MAP OF THE PLEISTOCENE LAKES OF THE BASIN-AND-RANGE PROVINCE AND ITS SIGNIFICANCE¹

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(Read before the Society December 29, 1921)

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INTRODUCTION

The Basin-and-Range physiographic province, as outlined by a committee of the Association of American Geographers and the Physiographic Committee of the U. S. Geological Survey,² extends in the United States from southern Oregon to trans-Pecos Texas, and contains not less than 125 closed drainage basins—that is, basins which have no surface outlets for the water that falls upon them. The mountainous rims of these basins, with their great relief and remarkable exposures of geologic formations and structures, have, from the beginning of explorations in the region, compelled the attention of geologists. In contrast, the interior depressions of the basins, mantled by recent sediments and with surface features that are hardly discernible except by an experienced observer, have received relatively little attention and are commonly regarded as lacking in geologic interest. However, the serious work that has been done in these interior depressions, or basin valleys, has shown that they contain physiographic and hydrologic features of absorbing interest and much geologic significance, and also sufficient natural and artificial ex-

¹ Manuscript received by the Secretary of the Society February 23, 1922.

Submitted by permission of the Director of the U. S. Geological Survey.

² N. M. Fenneman: Physiographic divisions of the United States. *Annals Assoc. Amer. Geographers*, vol. 6, 1916, pp. 19-98. The north boundary of this province was slightly modified for the present paper in order to include Harney Valley, Oregon.

posures to afford important results in Tertiary and Quaternary stratigraphy, structure, and paleontology. I have spent a good many summers in these basin valleys, studying their water resources, and I am deeply impressed with the opportunity they present for further geologic work.

The early geologists were struck by the contrast between these basin valleys and the valleys in humid regions, and they did some memorable work in the valley areas which resulted in such classic papers as the Bonneville and Lahontan monographs. Later geologists working in the region, however, largely ignored the valleys or gave them only superficial attention. In recent years interest has been revived in these valleys through two lines of economic geology—the study of the ground-water resources of the desert region and the search for potash.

The main purpose of the present paper is to present a nearly complete map of the Pleistocene lakes of the Basin-and-Range Province which has resulted from this recent work. In addition, I will discuss briefly the relation of ground-water discharge by evaporation and transpiration in this province to the discharge from surface lakes, as developed by our recent water-resource investigations, and will call attention to studies of Pleistocene climate which I hope can be made in the future by comparing the Pleistocene with the present hydrology of the province.

PLEISTOCENE LAKES

The map of Pleistocene lakes presented herewith (figure 1) shows 68 ancient lakes, including the two giant lakes—Bonneville and Lahontan. A few Pleistocene lake beds probably still remain undiscovered, but for most of the region the map is complete. The ancient lakes were mapped chiefly by their shore features, many of which are still very conspicuous and distinct. In addition to the closed basins that held these lakes with definite shorelines, there are doubtless others that contained small ephemeral lakes which left no distinct shore features.

Somewhat more than half of these lakes were mapped by Russell and Gilbert many years ago, but about 25 have been mapped (and, for the most part, discovered) in recent years in connection with the ground-water and potash investigations of the U. S. Geological Survey. It should be noted that the newly mapped lakes are distributed over a large region which had previously been almost unexplored for these features, and that they represent a wide range in latitude, altitude, and climate. They are, therefore, especially significant in the interpretation of the hydrology and climate of the epoch in which they existed. The lakes mapped by Russell and Gilbert were found in northern and middle Nevada and adjacent

parts of Utah, Oregon, and California; the recently mapped lakes were distributed through middle and southern Nevada, southern California, and the parts of Arizona and New Mexico that lie in this province. Moreover, nearly all parts of the province that are devoid of Pleistocene lake beds have been examined for these features in recent years.

FIGURE 1.—Map of the Pleistocene Lakes in the Basin-and-Range Province

The presence or absence of Pleistocene lakes in a given drainage basin and the size of each lake relative to the size of its basin are conditions controlled by a number of rather complexly interrelated factors, such as the size of the basin, the permeability or impermeability of its bedrocks,

its altitude, relief, and topography, and the latitude and climatic belt in which it lies.

The map shows very plainly the relation of latitude to the size and abundance of lakes. There is at present a general southward increase in the rate of evaporation and decrease in precipitation. The distribution of the Pleistocene lakes shows that at the time they existed there was a comparable southward change in at least one of these factors. The northern part of the province was crowded with Pleistocene lakes, most of them of good size; farther south the lakes were smaller and less abundant, and some large basins contained no lakes of sufficient size and permanence to leave distinct shore features. In southwestern Arizona lakes were absent, because there were no closed basins that could hold lakes, but in southeastern California and trans-Pecos Texas closed basins occurred, and the absence or scarcity of lakes in these parts of the province was apparently due to aridity.

The map also affords good examples of the influence of altitude, relief, and topography on the existence and size of the lakes. The rapid transition from central Nevada, with its abundant Pleistocene lakes, to the relatively desiccated region of southern Nevada and southeastern California is largely due to rapid decrease in altitude with great increase in temperature and evaporation. Lake Estancia, in central New Mexico, whose strand is 6,200 feet above sealevel, was one of the highest of the Pleistocene lakes, and consequently, though it lies far south, it occupied 22½ per cent of its drainage basin. Lakes Bonneville and Lahontan evidently owed their great size to the productivity of the lofty Wasatch Mountains and Sierra Nevada, respectively. Lake Bonneville occupied 38 per cent of its basin and then overflowed. Lake Lahontan occupied about 20 per cent of its basin, the smaller percentage being due largely to the extensive area of relatively low, unproductive country east of the lake that was included in its drainage basin. Aside from the effects of altitude and relief in influencing evaporation and precipitation, the shape of the drainage basin is important in concentrating the surface waters in one locality, where they may accumulate to form a lake, or spreading them to such an extent that they are dissipated without forming a lake. The most striking example of the effect of concentration of the drainage is afforded by the Salton Sea, which developed rapidly in the midst of an intensely arid region when the Colorado, with its vast drainage basin, became tributary to it. The ancient lake in Coal Valley, Nevada, is another good example of this kind on a smaller scale.

PRESENT LAKES AND AREAS OF GROUND-WATER DISCHARGE

Figure 2 is a map of the Basin-and-Range Province showing approximately the lakes that exist in this province at the present time. As most of these lakes lie on very flat bottoms of the ancient lakes, they fluctuate

FIGURE 2.—Map of the present Lakes in the Basin-and-Range Province

greatly in area with the changing seasons. For this reason they are more difficult to map than are the ancient lakes, which had more definite shore-lines.

The region is at present not nearly so destitute of a water supply as has often been assumed or as might be inferred from this map. The

basins are of three types: (1) those in which lakes still exist, (2) those which do not have lakes, but are discharging water from the subterranean reservoirs into the atmosphere by evaporation and transpiration, often in large quantities, and (3) those which do not have lakes and in which, moreover, the water-table is everywhere so low that they do not discharge ground-water except by subterranean leakage out of the basin. A basin with ground-water discharge has a different aspect from one without such discharge and it functions differently. Instead of being completely desiccated except in brief rainy seasons, as was the conception once usually held, it may in fact contain a vast reservoir of ground water that is discharging large quantities of water by evaporation and by transpiration from plants throughout all the dry, hot, summer season, though no water may be visible at the surface. Only a few of the basins at the present time have perennial lakes that are discharging water by evaporation, but many of them have extensive areas of ground-water discharge. Data are being accumulated for constructing a map of the areas of ground-water discharge in the Basin-and-Range Province. This map will probably show that, excepting the basins of Lakes Bonneville and Lahontan, the aggregate area at present discharging water by evaporation and transpiration from ground-water reservoirs is not greatly inferior to the aggregate area which in the Pleistocene was discharging by evaporation from lakes. The north basin of Big Smoky Valley, Nevada, may serve to illustrate the importance of ground-water discharge (figure 3). In this basin there is an area of 160 square miles in which ground water is being discharged into the atmosphere. The average rate of discharge in this area has been roughly estimated to be 6 inches of water a year, which would amount to about 50,000 acre-feet a year, or 45 million gallons a day—about 8 per cent of the water that falls on the basin as rain or snow.

While the aggregate discharge of ground water is a very large quantity, it should be noted that the rate of discharge is much lower than the rate of evaporation from a lake under the same atmospheric conditions. If the average annual evaporation from a free water surface in Big Smoky Valley is 60 inches and the average annual rate of loss from the area of ground-water discharge is only 6 inches, then the ground-water discharge is equal to the evaporation from a lake of 16 square miles occupying $1\frac{1}{4}$ per cent of the drainage basin. The Pleistocene lake in this basin occupied 225 square miles, or 18 per cent of the basin (figure 4). The quantity of water that would be discharged by evaporation from a lake of this size under present climatic conditions would, according to the assumptions made, be about 14 times the present ground-water discharge and

would be greater than the entire quantity of water that falls on the basin as rain or snow.

INTERPRETATION OF PLEISTOCENE CLIMATE

I believe these basins afford a feasible approach to the problem of past climate that has not been exploited. I hope that with further work it

FIGURE 3.—Map of Part of the North Basin of Big Smoky Valley, Nevada
Showing intake and discharge areas.

will be possible to make a quantitative estimate of Pleistocene climate by comparing the Pleistocene and present hydrology of the basins. The problem is, indeed, rendered complex by the variables that are involved

and especially by the fact that the unknown quantity (Pleistocene climate) contains at least two unknown factors—temperature and precipitation. But, on the other hand, it is made tangible by the large number

FIGURE 4.—Map comparing the Pleistocene Lake and the Present Areas of Ground-water Discharge in the North Basin of Big Smoky Valley, Nevada

Figure on left represents present area of ground-water discharge, 160 square miles.

Figure on right represents the Pleistocene lake, 225 square miles.

and convenient variety of basins, by the fact that these basins are so nearly independent of one another that they lend themselves well to com-

parison, and by the fact that the topography of the basins has changed very little since the ancient strands were formed.

The range in humidity (or aridity) among the various basins in the Pleistocene epoch was apparently as great as the difference in a given basin between the Pleistocene and the present. A considerable number of the closed basins in the province were too arid in the Pleistocene to contain lakes of any consequence, whereas a few are humid enough at present to contain perennial lakes of considerable size. The relatively humid parts of the province at the present time seem to be comparable to the most arid parts in the Pleistocene epoch (compare figures 1 and 2). The region of southwestern New Mexico and southeastern Arizona in the Pleistocene is apparently comparable to southern Oregon at present, for the Pleistocene lakes near the Mexican border do not seem to amount to much more than do the present lakes of Oregon. The south end of Nevada in the Pleistocene can perhaps be compared to northeastern Nevada at present, with its few small lakes, the difference in latitude here being less than in the first case because there is a great difference in altitude. Parts of southeastern California and trans-Pecos Texas in the Pleistocene can perhaps be compared to parts of Nevada at present where the climate is just too arid for perennial lakes. Lastly, the Pleistocene lakes of the somewhat dismembered Death Valley basin, including the Owens, Amargosa, and Mohave River drainage basins, seem to have their approximate counterparts in the existing remnants of Lake Lahontan.

These generalizations are, of course, interesting rather than accurate, but they suggest a somewhat tangible method of attack. That they involve a substantial difference in climate is shown by the fact that in each of the four comparisons that have been made there is at present a difference in mean annual temperature between the regions compared of more than 15 degrees Fahrenheit. What is needed for even an approximate solution of the problem is adequate topographic maps of the basins, a general knowledge of their rock formations and structures, complete maps and data regarding their Pleistocene and present lakes and their present areas of ground-water discharge, adequate data as to the physiographic changes that have taken place in them since the Pleistocene, and abundant records of their temperature, precipitation, stream flow, evaporation, and ground-water discharge.

LIST OF PLEISTOCENE LAKES IN THE BASIN-AND-RANGE PROVINCE
(SEE MAP, FIGURE 1)

(Asterisk indicates lake that had outlet)

Map number.	Name of lake or of containing valley or basin.	Principal authorities.	References.
1	Silver and Christmas	I. C. Russell	U. S. Geological Survey, Fourth Annual Report, plate LXXXIII.
		G. A. Waring	Water-Supply Paper 220.
2	Abert and Summer	do.	do.
*3	Harney	do.	Fourth Annual Report, plate LXXXIII; Water-Supply Paper 231.
4	Warner	do.	Fourth Annual Report, plate LXXXIII; Water-Supply Papers 220 and 231.
5	Guano	I. C. Russell	Fourth Annual Report, plate LXXXIII.
6	Catlow	do.	Fourth Annual Report, plate LXXXIII.
		G. A. Waring	Water-Supply Paper 231.
7	Alvord	do.	do.
8		I. C. Russell	Fourth Annual Report, plate LXXXIII; Eighth Annual Report, plate XVI; U. S. Geological Survey Monograph XI, plate I.
*9	Klamath	do.	do.
*10	Goose	do.	Fourth Annual Report, plate LXXXIII.
		G. A. Waring	Water-Supply Paper 220.
11	Surprise	I. C. Russell	Monograph XI, plate XLVI.
12	Long	do.	do.
*13	Madeline	do.	do.
*14	Eagle Lake	do.	do.
*15	Horse Lake	do.	do.
16	Lake Lahontan	do.	Third Annual Report, plate XVIII; Monograph XI, plate XLVI.
17		do.	Monograph XI, plate XLVI.
18	Granite Spring	do.	do.
*19	Washoe	do.	do.
*20	Buffalo Springs	do.	do.
21	Osobb, Dixie, or Humboldt Salt Marsh	do.	do.
22	Edwards Creek	do.	do.
23	Fairview	do.	do.

Map number.	Name of lake or of contain- ing valley or basin.	Principal authorities.	References.
24	Smith Creek.....	I. C. Russell.....	Monograph XI, plate XLVI.
25	Gabbs	do.....do.....	do.....do.....
26	Mono Lake.....	do.....	Monograph XI, plates I and XLVI; Eighth Annual Re- port, plate XVI.
27		do.....	Monograph XI, plate XLVI.
28		do.....	Monograph XI, plate XLVI.
29	Excelsior Flat.....	do.....do.....	do.....do.....
30	Spring	do.....do.....	do.....do.....
31	Columbus Salt Marsh.	I. C. Russell.....	Monograph XI, plate XLVI.
		H. S. Gale.....	U. S. Geological Survey Pro- fessional Paper 95, figure 1.
32		I. C. Russell.....	Monograph XI, plate XLVI.
33	Big Smoky (Lake Tonopah)	O. E. Meinzer.....	Water-Supply Paper 375, plate VII; Water-Supply Paper 423, plate I.
34	Big Smoky (Lake Toyabe)	I. C. Russell.....	Monograph XI, plate XLVI.
		O. E. Meinzer.....	Water-Supply Paper 375, plate VI; Water-Supply Paper 423, plate I.
35		I. C. Russell.....	Monograph XI, plate I; Eighth Annual Report, plate XVI.
*36	Diamond	do.....do.....	do.....do.....
37	Ruby	do.....do.....	do.....do.....
38	Clover	do.....do.....	do.....do.....
39	Butte	W. O. Clark and C. W. Riddell....	Water-Supply Paper 467, plate III.
40	Goshute	I. C. Russell.....	Monograph XI, plate I; Eighth Annual Report, plate XVI.
*41	Lake Bonneville.....	G. K. Gilbert....	Second Annual Report, plate XLII; Monograph I.
42		I. C. Russell.....	Monograph XI, plate I; Eighth Annual Report, plate XVI.
*43	Steptoe	W. O. Clark and C. W. Riddell....	Water-Supply Paper 467, plate III.
44	Antelope	do.....do.....	do.....do.....
45	Spring	do.....do.....	do.....do.....
46	Railroad	E. E. Free.....	Mining and Scientific Press, volume 107, page 176; U. S. Department of Agriculture Bulletin 54, pages 35 and 36. Everett Carpenter
*47	Duck	do.....do.....	Water-Supply Paper 365, plate I.
48	Coal	do.....do.....	do.....do.....

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Map number.	Name of lake or of containing valley or basin.	Principal authorities.	References.
49	Bristol	Everett Carpenter	Water-Supply Paper 365, plate I.
50	Delamar	do.	do.
51	Indian Spring	do.	do.
*52		do.	do.
*53	Owens	H. S. Gale.	U. S. Geological Survey Bulletin 580, plate VII.
*54	Indian Wells, Salt, Wells, and Searles	do.	do.
*55	Panamint	do.	do.
56	Antelope	D. G. Thompson.	Water-Supply Paper (in preparation).
*57	Mohave (Lake Manix)	J. P. Buwalda.	University of California Publication Bulletin, Department of Geology, volume 7, number 24, plate XXII.
58	Cronise (Little Mohave Lake)	D. G. Thompson.	Water-Supply Paper (in preparation); Journal of Washington Academy of Sciences, volume 11, page 424.
*59	Silver and Soda (Lake Mohave)	do.	do.
60	Salton Sea	W. P. Blake.	Report of exploration and survey for railroad, Senate Executive Document 78, Thirty-third Congress, Second Session, volume 5, part 2.
		W. C. Mendenhall	Water-Supply Paper 225, Plate I.
61	Sulphur Spring (Lake Cochise)	O. E. Meinzer.	Water-Supply Paper 320, plate I.
62	Animas	A. T. Schwennesen	Water-Supply Paper 422, plate I.
63	Playas	do.	do.
64	San Luis (Lake Cloverdale)	Ellsworth Hunt.	Carnegie Institute of Washington, Publication 192, page 70.
		A. T. Schwennesen	Water-Supply Paper 422, plate I.
65	Hachita	do.	Water-Supply Paper 422, plate I.
66	Estancia	O. E. Meinzer.	Water-Supply Paper 275, plate I.
67	Encino	do.	Water-supply Paper 275, plate XII.
68	Tularosa (Lake Otero)	R. S. Tarr.	American Naturalist, volume 25, page 524.
		C. L. Herrick.	American Geologist, volume 34, page 185.
		O. E. Meinzer.	Water-Supply Paper 343.