SCIENCE

VOL. LXXI FRIDAY, JANUARY 17, 1930 No. 1829

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS
New York City: Grand Central Terminal
Lancaster, Pa. Garrison, N. Y.
Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

PROBLEMS OF THE GLACIALIST[1]

By FRANK LEVERETT

A YEAR ago, at the New York meeting of this association, I discussed the Pleistocene glaciation of the northern hemisphere, as a contribution to the symposium on the centenary of glacial geology. This year I will take up some of the problems confronting the glacialist. Last year's paper outlined the results of past work. The present paper endeavors to outline future work. Some of the problems are matters of local application, but the majority of those here considered are of world-wide bearing.

THE PROBLEM OF GLACIAL EPOCHS

Inasmuch as the normal climate of the earth has been non-glacial the cause for glacial epochs has excited wide interest, and its solution has been attempted by a wide range of students, including astronomers, physicists and biologists, as well as geologists and climatologists. Unfortunately, the climatologists, who should be the leaders in this study, have been baffled by the complexities of climatic factors. They differ widely in the interpretation of present climate, as well as in that of past climates. Some of the leading ones have opposed their speculative views to the plain teaching of observations on the existing ice-sheets, as has been clearly shown by Hobbs in his recent book on the glacial anticyclones.[2] The doctrine of circumpolar cyclones, to which Ferrel Maury and James Thomson contributed in the 1850's, was still supported by Hann in 1897, when he wrote in his "Klimatologie" (p. 543):

> The whole Antarctic circumpolar area presents us, as already stated, with a vast cyclone, of which the center

[1] Address of the retiring vice-president and chairman of Section E—Geology and Geography, American Association for the Advancement of Science, Des Moines, Iowa, December 30, 1929.

[2] "The Glacial Anticyclones: The Poles of the Atmospheric Circulation," Univ. of Michigan Studies, Scientific Series, Vol. IV, 1926, by William Herbert Hobbs.

is at the pole, while the westerly winds circulate around it.

After observations on the Antarctic continent by members of Scott's expedition had clearly indicated that an anticyclone, and not a cyclone, lies over that continent, Hann, in correspondence with the British Meteorological Office, granted the presence of an anticyclone on the immediate surface of the continent, but maintained that at a moderate elevation the cyclone must reestablish itself, there being no chance for the existence of a real continental anticyclone. Because of the strong influence of Hann the true significance of the anticyclonic winds was not grasped by the members of that expedition, nor by Sir Napier Shaw, the director of the British Meteorological Office, who prefaced the report on meteorology by a statement consistent with Hann's idea of a shallow anticyclone. Meinardus has similarly interpreted results of the German expedition under Drygalski. When speculative ideas thus control the interpretations of observers it is no wonder that progress has been slow toward a proper understanding of our present climate. Such an understanding will be difficult enough if observation is made the basis for interpretation. In this connection I would remark that the existing ice-sheets probably hold the key to a proper solution of the climatic conditions of the glacial epochs. The striking difference between the polar and equatorial regions which prevails to-day is in sharp contrast to that of the non-glacial periods and represents the waning phase of the Pleistocene glacial epoch. The existing ice-sheets also are likely to throw light upon the method of growth and the movement of the Pleistocene ice-sheets. Rapid advance in our knowledge may be expected now that the aeroplane can be pressed into service and radio communications established.

It seems to be fairly well established that such astronomical factors as variations in the eccentricity of the orbit of the earth, the precession of the equinoxes and changes in the plane of the ecliptic, which at one time were considered by glacial students as of dominant influence in glacial epochs, are subordinate to the geographical conditions, and only at times supplementary to them. The recurrence of glacial stages in the Pleistocene epoch does not correspond, even rudely, to the calculated times of greatest eccentricity of the earth's orbit, nor was there an alternation of glaciation in the northern and southern hemispheres during a precession cycle. It is known that a glacial stage required a much longer period than half of the precession cycle. Attempts to fix glacial chronology in terms of these astronomical factors are without support and entirely misleading. It is not so easy to dispose of another astronomical factor—the variation in solar radiation. So far as known, this variation is very slight, but observations cover so brief a period that it can not be assumed that the full amount of variation is known. There is a possibility that this factor has had considerable influence on the climate. Should terrestrial factors, when fully evaluated, prove inadequate to account for the conditions attending a glacial epoch, it may be necessary to fall back on solar variation. But even then it may be incapable of demonstration.

The hypothesis of continental drift, made prominent by Alfred Wegener, was given consideration as far back as 1866, when Sir John Evans presented a paper before the Royal Society "On a Possible Cause for Climatal Changes," which is published in abstract in the *Geological Magazine* for that year. Wegener's hypothesis was made the subject of discussion in a symposium participated in by fourteen scientists and published by the American Association of Petroleum Geologists in 1928 in a volume of 240 pages. Wegener contributed a brief paper of five pages, designed to meet objections to the hypothesis and to call attention to recent geodetic surveys in Greenland that seemed to him to support it. He first presented the hypothesis in 1912 in *Petermanns Mitteilungen.* In 1915 he brought out a book, "Die Entstehung der Kontinente und Ozeane." This went to a second edition in 1920 and a third in 1922 and was translated into English in 1924. It appears to have met with favorable consideration by many European students, but it has not been so well received in America.

It is not my intention to go into the discussion of the Wegener hypothesis further than to indicate its irrelevancy so far as applied to the several stages of Pleistocene glaciation. It assumes a migration of the north pole from a position west of Greenland eastward over that island into the Arctic Ocean and then northward to its present position. It interprets the glaciation to have started in the northwestern part of the North American continent and extended eastward across the continent and Greenland into Europe. Meantime Greenland became separated from Scandinavia by a westward drifting, thus giving the Atlantic a northward extension. It fails to recognize that the drift sheets, both in North America and in Europe, show a repetition of glaciation at widely separated intervals, and that successive glaciations covered essentially the same parts of each continent. So far as the last two glacial stages in North America are concerned, the Laurentide ice-sheet made a growth from east to west, or in the reverse direction from that indicated by Wegener. Were continental drift made the dominant factor it would be necessary to carry the pole westward in our Illinoian and Wisconsin glacial stages. But in view of what is clearly established in the glacial succession in Europe and America the Wegener hypothesis is purely fantastic and scarcely worthy of consideration in this connection.

The Wegener conception that the opening of the North Atlantic took place in Pleistocene time through a westward drifting of Greenland is opposed by the distribution of the Pleistocene isotherms. In last year's paper the following statement was made on this point:

It is a matter of some significance, concerning the influence of planetary winds on the oceans in the glacial epoch, to note that the southern limit of glaciation on the European side of the Atlantic is 10° to 12° of latitude farther north than on the North American side, from which it may be inferred that the isotherms showed a difference in latitude on opposite sides of the Atlantic similar to what is found to-day. This relation shows clearly that the warm waters were driven northeastward across the north Atlantic by winds in the Pleistocene glacial stages about as they are to-day.

Wegener's claim that longitude determinations in Greenland support his view of continental drift, and show that it is still continuing, has been analyzed by Sir Charles Close, director general of the British Ordnance Survey, who finds that the differences are all within the limits of probable error and are not sufficient to prove westerly drift.[3]

Marsden Manson has brought out an elaborate hypothesis of geological climates, in a series of papers appearing in the *American Geologist* in 1899, based on the rôle of clouds as reflectors of solar radiation and of terrestrial radiation in conjunction with an assumed gradual waning of the internal heat of the earth. As a consequence of this cloud envelop it is inferred that, prior to the glacial epoch, the earth did not have the present sharply distinguished tropical, temperate and frigid zones. The conditions are most nearly realized at present in the equatorial rain belt, in which the land is maintained at the same temperatures as the neighboring ocean. While the solar radiation was greater in the low latitudes, the earth heat was not thus restricted, but was as great in high latitudes as in the equatorial region. The Permo-Carboniferous glaciation coincided to some degree with the present subtropical high-pressure belts, and it is thought that cold anticyclonic winds cooled the land most rapidly in those belts. After this the terrestrial radiation gradually diminished until the polar oceans became cold and the Quaternary glaciation followed. This glaciation was centered in the cold temperate belt of greatest precipitation, which it is thought was still overcast with a cloud belt. With progressive cooling of the oceans, the evaporation failed to supply sufficient moisture to maintain this cloud belt, and glaciation passed into the waning stage. It is still continuing in diminishing degree. The distribution of fossil plants and delicate marine organisms is such as to indicate that over long periods the present degree of climatic zoning was not in vogue. But it is a question whether cloudiness has been the controlling factor in giving this condition. The following statement concerning Manson's hypothesis is from the pen of C. E. P. Brooks, the British meteorologist:[4]

The theory is interesting, but there are some insuperable difficulties. With warm oceans and an unbroken cloud canopy, the land surfaces, unless at a great altitude, would not be likely to freeze; the conditions are most nearly realized at present in the equatorial rain belt, in which the land is maintained at the same temperature as the neighboring oceans. "Cold anticyclonic winds" presuppose cooling by radiation. Even if under world-wide isothermal conditions the pressure distribution could remain unaltered, which is highly improbable, we must suppose either that the anticyclone would break down the cloud canopy, in which case the tropical sun would certainly prevent glaciation, or that the clouds would remain in spite of the anticyclone, in which case the descending air would not be cold. Finally, the moist conditions supposed by Marsden Manson to have prevailed during the warm periods are in direct opposition to the dry conditions demonstrated by the geological evidence set out in the Introduction.

It was pointed out by Brooks in the introduction to the volume just cited that the predominant features of the normal geological climate were warmth and dryness. "Deserts have apparently existed throughout geological time, but during most of the warm periods, and especially in the Mesozoic, they expanded greatly, extending from the sub-tropical regions far into the present temperate zones." It is probable that existing ice-sheets are responsible to a high degree for the present strong contrast in climatic zones. On this point Hobbs has expressed the following opinion:[5]

The atmospheric circulation is given its vigor at the present time not alone through a pushing upwards of currents within the tropics as a consequence of excessive insolation within that region, but also by a pulling down by the refrigerating engines of the continental glaciers. . . .

During both the Permian and the Pleistocene geological periods there were vast continental glaciers in addition to those which were located over the Antarctic and Greenland. Presumably there was glaciation of these areas since there were ice-sheets in lower latitudes. The in-

[3] *Geographical Journal,* Vol. 63, 1924, pp. 147–150.

[4] "Climate through the Ages," pp. 145–146.

[5] "Glacial Anticyclones: The Poles of the Atmospheric Circulation," pp. 168–169.

fluence of these vast domes of ice in stimulating a vigorous circulation must have been of the utmost importance, and the zonal distribution of climates should in consequence have been so much the more pronounced.

That the present zonal contrasts are connected with glacial climate is expressed in papers by leading American paleontologists which have appeared since Manson's hypothesis was brought out.[6] Of strikingly different attitude is the recent work by Köppen and Wegener, "Die Klimate der geologischen Vorzeit," Borntraeger, Berlin, 1924, which assumes that at all times in the history of the earth the same climatic contrasts have been exhibited. They also state that the changes of climate for a given region are to be interpreted as due to continental drift.[7]

A leading hypothesis based upon atmospheric conditions pertains to variations in the amount of carbon dioxide and of water vapor in the air, which was brought out by Arrhenius in 1896[8] and subsequently elaborated by Chamberlin.[8] It is suggested that the cold periods were characterized by a depletion of the carbon dioxide and warm periods were times when it was more abundant in the atmosphere. This depletion it is thought might be due to geological processes, the formation of coal and limestone being cited by Arrhenius, and the weathering of rocks made prominent by Chamberlin, as well as the agency of organisms. Variations of volcanic activity are also considered of importance. Chamberlin also developed an elaborate interpretation of the effect of the variations in carbon dioxide upon oceanic circulation, and showed that a reversal of the oceanic circulation might give rise to warm periods in high latitudes. This hypothesis has the advantage of being world-wide in its application and thus meets a need that is not met by hypotheses based chiefly upon local geographic influences. There is, however, considerable doubt expressed by meteorologists as to carbon dioxide having the influence attributed to it by Arrhenius and Chamberlin. Ångström maintains that the absorption effects attributed by Arrhenius to carbon dioxide are principally due to water vapor.[9] The water vapor content is determined by the amount of radiant energy received from the sun. Its variations are not, therefore, an ultimate cause for climatic variations. It has been pointed out by Humphreys that an increase in carbon dioxide could only affect the temperature by absorption at high levels in the atmosphere where water vapor is nearly absent, and he concludes that carbon dioxide can never have been an important factor in climatic variations.[10] A similar view is expressed by Brooks,[11] who grants that the quantity of carbon dioxide may have had considerable variation, but that these variations could not have had a great climatic effect, for the part of the terrestrial radiation taken up by carbon dioxide is almost completely absorbed by water vapor, and no increase in the amount of carbon dioxide could appreciably increase the total absorption.

It has been shown by several students that volcanic dust in the atmosphere is likely to have had a cooling effect, because of a scattering and reflection of solar radiations which it occasions. Benjamin Franklin suggested that the severe winter of 1783–84 might be due to great quantities of volcanic dust in the air. Observations on the eruption of Katmai in 1912 showed that the Katmai dust reduced the solar radiation reaching the earth by about 20 per cent., which if long maintained would lower the mean temperature of the earth about 10° F., an amount sufficient to initiate an ice-age.[12]

In view of the dissenting opinions among those who have given most attention to the effect of variations of the amount of carbon dioxide on climate it seems necessary to hold this hypothesis and that of volcanic activity as a factor in glacial climate open for further light.

One of the most significant contributions to the problem of glacial climate has been made by C. E. P. Brooks in his recent volume, "Climate through the

6 See David White and F. H. Knowlton, "Evidences of Paleobotany as to Geological Climate," SCIENCE, n. s., Vol. 31, 1910, p. 760. F. H. Knowlton, "Evolution of Geologic Climates," *Bull.* Geol. Soc. Am., Vol. 30, 1919, pp. 499–566. Charles Schuchert, "Climates of Geologic Time," Smithsonian Report, 1914, pp. 277–311.

7 "In diesem Buche werden die vorzeitlichen Klimawechsel unter den Voraussetzungen der Theorie der Kontinentenverschiebung behandelt, die hier als richtig angenommen wird" (page 1).

8 Svante Arrhenius, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground," *Phil. Mag.* (5), Vol. 41, 1896, pp. 237–276. T. C. Chamberlin, "An Attempt to Frame a Working Hypothesis of the Cause of Glacial Periods on an Atmospheric Basis," *Jour. Geol.*, Vol. 7, 1899, pp. 545–584, 667–685.

9 Knut Ångström, "Über die Bedeutung des Wasserdampfes und der Kohlensäure bei der Absorption der Erdatmosphäre," *Ann. der Physik* (4), Vol. 3, 1900, p. 720. See also Hann's "Handbook of Climatology," 1903, p. 399.

10 W. J. Humphreys, "Physics of the Air," 1920.

11 C. E. P. Brooks, "Climate through the Ages," 1926, pp. 132–133.

12 For discussions of this subject see: C. G. Abbot and F. E. Fowle, "Volcanoes and Climate," Ann. Astrophys. Obs. Smithsonian Inst., 1913, and Smithsonian Misc. Coll. No. 29, 1913. W. J. Humphreys, "Volcanic Dust and Other Factors in the Production of Climatic Changes, and Their Possible Relation to Ice-ages," *Jour. Franklin Inst.*, Vol. 176, 1913, pp. 131–172. Also *Jour. Wash. Acad. Sci.*, Vol. 3, 1913, pp. 365–371. C. E. P. Brooks, "Climate through the Ages," 1926, pp. 133–136. H. Arctowski, "Volcanic Dust Veils and Climatic Variations," *Annals N. Y. Acad. Sci.*, Vol. 26, 1915, pp. 149–174.

Ages," noted above. He points out that glacial periods have occurred at times of high altitude of the land, while non-glacial periods are times of relatively low relief. He also expresses the opinion that in periods of low relief the barometric depressions, or cyclones, were less definitely developed than in periods of high relief and that storms were the thunderstorm type rather than long steady rains, such as are associated with the passage of barometric depressions. If the relief were sufficient in the district traversed by the cyclonic storms to cause precipitation as snow throughout the winter months, there would be a tendency to lower the temperature over the bordering seas and cause them to become ice-covered. When the ice cover reached a certain size the temperature on its edge would fall below the freezing-point of sea water, and it would continue to expand owing to the lowering of temperature which the ice itself introduced. By a series of mathematical calculations it is shown that a great climatic effect may follow such a covering of the polar oceans with ice, so it is merely a matter of getting the freezing process started. This might be brought about by only a slight general lowering of the earth's temperature. It is estimated that if the present average elevation of 2,500 feet were to be increased to 3,500 feet the effect on cloudiness, evaporation and area above the snow line would produce a lowering of temperature somewhere between 5° and 15° with a probability of about 9° F. While elevation is, by itself, and directly a very important factor in climate, it also causes, secondarily, changes in distribution of the land and sea, in the course of ocean currents, etc., all of which must be considered in accounting for the glacial epochs.

None of the hypotheses of purely terrestrial application appears to satisfactorily account for the great climatic fluctuations that characterized the Pleistocene glacial epochs. The glacial stages were interrupted by long intervals in which the temperature appears to have been similar to the present and the ice-sheets reduced to their present dimensions, if not more completely dissipated. It is difficult to picture geographic changes of sufficient influence to meet the conditions, though Brooks maintains that they need not be of great magnitude. He recognizes, however, that measurable climatic changes in historic time have had no basis in geographic changes and calls in extra-terrestrial influences to account for them. It is also difficult to picture changes in the amount of carbon dioxide resulting from variations in weathering processes or from volcanic eruptions of sufficient importance to meet the conditions. It is becoming increasingly apparent that some peculiar combination of several factors is necessary to account for the climatic variations exhibited in a glacial epoch. The key to this combination is yet to be discovered. It probably will be found when the factors affecting present climate are more fully understood.

As indicated above, it is probable that observational data on the existing ice sheets will aid in the interpretation of conditions attending the Pleistocene and earlier ice-sheets. At my request, Professor W. H. Hobbs has kindly outlined the lines of study that seem most desirable, as follows:

Extension of observational data on existing continental glaciers:

(1) Measurement of ice movement within the marginal portions.

(2) Determination of depth of ice to rock base by echo method.

(3) Determination of snow density in all sections and structure beneath by the Mt. Rose method.

(4) Determination of time and place of snow precipitation over the ice-sheet and redistribution as drift snow.

(5) Evidences of fusion of surface snow on the ice-sheet.

(6) Measurements of outward radiation from the surface of the ice-sheet compared to land (bare or snow covered), to sea water and to sea ice.

(7) Exhaustive study of the glacial anticyclone from weather stations upon and about the ice-sheet with aid of pilot and sounding balloon studies of the upper air. A station within the interior to be compared to aerological stations about, but close to, its borders. Variations in the energy of the mechanism, with corresponding variation in the dimensions of the model, should be studied (winter and summer seasonal changes).

For such studies the Greenland ice-sheet offers better opportunities, because of its greater accessibility, and its simpler model. It seems to lack the interior mountain ranges, which greatly complicate the problems of the Antarctic. Aerological stations about but above its borders should tell as much.

WORLD-WIDE CORRELATIONS OF GLACIAL STAGES

While it is coming to be generally recognized that the Pleistocene glaciation was interrupted by relatively warm interglacial stages, much is yet to be done to clear up the correlation of glacial stages in the different areas of glaciation. There is still only a partial correlation of the stages in the Scandinavian field with those of the Alpine field. There is similar uncertainty as to correlations between certain drifts in the eastern and western parts of the Laurentide area of glaciation in North America. It will be well to settle the correlations within each of these continents as a preliminary to full correlations between the continents. The clearing up of these correlations between Europe and America and between the glacial stages of the northern and southern hemispheres is probably merely a matter of more detailed study of the glacial and interglacial deposits in the several fields.

Length of Pleistocene Glacial and Interglacial Stages

The length of time involved in the Pleistocene glacial epoch, with included interglacial stages, has been variously estimated, though there seems to be a general consensus of opinion that at least a half million years would be required for the changes wrought since the earliest drift of Europe or of North America was laid down. Some students are inclined to double the time and put the beginning of the glacial epoch back a full million years. The main basis for estimates of the time involved has been the amount of erosion and degree of weathering that have taken place in Pleistocene time. The length of interglacial stages has been determined by a comparison of the erosion and weathering of the drift of a given glacial stage with that of the next succeeding glacial stage, allowance being made for the probable time involved in the glacial stage. This allowance, however, is a difficult matter to estimate. To properly measure a glacial stage one must determine the time involved in the advance to the culminating position, and the time involved in the development of moraines formed in the course of the waning part of the glaciation, as well as the time between successive moraines. The measurement of the varves, or annual deposits of laminated clays, introduced by De Geer in Europe and North America, and carried on widely by Antevs in the United States and Canada,[13] pertains to the time involved in the recession from one moraine to another, but not the time involved in forming a moraine. In some cases also a readvance of the ice border has buried part of the record of the recession. An entire glacial stage is likely, therefore, to require several times as long a period as that measurable by the varves. The time involved in the recession of waterfalls, such as Niagara and the Falls of St. Anthony, also covers only a small part of the waning stage, and the estimates are of chief value in giving a measure of postglacial time. From these estimates, combined with a study of the erosion of the latest drift sheet, it is calculated that it requires about 10,000 years to effect one foot of average erosion of the till. On this basis the Illinoian till, with an estimated erosion of fifteen feet, would be 150,000 years old, and the Kansan till, with an estimated erosion of fifty feet, would be 500,000 years. These estimates are perhaps of some value in giving a rough approximation as to the time involved, but should be supplanted by more refined methods of measurement. It is also important, as above noted, to work out some method for estimating the time involved in the glacial stage, and determine what proportion of the Pleistocene glacial epoch was under glacial conditions and what under the relatively warm interglacial conditions. Much is yet to be learned as to the periodicity of moraine development. It also is a matter of importance to determine why certain districts have a fuller series of moraines than neighboring ones. Our studies have shown how the ice-sheet distributed moraines but not why it did so.

[13] Gerard De Geer, "A Geochronology of the Last 12,000 Years," Compte Rendu du XIth Congrès Géologique International, 1910, pp. 241–253. The studies were begun by De Geer in 1879 and the results appear in papers in the Swedish language beginning in 1882. Ernst Antevs, "The Last Glaciation," Am. Geogr. Soc'y, Research Ser. No. 17, 1928, 292 pages. See also "The Recession of the Last Ice-sheet in New England," Ditto, No. 11, 1922, 120 pages. Also Canada Geol. Survey, Memoir 146, 1925, 142 pages.

Relation of Glaciation to Pleistocene Diastrophism

It is well established, through a study of tilted shore-lines, that the interior part of the glaciated districts in northeastern North America and in northwestern Europe have risen several hundred feet since the ice-sheet melted from them. They appear to have only partially recovered an altitude they possessed prior to the glacial epoch. The depression of the land is referred to weighting of the ice-sheet, and its recovery to relief from weighting. The presence of thick deposits of drift and of bodies of water in the lake basins is thought to have influence in preventing a complete recovery of the preglacial altitude.

The study of the shore-lines of the glacial lakes has brought out a marked lack of correspondence between the area of ice weighting and the uplifted area. It is found that the shore-lines show no tilting in the south half of the Lake Michigan basin, nor in all the Erie basin except the northeast end. Yet the ice-sheet extended far beyond the limits of these basins, and must have been thousands of feet thick in the parts unaffected by tilting. These studies and studies in other basins occupied by glacial lakes have shown that the uplift extends only a short distance beyond the Precambrian lands into the lands covered by Paleozoic formations. There appears to be a closer correspondence with the border of the Precambrian lands than with the amount of ice weighting. It appears that the ice weight was insufficient to cause such a depression in the stable areas covered with sedimentary Paleozoic formations as it was able to produce in the highly eroded Precambrian areas. There is thus an interesting problem in the relative stability of an area of great erosion and one in which sediments have accumulated. A recent paper by Bowie deals with this matter, as indicated by the following quotation:[14]

> The term residual rigidity is frequently used in discussing earth problems. A material that is said to have residual rigidity is supposed to resist deformation unless the force exerted on it approaches the elastic limit of the material. In this sense the residual rigidity is equivalent to the term strength. . . .
>
> It would seem probable that the strength of the crust under the sedimentary zone should have been augmented rather than decreased by the consolidated sedimentary material. . . .
>
> If there are any weak zones of the earth's crust it would seem that they underlie the regions which have undergone great erosion.

In this connection attention is directed to an erroneous map[15] prepared by a leading American glacialist, in which isobases of postglacial uplift are made to correspond to an estimated thickness of the ice-sheet in the region east of the Mississippi River, thus disregarding the results previously published of observations showing that there is no such close correspondence. No progress can be made where office speculation is substituted for or given more weight than field studies.

THE LOESS PROBLEM

Although loess is now generally recognized to be a wind deposit, it seems to have been developed under conditions related to if not dependent upon glaciation. In America its distribution along main watercourses, such as the Mississippi and Missouri valleys, and its northward limitation on the border of the glacial deposits led to an early interpretation that it was transported by streams heading in the ice-sheet. The Mississippi valley was supposed to have been down to a level low enough to give rise to fluvio-lacustrine conditions. Similar views were held by European students as to the distribution of the loess there. It soon became evident, however, that the distribution of the loess and also its fossil content favor deposition on the land, and that it was redistributed by streams down the valleys. It has also been determined that the greater part of the loess of the Mississippi basin was brought in from the semi-arid plains to the east of the Rocky Mountains, only a minor part being derived from the glacial deposits. The European and Asiatic loess deposits were also found to have been derived mainly from semi-arid districts.

The chief problem now seems to be in reference to the time of deposition of loess in relation to glacial stages. By some students loess deposition is considered a forerunner of glaciation and to some degree dependent on the conditions that produced glaciation. In places it seems to correlate with the culmination of a glacial stage. Such is the case on the early Wisconsin drift in Illinois, there being loess on the unweathered surface of the drift near its border. The waning part of a glacial stage seems to have been characterized by more humid conditions than attended the culmination, the glacial drainage being more vigorous. Such being the case it probably would be an unfavorable time for loess deposition. The molluscan fauna of the loess is very similar to the present fauna of the region and thus of a more temperate type than seems consistent with a glacial stage. This has been the main reason for giving it an interglacial position. Much, however, is to be learned as to the degree to which such a fauna would accommodate itself to climatic changes.

It is well established that there have been two if not three periods of extensive loess deposition on or near the border of the drift sheets in Europe and in North America. It will be of importance to determine whether these periods can be correlated on opposite sides of the Atlantic. Such correlations will depend upon the success achieved in correlating the drift sheets with which the loess deposits are associated.

The characteristics of loess are so different from those of other wind deposits as to raise the question of its mode of transportation. It possesses a homogeneity that is strikingly in contrast with the heterogeneous material now swept by the wind over the surface of the ground. It also is of much finer material than dune sand. It seems to be a dust that would be susceptible to long-distance transportation, and its wide distribution as well as its composition support such a history. It appears to have settled on the land which it covers and not to have been swept across it. In general, it forms a continuous sheet, allowance being made for subsequent erosion. But on the outskirts it is more patchy. Some of this patchiness may be due to subsequent sweeping by surface winds. There are strips of loess-free land alternating with loess-covered strips in such manner as to indicate much diversity in wind effect, the loess-free strips having been exposed to strong wind action from which the loess-covered strips were protected, perhaps through some difference in vegetation. Such features are well exhibited in northeastern Iowa, near the border of the Iowan drift. They may prove to be related to wind action from the Iowan ice.

RELATION OF MAN TO THE GLACIAL EPOCH

The evolution of man from lower animal forms appears to have taken place at least as far back as

[14] William Bowie, "Zones of Weakness in the Earth's Crust," SCIENCE, n. s., Vol. 70, 1929, pp. 589–592.

[15] *Bull. Geol. Soc. of America*, Vol. 29, 1918, p. 202, fig. 1.

the early part of the Pleistocene epoch. Some students hold the opinion that the human stage was reached at a much earlier time. The skeletal remains of man imbedded in deposits of early and middle Pleistocene age in Europe, the Heidelberg, Sussex and Neanderthal remains, are of a crude type compared with those of the late Pleistocene Cro-Magnon race and suggestive of a lower order of mentality. It is a matter of importance to determine whether the inhospitable conditions of the glacial epoch stimulated mental development or had instead a brutalizing effect. Did the cruder races become exterminated under the adverse conditions attending glaciation, or instead did they develop into the superior types of men that held possession of Europe in late glacial and early postglacial time? It is a question whether the highly developed Cro-Magnon race was evolved under these adverse conditions or whether its development took place in a part of the earth where the climate was more genial and from which the race migrated into Europe as climatic conditions there became more favorable. As the race showed a strong artistic bent its origin may be determined by a wide-spread study of the works of art of primitive people.

There appears to be as yet no clear evidence of human occupancy of the American continent during the glacial epoch. There have been frequent reports of the finding of chipped implements in the glacial gravel, and in the loess, but examination into the evidence by archeologists and geologists has led to the conclusion that the implements had been recently imbedded.

Problems of Glacial Oscillations

Attention was called in the discussion of the duration of the glacial epoch to the lack of knowledge of the length of time involved in forming a terminal moraine. There is also a lack of knowledge as to the cause for the oscillations of the ice border so clearly shown in the waning part of a glacial stage. Many moraines show a readvance of the ice border. These readvances are separable into major and minor ones. The moraines forming the limits of the middle Wisconsin and the late Wisconsin drift illustrate the major class and mark a pronounced readvance of the ice border, also considerable shifting in the direction of the ice movement. It is on the basis of these readvances and realignments that the middle and late substages of the Wisconsin glacial stage have been recognized and named. The minor readvances amount usually to but a few miles, but like the major ones they serve to show that there was some factor in operation to intensify glacial conditions at certain times during the waning part of the glacial stage. The geographic factors are unlikely to have varied in such way as to cause this oscillation of the ice border. Nor do atmospheric factors, such as variations in the carbon dioxide or in the presence of volcanic dust, seem likely to have played an important part in intensifying glacial conditions. Seemingly it must be a climatic cause; yet the nature of the climatic change remains a problem.

Origin of Drumlins, Kames and Eskers

Widely different interpretations of the origin of these features are found in the glacial literature, European as well as American. It is probable that some drumlins are due largely to erosion by the ice-sheet, while others are of constructional type, built up beneath the ice-sheet. Kames are likely also to have had more than one method of development. In some cases they are evidently the product of drainage in connection with an active phase of the ice border, for they show disturbed stratification, apparently due to an advance of the ice border. This has given them greater relief and incorporated till with the gravel. In other cases where composed entirely of gravel and sand in undisturbed position there may have been a stagnant or stationary position of the ice border. The long gravel ridges known as eskers, while probably formed by streams flowing within or beneath the ice-sheet, can scarcely have been formed from end to end at one time, even though the ice-sheet had become stagnant. The upper ends are probably of later development than the lower, there being a lengthening headward with the recession of the ice border. Long eskers are in many cases diversified by a plexus of ridges, occurring at short intervals. The plexus may mark the starting of a new system of drainage within the ice-sheet not far back from the ice border. Detailed study should clear up the manner in which these ridges were formed.

Origin of Gumbotil

In a part of the Mississippi drainage basin, chiefly in Iowa, Missouri and Illinois, the surface of the Illinoian, Kansan and pre-Kansan drifts, where exceptionally flat, is characterized by a gummy gray clay to which Kay has given the name gumbotil.[16] It is interpreted by him to be mainly the product of weathering of the surface portion of the drift, and its thickness to be a measure of the time involved in its development. It has a thickness of two to five feet on the Illinoian till where best developed and a greater thickness on the Kansan and pre-Kansan tills. Its greatest thickness is on the flat divides on the Kansan drift of southern Iowa and northern Missouri, where it commonly is about eight feet and

[16] G. F. Kay, Science, n. s., Vol. 44, 1916, pp. 637–638.

occasionally twelve feet or more. It is singularly lacking in coarse pebbles, even in places where the underlying drift carries coarse pebbles of quartzite which would be likely to withstand dissolution for a much longer period than is embraced in the Pleistocene glacial epoch. There are small quartz pebbles in the deposit at all levels, but large pebbles are only found close to the underlying till. The thickness of the gumbotil decreases in passing northward, but it has been found on the Kansan till in northeastern Iowa beneath the Iowan till. It is, however, not so thick there as it is beneath the Illinoian till in southeastern Iowa, or beneath the loess in other parts of southern Iowa and in northern Missouri. The gumbotil on the Illinoian drift is thickest at the western edge of the drift, in southeastern Iowa and western Illinois. It is inconspicuous or wanting in eastern Illinois, Indiana and Ohio. It has not been noted on the Illinoian drift of Pennsylvania and New Jersey. Nor has it been observed on the Jerseyan drift in those states.

The restriction in distribution and the variation in thickness on a given drift seem to indicate that there is some factor other than mere lapse of time that governs the development of gumbotil. The restriction of coarse pebbles to the base of the deposit raises the suspicion that it may be only to a moderate degree the result of weathering of the till. The small pebbles in its upper part may in that case have been brought up into it by crayfish, as is the case in poorly drained parts of the loess. There is perhaps significance in the fact that the gumbotil shows variations in thickness that correspond in some degree to variations in the thickness of the loess. The thickness of the gumbotil thus may be found to depend partly upon wind deposition. If the wind brought in material at a very slow rate it might become weathered to a gummy condition, as the fine material in the till is supposed to have been. The deposition of the loess was probably at a sufficiently rapid rate to escape conversion into such a condition. Whatever its origin the gumbotil appears to have required a period of considerable length for its development, for its material shows throughout an advanced degree of weathering.

Kay has expressed the opinion that the gumbotil was formed under conditions of low altitude unfavorable for the erosion of the drift and has assumed that its development was nearly completed prior to a hypothetical uplift of the land that gave favorable conditions for erosion.[17] On this supposition a long period must be given for gumbotil development and another long period for the erosion of the drift, as indicated in the following quotation:

[17] *Bull. Geol. Soc. Am.*, Vol. 27, 1916, pp. 115–117.

After the gumbo plain had been developed by weathering processes on the Kansan drift plain, diastrophic movements seem to have occurred, the plain having been elevated to such an extent that erosion became effective and valleys began to be cut into the gumbo plain. Erosion of the gumbo plain progressed to such an extent that some valleys were cut to a depth of more than 150 feet before grade was reached and a mature topography was developed. There are now only remnants of the original gumbo plain, the most conspicuous of these being flat, poorly drained areas, known as tabular divides.

It is a matter of considerable importance in estimating the time since the Kansan stage of glaciation to determine whether conditions favorable for the erosion its drift displays were operative as soon as the ice uncovered it or only came into operation after a long period as Kay has suggested. It seems unnecessary for the gumbotil to have been completely developed before erosion began if the land had an attitude favorable for erosion from the beginning. The gumbotil, it would seem, might have been developing on flat areas throughout the time in which erosion was active, until prevented from further development by the deposition of a sheet of loess over it. The loess deposition is known to have taken place after the Kansan drift had become greatly eroded. So far as I am aware, Kay has produced no evidence that would clearly establish the uplift of the Kansan drift area which he has postulated, but has merely made the assertion that diastrophic movements seem to him necessary to succeed gumbotil development. This matter concerns Illinoian as well as Kansan gumbotil development and naturally leads to the consideration of drainage conditions in the Mississippi basin in the Kansan and Illinoian stages of glaciation.

Conditions of Glacial Drainage in the Mississippi Basin

So far as can be determined after allowing for the great amount of erosion that the Kansan drift and its outwash have experienced, there was very little material carried from the border of the Kansan ice-sheet into the valleys that led away from it. There is a moderate amount of gravel in the Mississippi valley at Hannibal, Missouri, where the Kansan drift border passes across the valley from Illinois into Missouri, and also at a few points below, which appear to indicate that conditions were favorable for the discharge of water down the valley while the ice was melting. The Missouri valley in Missouri was largely outside the Kansan drift border, but the drift extends south of the valley in Saline County, and there considerable sand and gravel are present along the edge of the drift and interbedded with the till. Below there, in Cooper County, the valley was filled sufficiently to cause a temporary flow of the Missouri through a low passage only two to three miles south of the river. These features combine to show that the ice-sheet was not terminating in ponded water in either of these main valleys. There is, however, such general scarcity of sand and gravel in the Kansan drift in its entire area of exposure, in Missouri, Kansas, Nebraska, Iowa, Wisconsin, Minnesota and South Dakota, as to indicate that there was very weak flow of water from its border as it was melting back across these states. So far as known also no morainic ridges were formed in the course of its retreat. It becomes, therefore, a matter of interest to determine the cause for these conditions. The lack of moraines suggests a steady recession of the ice border, without such oscillations as characterized the Wisconsin stage. The lack of outwash, if not due to poor drainage conditions, may perhaps be accounted for by the slow rate of melting of the ice.

The Illinoian drift also is remarkably free from outwash over a considerable part of its area of exposure, from southwestern Ohio westward into southeastern Iowa. But along its border in southeastern Iowa there is a well-defined channel opened by the temporary Mississippi River at the time its present valley between Clinton and Ft. Madison was occupied by the ice-sheet. There is a deposit of sand and gravel of probable Illinoian age in the Mississippi valley below Keokuk. But none has been noted on the border of the Illinoian drift in southeastern Iowa or in Illinois. The temporary Mississippi channel is nearly free from sand and gravel, though it appears to have had free discharge. This gives rise to the question whether the temporary Mississippi River was mainly carrying the drainage from the outlying land and receiving very little water from the melting Illinoian ice-sheet. In that case the rate of melting of the ice was probably very slow. The Illinoian ice-sheet formed several definite morainic ridges as it was melting back across Illinois and has a definite morainic ridge along most of the drift border in Illinois, Iowa and southern Wisconsin. It also carries gravel in the form of kames and eskers over much of its area of exposure in these states and farther east. There is a change from very scanty outwash to a conspicuous outwash at the Scioto valley in southern Ohio, and this condition is maintained from there eastward to the Allegheny Mountains and is also found on the Susquehanna valley in eastern Pennsylvania. Inasmuch as the Ohio valley was covered for a long distance by the Illinoian ice-sheet at its culmination, in the part below the mouth of the Scioto River, it is probable that the vigorous Illinoian drainage on the Scioto and streams farther east came after the ice-sheet had vacated the Ohio valley.

The Iowan drift is characterized by very scanty outwash in northeastern and northwestern Iowa, but has conspicuous outwash into Big Sioux valley and several of its eastern tributaries in South Dakota. The scantiness of outwash in Iowa seems not to have been due to obstructed drainage. It may prove to be due to the slow rate of melting of the ice.

Outwash is very scanty in connection with the moraines of the early Wisconsin drift in Illinois, Indiana and Ohio, but is conspicuous in connection with the moraines of the middle and late Wisconsin drift in these states. The difference is not attributable to less favorable conditions for the discharge of water from the early Wisconsin moraines. In this case, as in the older drifts, there may have been too slow a rate of melting to give vigorous flow from the ice border. The early Wisconsin moraines carry a thin deposit of silt loam of loess-like character, and this, as already indicated, appears to have been deposited before the surface of the moraines had suffered perceptible weathering or erosion. Perhaps this silt loam was carried up on the edge of the ice-sheet by wind blowing from the loess-covered district outside, in which case it would tend to protect the ice from the sun and lower the rate of melting. It is to be expected also that the rate of melting of the ice-sheet when at its culminating position would be slower than in the waning stage, when warmer conditions had set in.

The Iowan Drift Problem

The Iowan, or third drift of the region west of the Driftless Area of the upper Mississippi valley, is of such a problematical character that the students who have examined it have been unable thus far to come to an agreement as to its place and rank in the glacial series. It is a very thin and somewhat patchy deposit, whose eastern limits in Iowa and Minnesota are so difficult to define that there is no agreement as to its extent. The western limits, in northwestern Iowa and northward into South Dakota, are better defined, being marked in places by a weak morainic ridge. The western part was interpreted by Macbride, and also by Leverett and Sardeson, to be referable to the Wisconsin stage of glaciation. But later studies by Leverett and by Kay and Carman have led them to consider it a probable correlative of the Iowan drift of eastern Iowa. This interpretation is based upon the degree of weathering that the drift exhibits, and the presence of a loess deposit on a considerable part of its surface. It is also very thin and patchy like the eastern area of Iowan drift. In both areas it overlies a greatly eroded Kansan drift, and is accordingly interpreted to be much younger than that drift. In constitution it is very similar to the Kansan drift, and probably was largely derived from it.

The principal question now in dispute is the relation of the Iowan to the Illinoian drift. Chamberlin and Leverett in recent years have referred it tentatively to the same glacial stage as the Illinoian drift. But Kay and his associates on the Iowa Geological Survey and Alden of the U. S. Geological Survey hold to an early idea that it is the product of a distinct glacial stage standing between the Illinoian and the Wisconsin. They grant, however, that there does not seem to be any equivalent of the Iowan drift in the district east of the Mississippi valley. They thus restrict the Illinoian drift to the Labrador part of the Laurentide field of glaciation, and the Iowan to the Keewatin part, which seems a very doubtful and unnatural restriction.

The reference of the Iowan drift to a later glacial stage than the Illinoian is based by these students on the lack of a gumbotil deposit on its surface, such as is found on neighboring parts of the Illinoian drift. They also maintain that the erosion and weathering and especially the leaching of lime is less on the Iowan drift. Recently Kay has announced the presence of a loess deposit on the Illinoian drift that seems to him to correlate with a loess that underlies the Iowan drift. The absence of gumbotil on the Iowan drift seems to be due to a lack of favorable conditions for its development rather than to a lack of time. It is hoped that further field study may clear up the remaining points of difference.

CONCLUSION

From what has been outlined it will be seen that there are problems of various kinds awaiting solution. These problems call for training in various lines. There will be work for students of various degrees of ability. But, as remarked by one of my associates, it will require native ability, thorough training and a steady scientific aim to clarify the main problems of glacial geology.

A NEW SCIENCE[1]

By Dr. R. L. SACKETT

DEAN OF ENGINEERING, THE PENNSYLVANIA STATE COLLEGE

The most ancient art—and still an art—emerges into the most modern science, one that began to develop with the "Machine Age" and never will be completed.

We need science in education, and much more of it than we now have, not primarily to train technicians for the industries which demand them, though that may be important, but much more to give everybody a little glimpse of the scientific mode of approach to life's problems.—R. A. MILLIKAN.

"NECESSITY—thou best of peacemakers, as well as surest prompter of invention," said Sir Walter Scott. Necessity has often been described as the mother of invention, but there have been other parents such as desire and even accident. Whatever the economic urge behind invention may have been, it is clear that to-day science is the father of both discovery and invention so far as method is concerned. What have been the forces which have propelled individuals toward new goals? The search for the beginning of an idea usually leads far back of the date of the invention, and it is difficult to place a historical finger on the individual who originated an idea. National urges and movements are much easier to trace and in the long run are as important in measuring the causes of and steps in discovery and the resulting influences on the social organism.

Just what was the motive force five thousand years ago in the Nile Valley? A desire for a form of immortality led to the construction of the tombs and pyramids of Egypt. The temples of Thebes, Amenra, Edfu, Luxor, Memphis, Baalbeck and others were erected to perpetuate a cult. They represent a national skill, but not a national culture, as the erection of such monuments was by the decree of a despot and at the expense of thousands of slaves.

Greece was a democracy, and the national search for beauty gave us the Parthenon and the attendant philosophy of Plato. Not less impressive were certain scientific gifts contributed by Greek culture of which much less is said.

Religious zeal also gave us the Gothic period, which was the first architectural style to emphasize the vertical line. The cathedrals of Bourges, Chartres, Amiens, Rheims, Notre Dame, Salisbury, Wells, York, Lincoln, Cologne and Milan represent a wide-flung culture and a reborn skill.

Whatever have been the incentives to progress and whatever scale of intelligence may have been reached, there have been limitations to the skill or productivity of nations, and the most obvious has been the tools which they used. The implements of primitive man were the product of hunger, fear, love and his environment, but the later national advances were limited by the tools available, and tools have been a product of science as the latter has fabricated new materials and

[1] Address of the retiring vice-president of Section M—Engineering, American Association for the Advancement of Science, Des Moines, December, 1929.