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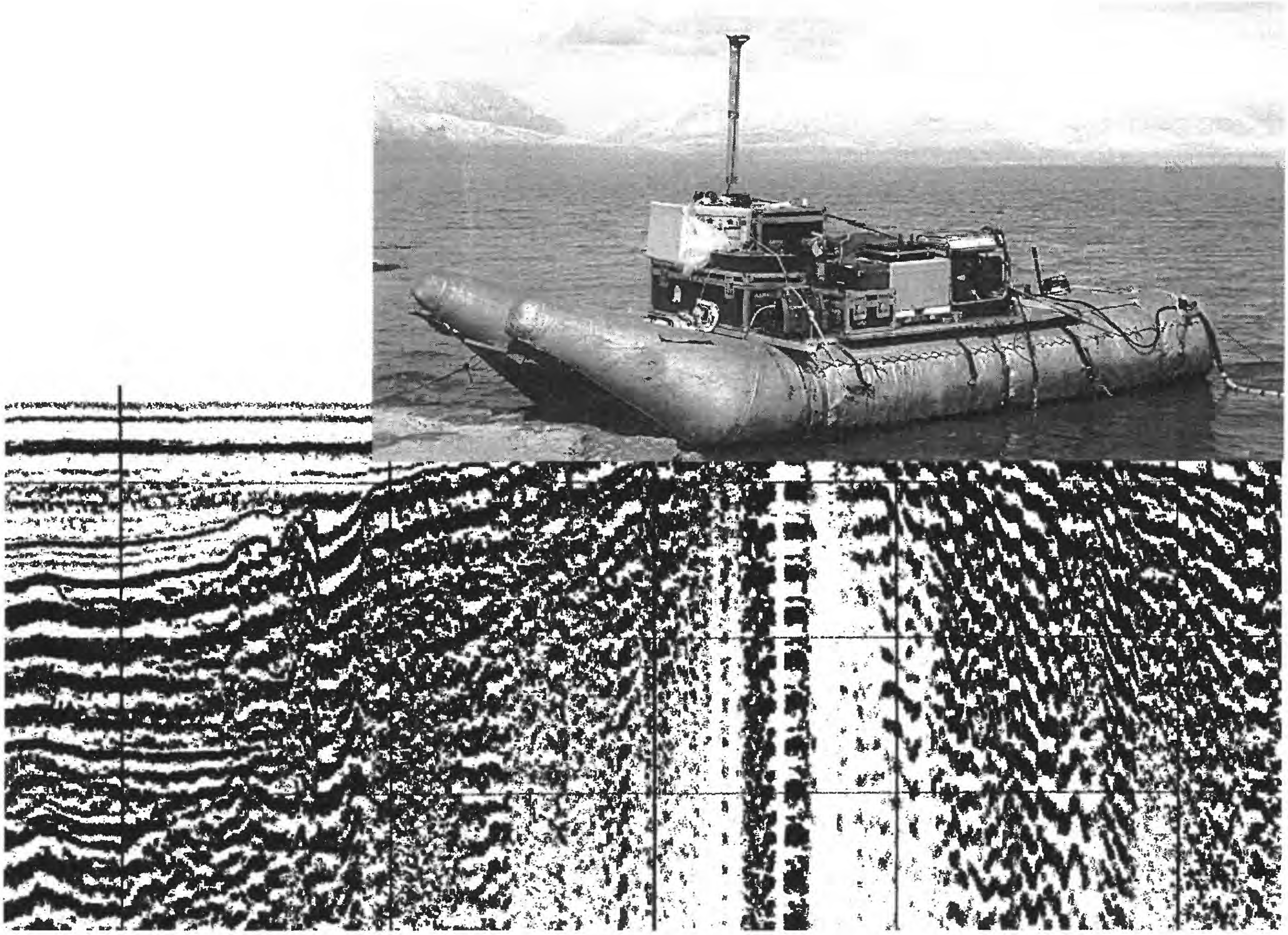
Geologic analysis of continuous high-resolution, seismic-reflection data from the Lincoln Point- Bird Island area, Utah Lake, Utah

Water-Resources Investigations Report 96-4236

Prepared in cooperation with the Central Utah Water Conservancy District



U.S. Department of the Interior
U.S. Geological Survey

GEOLOGIC ANALYSIS OF CONTINUOUS HIGH-RESOLUTION, SEISMIC-REFLECTION DATA FROM THE LINCOLN POINT - BIRD ISLAND AREA, UTAH LAKE, UTAH

By Robert L. Baskin and Henry L. Berryhill, Jr.

U.S. GEOLOGICAL SURVEY

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CENTRAL UTAH WATER CONSERVANCY DISTRICT

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Salt Lake City, Utah
1998

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

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Appendix

PLATES

[Plates are in pocket]

FIGURES

FIGURES—Continued

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
centimeter	0.3937	inch
meter	3.2808	foot
kilometer	0.6213	mile
square kilometer	0.3861	square mile
kilometer per hour	0.6214	mile per hour
joule	0.0009478	British Thermal Unit

Values reported in English units are noted in parentheses following the metric value.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

GEOLOGIC ANALYSIS OF CONTINUOUS HIGH-RESOLUTION, SEISMIC-REFLECTION DATA FROM THE LINCOLN POINT - BIRD ISLAND AREA, UTAH LAKE, UTAH

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ABSTRACT

During March 1991, the U.S. Geological Survey, in cooperation with the Central Utah Water Conservancy District, conducted a seismic investigation of the shallow subsurface sediments in the Lincoln Point - Bird Island area of Utah Lake, Utah, using a continuous, high-resolution profiler. This investigation was designed to identify the depositional, structural, and erosional features preserved in the sediments of the Lincoln Point - Bird Island area to locate areas where spring water may be entering Utah Lake and to estimate the path that ground water may take to the springs.

Continuous seismic-reflection data were gathered along 13 profiles in the Lincoln Point - Bird Island study area. The combined length of the 13 profiles was about 39.4 kilometers (24.5 miles). Faulting is prominent in the study area and the majority of faults show only minor offset. Faults possibly underlie mound-shaped structures in the Lincoln Point - Bird Island area, but acoustical wipeout and multiples beneath the structures precluded their identification. Faulting of recently deposited sediments shows that uplift is continuing in the area.

The principal geologic structure in the study area is a dome beneath and including the Bird Island area. The dome structure probably is the result of the uplift of consolidated rocks and overlying sediments, and the subsequent deposition of travertine in the vicinity of the uplift.

Three distinct sedimentary sequences were identified in the seismic profiles and represent the depositional history of Utah Lake. Seismic features anomalous to the generally stratified nature of the sedimentary sequences were noted in places. Most of these anomalous features are mound shaped on the profiles and, based on acoustical ringing, have a hard, highly reflective surface. Direct correlation of drill and core samples was not attempted during this study; however, the occurrence of "spring deposits" in drill holes and core samples indicates that the mound-shaped structures are probably travertine deposits. Although no specific spring locations were found during the seismic profiling, the travertine likely was deposited by precipitation from warm water leaking upward along faults and fault-related fractures.

INTRODUCTION

The physical characteristics and quality of water from selected springs and wells in the Lincoln Point - Bird Island area of Utah Lake, Utah, were evaluated during 1991-92 by the U.S. Geological Survey in cooperation with the Central Utah Water Conservancy District (Baskin, Spangler, and Holmes, 1994). As part of the investigation, a continuous seismic-reflection survey was conducted March 20-23, 1991, in the Lincoln Point - Bird Island area (fig. 1). The purpose of the survey was to identify the major depositional, structural, and erosional features preserved in the sediments of the Lincoln Point - Bird Island area to locate areas where spring water may be entering Utah Lake and to estimate the path that ground water may take to the springs.

Continuous seismic-reflection data were gathered along 13 profiles in the Lincoln Point - Bird Island study area (fig. 2). The combined length of the 13 profiles was about 39.4 kilometers (24.5 miles). Seismic data were recorded on both digital tape and graphic recorder during the surveys. Water depth, lake-bottom material, and location were measured and recorded during collection of the seismic data.

Water depth measured during the geophysical survey ranged from about 0.5 to 2.9 meters (1.6 to 9.5

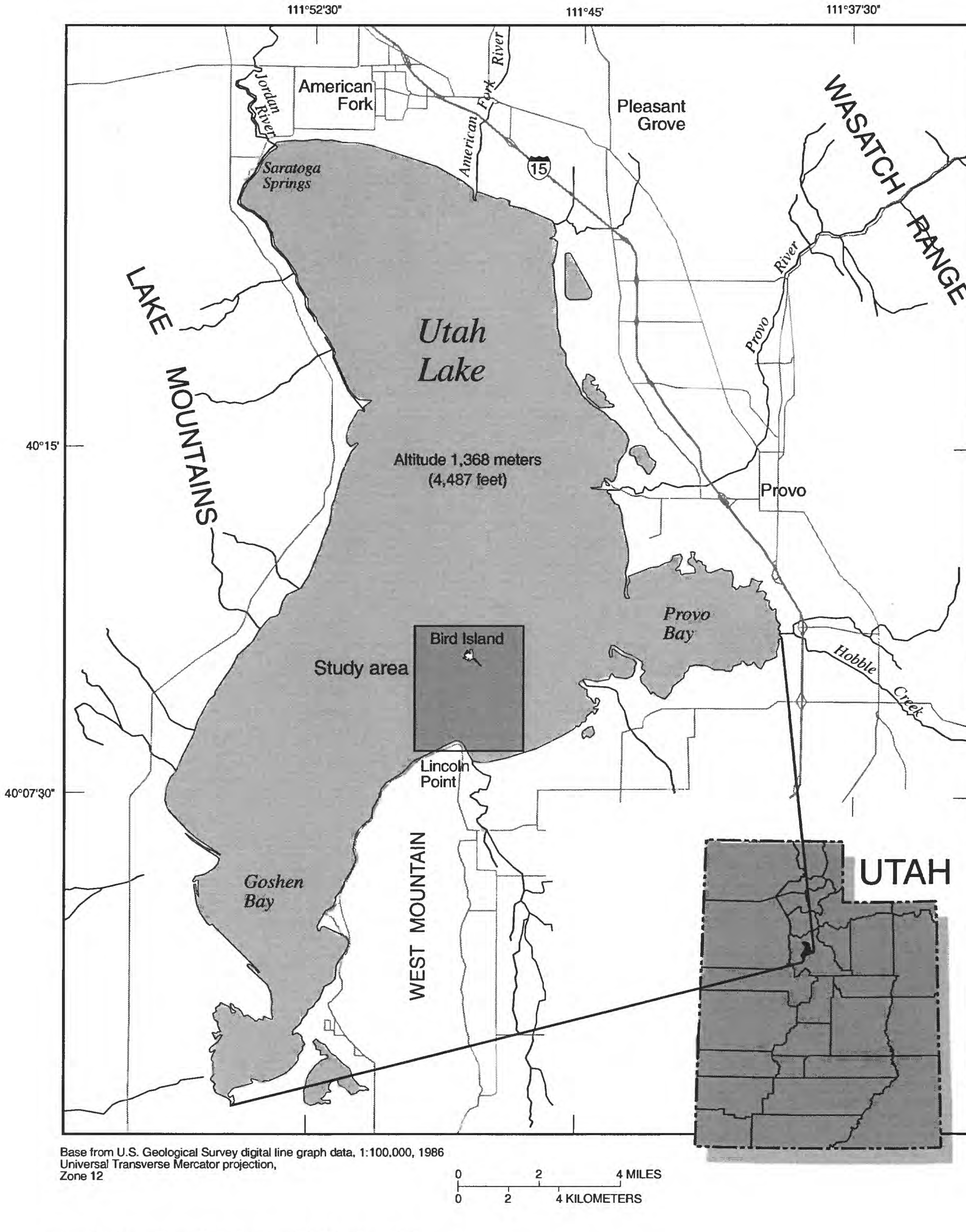
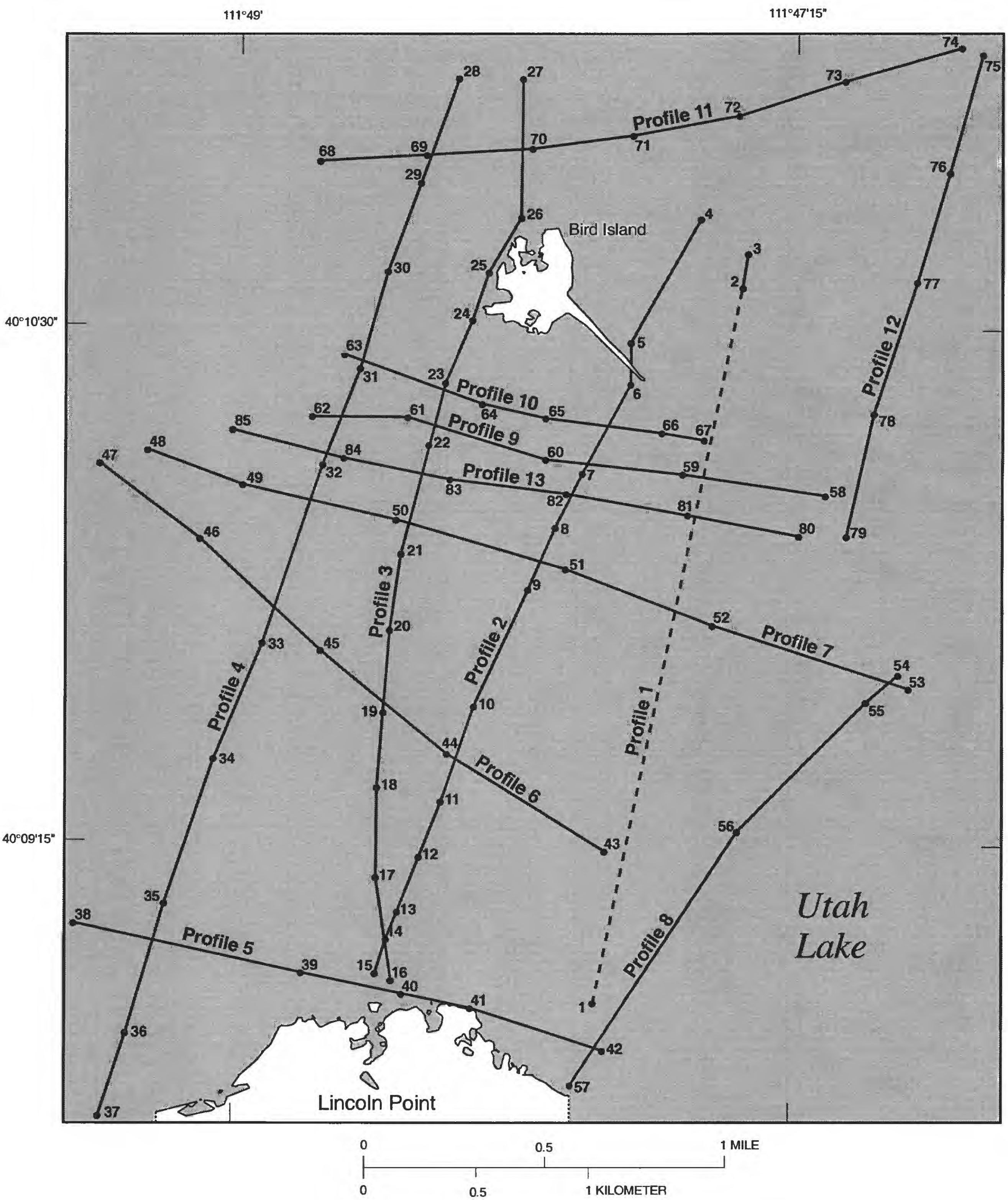


Figure 1. Location of study area,Utah Lake, Utah.



EXPLANATION

——— — — **Seismic-survey profile**—Dashed where approximately located

• 37 **Seismic-survey profile control location and identifying number**

Figure 2. Location of seismic-reflection profiles and control locations in the Lincoln Point - Bird Island area, Utah Lake, Utah.

feet). Bottom material varied from a calcareous ooze throughout most of the survey area to travertine deposits near Lincoln Point and Bird Island. A submerged gravel spit occurs along the eastern edge of Bird Island.

Purpose and Scope

This report describes the methods and results of the continuous seismic-reflection survey conducted during March 1991 in the Lincoln Point - Bird Island area of Utah Lake, Utah. The survey includes that part of Utah Lake north of Lincoln Point, to, and immediately beyond, Bird Island (fig. 1). Survey data were interpreted for each of the 13 seismic profiles from the analog graphic output, and maps showing depth below lake bottom for the three identified sedimentary sequences were generated from the interpreted data.

Description of Study Area

The Lincoln Point - Bird Island study area is along the southern edge of Utah Lake, north of West Mountain in Utah County, Utah (fig. 1), and encompasses about 26 square kilometers (10 square miles). The lake surface makes up about 95 percent of the total area. The actual percentage of lake surface in the study area varies because of seasonal and long-term fluctuations in the level of Utah Lake. Most of the land surface in the study area, including that of Bird Island and the shoreline at Lincoln Point, consists of travertine deposits. Utah Lake, which surrounds and makes up most of the study area, is at the eastern edge of the Basin and Range Physiographic Province (Fenneman, 1931) and is a remnant of Lake Bonneville of Pleistocene age (Gilbert, 1890).

Maximum altitude in the study area is about 1,384 meters (4,540 feet), at a point on the northern edge of West Mountain. Minimum known land-surface altitude in the study area is about 1,360 meters (4,462 feet), beneath the surface of Utah Lake at the bottom of a depression in lake-bottom sediments west of Bird Island. This depression is caused by discharge from a spring that prevents the accumulation of sediment over the spring orifice. Mean altitude of the lake bottom within the study area is about 1,365 meters (4,478 feet).

Historical water levels of Utah Lake range from an altitude of 1,364.66 meters (4,477.22 feet) in October 1935 to 1,370.00 meters (4,494.74 feet) in June 1984. Lake-level altitude during the seismic survey varied from about 1,366.95 to 1,367.00 meters (4,484.74 to 4,484.91 feet) (David B. Gardner, Utah Lake and Jordan River Water Commissioner, oral commun., 1992).

The water level in Utah Lake is controlled primarily by inflow from major streams that have headwaters in the Wasatch Range (east of the study area), by outflow down the Jordan River, by withdrawal from the lake, and by evaporation. No surface water enters the study area except for lake water from circulation, a small amount of runoff from precipitation, and direct precipitation to the lake surface. Utah Lake provides water for irrigation, culinary use, industry, and recreation and is classified as a warm-water fishery (Utah Department of Health, 1988, p. 39).

GEOHYDROLOGIC SETTING

Water-bearing deposits in the Lincoln Point - Bird Island area include fractured conglomerate, travertine and tufa, and unconsolidated lake deposits (U.S. Bureau of Reclamation, 1965). Movement of water through these deposits is influenced by geologic structure, ground-water head gradients, and the altitude of the surface of Utah Lake. Three distinct geohydrologic subareas can be identified in the study area: Lincoln Point, Bird Island, and the bottom sediment of Utah Lake.

Lincoln Point is at the north end of West Mountain, a complex north and south trending, steep-sided, isolated horst formed by large-scale displacement faulting (U.S. Bureau of Reclamation, 1965). Older bedrock assemblages of West Mountain are folded, broken by many faults, and consist of limestone and quartzite of the Oquirrh Formation of Paleozoic age. The dip of the bedding at West Mountain ranges from about 30 to 90 degrees, and some beds have been overturned.

Overlying the older bedrock in the Lincoln Point area is the North Horn Formation of Cretaceous and Tertiary age, a moderately cemented, rounded, sand and gravel conglomerate with a red clay matrix (U.S. Bureau of Reclamation, 1965). This conglomerate is fractured, and is exposed along the break in slope at Lincoln Point.

Overburden in the Lincoln Point area consists almost entirely of slopewash characterized by rounded, clayey gravel with varying amounts of subangular boulders derived from weathering of the conglomerate, limestone, and quartzite formations to the south (U.S. Bureau of Reclamation, 1965). Springs along the shore at Lincoln Point discharge warm, saline water from deposits of rounded gravel at the edge of the overburden.

The area along the shoreline at Lincoln Point consists of travertine and tufa deposits interbedded with unconsolidated lake sediment. The travertine and tufa deposits extend about 1.6 kilometers (1 mile) to the east of Lincoln Point and about 4.8 kilometers (3 miles) to the west into Goshen Bay. The travertine and tufa deposits generally are irregular and thinly bedded and frequently occur as cementing material in the gravels along the Utah Lake shoreline. Travertine deposits were encountered in test hole PRG-1 (fig. 3), about 610 meters (2,000 feet) northwest of the shoreline at Lincoln Point (U.S. Bureau of Reclamation, 1963), and may extend farther into Utah Lake.

Most of the springs in the Lincoln Point area are aligned in a northwest trend that is parallel to the northeastern edge of Lincoln Point and are at an altitude of about 1,368 meters (4,488 feet) (fig. 4). The springs are at the base of a break in slope and discharge through wave-worked sand, gravel, and cobble deposits. Some of the springs discharge from areas primarily composed of broken travertine and tufa and likely issue directly from consolidated travertine and tufa deposits beneath the broken surface materials.

Many of the springs in the Lincoln Point - Bird Island area discharge at discrete locations; however, diffuse seepage through the unconsolidated surface materials at Lincoln Point is widespread. Most of the diffuse springs (seeps) discharge from gravel, cobble, and boulder deposits along the northern edge of Lincoln Point. Discharge from springs and seeps in the Lincoln Point area generally flows north over surface travertine and tufa deposits and into Utah Lake. Some of this flow may re-enter the travertine and tufa deposits before reaching the lake and discharge below the initial spring site.

Bird Island is a small island (about 0.13 square kilometer (0.05 square mile) in area when the altitude of the water surface of Utah Lake is 1,367 meters (4,485 feet)) about 3.2 kilometers (2 miles) north-northeast of Lincoln Point. The island is composed of travertine and tufa deposits with wave-worked, rounded, travertine and tufa gravels along the island beaches. Warm, saline water from springs discharges along the edge of the island and beneath the surface of Utah Lake in the vicinity of Bird Island in embayments formed by spring-water-deposited travertine (fig. 5) (Baskin, Spangler, and Holmes, 1994). Cottam (1926), in discussing the occurrence of tufa in the Lincoln Point - Bird Island area, states "The tufa unit crops out in a small area north of West Mountain near Lincoln Beach and along a small strip of shore directly west. It also comprises most of Rock Island [Bird Island], although this island has a pedestal of quartzite." Original data for Cottam's study cannot be located to verify the existence of a quartzite pedestal.

Lake-bottom sediment in the study area consists primarily of calcium carbonate mud containing small concentrations of magnesium, strontium, and other impurities (Brimhall and Merritt, 1981, p. 30). Bissell (1963) reported that "The upper 5-8 feet [1.5-2.4 meters] of sediment on the bottom of Utah Lake is light to medium gray silty clay that is fairly well sorted, poorly compacted, and contains 50 to 60 percent water. This bed grades downward into more compact medium to dark-gray clay, which extends to a depth of 15 feet [4.6 meters]. The more compact clay is poorly sorted and contains 40 to 50 percent water. Below this is a 10 foot [3 meter] bed of well-sorted dark-gray to black compact silty clay containing 33 to 43 percent water; it becomes sandy at a depth of about 25 feet [7.6 meters].... Soundings and core sampling indicate fairly large areas of tufa beneath the lake, now covered by water or clay." Horton (1905) reports a simplified but similar lithology for Utah Lake sediments: "The material in the lake bottom away from the shores was found to be a very fine, smooth, slick clay, light colored on top, and changing in most cases to a bluish color under the surface. Nearer the shores, the clay is stiffer and is mixed with sand to some extent, but well away from the shore, in the deeper water, the clay is very soft."

Drillers' logs (U.S. Bureau of Reclamation, 1963) reported interbedded clay, silt, and sand in drill holes PRG-1, PRG-2, PRG-3, PRG-4, PRG-21, PRG-22, and PRG-23, all of which are in the study area (fig. 3). Depth of the drill holes ranged from 2.3 meters (7.5 feet) to 21.5 meters (70.5 feet) below lake bottom. Travertine or "spring deposits" were specifically noted on the drillers' logs in all of the drill holes in the study area except PRG-3 and PRG-4 (Appendix). The drillers' log from PRG-22 noted that the last 1 meter (3 feet) of material was "probably spring deposits of travertine" and that water "flowed freely over the top of the casing" when the plug was pulled at 15.2 meters (50 feet) (13 meters (42.5 feet) below lake bottom).

As part of a regional gravity survey along the central and southern Wasatch Front of Utah, Cook and Berg (1961, pl. 13) mapped a continuous and steep gravity anomaly on the east edge of West Mountain and through the center of Utah Lake to the northwest past Saratoga Springs (fig. 6) that indicates the presence of

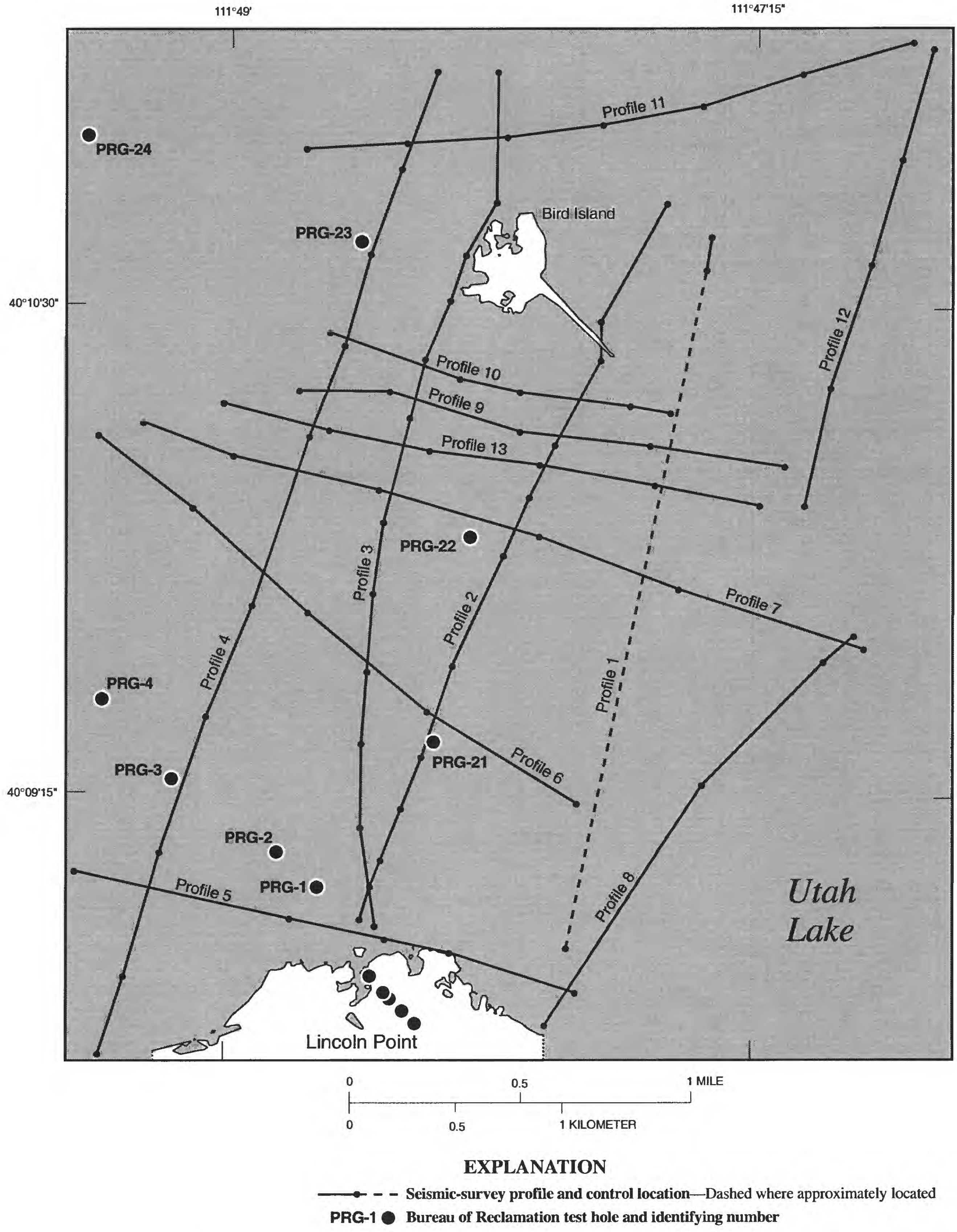


Figure 3. Location of U.S. Bureau of Reclamation test holes in the Lincoln Point - Bird Island area, Utah Lake, Utah.

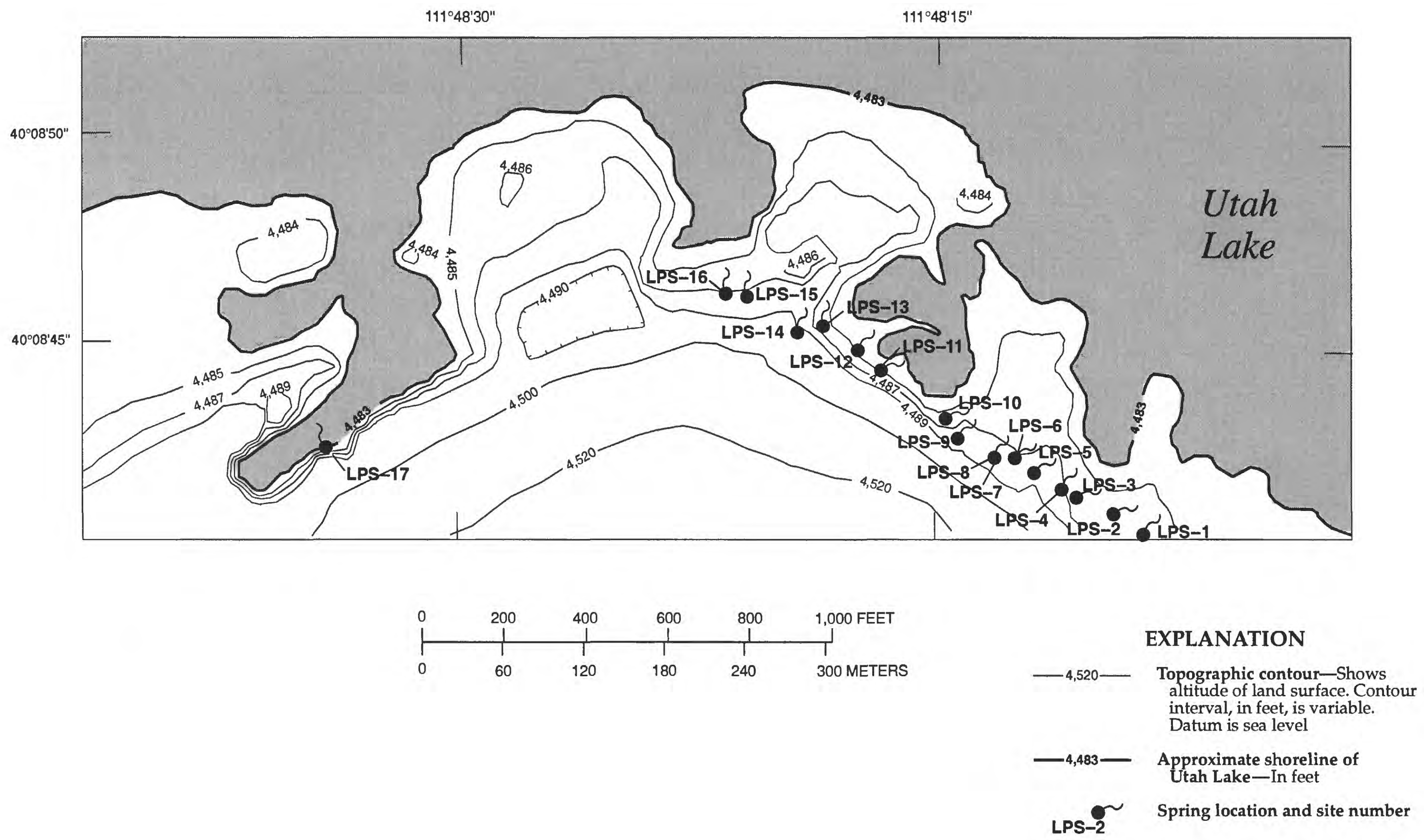


Figure 4. Location and approximate altitude of springs in the Lincoln Point area, Utah Lake, Utah.

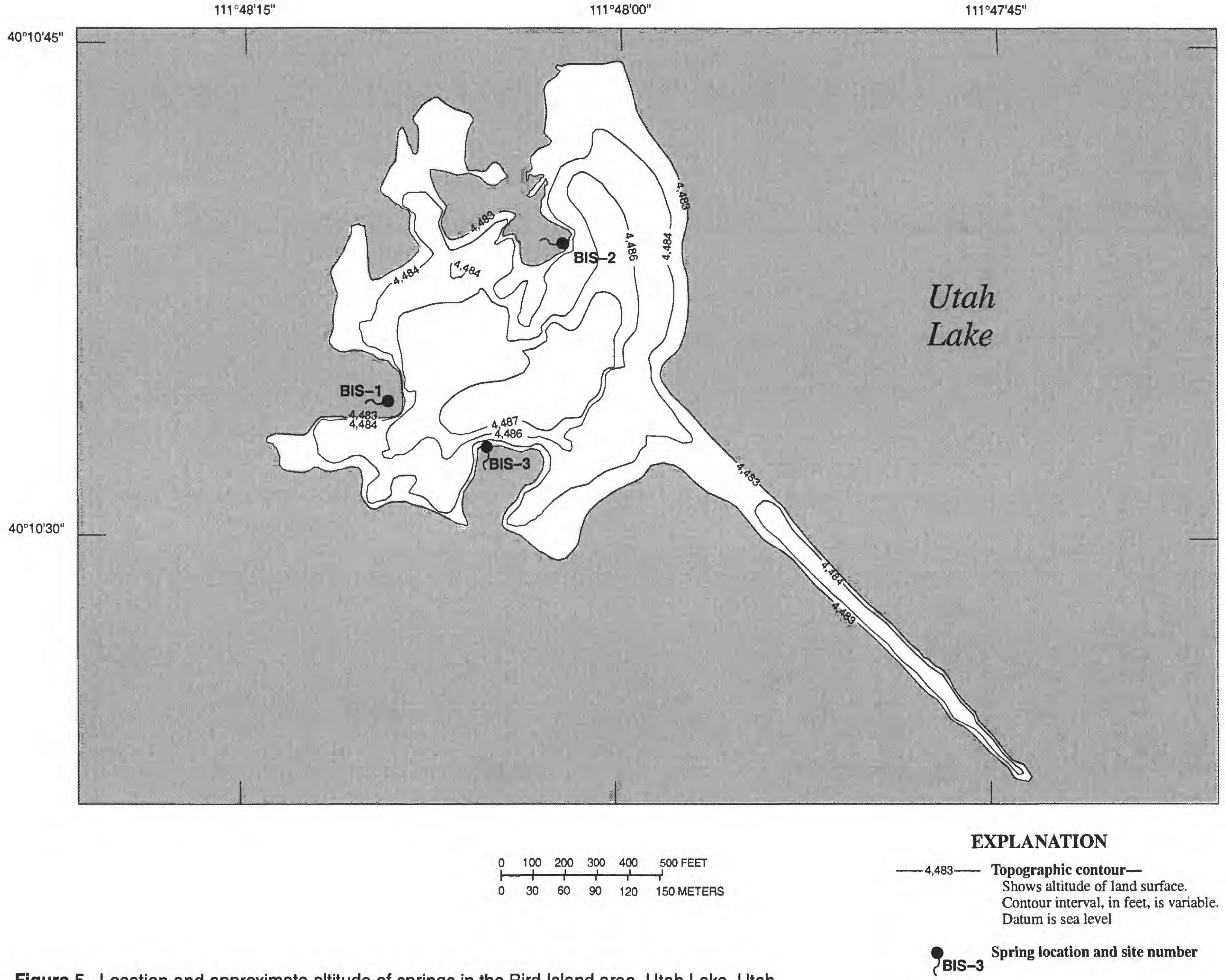


Figure 5. Location and approximate altitude of springs in the Bird Island area, Utah Lake, Utah.

a major fault zone. This "Utah Lake Fault Zone" passes close to Bird Island and is an expression of buried fault scarps that mark the west side of the Utah Valley Graben (Cook and Berg, 1961, p. 82).

Brimhall and Merritt (1981), using data from an acoustic profiler (Brimhall, Bassett, and Merritt, 1976), mapped displacements in the sediments of Utah Lake and identified faults passing to the east and west of West Mountain and in the vicinity of Bird Island (fig. 7). Twenty-three seismic profiles were recorded during this earlier study; however, none of the acoustic profiles passed between Lincoln Point and Bird Island.

SEISMIC REFLECTION SURVEY

The seismic-reflection survey conducted for this study used a single-channel profiling system that allowed for production of a near-real-time graphic record of the sediments underlying the hydrophone array. This type of survey is commonly referred to as high-resolution continuous seismic-reflection profiling. The technique and equipment used in the survey were originally designed for use in deep-water marine-geology investigations (Ewing and Tirey, 1961; Hersey, 1963). Modifications of these deep-water techniques (Haeni, 1971; E.G. and G. Environmental Equipment Division, 1977; Sylwester, 1983; Trabant, 1984) allow for examination of shallow water areas where information is needed regarding the top hundred meters or so of underlying sediments.

Methods of Data Collection

The theory of operation and the most common methods used in continuous shallow-water seismic-reflection surveys are described by Haeni (1971, 1986), E.G. and G. Environmental Equipment Division (1977), Sylwester (1983), and Trabant (1984). In general, seismic signals are generated by a release of energy from a sound source, travel through the water column, and then penetrate the subbottom materials. The seismic waves are reflected back to the water surface from interfaces where there is a contrast in acoustical impedance (a product of the density and acoustic velocity of each medium) between adjacent layers of sediments with differing physical properties. The strength or amplitude of the reflected seismic signal, and thus the ability to trace the reflector on seismic profiles, depends on the contrast in acoustic impedance between two lithologic units or within lithologic units. The reflected signals that return to the water surface are received by the hydrophone array, converted to electrical current, and then amplified, filtered, and displayed on a graphic recorder.

Equipment used in the seismic-reflection survey consists of power supplies, a graphic recorder, filter-amplifier unit, digital magnetic tape recorder, hydrophone streamer, and sound source (acoustical plate) (fig. 8). The equipment used for this survey was a Geopulse System manufactured by Farranti O.R.E., Inc.

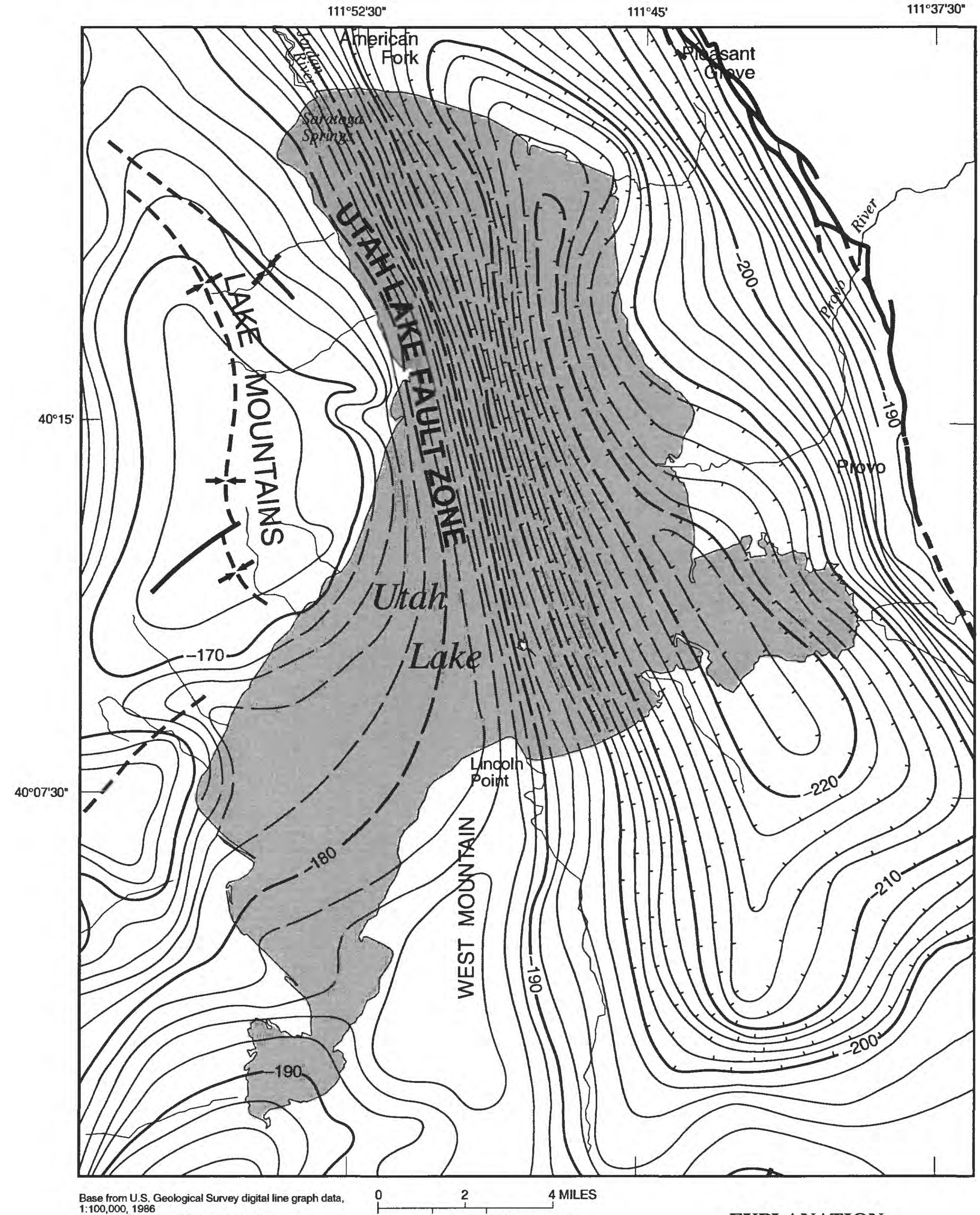
Data were gathered at a sweep rate of 200 milliseconds. Bandpass filters were set from 300 to 2,000 hertz to remove unwanted acoustic signals below and above those settings. Raw data from the 24-element hydrophone array were simultaneously recorded on digital audio tapes and amplified and filtered for plotting on the graphic recorder. Data from the tapes were then filtered and replotted at a 100-millisecond sweep rate for interpretation.

The power supply for the acoustical plate was operated at a power level of 750 joules and was fired every second. The equipment set-up and typical seismic-ray paths are shown schematically in figure 9.

The seismic survey was conducted from an 8-meter (26-foot) snout-rig inflatable catamaran (fig. 10) with the acoustical plate and hydrophone array deployed behind the boat. The acoustical plate was mounted on a small catamaran towed about 10 meters (32.8 feet) behind the rear of the boat and the hydrophone array was towed about 20 meters (65.6 feet) behind the acoustical plate. Towing speed, which was limited to prevent boat wake from interfering with the acoustical plate, ranged from about 3.8 kilometers per hour (2.4 miles per hour) to about 5.0 kilometers per hour (3.1 miles per hour) and averaged about 4.3 kilometers per hour (2.7 miles per hour). Geographic control was provided by a global positioning system accurate to about 18 meters (59 feet), root-mean-square error.

Methods of Data Interpretation

The seismic-reflection record is a time section that resembles a vertical geologic profile, except that the vertical dimension represents the time required for a seismic signal to travel from the sound source to a reflector and back to the hydrophone array (fig. 11). To convert the vertical scale on the profiles to depth, the velocity of sound in the various geologic layers must be



EXPLANATION

—190— — **Gravity contour**—Dashed where inferred. Contour interval 2 milligals. Hachures indicate depression

Fault—Dashed where uncertain

Syncline—Dashed where approximately located

Figure 6. Location of Utah Lake fault zone, Utah. (Modified from Cook and Berg, 1961.)

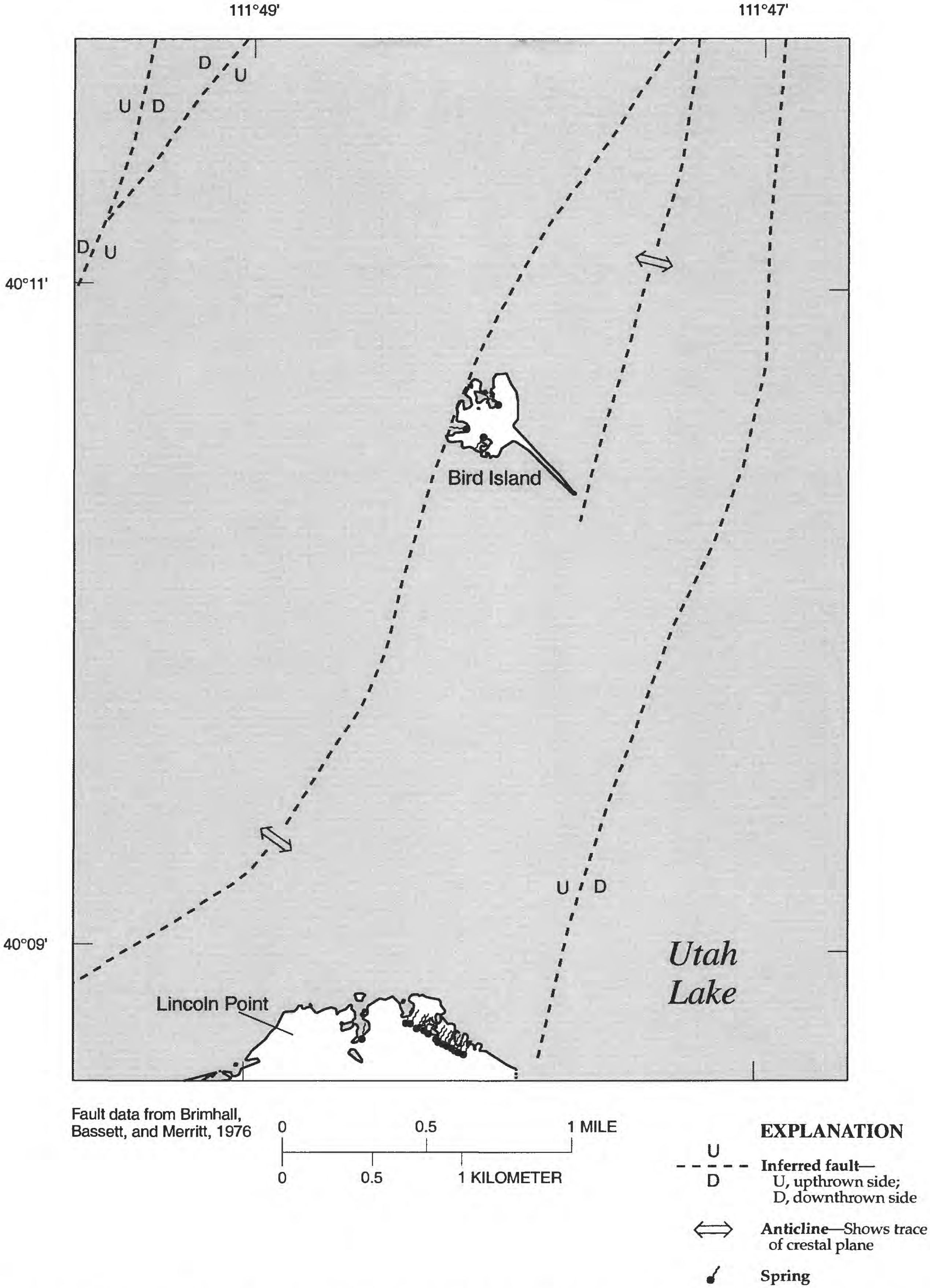


Figure 7. Approximate location of inferred faults and anticlines in the Lincoln Point - Bird Island area, Utah Lake, Utah. (Modified from Brimhall and Merritt, 1981.)

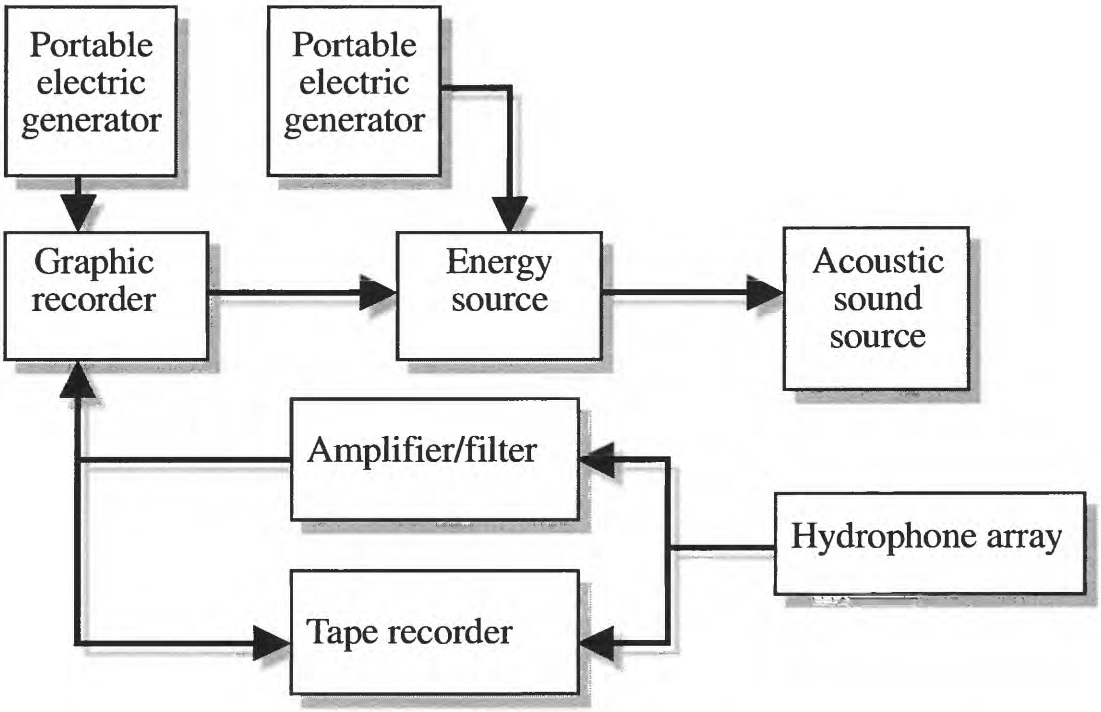


Figure 8. Typical continuous high-resolution, marine seismic-reflection--survey system. (Modified from Haeni, 1986.)

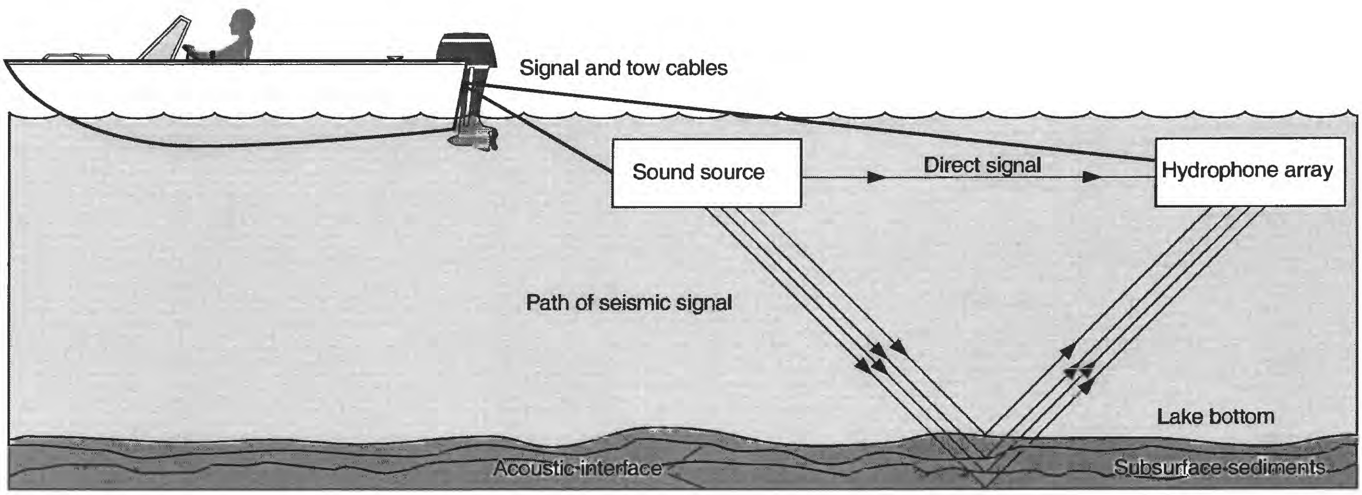


Figure 9. Seismic survey equipment and path of signals. (Modified from Haeni, 1986.)

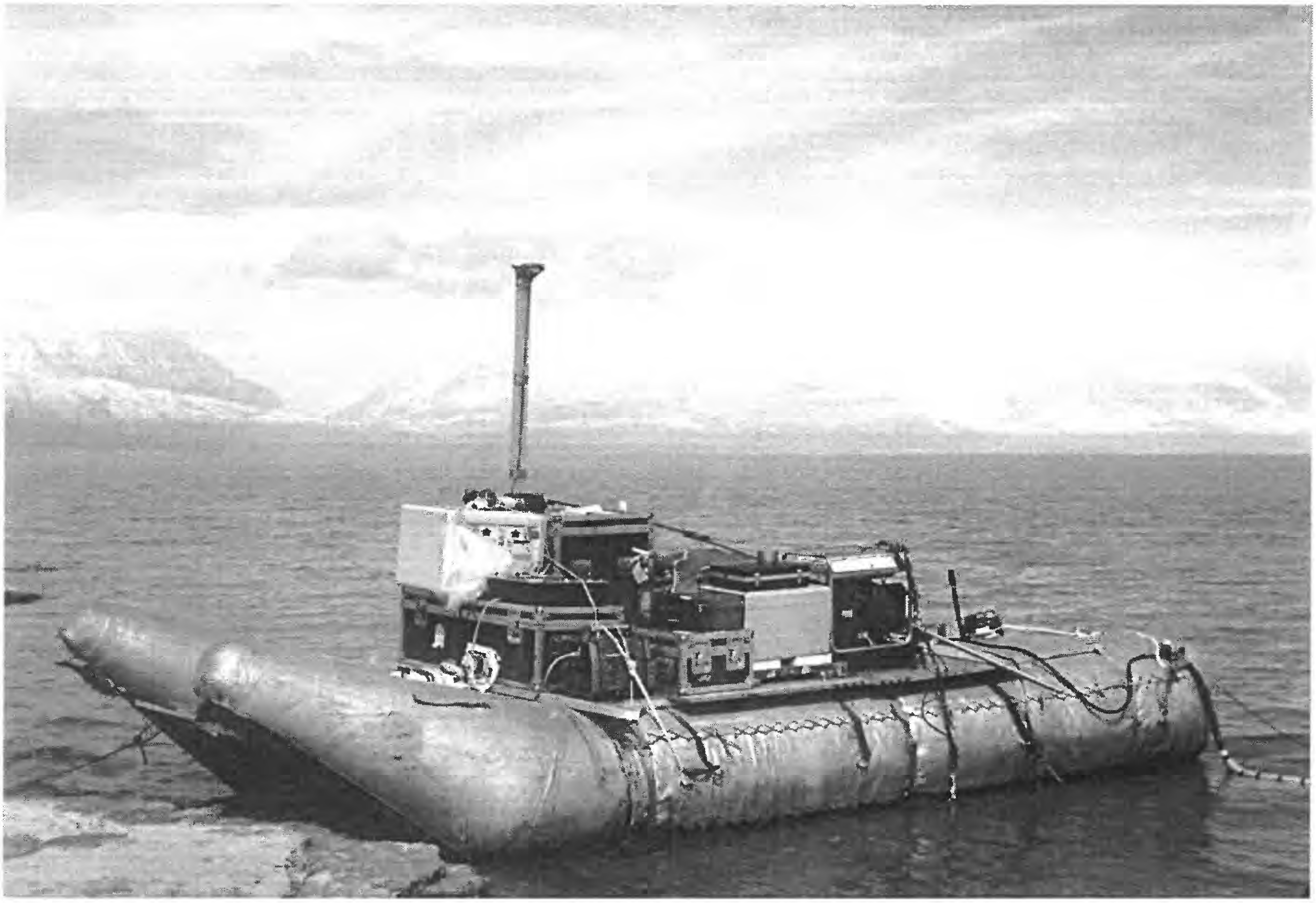


Figure 10. Catamaran used during seismic survey on Utah Lake, Utah.

known, and to translate seismic velocity to thickness or sub-lake depth, the two-way travel time for the seismic signal must be accounted for. Typical velocities of sound in the type of sediment found on the bottom of Utah Lake range from about 1,490 meters per second (4,900 feet per second) to about 2,000 meters per second (6,600 feet per second) (Hamilton, 1970; Sylwester, 1983; Bourbie, Coussy, and Zinszner, 1987; Locker, Brooks, and Doyle, 1988). Because of the saturation of shallow sediments underlying Utah Lake (Bissell, 1963), a seismic velocity of 1,600 meters per second (5,250 feet per second) was chosen for this report. This velocity is near that of water (about 1,500 meters per second (4,920 feet per second)) but might increase with depth as the sediments become compacted. Because the two-way travel time of the seismic signal must be taken into account, the 1,600 meters-per-second (5,250 feet-per-second) velocity was divided in half (to 800 meters per second (2,625 feet per second)) so the depth to reflectors could be calculated directly from measurements on the profiles. Each 10-millisecond time division on the profiles (fig. 11 and pl. 1 and 2) equals about 8 meters (26 feet).

Changes in the composition or physical characteristics of sediments in Utah Lake may affect the velocity of the seismic signal. Velocities for limestones are highly variable and can range from 2,500 to more than 7,000 meters per second (8,200 to more than 23,000 feet per second) (Schlumberger Limited, 1972; Bourbie, Coussy, and Zinszner, 1987; Badley, 1985; Locker, Brooks, and Doyle, 1988). For areas of travertine or calcic-cemented sediments, the velocity of the seismic signal may greatly increase, thereby shortening the calculated depth.

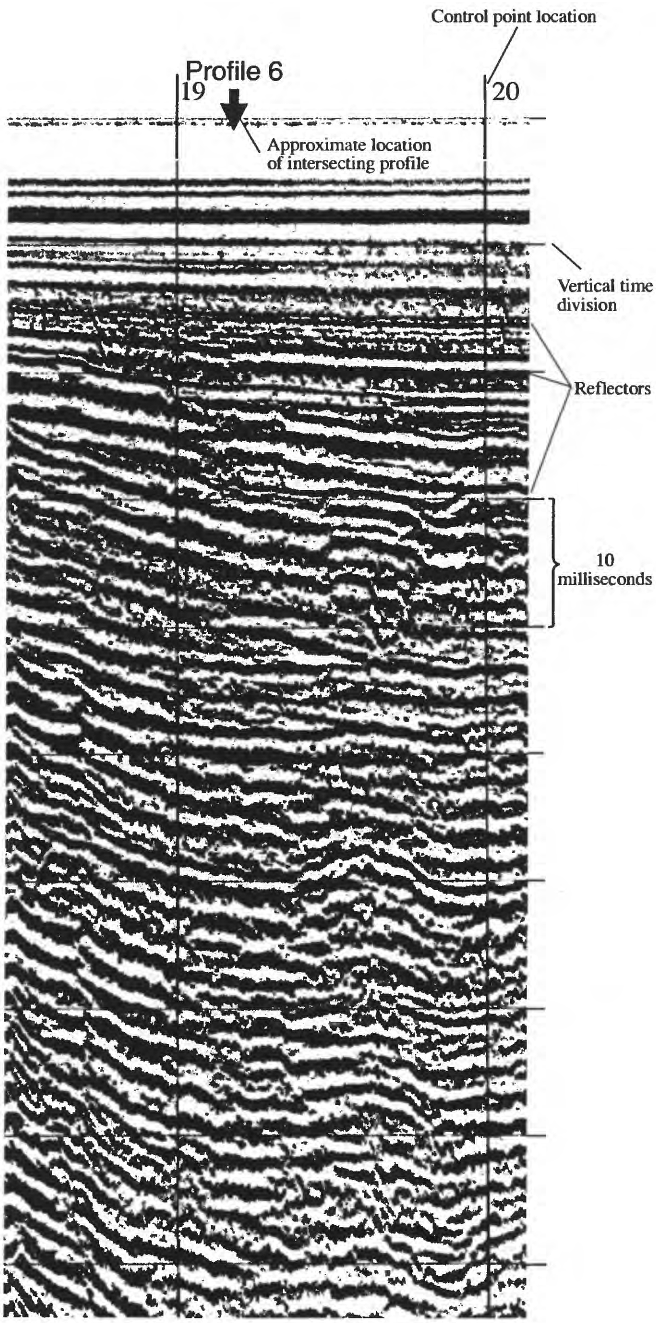


Figure 11. Annotated seismic section.

Geologic Analysis of Seismic Reflection Data

Continuous high-resolution seismic profiling has been used in a variety of hydrologic studies. This method has been used to help determine the thickness of stratified glacial drift aquifers in Connecticut (Haeni and Melvin, 1984), to study sedimentation in glacial lake basins (Eyles, Mullins, and Hine, 1990; Mullins and Hinchey, 1989), to examine the stratigraphy of offshore areas and lakes in Florida (Evans and Hine, 1988; Locker, Brooks, and Doyle, 1988; Missimer and Gardner, 1976), and to evaluate the extent of polychlorinated biphenyl (PCB) contamination in rivers (Frink and others, 1982).

The lithologic interpretation of continuous seismic-reflection profiles is outlined by Roksandic (1978) and Sangree and Widmier (1979) and is further discussed by Badley (1985). These studies show that the character of the reflected seismic signal, as seen on the analog record, often can be related to a specific sedimentary facies or depositional sequence. The continuity of subsurface reflectors, and consequently the subsurface geologic structure the reflectors represent, can be determined visually if the seismic record is clear and continuous. Interpretation can be complicated by competing signals from multiple reflections, diffraction, shoreline reflections, boat or motor noise, and also by the lack of signal penetration in some materials. Systematic variations in depth of the initial subsurface reflectors representing the lake bottom also may occur as a result of wave action on the sound source, changes in the depth of the hydrophone array, or both.

The characteristics of the sound source used in this investigation, depth to the lake bottom, and the geometry of the sound source and hydrophone array result in a series of reflections that mask the exact location of the lake bottom. For the purposes of this report, the lake bottom is assumed to be co-incident with the second reflector on the profile. This decision is primarily based on the assumption that the first arrival at the hydrophone array will be the direct signal from the sound source.

Geologic analysis of seismic-reflection data was limited to the uppermost section of each profile. The downward loss of seismic resolution, lack of geologic control information, and the presence of sound multiples make accurate mapping of deeper features throughout the study area impossible. The recorded seismic information was reproduced and is shown on plate 1 (profiles 1- 6) and plate 2 (profiles 7-13).

Faulting is prominent in the study area, although most faults show only minor offset. The fault pattern is that of a fracture-type breaking resulting from lateral extension or warping caused by pressure from directly beneath the Bird Island area, not from lateral compression. A number of small grabens are evident in the profiles and provide evidence for a lateral extension type of movement. Examples of these grabens and the fracture-type fault pattern are shown on profile 2, control points 4 to 6; profile 3, control points 22 to 23; and profile 4, control point 28.

Examination of the seismic profiles shows that three fairly distinctive sedimentary sequences are found in the shallow sediments in the Lincoln Point - Bird Island area and are mappable throughout the area. Additional sedimentary sequences beneath the shallow sediments are noted on some of the profiles but are not correlated among the profiles. Anomalous sedimentary features, such as possible stream-channel cuts and travertine deposits, also are apparent in the profiles.

The principal geologic structure in the study area is a dome beneath the Bird Island area. South of Bird Island, the older sediments underlying recent lake deposits dip gently into a structural low and then rise toward Lincoln Point. Sediments beneath the marked units on profile 12 (control points 77 to 79) show an upwarped structure in the vicinity of Bird Island. Profiles 2, 3, and 4 (pl. 1) and figures 12 to 14 also show this structure. Uplift of the dome structure probably took place during a late stage of Lake Bonneville (during the Pleistocene). The dome structure beneath and including Bird Island probably is the result of the uplift of consolidated rocks and overlying sediments, and subsequent deposition of travertine in the vicinity of the uplift.

Faulting

Major faults and their apparent direction of movement are noted on the profiles and shown in figure 12. Features interpreted as faults on the profiles have been marked in red with the direction of displacement indicated where the direction of relative movement is apparent.

The fault trend in the Lincoln Point - Bird Island area is north-south. The most prominent faults are shown on profile 4, near control points 32 and 37. At both localities, as well as on profile 6 at control points 44, 46, and 47, sediments of Unit 1 have been offset by faulting. Only on profile 4 at control point 37 does faulting appear to reach the lake bottom. The displacement of the upper sequence of sediments near Bird Island (profile 4, control points 32 and 37 and profile 6, control points 44, 46, and 47) shows that uplift is continuing in the area. Some deeper faults have been identified and are shown on profile 11, control point 73 and profile 9, between control points 58 and 59.

A few faults appear to be correlative from profile to profile (fig. 12). The faults southwest of Bird Island (profile 9 control point 62, profile 13 control point 82, profile 4 control point 32, and profile 7 between control points 49 and 50) appear to extend to shallow lake-bottom sediments, inferring that they have been active in recent geologic time. Clusters of small faults identified on the seismic profiles are noted on figure 12 as fault/fracture zones. The close spacing and small offset of faults in these fault/fracture zones, especially near the uplift beneath Bird Island, prevents an accurate correlation of faults in these areas.

Faults possibly underlie mound-shaped structures in the Lincoln Point - Bird Island area, but acoustical wipeout and multiples beneath the structures precluded their identification. Many of the fault/fracture zones in figure 12 are in areas of suspected travertine deposition. Faults and associated fractures probably provide conduits for warm, saline water moving from the subsurface to springs beneath the surface of Utah Lake.

Stratified Sedimentary Features

The depositional history of the shallow sediments beneath Utah Lake can be reconstructed by studying the characteristics of the seismic signal as plotted on the seismic profiles. Examination of the profiles shows that three fairly distinctive sedimentary sequences are found in the shallow sediments in the Lincoln Point - Bird Island area. For purposes of this report, the sedimentary sequences are designated in downward order as Unit 1 (unit is shown in yellow on the plates), Unit 2 (unit is shown in blue on the plates), and Unit 3 (unit is shown in green on the plates). The base of other sedimentary sequences in addition to those already mentioned is shown in orange. Depth to the sedimentary features are relative to lake bottom. A bathymetric map of the study area is included as figure 13 for reference.

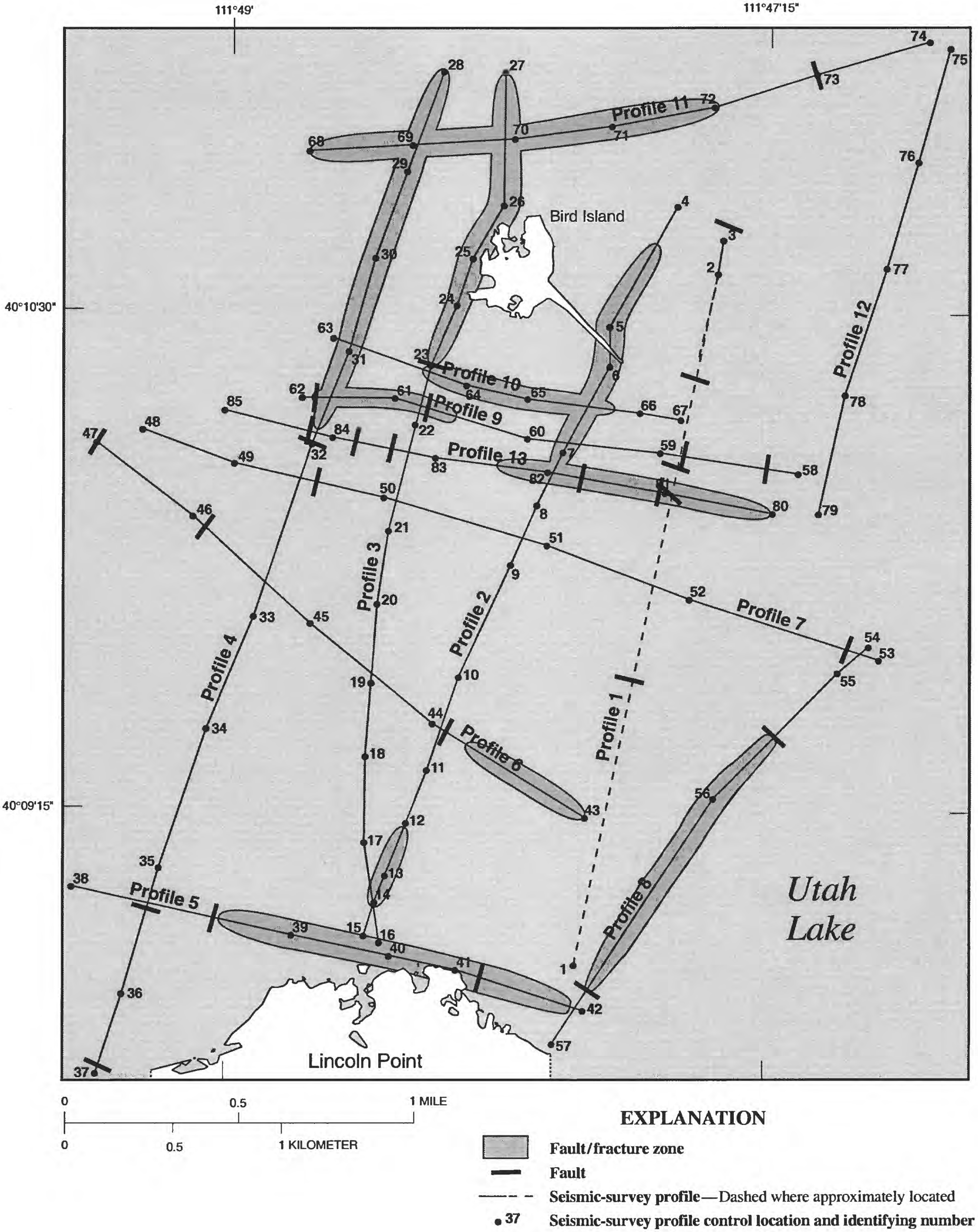


Figure 12. Location of faults and fault/fracture zones in the Lincoln Point - Bird Island area, Utah Lake, Utah.

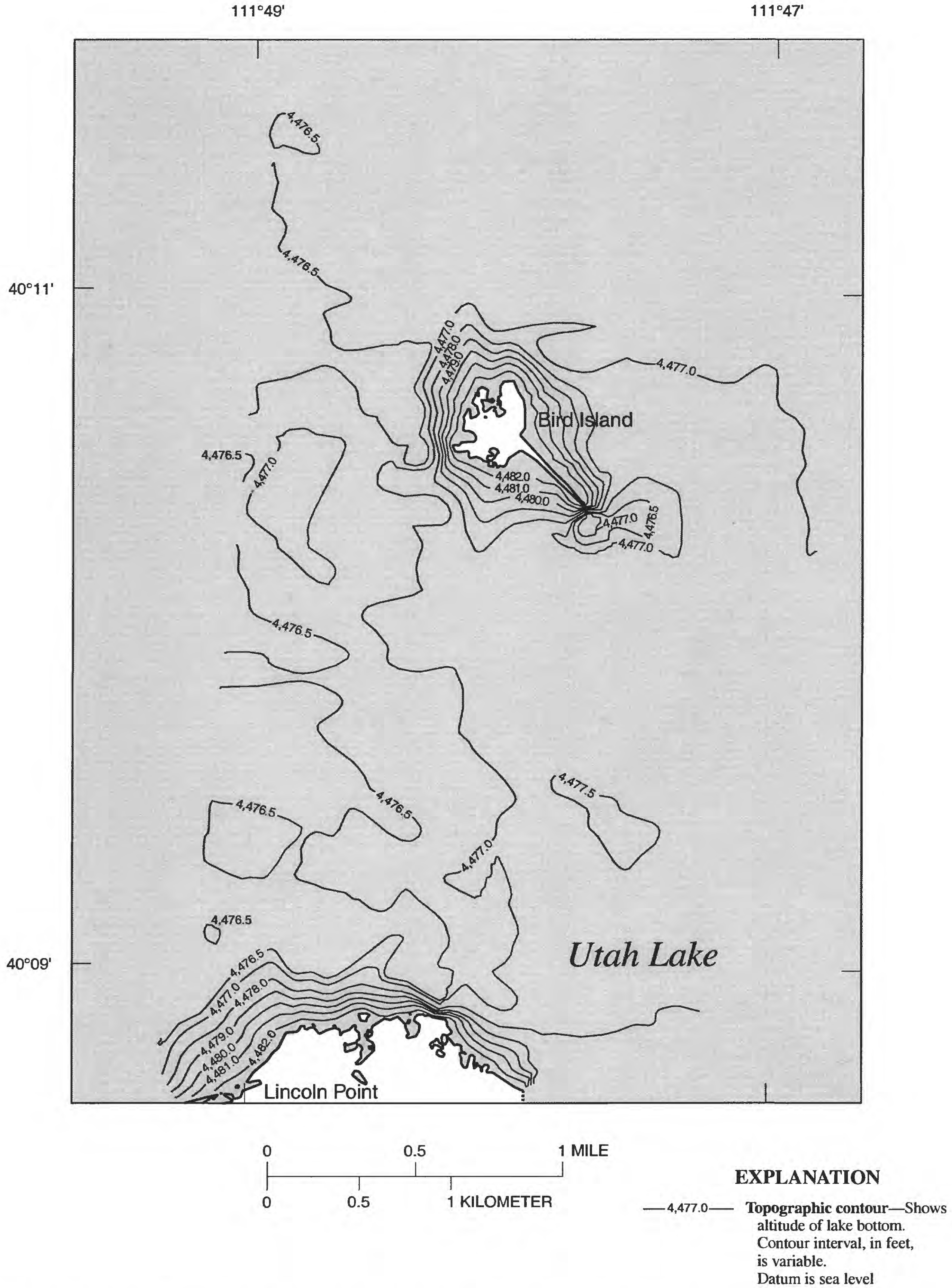


Figure 13. Computer-generated contours of lake-bottom altitude in Lincoln Point - Bird Island area, Utah Lake, Utah.

Unit 1

Unit 1 generally is stratigraphically flat. Unit 1 thins across the uplifted areas beneath Lincoln Point and Bird Island as shown on the profiles, but nowhere has it been affected by the uplift that is evident in the two older sequences (Units 2 and 3). Unit 1 is interpreted as representing the non-stratified lake-bottom sediments (Holocene) deposited in Utah Lake.

Unit 1 shows no major change in acoustic impedance and consequently is seismically transparent, indicating little difference in the characteristics of the sediments. However, several prominent and widespread reflectors are apparent in the profiles. These reflectors range in number from two to four and tend to bifurcate, lens out, or overlap each other locally. The two most persistent reflectors in Unit 1 are at average sub-lake-bottom depths of 0.8 meters and 2.5 meters (2.6 and 8.2 feet, respectively). The several test holes (fig. 3) drilled through Unit 1 do not indicate what the reflectors represent. The stronger reflectors could represent either increased calcium carbonate content and cementation or slightly coarser and more compacted sediment layers. The differences in deposit composition may have resulted from climatic changes, changes in lake level, or both. Otherwise, the general transparency of Unit 1 indicates uniform composition of sediments.

The thickness of Unit 1 ranges from a few centimeters to about 6 meters (19.7 feet) (fig. 14). Average thickness is about 4 meters (13.1 feet). Unit 1 pinches out toward Lincoln Point and toward Bird Island.

Unit 2

Unit 2 is distinguished from Unit 1 by two prominent features: (1) Unit 2 has stronger reflectors than Unit 1, and (2) Unit 2 was subjected to progressive uplift during deposition, as shown by the features on profiles 2, 3, and 4 (pl. 1). Though generally less seismically transparent than Unit 1, the degree of transparency in Unit 2 varies. An example of the variation in character of the reflection pattern in Unit 2, from top to base, is shown on profile 11 between control points 71 and 74. The more pronounced layering in Unit 2, when compared with Unit 1, and the stronger reflection pattern indicate more heterogeneity in grain size with increasing depth and a greater degree of consolidation.

Uplift has resulted in the gentle folding and erosion of Unit 2 sediments in the topographically high areas near Lincoln Point and Bird Island. The overlapping of reflectors in Unit 2 can be seen on profile 2 between control points 6 and 9 and on profile 11 between control points 69 to 72 (pl. 2). The erosional truncation of Unit 2 beds can be seen on profile 2 between control points 7 to 12 and on profile 11 between control points 70 to 72. Erosion is most pronounced on the topographically high areas.

An important feature of Unit 2 is the unconformity at its top. The strata of Unit 2 were truncated by erosion prior to deposition of Unit 1. This unconformity is prominent on profiles 2, 3, 4, and 12 and possibly indicates a complete withdrawal of the earlier Lake Bonneville from this area and subaerial erosion of Lake Bonneville sediments before formation of Utah Lake. Some prominent examples of the unconformity are on profile 2 between control points 4 and 9, profile 3 control point 26, profile 4 between control points 28 and 31, profile 9 between control points 61 and 62, and profile 11 between control points 69 and 72.

Unit 2 generally can be subdivided into two subunits. This subdivision can be seen on most of the profiles and is labeled as "A" and "B" in the right margin at the edge of profile 11. Subunit "A" has coarse, less-defined layers than subunit "B," is more transparent than subunit "B," and pinches out in part against the older and deformed subunit "B." Subunit "A" has been uplifted and erosionally truncated but less so than subunit "B." The lower subunit "B" shows finer, more-defined layering, has been uplifted onto the topographic highs, and has been erosionally truncated.

Maximum thickness of Unit 2 is about 11 meters (36.1 feet). Thickness across the saddle area that separates Lincoln Point from the submerged structural high at Bird Island averages about 8 meters (26 feet). Sub-lake-bottom depths to the base of Unit 2 are shown in figure 15.

Unit 3

Within the study area, Unit 3 forms a lenticular basin with an irregular base that indicates deposition over an older, eroded surface. The lenticular shape and irregular base of the deepest sediments in Unit 3 provide evidence of channel-fill deposits. The lenticular character of the unit and the irregular base are shown on profiles 2, 3, and 4 (pl. 1). The channel-fill deposits at the base of the unit are shown on profiles 2 and 12 (pl. 1 and 2, respectively).

The seismic character typical of Unit 3 is shown by profile 12 (pl. 2). Dense, widely separated horizontal reflectors are common and lap out at the basin edges. Irregular and lenticular patterns of reflectors in the

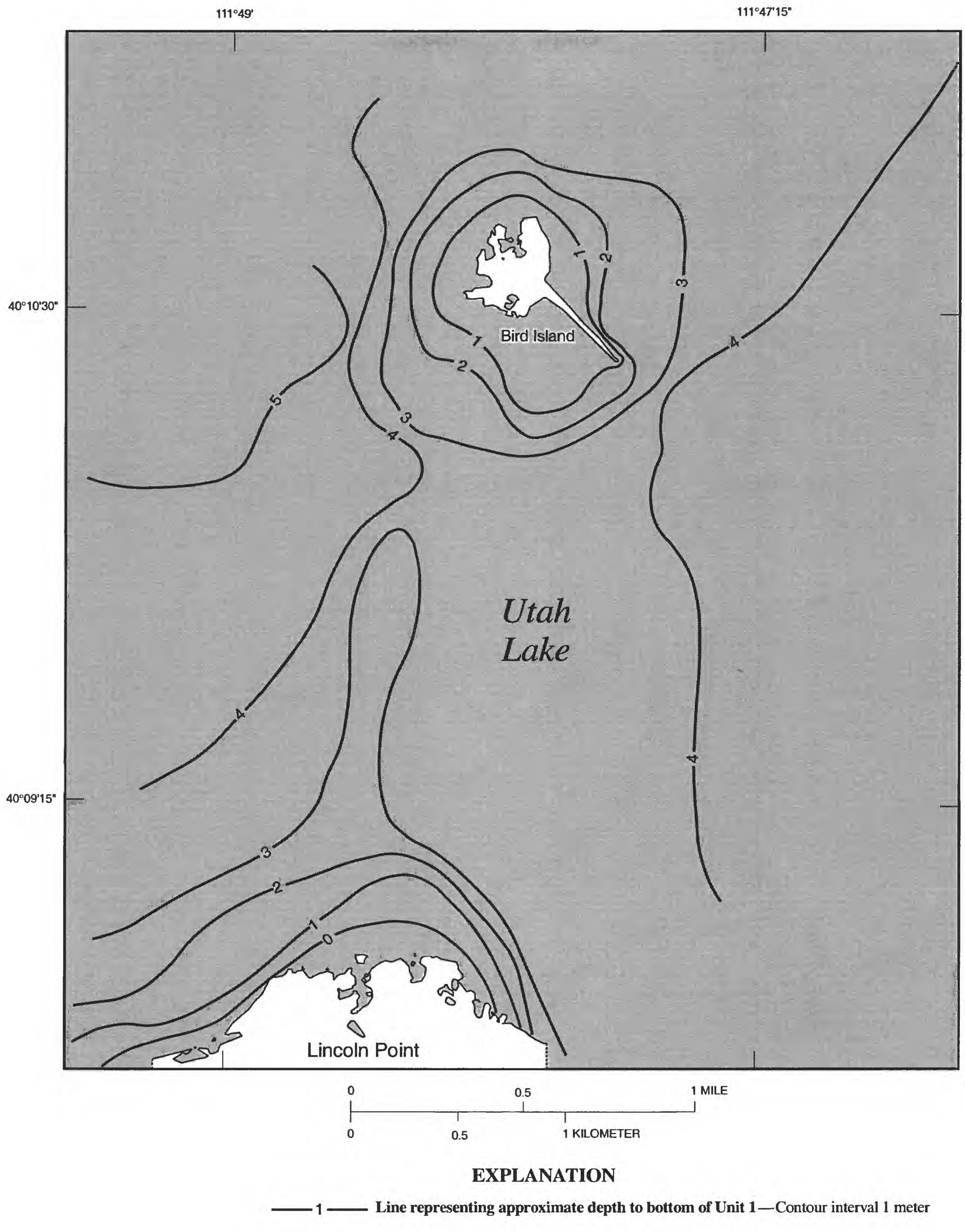


Figure 14. Approximate depth of base of Unit 1 below bottom of Utah Lake in the Lincoln Point - Bird Island area, Utah Lake, Utah.

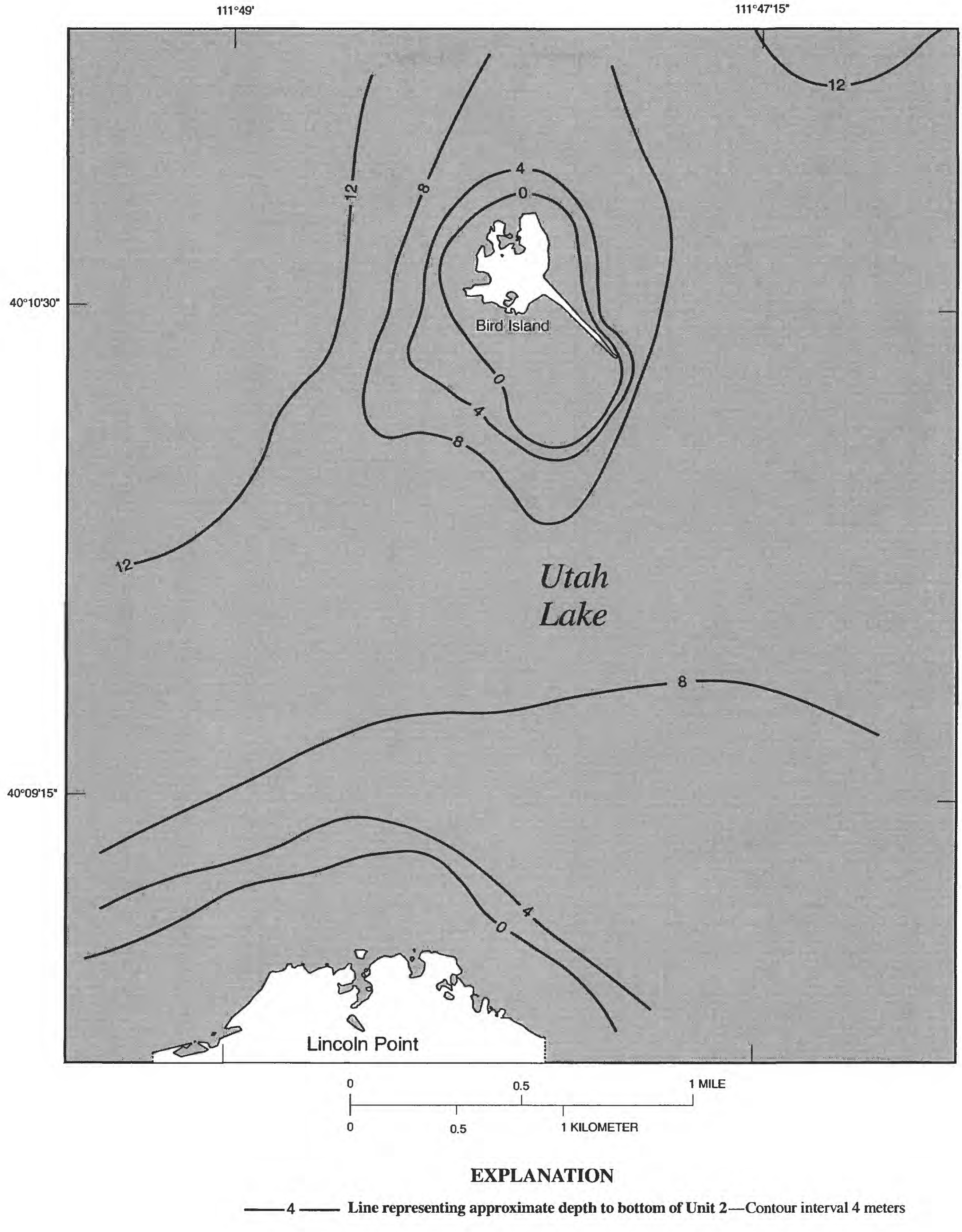


Figure 15. Approximate depth of base of Unit 2 below bottom of Utah Lake in the Lincoln Point - Bird Island area, Utah Lake, Utah.

lower part of the unit (profiles 2, 7, and 11) indicate the presence of alluvial deposits, although this cannot be confirmed with existing geologic data. The more evenly spaced reflectors above the alluvial deposits probably represent coarser, thickly bedded sand and conglomerate deposits and probably are some of the initial deposits in Lake Bonneville. Locally, Unit 3 was uplifted on the rising structural highs, as shown on profile 2, control points 10 to 13.

Maximum thickness of Unit 3 is about 8 meters (26.2 feet). The greatest thicknesses are where channel-fill deposits underlie the main part of Unit 3. Average thickness is about 4 meters (13 feet). Sub-lake-bottom depths to the base of Unit 3 are shown in figure 16.

Other Sedimentary Sequences

Although the reflectivity patterns on the seismic profiles indicate stratified sedimentary sequences below Unit 3, the downward loss of seismic resolution and the presence of sound multiples made mapping of deeper sequences throughout the area difficult and subject to miscorrelation. A fourth sedimentary unit was identified from the reflectivity patterns on profiles 4 and 6 (pl. 1).

The reflectors attributed to these sequences indicate alluvial and channel-fill deposits, although this cannot be confirmed with existing geologic data. Attempts at mapping sedimentary sequences below Unit 3 typically gave incomplete results and are not included in this report.

Anomalous Sedimentary Features

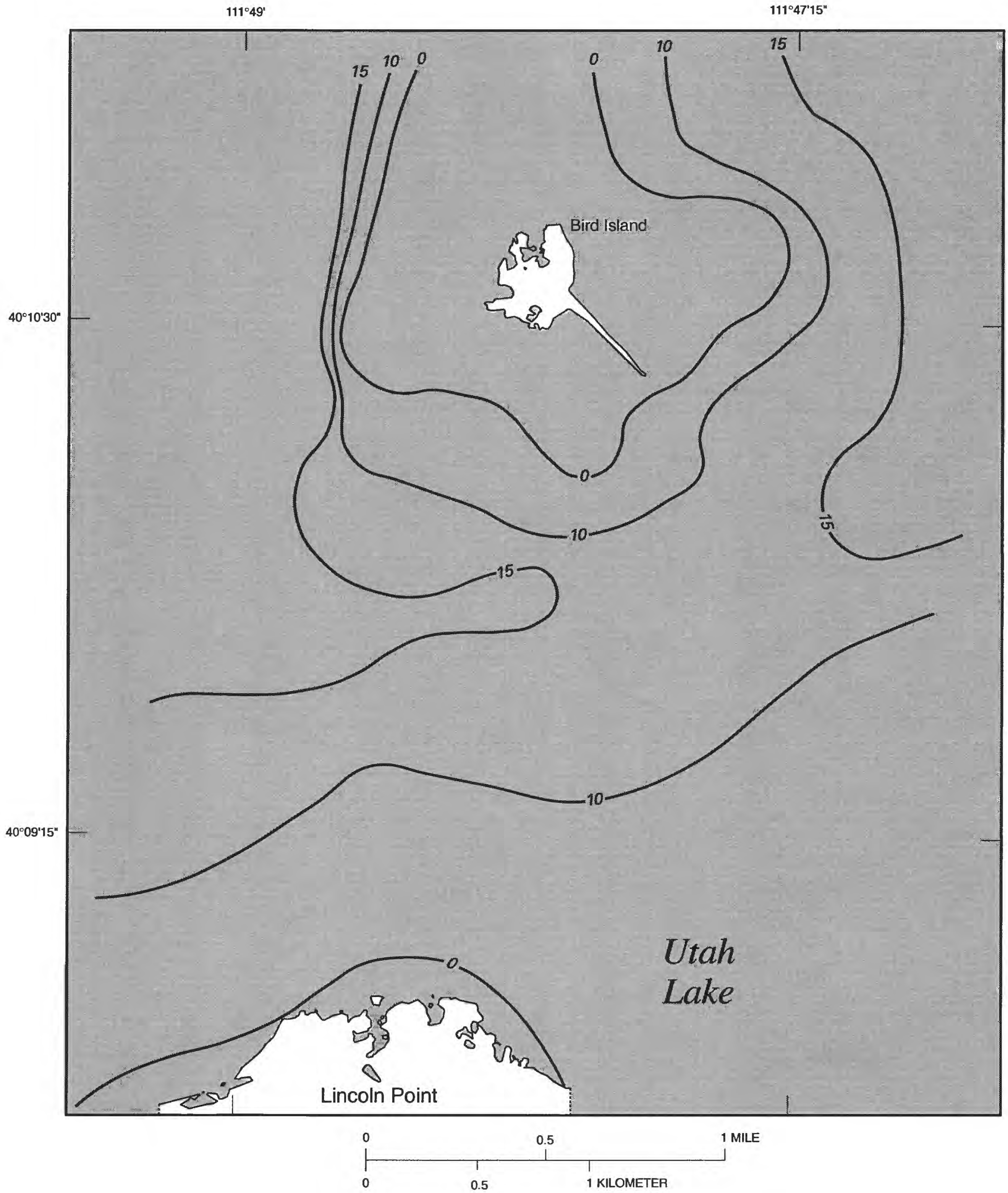
Seismic features anomalous to the generally stratified nature of the four sedimentary sequences already described were recorded at several locations. Most of the features indicated have a mound-shaped profile; in two localities, tabular/lenticular features are indicated. The concentric banding of the larger mound-shaped features (sound analogs) indicates acoustical ringing and a hard, highly reflective upper surface. Although these structures are described as mound shaped, the seismic profiles depict only a two-dimensional profile through the structures. The actual shape of the structure may not be circular. The thickness of these structures is difficult to determine because of probable increases in the velocity of the seismic signal and loss of signal beneath the structures.

The mound-shaped structures previously described are interpreted as representing travertine accumulations deposited by spring water. Warm, saline water from springs discharges from travertine orifices beneath the surface of Utah Lake at Bird Island and above the surface of Utah Lake in the Lincoln Point area (Baskin, Spangler, and Holmes, 1994). Springs also may discharge water beneath the surface of Utah Lake from travertine accumulations identified during this study. Examination of each anomalous structure beneath the surface of Utah Lake was beyond the scope of this project, and although many of the anomalous structures shown on the seismic profiles are assumed to be travertine, each would need to be tested by drilling to confirm the composition. Direct correlation of drill and core samples was not attempted during this study; however, the occurrence of "spring deposits" in drill holes and core samples (Bissell, 1963, U.S. Bureau of Reclamation, 1963) indicates that the mound-shaped structures are probably travertine deposits.

A pronounced mound-shaped structure can be seen on profile 2 at control point 6 (pl. 1). The base appears to be beneath the sediments of Unit 2, and the upper surface is exposed on the lake floor. The mound is east-southeast of Bird Island and is a submerged part of a linear travertine ridge trending southwest from the main area of Bird Island above lake level to beneath the lake level and recent sediments. The linear nature of the structure and the abrupt relief shown on the seismic profile indicate either that accumulation of travertine has continued at the same location since pre-Utah Lake time at a rate sufficient to keep the mound from being buried by lake sediment, or that the travertine mound was formed rapidly in the early stages of Utah Lake history and has not yet been covered by sediment. The linear nature of the structure also indicates precipitation of travertine along a fault or fracture, although this cannot be confirmed with available data.

Another larger structure with similar acoustical properties as the travertine ridge previously described can be identified on the seismic sections passing through profile 10 control point 65, profile 9 control point 60, profile 13 control point 82, and profile 2 control points 7 to 8. This structure appears to decrease in size away from Bird Island and is assumed to be connected with the main body of travertine at Bird Island (fig. 17). The structure is generally linear and has a length greater than 0.5 kilometer (0.3 mile), assuming it is connected to the main body of travertine at Bird Island.

Features similar to the structures already discussed but at sub-lake-bottom depths are common throughout the Bird Island area and are shown on pro-



EXPLANATION

—*10*— **Line representing approximate depth to bottom of Unit 3**—Contour intervals 5 and 10 meters

Figure 16. Approximate depth of base of Unit 3 below bottom of Utah Lake in the Lincoln Point - Bird Island area, Utah Lake, Utah.

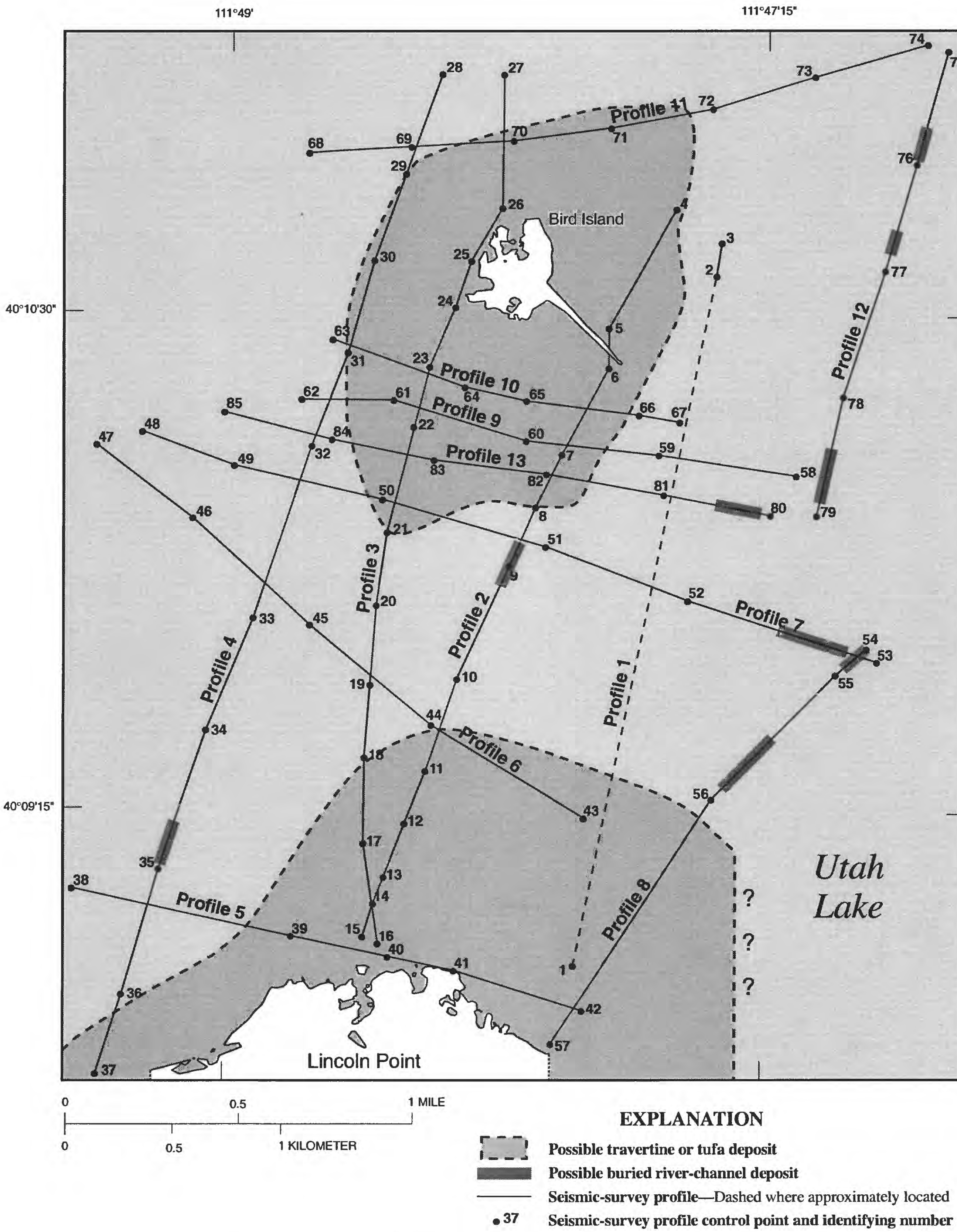


Figure 17. Locations of anomalous sedimentary structures in the Lincoln Point - Bird Island area, Utah Lake, Utah.

file 4 from control point 28 to just beyond control point 32, on profile 7 between control points 49 and 50, and on profile 11 between control points 70 and 71 (pl. 1 and 2). Many are small, such as those on profile 7 between control points 49 and 50 and on profile 4 between control points 29 and 32. The bases of most of the smaller features appear to coincide with the base of Unit 1 or one of the prominent reflecting surfaces in Unit 1.

Many of the mound-shaped structures in the Bird Island area appear to be part of a larger travertine structure that underlies the present surficial expression of Bird Island. This larger structure extends west and north of Bird Island beyond the limits of the current seismic coverage and extends to the east and south of Bird Island less than 1 kilometer (0.6 mile) (fig. 17).

Reflection characteristics of sediments in the Lincoln Point area are similar to those of travertine deposits in the Bird Island area. Travertine deposits occur along the shoreline at Lincoln Point and indicate that sediments offshore of Lincoln Point with reflection characteristics similar to those of the travertine deposits near Bird Island probably also are composed of travertine. These deposits are shown on profile 2 between control points 12 and 15, profile 4 between control points 35 and 37, profile 5 between control points 39 and 41, and profile 8 between control points 56 and 57 (pl. 1 and 2). Travertine accumulations along the shoreline at Lincoln Point and to the west and east of Lincoln Point indicate that more extensive accumulations of travertine may occur beneath the shallow sediments that surround the Lincoln Point area (fig. 17).

A large structure resembling a channel-fill deposit is shown on profile 8 between control points 55 and 56 (pl. 2). This structure occurs at the base of Unit 3 and is similar to other similar channel-fill-like structures in the Lincoln Point - Bird Island area (fig. 17) (profiles 2, 4, 7, 8, 12, and 13). The large channel-fill structure is located about 1.6 kilometers (1 mile) northeast of Lincoln Point.

The dome structure beneath and including Bird Island probably is the result of both uplift of consolidated rocks and overlying sediments and the subsequent deposition of travertine in the vicinity of the uplift. Faulting and fracturing of the consolidated rock and displacement of sediments in the vicinity of Bird Island and Lincoln Point provided conduits for warm, saline waters to migrate laterally and to the surface. The emerging ground waters presumably became supersaturated with respect to calcium carbonate and deposited travertine near the points of discharge to form the anomalous sedimentary structures identified on the seismic profiles. No previously unidentified springs were located during the seismic investigation; however, springs may exist in areas identified as fault/fracture zones or in areas of possible travertine deposition.

SUMMARY

During March 1991, the U.S. Geological Survey, in cooperation with the Central Utah Water Conservancy District, conducted a seismic investigation of the shallow subsurface sediments in the Lincoln Point - Bird Island area of Utah Lake, Utah, using a continuous, high-resolution profiler. This investigation was designed to identify the depositional, structural, and erosional features preserved in the sediments of the Lincoln Point - Bird Island area to locate areas where spring water may be entering Utah Lake and to estimate the path that ground water may take to the springs.

Continuous seismic-reflection data were gathered along 13 profiles in the Lincoln Point - Bird Island study area. The total distance covered by the 13 profiles was about 39.4 kilometers. Faulting is prominent in the study area, although most faults show only minor offset. The fault pattern is that of a fracture-type breaking resulting from lateral extension or warping caused by pressure from directly beneath the Bird Island area, not from lateral compression. A number of small grabens are evident in the profiles and provide evidence for a lateral extension type of movement.

The faults southwest of Bird Island appear to extend to shallow lake-bottom sediments, inferring that they have been active in recent geologic time. Faults possibly underlie mound-shaped structures in the Lincoln Point - Bird Island area, but acoustical wipeout and multiples beneath the structures precluded their identification. Many of the fault/fracture zones are in areas of suspected travertine deposition.

The principal geologic structure in the study area is a dome beneath and including the Bird Island area. The dome structure probably is the result of the uplift of consolidated rocks and overlying sediments, and the subsequent deposition of travertine in the vicinity of the uplift.

Three distinct sedimentary sequences were mapped during the study and were labeled, in downward order, Unit 1, Unit 2, and Unit 3. Although the reflectivity patterns on the seismic profiles indicate stratified sedimentary sequences below Unit 3, the downward loss of seismic resolution and the presence of sound multiples made mapping of deeper sequences

throughout the area difficult and subject to miscorrelation.

Unit 1 generally is stratigraphically flat and thins across the uplifted areas beneath Lincoln Point and Bird Island. Unit 1 shows no major change in acoustic impedance and consequently is seismically transparent, indicating little difference in the characteristics of the sediments. However, several prominent and widespread reflectors are apparent. Unit 1 is interpreted as representing the non-stratified lake-bottom sediments (Holocene) deposited in Utah Lake. The thickness of Unit 1 ranges from a few centimeters to about 6 meters and averages about 4 meters. Unit 1 pinches out toward Lincoln Point and toward Bird Island.

Unit 2 is distinguished from Unit 1 by two prominent features: (1) Unit 2 has stronger reflectors than Unit 1, and (2) Unit 2 was subjected to progressive uplift during deposition. Though generally less seismically transparent than Unit 1, the degree of transparency in Unit 2 varies. More pronounced layering in Unit 2 and the stronger reflection pattern indicate more heterogeneity in grain size with increasing depth and a greater degree of consolidation.

An important feature of Unit 2 is the unconformity at its top. This unconformity possibly indicates a complete withdrawal of the earlier Lake Bonneville from this area and subaerial erosion of Lake Bonneville sediments before formation of Utah Lake.

Unit 2 generally can be subdivided into two subunits. Subunit "A" has coarse, less defined layers, is more transparent, and pinches out in part against the older and deformed subunit "B." Subunit "A" also has been uplifted and erosionally truncated but less so than subunit "B." The lower subunit "B" shows finer, more-defined layering and has been uplifted onto the topographic highs and erosionally truncated. Maximum thickness of Unit 2 is about 11 meters. Thickness across the saddle area that separates Lincoln Point from the submerged structural high at Bird Island averages about 8 meters.

Within the study area, Unit 3 forms a lenticular basin with an irregular base that indicates deposition over an older, eroded surface. Dense, widely separated horizontal reflectors are common and lap out at the basin edges. Irregular and lenticular patterns of reflectors in the lower part of the unit indicate the presence of alluvial deposits, although this cannot be confirmed with existing geologic data. The more evenly spaced reflectors above the alluvial deposits probably represent coarser, thickly bedded sand and conglomerate deposits and probably are some of the initial deposits in Lake Bonneville. Maximum thickness of Unit 3 is about 8 meters. The greatest thicknesses are where channel-fill deposits underlie the main part of Unit 3. Average thickness is about 4 meters.

Features in the seismic record anomalous to the generally stratified nature of the sedimentary sequences were recorded at several locations. Most of the features indicated have a mound-shaped profile; in two localities tabular/lenticular features are indicated. The concentric banding of the larger mound-shaped features (sound analogs) indicates acoustical ringing and a hard, highly reflective upper surface. Direct correlation of drill and core samples was not attempted during this study; however, the occurrence of "spring deposits" in drill holes and core samples (Bissell, 1963, U.S. Bureau of Reclamation, 1963) indicates that the mound-shaped structures are probably travertine deposits. In addition to the mound-shaped structures, structures resembling channel-fill deposits were noted in a few locations.

Many of the anomalous structures in the Bird Island area appear to be part of a larger travertine structure that underlies the present surficial expression of Bird Island. This larger structure extends west and north of Bird Island beyond the limits of the current seismic coverage and extends to the east and south of Bird Island less than 1 kilometer.

Reflection characteristics of sediments in the Lincoln Point area are similar to those of travertine deposits in the Bird Island area. Travertine deposits occur along the shoreline at Lincoln Point and indicate that sediments offshore from Lincoln Point probably also are composed of travertine. Travertine accumulations along the shoreline at Lincoln Point and to the west and east of Lincoln Point indicate that more extensive accumulations of travertine may occur beneath the lake surface and shallow sediments that surround the Lincoln Point area.

Warm, saline water from springs discharges from travertine orifices beneath the surface of Utah Lake at Bird Island and above the surface of Utah Lake in the Lincoln Point area and at Bird Island. Springs also may discharge water beneath the surface of Utah Lake from possible travertine accumulations identified during this study. Drillers' logs report that penetration of the last 1 meter of material in drill hole PRG-22 was "probably through spring deposits of travertine" and that water "flowed freely over the top of the casing" when the plug was pulled at 15.2 meters.

The dome structure beneath and including Bird Island probably is the result of uplift of consolidated rocks and overlying sediments, and the subsequent deposition of travertine in the vicinity of the uplift. Faulting and fracturing of the consolidated rock and displacement of sediments in the vicinity of Bird Island and Lincoln Point provided conduits for warm, saline waters to migrate laterally and to the surface. The emerging ground waters presumably became supersaturated with respect to calcium carbonate and deposited travertine near the points of discharge to form the anomalous sedimentary structures identified on the seismic profiles. No previously unidentified springs were located during the seismic investigation; however, springs may exist in areas identified as fault/fracture zones or in areas of possible travertine deposition.

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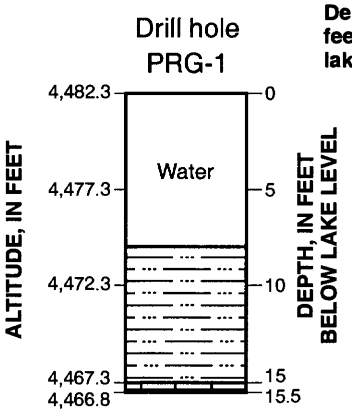
Appendix

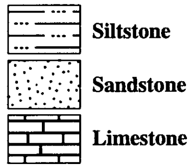
Material

Remarks from Drillers' log

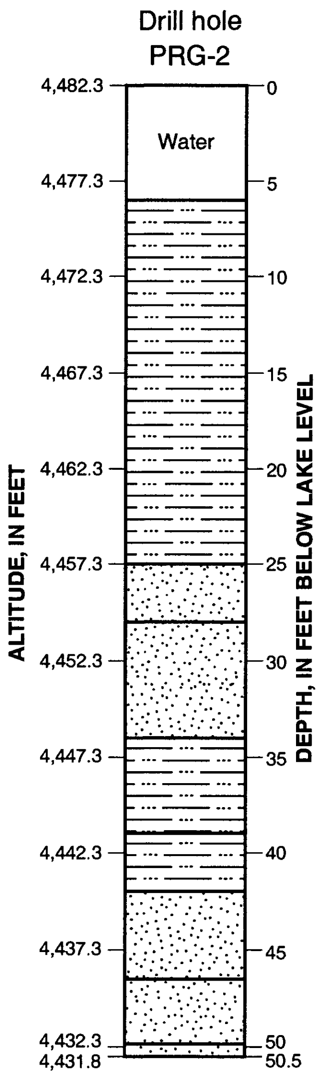


Depth, in feet below lake level	Description
0	Water surface (altitude 4,482.3 feet).
8	Silt. gray, no sand, low plasticity, very soft, clayey, ML-CL, very wet.
15	Silt. gray-white, low plasticity, 30 percent fine sand, hard, ML-CL.
15.5	Rock. travertine, moderately hard to fairly soft, white to gray. Spring deposit.

EXPLANATION

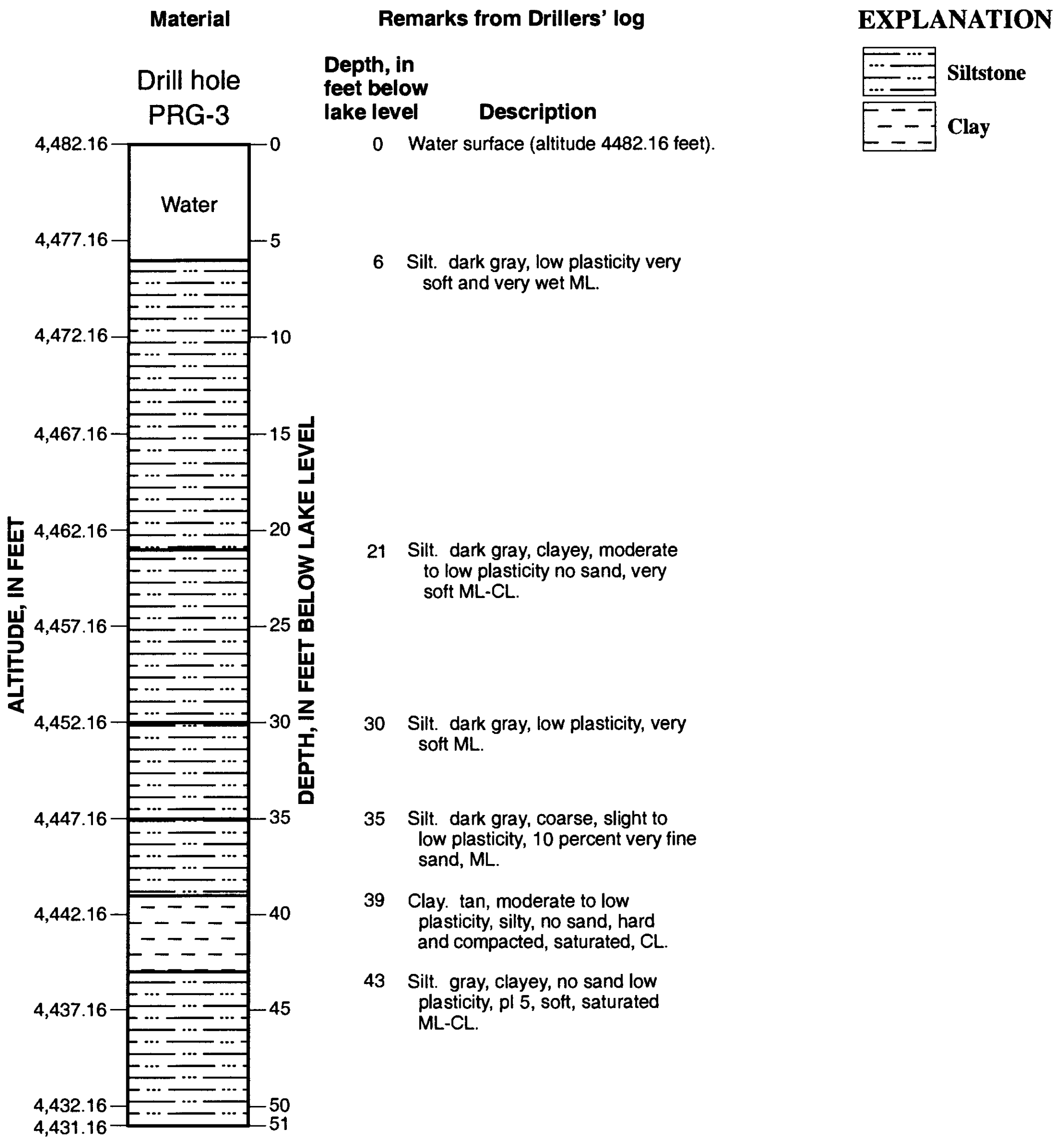


Remarks from Drillers' log



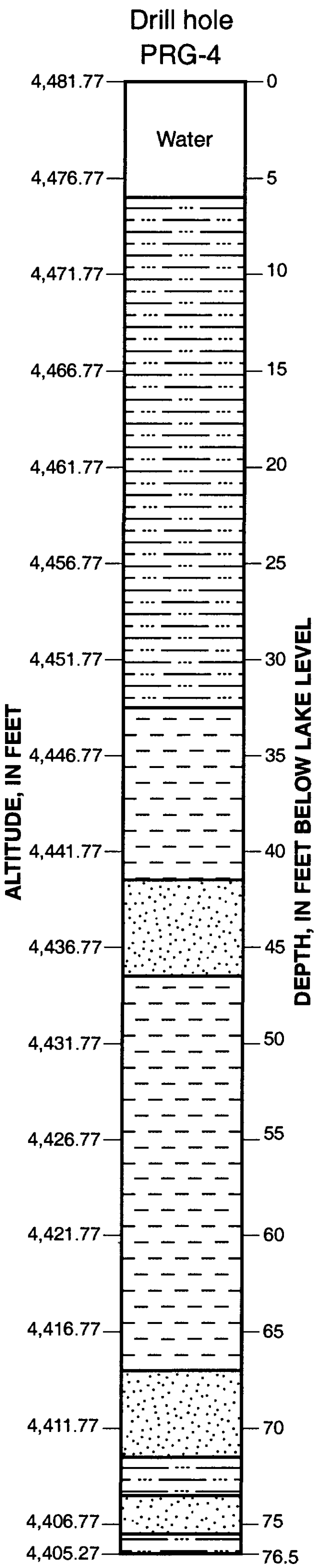
Depth, in feet below lake level	Description
0	Water surface (altitude 4,482.3 feet).
6	Silt. dark grey, moderate to low plasticity, no sand, very soft and watery, ML.
25	Sand. darkbrown, 40 percent silt 10 percent + No. 4 gravel, max size No. 3/8 inch 100 to 200 sieve size, firm SM-ML nonplastic.
28	Sand. dark brown, No. 50 & 100 sieve size, 20 percent silt, Hard SM nonplastic some No. 4 gravel.
34	Silt. light brown, low plasticity, little or no fine sand, some No. 8 sand. Nonplastic SM-ML.
39	Silt. clayey 25-30 percent very fine sand, light gray 30-40 percent gravel (spring deposits) HARD. ML-CL.
42	Sand. light brown, cemented sand layer, 40 percent silt, slight to low plasticity, lime cement (free water) exceptionally hard SM.
46.5	Sand. light gray, clean, nonplastic No. 10-50 sieve size mostly No. 30, Hard 10 percent No. 8 + max size No. 4 SM.
49	Sand. gray, lean, No. 10-30 some No. 50, 10 percent No. 8, sieve size, cemented, nonplastic, Hard, SM.

Appendix Drillers' logs for Bureau of Reclamation test holes in the Lincoln Point - Bird Island area, Utah Lake, Utah.



Appendix Drillers' logs for Bureau of Reclamation test holes in the Lincoln Point - Bird Island area, Utah Lake, Utah—Continued.

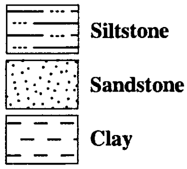
Material



Remarks from Drillers' log

Depth, in feet below lake level	Description
0	Water surface (altitude 4,481.77 feet).
6	Silt. gray, clayey, no sand, low plasticity, very soft to 30 feet ML-CL.
32.5	Clay. gray, very silty, low plasticity, soft & saturated, CL to CL-ML.
41.5	Clay. gray, very silty, low plasticity, soft & saturated, CL to CL-ML.
46.5	Clay. light gray-brown, moderate to high plasticity, hard, wet, not saturated, CL-CH. Material is very difficult to drill.
67	Sand. gray-brown, silty, 35 percent silt. Nonplastic very hard, SM.
71.5	Silt. gray 20 percent, No. 200 sand, slight plasticity, wet firm ML.
73.5	Sand. light brown 20 percent silt. No. 50 & 100 sieve size. Some No. 30. Nonplastic, hard, SM.
75.5	Silt. light brown, clayey, 20 percent sand No. 200 sieve size, hard ML-CL.

EXPLANATION



Appendix Drillers' logs for Bureau of Reclamation test holes in the Lincoln Point - Bird Island area, Utah Lake, Utah—Continued.

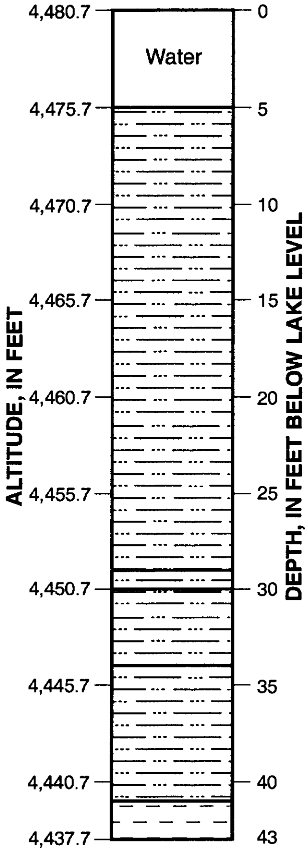
Material | **Remarks from Drillers' log**

EXPLANATION

Siltstone

Clay

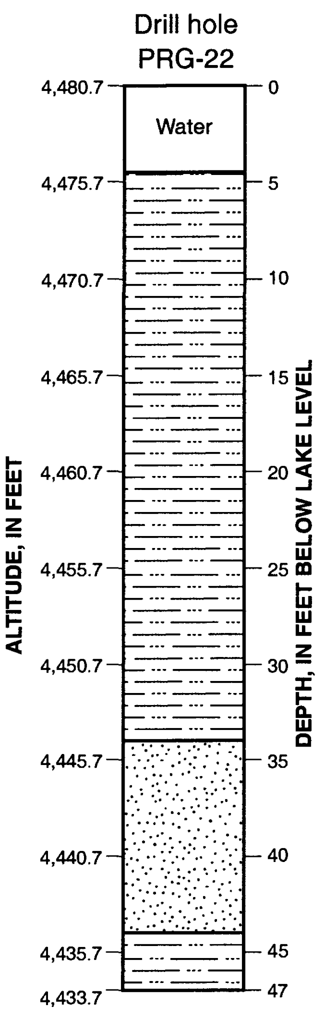
Drill hole PRG-21



Depth, in feet below lake level	Description
0	Water surface (altitude 4,480.7 feet).
5	Silt. dark gray, clayey, low plasticity, no sand, very soft, high water content. ML.
29	Silt. dark gray, about 25 percent very fine sand, silt coarse, nonplasticity, hard. ML.
34	Silt. light brown coarse, low plasticity, about 10 percent very fine sand, about 5 percent 1/4 to 3/8 sub-rounded.
41	Clay. dark gray-green, silty, low to moderate plasticity, no sand, soft, saturated. ML-CL.

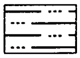
Appendix Drillers' logs for Bureau of Reclamation test holes in the Lincoln Point - Bird Island area, Utah Lake, Utah—Continued.

Material | **Remarks from Drillers' log**

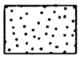


Depth, in feet below lake level	Description
0	Water surface (altitude 4,480.7 feet).
4.5	Silt. dark, clayey, low to moderate plasticity, no sand, very soft, very high water content. ML-CL.
34	Sand. light brown, maximum size No. 4 sieve. Mostly No. 30. Coarse and medium, clean. SP.
44	Silt. white to gray, clayey, very limey, 15-20 percent fine and medium sand, firm saturated. ML-CL. Probably spring deposits of travertine.

EXPLANATION

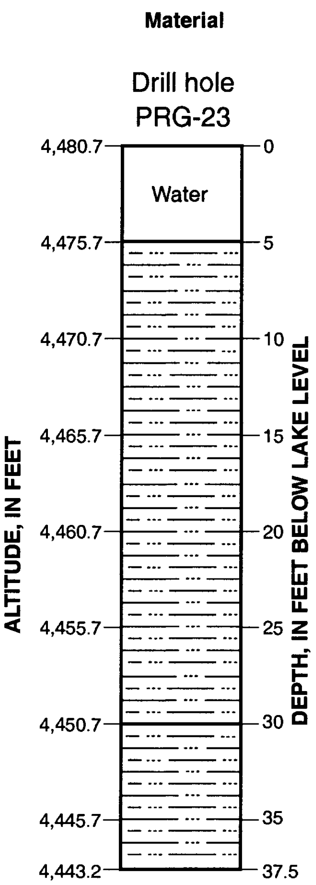


Siltstone



Sandstone

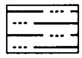
Appendix Drillers' logs for Bureau of Reclamation test holes in the Lincoln Point - Bird Island area, Utah Lake, Utah—Continued.



Remarks from Drillers' log

Depth, in feet below lake level	Description
0	Water surface (altitude 4,480.7 feet).
5	Silt. dark gray, clayey, low to moderate plasticity, no sand, very soft, high water content. CL-ML.
37.5	Hit rock at 40.5' lime, spring deposits, could not penetrate with sampler or auger.

EXPLANATION


Siltstone