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GEOTHERMAL ASSESSMENT OF THE LOWER BEAR RIVER DRAINAGE AND NORTHERN EAST SHORE GROUND-WATER AREAS, BOX ELDER COUNTY, UTAH

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ABSTRACT

The Utah Geological and Mineral Survey (UGMS) has been researching the low-temperature geothermal resource potential in Utah as per U.S. Department of Energy (DOE) Contract DE-AS07-77ET28393. This report, part of an area-wide geothermal research program along the Wasatch Front, concerns the study conducted in the lower Bear River drainage and northern East Shore ground-water areas in Box Elder County, Utah. The primary purpose of the study is to identify new areas of geothermal resource potential. There are seven known low-temperature geothermal areas in this part of Box Elder County.

Geothermal reconnaissance techniques used in the study include a temperature survey, chemical analysis of well and spring waters, and temperature-depth measurements in accessible wells. The geothermal reconnaissance techniques identified three areas which need further evaluation of their low-temperature geothermal resource potential. Area 1 is located in the area surrounding Little Mountain, area 2 is west and southwest of Plymouth, and area 3 is west and south of the Cutler Dam.

Area 1 is identified by geochemical techniques. Common ion concentrations indicate that the water is either Na-Ca Cl or Na Cl in character, thereby similar to analysis of known thermal areas sampled. Trace element analyses show that concentrations of Sr, Li, and B are comparable with thermal springs in the study area and are generally much higher than in the non-thermal samples. The ratio of Ca/HCO_3 for water in area 1 is similar to ratios for thermal samples. Chemical geothermometry indicates similarities between non-thermal samples and Little Mountain and Stinking thermal springs samples, all within area 1.

Areas 2 and 3 are identified by temperature-depth logging. No anomalous chemical concentrations are found in the samples analyzed from wells. Both of these areas have temperature-depth profiles with extremely high calculated gradients. In addition, bottom-hole temperatures are greater than 20°C.

INTRODUCTION

The Utah Geological and Mineral Survey (UGMS) has been doing research to increase the use of low-temperature geothermal resources in Utah as per U.S. Department of Energy (DOE) Contract DE-AS07-77ET28393. Prior to this study, UGMS was concentrating efforts on known geothermal areas along the Wasatch Front from Utah Valley north to the Idaho-Utah State line, to encourage development of known geothermal resources near major population centers.

In February, 1980, UGMS began to evaluate the area-wide geothermal resource potential along the Wasatch Front and adjacent areas because of: 1) the low-temperature geothermal potential, and 2) the proximity of three major metropolitan centers. This report covers the work done in Box Elder County. It should be noted that this study is limited in scope, and that the lack of evidence for additional resources does not preclude their existence. Additional exploration may establish that a deep resource is present.

The study area includes the lower Bear River drainage basin, and the very northern portion of the East Shore area which includes Willard and the area to the south (fig. 1). This area is at the eastern extent of Box Elder County, in north-central Utah, and lies within the Basin and Range physiographic province. The area encompasses approximately 730 mi^2, two-thirds being valley terrain and one-third mountainous. This north-trending basin is approximately 4 mi in width at the Utah/Idaho border, and expands to nearly 18 mi in width over a distance of nearly 40 mi to the south. The basin is bounded to the east by Clarkston Mountain, Junction Hills, the Wellsville Mountains, and the Wasatch Range and to the northwest by the West Hills and the Blue Spring Hills (Plate 1). Little Mountain is located four mi southeast of Blue Spring Hills. Elevations reach 9,372 feet on Box Elder Peak in the Wasatch Range, and valley elevations range from 4200 to 5200 feet.

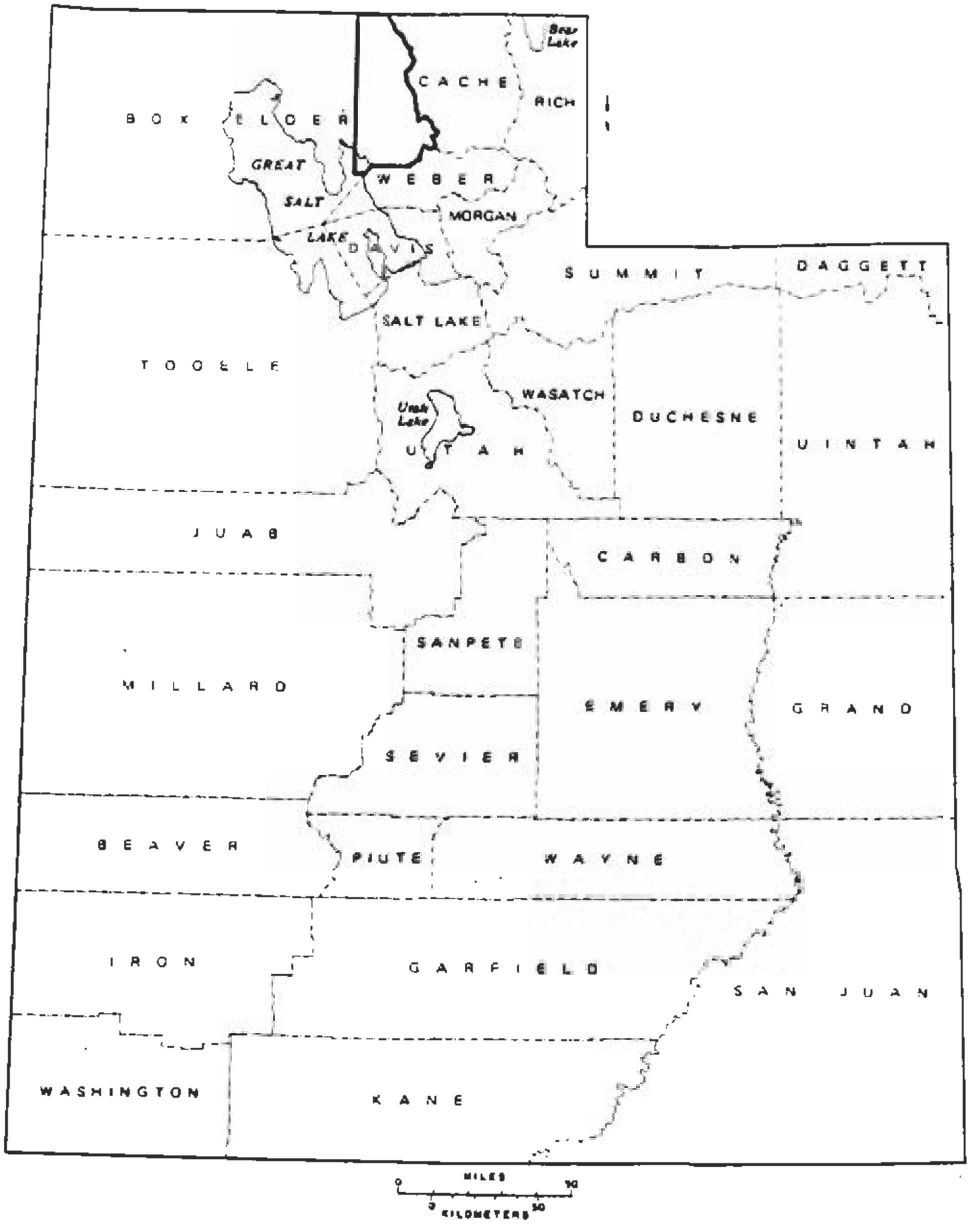

Figure 1. Index map of the lower Bear River drainage and the northern east shore ground-water areas, Box Elder County, Utah.

The Bear River flows into North and South Bay, Bear River Bay, and Willard Bay all of which are separated by extensive marshes and mudflats and are part of the Great Salt Lake. Brigham City is the largest metropolitan center and lies in the southeast portion of the basin. The principal community north of Brigham City is Tremonton.

GENERAL GEOLOGY AND STRUCTURE

Typical of the Basin and Range physiographic province, the lower Bear River drainage basin exhibits north-south elongated mountain ranges separated by a wide valley. The valley is filled with unconsolidated Quaternary sediments, as well as unconsolidated and consolidated Tertiary sediments (Plate 1). The Quaternary units are generally horizontally bedded. The Tertiary fanglomerate, conglomerate, and tuffaceous sandstone and limestone of the Salt Lake Formation in the vicinity of Junction Hills have a general easterly dip (Doelling, 1980). A maximum depth of valley fill (Cenozoic rocks) of about 8,000 ft is indicated by a gravity survey and modeling (Peterson, 1974).

The Precambrian and Paleozoic strata exposed in the mountain ranges bordering the study area were not greatly disturbed by tectonic activities until Mesozoic and Cenozoic times. Basins formed with the onset of Basin and Range faulting producing the mountain and basin pattern, whereas earlier orogenies produced the interior structures of the individual mountain ranges. Tensional deformation resulting in north-south trending normal faults is characteristic of the Basin and Range orogeny. Compressional deformation, characteristic of earlier events, resulted in intrusion, metamorphism, high-angle to low-angle thrust faults, and folds (Doelling, 1980).

The West Hills and the Blue Springs Hills in the northwestern corner of the study area are dominated by Pennsylvanian and Permian exposures, with the exception of Ordovician to Mississippian limestones, dolomites, quartzites, and minor sandstone in the northeast part of West Hills (Plate 1). The Pennsylvanian and Permian strata are deformed into tight parallel folds trending north-south or northwest-southeast. Two important faults associated with the West Hills are: 1) a principal Basin and Range fault on the east side of West Hills, and 2) an interior fault extending northwesterly across the range, with Ordovician to Mississippian rocks to the northeast (Plate 1). The interior high angle fault has a displacement of 3,500 feet, with the downdropped block to the southwest (Doelling, 1980). A thrust fault is thought to break through within Blue Springs Hills. Little Mountain, a large outlier knoll southeast of Blue Springs Hills, consists of Devonian to Permian rocks, including limestone, dolomite, sandstone, siltstone, and quartzite. The principal faults at Little Mountain are oriented north-south (Doelling, 1980).

The northern Wasatch Range is bound on the west by a principal north-south Basin and Range fault which is a part of the Wasatch fault system. Irregularly spaced transverse faults cut the eastward or northeastward dipping strata, particularly across the Wellsville Mountains (Plate 1). Clarkston Mountain, seven miles long and three miles wide, is composed of Upper Cambrian, Ordovician, and Silurian dolomite, limestone, and lesser amounts of quartzite cut by north-northwest trending normal and reverse faults.

A complete section of east-dipping Precambrian to Permian strata, including limestone, dolomite, quartzite, siltstone, and sandstone, is exposed in the north-northwest trending Wellsville Mountains (Plate 1). This trend extends southward into the Wasatch Range exposing older rocks, including schist, slate, phyllite, and gneiss. The Willard thrust fault is present to the south with a strike and dip nearly parallel to bedding. In addition, numerous westward-dipping parallel faults, along with high angle transverse faults, are present (Doelling, 1980).

HYDROLOGIC SETTING

Lower Bear River Drainage Basin

The lower Bear River drainage basin is north of and adjacent to Bear River Bay, which is an arm of the Great Salt Lake. The Malad River flows into the Bear River approximately 7 mi northwest of Brigham City. Approximately 1,180,000 acre-feet of surface water entered the basin annually in the 1960 to 1971 water years (Bjorklund and McGreevy, 1974). The largest volume entered via the Bear River, as well as in canals diverted from the Bear River. Springs within the basin generate several streams and this ground-water discharge adds considerably to the flow of both the Bear and Malad Rivers. On the average, 972,000 acre-feet of surface water leaves the drainage basin annually, flowing toward the Great Salt Lake (Bjorklund and McGreevy, 1974).

Quaternary marginal deposits of the Lake Bonneville basin, primarily sand and gravel, as well as fractured limestone and sandstone of the Pennsylvanian and Permian Oquirrh Formation, are the most productive water-bearing units in the lower Bear River drainage basin. The interior (deeper-lain) deposits of the Lake Bonneville basin supply only a small amount of water to wells, but are important as they are the only water-bearing units in a large part of the study area (Bjorklund and McGreevy, 1974).

Ground water is present under the following conditions: 1) both confined and unconfined in a principal system, 2) in a shallow unconfined system in the central-plain area, and 3) in perched systems. Most ground water is included in the principal ground-water system. Small and discontinous perched ground-water systems are primarily found in the marginal deposits of the Lake Bonneville basin, in colluvium, alluvium, and undifferentiated deposits in the mountains, as well as in the Oquirrh Formation (Bjorklund and McGreevy, 1974).

Of the 820,000 acre-feet of water which enters the basin annually as recharge, 505,000 acre-feet is lost to evapotransporation and runoff. The remaining 315,000 acre-feet, which enters the principal ground-water reservoir, originates from three sources: 1) precipitation within the basin primarily in and near the mountains; 2) surface water entering the basin and diverted for irrigation, and 3) subsurface inflow (Bjorklund and McGreevy, 1974).

General ground-water movement is from the mountains toward the valley, and then south and southeast toward the lower part of the basin. The annual discharge of approximately 315,000 acre-feet of ground water is comprised of the following: 1) about 210,000 acre-feet discharges from the ground-water aquifer system to springs and drains; 2) approximately 100,000 acre-feet of ground water is discharged annually by evapotranspiration from mudflats and phreatophyte areas; 3) approximately 1,000 acre-feet of ground water is thought to migrate from the area as subsurface outflow in the vicinity of the Bear River Migratory Bird Refuge; and 4) the remaining 4,000 acre-feet are discharged from wells. Overall, ground-water levels have fluctuated little since the mid-1930's (Bjorklund and McGreevy, 1974).

An attempt was made to establish the depth to the top of the major aquifer in the Bear River drainage basin by examining well drillers' logs. Criteria used to determine depth to the aquifer were perforations and/or the stated depth to water bearing strata. No pattern was evident, however, which is thought to be partially due to the unreliability of the logs.

Within the shoreline sediments of Lake Bonneville that blanket the Malad River Valley in the Portage area, and flank the West Hills, Blue Spring Hills, Clarkston Mountain, and Wellsville Mountains, aquifer thicknesses and depths are relatively undefined on the basis of well perforation and water levels. The lithology, however, indicates thick sequences of coarse-grained sediments.

Interior Lake Bonneville sediments prevail at lower elevations; i.e. the Bear River Valley, the bird refuge (along South Bay), and the waterfowl management area (north of Little Mountain) (Plate 2). In these areas the sediments are fine-grained and relatively impermeable. Aquifers consist of these fine-grained sands and gravels. Wells are generally perforated throughout the coarse-grained lake facies (sand and gravel), enabling the thicknesses and depths of these units to be readily determined from inspection of well logs. These coarse-grained units, however, do not appear to be significantly better aquifers than the fine-grained units.

It appears that no individual unit forms a principal aquifer throughout the lower Bear River drainage basin, although a principal ground-water system is used to describe the distribution and occurrence of ground water in the area. Utilization of a large number of permeable beds throughout the area indicates that transmissivity within individual aquifers is not laterally uniform. This restricted lateral permeability, along with local high vertical permeability, could account for the small lateral distribution of geothermally heated waters in the area.

East Shore Ground-Water Area

The southeastern corner of the study area, the area south of Willard and southeast of Willard Bay, is part of the East Shore ground-water area. The East Shore area extends from Willard south to the Davis County/Salt Lake

County line and from the Wasatch Range to the east shore of the Great Salt Lake. The area includes approximately 450 mi^2, ranging in width from three to 20 mi and extending about 40 mi in length (Bolke and Waddell, 1972). Only the part of the East Shore area in Box Elder County is included in this report.

The ground-water reservoir in the East Shore area is composed of unconsolidated and semiconsolidated sediments, ranging in grain size from clay to boulders. The deposits include coarse-grained delta, alluvial-fan, and slope-wash in the east, grading westward into fine-grained, well-sorted lacustrine units. The principal aquifers consist of gravel or gravel and sand in the east, and of sand in the west. The major sources of recharge include subsurface flow from the Wasatch Range, direct infiltration from precipitation, and seepage from mountain front streams and irrigated areas. Almost half of the natural recharge to the East Shore reservoir is subsurface flow from the Wasatch Range (Bolke and Waddell, 1972).

Ground water in the East Shore area occurs under artesian conditions in a multiaquifer reservoir. Water-table and perched conditions are found locally in the stream deltas and along the Wasatch Front. The majority of wells in the area are artesian. Ground-water movement is westward from areas of recharge toward the Great Salt Lake. Most water is intercepted and discharged by wells although some water moves upward through confining beds and is eventually discharged by springs, seeps, or evapotranspiration in the lowlands near Great Salt Lake. In addition, some water moves through the aquifers westward under the lake (Bolke and Waddell, 1972, Glenn and others, 1980).

KNOWN THERMAL AREAS

The locations of known hot or warm springs in the lower Bear River drainage basin are shown on Plate 2 and discussed below. The lowland west of the Wasatch Range is a series of northward trending grabens separated by horsts or bedrock highs. The known thermal water in the study area is found at the margins of grabens where bedrock is relatively near or at the surface. The thermal waters along the Wasatch Front are warmed by deep circulation of meteoric water in a region of high heat flow. In the Basin and Range Province, temperatures increase with depth at an approximate rate of 35^{o}C/km (Chapman, personal communication, 1982). Heat from volcanic sources is not thought to contribute to the warming of these waters.

Recharge to the thermal systems in the Wasatch Range is probably the result of precipitation in the form of rain and smowmelt. This water travels downward through permeable rocks and fault zones and intersects zones of high vertical permeability, such as range front faults, which serve as conduits for the rapid, upward convection of the warmed water to the surface. This rapid ascension allows the water to maintain much of the heat transferred from the rock. Primary factors affecting fluid temperature are depth of descent, rate of ascent, and degree of mixing with non-thermal water (Murphy and Gwynn, 1979).

The information presented in the following sections regarding the individual thermal areas is primarily from Mundorff (1970). Additional sources are referenced.

Utah (Bear River) Hot Springs

Utah Hot Springs, approximately 8 mi northwest of Ogden, issues from valley fill near complexly faulted Cambrian quartzite, shale, dolomite, and limestone. From 1843 to 1967 the temperature was a constant 57.5^{o} to 58.5^{o}C with a fairly steady discharge of 500 gpm. Murphy and Gwynn (1979) recorded a temperature of 63^{o}C. The water, once used to heat a now abandoned resort, is heating a greenhouse. Dissolved solids range from 18,900 to 25,200 ppm. The water is sodium chloride type (almost 90 percent of the total dissolved solids are Na and Cl), and probably moves through saline sediments. Manganese, and to a lesser extent, germanium concentrations are high. The fluid has measurable quantities of radium (66 ug/l) and uranium (0.04 ug/l) (Felmlee and Cadigan, 1978).

Stinking Hot Springs

Stinking Hot Springs, about 6 mi southwest of Bear River City, issues from a fault in Mississippian limestone at the base of the south end of Little Mountain. The name refers to the presence of hydrogen sulfide gas. Measured water temperatures between 1951 and 1967 varied from 39.5° to $51^{\circ}C$. Estimated discharge varies from 5 to 45 gpm. Dissolved solids content of the sodium chloride type water ranged from 29,000 to 30,400 ppm from 1911 to 1967. Lithium, bromide, and particularly, iodide concentrations are high. The large dissolved solids content of the water results from the highly saline characteristics of both the surface and the subsurface material through which the water moves.

Crystal (Madsens) Hot Springs

Crystal Hot Springs, located nearly 10 mi north of Brigham City, flow out of Paleozoic rocks along the Wasatch fault zone. Temperatures reported between 1843 and 1966 ranged from 49.5° to $57^{\circ}C$. Spring discharge estimates over many years vary from 500 to 1,800 gpm. Crystal Hot Springs water contains 43,500 mg/l of dissolved solids, more than any other Utah hot spring (Bjorklund and McGreevy, 1974). Sodium and chloride account for approximately 95 percent of the dissolved solids by weight. Elevated levels of radium (220 uug/l) and uranium (1.5 ug/l) are also present (Felmlee and Cadigan, 1978).

The source of this spring is probably deeply circulating water originating from the mountains east of the Wasatch fault zone. The upward movement through several thousand feet of unconsolidated valley fill near the fault zone, and the mixing with the highly concentrated interstitial brines in the unconsolidated sediments, causes the high dissolved solids content of the water. The primary structure which allows for the transport of the thermal water is a major northwest striking fault. The main thermal spring orifice is at the intersection of this fault with a northeast striking fault system (Murphy and Gwynn, 1979).

Udy (Belmont) Hot Springs

Udy Hot Springs, presently known as the Belmont Resort, is one mi southwest of Plymouth, and consists of a group of springs which flow out of Paleozoic limestones at a small escarpment between the flood plain and the higher terraces of the Malad River Valley. The springs may be near a fault concealed beneath Quaternary valley fill. Water temperatures range from 34° to $43.5^{\circ}C$, and discharge ranges from 900 to 3,600 gpm. Dissolved solids content of the sodium chloride type water is moderately high (7,850 ppm), with 90 weight percent being sodium chloride.

Little Mountain Warm Spring

Little Mountain Warm Spring, at the south end of Little Mountain, has a water temperature of $32^{\circ}C$. Predominant ions present in the water are bicarbonate, sodium, and chloride (Murphy and Gwynn, 1979). Little Mountain Warm Spring and Stinking Hot Springs may be related to the same fault system, as well as to the same source of dissolved solids.

Bothwell (Salt Creek) Warm Springs

Bothwell Warm Springs, 20 mi northwest of Brigham City, issues from a small outcrop of fissured Paleozoic limestone. Water temperatures vary from 21° to 23°C; average dissolved solids content is 2,000 ppm. The heavy discharge ranges from 2,244 to over 13,465 gpm, with annual fluctuations indicating a meteoric origin of the water. No evidence of this spring was found in sec. 2, T. 11 N., R. 4 W. as was reported by Mundorff (1970). Mundorff (1970) also refers to Bothwell as Salt Creek Warm Springs. A Salt Spring was located and sampled, however, in sec. 6, T. 11 N., R. 3 W. (approximately 2 mi directly east of the location stated for Bothwell).

Cutler Warm Springs

Cutler Warm Springs, 10 mi northeast of Tremonton, issues from Paleozoic limestones along the bed and banks of the Bear River, about 1 mi east of the Wasatch fault. Water temperatures range from 21° to 27°C. Dissolved solids contents of 5,000 ppm and 2,000 ppm have been reported for the sodium chloride-type water. The spring's probable origin is meteoric water. Attempts to locate the spring were unsuccessful. The construction of Cutler Dam may have covered the orifices or altered the plumbing so that the springs no longer exist.

CHESAPEAKE DUCK CLUB WELLS

In 1925 a 502-foot deep water well was drilled for the Cheapeake Duck Club in the NE 1/4, NW 1/4, SW 1/4 sec. 27, T. 9 N., R. 3 W. (Goode, 1978). The well, with a recorded temperature of 74°C, produced gas and was plugged. Goode (1978) reports that a second well was drilled to a depth of 500 feet in the same area, but also produced gas and was plugged. No recorded temperature is found in the literature for this well. The two wells are located in an area where concealed, possibly intersecting, faults have been located by Bjorklund and McGreevy (1974). The fault(s) may be conduit(s) for the deeply circulating water which was intercepted by these wells.

HIGH TEMPERATURE GEOTHERMAL EXPLORATION

On February 22, 1974, a geothermal test well was spudded in the SW 1/4, SW 1/4, NW 1/4 sec. 16, T. 10 N., R. 2 W., in Box Elder County, Utah for Utah Power and Light. The well was completed on August 22, 1974 at a depth of 11,005 ft with a bottom-hole temperature of only 105°C (Goode, 1978).

TEMPERATURE SURVEY

Temperatures measured at 52 well and spring locations in the study area, using a Yellow Springs Instrument (YSI) Model 33 Temperature-Conductivity Meter, are listed in table 2. The well and spring locations are shown on Plate 2.

Well and spring temperatures range from 11°C to 51°C. Nathenson and others (1982) define low-temperature geothermal resources as less than 90°C, but no lower than 10°C above the mean annual air temperature. The mean annual air temperature in the study area is considered to be 10°C, therefore, temperatures of 20°C and greater are thought to have low-temperature geothermal potential and are referred to as thermal water. Based on this criteria, seven wells and springs have temperatures in the thermal range.

The warmest ground-water temperatures are measured at or nearby thermal springs: 51°C and 42°C at Udy Hot Springs; 46°C at Crystal Hot Springs; 44°C at Stinking Hot Springs; and 41°C at Little Mountain Warm Springs.

Two marginally warm ground-water temperatures were recorded: 1) 21_0C, one mile south of Thatcher, and 2) 22^{O}C approximately 1.8 mi west of Brigham City.

The warm temperature measured at Crystal Hot Springs (46^{O}C) is associated with a principal north-south Basin and Range fault which is a part of the Wasatch fault system. The warm temperature found at Little Mountain Warm Springs (41^{O}C) is associated with a north-south trending fault in the valley fill west of Little Mountain.

WATER CHEMISTRY AND ANALYSES

Fifty-two water samples were collected (Plate 2) and analyzed as part of this study. The chemistry for Utah Hot Springs is obtained from Glenn and others (1980). The on-site analyses consisted of: (1) pH, (2) alkalinity, and (3) conductivity. A Corning-Orion Model 407A/F specific ion meter with an Orion gel-filled Model 91-05 combination pH electrode was used to measure pH. Three readings were taken and averaged. A YSI Model 33 Temperature-Conductivity Meter was used to measure conductivity. Alkalinity was measured using a Hach Alkalinity Model AL-AP test kit.

Three (two 570 ml and one 65 ml) polyethylene bottles were filled at each sampling location by filtering the water through a GeoFilter Peristaltic Pump - Model #004 using a 0.45 micron filter paper. The water was analyzed at the University of Utah Research Institute/Earth Science Laboratory (UURI-ESL). The 65 ml bottle was acidified with reagent grade HNO_3 to a final concentration of 20 percent HNO_3, for analysis of cations by an APL Inductivity Coupled Plasma Quantometer (ICPQ). Results are listed in table 1. One 570 ml

Table 1: Limits of quantitative detection (LQD) for solution analysis by the University of Utah Research Institute/Earth Science Lab Inductively Coupled Plasma Quantometer.

Element	Concentration (mg/l)
Na	1.25
K	2.50
Ca	0.250
Mg	0.500
Fe	0.025
Al	0.625
SiO_2	0.250
Ti	0.125
P	0.625
Sr	0.013
Ba	0.625
V	1.25
Cr	0.050
Mn	0.250
Co	0.025
Ni	0.125
Cu	0.063
Mo	1.25
Pb	0.250
Zn	0.125
Cd	0.063
As	0.625
Sb	0.750
Bi	2.50
Sn	0.125
W	0.125
Li	0.050
Be	0.005
B	0.125
Zr	0.125
La	0.125
Ce	0.250
Th	2.50

LQD concentrations represent the lowest reliable analytic values for each element. Precision at the LQD is approximately ± 100% of the given value at a confidence level of 95%.

bottle was acidified with concentrated HCl, to a final concentration of one percent HCl, analysis of SO_4. The remaining bottle was not acidified and the water was analyzed for Cl, F, and total dissolved solids (TDS). Results of the analyses are in table 2.

Common Ion Analysis

Common ion analyses are plotted on the trilinear diagram in figure 2. Samples BE-10, BE-22, BE-23, BE-40, BE-41, BE-48, BE-50, and BE-52 are omitted because of their unacceptable high percent of error (greater than 15%) after common ion balancing. The data plotted in figure 2 indicate that there are four major types of water in the study area, which are designated as types I, II, III, and IV. Type I water is calcium-sodium bicarbonate-chloride-sulfate (Ca-Na HCO_3-Cl-SO_4) in character and dilute with TDS concentrations ranging from 164 to 542 mg/l. The samples, with the exception of BE-17 (pH 6.91), are slightly basic. All samples are enriched in Ca with respect to other cations, and in HCO_3 with respect to other anions. The water is typical of the recharge from the Wasatch Range and the West Hills (Bjorkland and McGreevy, 1974). Sample BE-1 is also from a recharge area but exhibits somewhat different ion concentrations, therefore, is not included in Type I water. BE-1 is calcium-sodium chloride-sulfate-bicarbonate (Ca-Na Cl-SO_4-HCO_3) in character, slightly basic, and dilute with a TDS concentration of 516 mg/l. BE-1 is enriched in Ca with respect to other cations, as is typical of Type I water; however, Cl is the predominant anion.

Type II water is characteristic of water in lower parts of the basin which is farther removed from the recharge areas. The water varies in character being calcium-sodium bicarbonate-chloride-sulfate (Ca-Na HCO_3-Cl-SO_4), calcium-sodium chloride-sulfate-bicarbonate (Ca-Na Cl-SO_4-HCO_3), sodium-calcium chloride-sulfate-bicarbonate (Na-Ca Cl-SO_4-HCO_3), and

Table 2. Water analysis from wells and springs in the lower Bear River drainage and northern east shore ground-water areas in Box Elder County, Utah.

(u - elements not present or below detection limits.)

Sample #		BE-1	BE-2	BE-3	BE-4	BE-5	BE-6
Location		(B-15-3)33acc 41°59'44" 112°11'51"	(B-14-3)4abc 41°59'08" 112°11'49"	(B-14-3)4dac 41°58'38" 112°11'31"	(B-14-3)11bba 41°57'25" 112°13'21"	(B-14-3)17dcb 41°56'44" 112°12'53"	(B-14-3)20adb 41°56'22" 112°12'35"
Temp.	°C	17	15	15	11	15	15
pH		7.14	7.26	7.32	7.41	7.34	7.45
TDS	mg/l	516	326	284	794	874	444
HCO_3	mg/l	209	250	292	442	376	376
Na	mg/l	27	39	26	287	299	149
K	mg/l	u	3	3	9	13	5
Ca	mg/l	63	45	41	38	58	32
Mg	mg/l	30	25	31	18	25	14
Fe	mg/l	0.04	u	0.20	u	u	0.23
SiO_2	mg/l	11	19	20	28	22	27
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.17	0.18	0.20	0.47	0.79	0.31
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	0.3	u
Zn	mg/l	0.4	0.2	u	u	u	u
Li	mg/l	u	u	u	0.08	0.10	0.06
B	mg/l	u	u	u	u	u	u
F	mg/l	0.2	0.2	0.2	0.6	0.5	0.6
Cl	mg/l	146	37	33	269	359	103
SO_4	mg/l	14	14	11	21	8	u

Table 2. (continued.)

Sample #		BE-7	BE-8	BE-9	BE-10	BE-11	BE-12
Location		(B-13-2)17bbc 41°52'10" 112°06'24"	(B-13-3)15dda 41°51'39" 112°09'57"	(B-13-3)23baa 41°51'21" 112°09'24"	(B-13-3)23abc 41°51'14" 112°09'07"	(B-13-2)30bbb 41°50'36" 112°07'35"	(B-13-3)25daa 41°50'09" 112°07'35"
Temp.	°C	12	16	42	51	15	11
pH		7.12	7.29	6.82	6.97	7.16	7.22
TDS	mg/l	708	352	6602	9040	704	892
HCO_3	mg/l	442	275	401	401	434	668
Na	mg/l	92	40	2590	3688	86	133
K	mg/l	10	10	109	131	30	37
Ca	mg/l	63	49	196	274	66	70
Mg	mg/l	64	22	51	59	61	84
Fe	mg/l	u	0.19	0.09	0.22	u	u
SiO_2	mg/l	53	70	57	26	51	51
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.77	0.31	5.09	6.62	0.64	0.82
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	u	u	0.5	3.0	u	0.5
Li	mg/l	0.07	u	0.80	1.17	0.06	0.08
B	mg/l	u	u	0.7	0.9	u	0.2
F	mg/l	1.8	0.6	1.1	1.2	0.8	1.1
Cl	mg/l	53	46	3640	5070	107	110
SO_4	mg/l	147	19	74	89	83	96

Table 2. (continued.)

Sample #		BE-13	BE-14	BE-15	BE-16	BE-17	BE-18
Location		(B-12-2)3dab 41°48'29" 112°03'03"	(B-12-3)3daa 41°48'23" 112°09'51"	(B-12-3)11bbc 41°47'45" 112°09'46"	(B-12-2)9cdc 41°47'12" 112°04'44"	(B-12-2)17cad 41°46'32" 112°05'48"	(B-12-2)19aab 41°46'15" 112°06'33"
Temp.	°C	14	18	17	13	14	11
pH		7.25	7.01	7.11	7.08	6.91	7.20
TDS	mg/l	436	392	330	530	292	1424
HCO_3	mg/l	167	284	242	351	234	309
Na	mg/l	110	39	33	38	24	379
K	mg/l	13	9	4	8	4	12
Ca	mg/l	50	63	69	105	51	98
Mg	mg/l	32	21	12	15	14	45
Fe	mg/l	0.13	0.05	u	u	u	0.88
SiO_2	mg/l	41	71	29	58	33	56
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.26	0.29	0.26	0.37	0.34	1.31
Ba	mg/l	u	u	u	u	u	0.7
Mn	mg/l	u	u	u	u	u	0.6
Zn	mg/l	1.2	0.6	0.2	u	u	u
Li	mg/l	0.10	u	u	u	u	0.12
B	mg/l	u	u	u	u	u	u
F	mg/l	2.6	0.4	0.3	0.4	0.4	0.5
Cl	mg/l	64	51	31	59	22	643
SO_4	mg/l	40	15	24	58	15	7

Table 2. (continued.)

Sample #		BE-19	BE-20	BE-21	BE-22	BE-23	BE-24
Location		(B-12-4)27bab 41°44'52" 112°17'04"	(B-12-4)35bcb 41°44'06" 112°16'37"	(B-12-4)36dca 41°43'39" 112°14'43"	(B-11-3)5baa 41°43'30" 112°12'36"	(B-11-3)6aca 41°43'05" 112°13'33"	(B-11-3)6dbd 41°42'57" 112°13'33"
Temp.	°C	14	16	18	15	17	19
pH		6.89	7.14	7.11	7.06	7.29	7.14
TDS	mg/l	988	876	898	542	938	892
HCO_3	mg/l	284	284	476	309	426	334
Na	mg/l	181	205	169	85	313	307
K	mg/l	3	4	12	9	16	15
Ca	mg/l	97	81	92	119	79	54
Mg	mg/l	42	35	51	22	30	23
Fe	mg/l	u	0.04	u	0.16	0.15	u
SiO_2	mg/l	20	21	23	60	21	20
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	2.75	1.71	1.81	0.48	0.68	0.79
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	0.2	0.3	0.2	1.8	2.0	u
Li	mg/l	u	0.06	0.08	u	0.11	0.10
B	mg/l	u	u	0.3	u	0.2	0.2
F	mg/l	0.3	0.3	0.3	0.2	0.4	0.4
Cl	mg/l	360	324	130	115	311	343
SO_4	mg/l	38	35	161	35	78	36

Table 2. (continued.)

Sample #		BE-25	BE-26	BE-27	BE-28	BE-29	BE-30
Location		(B-11-3)6dcc 41°42'43" 112°13'41"	(B-11-4)12ada 41°42'23" 112°14'20"	(B-11-3)7daa 41°42'03" 112°31'09"	(B-11-3)17daa 41°41'11" 112°11'57"	(B-11-4)11ddc 41°41'45" 112°15'44"	(B-11-3)18abb 41°41'40" 112°13'38"
Temp.	°C	17	14	16	11	17	12
pH		7.28	7.59	7.21	7.54	7.09	7.21
TDS	mg/l	1258	624	628	1044	3628	1552
HCO_3	mg/l	292	292	209	217	353	292
Na	mg/l	387	143	103	332	432	464
K	mg/l	15	5	10	8	15	13
Ca	mg/l	81	56	70	53	425	79
Mg	mg/l	37	27	36	22	219	42
Fe	mg/l	u	0.07	0.09	0.20	0.03	u
SiO_2	mg/l	18	53	70	57	43	24
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	1.46	0.63	0.95	0.65	5.40	2.44
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	0.3	0.2	0.3	0.8	u	u
Li	mg/l	0.13	u	0.09	0.07	0.14	0.13
B	mg/l	0.1	u	u	0.1	u	0.2
F	mg/l	0.4	0.5	0.4	0.5	0.4	0.5
Cl	mg/l	516	189	203	443	580	693
SO_4	mg/l	88	37	47	30	1604	88

Table 2. (continued.)

Sample #		BE-31	BE-32	BE-33	BE-34	BE-35	BE-36
Location		(B-11-3)17caa 41°41'19" 112°12'30"	(B-11-4)15dcc 41°40'51" 112°17'05"	(B-11-4)23bbb 41°40'47" 112°16'33"	(B-11-4)23bcc 41°40'25" 112°16'32"	(B-11-3)20daa 41°40'26" 112°11'56"	(B-11-4)28ada 41°39'42" 112°17'51"
Temp.	°C	14	21	14	18	11	18
pH		7.82	6.73	7.27	7.25	7.44	7.18
TDS	mg/l	766	984	1564	766	1224	974
HCO_3	mg/l	217	234	284	259	785	376
Na	mg/l	194	182	499	166	322	251
K	mg/l	10	9	14	8	33	14
Ca	mg/l	56	89	80	71	56	77
Mg	mg/l	26	41	40	35	76	41
Fe	mg/l	0.06	0.07	u	u	u	0.08
SiO_2	mg/l	68	47	19	63	37	47
Ti	mg/l	u	u	11.7	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.69	2.29	2.40	1.35	0.64	2.14
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	0.3	0.1	u	u	u	0.2
Li	mg/l	0.12	0.05	0.13	0.06	0.19	0.12
B	mg/l	0.1	u	0.1	u	0.5	0.2
F	mg/l	0.5	0.4	0.4	0.5	0.9	0.4
Cl	mg/l	290	314	702	234	217	281
SO_4	mg/l	47	70	89	99	138	130

Table 2. (continued.)

Sample #		BE-37	BE-38	BE-39	BE-40	BE-41	BE-42
Location		(B-11-4)29oac 41°39'35" 112°05'10"	(B-11-4)32aaa 41°38'59" 112°18'50"	(B-11-4)34dab 41°38'37" 112°16'43"	(B-11-4)2cad 41°38'14" 112°17'03"	(B-10-4)2cad 41°37'39" 112°16'01"	(B-10-4)6cda 41°37'29" 112°20'35"
Temp.	°C	46	15	19	16	16	16
pH		6.24	7.41	7.14	7.10	7.26	7.40
TDS	mg/l	34850	871	4352	9444	9762	2622
HCO_3	mg/l	442	609	426	384	367	334
Na	mg/l	13857	222	1574	3717	3998	938
K	mg/l	566	20	58	126	130	24
Ca	mg/l	644	67	123	210	190	96
Mg	mg/l	159	51	69	114	108	58
Fe	mg/l	0.19	0.06	u	u	u	u
SiO_2	mg/l	24	54	35	34	28	18
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	19.75	1.07	4.04	6.94	5.13	2.25
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	0.4	0.3	u	u	u	u
Li	mg/l	6.56	0.16	0.47	1.14	1.25	0.23
B	mg/l	3.6	0.3	0.5	1.2	1.2	0.2
F	mg/l	1.2	0.4	0.7	0.5	0.8	0.4
Cl	mg/l	19600	156	2190	5090	5460	1320
SO_4	mg/l	377	99	149	212	150	84

Table 2. (continued.)

Sample #		BE-43	BE-44	BE-45	BE-46	BE-47	BE-48
Location		(B-10-4)24ccc 41°34'49" 112°15'14"	(B-10-3)30bbd 41°34'37" 112°13'56"	(B-9-2)15dad 41°30'55" 112°02'40"	(B-9-2)22cbb 41°30'08" 112°03'44"	(B-9-2)25ccb 41°29'04" 112°01'17"	(B-9-2)35bac 41°28'43" 112°02'09"
Temp.	°C	41	44	18	22	15	13
pH		6.39	6.38	8.63	7.30	7.36	8.54
TDS	mg/l	36110	31080	396	1618	298	562
HCO_3	mg/l	543	409	367	951	225	401
Na	mg/l	14291	11896	177	671	26	239
K	mg/l	566	505	u	19	3	14
Ca	mg/l	641	758	5	37	52	5
Mg	mg/l	213	321	1	34	22	2
Fe	mg/l	0.66	0.17	0.28	0.30	u	0.15
SiO_2	mg/l	24	41	16	79	14	40
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	1.2	u	u	3.2
Sr	mg/l	17.80	24.05	u	0.39	0.36	u
Ba	mg/l	u	5.6	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	u	u	u	0.7	u	u
Li	mg/l	6.93	6.19	u	0.36	u	0.08
B	mg/l	4.1	3.8	0.2	0.3	u	0.5
F	mg/l	1.5	1.1	0.8	1.0	0.3	1.2
Cl	mg/l	20400	17800	15	499	27	21
SO_4	mg/l	351	21	u	u	21	u

Table 2. (continued.)

Sample #		BE-49	BE-50	BE-51	BE-52
Location		(B-8-2)15dbc 41°25'41" 112°03'04"	(B-8-2)23bba 41°25'15" 112°02'28"	(B-8-2)23bcc 41°24'56" 112°02'35"	(B-8-2)26bca 41°24'16" 112°02'16"
Temp.	°C	17	19	13	15
pH		8.60	8.13	7.53	7.12
TDS	mg/l	330	164	114	106
HCO_3	mg/l	192	150	142	117
Na	mg/l	136	8	55	32
K	mg/l	7	u	3	4
Ca	mg/l	4	27	9	3
Mg	mg/l	2	8	3	4
Fe	mg/l	0.20	u	0.30	u
SiO_2	mg/l	11	10	6	13
Ti	mg/l	u	u	u	u
P	mg/l	3.3	u	1.1	u
Sr	mg/l	0.04	0.17	0.03	0.04
Ba	mg/l	u	u	u	u
Mn	mg/l	u	u	u	u
Zn	mg/l	u	u	u	u
Li	mg/l	u	u	u	u
B	mg/l	0.2	u	u	u
F	mg/l	0.6	0.2	0.3	1.2
Cl	mg/l	72	9	21	11
SO_4	mg/l	15	18	u	8

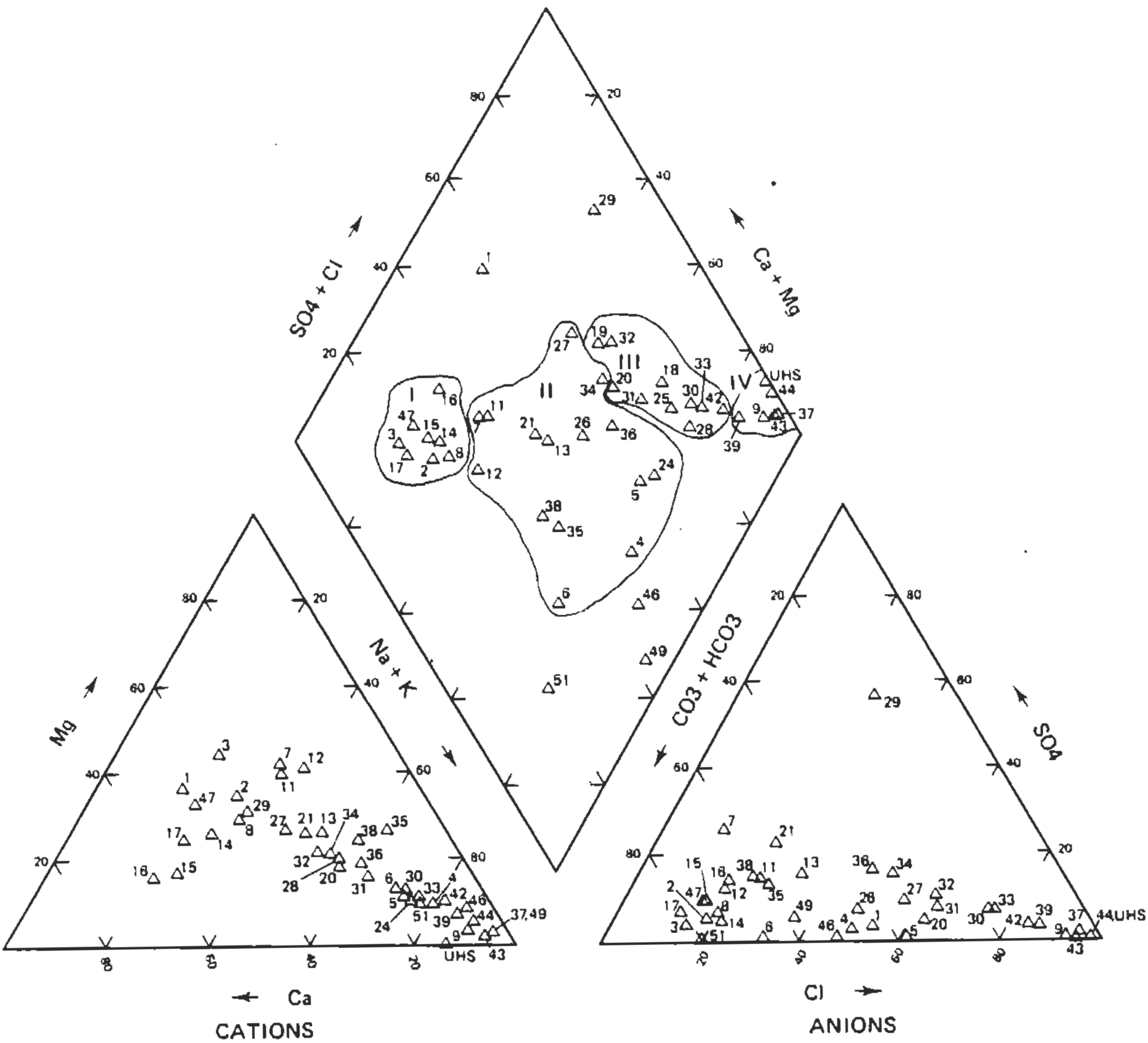

Figure 2. Piper diagram of common ions in samples collected in the lower Bear River drainage and northern east shore areas in Box Elder County, Utah.

sodium-calcium bicarbonate-chloride-sulfate (Na-Ca HCO_3-Cl-SO_4). The dilute water has relatively high TDS concentrations ranging from 436 to 1224 mg/l. Type II water is slightly basic, Na is usually the predominant cation, and HCO_3 or Cl are the predominant anions.

Type III water is predominantly sodium-calcium chloride-sulfate-bicarbonate (Na-Ca Cl-SO_4-HCO_3) in character, dilute to slightly saline with TDS concentrations ranging from 766 to 1564 mg/l, and slightly acidic to slightly basic. BE-19, an exception, is Ca-Na Cl-SO_4-HCO_3 in character. All samples are enriched in Na with respect to other cations and in Cl with respect to other anions. Type III water is thought to represent Na Cl water from deeper parts of the principal aquifer which originated from soluble mineral accumulation in the closed basin for at least the past 100,000 years (Bjorklund and McGreevy, 1974).

Type IV water is sodium-calcium chloride (Na-Ca Cl), sodium chloride (Na Cl), and sodium-calcium chloride-sulfate-bicarbonate (Na-Ca Cl-SO_4-HCO_3) in character. Type IV water includes Udy (Belmont) Hot Springs (BE-9), Stinking Hot Springs (BE-44), Little Mountain Warm Spring (BE-43), Crystal (Madsen) Hot Springs (BE-37), and Utah Hot Springs (BE-53). Type IV water is slightly saline to briny with TDS concentrations ranging from 2,622 to 36,100 mg/l. The water is highly enriched in Na with respect to other cations and in Cl with respect to other anions present. Samples with temperatures greater than $20^{o}C$ are slightly acidic; the remaining samples are slightly basic.

Two samples not included in any of the four water types are BE-49 and BE-51. These two samples are sodium bicarbonate-chloride-sulfate (Na HCO_3-Cl-SO_4) and sodium-calcium bicarbonate-chloride-sulfate (Na-Ca HCO_3-Cl-SO_4) in character, respectively. TDS and pH values for BE-49 are 330 mg/l and 8.6 (basic), and values for BE-51 are 114 mg/l and 7.53 (slightly basic). Both samples are enriched in Na with respect to other cations, and in HCO_3 with respect to other anions. The water is characteristic of ground water from Brighan City south to the Box Elder County line. The water is located downgradient from Type I water, and its high Na content is attributed to the cation exchange of Na for the Ca and Mg of recharge water (Type I), as it migrates through the sediments (Feth and others, 1966).

Sample BE-46 is slightly basic and is also sodium-calcium bicarbonate-chloride-sulfate (Na-Ca HCO_3-Cl-SO_4) in character, but is not included with samples BE-49 and BE-51 because of its high TDS concentration of 1618 mg/l. BE-46 is farther removed from the recharge area than are BE-49 and BE-51, and the high TDS content may result from the longer residence time of the water within the aquifer.

Sample BE-29 is unique and, therefore, was not included in any of the previous water types. BE-29 is calcium-sodium chloride-sulfate- bicarbonate (Ca-Na Cl-SO_4-HCO_3) in character, moderately saline (3,628 mg/l TDS), and slightly basic. The water is enriched in Ca plus Mg with respect to other cations, and in SO_4 with respect to other anions. The cause of the chemical signature is unknown.

Trace Elements and other Geochemical Indicators

Certain trace element concentrations, such as strontium (Sr), lithium (Li), and boron (B), may be helpful to qualitatively distinguish thermal from non-thermal waters. Strontium concentrations in Type IV waters range from 4.04 to 24.05 mg/l. Concentrations in the remaining samples are less than or equal to 2.75 mg/l, with the exception of BE-29 with 5.4 mg/l Sr. Lithium concentrations in Type IV waters range from 0.47 to 14 mg/l, while concentrations in the other water types are less than or equal to 0.36 mg/l. Boron is also high in Type IV waters, ranging from 0.5 to 4.1 mg/l, whereas all remaining samples have less than or equal to 0.50 mg/l B.

The ratio of Ca/HCO_3 ranges from near zero to 1,000 for natural thermal waters. The qualitative comparison of Ca and HCO_3 is useful to distinguish thermal from non-thermal waters (White, 1970). Ca/HCO_3 ratios appear to be a viable method for distinguishing thermal waters in this study. The ratios for hot springs and other samples included in Type IV water range from 0.88 to 14.76. Ca/HCO_3 ratios for all remaining samples range from 0.04 to 1.17, with the exception of BE-29 with 3.67.

The ratios of soluble constituents, such as Cl/B and Na/Li, are commonly used as aids in determining the areal extent of a geothermal aquifer (Ellis and Mahon, 1977). Unfortunately, B and Li concentrations in the study area were often below detectable limits; therefore, the limited use of these techniques provided no definitive results.

Geothermometry

Applicable geothermometers used in this study are: 1) silica (quartz conductive and chalcedony); and 2) sodium-potassium-calcium (Na-K-Ca). Equations, from Fournier (1981), expressing the temperature (t) relationships in selected geothermometers, are presented below:

Quartz (conductive):

$$t(^{o}C) = \frac{1309}{5.19 - \log SiO_2} - 273.15$$

Chalcedony:

$$t(^{o}C) = \frac{1032}{4.69 - \log SiO_2} - 273.15$$

Na-K-Ca:

$$t(^{o}C) = \frac{1647}{\log (Na/K) + \beta\,[\log (Ca^{1/2}/Na) + 2.06] + 2.47} - 273.15$$

where: $\beta = 1/3$ for t greater than $100^{o}C$
$\beta = 4/3$ for t less than $100^{o}C$
SiO_2, Na, K, and Ca concentrations are in mg/l

The reliability of the SiO_2 and Na-K-Ca geothermometers depends upon five assumptions (Fournier and others, 1974). These assumptions are:

1. temperature-dependent reactions occur at depth,
2. all constituents involved in the temperature-dependent reactions are sufficiently abundant,
3. water-rock chemical equilibration occurs at the reservoir temperature,
4. little or no equilibration or change in composition occurs at lower temperatures as the water flows from the reservoir up to the surface, and
5. the hot water coming from deep in the system does not mix with cooler, shallow ground water.

Fournier and Potter (1979) believe that the Na-K-Ca geothermometer gives anomalously high results for waters rich in Mg. They derived a temperature correction for Mg-rich waters which can be used when:

(1) Na-K-Ca temperature equal to or greater than 70°C, and

(2) R equal to or less than 50

$$R = \frac{Mg}{Mg + Ca + K} \times 100$$

A graphical method is used to obtain the temperature.

Most low-temperature thermal systems occur in hydrologic regimes which preclude all or some of the five assumptions. Mixing occurs in the study area, where warm water areas result from the mixing of hotter water with cool water from near-surface aquifers. The effect of dilution on the Na-K-Ca geothermometer is generally negligible if the higher temperature geothermal water is more saline than the diluting water. If the warm water component is 30 percent or less, however, the effects of mixing should be considered. The Mg-corrected Na-K-Ca geothermometer is subject to error from the continued water-rock reaction as ascending water cools (Fournier, 1981).

Quartz is the most stable and least soluble polymorphic form of silica in the temperature and pressure range of low-temperature geothermal systems. Ground waters less than 80^{o} to 90^{o}C, have silica concentrations greater than those predicted by the solubility of quartz, indicating that these low-temperature waters may have equilibrated with chalcedony (Fournier, 1981). Fournier (1977) suggests that if the Na-K-Ca geothermometer indicates a temperature of less than 100^{o}C, the silica content of the water is a function of chalcedony solubility. For temperatures greater than 100^{o}C, the silica temperature should be calculated assuming the silica content is a function of quartz solubility. In Iceland, Arnorsson (1975) found that when undissociated silica is less than 60 mg/l, the silica temperature refers to equilibrium with chalcedony, and that between 60 and 250 mg/l SiO_2, it is unknown whether chalcedony or quartz governs the amount of silica in the system. Due to this disagreement on silica form, both chalcedony and quartz temperatures are given in table 3. When ascending warm water is diluted by cooler water, a new water rock chemical equilibrium may or may not be attained after mixing. If chemical equilibrium is not attained, application of the silica geothermo- meter will give a temperature that is too low and, therefore, mixing must be accounted for (Fournier, 1981).

Measured temperatures and calculated geothermometer temperatures for wells and springs sampled within the study area are given in table 3. Silica concentrations range from 6 to 79 mg/l, regardless of temperature, making most silica geothermometer temperatures (quartz and chalcedony) erroneous. For many parts of the study area, silica concentrations for thermal water are much lower than for adjacent non-thermal water. Attempts to apply the mixing models of Fournier (1977) and Truesdell and Fournier (1977) were unsuccessful because silica concentrations for non-thermal water are much greater than for thermal water.

Table 3. Chemical geothermometers with magnesium correction where applicable, and surface temperatures for water in (°C) for well and spring samples in the lower Bear River drainage and east shore ground-water areas, Box Elder County, Utah

Sample	Meas.# Temp.	Quartz (Conductive)	Chalcedony	Na-K-Ca	Na-K-Ca (Mg corr.)
E-1	17	42	10	*	*
BE-2	15	62	29	37	+
BE-3	15	63	31	35	+
BE-4	11	77	45	95	42
BE-5	15	67	35	97	44
BE-6	15	75	44	70	53
BE-7	12	105	75	164	R>50
BE-8	16	118	90	197	33
BE-9 (Udy HS)	42	108	79	163	68
BE-11	15	103	73	230	R>50
BE-12	11	103	73	224	R>50
BE-13	14	93	62	88	33
BE-14	18	119	90	61	+
BE-15	17	78	47	36	+
BE-16	13	109	79	48	+
BE-17	14	83	52	38	+
BE-18	11	107	78	84	44
BE-19	14	63	31	37	+
BE-20	16	65	33	49	+
BE-21	18	69	37	77	40
BE-24	19	63	31	146	36
BE-25	17	60	27	97	41
BE-26	14	105	75	59	+
BE-27	16	118	90	72	45
BE-28	11	108	79	83	49
BE-29	17	95	64	62	+
BE-30	12	70	39	95	35
BE-31	14	117	88	83	45
BE-32	21	99	69	69	+
BE-33	14	66	29	98	37
BE-34	18	113	84	69	+
BE-35	11	88	57	184	R>50
BE-36	18	99	69	91	37
BE-37 (Crystal HS)	46	70	39	180	81
BE-38	15	105	76	169	R>50
BE-39	19	86	55	152	27
BE-42	16	60	27	130	24
BE-43 (Little Mtn HS)	41	70	39	170	62
BE-44 (Stinking HS)	44	93	62	178	44
BE-46	22	124	96	136	R>50
BE-47	15	51	18	31	+
BE-49	17	42	10	156	53
BE-51	13	24	-9	70	68
Utah HS	56	82	51	231	222

Explanations for symbols are found on following page (34).

Explanations for Table 3 (page 33):

Measured temperatures greater than or equal to 20°C are referred to as thermal waters.

* indicates K not present or below detection limit which precludes the use of the Na-K-Ca geothermometer.

R >50 indicates the underground water temperature is probably equal to the measured temperature.

+ indicates Na-K-Ca temperature less than 70°C; therefore, the Mg-correction does not apply.

Na-K-Ca temperatures are also somewhat uncertain. The computed temperatures for non-thermal samples range from 31° to 230°C. Na-K-Ca temperatures for thermal samples range from 69° to 231°C. The range of temperatures for thermal and non-thermal samples is quite similar.

Mg-corrected Na-K-Ca temperatures, where applicable for the above non-thermal group of samples, ranged from 24° to 68°C. Samples with high Mg concentrations have R values greater than 50, indicating that the underground water temperature is equal to the measured temperature. Sample BE-39 has a Mg-corrected temperature of only 27°C, but has a significantly high concentration of Mg (76 mg/l). This indicates that water-rock reaction may have occurred as the water cooled, thereby subjecting the correction to error and indicating the non-corrected temperature of 152°C may be more accurate. Where applicable, the Mg-corrected temperatures for thermal samples range from 68°C to 222°C.

Although the results obtained from the three geothermometers are considered suspect, comparisons of hot springs samples and thermal water samples merit discussion. The 68°C Mg-corrected temperature for sample B-9 collected at Udy Hot Springs roughly compares to the 79°C chalcedony temperature. The 81°C Mg-corrected temperature derived for Crystal (Madsen) Hot Springs (BE-37) agrees with the quartz (conductive) temperature of 70°C. The Mg concentration for this sample is exceedingly high (159 mg/l), however, indicating that water-rock reactions probably occurred as the ascending thermal water cooled, and invalidates the Mg-correction. The Na-K-Ca temperature of 180°C for BE-37 is significantly higher than all the other geothermometer temperatures. Little Mountain Warm Spring (BE-43) and Stinking Hot Springs (BE-44) have extremely high Mg concentrations (321 and 213 mg/l, respectively), indicating that water-rock reaction occurred during the ascension of the thermal water. There is poor agreement between the Na-K-Ca temperatures and the silica geothermometer temperatures for BE-43 and BE-44. The Mg concentration for Utah Hot Springs (Sample UHS) is low (24 mg/l), but the Mg-correction made little difference, lowering the temperature from 231° to 222°C. These temperatures are significantly higher than the 51°C (chalcedony) and 82°C (quartz) silica geothermometer temperatures. Thermal sample BE-32 has a Na-K-Ca temperature of 69°C which agrees with the 69°C chalcedony temperature. Thermal sample BE-46 has a Na-K-Ca temperature of 136°C; however, the Mg-correction has an R value greater than 50 indicating that the temperature at depth is no greater than 22°C, thereby invalidating the Na-K-Ca temperature.

TEMPERATURE-DEPTH MEASUREMENTS

Temperature-depth measurements and temperature gradients are useful in exploration for geothermal resources since they can detect thermal anomalies (Laughlin, 1982). Temperature gradients are affected by heat flow and thermal conductivity. Heat flow is the conductive transfer of heat from the earth's interior and, therefore, the surface expression of geothermal conditions at depth. For a given heat flow, the temperature gradient is inversely proportional to the thermal conductivity of the material through which the heat is being transmitted by conduction (Kappelmeyer and Haenel, 1974). At shallow depths, temperature gradients are affected by surface conditions such as temperature and precipitation. These effects are eliminated below 30 m in depth (Kappelmeyer and Haenel, 1974). Temperature measurements are strongly influenced by the movement of ground water (sometimes to depths of thousands of meters), and it should always be recognized that temperature gradients are valid only for conductive heat transfer and that vertical, as well as horizontal, convection can upset the extrapolation of temperature information (Laughlin, 1982; Lumb, 1981).

Temperature-depth measurements were made in 12 shallow, abandoned, steel-cased, water and oil wells in the northern portion of the lower Bear River drainage area (Plate 2). The few wells present in the southern part of the study area along the Wasatch Range were artesian and, therefore, not suitable for temperature-depth logging. Temperatures were measured with a thermistor probe connected by a four wire configuration to a digital ohmmeter. A Fenwal K212E thermistor probe with a nominal resistance of 10,000 ohms at 20 ^{o}C, power dissipation of 50m WK^{-1} in still water, and a response time of five seconds was used. Temperature readings were taken at 2.5 m intervals in water and at 5 m intervals in air, after the temperature had stabilized at each position. The holes ranged in depth from 30 to 184 m. Gradients were calculated using linear regression, with standard error. The location and calculated gradients of each hole are listed in table 4, and the temperature-depth data are in Appendix C. Temperature-depth profiles are presented in figures 3 through 5 and grouped on the basis of geographic proximity.

Table 4. Geothermal gradient data, lower Bear River drainage area, Utah

USGS 71/2' Topog. Quadrangle	Well	Latitude	Longitude	Elevation (m)	Depth interval for calculated gradient (m)	Calc. gradient °C/km
Blind Springs	BEP-1	41°45'12"	112°17'21"	1,377	10-37	64 +/- 8
Riverside	BEP-2	41°47'43"	112°9'7"	1,342	25-35	27 +/- 8
Cutler Dam	BEP-3	41°48'14"	112°2'5"	1,565	45-80	135 +/-30
Portage	BEP-4	41°52'32"	112°9'55"	1,353	30-42.5	140 +/- 6
Tremonton	BEP-5	41°43'30"	112°13'42"	1,357	G1--30-41.5 G2--15-41.5	34 +/- 3 22 +/- 3
Thatcher Mountain	BEP-6	41°43'12"	112°17'46"	1,370	35-86	18 +/- 2
Thatcher Mountain	BEP-7	41°43'2"	112°17'53"	1,371	G1--25-60 G2--65-85	21 +/- 2 13 +/- 1
Riverside	BEP-9	41°50'35"	112°10'3"	1,362	25-72	129 +/-10
Cutler Dam	BEP-10	41°48'45"	112°3'11"	1,391	10-87.5	11 +/- 3
Portage	BEP-11	41°54'21"	112°9'8"	1,501	95-127.5	10 +/- 3
Cutler Dam	BEP-12	41°49'24"	112°4'0"	1,369	G1--107.5-167.5 G2--172.5-184 G3--102.5-184	65 +/- 7 380 +/-29 113 +/-63
Riverside	BEP-13	41°50'14"	112°10'64"	1,400	10-30	185 +/-25

The average thermal gradient in the Basin and Range Province is 35 ^{o}C/km. Thermal data from seven holes near Cedar City, Utah indicate an average thermal gradient of 27 ^{o}C/km in this area of the Basin and Range (Sass and others, 1971). A gradient of 57.7^{o}C/km was calculated by Costain and Wright (1973) from drill hole data in Jordan Valley, near Salt Lake City. This high value is thought to reflect the low thermal conductivity of unconsolidated Lake Bonneville deposits (Costain and Wright, 1973). The temperature-depth data collected in the lower Bear River drainage area is taken from wells located in the unconsolidated sediments, alluvium, and colluvium comprising the valley fill; consequently, a gradient of greater than or equal to 60 ^{o}C/km is considered anomalous.

Calculated gradients for the 12 wells in the lower Bear River drainage basin range from 10 +/- 3 ^{o}C/km to 380 +/- 29 ^{o}C/km. Anomalous gradients were only found at sites BEP-1, 3, 4, 9, 12, and 13, and are discussed below.

BEP-4, BEP-9, and BEP-13, in the vicinity of Udy (Belmont) Hot Springs, have anomalous thermal gradients (fig. 3). The two inflection points at depths of 30 and 42.5 meters (98 and 139 ft) in BEP-4, suggest an area of conductive heat flow between two areas of convective heat flow, as is indicated by the isothermal gradients above and below the inflection points. The gradient calculated for the conductive heat flow interval is 140 +/- 6 ^{o}C/km. The gradients for BEP-9 and BEP-13 of 129 +/- 10 and 185 +/- 25 ^{o}C/km, respectively, are indicative of conductive heat flow.

Two wells with anomalous gradients are also present east and northeast of Fielding (fig. 4). The gradient of 135 +/- 30 ^{o}C/km for BEP-3 was calculated in what appears to be a conductive heat flow area, below a short interval of convective heat flow between 35 and 45 meters. Three gradients were calculated for BEP-12 which is located approximately 1.2 mi west of the

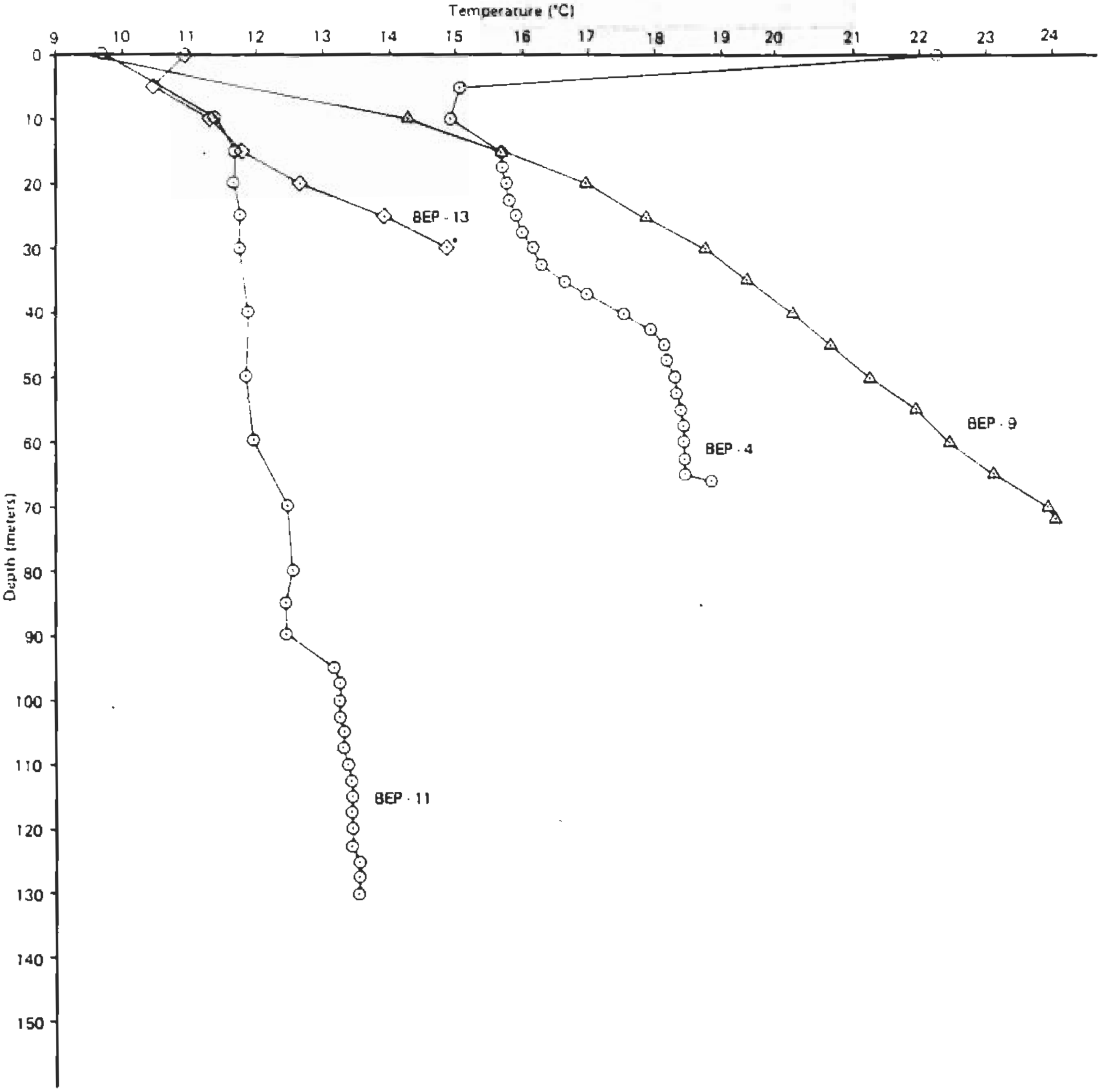

Figure 3. Temperature-depth profiles of BEP 4, 9, 11, and 13 logged in the lower Bear River drainage area in Box Elder County, Utah.

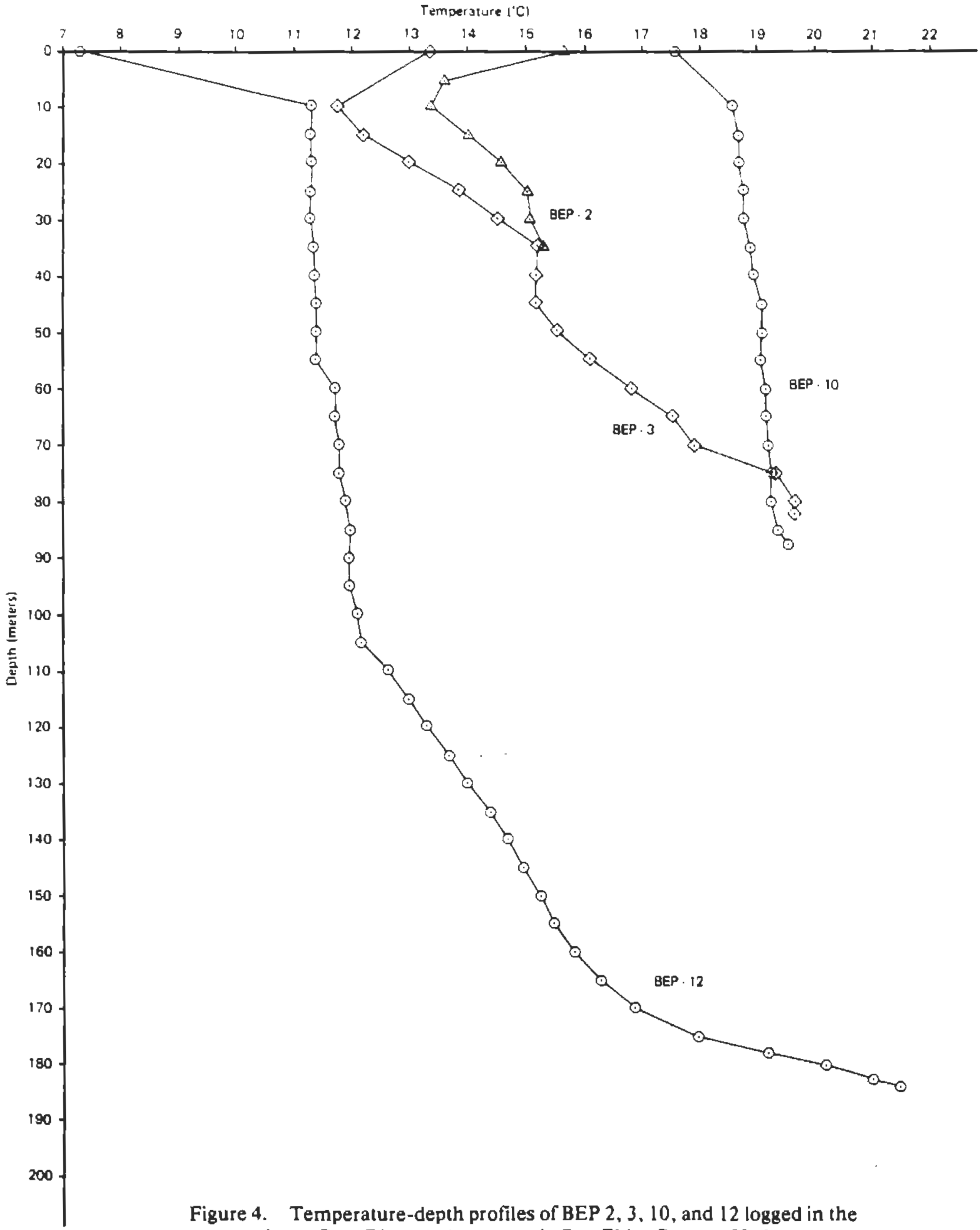

Figure 4. Temperature-depth profiles of BEP 2, 3, 10, and 12 logged in the lower Bear River drainage area in Box Elder County, Utah.

location for Cutler Warm Springs. A gradient of 65 +/- 7 ^{O}C/km, calculated from 107.5 to 167.5 m, indicates conductive heat flow and is thought to be fairly representative of the area. The high gradient of 380 +/- 29 ^{O}C/km calculated at a greater depth (172.5 to 184 m), could reflect a separate aquifer which contains warm water moving laterally, perhaps in relation to faults within the northern Wasatch fault system. Gradient #3 is the composite calculated from the end points of gradients #1 and #2. The large error associated with this gradient, 113 +/- 63 ^{O}C/km, lessens its validity.

Only one well proved to be anomalous in the vicinity of Bothwell Warm Springs (fig. 5). BEP-1, 2.7 mi northwest of Bothwell Warm Springs, has a gradient of 64 +/- 8 ^{O}C/km calculated in an area indicative of conductive heat flow.

DISCUSSION

Prior to this study, the following low-temperature geothermal systems were known in the lower Bear River and east shore ground-water areas in Box Elder County: (1) Udy (Belmont) Hot Springs, (2) Crystal (Madsen) Hot Springs, (3) Utah Hot Springs, (4) Stinking Hot Springs, (5) Little Mountain Warm Spring, (6) Cutler Warm Springs, and (7) Bothwell Warm Springs. The purpose of this study, however, is to detect unknown low-temperature geothermal systems, or to further expand on known systems. Three areas are identified which warrant further investigation for low-temperature geothermal resource potential.

Area 1, northwest of Little Mountain, is identified solely by geochemical techniques on three samples, as no suitable temperature-depth holes could be located. Because the area may be part of the same geothermal system supplying Stinking and Little Mountain thermal springs, the entire area has been delineated as having thermal potential on Plate 2. Common ion concentrations of samples collected northwest of Little Mountain in area 1 are similar to

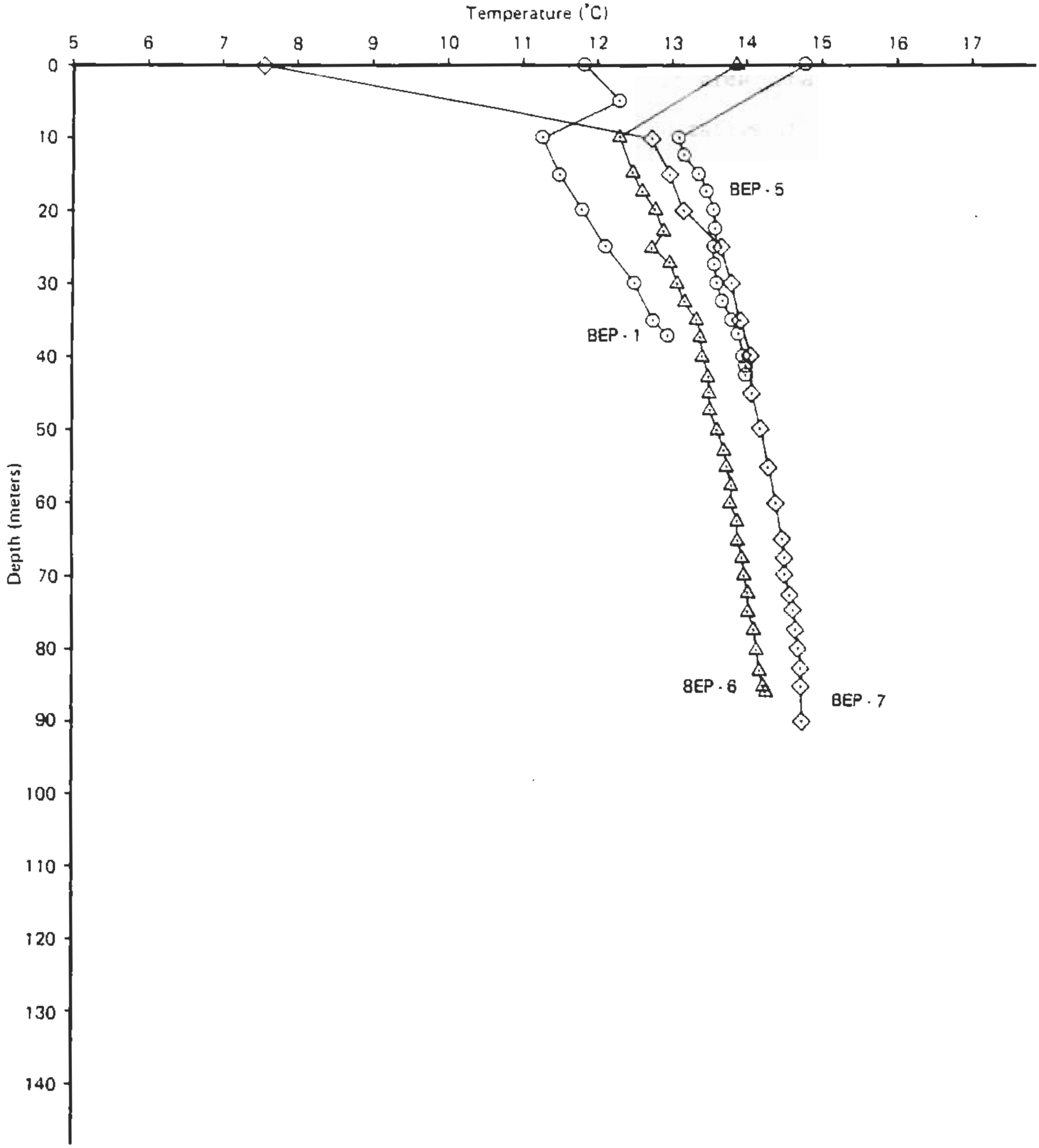

Figure 5. Temperature-depth profiles of BEP 1, 5, 6, and 7 logged in the lower Bear River drainage area in Box Elder County, Utah.

those for thermal samples. Sample BE-39, although only 19^{O}C, is also Na-Ca Cl in character.

Trace element analyses for samples included in area 1 have anomalous concentrations of Sr, Li, and B, which may be indicative of thermal water. Strontium concentrations for BE-39, BE-40, and BE-41 are 4.04 mg/l and greater, and compare with concentrations for samples from other thermal springs which range from 5.09 to 24.05 mg/l. Lithium concentrations for BE-39, BE-40, and BE-41 range from 0.47 to 1.25 mg/l and compare with concentrations for all the warm and hot springs in the study area (0.80 to 14.00 mg/l). Boron concentrations for these three samples range from 0.5 to 1.2 mg/l, whereas concentrations for the thermal springs range from 0.8 to 14.00 mg/l.

Ratios of Ca/HCO_3, although not as definitive, do provide evidence of a possible thermal anomaly in area 1. Ca/HCO_3 ratios in area 1 range from 0.88 to 1.67. The range for all the thermal springs in the study area is 1.49 to 14.76, whereas the range for all the other samples (exluding BE-29 with 3.67) is from 0.04 to 1.16.

Results of previous studies at Udy (Belmont), Crystal (Madsen), and Utah hot springs, as well as at other sites along the Wasatch Front, indicate that low-temperature thermal systems are convective, resulting from the deep circulation of meteoric water. It appears that Stinking Hot Springs, Little Mountain Warm Springs, and other thermal anomalies in this study are also heated by convection. Structure plays a significant role in controlling the locations of these thermal anomalies by providing the necessary conduits. Faults and/or fault zones provide conduits for deep circulation. Two inferred faults in the vicinity of area 1, northwest of Little Mountain, are located by Bjorklund and McGreevy (1974). The orientations of these faults indicate a possible fault intersection in area 1. The brecciated zone created by the intersection of the two faults, may provide a conduit for the thermal water to rise and mix with the principal aquifer before being intercepted by wells. Furthermore, the area may be part of a larger system which also supplies Stinking Hot Springs and Little Mountain Warm Springs.

Chemical geothermometry conducted for the Little Mountain area indicates similarities between BE-39, Little Mountain, and Stinking Hot Springs samples. The Na-K-Ca temperature of 152^{o}C for BE-39 is similar to the 178^{o} and 179^{o}C temperatures for Little Mountain Warm Springs and Stinking Hot Springs. The (Mg) corrected Na-K-Ca temperatures computed for these two thermal springs are similar to the surface temperatures measured, which may indicate that temperatures at depth in this geothermal system are similar to these surface temperatures. The high Mg concentrations for these two samples, however, indicate that water-rock reactions continue as the heated water ascends and is cooled. If this occurrs, the Mg-corrected temperatures are too low. The temperatures likely to be expected at depth are somewhere between the Mg-corrected and the non-corrected Na-K-Ca temperatures.

The remaining two areas (Plate 2) having possible geothermal potential are identified from temperature-depth logging. Chemical analyses of available well and/or spring samples, are not anomalous.

Area 2 is located west and southwest of Plymouth, Utah. The area includes Udy (Belmont) Hot Springs. Udy may be a surface manifestation of a larger system indicated by the temperature-depth logs. Two gradient holes were drilled as part of Murphy and Gwynn's (1979) study of Udy Hot Springs. The first hole (Udy/GH-A) flowed artesian and no temperature-depth profile was published. Temperatures recorded at the collar of the hole over a 4.5 month period vary from 18.8^{o}C on 1-22-79 to 27^{o}C on 6-8-79. The temperature-depth log of the second hole gives a computed gradient of 330°C/km. The maximum temperature for this log is 44°C at a depth of approximately 81 m. Temperature-depth holes BEP-9 and BEP-13 have maximum calculated gradients of 129° and 185°C/km, respectively. These two gradients are significantly higher than the 57.7°C/km calculated for unconsolidated sediments in the Jordan Valley by Costain and Wright (1973), and compared with the 27°C/km considered to be average for this part of the Basin and Range by Sass and others (1971). BEP-13 has a maximum bottom hole temperature of 14.9°C at a depth of 30 m, making the calculated gradient suspect due to the possible affects of atmospheric temperature and precipitation in the upper 30 m. BEP-9, however, located 1.4 mi north-northwest of BEP-13, appears to have a conductive gradient to a depth of 72 m and has a bottom temperature of 24.2°C. The heat source for this gradient may be to the west, because recharge to the aquifer supplying this well is to the west. BEP-4, located north of Udy Hot Springs, has a maximum bottom hole temperature of 18.9°C. The gradient of 140 $\pm$ 6°C/km for this profile is calculated between 30 and 42.5 m in depth, with convective interference above and below this interval. The last point measured indicates a conductive zone could exist below the depth of this profile. The gradient calculated for this profile is speculative, but with a 19°C bottom hole temperature in the vicinity of Udy Hot Springs, further investigation of this area is warranted.

Area 3, identified as having low-temperature geothermal potential based on temperature-depth logging, is located west and south of Cutler Dam. BEP-12, located approximately 2 mi west of the dam, indicates convective interference to a depth of 107.5 m. Below this depth two gradients are apparent. From 107.5 to 167.5 m, a gradient of 65°C/km is calculated, which is somewhat consistent with the background gradient of 57.7°C/km. Below 107.5 m, a gradient of 380°C/km is calculated which is similar to the gradient calculated by Murphy and Gwynn (1979) for Udy Hot Springs. This gradient is extremely high, and may be the result of heat flow recovery resulting from convective interference at a shallower depth. The bottom hole temperature of 21.5°C, however, is somewhat encouraging. BEP-3 located approximately 2.6 mi south-southeast of Cutler Dam has a calculated gradient of 135°C/km from a depth of 40 m to the total depth logged of 80 m. BEP-10, located between BEP-12 and BEP-13, only has a calculated gradient of 11°C/km with a bottom hole temperature of 19.6°C at 87.5 m. Although the gradients calculated for this area are highly speculative at present, the data merits further investigation. Structural controls in this area are not yet understood. No significant fault that could control the location of these warm areas has been identified.

CONCLUSIONS

Three areas of possible low-temperature geothermal resources are identified in the study area. One area, northwest of Little Mountain, is identified by geochemical techniques. The other two areas are identified by temperature-depth logging, and the interpretation is somewhat speculative. Further research is needed in each of these areas to determine if a geothermal resource exists. Additional studies need to be conducted to: 1) determine the structural controls and source of the thermal fluids, 2) delineate the distribution of these fluids in the near surface, and 3) determine the maximum temperature and volume of these fluids.

This study is limited in scope and can only identify geothermal anomalies affecting the near-surface unconsolidated aquifers. The lack of evidence for additional geothermal anomalies does not eliminate the possibility that additional resources do exist. Further exploration may establish the presence of a deep resource(s).

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APPENDIX A
WELL AND SPRING NUMBERING SYSTEM

APPENDIX A

WELL AND SPRING-NUMBERING SYSTEM

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by uppercase letters as follows: A, northeast; B, northwest; C, southwest; and D, southeast. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section, -- generally 10 acres (4-hm^2); the quarters of each subdivision are designated by lowercase letters as follows: a, northeast; b, northwest; c, southwest; and d, southeast. The number after the letters is the serial number of the well or spring within the 10-acre (4-hm^2) tract; the letter "S" preceding the serial number denotes a spring. Thus (C-36-16) 36abd-1 designated the first well constructed or visited in the SE1/4 SE1/4 NE1/4 sec. 36, T. 36 S., R. 16 W. If a well or spring cannot be located within a 10-acre (4-hm^2) tract, one or two location letters are used and the serial number is omitted. Other sites where hydrologic data were collected are numbered in the same manner, but three letters are used after the section number and no serial number is used. The numbering systems is illustrated in figure A1.

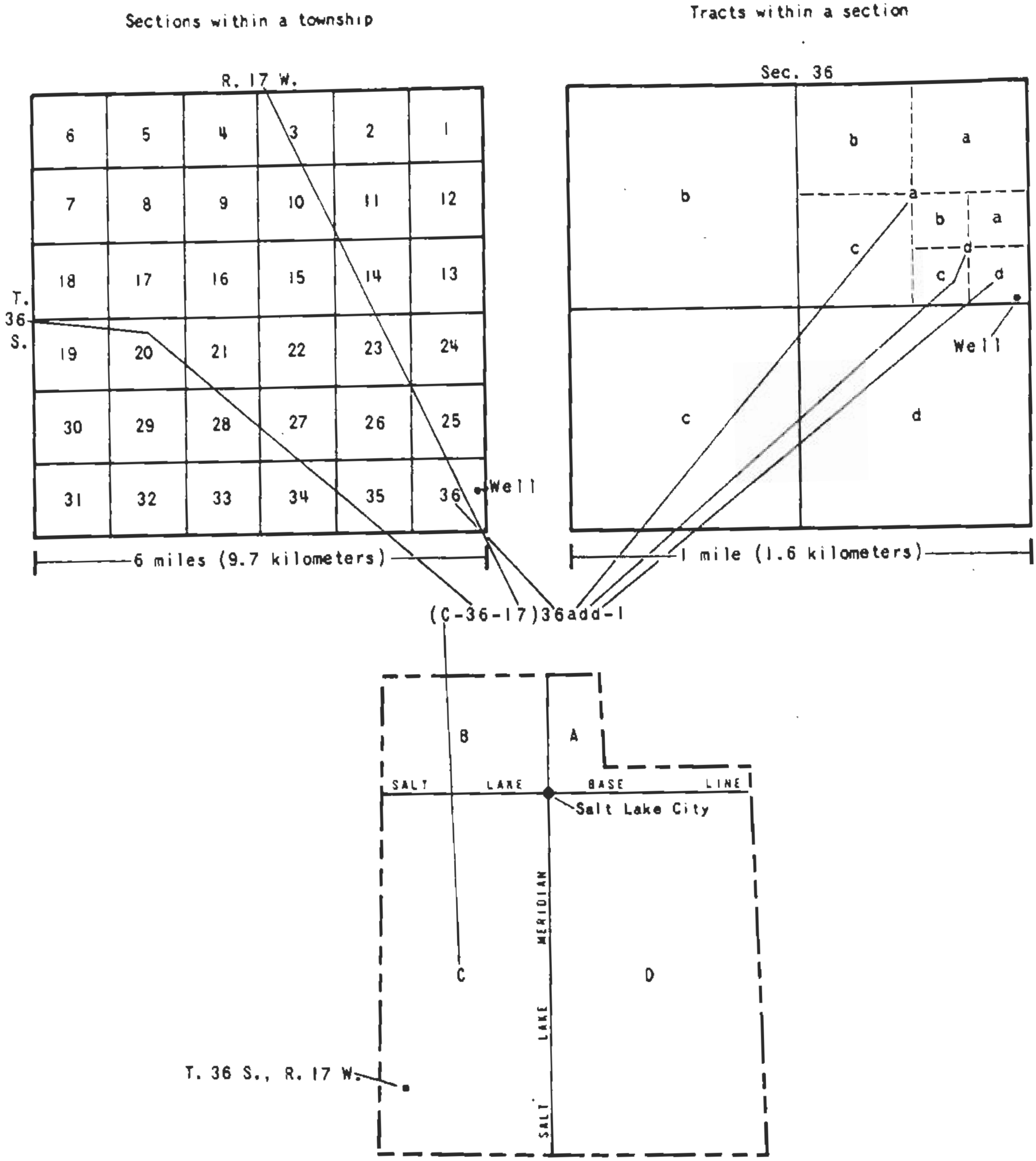

Figure A-1. Well-, and spring-, and other data site-numbering system used in Utah.

APPENDIX B
CONVERSION FACTORS

CONVERSION FACTORS

Distances and depth reported in the text are given in English units. Miles (mi.) can be converted to kilometers (km) by the following equation: 1 mi = 1.62 km. Feet (ft) can be converted to meters (m) by the following equation: 1 ft = 0.305 m. Temperatures reported in the text are given in degrees centigrade (^{o}C). Temperatures can be converted from degrees centigrade (^{o}C) to degrees Farenheit (^{o}F) by the following equation: ^{o}F = 1.8 (^{o}C) + 32.

APPENDIX C

TEMPERATURE-DEPTH DATA FOR BEP-1 THROUGH BEP-13, BOX ELDER COUNTY, UTAH

7.5 Minute Series Quadrangle: Blind Springs
Location: T12N/R4W/S22
Well: BEP-1
Site Latitude: 41° 45' 12"
Site Longitude: 112° 17' 21"
Site Elevation: 1,377 m
Depth Interval for Gradient Calculated: 10-37 m
Calculated Gradient: 64 +/- 8 °C/km

Depth (m)	T (°C)
0	11.818
5	12.288
10	11.250
15	11.539
20	11.784
25	12.104
30	12.526
35	12.764
37	12.972

7.5 Minute Series Quadrangle: Riverside
Location: T12N/R3W/S11
Well: BEP-2
Site Latitude: 41° 47' 43"
Site Longitude: 112° 9' 7"
Site Elevation: 1,342 m
Depth Interval for Gradient Calculated: 25-35 m
Calculated Gradient: 27 +/- 8 °C/km

Depth (m)	T (°C)
0	15.696
5	13.609
10	13.420
15	14.067
20	14.615
25	15.060
30	15.130
35	15.331

7.5 Minute Series Quadrangle: Cutler Dam
Location: T12N/R2W/S2
Well: BEP-3
Site Latitude: 41° 48' 14"
Site Longitude: 112° 2' 5"
Site Elevation: 1,565 m
Depth Interval for Gradient Calculated: 45–80 m
Calculated Gradient: 135 +/- 30 °C/km

Depth (m)	T (°C)
0	13.439
10	11.780
15	12.206
20	12.989
25	13.846
30	14.553
35	15.172
40	15.198
45	15.230
50	15.587
55	16.148
60	16.858
65	17.582
70	17.957
75	19.422
80	19.685
82	19.680

7.5 Minute Series Quadrangle: Portage
Location: T14N/R2W/S11
Well: BEP-4
Site Latitude: 41° 52' 32"
Site Longitude: 112° 9' 55"
Site Elevation: 1,353 m
Depth Interval for Gradient Calculated: 30-42.5 m
Calculated Gradient: 140 +/- 6 °C/km

Depth (m)	T (°C)	Depth (m)	T (°C)
0	22.263	45	18.165
5	15.093	47.5	18.203
10	14.957	50	18.363
15	15.750	52.5	18.399
17.5	15.761	55	18.440
20	15.813	57.5	18.466
22.5	15.851	60	18.452
25	15.963	62.5	18.521
27.5	16.076	65	18.540
30	16.232	66	18.932
32.5	16.565		
35	16.885		
37.5	17.202		
40	17.623		
42.5	17.987		

7.5 Minute Series Quadrangle: Tremonton
Location: T11N/R3W/S5
Well: BEP-5
Site Latitude: 41^{o} 43' 30"
Site Longitude: 112^{o} 13' 42"
Site Elevation: 1,357 m
Depth Interval for Gradient Calculated: G1--30-41.5 m
G2--15-41.5 m
Calculated Gradient: G1--34 +/- 3 $^{o}C/km$
G2--22 +/- 3 $^{o}C/km$

Depth (m)	T (^{o}C)
0	14.785
10	13.144
12.5	13.199
15	13.375
17.5	13.464
20	13.543
22.5	13.588
25	13.566
27.5	13.579
30	13.627
32.5	13.719
35	13.810
37.5	13.909
40	13.979
41.5	14.010
42.5	14.032

7.5 Minute Series Quadrangle: Thatcher Mountain
Location: T11N/R4W/S3
Well: BEP-6
Site Latitude: 41° 43' 12"
Site Longitude: 112° 17' 46"
Site Elevation: 1,370 m
Depth Interval for Gradient Calculated: 35-86 m
Calculated Gradient: 18 +/- 2 °C/km

Depth (m)	T (°C)	Depth (m)	T (°C)
0	13.853	50	13.642
10	12.317	52.5	13.688
15	12.463	55	13.753
17.5	12.623	57.5	13.842
20	12.797	60	13.836
22.5	12.888	62.5	13.896
25	12.764	65	13.934
27.5	12.964	67.5	13.962
30	13.122	70	13.997
32.5	13.243	72.5	14.047
35	13.362	75	14.083
37.5	13.402	77.5	14.133
40	13.436	80	14.170
42.5	13.488	82.5	14.210
45	13.540	85	14.250
47.5	13.556	86	14.274

7.5 Minute Series Quadrangle: Thatcher Mountain
Location: T11N/R4W/S4
Well: BEP-7
Site Latitude: 41° 43' 2"
Site Longitude: 112° 17' 53"
Site Elevation: 1,371 m
Depth Interval for Gradient Calculated: G1--25-60 m
G2--65-85 m
Calculated Gradient: G1--21 +/- 2 °C/km
G2--13 +/- 1 °C/km

Depth (m)	T (°C)	Depth (m)	T (°C)
0	7.571	60	14.405
10	12.764	65	14.484
15	13.016	67.5	14.503
20	13.159	70	14.532
25	13.639	72.5	14.573
30	13.807	75	14.603
35	13.954	77.5	14.629
40	14.043	80	14.668
45	14.131	82.5	14.716
50	14.202	85	14.745
55	14.306	90	14.768

7.5 Minute Series Quadrangle: Riversiae
Location: T13N/R3W/S22
Well: BEP-9
Site Latitude: 41° 50' 35"
Site Longitude: 112° 10' 3"
Site Elevation: 1,362 m
Depth Interval for Gradient Calculated: 25-72 m
Calculated Gradient: 129 +/- 10 °C/km

Depth (m)	T (°C)	Depth (m)	T (°C)
0	9.393	55	21.948
10	14.294	60	22.543
15	15.748	65	23.187
20	17.025	70	24.007
25	17.883	72	24.157
30	18.814		
35	19.645		
40	20.165		
45	20.698		
50	21.278		

7.5 Minute Series Quadrangle: Cutler Oam
Location: T12N/R2W/S3
Well: BEP-10
Site Latitude: 41° 48' 45"
Site Longitude: 112° 3' 11"
Site Elevation: 1,391 m
Depth Interval for Gradient Calculated: 10-87.5 m
Calculated Gradient: 11 +/- 3 °C/km

Depth (m)	T (°C)	Depth (m)	T (°C)
0	17.586	55	19.103
10	18.579	57.5	19.204
15	18.681	60	19.192
17.5	18.698	62.5	19.189
20	18.698	65	19.234
22.5	18.702	67.5	19.223
25	18.785	70	19.244
27.5	18.789	72.5	19.255
30	18.801	75	19.295
32.5	18.847	77.5	19.293
35	18.938	80	19.310
37.5	18.946	82.5	19.388
40	18.984	85	19.420
42.5	18.976	87.5	19.501
45	19.105	87.8	19.641
47.5	19.080		
50	19.076		
52.5	19.149		

7.5 Minute Series Quadrangle: Portage
Location: T14N/R3W/S35
Well: BEP-11
Site Latitude: 41° 54' 21"
Site Longitude: 112° 9' 8"
Site Elevation: 1,501 m
Depth Interval for Gradient Calculated: 95-127.5 m
Calculated Gradient: 10 +/- 3 °C/km

Depth (m)	T (°C)
0	9.695
10	11.414
15	11.659
20	11.718
25	11.769
30	11.784
40	11.938
50	11.862
60	12.189
70	12.551
80	12.647
85	12.540
90	12.539
95	13.261
97.5	13.272
100	13.299
102.5	13.331
105	13.365
107.5	13.383
110	13.428
112.5	13.470
115	13.480
117.5	13.483
120	13.488
122.5	13.496
125	13.600
127.5	13.603
130	13.603

7.5 Minute Series Quadrangle: Cutler Dam
Location: T13N/R2W/S28
Well: BEP-12
Site Latitude: 41° 49' 24"
Site Longitude: 112° 4'
Site Elevation: 1,369 m
Depth Interval for Gradient Calculated: G1--107.5-167.5 m
G2--172.5-184 m
G3--102.5-184 m (four end points)
Calculated Gradient: G1--65 +/- 7 °C/km
G2--380 +/- 29 °C/km
G3--113 +/- 63 °C/km

Depth (m)	T (°C)	Depth (m)	T (°C)
0	7.341	110	12.630
10	11.323	112.5	12.797
12.5	11.293	115	12.976
15	11.249	117.5	13.176
17.25	11.242	120	13.323
20	11.296	122.5	13.535
22.5	11.298	125	13.727
25	11.304	127.5	13.871
27.5	11.313	130	14.048
30	11.319	132.5	14.225
32.5	11.341	135	14.407
35	11.364	137.5	14.551
37.5	11.355	140	14.708
40	11.382	142.5	14.865
42.5	11.369	145	14.966
45	11.398	147.5	15.105
47.5	11.421	150	15.273
50	11.421	152.5	15.400
52.5	11.454	155	15.542
55	11.471	157.5	15.667
57.5	11.677	160	15.847
60	11.720	162.5	16.019
62.5	11.714	165	16.309
65	11.732	167.5	16.582
67.5	11.758	170	16.896
70	11.824	172.5	17.254
72.5	11.815	175	18.019
75	11.842	177.5	19.221
77.5	11.883	180	20.253
80	11.917	182.5	21.016
82.5	11.952	184	21.495
85	11.959		
87.5	11.977		
90	11.991		
92.5	11.991		
95	11.994		
97.5	12.015		
100	12.107		
102.5	12.245		
105	12.362		
107.5	12.471		

7.5 Minute Series Quadrangle: Riverside
Location: T13N/R3W/S28
Well: BEP-13
Site Latitude: 41° 50' 14"
Site Longitude: 112° 10' 64"
Site Elevation: 1,400 m
Depth Interval for Gradient Calculated: 10-30 m
Calculated Gradient: 185 +/- 25 °C/km

Depth (m)	T (°C)
0	10.971
5	10.492
10	11.333
15	11.838
20	12.685
25	13.959
30	14.885


Geologic Map of the Lower Bear River Drainage and Northern East Shore Ground-water Areas in Box Elder County, Utah
EXPLANATION
QUATERNARY
Qs SEDIMENTS—ALLUVIUM, COLLUVIUM, AND LAKE BONNEVILLE DEPOSITS, UNDIFFERENTIATED.
TERTIARY
Tu SALT LAKE GROUP, WASATCH GROUP, AND GRAVELS, UNDIFFERENTIATED.
PENNSYLVANIAN AND PERMAIN
PPu OQUIRRH GROUP AND DIAMOND CREEK SANDSTONE(?), UNDIFFERENTIATED.
ORDOVICIAN THROUGH MISSISSIPPIAN
OMu SEDIMENTARY ROCKS—DOMINANTLY LIMESTONE, DOLOMITE, AND QUARTZITE, UNDIFFERENTIATED.
PRECAMBRIAN AND CAMBRIAN
p€€u DOMINANTLY LIMESTONE, DOLOMITE, AND QUARTZITE, WITH SOME SCHIST, SLATE, PHYLLITE, AND GNEISS, UNDIFFERENTIATED.
CONTACTS BETWEEN UNITS.
FAULT, DASHED WHERE IMPLIED. U, UPTHROWN SIDE; D, DOWNTHROWN SIDE.
INFERRED FAULT OR FAULT ZONE, IMPLIED BY GEOPHYSICAL OR INDIRECT GEOLOGIC EVIDENCE.
THRUST FAULT, DASHED WHERE IMPLIED; SAW-TEETH ON SIDE OF UPPER PLATE.
Compiled from: Bjorklund and McGreevy, 1974; Davis, 1983; Doelling, 1980; Murphy and Gwynn, 1979; Peterson, 1974; and Stokes, 1963.
IDAHO
UTAH
CLARKSTON MOUNTAINS
JUNCTION HILLS
WELLSVILLE MOUNTAINS
WASATCH RANGE
BLUE SPRINGS HILLS
Whites Valley
Portage
Plymouth
Fielding
Riverside
Garland
Tremonton
Bothwell
Thatcher
Elwood
Cropley
Penrose
SALT CREEK WATERFOWL MANAGEMENT AREA
LITTLE MOUNTAIN
Evans
Bear River City (Bear River)
PUBLIC SHOOTING GROUNDS
Corinne
Brigham City
Mantua
Perry
Willard Peak
WILLARD THRUST FAULT
BEAR RIVER
MALAD RIVER
BEAR RIVER VALLEY
BEAR RIVER BAY
BEAR RIVER MIGRATORY BIRD REFUGE
WILLARD BAY
HAROLD S. CRANE WATERFOWL MANAGEMENT AREA
WILLARD BAY UPLAND
BOX ELDER CO
WEBER CO
Logan 9 Mi.
Logan 23 Mi.
CONTOUR INTERVAL 100 FT.
Base map adapted from: U.S. Geological Survey, Great Salt Lake and vicinity, Utah, 1974, with Utah Geological and Mineral Survey additions.

Locations of Wells and Springs Sampled, Temperature-depth Logging Sites, and Known Hot or Warm Springs in the Lower Bear River Drainage and Northern East Shore Ground-water Areas in Box Elder County, Utah.

Base map adapted from: U.S. Geological Survey, Great Salt Lake and vicinity, Utah, 1974, with Utah Geological and Mineral Survey additions.