

Paleoecology of fossil diatoms (the thermometers of salinity) of lake Bonneville, Utah U. S. A.

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Kolbe (1927) described diatoms as indicators of salinity hence the fossil diatoms can yield paleoecological information of considerable importance to the geologist regarding the environment in which their enclosing sediments were deposited.

The progressive increase in salt content of the former fresh water Lake Bonneville to slightly saline to highly saline and to the extremely saline conditions of the present day Great Salt Lake is revealed by the different types of fossil diatoms that are characteristic of different saline conditions found as diatomite deposit at various terraces of the lake.

The diatom assemblages differentiated into their respective habitats show that *Cyclotella meneghiniana*, *Epithemia hyndmanii*, *Cymbella tumida*, and *Surirelia ovalis* are characteristic of Bonneville and Alpine sediments at 5,130-4,340 ft levels (in oligohalobien or freshwater condition); *Surirelia regina*, *Navicula formosa*, *Cambylodus Sicostata*, *Amphora Kyaliana*, *Synedra pulchello*, *Nitzschia clausii* and *Denticula valida* are characteristic of Provo sediments at 4,840-4,800 ft levels (in mesohalobien or brackish water), and *Navicula peregrina*, *N. impressa*, and *Nitzschia scutellum* are characteristic of Stansbury level (in euhalobien waters). This euhalobien condition is, similar to marine water conditions. As the water level of the lake fell further slowly, thus increasing its salinity, the diatom population decreased very sharply and finally disappeared. At 4,194 feet the Lake Bonneville is only a remnant and is presently the Great Salt Lake of Utah, having a salinity of 276‰. It is estimated that the saline content changed at the rate of 1‰ per foot in stages, which is due to variation in the balance between precipitation and inflow and evaporation and outflow.

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A large body of fresh water of Pleistocene time known as Lake Bonneville in Utah was approximately equal to that of Lake Michigan. It originally covered an area of 19,750 sq miles, stood at a maximum elevation of 5,200 feet above the sea level, having an approximate maximum depth of 1,050 feet (Gilbert, 1890). It enclosed more than half of Utah State and one of its embayments even extended into the neighbouring State of Nevada. It was fed by three fresh water rivers, viz., the Jordan, the Weber, and the Bear. As the lake had no outlet, as a result of high rate of evaporation and closing of its drainage system, the Lake Bonneville gradually became saltire and stood at several levels forming terraces. Today, it is occupying a very small area and is known as the Great Salt Lake. A number of major and minor terraces formed are very prominently seen in western Utah which are part erosional and in part depositional and represent fairly a constant elevation of the lake which stood for a considerable time and thus attests to the existence of the lake. Three of these

terraces namely, (1) the Bonneville, at 5,135 feet (Bissell, 1963, P 107); (2) the Provo, at 4,820 feet (Jones & Marsell, 1955, P 97); and (3) the Stansbury, at about 4,500 feet (Gilbert, 1890, p. 134-135; Bissel, 1963, p. 122) are very prominent. Another prominent beach marked a stillstand of the lake, has been called as the Gilbert shore line (Eardley *et al*, 1975 p. 1169). The intermediate terraces of Bonneville and Provo are referred to as the Alpine terraces which are believed to have been marked by a lake earlier than the Lake Bonneville (Hunt *et al*, 1953, p. 17). The Alpine sediments include those of Bonneville, the Alpine and partly the Provo 1 and partly the Provo 2 stages (Jones & Marsell 1955, p. 103; Eardley *et al*. 1957, p. 1167). These terraces and a number of other minor terraces at all levels are characterised by sedimentary deposits. The age of Bonneville lake deposits is correlated with the Wisconsin Glacial epoch of the Pleistocene period (Hasler & Crawford, 1938). The age of Stansbury deposit is estimated as to be 23,000 to 13,500 years (Schreiber, 1958)

The Lake Bonneville was a fresh water lake, while the present day remnant of it, the Great Salt Lake, showed a salt content of 276‰ when it stayed at 4,194 feet and it is estimated that the saline content changed at the rate of 1‰ per foot in stage (Eardley, 1938, p. 1319). This concentration is considered to be due to a variation in the balance between precipitation and inflow, and evaporation and outflow.

Among the sedimentaries found at various levels or terraces of the Lake Bonneville, pockets of diatomaceous earth or diatomate are found as white clayey outcrops in the protected regions of the mountains and other former islands. Wimber and Crawford (1933) reported the occurrence of flat-lying diatomite deposits of nearly 40 feet thick along the western shores of the Great Salt Lake. These outcrops are patchy and occur as mounds composed of several layers of elastic sediment and white fluffy and soft diatomaceous material.

A total of 126 species of diatoms are identified from the samples collected at various terraces. Many of these diatoms have their living representatives today, while some others are found to be reworked from the Pliocene and probably earlier? Tertiary deposits. In the present paper the varying phases of salinity indicated by diatom assemblages as 'thermometers of salinity' of Lake Bonneville are presented (Chart 1).

SALINITY, WATER AND CLASSIFICATION

Unless otherwise stated the salinity of a water body is normally considered as marine when its salt content is between 30-40‰; as fresh water when it is less than 5‰; as brackish water when it is between 5 to 30‰; as hypersaline water when it is between

40-80‰. The range of salinity between 5‰ to 10‰ is considered as Stenohaline or Stenosaline waters, while the range between 10 to 30‰ is termed as Euryhaline or Eury-saline waters (Kinne, 1964). The author feels at this juncture, that it would be convenient to divide euryhaline waters of Kinne (1964), as mesohaline or mesosaline waters when the range is between 10-20‰, and euryhaline or eury-saline waters referred to when the range is 20-30‰, instead of treating the entire 10-20‰ range euryhaline or eury-saline waters.

The distribution of diatom populations in various environments and in different regimes shows, that the salinity influence cannot be underestimated. The progressive increase in salt content of the former fresh water body, the Lake Bonneville, to slightly saline to more saline and later to highly saline conditions of the present day Great Salt Lake is revealed by the application of the halobitic system of diatoms that are characteristic of different saline conditions. Thus the fossil diatoms can yield valuable paleoecological information to the geologist regarding the environment of deposition.

According to Kolbe (1927) the diatoms are indicative of salinity of water than any other organic group and through specific types of diatoms a qualitative determination of the salt content in it can be made. Kolbe's system of salinity regime was revised by Buddé (1931, 1933) and later by Hustedt (1953, 1957).

Kinne (1971) pointed out several major differences in the classifications of halobitic systems of diatoms as proposed by Budde and Hustedt (l. c.) Hence, this author preferred to follow Kolbe's classification with minor modifications, which is as follows :

Chart 1 : Classification of water based on salinity and critical diatom indices

| | |
|------------------------|---|
| 1. Euhalobien (Marine) | 30‰ to 40‰ of salt content |
| Euhalob euryhaline | Completely marine but never brackish, e. g. <i>Corathron</i> . |
| Euhalob stenohaline | Chiefly marine but does occur in brackish water though weakly developed. e. g. <i>Achnanthisidium brevipes</i> f. typ. |
| 2. Mesohalobien | (brackish)-5‰ to 20‰ of salt content |
| Mesohalob euryhaline | Chiefly brackish water but occasionally in less saline water but never in fresh water, e. g. <i>Achnanthisidium brevipes</i> var. <i>interrupta</i> . |
| Mesohalob mesohaline | Chiefly brackish water but also in somewhat more saline waters, e. g. <i>Navicula salinarum</i> , <i>Diploesis interrupta</i> . |
| | Chiefly brackish but also found in fresh water, e. g. <i>Bacillarium paradoxa</i> . |

| | |
|------------------|--|
| 3. Oligohalobien | (fresh water) 5‰ and less of salt content. |
| Halophil | (euhaline fresh water) definite salt dosages stimulate the growth, e. g. <i>Cyclotella meneghiniana</i> , <i>Navicula hungarica</i> , <i>Diatoma elongatum</i> . |
| Indifferent | (mesohaline fresh water) usually termed fresh water but many take a little salt too—(Limnophil), e. g. <i>Cymbella</i> sp., <i>Cyclotella</i> sp., <i>Gomphonema</i> sp., <i>Tetracyolus</i> sp. |
| Halophobe | (Stenohaline fresh water) totally fresh water, not even minute quantities of salt tolerated, (Sphagnophil) e. g. <i>Enotia stenoptorobia</i> certain <i>Pinnularia</i> sp. (Common in Peat bogs and mountain lakes). |

DISCUSSION AND PALEOECOLOGY

Though these major divisions are made, considerable caution is necessary in interpreting the ecological conditions. Boundaries between division of the water bodies are vague because they are susceptible to rapid variations in salinity by factors like currents, inflow and dilution, suspended matter and turbidity, settling debris and organic matter and other factors. Broad inferences drawn from the available data should, therefore, be taken with caution. However, the value of diatoms as thermometers of salinity is undisputed.

The diatom assemblages of the diatomite collected were differentiated in to their respective habitats and their planktonic/benthonic ratios were determined. An analysis of this data revealed that the appearance and the degree of abundance of certain species will reflect the salinity conditions of the water at those strand lines

1. *At 5,135 to 5,050 foot levels*—This level is marked by the Bonneville and Alpine sediments. The water at 5,135 and 5,050 foot levels was fresh or Oligohalobien (oligohalob-in different) in condition. This is indicated by the presence of species like *Cyclotella meneghiniana*, *Epithemia hyndmanii*, *Cymbella tumida*, *Surirella ovalis*, and *Surirella elegans*.

2. *At 4,840 foot level*—The water at this elevation is considered still fresh (oligohalob-Indifferent) However, it seemed to tend slowly to oligohalob-halophile to mesohalobien condition as seen by an increase in species like *Melosira varians*, *Rhoicosphenia curvata*, *Cymbella aspera*, *Surirella ovalis* var. *ovalis*, *Cymatopleura solea* and others. Some of the mesohalobien and even the euhalobien forms which occur in this assemblage (Chart 2-3; Table 1) are fragmentary and hence should be considered as displaced fauna and partly those of Provo (1 and/or 2) sediments.

3. *At 4,830 foot level*—The above species continue to exist here but they are supplemented by the introduction of halophile to mesohalob-mesohaline types like *Navicula formosa*, *Surirella regina*, *Campyiodiscus bicostatus* and others. The presence of the oligohalob-indifferent species in the assemblage indicates that they were either relict or appeared when the lake became fresh again. The excellent state of preservation and the high ratio of benthonic over the planktonic species indicates quite water and nearshore deposition. The presence of estuarine species like *Synedra ulna* suggests that the lake must have been fed by fresh water streams nearby.

4. *At 4,820 foot level (Provo Strandline)*—At this level an increase of mesohalob-mesohaline species like *Synedra lancesolata*, *Synedra pulchella*, *Epithemia argus* var. *alpestris*, *Amphora hyalina*, *Navicula smchii*, *Surirella striatula* and others are noticed. It further indicates a quiet shallow water condition. Bissel (personal communication, 1962) stated that of diatoms collected by him and Lohman (USGS diatom locality No. 3304 and Bissel coll. no. 311a) from the silt member of Provo formation of Goshen Valley east of Tintic mountains. some of the dominant species indicate estuarine conditions and some of them are living today in the Pyramid Lake of Nevada.

5. *At 4,800 foot level*—At this level the mesohalob-mesohaline species continue to flourish and *Nitzschia clausii*, *Denticula valida* and *Amphora pellucida* predominate.

The lithology and poor preservation and fragmentary nature of diatoms here indicate agitated waters; the presence of some oligohalob forms suggests displaced and/or reworked material and presence of concretions of diatomite indicates current transportation, and lastly the presence of large amounts of pollen and spores suggests dystrophic waters in a near-shores environment.

TABLE 1
Distribution of Halobtic system of diatoms at various elevation.

| Elevation & Strandlines | OLIGOHALOBIEN | | MESOHALOBIEN | | EUALOBIEN | | ESTUARINE | | PLANKTONIC | | BENTHONIC | | |
|-------------------------|-------------------|----------|--------------|------------|--------------|------------|-----------|---|------------|---------|-----------|---------|----|
| | Indifferent (F-W) | Halophil | Meso-haline | Euryhaline | Steno-haline | Euryhaline | — | — | Vagrant | Sessile | Vagrant | Sessile | |
| 5135 to 4840 ft.] | 7 | 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 4 | 7 |
| 4+30 ft. | 10 | 6 | 4 | 2 | — | 1 | 1 | 1 | 4 | 4 | 8 | 4 | 7 |
| 4820 ft. | 6 | 1 | 1 | 1 | 2 | 2 | — | — | 4 | 2 | 6 | 2 | 5. |
| (Provo Strandline) | | | | | | | | | | | | | |
| 4840 ft. | 8 | 6 | 2 | 1 | 2 | 2 | 1 | 1 | 3 | 8 | 8 | 5 | 4 |
| 4780 ft. | 10 | 7 | 1 | 4 | 4 | 3 | — | — | 6 | 10 | 10 | 7 | 7 |
| 4765 ft. | 8 | 4 | 1 | 2 | 2 | 2 | — | — | 1 | 6 | 6 | 7 | 5 |
| 4600 ft. | 8 | 11 | 2 | 3 | 5 | 3 | — | — | 6 | 6 | 6 | 9 | 11 |
| 4500 ft. | 7 | 11 | 4 | — | 6 | 2 | — | — | 4 | 10 | 10 | 8 | 9 |
| (Stausbury Strandline) | | | | | | | | | | | | | |

6. At 784,0 foot level—Though mesohalob-mesohaline species continue to occur, the first appearance of mesohalob-euryhaline forms like *Coscinodiscus velatus*, *Fragilaria pacifica*, *Navicula mormanorum*, *Surirella angusta* and *Denticula lauta* strengthen the belief that the salinity of the lake water has increased considerably.

The lithological analysis revealed large grains of salt being present in coarse clastic sediment with fragmented, poorly preserved diatoms. This indicates a high energy and nearshore condition.

However, in quiet water and undisturbed conditions, species like *Surirella ovalis* var. *ovata*, *Navicula mormanorum*, *Cocconeis lineata* are well developed and well preserved with planktonic species of *Melosira*, *Cyclotella* and *Coscinodiscus*. The presence of oligohalobien forms suggests mixing of fresh water through streams and/or reworking.

7. At 4,600 foot level—There is a marked increase in number and kind of mesohalob to nearly euhalobien forms over all others as seen by the presence of *Coscinodiscus elegans*, *Fragilaria pacifica*, *Navicula bombus*, *Nitzschia thermalis*, *Denticula valida*, *Surirella striatula* and others.

8. At 4,500 foot level (Stausbury Strandline)—As the water level fell 100 feet below the 4,600 foot level, it became more concentrated in salt than it was before. This is clearly indicated by an increase in mesohalob-euryhaline and euhalobien forms like *Navicula peregrina*, *N. impressa*, *Nitzschia scutellum* and others. The presence of any oligohalob species in this assemblage (Table 1) is clearly due to an influx through streams or reworked wind-blown material.

As the water level of the lake fell further slowly, thus increasing its salinity, the population decreased sharply, and finally disappeared. No diatom flora is found to be living in the present lake today. However, living forms of diatoms reported from this lake have been found in the surrounding brackish marshes and rivers which have a lower salt concentration.

As a result of this investigation, it is very clear that diatoms indicate various milieus of salinity (as thermometers of salinity) of a lake which was fresh water to begin with and as it shrank due to evaporation and other causes slowly got enriched in salinity and this change is recorded by the diatoms at its various terrace levels. So, it is logical to conclude that the lake Bonneville was

oligohalob indifferent (fresh water) from 5,200-4,840 foot level; it had halophil condition at 4,830 foot level; it became mesohalob-mesohaline at 4,820 foot level; it remained mesohalobien (brackish water) upto 4,800 foot level; it became mesohalob-euryhaline at 4,780 foot level; but it became definitely euhalobien when it reached the 4,500 foot level. Patrick (1936), contends that true marine forms seem never to have established themselves in the lake. Earlier, according to Patrick (1936), Ehrenberg (1870) also mentioned of the rarity of marine forms in the lake.

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