surface, as Hildebrandsson has already shown (6), is divided into positive and negative centers of action separated by intermediate regions which may be of a transition type, or may be under the sway first of one center and then of another. In these centers, apparently in harmony with solar changes, there occur almost synchronous changes of pressure as well as of temperature. These changes are, apparently, common to all the centers of action, but their character is reversed according as the centers are positive or negative. The changes in pressure appear to precede the changes in temperature. Another noteworthy feature of the centers of action is that one type suffers changes of temperature roughly in harmony with the changes which occur in tropical midcontinental regions and which are apparently due in good part to variations in the radiation of solar heat. The final conclusion of our Norwegian authors is that changes in pressure and winds which are presumably of solar origin, generally precede changes in temperature and are on the whole the more important subject of study.

This conclusion bridges the gap between the present writer's cyclonic hypothesis of variations in temperature and the hypothesis of the present paper as to the effect of nonthermal solar variations. Apparently these solar variations follow a course roughly, but not strictly, parallel with that of changes in the sun's emission of heat. Increased solar heat warms the earth's surface in certain regions, specially within the Tropics or in continental interiors where there are few clouds. This tends to increase the rapidity of both oceanic and atmospheric circulation. At the same time the seemingly nonthermal energy with which we have been mainly dealing in this paper, apparently causes an expansion of areas of high pressure and a consequent weakening of gradients in their centers. This crowds the low-pressure areas and thus in such areas strengthens the gradients. Perhaps, as Veeder has suggested (7), these changes are due to an actual transfer of parts of the upper air toward the centers of high pressure. However this may be, the result seems to be a remarkably quick readjustment of atmospheric pressure. This is apparently followed at once by a strengthening of the winds, and an increase in cyclonic activity. Hence in the high-pressure areas the cold upper air must begin to settle downward, so that the temperature of the earth's surface is lowered. In the low-pressure areas, or at least along their equatorward sides, an unusual amount of warm air must be drawn inward. Thus the temperature rises, and the condition of such places varies inversely to that of the centers of high pressure. Ultimately the warm air is carried upward so that the general temperature of the earth's surface is lowered. This, however, does not happen until certain areas have been warmed by the winds while other areas are being warmed by the sun and still others are being cooled by the descent of air from aloft. One of the next great tasks of meteorologists would seem to be to map the areas of these three types under different conditions of solar activity.

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CORRIGENDA.

PART I.—Page 127, legend for figure 4, the dotted line and the solid line should be interchanged.

Page 129, lower margin of right-hand of figure 5, "increase" should read "decrease."

Page 139, column 2, line 14 from bottom, sentence beginning "Let it" should read "Let us."

II.—Page 170, Table 8, column 1, third line, "1907" should read "1908".

Page 176, second line of note to figure 14, "sun" should read "sun's"; at beginning of fourth line "from" should read "of", and "NS" in same line should read "NE".

LACUSTRAL RECORD OF PAST CLIMATES.

By CHARLES ROLLIN KEYES, Ph. D.

[Dated Des Moines, Iowa, July 14, 1917.]

It is not at all surprising that such apparent climatic anomalies as the occurrence in arid regions of large bodies of inland waters should call forth varied explanations. At first glance interior seas seem to portend former meteorological conditions that were fundamentally different from those now existing. They even suggest that they may be tell-tale clues to epochs when greater humidity prevailed. In this regard the vast extinct lakes of the Great Basin of western North America especially are the theme of warm and prolix discussion on possible climatic changes in late geological times. Whether or not ultimate analysis of recorded observation support the thesis of permanency of climate, rhythmic alternation of climatic change, or variable and irregular succession, it is quite certain that the tendency of opinion toward the middle course thus far finds greatest favor.

When the sumptuous monographs on the vanquished Great Basin lakes were written by King, Whitney, Gilbert, and Russell, such a thing as desert geology was entirely unknown in the United States. Principles of modern physiography were not yet formulated. The tremendous potency of eolic erosion under conditions of aridity was unsuspected. On the other hand, the duality of the Glacial Epoch was just beginning to receive credence, although its real multiplicity and complexity were yet undreamed. Since these new fields of investigation have opened up, old views are capable of something like quantitative measurement, where before much was either pure fancy or unwarranted distortion to fit dimly outlined hypotheses.

Arid regions present as their most characteristic relief expression innumerable shallow depressions. In a tract of close-patterned orogeny as, for example, the Great Basin, these broad depressions are usually coterminous with the intermontane plains. To the explorer fresh from his homeland of humid climate the surface hollows appear as potential lake basins. As a direct consequence of desert erosion they are really not an expression of drainage features at all. That some of them, under such dry-climate conditions, should be actually occupied by broad expanses of water is a wholly unexpected phenomenon; and at first thought the fact appears singularly incongruous.

At the present time the lakes of the notably arid Great Basin possess special interest not only because of their number and the great size of some of them, but on account of the fact that there has been a concerted effort on the part of writers on the region to establish for all of them the same climatic origin. That all of these lakes can not possibly be brought under a single genetic control is only beginning to be realized. That they really have widely different and wholly unrelated origins is amply attested by recent critical observations. That some are composite and others complex is a late conclusion from which there is no escape. Although all the details of the life histories of many of these strange bodies of water are yet to be deciphered, enough is now definitely known to assume that all are capable of satisfactory explanation without recourse to climatic conditions so very different from those now prevailing in the region.

The vastness of expanse of two of the ancient bodies of water in the Great Basin, Lakes Bonneville and Lahontan, is no doubt the chief cause for seeking an adequate explanation by appeal to atmospheric conditions different from those now enjoyed. Instead, however, of a single genetic agency controlling the existence of these two lakes and numerous other smaller bodies of water in the region, recent inquiry indicates rather a multiple origin. In place of an assumed common genesis each lake has to be separately tested concerning its being. Whether classified according to the genesis of lake-basin or according to source of lake waters, there are so many different means of development that any broader controlling agent, as a climatic one, is entirely precluded. Grouped with reference to origin of lake-basin a dozen distinct categories of lakes are found to be represented in the Great Basin. Arranged as to sources of water-supply there are half as many additional categories to be taken into account.

In humid climates the lineaments of lake genesis are masked because of the fact that the barriers are usually overflowing, and it is not always possible clearly to distinguish the underlying factors. In arid lands expansive bodies of water seldom overflow their basins. The specific derivation of each is more or less readily discerned. Even those bodies of water that are close together may have widely different origins. How great then must be the incongruities encountered when such lakes as Bonneville and Lahontan, for instance, are grouped together in the same class, especially when the essential taxonomic factor is made the number of prominent shore-lines corresponding to the number of postulated advances of a continental ice-sheet. The inadequacy of such a climatic test is indicated by the recent recognition of an entirely different number of glacial epochs. Neither of these lakes is to be regarded as arising from imperfect drainage such as ordinarily prevails in pluvial lands. Both are accidental features of the arid country in which they are found.

When the data for the Bonneville and Lahontan monographs[1] were being assembled the novelty of conception of the duality of the Glacial Epoch was noisily occupying the front of the geological stage. The main purpose of these accounts almost seems to have been to establish the truth of the notion. Discovery of two shore terraces more conspicuous than others is cited as indisputable evidence of a twofold Ice Age. Without adducing any really critical testimony, a marked moderation of the present arid climate is made to account for the lake conditions. Singular as it now seems that recourse should be limited to a single working hypothesis, the fact is easily explained when it is remembered how overpowering in that day was the Glacial argument.

For a long time there has been a general tendency to connect in some way or other the existence of the Great Basin lakes with the presence of glaciers and to associate the desiccation of the former great bodies of water with the waning of the Glacial Epoch. The various views may be all grouped under three heads. Dr. E. M. Endlich was under the impression that the old glaciers of the Rocky Mountains in Colorado were produced by the excessive moisture derived from the broad sheets of water formerly existing to the westward. A second hypothesis, advanced by Prof. J. D. Whitney, regards the Pleistocene lakes as sequels to the glaciers, being produced by their melting. In the "Geological History of Lake Bonneville" Prof. G. K. Gilbert considers that the same changes in climate introduced both the glaciers and the lakes.

The fundamental weakness of both of the last-mentioned hypotheses as general explanations lies in the fact that in the Sierra Nevada, where Whitney mainly worked, the glaciation was sufficiently extensive to be competent to produce the results; while in the Wasatch Mountains, where Gilbert studied, the larger lake was in reach of such petty glaciers that the Whitney explanation could not possibly be sustained.

At the same time that the Great Basin lakes were associated with the regional glaciation there also developed the idea that with the passing of the mountain glaciers the region entered into a stage of general and greatly accelerated desiccation. Whitney, indeed, fancied that all the intermontane plains or basins of Nevada were formerly occupied by beautiful inland seas. But potential lake basins extend far beyond the limits of the Great Basin. They reach southward a distance of 2,000 miles to the Tropics. That these so-called lake basins were really a characteristic surface feature of desert lands generally was not then suspected. Neither was it dreamed that they were not drainage features at all, but owed their origin and prevalence to erosional powers in which running water takes no part. For this reason mainly the real significance of the phenomenon of desert lakes is so often entirely mistaken or largely misinterpreted.

A marked proneness to generalize too widely with regard to these desert lakes, and the attempt to bring all of them under the same genetic head, have done more than anything else to obscure the real issues involved. The forced efforts to consider the ancient bodies of water as glacier-born is only one angle of the problem. Throughout the West the lacustral hypothesis of the origin of geological formations has been so long overworked that it would be no surprise if the reaction that is now setting in against it go much too far. Many of the so-called old lake beds are now known to be fluviatile deposits. Still larger numbers are manifestly strictly epirotic in character. Others are partly one and partly the other. Very few are actually lake-laid strata. The widely recognized "Severn Lake" deposits of Nevada are discovered to be marine in origin, at least in large part. In the last-mentioned deposits are fossils as old as the Eocene age, and the strata, infolded as they are in the Sierra Nevada and Sierra Madre, are traceable in a broad belt to the Pacific Ocean. So the published data on the terranal aspects of the ancient desert lakes can

[1] Mon. U. S. Geol. Surv., Vols. I and XI.

not now be viewed with the same equanimity that they were a few years ago. Before confidence is again restored much of the region of the Great Basin has to be critically examined anew.

Without outlining a full genetic scheme of lacustral taxonomy, which arid regions seem to supply the data for in unmasked form, it is important in this connection to note that each body of water requires separate consideration when its genesis is under surveillance. Many desert lakes of consequence are no doubt simply the exposure of the ground-water table to sky, due to local accentuation of the deflative processes. Others, as Lake Bonneville, seem to be due to orographic movements chiefly. Lake Bonneville's history is a long one. It goes back far beyond the inauguration of the Glacial Epoch. To all appearances many traces of its early development are still retained; and they antedate even the coming of the arid climate. Briefly, the course of events seems to be that this vast body of water of which Great Salt Lake is commonly believed to be a last vestige, is not after all an anomaly among desert features, but that it merely represents a special phase of a through-flowing stream that was not quite large enough to master the orogenic barrier which chanced to arise athwart its path. On the other hand, its nearest neighbor and parallel relative, the Green River, reinforced by the Grand and other large eastern tributaries, was sufficiently powerful to hold its own against all vicissitudes and to carve through the rapidly bulging Colorado dome a Titan among chasms. Blocked by such a formidable rampart, the Old Virgen River, as it may be called, spread out far and wide over the adjoining intermontane plains, and rivaled in magnitude the Laurentide Great Lakes, with 20,000 square miles of area and a depth of 1,000 feet. Finally, the principal supplies being diverted, the waters of the great lake were allowed to evaporate until equilibrium was again established between it and its remaining tributaries.[1]

That the seemingly vast changes in the water conditions of this desert region were physiographic rather than climatic in their nature finds strong support in the recent results of Prof. W. W. Atwood,[2] in southwestern Montana. This author shows by quite conclusive evidences that immediately before the inauguration of the Glacial Epoch the basin of the Snake River extended nearly 200 miles farther to the northeastward than it does at the present time, and included an area of nearly 300 miles square that has since been separated from it. This area was mainly that part of the basin of the present Missouri River lying above Great Falls. Passing Idaho Falls and Pocatello, was a combined volume of waters of the present Snake River and the Missouri River at the Great Falls gorge. This noble stream is believed to be the Old Virgen River, the superior companion of the Green River. In the recent migration westward a distance of 150 miles of the Continental Divide in Montana, the Yellowstone River took part of the old Snake or Virgen headwater drainage, the Missouri River the greater portion, Clarke's Fork of the Columbia a part, and the Salmon River of Idaho a part. Deprived of so large a portion of its headwaters, and later blocked by basalt flows at Pocatello, the remnantal pre-Glacial stream turned out over the Idaho lava fields the diminutive Snake River that we find to-day.

In the early considerations of Bonneville Lake the geological age of the attendant deposits was a matter of extreme uncertainty. Bearing on this point no satisfactory testimony was ever adduced. More recently several distinct but mutually supporting lines of evidence seemed to settle this question. The elevation of the southern mountain barrier of the old valley was manifestly coeval with the formation of the inner gorge of the Grand Canyon of the Colorado River in Arizona—Mid or Late Tertiary in date. At Red Rock Pass, the low-rim point of the basin at the north and an assumed outlet of the lake, the gravels and silts proved to be a direct continuation of the Bozeman beds of southwestern Montana and southern Idaho. In age these were mainly Mid Tertiary. The uplifting of the Beaverhead range athwart the drainage and the capture of the original headwaters of the Snake River by the Missouri River took place in Late Tertiary time. The complete diversion of the Snake River drainage from the Bonneville basin was probably also a Late Tertiary occurrence. Antedating Pleistocene or Glacial times there still remained the Early Quaternary Epoch.

Thus before the Glacial Epoch set in was Lake Bonneville already a mature body of water, it had far passed its widest expansion, and it was really more than two-thirds desiccated. All drainage communication with the Continental Divide about Butte, Mont., being cut off, the lake basin received no augmentation to its waters from the mountain glaciers in this direction. Since the recent careful mapping of the old glaciers of the Wasatch and Uinta mountains the most conspicuous feature brought out concerning them is their utter insignificance. So inconsequential must have been their influence on lake conditions that one can not but wonder why the two phenomena were ever genetically associated. The Glacial Epoch came too late to be witness at the lake's birth. It narrowly escaped not being present at the death.

Whatever may have been the course of events in the history of Lake Bonneville, it is not at all probable that that of the other great body of Great Basin water, Lake Lahontan, had nearly the close parallel which a climatic hypothesis demands. In duration, in expanse, in magnitude of gathering ground the last-mentioned body of water is hardly to be compared in importance with ancient Lake Bonneville. Whether or not Lake Lahontan still retains any vestige of pre-arid drainage lines is hard to say. There are good reasons for believing that it stands in the path of a former through-flowing river that was comparable to the Green or Snake River of to-day. Relatively recent orogenic movements and volcanic disturbances are ample effectually to block the course of any stream that happened to skirt the eastern foot of the Sierra Nevada and to empound its waters. If such a master stream did actually exist in pre-lacustral or pre-arid times, nearly if not all traces have probably long since completely disappeared through the operation of the ordinary desert erosional processes. Yet, in this connection, such features as the thousand-feet-deep canyon at the south end of Death Valley, Cal., now occupied for a number of miles by the little brook called Amargosa River, need careful examination.

The lakes which, in long succession, now lie at the foot of the great orographic block of the Sierra Nevada may be, however, merely the basal reservoirs of the different mountain streams and may have no relations to any former connection with a pre-arid master-stream of the region. In pre-Glacial times these mountain rivers probably were much larger than now, owing to the

[1] Bull. Geol. Soc. America, Vol. XXVIII, p. 351, 1917.
[2] Economic Geology, Vol. XI, pp. 697-740, 1917.

fact that the position of the Sierra Divide was much farther to the westward than at present. Waning glaciation over this lofty region was certainly competent to appreciably augment the basal lake supplies. It is thus quite possible that Whitney's explanation of melting ice is partly correct.

The disappearance of the great Lake Lahontan, as well as the dimunition in size or vanishing of many of the other bodies of water once much larger than now, is readily explained by postulating greatly diminished inflow occasioned not so much by a change from moister climatic conditions as by the rapid eastward migration of the Sierra Nevada watershed and by the capture of its chief catchment basin by the Columbia River. The east base of the great snowy range is 4,000 feet higher than the west foot. Headwater erosion thus goes on so much more speedily on the sunset flank than on the other side that the divide has already nearly reached the eastern margin of the orographic block. Some of these west-flowing streams are now actually crowding down the east slope of the ridge. The headwaters of Feather River in California reach even now quite to the brow of the high escarpment overlooking the Great Basin. Pitt River in the same State has already broken through the range and drains lakes that not so very long ago were strictly Great Basin features. The time can not be long until the canyon of the American River, along the brink of which the Southern Pacific railway runs 3,000 feet above the bottom, shall have been cut back completely through the Sierra, capturing the Truckee River on the eastern side. At a little later date the waters of Humboldt River may be flowing uninterruptedly to the Golden Gate.

Bearing directly on the question of an independent genesis of the two largest lakes of the Great Basin is the attitudes of the minor lakes of the region. Admittedly of a half score distinct origins, these several classes of desert waters retain their characteristics far beyond the confines of the Great Basin. Their congruous relations to normal desert environment continue southward quite to the Tropics; so they are the same in regions far beyond supposed influences of Glacial climate. In climatic discussions of the Great Basin the significance of this fact is little considered. It is one of the strongest arguments against appreciable change in climate since the time when these lakes began to form. The continental glacier front is far too remote to influence the climate of Nevada. All lacustral testimony seems to support conclusively the postulate that during late geologic times the climatic fluctuation in the region has been no more rapid than the larger orographic change. It is doubtful whether during the Glacial Epoch there was any appreciable modification in the climatological features of the arid lands.

CROP CENTERS OF THE UNITED STATES.

By J. WARREN SMITH, Meteorologist.

[Dated: Weather Bureau, Washington, D. C. June 28, 1918.]

Dr. Adolph E. Waller, Associate at the Botanical Laboratory of the Ohio State University, Columbus, Ohio, contributes an article under the above head in the Journal of the American Society of Agronomy for February, 1918, vol. **10**, pages 49–83, that is of more than passing interest to students of agricultural meteorology. The author writes from the point of view of the ecologist, and relates farm practice, as shown in the development of commercial field crops, with natural vegetation as influenced by climate and soil.

The article opens with a discussion of the climate of the United States, particularly in the inter-relation of temperature, rainfall, and evaporation, and the effect upon certain marked types of vegetation. Unfortunately, in explaining the influence of high and low pressure areas upon rainfall, the author makes the serious error of saying that "the eastern side of a high and the western side of a low are regions of ascending, converging, cooling air," and is thus "the region of increasing moisture," while "the western side of a high and the eastern side of a low are regions of descending, diverging, warming, drying air." He indicates in the next paragraph that the wind blows away from areas of low pressure, which is contrary to the well-known fact that the wind blows *away* from high and *toward* low pressure areas. While these errors are regrettable, they do not vitiate the general excellence of the paper as a whole.

In his discussion of climatic and edaphic factors, the author states that:

> In every stage of their development plants respond to the moisture and temperature changes of the habitat. The nature of the soil has such a far-reaching influence upon plant life that it must be considered second in importance to but one factor, the climate. Those plant-growth factors related to the soil have been named by Schimper (1903) the edaphic factors.
>
> Warming (1909), impressed with the fundamental relation between plant growth and available water supply of the habitat, grouped vegetation into three principal classes, hydrophytes, mesophytes, and xerophytes. The water-content of soils was made the basis of his work, but when he recently reclassified the three types in order to accommodate them more closely to plant distribution, the new system was too involved to receive general recognition from plant geographers. Schimper made practically the same grouping that Warming made of water-content associations. He also pointed out that the terms forest, grassland, and desert are a subconscious classification of the principal climatic formations and are only another way of expressing the water-content of soils.
>
> The effect of the edaphic factors is to modify the climatic influences. The physical and chemical properties of soils tend to diminish or intensify the effect of climatic factors upon plant growth. * * *
>
> The physical nature of soil structure is more important to plant life than the chemical composition of the soils due to the relation between soil texture and water-content.

In discussing the relation between the crop centers and centers of natural vegetation, the author says:

> The corn and wheat belts agree with the deciduous forest and the prairie centers in the United States. * * *
>
> Three sets of factors are operating in combination to establish this region as the center for the production of our great cereals. These factors may be grouped as climatic, edaphic, and economic.
>
> By reason of the hot, almost tropical summers with the relative humidity rather high and the annual rainfall sufficient for the growth of the plant, the entire area from Ohio to central Nebraska on the north and southward to the Gulf of Mexico is suited to corn production. * * *
>
> The climatic factor in Indiana and Ohio is suited to the profitable production of corn, but production centers in Illinois for edaphic reasons. * * *
>
> In the United States wheat production centers on the 60 per cent rainfall-evaporation ratio line. This means that the center of wheat production lies west of the best corn lands, although on many farms throughout the prairie and deciduous forest climaxes both wheat and corn are usually grown, if rotations are practiced. In the matter of growing wheat in regions too dry for corn, the United States is not an exception to the rule. The great wheat-producing regions all over the world are level plains with a cool, rather dry climate. It is known that wheat, particularly winter wheat, yields larger crops in the more humid sections, yet in normal times other crops can be grown in the humid parts of the United States with greater profit than wheat. It is competition with these crops that drives wheat to the plains. * * *