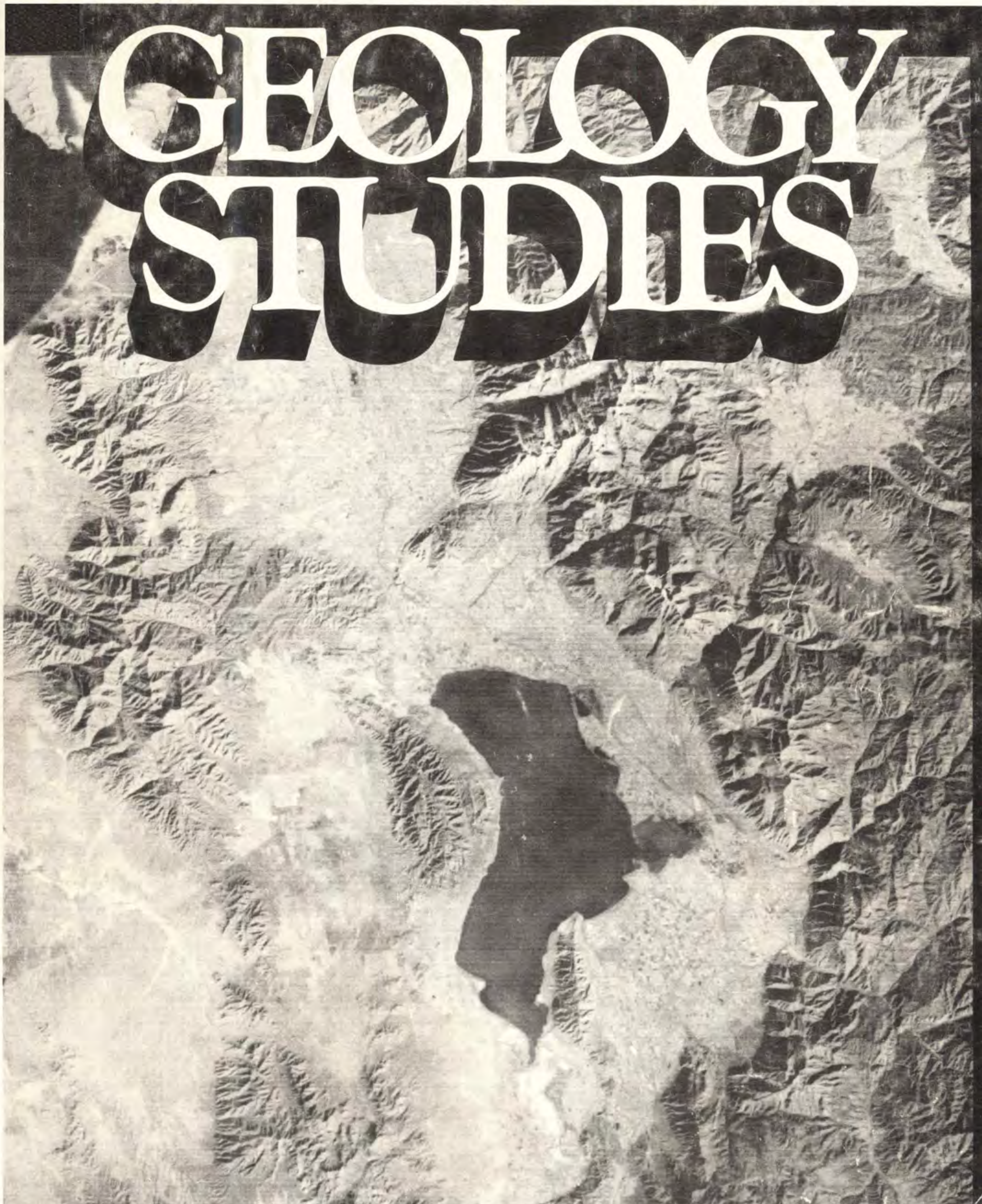
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



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Cover: Aerial photo of Utah Valley and surrounding area.

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The Rate of Sedimentation in Utah Lake and the Use of Pollen as an Indicator of Time in the Sediments

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Abstract.—Utah Lake is a large, shallow, eutrophic freshwater lake situated in a structural basin which contains a major part of the population of the state of Utah.

This study is concerned with determining the distinctive physical features of the lake, primarily in regard to those that affect the rate of sedimentation, and suggests that human activities have had a very significant effect in modifying the lake environment and increasing the rate of sedimentation.

A study of the pollen deposited in the lake sediments suggests that the rate of sedimentation has been 1.38 cm per year since 1849, when Mormon pioneers first established themselves as permanent residents of Utah Valley.

Recent studies of similar freshwater lakes emphasize that the rate of sedimentation has increased dramatically as a result of human activities, and the actual rate of sedimentation of some of these lakes is of the same order of magnitude as that found for Utah Lake.

INTRODUCTION

Utah Lake is a large, shallow, eutrophic freshwater lake located in a fault graben basin in a semiarid environment in north central Utah.

The lake is of major importance as a source of water for irrigation. It is also of importance for recreation, for fishing, and for a wildlife habitat.

There are major problems associated with the different uses of the lake, and several studies have been made to determine the various factors that effect the quantity and quality of the water in the lake.

This study is concerned with the rate of sedimentation in the lake, particularly since 1849 when white settlers first arrived in the valley and proceeded to modify the environment by irrigation, livestock grazing, urban pollution, industrialization, etc. Pollen has been used to determine approximately this time horizon in the sediment and to suggest a minimum rate of sedimentation since 1849.

Twenhofel and McKelvey (1941) listed fifteen factors they considered significant in the deposition of sediments in the freshwater lakes of the upper Mississippi Valley: (1) mode of origin of the lake basin, (2) size and depth of the lake basin, (3) relief of the drainage areas, (4) extent of shallow water adjacent to shore, (5) degree of vegetation protection over the drainage areas, (6) character of surrounding rock and soil terraces, (7) topography of the bottom of the lake, (8) circulation of the lake waters, (9) climatic conditions, (10) organisms in the lake, (11) thermal stratification of the lake, (12) character of the lake water, (13) sources of lake sediments, (14) rate of deposition in the lake, (15) changes in lake sediment after deposition.

Most of these factors are considered in this study of Utah Lake sediments.

PREVIOUS STUDIES

There have been many, varied reports made of Utah Lake and its sediments, and the following are some of the most significant: The Geology of Utah Lake—Implications for Resource Management, Willis H. Brimhall and LaVere B. Merritt, 1981; Recent History of Utah Lake as Reflected in Its Sediments—A First Report, Willis H. Brimhall, 1972; Recent Sedimentation Trends in Utah Lake, Clair Bingham, 1975; Lake Bonneville—Geology of Southern Utah Valley, Utah, Harold J. Bissell, 1963; Hydrology and Water Quality of Utah Lake, Fuhriman and others, 1981; A Study of the Plant Ecology of Salt Lake and Utah Valleys before the Mormon Immigration, Homer J. Wakefield, 1933; An Ecological Study of the Flora of Utah Lake, Utah, Walter P. Cottam, 1926; The Physical and Cultural Environment of Utah Lake and Adjacent Areas, Richard H. Jackson and Dale J. Stevens, 1981; Hydrologic Inventory of the Utah Lake Drainage Area, M. Leon Hyatt and others, 1969; The Water Chemistry and Pesticide Levels of Utah Lake, J. S. Bradshaw and others, 1969; and The Changing Biota of Utah Lake, D. A. White and others, 1969.

These studies, with others referred to later, give a background of information on the environment of Utah Lake and data on conditions that affect the sediments of the lake with suggestions as to the rate of sedimentation.

PHYSICAL CHARACTERISTICS OF UTAH LAKE AND ITS ENVIRONMENT

Utah Lake is located in north central Utah and is part of the Basin and Range physiographic province. The lake occupies about one-fourth of Utah Valley, which is a graben-structured valley bordered by hills and mountains on all sides. The lake has a crescent shape that basically conforms to the alignment of the adjoining mountain ranges. The land elevation above sea level ranges from 1,367.03 to 1,368.55 m at lake level to nearly 3,658 m in the Wasatch Mountain Range on the east side.

The major surface drainage into the lake, also the major source of detrital sediment carried into the lake, is located along the north and east sides of the valley, associated with the higher elevations. The principal streams, starting at the north end (fig. 1), are Dry Creek, American Fork River, Provo River, Hobble Creek, and Spanish Fork River. Altogether there are some 51 surface flows into the lake (Fuhriman and others 1981). Along the south, east, and north margins of the lake are numerous springs and some marshy ground. There are at least 38 spring areas within the lake itself which contribute approximately 16 percent of its inflow (Brimhall and others 1976). The springs in and on the margins of the lake vary from hot to cold, and some are heavily charged with minerals in solution. Fuhriman and others (1981), in speaking of the mineralized springs, says, "These springs provide 4.4 percent of the water, but 21.3 percent of the total dissolved solids which include sodium, potassium, chloride, and sulfate ions. Associated with these springs are distinctive calcium carbonate beach rock

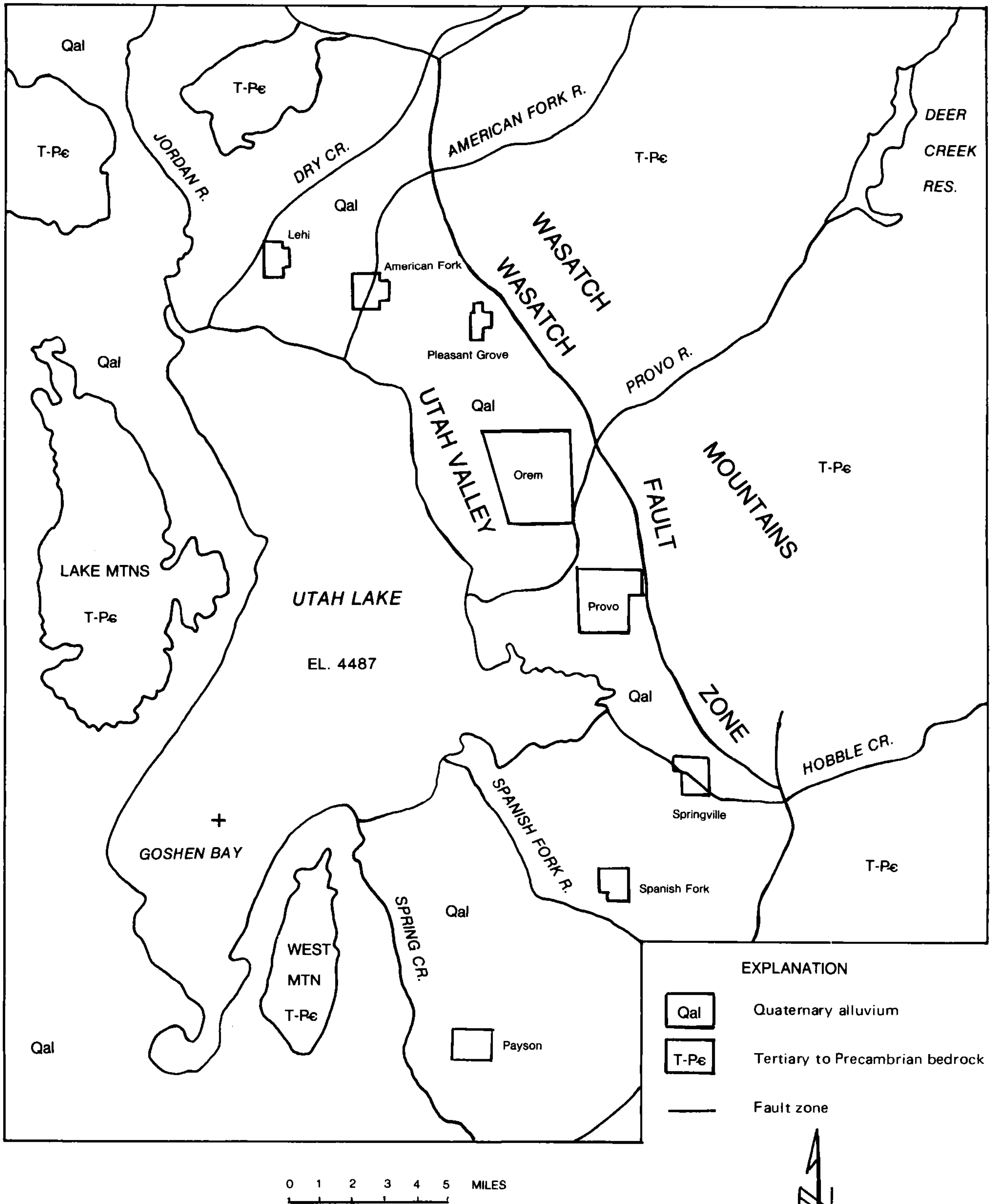

FIGURE 1.–A simplified map of the geology and drainage in the vicinity of Utah Lake (modified from Fuhriman and others 1981). Note: + marks the approximate location of the core taken in Goshen Bay.

areas." Fuhriman and others (1981) report for the years 1970–73 a surface inflow of 519,751 acre feet per year, shallow subsurface inflow of 86,467 acre feet per year, deep subsurface inflow of 27,888 acre feet per year, and 88,350 acre feet per year added directly to the lake surface by precipitation. Evaporation from the lake was 342,077 acre feet per year.

Utah Lake is about 35 km long and 19 km wide at its widest part. Its depth fluctuates from season to season and over longer term cycles. The best reference depth is obtained by using what is called "compromise level." This level was established in 1884 and was modified by the United States Coast and Geodetic Survey to an elevation of 4,489.34 feet (1,368.37 m) above sea level (Hyatt and others 1969). The average depth of the lake from "compromise" is 2.9 m (Fuhriman and others 1981). The maximum depth is about 4 m, with certain exceptions in the vicinity of deep-water springs where the depth is much greater. The overall bottom topography is remarkably flat, producing a large shallow lake. The shallow depth essentially prevents any thermal stratification in the lake water because wind action and wave movement effecively mix the water and stir up the bottom so that it remains in an almost constant turbid state. Turbidity readings taken at 11 stations by Lawler (1961) with a Hellige turbidity meter ranged from 7.5 to 45.0 ppm of SiO_2. Hansen and others (1974) give Secchi disk readings averaging 24 cm and ranging from 50 cm to 12 cm or less.

The environment is semiarid with an annual average precipitation ranging from 22.86 cm at the northeast end of the lake to 45.72 cm at the south end of the lake. In the nearby Wasatch Mountains the annual precipitation of snow and rain can exceed 127 cm (Jackson and Stevens 1981).

The average maximum July temperature is 33°C (92°F), and the average minimum is 12°C (53°F). The average maximum temperature in January is 3°C (37°F) and the average minimum, -10°C (14°F). Temperatures over 38°C (100°F) occur during a few days in the summer and drop to less than -26°C (-15°F) during a few days of the winter months (Jackson and Stevens 1981). In a typical year the water temperature in Utah Lake varies from 10°C (50°F) in the early spring to 25°C (75°F) in August and to 7°C (45°F) in late December (Bradshaw and others 1969). The shallow water of the lake warms up very rapidly in response to the heat from the sun.

Each year the lake freezes over, and the spring thaw results in ice ramparts being formed as the ice cover breaks up and the wind pushes the ice plates up on the shores of the lake.

The dominant direction for the wind is from the northwest, next from the southeast, and then from the southwest or south. Prevailing winds are predominantly from the northwest in the spring, from the west and southwest in the summer, and from the west in autumn. Winds are commonly gusty with some cyclonic winds up to 120 km per hour (Hales 1948). Daily winds occur every day in Provo and Spanish Fork Canyons, and Markham (1939) reports wind velocities up to 29 km per hour coming out of Spanish Fork Canyon.

In addition to the waves generated by the wind, a seiche is often produced with a water level up to 0.6 m higher on the downwind side of the lake (Fuhriman and others 1981).

Utah Lake is an eutrophic lake with a pH range from 7.5 to 9.4 and an average of 8.6 (Sundrud and others 1970).

Bingham (1975) reports that, with the exception of algae, a large part of the lake bottom is free from living plant growth, and sediment samples from this part of the lake contain less than 2.0 percent organic carbon. The wave action effect in shallow water causes these bottom sediments to be well oxygenated preventing accumulation of large amounts of organic carbon. Higher amounts of organic carbon, up to 6.0 percent, are found associated with the bays and sloughs of the lake.

The total dissolved salts in the lake range from 700 to 1,000 mg/l during average inflow years (Fuhriman and others 1981). A significant part of the dissolved salts is brought into the lake by the Spanish Fork River, the inflow from the south end of the lake, and from mineralized springs at the margin and within the lake.

Bradshaw and others (1969) report low pesticide levels in the lake.

There are nine sewage plants that dump their effluent into the lake. Three of these plants discharge high concentrations of nutrients into Provo Bay, which becomes a biological oxidation system, and during the summer months extensive algal blooms occur (Bradshaw and others 1973).

One of the most significant features of Utah Lake is the seasonal and cyclic long-term fluctuation of the water level. This fluctuation has a pronounced effect on shoreline features and upon the flora and fauna that live in the lake. About 50 percent of the inflow is evaporated each year (Furhiman and others 1981). Another factor influencing the water level is the fact that it is a storage reservoir for water users in Salt Lake Valley to the north. The amount of stored water is regulated by an upper water level limit agreement (compromise level) with the landowners around Utah Lake. In dry years much of the water is pumped out.

Cottam (1926) indicates that the average seasonal change of the lake level is 0.82 m. Because the lake bottom and valley floor are flat, such changes in water depth produce major advances and retreats of the shoreline, a characteristic feature of Utah Lake.

UTAH LAKE SEDIMENTS

Utah Lake is the remnant of a much larger, older body of water, Lake Bonneville, a product of the Pleistocene Ice Age. Lake Bonneville gave way to Utah Lake about 8,000 years ago, but it left its imprint in the flat valley bottom filled with Bonneville Lake deposits, in the numerous lake terraces on the hill slopes bordering the valley, and in ancient delta lobes built out into the valley. These older lake sediments are being weathered, eroded, and redeposited in Utah Lake.

Older rock outcrops which border the valley range from Precambrian metamorphics through Paleozoic limestone, sandstone, and shale. Part of the drainage to the southeast is an extensive area covered by the Eocene Green River Formation which is dominantly shale. Erosion also brings sediments derived from both acidic and basic igenous rocks (see fig. 1). Rock types that contribute the most to sediments carried into the lake are limestones, sandstones, and shales. Springs within the lake add chlorides and sulfates, and drainage into the south end of the lake provides more salts from Jurassic evaporites (Bissell 1963).

Investigation of the sediments taken in cores from the lake away from river deltas and influx of coarse detrital material shows a fairly uniform accumulation of dominantly silt- and clay-size sediments.

Bissell (1942) made a study of the upper 9.14 m of the sediments from cores taken at 11 localities. The upper 1.52–2.44 m of sediments on the bottom of Utah Lake are light to medium-gray silty clay, fairly well sorted, poorly compacted, and containing 50 to 60 percent water. This bed grades downward into more compact medium to dark gray clay which extends to a depth of 4.57 m. The more compact clay is poorly sorted and contains 40 to 50 percent water. Below it is a 3.05-m bed of well-sorted, dark gray to black, compact, silty clay containing 35 to 43 percent water; it becomes sandy at a depth of about 7.6 m.

Bolland (1974) described the sediments in the core (510 cm long) used in his diatom study, taken west of the Geneva Steel plant. The upper 10 cm were lost, but from 10 cm to 462 cm the core consisted of nonlaminated, greenish gray clay and silty clay. From 462 cm to 510 cm the sediments were sandy and contained a thin lens of peat at 490 cm.

No attempt is made here to explain the difference in the depth at which sand becomes a distinctive part of the sediment in the two descriptions. Bissell was able to correlate his three units among 11 coring locations and perhaps gives a better representation of the upper 76.2 cm of lake sediments.

Bingham (1975) took 50.8-cm cores from 60 localities in a grid pattern covering the lake. Concentration of sand is mostly along the eastern margin where the rivers build deltas. Organic matter is concentrated in the sloughs and bays. Cores from most locations had 2 percent or less organic matter present. Illite, kaolinite, and mixed illite-montmorillonite are present, with illite being the dominant clay mineral. These minerals are somewhat uniform in their distribution throughout. Water content varied from 17.39 percent to 67.56 percent. This wide range of water present may be related to sampling procedures.

Fifteen samples (UL-16, 18, 30, 41, 43, 55, 57, 69, 71, 73, 93, 95, 99, 115, 126) essentially represent what Bingham refers to as Type A–Midlake Sediments. They are similar, and the basic description of this typical lake sediment is as follows: silty, clayey lime mud, firm (four samples were watery), structureless, medium gray when wet and light gray when dry (there were a few minor variations from this); shells with varying numbers of ostracods, gastropods, and bivalves (seven samples had no shells); 1 percent or less coarse clastics with quartz the dominant mineral, some rock fragments, a few heavy minerals and black accessories; clay lumps were found in two samples, oolites in two samples, and there were occasional flakes of mica. Calcium carbonate is extremely abundant in these cores and makes up 61 to 73 percent of the sediment. High concentrations of calcite, found in the northwest part and in the southwest end of the lake, are thought to be related to the discharge of springs with high mineral content.

In Bingham's description of the midlake samples the significant lithologic similarity of the samples and the oft-repeated indication of lack of structure in the core are reflections of the lake's shallowness, nearly flat lake bottom, and constant stirring of the bottom by wave action. Disturbance of the water by a passing motorboat often leaves a trail of churned-up sediment, which can be seen from an airplane flying over the lake. Brimhall and Merritt (1981) report that, as they took samples from the lake bottom, there was a transition zone of loose sediment above firm lake bottom sediment consisting of 0.5 m of thin to thick soup. It is likely that sedimentary particles, including pollen grains, are deposited and picked up several times before they become a permanent part of a sediment sequence. All this suggests a fairly uniform distribution of fine sediment in the inner part of the lake.

At Lincoln Point near the south end of the lake the water is almost always milky in appearance because of calcium carbonate being precipitated there in the form of colloidal and silt-sized crystals that remain suspended for a long time (Fuhriman and others 1981). Warm, heavily charged, mineral spring waters help to produce the high percent of calcium carbonate precipitation and the development of the beach rock at Lincoln Point.

Sixty percent of the sediment in the lake is calcium carbonate, and a large part of it is developed from chemical precipitation in the lake. Therefore conditions that favor or modify the precipitation of calcium carbonate play a major role in the accumulation of lake sediments in terms of quantity as well as type of sediment.

Fuhriman and others (1981) calculated that the ion balance relationship during the 1970–73 period indicated that about 60 mg/l/yr of calcite was precipitated, with a rate of accumulation of 0.2 mm per year. They concluded that 25 percent of the total sediment and 35 percent of the calcite was deposited in the lake by mineral precipitation.

CHANGES IN UTAH LAKE AND ITS SEDIMENTS SINCE 1849

Much discussion has centered around the original nature of the water of Utah Lake and whether it was clear or turbid. Historically, before 1849, we find little to enlighten us on the subject. From the journal of William Clayton, June 1847 (Wakefield 1933), we have this reference to the Jordan River where it leaves Utah Lake: "The outlet of Utah Lake does not form a large river neither a rapid current but the water is muddy and low banks." On July 27 an exploration party that included Brigham Young crossed the Jordan River on their way to the south end of Great Salt Lake and Black Rock. "The Utah Outlet, which they forded, was described as being about six rods wide and three feet deep, with a gravel bottom; the water, unlike that of the mountain streams, being *unclear* and the current not very rapid" (Whitney 1892; italics added).

W. C. Cottam (1926) described Utah Lake as follows:

> Utah Lake is unique in that it is always muddy. Lakes generally act as settling ponds for muddy streams, but here is a body of water fed by clear mountain streams that is itself never clear. This fact is due to the extreme shallowness of the water upon a loose bed of whitish clay almost colloidal in nature. A strong wind will, in an incredibly short time, transform this body of water into a choppy, foaming mass of mud."

Tanner (1931) recorded 12 observations of the turbidity of Utah Lake taken from 1929 to 1931. Testing was done by lowering a white object into the lake and noting the depth at which it disappeared. The depths recorded ranged from 15 to 100 cm.

Wakefield (1933) quotes from the Stansbury report:

> The fertile valley of Lake Utah. This is a beautiful sheet of pure fresh water, thirty miles in length, and about ten in breadth, surrounded on three sides by rugged mountains and lofty hills, with a broad grassy valley sloping to the water's edge, opening to the northward. Through this opening flows the river Jordan, by which its waters are discharged into the Great Salt Lake.

Bertrand Harrison (personal communication) recalls back in 1917–20 going fishing with his father in Provo Bay. He states that the lake water was clear at that time. This area may have been influenced considerably by the inflow of Spring Creek and Hobble Creek at that time. Other people living in

Utah Valley at the turn of the century have made the same comment about the clarity of the lake water.

Sundrud and others (1970) state: "Formerly a clear sulfate lake, it has become a bicarbonate and eutrophic to dystrophic lake, with high colloidal turbidity when ice cover is lacking."

O. T. Swallow (1932) wrote:

> The type of life which we would expect to inhabit a place such as this, would necessarily be that which would thrive in turbid riley, rough water. Neither could we expect to find organisms that live on rooted plants, and use them for food, as the lake which was once almost completely carpeted with vegetation is now practically barren of such life.
>
> Along with the disappearance of the trout, there have been many other changes take place. At one time the lake bottom was carpeted with plant life, and no doubt an abundant fauna found optimum living conditions there. Now, search as we will, those plants are almost completely gone, and as a result, the entire biota of the lake has been forced to make definite adjustments or cease to survive. Many no doubt have done the latter.

Cottam (1926):

> Utah Lake today is astonishingly free from aquatic vegetation yet it is within the memory of many when various species of *Potamogeton* and similar forms made rowing almost impossible along the shores and in the protected parts of the lake. The disappearance of vegetation in the lake followed the introduction of an herbivorous fish–the German carp. With no enemies to impede its enormous reproductive powers the carp was soon master of the lake.
>
> The introduction of carp into the lake is without doubt the chief retrogressive factor involved in the present status of the lake flora; still the increased salinity of the water might well effect the nature of the plankton.

However, Hanson and others (1974), in a recent study of the diatoms of Utah Lake, concluded, "We have found that the diatom flora dominating the lake today is very similar to that which existed as long as 11,000 years ago. It is therefore possible that man has had a minimal effect on Utah Lake, contrary to what many have previously believed." Brimhall and Merritt (1981) did not see much variation in the sediments of Utah Lake and suggest that natural processes and not human factors dominate the rate of sedimentation today as in the past.

With the limited information available, it seems that the physical conditions of the lake have always made it susceptible to the development of turbid waters by wind action but not to the extent of today's turbidity. It is likely that in the past patches of clear water prevailed for longer periods of time along the inlets and bays of the lake.

There are many factors spoken of that have greatly increased the turbidity of the lake. The earliest account of Utah Valley is that of Dominguez and Escalante in 1776 who considered the valley to be the most beautiful in all of New Spain and described the grassy plains and abundant fish and wild fowl (Auerbach 1943). The best source of historical information on the vegetation in the valley is given by Wakefield (1933) who reports on data from many historical accounts. Utah Valley was covered primarily with grass with a few stands of juniper on the benches and extending up the hill slopes. There were thick stands of large willows and cottonwood trees bordering the streams that entered Utah Lake. Jack D. Brotherson of the Brigham Young University Botany Department told me that Earl M. Christensen had concluded from his studies that in the past 800 to 900 acres of deciduous trees were located at the mouth of the Provo River.

The stands of trees along the rivers and the junipers along the bench and hill slopes were greatly reduced as they were cut down for lumber or firewood or, as in the case of a stand of junipers on West Mountain, were destroyed by fire (Brotherson personal communication).

Vegetation around the lake and in the lake has been modified considerably by human activities, the introduction of new species, and the rise and fall of the water level in the lake. White and others (1969) indicate that the rooted emergent vegetation in the lake and the pond weeds which covered wide areas of shallow bays and open water in 1850 had been drastically reduced to a few species scattered around the lake and rarely occurred in large patches. They attributed this decline to the introduction of carp in 1886, increased turbidity of the water, and the drawdown of the water level due to the water use in Salt Lake Valley. The woody littoral zone of the lake has been more and more taken over by *Tamarix* which invades newly exposed lake bottom more rapidly than other plants. During the drought of 1934, *Tamarix* extended itself far across the lake bottom.

Because of the use of Utah Lake as a reservoir, the average annual fluctuation of the water level is twice what it used to be (White and others 1969). This variation has made it far more difficult to establish a stable shoreline with its associated plant types, sediments, and habitat for lake fauna.

R. E. Coombs (1970) made a comparison between the plants studied by him in 1968 and those studied by W. P. Cottam in 1925. Cottam (1926) recorded 333 plant species and Coombs 305 species. Cottam reported 159 species in 1925 not obseved in 1968, and Coombs reported 131 species not seen in 1925. Brotherson (1981), in a study of the aquatic and semiaquatic vegetation of Utah Lake, reports 489 species of plants and suggests that there has been and there will be more significant changes in the plant communities around Utah Lake.

White and others (1969) also report significant changes in the invertebrate and vertebrate fauna of the Utah Lake environment, indicating how changes in their numbers and types have been strongly influenced by human activities since 1850. They list the factors that have affected the biota of the lake: shallow depth of the lake and wind-produced turbidity; reservoir use of the lake with increased annual lowering of the lake water level; agricultural practices with increased irrigation, urban waste, pollution, livestock pollution, extensive grazing, reduced inlets and marshes, straightening and channeling of streams, manipulation of drainage basin with new sources of water supply, diking and drainage canals developed; increased siltation; and introduction of new species into the environment.

There is good evidence that the average annual amount of detrital sediment carried into Utah Lake has increased since 1849.

There has been some deforestation along the Wasatch Front since 1849, but the major factor affecting runoff from the eastern and western margins of Utah Valley has been overgrazing. This factor is especially evident in Spanish Fork Canyon, which has been a stock trail for many years with thousands of sheep and cattle moving in and out of the canyon.

Other contributing factors are the construction of a highway and the establishment of a railroad gradient through the canyon.

B. S. Markham (1939) indicates that during his lifetime the Spanish Fork River changed from a clear-running stream to one loaded with debris. He describes the effect of a local thunderstorm on an area stripped of the natural cover of vegetation resulting in extensive erosion and flooding of the highway and railroad tracks.

C. K. Williams (1972) describes the Spanish Fork Canyon drainage area in this fashion:

> The vegetation of the area has long been subjected to heavy grazing pressure at least as far back as when it formed part of the Old Spanish Trail. Deer have also overbrowsed some areas. The use of the canyon by the railroad and as a stock trail made it serve as a route of invasion by new plants that were less prone to damage by grazing. In the past decade, there appears to have been a gradual improvement of the quality of the plant cover in those areas that grazing pressure has lessened.... The overgrazing of the plant cover has contributed to the silt load carried by the river.

Williams mentions that settlers in Utah Valley used the drainage basin of the Spanish Fork River as a summer range for up to 10,000 cattle and also large numbers of sheep and horses. This overgrazing resulted in more frequent and more intense floods.

R. R. Woolley (1946) lists 45 cloudburst floods in Utah Valley between 1920 and 1938. Of these floods 16 were in Spanish Fork Canyon and 11 in Provo Canyon.

Coombs (1970) reports that although flooding started around 1900, the most severe floods came in the 1950s at Hobble Creek Canyon, Spanish Fork Canyon, American Fork River, and Dry Creek.

On May 4, 1952, a major flood occurred in Spanish Fork Canyon producing 1,800 cubic feet per second. In Hobble Creek on this day there was also a flood with 1,250 cubic feet per second (Hyatt and others 1969).

C. K. Williams (1972) reports that 1952 was the highest water year recorded for the Spanish Fork River:

> The month of May alone had a runoff of 114,131 acre feet. This amount is greater than the 18-year average for annual stream flow. The high water washed out many dams and intakes to canals, hundreds of acres of bottom land were flooded, and the tracks of the Denver and Rio Grande Railroad were damaged.

The channeled lower part of the Spanish Fork River was breached in 1952, and floodwater spread out over a major part of the Spanish Fork River delta.

Another factor contributing to the erosion in Diamond Fork and Spanish Fork Canyons is the increase in water volume due to the adding of Strawberry Reservoir water to that of Diamond Creek, starting back in 1915.

As an indicator of the amount of sediment being added to the lake, dead branches of *Tamarix* in nearly vertical growth position were encountered a little more than a meter below the surface in a pit dug on the delta of the Spanish Fork River in 1979; *Tamarix* was introduced to the valley about 1900.

A very significant factor related to the increase of sedimentation in Utah Lake is the change in the influx of dissolved solids since 1849. Much of the lake sediment is composed of carbonate material, mainly calcium carbonate; 60 percent is the average for the lake, but in some places it is as high as 80 percent.

Bissell (1942) said that there was a general decrease from the surface downward of acid-soluble materials in the cores that he took in Utah Lake, and that below depths of 7–9 m most samples contained less than 45 percent $CaCO_3$ compared with approximately 70 percent acid-soluble material at the surface. This finding suggests a recent increase in the amount of $CaCO_3$.

Many factors contribute to the precipitation of $CaCO_3$: the lake is shallow, warms up rapidly, and is agitated by wave action so that CO_2 escapes into the atmosphere; algal growth and photosynthesis aid in the precipitation of $CaCO_3$; the alkaline nature of the water increases the insolubility of $CaCO_3$; the rate of evaporation of lake waters is high; and there is an influx of highly charged mineral waters from springs and stream flow.

Chemical studies have been made in the past, but evaluating them is difficult because of the considerable variation in the amount of dissolved solids in different parts of the lake and the fact that the place where some of the early samples were taken is not known. Another contributing factor to the problem of determining change through time of the amount of dissolved material in the lake is the considerable fluctuation in the volume of the lake water.

Since 1849 people have modified the lake environment by draining lowlands with drainage canals and pumping the drained water with leached salts present into the lake. Jones (1974) showed that in the Spanish Fork area, drained land decreased in salinity up to 7,000 ppm, and soils closer to the lake increased in soil salt concentration. The major contributor, however, to new mineral matter in the lake has been the extensive irrigation of the lowlands around the lake. Irrigation waters make their way back to the natural water-courses and flow into the lake. During the summer months, in particular during dry years, about the only water that reaches the lake from several major streams is irrigation water that has returned to the stream channels. Williams (1972), writing about the Spanish Fork River, says,

> By the early 1900's the flow of the river was fully utilized in a normal year and at times during the irrigation season all the water of the river was diverted before it flowed into the lake. In years of less than normal flow the river did not supply water to meet the demands of the water users.

Turley (1969) states that the salt content at the mouth of Spanish Fork River is three times that in the river where it is taken out for irrigation. The average salinity at the mouth of Spanish Fork River is 900 ppm compared to 650 ppm average inflow of all sources for the lake (Hyatt and others 1969). Fuhriman and others (1981) suggest a range in total dissolved solids from 700 to 1,000 mg/l during average inflow years to Utah Lake.

Edna Snow (1931) showed that there was a continuing increase in salinity from 1884 to 1926; 1884–306 ppm, 1889–892 ppm, 1903–1281 ppm, 1904–1165 ppm, and 1926–2600 ppm. She attributed the increased salinity to practices of irrigation and drainage. However, we have no information as to where in

Utah Lake the samples were taken that she used in her evaluation.

In an unpublished report (1933?) Tanner refers to several of the chemical analyses mentioned by Snow and later states, "The solution content of the lake water has changed, being four times as saline as it was fifty years ago." Tanner also indicated that there was an increase in the average pH over the years (personal communication 1979).

Bradshaw and others (1969) state that the number of inorganic contaminants increased almost twofold between 1884 and 1899. The chloride-ion content increased by a factor of 25. However, if this number is modified to account for a decrease in the water level, the relative chloride-ion increase would be by a factor of 17. The increase in chloride ion was attributed to a rapid increase in the total amount of irrigation and the resultant leaching of salt from the soil.

Precipitation of $CaCO_3$ is a major contributor to sediment in Utah Lake, and the changes in the lake environment brought about by settlers in Utah Valley since 1849 have produced an increased rate of precipitation of $CaCO_3$.

RATE OF SEDIMENTATION IN UTAH LAKE

Various methods have been used to determine the rate of sedimentation in Utah Lake.

Brimhall (1972) analyzed chemically a core 500 cm long originally taken from Utah Lake in 1970 by Robert F. Bolland to study diatoms. The location of the core was about 2½ km west of the shoreline adjacent to the U.S. Steel Corporation plant at Geneva. Brimhall concluded that postsettlement times were reflected in the sediments above the 300-cm level, that the average rate of sedimentation from 1885 to 1935 was 2.6 cm per year, and between 1935 and 1965 it was 3.3 cm per year. In a later study (1981) Brimhall and Merritt revised the previous estimate with a postsettlement rate of 2 mm per year.

Bolland (1974), in his study of diatoms from the same core used by Brimhall in 1972, obtained a radiocarbon date from fossil peat at 490-500 cm which gave a date of 11,400 ± 850 years B.P. This would give a sedimentation rate since 9,450 B.C. of about .0438 cm per year. Bolland questioned this radiocarbon date and preferred to follow Brimhall's 1972 interpretation of the rate of sedimentation since the settlement of the pioneers in Utah Valley. Bolland suggested 2.4 cm per year between 1885 and 1935 and 3.43 cm between 1935 and 1970. Brimhall and Merritt (1981) also questioned the validity of the radiocarbon date and suggested possible contamination by small pieces of detrital calcite. There is also the possibility of redeposition of organic material eroded from older sediments. Nambudiri, Teller, and Last (1980) review the literature on errors in radiocarbon dating and suggest the use of a comparative ratio between reworked pollen grains and autochthonous pollen grains as a guide in correcting anomalous carbon-14 dates.

Bolland (1974) searched for varves as a means for determining the rate of sedimentation, but, apart from thick laminations below 488 cm, there were no distinctive varves. The core was composed almost entirely of uniform unconsolidated clays.

STUDIES OF OTHER LAKES

In the last 10 years, there have been an increasing number of studies of lake sediments and the factors that effect the rate of sedimentation in the lakes.

Kemp and others (1974) compare sedimentation rates of a number of lakes around the world with the rates found in the Great Lakes of the United States. The Black Sea has an average sedimentation rate of 0.3 mm per year; Lake Tanganyika, 0.5 mm per year, Lake Superior, 0.15 mm per year. These rates of sedimentation are estimates over a time interval of 1,000 years. Studies of lake sediments using recent time intervals give more rapid rates of sedimentation; Lake Washington, 3.1 mm per year; Wisconsin Lakes, 1.0 to 7.0 mm per year, English Lake District, 0.6 to 11.1 mm per year, Lake Huron, 0.7 to 1.4 mm per year; Lake Erie, 1.1 mm to 13.4 mm per year; Lake Ontario 1.0 mm to 5.4 mm per year; and Lakes Titicaca and Tahoe 1.0 mm per year.

Rates of sedimentation in lakes are determined through the use of pollen, changes in diatom assemblages, chemical changes related to industrial and urban wastes, carbon 14, cesium 137, lead 210, thorium 278-thorium 232, volcanic ash falls, and annual varve deposition.

Bortleson and Lee (1972) report that various human activities contribute to accelerated enrichment (cultural eutrophication) of waters. Among the symptoms of cultural eutrophication are nuisance blooms of algae, increased nutrient levels, depletion of hypolimnetic oxygen, increased turbidity, and changes in the species composition of phytoplankton, invertebrates, and fishes. Their study was of Lake Mendota, a hardwater eutrophic lake near Madison, Wisconsin. The lake receives domestic drainage from agricultural lands, urban runoff, and some municipal and industrial waste effluents contained in entering streams.

The sediments show a decided increase in the rate of sedimentation from 1820 (time of settlement) to 1920. The increase is a consequence of farm and urban activities in the lake basin. The chemical nature of the lake has also been significantly modified. The mean sedimentation rate for the past 100 years, studied in three cores, is 5.0 mm per year, 5.6 mm per year, and 6.2 mm per year.

Kemp and others (1974) state, "The sediments of a lake reflect the environmental conditions of the lake and land-use practices in the drainage basin at the time of deposition." They also point out that the total dissolved solids for Lakes Ontario and Erie have increased 43 percent in the last 60 years and suggest that this increase is due to larger populations and greater urban and industrial wastes discharged into the lakes. There was a threefold increase in sedimentation rates since 1935 in Lake Erie and since 1930 in the Kingston Basin of Lake Ontario. Erosion of fine-grained sediment in bluffs along the north shore contribute to the large annual deposition in Lake Erie. The recent sedimentation rate in Lake Erie ranged from 1.1 mm per year to 13.4 mm and for Lake Ontario, 1.0 mm to 5.4 mm per year.

Kemp (1971), in his discussion of the surface sediments of Lakes Ontario, Erie, and Huron, comments, "The recent increase in the carbonate content observed in Lakes Erie and Ontario cores is believed due to the acceleration of biogenic precipitation concurrent with the accelerating eutrophication of the lakes mentioned previously."

Davis (1975) made a pollen study of a small, shallow lake in Whitman County, Washington, in which the rate of sedimentation doubled since 1890 because of overgrazing by horses, cattle, and sheep. Volcanic ash beds gave a specific time from which to evaluate the rate of sedimentation over the last 450 years, and a dramatic increase in spores, many of the type associated with fecal matter, is considered to reflect the 1890 date when livestock grazing had its impact in producing an increased rate of erosion.

POLLEN IN UTAH LAKE SEDIMENTS

The large number of plants introduced into Utah Valley since 1849 provide a useful method for determining a time horizon in the sediments of the lake. Such a method is possible because of the great numbers of pollen grains distributed by wind and water currents and carried with other sediments into the lake.

Dr. Stanley Welsh provided a list of 50 plant types (see appendix), with the time of their introduction into the state of Utah. It is by no means a complete list; for example, only one out of about 40 introduced pine types is included. However, the list provides a broad variety of pollen types to work with. Reference pollen slides were prepared of most of the 50 plants listed, and the majority of the pollen samples were taken from the BYU Herbarium.

Pollen from 45 plants were selected for the purpose of the study in terms of distinctive appearance and greater likelihood of being transported into the lake.

A 5-m core taken in 1972 by Robert Finley Boland, a graduate student from the University of Utah, was used for the pollen study. This core was taken from Goshen Bay in the southern part of Utah Lake. The site of the core was one-third of the distance from West Mountain beach to the west shoreline between the east and west shores of the lake (fig. 1) and was considerable distance from any influx of detrital material by stream transportation. Slices of the core, 2 cm thick, were cut from the core every 10 cm, except for the top of the core where 5 samples were taken from the upper 10 cm. Altogether, 58 samples were cut, and 41 of them were processed to extract the pollen. Seventy-five slides were prepared, and 67 of them were studied. One hundred grain counts were made on 23 slides, and 200 grain counts were made on 13 slides so that percentage relationships between the different types of pollen could be determined.

The inaperturate-monoporate forms (mostly grass) pollen were the most abundant throughout the samples studied, with a distinctive increase from 230–232 cm to the top of the core. The vesiculate (pine type) forms showed fluctuations in abundance with a decrease in the last 8 cm of the core. The periporate pollen count was very constant throughout with one low count at 150–152 cm. Tricolpate pollen showed a decreasing trend from 250–252 cm to the top of the core, except for the very top where there was a slight increase. Echinate pollen grains were not common and fluctuated in importance from sample to sample. Spores were not present in 8 samples and showed an increase in numbers in the upper 60 cm of the core.

One of the most interesting occurrences was the appearance of algae in several samples. In one slide the algal forms represented 21 percent of all forms counted. In another slide 42 percent of all forms were algae. The large numbers of algae suggest algal blooms in the past. Dr. Sam Rushforth of the BYU Botany Department identified two of the more common algal forms present as *Pediastrum boryanum* and *Pediastrum simplex* var. *duodenarium.*

Taraxacum officinale, or the common dandelion, proved to be the means by which a useful approximate age level was determined from the core studied. *T. officinale* was found in five samples, 2–4 cm, 20–22 cm, 30–32 cm, 50–52 cm, and 170–172 cm. Very few forms were present, and one might ask why the dandelion pollen was not present in the intervening samples. If more slides were prepared and more samples taken from each of these levels very likely the presence of *T. officinale* would be established in each of the intervening levels. Another very distinctive pollen form, *Ephedra,* was found in the lowermost sample 484–486 cm and at 2–4 cm but was missing in 17 samples studied.

Taraxacum officinale is one of the plants considered to be introduced into the valley in 1849. At present it is found growing throughout the valley and around the lake shore and even on Bird Island. There is no way of knowing how long it took for the dandelion to become abundant enough so that its pollen became a significant part of what was trapped in the lake sediments, nor do we know for sure that 170–172 cm represents the oldest sediments in the lake containing dandelion pollen. Therefore the rate of sedimentation determined by the 170–172 cm level must be considered as a minimum rate of sedimentation.

If we use 170 cm as the amount of sediment deposited since 1849, it would give an average rate of deposition from 1849 to 1972 of 1.38 cm per year.

CONCLUSIONS

The presettlement condition of Utah Lake and its environment is still not clearly demonstrated, but the bulk of the evidence available at the present time indicates that marked changes have taken place in the lake and its surroundings and that human activities have significantly contributed to these changes.

The study of pollen in the Utah Lake sediments indicates that a rate of sedimentation of 1.38 cm per year has occurred since 1849. This rate is perhaps the most reliable rate so far determined because it is of the same order of magnitude as that reported in studies of lakes similar to Utah Lake. It is important to note that these lake studies call attention to the greatly increased rate of sedimentation in these lakes due to the effect of human activities on the environment.

Additional cores should be taken of the Utah Lake sediments to check the sedimentation rate of 1.38 cm per year and to obtain additional information about the rate of sedimentation before 1849.

There is a need for additional data on the input of dissolved minerals into the lake particularly from the springs within the lake. The suspended load of detritus brought into the lake by streams needs to be studied for the amount and composition of the materials being transported. This study should be done on a seasonal and on a long-range basis. The average percent of calcium carbonate present in the lake sediments is 60 percent, and it reaches 80 percent in some places. Where does all that carbonate material come from? Bissell's (1942) evaluation of Utah Lake sediments indicates a very significant increase upward in the calcium carbonate content of the sediments in the upper part of the cores that he studied. What is primarily responsible for the increase in the accumulation of calcium carbonate?

Future studies of cores from Utah Lake should take into consideration the percent of water in the cores and the amount of compaction as dewatering occurs. These matters were not considered in the present study of the rate of sedimentation in Utah Lake.

APPENDIX

Plants introduced into Utah since 1847 (partial listing)
Stanley Welsh

1920	1. *Acer platanoides*	Aceraceae	Norway maple
1847	2. *Amaranthus graecizans*	Amaranthaceae	Redroot pigweed
1935	3. *Anchusa officinalis*	Boraginaceae	Bugloss
1850±	4. *Arctium minus*	Compositae	Burdock

1850	5. *Asparagus officinalis*	Liliaceae	Asparagus
1900±	6. *Berberis thunbergii*	Berberidaceae	Barberry
1860	7. *Beta vulgaris*(?)	Chenopodiaceae	Sugar beet
1875	8. *Betula alba*	Betulaceae	White birch
1850	9. *Brassica sp.*	Cruciferae	Mustard
1850	10. *Cardaria draba*	Cruciferae	White tip
1930	11. *Chorispora tenella*	Cruciferae	Mustard
1850–60	12. *Cirsium arvense*	Compositae	Canadian thistle
1860	13. *Convolvulus arvensis*	Convolvulaceae	Bindweed
1860	14. *Daucus carota*	Umbelliferae	Carrot
1910–15	15. *Elaeagnus angustifolia*	Elaeagnaceae	Russian olive
1880–90	16. *Erodium cicutarium*	Geraniaceae	Storksbill
1890	17. *Fraxinus pennsylvanica*	Oleaceae	Red ash
1890	18. *Gleditsia triacanthos*	Leguminosae	Honey locust
1934	19. *Halogeton glomeratus*	Chenopodiaceae	Halogeton
1925	20. *Hyocyamus niger*	Solanaceae	Henbane
1900	21. *Iris spuria*	Iridaceae	Iris
1860	22. *Juglans nigra*	Juglandaceae	Black walnut
1900±	23. *Juniperus chinensis*	Cupressaceae	Chinese juniper
1875	24. *Lactuca scariola*	Compositae	Prickly lettuce
1890	25. *Lonicera tatarica*	Caprifoliaceae	Honeysuckle
1850	26. *Malus sp.*	Rosaceae	Apple
1850	27. *Marrubium vulgare*	Labiatae	Horehound
1850	28. *Medicago sativa*	Leguminosae	Alfalfa
1850	29. *Mentha spicata*	Labiatae	Spearmint
1850	30. *Morus alba*	Moraceae	Mulberry
1860	31. *Neptea cataria*	Labiatae	Catnip
1860	32. *Phaseolus vulgaris*	Leguminosae	Garden bean
1860	33. *Pisum sativum*	Leguminosae	Garden pea
1860	34. *Populus nigra*	Salicaceae	Lombardy poplar
1851	35. *Prunus sp.*	Rosaceae	Cherries, plums, apricots, peaches
1930	36. *Ranunculus testiculatus*	Ranunculaceae	Bur buttercup
1860	37. *Robinia pseudoacacia*	Leguminosae	Black locust
1860	38. *Rorippa nasturtium-acquaticum*	Cruciferae	Watercress
1850	39. *Rubus idaeus*	Rosaceae	Raspberry
1900	40. *Salsola pestifer*	Chenopodiaceae	Russian thistle
1875	41. *Sisymbrium altissimum*	Cruciferae	Tumble-mustard
1850	42. *Solanum tuberosum*	Solanaceae	Potato
1900	43. *Tamarix ramossisima*	Tamaricaceae	Salt cedar
1847	44. *Taraxacum officinale*	Compositae	Dandelion
1847	45. *Tragopogon dubius*	Compositae	Goatsbeard
1915	46. *Tribulus terrestris*	Zygophyllaceae	Puncture vine
1850	47. *Trifolium pratense*	Leguminosae	Red clover
1900	48. *Ulmus pukila*	Ulmaceae	Siberian elm
1900	49. *Verbascum thapsus*	Scrophulariaceae	Mullein
1875	50. *Xanthium strumarium*	Compositae	Cocklebur

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