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Report of Investigation

Utah Geological and Mineral Survey

No. 140

Geothermal Investigation of the Warm Springs Fault Geothermal System Salt Lake County, Utah

by
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Research Section
October 1979

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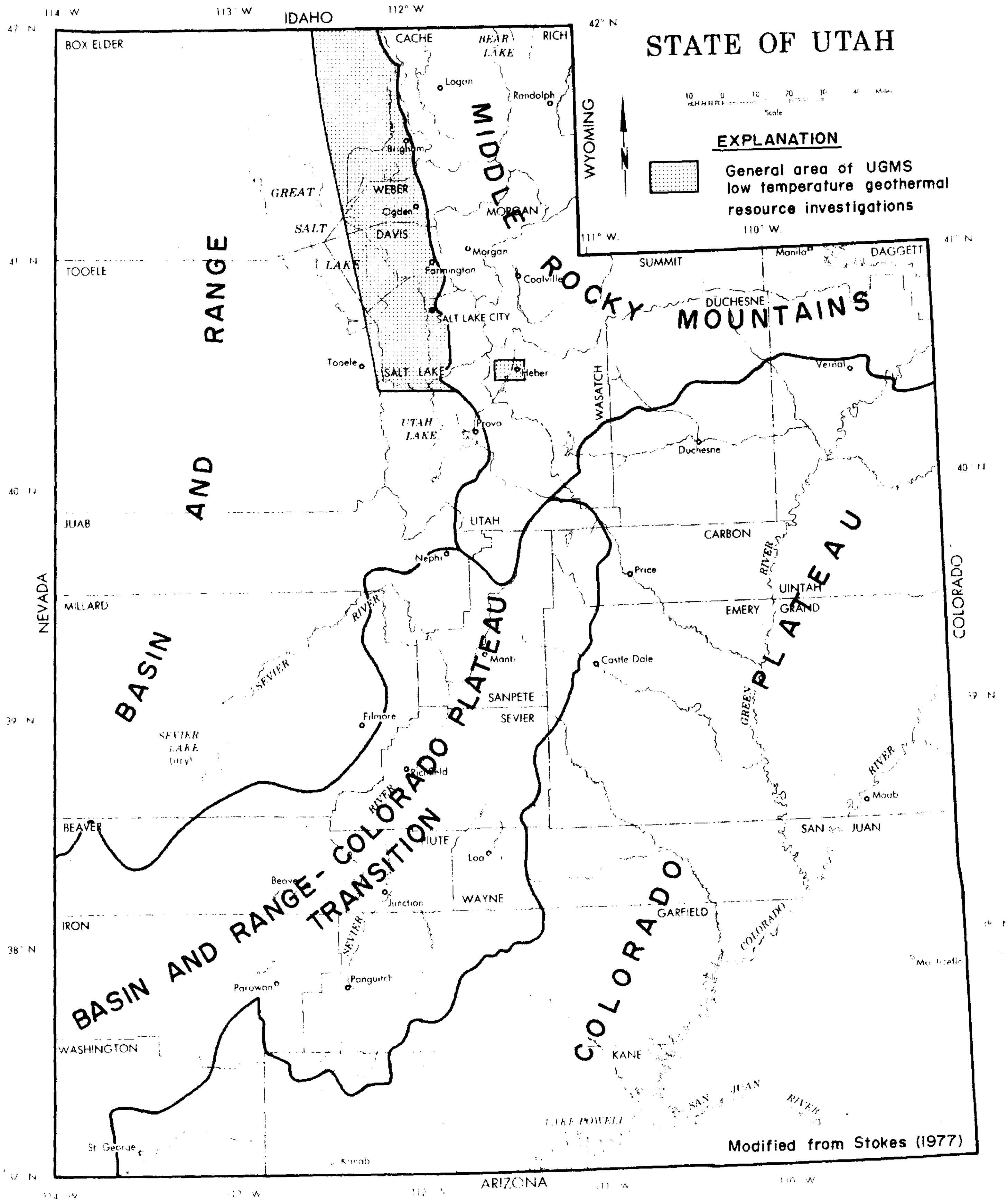
ABSTRACT

The Warm Spring Fault geothermal system is located in northern Salt Lake County at the northern limit of the Salt Lake City corporate boundary. The system is immediately west of the Wasatch Mountains at the easternmost edge of the Basin and Range physiographic province within an active seismic zone referred to as the intermountain seismic belt. The thermal springs of the system are located at the western edge of the Salt Lake salient that is intermediate in elevation between the Wasatch Range to the east and the deep valley graben to the west. Displacement from the salient into the graben occurs along two faults. The Warm Springs Fault has a minimum displacement of approximately 180 m (600 ft), and the down thrown block is buried beneath approximately 120 m (400 ft) of valley fill. A second fault referred as the Hobo Springs Fault lies to the west and has a total displacement of approximately 1220 m (4000 ft). Major thermal springs appear to be located near the intersections of these major normal faults with each other and with relatively minor pre-Basin and Range structures of the salient. Recharge to the system is believed to be from an undefined source area in the Wasatch Range, and the water is heated in the normal geothermal gradient by circulation to depths of 1.5 to 2 km. Data collected at the Warm Springs Fault geothermal system under the DOE/DGE state coupled program is presented for use by individuals interested in the system.

INTRODUCTION

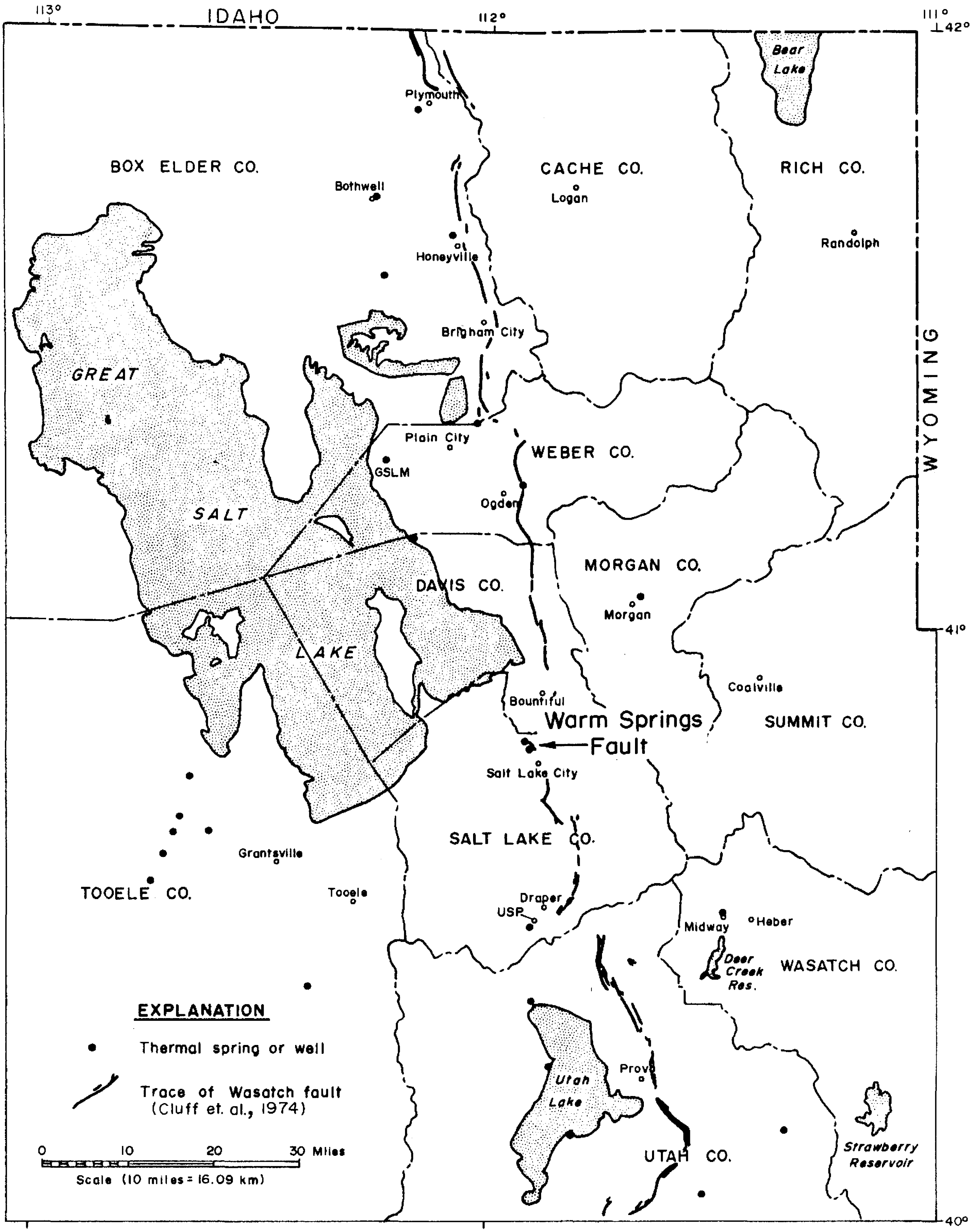
Under contract with the U. S. Department of Energy/Division of Geothermal Energy (DOE/-DGE), the Utah Geological and Mineral Survey (UGMS) has been conducting research to advance the utilization of low temperature geothermal heat in the state of Utah. Activities related to the contract (originally EG-77-S-07-1679 but later changed to DE-AS07-77ET28393) began on July 1, 1977 and will continue into 1980.

To date, UGMS has concentrated its investigations along the Wasatch Front from Utah Valley on the south to the Utah-Idaho state line on the north (figures 1 and 2). The reasons for the concentration of effort in this area of the state are as follows: 1) the concentration of apparent geothermal resources in this area and 2) the three major population centers of the state: (north to south) Ogden,



Index map showing major physiographic provinces of Utah

Figure 1



Location of the Warm Spring Fault geothermal system, Salt Lake County, Utah

Figure 2

Salt Lake City, and Provo lie within the region. The co-location of low temperature geothermal resources and potential users increases the possibility of timely resource development. Therefore, resource definition in populated areas should encourage the development of low temperature resources for direct heat applications by providing a data base from which potential users can make informed decisions. At the same time, investigations of the Basin and Range Province geothermal systems of the Wasatch Front will aid in the development of models that will be applicable to other Basin and Range geothermal systems.

Because of the proximity of the Warm Spring Fault geothermal system to major industrial and commercial developments, water from the system may potentially be used in a series of direct heat applications. The quality of the water is not as good as that from other area resources, but location of the system remains the most attractive characteristic of the resource. Should the extent of the system prove to be larger than presently known, the potential impact on space conditioning in downtown Salt Lake could be significant. Future investigations at the Warm Spring Fault system will be tied to an area wide investigation of the Jordan Valley during the 1979-1980 fiscal year.

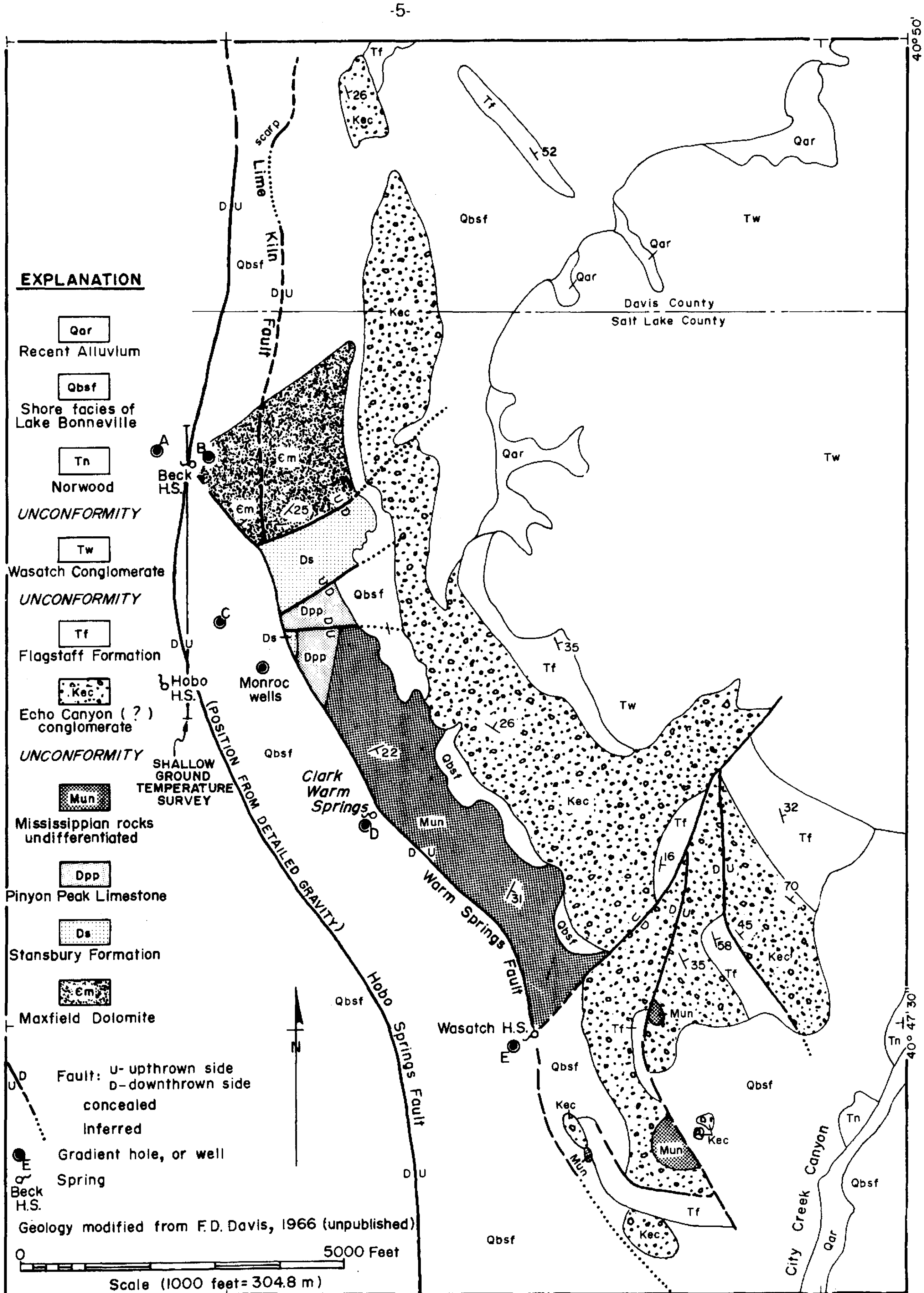
Regional Structural Setting of the Warm Springs Fault Area

Major tectonic elements of the Salt Lake City area include: 1) the westward extension of the Uinta arch and the associated Parley's Canyon synclinorium, 2) the Thrust Belt, and 3) the Intermountain seismic zone. The western extension of the Uinta arch intersects the Wasatch Front 12 miles to the south of the Warm Springs Fault. North of the arch the Parley's Canyon synclinorium is the primary structure of the Wasatch Mountains in the vicinity of Salt Lake City. The Thrust Belt is a north-south trending zone of Cretaceous to early Tertiary thrusting that extends from Mexico to Alaska, and influences the geology of central and western Utah. The Intermountain seismic zone is a north-south trending zone of relatively high seismicity that extends from northern Arizona to northwestern Montana, and is locally coincident with the Wasatch Front.

PHYSICAL DESCRIPTIONS

Warm Spring Fault

The Warm Spring Fault geothermal area is a strip approximately three miles long by 3/4 mile wide that parallels the western edge of the Salt Lake salient to the northwest of the Utah State Capitol Building. The area is heavily industrialized, and to the west and south includes residential, commercial areas and downtown Salt Lake City. The observed occurrences of warm water along the Warm Springs Fault are bound on the north by Beck Hot Springs, and on the south by Wasatch Warm Springs. Occurrences within these limits include Hobo Warm Springs, 1.2 km (3/4 mile) south of Beck Hot



Geologic map of Warm Springs fault area, Salt Lake and Davis Counties, Utah

Figure 3

Springs, Clark Warm Spring, and two shallow holes at the Monroc Corporation from which water is pumped. The locations of these warm water sources are shown in figure 3; temperature and water chemistry variables are presented in table 1. Additional reports of warm water in the subsurface have occasionally been made by individuals digging shallow trenches. Warm water was encountered in three of the five temperature gradient holes drilled by UGMS.

Becks Hot Springs

Many interesting descriptions of Becks Hot Springs, (B-1-1) 14dcb, and the surrounding area have been reported in Mundorff (1970). Before the spring orifice at Becks was modified, the spring apparently flowed from unconsolidated deposits covering the Maxfield Dolomite and drained westward into a large shallow lake referred to as Hot Spring Lake. Presently, the spring orifice is confined in a concrete box beneath the south bound lane of Beck Street and the spring discharge flows west through a series of drainage tiles and open ditches into the Jordan River. Hot Spring Lake no longer exists. Discharge from the spring varies on an annual cycle, but very few accurate discharge measurements are available. Reported spring temperatures range from 51 to 56° C. At the present time, the water is not being used as a source of heat, although some of the water is used to wash aggregate at a site approximately one half mile from the spring.

Hobo Hot Springs

Hobo Hot Springs, (B-1-1) 23 bdd, is a name used for a remnant of a larger area of springs that existed prior to urbanization of the area. The springs are presently confined to a narrow strip of swampy ground north of 1800 North St., between the Union Pacific railroad tracks and the unnamed road west of the tracks. Flow from the springs is drained to the north through a series of open ditches and drains, and is discharged with water from Becks Hot Spring into the Jordan River. The maximum recorded temperature at the spring is 37° C. The measurement was obtained by probing a spring orifice to a depth of 1.5 meters (5 ft). No discharge measurements are available for these springs. This water is not being used as a heat source, but combined with the flow of Beck Hot Springs the water is being used to wash aggregate.

Clark Warm Spring

The spring referred to here as Clark Warm Spring (figure 3) is located northeast of the Clark Tank Line facilities at 1450 N. Beck Street only 20 or 30 feet from the Warm Springs Fault scarp. The spring is an area of diffuse seepage and a number of small, shallow ponds. The ponds were formed by the placement of gravels on the down slope side of the spring by the property owners to prevent the flow of water on to Beck Street. These ponds do not freeze during the coldest winter months. During June of 1978, the spring temperature was 27° C. The flow of water from these springs is very small no use has ever been made of the water.

Wasatch Hot Spring

Wasatch Hot Spring, (B-1-1) 25 db, is approximately one mile northwest of the Utah State Capitol Building between Victory Road and Beck Street. The spring at one time supplied water to a popular bathing resort; over the years a series of 6 tunnels have been driven in attempts to increase spring flow. The tunnels were driven northeastward into cemented alluvium and tufa deposits. The tunneling usually increased the flow of the spring temporarily, but the discharge eventually decreased with time (Milligan, et. al., 1966). The spring discharge also varies with seasonal and climatic variations. Temperatures ranging from 38 to 42° C have been reported. The flow from the springs is not presently being used, and the water drains away from the site in a number of buried pipes. Much of the water is discharged into the storm sewer; eventually discharging into the Jordan River. The water rights for the spring are owned by the City of Salt Lake.

GEOLOGY AND STRUCTURE OF THE SALT LAKE SALIENT

The Salt Lake salient is an intermediate fault block of the Wasatch range. The general southeast dip of the early to mid Plaeozoic rocks exposed at the Warm Springs fault is similar to the dip of the Paleozoic rocks in the Parleys Canyon Synclinorium of the adjacent Wasatch range. On the salient, the Paleozoic sediments are unconformably overlain by a complex series of Cretaceous and Tertiary conglomerates and Tertiary lacustrine and volcanic units. The conglomerates are exposed from the Warm Springs fault to the main Wasatch range covering most of the pre-Cretaceous features of the salient. Lake Bonneville shoreline deposits of both Bonneville and Provo stages mantle the perimeter of the salient.

The Salt Lake salient is bound on all four sides by Basin and Range faulting. The salient is separated from the main Wasatch range by a normal fault located about 2 miles east of the area shown on figure 3 and having approximately 220 m (4000 feet) of throw. On the north flank of the spur, a number of southwest trending scarps in Quaternary deposits have been reported by Rogers (1978). An east-west trending scarp in both Tertiary and Quaternary deposits has been mapped by Davis, 1966 east of the are in figure 3.

Evidence of faulting is most prominent on the western edge of the salient (figure 3), where extensive quarrying of Lake Bonneville sands and gravels has exposed a two-mile section of fault scarp referred to as the Warm Springs Fault. The fault strikes northwest, but the trace is somewhat sinuous. The slickensided scarp exposure is 60 to 90 m (200 to 300 ft.) in height. and the fault dips to the southwest at approximately 65 to 70°.

Exposed in the north end of the Warm Springs Fault scarp are three high angle normal faults, which strike east to northeast and intersect the main scarp at close to right angles (figure 3). East of the main scarp, the faults are buried under Lake Bonneville shoreline facies and Cretaceous conglomerates that do not appear to be displaced. The total displacement across these faults is less than the total thickness of the Stansbury Formation which is approximately 91 m (300 ft.) thick. There is little doubt that these same fractures are present on the downthrown block of the Warm Springs fault that is buried beneath approximately 120 (400 ft.) of valley fill to the west of the Warm Spring fault.

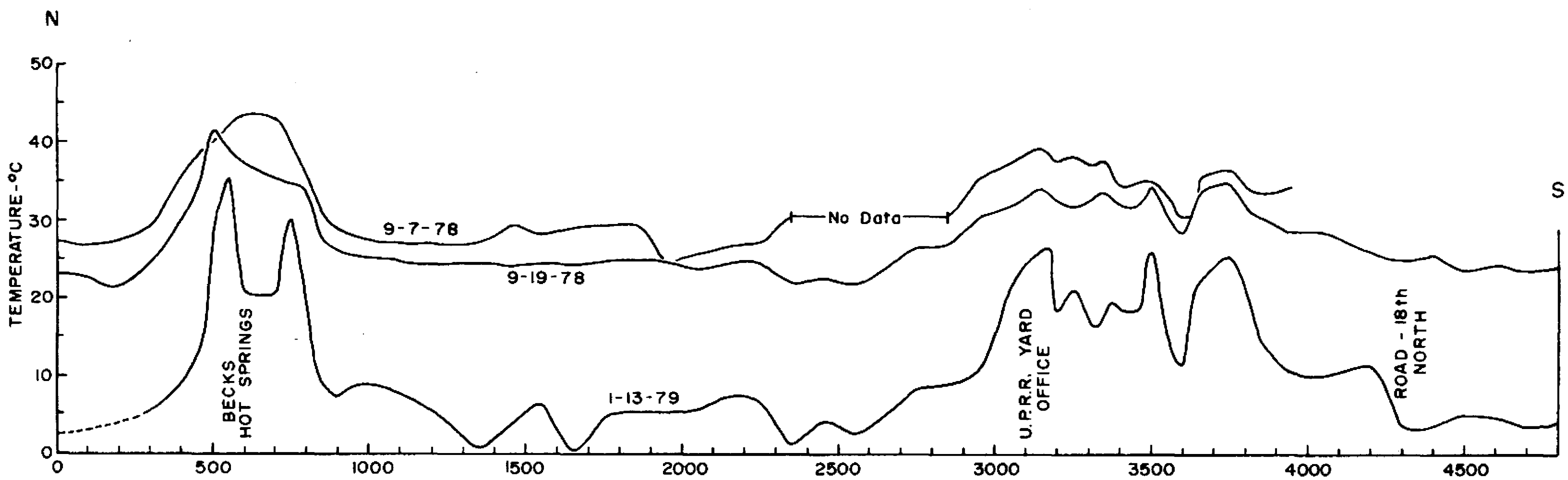
The southwestern corner of the salient is broken into a number of rotated fault blocks by a series of normal faults (figure 3) that strike northwestward, subparallel to the Warm Springs fault. In the vicinity of Hell Canyon, the faults change strike, to north-northeast, and terminate against the northeast trending Hell Canyon fault. Although the Hell Canyon fault is covered by slopewash and Lake Bonneville shoreline facies, the fault has been projected to the Warm Springs fault where it intersects the plane of the fault in the vicinity of Wasatch Hot Spring.

SHALLOW GROUND TEMPERATURE SURVEY

In an effort to locate and define areas where warm water is present in the near surface between Hobo Warm Springs and Becks Hot Spring, UGMS augered a series of holes to an approximate depth of one meter on 15 to 46 m (50-150 foot) spacings along the west edge of Beck Street (figure 3). After augering, a 3/4 inch diameter PVC pipe was inserted in the holes and time was allowed for drilling induced temperature effects to dissipate. Two sets of temperature measurements, (see figure 4) were taken during September, the first being separated from the second by a week of cool temperatures and rain showers. A third set of temperatures, seen in figure 4, was taken the following January.

The temperatures profiles in figure 4 graphically illustrate the influence of solar warming on shallow ground temperatures. In September, the background temperatures were high as a result of an entire summer of solar warming, and the thermal anomalies were poorly defined. In January, solar warming had been negligible for several months, and the solar heat stored in the upper few meters of the ground had dissipated into the atmosphere, decreasing the background temperatures. The thermal anomalies induced by the presence of warm water in the shallow subsurface were sharply defined against the low January background temperatures.

The thermal anomaly associated with Becks Hot Springs in the January profile is a 500 foot wide



Shallow ground temperatures- Beck Hot Springs to 1800 north
Warm Springs fault geothermal area, Salt Lake County, UT.

Figure 4

Table 1. Temperatures and chemical analyses of spring and well water from the warm springs fault geothermal area, Salt Lake County, Utah

Owner or Name	Temp.	Date of Collection	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	SO_4	Cl	No_3	F	T D S	Cond. µmho	pH
			mg/l													
Beck Hot Spring[1]	55°C	1977	40	0.21	793	138	4,380	206.8	285	880	7,900	–	–	–	–	6.14
Beck Hot Spring[2]	55°C	7-26-67	32	–	746	131	4,250	156	221	985	7,470	0.7	3.3	13,900	2.08×10^4	7.4
Hobo Warm Spring[3]	33°C	6-19-78	35	–	660	146	3,650	250.	208	950	6,700	–	–	12,620	2.0×10^4	6.4
Monroc Wells[3]	39°C	6-20-78	37	–	620	158	3,500	175.	119	890	6,700	–	–	12,820	2.06×10^4	6.4
Clark Warm Spring[3]	27°C	6-27-78	22	–	580	146	2,100	130.	183	1,230	4,700	–	–	9,700	1.49×10^4	6.8
Wasatch Hot Springs[2]	40°C	7-26-67	10	–	433	90	1,620	70.	244	818	2,820	7.3	2.8	6,000	9.54×10^3	7.9

[1] Parry and Cleary (1978)
[2] Mundorff (1970)
[3] Samples by UGMS not treated by USGS standards

dual peaked anomaly reaching a maximum temperature of approximately 25°C above background values. The peaks occur 100 feet either side of the entrance to the concrete box that confines the spring, and may indicate the presence of two spring orifaces. An alternative explanation of the anomaly is that the relatively low temperatures in the vicinity of the box are a result of the efficient draining of the thermal waters away from the spring, thus lowering the surrounding ground temperatures.

A second thermal anomaly is present between the UPRR yard office and 1800 North St. The anomaly is approximately 460 m (1500 feet) wide and is composed of three major peaks that reach a maximum of 18°C above background values. The width of the anomaly is an indication that leakage is occurring through a number of orifaces over a wide zone. A similar situation can be observed at the surface just west of the railroad yard anomaly at Hobo Hot Springs; the two systems are undoubtedly related and may be controlled by the same structures. Employees at the railroad terminal indicated that prior to the construction of the terminal, a series of warm ponds were located on the site. Aerial photography taken in 1946 confirms the presence of the ponds.

Milligan, et. al. (1966) report the existence of a number of springs and seeps in this region stating: "For a distance of one-half mile south of Becks Spring, and bordering the railroad tracks, thermal waters maintain several pools and swamps, . . .". If springs were at one time present between Becks Hot Springs and Hobo Hot Springs, they are either being efficiently drained or have ceased flowing, as no evidence for other warm water seeps or springs were found in the shallow ground temperature survey.

WATER CHEMISTRY

The TDS content of Warm Spring Fault thermal waters range from 6000 to 14000 mg/l. In general, water with the highest TDS value is found at the northern end of the system. Becks Hot Springs, Hobo Hot Springs, and the Monroc water wells (figure 3) all produce water that ranges in TDS content from 12,800 to 13,900 mg/l. At the southern extent of the known warm water occurrences, Wasatch Hot Springs has a TDS value of approximately 6000 mg/l. Between these two extremes the TDS content of water from Clark Warm Spring is approximately 9700 mg/l.

In general, the concentrations of individual ions vary directly with the value of TDS, for example as the TDS increases so do the values of calcium and magnesium. However, in the high TDS waters most of the increase is found in the sodium and chloride concentrations. Using the ion concentrations reported in table 1, sodium and chloride concentrations increase by a factor of 3 from Wasatch Hot Spring to Becks Hot Springs while the concentrations of other ions remain constant or increase by no more than a factor of 1.5. In the Warm Springs Fault area, 45 to 80% (by weight) of the TDS content is due to the sodium and chloride ions.

Generally, water in the valley fill aquifers to the west of the salient is also high in TDS. A water test well drilled south of Wasatch Hot Springs (B-1-1-3abb, encountered saline water in the permeable intervals of the aquifer; the TDS of the water increased markedly with depth. A number of water wells drilled to the west of the area have been plugged and abandoned because the water was too saline to be used.

The relationship between the thermal water and the water in the valley fill aquifers is not fully understood, and a number of possible mechanisms might be used to explain the water chemistries observed at the western edge of the Salt Lake salient. A comprehensive water sampling program, planned for the 1979-1980 field season, may provide new insight into the chemistry of the Warm Spring Fault geothermal area.

SUBSURFACE DATA

Holes of Opportunity

Only a very limited number of water wells have been drilled in the vicinity of the Warm Spring Fault, and most are 1 to 1.5 miles to the west. A deep water well near the radio towers of Radio Station KLUB, (B-1-1)15dbd, was drilled to 223 m (732 ft) and encountered alternating layers of sand and clay. Another deep water test hole drilled by Amoco to the south of the area encountered sands and clays to a depth of over 300 m (1000 feet). Monroc Inc., operates two large diameter warm water wells that are less than 30 m (100 feet) in depth at their Beck St. plant. None of the above wells were available for temperature gradient measurements, and none encountered bedrock.

Two closely spaced oil tests have been drilled approximately one mile west of the salient. The top of the Tertiary is reported at two vastly different elevations, and its actual depth in the graben to the west is undetermined.

Temperature Gradient Holes

In the fall of 1978, UGMS contracted with Petersen Brothers Drilling Company of Salt Lake City, Utah to drill 13 temperature gradient holes in northern Utah. Five of these holes were located along the Warm Spring Fault (see figure 3). All five of the holes were to be drilled to depths of 75 to 90 m (250 - 300 feet) however, drilling problems precluded reaching over 75m (245 feet) in a number of the holes. The holes were logged by UGMS and samples were taken every 5 to 10 feet. Lithological logs for each hole are presented in Appendix A, and temperature gradients are presented in figure 5.

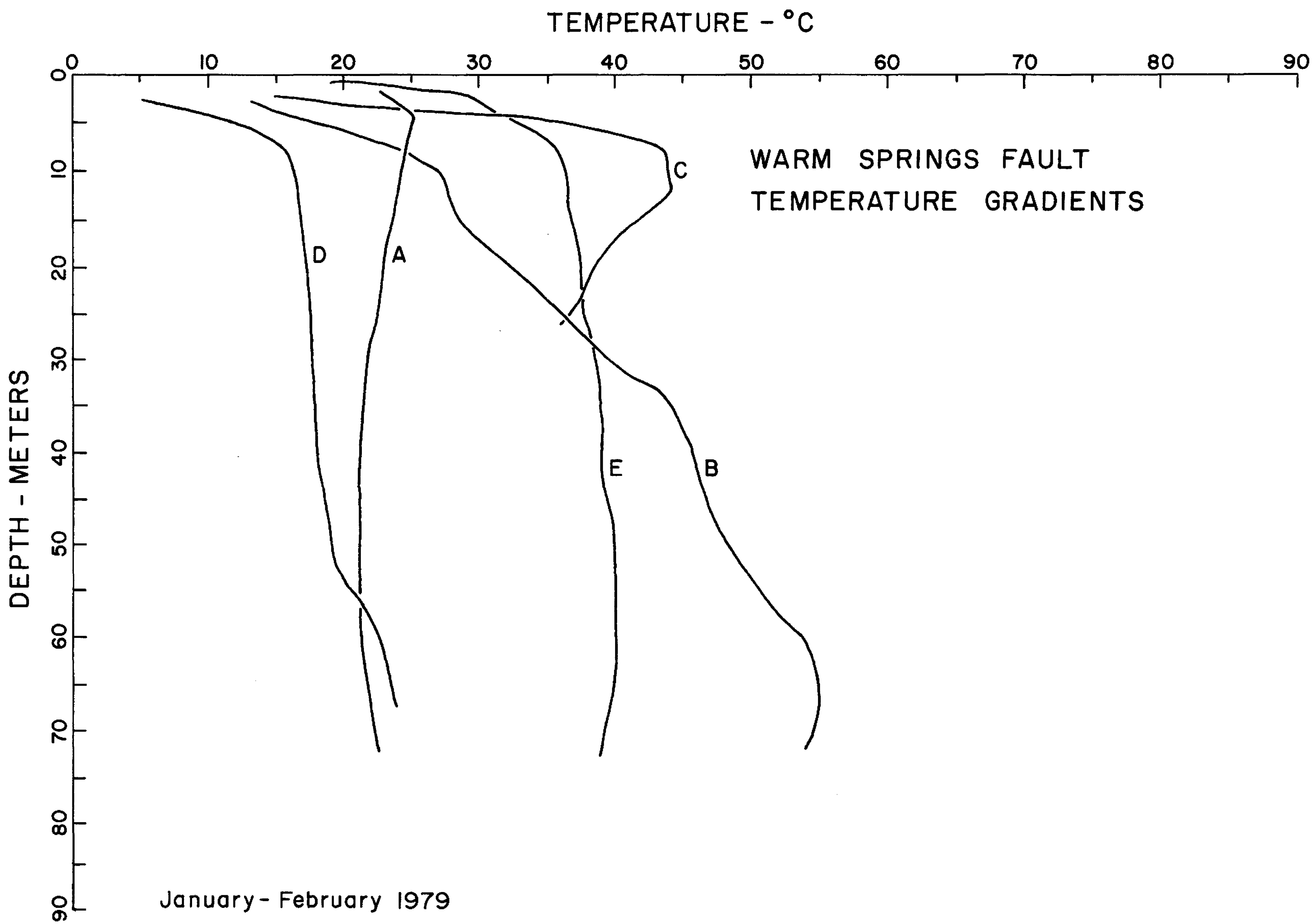
The drill holes encountered a variety of materials. Holes C,D, and E were drilled in Lake Bonneville shoreline deposits consisting mainly of sand and gravel with occasional intervals of clay. Hole A encountered sandy clay from the surface to total depth, and hole B encountered weathered and fractured dolomite to total depth. Warm water was blown from holes B, C, and E during drilling.

Holes A and B flank Beck Hot Springs to the west and east respectively. Hole B is under the direct influence of the Becks Hot Spring system, and large volumes of water with temperatures ranging from 21 to 47.5°C were blown from the hole during drilling. The gradient for hole B in figure 5 is somewhat irregular, but is in general a gentle curve as the gradient gradually decreases with depth. There is some indication of a reversal in the gradient at the bottom of the hole, possibly indicating that the highest temperature recorded in the hole is the result of lateral hot water flow. Hole A did not contain warm water, but is influenced by the hot spring system. The hole penetrated clay and sandy clay from the surface to the total depth. The upper portion of the gradient curve is elevated in temperature with respect to the lower portion of the curve; the heat causing the elevated temperatures is not coming from below. Solar effects can be discarded as a possible source because the warming is too deep and the temperatures in figure 5 were taken in January-February and April when solar heating is at a minimum. The probable cause of the elevated shallow temperatures is lateral conduction of heat from a source in the near surface. Water from the Becks Hot Spring system may be present in gravels to the east thus elevating the surface temperatures in hole A. The gradient in the bottom of hole A, obtained by fitting a straight line to the bottom portion of the curve, is estimated to be 100°C/km.

Hole C was the first hole drilled along the Warm Springs Fault and an unexpectedly thick sequence of sand and gravel caused the steel well casing to pinch and precluded advancing the hole past a depth of 26m (86 feet). The temperature in hole C increases to a maximum of approximately 45°C between 8 to 12 meters (25-40 feet) in depth, then decreases over the remainder of the hole. The reversal indicates the lateral flow of warm water in a near surface zone of permeability. The warm water may be flowing laterally away from the Hobo warm spring system present to the west, or away from some as yet undetected fracture in the subsurface.

Hole D encountered thick units of sand and gravel separated by relatively thin units of clay. The maximum temperature recorded in the hole was 24.3°C. An estimated gradient for the upper 50 meters of the hole is 64°C/km, while a straight line fitted to the bottom 15 meters of the curve yields a gradient of 150°C/km.

Hole E encountered a series of sands and gravels containing varying percentages of clay and is located approximately 75 meters (250 feet) west of the present outlet of Wasatch Hot Springs. The generally elevated temperatures measured below 5 meters are the result of the lateral flow of warm



TEMPERATURE - °C
0
10
20
30
40
50
60
70
80
90
DEPTH - METERS
WARM SPRINGS FAULT
TEMPERATURE GRADIENTS
A
B
C
D
E
January - February 1979

Figure 5

water through the sands and gravels from the spring system located to the east.

DETAILED GRAVITY SURVEY

A detailed gravity survey of the Warm Springs Fault geothermal area was contracted for by UGMS in November of 1978. Richard C. Fox, Geophysical Consultant was the successful bidder, and completed the survey in February of 1979. The survey consisted of 12 east-west gravity lines along which stations were spaced at 152 to 304m (500 to 1000 feet) intervals. The distance between lines varied from 0.4 to 1.2 km (0.25 to 0.75 miles) figure 6.

Although detailed modeling of the survey results has not yet been completed, some preliminary results are available. The gravity values contoured in figure 6 are observed Bouguer values; the regional gradient has not been removed for calculation of accurate depths to bedrock however the positions of structures and approximate depths to bedrock can be obtained from the data in figure 6.

One of the 12 gravity profiles has been modeled using a three dimensional gravity modeling program. The observed gravity profile, the modeled gravity profile, and a simple bedrock-alluvium model for profile 5 are presented in figure 7. Good agreement was obtained between the observed Bouguer gravity profile and the gravity profile computed for the model. The model consists of two faults on the eastern edge. a deep alluvium-filled graben, and a horst block on the western edge. The eastermost fault corresponds to the Warm Spring Fault, and the down thrown block is covered by several hundred feet of alluvium. Approximately 460 m (1,500 feet) to the west, a single and almost vertical fault having approximately 1220 m (4,000 feet) of relief defines the eastern edge of the deep graben. This fault corresponds to the Hobo Springs Fault in figure 3. At the western edge of the graben, a horst block rises to within approximately 460 m (1500 feet) of the surface.

There are a number of variations in the shapes of the gravity profiles from line to line figure 6, however the general model described above appears to be applicable to each profile. The steeply dipping gravity surface is an indication that the major displacement occurs over a very short horizontal distance and may actually occur on a single fault plane. The width of, and depth to the downthrown block of the Warm Springs Fault increase to the south of line 5, but displacement across the Warm Springs fault remains minor in comparison to the Hobo Springs Fault to the west. Becks and Wasatch hot springs are located near major breaks in the north-northwest trend of the gravity contours.

The above comments are based on limited modeling of the detailed gravity survey data, and additional work will better define the location of the main range from fault and provide better esti-

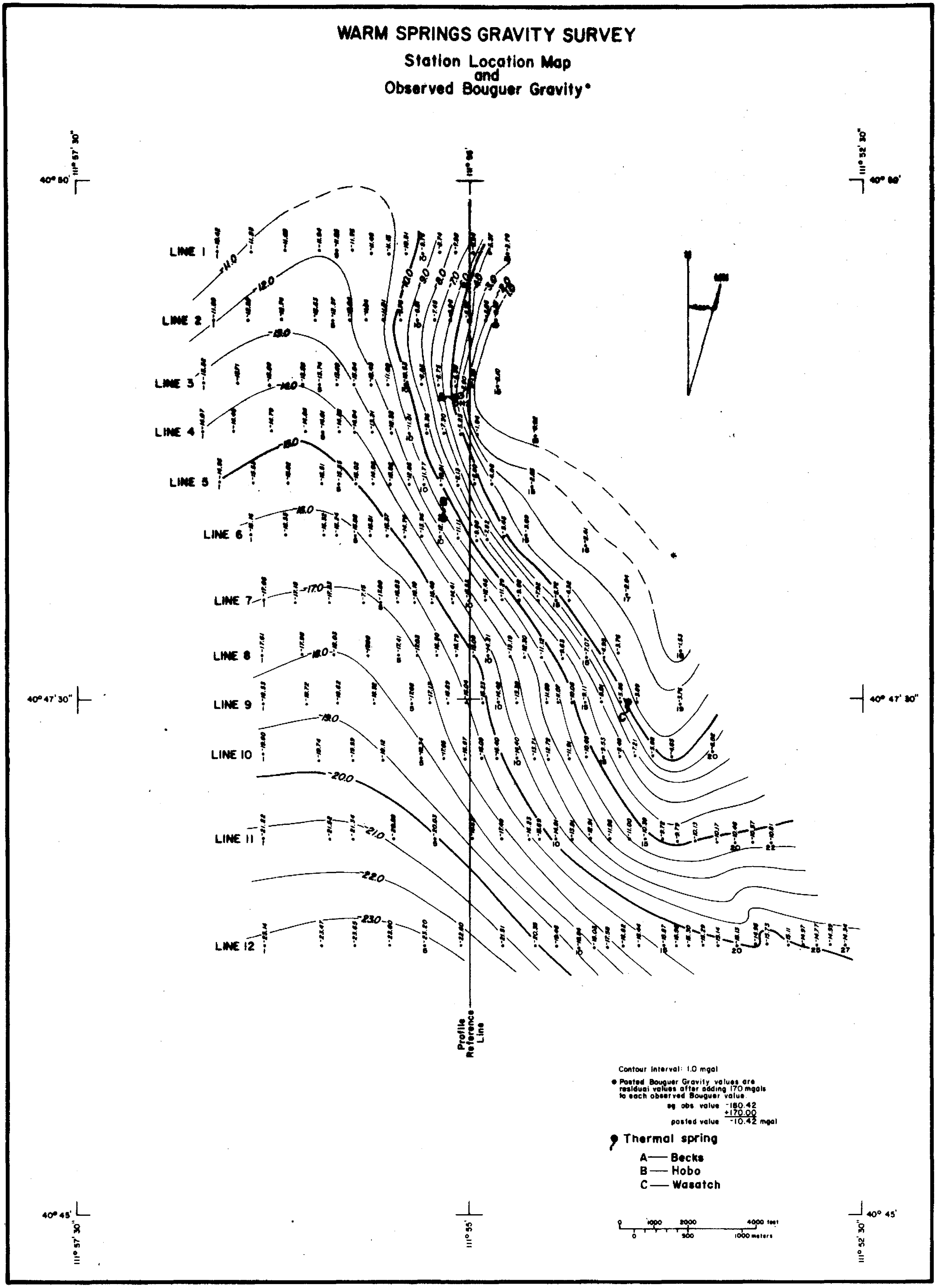
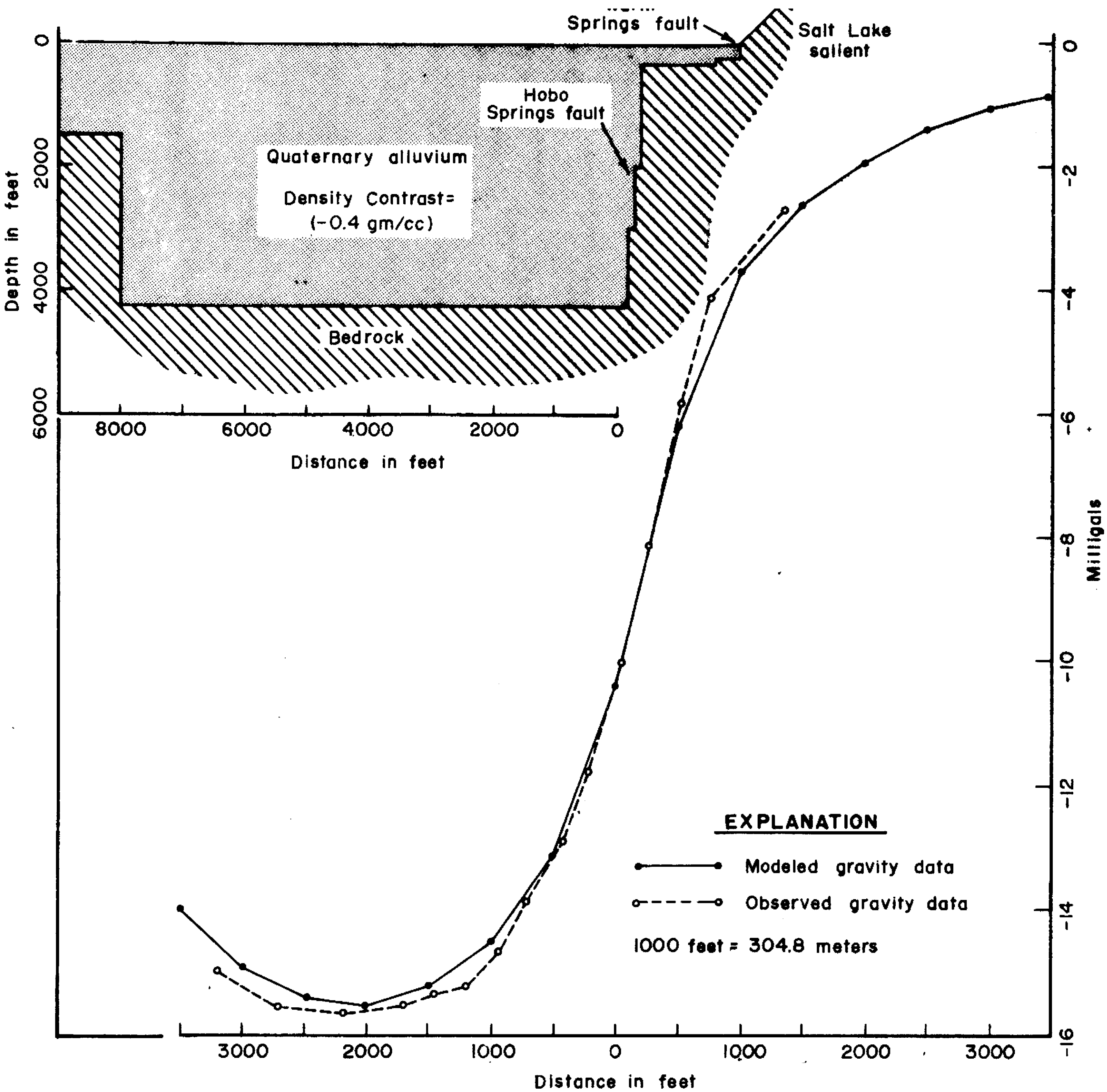

WARM SPRINGS GRAVITY SURVEY
Station Location Map
and
Observed Bouguer Gravity*
LINE 1
LINE 2
LINE 3
LINE 4
LINE 5
LINE 6
LINE 7
LINE 8
LINE 9
LINE 10
LINE 11
LINE 12
40° 50'
40° 47' 30"
40° 45'
111° 57' 30"
111° 55'
111° 52' 30"
Profile Reference Line
Contour Interval: 1.0 mgal
* Posted Bouguer Gravity values are residual values after adding 170 mgals to each observed Bouguer value
eg obs value -180.42
+170.00
posted value -10.42 mgal
Thermal spring
A — Becks
B — Hobo
C — Wasatch
0 1000 2000 4000 feet
0 500 1000 meters

Figure 6



Model and gravity profiles for line 5,
Warm Springs fault, detailed gravity survey
Salt Lake County, Utah

Figure 7

mates of depth to bedrock. The additional work will be done as part of a UGMS investigation of geothermal resources in the Jordan Valley during the contract year of 1979-1980.

SYSTEM CONTROLS AND EXTENT

The occurrence of warm water in the Warm Springs Fault geothermal area appears to be controlled by two main Basin and Range structures: 1) the Warm Springs Fault striking northwest and dipping 65 to 70° to the southwest, and 2) the Hobo Springs Fault striking subparallel to the Warm Springs Fault and dipping slightly to the southwest. There are some indications that the major springs (Becks, Hobo, and Wasatch) occur at the intersections of the major range front structures with older and minor structures striking roughly perpendicular to the main structures. Smaller volumes of water may be transported upward along the main portions of the range front structures independent of structural intersections (Clark Warm Spring). At the north and south extents of the thermal water occurrences there are major changes in structural trends observed on the gravity surface seen in figure 6. The structures responsible for these changes may or may not limit the occurrence of thermal water in the near surface.

SYSTEM RECHARGE

There is little doubt that recharge to the Warm Springs Fault thermal spring system originates in the Wasatch Mountains east of the Salt Lake salient. Steeply dipping aquifers and numerous faults could easily transport the water to the required depth. The path by which the water actually descends to depth, however, is not presently known.

HEAT SOURCE

The Warm Springs Fault geothermal system is a fault controlled, convective system in which metoric water circulates to depth and is heated by the ambient temperature of rocks at depth. The heat is derived from normal heat flow originating in the earths interior. Within the Basin and Range province heat flow is relatively high and the thermal gradient, or change in temperature with depth, is normally about 32°C/km. Water entering the system at the average annual air temperature of 10°C must circulate to depths of approximately 1.5 to 2 km (.9 to 1.2 miles) in order to obtain the maximum observed temperature of 55°C if some loss of fluid temperature is assumed to occur by mixing or by conduction to wall rock as the water ascends to the surface, then the water may be circulating to even greater depths. At depth, the heated water enters zones of high vertical permeability associated with faults and quickly returns to the surface.

The heat source for the water at the Warm Springs Fault is not believed to be the cooling of igneous rock present at depth. The Little Cottonwood stock, the youngest dated intrusive body in the region, is over 15 miles to the southeast and has been dated at between 24 and 31 million years in age (Crittenden, et. al. 1973). Theoretical cooling models developed by Smith and Shaw (1978) tend to support the theory that even the largest siliceous intrusive bodies are effectively cooled within 10 million years of the last intrusion.

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APPENDIX

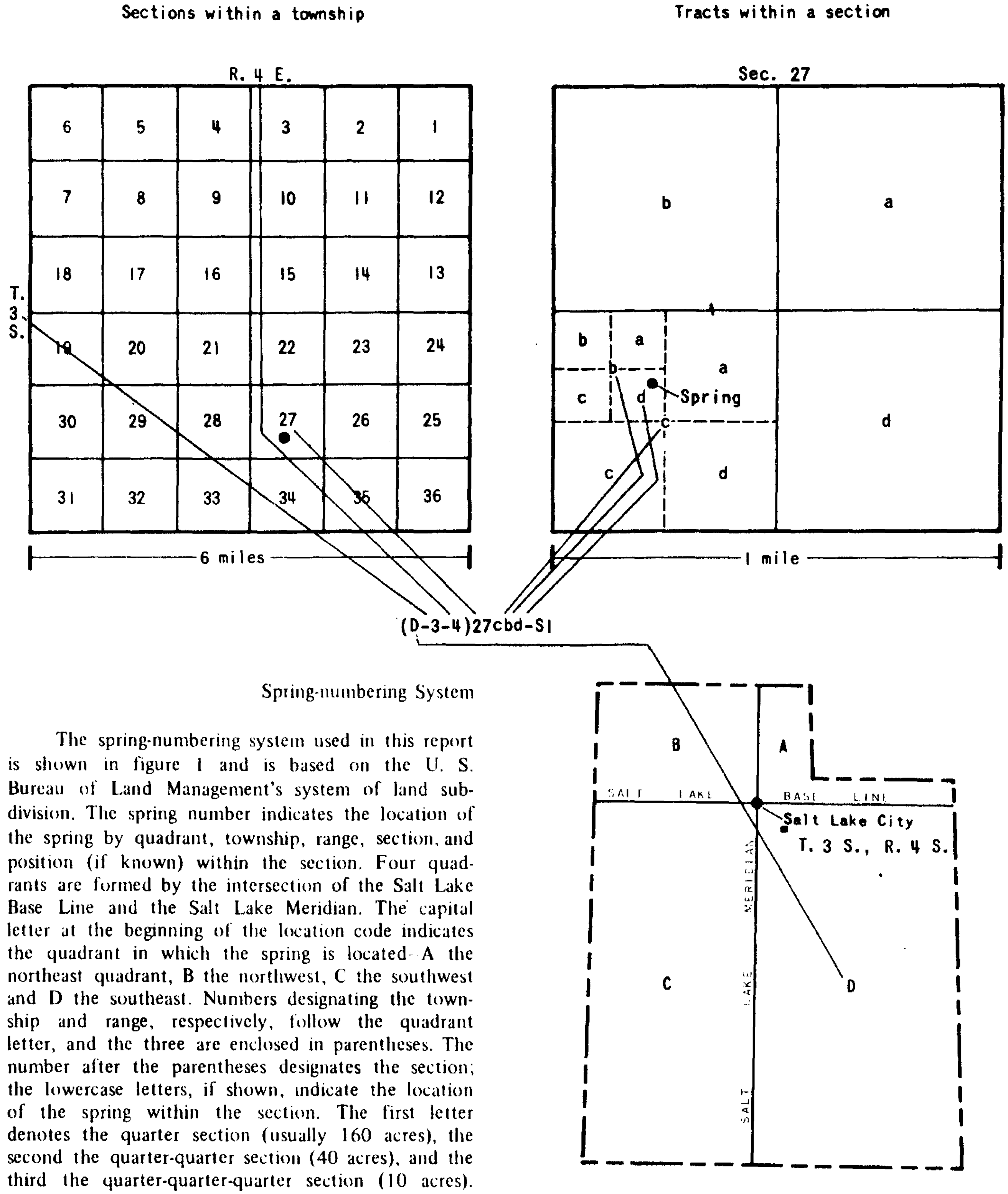
Well - and spring numbering system

Thermal gradient hole lithologic logs

Abbreviations

WT = water temperature

C = conductivity of water in μmohs/ cm @ 25° C



Spring-numbering System

The spring-numbering system used in this report is shown in figure 1 and is based on the U. S. Bureau of Land Management's system of land subdivision. The spring number indicates the location of the spring by quadrant, township, range, section, and position (if known) within the section. Four quadrants are formed by the intersection of the Salt Lake Base Line and the Salt Lake Meridian. The capital letter at the beginning of the location code indicates the quadrant in which the spring is located- A the northeast quadrant, B the northwest, C the southwest and D the southeast. Numbers designating the township and range, respectively, follow the quadrant letter, and the three are enclosed in parentheses. The number after the parentheses designates the section; the lowercase letters, if shown, indicate the location of the spring within the section. The first letter denotes the quarter section (usually 160 acres), the second the quarter-quarter section (40 acres), and the third the quarter-quarter-quarter section (10 acres). The letters are assigned within the section in a counterclockwise direction beginning with "a" in the northeast quarter of the section. Letters are assigned within each quarter section and each quarter-quarter section in the same manner. The capital letter "S" completes the designation of a spring. When two or more springs are within the smallest subdivision, consecutive numbers beginning with 1 are added after the letter "S." For example, (D-3-4)27cbd-S1 indicates a spring in the southeast quarter of the northwest quarter of the southwest quarter of sec. 27, T. 3 S., R. 4 E., and shows that this is the first spring recorded in the quarter-quarter-quarter section. The capital letter D indicates that the township is south of the Salt Lake Base Line and that the range is east of the Salt Lake Meridian.

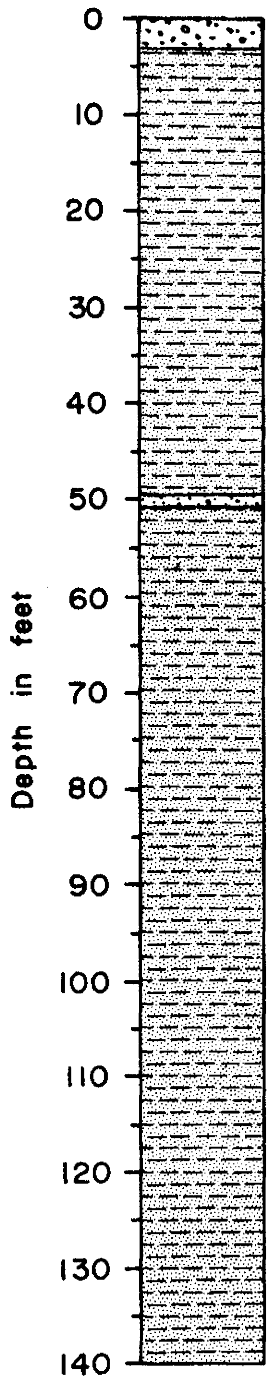
Page 1

Temperature Gradient Hole Log

Hole WSF/GH - A Location (B - 1 - 1) 14 cad

Surface Elevation 4240 Comp. Date 12 - 11 - 78 T. D. 250'

Comments



Gravel fill

Clay damp at 8 feet

Sandy Clay

Drilling medium
0' - 40' Air
40' - 250' Mud

Casing ends

Well rounded gravel and sand

Sandy clay with fine angular gravel

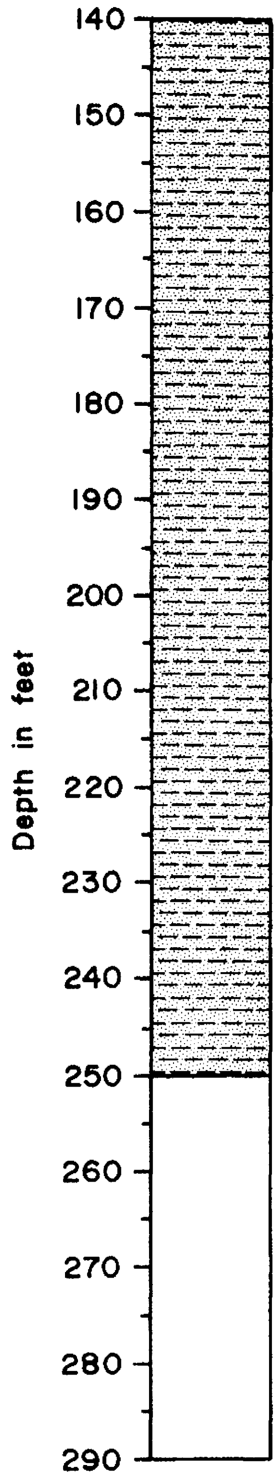
10 feet = 3.048 meters

Page 2

Temperature Gradient Hole Log

Hole WSF/GH - A (continued)

Comments



Sandy Clay with fine angular gravel (190 ft)

Total depth (250 ft)

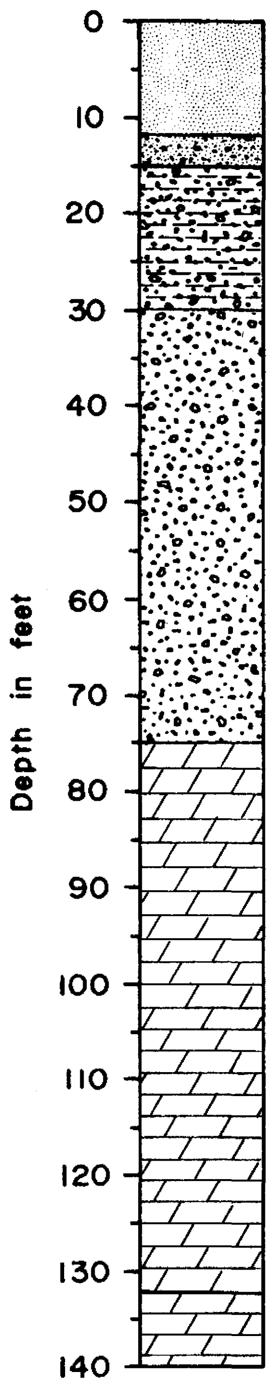
Page 1

Temperature Gradient Hole Log

Hole WSF/GH - B   Location (B - 1 - 1) 14 dcb

Surface Elevation 4275'   Comp. Date 1 - 18 - 79   T. D. 253'

Comments



Dry silt (loess?) tan 0' - 5'
red 5' - 9'
yellow 9' - 12'

Sand and gravel with yellow silt

Gray clay with occasional minor gravel

Water encountered in minor amounts

WT = 13°C

WT = 15°C

Angular dolomite gravels, medium to fine, with varying percentages of sand and clay

WT = 21°C

WT = 26°C, C = 2.02×10^3

WT = 28.5°C, C = 2.36×10^3

WT = 31.5°C, C = 3.06×10^3, 25-35 gpm

Stiff white clay

Weathered and fractured dolomite. Drilling rate alternated between fast and slow over 5-10' sections

WT = 31.5°C, C = 1.09×10^4, volume increases, H_2S

WT = 38°C, C = 1.0×10^4

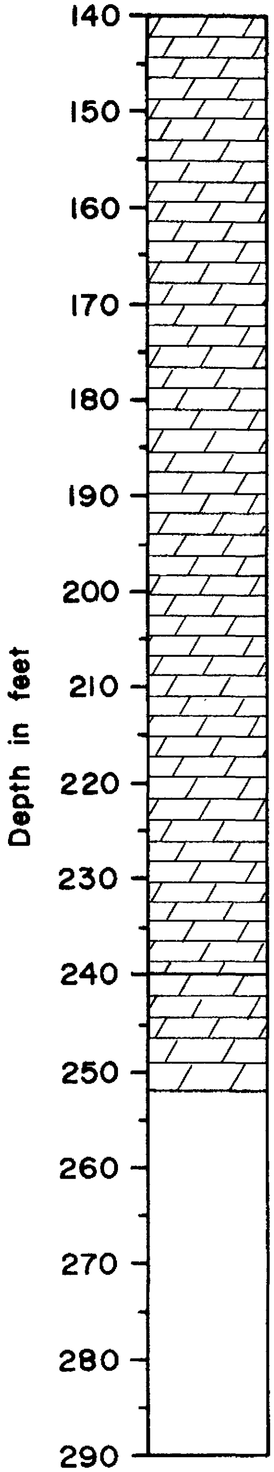
6 inch casing ends

Fractured gray dolomite

10 feet = 3.048 meters

Temperature Gradient Hole Log

Hole WSF/GH - B **(continued)**



Comments

140: $C = 1.34 \times 10^4$

173: Fractured gray dolomite

190: WT = 44.5°C, $C = 1.92 \times 10^4$

208: WT = 44.5°C, $C = 2.1 \times 10^4$

230: Hole producing 60-100 gpm

240: WT = 47°C, $C = 2.14 \times 10^4$

245: Gray dolomite (less fractured than above)

252: Total depth

All units below 30' were saturated

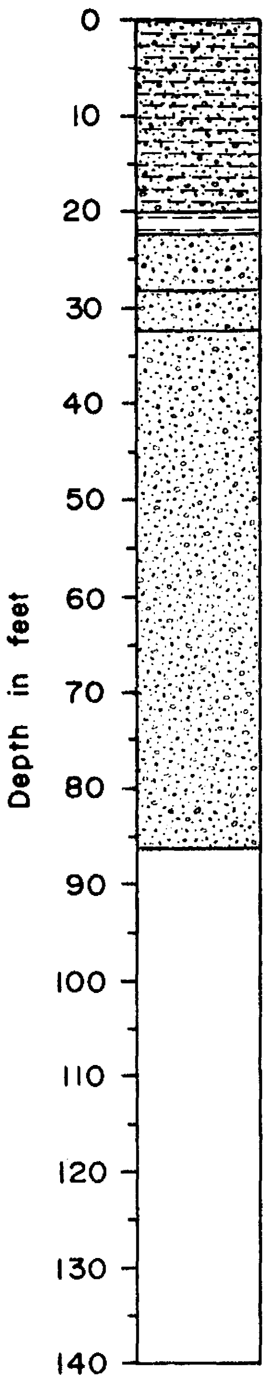
Page 1

Temperature Gradient Hole Log

Hole WSF/GH - C Location (B - 1 - 1) 23 acb

Surface Elevation 4245 Comp. Date 10 - 26 - 78 T. D. 86'

Comments



Medium sand with minor fine gravel, and clay

Moist tan clay

Sand and gravel, water encountered at about 28 feet

Partially cemented sand and gravel

Sand and gravel in varying proportions. Gravel is dolomite and quartzite with some metamorphics

WT = 37°C

WT = 38°C

Total Depth (casing ends)

Note: Conductivities were not taken, and the casing pinched thus ending hole. All permeable units below 30 feet were saturated with water.

10 feet = 3.048 meters

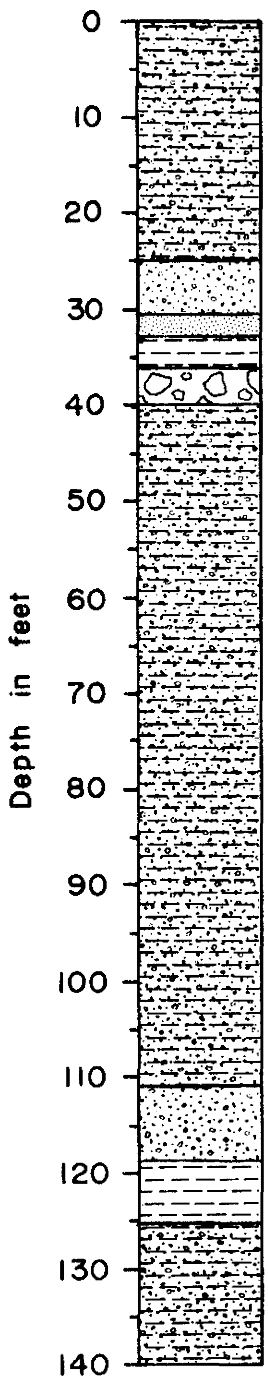
Page I

Temperature Gradient Hole Log

Hole WSF/GH - D Location (B - 1 - 1) 24 cab

Surface Elevation 4245' Comp. Date 11 - 8 - 78 T. D. 240'

Comments



Sand and gravel with minor clay. Hematite particles clinging to sand and gravel

Greenish brown sandy clay with minor gravel and mica

Sand

Saturated tan clay (water encountered)

Conglomerate, well cemented

WT = 12°C

Sand and medium gravel in varying proportions with minor mica and clay

Clays change in color : gray to tan

Hole producing approximately 50 gpm

Clay changes back to gray

Fine to very fine sand and medium gravel

Clay (no returns, easy drilling)

Sand and gravel in wet clay matrix. Clay content decreases with depth.

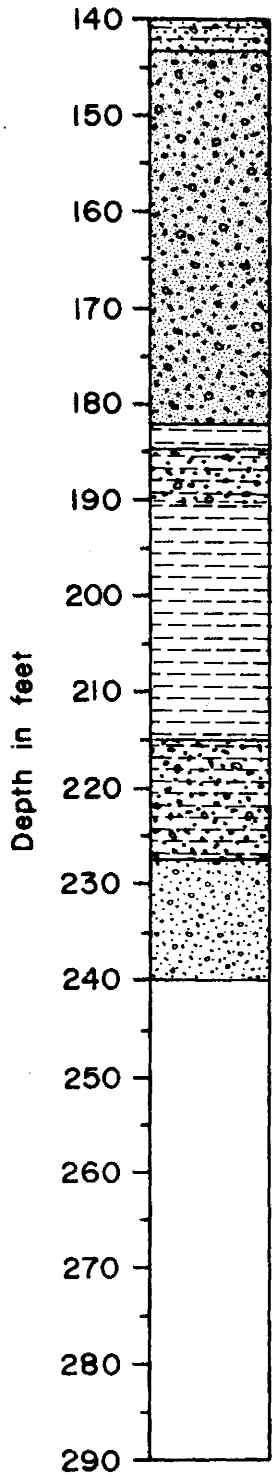
10 feet = 3.048 meters

Page 2

Temperature Gradient Hole Log

Hole WSF/GH - D (continued)

Comments



Same as above

Gravel and sand with occasional mica

Clay

Gravel in stiff gray clay (casing ends at 190')

Stiff gray clay, no water

Gravel in clay

Sandy gravel

Total depth (casing ends)

All permeable formations below 35 feet were saturated.

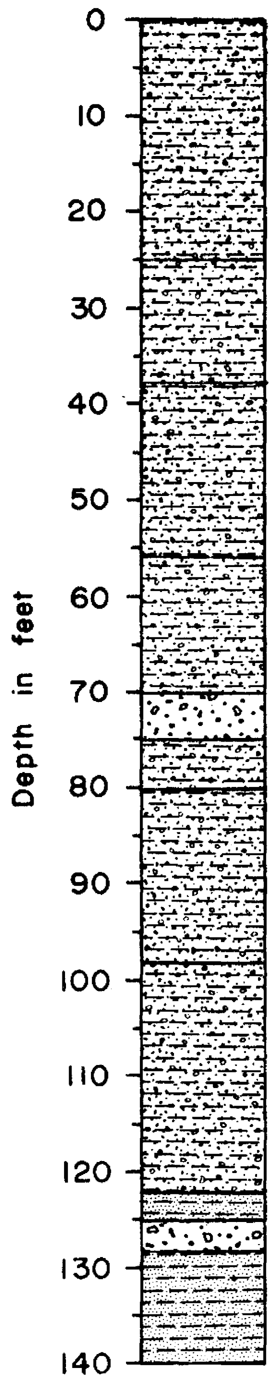
Page 1

Temperature Gradient Hole Log

Hole WSF/GH - E Location (B - 1 - 1) 25 bcc

Surface Elevation 4270' Comp. Date 11 - 21 - 78 T. D. 250'

Comments



Sand and clay with minor gravel
Water encountered

Minor black sandy clay with minor fine gravel

WT = 20°C
Sand and gravel with minor clay

WT = 35°C
Sandy clay with minor gravel

Coarse gravel and minor sand, water
Clay with minor gravel

Sand and gravel in wet clay (clay decreases with depth)

Sand and gravel with minor clay

Sandy clay
Gravel with some sand, wood returns

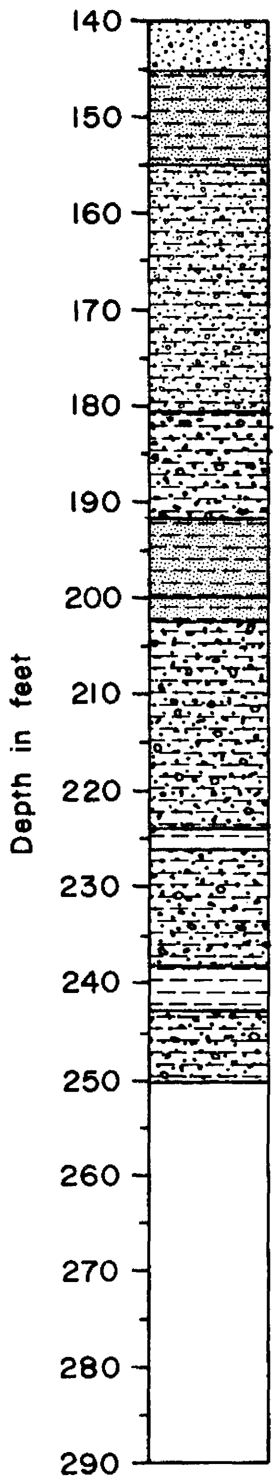
Saturated sand and clay, more wood

10 feet = 3.048 meters

Page 2

Temperature Gradient Hole Log

Hole WSF/GH - E (continued)



Comments

Sand with minor fine gravel

Saturated sandy gray clay

Sand, gravel and clay in varying proportions

Gravel and sand with minor clay

Stiff sandy green clay, sand medium to coarse

Saturated sandy green clay

Gravely sand with minor clay

Stiff clay

Gravely sand with minor clay

Clay (no returns)

WT = 37°C

Gravel and sand with minor clay

Total depth 250', casing ends

All permeable units below 10 feet were saturated.