Paleolimnology of the Trona Beds in the Green River Formation of Wyoming

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ABSTRACT

More than a score of trona, or trona and halite, beds have been found in the Wilkins Peak Member of the Green River Formation of Wyoming. The trona beds have an areal extent much smaller than that of the Wilkins Peak lake beds, which contain them. No compelling geologic evidence indicates that the lake ever shrank down essentially to dryness. On the contrary, the mineral and organic constituents of the trona beds indicate they were deposited at the bottom of a shallow lake that repeatedly alternated in concentration between strong brine and relatively low salinity, the brine stages being the low-level stages when trona and halite precipitated.

Reasoning by analogy with the present-day Great Salt Lake and certain other present-day saline lakes, it is inferred that low ridges in the lake bottom partially isolated an area of Gosiute Lake in the central and south-central part of the Green River Basin. Significantly, this partially isolated area received less inflow from streams than did the rest of the lake. In consequence, it became, at low stages, an evaporating sump into which flowed somewhat less concentrated (saline) water from the other two parts of the lake, which were themselves evaporating basins, but ones fed by rather large streams.

INTRODUCTION

The trona, the halite and trona beds, and the associated saline minerals of the Green River Formation of Wyoming are restricted to the saline facies of the Wilkins Peak Member, which has a lesser areal extent than the other members of the formation. The lithology of the Wilkins Peak Member and its stratigraphic relations to the rest of the Green River Formation have been described rather fully in another report (Bradley, 1964). Also, the limnology of the Wilkins Peak Member has been outlined in a brief discussion of the paleolimnology of the Green River Formation (Bradley, 1963). From these two accounts the following brief summary of the Wilkins Peak Member and its history is drawn to serve as a setting for this paper on the paleolimnology of the trona and halite beds.

GEOLOGIC SETTING

The Green River Formation, of early and middle Eocene age, is a great lens of lacustrine beds enclosed within a matrix of generally fine-grained fluviatile sediments that belong to the Wasatch Formation below, and the Bridger Formation above.

Gosiute Lake in which the sediments of the Green River Formation accumulated formed by gradual and progressive downwarp of the earth's crust -- a downwarp that made room for successive increments of sediment.

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Although Gosiute Lake passed through a complex series of changes in area and depth, during its roughly 4-million-year life, it had three major changes in size. During the first, or Tipton plus Luman stage, which lasted about one million years, it had an area of some 12,500 mi^2 and was a fresh water lake with an outlet. It occupied much of the Green River Basin, all of Washakie Basin, and extended far northeastward into the Great Divide Basin. Presumably there was a large central island made by the Upper Cretaceous rocks of the ancestral Rock Springs uplift. (See Fig. 1).

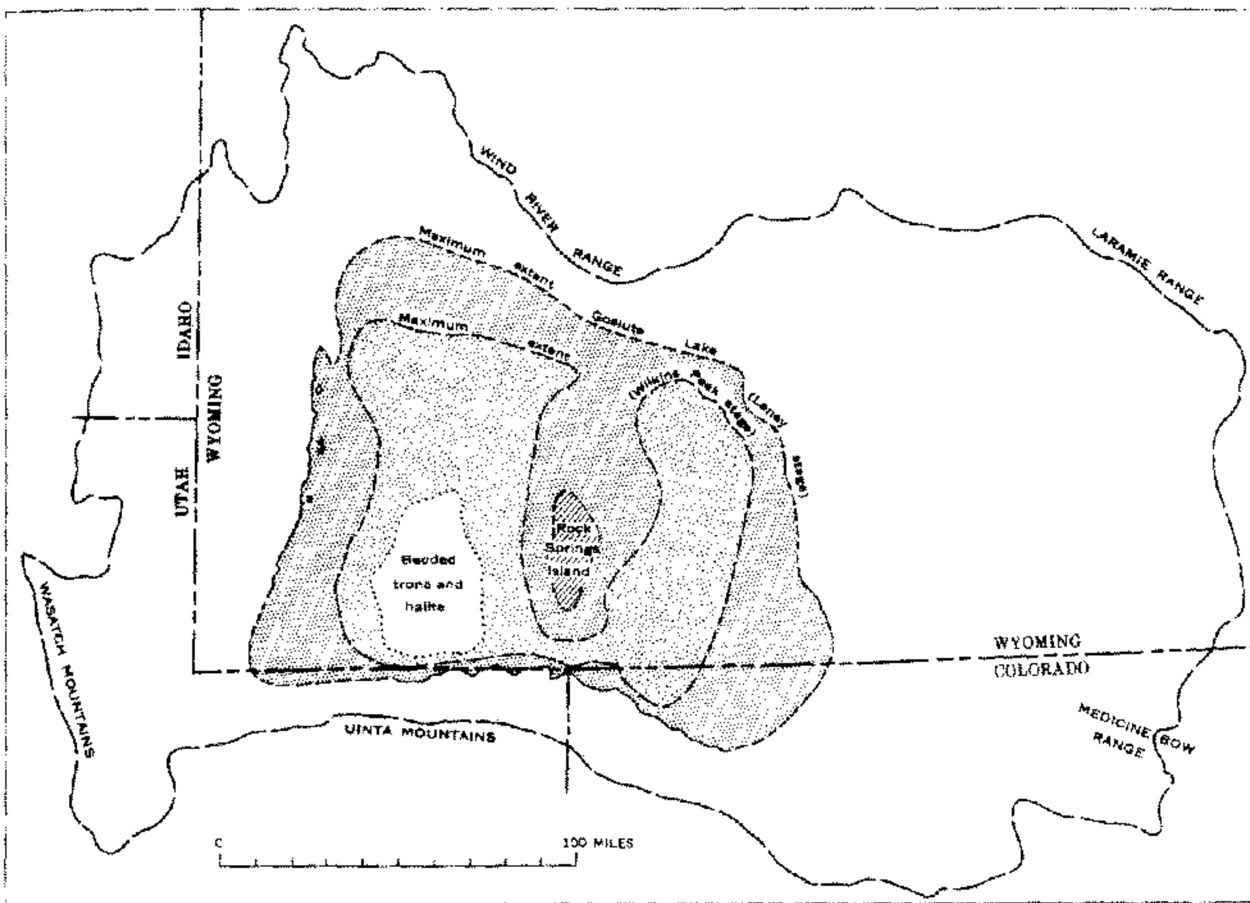

Figure 1. Inferred maximum extent of the Eocene Gosiute Lake during the Wilkins Peak and Laney stages and the inferred extent of the hydrographic basin. Shown also is the locus of bedded salt deposition in the Green River Basin and the large island made by the Upper Cretaceous rocks of the Rock Springs uplift.

At the end of the Tipton stage the climate became considerably more arid and Gosiute Lake shrank to about two thirds, or less, of its former area. It then occupied only a part of the Green River Basin, and an area south and east of the Rock Springs uplift. It had no outlet, and became, at times, very saline. During this stage, which also lasted about a million years, the Wilkins Peak Member formed. As all closed lakes do, Gosiute Lake fluctuated frequently in area and depth. It ranged from a probable maximum area of 8,000 mi^2 to a minimum of perhaps half that.

When the arid climate, which had produced the Wilkins Peak stage, reverted to a moister climate, Gosiute Lake expanded to its maximum size of about 15,500 mi^2, and again became a fresh water lake with an outlet. Even at this stage, however, it probably lost much more of its water by evaporation than by overflow. This most extensive stage of Gosiute Lake lasted the longest -- roughly 2 million years -- and during this stage the Laney Shale Member of the Green River Formation was deposited. The upper part of the Laney Shale Member contains much volcanic ash, and it may well be that these repeated influxes of volcanic ash filled the basin faster than downwarp could accommodate them and so brought Gosiute Lake to its end, some 4 million years after it came into being.

PALEOLIMNOLOGY OF TRONA DEPOSITION

The enormous tonnage of trona and halite found in more than a score of laterally extensive beds seems to compel the conclusion that Gosiute Lake repeatedly shrank to small size and that its waters repeatedly became a brine so concentrated that first trona and then halite precipitated out on the lake bed. But the geology of the Wilkins Peak Member argues rather strongly against this concept of extreme shrinkage. With minor exceptions the beds of this member are of lacustrine origin and have far greater lateral extent than either the trona-halite beds or the somewhat more extensive beds that contain dispersed crystals, or molds, of saline minerals. Moreover, few breaks (disconformities) in the sequence of beds have been found except at the base of the 11 greenish-gray, muddy sandstone or silty mudstone marker units described by Culbertson (1961).

The geologic evidence leads me to believe, then, that Gosiute Lake remained a large lake, one whose surface area measured thousands of square miles -- possibly never less than 4,000 mi^2 -- even at its lowest levels. And yet the bedded salts formed only in a much smaller area in the southern and central part of the Green River Basin.

These facts lead me to reconstruct the following picture of Gosiute Lake at one of the times when a bed of trona was forming. Although the lake had great lateral extent west, east, and south of the Rock Springs uplift, it was probably all rather shallow and all saline. The long eastern arm, or bay, however, was probably always somewhat less saline than that part of the lake in the Green River Basin because of the two large rivers that emptied into it; one at the northeastern end, which drained the Granite Mountains (Fremont and Natrona counties, Wyoming) and the other entering the southern end in the vicinity of the present Canyon Creek (T. 12 N., R. 102 W., Sweetwater County, Wyoming). This second river evidently drained a large part of the eastern end of the Uinta Range. Furthermore, no salt crystals or salt crystal molds have yet been found in the Wilkins Peak beds that were deposited in this eastern and southern arm, though mud cracks are not uncommon.

In order to account for the localization of trona-halite beds in the southern part of the Green River Basin it is necessary to postulate one shoal, or bar, extending westerly across the central part of the Green River Basin, and another extending south or southwesterly from the south end of the Rock Springs uplift, despite the fact that we know of no certain field evidence to support this postulate. The inferred shoals must have partially isolated the southern half of the Green River Basin. No large rivers entered this lower half. I assume that the surface of this part of the lake must therefore have remained at a lower level than in the remainder of the lake. Consequently, saline water from the northern part of the lake and also from the eastern arm must have flowed continuously into this partially isolated sump. This process would inevitably have led to progressive concentration of the brine in the southern part of the Green River Basin. This mechanism permits the progressive concentration of the brine in one segment of Gosiute Lake without significantly decreasing the size of the lake. Under these conditions trona and, at times, halite would have precipitated out on the bottom just as halite and mirabilite are doing today in a partially isolated segment of Great Salt Lake, Utah (Adams, 1964).

Such a mechanism permits the deposition of really thick and extensive beds of salts because it provides for continuous concentration of brine and continuous deposition of salts. The supply is drawn from the enormous reservoir of dissolved salts in all the rest of the lake, which acts as a great generator of brine. Furthermore, such systems are so large they tend to stay in equilibrium for long intervals of time.

This mechanism for the deposition of thick salt beds is, of course, not new. Probably the classic, and most extreme, present-day example of such a hydrographic system is the Karabugaz Gulf on the east side of the Caspian Sea. The water surface of the Gulf is now some 12 feet, or more, below the level of the Caspian Sea. Great volumes of salt are precipitating in the Gulf from its concentrated brine. A much less extreme example of this system is the Mediterranean Sea, which looses more by evaporation than it receives from direct precipitation and runoff from the land. Atlantic Ocean water flows into the Mediterranean to make up the loss. As a result, the water at the eastern end of the Mediterranean is about 14 per cent more saline than is the Atlantic Ocean water.

A closer analogy with the regimen of Gosiute Lake (as I visualize it) is Great Salt Lake, Utah, in which a partially isolated bay has been created artifically by the construction of the Southern Pacific Railroad's causeway. Although this causeway has openings through it to allow free passage of water between the two parts of the lake, the flow is mostly northward into the northwestern bay (which is roughly one-third of the total area of the Lake) because that bay is not as well supplied with runoff from the land as the rest of the lake. Consequently, evaporation from the water surface tends to make its level sink, and brine from the rest of the lake flows in to make up the loss (Adams, 1964). Virtually all of Adams' article is pertinent, but the following passage (p. 1028) is especially so:

> "About 30 or more centimeters of solid salt now covers the bed of the northwest water body and the band of adjacent dry lake bed. This quantity of salt is about 10^9 metric tons. Coincidentally, the main body of the lake, which before 1959 became saturated in the summer when the surface elevation reached -30 centimeters on the gage at Saltair, now (in 1963) does not become saturated until the surface elevation reaches about -140 centimeters. These observations of change in surface elevation at which salt saturation occurs may be used in conjunction with the known salt concentration at saturation and the change in the water volume with surface elevation to calculate that about 10^9 metric tons of salt have been removed from solution in the main body of the lake. This is one-quarter of the salt formerly in solution in this body. Five summer seasons, 1959 to 1963 inclusive, have passed since the railroad embankment was completed.
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> "The part of the salt layer above the present water level is an important part of the total solid salt. It results from stranding of salt by annual lowering of lake level as well as from progressive, net lowering for several years, and from stranding of salt which has crystallized from the water brought to the otherwise dry area by wind tides."

Adams pointed out that the changed regimen of Great Salt Lake is not simple and no such system would be expected to be. Storms and wind-generated seiches in the lake cause intermittent reversals of flow. Seasonal changes in the distribution of runoff and in rates of evaporation from the two parts of the lake also change the balance so as to cause occasional flow of brine southward into the main body of the lake. The net effect, however, in Great Salt Lake is decisive and results in the deposition of bedded salt on the bottom and at the margins of this partially isolated arm of the lake. It is this hydrographic mechanism which I visualize as the major factor to account for the bedded trona and halite in the Wilkins Peak Member.

This hydrographic system accords with the observed characteristics of the trona-halite beds in the Wilkins Peak Member. Nearly all the salt beds have partings of dolomitic marlstone or more or less rich oil shale whose upper and lower boundaries are sharp. These partings evidently began to be deposited as soon as the lake level rose above the shoals or bars and permitted a free interchange of water throughout the lake. During these rises of lake level the lake water must have become considerably less saline because a strongly concentrated brine could not have held and distributed over the whole lake enough calcium in solution to account for the dolomitic marlstone and mudstone, and the carbonate-rich oil shale partings found in the trona-halite beds. Moreover, less saline water is necessary to account for the large production of microorganisms needed to account for the organic matter in the partings, and especially in the oil shale partings.

Just as relatively high level stages of the lake produced the series of dolomitic marlstone and mudstone beds and beds of oil shale that make partings in the salt beds, so also prolonged high-level stages account for those beds that lie between the trona-halite beds and that extend laterally far beyond the limits of the saline facies of the Wilkins Peak Member. These relatively high-lake level stages represent, I believe, intervals when the climate was somewhat less arid than it was when the lake level was low and the beds of trona and halite were deposited.

In the hydrography postulated, it would be expected that the lake, at its relatively higher stages, would have been chemically stratified -- the brine forming the deeper body of water and the fresher body of water floating on the more saline water.

These relatively higher stages of lake meant interruptions in deposition of salt but, more importantly, they meant long intervals of time while the lake (still with no outlet) was continuously accumulating more salt -- a great reserve of salt ready to be drawn on at the next low stage when the next bed of trona would be precipitated.

The significance of this can be appreciated when we consider that the beds of trona, or trona and halite, may have accumulated at a rate of one foot in somewhere between 5 and 150 years, whereas 1 foot of the material in the partings or the beds between the salt beds, required 1,500 to 3,000 years to accumulate.

At the other extreme, we can imagine that, at times, the lake level fell so low that the southern basin of the Green River Basin was almost cut off from the rest of the lake. At these stages halite as well as trona precipitated. But even at such extremely low stages we can be sure that the brine never went down to dryness, or near dryness, because none of the bedded salts contain the very soluble K and Mg chlorides and sulfates, or other soluble complex double salts found in evaporites.

I believe that Gosiute Lake was shallow all during the Wilkins Peak epoch. In the brine sump where the trona and trona-halite beds precipitated the brine might have had a depth of 20 to 50 feet. Even at the lowest stages Gosiute Lake's probably was of the order of 4,000 mi^2.

Rather late in the Wilkins Peak stage the locus of trona deposition shifted northward. This shift took place in time to extend the trona bed now being mined at Westvaco much farther north than any of the underlying beds. The still younger trona beds have their centers offset progressively farther north. I infer that the hydrography of Gosiute Lake did not change significantly, only the geographic position of the partially isolated basin where the brines were concentrated and where the salt beds were deposited. This northward shift in the locus of trona deposition was discovered by D.L. Deardorff of the Diamond Alkali Company, who has contributed so much to our understanding of the history of the saline deposits in the Wilkins Peak Member (Deardorff, 1963, pp. 176-195).

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