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GEOTHERMAL ASSESSMENT OF PART OF THE EAST SHORE AREA, DAVIS AND WEBER COUNTIES, UTAH

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ABSTRACT

The Utah Geological and Mineral Survey (UGMS) has been conducting research to advance the utilization of low-temperature geothermal resources in Utah as per U.S. Department of Energy (DOE) contract DE-AS07-77ET28393. This study includes portions of Weber and Davis counties and is part of an area-wide geothermal research program conducted along the Wasatch Front. Although three known low-temperature geothermal areas are located in these two counties (Ogden and Hooper Hot Springs and the Little Mountain South geothermal area), the purpose of this study was to locate other resources not previously identified.

Geothermal reconnaissance techniques attempted in this study included a water temperature survey, and chemical analyses of springs and wells. The temperature survey identified 12 wells with water temperatures 20°C or higher. These wells were, however, located throughout the study area and with the exception of one location (W-15), exhibited no other low-temperature thermal characteristics that indicated warmer temperatures could be expected at depth or within the vicinity.

Sample location W-15 was similar, chemically, to Hooper and Ogden Hot Springs as well as samples collected from three other non-thermal wells in the area. Although these three samples had temperatures that only ranged from 14° to 16°C, chemical geothermometer results indicate temperatures to be expected at depth range from 60° to 90°C. Other chemical characteristics of these samples indicative of low-temperature geothermal potential not previously identified include common ion concentrations high in Na and Cl, high concentrations of trace elements such as Li, Ba, and Sr, as well as Ca/HCO_3 and Cl/B ratios greater than background.

Introduction

The Utah Geological and Mineral Survey (UGMS) has been conducting research to advance the use of low temperature geothermal resources in the State of Utah as per U.S. Department of Energy (DOE) contract DE-AS07-77ET28393. Prior to this study, UGMS was concentrating its investigations on known geothermal areas along the Wasatch Front from Utah Valley north to the Utah/Idaho state line. The concentration of studies in this region was done primarily to encourage development of known geothermal resources near major population centers of the state.

In February, 1980, it was determined that efforts should begin to evaluate area-wide geothermal resource potential along the Wasatch Front and adjacent areas because of the inherent low-temperature geothermal potential and because of the inclusion of the three major metropolitan centers of the state. This report is the result of that study. It should be noted, however, that this study was limited in scope, and that the absence of evidence for additional resources doesn't eliminate the possibility that they exist. Additional exploration may establish that a deep resource does exist.

This study area includes those portions of Weber and Davis counties that lie west of the Wasatch Mountains and east of the Great Salt Lake (Figure 1). This area is a gently sloping surface with relief increasing eastward toward the foothills of the Wasatch Mountains. Both counties are involved to some extent in agriculture and industry but much of the expansion in the last two decades has been for homes for people who work in the Salt Lake Valley (Goode, 1978). Ogden is the largest city located at the mouth of Ogden Canyon in Weber County. Other communities include Bountiful, Centerville, Kaysville,

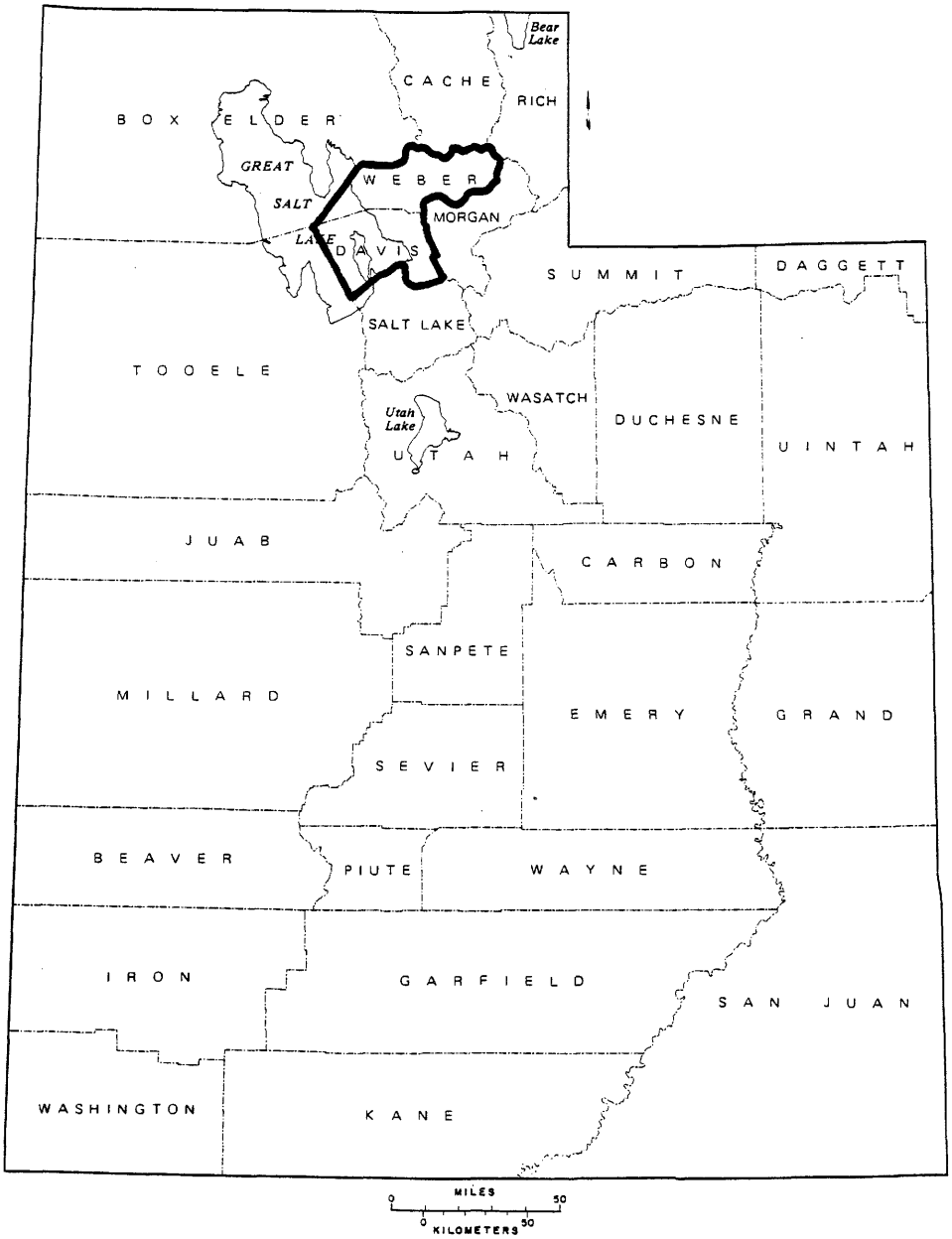

Figure 1. Index map of the study area in Weber and Davis Counties, Utah

Layton, and Roy. Hill Air Force Base, a major military installation, is also located in this area.

Two areas within the East Shore have been investigated previously. Glenn et al. (1980) attempted to locate a low- or moderate-temperature geothermal resource at Hill Air Force Base (HAFB), Ogden, Utah. These investigators conducted a "phased exploration program" which included: 1) examining published geological, geochemical, and geophysical reports; 2) regional exploration; and 3) drilling two thermal gradient holes. This study did not identify a thermal anomaly at the base. In the second area studied, Little Mountain-South geothermal area west of Ogden, Utah, Murphy and Gwynn (1979) incorporated the work of Bolke and Waddell (1972) with a gradient hole drilled (see Known Geothermal Resources section, p. 8). Hill AFB and Little Mountain-South were investigated in more detail than intended for the scope of this report and, therefore, have not been included.

GEOLOGY AND STRUCTURE

The study area is situated along the eastern edge of the Basin and Range physiographic province with the Wasatch Range to the east. Mountains in Weber and Davis counties contain rocks of Precambrian through Tertiary age (Plate 1). Consolidated rocks of Precambrian and Paleozoic age are exposed to the east in the Wasatch Range, in Little Mountain to the west, and the Pleasant View Salient to the north (Plate 1). Metamorphic rocks of the Farmington Canyon Complex are the oldest formation present and span the entire length of the study area, while the youngest rocks in the range are volcanic tuffs and conglomerates of Pliocene age belonging to the Salt Lake Group (Davis, 1983a and b). In the study area these Tertiary rocks are exposed only along the

east margin of the Wasatch Range but are presumed to be present between pre-Tertiary basement rocks and the extremely thick and extensive Quaternary deposits in the valley (Feth et al., 1966).

Near-surface Quaternary deposits consist primarily of detritus brought into the valley by the Weber and Ogden rivers; during high cycles of Lake Bonneville these rivers formed deltas which presently account for nearly 1,000 ft of relief above the lake plain (Goode, 1978). The deeper, unconsolidated sediments are intertonguing alluvial and lacustrine deposits which consist of sand and gravel near the mountain front and largely sand, silt and clay to the west (Goode, 1978). Unconsolidated Holocene deposits at the surface in much of the study area range up to 40 ft in thickness (Feth et al., 1966).

Geophysical studies have determined the shape of the bedrock surface underlying this area to be an elongate trough structurally controlled on the east by the Wasatch Fault Zone and to the west by buried north-trending step faults (Feth et al., 1966). Feth et al. (1966) consider maximum unconsolidated sediment thickness in this trough to be from 6,000 to 9,000 ft Seismic data from Glenn et al. (1980) indicate several north-south faults in the subsurface between the range front and the center of Hill AFB.

The Wasatch fault zone lies along the east edge of the area, with individual faults within this zone having dips which range from 20° to 70° west (Feth et al., 1966). Maximum displacement across the zone is 10,000 ft (Feth et al., 1966). This fault zone is characterized by branching and braiding patterns, curvilinear en echelon faulting with some eastward dips (Glenn et al., 1980) (Plate 1). West of the Wasatch fault zone a number of north-south trending faults have been mapped both within the structural trough and bordering it on the west (Feth et al., 1966; Stokes, 1963; and Davis, 1983 a and b). Glenn et al. (1980) also suggest that north-south trending normal

faults are located within this structural trough, some of which have eastward dips.

GROUND WATER

Ground water in the study area occurs mainly under artesian conditions in a multiaquifer reservoir (Feth et al., 1966). Although the various artesian aquifers are separated by fine-grained beds, Smith and Gates (1963) suggest that hydraulic interconnection is such that these individual aquifers can be included as a single system. Ground water also occurs in deltas and along the mountain front as local bodies of perched water above the main saturated zone and under water-table conditions in shallow aquifers (Bolke and Waddell, 1972). Bolke and Waddell (1972) also state that the majority of wells in the area are completed in artesian aquifers, with only a few wells completed within the water-table reservoir.

The ground-water reservoir consists of unconsolidated and semi-consolidated deposits primarily of Quaternary age (Bolke and Waddell, 1972). At the base of the Wasatch Range, the deposits consist chiefly of coarse-grained delta, alluvial-fan, slope-wash, and mud-rock flow deposits; these deposits grade into fine-grained but well-sorted lacustrine deposits to the west (Bolke and Waddell, 1972). Bolke and Waddell (1972) also report that stream deposits are composed of boulders, gravel, sand, and clay in elongate, discontinuous bodies while impermeable mud-rock flow deposits are unsorted, contain clay, sand, and large fragments, and prohibit local recharge. Smith and Gates (1963) report that the lacustrine deposits include fairly continuous and well-sorted bodies of clay, sand, silt, and gravel, and that near-shore

currents deposited elongate bodies of coarser lake deposits parallel to shorelines. The coarser, well-sorted material, such as stream-channel or lake-shore deposits, make the best aquifers.

Feth et al. (1966) have described two major artesian aquifers in the northern part of the study area. The more productive and largest of the two is the Delta aquifer; its top is 500-700 ft below the surface and is generally 50-150 ft thick. The second, the Sunset aquifer, is less productive, only 250-400 ft below the surface and 50-250 ft thick. Due to a buried bedrock high, these aquifers do not extend south of Kaysville. They are not recognizable as separate units in the area of Ogden, Plain City, and North Ogden (Feth et al., 1966). Feth et al. (1966) also identify undifferentiated artesian aquifers above the Sunset aquifer but these are less productive and smaller. South of Kaysville, three separate artesian aquifers have been defined by Thomas and Nelson (1948). Thomas and Nelson (1948) identified these aquifers as shallow, intermediate, and deep. Due to local differences in lithology within this area, it is frequently impossible to distinguish individial aquifers. Depths to the tops of each aquifer range from 60-250 ft, 250-500 ft, and more than 500 ft, respectively (Thomas and Nelson, 1948).

Recharge to the ground-water system in the study area is mainly precipitation which falls primarily in the form of snow on the Wasatch Range and the Uinta Mountains to the east. Feth et al. (1966) estimate that almost half the recharge to the ground-water reservoir in the northern portion of the study area is subsurface inflow from the bedrock of the Wasatch Range, slightly less than one-quarter of the recharge is leaked from the Weber River, and the remainder includes infiltration from precipitation, irrigation, the streams draining the mountain front, and the Ogden River. Areas to the south

have no major rivers but still receive recharge as seepage from the Wasatch Range as well as lesser amounts from mountain-front streams, irrigation, and direct precipitation in the bench areas.

Ground water moves generally westward from the areas of recharge toward the Great Salt Lake. Although discharge of ground water occurs from wells, springs, seepage into drains and sloughs, and by evaporation and evapotranspiration from croplands, open-water surfaces, saltgrass pastures, cattail swamps and mud surfaces, most discharge is in the form of subsurface flow into the Great Salt Lake (Feth et al., 1966).

Known Geothermal Areas

Weber and Davis counties have two known thermal areas which are manifested at the surface by warm springs. Ogden Hot Springs, located at the mouth of Ogden Canyon in Weber County, has a temperature of 55°C. Hooper Hot Springs, with a temperature of 56°C, is located about 10 mi. southwest of Ogden on the east shore of the Great Salt Lake in Davis County. Glenn et al. (1980) state that the thermal waters have mixed with cooler shallow ground waters and that the temperatures of these hot spring waters, prior to mixing, are estimated to be between 70° and 150°C.

Little Mountain geothermal area is not manifested at the surface by a major thermal spring. This geothermal area is located approximately 15 mi. west of Ogden, Utah, and consists of numerous shallow flowing wells and springs. Water temperatures measured at these wells and springs range from 14° to 20°C (Murphy and Gwynn, 1979). Murphy and Gwynn (1979) conclude that the distribution of flowing warm water wells may indicate an east-west

striking fault and that an area of warm water may also exist at the southern end of Little Mountain.

TEMPERATURE SURVEY

Temperatures ranging from 12° to 24°C were measured in 58 water wells in the study area (Plate 2). Depths of these wells range from approximately 118 ft to 1,000 ft Only 12 of these wells are considered thermal (have temperatures equal to or greater than 20°C).

Five of the thermal wells, as well as Hooper Hot Springs, are located in Davis County. Wells D-9, D-11 and D-14 are located between the Wasatch Range and Farmington Bay along a narrow strip of land separating Centerville and Farmington (Plate 3). These wells are 545 ft, 332 ft, and 412 ft deep with temperatures of 23°, 22°, and 21°C, respectively. Near Layton, thermal wells D-18 and D-20 have depths of 442 ft and 258 ft and temperatures of 24°C and 22°C, respectively. The remaining seven thermal wells, as well as Ogden Hot Springs, are located in Weber County (Plate 2). Wells W-3 (20°C) and W-5 (23°C) are situated in Washington Terrace and have depths of 857 ft and 910 ft, respectively (Plate 3). Well W-2, near Hooper Hot Springs, has a depth of 570 ft and a surface temperature of 23°C. Two of the remaining thermal wells, W-14 and W-15, are located between West Warren and West Weber and have temperatures of 20°C and 21°C, respectively. Well W-14 has a depth of 539 ft while W-15 is 483 ft deep. Well W-20, located approximately 2.5 mi. south of North Ogden, is less than 150 ft deep with a temperature of 21°C. Well W-22, northeast of Little Mountain, was completed to a depth of 540 ft and recorded a temperature of 22°C (Plate 3).

Warming by the natural thermal gradient of the earth of meteoric waters circulating to depth is the generally accepted theory for warm water occurrences along the Wasatch Front (Cole, 1982; Glenn et al., 1980; Murphy and Gwynn, 1979). Waters, with the exception of W-15, identified as thermal ($\geq 20^{o}C$), although located near or in the vicinity of known or implied fault zones, do not exhibit chemical compositions that are characteristic of geothermal systems. These characteristics, or lack thereof, will be discussed in the following sections. Three explanations which could account for the somewhat abnormally warm natural water are: 1) major dilution of warm water in the near surface aquifer; 2) meteoric water that has circulated to only moderate depths resulting in only slight warming; or 3) conductive heating, in place, of shallower water by heat from a deeper thermal reservoir. A fourth, less likely, explanation involves exothermic reactions in thick organic clays heating water. This theory was suggested by Marine and Price (1964) as a possible source for the warm water located in northern Jordan Valley.

WATER CHEMISTRY AND ANALYSIS

Fifty-eight water samples were collected and analyzed as part of this study. See Plate 3 for sample locations. The on-site analyses consisted of: (1) pH, (2) alkalinity, and (3) conductivity. A Corning-Orion Model 407A/F specific ion meter in conjunction with an Orion gel-filled Model 91-05 combination pH electrode was used to measure pH. Three readings were taken and the average was recorded as the final value. 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 polyethylene bottles (two 570 ml and one 65 ml) were filled at each sampling location with water filtered through a GeoFilter Peristaltic Pump - Model #004 using a 0.45 micron filter paper. This water was subsequently 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 cation analysis of elements presented in Table 1 by an APL Inductivity Coupled Plasma Quantometer (ICPQ). One 570 ml bottle was acidified with concentrated HCl to a final concentration of 1 percent HCl for SO_4 analysis. The remaining bottle was unacidified and the water was analyzed for Cl, F, and total dissolved solids (TDS). Results of the analyses are presented in Table 2.

Common Ion Analyses

Common ion analyses are presented on trilinear diagrams in Figures 2 through 4. Wells D-2, D-15, D-16, and W-17 are omitted from these diagrams due to the high percent of error with common ion balancing which makes their use unacceptable. Figure 2 represents samples collected in Davis County. Samples collected in Weber County are represented in Figure 3. A composite trilinear diagram of all samples is presented in Figure 4.

Data plotted in Figure 4 indicate there are three major types of water present in Weber and Davis counties which have been designated as Types I, II and III. Type I water comprises the majority of samples analyzed and is either calcium-magnesium bicarbonate (Ca-Mg HCO_3), calcium-sodium bicarbonate (Ca-Na-HCO_3), or calcium-sodium bicarbonate-chloride-sulfate (Ca-Na-HCO_3-Cl-SO_4) in character, dilute, with TDS values ranging from 140 to 780 mg/l, as well as slightly acidic to slightly basic. All samples

Table 1. Limits of Quantitative Determination (LQD) for solution analysis by the University of Utah Research Institute/Earth Science Lab Inductively Coupled Plasma Quantaometer (ICPU).

Element	Concentration (mg/l)
Na	1.25
K	2.50
Ca	0.250
Mg	0.500
Fe	0.025
Al	0.625
Si	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
Ag	0.050
Au	0.100
As	0.625
Sb	0.750
Bi	2.50
U	6.25
Te	1.25
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

Note: When elements are present in detectable limits the mg/l concentration is rounded to the nearest whole number. LQD concentrations represent the lowest reliable analytic values for each element. Precision at the LQD is approximately ±100% of the given value with a confidence level of 95%.

Table 2. Water Analysis from Wells and Springs in Weber and Davis Counties, Utah.

(u - elements not present or not present in detectable concentrations.)

Sample #		W-1	W-2	W-3	W-4	W-5	W-6
Location		(B-5-1)22cda 41°08'59" 111°56'22"	(B-5-3)22adb 41°09'23" 112°09'54"	(B-5-1)17ddd 41°09'43" 111°58'05"	(B-5-2)17ccd 41°09'49" 112°05'57"	(B-5-1)17cbc 41°09'59" 111°59'10"	(B-5-2)15baa 41°10'29" 112°03'15"
Temp.	°C	15	23	20	17	23	16
pH		7.11	7.41	7.20	7.21	7.20	6.79
TDS	mg/l	420	178	292	200	269	460
HCO_3	mg/l	376	192	309	225	225	384
Na	mg/l	28	51	22	24	19	34
K	mg/l	3	3	3	2	2	9
Ca	mg/l	96	21	63	44	62	77
Mg	mg/l	25	6	18	10	15	41
Fe	mg/l	2.15	u	0.03	0.29	u	u
SiO_2	mg/l	15	24	20	20	20	29
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.29	0.20	0.27	0.29	0.25	0.51
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	0.5	u	u	0.2	0.4	0.2
Li	mg/l	u	u	u	u	u	u
B	mg/l	u	u	u	u	u	u
F	mg/l	0.2	0.3	0.2	0.2	0.2	1.0
Cl	mg/l	29	23	24	20	22	36
SO_4	mg/l	24	u	17	7	21	50

Table 2. (continued.)

Sample #		W-7	W-8	W-9	W-10	W-11	W-12
Location		(B-5-3)14aaa 41°10'34" 112°08'31"	(B-5-2)12aac 41°11'20" 112°00'33"	(B-5-1)6ccc 41°11'33" 112°00'20"	(B-5-2)3bbb 41°12'15" 112°03'46"	(B-6-2)31ddd 41°12'21" 112°06'09"	(B-6-2)28cdd 41°13'15" 112°04'26"
Temp.	°C	19	18	15	16	17	19
pH		7.48	7.14	6.99	7.27	7.38	7.17
TDS	mg/l	200	270	286	239	202	200
HCO_3	mg/l	217	326	242	242	267	192
Na	mg/l	33	26	19	29	42	34
K	mg/l	3	3	2	5	5	4
Ca	mg/l	46	68	63	44	42	44
Mg	mg/l	10	17	16	14	13	8
Fe	mg/l	0.14	0.07	u	0.42	0.10	0.07
SiO_2	mg/l	21	13	12	16	21	21
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.31	0.22	0.22	0.19	0.35	0.30
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	0.5	0.4	u	u	u	0.2
Li	mg/l	u	u	u	u	u	u
B	mg/l	u	u	u	u	u	u
F	mg/l	0.3	0.3	0.2	0.3	0.2	0.2
Cl	mg/l	25	23	26	22	20	27
SO_4	mg/l	u	15	30	5	u	4

Table 2. (continued.)

Sample #		W-13	W-14	W-15	W-16	W-17	W-18
Location		(B-6-2)25cdb 41°13'21" 112°01'04"	(B-6-2)19dca 41°14'17" 112°06'32"	(B-6-2)21add 41°14'31" 112°03'51"	(B-6-3)14cdd 41°15'04" 112°09'10"	(B-6-2)17aca 41°15'34" 112°05'21"	(B-6-2)10cda 41°15'54" 112°03'17"
Temp.	°C	18	20	21	17	19	14
pH		6.93	7.47	6.96	7.44	6.83	7.17
TDS	mg/l	1152	166	988	230	444	1470
HCO_3	mg/l	584	209	209	259	309	267
Na	mg/l	106	46	136	54	176	395
K	mg/l	76	3	19	9	7	45
Ca	mg/l	134	34	111	23	22	84
Mg	mg/l	73	7	27	10	6	36
Fe	mg/l	u	0.09	0.40	0.11	0.25	1.54
SiO_2	mg/l	19	19	23	33	19	19
Ti	mg/l	u	u	u	u	u	u
P	mg/l	2.9	u	u	u	u	u
Sr	mg/l	0.69	0.26	1.68	0.12	0.31	1.13
Ba	mg/l	u	u	0.8	u	u	0.8
Mn	mg/l	1.0	u	0.4	u	u	0.4
Cu	mg/l	u	u	u	u	0.6	u
Zn	mg/l	0.2	0.1	u	u	u	u
Li	mg/l	0.05	u	0.13	0.07	0.20	0.49
B	mg/l	0.3	u	u	u	0.4	0.3
F	mg/l	0.3	0.3	0.2	0.5	0.8	0.3
Cl	mg/l	176	23	396	24	96	756
SO_4	mg/l	105	u	u	u	u	u

Table 2. (continued.)

Sample #		W-19	W-20	W-21	W-22	W-23	W-24
Location		(B-6-1)8bda 41°16'20" 111°58'38"	(B-6-1)8bda 40°16'20" 111°58'40"	(B-6-2)6dbd 41°16'57" 112°06'28"	(B-6-3)4dab 41°17'09" 112°10'59"	(B-7-1)32dca 41°17'42" 111°58'19"	(B-7-1)31dac 41°17'52" 111°59'21"
Temp.	°C	16	21	17	22	13	15
pH		7.47	6.77	7.40	8.20	7.10	7.20
TDS	mg/l	272	712	490	530	156	140
HCO_3	mg/l	225	551	284	559	209	192
Na	mg/l	60	118	136	225	12	12
K	mg/l	9	25	22	5	u	3
Ca	mg/l	40	93	54	4	42	34
Mg	mg/l	13	49	16	2	8	10
Fe	mg/l	0.74	u	0.31	0.31	u	u
SiO_2	mg/l	18	21	23	27	13	24
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.24	0.49	0.43	0.02	0.13	0.11
Ba	mg/l	u	u	0.7	u	u	u
Mn	mg/l	u	u	u	u	u	u
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	u	0.2	0.6	u	u	u
Li	mg/l	u	0.09	0.24	0.07	u	u
B	mg/l	u	0.2	0.2	0.6	u	u
F	mg/l	0.2	0.5	0.4	1.9	0.1	0.2
Cl	mg/l	84	112	166	36	11	10
SO_4	mg/l	u	40	u	u	3	4

Table 2. (continued.)

Sample #		W-25	W-26	W-27	W-28	W-29	D-1
Location		(B-7-1)32bda 41°18'05" 111°58'40"	(B-7-1)33bba 41°18'19" 111°57'47"	(B-7-1)32aaa 41°18'24" 111°58'07"	(B-7-2)27dcc 41°18'28" 112°03'11"	(B-7-2)21dcc 41°19'23" 112°04'21"	(A-2-1)32ccb 40°51'34" 111°52'11"
Temp.	°C	15	12	13	16	15	13
pH		7.30	7.11	7.12	7.29	7.60	7.20
TDS	mg/l	160	170	172	2906	3296	456
HCO_3	mg/l	217	200	217	209	167	359
Na	mg/l	21	8	14	766	601	39
K	mg/l	u	u	u	64	41	2
Ca	mg/l	42	50	51	185	304	94
Mg	mg/l	7	8	10	51	96	27
Fe	mg/l	u	u	0.15	1.92	3.10	u
SiO_2	mg/l	16	12	11	18	14	17
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.13	0.09	0.10	3.86	5.18	0.24
Ba	mg/l	u	u	u	1.7	2.4	u
Mn	mg/l	u	u	u	0.6	0.6	u
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	0.2	u	u	u	u	0.3
Li	mg/l	u	u	u	0.83	0.69	u
B	mg/l	u	u	u	0.4	0.3	u
F	mg/l	0.2	0.1	0.1	0.3	0.3	0.2
Cl	mg/l	9	9	7	1540	1700	58
SO_4	mg/l	u	5	5	u	u	37

Table 2. (continued.)

Sample #		D-2	D-3	D-4	D-5	D-6	D-7
Location		(B-2-1)36cbc 40°51'41" 111°54'35"	(B-2-1)35aad 40°52'03" 111°54'44"	(A-2-1)30cbd 40°52'30" 111°53'17"	(A-2-1)30acd 40°52'44" 111°52'38"	(A-2-1)28bca 40°52'52" 111°50'59"	(B-2-1)24bda 40°53'42" 111°54'04"
Temp.	°C	14	14	13	12	15	16
pH		7.03	7.12	7.20	7.22	7.19	7.39
TDS	mg/l	780	600	500	382	294	244
HCO_3	mg/l	351	284	359	301	209	184
Na	mg/l	116	93	63	34	26	80
K	mg/l	4	3	3	2	2	1
Ca	mg/l	164	89	89	76	56	19
Mg	mg/l	41	32	33	21	16	5
Fe	mg/l	0.19	u	u	u	0.10	0.05
SiO_2	mg/l	16	15	14	13	15	16
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.31	0.31	0.24	0.17	0.17	0.06
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	2.0	u	u	u	u	u
Li	mg/l	u	u	u	u	u	u
B	mg/l	u	u	u	u	u	u
F	mg/l	0.2	0.2	0.2	0.2	0.2	0.3
Cl	mg/l	123	108	60	48	30	33
SO_4	mg/l	183	98	54	32	49	20

Table 2. (continued.)

Sample #		D-8	D-9	D-10	D-11	D-12	D-13
Location		(A-2-1)18ddd 40°54'03" 111°52'19"	(B-2-1)12cda 40°55'01" 111°54'08"	(A-2-1)8bdd 40°55'19" 111°51'52"	(A-2-1)6dad 40°56'04" 111°52'24"	(B-3-1)26acd 40°57'56" 111°54'58"	(A-3-1)19cda 40°58'34" 111°52'59"
Temp.	°C	15	23	15	22	17	12
pH		7.11	7.40	7.40	7.30	7.11	7.17
TDS	mg/l	460	228	172	290	438	226
HCO_3	mg/l	292	242	150	267	459	134
Na	mg/l	48	60	26	41	109	18
K	mg/l	2	2	2	3	3	3
Ca	mg/l	76	28	26	40	50	41
Mg	mg/l	25	6	11	18	14	11
Fe	mg/l	u	0.35	u	u	0.78	u
SiO_2	mg/l	18	20	18	21	36	18
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.25	0.15	0.15	0.43	0.29	0.11
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	0.2	u	u	u	u	0.4
Li	mg/l	u	u	u	u	u	u
B	mg/l	u	u	u	u	u	u
F	mg/l	0.2	0.3	0.2	0.9	0.3	0.2
Cl	mg/l	64	28	16	40	54	26
SO_4	mg/l	53	2	19	26	u	19

Table 2. (continued.)

Sample #		D-14	D-15	D-16	D-17	D-18	D-19
Location		(B-3-1)14cdd 40°59'17" 111°55'18"	(B-3-1)14bbb 41°00'04" 111°55'38"	(B-3-1)1abc 41°01'39" 111°54'01"	(B-3-1)6aab 41°01'50" 111°59'26"	(B-4-1)29dbb 41°03'09" 111°58'31"	(B-4-2)27acc 41°03'11" 112°03'08"
Temp.	°C	21	17	13	16	24	15
pH		7.37	7.11	6.71	7.21	7.51	7.48
TDS	mg/l	252	332	256	160	140	176
HCO_3	mg/l	242	351	159	184	159	175
Na	mg/l	17	22	67	21	20	15
K	mg/l	2	4	2	1	2	1
Ca	mg/l	56	43	54	28	30	37
Mg	mg/l	13	13	8	8	7	8
Fe	mg/l	u	0.03	0.29	0.09	0.16	u
SiO_2	mg/l	10	13	29	20	21	17
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.21	0.12	0.29	0.11	0.09	0.15
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	0.3	u	u	u
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	u	u	u	0.2	0.3	0.1
Li	mg/l	u	u	u	u	u	u
B	mg/l	u	u	u	u	u	u
F	mg/l	0.2	0.2	0.2	0.2	0.3	0.2
Cl	mg/l	21	35	22	16	14	14
SO_4	mg/l	23	u	55	u	u	3

Table 2. (continued.)

Sample #		D-20	D-21	D-22	D-23	D-24	D-25
Location		(B-4-1)22ddd 41°03'37" 111°55'51"	(B-4-2)20bbb 41°04'28" 112°06'05"	(B-4-1)16bda 41°04'59" 111°57'30"	(B-4-1)8dcd 41°05'22" 111°58'24"	(B-4-1)3ccd 41°06'16" 111°56'43"	(B-4-2)6abb 41°07'03" 112°06'40"
Temp.	°C	22	15	18	13	12	16
pH		7.10	7.41	7.20	7.20	7.31	7.19
TDS	mg/l	230	212	154	224	294	240
HCO_3	mg/l	209	192	125	209	242	234
Na	mg/l	18	18	13	15	17	20
K	mg/l	3	2	u	u	2	2
Ca	mg/l	47	40	30	50	67	51
Mg	mg/l	12	10	8	12	15	15
Fe	mg/l	0.03	u	u	u	u	u
SiO_2	mg/l	24	19	16	15	16	16
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.09	0.19	0.07	0.12	0.15	0.27
Ba	mg/l	u	u	u	u	u	u
Mn	mg/l	u	u	u	u	u	u
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	u	u	u	u	u	u
Li	mg/l	u	u	u	u	u	u
B	mg/l	u	u	u	u	u	u
F	mg/l	0.2	0.2	0.2	0.2	0.2	0.3
Cl	mg/l	15	18	11	15	17	23
SO_4	mg/l	16	u	5	15	23	14

Table 2. (continued.)

Sample #		D-26	D-27	D-28	D-29	Ogden Hot Sprg.*	Hooper Hot Sprg.*
Location		(B-5-1)35baa 41°07'55" 111°55'14"	(B-5-1)27dcc 41°07'58" 111°56'13"	(B-5-3)25dbd 41°08'12" 112°07'40"	(B-5-2)26aaa 41°08'49" 112°01'34"	(B-6-1)23cca 41°14'09" 111°55'24"	(B-5-3)27cbd 41°08'13" 112°10'30"
Temp.	°C	14	12	18	17	56	57
pH		7.14	7.19	7.21	7.17	7.1	6.5
TDS	mg/l	286	320	246	270	9040	3830
HCO_3	mg/l	284	301	217	284	214	233
Na	mg/l	21	19	19	17	2948	2326
K	mg/l	1	1	2	1	354	222
Ca	mg/l	72	79	53	63	344	477
Mg	mg/l	15	18	14	17	6.6	76
Fe	mg/l	u	u	u	u	1.9	1.8
SiO_2	mg/l	16	14	19	13	45	28
Ti	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Sr	mg/l	0.17	0.26	0.30	0.26	8.5	10
Ba	mg/l	u	u	u	u	0.5	1.6
Mn	mg/l	u	u	u	u	0.7	1.4
Cu	mg/l	u	u	u	u	u	u
Zn	mg/l	0.2	0.4	0.1	u	u	0.2
Li	mg/l	u	u	u	u	6.9	2.4
B	mg/l	u	u	u	u	3.2	0.9
F	mg/l	0.3	0.2	0.3	0.2	3.6	0.9
Cl	mg/l	28	29	20	22	5060	4720
SO_4	mg/l	22	24	16	28	106	36

* Data collected from Glenn et al., 1980, Earth Science Laboratory Report No. 34.

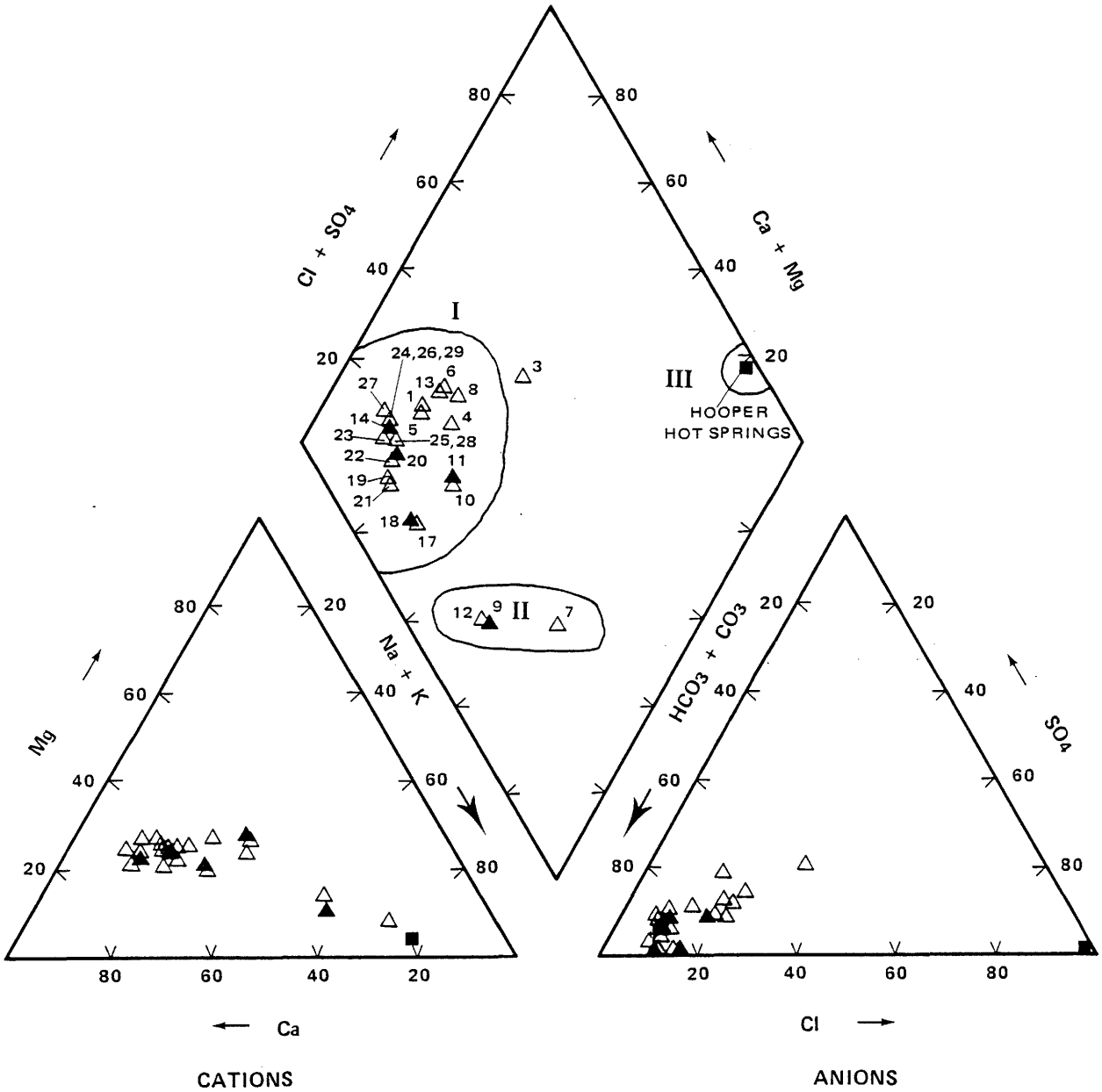

Figure 2. Piper diagram of common ions from samples collected in Davis County, Utah. Chemical constituents are plotted as percentage of total milliequivalents. Darkened symbols indicate samples with temperatures $\geq 20^{o}C$. Roman numerals indicate classification of water types.

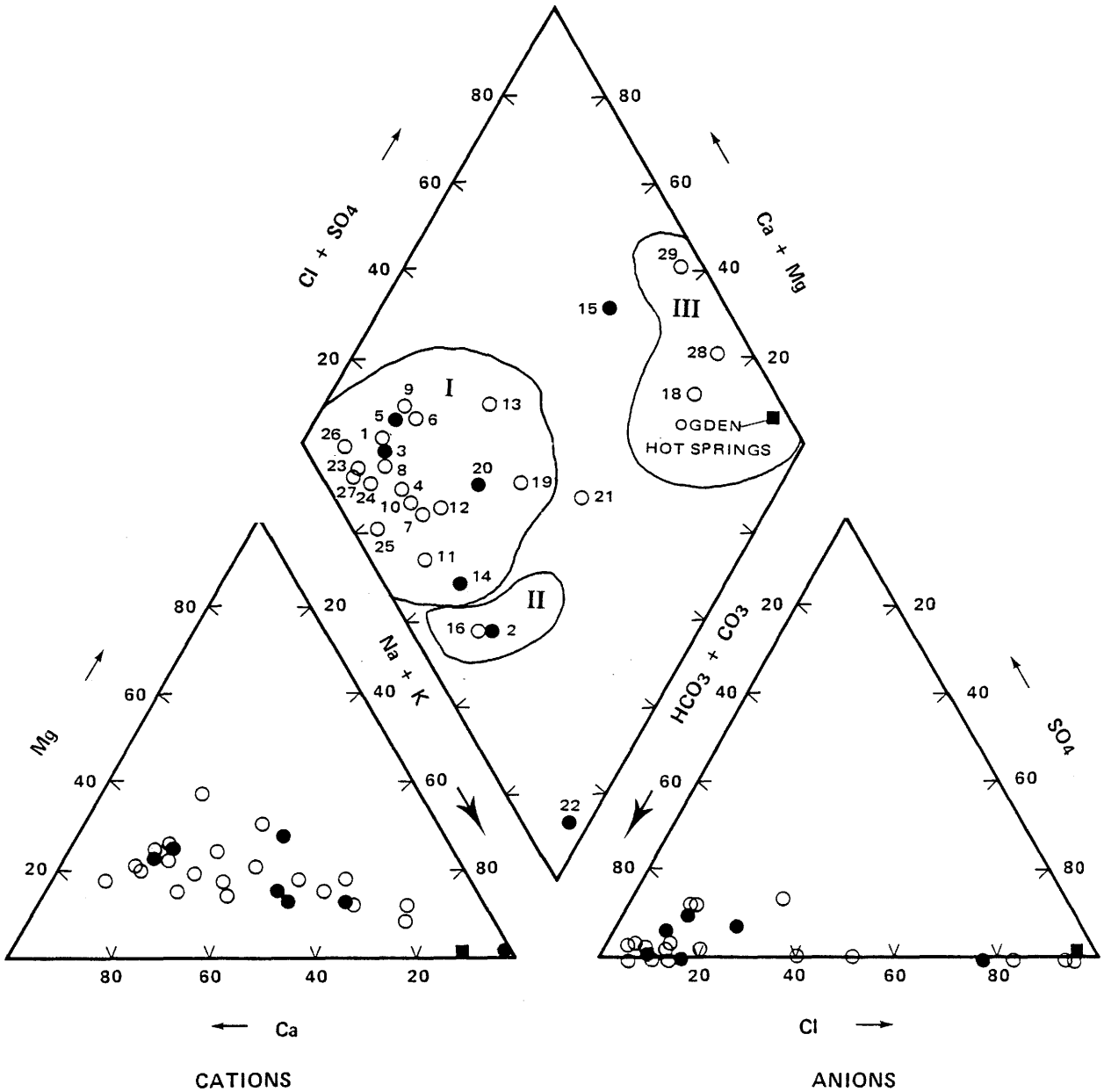

Figure 3. Piper diagram of common ions from samples collected in Weber County, Utah. Chemical constitutents are plotted as percentage of total milliequivalents. Darkened symbols indicate samples with temperatures $\geq 20^{o}C$. Roman numerals indicate classification of water types.

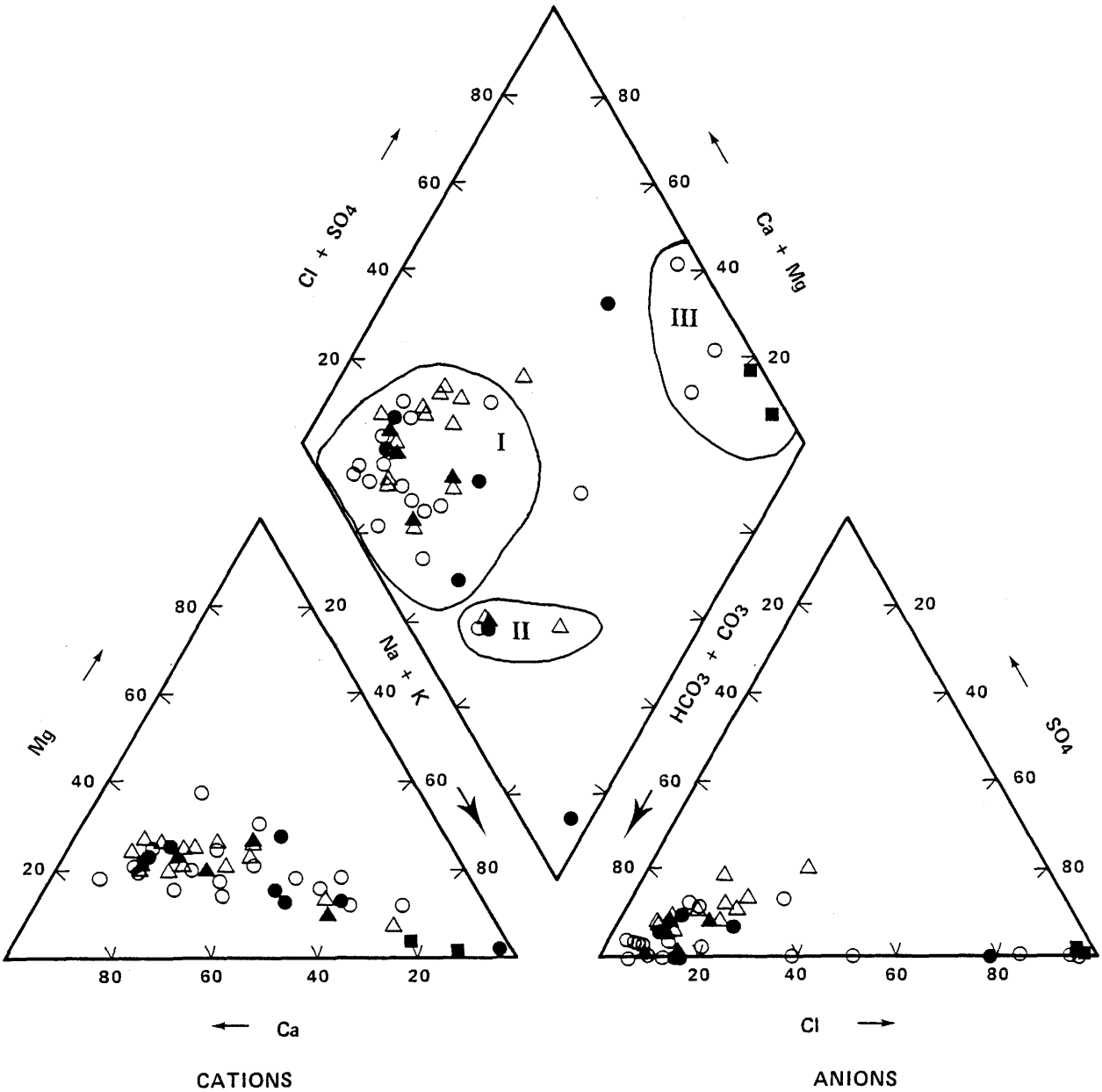

Figure 4. Piper diagram of common ions from all samples collected in Davis (△) and Weber (○) Counties, Utah. Squares represent Ogden and Hooper hot springs. Chemical constituents are plotted as percentage of total milliequivalents. Darkened symbols indicate samples with temperatures ≥ 20°C. Roman numerals indicate classification of water types. See figures 2 and 3 for identification of individual samples.

composing Type I water were enriched in calcium or calcium and magnesium with respect to other cations present and bicarbonate to other anions. Type I waters are representative of most ground-water recharge in the area and are characteristic of the Weber and Ogden Rivers, mountain-front streams, and seepage from the Wasatch Range. One other sample, not included in this group, was also Ca-Na HCO_3-Cl-SO_4 in character but contained significantly more TDS (1,152 mg/l).

Type II water is sodium - calcium bicarbonate - chloride - sulfate (Na-Ca HCO_3-Cl-SO_4) in character, dilute with TDS ranging from 178 to 438 mg/l, and slightly basic. All samples are enriched in sodium with respect to other cations present and bicarbonate to other anions. All samples included in Type II occur in the western margin of the study area both in Weber and Davis counties. These waters, occurring downgradient from Type I waters, have been attributed to calcium and magnesium being exchanged for sodium as the water moves through the lake clays (Feth et al., 1966).

Type III water is sodium-calcium chloride (Na-Ca Cl) in character with the exception of sample W-18 which has a sodium-calcium chloride-sulfate-bicarbonate (Na-Ca Cl-SO_4-HCO_3) character. Included with Type III are Ogden and Hooper Hot Springs. Type III water is slightly to moderately saline (TDS concentrations ranging from 1,470 to 9,040 mg/l) and slightly basic. Sample W-15 was not included with Type III because the TDS concentration was only 988 mg/l (dilute), the pH indicated the water was slightly acidic, and the water was calcium-sodium chloride-sulfate-bicarbonate (Ca-Na Cl-SO_4-HCO_3) in character. Unlike Type III water, W-15 was enriched in calcium plus magnesium with respect to other cations present. Type III waters are considered to be characteristic of thermal water defined by Cole (1982) as leakage from deeper geothermal reservoirs.

Three samples not included in the three major water types are D-3, W-21, and W-22. Sample D-3 is calcium-sodium chloride-sulfate-bicarbonate (Ca-Na Cl-SO_4-HCO_3) in character and dilute with a TDS concentration of 600 mg/l. Unlike W-15, however, D-3 is enriched in bicarbonate, has a considerably higher concentration of sulfate, and is slightly basic. Sample W-21 is sodium-calcium chloride-sulfate-bicarbonate (Ca-Na Cl-SO_4-HCO_3) in character, but unlike W-18, is dilute with a TDS concentration of 490 mg/l. Sample W-22 is unique with respect to other samples collected. Excluding the TDS concentration of 530 mg/l, W-22 is sodium bicarbonate (Na HCO_3) in character and basic (pH=8.2).

Plate 4 presents TDS distributions in the study area, depicting the anomalous concentrations for the potential low-temperature geothermal area. Plate 5 presents anomalous chloride distributions for the same area.

Stable Isotope Analysis

Stable isotope analysis was conducted by Cole (1982) in the East Shore area to determine the origin of the thermal waters located there. Results of this study indicate the thermal hot spring waters result from fault-controlled deep circulation of meteoric waters derived from high elevations in the mountains. This study also indicates leakage of thermal waters in the vicinity of those hot springs occurs from deeper reservoirs into overlying cooler aquifers.

Trace Elements

Certain trace element concentrations may be helpful in qualitatively distinguishing thermal from non-thermal waters in Davis and Weber counties. Li concentrations for those waters not included with the hot springs or proposed thermal anomaly in Figure 4 were primarily below detectable limits (0.050 mg/l). Six samples, however, had concentrations which ranged from 0.05 to 0.24 mg/l. The hot springs and the samples included in the thermal anomaly had, in comparison, Li concentrations ranging from 0.13 to 6.90 mg/l. Sr concentrations for hot spring waters and the thermal anomaly ranged from 1.13 to 10 mg/l. Strontium concentrations for all other samples ranged from 0.02 to 0.69 mg/l. Barium concentrations ranged from less than .50 to 2.40 mg/l for hot spring waters as well as those within the thermal anomaly. With the exception of sample W-21 (0.7 mg/l), Ba concentrations were below detectable limits (less than .625 mg/l) in all other waters sampled.

Other Geochemical Indicators

According to White (1970), the ratio of Ca/HCO_3 ranges from near 0 to 1,000 for natural thermal waters. White (1970) also states that qualitiative comparison of Ca and HCO_3 is often useful in distinguishing thermal from non-thermal waters. Ca/HCO_3 ratios seem to be a viable method for this purpose in Weber and Davis counties. Ca/HCO_3 for hot spring and the thermal anomaly water ranged from 0.96 to 6.23. Excluding D-2 (1.42), Ca/HCO_3 ratios ranged from 0.02 to 1.03 for all remaining samples collected and analyzed.

According to Ellis and Mahon (1977) ratios of soluble constituents such as Cl/B and Na/Li have been used in most explored geothermal areas as aids to determining the areal extent of a geothermal aquifer. Unfortunately, B and Li concentrations in this study area were below detectable limits in many samples collected and, therefore, use of these techniques was somewhat limited. Na/Li ratios for those samples with measurable Li provided no definitive results. Cl/B ratios where B was measurable, however, indicate that hot spring and proposed thermal waters are anomalous with respect to other samples with measurable B. Cl/B ranged from 476 to 1,667 for all thermal waters (hot spring and those in the anomaly); the remaining samples had Cl/B ratios ranging from 10 to 250.

Geothermometry

Chemical geothermometers were calculated for all water samples collected in Weber and Davis counties and for Ogden and Hooper Hot Springs, for which data were extracted from Glenn et al. (1980). Geothermometers considered applicable, and used in this study are: 1) silica (quartz conductive and chalcedony); 2) sodium - potassium - calcium (Na-K-Ca) with and without magnesium correction (Mg); and 3) sodium/lithium (Na/Li).

The reliability of SiO_2 and Na-K-Ca (with/without Mg correction) geothermometers depends upon five assumptions (Fournier et al., 1974). These assumptions are:

1. Temperature-dependent reactions occur at depth.
2. All consitutents involved in the temperature-dependent reactions are sufficiently abundant.

3. Water-rock chemical equilibrations occur at the reservoir temperature.
4. Little or no equilibration or change in composition occurs at lower temperatures as the water flows from the reservoir to the surface.
5. The hot water coming from deep in the system does not mix with cooler, shallow ground water.

Realistically, most low temperature thermal systems occur in hydrologic regimes which preclude all/some of these assumptions. Also, Fournier and Potter (1979) presented data which indicate the Na-K-Ca geothermometer gives anomalously high results for waters rich in Mg. They derived a temperature correction to accomodate this occurrence. Unfortunately, this correction is subject to error if the Mg concentration increases during upward flow while the water cools. This condition will result in an anomalously low calculated reservoir temperature.

Fouillac and Michard (1981) have suggested a third geothermometer based on Na/Li ratios. This geothermometer, understandably, should not be used alone, but does provide for comparison.

The SiO_2, Na-K-Ca, and Na/Li geothermometers are all commonly used in geothermal exploration. Each geothermometer, however, has certain limitations which preclude its use exclusively. Therefore, use of these geothermometers, in this report, will be limited to 1) providing temperature ranges that can be expected at depth, and 2) highlighting anomalies within the calculated results which could be indicative of low-temperature geothermal reservoirs.

Fournier (1977) suggests that if the Na-K-Ca geothermometer indicates a temperature of less than 100°C, the silica content of the water is a function of chalcedony solubility. For temperatures greater than 100°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 between 60 and 250 mg/l, it has not been determined whether chalcedony or quartz governs the amount of silica in the system. Due to the lack of concensus regarding which form of silica governs concentrations from temperatures between 100 and 180°C, both chalcedony and quartz temperatures were calculated.

Table 3 presents measured and calculated geothermometer temperatures for water samples collected in Davis County. SiO_2 (chalcedony) temperatures, for well samples with Na-K-Ca temperatures less than 100°C, ranged from 7 to 56°C while Na-K-Ca temperatures for those same samples ranged from -1 to 44°C. Two samples (D-22 and D-23) had K concentrations below detectable limits, thereby precluding the use of the Na-K-Ca method. Hooper Hot Springs provided a Na-K-Ca temperature of 197°C, the only sample with a Na-K-Ca temperature greater than 100°C. The SiO_2 (quartz) computed temperature for Hooper Hot Springs is 81°C while the Na/Li geothermometer provided a temperature of 78°C.

Excellent agreement between the SiO_2 (quartz) and Na/Li geothermometers for Hooper Hot Springs exists, but the Na-K-Ca temperature is significantly higher. However, the Mg correction provides a temperature of 103°C, which is in much better agreement. The Mg concentration for this sample, however, is significantly high which, according to Fournier (1981), indicates water rock reactions have occurred at relatively low temperatures which could subject this correction to error. A maximum temperature of no greater than 100°C is considered feasible for the system supplying Hooper Hot Springs unless significant dilution is occurring. Although five other samples

Table 3. Chemical geothermometers and surface temperatures for fluids in (°C) from Weber and Davis Counties, Utah.

Sample Number	Meas. Temp.	Chalcedony	Qtz. (Cond)	Na-K-Ca	Na-K-Ca (Mg corr.)	Na/Li*
W-1	15	21	53	22		
W-2	23	39	70	53		
W-3	20	31	63	27		
W-4	17	31	63	24		
W-5	23	31	63	17		
W-6	16	47	78	56		
W-7	19	33	65	35		
W-8	18	15	48	27		
W-9	15	13	45	16		
W-10	16	23	55	48		
W-11	17	33	65	52		
W-12	19	33	65	44		
W-13	18	29	67	279	48	41
W-14	20	29	62	43		
W-15	21	37	69	86	72	74
W-16	17	52	83	85	51	91
W-17	19	29	62	91	68	83
W-18	14	29	67	190	41	89
W-19	16	27	60	74	65	
W-20	21	33	65	98	37	63
W-21	17	37	74	108	60	110
W-22	22	44	79	129	48	24
W-23	13	15	48			
W-24	15	39	70	32		
W-25	15	23	55			
W-26	12	13	45			
W-27	13	10	42			
W-28	16	27	65	178	62	81
W-29	15	18	57	107	53	84
+Ogden H.S.	57	69	100	223		201
D-1	13	25	57	16		
D-2	14	23	55	32		
D-3	14	21	53	33		
D-4	13	18	51	30		
D-5	12	15	48	18		
D-6	15	21	53	20		
D-7	16	23	55	30		
D-8	15	27	60	20		
D-9	23	31	63	38		
D-10	15	27	60	33		
D-11	22	33	65	39		
D-12	17	56	87	44		
D-13	12	27	60	32		
D-14	21	7	39	17		
D-15	17	15	48	40		

Sample Number	Meas. Temp.	Chalcedony	Qtz. (Cond)	Na-K-Ca	Na-K-Ca (Mg corr.)	Na/Li*
D-16	13	47	78	28		
D-17	16	31	63	14		
D-18	24	33	65	28		
D-19	15	25	57	7		
D-20	22	39	70	30		
D-21	15	29	62	23		
D-22	18	23	55			
D-23	13	21	53			
D-24	12	23	55	15		
D-25	16	23	55	20		
D-26	14	23	55	1		
D-27	12	18	51	-1		
D-28	18	29	62	19		
D-29	17	15	48	1		
+Hooper H.S.	57	45	81	197	103	78

Spaces are blank if an element was undetectable or if $R > 50$, precluding the use of a particular geothermometer.
+Data collected from Glenn et al., 1980.

Equations for geothermometers used to compute subsurface temperatures:

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:

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

Where $B = 1/3$ for $t > 100^{o}C$
$= 4/3$ for $t < 100^{o}C$

SiO_2, Na, K, and Ca values in mg/l

Magnesium correction:

Temperature $70^{o}C$
$R > 50$
$R = (Mg/Mg+Ca+K) \times 100$

Mg, Ca, K in equivalent units of concentration

Na/Li:

$$t(^{o}C) = \frac{1000}{\log (Na/Li) + 0.38}$$

Na and Li in molarity

Sources: Fournier, 1981
Fournier and Potter, 1979
Fouillac and Michard, 1981

provided well head temperatures above 20°C, the chemical geothermometers indicate no significantly warmer thermal waters at depth.

Measured and calculated geothermometer temperatures for wells sampled in Weber County are also presented in Table 3. SiO_2 (chalcedony) temperatures for Na-K-Ca temperatures less than 100°C ranged from 15 to 47°C. Four samples (W-23, 25, 26 and 27) had K concentrations below detectable limits and, therefore, precluded the use of the Na-K-Ca geothermometer. SiO_2 (chalcedony) temperatures for these samples ranged from 10 to 23°C. SiO_2 (quartz) temperatures for samples with Na-K-Ca temperatures greater than 100°C ranged from 57 to 79°C. After employing the Mg correction, the Na-K-Ca temperatures were all less than 100°C and ranged from 41 to 62°C. Na/Li temperatures for these samples ranged from 41 to 110°C.

Samples from Weber County, other than Ogden Hot Springs, with geothermometer temperatures thought to be indicative of heat by deep circulation are W-15, W-28 and W-29. Other samples collected provided some warm temperatures, but failed to provide consistent results between all three geothermometers employed. Sample W-15 had the most consistent results, with temperatures of 69, 72 and 74°C for the SiO_2 (quartz), Na-K-Ca (Mg corrected), and Na/Li geothermometers, respectively. SiO_2 (quartz), Na-K-Ca (Mg corrected) and Na/Li temperatures for W-28 were 65, 62 and 81°C, respectively; results for sample W-29 were 57, 53 and 84°C. Na-K-Ca and Na/Li temperatures for Ogden Hot Springs were 223 and 201°C, respectively.

Generally, chemical geothermometer temperatures for well samples collected in Weber County indicate one area in addition to Ogden Hot Springs that might have potential as a low temperature geothermal resource. This area has been designated previously as having low-temperature geothermal potential (Plate 3). Although the temperatures in this area, with the exception of W-15, are

not anomalously warm, the geothermometers do indicate mixing has occurred and warmer water could be expected at depth. Sources for this water could be the result of leakage from concealed faults which are indicated to be present in this area on Plate 1. Another possibility is lateral flow resulting from leakage from Utah Hot Springs and/or Ogden Hot Springs.

Samples W-2, W-3, W-5, W-14, W-20 and W-22 have measured temperatures 20°C or greater, but common ion analysis and chemical geothermometry do not indicate any anomalous significance when compared to other samples collected in this area.

TEMPERATURE-DEPTH MEASUREMENTS

Temperature-depth measurements, and the subsequent temperature gradients derived thereof, 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 near-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 temperature. This effect is eliminated below 98 ft in depth (Kappelmeyer and Haenel, 1974). Also, temperature measurements are strongly influenced by the movement of ground water (sometimes to depths of hundreds of meters and it should always be recognized that temperature gradients are meaningful only for conductive heat transfer and that vertical,

as well as horizontal, convection can upset the extrapolation of temperature information (Laughlin, 1982; and Lumb, 1981).

Considerable time was spent trying to locate suitable "holes of opportunity" in Davis and Weber counties for the purpose of temperature-depth logging. Unfortunately, no suitable holes were located. However, two thermal gradient holes, as mentioned previously, were drilled at Hill Air Force Base near Ogden, Utah for a study conducted by Glenn et al. (1980) . According to the report, cold water near-surface aquifers of the Weber delta likely mask any deeper warm fluids that may be present; drilling to 3280 ft failed to identify any anomalously warm zones.

SUMMARY AND CONCLUSIONS

Geothermal reconnaissance techniques employed in Davis and Weber counties, Utah have identified an area as having low-temperature geothermal resource potential. This area is generally depicted by sample locations W-29, W-28, W-18, and W-15 and is identified on Plate 3 and other plates. Measured temperatures for these samples were generally quite low (14 to 16°C) with the exception of W-15 (21°C). However, geochemically this area is quite anomalous from other well waters sampled, but similar to Ogden and Hooper Hot Springs.

Common ion analysis for this area indicate these waters are Na-Ca Cl, Na-Ca Cl-SO_4-HCO_3 and Ca-Na Cl-SO_4-HCO_3 in character. Ogden and Hooper Hot Springs are also Na-Ca Cl waters. Samples W-29, W-28, W-18, and W-15 have common ion concentrations that are significantly different from all other samples collected in the study area; Na and Cl concentrations are much greater.

Na-K-Ca with/without the Mg-correction, SiO_2 (chalcedony and quartz), and Na/Li geothermometers identify this proposed low-temperature thermal area as having somewhat significant temperatures at depth. Temperatures to be expected range from 60 to 90°C while temperatures for other samples are primarily less than 50°C. These temperatures seem reasonable and compare favorably with research conducted previously by Cole (1982) and Glenn et al. (1980).

Trace element analyses indicates concentrations of Li, Sr, and Ba were generally higher for this proposed thermal area, as well as Hooper and Ogden Hot Springs, than for all other waters sampled in the study area. Lithium, Sr, and Ba concentrations range from 0.13 to 14.00 mg/l, from 1.13 to 10.00 mg/l, and from 0.50 to 2.40 mg/l, respectively. Concentrations of these trace elements for all remaining samples are as follows: 1) Li - undetectable to 0.25 mg/l; 2) Sr - 0.02 to 0.69 mg/l; and 3) Ba - undetectable with the exception of sample W-21 (0.70 mg/l).

Ratios of Ca/HCO_3 and Cl/B provided further evidence of a geochemical anomaly pertaining to the proposed thermal area. Ca/HCO_3 ratios for this area ranged from 0.96 to 5.54, were similar in value to Ogden and Hooper Hot Springs which had ratios of 5.66 and 6.23, respectively, and were significantly higher than all other samples with the exception of D-2 (1.42). Cl/B ratios for this area ranged from 476 to 1,667, were quite similar to Hooper and Ogden Hot Springs (1,667 and 1,000, respectively) and were also significantly greater than all other samples with detectable B. Na/Li ratioing provided no conclusive results.

This study was extremely limited in scope. Only geothermal anomalies affecting the near-surface unconsolidated aquifers could be identified by this approach. The absence of evidence does not eliminate the possibility that

additional resources do exist. Further exploration may establish a deep resource(s) heretofore unidentified.

PROPOSED GROUND-WATER MODEL

On the basis of previous investigations and fluid chemistry analysis, a geothermal model is propsed which accounts for the possibilty of a geothermal anomaly being identified in the area generally depicted on Plate 3. The model assumes the source of the thermal anomaly to be deep circulation of meteoric waters as was determined by Glenn et al. (1980), and Cole (1982). The model, as depicted in Figure 5, involves meteoric water migration to depths within the bedrock regime and heated from 60 to 90°C. This water is warmed and enriched in Na+K and Cl, and subsequently rises vertically within permeable fault zones eventually returning to the surface as hot springs (i.e. Ogden Hot Springs) or laterally, eventually intercepting and migrating up concealled faults within the basin further to the west and mixing with the near-surface aquifer. This mixing reduces the temperature and possibly somewhat changes the chemistry. This diluted, low-temperature water is then intercepted by water wells.

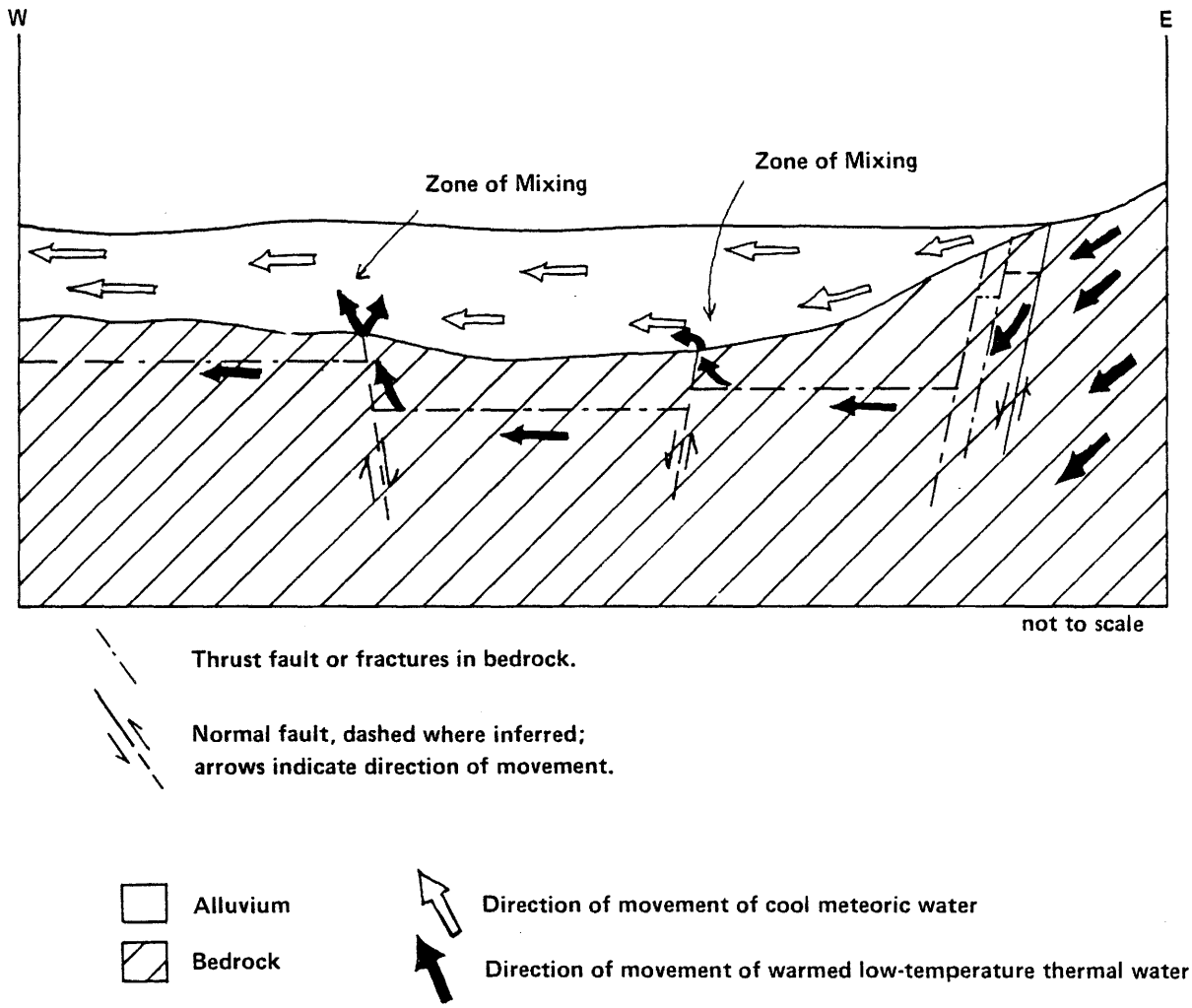

Figure 5. Model to account for the proposed thermal anomally generally depicted by samples W-29, W-28, W-18, and W-15 on Plate 3 as modified by Glenn et al.

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APPENDIX A

WELL AND SPRING NUMBERING SYSTEM

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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 SE1/4SE1/4NE1/4 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.

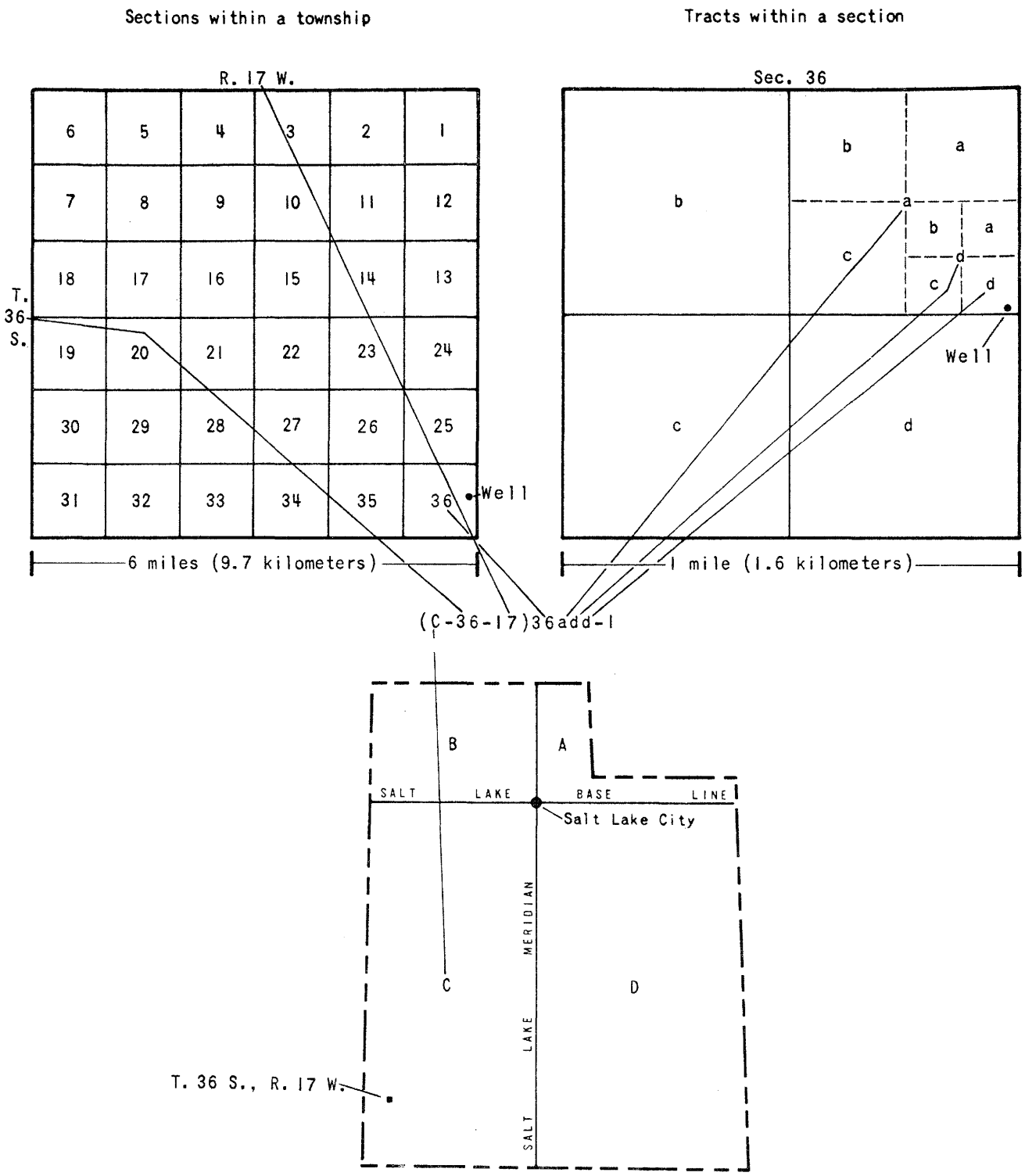


Figure 6. Well-, and spring-, and other data site-numbering system used in Utah.

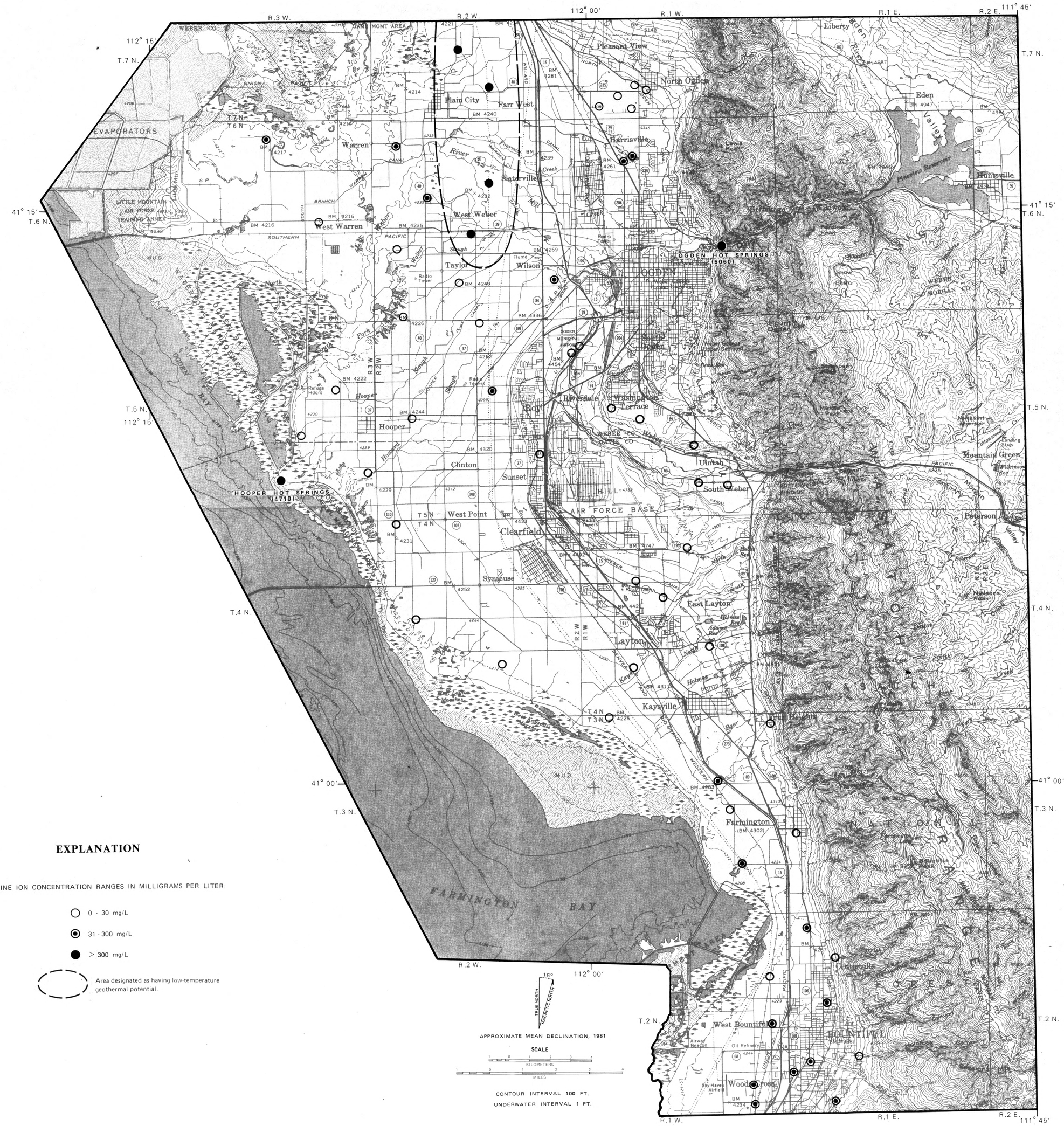
APPENDIX B

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.

CHLORIDE ION CONCENTRATIONS IN PARTS OF WEBER AND DAVIS COUNTIES, UTAH



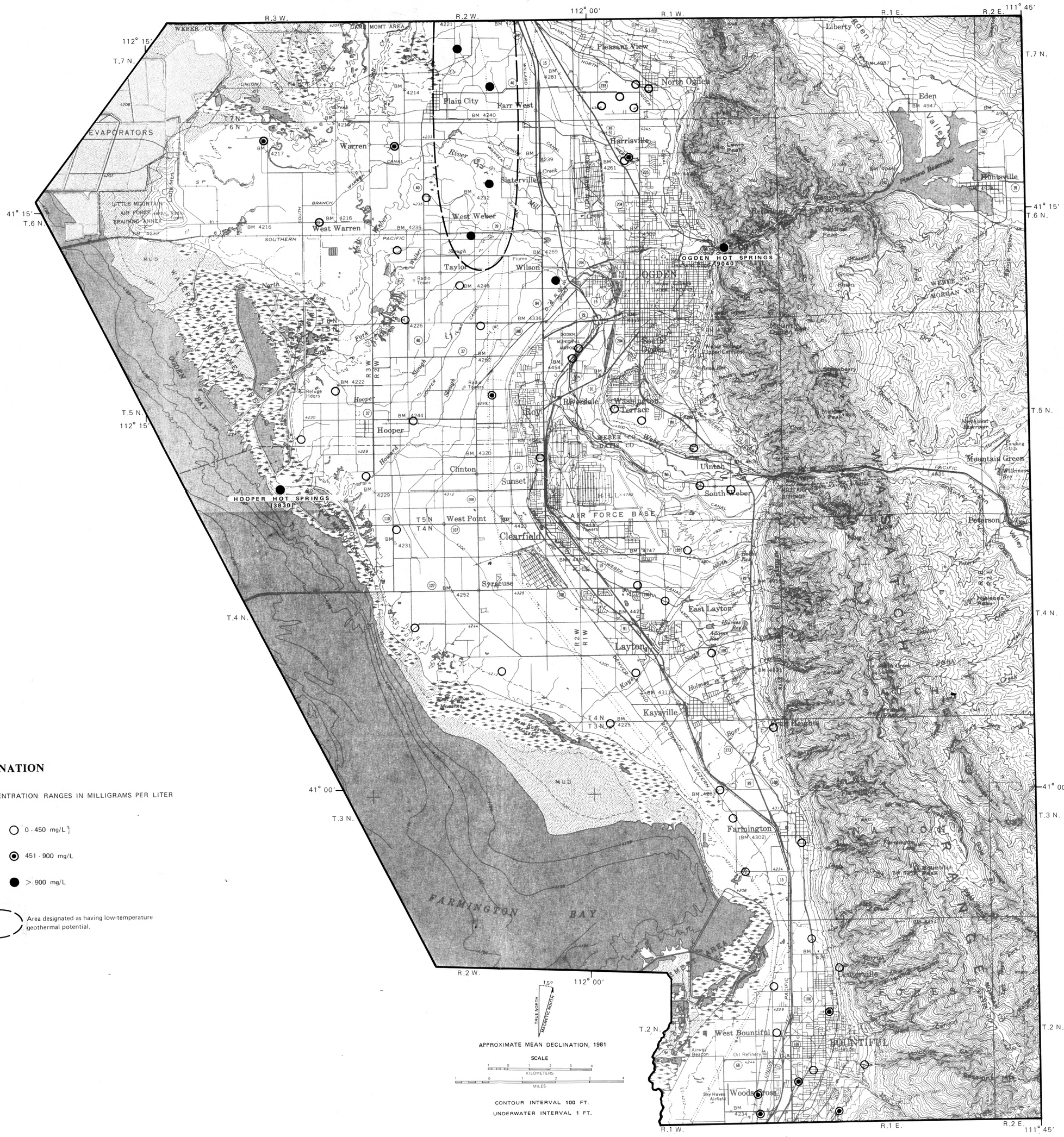
EXPLANATION

CHLORINE ION CONCENTRATION RANGES IN MILLIGRAMS PER LITER

- ○ 0 - 30 mg/L
- ◉ 31 - 300 mg/L
- ● > 300 mg/L
- Area designated as having low-temperature geothermal potential.

BASE FROM U.S. GEOLOGICAL SURVEY, GREAT SALT LAKE AND VICINITY 1:125,000, 1974

TOTAL DISSOLVED SOLIDS (TDS) IN PARTS OF WEBER AND DAVIS COUNTIES, UTAH



EXPLANATION

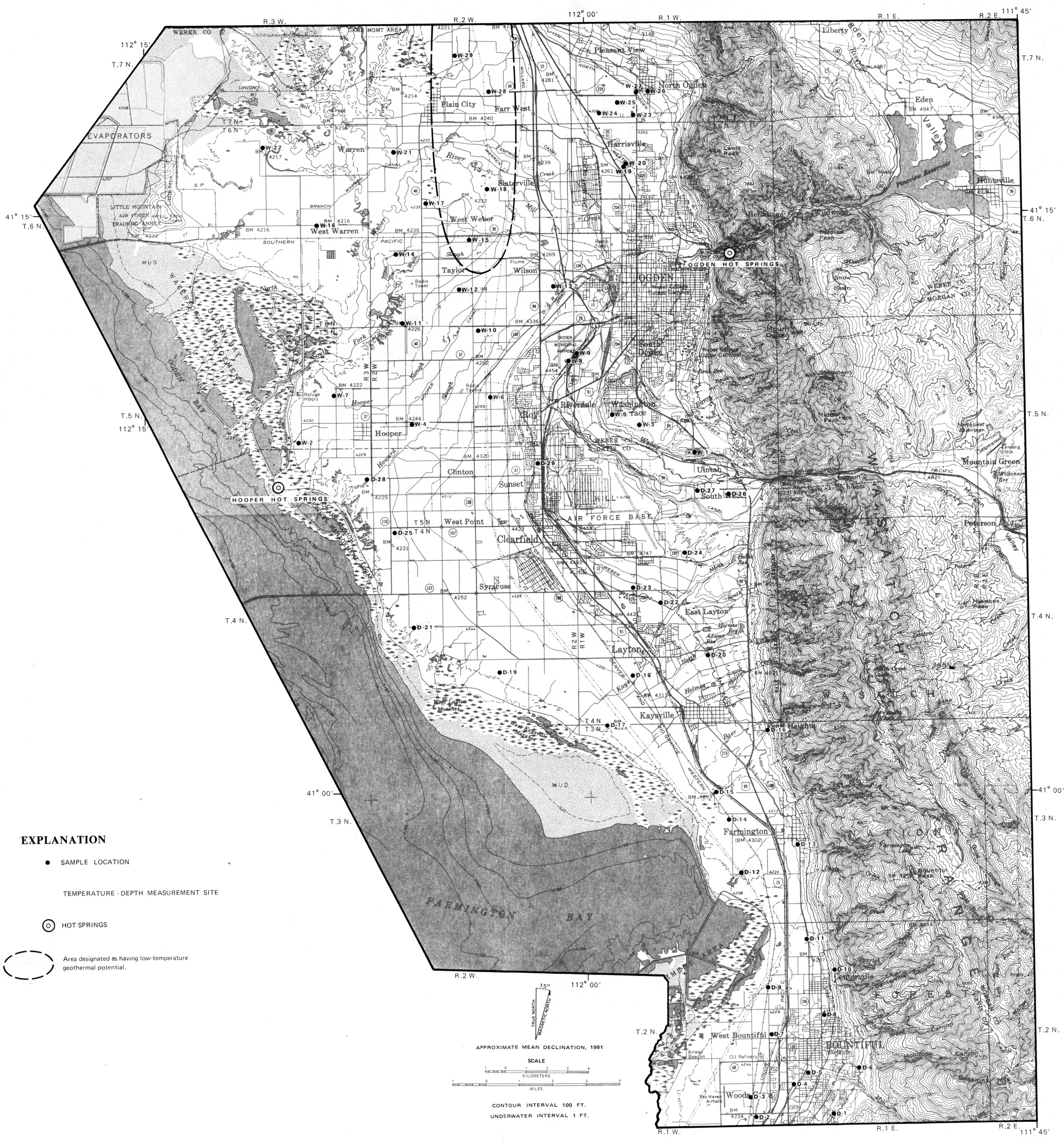
TDS CONCENTRATION RANGES IN MILLIGRAMS PER LITER

- 0 - 450 mg/L
- 451 - 900 mg/L
- > 900 mg/L

Area designated as having low-temperature geothermal potential.

BASE FROM U.S. GEOLOGICAL SURVEY, GREAT SALT LAKE AND VICINITY 1:125,000 , 1974

WELL AND SPRING SAMPLE LOCATIONS IN PARTS OF WEBER AND DAVIS COUNTIES, UTAH



EXPLANATION

● SAMPLE LOCATION

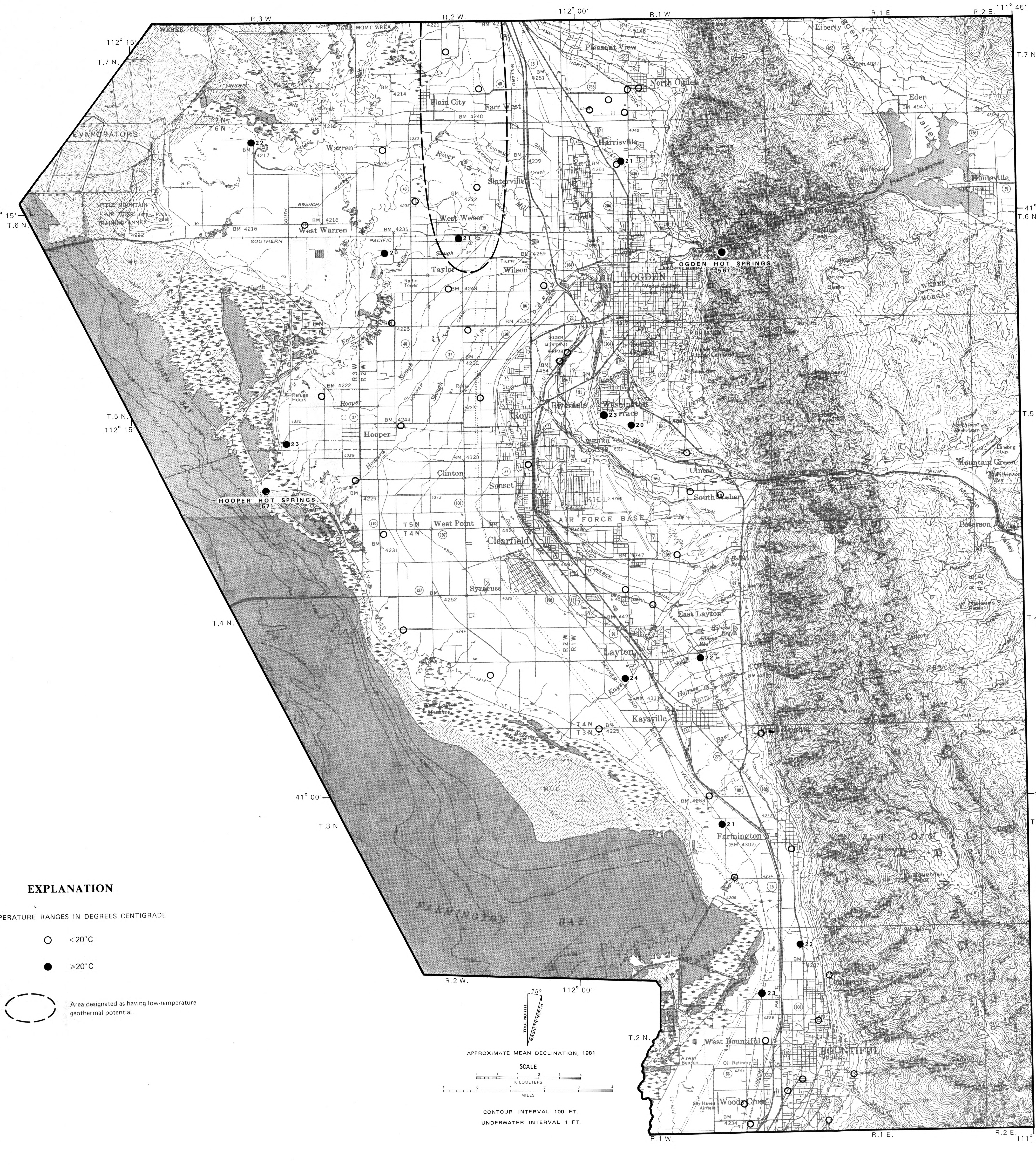
TEMPERATURE - DEPTH MEASUREMENT SITE

HOT SPRINGS

Area designated as having low-temperature geothermal potential.

BASE FROM U.S. GEOLOGICAL SURVEY, GREAT SALT LAKE AND VICINITY 1:125,000 , 1974

GROUND-WATER TEMPERATURE MAP FOR PARTS OF WEBER AND DAVIS COUNTIES, UTAH



EXPLANATION

TEMPERATURE RANGES IN DEGREES CENTIGRADE

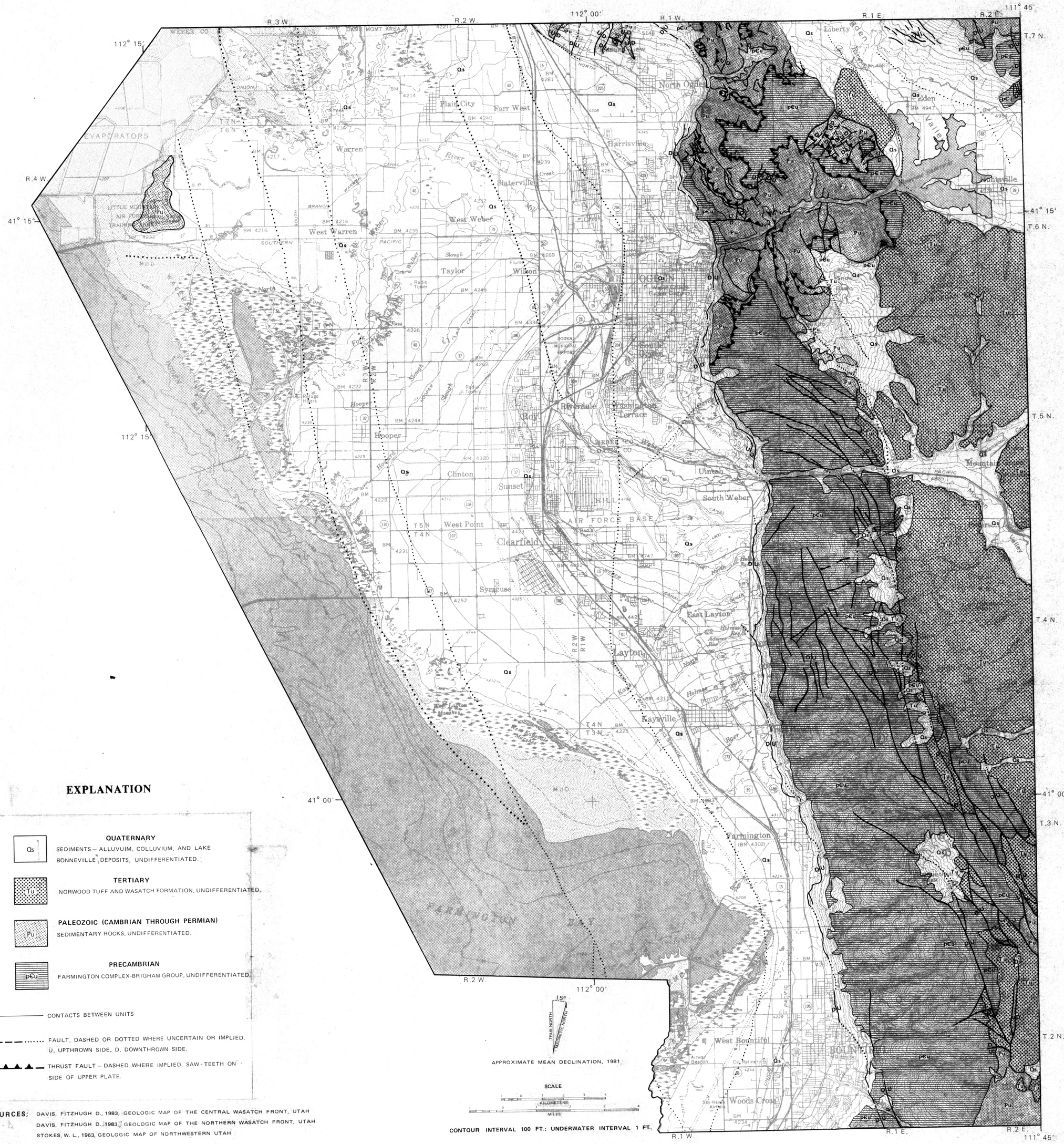
○ <20°C

● >20°C

Area designated as having low-temperature geothermal potential.

BASE FROM U.S. GEOLOGICAL SURVEY, GREAT SALT LAKE AND VICINITY 1:125,000, 1974

GEOLOGIC MAP OF PARTS OF WEBER AND DAVIS COUNTIES, UTAH



EXPLANATION

QUATERNARY
Qs — SEDIMENTS – ALLUVUIM, COLLUVIUM, AND LAKE BONNEVILLE DEPOSITS, UNDIFFERENTIATED.

TERTIARY
Tu — NORWOOD TUFF AND WASATCH FORMATION, UNDIFFERENTIATED.

PALEOZOIC (CAMBRIAN THROUGH PERMIAN)
Pu — SEDIMENTARY ROCKS, UNDIFFERENTIATED.

PRECAMBRIAN
pCu — FARMINGTON COMPLEX-BRIGHAM GROUP, UNDIFFERENTIATED.

CONTACTS BETWEEN UNITS

FAULT, DASHED OR DOTTED WHERE UNCERTAIN OR IMPLIED. U, UPTHROWN SIDE, D, DOWNTHROWN SIDE.

THRUST FAULT – DASHED WHERE IMPLIED. SAW-TEETH ON SIDE OF UPPER PLATE.

SOURCES; DAVIS, FITZHUGH D., 1983, GEOLOGIC MAP OF THE CENTRAL WASATCH FRONT, UTAH
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