated if needful; we have then a skew correlation of the system of errors. Approximately the divergences of any random selection from the characters of the general population form in themselves a normally correlated system, and we can predict from a knowledge of the divergence in one character the probable divergences in all the others.

The general formulæ are applied to the problems of

(i.) *The random selection out of a population having* n *normally correlated organs.*

If one character be changed, say the variability of one organ be altered, it is shown how the probable changes in all the other characters may be found; for example, the changes in the correlation of other organs. This is the death-blow to any theory that either variability or correlation can be constant for local races.

(ii.) *Skew Variation*, for all the three types discussed in a previous memoir.

Criteria are obtained for determining when skewness is significant; when the mode really diverges from the mean, &c.

In many cases in which the normal curve of errors is used, the skewness is really significant, and thus many of the results used are illegitimate. For example, personal equation is generally sensibly skew, curves for size of organs during growth, and nearly all cases of botanical distribution.

These points are illustrated in the memoir by three numerical examples:—

(I.) Müllerian glands in the legs of swine; data from the observations of two American naturalists. The skewness can be determined with less than 5 per cent. of probable error. It is therefore significant, and the use by the above-mentioned biologists of the ordinary theory of errors is in this case to be deprecated.

(II.) Enteric fever. Skewness is known to 1 per cent. of probable error.

The effect of raising mean age, or altering the incidence, &c. on the character of the disease follows at once from the tables given.

(III.) Stature during growth; a critical case, taken because the distribution is almost normal. The skewness is, however, probably significant, and the influence indicated of random selection on stature during growth is in accordance with experience.

MODIFICATION OF THE GREAT LAKES BY EARTH MOVEMENT.[1]

THE history of the Great Lakes practically begins with the melting of the Pleistocene ice-sheet. They may have existed before the invasion of the ice, but if so their drainage system is unknown. The ice came from the north and north-east, and, spreading over the whole Laurentian basin, invaded the drainage districts of the Mississippi, Ohio, Susquehanna and Hudson. During its wandering there was a long period when the waters were ponded between the ice front and the uplands south of the Laurentian basin, forming a series of glacial lakes whose outlets were southward through various low passes. A great stream from the Erie basin crossed the divide at Fort Wayne to the Wabash river. A river of the magnitude of the Niagara afterwards flowed from the Michigan basin across the divide at Chicago to the Illinois river; and still later the chief outlet was from the Ontario basin across the divide at Rome to the Mohawk valley.

The positions of the glacial lakes are also marked by shore-lines, consisting of terraces, cliffs, and ridges, the strands and spits formed by their waves. Several of these shore-lines have been traced for hundreds of miles, and wherever they are thoroughly studied it is found that they no longer lie level, but have gentle slopes towards the south and south-west. Formed at the edges of water surfaces, they must originally have been level, and their present lack of horizontality is due to unequal uplift of the land. The region has been tilted towards the south-south-west. The different shore-lines are not strictly parallel, and their gradients vary from place to place, ranging from a few inches to three or four feet to the mile.

Early History of the Lakes.

The epoch of glacial lakes, or lakes partly bounded by ice, ended with the disappearance of the ice-field, and there remained only lakes of the modern type, wholly surrounded by land. These were formed one at a time, and the first to appear was in the Erie basin. It was much smaller than the modern lake, because the basin was then comparatively low at the north-east. Instead of reaching from the site of Buffalo to the site of Toledo, it extended only to a point opposite the present city of Erie, and it was but one-sixth as large as the modern lake. Since that time the land has gradually risen at the north, canting the basin towards the south, and the lake has gradually encroached upon the lowlands of its valley.

The next great lake to be released from the domination of the ice was probably Ontario, though the order of precedence is here not equally clear. Before the Ontario valley held a land-bound lake it was occupied by a gulf of the ocean. Owing to the different attitude of the land, the water surface of this gulf was not parallel to the present lake surface, but inclined at an angle. In the extreme north-east, in the vicinity of the Thousand Islands, the marine shores are nearly 200 feet above the present water level, but they descend southward and westward, passing beneath the lake level near Oswego, and towards the western end of the lake must be submerged several hundred feet. This condition was of short duration, and the rising land soon divided the waters, establishing Lake Ontario as an independent water body. The same peculiarity of land attitude which made the original Erie a small lake served to limit the extent of Ontario, but the restriction was less in amount because of the steeper slopes of the Ontario basin. Here again the southward tilting of the land had the effect of lifting the point of outlet and enlarging the expanse of the lake.

There is some reason to think that the upper lakes, Huron, Michigan and Superior, were at first open to the sea, so as to constitute a gulf, but the evidence is not so full as could be desired. When the normal lacustrine condition was established they were at first a single lake instead of three, and the outlet, instead of being southward from Lake Huron, was north-eastward from Georgian bay, the outlet river following the valleys of the Mattawa and Ottawa to the St. Lawrence. The triple lake is known to us chiefly through the labours of Mr. F. B. Taylor, who has made extensive studies of its shore-line. This line, called the Nipissing shore-line, is not wholly submerged, like the old shores of lakes Erie and Ontario, but lies chiefly above the present water surfaces. It has been recognised at many points about Lake Superior and the northern parts of lakes Huron and Michigan, and measurements of its height show that its plane has a remarkably uniform dip, at 7 inches per mile, in a south-south-west direction, or, more exactly, S. 27° W. The southward tilting of the land, involving the uplift of the point of outlet, increased the capacity of the basin and the volume of the lake, gradually carrying the coast-line southward in Lake Huron and Lake Michigan until finally it reached the low pass at Port Huron, and the water overflowed *viâ* the St. Clair and Detroit channels to Lake Erie. The outlet by way of the Ottawa was then abandoned, and a continuance of the

[1] Abridged from a paper, by Prof. G. K. Gilbert, in the *National Geographic Magazine* (September 1897).

uplift caused the water to slowly recede from its northern shores. This change after a time separated Lake Superior from the other lakes, bringing the St. Marys river into existence, and eventually the present condition was reached.

These various changes are so intimately related to the history of the Niagara river that the Niagara time estimates, based on the erosion of the gorge by the cataract, can be applied to them. Lake Erie has existed approximately as long as the Niagara river, and its age should probably be reckoned in tens of thousands or hundreds of thousands of years. Lake Ontario is much younger. All that can be said of the beginning of Great Lake Nipissing is that it came long after the beginning of Lake Erie, but the date of its ending, through the transfer of outlet from the Mattawa to the St. Clair, is more definitely known. That event is estimated by Taylor to have occurred between 5000 and 10,000 years ago.

The lake history thus briefly sketched is characterised by a progressive change in the attitude of the land, the northern and north-eastern portions of the region becoming higher, so as to turn the waters more and more towards the south-west. The latest change, from Great Lake Nipissing to Great Lakes Superior, Michigan and Huron, involving an uplift at the north of more than 100 feet, has taken place within so short a period that we are naturally led to inquire whether it has yet ceased. Is it not probable that the land is still rising at the north, and the lakes are still encroaching on their southern shores? Dr. J. W. Spencer, who has been an active explorer of the shore-lines of the glacial lakes, and has given much study to related problems, is of opinion that the movements are not complete, and predicts that they will result in the restoration of the Chicago outlet of Lake Michigan and the drying of Niagara.

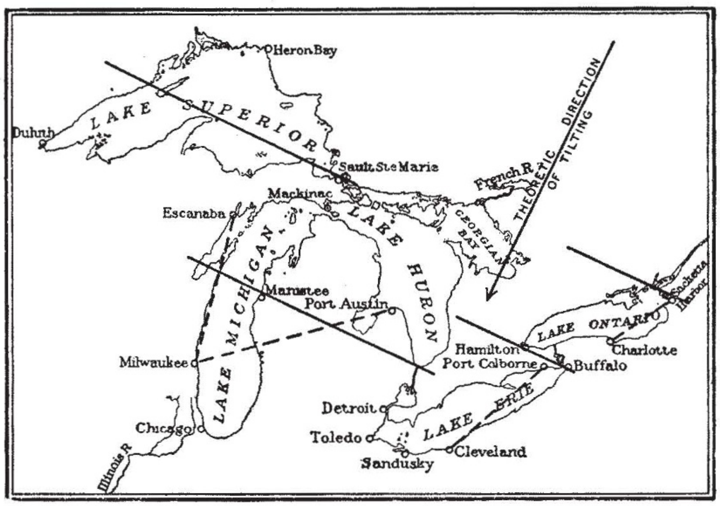

FIG. 1.—Map of the Great Lakes, showing pairs of gauging stations and isobases of outlets. The isobases are marked by full lines. Broken lines show the pairs of stations.

Measurements of Changes in the Shore-lines.

The importance of testing this question by actual measurements was impressed upon me several years ago, and I endeavoured to secure the institution of an elaborate set of observations to that end. Failing in this, I undertook a less expensive investigation, which began with the examination of existing records of lake height as recorded by gauge readings, and was continued by the establishment of a number of gauge stations in 1896.

If the volume of a lake were invariable, and if its water were in perfect equilibrium under gravity, its surface would be constant and level, and any variation due to changes in the height of the land could be directly determined by observations on the position of the water surface with reference to the land; but these conditions are never realised in the case of the Great Lakes, where the volume continually changes and the water is always in motion. The investigator therefore has to arrange his measurements so as to eliminate the effect of such changes.

The various oscillations of the water, though differing widely in amplitude, rate and cause, yet coexist, and they make the actual movement of the water surface highly complex. The complexity of movement seriously interferes with the use of the water plane as a datum level for the measurement of earth movements, and a system of observations for that purpose needs to be planned with much care. The main principles of such a system are, however, simple, and may readily be stated. The most important is that the direct measurement of the heights of individual points should not be attempted, but comparison should always be made between two points, their relative height being measured by means of the water surface used as a levelling instrument.

It will not be necessary to give here the details of observation and computation, as they are fully set forth in a paper soon to be printed by the U.S. Geological Survey, but the general scope of the work may be briefly outlined. As the tilting shown by the geological data was towards the south-south-west, stations were, so far as possible, selected to test the question of motion in that direction. The most easterly pair were Sacketts Harbour and Charlotte, New York, connected by the water surface of Lake Ontario (Fig. 1). From observations by the U.S. Lake Survey in 1874, it appeared that a bench mark on the old lighthouse in Charlotte was then 18·531 feet above a certain point on the Masonic Temple in Sacketts Harbour. In 1896 the measurement was repeated, and the difference found to be 18·470 feet, the point at Sacketts Harbour having gone up, as compared to the point at Charlotte, 0·061 foot, or about three-fourths of an inch. Similarly it was found that between 1858 and 1895 a point in Port Colborne, at the head of the Welland Canal, as compared to a point in Cleveland, Ohio, rose 0·239 foot, or nearly three inches. Between 1876 and 1896 a point at Port Austin, Michigan, on the shore of Lake Huron, as compared to a point in Milwaukee, on the shore of Lake Michigan, rose 0·137 foot, or one and one-half inches; and in the same period a point in Escanaba, at the north end of Lake Michigan, as compared to the same point in Milwaukee, rose 0·161 foot, or about two inches.

There is not one of these determinations that is free from doubt; buildings and other structures on which the benches were marked may have settled; mistakes may have been made in the earlier levelling, when there was no thought of subjecting the results to so delicate a test; and there are various other possible sources of error to which no checks can be applied. But the fact that all the measurements indicate tilting in the direction predicted by theory, inspires confidence in their verdict.

The stations of the several pairs are at different distances apart, the directions of the lines connecting them make various angles with the theoretical direction of tilting, and the time intervals separating the measurements are different. To reduce the results to common terms, I have computed from each the rate of tilting it implies in the theoretical direction, S. 27° W., and determined the change in relative height of the ends of a line 100 miles long during a century.

Compared in this way, the results are remarkably harmonious, the computed rates of tilting ranging only from 0·37 foot to 0·46 foot per 100 miles per century; and in view of this harmony it is not easy to avoid the conviction that the buildings are firm and stable, that the engineers ran their level lines with accuracy, that all the various possible accidents were escaped, and that we have here a veritable record of the slow tilting of the broad lake-bearing plain.

The computed mean rate of tilting, 0·42 foot per 100 miles per century, is not entitled to the same confidence as the fact of tilting. Its probable error, the mathematical measure of precision derived from the discordance of the observational data, is rather large, being one-ninth of the whole quantity measured. Perhaps it would be safe to say that the general rate of tilting, which may or may not be uniform for the whole region, falls between 0·30 and 0·55 foot.

Future of the Great Lakes.

The geographical effects of the tilting are of scientific and economic importance. Evidently the height of lake water at a lake's outlet is regulated by the discharge, and is not affected by slow changes in the attitude of the basin; but at other points of the shore the water advances or retreats as the basin is tipped. Consider, for example, Lake Superior. On the map (Fig. 1) a line has been drawn through the outlet at the head of St. Marys River in a direction at right angles to the direction of tilting. All points on this line, called the *isobase* of the outlet, are raised or lowered equally by the tilting, and are unchanged with reference to one another. All points south-west of it are lowered, the amount varying with their distances from the line, and all points to the north-east are raised. The water, always holding its surface level, and always regulated in volume by the discharge at the outlet, retreats from the rising north-east coasts, and encroaches on the sinking south-west coasts. Assuming the rate of tilting to be 0·42 foot per 100 miles per century, the mean lake level is rising at Duluth 6 inches per century and falling at Heron Bay 5 inches. Where the isobase intersects the north-western shore, which happens to be at the international boundary, there is no change.

Lake Ontario lies altogether south-west of the isobase of its outlet, and the water is encroaching on all its shores. The estimated vertical rise at Hamilton is 6 inches per century. The whole coast of Lake Erie also is being submerged, the estimated rate at Toledo and Sandusky being 8 or 9 inches per century.

The isobase of the double Lake Huron-Michigan passes south-west of Lake Huron and crosses Lake Michigan. All coasts of Lake Huron are therefore rising as compared to the outlet, and the consequent apparent lowering of the mean water surface is estimated at 6 inches per century for Mackinac, and at 10 inches for the mouth of the French river on Georgian Bay. In Lake Michigan the line of no change passes near Manistee, Michigan. At Escanaba the estimated fall of the water is 4 inches per century; at Milwaukee the estimated rise is 5 or 6 inches, and at Chicago between 9 and 10 inches.

These slow changes of mean water level are concealed from ordinary observation by the more rapid and impressive changes due to variations of volume, but they are worthy of consideration in the planning of engineering works of a permanent character, and there is at least one place where their influence is of moment to a large community. The city of Chicago is built on a smooth plain little above the high-water level of Lake Michigan. Every decade the mean level of the water is an inch higher, and the margin of safety is so narrow that inches are valuable. Already the older part of the city has lifted itself several feet to secure better drainage, and the time will surely come when other measures of protection are imperatively demanded.

Looking to the more distant future, we may estimate the date at which the geographical revolution, prophesied by Spencer, will occur. Near Chicago, as already mentioned, is an old channel made by the outlet of a glacial lake. The bed of the channel at the summit of the pass is about 8 feet above the mean level of Lake Michigan and 5 feet above the highest level. In 500 or 600 years (assuming the estimated rate of tilting) high stages of the lake will reach the pass, and the artificial discharge by canal will be supplemented by an intermittent natural discharge. In 1000 years the discharge will occur at ordinary lake stages, and after 1500 years it will be continuous. In about 2000 years the discharge from Lake Michigan-Huron-Erie, which will then have substantially the same level, will be equally divided between the western outlet at Chicago and the eastern at Buffalo. In 2500 years the Niagara river will have become an intermittent stream, and in 3000 years all its water will have been diverted to the Chicago outlet, the Illinois river, the Mississippi river, and the Gulf of Mexico.

FORESTS AND RAINFALL.[1]

CAN it be possible that the cutting away of forests affects the amount of precipitation in any locality? To many, no doubt, this question will seem easy of answer; but we find the results of study by no means reassuring, and recent investigations have led to almost diametrically opposite conclusions, depending, somewhat at least, upon the feeling of the writer. When we reflect that our rain storms are of very wide extent, oftentimes over 1000 miles in diameter, and may take their origin and bring their moisture from distances of 1000 miles or more, the thought that man, by his puny efforts, may change their action, or modify it in any manner, seems ridiculous in the extreme.

It has been well established that forests have a most important bearing upon the conservation of rainfall; that the forest floor permits a seepage of water to the source of springs, and thus maintains their steady flow; that they hold back the precipitation that falls, especially in the form of snow, thus preventing or ameliorating the effects of dangerous freshets. There is not the slightest doubt of their great importance to the welfare of man, but all these facts do not affect the question of their influence upon precipitation. The following paper is prepared from the standpoint of a meteorologist, and is an attempt to present facts.

The Historical Argument.

Formerly the historical argument was a favourite one. I quote one of these: "It is a familiar fact that there are many regions in Asia and southern Europe, once exceedingly fertile and densely populated, that are now utterly sterile and desolate. The country bordering on the Euphrates and portions of Turkey, Greece, Egypt, Italy and Spain are now incapable of cultivation from lack of rain due to deforestation." The most fertile of all provinces in Bucharia was that of Sogd. Malte Brun said, in 1826, "For eight days we may travel and not be out of one delicious garden." In 1876 another writer says of this same region: "Within thirty years this was one of the most fertile spots of central Asia, a country which, when well wooded and watered, was a terrestrial paradise. But within the last twenty-five years a mania of clearing has seized upon the people, and all the great forests have been cut away, and the little that remained was ravaged by fire during a civil war. The consequences followed quickly, and this country has been transformed into a kind of arid desert. The water-courses are dried up and the irrigating canals are empty." It has also been said that in the older settled portions of New England and the Middle States there are arid hills and worn-out fields, due to the falling off of precipitation from the cutting away of the forest growth. Such quotations and statements might be made to fill a large volume. Without more precise data as to rainfall it would be hazardous to conclude that we have here a case of cause and effect. It is certain that the fertility of these regions in ancient times was due to stupendous irrigating devices and canals, and when these were neglected, through wars and other untoward circumstances, the fertility necessarily ceased. It is certain that there are ruins of enormous irrigating ditches and canals in Babylonia, where history indicates that there was once a teeming population and great fertility, but where now only a sandy desert greets the eye.

Constancy of Rainfall.

It has been said that where our densest forests are found there we have the greatest precipitation. There is no way whereby we can see that such forests would have started unless favoured by rainfall, so that the presence of the forest rather indicated the earlier occurrence of practically the same rainfall as at present. Meteorologists are agreed that there has been practically no change in the climate of the world since the earliest mention of such climates. Plants found in mummy cases in Egypt that were plucked thousands of years ago show the same size as those now found in that land. The "early and the latter rains" are experienced in Palestine to-day just as they were four thousand years ago. Jordan "overflows all its banks" to-day, in February, precisely as it did in Joshua's day. When we come down to recent times and to the records of rainfall measured in New England for more than one hundred years, or, at least, before and since the forests were cut, we find a constancy in the rainfall which shows its entire independence of man's efforts. Here it should be noted that totally barren lands of any extent, in New England for example, are to be found only in imagination. Even where the forest has been cut away mercilessly there springs up a growth of sprouts which covers the ground, and answers almost the same purpose in causing rainfall (if there is any effect of that kind) as the forest. Even where land is entirely cleared of a forest we have at times the green pasture, and at others still heavier crops which leave the ground anything but a sandy waste.

Rainfall Measurements in Forests and Open Fields.

But the strongest argument adduced in the past to show the influence of forest on rainfall has existed in a comparison between rain-gauge measures in the forest and the open field

[1] A paper by Prof. H. A. Hazen, presented at the annual meeting of the American Forestry Association at Nashville, Tenn., September 22. (Abridged from the *Monthly Weather Review*)