ENVIRONMENTAL GEOLOGY OF BEAR LAKE AREA, RICH COUNTY, UTAH

by Bruce N. Kaliser

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
affiliated with
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
University of Utah, Salt Lake City, Utah

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BEAR LAKE AREA, RICH COUNTY, UTAH

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ABSTRACT

Bear Lake, continually increasing in its aesthetic and recreational appeal, is certain to experience accelerated development around its shores. Drainage, slope, bearing strength, rippability, water table depth and fluctuation, flooding potential, availability of earth materials for fill and aggregate, and suitable quantity and quality water must be considered at the earliest stages of construction planning.

Current earthquake activity and old landslides distributed across the lake terrain must be regarded in major engineering structures.

This study contains interpretations of terrain and descriptions of specific localities of interest; it serves those interested in the geologic aspects of land use in the Bear Lake area—county, state and school planners, developers, industry and private citizens.

Isotope determinations were used to define the origin of subsurface waters. Abundant high-quality groundwater, much of which surfaces, must be protected from septic tank effluents and landfill leachants.

Industrial minerals and rocks available in the area are described and their locations given.

INTRODUCTION

This report, intended to be a tool for planning the Bear Lake area, is the result of a request to the state geologist from the Rich County Commission and the Rich Soil Conservation District. Field work was undertaken during the summer of 1968. The U. S. Department of Agriculture, Soil Conservation Service, released a special soils study of the same area simultaneously with this report (1969); use of both will assure full consideration being given to surface and subsurface aspects of the environment. Problems and unnecessary expenditures stemming from ignorance of the geology can thereby be avoided.

The report does not supplant specific on-site studies where necessary. Exploratory holes and the collection and testing of earth-material samples depending on site conditions and the type of engineering structure proposed are needed. No holes were drilled nor samples physically tested in the laboratory specifically for this overall study. Rather, an areal approach was adopted making full use of data provided by other agencies plus areal observation, mapping and interpretation in the field.

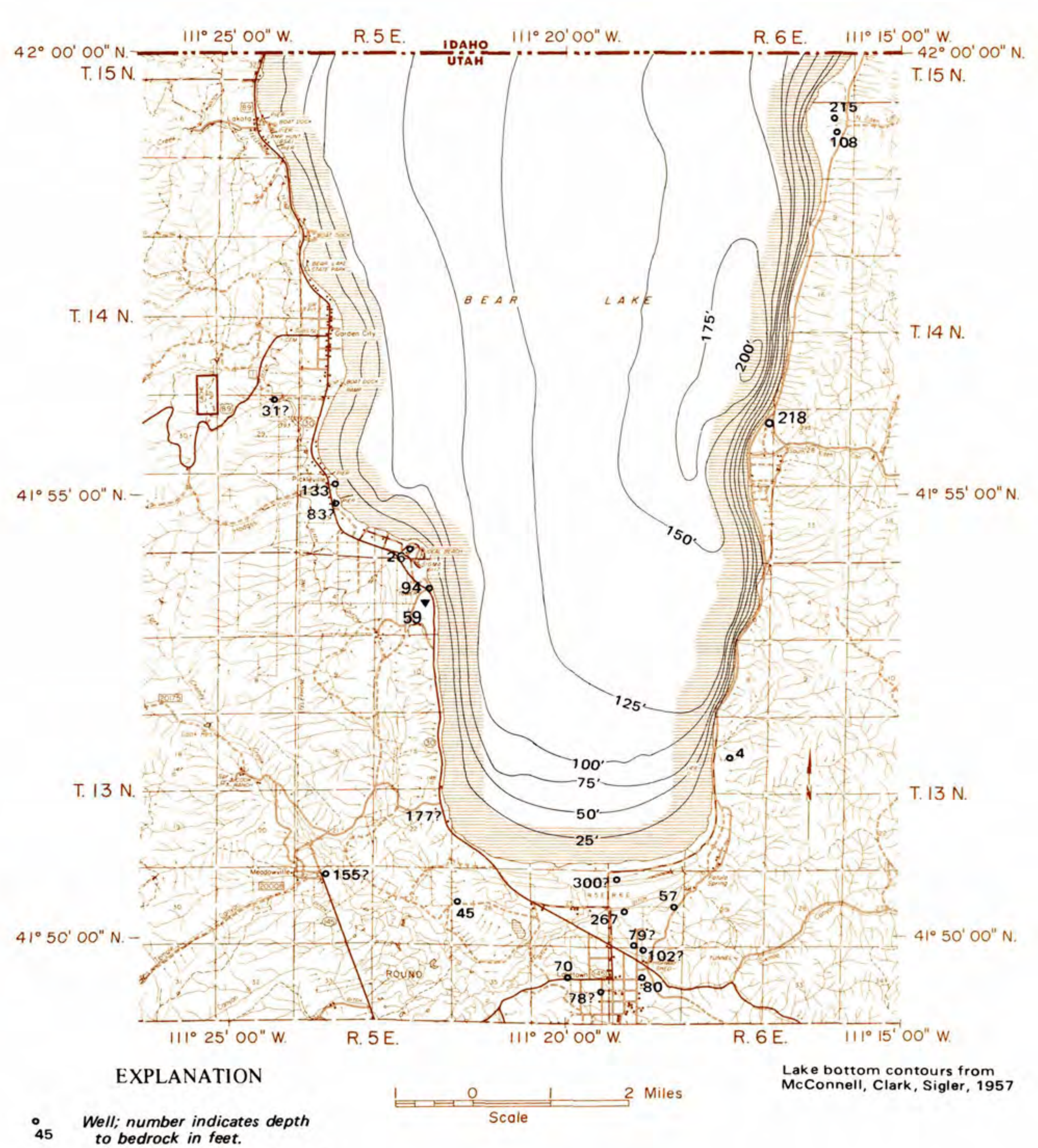
ACKNOWLEDGEMENTS

The author received the cooperation of many state and federal agencies that contributed data to this study (see References). Two agencies in particular launched cooperative agreements with the Utah Geological and Mineralogical Survey that proved fruitful in minimizing the expense of the investigation and in obtaining its objective: the U. S. Soil Conservation Service and the State Division of Environmental Health. The Survey's economic geologist, H. H. Doelling, assisted in the Mineral Resources section and with the photography. E. R. Kaliser assisted in the field. D. Grey, H. Dequasie and L. Jensen, University of Utah, Isotope Geology Laboratory, assisted in the sulfur isotope determinations of groundwaters.

GEOLOGY AND RELIEF

Bear Lake lies in Bear Lake Valley, a broad depression which resulted from recurrent faulting for a considerable period of time. Slightly more than half the 19-mile length of the lake is in Utah, the remainder in Idaho. The lake is 7½ miles wide at the state line, the widest point, and is more than 200 feet deep. Prior to 1911 Bear Lake had no direct connection with the Bear River drainage (the largest drainage in the North American continent not reaching the ocean). In 1911 inlet and outlet canals were constructed near the lake's north extremity to connect it with the river, thereby converting the lake into a storage reservoir. The level of Bear Lake fluctuates as requirements for power generation and irrigation dictate, subject to regulation as provided by the Bear River Compact (endorsed by Idaho, Utah and Wyoming in 1955).

[1] Engineering geologist, Utah Geological and Mineralogical Survey, Salt Lake City, Utah.



EXPLANATION

- 45 — *Well; number indicates depth to bedrock in feet.*
- ▼59 — *Well; number indicates Wasatch Formation thickness.*

Data from State Engineer's well file. Interpretation of driller's logs has been made by author.

Figure 1. Depths to bedrock and bottom contours of Bear Lake.

The surface of the Bear Lake area consists of soft sediments and soft to hard sedimentary rocks. The soft unconsolidated deposits vary considerably in thickness. Depths to bedrock are plotted on figure 1.

Surficial Deposits

Material covering bedrock consists of sediments deposited by streams (1) in their channels (alluvium), (2) as they spread over lowlands (forming alluvial fans) or (3) as they debouched into the lake (deltaic). Wave action may have reworked the deltaic. The land forms at the mouths of North and South Eden canyons (delta-fans) resulted from subaerial and subaqueous sedimentation by the respective stream distributaries. Sediments (lacustrine) deposited in the lake at a time when its level was higher also are exposed. Three former lake levels can be distinguished at elevations of 5,929, 5,938 and 5,948 feet (Williams and others, 1962). At various places around the lake, steep breaks in slope have resulted from the preservation of the old beach levels. Similar breaks in slope of frequently greater relief occur where geologic faulting has displaced unconsolidated materials. The east shore has a considerably steeper gradient than elsewhere. Slopes on sediments submerged by the lake are not of uniform grade.

Slope wash material is a mixture of all-sized particles on subaerial slopes below rock outcroppings. The material, with a large assist from gravity, works its way to lower elevations.

Bedrock

Bedrock crops out spectacularly in considerable relief in places; in others it is buried to a considerable depth.

Characteristics of bedrock types vary greatly; they are discussed in later sections where their relevance is readily apparent.

CLIMATIC BEARING ON GEOLOGY

Precipitation

Precipitation is important inasmuch as it is the origin of all the water that eventually becomes stored in underground reservoirs (aquifers). The mean annual precipitation at Laketown is 10.60 inches; that recorded at the Lifton Station at the north end of the lake, 9.62 inches.

The curve plotted on figure 2 illustrates the relationship between the mean annual precipitation and erosion (Langbein and Schumm, 1958). Plotted for a climate with an average annual temperature of 40° F,

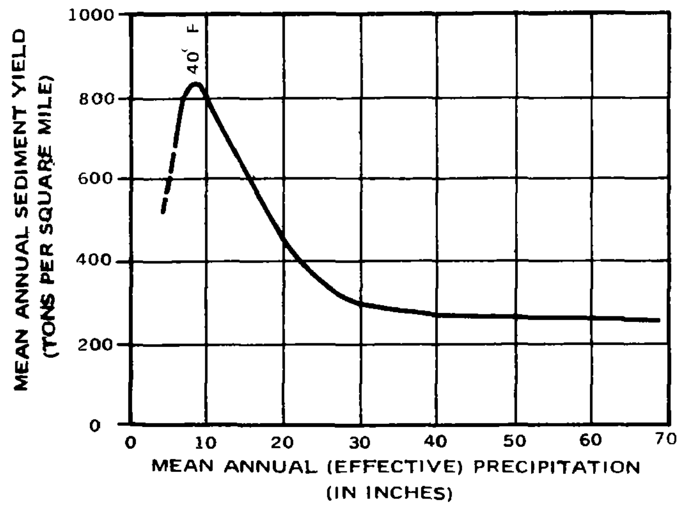


Figure 2. Relation between sediment yield and precipitation adjusted to a mean annual temperature of 40° F.

as in the Bear Lake area, it reveals that erosion (sediment yield) is at a maximum at about 8 to 9 inches of mean annual precipitation. This situation is closely approximated in the Bear Lake area. When precipitation decreases, runoff also decreases; when precipitation increases, vegetation increases in density and markedly begins to retard erosion, curtailing sediment removal and transport.

Rainfall intensity is as important as total precipitation. A large quantity of rain falling in a short time can provide perfect conditions for removal and transport of large deposits of soil and loose rock. Cloudburst flooding frequently results in mud or debris flows. Fortunately the Bear River Range protects the Bear Lake area from this occurrence with few exceptions. In 18 years of daily meteorologic record, only two possible instances of cloudburst are shown. In June 1964, 1.29 inches fell in one storm and in September 1965, total rainfall for a storm was 1.45 inches. Care must be exercised to ensure that drainage gullies, ravines and canyons are not blocked by new construction and that their courses are not altered without careful and thorough hydrologic and engineering investigations.

Temperature and Wind

Bear Lake freezes over four out of five years. Northwest winds funneling down from the pass to the north and easterly winds blowing from North and South Eden canyons accumulate ice floes along the west side of the lake making riprap protection necessary (p. 26). Waves 2½ meters high are theoretically possible on the lake.

Reports from Evanston, Wyoming and Woodruff, Utah, during the winter of 1961 to 1962 indicated the ground froze to a depth of 6 feet, "possibly a record in this portion of the country" (Peck and Richardson, 1962). This figure must be considered in the placement of water lines, footings for buildings, etc.

Ground frost prevents snow melt and rainfall from penetrating subsurface aquifers. Since the precipitation is carried away in surface runoff, flooding is promoted. This is relevant when considering the relation of groundwater levels to cumulative departure from the average annual precipitation (figure 3). The small crest at the end of 1963 on the curve for well (A-13-5)21dab-1 appears in a broader trough beginning in 1959. This crest reflects the precipitation and also the last freeze period.

Evaporation Potential

As is normal for this part of the country, evaporation exceeds precipitation in the Bear Lake area during the summer.

Month	Average (in inches)		Difference (deficit)
	Evaporation[1]	Precipitation	
May	6.36	1.16	5.20
June	7.61	.94	6.67
July	9.15	.58	8.57
August	8.22	.75	7.47
September	5.72	.78	4.94
October	3.25	.91	2.34

[1]As measured in 4-inch pan at Lifton Pump Station.

These figures emphasize the importance of snow melt to groundwater recharge, since no water is available for recharge over much of the year.

The precipitation from May to October accounts for more than half of the total annual precipitation. Transpiration from plants and sublimation of snow also subtract from the water available for aquifer recharge.

GEOLOGY AND GENERAL CONSTRUCTION CONDITIONS

Geologic aspects that affect construction are drainage, slope, bearing strength, rippability, water table depth and fluctuation, flooding potential, availability of earth materials for fill and aggregate and the availability of water. Many of these factors are discussed elsewhere in the report.

Hydrogen sulfide odors from shallow wells around the lakeshore suggest the presence of organic material in the fine lacustrine deposits. Such organic material incorporated in sediments is detrimental to good bearing strength; differential compaction under load can be expected to occur.

Excavations in saturated lacustrine and alluvial sediments likely will require shoring for protection. Slope wash on the west side of the lake also may require shoring in excavations.

Rippability (ease with which rock can be broken by tractor-drawn rippers into pieces that can be economically moved by other equipment) of surficial deposits is a problem only where cemented calcium carbonate caliche zones are encountered. This hard pan was observed in erosional ravines in slope wash on the west side of the lake. Too few excavations in lacustrine sediments were examined to determine whether cementing of the sands and gravels has occurred. Some exposures of what appear to be cemented former lakeshore gravels closely resemble Wasatch Formation bedrock gravel beds in appearance.

Rippability conditions change markedly over short distances in the Wasatch Formation. Thin cemented gravel beds may be undermined by removal of easily excavated underlying siltstones and claystones that are semiconsolidated. The other bedrock formations pose problems in rippability except where they are locally highly fractured. Faulting along the foothills bordering the west side of the lake has fractured the Brigham Quartzite to the point where this normally highly resistant rock has been made completely rippable (see figure 13, p. 24).

Subsurface water contributes to the instability of excavations in unconsolidated deposits. Dewatering of much of the vicinity around Bear Lake will be necessary for construction. Consult the Groundwater Occurrence section for dewatering possibilities of alternate sites.

Special caution and careful study of hydrologic data should precede construction of dam structures across drainage channels in the foothills and mountains in the Bear Lake area. Foundations, regardless of dam height, should be explored. The reservoir area, too, must be investigated to determine if a suitable site was selected and sources of earth materials must be evaluated; selected fill material must be placed in the embankment according to proper engineering practice to ensure the safety of lower riparian residents and communities. One dam in Cottonwood Canyon southwest of Laketown with an earth-fill embankment of 10 feet failed in the spring of 1962 when the reservoir was full. The natural environment was damaged but fortunately no communities laid downstream in the path of the flood crest.

Sedimentation of the reservoir must be considered wherever impoundments are proposed. Figure 2 clearly shows that the sedimentation rate is expected

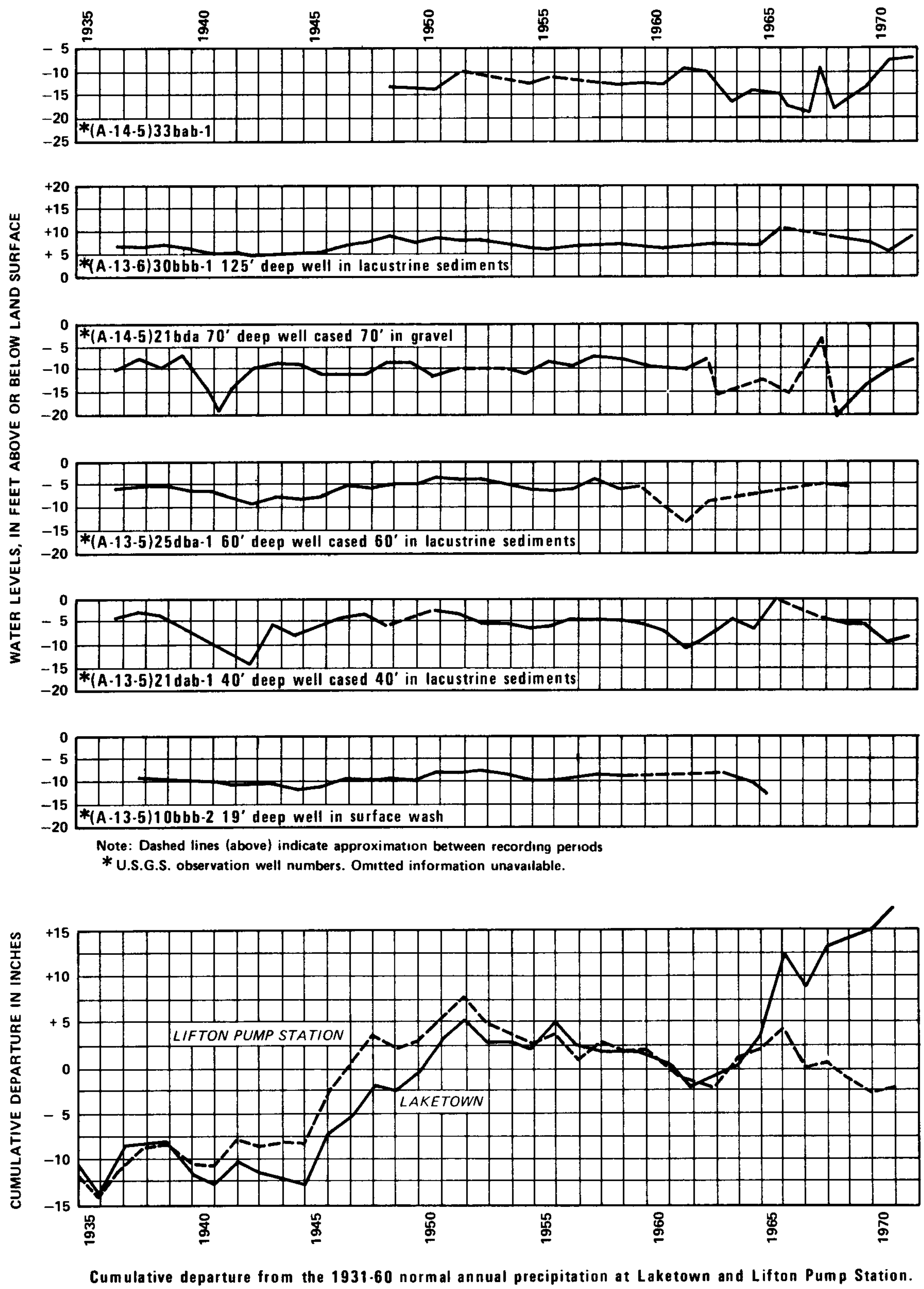


Figure 3. Relation of groundwater levels in observation wells in the vicinity of Bear Lake to cumulative departure from the average annual precipitation (as recorded at Laketown and Lifton Pump Station).

Table 1. Chemical analyses of water from sources in the vicinity of Bear Lake.

Sample Number[1]	Date of Collection	Temperature (°F)	Parts per million											
			Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hydroxide (OH)
LAKE SAMPLE														
BL-1	7-28-68		11.0	20	68	45.0	6.0	330	7.3	74.0	58	0.24	0.10	0.07
WASATCH FORMATION (AQUIFER)														
BL-2	7-28-68		10.0	46	21	20.0	2.0	245	1.9	18.0	22	0.17	1.00	0.02
BL-7	7-29-68		11.0	59	21	14.0	1.0	237	2.3	16.0	30	0.30	17.00	0.03
BL-8a	6- 8-67		12.0	69	9	11.0	1.0	266	0.58	5.0	20	0.17	0.40	0.01
BL-8b	7-30-68		13.0	70	12	10.0	2.0	280	1.5	5.0	20	0.18	0.00	0.02
BL-11	7-31-68		9.0	58	16	11.0	1.0	237	1.0	8.0	29	0.17	1.20	0.01
BL-16	8- 4-68		7.0	50	23	9.0	2.0	236	2.9	16.0	25	0.15	0.00	0.04
BL-17	8- 4-68	50	7.0	48	26	8.0	2.0	237	2.1	13.0	20	0.17	5.10	0.03
BL-18	8- 4-68	47	8.0	57	28	11.0	2.0	298	2.7	13.0	20	0.14	5.50	0.02
BL-27a	7-26-41		10.0	73	6.2	13.0				6.0	16	0.65	trace	
BL-27b	12-22-59			79	3	7.5	2.0	236	1.6	4.0	13	0.42	1.10	
BL-27c	7-21-68	44	11.0	69	7	9.0	2.0	238	2.1	8.0	19	0.21	2.00	0.03
LACUSTRINE SEDIMENTS–INCLUDING DELTAIC SEDIMENTS (AQUIFER)														
BL-3	7-28-68		10.0	56	25	19.0	2.0	280	1.7	20.0	22	0.16	2.50	0.02
BL-4	7-28-68		10.0	19	24	18.0	2.0	169	2.9	16.0	19	0.15	1.10	0.05
BL-5	7-28-68		11.0	45	25	20.0	2.0	280	1.5	13.0	17	0.24	0.10	0.02
BL-6a	7-30-63		10.0	227	91	26.0	2.7	235	0.46	714.0	51	0.71	0.00	0.01
BL-6b	7-29-68		12.0	181	55	36.0	3.0	249	0.86	498.0	51	0.85	0.00	0.01
BL-13	7-31-68		24.0	56	19	7.0	3.0	251	1.7	15.0	10	0.17	0.80	0.02
BL-14	7-13-68	49½	13.0	54	27	26.0	3.0	246	2.2	50.0	42	0.20	0.60	0.03
BL-15	7-13-68	47	25.0	50	20	7.0	2.0	246	2.2	8.0	17	0.13	0.00	0.03
BL-19	8- 4-68		14.0	93	77	70.0	4.0	587	4.1	124.0	71	0.45	5.90	0.02
BL-20	8- 4-68	47	15.0	87	31	28.0	4.0	331	2.1	86.0	43	0.42	1.80	0.02
BL-21	8- 4-68		14.0	128	55	105.0	5.0	242	1.1	319.0	192	0.20	1.20	0.01
BL-25	8-16-68	56	10.0	47	24	7.0	2.0	253	2.5	11.0	18	0.14	0.70	0.03
BL-28	8-21-68	50	13.0	70	13	9.0	2.0	285	2.5	7.0	17	0.20	3.40	0.03
BL-29	8-21-68	50	14.0	72	16	8.0	2.0	290	2.8	5.0	15	0.18	2.50	0.03
BL-32	8-21-68		6.0	43	17	3.0	1.0	204	2.8	2.0	13	0.06	0.50	0.04
BL-34	9-19-68	48	8.0	64	27	14.0	1.0	281	1.6	17.0	30	0.09	17.00	0.02
BL-35	9-19-68	47½	10.0	55	22	8.0	1.0	247	0.76	13.0	20	0.10	0.00	0.01
BL-37	9-20-68	50	24.0	64	22	9.0	1.0	267	0.93	16.0	25	0.13	10.00	0.01
BL-38	9-28-70	56	13.0	53	25	45.0	2.0	342	0.84	0.5	37	0.13	0.60	0.01
ALLUVIUM AND SLOPE WASH (AQUIFER)														
BL-10	7-31-68	48	10.0	72	10	11.0	1.0	253	1.4	8.0	25	0.16	1.20	0.02
BL-30	8-21-68		12.0	85	22	60.0	7.0	330	5.1	36.0	75	0.48	31.00	0.05
BL-36	9-20-68	48	19.0	80	22	10.0	1.0	347	1.5	6.0	16	0.29	12.00	1.01
NUGGET SANDSTONE (AQUIFER)														
BL-9	7-31-68	53	8.0	46	23	10.0	1.0	229	1.4	21.0	22	0.16	0.80	0.02
BL-12	7-31-68		29.0	66	83	120.0	3.0	456	4.5	199.0	146	0.40	3.00	0.03
BRIGHAM QUARTZITE (AQUIFER)														
BL-22	8-14-68	57	9.0	52	20	4.0	2.0	255	2.3	9.0	14	0.10	0.50	0.03
BL-23	8-14-68	56	9.0	48	18	3.0	2.0	227	2.8	8.0	13	0.07	0.40	0.04
CARBONATE ROCKS–LIMESTONE AND DOLOMITE (AQUIFER)														
BL-24a	7-22-55		6.6	47	10			211	0.82	77.0	6	0.75	1.00	0.01
BL-24b	10-28-59		5.8	47	15	3.2	0.0	210	0.58	3.7	8	0.09	0.31	0.01
BL-24c	8-14-68	42	7.0	43	16	3.0	1.0	206	2.0	6.0	14	0.06	0.70	0.02
BL-31	8-21-68	48½	7.0	35	30	7.0	2.0	241	4.2	6.0	20	0.14	0.60	0.05
BL-33	9-18-68	50	8.0	54	23	5.0	1.0	264	2.6	7.0	12	0.10	0.60	0.03
HOT SPRINGS														
BL-26	8-19-68	112	31.0	208	51	150.0	40.0	235	0.82	792.0	83	4.70	3.00	0.01

[1] Number denotes sampling station (see plate 1).

Note: All samples were analyzed for silver, selenium, barium, cadmium, chromium and lead, but no traces were found. Sources (aquifers) for BL-31 and BL-35 not certain; may be multiple. Temperature taken to nearest ½°.

Table 1. (continued)

Parts per million															
Phosphate (PO_4)	Arsenic (As)	Boron (B)	Copper (Cu)	Iron (Total) (Fe)	Iron (in filtered samples) (Fe)	Manganese (Mn)	Zinc (Zn)	Surfactant (ABS)	Total Dissolved Solids	Total Hardness as $CaCO_3$	Total Alkalinity as $CaCO_3$	Sodium Adsorption Ratio	Specific Conductance (Micromhos/cm at 25° C)	pH	Turbidity (Turb. Units)
LAKE SAMPLE															
1.4	0.01	0.14	0.00	0.00	0.00	0.00	0.01	0	470	328	283	1.08	795	8.6	0.5
WASATCH FORMATION (AQUIFER)															
1.3	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0	254	202	204		485	8.15	0.0
1.4	0.00	0.12	0.00	0.00	0.00	0.00	0.02	0	320	232	198		530	8.25	0.0
0.8	0.00	0.00	0.01	0.01	0.00	0.05	0.02	0	258	220	219		480	7.6	5.0
2.0	0.00	0.12	0.00	0.10	0.00	0.00	0.00	0	275	226	232		490	8.05	0.0
1.3	0.00	9.0	0.00	0.00	0.00	0.00	0.02	0	232	210	196		470	7.9	0.0
1.3	0.00	0.03	0.00	0.C0	0.00	0.00	0.00	0	278	218	198		460	8.35	2.0
1.0	0.00	0.04	0.00	0.00	0.00		0.02	0	260	228	198		470	8.2	0.0
1.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	300	258	248	0.30	540	8.15	0.5
				0.00	0.00			0	242	207	208			7.56	
	0.00	0.00	0.00	0.03		0.00	0.2	0	248	209	196				0.0
0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0	250	202	199		455	8.2	0.0
LACUSTRINE SEDIMENTS–INCLUDING DELTAIC SEDIMENTS (AQUIFER)															
1.4	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0	298	242	232		530	8.05	0.0
1.5	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0	220	144	143		355	8.5	0.0
1.5	0.06	0.18	0.00	0.00	0.00	0.00	0.00	0	272	214	232	0.26	500	8.0	0.0
0.2	0.03	0.11	0.00	0.71	0.03	0.11	2.7	0	1,395	931	193		1,630	7.55	5.5
1.5	0.01	0.14	00.0	0.00	0.00	0.00	0.00	0	1,052	680	205		1,370	7.8	0.0
3.0	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0	294	220	208		485	8.1	0.0
1.8	0.00	0.14	0.00	0.00	0.00	0.00	0.04	0	556	248	205		615	8.2	0.5
3.3	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0	252	206	205		445	8.2	0.0
2.4	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0	788	550	487	1.30	1,250	8.1	0.5
2.1	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0	498	344	275		835	8.05	0.0
2.0	0.00	0.17	0.01	0.02	0.00	0.00	0.08	0.35	1,012	544	200	1.96	1,660	7.9	0.5
0.20	0.00	0.08	0.00	0.00	0.00	0.00	0.02	0	238	218	212		460	8.25	0.5
0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0	286	230	238		510	8.2	0.0
0.30	0.00	0.09	0.00	0.00	0.00	0.00	0.01	0	302	246	242		515	8.25	0.0
0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.04	0	184	177	172		365	8.4	0.5
0.40	0.00	0.16	0.00	0.00	0.00	0.00	0.04	0	338	270	238		540	8.0	0.0
0.50	0.00	0.12	0.00	0.00	0.00	0.00	0.03	0	250	228	203		430	7.75	1.0
0.50	0.01	1.1	0.00	0.00	0.00	0.00	0.28	0	316	252	220		535	7.8	0.0
0.20	0.00	0.13	0.01	4.00	0.00	0.01	0.00	0	350	234	282		570	7.65	45.0
ALLUVIUM AND SLOPE WASH (AQUIFER)															
1.3	0.00	0.10	0.00	0.00	0.00	0.00	0.02	0	254	222	210		470	8.0	0.0
1.0	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0	514	302	278	1.50	850	8.45	1.5
1.0	0.00	0.13	0.00	0.00	0.00	0.00	0.12	0	326	290	287		570	7.9	0.0
NUGGET SANDSTONE (AQUIFER)															
1.0	0.00	0.08	0.00	0.00	0.00	0.00	0.02	0	258	210	190	0.30	450	8.05	0.0
3.5	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0	920	508	381		1,445	8.25	1.0
BRIGHAM QUARTZITE (AQUIFER)															
0.10	0.00	0.05	0.04	0.00	0.00	0.00	0.04	0	240	214	213		440	8.2	0.0
0.00	0.00	0.07	0.02	0.00	0.00	0.00	0.01	0	230	194	191		400	8.35	0.0
CARBONATE ROCKS–LIMESTONE AND DOLOMITE (AQUIFER)															
				0.1	0.00			0	202	158	174			7.85	
	0.00	0.00	0.00	0.02		0.00	0.05	0	187	178	173			7.7	0.0
0.10	0.00	0.05	0.00	0.00	0.00	0.00	0.02	0	182	174	171	0.09	355	8.1	0.0
0.0	0.00	0.08	0.01	0.00	0.00	0.00	0.02	0	242	213	205	0.23	460	8.5	0.0
0.50	0.00	0.14	0.00	0.00	0.00	0.00	0.01	0	245	228	221		440	8.25	0.0
HOT SPRINGS															
0.70	0.00	0.90	0.00	0.00	0.00	0.00	0.03	0	1,556	728	194	2.42	1,700	7.8	0.0

to be greatest in the vicinity of Bear Lake. In the higher mountain elevations conditions are not comparable, as temperature, precipitation and vegetation are different.

In the lower regions around the lake, erosion must be prevented wherever modification of the land surface is anticipated, as in farming, grading, landscaping and building. Subsequent sections deal specifically with particular problems in construction, including slope stability, seismicity, earth materials and waste disposal.

GROUNDWATER OCCURRENCE

In the Bear Lake area several aquifers yield water to springs or wells penetrating them. A discussion of each follows.

Plate 1 shows the location of wells recorded in the State Engineer's office to September 1971. Representative wells were sampled and they are noted on the plate. Springs observed during the course of field work also were plotted and sampled. Table 1 shows the chemical analyses of samples collected by the writer and run by the Utah Department of Health. These analyses are discussed in the Water Quality section.

Lacustrine and Deltaic Sediments

Lacustrine sediments in Bear Lake are materials deposited in the lake in the past; from coarse beach gravels to deep-water clays are represented in the sequence. Deltaic sediments, particularly from North and South Eden deltas, are included since they were deposited in the lake and are interstratified with lacustrine sediments.

Coarser sediment beds or layers yield the greater quantities of water; alternation of fine and coarse sediments permits artesian conditions in almost every well penetrating the aquifer. Specific capacities (yield-per-foot of drawdown) for existing wells range from less than 1 to 75 gpm. Potential for development of substantial quantities of water from selected beds in the aquifer is considerable. For maximum yield, however, proper well development techniques should be employed. To date, such techniques have not been evidenced in the area.

Over much of the aquifer the water table is near the surface; irrigation waters contribute to recharge along with precipitation and lake water. Recharge from the lake is naturally related to the lake level which is governed by Lifton Pump Station requirements at the north end of the lake. Figure 3 illustrates any relationship that might exist between water levels as observed once or twice a year in U. S. Geological Survey observation wells (plate 1) and annual precipitation over the area. Where a relationship is not apparent may indicate merely a closer relationship of the water levels with the base lake levels. With little topographic relief in the area of lacustrine sediments, a paucity of springs is expected.

A spring was sampled in sec. 5, T. 14 N., R. 5 E. on the grounds of the Boy Scout Camp. Its anomalously high temperature parallels that of two springs to the north in the Brigham Quartzite. These high temperatures might be attributed to emission from an underlying fault in bedrock. Other springs and seepage areas have been reported along the west shore of the lake as far south as Ideal Beach.

Alluvium and Slope Wash

Few wells exist in alluvial or slope wash materials. Slope wash consists of all sizes of material deposited more or less uniformly over bedrock; shallow wells may draw sufficient water for domestic purposes from this material. Alluvium is better sorted material with better stratification, having been deposited in water courses. It interfingers with lacustrine deposits in the flat areas bordering the lake. Only one spring in alluvium, in sec. 28, T. 13 N., R. 6 E., is known to be in use. Water most frequently occurs under normal water table conditions (nonartesian) in the aquifer.

Wasatch Formation

Much of the foothill and higher mountain terrain is covered by the Wasatch Formation in varying thicknesses. In a few cases considerable water has been derived from wells tapping this aquifer. The water-yielding beds in this heterogeneous geologic unit are the sandstone, conglomerate and freshwater limestone strata. The spring in sec. 3, T. 13 N., R. 6 E. issues from a concretionary limestone with solution channelways.

Sandstone and conglomerates have considerable pore space, sometimes accentuated by the dissolution of limestone particles up to boulder size. Spherical cavities attributable to this process can be observed in outcrops of conglomerate. Pickleville's water is supplied by a spring in the Wasatch Formation in sec. 31, T. 13 N., R. 5 E.

It is difficult to determine when the Wasatch Formation has been penetrated when drilling through slope wash or other unconsolidated material. This makes interpretations of drillers' logs difficult.

The large outcrop area of the Wasatch Formation permits ready recharge by precipitation. Groundwater migration is largely downdip but faults alter paths locally as impermeable beds abut against permeable beds.

Carbonate Rocks

The outcrop area of Paleozoic carbonate rocks is large compared to other single rock types (see figure 10, p. 20).

Swan Creek Spring emitting from the rocks in sec. 6, T. 14 N., R. 5 E. may have a yield as great as Mammoth Spring in southwest Utah. An instantaneous discharge of 314 cfs was observed at Mammoth Spring, but no reliable maximum figure for discharge is available for the Swan Creek Spring. The only available daily record of Swan Creek's flow was for 1944 and 1945 when Swan Creek was gaged. Estimates for instantaneous discharge of about 300 cfs have been made, however, for the spring. Rain and snowfall readily recharge the aquifer especially through the large sink holes on the Bear River Range (figure 4). Recharge west of the divide probably contributes to the flow of Swan Creek Spring.

Swan Creek Spring contributes by far the greater part of Swan Creek's total discharge. Another spring of significant magnitude (station 3) also is tributary to Swan Creek, and located in the same geographic section. Figure 5 plots the Swan Creek hydrographs for 1944 and 1945 in relation to the daily precipitation at Lifton Pump Station. Although the precipitation regime at Lifton is not exactly that of the Bear River Range, it was the closest station at which daily precipitation rates were recorded. The better situated Tony Grove Station (figure 4) recorded only monthly figures (table 2). The hydrographs reflect the rapid response of the carbonate springs to snow melt during April and May and to rainfall throughout the year. The close correlation with the rainfall record indicates an exceptional transmissibility of the aquifer. This must be the result of a subterranean network of open channels caused by solution along fracture systems in the carbonate rock formations. In the carbonate terrain around Bear Lake, springs probably offer greater prospect for development than do wells, as wells are far more difficult to intercept a channel.

Brigham Quartzite

Like Paleozoic carbonates, quartzite is a tough dense rock, but more abrasive to drill bits, with little if any capacity to hold interstitial water. Water in the aquifer is held and transmitted through fractures. Much of the Brigham Formation bounding the lake on the west is faulted and highly fractured; old landslides in the formation attest to this fact. At least two springs originate in this unit in sec. 5, T. 14 N., R. 5 E., probably from the border fault. Natural recharge is limited on the hills comprised of quartzite. If wells were drilled in the quartzite, they possibly would yield sufficient water for domestic needs.

Nugget Sandstone

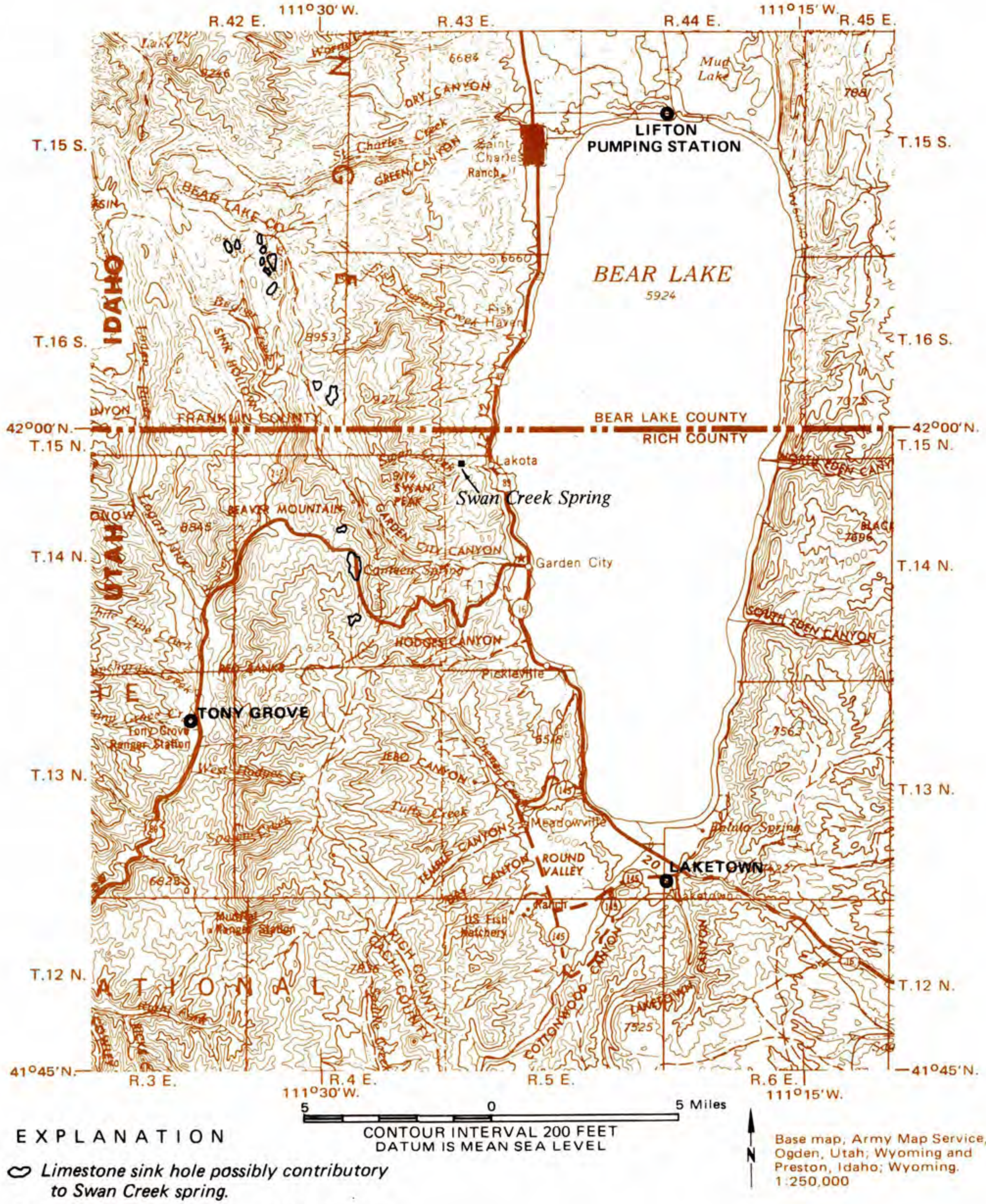
Underlying Falula Spring (sec. 29, T. 13 N., R. 6 E.) is Nugget Sandstone. The prodigious water potential from the spring, however, may come from a stratum of unconsolidated sediment overlying the sandstone. About 1,400 gpm were pumped from the spring with a 5-foot drawdown (Siddoway, personal communication, 1968). No evidence of a fault was observed, but the spring is possibly the result of water rising along a fault.

A well at station 12 in sec. 17, T. 13 N., R. 6 E. was drilled through 25 feet of Wasatch before penetrating Nugget; it has a specific capacity of 4 gpm. The well probably penetrates a fault (see Seismicity and Faulting).

Table 2. Precipitation for stations nearest to area of recharge for Swan Creek Spring.

	Lifton Pump Station[1]			Laketown[2]			Tony Grove R.S.[3]		
	Monthly total (inches)	Unmelted Snowfall (inches)	Number of Days >.01" precip.	Monthly total (inches)	Unmelted Snowfall (inches)	Number of Days >.01" precip.	Monthly total (inches)	Unmelted Snowfall (inches)	Number of Days >.01" precip.
1944								Not recorded	Not recorded
March	1.15	18	11	1.52	21	13	3.00		
April	2.02	8.5	13	2.31	12.2	16	4.14		
May	0.93	trace	8	0.66	trace	7	3.00		
June	2.01		12	2.23		12	1.52		
July	0.30		3	0.26		1	0.48		
Aug.	0.00		0	0.00		0	0.00		
Sept.	0.53		4	0.69		2	0.50		
1945									
March	0.37	5	7	0.64	3.9	10	3.22		
April	1.02	12	7	0.66	.37	7	2.60		
May	2.26		13	2.34		13	5.25		
June	2.10		12	2.35		11	2.25		
July	1.29		5	0.59		4	2.70		
Aug.	1.33		11	1.99		9	2.30		
Sept.	1.38		7	1.33		6	1.68		

[1]Elevation 5,926 feet.
[2]Elevation 5,988 feet.
[3]Elevation 6,200 feet.

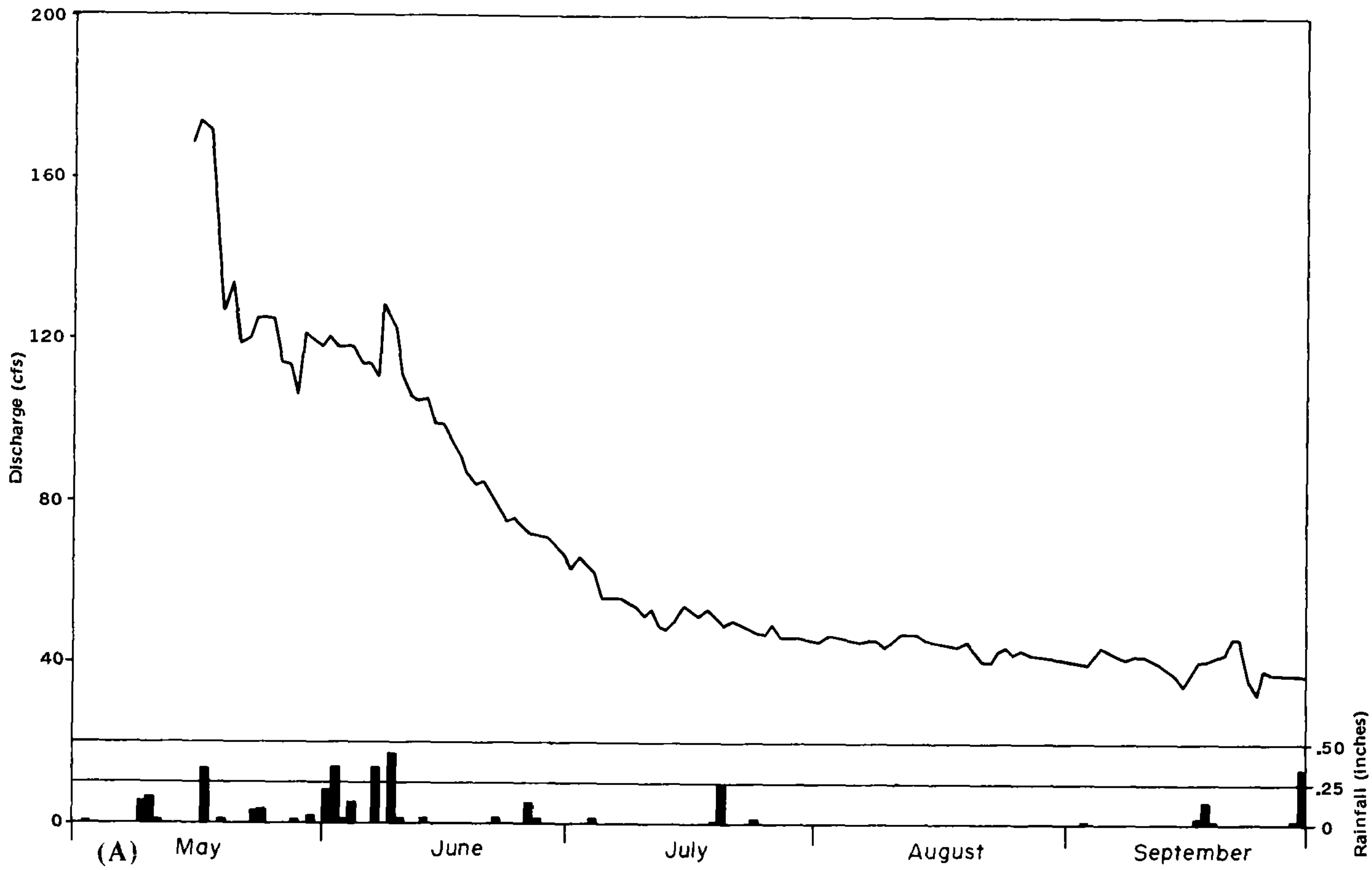


EXPLANATION

Limestone sink hole possibly contributory to Swan Creek spring.

U.S. Weather Bureau precipitation station

Figure 4. Location of precipitation stations (1944-1945) and largest sink holes.



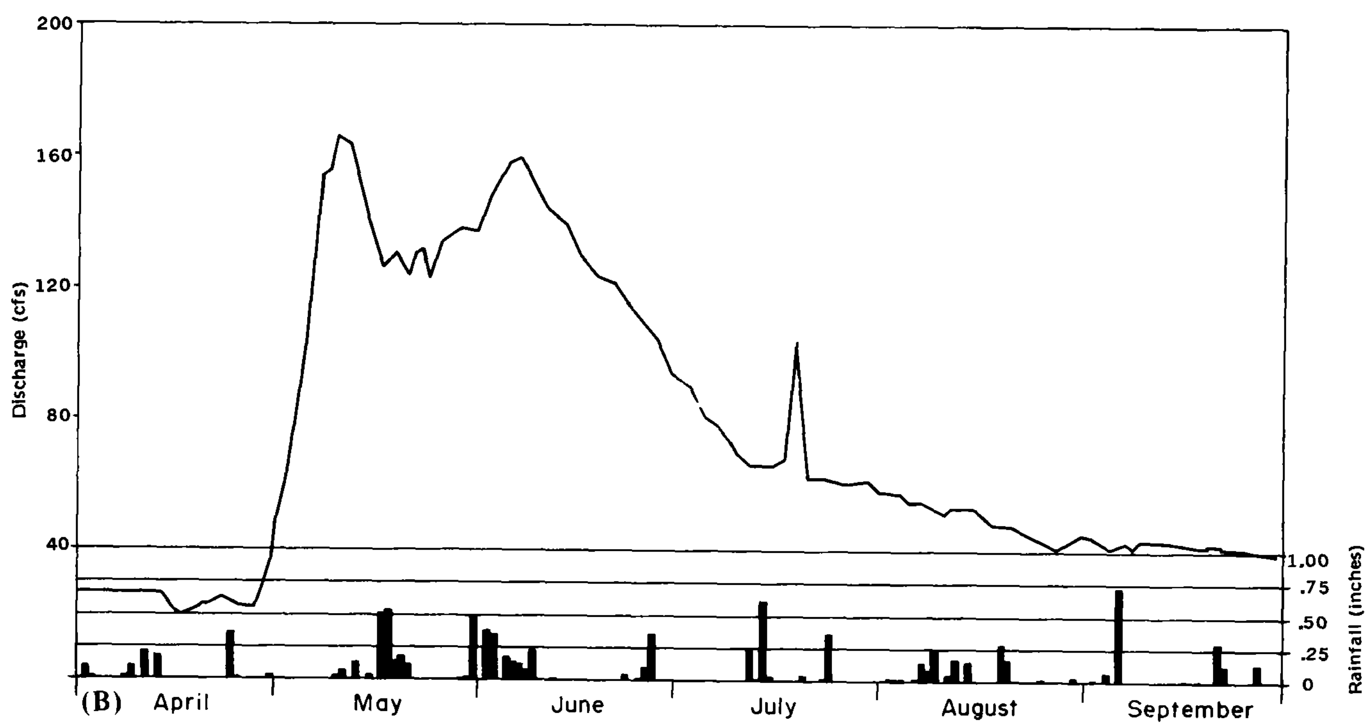


Figure 5. Relation of Swan Creek discharge to daily precipitation (a) 1944 and (b) 1945. Recorded at Lifton Pump Station.

The Nugget Sandstone recharges directly from precipitation and from percolation through overlying Wasatch beds. The need to tap the Nugget for water is considerably diminished because of the nature of the area where it occurs. Satisfactory yields for domestic purposes, however, may be obtained when necessary.

Seepage areas are defined by vegetation patterns on the steep westward-facing mountain slopes.

WATER QUALITY

Water percolating slowly through subsurface materials comes into close and long contact with an assortment of minerals in the earth's crust and takes chemical substances into solution to a greater or lesser degree.

The most significant aquifers in the Bear Lake area are composed of debris from several older geologic units. Alluvium, for example, is derived from material washed down by streams from bedrock hills comprised of several formations and rock types.

The Wasatch Formation, largely of consolidated and cemented alluvial material, permits the dissolution of many minerals resulting in wide variations in the chemical character of groundwater. In addition bedrock structures, including faults, transect strata and perhaps geologic units, thus conducting water through still a wider diversity of materials. Water analyses reflect the dissolution of these diverse materials.

A water's usability is directly related to the substances dissolved or suspended in it as determined by chemical and biological analyses. A water source should be tested over a period of time if possible. Swan Creek Spring, for example, fluctuates by more than a factor of ten each year. Chemical characteristics can change. Minerals in excess of the amount that can be tolerated for a given use sometimes may be reduced or removed through treatment. Groundwater frequently has the advantage over surface water; it normally contains no suspended matter and few bacteria, is usually clear and colorless and has a relatively constant temperature.

Groundwater quality is subject to defilement by man, although not as obviously as in the case of surface water. Adherence to Utah Health Department provisions for well construction and sewage disposal will help to assure the maintanence of the groundwater quality.

Water Quality in Relation to Use

Agricultural

Sodium ions in excess of calcium and magnesium ions in a soil are detrimental to plant growth. The sodium imparts a sticky, slick quality to a wet clayey soil; permeability is curtailed and with sufficiently high concentration, alkali soils form in which little or no vegetation grows.

In 1948 the U. S. Department of Agriculture Salinity Laboratory devised the SAR or "sodium-adsorption ratio" to express how much an irrigation water is likely to be hazardous to a soil. Irrigation water with a high SAR value results in development of excessive sodium in the soil. Values of 18 or more are considered high, 10 to 18 medium and below 10 are low with little danger of sodium buildup. Fruit crops can tolerate an SAR of irrigation water of about 4. Greater amounts cause damaging sodium accumulations in the sensitive crops (ASTM, 1967). SAR values were computed for representative waters in the study and for those most likely to be used for irrigation (table 1 and figure 6). Since the highest SAR value determined for the groundwaters sampled in this study was about 2 (excluding the hot springs), apparently no sodium hazard from groundwater usage exists in the area.

To be suitable for irrigation, water also must have a sufficiently low quantity of total dissolved salts or salinity.

The relationship between total dissolved solids (TDS) and specific conductance in water, measured in micromhos, was plotted for 31 samples on figure 7. The samples are from different well or spring sources and they represent each aquifer in the Bear Lake area (figure 7, explanation). From figure 7, the average dissolved solids value for the entire study area is approximately 62 percent of the specific conductance (in micromhos per cm at 25° C; specific conductance x 0.62 = approximate TDS). This percentage factor is considered normal.

The salinity hazard of water is considered high when its conductivity exceeds 750 (micromhos per cm at 25° C). Most of the Bear Lake analyses fall in the medium-salinity hazard range between 250 and 750. Most of the exceptions, ranging to 1,700, are samples from wells along the east shore of the lake where the aquifers are predominantly deltaic sediments. The deeper well of the two on North Eden delta yields water considerably more saline than the shallower. This relationship of water depth to TDS does not hold true, however, as a generalization for all aquifers sampled in the Bear Lake area.

Boron, a minor element, is critical in irrigation water, essential to plant growth but extremely toxic at concentrations only slightly above optimum. Concentrations in excess of 1.25 ppm in irrigation water normally are considered as toxic to most farm crops.

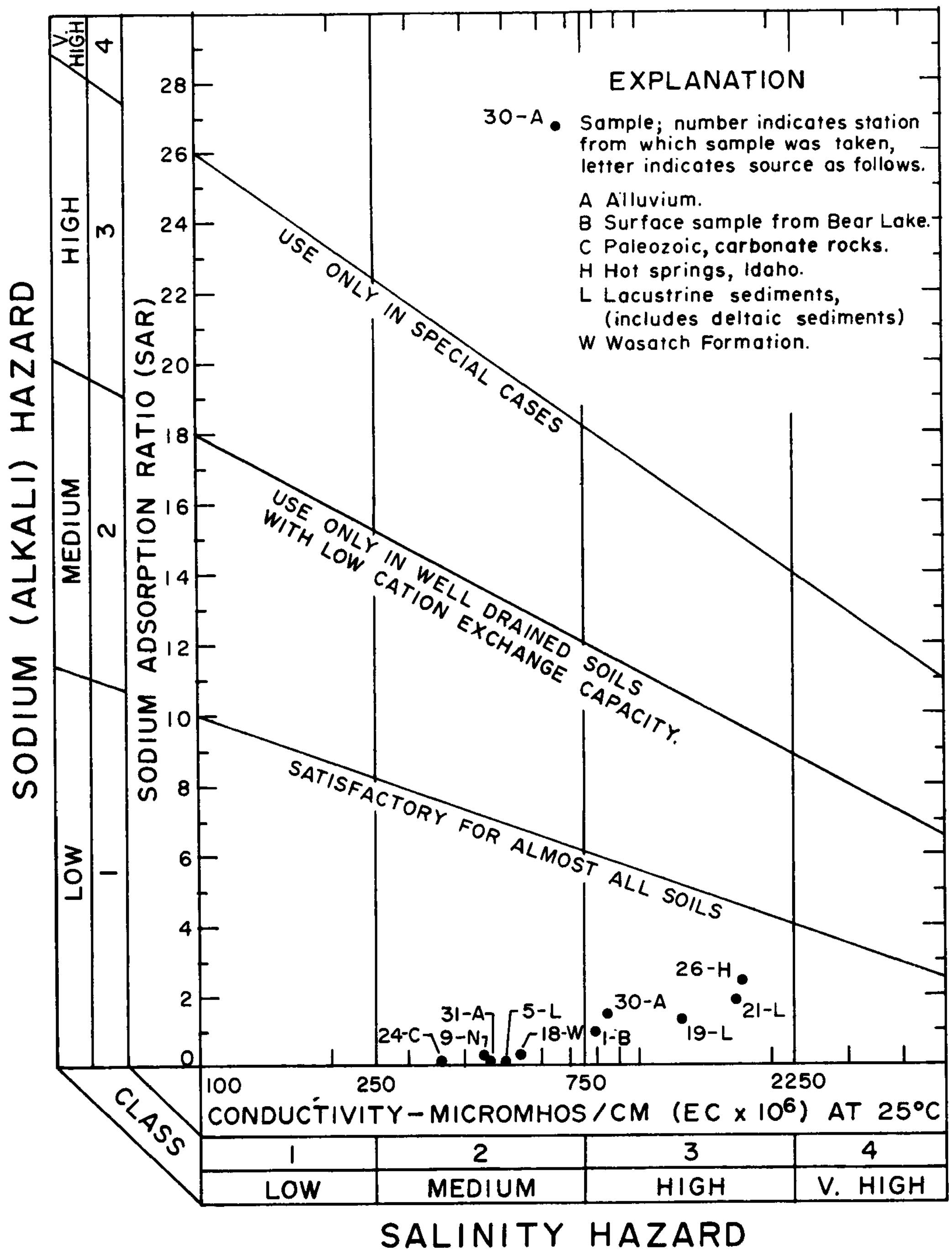


Figure 6. Classification of groundwater for irrigation in the Bear Lake area.

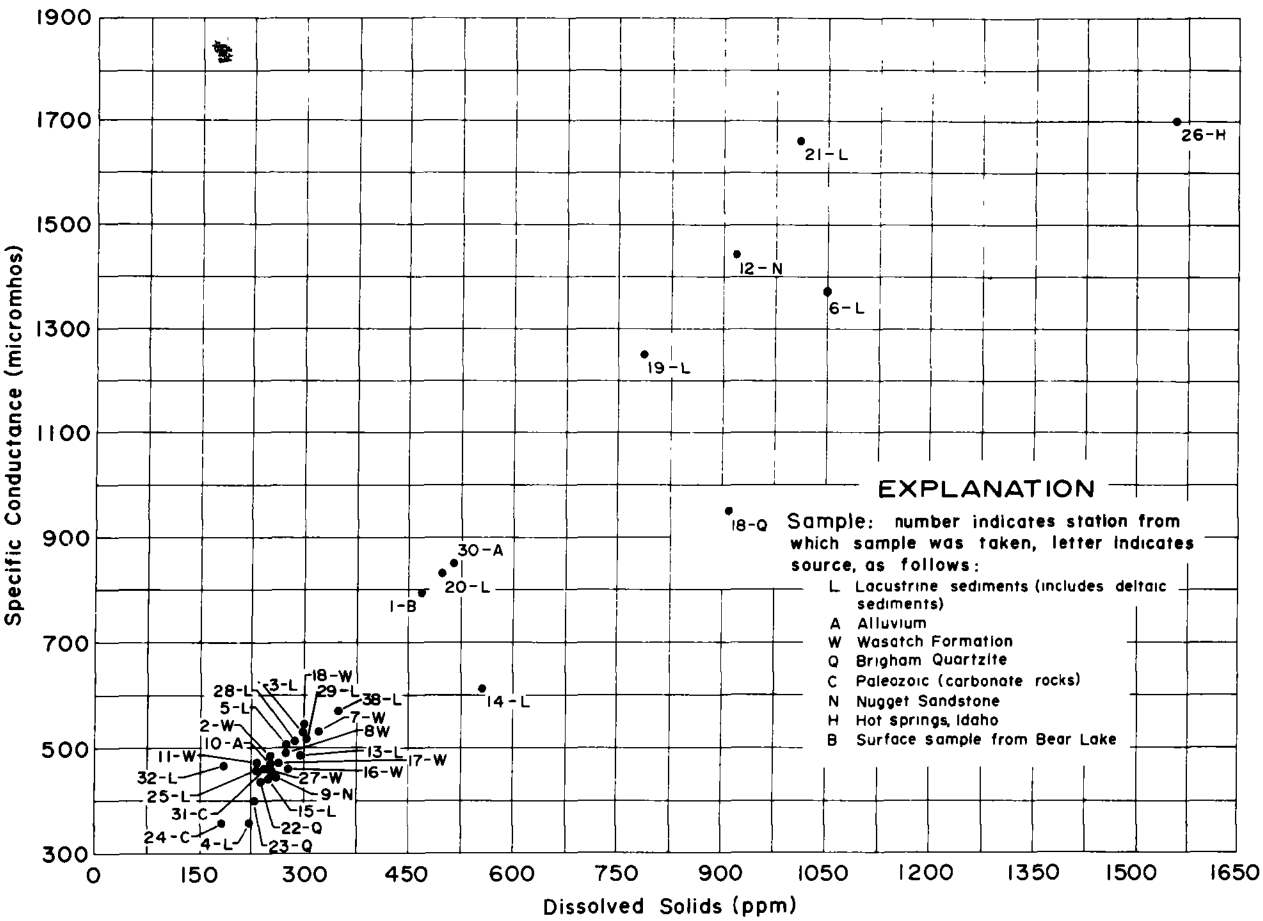


Figure 7. Relation between total dissolved solids and electrical conductivity for groundwaters of the Bear Lake area.

The most sensitive crops can tolerate boron in irrigation water ranging from 0.33 to 1.25 ppm (Schofield, 1936). Except for two, all analyses are well below the lowest figure in this range. One 100-foot well in Laketown (station 37) perforated in lacustrine sediments yielded water with a boron analysis of 1.1 ppm. A spring (station 11) used for stockwater in Upper Left Hand Canyon, in the mountains east of the lake, provided water with 9.0 ppm boron. This spring emanates from a Wasatch Formation outcrop.

Domestic

Water for human consumption is evaluated according to the U. S. Public Health Service standards of 1962. The standards suggest limits for certain chemical substances. Where these limits are exceeded in the groundwater analyses in this report, they are discussed below.

Arsenic. Arsenic appears in four groundwater sources and in the Bear Lake surface water analysis (BL-1; table 1), but in only one analysis does the quantity exceed the maximum permissible (0.05 ppm). This analysis (0.06 ppm) was from a well at station 5 near the shoreline in Pickleville. Samples BL-5, BL-6 and BL-37 are from wells perforated in lacustrine sediments and sample BL-2 is from a well perforated in the Wasatch Formation below the elevation of the lake surface. The latter well is situated on a hillside immediately adjacent to the lake at the spot where sample BL-1 was taken. Hydraulic connection between the lake and the bedrock Wasatch aquifer is a possibility.

Iron. Concentrations of 1 to 5 ppm of iron in groundwater are common. These concentrations, however, stain clothes and plumbing fixtures, and form crusts on well screens and plug pipes. Two stations (8 and 21) presently yield insignificant traces of iron.

Nitrate. Normal groundwater contains less than 22 ppm of nitrate. Higher values may indicate pollution from animal wastes, nitrate fertilizers and sewage. The suggested limit is 45 ppm; 5 ppm is the suggested tolerance level for babies (Cannon and Davidson, 1967). Although none of the Bear Lake stations approached the critical 45 ppm value, eight stations (7, 16, 17, 19, 30, 34, 36 and 37) exceed the 5-ppm value. Station 30 yields the highest nitrate content, 31 ppm. When this value is considered with other determinations, especially an anomalously high chloride content, it is apparent that this shallow well is almost certainly contaminated. No plumbing exists in the inhabited dwelling at the station.

Sulfate. The recommended limit of 250 ppm of sulfate is exceeded at two stations (6 and 21), both on the east shore of the lake.

Both sodium sulfate and magnesium sulfate are well known laxatives.

Total Dissolved Solids. Figure 7 shows the distribution of TDS for the latest analysis from each station. Six analyses (BL-6, BL-12, BL-14, BL-19, BL-21 and BL-30; table 1) exceed the suggested limit of 500 ppm TDS (U. S. Public Health Service, 1962). With the exception of BL-12 and BL-30, all are from lacustrine sediments. Well station 12 probably penetrates a major fault zone. A void space was encountered in which the drilling tools dropped from a depth of 34 to 43 feet (Utah State Engineer's files: Siddoway, driller, personal communication). BL-30 is from an open hand-dug well. All but station 30 are on the east side of the lake.

Surfactant (ABS). The ABS value is the degree of contamination by synthetic detergents. The U. S. Public Health Service recommends a limit of 0.5 ppm although toxic effects do not occur up to 50 ppm in drinking water. An astringent taste is imparted to the water if the ABS value exceeds 5.0 ppm. Only at station BL-21 was surfactant detected, at 0.35 ppm. Although a relatively deep well, station 21 clearly has been contaminated. This may illustrate pollution of a subsurface water supply through improper well construction. A direct passage is hereby afforded for fluids from the surface to the aquifer. The well is used for irrigation and nearby farm workers drink the water directly from the well head.

Other Constituents. The majority of the most critical elements listed in the U. S. Public Health standards are not present in the analyses: barium, cadmium, chromium, lead, selenium and silver.

Several other elements present in the analyses are quantitatively well below the specified U. S. Public Health Service limits: chloride, copper, fluoride, manganese and zinc.

Noncritical Factors. Hardness is caused by the dissolution of calcium and magnesium salts. The bicarbonates of calcium and magnesium cause "carbonate" or "temporary" hardness; the sulfates and chlorides cause "noncarbonate" or "permanent" hardness. The sum of the carbonate and noncarbonate hardness is the total hardness.

Bear Lake area groundwater ranges from hard (100 to 200 ppm) to very hard (more than 200 ppm). Water this hard is normal, however, for the state as a whole. Water with less than 150 ppm is preferable for domestic purposes which means that softening is desirable. Deposition of considerable scale in boilers may be expected.

Dissolved gases were not determined in the water analyses, but the presence of hydrogen sulfide with its characteristic rotten-egg odor is possible in certain waters. This has bearing on the use of water for domestic purposes. Amounts as small as 0.5 ppm of the gas in cold water can be noticed and the odor imparted by 1.0 ppm is definitely offensive.

When oxygen is absent, bacteria change sulfates to hydrogen sulfide. In water hydrogen sulfide forms a weak acid and the water is usually corrosive.

A rotten-egg odor from station 6 is unmistakable. A sample containing a fine black substance was collected following a period in which the pump on the well was shut down. The sample was analyzed specifically for organic matter and showed positive results. The sulfate value for BL-6 also was determined to be high (498 ppm). In all likelihood the well is perforated in a stratum of organic silt deposited in an ancient lake.

Other wells, especially at the south end of the lake, possess this distinctive odor. The odor of sulfur-containing water may be attributable, however, to an alkaline sulphide, such as sodium sulfide, rather than hydrogen sulfide.

Industrial

Most industries have set up standards of water quality for specific purposes within the industry. Some generalizations on the most important characteristics are given here; refer to the Manual on Industrial Water and Industrial Wastewater of the American Society for Testing Materials for tolerances for specific uses.

Waters used in industrial plants may be classified as (1) boiler feed water, (2) cooling water, (3) process water and (4) general purpose water.

Hard boiler feed water forms scale on the surfaces of tubes and metal plates as the water evaporates. Boiler scale reduces heat transferability from 7 to 16 percent for a scale thickness of from 0.02 to 0.11 inches. This represents an economic loss.

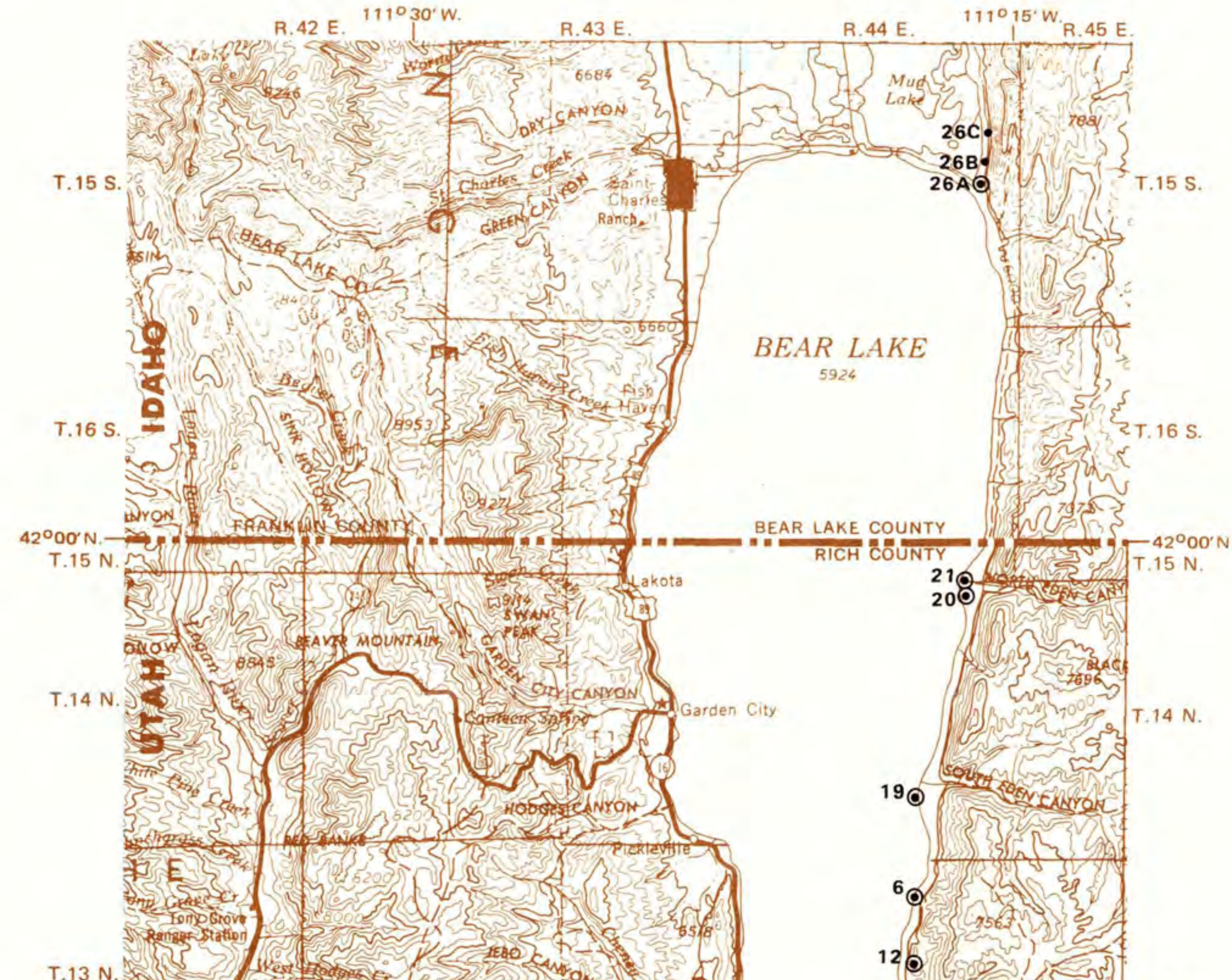


Figure 8. Sampling stations, Bear Lake area.

Sulfates, chlorides, nitrates and silicates are called incrustants because of the tenacity of the scales produced by precipitation of the corresponding calcium and magnesium salts.

Tolerance levels of impurities for steam generation depend directly on operating pressures of the system.

The temperature of water used for cooling, condensing and air-conditioning often is claimed more economically significant than the composition and chemical quality of the water. Groundwaters are usually more satisfactory than surface waters because they are cooler and more uniform in temperature throughout the year.

Industrial water supply problems are so varied and complex that specific solutions must be sought for each plant.

Isotope Determinations

The occurrence of groundwater of erratic and poor quality along the east shore of the lake led the author to conduct sulfur isotope studies on samples from wells and springs (figure 8). Hopefully the S^{34}/S^{32} ratios would shed further light on the source or sources of the poorer quality waters. To what degree the Bear Lake fault affords ingress of deep juvenile and/or connate water and/or recirculated meteoric waters to shallow aquifers and the surface is important.

The east shore groundwater is generally high in SiO^2, Ca, Mg, Na, HCO_3, SO_4, Cl, F and PO_4, total dissolved solids and hardness. Group differences in chemical quality from different sampling sites are shown on figure 9.

No definite conclusions can be drawn from this diagram. No clear gradation is displayed between hot

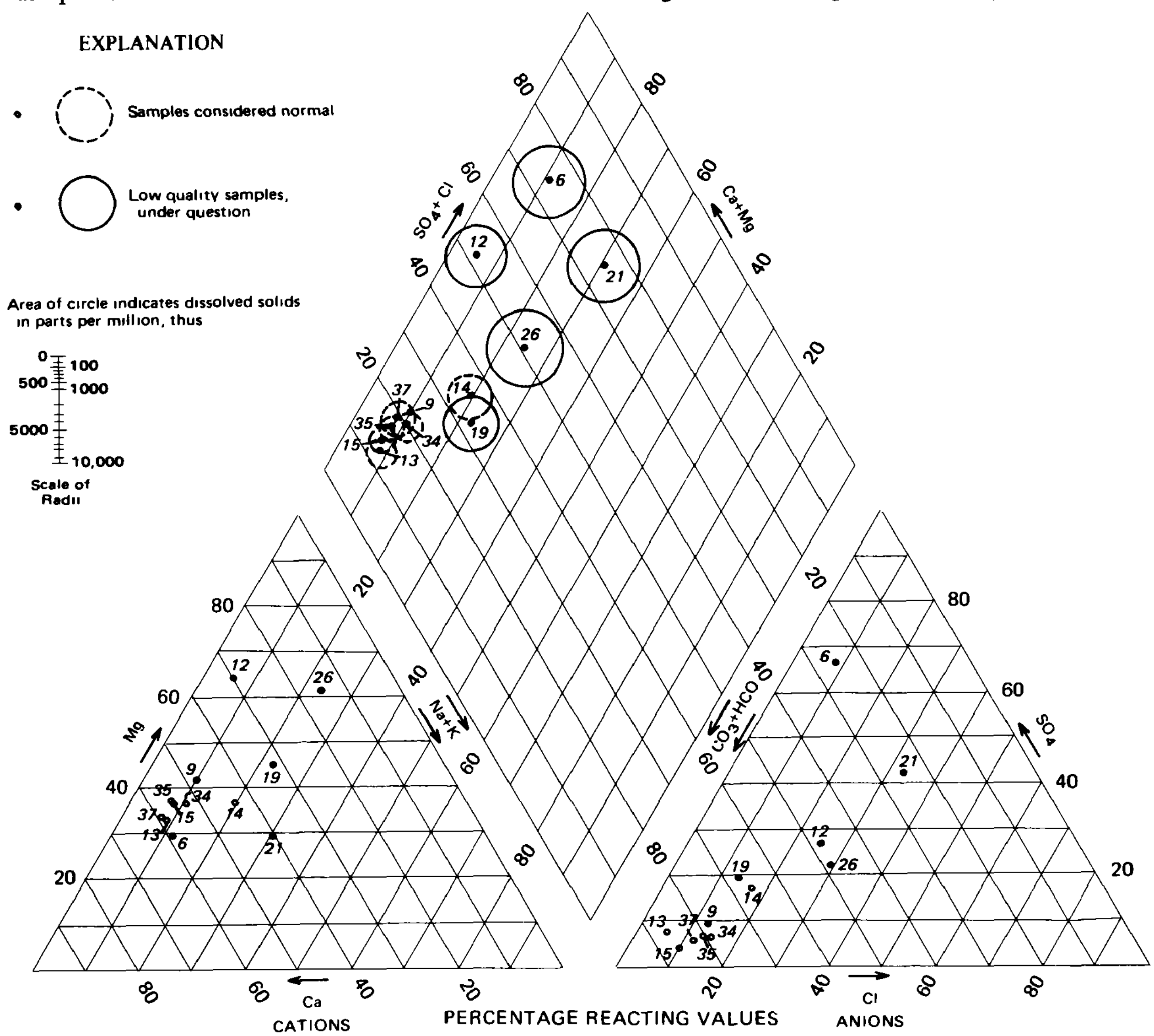


Figure 9. Piper trilinear plot.

springs water and other groundwater from sources along the Bear Lake fault. Sufficient trend, however, exists to justify further exploration of the subject.

Isotope determinations aided in researching the causative factors of this relative quality differentiation.

In July and October of 1969, samples were collected from identical and nearby stations for sulfur-isotope analyses (table 3). The sulfur-isotope values are expressed as parts-per-thousand (per mille) departures of S^{34}/S^{32} ratio of the sample from that of the international meteorite standard.

Table 3. δS^{34} values for waters in the Bear Lake area.

	Station No.	Well Depth (feet)	Collection Date	δS^{34}
Flowing well	15	125	7/69	16.32
Hot spring	26B		7/69	13.08
Lake surface			7/69	12.72
Hot spring	26A		7/69	12.70
Well, North Eden (delta fan)	20	112	7/69	8.88
Well, Boy Scout Camp	6	102	7/69	8.23
Flowing well	15	125	10/69	7.43
Packing plant well	34	110	7/69	6.69
Falula Spring	9		7/69	5.88
Ranch well	12	71	10/69	5.34
Hot spring	26C		10/69	4.68
Well		56	10/69	4.17
Well, South Eden (delta fan)	19	43	10/69	3.29
Packing plant well	34	110	10/69	1.75
Well, North Eden (delta fan)	21	215	10/69	-1.62
Well		28	10/69	-2.06
Farm well	37	100	10/69	-9.74

Three recognizable divisions of the sulfur-isotope values consist of about 11 or greater, from 1 to 9 and negative values as low as about -10. Values intermediate to the last two groups may represent various degrees of mixing.

The high positive values occur in Bear Lake and in some sulfur hot springs arising along the Bear Lake fault near the northeast corner of the lake. No comparable high values appear from wells (stations 20 and 21) and springs (station 9) which are suspected of intersecting the fault some miles to the south of the hot springs.

Biological fractionation plays an important role in the isotopic composition of sulfate and sulfide materials in the lake water and sediments. Anaerobes in the sediment reduce the sulfate in the water and release hydrogen sulfide. The hydrogen sulfide is mainly converted to sulfides where adequate iron is present. Some of the gas will escape although it is rapidly oxidized in passing through oxygenated water. Stations 6 and 15 as well as the hot springs emit a characteristic sulfurous odor probably from released hydrogen sulfide. A deposit floating on a sample from the well at station 6, when tested, proved highly organic. The lighter isotopes are preferentially transferred to the hydrogen sulfide, while the sulfate becomes isotopically heavy.

The group of sulfur-isotope values in the 10 to 16 range appear most probably the result of biological concentration of heavy isotopes in the sulfate phase; the light values, near -9, are likely the result of recent oxidation of old, isotopically light sulfides which resulted from biological production of light hydrogen sulfide. The difference of about 25 per mille between the two groups is more representative of a saline or brackish environ than of fresh water. Prior to 1911, however, Bear Lake had no direct connection with the Bear River drainage. In that year inlet and outlet canals were constructed to connect the lake with the river near its northern extremity, thereby converting the lake into a storage reservoir. Some of the water being pumped today likely is derived, at least in part, from connate waters of the old lake sediments.

Two hot springs near the north end of Bear Lake show values rather close to that of the lake itself, while a third hot spring farther from the lake shows a value more nearly like the surface-water sulfates. More than one source for the waters arises along the Bear Lake fault—apparently lake water and meteoric water finding entrance through shallow aquifers. Juvenile water as such is not recognized by the author, but could conceivably contribute to a small degree to the hot springs.

The decreases in isotope values between July and October shown in two wells (table 3; stations 15 and 34) near the south end of the lake possibly represent on-going mixing of two or more bodies of sulfate. The two wells are about a mile apart and of similar depth. A well located equidistant from the two wells showing the changing values demonstrated a δS^{34} value of -9.74 at the second sampling period. This may indicate the presence of dissolving sulfides derived from old sediments of the brackish lake. The high value in the well at the lakeshore (station 15, δS^{34} of 16.32) in July may represent sulfate from connate water in the brackish lake sediments. If the water with the lighter isotope values is moving toward the lake, the result would be a decrease in the isotopic values observed in some of the near-lake wells.

Tentatively the sulfur-isotope values measured in these samples represent three major source characteristics:

(1) sulfate from connate waters emplaced during a brackish phase of the lake (δS^{34} 12-17),

(2) sulfates possibly derived from the oxidation of biogenic sulfides, again associated probably with a brackish-lake phase (δS^{34} -10) and

(3) surface waters having values in the range of about 6 to 10.

Additional data are required to unequivocally determine the sources of waters. Further study of the hot springs is needed to determine whether these springs are reflecting old lake and surface water values or whether they represent other sources. The dissolution of old sulfides depends on the oxidation potential of the waters involved, so several chemical factors must be considered to interpret isotopic data.

The isotopic data presented here indicate the sampled waters represent various mixtures of meteoric origin and waters bearing sulfur which was most probably strongly fractionated in an antecedent brackish-water phase of the lake.

GEOLOGIC APPLICATION TO SANITATION

Fluid Effluent Disposal

All sewage disposal systems in the Bear Lake area are the subsurface type. With greater density of homes and resorts, care must be taken to avoid pollution of surface and groundwaters.

> The *first* step in the design of subsurface sewage disposal systems is to determine whether the soil is suitable for the absorption of septic tank effluent and, if so, how much area is required. The soil must have an acceptable percolation rate, without interference from groundwater or impervious strata below the level of the absorption system (U. S. Public Health Service, 1967b).

A knowledge of the geology will enable planning for site selection and design of soil absorption septic systems. Much of the area around Bear Lake should be avoided entirely or considered as only marginal because of existing geologic conditions.

Familiarity with the minimum specifications outlined in the Utah Division of Health Code of Waste Disposal Regulations, which emphasize the importance of the geological considerations, is essential.

The Soil Conservation Service (SCS) maps (Soil Survey Interpretations, Bear Lake area) may be consulted for broad planning purposes. They do not, however, supplant the need for on-site exploration and percolation tests.

The SCS Soil Survey Mapping Unit Descriptions show much of the soil in the Bear Lake area to be more or less impermeable clay. Where this poor soil exists the underlying geology may be satisfactory or conversely poor. Each geologic unit and its overlying soil mantle is discussed below with regard to its permeability. For a summary see table 4.

Quartzite: Soil thickness ranges from 0 to 3 feet. Generally the soil is heavy with clay and probably unsatisfactory. The quartzite itself varies from well faulted and sealed with clay gouge to an extremely resistant rock which is nevertheless jointed. It is possible that the jointed rock could conduct liquids, but in view of the emission of some springs from this

Table 4. Limitations for septic tank filter fields in various geologic terrains.

Geologic Unit Properties (influencing limitations)	Quartzite	Carbonate Rocks[1] (limestone)	Sandstone	Wasatch Formation	Surface Wash	Lacustrine Deposits
Permeability	2	3*	1	2	2	3
insufficient	A	A	NA	A	A	A
excessive	A	A	NA	A	NA	A
Rippability	3	3	2	2	0	1
Relief and slope	3	2	3	2	1	0
Water table	1	1	0	2	2	3*
Depth of soil mantle	3	2	3	2	1	0
All considerations	3	3	2	2	2	3

[1]Twin Creek Limestone not included (east of area).

EXPLANATION
0=No limitations
1=Limitations in exceptional circumstances only
2=Occasionally limited by this property
3=Generally limited by this property
*=Extreme caution necessary for utilization of sites
A=Applicable–may be *the* limiting factor
NA=Not applicable

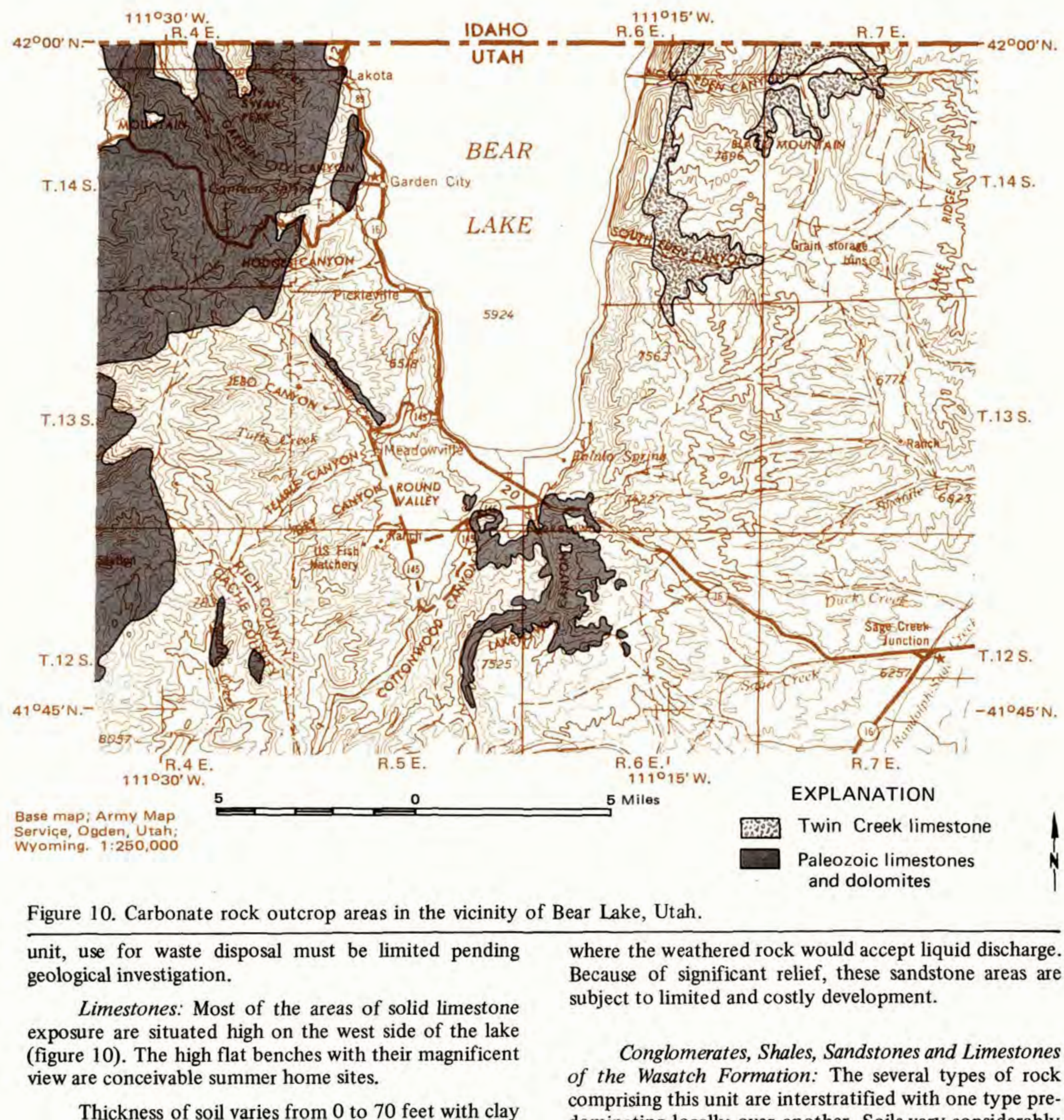


Figure 10. Carbonate rock outcrop areas in the vicinity of Bear Lake, Utah.

unit, use for waste disposal must be limited pending geological investigation.

Limestones: Most of the areas of solid limestone exposure are situated high on the west side of the lake (figure 10). The high flat benches with their magnificent view are conceivable summer home sites.

Thickness of soil varies from 0 to 70 feet with clay a normal constituent. Several large springs issue from limestone in the area and great care should be taken to insure against pollution of the groundwater in limestone outcrop areas. Where the soil is sufficiently thick for consideration, its type and permeability at all depths must be determined carefully.

Sandstones: Solid sandstone crops out profusely in hills immediately to the east of the lake. It has little or no soil cover. Exploration may reveal limited areas where the weathered rock would accept liquid discharge. Because of significant relief, these sandstone areas are subject to limited and costly development.

Conglomerates, Shales, Sandstones and Limestones of the Wasatch Formation: The several types of rock comprising this unit are interstratified with one type predominating locally over another. Soils vary considerably in thickness depending on the local rock material closest to the surface. Normally clay hinders the permeability of this soil. Marginal conditions are possible but soil exploration is a necessity because of the several rock types and their limited lateral extents. The Wasatch Formation occurs widespread over the foothills where many sites with views will undoubtedly attract future attention. These soils may appear satisfactory when dry but they become plastic and swell when wet.

Surface Wash: This unit of geology consists of all size debris from higher elevated rock units. Soil on this material may be thick and grade into the underlying sedimentary unit. Surface wash is distributed along the base of the foothills on the west side of the lake where sites overlooking the lake should prove attractive. Soil descriptions show the greater part of the soil contains considerable clay; deeper exploration may reveal more permeable horizons. The water table in this geologic unit is subject to seasonal fluctuation.

Lacustrine Sediments: Most of the current developments are sitting on lacustrine sediments–those sediments laid down under Bear Lake some time in the past. Included in this geologic unit are two deltas on the east shore of the lake, North Eden and South Eden, although their history of deposition is more complex. In the immediate future developments will continue to be situated on this flat land bordering the lake.

Most of the lacustrine sediments remain unconsolidated. They differ from surface wash in being clean and poorly graded particles, uniform in size. Up to many hundreds of feet of alternating clays, silts, sands and gravels comprise the unit.

A fertile soil covers these strata. Permeability tests may show the soil to be unsatisfactory for fluid disposal; in this event deeper exploration is warranted. A number of problems, which are discussed below, prevail in this low flat land. They deserve careful attention before pollution becomes gravely aggrevated.

In places coarse, clean gravel layers immediately underlie the soil on the lake shore. The gravel beds are extremely permeable and conduct fluids away as well as any open drain. Liquid wastes from septic tanks now flow in this manner directly into the lake polluting the beaches. No filtration is possible with clean gravels.

The water table in lacustrine sediments is subject to fluctuation for several reasons. The lake level itself is not constant and with elevation the lake contributes readily to groundwater storage. Absorption fields may become flooded at this stage, ruling out soil-absorption systems at the lowest beach levels. Terraces or ancient lake beaches above this lowest beach may be satisfactory. Even the levels well above the present-day lake's reach are subject to a fluctuating water table. The fluctuation is seasonal and undoubtedly recharge is contributed to by irrigation to the west. Because of the break in slope between terraces or old beach levels this water can appear on the surface through seepage or boils under hydrostatic head. In these areas exploration of depth and of lateral extent must be performed to safeguard surrounding properties.

Because of the stratified nature of these sediments permeability is far greater in a horizontal direction. A seemingly satisfactory horizon may not have the necessary 2- to 4-foot thickness required for acceptance. The continuity of strata laterally must be established by auger holes or dug exploration holes. Farther from the lake at higher elevations deeper exploration is warranted in this loose material. The water table, however, everywhere in these sediments is critical and its maximum level must be determined.

Solid Waste Disposal

Placement of solid waste disposal sites or sanitary landfills must all depend on hydrogeologic conditions. Type and thickness of earth material, depth and fluctuation of the water table, depth to bedrock and drainage should govern the location of the facility. The information provided above and elsewhere in this bulletin is just as relevent in safeguarding groundwater against potential pollution from solid wastes as from liquid wastes.

Certain earth materials handle easier than others. Material handling can be the largest economic factor in a solid waste operation so site selection with this consideration has considerable importance. Locations with shallow bedrock should be avoided for this reason.

Water is withdrawn from lacustrine sediments to satisfy culinary needs and the potential is there for far greater withdrawals. Fortunately, this water is safeguarded naturally by the layered or bedded deposits. A sand aquifer 40 feet deep is overlain by clay beds that prevent surficial groundwater from a 5- to 10-foot sand bed from entering the deeper sand. Little or no hydraulic connection exists between the two bodies of stored water and the possibility of pollution of the deeper water is considerably diminished. The same would be true of a third and a fourth water-bearing sand or gravel layer at perhaps 140 feet or 400 feet depth.

At present there is every reason to believe that this natural safeguard is working efficiently. Proper well design and construction in the future (Pacific Southwest Interagency Committee and Columbia Basin Interagency Committee, 1963b) will ensure against groundwater pollution. Drilling a well or digging a deep hole creates an artificial connection between hitherto separated strata. Proper backfilling of exploration holes and casing and grouting of wells would reseal these strata and sever the artificial connection.

Soil and geological investigation should be performed first and siting, design and finally construction should follow to assure against health department rejection and system failure.

SEISMICITY AND FAULTING

Little doubt exists that the Bear Lake fault, roughly parallel to the east side of the lake, is active. Table 5 lists the earthquakes that were reported or recorded on seismograms since settlement of the area.

The evidence for much larger earthquakes (by several orders of magnitude) in the recent past is an almost continuous line of scarplets in recent sediments on the east side of the lake. The delta fans at the mouths of North and South Eden canyons are clearly displaced by recent faulting. The most obvious evidence is the topographic expression or the scarplet. Two wells were drilled on the North Eden delta, one atop the scarplet and the other near its base a relatively short distance away (figure 1 and plate 1). The well atop the scarplet penetrated bedrock at a depth of 108 feet. The second well never penetrated bedrock throughout its 215-foot depth. This is evidence of a minimum displacement of about 140 feet.

The well at station 12 appears to have penetrated the fault zone. The analysis of water from this well and the wells at stations 20 and 21 show a relationship to the hot springs water at the northeast corner of the lake. The trilinear plot (figure 9) of waters in the Bear Lake area adds credence to this suggestion. The hot springs issue directly from the faults at several locations in Idaho. Immediately to the south of the southernmost hot spring (east of the resort buildings) the fault is exposed in a gravel pit (figure 11). Alluvial deposits are displaced by the fault at the base of a truncated alluvial fan. Just around the corner in this same gravel pit and to the west of the truncated spur (downthrown side) the beds of the alluvial fan dip in reverse fashion towards the mountain indicating that a block was dropped differentially by the fault. The alluvial fan at this locality clearly has been truncated and presents a classic triangular facet facing the lake. Virtually no dissection of this facet has occurred though the material of which it is composed is unconsolidated.

Table 5. Catalogue of earthquakes in the Bear Lake area.

Year	Month	Date	North Latitude	West Longitude	Magnitude	Intensity	Focal Depth	Remarks
1873	Dec.	18			3.7[1]	IV		Bear Lake Fault
1876	April	6						Bear Lake Fault
1876	April	6						Bear Lake Fault
1884	Nov.	10			6.1[1]	VIII		Northeast Utah; severe damage
1884	Nov.	10			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	10			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	10			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	10			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	11			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	11			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	12			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	12			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	12			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	13			2.0[1]	II		Crawford Mountain Fault
1884	Nov.	13			2.0[1]	II		Crawford Mountain Fault
1902	Jan.	5			3.1[1]	III		Bear Lake Fault
1959	Jan.	4			4.3	V		North of Bear Lake; damage
1963	April	4	42.2	111.2			33 km	North of Bear Lake
1964	June	19	42.02	111.14			20 km	East of Bear Lake
1965	April	2	42.03	111.62			20 km	West of Bear Lake
1966	March	17	41.8	111.6	4.7		30 km	Felt in north Utah south to Salt Lake City
1966	March	19	41.9	111.3	>2.7		20 km	
1966	June	11	42.6	11.3	>3.0			North of Bear Lake
1968	July	13			1.5-2.0			
1968	Aug.	3			1.5-2.0			

Figure 11. Recent faulting along the Bear Lake fault near hot springs, northeast corner of Bear Lake, Idaho. (A) Faceted alluvial fan. Fault revealed in borrow pit at base of fan (arrow). (B) Fault in alluvial fan material, south exposure. (C) Reverse dip of faulted block of fan, north exposure (hammer handle paralleling bedding is circled).

The bedrock mountains and spurs, too, along the east shore show steeply westward-sloping planar surfaces that were clearly truncated by the Bear Lake fault (figure 12). The fault plane itself is exposed in Nugget Sandstone at the base of the ridge alongside the road between North and South Eden deltas (figure 13).

Faults and scarplets in the lake bottom sediments have been revealed in fathograms (Williams, Willard and Parker, 1961). These records document recent faulting to the west of the major fault.

Several springs on the west shore of the lake show anomalous water temperatures. Stations 22, 23 and 25 (plate 1) registered water temperatures of 56° to 57° F – several degrees above normal. Stations 22 and 23 issue from the base of fractured Brigham

Figure 12. Planar mountain slopes–result of major fault bordering Bear Lake on the east. Triangular facets where spurs have been truncated are clearly shown on left photo.

Quartzite. Faulting of the bedrock is clearly evidenced in the area although nothing indicates recent activity.

The seismicity of the area should preclude building astride the active faults. Public buildings in particular should be removed from immediate fault traces. Ground stability during an earthquake is perhaps even more important than ground breakage in this area; it is discussed in the Seismic Influence on Earth Stability section.

EARTH STABILITY AND LANDSLIDE POTENTIAL

Both consolidated and unconsolidated materials are frequently subject to failure and slippage on slopes. Clear evidence indicates that slides occurred in the past in the Bear Lake area and that today there is not complete stability. When man disturbs natural hillside slopes he promotes instability.

Old slides in various geologic units are distributed around the periphery of the lake. It has been postulated that sliding is responsible for damming the outlet of Bear River and for the rising of Bear Lake, holding at the Garden City stage (Williams, Willard and Parker, 1961). Weak Tertiary rocks were probably involved in that event in Idaho. In Utah, too, however, the Tertiary Wasatch Formation has slid in several places. The Brigham Quartzite, having been highly fractured by faulting, shows evidence of having slid in several places also (figure 14). These two units show evidence of having been most susceptible to mass movement. On

Figure 13. Fault exposures. (A) Faulted Brigham Quartzite exposed in gravel pit, west side of lake (arrows along fault planes show directions of movement). (B) Polished and slickensided Nugget Sandstone exposed at base of hill on east side of lake between North and South Eden canyons.

Figure 14. Landslides. (A) Subdued relief of ancient landslide in Brigham Quartzite. Note bowl-shaped depression in gently sloping hillside. (B) Active slide. Fresh scarp in upper right. Fence pushed out to left, towards road.

the east side of the lake in South Eden Canyon the highly cleared Twin Creek Limestone is seen to have slid. Fracturing of the Nugget Sandstone through horizontal shearing (thrusting) has created a minor rock slide in one location.

The old landslides are significant for several reasons. They indicate that many of the bedrock formations in the area are either inherently weak or have been weakened through subsequent earth movements and pressures. This must be considered when cuts into hillsides are planned or foundations for large structures are designed. With time a landslide gradually stabilizes itself, but to what degree an old landslide is presently stable is difficult to determine. Minor modification of the old landslide mass, for example, by grading atop it, may destroy its stability and reactivate slippage. Every need, therefore, exists for caution in constructing in the immediate vicinity of old proven landslides. The same is true of rock fall or talus slopes so common along the east shore of the lake. Trains of cobbles and boulders lead down the mountain sides to the road's edge. Dead trees and brush on the slopes indicate the activity of rock movements. Lichen-covered boulders with bare surfaces exposed afford further evidence of relatively recent activity. Disturbance of these slopes, especially near their toe along the road, is hazardous. Geologically these rocks are only momentarily at rest.

The Wasatch Formation, because of its heterogeneity of stratum type, may be subject to erosion and undermining where it is exposed in cuts. Beds of fine semiconsolidated material are easily weathered and eroded out from under the more resistant indurated conglomerate beds. Eventually large fragments of conglomerate may become unstable and fall. The mudstone and siltstone in the sequence may be easily eroded. Thick mudstones may be subject to rotational sliding. Where encountered at grade level this fine material should be tested to determine where it is expansive. If expansive, considerable damage may ensue to light structures, pavement and utilities.

Present-day potential for sliding of unconsolidated material is evidenced by a slide on a relatively gentle slope on the west side of the lake and the road, north of the Idaho line. The head of the slide occurs at a break in slope from 7½° to 13½°. Spliced telephone lines overhead indicate displacement of poles through sliding which occurred in the recent past. The fence posts bordering the property were tilted and shoved towards the road (figure 14). This slide is the shallow arcuate or rotational type in a predominately tan silty clay. The slide, 115 feet wide by 150 feet long, though small, is large enough to have easily destroyed one or two homes had they existed on the slope. This site, while at present undeveloped, offers many advantages for future consideration, including ready accessibility, readily drained surface and a fine view of the lake. But no number of attributes must take precedence in planning over the unstable soil condition. The slide is economically unfeasible to stabilize for subdivision.

The slide demonstrates what could happen in several areas along the west shore of the lake. Terrain comprised of alluvium and slope wash is prone to sliding, in particular where a natural break in slope or an artificial cut occurs. Suspect soils require physical testing. Lawn irrigation and septic tank effluent will, by addition of subsurface water, increase the soil stability problem. Field irrigation to the west already contributes prodigious amounts of groundwater. Springs issue at the base of many of the hill slopes. A few of the older homes on these gentle slopes have springs under their foundations. In limited areas covered with slope wash, an underlying white caliche hardpan lies. This horizon is exposed in gullies where it averages a depth of 2 feet. By preventing percolation of water downward, the horizon may be detrimental by promoting lateral migration of groundwater downslope, thus increasing pore water pressures. Test holes should be dug on slopes of alluvium and slope wash material, especially near or below breaks in slope.

Seismic Influence on Earth Stability

A severe earthquake along the Bear Lake fault would almost certainly trigger landslides in the area. Most of the resulting slides and slumps would occur in unconsolidated material, probably associated with the delta fans along the east shore of the lake. Slides in bedrock, especially the Wasatch Formation, are also possible. Loose boulders comprising talus slopes could move downslope in rock avalanches.

The wet unconsolidated sediments comprising the delta fans range from silt to coarse gravel in composition. Long periods of shaking accompanying an earthquake would mobilize this material and the sediment would spread radically downslope toward the delta fan margins. The relatively steep slopes at the front of the delta fans (figure 1) provide an unconfined face toward which the material is free to move.

Differential compaction, vertical and horizontal, of the unconsolidated sediments also would result from a severe earthquake.

Sliding and differential compaction would create ground cracking; an underlying movement along an established fault in bedrock, a likely occurrence across the delta fans, also results in ground cracking. Should a severe quake occur, types of ground cracks would be difficult to distinguish.

Round Valley and the Laketown area also are subject to ground cracking.

Seiche waves are another destructive factor that can be expected around the shores of the lake. Slippage along the Bear Lake fault bounding the lake on the east would tilt the valley and produce seiching. Structures situated just inshore from abruptly shallowing areas would be subjected to resultant destructive waves.

Local waves might be generated by landsliding, especially of the large North and South Eden deltas. One type of resultant wave would overtop the delta as water rushed in to fill voids left by sinking slide masses. Other waves may be forced ahead of advancing slide debris to cross the lake and overrun the opposite slopes.

In summary building sites in the low areas, especially the delta fans, may be subjected to: (1) extremely destructive waves, (2) severe ground cracking, (3) submergence and (4) landslides.

EARTH MATERIALS

Borrow

Rock and soil may be required for highway, airfield, dike and embankment fill. Qualifications of the material are directly dependent on the design of the particular structure. Extensive sources for fill from diverse geological environments exist in the area, but exploration and testing to date are meager and not sufficient even to serve as a guide. The lacustrine sediments, alluvium, deltaic deposits, surface wash, talus and weathered and fractured rock all could be considered. Impounding earth structures, in particular, require selection of *proper* fill for safety (p. 4).

Dimension Stone

Both the Brigham Quartzite and the Nugget Sandstone warrant consideration as sources for rough building stone in the area. Sound blocks of moderate to large size are easily procured. Textures and grain size of both rocks are consistent; both are resistant but quartzite is the hardest stone available anywhere.

These formations dip at a considerable angle from the horizontal wherever they are exposed in the area. This characteristic could facilitate quarrying operations.

The attractive red Nugget Sandstone crops out in immense quantities, more than sufficient to satisfy local needs on the east shore of the lake; it perhaps is best revealed in North Eden Canyon. Stone quarried several miles to the north in Idaho has served for monumental stone, paving blocks, curbing, flagging, building stone and ornamental stone. An example of an edifice built entirely of this stone is the Paris, Idaho, Church of Jesus Christ of Latter-Day Saints Tabernacle.

The Brigham Quartzite is well exposed just north of Swan Creek, facing the lake and across from the highway rest area at the southwest corner of the lake.

Riprap

Increased development along and in the lake requires riprap for protection from storm-generated waves and from large ice floes. The best sources for this material are the Brigham Quartzite and Nugget Sandstone. A ready supply is available in the talus or rock debris at the base of the steep slopes supported by these formations. Both formations yield dense, hard, angular and durable blocks.

Road Metal

Geologic faulting along the ridge bordering the lake on the west, north of Meadowville, has produced a supply of road metal. The quartzite in this vicinity has been thoroughly fractured. Clay gouge in the brecciated rock acts as a binder so that a secondary road surface bonds together into a solid mass. The faulting has brecciated the normally resistant rock into well-graded sharp angular particles. Two small county pits dug in this ridge (figure 13b) yielded material proven to be rippable. Different size particles are obtained in the same pit with varying distance from the fault. This material sets up remarkably well in little time under loads applied by normal traffic.

Sand and Gravel

Sources for sand and gravel are primarily in the lacustrine sediments; alluvial fans yield local deposits. Exploratory probings are necessary to locate proper size material. Clean sands and gravels in poorly graded beds or layers appear in the shore facies or ancient beaches, including spits and bars, of former lake levels. Better graded material can be obtained easily by mixing several alternating strata. Strata may be thin. Several geomorphic beach forms representing former lake levels are seen along the lake shore. One such crescent bar occurs parallel to and along the south lake shoreline. They offer sure prospects for sand and gravel exploitation.

MINERAL RESOURCES

Limestone and Dolomite

Limestone and dolomite are carbonate rocks with wide applications in industry and engineering. They occur in relative abundance in the Bear Lake area (figure 10).

Two traverses were made: to collect grab samples from extensive outcrop areas along the Swan Creek drainage west of Garden City on carbonate rocks of Ordovician and Cambrian age and through a sequence of carbonate rocks of Ordovician to Pennsylvanian age on the road east of Laketown. The traverses permitted the sampling of the entire carbonate sequence in this part of the state (table 6).

Approximately 11 square miles of the younger Twin Creek Limestone, quarried elsewhere in Utah as a cement rock, outcrop in the drainages of North and South Eden canyons east of the lake. The lithology and physical appearance closely resemble that where the rock is being used.

Phosphate

Phosphate occurs predominantly in the Phosphoria Formation, exposed in the road cut about 1 mile east of Laketown. Exploratory workings are evident along Six Mile Canyon in the same vicinity. Phosphate is reported in the Brazer Limestone in the same area (Richardson, 1941).

The firm with the longest history in the region, Stauffer Chemical Company (formerly San Francisco Chemical Company) at Montpelier, Idaho, reports no recorded exploration activity conducted by them in this area east of Laketown (written communication, March 1969).

Ore is being extracted from the Crawford Mountains southeast of Laketown. The 10-foot section of ore assays from 29 to 32 percent P_2O_5 depending on depth and degree of weathering.

Whether or not interest will continue in the Laketown area is uncertain.

SCENIC SIGHTS OF GEOLOGICAL SIGNIFICANCE

Swan Creek Spring

Swan Creek Spring issues from a large solution channel in limestone. Its discharge–at times more than 100,000 gpm–supplies water for the Garden City System and for the irrigation canal which extends north and south along the foothills from Swan Creek Canyon.

Over many thousands, possibly millions of years, water has eroded, principally by chemical solution, limestone walls of crevices, faults and bedding planes, enlarging them considerably. Evidence exists that an extensive underground network of conduits and large reservoirs pervades the Bear River Range west of Bear Lake. As shown by analyses included in this report (table 1), the spring's waters are of superb quality for domestic as well as agricultural needs.

Access to Swan Creek Spring is north of Garden City, across from the Lakota Resort on the gravel Swan Creek Canyon road (about 1½ miles north of the State Park Marina) which leads directly to the spring, a distance of approximately 1 mile.

Bear Lake Overlook

From Bear Lake Overlook the mouth of one of the major canyons, South Eden, can be observed due east across the lake. The flat area consists of sediments deposited on land and under water as the lake level fluctuated; the sediments were derived from the canyon's watershed. It is a land form that is both a delta and an alluvial fan. A second delta fan lies 4 miles to the north at the mouth of North Eden Canyon.

Table 6. Analyses of carbonate rocks outcropping in the Bear Lake area, Utah.

	Assays (percent)								Computed Mineralogy				
Geologic Formation[1]	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I.	Dolomite	Calcite	Clay	Quartz	Hematite
	Road Cut East of Laketown												
1. Wells Fm.	2.35	0.11	0.56	31.31	19.37	0.00	0.00	46.64	89.07	7.50	1.91	1.75	0.11
2. Wells Fm.	1.18	0.07	0.20	52.60	0.40	0.00	0.00	43.77	1.84	92.92	2.46	0.94	0.07
3. Brazer Ls.	23.66	0.98	0.81	26.00	13.20	0.01	0.10	34.67	60.72	12.80	2.22	22.68	0.98
4. Madison Ls.	5.69	0.39	0.58	59.62	1.19	0.01	0.10	31.63	5.51	66.90	17.26	–	0.39
5. Jefferson Dol.	6.33	0.23	0.69	28.87	17.75	0.01	0.13	45.94	81.69	7.20	5.37	5.52	0.23
6. Laketown Dol.	12.62	0.93	3.12	22.68	15.95	0.01	0.66	39.60	73.41	0.60	11.73	8.88	0.93
7. Fish Haven/ Laketown	0.06	0.08	0.44	32.70	18.35	0.00	0.00	47.40	84.45	12.50	1.61	–	0.08
8. Fish Haven Dol.	0.06	0.01	0.43	31.51	19.77	0.00	0.00	47.06	90.91	6.90	0.68	–	0.01
	Swan Creek Drainage												
9. Garden City Ls.	4.36	0.28	0.80	50.12	0.52	0.00	0.38	42.29	2.39	88.20	4.48	3.40	0.28
10. Garden City Ls.	6.85	0.70	1.43	49.51	0.62	0.00	0.22	40.76	2.92	86.81	4.47	5.17	0.70
11. St. Charles Ls.	7.48	0.26	1.27	50.64	0.47	0.00	0.53	39.75	2.20	87.90	4.53	6.06	0.26
12. St. Charles Ls.	3.94	0.24	0.92	31.35	17.57	0.01	0.14	44.94	80.79	12.10	3.12	2.88	0.24
13. Nounan Ls.	1.08	0.30	0.86	32.01	19.44	0.00	0.07	45.20	89.42	5.50	3.63	0.12	0.30
14. Nounan Ls.	0.09	0.09	0.33	31.74	20.36	0.00	0.00	46.47	93.66	3.80	0.20	–	0.09
15. Nounan Ls.	0.06	0.01	0.43	33.71	21.52	0.00	0.00	43.18	90.27	–	0.11	–	0.01
16. Bloominton Fm.	1.23	0.01	0.45	47.84	2.43	1.04	0.06	47.32	10.90	79.30	9.07	0.78	0.01
17. Bloomington Fm.	1.05	0.14	0.49	43.26	9.07	0.01	0.09	45.39	41.76	54.60	2.60	0.48	0.14
18. Bloomington Fm.	0.20	0.58	1.50	31.45	18.14	0.00	0.00	47.17	83.37	10.90	2.86	–	0.58
19. Blacksmith Ls.	5.24	0.32	0.59	49.41	2.25	0.01	0.18	41.17	10.31	82.40	1.61	4.50	0.32
20. Ute/Langston	5.42	0.33	0.61	44.42	2.26	0.01	0.27	40.96	10.47	73.60	7.68	4.68	0.33
21. Langston Ls.	0.08	1.87	0.50	31.58	18.89	0.00	0.00	46.86	86.86	9.20	1.41	–	1.87

[1] Numbers correspond to rock descriptions given below.

Rock Sample Descriptions: Rock sample numbers correspond to analyses given in table 6. Formational thicknesses from Richardson (1941, plate 6). Color-coded by use of the Rock Color Chart, 2nd printing (1951).

Sample	Formation and Description	Age
	Wells Formation (approx. 1,000 feet thick)	Pennsylvanian
1	Dolomite, very light gray (N-8), weathers to very light tan, fine- to medium-grained, mostly medium-bedded, hairline calcite veins common, very slight effervescence.	
2	Limestone, medium dark gray (N-4), weathers to medium gray, medium-grained, mostly medium-bedded, white calcite veins, strongly effervescent.	
	Brazer Limestone (approx. 1,100 feet thick)	Mississippian
3	Dolomite, medium light gray (N-6) and medium gray (N-5), weathers to light gray, fine- to medium-grained, massively bedded, very slightly effervescent.	
	Madison Limestone (approx. 1,000 feet thick)	Mississippian
4	Limestone, medium dark gray (N-4), weathers light to medium tan-gray, medium-grained, strongly effervescent.	
	Jefferson Dolomite (approx. 1,200 feet thick)	Devonian
5	Dolomite, medium dark gray (N-4), weathers to medium greenish gray, fine-grained, massively bedded, very slightly effervescent.	
	Laketown Dolomite (approx. 1,000 feet thick)	Silurian
6	Dolomite, yellowish gray (5Y7/2), weathers to earthy medium tan, massively bedded, fine-grained, very slightly effervescent.	
	Fish Haven/Laketown Dolomite	Ordovician-Silurian
7	Dolomite, dark gray (N-3) to grayish black (N-2), weathers to medium-gray brown, fine- to medium-grained, massively bedded, numerous hairline calcite veins, very slightly effervescent.	
	Fish Haven Dolomite (approx. 500 feet thick)	Ordovician
8	Dolomite, light gray (N-7) to very light gray (N-8), weathers to white, fine- to medium-grained, very slightly effervescent.	

Rock Sample Descriptions (continued)

Garden City Limestone
(approx. 1,900 feet thick) Ordovician

9 Limestone, medium light gray (N-6) to medium gray (N-5), weathers to light medium gray and tan, thin- to thick-bedded, fine-grained, strongly effervescent.

10 Limestone, light gray (N-7) to pale yellowish brown (10YR6/2), thin- to thick-bedded, fine- and coarse-grained (intraformational conglomerate), strongly effervescent, slightly fossiliferous.

St. Charles Limestone
(approx. 400 feet thick) Cambrian

11 Limestone, medium light gray (N-6), weathers to light gray, massive, fine-grained, tan calcite veins, strongly effervescent.

12 Dolomite, medium gray (N-5), weathers to light medium gray and tan, medium-grained, slightly effervescent.

Nounan Limestone
(approx. 950 feet thick) Cambrian

13 Dolomite, medium dark gray (N-4), medium- to thick-bedded, weathers light medium gray, fine- to medium-grained, very slightly effervescent, slightly cavitatious.

14 Dolomite, very light gray (N-8), weathers to light gray, fine- to medium-grained, very slightly effervescent.

15 Dolomite, medium gray (N-5) to medium dark gray (N-4), weathers to light medium gray, fine- to medium-grained, very slightly effervescent.

Bloomington Formation
(approx. 1,250 feet thick) Cambrian

16 Limestone, medium gray (N-5), weathers to light gray, thin-bedded, oolitic, oolite in fine- to medium-grained matrix, strongly effervescent.

17 Limestone, medium gray (N-5) to medium dark gray (N-4), weathers to light gray, fine-grained, strongly effervescent.

18 Limestone, medium light gray (N-6), weathers to very light tannish gray, medium- to coarse-grained, very slightly effervescent.

Blacksmith Limestone
(approx. 725 feet thick) Cambrian

19 Dolomite, dark gray (N-3), weathers to light to medium tan and purple, massively bedded, fine- to medium-grained, violently effervescent.

Ute/Langston
(Ute Limestone; approx. 500 feet thick)

20 Dolomite, dark gray (N-3) to grayish black (N-2), weathers to light to medium tan, thin- to medium-bedded, fine-grained, medium gray fine calcite veins, strongly effervescent.

Langstone Limestone
(approx. 375 feet thick) Cambrian

21 Limestone, medium light gray (N-6), medium- to thick-bedded, medium-grained, very slightly effervescent.

On the peak in the slightly greater distance between North and South Eden canyons, Black Mountain, the only volcanic lava rock in the vicinity, is exposed. The basalt lava rock may have had a much greater distribution before erosion left only this remnant.

The straight planar slopes of the mountain side bordering and facing the lake on the east side (figure 12) give every appearance of relatively recent geologic movement of faulting. Other evidence support this as well.

An interesting drainage system lies on the foothills on the west side of the lake. The canyons are parallel with northeast-flowing drainages in rock strata inclined in the same direction. These northeasterly flowing streams are consequent streams, that is, a consequence of the natural rock slope or dip of the beds. Tributaries flowing at right angles are subsequent streams.

Bear Lake Overlook is approximately 1 mile east of the summit on the main state road from Logan Canyon to Garden City.

Inclined Quartzite Strata

North of Route 89, ½ mile south of the Idaho border past Lakota Resort, inclined or dipping beds of quartzite crop out. These resistant beds dip about 47° east towards the lake. Left at Lakota, up Swan Creek Canyon, this same formation dips in the opposite direction at a considerable angle. This reversal in dip over such a short distance probably denotes the presence of a fault or fracture along which the two sides were displaced relative to one another.

Fault Exposure in Road Cut

Southeast of Pickleville, Route 30 passes through a cut in the hill. At the north end of the cut, vertical displacement of 38 feet is evident along a fault between the red and the white conglomerate; smaller displacements occur elsewhere along the cut. The shearing of the rock along the faults has created zones of weakness along which weathering of loose debris is more rapid.

Raised Sand Bar

South along the west shore of the lake, where Route 30 diverges from the lakeshore in a southerly direction towards Laketown, ridges rise above the Laketown lowland. One and a half miles from the point where the road leaves the lakeshore, a gravel road atop one of the concentric sandbars heads east off the paved road. These raised sandbars are evidence

Figure 15. Specimens for collectors. (A) Fossil worm tubes in Brigham Quartzite. (B) Salt casts * in Threeforks Formation mudstone.

that Bear Lake was once 25 feet above its present level in the recent geologic past.

The geologic history for the past almost 600 million years–from the laying of the Brigham Quartzite beach sand more than ½ billion years ago to the creation of a cavernous underground system of conduits by the waters still profusely flowing from the Swan Creek Spring at the present–is revealed.

Chemical and mechanical erosion by streams, deposition of sediments by intermittent streams at their mouths, erosion by the storm-generated waves of Bear Lake, seasonal ice-riving of rock, creeping and more rapid movement of the soil on both gentle and steep slopes and earthquake activity, are all ongoing to shape the future form of the Bear Lake area.

SPECIMEN COLLECTING

The Bear Lake vicinity offers several collecting sites which afford unique specimens and easy access.

Normal collecting quantities only should be removed from the collection localities. Of greatest benefit is *in-situ* observation of the specimens and the removal of none–such as at Dinosaur National Park. Limited quantities are available at each site and specimens may be quickly exhausted if care is not taken.

Petrified Worm Tubes

Evidence of burrowing creatures from the Lower Cambrian period some 575 million years ago is all the trace of life that remains of this early period in the earth's history. The cylindrical cavities occur in a hard and otherwise solid quartzite, the Brigham Quartzite, which is a sedimentary rock that was originally an oceanic beach sand. Tubes all nearly parallel one another perpendicular to the bedding plane (lower surface in slight shadow in figure 15a) which at the time in the Cambrian was the exposed beach surface.

The petrified worm tubes are located on a ridge along the west shore of the lake from southwest of the highway rest area (near southwest corner of lake), north 2 miles towards Ideal Beach. The best site is near the mouth of Cheney Creek directly across from rest area. The inclination of the bedding planes towards the planes, about 70° from the horizontal, is clear.

Salt Crystals

Crystals in cubical forms similar to those shown in figure 15b occur in the Threeforks Formation of Devonian age in mudstone that represents a desert environment. Ephemeral lakes were present in the desert. Experiencing little recharge through precipitation with rapid evaporation, these lakes became more and more concentrated in salt. After sufficient concentration the salt precipitated and the crystals grew larger around pre-existing forms (on figure 15b, the growth lines parallel the crystal edge–evidence also of the remarkable degree to which these have been preserved). Rain falling on the crystals or inundation by a brief desert flood quickly dissolved the salt leaving impressions or molds where the salt crystals previously were seated in the mud. Silt washed into the area filled in the depressions and left a thin deposit behind as drying out ensued. Much later the sediments consolidated into firm rock. Upon exposure the overlying and underlying sediments of different compositions weathered out the cubic forms–perfect salt casts from an ancient desert that had not seen the sun for about 350 million years.

The crystals occur on a road cut east of Laketown on Route 30 southeast of town, past the highway shed on the left, starting up the canyon. Red shaley beds of Threeforks Formation are on the right.

Figure 16. Unaltered algal nodules from Wasatch Formation. (A) Fossil freshwater snail forming nucleus of nodule. (B) Spherical nodules showing concretionary growth.

Flat exposed surfaces of shales and mudstones and pried-apart rock layers or beds reveal specimens.

Fossil Algal Balls

Algal balls, more properly referred to as nodules, weather bountifully from the Tertiary Wasatch Formation. Nodules broken open reveal concentric calcareous bands formed around a nucleus. The central nuclei are grains of sand or pebbles or occasionally a complete fossil shell; some possess calcite crystals which also may line the chambers of the fossil shells (figure 16). Many of the forms are perfect spheres, others are slightly flattened or elongated–all are collector's pieces, over 40 million years old.

The algal balls are located in the southeast corner of the lake. The road due north of Laketown leads to the east shore road of the lake; it turns right and passes the beach cottages on the left. Past the summer homes, many of the nodules have weathered loose and have rolled down the low hillside on the right almost to the road's edge. They are emplaced in the conglomeratic rock higher on the hillside.

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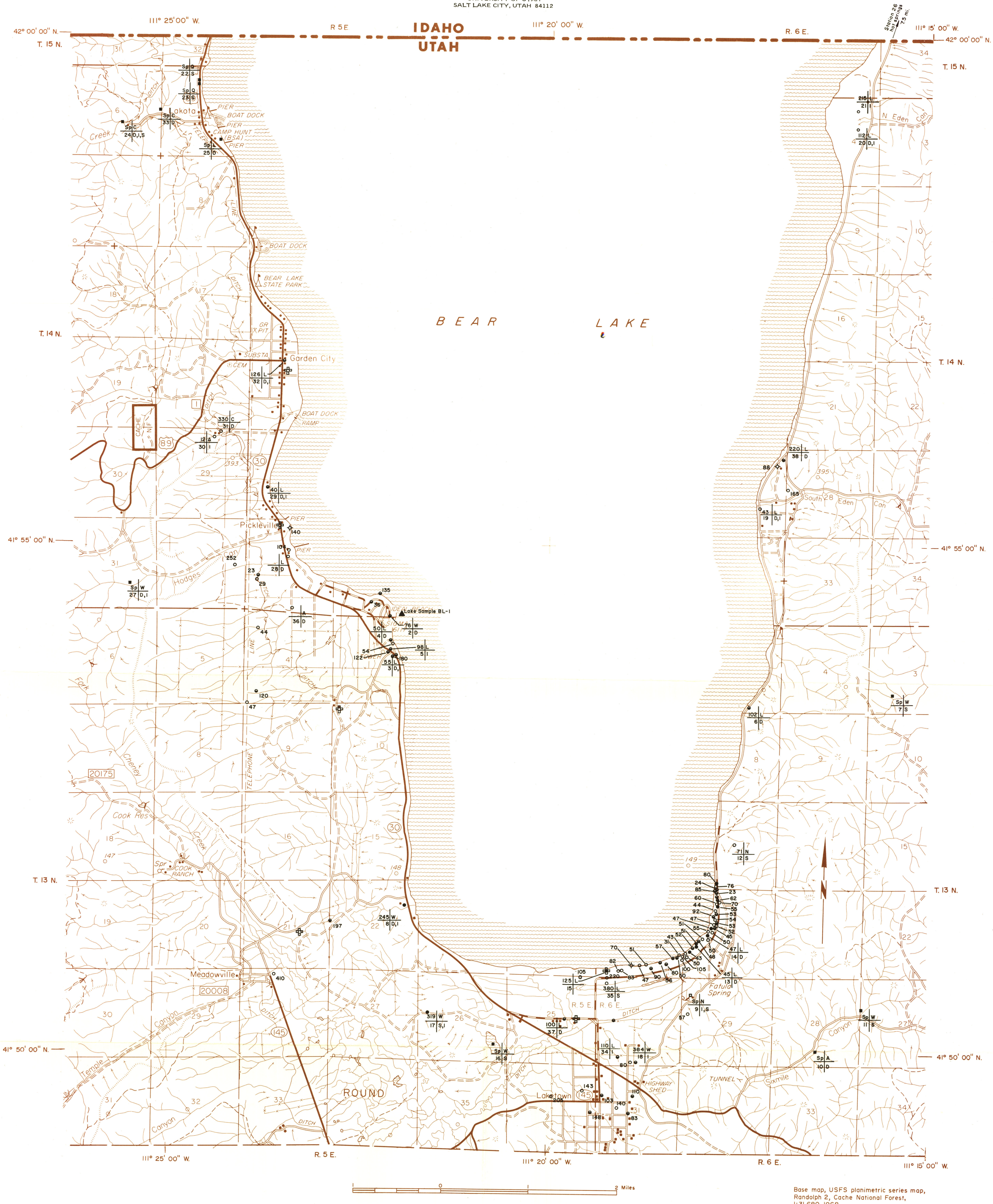

EXPLANATION

- ○ Well (77)
- ● Artesian well (54)
- • Flowing well (38)
- ✧ Dry well (41)
- ■ Spring (65)
- ▲ Lake sample
- ⊕ USGS observation well (92)

Note: Number indicates total depth in feet.

Well Depth — 76 | W — Aquifer; Station — 2 | D — Use: Sampling station (well or spring)

Well Depth:
Total depth in feet except where Sp is used, which denotes spring.

Aquifer:
- L = Lacustrine sediments, including deltaic sediments.
- A = Alluvium and slope wash.
- W = Wasatch Formation.
- N = Nugget sandstone.
- Q = Brigham quartzite.
- C = Carbonate rocks, including limestone and dolomites, (Paleozoic)

Use:
- D = Domestic
- I = Irrigation
- S = Stockwater

WATER-SAMPLING STATIONS AND WELLS IN BEAR LAKE AREA

RICH COUNTY, UTAH

by

B. N. Kaliser

1971

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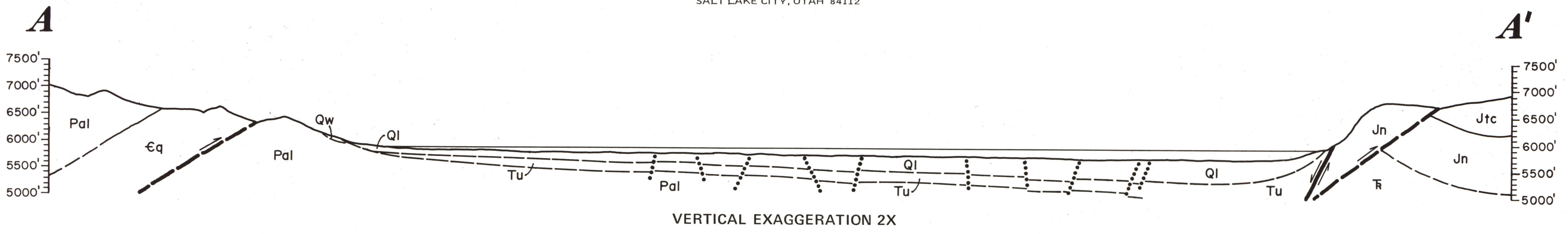

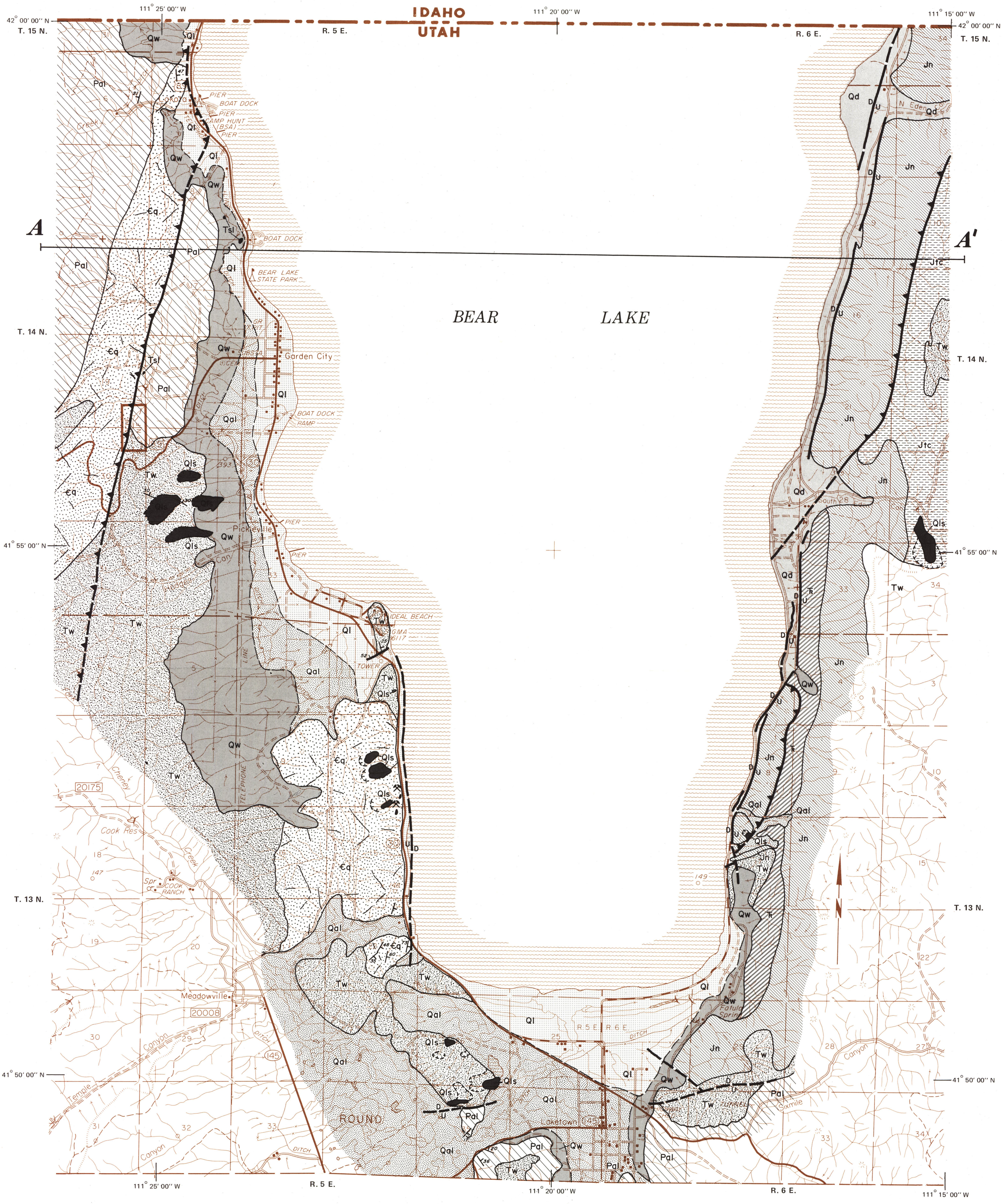

1 0 1 2 Miles

Base map, USFS planimetric series map, Randolph 2, Cache National Forest, 1:31,680. 1968

EXPLANATION

SURFICIAL SEDIMENTS

CENOZOIC — Quaternary

- **Qal** — Alluvium: *Sediments deposited in drainage courses*
- **Qw** — Slope Wash: *Material deposited relatively uniformly on slope, mantling bedrock*
- **Qls** — Landslide Debris: *area from which debris originated (scarp)*
- **Ql** — Lacustrine Sediments: *Material deposited in Bear Lake during Quaternary time*
- **Qd** — Delta-Fan Sediments: *Deposits formed at the mouths of drainage courses, subaqueously in the lake and subaerially elsewhere*

BEDROCK

Tertiary

- **Tsl** — Salt Lake Formation: *White marl and variegated mudstone*
- **Tw** — Wasatch Formation: *Conglomerate, sandstone, mudstone, shale and limestone*
- **Tu** — Undifferentiated

BEDROCK

MESOZOIC — Jurassic

- **Jtc** — Twin Creek Limestone: *Highly fragmented*
- **Jn** — Nugget Sandstone

MESOZOIC — Triassic

- **Ꞧ** — Ankarah and Thaynes Formations: *Sandstone and shale*

PALEOZOIC

- **Pal** — Paleozoic Limestones and Dolomites *(Cambrian to Permian)*

Cambrian

- **Ꞓq** — Brigham Quartzite

SYMBOLS

- Contact: *Dashed where inferred or poorly exposed*
- Fault, showing dip: *Dashed where approximately located, dotted where concealed. U, upthrown side; D, downthrown side*
- Thrust fault: *Dashed where approximately located, saw-teeth on side of upper plate*
- Strike and dip of beds
- Sand and gravel pit

GEOLOGY OF THE BEAR LAKE AREA

RICH COUNTY, UTAH

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1971