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Contents

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Recent Sedimentation Trends in Utah Lake*

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ABSTRACT.—A detailed study of the lake bottom sediments being deposited in Utah Lake was made with major emphasis placed on grain-size analysis, organic carbon content, carbonate content, and clay types. Computer-generated trend surface maps were constructed showing the areal distribution of these constituents. Where feasible the substrate flora and fauna of the lake were compared to sediment type.

Calcium carbonate is the most abundant sediment present, the measured weight percent total ranging from 6 to 73 percent. Clastic grains, which make up essentially the remainder of the sample, range from granule to clay size with silt being the most abundant size.

The coarser fractions (granule to very fine sand size) are concentrated near the mouths of and in a southerly direction from the major rivers entering Utah Lake. Smaller percentages of the coarse fractions ring the lake, while very few of the coarse sizes are found near the center. Silt and clay sizes are more abundant in the center portions of the lake and generally farther from the depocenters.

Organic material tends to be the highest in isolated bays and sloughs that harbor abundant plant life. Three high carbonate concentrations were mapped: northwest, center, and southwest portions of the lake.

The clay mineralogy includes kaolinite, illite, and mixed-layer illite-montmorillonite. Proportionately, illite in the form of discrete mica was the most prevalent. The uniformity of clay-type distribution across the lake is most likely due to the formations of clays under the same climatic conditions.

Sediment type generally cannot be used as a factor in predicting which plant community will prefer one location over another. Invertebrates in Utah Lake tend to be more selective, with worms and midge fly larvae preferring the lime mud areas, and small crustaceans the firm tuffa beaches.

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*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, June 1974: Morris S. Peterson, thesis chairman.

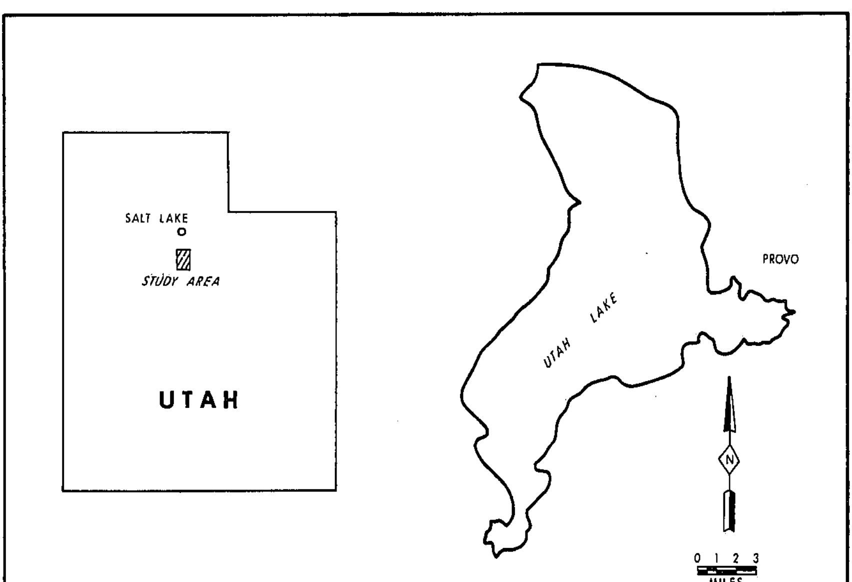
INTRODUCTION

Location and Description

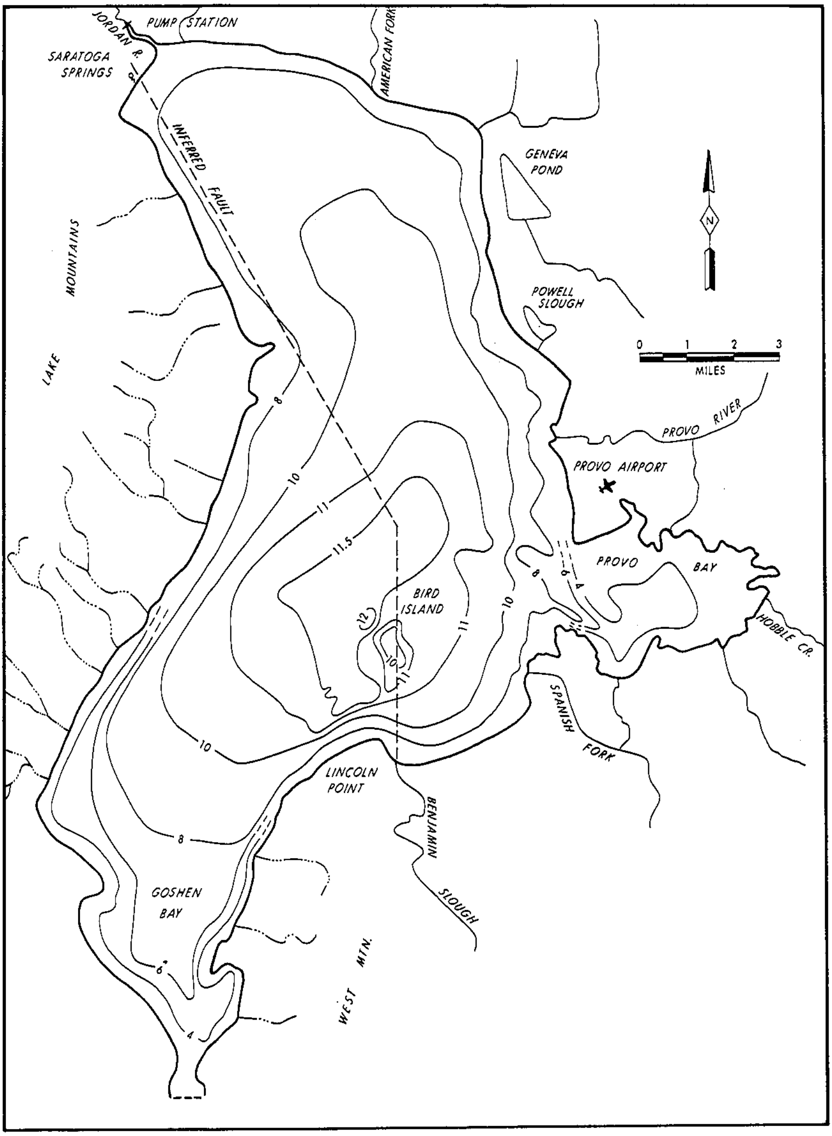
Utah Lake, the third largest body of water in Utah, is located near the western city limits of the Provo/Orem city complex (Text-fig. 1). Situated in central Utah's Utah County, the lake is basically bounded on all sides by mountainous terrain. At the time of sampling the lake was approximately 22 miles long, following the general outline, and 12 miles at its greatest width, which includes Provo Bay. The water is fresh and has an average depth of 8 feet. A few deep areas have been located, none of which exceeds 12 feet. Utah Lake receives water from a number of tributaries that are located primarily at the eastern shore and that drain the Wasatch Mountains. Provo River, Spanish Fork River, and American Fork River are the main streams contributing water and sediment to the lake. Minor amounts come from the remaining canals, creeks, and springs, usually originating within the lake basin (Text-fig. 2).

Purpose and Scope

The objectives of this study are to (1) determine the component sediment sizes of Utah Lake; (2) map, on a broad basis and through the use of com-



TEXT-FIGURE 1.—Index map showing location of Utah Lake.



TEXT-FIGURE 2.—Bathymetric and source map of Utah Lake. Bathymetry is measured in feet. Dashed line indicates inferred faulting.

puterized multivariate regression methods (trend surface maps), the areal distribution of these fractions; and (3) relate, where possible, these sizes to present biological communities throughout the lake. Major emphasis was placed on the size distribution of the sediment fractions; the composition of the fractions was subordinated.

Previous Work

Previous sedimentation study of Utah Lake is restricted primarily to a paper by Bissell (1942) in which 157 cores taken at 11 locations in the lake were analyzed for grain size, water content, organic content, and acid-soluble material.

Geochemical studies have been conducted on the lake by Brimhall (1972) and Sonerholm (1973). Brimhall established a recent history of Utah Lake by examining certain chemical profiles. Sonerholm (1973) chemically analyzed the bottom sediments over the entire lake and mapped general trends in sediment type. Water chemistry studies have also been carried out by Bradshaw (1969).

Much work has been completed on the biological communities of Utah Lake. The best recent plant study, conducted by Coombs (1970), involved the mapping of all plant communities in and around the lake. Many studies have been made on the benthic animal communities, the most detailed of which is being conducted by Barnes (1974) in connection with the Utah Lake Research Station, Brigham Young University.

ACKNOWLEDGMENTS

Deep appreciation is expressed by the writer for the assistance received from the following individuals: Dr. Morris S. Petersen, professor of geology at Brigham Young University, who made the continuation of this problem possible and offered numerous suggestions concerning the approach and organization of the report; Dr. Willis H. Brimhall, professor of geology at Brigham Young University, who assisted in adapting data to available trend surface computer programs; and Dr. John B. Hayes, of Marathon Oil Company, who ran independent checks of clay mineral identification.

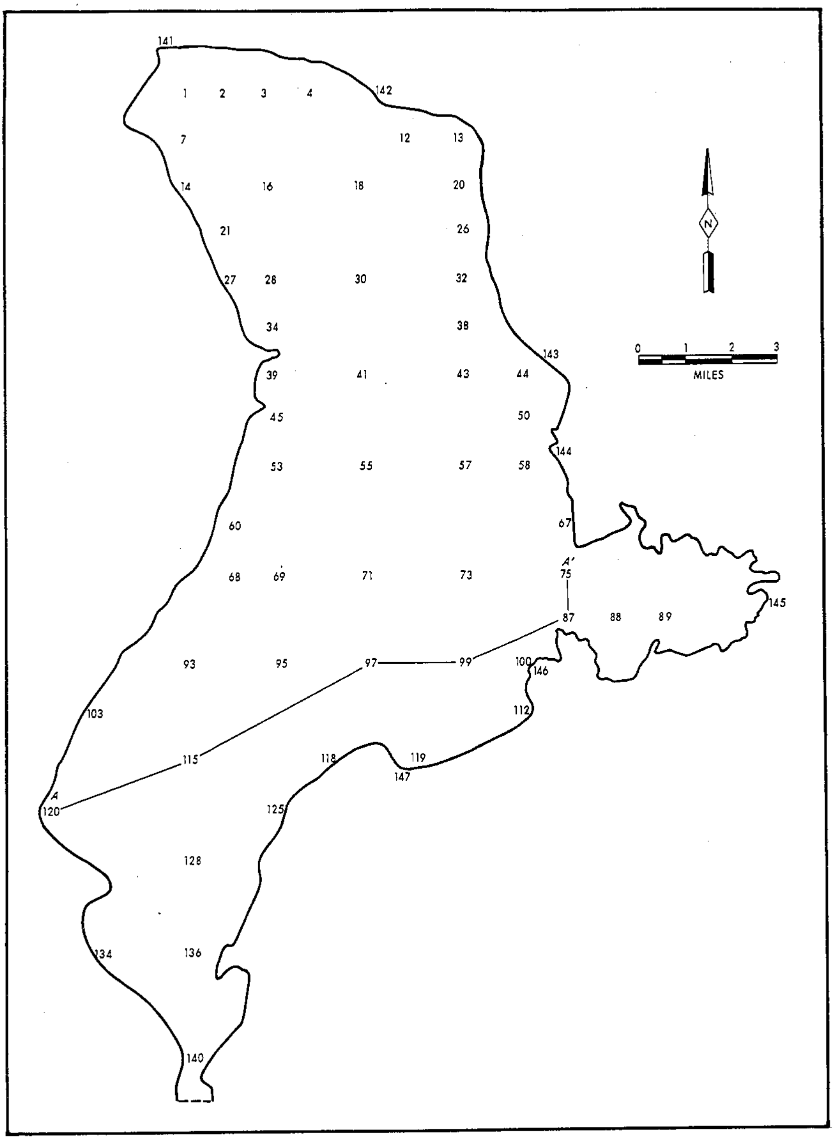
The writer also acknowledges the many people who aided in all facets of the study, not the least of whom is Sid Petersen, who helped in the collection of samples, and Rita Bingham, wife of the writer, who assisted in assembling the report.

FIELD METHODS

Sample locations were selected from a base map prepared by extending section lines across a topographic map of Utah Lake and its adjacent areas (Text-fig. 3). Generally, every other intersection of these lines was chosen with additional points being selected where sections crossed close to the shoreline. Sediments at the mouths of all major streams were sampled, as well as those from a few minor tributaries.

Because this problem deals with recent sedimentation, only the top few inches were necessary for study. Two different sampling devices were originally used, the clam shell "snapper" and a coring device. The snapper proved ineffective, due to the amount of sediment lost by water rushing through the device as it was pulled to the surface. Core samples were then taken from a boat using a Davis peat sampler, modified by Bissell (1942). Cores were preserved wet in plastic bags and coded with each station number.

By regulating the feet-per-second rate of the boat to a preset engine RPM, sample locations could be determined relatively well. Traverses were taken in an east-west direction, since this was the shortest distance and would mini-



TEXT-FIGURE 3.—Sample location map. Section A-A' refers to histogram cross section.

mize errors in estimated rates of travel. Drift was not a problem because fixed land bearings were used to keep the boat headed in the direction of the line of samples. Near the shore samples were located using a topographic sheet and an enlargement of a recent high-altitude aerial photograph of the lake.

LABORATORY METHODS

General

The 60 samples were removed from their plastic bags and the upper several inches of each core split into equal portions to determine water content, organic carbon, acid-soluble material, and grain-size distribution. A brief examination was made on each core and is presented with the description of the samples.

Water Content

To determine the quantity of physically bound water within the sediment, a split sample from each core was weighed while wet, allowed to dry, and reweighed. The difference was the amount of pore space water contained in the sample. Chemically bound water within the clay minerals was unaffected by the process and was not measured.

Organic Carbon

Active organic content of the samples was determined by the wet combustion chromic acid method (Walkley-Black, 1934). This method discriminates between the highly condensed forms of organic carbon such as graphite, coal, charcoal, etc., and the active organic or oxidizable matter found in recent sediments and soils. Since soil organic matter averages about 58 percent carbon, a conversion factor of 1.72 was utilized in expressing organic carbon as organic matter (% organic matter = %C x 1.72 where the factor 1.72 = 100 ÷ 58).

Acid-Soluble Material

Because mollusk and bivalve shells were relatively uncommon in most of the cores, they were removed by hand picking prior to splitting to avoid errors in the final results of the various processes by the presence of one or two large shells. The appropriate split sample was then dissolved in dilute HCl to establish the weight percent of acid-soluble material present. Standard methods for this process were employed.

Size Distribution

Samples for this process were dried at approximately 50°C and weighed. Forty-gram samples were used to allow ample sediment for coarse and fine size separations after the $CaCO_3$ was removed. Because of the high carbonate content, disaggregation of the dry sample was accomplished by digestion in dilute HCl. Organic matter was removed from this portion by using reagent grade H_2O_2 in a process described by Jackson (1949).

All samples were dispersed at this point using sodium oxalate as the dispersing agent. The sediment was then wet sieved to separate coarse and fine fractions using standard practices. Coarse fractions, 230 mesh and larger, were dried and sieved with the aid of a Ro-Tap shaker. Further separation of the fines was achieved by the pipette method described by Folk (1961).

Clay Preparation

Clay-size particles, particularly the clays themselves, make up a significant portion of the fines. These particles were separated from the sediment, the

TABLE 1
CLASSIFICATION BY SIZE: UTAH LAKE SEDIMENTS

	Percentages by weight										
				Screen analysis						Wet analysis	
					Sand					Silt	Clay
Station no.	Water content	Acid-soluble material	Organic matter	Granule 4mm-2mm	Very coarse 2mm-1mm	Coarse 1mm-.5mm	Medium .5mm-.246mm	Fine .246mm-.125mm	Very fine .125mm-.062mm	.062mm-.0039mm	.0039mm
1	51.00	68.65	1.30			.03	.14	.45	2.29	13.12	11.88
2	36.81	70.69	1.36			.02	.07	3.05	1.36	13.50	12.88
3	35.65	67.72	2.22					.05	.44	16.13	13.13
4	44.04	66.83	1.36				.02	.05	.21	16.50	14.00
7	47.36	49.25	4.94		.04	.05	.08	.19	.70	26.80	14.50
12	38.34	68.44	1.66					.03	.06	11.88	16.88
13.	25.82	42.97	1.77		.01	.01	.04	2.04	2.66	35.13	13.38
14	25.87	35.24	4.69		T	.06	.31	2.69	14.07	32.75	9.00
16	38.87	69.13	1.37					.04	.28	12.63	16.50
18	36.59	68.96	1.65				.02	.04	.17	13.00	16.63
20	29.99	34.86	1.02			T	.79	7.83	15.04	30.13	10.13
21	35.24	68.71	1.67				.04	.21	1.54	14.88	10.63
26	43.57	71.60	1.70			.03	.05	.11	.25	11.75	16.50
27	35.54	27.27	1.67		.10	.15	.57	1.20	3.19	35.74	32.13
28	36.43	61.22	1.47				.01	.07	.58	20.13	15.13
30	35.39	64.88	1.85				.05	.20	.11	11.63	19.38
32	24.09	18.23	.26			.23	17.64	38.65	11.50	6.88	4.63
34	26.80	57.06	1.07	.21	.02	.03	.07	1.19	13.01	21.25	8.15
38	43.46	65.99	1.40				.01	.11	.26	11.25	20.63
39	31.51	40.65	1.23			T	.02	.76	15.94	32.13	9.25
41	43.01	66.36	1.73			.01	.02	.06	.17	14.88	18.63
43	44.28	64.03	1.68				.04	.04	.10	14.38	18.25
44	35.53	22.99	1.41			T	.67	14.50	31.30	17.11	10.03
45	43.41	62.69	1.48					.08	.94	16.20	16.79
50	45.99	61.79	2.17			T	.08	.15	.15	17.25	18.38
53	40.08	65.44	1.60				.01	.01	.01	12.38	19.25
55	44.79	67.35	1.87					.02	.11	14.75	16.63
57	42.17	63.55	1.95				.04	.08	.07	19.50	15.25

Table 1 (continued)

58	46.07	60.30	2.03			.03	.31	.42	.19	20.38	18.38
60	No Sample										
67	17.39	8.95	.22		.21	.58	16.38	54.69	16.92	1.38	.63
68	40.95	70.66	1.81				.01	.07	.51	9.88	16.00
69	40.05	73.15	2.03					.04	.14	11.85	15.03
71	47.58	67.72	.73					.03	.19	12.50	19.75
73	52.91	61.13	1.52			.03	.05	.08	.18	16.75	19.00
75	19.74	8.08	T	.07	.05	1.66	14.11	48.76	24.47	1.63	.75
87	52.27	34.58	6.41			.21	.40	1.03	9.52	32.88	13.00
88	44.39	28.66	4.84			.03	.12	.38	10.60	45.13	8.13
89	54.95	57.65	6.14		.03	.03	.03	.04	.59	22.00	13.38
93	37.41	72.07	1.94				.01	.09	.55	10.75	16.25
95	42.82	69.44	1.33				.02	.03	.18	10.75	19.38
97	44.72	69.98	1.55				.03	.51	2.63	12.75	14.88
99	43.43	65.08	1.60			T	.01	.05	.43	18.25	15.63
100	21.72	21.52	1.39		.07	.34	3.96	58.44	10.79	2.38	1.38
103	29.44	27.45	.17		.05	.06	.22	.95	7.20	48.75	13.63
112	23.10	21.10	.71		.04	.10	4.98	42.00	16.85	12.88	2.00
115	39.63	68.85	1.70				.01	.05	.24	12.00	18.38
118	Rock	61.65	----			.22	1.73	5.04	11.11	15.18	7.18
119	33.83	20.69	.61			T	.02	.41	8.88	65.88	3.38
120	31.65	68.24	.98				.02	.09	.95	19.75	9.50
125	38.76	61.27	1.32		.03	.07	.15	.58	2.46	19.50	14.00
128	35.41	67.10	1.65				.02	.03	.12	14.00	16.88
134	30.61	60.14	1.03			.02	.12	.27	.64	25.38	10.38
136	41.21	59.76	2.13				.02	.07	.44	22.00	16.88
140	31.93	50.07	1.44			.02	.04	.07	.59	37.85	12.03
141	32.42	37.01	2.82	.60	.15	.05	.05	2.55	15.24	34.88	8.38
142	38.56	32.03	.97	.40	1.11	2.88	15.85	27.40	12.48	7.13	1.88
143	67.56	33.34	16.29				.05	.22	2.27	31.25	14.63
144	not valid	6.47	.25		.15	.44	16.20	63.39	6.62	2.63	2.50
145	23.30	22.69	.99	.31	.46	1.12	.75	5.96	21.80	32.63	11.75
146	24.30	25.32	.46	.23	1.18	4.59	37.81	22.62	3.71	3.63	.88
147	67.00	37.65	6.37		.34	.66	.69	2.22	3.41	22.93	23.83

clay-size carbonate removed, and the remainder placed on glass slides for X-ray examination according to a method by Jackson (1956). X-ray diffraction patterns were obtained using the General Electric XRD-5 diffractometer. The slides were run first without further preparation and then were solvated with ethylene glycol and again X-rayed.

Interpretation of the X-ray data was done by comparing peak positions and intensities with traces of known clay standards. These standard traces were made available by Dr. John B. Hayes of Marathon Oil Company. Six samples were also run by Mr. Bud Holland of Atlantic Richfield Company, verifying the results obtained.

DATA PROCESSING

The weight percent data from each grain size studied in each sample were converted to logarithmic form and punched on computer cards. Raw values sometimes differed widely from point to point and would cause the trend analysis program to discount excessively high or low figures. Data from the carbonate content and organic carbon content did not vary to the same degree and were used in the original form. Sample location coordinates were punched on additional cards and added to the sample data. The trend analysis program processed the data for each sample and punched additional cards, which were used by the computer to construct the eight trend surface maps: (1) log weight percent coarse fraction, (2) log weight percent medium fraction, (3) log weight percent fine fraction, (4) log weight percent very fine fraction, (5) log weight percent silt fraction, (6) log weight percent clay fraction, (7) weight percent acid soluble material, and (8) weight percent organic matter. Granule or very coarse fractions were not used to construct maps because few samples contained these sizes.

The computer program used in the construction of the trend surface maps tends to have a smoothing effect; in that actual observed data are averaged over areas of similar values. This averaged figure is then compared with the original data and expressed as the coefficient of correlation, or basically, how closely the two sets of numbers agree.

All of the trend surface maps for the Provo Bay area have been modified slightly by the writer. The irregular outline of the lake plus insufficient control in and around this area posed difficult problems for computing trend surfaces. Some modifications through hand contouring were made on the maps in the vicinity of Provo Bay to make them more realistic.

CHARACTER AND DISTRIBUTION OF THE BOTTOM SEDIMENTS

General Description

Utah Lake is a freshwater lake that is being filled with sediment at a maximum rate of 3.3 cm per year (Brimhall, 1972). Most of the center portion of the lake is floored with a homogenous mass of light gray mud consisting primarily of calcite, silt, varying amounts of illite, kaolinite, interlayered illitic-montmorillonite clays, and water. Coarser sediment generally rings the lake but is absent in areas far removed from the sources of deposition.

A detailed description of the sediment grains is given in the Appendix and will not be discussed here. With few exceptions samples contained quartz grains, clear to cloudy, subangular to rounded; rock fragments; heavy minerals;

and black accessory or opaque minerals. River and near-river sediments contain a large percentage of rock fragments in the coarse fractions (granule to coarse sand size), while in the smaller fractions (medium to very fine sand size) quartz grains are more abundant. Near the mouths of the rivers small amounts of mica, clinkers, coal, feldspars, silicified oolites, and clay chunks are encountered. This may indicate a concentration of these components prior to dispersal by sedimentalogical processes.

Granule and Very Coarse Sand Size Fraction

Only a few grains larger than granule size were encountered in all sampled sediment. Where found, these grains were added to the next smaller sieve size.

Maps were not constructed of the granule and very coarse sizes because of the scarcity of data. Only six sample locations produced granule size fractions, and seventeen locations produced very coarse sizes. The scarcity of control for these two sizes would not allow the construction of realistic maps. The individual values for these fractions were generally near 1 percent, or less, of the total weight.

Sediment of these sizes was basically found at the mouths of major rivers and at the Jordan River pump station where dredging may have exposed lower coarse sand horizons (Text-fig. 2).

Coarse Sand Size Fraction

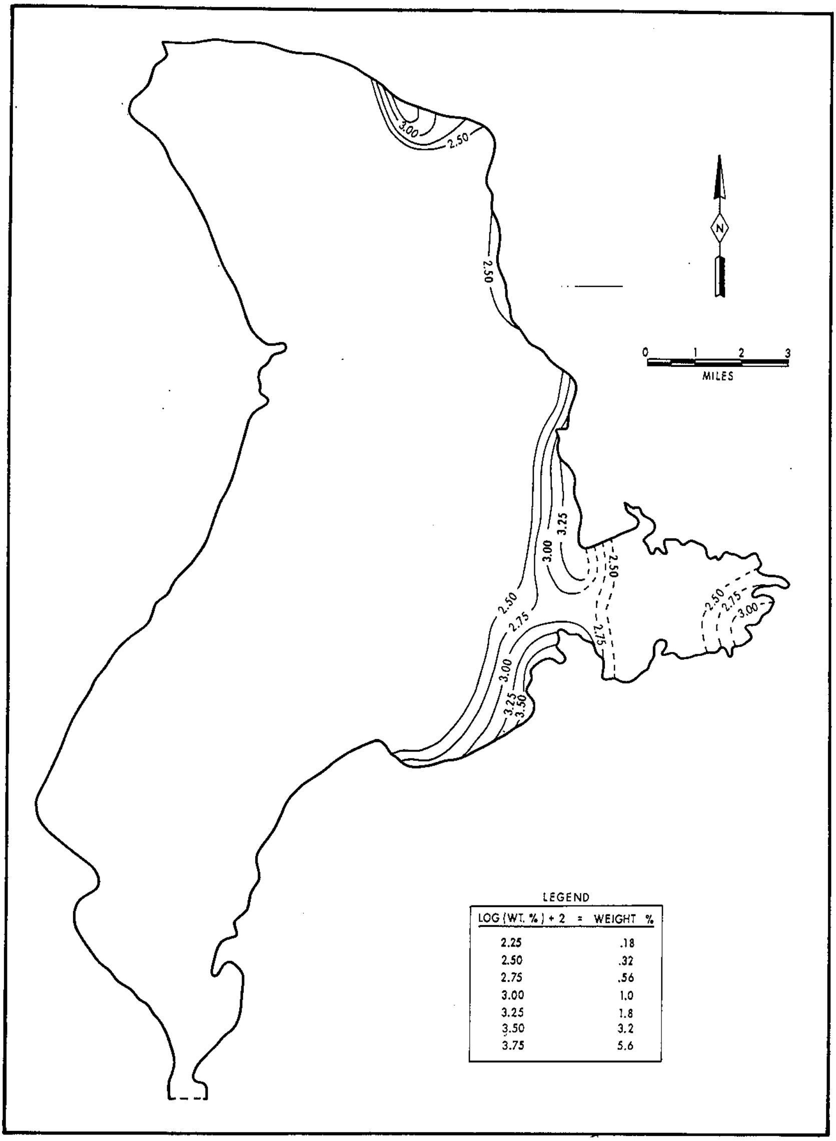
This is the first mappable horizon and consists of a thin band of sediment, usually less than 3 percent by weight, following the eastern shoreline (Text-fig. 4). This is directly associated with deposition of coarse clastics by the major streams flowing into Utah Lake. The most pronounced areas of deposition are the area surrounding American Fork River, the interground between American Fork River and Powell Slough, Provo River, and the area southward along the Provo City Airport to the mouth of Provo Bay. A small amount spills across the mouth of Provo Bay. The largest accumulation of coarse sand occurs immediately north of and extending south from the Spanish Fork River.

Medium Sand Size Fraction

High medium sand concentrations trend along the same areas as the coarse sands in the eastern shore areas. Text-figure 5 illustrates the heavy concentration of medium sand at the mouths of and trending south from the major rivers flowing into Utah Lake. The largest concentration of medium sand is in the area of Provo River and southward to Mud Lake (Provo Bay) and the area of Spanish Fork River. The center of the lake, for all practical purposes, is devoid of medium-size grains but has a slight increase along the western shore. Medium sand would have been deposited at the western shore by the many intermittent streams and gullies that drain the Lake Mountain area. Goshen Bay also has little medium sand, which would indicate an extremely low level of coarse clastic sedimentation from the south end of the lake.

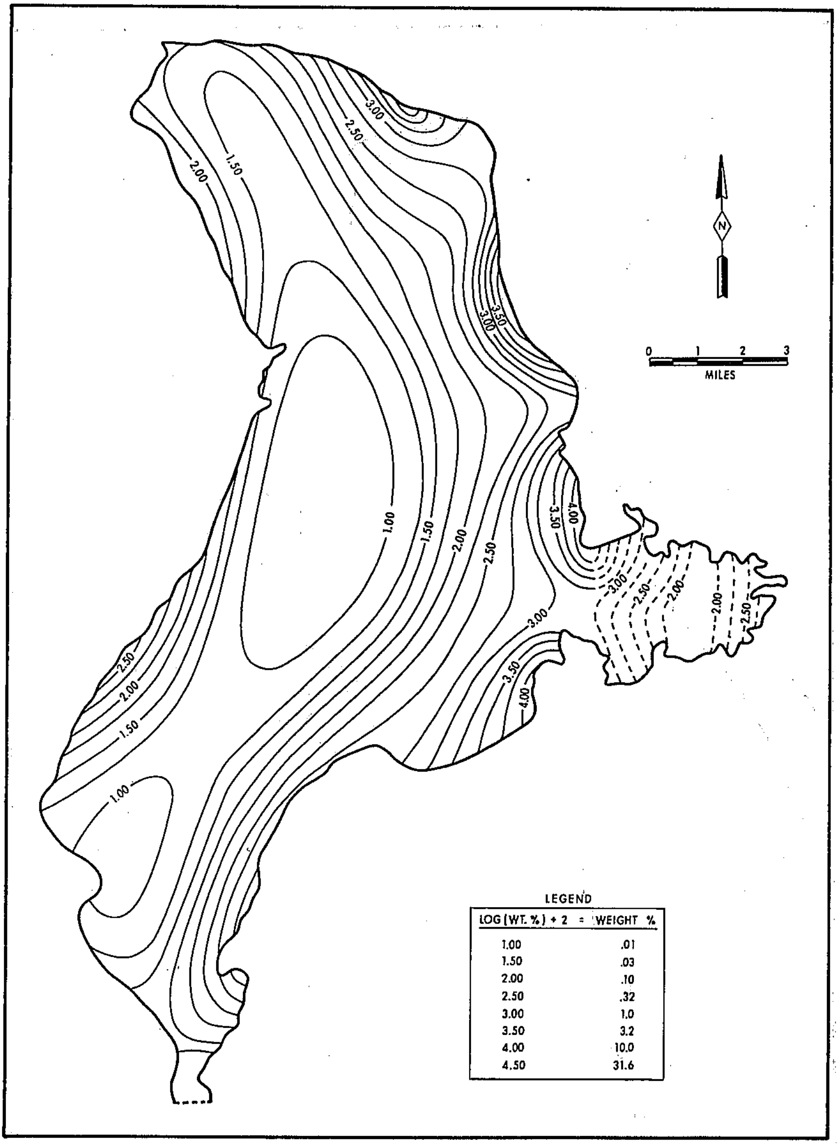
Fine Sand Size Fraction

Fine sand is more widespread than other coarse clastics. Still, there is an area trending north-south and following the outline of the lake that has little or no fine sand (Text-fig. 6). A slight correlation between deeper water



TEXT-FIGURE 4.—Trend surface map of the log weight percent coarse sand fraction. Contour interval 0.25.

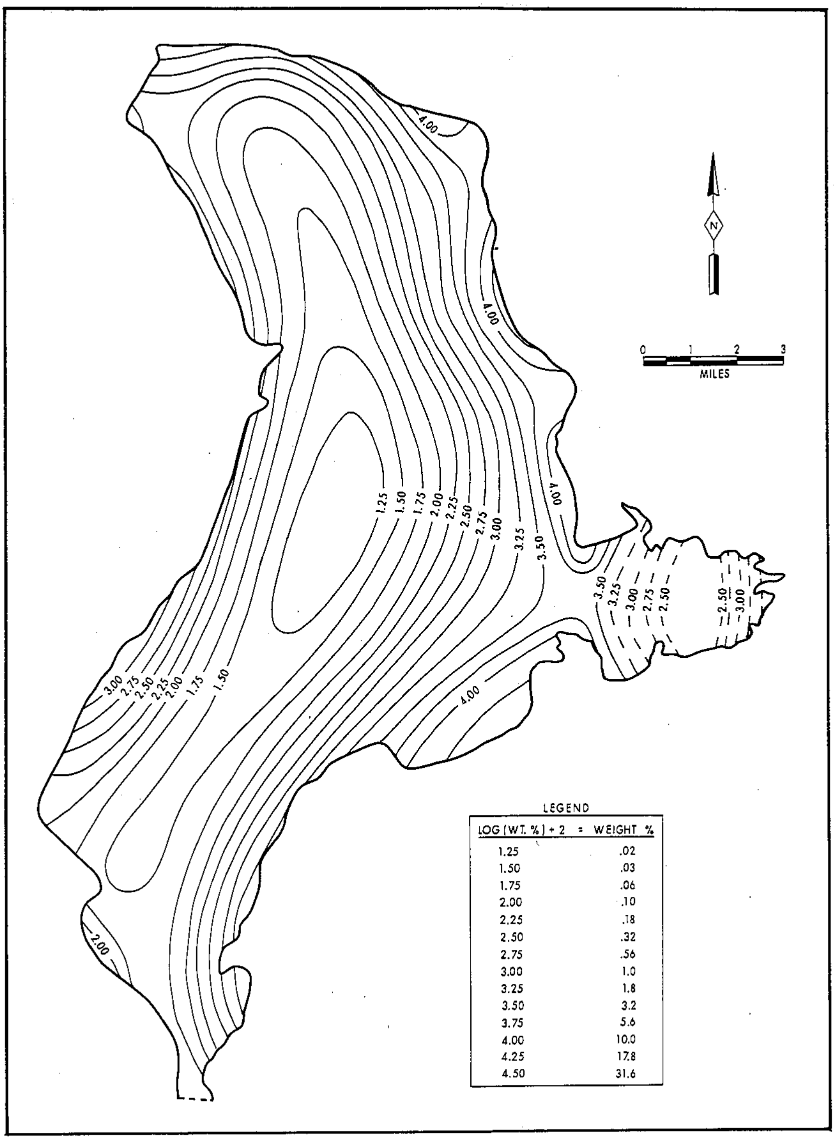
areas and smaller weight percent sand concentrations exists in all of the coarse clastic trend maps. Fine sand values as high as 65 percent are encountered at the mouths of major tributaries along the eastern shore. High value trends follow those of the previously discussed fractions. In the areas of active deposition the fine sand fraction tends to be the most dominant.



TEXT-FIGURE 5.—Trend surface map of the log weight percent medium sand fraction. Contour interval 0.25.

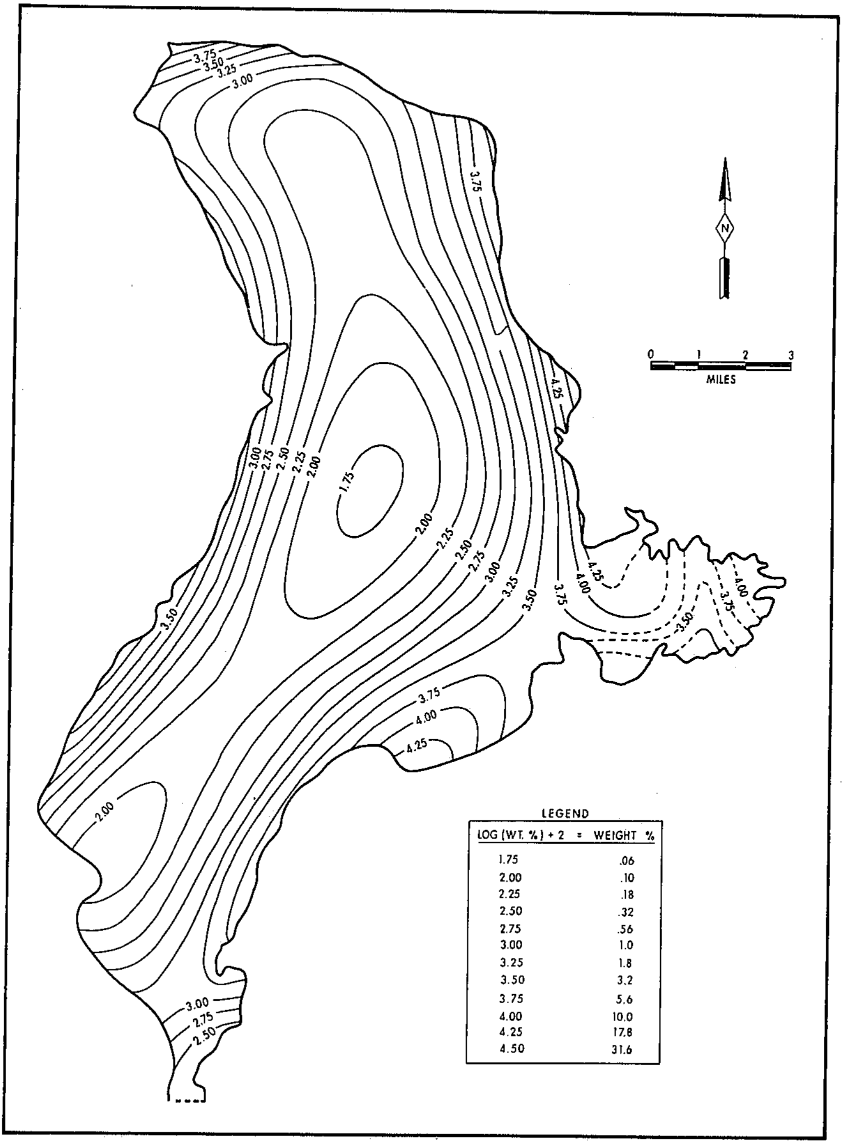
Very Fine Sand Size Fraction

Of the coarse clastics (granule to very fine grain sand), the very fine fraction is the most widespread with regard to area (Text-fig. 7). All locations produced some very fine sand from .05 percent to as high as 31 percent just west of Powell Slough. The latter seems to reflect the current-in-



TEXT-FIGURE 6.—Trend surface map of the log weight percent fine sand fraction. Contour interval 0.25.

fluenced southward lateral movement of the coarse clastics originating in the American Fork River depocenter. The same strand line effect can be seen south of Provo River along the shoreline opposite the Provo City Airport and extending as a spit into the mouth of Provo Bay. This spit is not readily recognizable at high water level but can be seen easily at lower levels as il-



TEXT-FIGURE 7.—Trend surface map of the log weight percent very fine sand fraction. Contour interval 0.25.

lustrated by the hooked water bottom contours in the mouth of Provo Bay (Text-fig. 2).

Similar basic trends exist as before with an increase in percent of very fine sand along the eastern and southern shores. Intermittent streams of the Lake Mountain and Goshen Bay areas carry predominantly fine and very fine grained sediment. The large tributary areas do not have as high a percent of this fraction as do the areas influenced by longshore currents south of Powell Slough and south of the airport. The shoreline northeast of Benjamin Slough has a large percentage of very fine sediments which probably originated from the Spanish Fork River and were transported southward by currents and wave action. Apparently the wind-influenced currents striking the Spanish Fork River delta from the northwest divide the sediment transportation to the northeast and southwest, causing a sandy shoreline in these areas.

Silt Size Fraction

The distribution of silt size particles is widespread and relatively uniform across a large portion of the lake (Text-fig. 8). Small anomalies representing high and low percent concentrations occur throughout the entire length of the lake. These anomalies compare favorably with the areas of high $CaCO_3$ concentration as seen in the carbonate map (Text-fig. 11). The reason for this correlation is unknown.

Smaller percent concentrations are located at or near the mouths of major streams. This is especially true at the mouth of the Provo River and southward along the shoreline where wind-generated currents tend to sift out the fines and redeposit them in quieter water.

Silt size particles are the most prevalent size in Provo Bay and are most likely due to the washing of sands near the airport. The silt from this area, along with the silt from Hobble Creek and the many drainage ditches emptying into Provo Bay, converge near midbay to form the highest concentration in the lake. The eastern margins of Provo Bay have high concentrations of silt size particles with low values for the coarser fractions. Most of the drainage emptying into the bay is by way of man-made ditches and canals (Text-fig. 2). The flow of Hobble Creek, the main source of sediment into the bay, has been diminished in its lower reaches by a series of irrigation dams which have resulted in decreased coarse clastic deposition.

Clay Size Fraction

Like the silt fraction, the clay size sediment is more evenly dispersed across the lake than the coarser sizes (Text-fig. 9). A general trend of high percentages is located in the centers of the middle and lower sections of Utah Lake. Again, low values exist at or near the mouths of major streams, indicating that clays and clay size particles are not deposited there but are swept away by wave action and/or currents. Clay sizes are nearly absent from the bottom sediments of Provo River and southward along the shoreline toward Provo Bay.

Clay Mineralogy

The clay minerals of Utah Lake appear to be somewhat uniform in their distribution and type. Three basic clay types were encountered: illite (discrete mica), kaolinite, and mixed-layer illite-montmorillonite. Chlorite in very minor amounts was also present in a few samples.

Illite is the most prevalent clay mineral and ranges in relative clay percent from 33 to 95 percent (Table 2). The average sample contains between 40 and 70 percent. There appears to be no obvious correlation between high

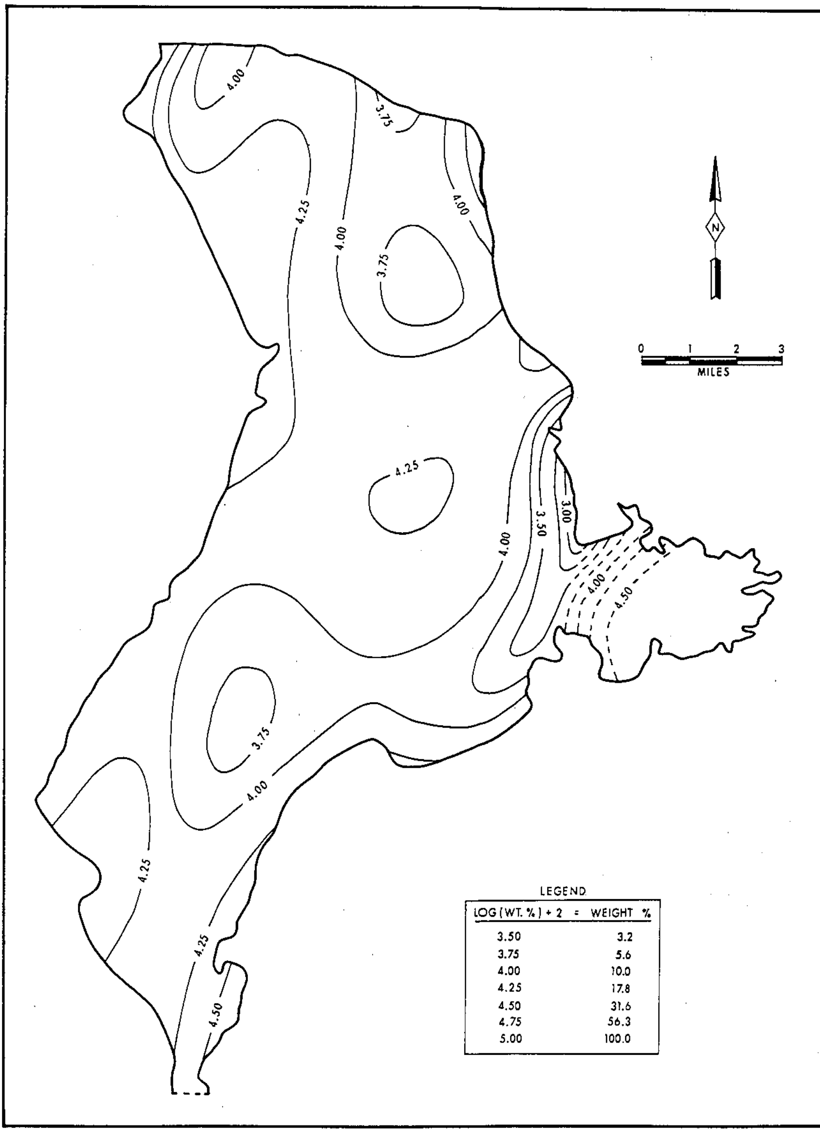
TABLE 2
RELATIVE CLAY MINERAL PERCENTAGE IN UTAH LAKE SAMPLES

Sample no.	Illite	Mixed-layer illite montmorillonite	% Illite and montmorillonite interlayering	Kaolinite	Sample no.	Illite	Mixed-layer illite montmorillonite	% Illite and montmorillonite interlayering	Kaolinite
1	47	41	50I 50M	12	68	64	21	60I 40M	16
2	34	56	20I 80M	10	69	57	29	50I 50M	14
3	67	18	75I 25M	15	71	60	25	50I 50M	15
4	43	46	30I 70M	11	73	72	12	80I 20M	16
7	75	12	80I 20M	13	75	NS			
12	43	46	50I 50M	11	87	49	32	50I 50M	19
13	37	54	40I 60M	9	88	66	16	80I 20M	18
14	NS				89	NS			
16	61	21	60I 40M	16	93	65	20	70I 30M	15
18	53	29	50I 50M	18	95	63	19	70I 30M	18
20	56	31	60I 40M	13	97	53	35	40I 60M	12
21	67	17	70I 30M	16	99	45	41	50I 50M	12
26	44	44	40I 60M	12	100	52	38	80I 20M	10
27	60	31	40I 60M	9	103	95	0		5
28	61	22	50I 50M	17	112	70	23	80I 20M	7
30	59	26	60I 40M	15	115	44	44	40I 60M	12
32	44	48	50I 50M	8	118	71	13	80I 20M	16
34	48	42	30I 70M	10	119	69	24	80I 20M	7
38	37	54	20I 80M	9	120	74	10	80I 20M	16
39	65	24	80I 20M	11	125	61	23	60I 40M	16
41	48	38	30I 70M	14	128	52	31	50I 50M	15
43	45	42	30I 70M	13	134	76	10	80I 20M	14
44	64	23	80I 20M	13	136	66	20	70I 30M	14
45	58	25	50I 50M	17	140	34	55	40I 60M	11
50	59	26	50I 50M	15	141	33	58	20I 80M	9
53	58	26	50I 50M	16	142	78	7	80I 20M	15
55	60	28	50I 50M	15	143	62	29	60I 40M	9
57	54	28	50I 50M	18	144	67	22	80I 20M	11
58	64	24	60I 40M	12	145	40	41	50I 50M	19
60	NS				146	42	43	50I 50M	15
67	NS				147	46	41	60I 40M	13

illite values and specific portions of the lake with the possible exceptions being the mouths of American Fork and Spanish Fork rivers. High relative illite percentages are observed at these two locations in direct response to heavy concentrations of illite being deposited in the lake basin as discrete mica.

Where high illite values are encountered, a converse value for the relative clay percentages for mixed-layered illite-montmorillonite exists. Illite and montmorillonite interlayer in proportions ranging from 80 percent montmorillonite and 20 percent illite to 80 percent illite and 20 percent montmorillonite. High proportions of montmorillonite interlayering generally correspond with high values of mixed-layered illite-montmorillonite or conversely with low values for the relative percentage of illite. This would be expected, for as illite interlayers with montmorillonite to form mixed-layered illite-montmorillonite, the concentration of discrete mica is diluted.

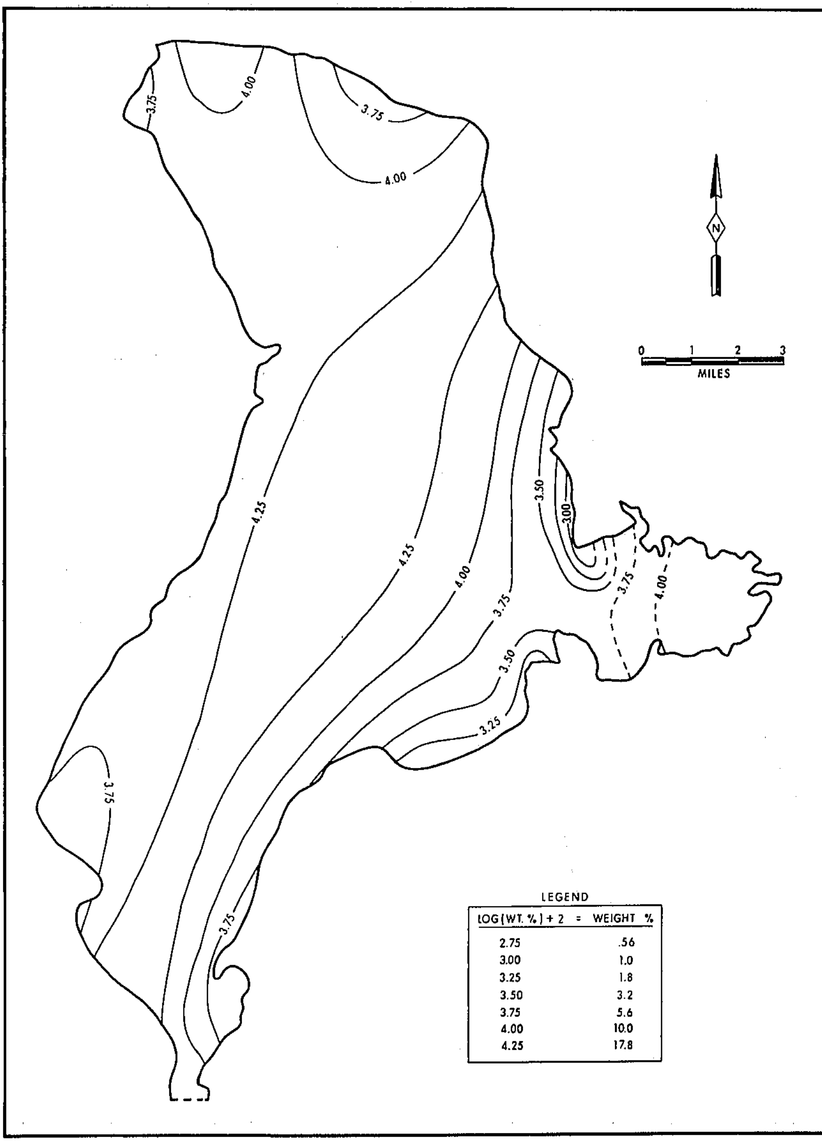
Relative percentages for kaolinite range from 5 percent to 19 percent and, like the other clays, have no obvious connection with any geographical or sedi-



TEXT-FIGURE 8.—Trend surface map of the log weight percent silt size fraction. Contour interval 0.25.

mentalogical feature. High or low kaolinite values also appear to be independent of any association with discrete illite or mixed-layered illite-montmorillonite concentrations.

All samples contained a certain amount of clay lumps or chunks; some had approximately 30 percent clay of this form. These chunks are illite in



TEXT-FIGURE 9.—Trend surface map of the log weight percent clay size fraction. Contour interval 0.25.

composition and are characteristically light gray buff to light gray green in color. The mouths of the American Fork and the Spanish Fork rivers are especially high in altered clay fragments.

In several samples close to the mouths of the above-mentioned rivers, mica showing good crystal outline was observed to be going through various stages of alteration. When these mica books were separated and magnified, parts of the crystal remained unchanged while other parts appeared to have undergone change to a clay form.

Many factors, including source area, diagenesis, water chemistry, water pH, dispersal patterns, and climate, aid in the formation of clay minerals. Climate probably plays a major role in dictating which clays are formed in a certain area. The various clays going into Utah Lake from many different source areas are subject to the same basic climatic conditions. Therefore, this could account for the uniformity of clay type distribution across Utah Lake.

Organic Carbon

Organic carbon, expressed as organic matter, is found in all sample locations in Utah Lake. As discussed earlier, organic matter content is a function of the weight percent organic carbon found in the sediment multiplied by a conversion factor.

Generally values for the organic matter of 2.0 percent and less are found in most of the lake area (Text-fig. 10). These locations are essentially barren of living plant material with the exception of algae, and, therefore, would not be considered important source areas for the organic carbon found there. The carbon has probably been transported from high organic areas.

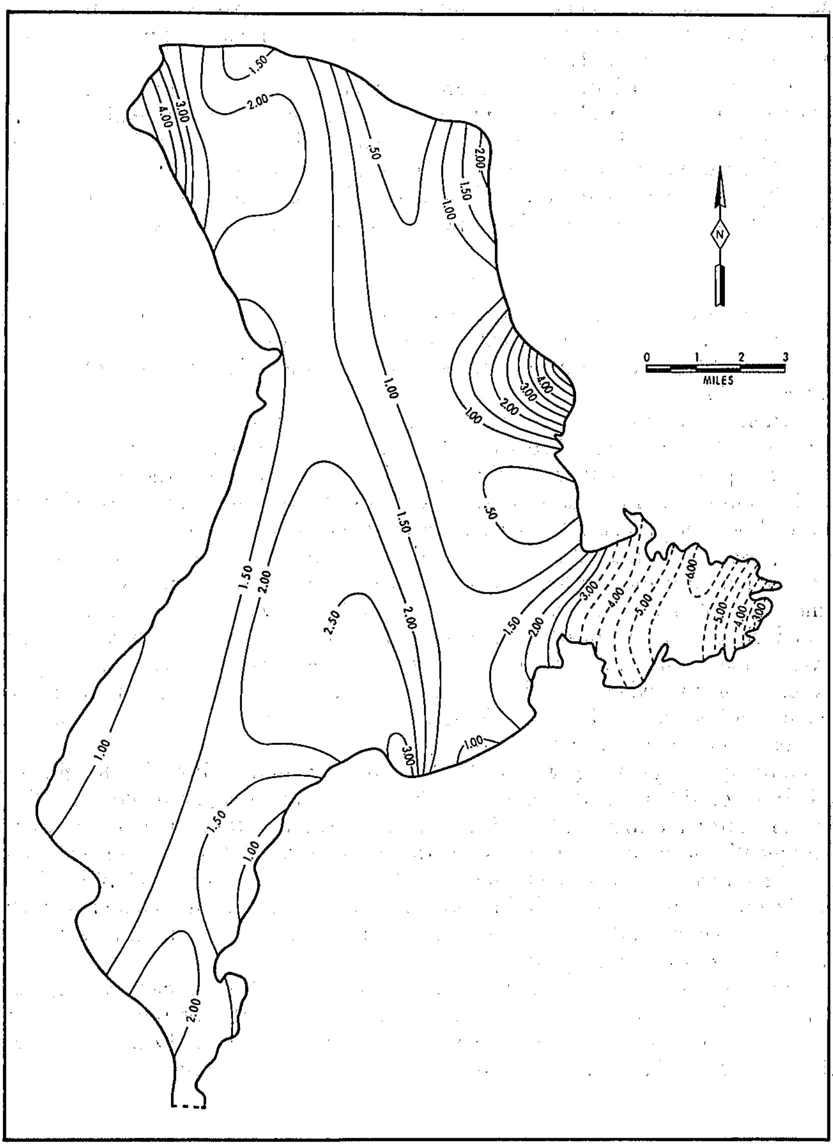
Because water immediately above the bottom sediments is oxygenated by wave action, organic matter is also oxidized rapidly, thus preventing the accumulation of large amounts of organic carbon. On the other hand, areas located close to or in nearly enclosed bodies of water such as Provo Bay and Powell Slough are high in organic carbon. These environments are slightly oxygen poor and when combined with a greater input of plant debris produce organic carbon-rich sediments. Waters in these enclosed bodies are aerated but not as consistently as water in the open lake.

Drainages originating within Utah Valley, including Powell Slough, several drainage ditches and sloughs in Provo Bay, and Benjamin Slough (Text-fig. 2), carry an increased load of organic matter. High organic values are consequently seen at the mouths of these tributaries. The bottom sediments at the mouths of larger rivers such as American Fork, Provo, Hobble Creek, and Spanish Fork, which drain mountainous areas, contain smaller percentages of organic matter which is most likely a result of currents sweeping away the fine organic material.

The relatively large organic concentration located near Saratoga Springs in the northwest portion of the lake is likely due to the presence of a large stand of reeds extending into the water for some distance. Dead fall material could accumulate quite rapidly in this area of thick reed growth.

Carbonate

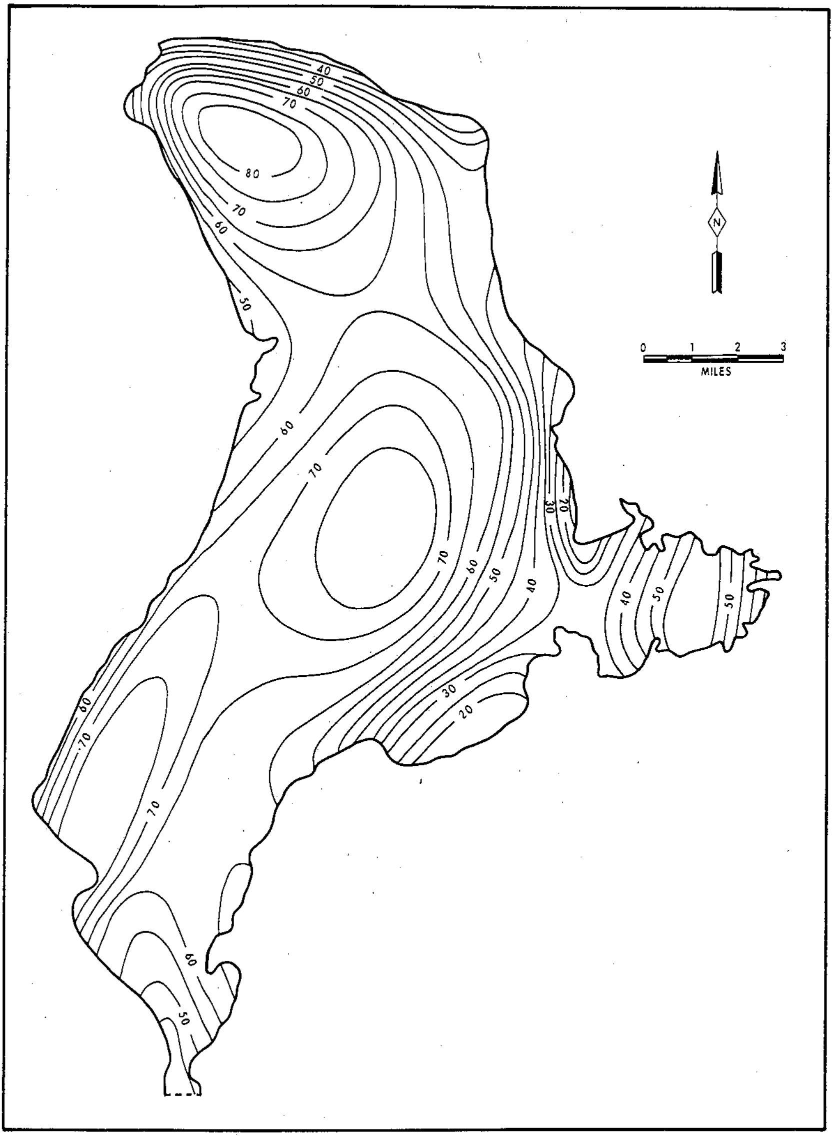
Carbonate trends are mapped (Text-fig. 11) and are similar to the total normative carbonate trend surface map published by Sonerholm (1973). Many common samples were used in the two studies; this accounts for the similarities. Different methods were used in analyzing the samples for carbonate content, so this would account for any deviation. Sonerholm (1973) analyzed the samples for calcium and magnesium carbonate using the atomic absorption spectrophotometer, whereas the writer used standard sedimentological methods of separation. The writer was mainly interested in the weight



TEXT-FIGURE 10.—Trend surface map of the organic material content. Contour interval 0.50 percent.

percent of acid soluble material which generally includes only calcium carbonate. Where values from the two procedures were compared, minor differences of only a few percent were observed.

High concentrations of carbonate (60 to 80 percent) extend in a north-south trend that generally follows the outline of the lake. These areas are



TEXT-FIGURE 11.—Trend surface map of the acid soluble material (carbonate). Contour interval 5 percent.

the farthest from coarse clastic deposition but seem to share the approximate locations for high silt and clay size concentrations (Text-figs. 8, 9).

Sediment nearest the mouths of the rivers exhibits the smallest concentrations of carbonate—American Fork River 35 to 40 percent, Provo River 20 to 30 percent, Hobble Creek 40 percent, Spanish Fork River 20 to 30 percent, and Benjamin Slough 25 to 30 percent. Part of the reason for this distribution is the absence of minute gastropods, bivalves, and ostracods that raise the carbonate level of samples generally found in the finer grained sediment.

Sonerholm (1973) equates the high carbonate value near Saratoga Springs (80 percent) with mineralization by warm springs and the subsequent eastward movement of this mineralized water by currents. Carbonate precipitation would then occur, resulting in the high concentration to the east. This may also be due to a bottleneck effect in which water, because of evaporation, becomes more concentrated in minerals and moves toward the major exit and into shallower areas with a corresponding change in temperature. High concentrations in the center (75 percent) and southern portions (75 percent) cannot be related to the same circumstances but rather to the distance from clastic deposition. The relatively high concentration of carbonate observed in Provo Bay (55 percent) is primarily due to the presence of fragmented and whole gastropod and bivalve shells.

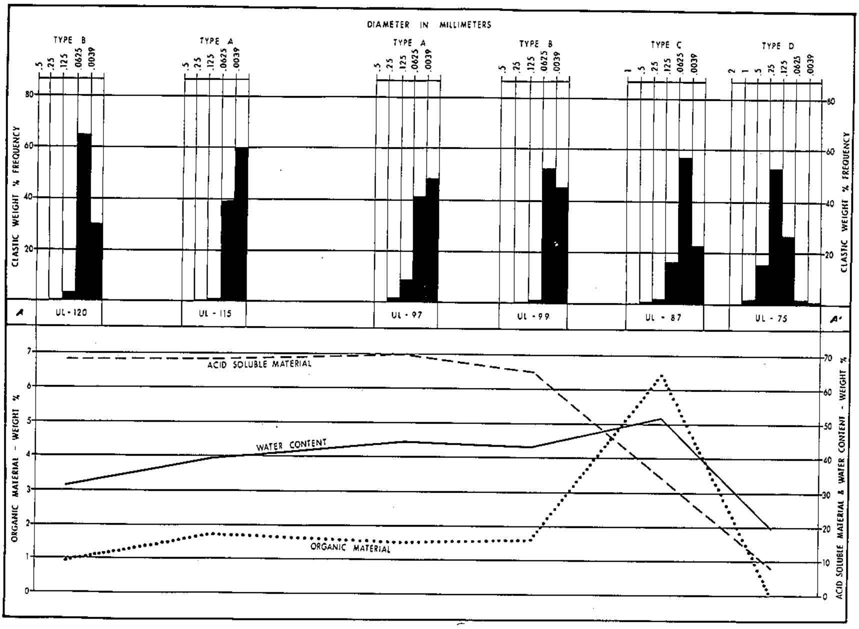
Two miles north of Lincoln Point on the north end of West Mountain is the lake's only island, Bird Island (Text-fig. 2). According to Bissell (1973, pers. comm.), Bird Island is a tufa cone built on a subcrop of Oquirrh formation (Pennsylvanian). Calcium bicarbonate rich springs situated along an inferred fault line connecting Bird Island and Lincoln Beach have produced the buildup of tufa at the outcrop during low water levels. Tufa accumulation is also observed at and near Lincoln Point where springs have produced carbonate that has cemented sediments together. The tufa of Bird Island and Lincoln Point is high in silt and very fine sand which appears to be similar to sediments transported by the Spanish Fork River. This could be accomplished by deposition of sediments from the Spanish Fork River in the direction of the deeper basin of Utah Lake west of Bird Island (Text-fig. 2). Heavy wave action during low lake levels would mix the calcium bicarbonate rich water with silts and sands and trigger the formation of carbonate cement. These "hardpan" areas are not expressed as separate high concentration anomalies due to the small size of the features compared to the mappable trends of the remainder of the map.

SUMMARY OF UTAH LAKE SEDIMENT TYPES

Based on size distribution, Utah Lake sediments can be divided into at least four types, each more or less characteristic of a given environment. Histograms of representative selected samples are shown in cross section A-A' (Text-figs. 3, 12).

Type A—Midlake Sediments

Typically these sediments contain very minor amounts of coarse clastics (coarse to very fine grained sand). Individual coarse fractions usually do not exceed 1 percent by weight of the total sample. The bulk of the type A clastic sediment is clay size (15 to 21 percent) with slightly lesser amounts of silt size particles (10 to 19 percent). Calcium carbonate, not shown by the histogram, is extremely abundant and makes up the majority of the sediment (61 to 73 percent). These sediments comprise most of the open lake and areas that are distant from the clastic depocenters.



TEXT-FIGURE 12.—Histograms illustrating the four basic sediment types. Cross section showing relationship between several Utah Lake sediment constituents.

Type B—Outer Offshore Sediments

This type of sediment is characterized by small amounts of coarse particles (0 to 5 percent) with an increase in very fine grained sand with respect to type A sediment. Silt sized particles (13 to 36 percent) dominate the clastics with clay percentages being slightly less (10 to 32 percent). Calcium carbonate is also abundant in this type (27 to 71 percent). Type A and B sediments contain abundant pore water plus minor amounts of organic material. These sediments generally ring the lake and are found in areas between midlake sediments and clastic depoareas. They are especially evident in the northern and southern areas and offshore east central.

Type C—Inner Offshore Sediments

These sediments are somewhat similar to type B but have moderate amounts (9 to 30 percent) of coarse fractions. Silt comprises the largest portion of the clastics (21 to 66 percent) with clay present in amounts nearly equal to the very fine grained sand size (3 to 14 percent). In most locations in these areas, the weight percent of acid-soluble material is greatly reduced (21 to 62 percent). Type C sediments are found closer to shore, near areas of active clastic deposition, and along the shore in locations between the depoareas such as the mouths of major rivers. Most of Provo Bay sediment is type C.

Type D—River Mouth Sediments

Sediments of this type contain a high percentage of coarse clastics (74 to 89 percent) with the most abundant being fine grained sand. Silt and clay are present but only in minor amounts (both 1 to 3 percent). Calcium carbonate is present in concentrations from 6 to 32 percent, which may reflect an abundance of limestone fragments in the bed load of some major streams. Organic material is almost completely lacking in type D sediments. These sediments are located at or very near the mouths of the larger streams flowing into Utah Lake. The Spanish Fork River transported this type of sediment also, but with a shift of the major sediment size to medium sand.

ANOMALOUS PYRITE CONDITIONS

An anomalous condition exists at a single location point in the northern extension of Utah Lake. Sonerholm (1973) has mapped a hematite low in the area of station no. 7 near Saratoga Springs resort (Text-fig. 3). In describing this particular sample, he noted that pyrite was present as one of the constituents. This was surprising because no other samples in Utah Lake contained observable pyrite. Furthermore, visual estimations of the amount of pyrite in the sample range considerably higher than the .70 to .75 percent assigned this sample. A possible explanation can be offered concerning this abnormally high iron in pyrite form versus low normative iron in hematite form mapped by Sonerholm (1973). Sample no. 7 may have been the only extremely high hematite value in a trend of low values; due to the nature of the trend surface mapping, this value may have been averaged or discarded by the computer program.

Pyrite is probably being introduced into the sedimentation system from a spring or series of springs. A spring or springs at this location would also give support to the idea of inferred faulting across Utah Lake proposed by Stokes (1962). He mapped a fault along the entire length of Utah Lake that crosses slightly east of Bird Island at the south and passes approximately through station no. 7 to the north (Text-fig. 2).

The pyrite appears to be replacing some form of organic material that has a high concentration (4.94 percent) compared with most of the lake (average around 1.60). Pyrite has taken the shape of elongate arcuate rods showing slight parallel striations. Carbonized rods are also present as is a suite of slightly pyritized carbonized rods to slightly carbonized pyritized rods. These rods could represent mineralized plant root hairs. The diameter is small (.25mm to .0625mm) and uniform in shape.

PLANT COMMUNITIES OF UTAH LAKE

The plant life of Utah Lake has been extensively studied and categorized by various workers in recent years. A complete study of the extant plant communities in and around the lake was completed by Coombs (1970), which not only delineates these communities but also attempts to trace the history of the major plant types since the beginning of biological studies of Utah Lake. This excellent paper is the basis for comparing plant communities and sediment type in this section.

Coombs (1970) has divided the plants of Utah Lake into four communities: aquatic herbaceous communities, semiaquatic herbaceous communities, lowland woody communities, and terrestrial communities. There are a total of 29 major types within the above four divisions. Because this paper deals strictly with recent sedimentation, only those types of communities that grow on soil that is continuously under water will be considered.

Type 1 of the aquatic herbaceous communities is the pondweed *Potamogeton latifolius* and is generally found in open water areas near shore at depths of from two to eight feet. These are small isolated stands that range in size from 10 to 350 square feet. Stands of pondweed dot most shorelines of the lake, but the density of these stands is not great. *Potamogeton latifolius* communities appear to grow in sediment that has a high concentration of fine clastics, that is, they locate themselves just far enough offshore to be in the silty, clayey, lime mud areas. Coombs (1970) stated that *P. latifolius* apparently owes its success in growing in Utah Lake, since its start between 1950 and 1960, to its ability to reproduce and grow in turbid water. The turbidity of the water in which pondweed grows is probably due to wind stirring up the muds on the bottom. If pondweed increases dramatically, some stability of the lake bottom could result.

The most abundant community type basically consists of bulrushes and cattails and forms the marshes of type 2. There are four different communities in type 2: *Scirpus acutus* or bulrush (tule), *S. acutus* and *Lemna minor* or duckweed, *S. acutus* and *Typha latifolia* or cattail, and *Typha latifolia* (cattail) alone. Bulrushes make up the bulk of this group, while the other types exist with the tules mainly in onshore, springfed ponds and sloughs near Powell Slough (Text-fig. 2).

Utah Lake is almost completely ringed with a nearly continuous stand of bulrushes. The community reaches its maximum development in Provo Bay and Powell Slough and its minimum along the shoreline from the mouth of Spanish Fork River to Benjamin Slough. *S. Acutus* is also present in lesser amounts along the shorelines on both sides of Goshen Bay at the approximate entrance of the bay.

Bulrushes are most abundant along the immediate shoreline in approximately four feet of water. *S. Acutus* appears to have no preference to soil type. It is found along shorelines consisting almost entirely of clayey lime mud as well as shorelines composed of as high as 90 percent coarser clastics. The carbonate content of the sediment likewise has no apparent effect on its distribution. Well-established stands of tules grow on the tuffa beaches along the north shoreline of West Mountain and on Bird Island. Sediment type is not then the governing factor for the location of this community. These observations were made using the trend surface maps constructed to delineate large sediment trends. At best they are approximations of the actual sediment type at the water-shore contact where most of the plant communities exist. In a larger sense these observations are valid but may not hold true on a local basis. White (1963) discovered that in Provo Bay *Typha latifolio* (cattail) was dominant in soft ooze, whereas on solid bottom (a greater percentage of coarse clastics present) *Scirpus acutus* was most common. It was unknown whether this condition was peculiar to Provo Bay or existed outside the bay as well.

Tamarix pentandra "tamaracks" is also abundant around Utah Lake in locations that usually lie between the bulrushes and the shore or on the shore. Tamaracks are in Coombs's (1970) lowland woody community with most of the stands on well-drained or seasonally staturated soil. *T. pentandra* is also found in deeper water but apparently is not suited for this environment because most deep water stands are dying out. The remains of these communities are seen as twigs and stumps at or near the water level and have probably been cut off by shifting ice during winter months.

Tamaracks, like bulrushes, appear to have no dependence upon soil type. They occur in the same locations around Utah Lake as bulrushes and in the same soil conditions. The only difference seems to be the depth of water in which they grow.

In general, then, sediment type cannot be used as a factor in governing or predicting which plant community will prefer one location over another. Other alternatives would be the pH of the water in which they live, the fertility of the sediment, water depth, dissolved oxygen, etc. A combination of these is a probable answer.

SOME INVERTEBRATE COMMUNITIES IN UTAH LAKE

The invertebrate life in Utah Lake has been studied in recent years by several workers but has not been done on an orderly basis encompassing the entire lake. Individual local studies have been made in isolated areas such as Provo Bay by White (1963), Powell Slough by Barnett (1964), and Goshen Bay (Barnes, 1974, pers. comm.). Complete comparisons of all the invertebrates of Utah Lake with sediment type would, therefore, be beyond the scope of this paper. Some observations by the above writers will be incorporated with sediment trends to give a general idea of some major organism-sediment associations.

The presence of two major types of organisms living in the silty and/or clayey lime mud area of Goshen Bay has been established (Barnes, 1974, pers. comm.). These are the oligochaetes (worms) and the chironomids (midge fly larvae). At least three species of oligochaetes are known to exist, with the majority of specimens being *Tubifex tubifex.* Chironomids in the lime mud areas are *Chironomus frommeri, Tanypus* sp. and *Procladios* sp. All of these populations can be considered detrivorous with the exception of *Procladios* sp., which is carnivorous. White (1963) suggests that within the chironomids present in Provo Bay, one genus will generally prefer a firm substrate while another will prefer a muddy bottom. Barnett (1964) found chironomids in the mucky sediment of Powell Slough, which confirms the association.

Because of the uniformity of the lime mud type throughout the major portion of Utah Lake, the animal communities would most likely be similar within this specific sediment. Further work on the remainder of the lake is needed to substantiate this statement.

Along the immediate shoreline from the north point of West Mountain into Goshen Bay for five miles, a hardpan (tuffa) and rubble beach exists. This beach is generally not illustrated by the trend surface maps because samples were taken offshore at considerable distance, missing the hard substrate. Sample no. 118 did encounter hard pan but was disaggregated and the component sizes mapped.

The dominant organism living on the hardpan area is the small crustacean *Hyallella azteca.* This amphipod and a chironomid inhabit and are dominant in the rubble area south of the hardpan. Trichopteran larvae are abundant on both bottom types. Microcrustaceans were also collected in Provo Bay in presumably both types of substrate (mud ooze and solid bottom) described by

White (1963). This latter observation may be due to the abundance of organic debris in Provo Bay which affords them a desirable environment.

The mollusks from the Utah Lake samples were identified under the direction of Dr. J. R. Barnes, professor of zoology at Brigham Young University. The following forms were found to be most common: bivalves—*Sphaerium pilsbryanum* and *Anodonta nuttallina; gastropods—Flumincola fusca, Valvata utahensis, Carinfex newberryi,* and *Physa utahensis.* The most abundant form is the bivalve *Sphaerium pilsbryanum,* and the least abundant is *Anodonta nuttallina.* Other forms are probably present in the bottom sediments but were not encountered in the samples collected.

Essentially no mollusks were found in the center portions of the lake. Probable reasons for their absence are (1) loose mud substrate causing burial, (2) absence of moving water resulting in stagnation, (3) general lack of organic material used as food, and (4) water depth (10 feet plus) possibly too great for these forms. The distribution of these invertebrates is fairly uniform around the perimeter of the lake. There does not seem to be a clearly defined preference of one organism to a certain sediment size. One possible exception is the gastropod *Physa utahensis,* which prefers a sandy or firm substrate. This form was found in samples along the sandy shorelines near the Provo Airport and the Spanish Fork River delta.

FUTURE WORK

Perhaps the most intriguing area for future work is the anomalous condition existing at station no. 7. Iron pyrite was sampled only at this location, indicating the possible presence of a mineralizing spring. Detailed work is needed in the immediate area to determine the lateral extent of the mineralization and the location of the spring(s). If this sample lies directly on the inferred fault zone, more detailed sampling along the fault strike toward Bird Island could produce additional pyritization from fault-caused springs. A closer examination could also indicate the origin of the arcuate rods the pyrite is selectively replacing.

The next area of interest is the origin of the clays in Utah Lake. The question exists, Have feldspars and micas altered to clays at the outcrop enroute to or in the confines of Utah Lake? Feldspars and micas from the igneous areas of American Fork River, Provo River, and Spanish Fork River drainages plus reworked feldspars and micas eroded from various sedimentary rock assemblages throughout these areas form the bulk of clay-producing minerals deposited in Utah Lake. Detailed sampling at outcrops over which the major rivers cross, plus sampling at regular intervals along these rivers and at their mouths, could allow a better explanation of the problem. A radiating sample pattern at the mouths of these rivers would be helpful in delineating the areas of greatest possible alteration, if, in fact, it does occur in the lake itself.

The third area of consideration is a more detailed investigation of the plant-animal-sediment association in Utah Lake. It has been shown that certain plant and invertebrate animal communities generally prefer a certain type of substrate, but how consistent this observation is would be subject to further work. Sediment sampling by the zoologist and botanist in the respective biological communities should produce a more clearly defined association with sediment type.

APPENDIX
DESCRIPTION OF SAMPLES OF UTAH LAKE BOTTOM SEDIMENTS

Station UL-1

Description.—Clayey, silty lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; fairly common bivalve and gastropod shells and shell fragments; rare ostracods tests; 3 percent coarse clastics; predominantly angular to subrounded quartz; some rock fragments; some heavy minerals increasing in the smaller fractions; a few clay lumps and black accessories.

Station UL-2

Description.—Clayey, silty lime mud; firm, structureless; medium gray when wet, light gray when dry; some bivalve and gastropod shells and shell fragments; a few ostracods tests; 5 percent coarse clastics; predominantly subangular to rounded quartz; some rock fragments; some clay chunks; a few heavy minerals; rare black accessories.

Station UL-3

Description.—Clayey, silty lime mud; firm, structureless; medium gray when wet, light gray when dry, a little organic matter; a few shell fragments; 1 percent coarse clastics; predominantly quartz; subangular to subrounded and clear; some rock fragments; a few heavy minerals and black accessories.

Station UL-4

Description.—Clayey, silty lime mud; firm, structureless; medium gray when wet, light gray when dry, a little organic material and shell fragments; 1 percent coarse clastics; predominantly clear and cloudy, angular to subrounded quartz; some pink quartz; some heavy minerals; a little mica.

Station UL-7

Description.—Clayey, silty lime mud; firm, mainly structureless; medium gray when wet, light gray when dry, thin light brownish layer near top; some small bivalve and gastropod shells; ostracods present; 1 percent coarse clastics; predominantly clear angular to subrounded quartz; some rock fragments; some consolidated clay fragments; some pyritized rods; a few heavy minerals and black accessories; a little organic material.

Station UL-12

Description.—Silty, clayey lime mud; firm, structureless, medium gray when wet, light gray when dry; subangular to subround quartz grains; a few heavy minerals and black accessories.

Station UL-13

Description.—Slightly clayey, silty lime mud; firm, heterogeneous mixture of very fine grained sand in silt and mud; sand dark gray when wet, medium gray when dry, mud medium gray when wet, light gray when dry; a few small bivalve and gastropod shells; 5 percent coarse clastics; predominantly clear angular to subrounded quartz; some rock fragments and oolites; a few black accessories; rare mica.

Station UL-14

Description.—Slightly sandy, silty lime mud; firm, structureless; medium gray when wet, light gray when dry; fairly common small bivalve and gastropod shells; a few ostracod tests; 17 percent coarse clastics; predominantly subangular quartz; some rock fragments; minor mica.

Station UL-16

Description.—Silty, clayey lime mud; firm, structureless; medium gray when wet, light gray when dry; fairly common gastropod and bivalve shells and shell fragments; ostracods present; 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; a few heavy minerals and black accessories.

Station UL-18

Description.—Silty, clayey lime mud; firm, structureless; light gray when wet, very light gray when dry; rare gastropod shells; less than 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; a few heavy minerals.

Station UL-20

Description.—Sandy, silty lime mud; firm heterogeneous mixture of very fine sand in silt size; 24 percent coarse clastics; predominantly subangular quartz; many rock fragments; a few heavy minerals and black accessories.

Station UL-21

Description.—Clayey, silty lime mud; firm, structureless; medium gray when wet, light gray when dry; very rare bivalve shells; 2 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; abundant rock fragments; a few heavy minerals and black accessories; rare oolites.

Station UL-26

Description.—Silty, clayey lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly subangular clear to clear and cloudy rounded quartz; some heavy minerals and black accessories.

Station UL-27

Description.—Limey clayey silt; firm, structureless; medium gray when wet, light gray when dry; some gastropod and bivalve shells and shell fragments; a little organic matter; ostracods present; 5 percent coarse clastics; predominantly rock fragments in coarser fractions going to predominantly clear subangular quartz in finer sizes; some heavy minerals and black accessories; some yellow orange oxides of iron; rare gypsum crystals.

Station UL-28

Description.—Clayey, silty lime mud; firm, structureless; medium gray when wet, light gray when dry; ostracods present; 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; some rock fragments; a few heavy minerals and black accessories, rare mica.

Station UL-30

Description.—Silty, clayey lime mud; firm, structureless; light gray when wet; very light gray when dry; very rare shell fragments; 1 percent coarse clastics; predominantly clear to subangular to rounded quartz; some rock fragments; a few heavy minerals and black accessories; rare oolites.

Station UL-32

Description.—Limey fine sand; slightly watery, structureless, medium gray when wet, light gray when dry; rare bivalve shells; predominantly clear to cloudy angular quartz; some pink grains; some rounded and frosted quartz grains; some rock fragments; some chert; a little mica; a little heavy minerals and black accessories; rare oolites.

Station UL-34

Description.—Sandy, silty lime mud; firm, structureless; medium gray when wet, light gray when dry; some gastropod and bivalve shells and shell fragments; ostracods present; 15 percent coarse clastics; predominantly cloudy angular to subrounded quartz, abundant rock fragments; a few heavy minerals, a few clinkers.

Station UL-38

Description.—Silty, clayey lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear subangular to subrounded quartz; some gypsum crystals; a few black accessories.

Station UL-39

Description.—Sandy, silty lime mud; firm, structureless; medium gray when wet, light gray when dry; rare shell fragments; very rare organic debris; ostracods present; 16 percent coarse clastics present; predominantly clear to cloudy subangular to subrounded quartz; a few rock fragments; a few black accessories and clinkers.

Station UL-41

Description.—Silty, clayey lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear subangular to rounded quartz; some brown stained rounded grains; some rock fragments; a few heavy minerals.

Station UL-43

Description.—Silty, clayey lime mud; firm, structureless, light gray when wet, very light gray when dry; ostracods present; 1 percent coarse clastics; predominantly clear subangular to subrounded quartz, some brownish red stained quartz; some rock fragments; some oolites; a few heavy minerals; rare mica, rare black accessories.

Station UL-44

Description.—Silty, limey, very fine sand; firm, heterogeneous mixture silt and clay sizes in very fine sand; medium gray when wet, light gray when dry; very rare organic material; predominantly subangular quartz, some well rounded; some rock fragments; some black accessories and clinkers; a few heavy minerals; a few clay chunks.

Station UL-45

Description.—Silty, clayey lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear to cloudy subangular to rounded quartz; a few heavy minerals; rare black opaques.

Station UL-50

Description.—Silty, clayey lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear angular to rounded quartz; some orange stained grains; a few oolites and black accessories.

Station UL-53

Description.—Silty, clayey lime mud; firm, structureless; medium gray when wet, light gray when dry; less than 1 percent coarse clastics; predominantly subangular to rounded quartz.

Station UL-55

Description.—Silty, clayey lime mud; firm, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; some rock fragments; a few heavy minerals and black accessories.

Station UL-57

Description.—Clayey, silty lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; some rock fragments; a few heavy minerals and black accessories.

Station UL-58

Description.—Clayey, silty lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear to cloudy subangular to rounded quartz; some rock fragments; a few heavy minerals and black accessories.

Station UL-60

No sample.

Station UL-67

Description.—Fine sand; fairly well sorted, structureless, dark medium gray when wet, light brownish gray when dry; some gastropod and bivalve shells; predominantly rock fragments in coarser fractions becoming predominantly clear to cloudy subangular to rounded quartz in finer sizes; an increasing amount of heavy minerals and black accessories in finer fractions; rare mica.

Station UL-68

Description.—Clayey lime mud; firm, structureless; medium gray when wet, light gray when dry; very rare gastropod and bivalve shells; ostracods present; 1 percent coarse clastics; predominantly clear to cloudy subangular to rounded quartz; a few heavy minerals; rare black accessories.

Station UL-69

Description.—Silty, clayey lime mud; firm, structureless; brownish medium gray when wet, light gray when dry; very rare gastropod and bivalve shells; ostracods present; less than 1 percent coarse clastics; predominantly clear to cloudy subangular to rounded quartz; a few heavy minerals and black accessories.

Station UL-71

Description.—Silty, clayey lime mud; firm, structureless; medium gray when wet, light gray when dry; less than 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; a few heavy minerals.

Station UL-73

Description.—Silty, clayey lime mud; fairly watery, structureless; medium light gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; some rock fragments and clay lumps; a few heavy minerals and black accessories.

Station UL-75

Description.—Fine sand; fairly well sorted, structureless; medium gray when wet, light gray when dry; rare shell fragments; predominantly rock fragments in coarser fractions becoming primarily clear to cloudy subangular quartz in finer sizes; many rounded quartz grains; increasing in heavy minerals with fineness; some black accessories; rare mica.

Station UL-87

Description.—Slightly sandy, clayey, silty lime mud; crumbly, structureless; brownish medium gray when wet, light grayish buff when dry; rare gastropod shells and shell fragments; fairly abundant organic material; 11 percent coarse clastics; predominantly clear to cloudy subangular to rounded quartz; some pink quartz grains; some oolites, a few rock fragments and clay chunks.

Station UL-88

Description.—Slightly sandy limey silt; crumbly, structureless; brownish medium gray when wet, light grayish buff when dry; rare gastropod shells; a little organic material; 11 percent coarse clastics; predominantly clear subangular to subrounded quartz; some rock fragments, a few oolites and black accessories.

Station UL-89

Description.—Clayey, silty lime mud; crumbly, structureless; dark medium brownish gray when wet, light grayish brown when dry; some gastropod and bivalve shells; some organic material; 1 percent coarse clastics; predominantly clear to cloudy subangular to rounded quartz; some clay chunks, a few clinkers, heavy minerals and black accessories; rare mica.

Station UL-93

Description.—Silty, clayey lime mud; fairly firm, structureless; medium gray when wet, light gray when dry; 1 percent coarse clastics; predominantly clear to cloudy angular to subrounded quartz; a few heavy minerals and black accessories.

Station UL-95

Description.—Silty, clayey lime mud; slightly watery, structureless; medium gray when wet, light gray when dry; less than 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; rare heavy minerals and black accessories.

Station UL-97

Description.—Silty, clayey lime mud; fairly firm, structureless, medium gray when wet, light gray when dry; rare gastropod and bivalve shells; 3 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; some rock fragments; a few heavy minerals and black accessories; rare mica.

Station UL-99

Description.—Clayey, silty lime mud; fairly firm, structureless; medium gray when wet, light gray when dry; very rare bivalves and shell fragments; 1 percent coarse clastics; predominantly clear to cloudy angular to subrounded quartz; some rock fragments; a few oolites and heavy minerals; rare mica.

Station UL-100

Description.—Limey fine sand; well sorted, structureless; reddish medium brown when wet, reddish light brown when dry; predominantly clear to cloudy subangular quartz; many orange red stained grains; some rock fragments; some clinkers and black accessories.

Station UL-103

Description.—Clayey limey silt; firm, structureless medium grayish brown when wet, light buff when dry; rare shell fragments; 8 percent coarse clastics; predominantly rock fragments in coarse fractions becoming primarily quartz grains in finer sizes; quartz is bimodal, well rounded, frosted, and angular; abundant clay chunks; some heavy minerals and black accessories; rare mica.

Station UL-112

Description.—Silty, limey fine sand; fairly well sorted, structureless; medium grayish brown when wet, light grayish brown when dry; predominantly rock fragments and clay chunks in coarser fractions becoming primarily clear and red brown stained subangular quartz and clay chunks in finer sizes; some clinkers; some heavy minerals and black accessories.

Station UL-115

Description.—Silty, clayey lime mud; firm, structureless; medium gray when wet, light gray when dry; rare shell fragments; less than 1 percent coarse clastics; predominantly clear subrounded quartz; some rock fragments; a few heavy minerals and black accessories.

Station UL-118

Description.—Sandy tuffa; microcrystalline calcite matrix with visible clastics, vugular; light reddish buff; 17 percent coarse clastics; predominantly clear to cloudy subrounded to well rounded quartz grains; some clear subangular grains; many brownish orange stained quartz grains and rock fragments; a few heavy minerals; rare black accessories.

Station UL-119

Description.—Slightly sandy limey silt; firm, structureless; medium brown when wet, light brown when dry; 9 percent coarse clastics; predominantly subangular quartz; approximately half clear to cloudy with the remainder stained brownish orange; some clay chunks; a few heavy minerals, black accessories, and clinkers; rare oolites and mica.

Station UL-120

Description.—Clayey, silty lime mud; firm, structureless; medium light gray when wet, light gray when dry; rare shell fragments and organic material; ostracods present; 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; abundant rock fragments; a few heavy minerals and black accessories.

Station UL-125

Description.—Clayey, silty lime mud; watery, structureless; brownish medium gray when wet, light grayish buff when dry; a few gastropod and bivalve shells; ostracods present; 3 percent coarse clastics; predominantly clear to cloudy subangular to rounded quartz; some rock fragments; a few heavy minerals and black accessories.

Station UL-128

Description.—Silty, clayey lime mud; firm, structureless; medium gray when wet, light gray when dry; ostracods present; less than 1 percent coarse clastics present; predominantly clear to cloudy subangular to subrounded quartz; some rock fragments; a few heavy minerals and black accessories.

Station UL-134

Description.—Clayey, silty lime mud; firm, structureless; medium light gray when wet, light gray when dry; some gastropod and bivalve shells and shell fragments; ostracods present; 1 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; a few rock fragments, heavy minerals, and black accessories.

Station UL-136

Description.—Clayey, silty lime mud; firm, light brown mottled streaks within matrix; medium light gray when wet, light gray when dry; rare bivalve shells; ostracods present; 1 percent coarse clastics; predominantly subangular to rounded quartz; half clear, half cloudy or pink grains; abundant rock fragments; some heavy minerals, a few black accessories.

Station UL-140

Description.—Clayey, silty lime mud; firm, structureless; medium light gray when wet, light gray when dry; some gastropod and bivalve shells and shell fragments, a little organic material; 1 percent coarse clastics; predominantly clear angular to rounded quartz; some brownish red stained grains; some rock fragments; a few oolites and heavy minerals; rare mica.

Station UL-141

Description.—Slightly clayey, sandy, silty lime mud; firm, structureless; medium gray when wet, light gray when dry; some gastropod and bivalve shells and shell fragments; 19 percent coarse clastics; predominantly rock fragments with heavy mineral inclusions in coarse fractions becoming primarily quartz grains in smaller sizes; quartz is mostly cloudy, angular to subrounded; some clay chunks; some mica; a few heavy minerals and black accessories; very rare feldspar.

Station UL-142

Description.—Fine sand; poorly sorted, structureless; dark medium gray when wet, medium gray when dry; predominantly high-temperature rock fragments; chiefly cloudy angular to subangular quartz rock fragments in coarser fractions; abundant dark igneous rock fragments; slight increase of subrounded quartz grains in finer fractions; abundant altered and unaltered mica; some clay chunks; fine fractions have an increase in heavy minerals and black accessories; a few clinkers and coal.

Station UL-143

Description.—Clayey, silty lime mud; watery, structureless; dark grayish brown when wet, medium grayish brown when dry; very common organic material; 3 percent coarse clastics; predominantly clear to cloudy subangular to subrounded quartz; abundant clinkers; a few heavy minerals and black accessories.

Station UL-144

Description.—Fine sand; well sorted, structureless; dark medium gray when wet, medium light gray when dry; predominantly cloudy quartz rock fragments in coarser fractions becoming clear to cloudy subangular to rounded quartz grains in the finer sizes; some igneous rock fragments with black heavy mineral inclusions; many heavy minerals and black accessories; rare oolites.

Station UL-145

Description.—Slightly clayey, limey sandy silt; watery; mottled heterogeneous sand in finer matrix; medium grayish brown when wet, medium light grayish brown when dry; 30 percent coarse clastics; predominantly rock fragments in coarse fractions becoming primarily cloudy subangular to subrounded quartz grains in the finer coarse sizes; some rock fragments stained yellow orange; some well-rounded quartz grains; a few clay chunks; rare mica.

Station UL-146

Description.—Medium sand; fairly well sorted, structureless; medium dark brownish gray when wet, medium gray when dry; predominantly clinkers and rock fragments in very coarse fractions; primarily quartz in the finer coarse sizes; quartz is clear to cloudy and subangular; abundant, well-rounded, frosted, orange brown stained quartz grains; many rock fragments in finer sizes; abundant clay chunks; a few heavy minerals and black accessories.

Station UL-147

Description.—Silty, clayey lime mud; firm, heterogeneous mixture of buff very fine sand and silt in dark gray organic silts and clay; basically dark gray to black when wet, medium light gray when dry; some gastropod shells and shell fragments; predominantly rock fragments in coarser fractions becoming primarily quartz in finer coarse sizes; quartz ranges from angular to rounded and clear to cloudy; abundant orange brown quartz staining; some heavy minerals and black accessories.

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