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# GEOLOGY OF UTAH LAKE: IMPLICATIONS FOR RESOURCE MANAGEMENT

Willis H. Brimhall<sup>1</sup> and Lavere B. Merritt<sup>2</sup>

**ABSTRACT.**— Utah Lake is a remnant of Lake Bonneville, from which it originated about 8,000 years ago. Analysis of sediment cores reveals significant variations in lake salinity and sedimentation rates. Notable examples are a very dry, high-salinity period between 5000 and 6000 years ago; a major freshening, wet period between 2700 and 3000 years ago; and a very dry, high-salinity period between 1400 and 2600 years ago. Smaller variations are interspersed through the lake's history.

Long-term sedimentation rates are estimated at about 1 mm (0.039 in) per year in most of the lake, but post-colonization rates appear to be about 2 mm (0.079 in) per year. Faults in the lake appear to be lowering the lake bottom at about the same rate as sediment has been filling it. Bottom sediments consist of about 60 to 80 percent calcite in the lake proper, much of which precipitates from the lake water itself.

The lake-bed faults are similar in character to those of the Wasatch Fault that bound the valley and mountains a few miles to the east. Lake bottom springs and seeps are localized, in the most part, along the eastern and northern lake margins where all major tributaries occur and groundwater recharge is largest. Only limited spring activity appears to be associated with the faults.

In a geological sense, Utah is an old lake—shallow, turbid, and slightly saline—and has been since its “birth” with the demise of Lake Bonneville approximately 8,000 years ago.

## GEOLOGIC HISTORY AND SETTING OF UTAH LAKE

Utah Valley, of which Utah Lake occupies more than one-fourth, lies near the junction of three of the great physiographic provinces of North America. To the west stretches the Great Basin, a vast expanse of arid intermontane valleys extending from the Wasatch Mountains to the Sierra Nevadas. To the east lies the western portion of the Rocky Mountains, expressed in central Utah by the high peaks of the Wasatch Mountains rising above the Wasatch Fault, one of the largest of the fractures of the earth's crust in North America. Not far away to the southeast is the colorful Colorado Plateau Province. The rich and varied physiographic setting of the valley and its lake suggests that they are heirs of a rich and varied natural history, the principal part of which, for present purposes, is that associated with the past 30,000 years.

Utah Valley and its companions in the Great Basin were born in the aftermath of convulsions that seized the crust in central Utah some 70 million years ago as North

America moved westward and collided with the lithosphere of the western Pacific Ocean. Huge sheets of sedimentary rock, crumpled in paroxysm, formed the ancestral Rocky Mountains of the region. Later, some 30 million years ago, the crumpled rocks began to be blocked into intermontane valleys by high-angle faults, one of the most famous of which is the Wasatch Fault that bounds Utah Valley on the east (Fig. 1). Recurrent movements on these faults continue to the present time, and thus maintain the intermontane basins in spite of erosion and infilling of sediments from the highlands.

The high-angle faults are the principal structures contributing to the intermontane physiography. Rock waste eroded from the rising mountains has been transported downward and deposited in the valleys. Probably sediment as thick as several thousand feet occupies the central portions of Utah Valley (Cook and Berg 1961); similar thicknesses of rock have been worn away from the ever-rising mountains. A dynamic equilibrium seems to have been maintained for some 30 million years between the uplifting of the

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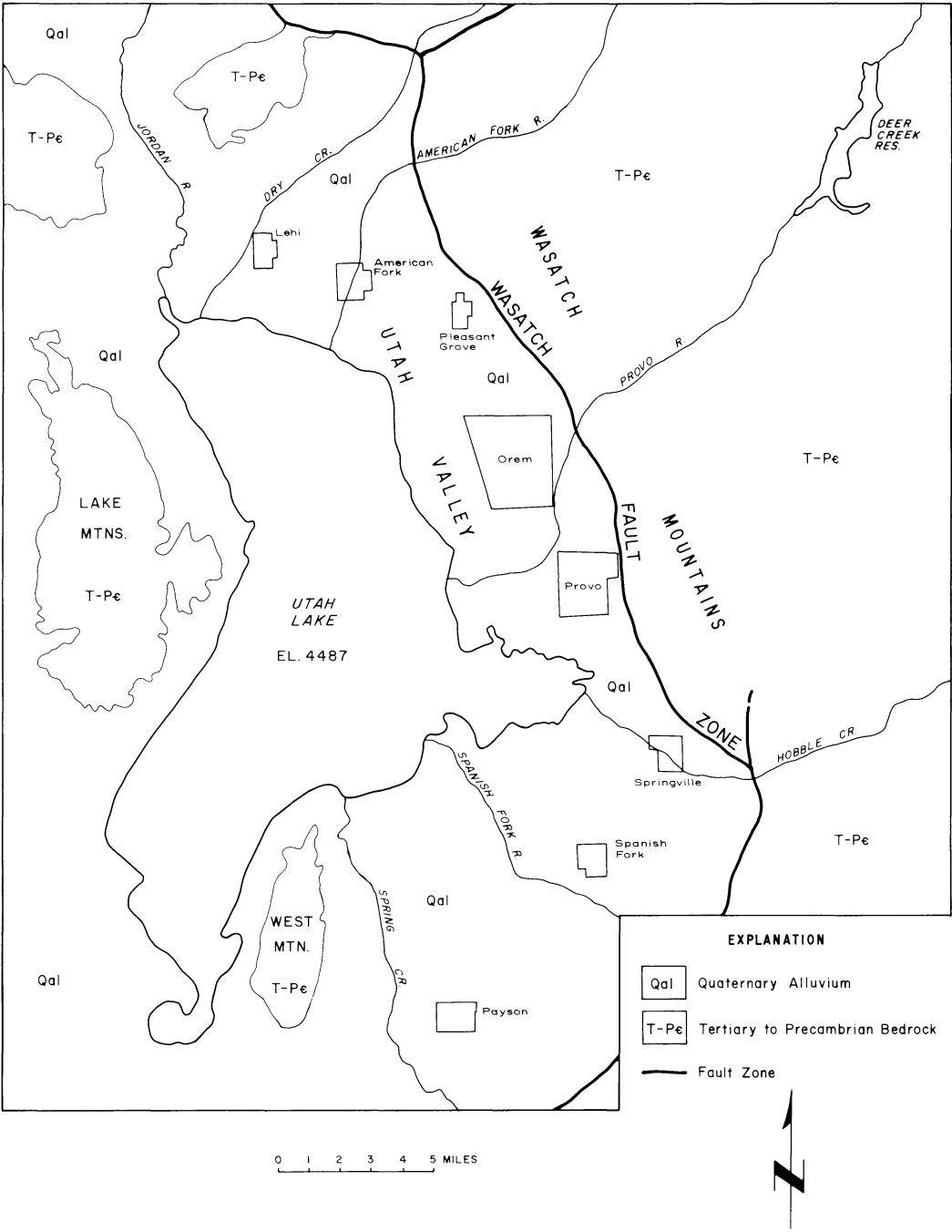


Fig. 1. A simplified geologic map of Utah Valley that shows the relationship of Utah Lake to its valley. The floor of the valley west of the Wasatch Fault is composed almost entirely of Quaternary Alluvium. The mountains east and west of Utah Lake are composed of bedrock ranging from Tertiary to Precambrian age. The Wasatch Fault marks the boundary between the two domains (modified from Stokes 1962).

mountains and the downdropping of the valley on the one hand, and of erosion and infilling on the other.

Lake Bonneville (Fig. 2), the ancestor of Utah Lake and the Great Salt Lake, occupied the intermontane basins to a greater or lesser

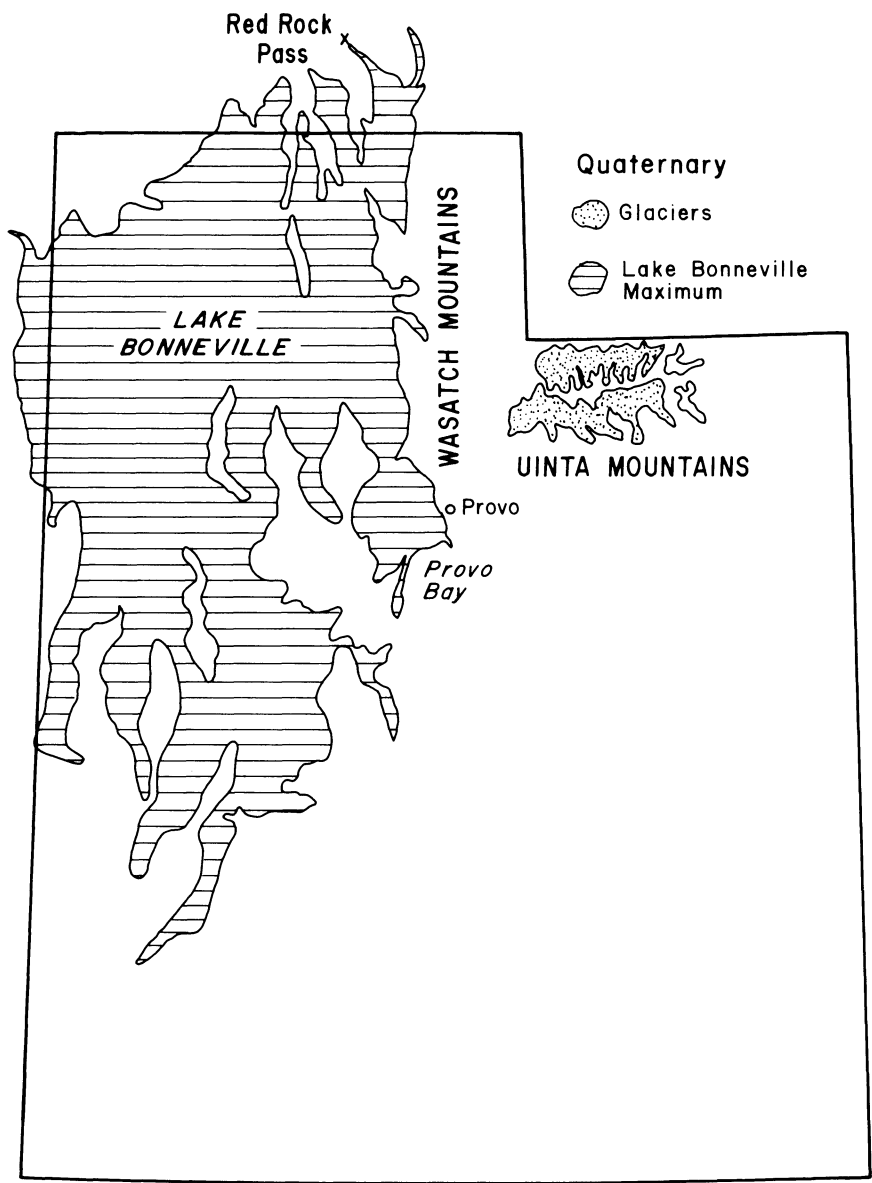


Fig. 2. The distribution of Lake Bonneville at its maximum size (adapted from Bissell 1968).

extent from about 75,000 years ago to about 8,000 years ago (Gilbert 1889, Bissell 1968). Lake Bonneville coincided in time with the Wisconsin stage of the Pleistocene Epoch; that is, with the last stage of the Great Ice Age that has so profoundly affected planet earth during the past one million years or so.

The size and depth of Lake Bonneville is recorded in the layers of sediments accumu-

lated on its margins and floor. The lake was largest during times of cool, wet climates, smallest in times of warm, dry climates (Bissell 1968). The level and extent of the lake fluctuated through three principal levels, designated the Alpine, Bonneville, and Provo substages (Fig. 3). At its highest level, some 30,000 years ago, Lake Bonneville spilled over into the Snake River drainage at Red

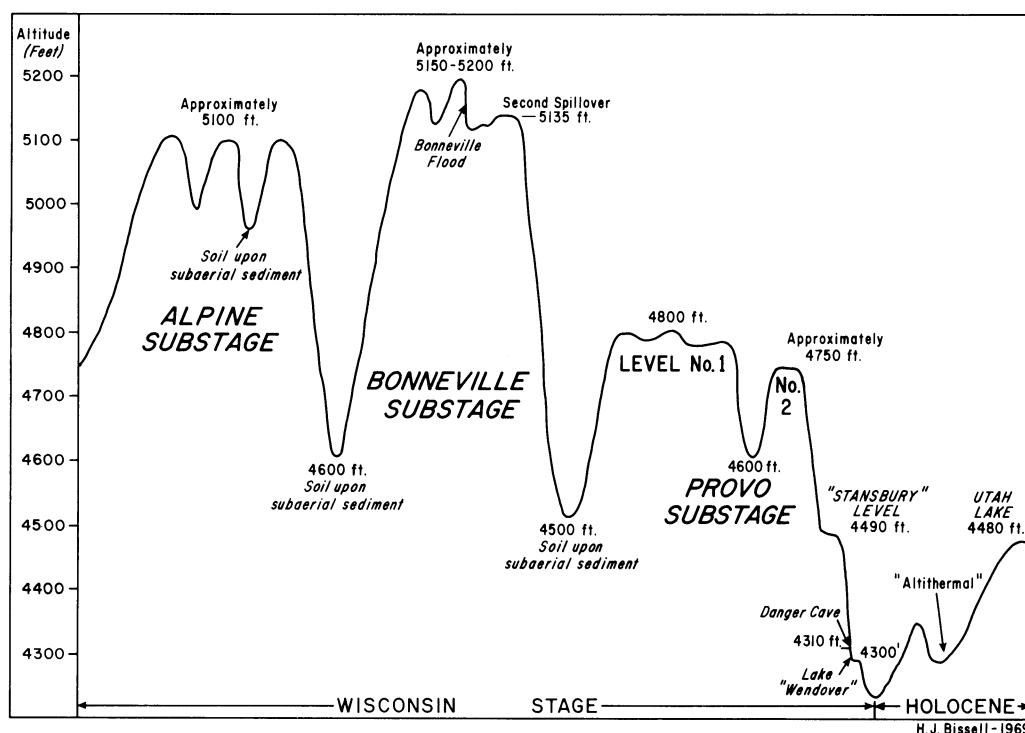


Fig. 3. Elevations associated with the principal substages and lesser fluctuations of Lake Bonneville. Lake Bonneville dried up and passed from existence at the end of the Wisconsin Stage, some 10,000 years ago. Utah Lake originated in the aftermath of Bonneville's passing and is associated with the Holocene Epoch, 10,000 years ago to the present (adapted from Bissell 1968).

Rock Pass near Preston, Idaho (Fig. 2), and quickly dropped from about 1585 m (5200 ft) above sea level to about 1463 m (4800 ft), where the lake stabilized at the Provo substage, with fluctuations, until about 8,000 years ago.

The relatively long period of Lake Bonneville's stability at the Provo substage led to the formation of some prominent benchlands, such as those at Orem, Mapleton, and Spanish Fork. These alluvial benchlands, formed where the rushing rivers met the lake, are among the most striking topographic features of Utah Valley.

The climates of North America generally became warmer and drier at the end of the Pleistocene (Great Ice Age) Epoch some 10,000 to 12,000 years ago. Ice sheets formerly occupying much of the northern por-

tions of the continent began to retreat. In the Great Basin, Lake Bonneville passed from existence, and in the aftermath the Great Salt Lake and Utah Lake were formed.

Utah Lake, born and orphaned of Lake Bonneville, records its nearly 10,000 years of history in its sediments. Hansen (1934) was first to recognize that variations of sand, silt, clay, and plant remains, including wood, exposed in a test pit northwest of the mouth of Provo River, associate with strong changes of the level of the lake and of changes of climate in the region during the past few hundred to thousands of years. Hansen did not assign ages to the variations; the carbon 14 dating method was not available at the time.

Bolland (1974) collected a core sample, 500 cm (197 in) deep, at a point about 2.5 km (1.6 miles) west of Geneva in the late summer

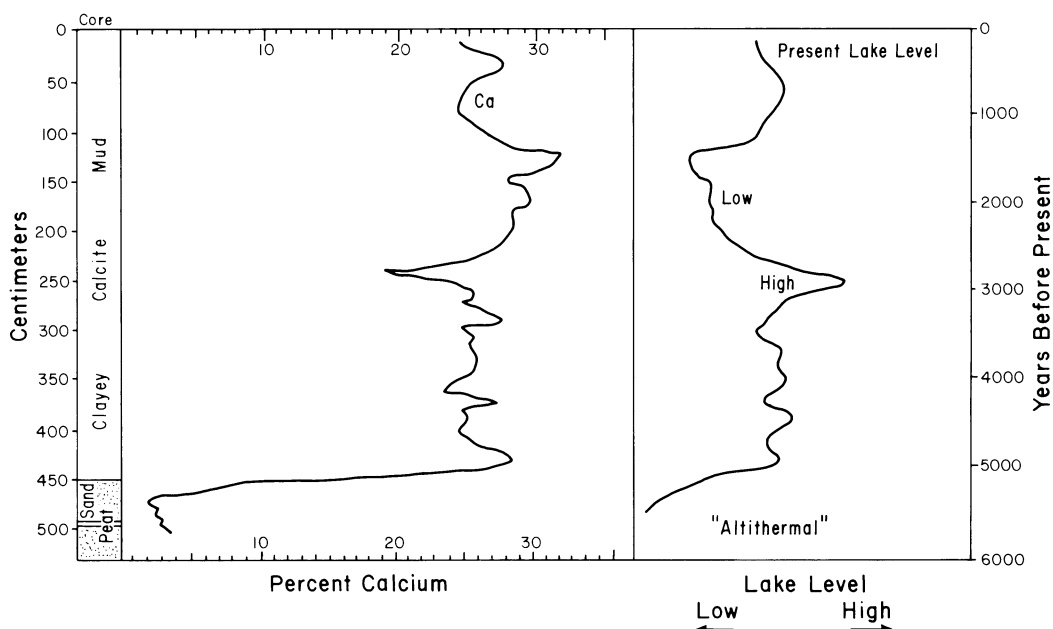


Fig. 4. Characteristics of a core sample of Utah Lake sediments collected approximately 2.5 km west of Geneva. High concentrations of calcium (calcite) are believed to associate with low levels of the lake as compared to recent levels. The sand and peat layers below 450 cm are believed to correlate with the altithermal, a time of extreme aridity described by Antevs (1948) (adapted from Brimhall 1973).

of 1970, to study the presettlement history of Utah Lake by means of sediment changes and variations in fossil diatoms. The core (Fig. 4) consisted of nearly uniform gray silt to a depth of 450 cm (175 in). Below that depth, to 510 cm (201 in), the core consisted of fine quartz sand with a small layer of peat at 490 cm (193 in). The change from silt to sand and to peat clearly indicates that at some time in the distant past, Utah Lake was much lower and smaller than at present, since the sand and peat must associate with an ancient shoreline that persisted over a considerable period of time. Bolland submitted a sample of the peat, weighing 1.8 grams (0.004 lb.), to Radiocarbon Ltd., Spring Valley, New York, for dating. The result was  $11,400 \pm 800$  years.

Brimhall (1973) performed a chemical analysis of the major constituents of the core and assigned some time lines based on apparent inputs of iron from the steel plant, phosphorous from sewage, and other criteria, but evidence obtained during the summer of 1975 (Brimhall, Bassett, and Merritt 1976)

make these data appear to be in error. We believe that the  $11,400 \pm 800$ -year-old dating of the peat layer is at least twice too large. Contamination of the sample with small amounts of detrital calcite could cause the result to be too high.

Based on data from the latter study, and reassignment of time lines in the core, it is presently believed that the sand layer at the bottom of the core correlates with a very dry period recognized in the Great Basin some 4,000 years ago (Antevs 1948). The beginnings of Utah Lake are believed to associate with sediments about 4 m deeper than the bottom of the core sample, as shown in the acoustical profile (Fig. 5). If this assignment is correct, as we believe, then approximately 8.5 m (28 feet) of sediment have accumulated since the beginning of Utah Lake. The average rate of accumulation of sediment is approximately 8.5 m (28 ft) in 10,000 years, or 0.00085 m (0.033 in) per year. Some questions still remain, however, as to the lake's sedimentation rate, and this value should still be regarded as tentative.



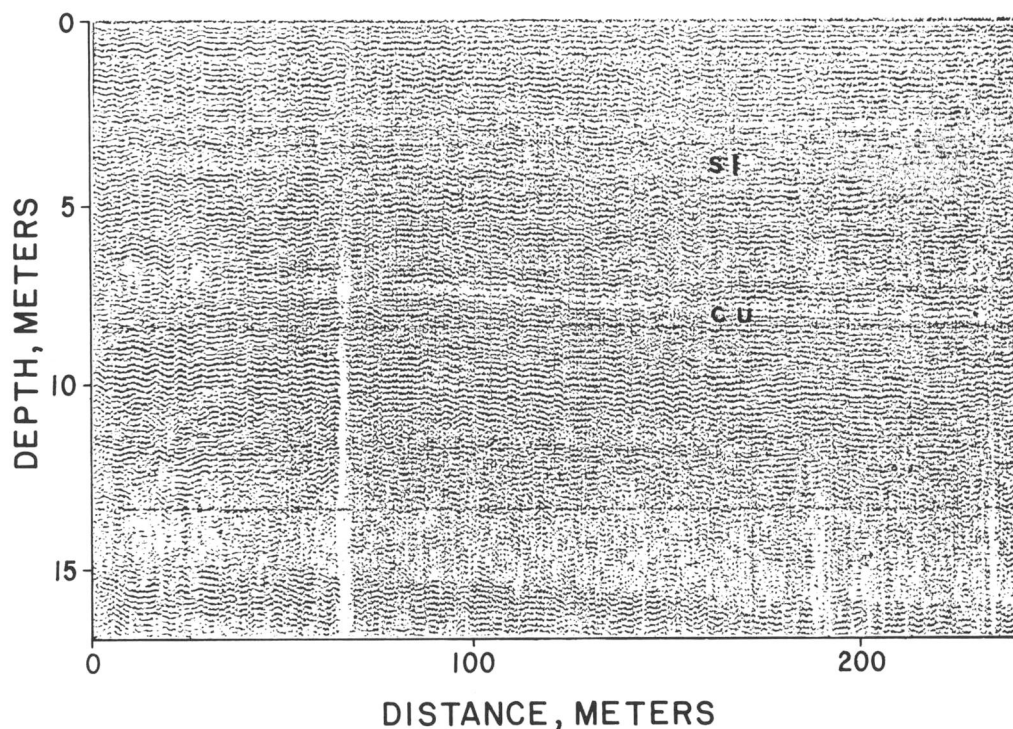


Fig. 5. Acoustical profile of sediments in the vicinity of the sample collected and analyzed by Bolland (1974) and Brimhall (1973). The reflection at about 4 m is believed to correlate with the sandy layer (sl) described by the above workers, and the second, stronger reflection at about 8.8 m is believed to correlate with the clay unit (cu) of the Provo Formation, deposited in the waning stages of Lake Bonneville.

Assuming a linear rate of deposition, the sand layer with its contained peat was deposited from 5300 to 6000 years ago during a long, dry period called the "altithermal" by Antevs (1948).

Variations of the calcium content of the cores between 18 and 32 percent (Fig. 4) are believed to associate with fluctuations of lake level caused by short-term wet and dry cycles of several years' duration, not as long as those associated with the sandy and peat layers. Rises in calcium content associate with decreased inflow during dry periods and contained large evaporation loss from the lake surface. An increased concentration of salts in the lake, including calcium and carbonate, and subsequent increased precipitation of calcite (calcium carbonate) occurs. Under natural conditions, lake level could vary at least 2 m (7 ft) since the flow rate in the outflowing Jordan River is a function of lake level. The lake level is a function of inflow, outflow, and evaporation over time.

Inspection of the calcium profile (Fig. 4) reveals some pronounced variations of concentration in the upper half of the core. Unusually high concentrations occur between 120 and 220 cm (47 and 87 in), and unusually low concentrations are present between 230 and 250 cm (90 and 98 in). Assuming that the high concentrations correlate with low lake level and size, and the low concentrations with high lake level and size, and assuming an average sedimentation rate of 0.85 mm/yr (0.033 in/yr), then the lake was small and shallow between 1400 and 2600 years ago, and larger and deeper between 2700 and 3000 years ago.

The profile also reveals that the level of the lake has fluctuated to a lesser extent than the above extremes during the past 1000 years. The sharp peak at about 25 cm (9.8 in) is believed to associate with a very dry period in the southwestern U.S. some years ago, based on tree ring data (Schulman 1956). It should be noted, however, that the upper 10

cm (3.9 inches) of the core sample was imperfectly obtained since the sediment-water interface was not sharply defined.

Reports have been made commonly in the news media in recent years that Utah Lake was a clear, blue lake in precolonization times, but the geological aspects of the lake as reflected in its sediments make the claim seem doubtful. Most of the reports by early settlers of the pristine quality of Utah Lake associate with diary accounts in which observers viewed Utah Lake from such distant points as Point-of-the-Mountain, or from nearshore localities where rivers emptied into the lake. Under these conditions, it is understandable that observers would conclude that the lake was clear. But the sediments in the lake, most of which were accumulated well before the coming of man into the valley, record that the lake has been a geologically old lake for a long time, stretching back to Lake Bonneville, and perhaps beyond. It is believed that geological factors are still the controlling factors in the lake, although human interaction and impact on the lake are important locally, particularly along the eastern shoreline.

Although Utah Lake has existed less than 10,000 years, a relatively short time in the span of geologic time, it is nevertheless an old lake from a geological point of view. The chief characteristic contributing to its senescence is its shallowness. At present, its average depth is about 2.8 m (9.2 ft) (Fig. 6), which contributes greatly to its turbidity, large evaporation losses, hence slightly saline waters, and warm summer temperatures, hence abundant communities of algae.

In summary, the geological setting and history of Utah Lake is rich and varied. The lake lies in one of the most scenic regions of North America. Climatic changes occurring in the region over the past 75,000 years, and especially the past 10,000 years, have been spectacular, for they range from very wet to very dry, and the record of these changes is preserved in the sediments of the lake as well as in other natural systems such as tree ring growth.

It is clear that these prehistoric changes occurred essentially independent of the influence of man. Natural forces still appear to dominate the lake as a whole although some

man-caused influences are locally important. The potential exists, under the influence of continuing growth of populations in the surroundings, for man-made influences to dominate. Whatever the outcome in the future, the geological history of Utah Lake will continue to give a useful perspective on the management of the lake and its resources.

#### SEDIMENT CHARACTER AND TRENDS IN UTAH LAKE

*Previous Work.*—Bissell (1942) published a preliminary report on the character of the sediments in Utah Lake. Sonerholm (1973) has described the broad outlines of the mineral compositions of the sediments of the lake and their distribution. Bingham (1975) has described the major trends of the particle sizes contained in the sediments and their distribution through the lake. Brimhall (1973) has studied the character of sediment in a core sample, 520 cm deep, to determine the broad outlines of the Holocene (recent) geologic history of the lake; and Brimhall et al. (1973) conducted a reconnaissance study of the sediments of Utah Lake, Holocene to upper Pleistocene age, by means of an acoustic profiler. The latter investigation yielded significant information, heretofore unavailable, on the character and distribution of deep-water springs and of the geologic faults in the lake floor, both of which are important to resource management.

*Sediment Types.*—Utah Lake is characterized as a carbonate-type lake because the principal constituent of its sediment is calcium carbonate,  $\text{CaCO}_3$ , whose mineral name is calcite. The compound as found in the lake is not pure, but carries small concentrations of magnesium, strontium, and other impurities. Quartz and other forms of silica are generally the next most abundant constituents, followed by clay minerals of the illite and montmorillonite and mixed layer types.

Locally, near the mouths of the major rivers joining the lake and near the existing shorelines where wave action is vigorous, quartz is concentrated in long, narrow ribbons of sand.

The shallowness of the lake intensifies the interaction of the water with sediment. During heavy storms the waves generated on the



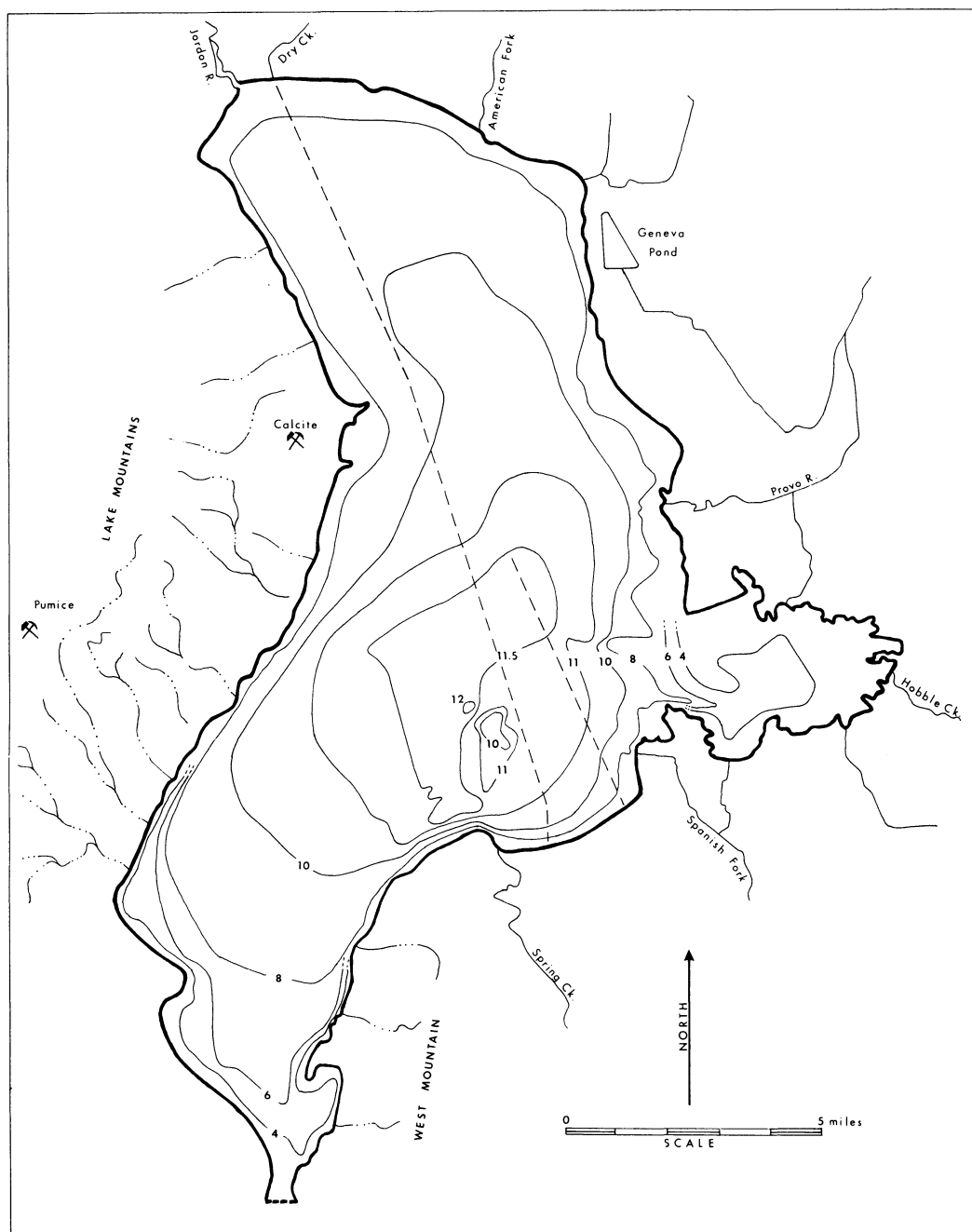


Fig. 6. Elevation contours of the floor of Utah Lake. The contours are given in feet below the level of the lake surface at 1367.94 m (4488 ft). Add 1.34 ft to the depths to reference them to compromise elevation (4489.34 ft) (adapted from Sonerholm 1973).

lake have sufficient amplitude to stir much of the lake floor, which contributes to the strong turbidity of the water, which in turn

imparts the impression of pollution, although this turbidity results from a natural process. The sediment-water interface on the lake

floor is not generally sharply defined, but is gradational. Core samples collected during the summer of 1975 indicate that the transition zone from water to sediment is usually about 0.5 m (1.6 ft). The consistency of the sediment in the transition zone ranges from thin to thick soup. The upper margins of these sediments are frequently stirred by storms and by bottom-dwelling organisms. This is a leading factor in the turbidity (quality) of the water; and the condition is due, in the main, to natural rather than man-caused processes. Based on the character of sediment core samples and the configuration of the valley floor, it appears that this condition has existed throughout the life of the lake.

*Distribution of Calcium Carbonate.*—Sonnerholm (1973) collected 140 samples of bottom sediment from localities spaced on a one-mile grid and analyzed them chemically to determine the composition of individual samples and the distribution of the elements throughout the lake. From these data, he determined the mineral constituents and trends for the lake as a whole. The contour map of calcite content ratio shown in Figure 7 is a statistical trend surface map that shows only the broad patterns present in the data.

Throughout most of the lake calcium carbonate exceeds 60 percent (dry weight) of the sediment. In two principal areas, the concentration exceeds 70 percent. The first and largest of these extends from the middle of the lake opposite Provo Boat Harbor to the western midportion of Goshen Bay. The second and smaller area lies in the northwestern portion of the lake between Pelican Point and Saratoga Springs. The pattern observed is easy to explain. Calcium is transported to the lake by surface waters and by subsurface waters. The valley and mountains surrounding the lake, and the sediment and bedrock beneath the lake are composed in the main of limestones and, to a large extent, sandstones, or combinations. Most of the calcium arrives in solution, but some arrives as particulate matter suspended in surface waters. Calcite is precipitated from lake water as evaporation increases the calcium and carbonate concentrations and by calcite depositing algae and other microorganisms abundantly present in the interior of the lake. The particles thus formed are tiny, ranging in the silt and clay

size (from less than  $\frac{1}{8}$  mm to submicroscopic dimension). Such particles are too small to settle readily in the nearshore regions where wave action is vigorous. Consequently, they accumulate more in the central parts of the lake.

The unusually high concentration of calcite in the northwestern portion of the lake associates with thermal springs, striking faults (see later section of this paper), and with an unusually large concentration of organic matter in the sediments, presumably derived from higher biological activity in the area (Bingham 1975).

*Distribution of Silica.*—Silica, as used in this report, means any of the several forms of silicon dioxide present in the lake sediments. These may include quartz,  $\text{SiO}_2$ , or hydrated and/or amorphous forms of variable composition that may be associated with organisms such as diatoms that gather silica from water and sediment to form their shells.

Inasmuch as calcium carbonate generally exceeds 60 percent of the sediment, and silica comprises most of the remainder, the distribution of silica shows an inverse pattern to that of calcium carbonate; in short, the carbonate dilutes the silica. Silica ranges from near 50 percent of the dry weight of sediment in the nearshore regions to less than 15 percent in the regions occupied by high carbonate concentrations. Again, the pattern is not difficult to explain. Quartz is a hard, durable mineral, as are the other forms of silica, when compared to calcium carbonate. Moreover, the individual grain sizes tend to be larger than those associated with carbonate. These two factors, plus the input of quartz in sediment from the major rivers and wave action near shore, tends to deposit the silica in the near shore portions of the lake.

*Distribution of Clay Minerals.*—The term *clay* is used commonly in two different meanings, both of which are used in literature bearing on this report, so a clarification must be made as to the meaning of the term. Clay on the one hand refers to any natural inorganic substance whose constituent particles are less than  $1/256$  mm in size. Clay on the other hand refers to any of a family of mineral aluminosilicates whose constituent elements are structured in sheets and whose individual particulates are typically less than

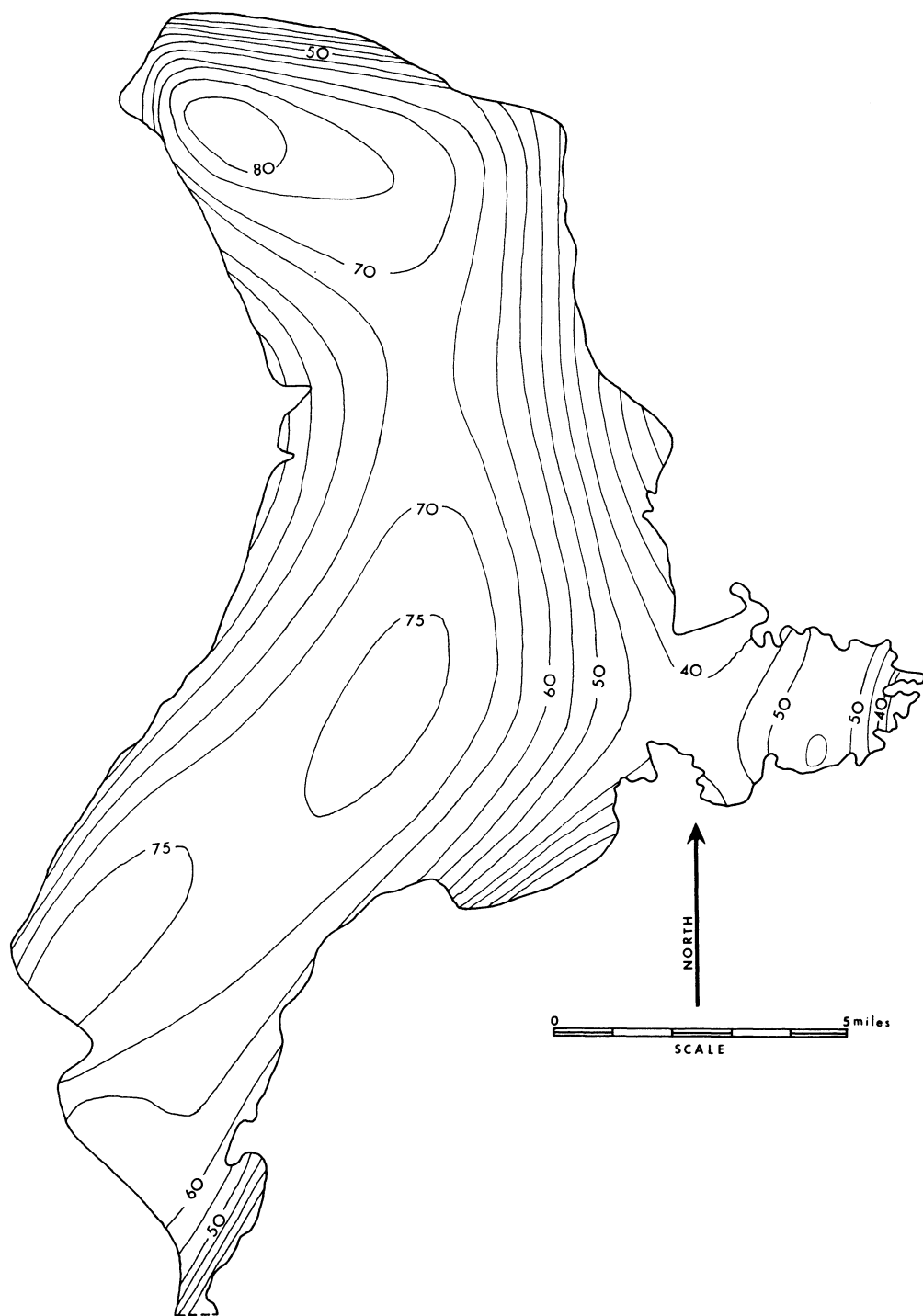


Fig. 7. Sixth degree trend surface map of calcite concentrations in Utah Lake sediments. Contours are in weight percent, dry sediment (adapted from Sonerholm 1973).

1/256 mm in size. In this paper, the term *clay* refers to the latter definition. The clay minerals of Utah Lake, ranging generally between 5 and 10 percent (dry weight), belong to the illite, montmorillonite, and mixed layer types.

The pattern of clay mineral distribution in Utah Lake is not easily defined because, among other things, it is a minor constituent diluted by carbonate and silica. Areas of high concentration, 9 percent or more, are located in the vicinity of the delta of the Spanish Fork River and near the mouths of the Provo and American Fork Rivers (Sonerholm 1973). It is clear that the source of the clay minerals is the detritus carried by the major rivers emptying into the lake. Longshore currents tend to disperse the clay minerals to the deeper waters adjacent to the shorelines.

Bingham (1975), studying the distribution of particle sizes of sediment, reports that most of the sediment of the interior of the lake is composed of particles in the silt and clay size range. He, of course, uses the term *clay* in the first of the senses described above. It is clear that much of Bingham's "clay" is in reality very fine-grained calcium carbonate.

*Minor Constituents.*— Minor constituents of the sediment of Utah Lake are numerous, but, in the main, they consist of calcium sulfate, probably as gypsum, iron oxides and/or sulfides, and organic material of varying kinds. Of course, water is a major constituent of the natural sediment. It ranges from a few percent to as much as 75 percent or more, depending on sediment type and location.

An area of relatively large organic concentration is present to the southeast of Saratoga Springs (Bingham 1975). Provo Bay carries a large concentration of organic material due to natural and man-caused biological activity. Powell and Benjamin sloughs also bear large concentrations of organic matter.

*Summary Statement on Sediment-Community Relationships.*— Bingham (1975) concludes that available evidence leads to the conclusion that plant communities of the lake do not associate with specific sediment types. Invertebrate animals, he says, tend to be more selective. Worms, midge flies, gastropods, bivalves, and ostracods prefer the carbonate muds of the open lake. Small crustaceans are found in the small, local exposures

of tufa, hard rock deposits of calcium carbonate, in the vicinity of Bird Island and Lincoln Beach.

We believe that detailed studies will reveal stronger associations between sediment types and various plant and animal communities. The properties and distribution of sediments, in broad outline, have only been learned in the past few years. Much is presently being discovered concerning the plant and animal communities in the lake.

*Sedimentation Rates.*— Accumulation of one stratum upon another in sequence of time permits the calculation of an average rate of sedimentation when the absolute age of two different strata can be determined. In the instance of the core samples from Utah Lake, the uppermost stratum associates with the present time. The age of older, deeper layers may be determined by radiocarbon dating, by association with known geological or climatological events in the past, by introduction of components such as chemical contaminants or pollen grains from plants introduced by man, etc.

Sedimentation rates in geologically young lakes (deep and not subject to large sediment inflows) are typically a few tenths to a few hundredths of a millimeter per year. In Utah Lake, a shallow and geologically old lake, sedimentation rates are expected to be higher, probably near 1 mm per year, depending on the portion of the lake under consideration. Rates are likely to be highest in the vicinity of the mouths of the major rivers, and in the deeper parts of the basin where gravity pulls the soupy water-sediment mixture.

Acoustical profiling during the summer of 1975 (Brimhall, Bassett, and Merritt 1976) permitted the recognition at depth of a very persistent layer, the upper surface of which ranges between 8 and 15 m (26 and 49 ft) deep, and whose thickness appears to range between 5 and 10 m (16 and 33 ft). The stratum is believed to associate with a dark gray, silty clay found at that depth during exploratory drilling for the proposed Goshen Bay dike (U.S. Bureau of Reclamation 1964). The position and lithology of the stratum suggest that it is the clay unit of the Provo Formation (Hunt, Varnes and Thomas 1953, Bissell 1963), deposited in deep water some 10,000

years ago just before the demise of Lake Bonneville. If the assignment is substantially correct, and the age is likewise correct, the average sedimentation rate in the deeper portions of the lake ranges between 0.8 and 1.5 mm (0.031 and 0.059 in) per year. These values are consistent with rates observed in similar lakes, and with the known inputs of clastic and dissolved materials to the lake (Fuhrman et al. 1975).

The average sedimentation rate, 3.3 cm/yr (0.13 in/yr), calculated by Brimhall (1973) is now believed to be more than 10 times too large. Most of the data presented in that paper can be reconciled with the rates tentatively assigned above by reassigning the times given to the upper 25 cm (9.8 in) of sediment instead of the upper 250 cm (98 in). It must be emphasized that all these assignments are tentative, but the latest assignments are most consistent with new knowledge gained in 1975, and with comparison of Utah Lake with similar lakes. One of the most urgent problems associated with the lake is the matter of establishing its presettlement history by means of taking several core samples to 20 m (66 ft) deep to delineate that history. In the meantime, the sedimentation rates and history of the lake must remain known only within broad terms.

During the summer of 1975, 17 shallow core samples, ranging from 30 cm to 120 cm (12 to 47 in), were collected in various parts of the lake. Cores taken lakeward from the Geneva waste pond showed a mixture of cinder or slag with sand and lime silt. The relative proportions indicate an average sedimentation rate, for the natural components of the sediment, of about 5 mm (0.2 in) per year. Another core taken southeast of Saratoga Springs in organically rich sediment showed a high organic layer at a depth of 400 mm (15.7 in). Tentatively, this layer is assigned to a low level of the lake thought to exist about 400 years ago when drought conditions persisted over the region (Schulman 1956). If the assignment is correct, the average sedimentation rate at this locality, is about 1 mm (0.039 in) per year. Features in the other cores are not easily recognized, and so no additional information is available from them at this time.

#### GEOLOGIC STRUCTURES IN LAKE SEDIMENTS

*Previous Work.*— Two geologic maps of the bedrock and alluvial deposits in Utah Valley have been published. That of Hunt, Varnes, and Thomas (1953) describes the northern half of the valley, whereas that of Bissell (1963) describes the southern half. Neither of these maps show faults or geologic structures in the vicinity of Utah Lake or of the rest of the valley except for the Wasatch Fault at the base of the Wasatch Mountains. The absence of the structures from the maps does not mean these investigators concluded that none exist, but rather that erosional processes have made them unrecognizable.

The measurement and description of gravity anomalies in the vicinity of Utah Valley lead Cook and Berg (1961) to recognize the probable existence of faults in the floor of Utah Lake. Stokes (1962) plots three inferred faults extending in a general northwestward direction along the east side of Utah Valley. The first of these stretches between the east side of West Mountain to the vicinity of Saratoga Springs. The second, from Payson to the middle of Utah Lake, and the third, from the mouth of Spanish Fork Canyon to Orem, American Fork, and Lehi. Markland (1964) demonstrates the probable existence of a fault near Arrowhead Resort.

Cluff, Brogan, and Glass (1975) investigated the Wasatch Fault in Utah Valley with respect to land use planning. Cluff, Hintze, Brogan, and Glass (1975) have also investigated the Wasatch Fault in northwestern Utah as regards recent to current seismic activity and recent fault displacements in Pleistocene strata. Geomorphic evidence, as well as tree ring data, indicate that recent faults in the Wasatch Fault zone may be no older than a few hundred years.

*Faults.*— As an outgrowth of a reconnaissance study of the deep-water springs of Utah Lake by means of a sonarlike device (Brimhall et al. 1976), an unusual opportunity was afforded to study the faults and other geologic structures present in the strata underlying the lake to a depth of as much as 25 m (82 ft). The faults beneath the lake are sometimes remarkably displayed (Fig. 8) by the reflect-



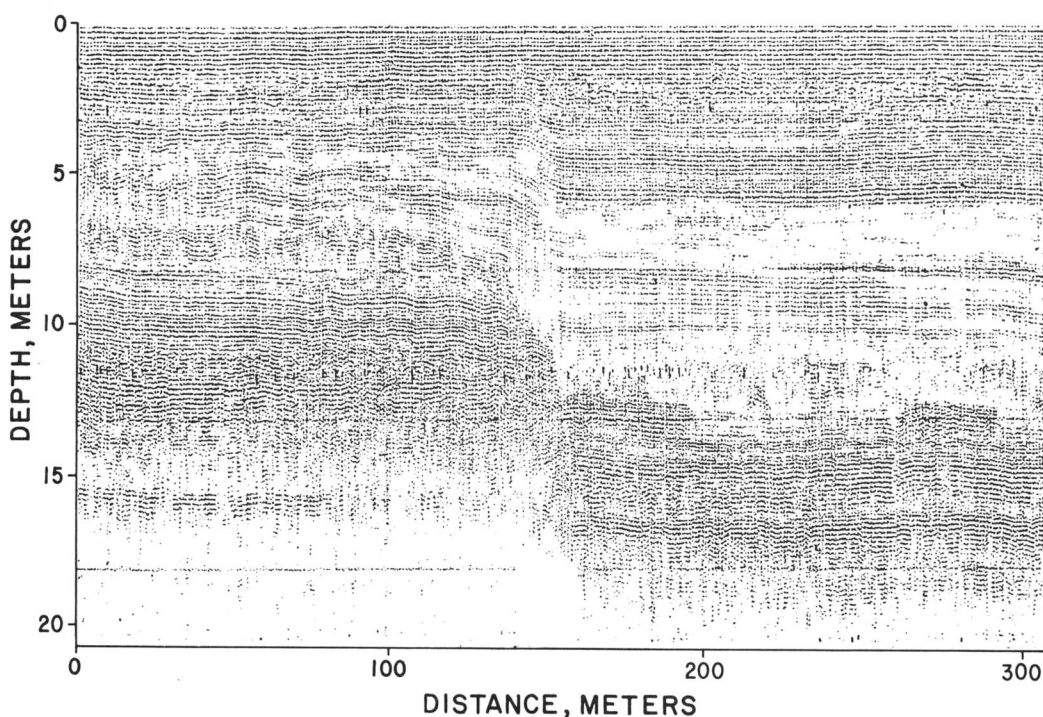


Fig. 8. The East Goshen Bay Fault, 2.4 km west of Lincoln Point. The top of the profile marks the present lake floor. The lower, dark layer on the left, whose top is 8 m below the floor, is offset on the right by about 5 m to a depth of 13 m. This stratum, a persistent marker stratum throughout the profiles, is believed to be the clay unit of the Provo Formation, uppermost Pleistocene age.

tion profiles obtained by sending pulses of sound waves into the lake floor and by recording the reflections, or "echoes" from the strata and structures beneath.

Heretofore, geologic structures of this kind, less than 10,000 years old (Pleistocene to Holocene age), have only been inferred to exist in the lake floor by extensions of faults observed in bedrock or alluvium in the lake surroundings, and by geophysical measurements such as gravity anomalies. Now, for the first time, the existence, character, and distribution of the faults in the lake floor have been observed. This section sets forth these findings and reports their significance as they apply to the history of Utah Valley and the management of the resources of the lake and its surroundings.

Three major faults (Fig. 9) are herewith designated as the Bird Island Fault, the East Goshen Bay Fault, and the West Goshen Bay Fault, which, along with several minor faults and a few folds, were discovered, mapped, and characterized by acoustical profiling in

the summer of 1975. These structures exhibit characteristics that are consistent with faults mapped elsewhere in the valley by previous workers, and they add considerable detail to the knowledge of the structural geology of Utah Valley. The faults are furthermore of considerable interest as regards resource management, inasmuch as some of the major spring areas of the lake appear to be controlled to some degree by the distribution of faults in the lake floor.

**Bird Island Fault.**— Bird Island Fault (Fig. 9) extends northeastward from the eastern part of Goshen Bay to the west side of Bird Island. It then continues northward opposite the mouth of Provo River, and then passes slightly west of north to the vicinity of the mouth of the American Fork River. The western side of the fault is downthrown relative to the eastern side. Observed displacements (past 10,000 years) range from 2 m (66 ft) to less than 0.5 m (1.6 ft). Generally, the larger displacements occur at the extremities of the fault.



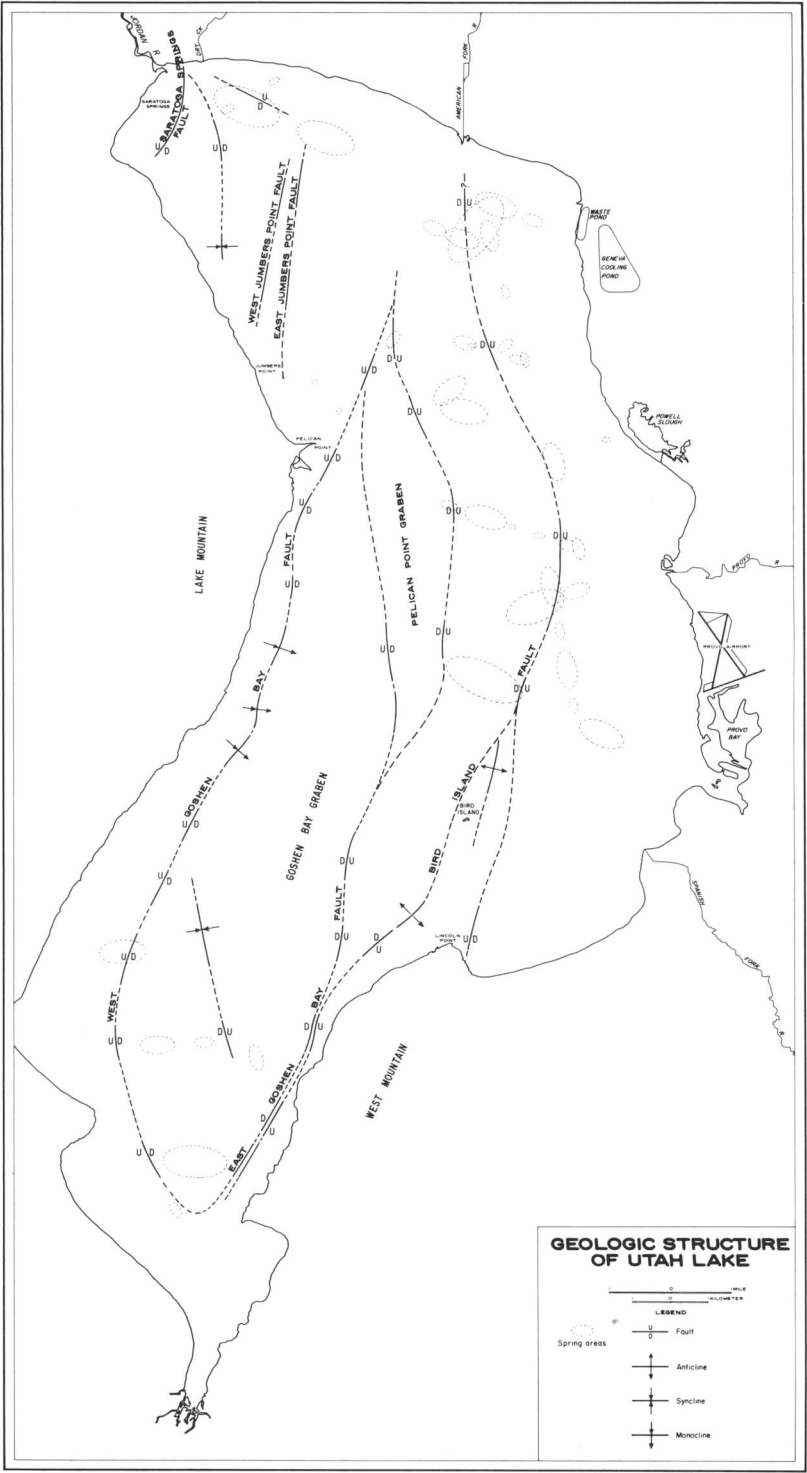


Fig. 9. The principal geologic structures present in the floor of Utah Lake, and the location of the presently known spring areas(adapted from Brimhall, Merritt, and Bassett 1976).

The eastern fork of the Bird Island Fault leaves the main fault and passes southward about 3 km (1.9 mi) north of Bird Island and is inferred to pass to the west of the Island toward the east side of West Mountain. The fault is clearly evident in the acoustical profiles just eastward of Lincoln Point. Since the eastern side of the fault is downthrown nearly 2 m (6.6 ft), it is clear that the block including West Mountain and Bird Island stands structurally high (horst).

One could be led to believe that the coincidence of the northern portion of the Bird Island Fault where thermal springs exist with a major spring zone on the eastern side of Utah Lake (Brimhall et al. 1976) accounts for the location of the springs, but we are of the opinion that the fault is at most only a contributing factor. Hydrologic and sedimentation factors are thought to be dominant because only a minority of the spring areas is shown to be directly associated with the fault.

*East Goshen Bay Fault.*— The East Goshen Bay Fault forks at a point about 2.5 km (1.6 mi) west of Bird Island (Fig. 9). The main portion extends southward from the juncture to a position west of, and parallel to, the Bird Island Fault in the eastern section of Goshen Bay. Adjacent to West Mountain the two faults are in such close proximity that they may be expressions of a compound fault rather than two separate, distinct faults. Westward of Lincoln Point, the fault exhibits approximately 5 m (16 ft) of displacement. The western side of the fault is downthrown to form a portion of the Goshen Valley Graben.

From the juncture, the east fork of the East Goshen Bay Fault passes first northeastward then northwestward through the approximate midsection of the lake to a point about 5 km (3.1 mi) northeast of Pelican Point. The west fork of the fault passes northward of the juncture to the vicinity of Pelican Point, where it appears to rejoin its partner northeast of Pelican Point. The interior block bounded by the two forks of the fault is displaced downward relative to the other blocks; hence, the interior block is a graben designated as the Pelican Point Graben. It represents the lowest point of Utah Valley from a structural standpoint.

Displacements of the faults bounding the graben range from about 1 m (3.3 ft) to less than 0.5 m (1.6 ft). The larger displacements are found on the southern side of the graben. In general, the displacements are smaller than those associated with the Bird Island Fault.

The section of the lake occupied by the Pelican Point Graben appears to have very little spring activity associated with it (Brimhall et al. 1976). Spring activity along other portions of the fault likewise appear to be slight.

*West Goshen Bay Fault.*— The West Goshen Bay Fault extends from the southern portion of Goshen Bay, where it may converge with and join the East Goshen Bay Fault (Fig. 9), to the vicinity of Pelican Point, where it appears to join the east and west branches of the East Goshen Bay Fault. The eastern side of the fault is displaced downward, which makes the block bounded by West Goshen Bay Fault and its partner to the east a graben, designated as the Goshen Bay Graben. Displacements on the fault range from approximately 2 m (6.6 ft) to less than 0.5 m (1.6 ft). Southward of Pelican Point 5 or 6 km (3.1 or 3.7 mi), the fault is replaced by a monocline that dips gently to the east.

The reconnaissance study of Brimhall et al (1976) shows that spring activity along the fault is very weakly expressed.

*Minor faults.*— The East and West Jumbars Point Faults, though minor faults in terms of length, exhibit some of the most spectacular displacements to be found in the lake. Figure 10 shows the acoustical profile obtained over the northern portion of the West Jumbars Point Fault. A similar fault is displayed on the southern section of the East Jumbars Point Fault. Displacements on the faults ranged from about 5 m to about 1 m (16 to 3.3 ft). The eastern blocks are displaced downward relative to the western. The unusual offsets on these faults indicate that the section of the lake occupied by these faults is active tectonically. The only other fault to compare is the East Goshen Bay Fault just west of Lincoln Point (Fig. 8).

None of these faults, as observed in profile, exhibited spring activity at the several points transected, although it is entirely reasonable

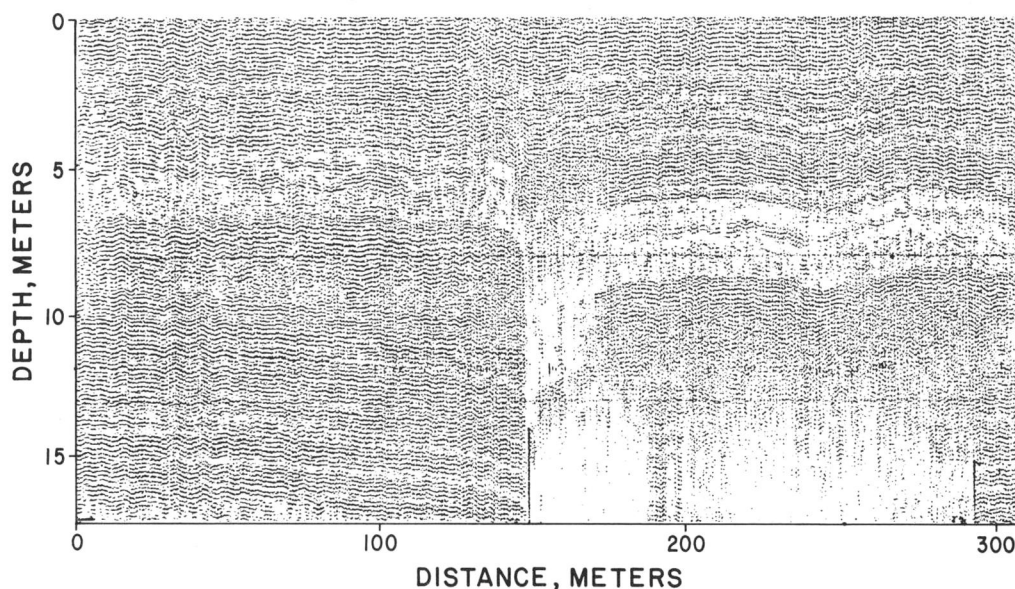


Fig. 10. A spectacular fault on the north end of West Jumbars Point Fault. The right-hand, eastern block is displaced downward about 2.5 m. The lower dark layer, between 7 and 9 m on the left side, is believed to be the clay unit of the Provo Formation.

to suppose that there are springs at places along the faults.

Another small fault, named the Saratoga Springs Fault, lies about 1 km (0.6 mi) east of Saratoga Springs Resort. The eastern side of the fault is displaced downward approximately 1 m (3.3 ft) as seen in profile. Almost certainly, some spring activity is associated with the fault, but such activity was not determined conclusively in the acoustical profile transects.

#### DEEP-WATER SPRINGS OF UTAH LAKE

During the summer of 1975, a 23-transect reconnaissance study of Utah Lake was made by means of a sonarlike device (Brimhall et al. 1976). It was possible to infer spring and seep areas from the profiles. The distribution of the areas containing springs is shown in Figure 9.

Inspection of Figure 9 reveals that less than 10 percent of the floor of Utah Lake is associated with springs or seeps. Most are located in a zone 1 to 3 km (0.6 to 1.9 mi) from shore on the eastern and northern portions of the lake.

The reason for such a distribution is clear when it is realized that the principal watersheds contributing to the lake occur in the eastern and northeastern zones. The springs/seeps occur in response to availability of water, to the thinning and wedging of permeable, water-bearing strata in a lakeward direction, to the thickening of fine-grained strata to confine the trapped water in a lakeward direction, and to the development of a hydraulic pressure by the aquifers sloping toward the interior of the lake. Thus, the springs/seeps occur principally as the result of prevailing sedimentary and hydrologic conditions.

Occasionally the springs/seeps are clearly controlled by faults, but in general, the pattern is weak. The northern extension of the Bird Island Fault coincides with the concentration of springs/seeps along the eastern side of the lake, but the fault in this section is weak in that its displacement is typically less than 0.5 m (1.6 ft) and the springs/seeps are widely scattered on opposite sides of the fault.

It is noteworthy that the faults showing the greatest displacements, the Jumbars Points

Faults and the East Goshen Bay Fault west of Lincoln Point, associate only slightly, if at all, with springs. If a strong association were present, the investigation during the summer of 1975 would have revealed it.

Three separate attempts were made in late August 1975 to sample water from springs previously located by the acoustical profiler, but the results were inconclusive. Vertical profiles, made with a portable Hydrolab water quality probe, showed no significant variation in conductivity from the surface of the lake to the inferred mouth of the spring/seep areas at three different localities investigated. The quality of water and the quantity of water being discharged from the deep-water springs is still unknown, and awaits further investigation.

#### IMPLICATIONS FOR RESOURCE MANAGEMENT

The geology of the lake includes its geologic history and setting, physiography, drainages, groundwater patterns, sediments and strata, and geologic structures (faults). These form a physical base upon which the plant and animal communities, including those of man, live and adapt, and they form the principal boundary conditions, subject to change by interaction, that impose upon the management of the resources of the lake.

The following items summarize some principal implications for resource management imposed by geological conditions known at the present time.

*The Life of the Basin.*—A significant question regarding Utah Lake is: How fast is the lake basin filling up? What is the expected life of the basin as presently constituted and operated? Available geological data indicate a rate of filling at about 1 mm (0.039 in) per year over the past 10,000 years, although the rate has likely more than doubled with the settlement and urbanization of Utah Valley. It is equally clear, however, from the character of the faults present in the lake floor, that the valley is deepening relative to the mountains at the same time it is receiving sediment. The displacement on the faults indicate an approximately equality of deepening and infilling, or an approximate state of dynamic equilibrium existing between deepening of the basin by the faults and the infilling of the basin by transport and

deposition of sediment derived from the surroundings. This trend is consistent with the overall geologic history of the region that has been characterized by recurrent movements on the Wasatch Fault since its origin some 30 million years ago. So the depth of the lake, relative to the elevation of the present shoreline, will probably remain constant for the foreseeable future. This does not mean, however, that the resources of the lake could not be improved by artificially deepening the water.

*Faults crossing proposed Goshen Bay dike.*—Although a proposed Goshen Bay Dike will cross some faults and folds, we do not believe they pose a serious threat to the safety or operation of a dike. Displacements would likely be no more than a few tens of centimeters, and probably much less, unless an earthquake of catastrophic proportions were to strike the area. Small displacements, if they occur, can be repaired quickly.

*The geological condition of the lake.*—A point commonly, almost pervasively, misunderstood by laymen and many experts as well, is that Utah Lake is a senile lake in the geological sense. It is a very shallow lake. It has a very large surface compared to volume. It is characterized by high evaporation rates. It is characterized by high rates of sedimentation. The exchange of impurities between water and sediment is likewise large.

Many mistakenly believe that the lake can be restored to a pristine state characterized by the waters of the mountain lakes of the region. The essential point missed is that Utah Lake cannot be returned to that condition. The natural history recorded in the sediment cores and profiles show that the lake has been in much the same as its present condition for centuries. This natural evidence opposes statements purportedly derived from diaries and journals of early settlers and observers that the lake was characterized by clear, blue water. Careful analysis of the conditions under which such observations were made indicates that most of them were made from some distant point such as the Point-of-the-Mountain where, even today, the lake has a clear, blue aspect, especially when incident light from the sun bears a critical angle just after sunrise or just before sunset. Reports of clear water and sandy beaches were made



mostly in the vicinity of the Provo River or other river inflows where the wide plume of clear water extended away into the lake. Under most of the conditions in which such observations were made, the water would have a clear aspect.

The character and conditions of observations, both from eyewitness accounts and from the natural record left in the sediments of the lake can be reconciled to the effect that the lake is and has been geologically old since its inception, with the water being turbid but sometimes appearing clear locally or completely, depending on the vantage point and conditions under which the lake was observed.

The foregoing should not be construed to mean that there have been no significant changes in the clarity of water in Utah Lake with the changes of level occurring over the past few thousand years; it simply means that the lake has not been a completely clear lake, in the same sense that many mountain lakes are clear, throughout most, if not all, of their histories.

*Sediment character and distribution.*— Research completed since 1973 has delineated the broad patterns of composition and grain size distribution of minerals being deposited on the lake floor. In all but the nearshore regions, the areas close to the mouths of the major rivers, and in the vicinity of Bird Island, calcium carbonate exceeds 60 weight percent. Silica and clay comprise most of the rest. In the same regions occupied by the calcium carbonate, the grain sizes are mostly and about equally in the silt and clay sizes, between 1/16 and 1/256 mm, and less than 1/256 mm, respectively. In the near-shore portions of the lake, silica in the form of sand is the most abundant constituent. Particle sizes are dominantly in the range between 1/16 and 2 mm.

We believe that these relationships have a larger bearing on the character of the plant and animal communities than previously realized, principally by reason of the lack of detailed study necessary to establish the relationships. Mapping of the lithologies of the near-shore regions and the related plant and animal communities is presently being done in a Water and Power Resources Services environment assessment study associated with proposed diking of Provo and Goshen Bays.

*Geologic faults in the lake.*— The geologic faults discovered and mapped in the floor of the lake during the summer of 1975 pose the same kind of threat that other faults pose in the valley, but none beyond those customarily assigned. That they exist and are consistent in character and distribution with the Wasatch and other faults bordering the valley is interesting and informative.

The faults exhibit displacements up to 5 m (16 ft) during the past 10,000 years or so, but it is unlikely that such displacements were achieved as the result of a single event. It is conceivable that the floor of the lake could be violently heaved by an earthquake, and that large lake waves could be produced, but, even if such did occur, the damage to the shorelines would probably be incidental to the damage wrought elsewhere in the valley by ground vibrations and movements.

The location and character of springs in the floor of the lake is more determined by existing hydrologic and sedimentation factors than by faults. The faults do appear to contribute substantially in a few places, however. In the event of strong earthquakes in the valley, it is not anticipated that the effect on springs in the lake floor would be large.

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