5-1984

Evaluation of Low-Temperature Geothermal Potential in North-Central Box Elder County, Utah

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Recommended Citation

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EVALUATION OF LOW-TEMPERATURE GEOTHERMAL POTENTIAL IN NORTH-CENTRAL BOX ELDER COUNTY, UTAH

by

Matthew C. Davis

A thesis submitted in partial
fulfillment of the requirements
for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah
1984

ACKNOWLEDGEMENTS

The author would like to thank Dr. Peter T. Kolesar, Dr. Donald W. Fiesinger, Dr. James McCalpin, and Dr. Clyde T. Hardy for critical reviews of the manuscript and helpful suggestions during its preparation.

Funding for this work was provided by the Utah Geological and Mineral Survey. Much of the analytical work was performed by Ruth L. Kroneman of the Earth Science Laboratory. The author is also grateful for field training and general guidance throughout the study by Robert H. Klauk, Chad Gourley, and Cheryll Proell.

A final thanks to Elizabeth Cooper, who willingly sacrificed numerous hours helping type the manuscript and assisting in the field work.

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ABSTRACT

Evaluation of Low-Temperature Geothermal Potential
in North-Central Box Elder County, Utah

by

Matthew C. Davis, Mater of Science

Utah State University, 1984

Major Professor: Dr. Peter T. Kolesar
Department: Geology

The purpose of this study was to continue the assessment of low-temperature geothermal resources in Utah started by the Utah Geological and Mineral Survey. The area of interest within this report is north-central Box Elder County, Utah. Exploration techniques used included chemical analyses of water from wells and springs, temperature surveys, and temperature-depth measurements in unused wells within the study area. The highest water temperatures (31, 30, and 29°C) recorded in this research were located in three separate geographic regions, suggesting that no single warm water occurrence dominates the study area.

Total dissolved solid (TDS) concentrations ranged from 294 to 11,590 mg/l. Areas of warm water occurrences generally had TDS values of greater than 1,100 mg/l. Three water types were distinguished using trilinear plots of common ion analyses of collected water samples. The warmest wells were of Type III water character, which has high (>75%) sodium and chloride concentrations.

Reservoir temperatures were estimated using the water chemistry. Both the silica and the Na-K-Ca geothermometers were used to calculate reservoir temperatures, averaging between 50°C and 100°C. If mixing effects are taken into account, reservoir temperatures might be as high as 198°C.

Temperature-depth measurements were logged in 16 unused wells. Thermal gradients calculated from the profiles ranged from isothermal to 267°C/km. The background gradient for the study area appears to be slightly above the average Basin and Range gradient of 35°C/km. The highest gradients were calculated for the area approximately 8 kilometers west of Snowville, Utah, which is also an area of warm water.

Several areas of possible low-temperature geothermal interest have been identified in the study area by considering water temperatures, calculated reservoir temperatures, and temperature-depth data. However, additional work is needed to more accurately define the possible geothermal resource in these areas.

(130 pages)

INTRODUCTION

In an attempt to fully evaluate the potential energy resources in Utah, the Utah Geological and Mineral Survey (UGMS), under contract with the U.S. Department of Natural Resources and Energy, is in the process of assessing Utah's potential for geothermal energy development. The present study is a continuation of the above assessment as it evaluates the low-temperature geothermal potential in north-central Box Elder County, Utah.

The exploration techniques used in this study included:

(1). Temperature survey of selected wells and springs and chemical analyses of water samples;

(2). Temperature profile measurements and calculation of thermal gradients in unused wells; and

(3). Application of the Na-K-Ca and silica geothermometers.

Using the above techniques, this study documents the existence of several low-temperature geothermal anomalies in the study area, and develops models to explain their occurrence.

DESCRIPTION OF THE AREA

The study area is located in the northeastern Great Basin physiographic province, between the North Promontory Mountains on the east and the Raft River Mountains on the west. The north-south constraints are the Utah-Idaho border on the north and the Locomotive Springs area on the south. The study area covers approximately 1,425 square kilometers and is outlined in Figure 1.

The two main drainage basins in the area of study are Hansel Valley and the Utah portion of Curlew Valley. Both valleys are in the Great Salt Lake drainage basin and are directly tributary to the lake. Hansel Valley lies between the 1,830 meter Summer Ranch Mountains (Hansel Mountains) to the west and the North Promontory Mountains to the east. The North Promontory Mountains reach 2,107 meters above sea level and are generally over 610 meters above the valley floor. Curlew Valley, Utah is situated between the 2,745 meter high Raft River Mountains to the west and the Summer Ranch Mountains to the east. Igneous extrusions are fairly common throughout Curlew Valley, forming the Wildcat Hills and the Cedar Hill regions.

The climate of the area is mostly semi-arid, with the basins receiving less than 28 cm of precipitation per year (U.S. Weather Bureau, 1963). Even the highest peaks within the drainage basin receive a maximum of only 89 cm. Lack of precipitation and the small amount of annual runoff result in only two perennial streams in Curlew Valley and no year-round flowing streams in Hansel Valley.

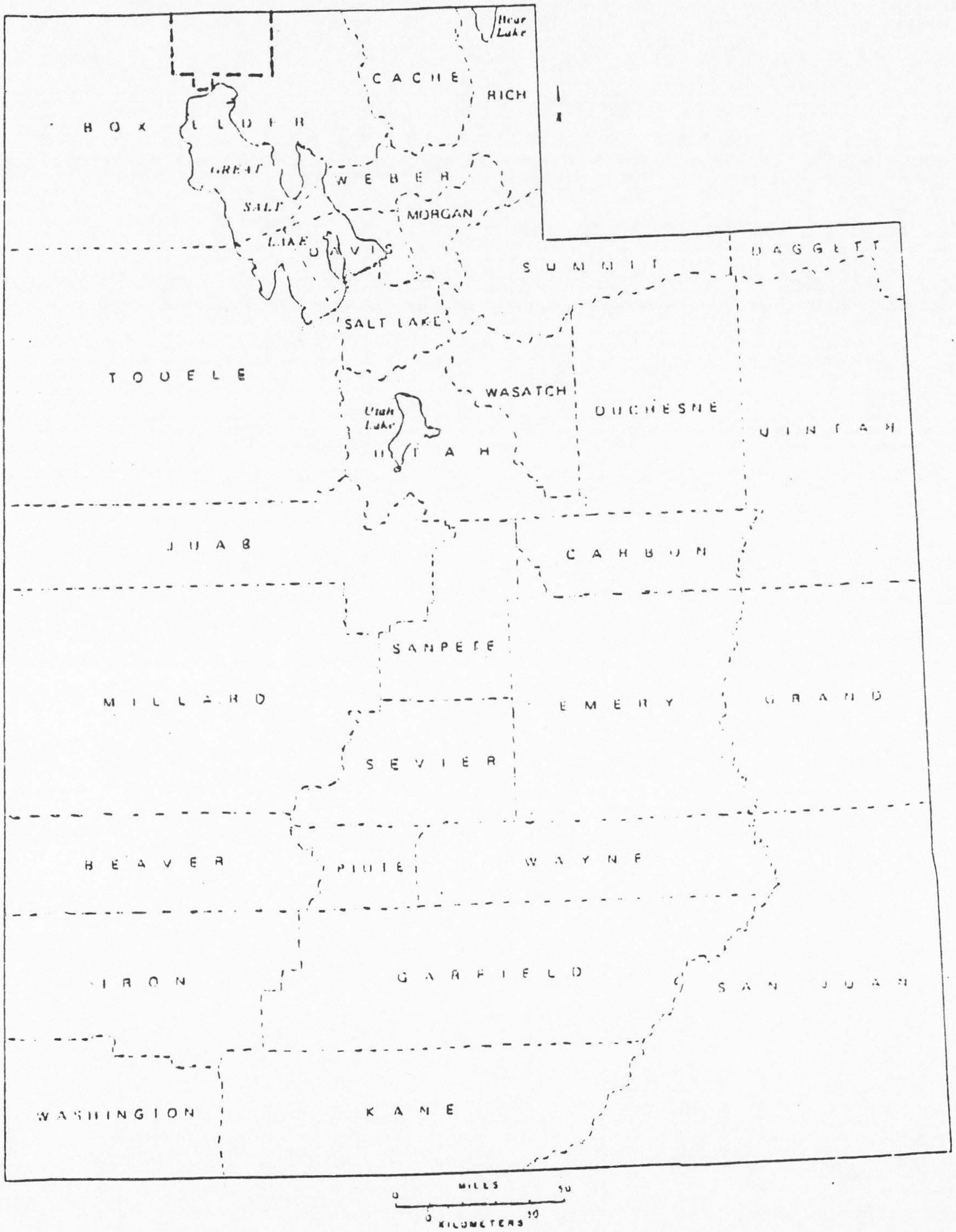

Figure 1. Location of project area within Utah

Outline of area - - - -

Neither of the streams, Indian Creek and Deep Creek, leave the drainage basin or transport water into the Great Salt Lake. Potential evapotranspiration in this area is estimated to be 105 cm annually. Average monthly temperatures during April and May, when sampling for this report took place, range from 4.8 oC to 11oC (Bolke and Price,. 1969).

The entire study area has fewer than 300 permanent residents, with over half of these people living in the only incorporated town of the region, Snowville, Utah (U.S. Department of Commerce, 1981). The economy of both Curlew Valley and Hansel Valley is based solely on agriculture. Most of the land is used for raising livestock, but a substantial part is for cultivation of hay and for feed. These farms are located mainly in the northern part of the study area, where water and tillable land are more easily found. The most productive croplands are in the areas surrounding Snowville, Utah.

PREVIOUS WORKS

Many general studies of mineralized and thermal water in Utah and the United States have been made in the past 30 years (White and Williams, 1975). Only a small part of this information is pertinent to the hydrology and geothermal occurrences of north-central Box Elder County, Utah. Analogous investigations such as those by Klauk and Gourley (1983), Struhsacker et al., (1983), Glenn et al., (1980), deVries (1982), and Mariner and Willey (1976) were helpful in establishing presentation methods and data interpretation.

Mundorff (1970) published a study on most of the major thermal springs in Utah, including information on water temperature and general geologic settings. He found that waters in northwestern Utah generally had low dissolved solid contents, relatively low temperatures, and were probably of local meteoric origin. Heylmun (1966) and Goode (1978) also located many occurrences of thermal waters in Utah and found results similar to Mundorff.

In more specific studies, Doelling (1980) described some of the springs in Box Elder County as having high radioactivity and high concentrations of chloride. Only Coyote Spring ,which is located approximately 8 kilometers north of the Wildcat Hills (Plate 1), falls within the study area; however, Doelling (1980) did not report its temperature.

Hood (1971) performed a hydrologic reconnaissance of Hansel Valley and northern Rozel Flat. He collected data on numerous wells, including name of owners, locality, year in which the well was drilled, depth of well, flow rate, chemical composition, and temperature. Most of the water was found to be from 13°C to 24°C.

Bolke and Price (1969) and Baker (1974) conducted extensive studies of the water resources in the Curlew Valley drainage basin, Utah and Idaho, and collected data at many well sites. Results of the studies showed water temperatures from 10°C and 24°C with the exception of Coyote Spring (43.5°C). Baker suggested that at least the western half of Curlew Valley might be underlain with hot, saline water, and that the geothermal gradient for this area may be abnormally high.

GEOLOGY

Regional Setting

During the Paleozoic Era, the Cordilleran Miogeosyncline subsided over what is now Nevada, central Utah, and part of Idaho (Eardley, 1962; Stewart and Poole, 1974). The basin filled with thick accumulations of sediment which presently make up the various Paleozoic formations underlying the Curlew and Hansel Valley regions (Peace, 1956). Various phases of the Antler Orogeny probably caused folding of the Paleozoic rocks in western Utah starting in the early Mississippian (Eardley, 1962).

A considerable thickness of Triassic and Jurassic sediments were also deposited within this geosynclinal basin. The Mesozoic rocks were removed by erosion when northwestern Utah was raised in a broad geanticline during late Jurassic time (Mische, 1960; Williams, 1962).

The Paleozoic rocks were again folded and faulted during the Laramide Orogeny of Cretaceous and early Tertiary time. This orogenic event was accomplished by the folding of sediments into a mountain system that completed destruction of the Cordillerean geosyncline. The characteristic Basin and Range faulting began in the Oligocene and has continued to the present (Nolan, 1943). During this orogenic period, basalt, perlite, rhyolite, tuff and andesite were also extruded into the area.

An increase in precipitation and a decrease in temperature and in evaporation during the Pleistocene glacial epoch created a system of fresh-water lakes in the Great Basin region (Gilbert, 1890). Most of the interior valleys of Utah were filled to an elevation of about 1,586 meters (5,200 feet) by sediments from the composite lake system known as Lake Bonneville (Crittenden, 1963). Substantial terraces and shorelines were cut into and deposited on the surrounding uplands during this time.

Rock Types and Occurrences

The general geology of the study area is presented in Plate 1. Precambrian and Paleozoic rocks make up most of the bounding mountain ranges, with rocks of Tertiary and Quaternary age forming the valley fill.

Precambrian rocks can be found in the east-trending Raft River Mountains which border Curlew Valley on the west. Rocks of Paleozoic age overlie these Precambrian rocks in an apparent thrust sheet (Felix, 1956; Compton et al., 1977). Paleozoic rocks, ranging from Mississippian to Permian in age, also occur extensively throughout the area. The composite stratigraphic section of Paleozoic rocks is at least 2,440 meters thick, as evidenced by test wells drilled in the Curlew Valley by Utah Southern Oil Company (Peace, 1956).

Mississippian to Permian rocks are found in the northeastern portion of the Hansel Mountains (Summer Ranch Mountains). These rocks are mapped by Adams (1962) as belonging to the Manning Canyon Formation and consist of interbedded, limonite-stained orthoquartzites and black shales. The Manning Canyon Formation locally shows intense deformation thereby distinguishing it from the overlying Oquirrh Formation.

The Pennsylvanian to Permian Oquirrh Formation (limestones, sandstones, and orthoquartzites) crops out extensively within the study area. This formation makes up a major portion of the Hansel Mountains as well as the North Promontory Mountains. Adams (1962) estimated a maximum thickness of 2,595 meters for the Oquirrh Formation. Paleozoic rocks are also found in the Showell Hills, Black Pine Mountains, Wildcat Hills, and as scattered outcrops within Curlew Valley. Oil test wells in Curlew Valley have shown as much as 915 meters of Oquirrh Formation at the base of the thick Tertiary and Quaternary valley fill (Peace, 1956).

Sedimentary and volcanic rocks of Tertiary age occur mainly as valley fill deposits within north-central Box Elder County. The oldest of these rocks are of continental sedimentary origin, and include tuffs, sandstones, tuffaceous shales, marlstones, and some interbedded conglomerates and volcanic lava flows. These thinly bedded, structurally deformed rocks are often referred to as the Salt Lake Formation. They can be found in the North Promontory Mountains, Hansel Mountains, and the Raft River Mountains.

Tertiary volcanic rocks are fairly abundant throughout the drainage basins of Curlew and Hansel Valleys. Late Tertiary basalt, andesite, rhyolite, perlite, and welded tuff were mapped by Howes (1972) in the Wildcat Hills area. The basalt is vesicular, with columnar jointing common.

Basalt and basaltic andesite flows also form Cedar Hill, surrounding knolls, and outcrops along the western border of the study area. Vesicular olivine basalt is common north of Hansel Valley in the northern portion of the North Promontory Mountains. Welded tuffs are also exposed locally in the Hansel Mountains (Adams, 1962). Smith (1953) described the basalt flows of the North Promontory Moutains as a southward extension of the Snake River basalt flows which were primarily of late Pliocene age.

Most of the Quaternary deposits belong to the Lake Bonneville Group. The Lake Bonneville Group consists primarily of unconsolidated to semiconsolidated clays, sands, and gravels. These alluvial and lacustrine deposits can be found as lake terraces and as undifferentiated valley-fill deposits. The terrace deposits consist mainly of sand and gravel formed by the pluvial Lake Bonneville. The most prominent of these depositional and wave-cut features are at the 1,586-meter (5,200-foot) and the 1,464 meter (4,800-foot) levels, coinciding with longer still-stands of the lake (Eardley et al., 1957). Clays and silts, mainly reworked from the Salt Lake Formation, were deposited in Lake Bonneville and now form a major part of the valley floors. Peace (1956) reported gravel at a depth of 256 meters in a test well in Curlew Valley, which indicates alluvial and lacustrine Lake Bonneville and pre-Bonneville deposits extend to at least that depth.

Recent erosion has produced well-developed alluvial fans from the deposition of weathered mountain slope material. Only two perennial streams are present within the study area; therefore, most of the alluvium is transported by floods, slope wash, and spring runoff.

Structures

The study area displays the typical fault-block structures that are characteristic within the Basin and Range Province. Most of these faults are high-angle normal faults with a general north-south trend. Thrust-faults are found throughout the Raft River Rangewith generally westward movement. Ring fractures and other volcanic structures such as vents, dikes, and basaltic necks are also found within the study area. Much of the initial basaltic and rhyolitic extrusions throughout the area probably occurred along Basin and Range faults.

Both the Hansel Mountains and North Promontory Mountains are bounded by north-to northeast-trending normal faults (Plate 2). Bedding of Paleozoic units within the Hansel Mountains generally dips to the east, with a synclinal axis along the east margin of the mountain range.

Hansel Valley is a typical graben, lying between normal faults along the western edge of the North Promontory Mountains and the eastern edge of the Hansel Mountains. Cross faulting is considered to be present beneath the valley, much like that in the adjacent North Promontory Mountains (Adams, 1962). Many earthquakes have occurred in Hansel Valley within recorded Utah history. Most of the vertical displacement has taken place along the southwest side of the valley, with subsidence of up to 1.3 meters in recent times (Adams, 1938; Cook and Smith, 1967).

Curlew Valley exhibits a variety of structural features. Bordering the east side of the valley along the Hansel Mountains is a normal fault (Plate 2). In addition a system of north to northeast-trending normal faults are inferred from gavity data to be present throughout the central part of the valley and the Wildcat Hills area (Cook et al.,1964). Ring fractures are found within the Wildcat Hills, suggesting subsidence of the roof rocks into a caldera. A pattern of curved perlite dikes now occupies this area (Howes, 1972). Howes (1972) also found compound basaltic necks with well-developed columnar jointing, and volcanic vents that once extruded perlite and rhyolite. These volcanic necks suggest that basalts of the Raft River Mountains, the Cedar Hill area, and the Wildcat Hills were each of local origin, even though similarities in composition and texture exist between basalts from these areas.

Geophysical Characteristics

Several gravity surveys have been made in Box Elder County since 1960. A regional gravity map was compiled (Cook et al., 1964) which covered Curlew Valley, west of longitude 112o45' west. Khattab (1969) and Halverson (1960) also did gravity surveys within the study area. Peterson (1974) made a gravity map of part of the northern Lake Bonneville Basin by compiling data from various authors. A gravity map for the study area is shown in Plate 2.

A steep gravity gradient extending between the Wildcat Hills and the Grouse Creek Mountains was interpreted by Khattab (1969) as the eastern border of mid-Mesozoic decollement thrusting. A north-trending gravity low suggests downwarping of late Paleozoic rocks to form a foredeep filled during Cenozoic time. The gravity feature adjacent to the Raft River Mountains indicates bedrock within the trough is approximately 915 meters beneath the alluvial surface (Halverson, 1960).

A gravity low in the Wildcat Hills is also present (Peterson, 1974). This low could result from the abundance of lower density volcanic rocks such as rhyolite within the hills.

North of the Wildcat Hills, a small gravity high reflects the shallowness of Cenozoic rocks. A drill hole near this high encountered pre-Cenozoic rocks at 134 meters (Peace, 1956). Another gravity high, with a mean diameter of approximately 21 kilometers, extends over Cedar Hill and the surrounding area (Cook et al., 1964). Outcropping Paleozoic limestones and dolomites within this anomaly suggests a doming of the pre-Cenozoic rocks because the basalts are not thick enough or sufficiently widespread to cause this gravity high. No evidence of structural depressions filled with low-density Cenozoic rocks can be found within the Curlew Valley gravity high.

Northwest of the above mentioned gravity high, the Curlew Valley Graben has been described (Cook et al., 1964). This depression, indicated as a gravity low, has been confirmed by logs of drill holes in southern Curlew Valley. More than 915 meters of sediments and volcanic rocks of Cenozoic age were penetrated in all of the drill holes within the gravity low (Peace, 1956).

Profiles constructed across a gravity low located approximately 15 kilometers north of the town of Snowville, revealed a deep, narrow depression. The depression contains more than 1,373 meters of Cenozoic rock and is probably caused by north-by northeast trending normal faults (Peterson, 1974).

HYDROLOGY

Surface Waters

Two perennial streams are located in the study area. Deep Creek, the larger of these streams, originates in the northeastern part of Curlew Valley, Idaho. Several streams and springs contribute water to its flow, but downstream most of the water is diverted for irrigation in Idaho and Utah. This diversion for agricultural purposes allows no surface water to reach the Great Salt Lake.

Bordering Curlew Valley, Utah on the west is Indian Creek, which drains the southeast end of the Raft River Mountains. The water from Indian Creek is also diverted for irrigational purposes and fails to leave the drainage basin before seeping into the alluvial valley deposits (Baker, 1974). Annual runoff from the remainder of the area that is not drained by either Deep Creek or Indian Creek is either intermittent or ephemeral. This water, small in volume, is derived from spring discharge and runoff.

Groundwater

The principal aquifers and sources of groundwater in the study area are primarily within the unconsolidated to semiconsolidated valley fill deposits, but also include the intercalated basalts. In addition, a groundwater reservoir may exist in the consolidated Paleozoic sedimentary rocks beneath valley floors. Groundwater in the study area is found mainly under water-table (unconfined) conditions, although artesian (confined) and perched conditions are locally present. In general, the groundwater moves from the north toward the lower parts of the valleys to the south. General geohydrologic units and their hydrologic properties are presented in Table 1.

GROUNDWATER IN PRE-CENOZOIC ROCKS: The Paleozoic and Precambrian rocks forming the mountains around Curlew and Hansel Valleys, as well as lining these basins, are generally well-indurated, with low primary permeabilities. These consolidated rocks provide little base flow to the surrounding streams and are not known to contain any important aquifers (Baker, 1974). Locally, these rocks can yield moderate quantities of water where fractures, joints, bedding planes, solution cavities, and/or faults may increase the permeability.

The Precambrian crystalline core of the Raft River Mountains has a well-developed fracture system. Although the rocks are not a productive aquifer, this secondary permeability allows precipitation to enter the subsurface as groundwater recharge. The surrounding Paleozoic rocks possess similar secondary permeability as evidenced by the discharge of springs throughout the east end of the mountains. The consolidated Paleozoic rocks in the lower part of Hansel Valley also have large spring discharge from apparent solution tunnels and fractures. Springs often occur when migrating water hits an impermeable aquaclude such as the shales of the

TABLE 1. GEOHYDROLOGIC UNITS AND THEIR HYDROLOGIC PROPERTIES (FROM BAKER, 1974, AND HOOD, 1971).

Geohydrologic Unit		Hydrologic Properties
Age	Litholgy	
Quaternary	Unconsolidated to semi-consolidated alluvial and lacustrine deposits (clay to gravel).	Forms the principle groundwater reservoir. Permeability of unit is highly variable both vertically and laterally because of lake deposits interbedded with coarser alluvial deposits. Permeability of the entire deposit considered moderate to high. This unit also acts as intake for recharge from precipitation and run-off. Warm saline water may be present at depths of more than 180-275 m below land surface, but locally at much shallower depths.
Quaternary & Teriary	Volcanic rocks; mostly basalts with some felsic rocks and intercalated basalts.	Low primary permeability; secondary permeability highly variable. May act as either an aquifer or a confining layer and is the principle source of water to several wells.
Tertiary	Semi-consolidated continental sedimentary rocks.	Generally low permeability due to cementation and induration, but locally, beds of sand have moderate permeability. May serve as part of the main groundwater reservoir together with the Quaternary alluvial deposits.
Pre-Cenozoic	Consolidated sedimentary and metasedimentary rocks. Quartzite, limestone, dolomite, sandstone, shale, and some intrusive igneous rocks (exposed in the core of the Raft River Mountains).	Low primary permeabilty, but some secondary permeability due to joints, fractures, and cavernous zones. Yields water to springs, but is of little importance as aquifer. May serve as intake for rechargefrommountain precipitation and run-off.

Manning Canyon Formation along the east border of the Hansel Mountains (Adams, 1962).

The consolidated rocks of Paleozoic age serve mainly as a source of recharge to the Cenozoic valley deposits and aquifers. This recharge is accomplished by the Paleozoic rocks acting as intake areas for the greater amounts of precipitation at the higher mountain elevations. These rocks also act as drains for water from overlying Cenozoic deposits within and around the valleys by allowing water to migrate to depth through permeability (Hood, 1971).

GROUNDWATER IN CENOZOIC ROCKS: Unconsolidated to semi-consolidated deposits as well as volcanic rocks of Quaternary and Tertiary age are found in the valleys within the study area. Aquifers within these deposits can yield up to a several thousand liters of water per minute to wells and are usually saturated for most of their thickness.

The sedimentary rocks of Tertiary age generally have low permeabilities because of thin bedding and fine grain size. These rocks do yield moderate amounts of water to some wells, however, especially along Deep Creek. Overlying the Tertiary continental sedimentary rocks is the main ground water reservoir. This aquifer consists of Pleistocene Lake Bonneville alluvial and lacustrine deposits as well as intercalated volcanic rocks. The Lake Bonneville deposits are fair to poorly flushed and have a moderate to high salt content (Bolke and Price, 1969). Both younger alluvium and the lake-shore deposits on higher slopes absorb runoff, thus recharging the ground water system.

Artesian conditions are created locally by confining clay beds or basalt flows. These conditions are found in various locations throughout Curlew and Hansel valleys, but usually possess low hydraulic heads. Perched water is also found in a few locations, and generally involves a deep water table in Paleozoic rocks with water present in small quantities in overlying Cenozoic beds.

GROUNDWATER FLOW SYSTEMS: Baker (1974) distinguished three shallow ground water flow systems within Curlew Valley. Based on Hood's (1971) hydraulic reconnaissance of Hansel Valley, two more flow systems can be added in the project area. The distinction between flow systems is built upon geologic and geographic features, chemical quality of water, and the hydraulic head of different areas. In this report, these flow systems are called the Kelton flow system, the Juniper-Black Pine flow system, the Holbrook-Snowville flow system, the Hansel flow system, and the Sage Valley flow system (Plate 3).

The Kelton flow system occurs along the western side of Curlew Valley and is bounded by a north-south bedrock ridge to the east. The ridge extends from near Pilot Spring to the Wildcat Hills and prevents most of the water's eastward movement. The water-bearing aquifers are generally in thin-bedded, poorly sorted detritus. The ground water is of good chemical quality, and moves south from the Black Pine Mountains of Idaho and southeast from the Raft River

Mountains toward the Great Salt Lake.

The central part of Curlew Valley contains the Juniper-Black Pine flow system. It is bounded on the west by the Kelton flow system and on the east by the Showell Hills (located northwest of Snowville, Utah) and the south-trending line of Paleozoic rocks (Plate 1). Water moves toward the center of the valley and then southward toward the Great Salt Lake. This flow system consists of alluvium interbedded with lenses of basalt and/or clay which locally cause leaky artesian conditions. In general, unconfined conditions exist, with most of the well-water coming from fractured basalts, clean sands and gravel, and/or poorly sorted clay, sand, and gravel deposits. Increasing salinity of the water southward is attributed to the dissolution of salts within sediments deposited during higher stages of the Great Salt Lake.

The Holbrook-Snowville flow system refers to aquifers in the valley fill and Paleozoic bedrock along the east side of Curlew Valley. This flow system consists of an upper trough of low-density material between the Showell Hills and the Hansel Mountains. The water here is mostly unconfined, but leaky artesian conditions are common (Bolke and Price, 1969). Farther south, the flow system becomes confined by extensive basalt layers. The water quality is fairly good throughout the system. The water of the system moves in a south-southwesterly direction towards Locomotive Springs eventually issuing from volcanic rocks (Baker, 1974). One area of unusually high total dissolved solid concentration near Cedar Hill is explained as a perched water zone of saline water.

Bounded by the Hansel Mountains to the west and the North Promontory Mountains to the east, the Hansel flow system moves southward and eastward. The eastward movement is through Cenozoic rocks and toward a structual trough along the North Promontory Mountains. This situation may indicate drainage into deeper Paleozoic formations. The water eventually flows southward toward Salt Wells Flat and the Great Salt Lake. Lake bottom silts locally act as confining layers to form artesian conditions. Most of the water is obtained from Cenozoic alluvial and lacustrine deposits, as well as from some intercalated basalt flows. The water quality deteriorates southward within the valley.

Smaller than the other systems, the Sage Valley flow system is located in the west to west-central portion of Hansel Valley. It is bounded on the west and east by a forking of the southern extent of the Hansel Mountains. This area has a relatively thin layer of unconsolidated to semi-consolidated material. Most of the rocks of Cenozoic age probably do not contain aquifers; instead, the regional water table is inferred to be in the underlying rocks of Paleozoic age. The Sage Valley flow system has movement generally from north to south, with recharge water from the Summer Ranch Mountains flowing southward toward Spring Bay. Water quality is generally poor; saline, and often warm water is found throughout the flow system.

A possible sixth flow system may exist at a greater depth in west-central Curlew Valley. This system has been referred to by

Baker (1974) as the Coyote Spring flow system. In addition to the isolated occurrence of warm (43.5°C), saline water at Coyote Spring, two wells drilled into the Kelton flow system encountered hot (>40°C), saline water at 214 meters and 156 meters below the surface.

METHODS

In order to evaluate geothermal occurrences adequately, detailed chemical analyses were performed on 84 water samples. The analyses included both laboratory tests and field tests. The geochemical phase of the study was also used to estimate probable reservoir temperatures by employing chemical geothermometers. To help determine conductive heat flow, thermal gradients were calculated from measured temperature profiles in unused wells within the study area. Predictions of source areas and flow paths of the warm (≥20°C) water are based on comparisons of compositional trends within the lithologic and hydrologic frameworks of the area.

Field Procedures

Due to the lack of previous geothermal work and the sparsity of wells in the area, nearly every accessible spring and well was sampled (Plate 4). Water sampling and on-site analyses were done in accordance with UGMS procedures (Kroneman, 1981). Samples were collected as close as possible to the well head or mouth of the spring to avoid errors associated with water not coming directly from the desired source. Wells were allowed to run until the water was considered to be fresh from the aquifers and not to have been standing in the well bore with the chance of re-equilibrating at a different temperature and pressure.

Mineral solubilites are significantly affected by changes in pressure and temperature after collection; therefore, on-site measurements were made of (1) pH, (2) alkalinity, (3) electrical conductivity, (4) salinity, and (5) temperature.

pH was measured with a Markson Digital pH/temperature meter. Three readings were taken at each site and their average was recorded as the final value. A YSI model 33 Temperature-Conductivity Meter was used for temperature, salinity, and conductivity measurements. Conductivity values provided a rough estimate of ion concentration of a water sample. Errors associated with these two meters and pH standards are estimated to be ±0.6°C for temperature, ±0.02 for pH, and ±4.5% for the salinity and conductivity measurements.

Alkalinity refers to the ability of waters to neutralize acids, with carbonates, bicarbonates, and hydroxides ($Ca(OH)_2$, $Mg(OH)_2$, and $Na(OH)$) as the most common causes of alkalinity. Alkalinity is reported in terms of equivalent amounts of HCO_3. The alkalinity of each site was determined using the Hach alkalinity test kit, Model AL-AP (Hach Chemical Company, 1975). Water samples were tested immediately to minimize degassing of CO_2. Brom-cresol green-methyl red was used as an indicator, and a standard solution of 0.030 N sulfuric acid was titrated into the sample. In order to keep the tests accurate to $\pm \leq 5\%$, sample volumes had to be appropriate for the expected concentrations. The indicator changes from green to red when the sample's alkalinity has been neutralized. The number of drops of dilute sulfuric acid used equals alkalinity expressed as grains $CaCO_3$ per gallon of solution.

Alkalinity expressed as HCO_3^- in mg/l is derived from:

$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca^{+2} + 2HCO_3^-$$

Alkalinity (expressed as mg/l HCO_3^-) =

$$\frac{\text{grains/gal. } CaCO_3}{\text{volume factor}} \times \frac{17.1187 \text{ mg/l}}{1 \text{ grain/gal.}} \times \frac{122.012 \text{ g/2 moles } HCO_3^-}{100.0782 \text{ g/1 moles } CaCO_3}$$

Most of the samples collected had alkalinities of between 150 and 400 mg/l HCO_3^-, and a volume factor of 2.5 was used. Higher or lower alkalinities required volume factors of 1.0 or 5.0, respectively. The bicarbonate alkalinity is not only bicarbonate, but includes carbonic acid (H_2CO_3) and carbonate ($CO_3^=$). Bicarbonate concentrations were then adjusted for the effects of the measured pH at each sample site (Krauskopf, 1979).

After the on-site analyses, three polyethylene containers (two 570 ml and one 65 ml) were filled with sample water by pressure filtration. The sample water was forced through a 0.45 micron membrane using a Geo Filter Peristalic Pump, Model #004. Prefiltration with a coarser filter was performed if the amount of suspended solids necessitated its use. Sample bottles were pre-cleaned by soaking in 20% nitric acid and rinsing in deionized water.

Acidification of the water samples prevents precipitation of sulfate and metals before analyses can be performed. Therefore, a 65 ml bottle was acidified with reagent grade nitric acid to a final concentration of 20% HNO_3 for later analyses of various cations. One of the 570 ml bottles was acidified with concentrated hydrochloric acid to a final concentration of 1% HCl for analysis of sulfate and calcium. The second 570 ml bottle was filled with only filtered water to be used for the analysis of silica, Cl^-, F^-, and also to determine total dissolved solids (TDS).

Thermal Gradients

Temperature-depth measurements were recorded in all accessible unused water wells within the study area. Temperature was measured with a Fenwal K212E thermistor probe in combination with a Digital Multimeter, Model 2530-A2. The resistance (R) of the thermistor varies with temperature (°C) according to the equation:

$$\log R = A + B/T + C/T^2$$

where A, B, and C are calibration constants. Errors resulting from the equipment and techniques are estimated to be ± 0.01°C (Sass et al., 1971).

Temperature readings were taken at 5 meter intervals in air and at 2.5 meter increments in water. Due to the generally low ground water levels in this area and possible draw down effects resulting from irrigation pumping, many of the wells measured contained little water. Portions of thermal gradients were often calculated from temperature measurements made in air because of the lack of sufficient amounts of water in the well bore. For this reason, the thermistor probe was allowed to equilibrate with its surroundings for 10 to 30 minutes at each interval before recording the resistance. The probe was considered at equilibrium when its resistance values stopped fluctuating.

Laboratory Analyses

Due to strict time restraints placed on this project, most samples were analyzed at the University of Utah Research Institute/Earth Science Laboratory (UURI/ESL) located in Salt Lake City, Utah. UURI/ESL analyses included : fluoride, chloride, and total dissolved solid determinations made on untreated, filtered samples by specific ion electrode, silver nitrate titration, and gravimetric methods, respectively (Brown et al., 1970); sulfate concentrations determined gravimetrically on samples filtered and acidified to 1% HCl; and other elements (Table 2) determined with an Inductively Coupled Plasma Quantometer (Christensen et al., 1980) on samples filtered and acidified to 20% nitric acid.

The author performed chemical analyses on 42 samples as a safety measure and also to compare the accuracy of the following geochemical techniques with the analyses from ESL.

Concentrations of Na, K, Ca, Mg, SiO_2, and Fe in mg/l were determined by atomic absorption spectrophotometry (Perkin-Elmer Model 303) using standard methods (Perkin-Elmer Corp., 1973) for samples acidified to 20% HNO_3. An air-acetylene flame was used for the determination of Na, K, Ca, Mg, and Fe and a nitrous oxide-acetylene flame for silica determinations.

The chloride and fluoride activities of filtered, untreated

TABLE-2. LIMITS OF QUANTITATIVE DETERMINATION (LQD) FOR SOLUTION ANALYSIS BY INDUCTIVELY COUPLED PLASMA QUANTOMETER.

Element	Concentration (mg/l)
Na	1.250
K	2.500
Ca	0.250
Mg	0.500
Fe	0.025
Al	0.625
Si	0.025
Ti	0.125
P	0.625
Sr	0.013
Ba	0.625
V	1.250
Cr	0.050
Mn	0.250
Co	0.025
Ni	0.125
Cu	0.063
Mo	1.250
Pb	0.250
Zn	0.125
Cd	0.063
As	0.625
Sb	0.750
Bi	2.500
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	2.500

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

water samples were determined using Orion specific ion electrodes and a Markson Digital pH/Temperature Meter, Model 90. The electrode potentials (millivolts) of a set of chloride standards were plotted on a semilogarithmic scale. The activity of Cl^-, in mg/l, for the water sample was then determined by measuring the electrode potential for the sample and reading the Cl^- value from the curve that was derived from the standards. The activity of the free fluoride ions in the sample was measured in millivolts, then 5 ml of 10 mg/l fluoride standard were added to 50 ml of the sample, and the new activity was recorded. The change in potential corresponds to a concentration ratio given in a conversion table provided with the probe.

A Varian Series G34 UV-Visible Spectrophotometer was used for the analysis of sulfate in water samples acidified to 1% HCl. The absorption of a set of sulfate standards was measured at a wavelength of 450 nm and these values were plotted versus sulfate concentration on standard graph paper. The measured absorption of each water sample was plotted on the curve derived from the standards and the sample sulfate concentration determined. Finally, the total dissolved solid concentrations were determined by evaporating 50 ml of untreated, filtered water to dryness and weighing the residue.

Cation and anion balances were performed on all samples to detect possible sources of error. This balancing was achieved by taking the difference in milliequivalent amounts of all cations and anions present in detectable amounts. Differences of less than 10% were acceptable, 10 to 15% questionable, and differences greater than 15% unacceptable without an explanation.

TEMPERATURE SURVEY

The measured groundwater temperatures in the study area vary from site to site due to a variety of reasons. Geologic factors, such as the depth of the unconsolidated valley fill or the presence of faults which can act as conduits to deeper groundwater systems, play major roles in temperature variations. The depth of the well, in addition to the length of the perforated and cased sections, are also important when considering groundwater temperatures at a particular site. The wells in the area are generally perforated throughout all aquifers penetrated and therefore composite temperatures are recorded at the well head.

Temperatures from 65 wells and 19 springs sampled, ranged from 5°C to 31°C. Most water wells measured were greater than 75 meters in depth, and all wells tested were less than 250 meters in depth. The relatively deep wells are in response to a water level that is generally more than 40 meters below the surface in most areas and as great as 110 meters at some locations in Curlew Valley (Baker, 1974).

Temperatures of 20°C or greater were found throughout the study area with the exceptions of the Kelton flow system to the west and the Locomotive Springs area to the south. For the purpose of this report, temperatures of 20°C or greater will be considered warm.

Areas of warm water include: (1) the eastern edge of the Hansel Valley; (2) the southern part of the Hansel Mountains; (3) the area

8 to 16 kilometers north of the Wildcat Hills; (4) along U.S. 30S, approximately 16 kilometers west of Snowville; (5) along the Utah-Idaho border, 1.5 to 6.5 kilometers west of Interstate 80N in T.15N., R.9W.; and (6) the western edge of the North Promontory Mountains, west of Snowville, Utah (Plate 5). Colder water ($\leq$16°C) was generally found at the base of recharge at higher elevations or in areas of deep alluvial fill such as north of Snowville. Water with temperature from 16°C to 20°C was found throughout the study area. Often water in this temperature range was found between the colder recharge areas and the warm waters, suggesting possible mixing.

WATER CHEMISTRY

Total Dissolved Solids

Mineral solubilities are often affected by temperature, with warmer waters generally capable of dissolving more solids than cold waters, although some minerals such as calcium carbonate and quartz, are more soluble in cooler temperatures. Several other factors contribute to the amount of dissolved solids within water, with one factor being the length of time water is in contact with surrounding rocks. Generally, the longer the contact time, the higher the total dissolved solid (TDS) concentrations become. The solubility of the surrounding material also plays a role in the amount of solids that will dissolve into the water. Very soluble evaporite beds from receding Lake Bonneville are present locally and account for anomalously high values in specific areas. Varying TDS values can also be accounted for by the grain size of the material through which the water passes. Finer grains present more opportunity for chemical exchage than coarser grains.

Concentrations of TDS vary widely throughout the study area, ranging from 294 to 11,590 mg/l (Plate 5). TDS concentrations were higher in the warmer wells and springs, increasing in concentration from north to south. This overall increase in TDS southward is probably due to the greater contact time of the groundwater as it moves down gradient toward the present-day Great Salt Lake. Also, because of low precipitation, little surface water recharge, and a lack of irrigation in the southern portion of the study area, there are probably more salt deposits, lake-bottom material, and saline water in the sediments from the previous higher stages of the Great Salt Lake than in the north. A final source of the greater dissolved solids southward may be the spray and dust which are blown onto the recharge areas from the Great Salt Lake and its adjacent salt flats.

Most of the water collected was slightly saline, possessing TDS concentrations between 1,000 and 3,000 mg/l. The freshest water was found near the western and north-western boundaries of the study area, coming out of the Raft River Mountains and the Black Pine Mountains (Plate 5). These waters were all below 18°C even to a depth of 187 meters as evidenced by sample C-63 from the southeast corner of T.15N., R.10W. (Plate 4). Low TDS concentrations were also found in northern Hansel Valley (except for sample site H-2 in T.13N., R.6W. which was 30°C) especially along the west side of the graben. Waters with less than 1,000 mg/l TDS were found along the two perennial streams, Indian and Deep creeks, where surface water recharge is likely.

Besides normal high TDS values recorded from the southern parts of Curlew and Hansel valleys, TDS concentrations greater than 3,000 mg/l were found in several other areas. One area is at the southern end of the Summer Ranch Mountains, where 4,724 mg/l was measured at site C-23 (Plate 5). The water temperature (31°C) was the highest recorded within the study area. Hood (1971) previously reported warm, high TDS water in a well located 8 kilometers to the north.

These waters are thought to come from highly fractured Paleozoic sedimentary rocks at shallow depths.

Another area of high TDS was found in T.15N., R.9W., along the Utah-Idaho border. Concentrations as high as 5,168 mg/l were measured. This area contains warm well-water temperatures. Concealed faults which act as conduits for deep, long residence time water and/or local saline waters are possible explanations for the high TDS concentrations.

A third area of high TDS is the southern portion of T.14N., R.10W., north of Wildcat Hills (Plate 5). This area is situated in a gravity high (Plate 3) with consolidated Paleozoic sedimentary rocks close to the surface. Groundwater may increase in salinity as it migrates to depths of up to 1,220 meters in a basin of unconsolidated fill to the north (Plate 2). This water is then forced nearer the surface along the basin's southern limit in T.14N. and subsequently is intercepted by wells and springs in the area.

A final area of high TDS was found in T.13N. east of Cedar Hill. Wells in T.13N., R.8W., and T.13N., R.9W., had TDS concentrations of over 5,000 mg/l, posssibly due to a perched saline groundwater condition.

The numerous possibilities for producing high TDS concentrations in water samples limit the usefulness of TDS values in interpretations. However, when used in conjunction with other data, more concrete conclusions can be drawn.

Common Ion Analysis

The wells and springs within the study area were grouped into 5 geographical areas based primarily on local flow-systems (Plate 4). Common ion analyses of each geographic area are presented in trilinear diagrams in Figures 2 through 6. All of the samples collected for chemical analyses are presented in Figure 7, from which general groupings were made based on common chemical characteristics. Trilinear diagrams were constructed by methods discussed by Hem (1970) and are based on percentage of total milliequivalents of either anions or cations per liter.

Three water types were derived based on the proportions of cations and anions in ground water from the study area . These compositional groupings do not define clear geographic regions but do correlate with recorded water temperatures, TDS concentrations, and geologic settings within the study area.

Type I waters are calcium-sodium bicarbonate-chloride-sulfate (Ca-Na HCO_3-Cl-SO_4) and calcium-sodium chloride-bicarbonate-sulfate (Ca-Na Cl-HCO_3-SO_4) in character, with calcium greater than 55% and sodium greater than 40% of the total cations. This water was found primarily in the western and north-western portions of the study area. Additionally, northern and western Hansel Valley also contained Type I water. Exceptions to the above are samples H-6 in Hansel Valley and C-42 in the Kelton area (Plate 4). These two

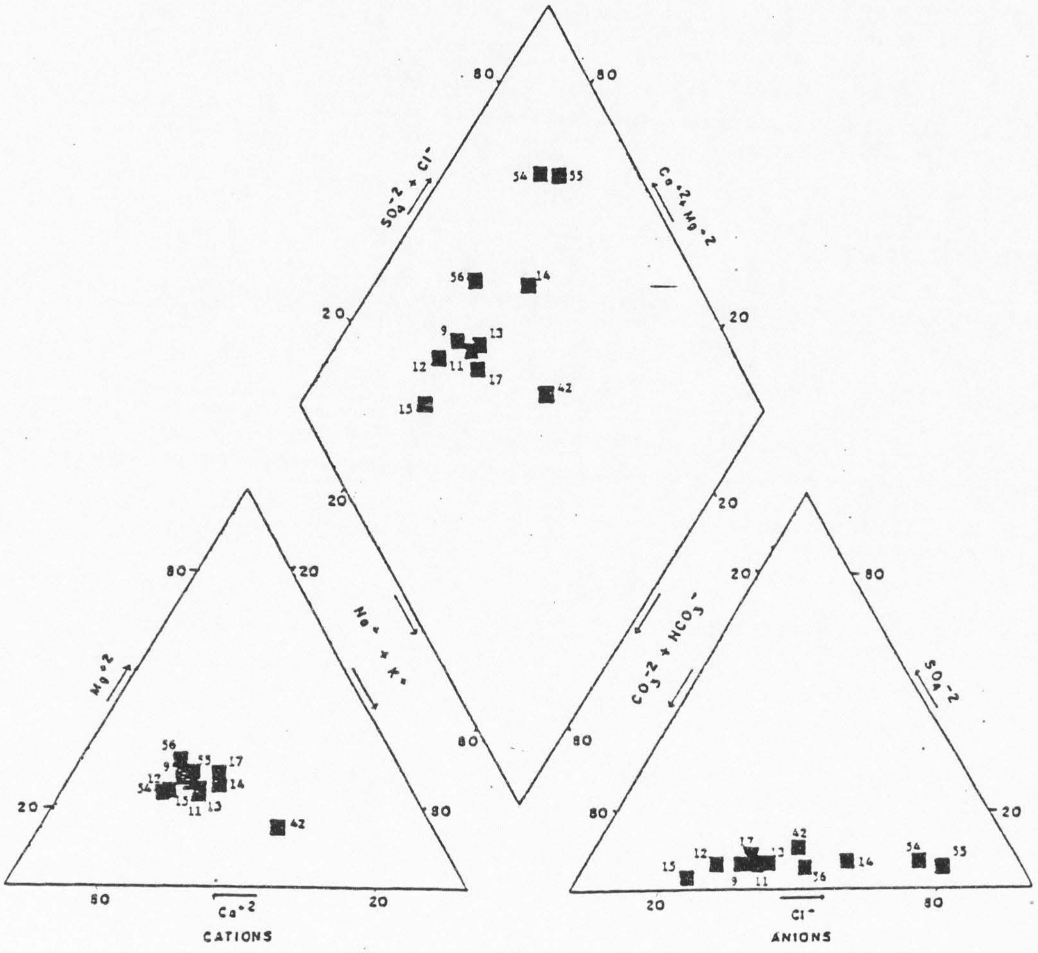

Figure 2. Piper diagram of common ions in samples collected from Area I (Plate 4) in north-central Box Elder Co., Utah. Chemical constituents are plotted as percentage of total milliequivalents.

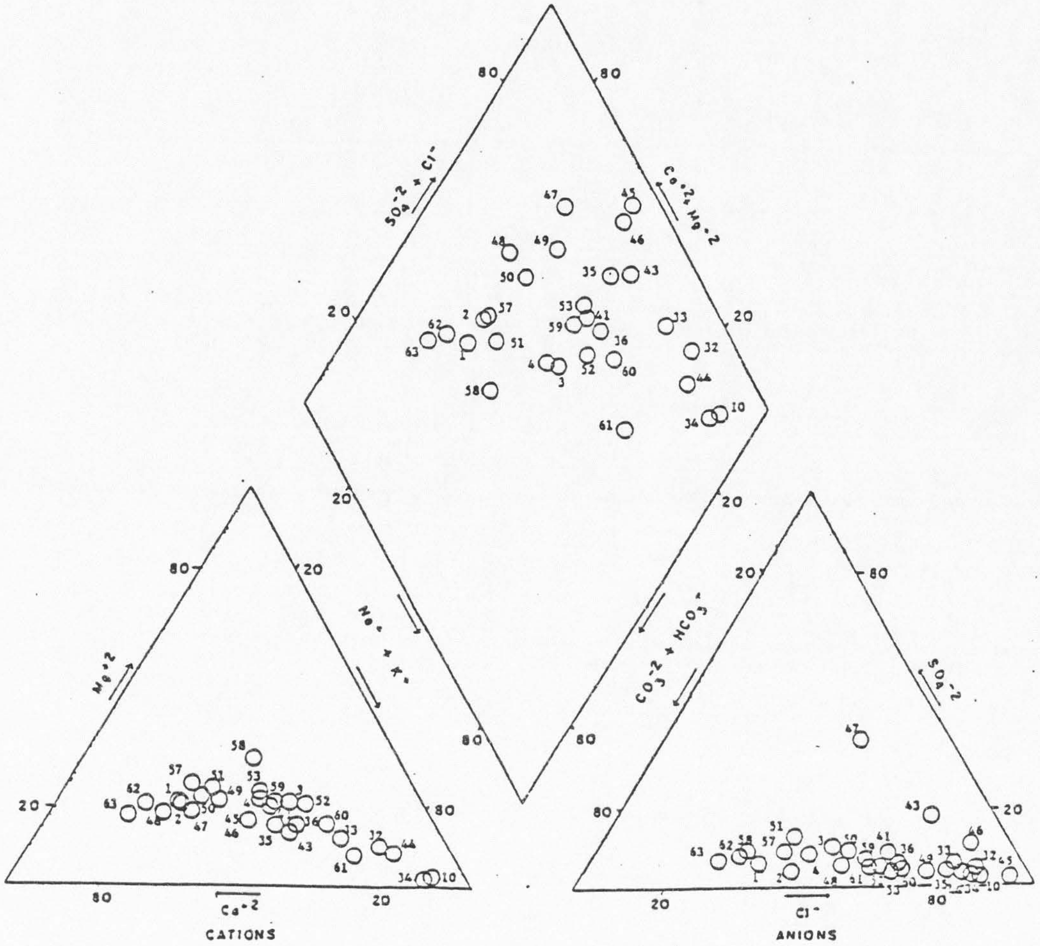

Figure 3. Piper diagram of common ions in samples collected from Area II (Plate 4) in north-central Box Elder Co., Utah. Chemical constituents are plotted as percentage of total milliequivalents.

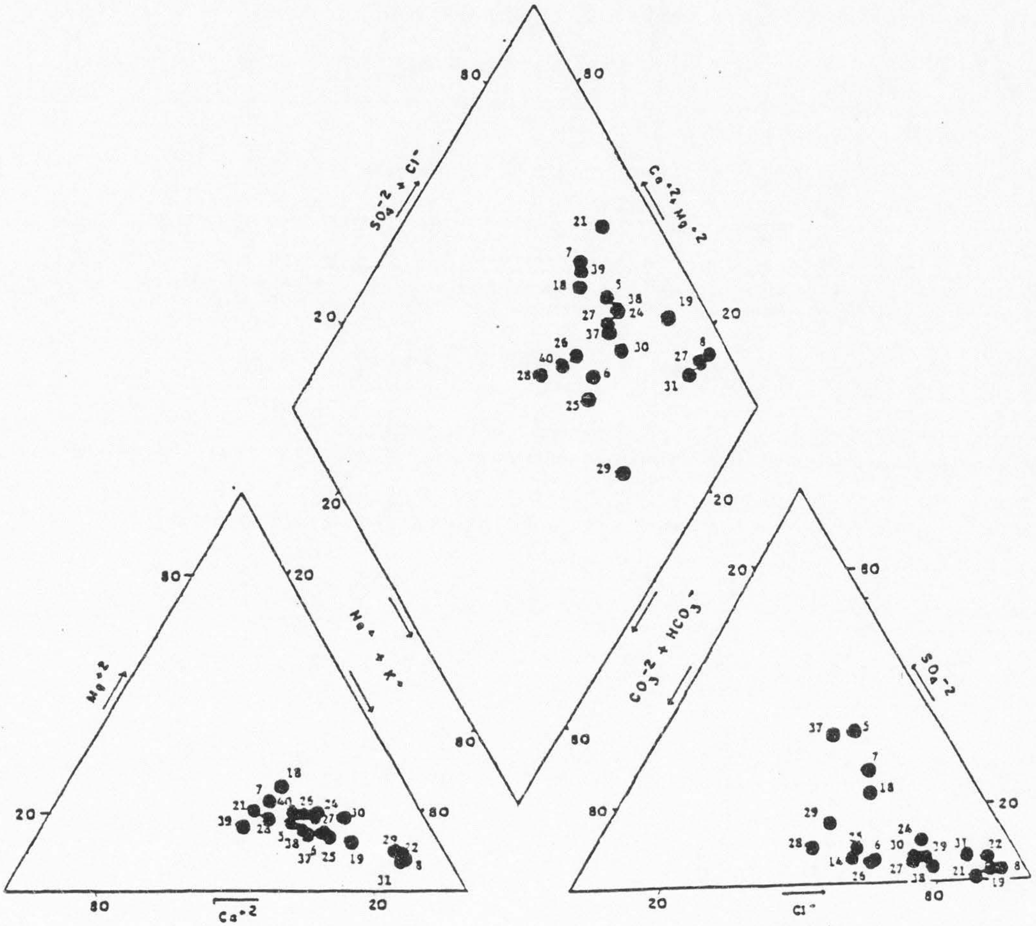

Figure 4. Piper diagram of common ions in samples collected from Area III (Plate 4) in north-central Box Elder Co., Utah. Chemical constituents are plotted as percentage of total milliequivalents.

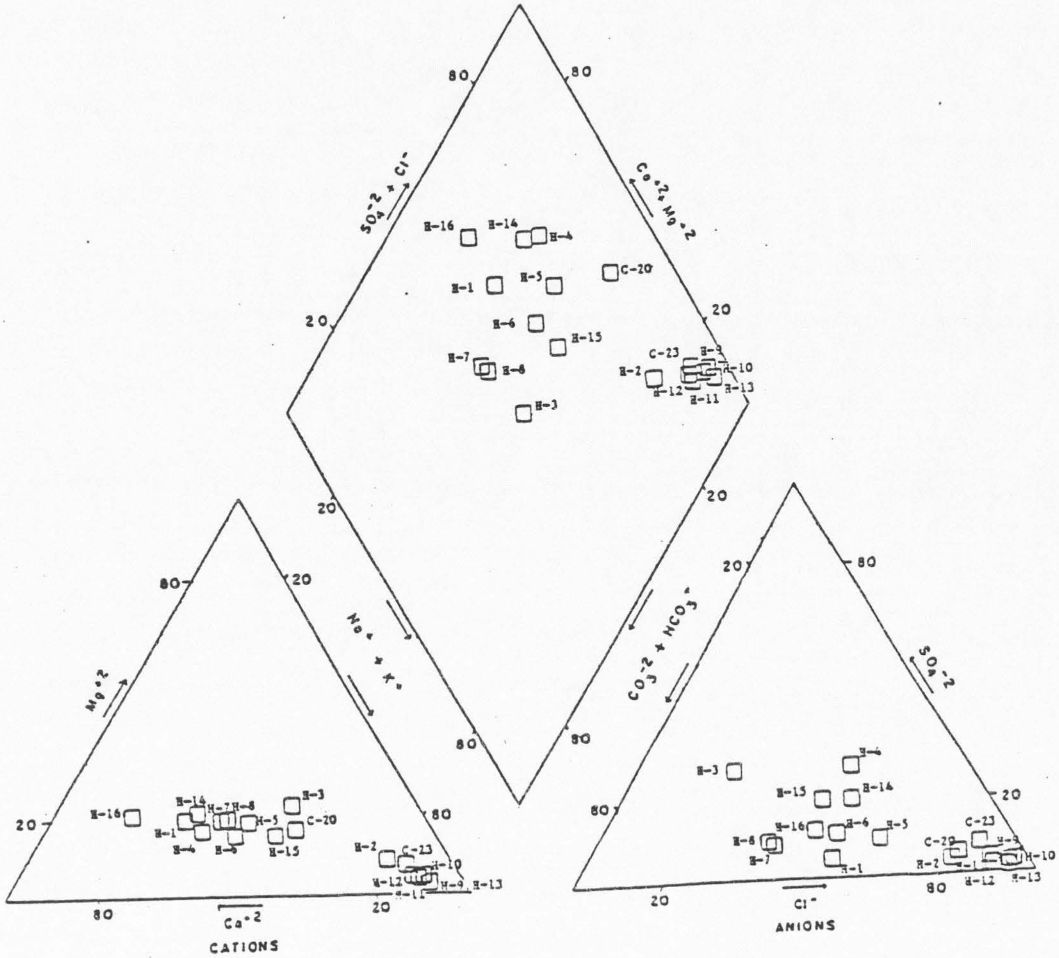

Figure 5. Piper diagram of common ions in samples collected from Area IV (Plate 4) in north-central Box Elder Co., Utah. Chemical constituents are plotted as percentage of total milliequivalents.

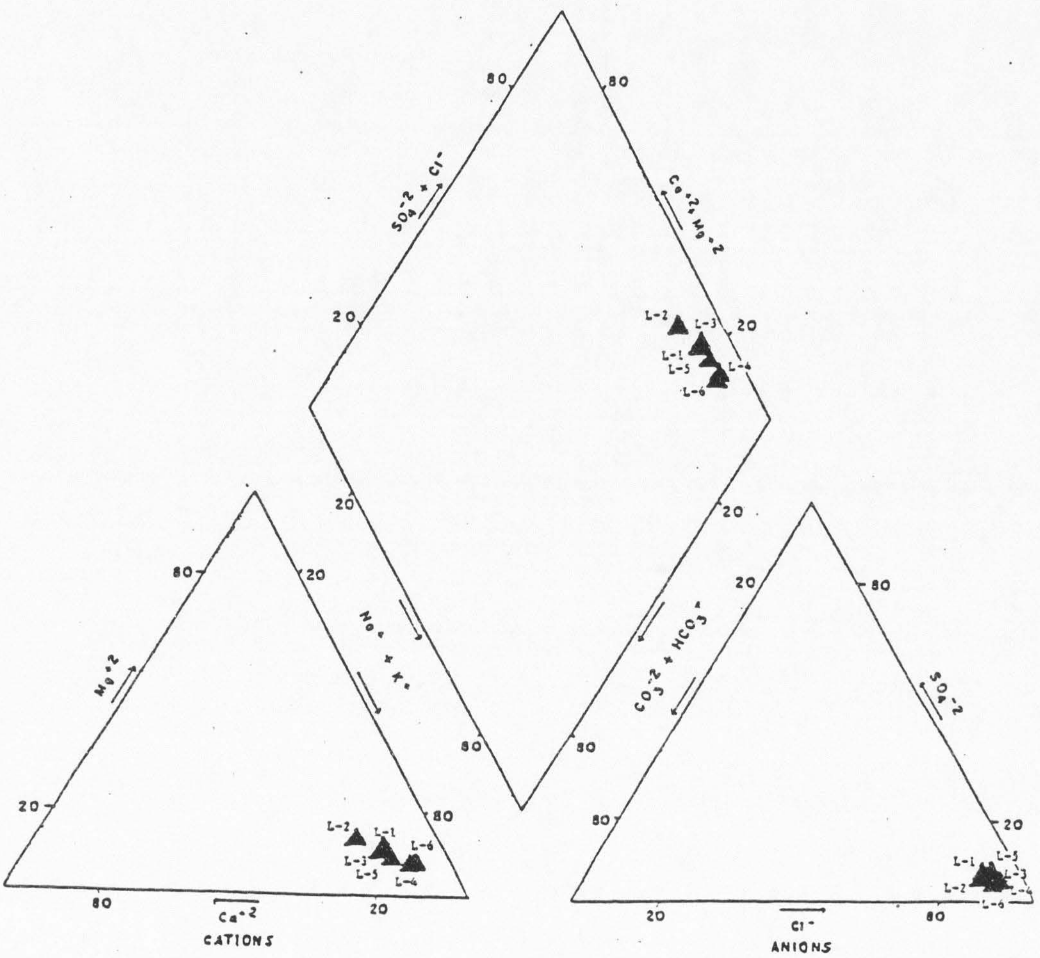

Figure 6. Piper diagram of common ions in samples collected from Area V (Plate 4) in north-central Box Elder Co., Utah. Chemical constituents are plotted as percentage of total milliequivalents.

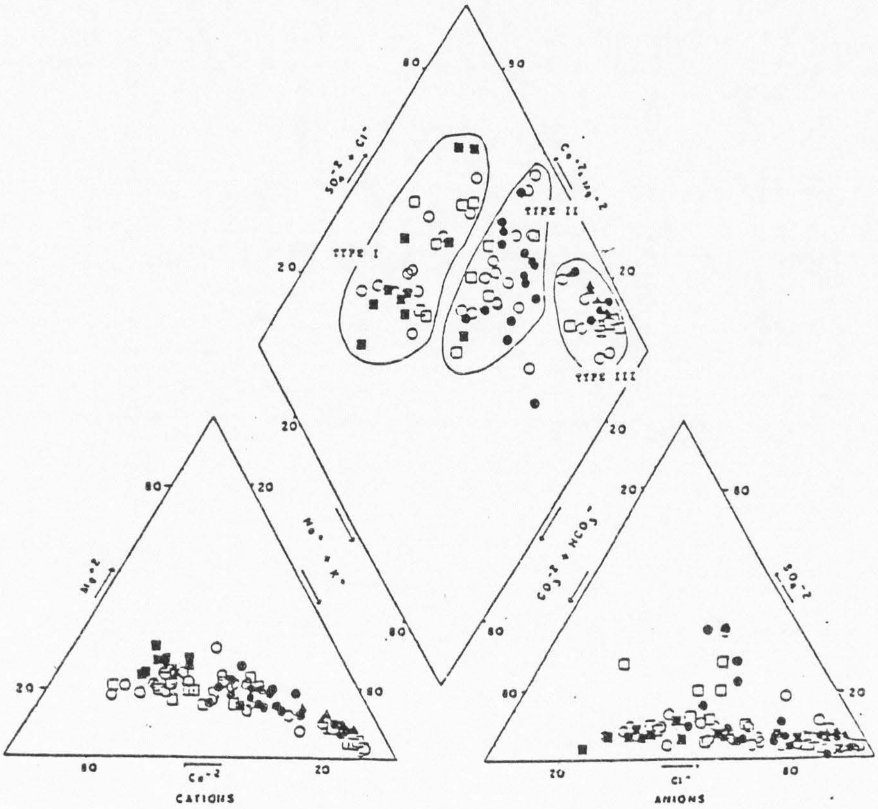

Figure 7. Piper diagram of common ions in all samples collected in north-central Box Elder Co., Utah. Chemical constituents are plotted as percentage of total milliequivalents. See Figures 2 through 6 for identification of individual samples.

samples had cation and anion imbalances of greater than 10% and 15% respectively, which suggests possible contamination of the water prior to the laboratory analyses.

Type I water, with the exception of sample C-48, generally has temperatures less than 16°C. TDS concentrations for Type I water range from 294 to 1,636 mg/l, with most of the values less than 500 mg/l.

Type II waters comprise the majority of samples collected, and are mainly sodium-calcium chloride-bicarbonate-sulfate (Na-Ca Cl-HCO_3-SO_4) in character. Generally this water is more concentrated in chloride and less concentrated in bicarbonate than Type I waters, as well as having $Na^+ + K^+$ values greater than 40% of the total cations. Type II water was found in the eastern half of Hansel Valley, in the Snowville area, along U. S. Interstate-84, and in the middle of T.14 N., R.10 W. where deeply migrating water is possibly forced closer to the surface due to a thinning of unconsolidated material. Water temperatures from this group range from 6°C to 25°C and include most of the warm water in the study area. The water was dilute to moderately saline, with TDS concentrations ranging from 484 to 5,168 mg/l.

Type III waters form a tight cluster within the Piper diagram despite consisting of 22 samples (Fig. 7). These waters are sodium-calcium chloride-bicarbonate-sulfate (Na-Ca Cl-HCO_3-SO_4) in character, with both Na^+ and Cl^- values greater than 75% of the total cations and anions, respectively. The warmest water within the study area is found within the Type III group. Water temperatures range from 12°C to 31°C. This water is located primarily in the southern portions of Curlew and Hansel valleys. Type III water is also found in areas where gravity highs indicate bedrock close to the surface such as north of the Wildcat Hills, northeast of Cedar Hill, and on the west side of the Showell Hills. An isolated well with Type III water and a temperature of 30°C is also found in north-eastern Hansel Valley. Most of the Type III water contains more than 3,000 mg/l TDS in the north and as much as 11,590 mg/l in the southern portion of the study area.

Water samples C-29 and C-61 are not defined within any of the three water types (Fig. 7), but they may belong in Type II water based on similar TDS values, water temperatures, and their geologic location within the study area.

Trace Elements and Silica

Detectable concentrations of trace elements were generally limited to water samples with high total dissolved solids and/or warm water temperatures. Table 2 presents the detection limits for the various trace elements. Trace elements present above detectable limits in some or all samples include iron (Fe), strontium (Sr), zinc (Zn), aluminum (Al), lead (Pb), phosphorus (P), manganese (Mn), uranium (U), cesium (Ce), lithium (Li), boron (B), barium (Ba), and fluoride (F).

High concentrations of trace elements within adjacent water wells or springs can help predict similarities of source waters when other nearby waters show no likeness to that water character. Fournier (1977) suggested the use of conservative element ratios, such as Cl/B, to indicate mixing of water. Variations in ratios of relatively conservative elements which do not precipitate from solution during water movement through rock indicate mixing is occurring between warm and cold waters in the study area.

Trace elements, in conjunction with the major ions, may also give information relating to the nature of the rocks in contact with the deep, hot waters (Ellis and Mahon, 1977). High boron, ammonia, bicarbonate, and carbon dioxide concentrations and low Cl/B ratios can indicate possible sedimentary rocks reacting with water at depth. Andesites and basalts often release high concentrations of boron and fluoride into solution. The reaction of water with other volcanic rocks, such as rhyolites, ignimbrites, and breccias, is suggested by appreciable concentrations of lithium and cesium in the water.

Examples of the first type of chemistry were found in several areas of thin, unconsolidated cover and presumably near-surface sedimentary bedrock within the project area as at sample sites C-23 and C-34. The chemistry types associated with volcanic rocks are difficult to distinguish because of the close relationship between high boron (>0.4 mg/l) and lithium (>0.5 mg/l) concentrations among some samples collected. Appreciable concentrations of these two elements and fluoride were found surrounding Cedar Hill and the Wildcat Hills area as well as along the southern extent of the study area where springs issue from basalts. High Li (>0.85 mg/l) and B (>1.0 mg/l) concentrations were found at C-34 and C-10 (Appendix B) indicating the possible presence of warm water.

Concentrations of silica (SiO_2) within the groundwaters sampled varied with little apparent dependence on water type or water temperature. Concentrations range from 14 to 89 mg/l. Areas of high and low concentration indicate some geographical dependence but could lack temperature dependence due to the specific silica phase dissolved in the water. Lower concentrations (less than 35 mg/l) were found along the North Promontory Mountains east of Snowville, near the Showell Hills, as well as throughout the southern portion of the study area. Concentrations of 60 mg/l or more were found clustered in the north-central part of the study area, along Deep Creek near Snowville, and in Hansel Valley. Anomalously high silica values may indicate warm water wells, as shown by C-45 and H-3 with concentrations of 87 and 89 mg/l, respectively.

Chemical Geothermometry

Geothermometry plays an important role in the initial exploration for sources of geothermal energy. Of the many different chemical geothermometers developed to estimate subsurface reservoir temperatures (Ellis and Mahon, 1977; Fournier, 1977), the silica (Fournier, 1977), Na-K-Ca (Fournier and Truesdell, 1973), and Na-K-Ca with Mg correction (Fournier and Potter, 1979) geothermometers, as well as some qualitative chemical indicators, were applied to the water chemistry of the study area. In order to employ geothermometers, a number of basic assumptions must be made (Fournier et al., 1974). The usual assumptions are:

1. Temperature-dependent reactions, such as the dissolution/precipitation of silica species, occur at depth.

2. All constituents involved in a temperature-dependent reaction are sufficiently abundant, so that their supply is not a limiting factor.

3. Water-rock equilibrium occurs at the reservoir temperature.

4. Little or no re-equilibration or change in composition occurs at lower temperatures as waters flow from the reservoir to the surface. If flow rates are less than 200 l/min from a single, isolated spring, the calculated temperature is probably lower than the actual reservoir temperature.

5. The hot water coming from deep in the system does not mix with cooler, shallow groundwater.

The Na-K-Ca geothermometer (Fournier and Truesdell, 1973) was developed in response to anomalously high calculated temperatures from the Na/K method (White, 1970; Ellis, 1970). Below approximately 180°C, the exchange between sodium and potassium feldspars may not be the dominant reaction, thus, the Na-K-Ca geothermometer was proposed to consider the participation of calcium in the aluminosilicate reactions at lower temperatures. The equation derived by Fournier and Truesdell (1973) was:

$$T^{o}C = \frac{1647}{\log\ (Na/K) + B\ \log(Ca^{1/2}/Na) + 2.24} - 273.15$$

where Na, K, and Ca concentrations are expressed in molality, and B is 1/3 or 4/3 if the calculated temperature is greater or less than 100°C, respectively.

Giordano and Swanberg (1978) studied the influence of reservoir rock type on the Na-K-Ca geothermometer and found no clear relationship exists between the actual water temperature and the cation chemistry in waters from carbonate aquifers. The calculated Na^+, K^+, and Ca^{+2} cation ratios were highly variable and were, generally, independent of each other for waters of similar temperatures. The effect of dilution on the Na-K-Ca geothermometer is generally negligible unless the hot water component is reduced to less than 20 or 30% (Fournier and Truesdell, 1974).

Fournier and Potter (1979) showed that waters rich in Mg^{+2} gave anomalously high calculated Na-K-Ca temperatures. A magnesium correction was developed for the Na-K-Ca geothermometer in which the magnitude of the correction was dependent on the estimated Na-K-Ca temperature and the Mg^{+2}, K^+, and Ca^{+2} concentrations in the water. Cation concentrations are expressed in equivalents. Temperature corrections are subtracted from the Na-K-Ca temperatures and can either be calculated or derived graphically based on R values and the estimated Na-K-Ca temperatures (>70°C), where $R = [Mg/Mg + Ca + K] \times 100$ with concentrations expressed in equivalents.

TABLE 3. CHEMICAL GEOTHERMOMETER AND SURFACE TEMPERATURES (IN ^{o}C) FOR WATER COLLECTED IN NORTH-CENTRAL BOX ELDER CO., UTAH.

Sample #	Least Supersaturated Silica Polymorph	Quartz (conductive)	Chalcedony	Na-K-Ca	Na-K-Ca-Mg	Surface Temperature
C-1	62	112	83	52	52	14
C-2	19	117	89	99	70	5
C-3	53	104	74	95	43	14
C-4	55	105	76	73	55	15
C-5	44	94	63	76	59	11
C-6	41	92	61	74	46	6
C-7	21	120	91	182	31	9
C-8	50	100	70	159	27	12
C-9	25	57	25	30	30	15
C-10	33	83	52	179	90	29
C-11	18	51	18	8	8	9
C-12	15	48	15	K Undetected	--	14
C-13	18	51	18	23	23	16
C-14	59	110	80	56	56	11
C-15	32	82	51	61	61	15
C-16	--	--	--	--	--	17
C-17	25	75	44	33	33	11
C-18	43	93	62	79	42	12
C-19	50	101	71	139	45	24
C-20	32	82	51	77	61	12
C-21	30	79	48	70	70	8
C-22	45	95	64	152	34	19
C-23	38	88	57	168	35	31
C-24	62	113	84	98	34	18
C-25	39	89	59	76	56	12
C-26	25	57	25	55	55	24
C-27	13	111	81	96	38	9
C-28	46	96	66	90	46	7

TABLE 3. (CONTINUED)

Sample #	Least Supersaturated Silica Polymorph	Quartz (conductive)	Chalcedony	Na-K-Ca	Na-K-Ca-Mg	Surface Temperature
C-29	16	114	86	143	30	9
C-30	17	115	86	155	18	9
C-31	46	96	66	151	38	15
C-32	35	85	54	134	34	17
C-33	44	94	63	97	50	17
C-34	33	83	52	177	104	14
C-35	20	118	90	93	61	18
C-36	23	71	40	96	55	19
C-37	32	82	51	91	56	17
C-38	25	57	25	82	58	20
C-39	29	62	29	75	71	24
C-40	29	62	29	60	60	25
C-41	46	96	66	88	43	18
C-42	31	81	50	80	65	16
C-43	24	122	94	156	60	21
C-44	40	72	40	111	47	25
C-45	27	126	98	160	55	24
C-46	20	118	90	161	55	17
C-47	63	114	85	88	70	16
C-48	22	120	92	85	79	21
C-49	19	117	89	93	56	25
C-50	19	117	89	84	63	24
C-51	24	122	94	82	55	17
C-52	19	69	37	59	59	16
C-53	37	69	37	49	49	20
C-54	27	77	45	66	66	16
C-55	35	85	54	77	58	15
C-56	31	63	31	35	35	18

TABLE 3. (CONTINUED)

Sample #	Least Supersaturated Silica Polymorph	Quartz (conductive)	Chalcedony	Na-K-Ca	Na-K-Ca-Mg	Surface Temperature
C-59	21	119	91	90	48	20
C-60	52	103	73	158	43	19
C-61	49	99	69	161	56	23
C-62	22	120	92	70	70	18
C-63	23	121	93	75	75	17
H-1	21	120	91	61	61	14
H-2	42	72	42	137	33	30
H-3	32	129	103	88	40	22
H-4	25	121	95	67	67	16
H-5	31	128	102	74	66	21
H-6	54	103	75	61	61	12
H-7	18	51	18	10	10	17
H-8	18	51	K Undetected	--	--	15
H-9	45	95	64	154	50	18
H-10	31	81	50	153	49	12
H-11	23	71	40	144	44	17
H-12	23	71	40	144	44	19
H-13	21	69	39	153	49	18
H-14	16	114	85	54	54	14
H-15	62	112	83	83	48	17
H-16	63	114	85	45	45	17
L-1	48	96	68	172	31	13
L-2	41	92	60	155	30	16
L-3	43	93	62	146	32	16
L-4	35	85	54	160	29	15
L-5	37	86	56	148	32	16
L-6	37	86	56	162	29	18

As with the Na-K-Ca geothermometer, the Mg-corrected Na-K-Ca geothermometer can be plagued by errors when conditions are less than ideal. Continued water-rock reactions as the water rises from its deep reservoir could allow Mg ions to be picked up by the ascending water, giving much lower estimated reservoir temperatures. Fournier and Potter (1979) discussed these and other problems associated with the magnesium correction and offered no exact rules as to when or when not to apply the Mg correction. Most of their data suggests that high Mg concentrations do indicate that water-rock reactions have occurred at relatively low temperatures. Because of uncertainties in the Na-K-Ca-Mg geothermometer, both the Na-K-Ca and Na-K-Ca-Mg results are given in Table 3.

A method of using silica concentrations in hot waters to estimate reservoir temperatures was derived by Fournier and Rowe (1966). They proposed that the silica content of water is controlled by crystalline-phase silica solubility at depth and not by the solubility of silica species found near the surface. The silica content of the water was assumed to be a function of quartz solubility if the Na-K-Ca geothermometer indicated a temperature over 100°C (Fournier, 1977). For temperatures less than 100°C, the silica content was assumed to be a function of chalcedony solubility. Uncertainties have risen over which form of silica (quart or chalcedony) governs concentrations between 100°C and 180°C (Arnorsson, 1975; Fournier, 1981); therefore, both quartz and chalcedony temperatures are given in Table 3.

Fournier (1977) developed silica geothermometers to consider fluid equilibrium with five of the most important silica polymorphs, based on their different solubilities. The use of silica geothermometers on the least supersaturated polymorph was also incorporated in this study to predict a minimum geothermometer temperature. The temperature dependence of the silica species from quartz through amorphous silica is shown in Figure 8.

The silica geothermometer is often more suseptible to miscalculation of reservoir temperatures after mixing than the Na-K-Ca geothermometer. This suseptibility is mainly due to the use of actual silica concentrations in the water rather than a ratio of ions as in the Na-K-Ca geothermometer. If chemical equilibrium is attained after mixing, the silica geothermometer will give the temperature of that last equilibrium. If chemical equilibrium is not attained, direct application of the silica geothermometer will result in a calculated temperature that is too low. Under favorable conditions, the original temperature of the hot water component and the proportion of cold water in the mixture can be estimated by using the measured temperature and silica content of warm spring water as well as the temperature and silica content of cold, nonthermal water in the region (Fournier and Truesdell, 1974). Truesdell and Fournier (1977) later presented a simplified graphical method for obtaining the same results. This technique was used in this study and the results are presented later in the text.

All calculated reservoir temperatures, and the equations expressing the temperature dependence of selected geothermometers,

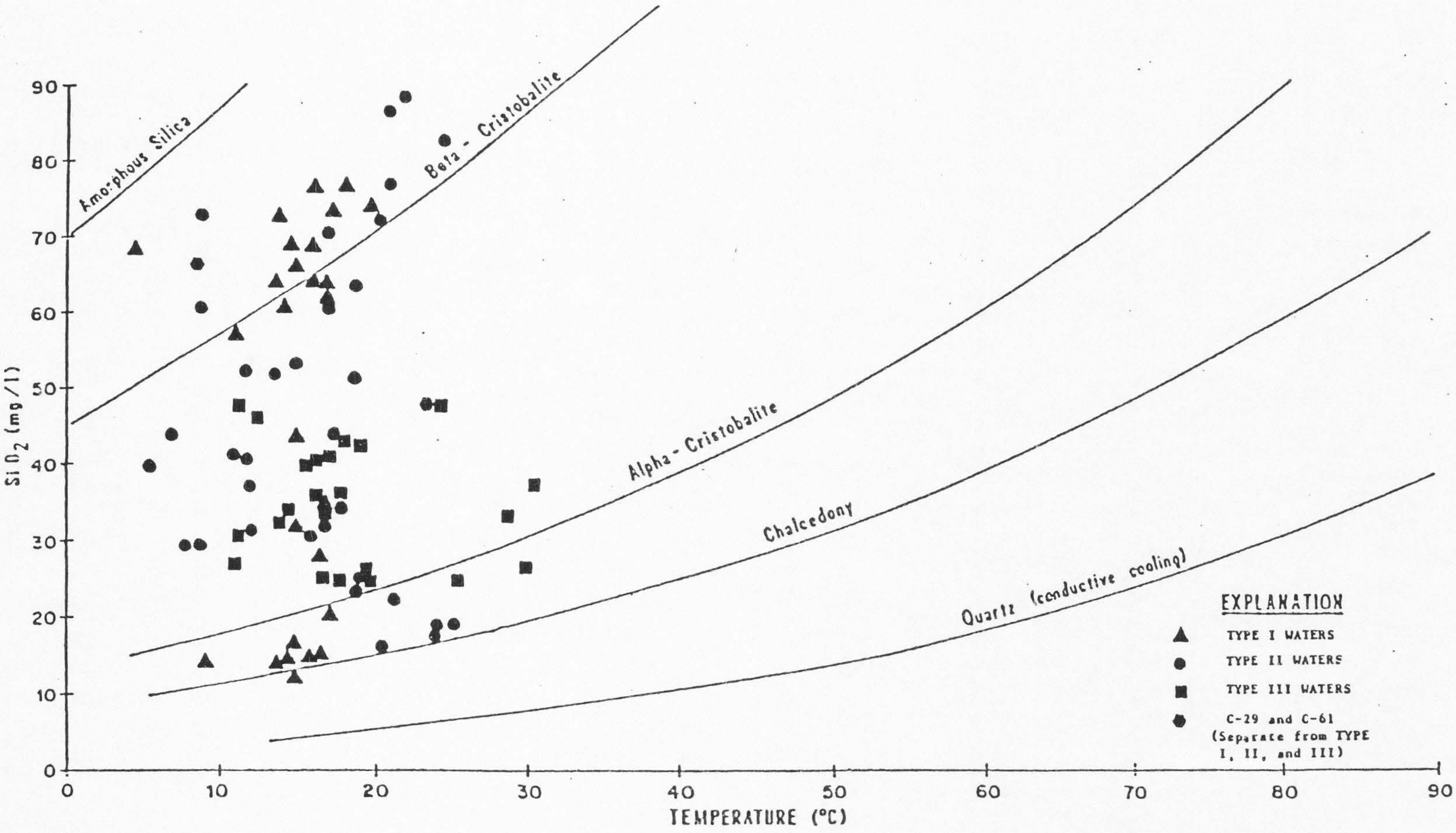

Figure 8. Silica concentrations versus surface temperature diagram of water samples from north-central Box Elder County, Utah. Mineral solubilities taken from Fournier (1977).

are presented in Tables 3 and 4, respectively. Qualitative chemical indicators of thermal reservoir temperatures were also examined, but the results were only used as supportive evidence of predetermined possible thermal areas. The chemical indicators occasionally employed to indicate areas of thermal water include: low concentrations of calcium and bicarbonate (Ellis, 1970); low Mg/Ca ratios (White, 1970); high Na/Ca ratios (Mahon, 1970); and highest ratios of chloride to total carbonate (Fournier and Truesdell, 1970), and chloride to fluoride (Mahon, 1970). The lack of proven results using any of the chemical geothermometers on low temperature areas or in various lithologic units, forced only qualitative use of the geothermometry calculations from this study.

Table 3 showns that Na-K-Ca temperatures (Mg corrected) ranged from 8°C to 104°C, with over 90% of the estimated reservoir temperatures between 30°C and 75°C. Areas with warm water temperatures at the surface, generally, had higher estimated reservoir temperatures. Anomalously high subsurface temperatures were calculated for sample sites C-10 and C-34, recording 90°C and 104°C, respectively. Although these two sample locations are close to each other and have similar chemical compositions, their measured water temperatures were 15°C apart, with C-10 twice as warm as C-34, suggesting that mixing has occurred in the area. Another area of higher than average Na-K-Ca-Mg temperatures was in the north-central portion of Area II (Plate 4). Estimated reservoir temperatures from this area are greater than 70°C and include sample sites C-62, C-63, C-48, C-47, and C-2.

TABLE 4. EQUATIONS EXPRESSING THE TEMPERATURE DEPENDENCE OF SELECTED GEOTHERMOMETERS. CONCENTRATIONS OF SILICA (SiO_2) ARE IN mg/l. Na-K-Ca CONCENTRATIONS HAVE UNITS OF MOLALITY.

Quartz (conductive): $$T(^{o}C) = \frac{1309}{5.19 - \log SiO_2} - 273.15$$

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

α-Cristobalite: $$T(^{o}C) = \frac{1000}{4.78 - \log SiO_2} - 273.15$$

β-Cristobalite: $$T(^{o}C) = \frac{781}{4.51 - \log SiO_2} - 273.15$$

Amorphous silica: $$T(^{o}C) = \frac{731}{4.52 - \log SiO_2} - 273.15$$

Na-K-Ca: $$T(^{o}C) = \frac{1647}{\log(Na/K) + B \log(Ca^{1/2}/Na) + 2.24} - 273.15$$

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

Magnesium correction for Na-K-Ca when temperatures $> 70^{o}C$

$R = [Mg/(Mg+Ca+K)] \times 100$ in equivalent units of concentration

Chalcedony temperatures ranged from 15°C to 103°C for all of the samples collected. It has not been determined which form of silica to use for silica geothermometry when undissociated silica concentrations are between 60 and 250 mg/1 (Arnorsson, 1975). Because of this discrepancy over which silica temperature gives the correct temperature from depth, the quartz temperatures for samples containing greater than 60 mg/l silica ranged from 111°C to 129°C. The minimum geothermometer temperatures estimated using the least supersaturated silica polymorph ranged from 13°C to 63°C. Most of the samples were supersaturated with chalcedony, which may be due to dissolution of volcanic glass, characteristically comprised of alpha-cristobalite and only one undersaturated with chalcedony (Fig. 8).

Comparing the results of the various geothermometers used in this study requires consideration of possible mixing of the water; re-equilibration, especially if the flow rate of the water is less than the recommended minimum of 200 l/min; and/or the possibility of not fulfilling any of the other basic assumptions of geothermometry (Fournier et al., 1974) mentioned earlier in this report. The most notable difference among the estimated temperatures in Table 3 is that Na-K-Ca temperatures with Mg corrections are consistently 20°C to 60°C lower than temperatures calculated from the chalcedony geothermometer (Fig. 9). This discrepancy is particularly noticeable for water samples with high (>90°C) Na-K-Ca temperatures. Mixing of cold and hot water may not be a possible reason for the

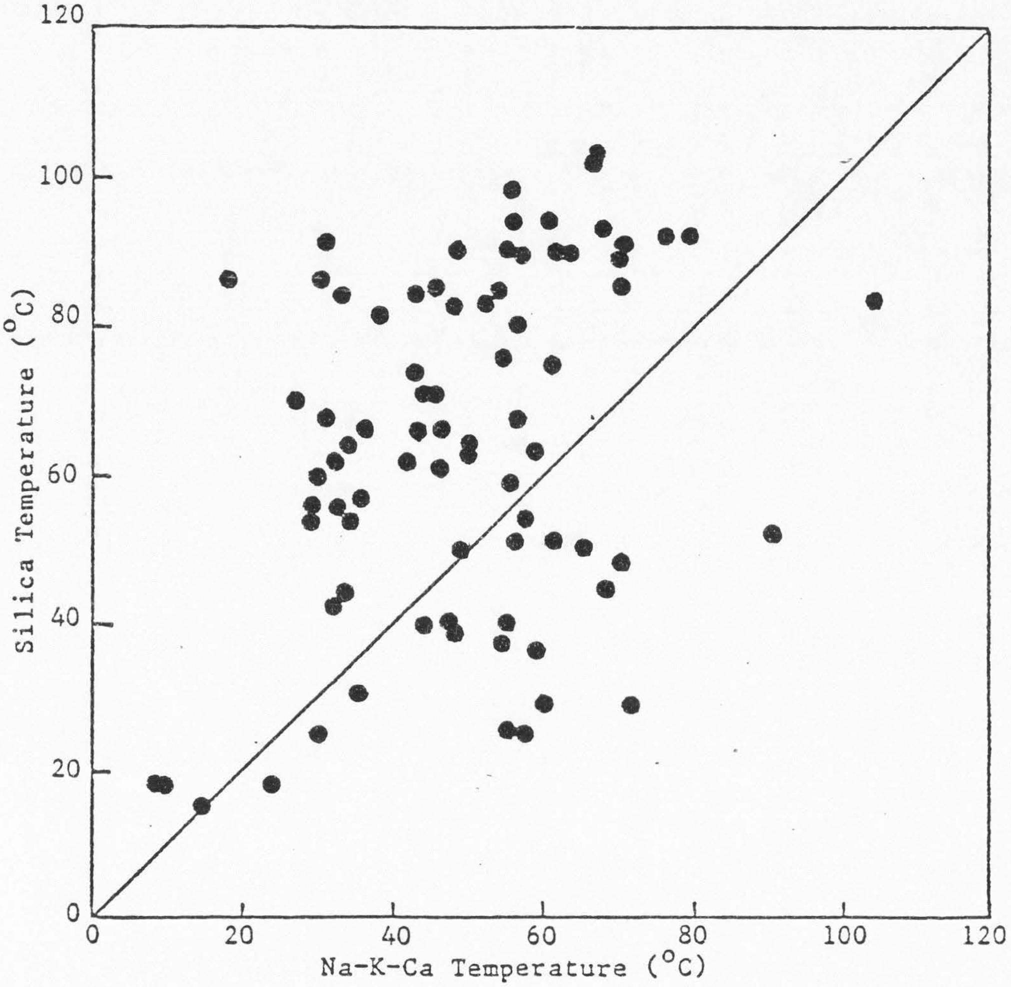

Figure 9. Plot of indicated silica temperature versus indicated Na-K-Ca temperature. Mg correction has been applied where necessary. The 1:1 ratio line represents ideal agreement between the two geothermometers.

difference. Mixing generally results in calculated silica temperatures that are too low. A possibility for the difference in temperatures is the Mg concentrations within the waters sampled may be in error. The ascending waters may have picked up Mg ions from Mg-rich wall rocks (dolomites, Mg-rich limestones, and/or clays) in the area. Without the Mg correction applied to the Na-K-Ca geothermometer, however, the estimated reservoir temperatures are apparently too high. This suggests that some type of Mg correction is needed, but possibly one with less of an effect on the Na-K-Ca geothermometer than proposed by Fournier and Potter (1979). As suggested before, the estimated silica temperatures may be high due to the dissolution of volcanic glass present in the silicic volcanic rocks and from tuffs of the weathered Salt Lake Formation within the unconsolidated valley fill material of the region. Kolesar and DeGraff (1978) suggested that the Na-K-Ca geothermometer may produce invalid results after ground water passes through saline, valley-fill sediments deposited from Lake Bonneville, dissolving soluble sodium- and potassium-rich minerals.

TEMPERATURE-DEPTH SURVEY

Accessible and useable heat from within the earth is the ultimate objective of geothermal prospecting, and temperature-depth measurements provide a useful exploration tool to accomplish this goal. Conductive heat flow within the earth and the thermal conductivity of the material through which the heat is being transmitted, together control temperature gradients in a particular area. As these conditions vary due to the geology of a region, so too does the temperature gradient vary, because the thermal gradient is inversely proportional to the thermal conductivity of the transmitting material (Kappelmeyer and Haenel, 1974). Temperature-depth measurements must be taken at sufficient depths to avoid the disturbing near-surface effects of local topography, precipitation, temperature, insulation, and movement of groundwater. These effects are supposedly eliminated below 30 meters in depth (Kappelmeyer and Haenel, 1974). However, many times these effects are adequately diminished at depths of more than 15 meters (Combs and Muffler, 1973). To be reliable, measurements should not be made in water wells that intercept flowing groundwater. Temperature gradients are only valid for conductive heat transfer, and convection both within and outside the well casing can disturb the temperature-depth readings (Lumb, 1981).

Temperature-depth measurements were made in 16 wells within north-central Box Elder County, Utah (Plate 6). Temperature-depth profiles of these measurements are presented in Figures 10 through 14. Gradients were calculated using linear regression, and no topographic corrections were employed. Table 5 presents the location, elevation, interval of gradient calculation, and calculated gradients of each hole. Appendix C includes more details regarding each location.

Several shallow (<40 meters) wells were included because of the lack of any previous thermal gradient data in the study area and because unused wells were scarce. Profiles from the temperature-depth measurements of the these and other wells were seldom linear because of: (1) ground water movement through aquifers intercepted at various depths; (2) the different lithologies encountered in the wells; porosity variations; and/or (3) circulating air. In light of these sources for error, most calculated gradient values in this study are only used to locate areas with anomalously high gradients relative to the background gradient of the region.

The thermal gradients calculated from the 16 temperature-depth measurements ranged from 11°C/km to 267°C/km. Only two profiles were below the average Basin and Range gradient, considered to be 35°C/km. Both of these gradients were calculated from measurements in wells of less than 30 meters in depth making their validity questionable. Generally, the background gradient in the study area appears to be slightly above average for the Basin and Range and therefore, readings of 50°C/km or 60°C/km are considered to be anomalously high for the study area. Considering the possibility of a slightly elevated average thermal gradient in the region, at least

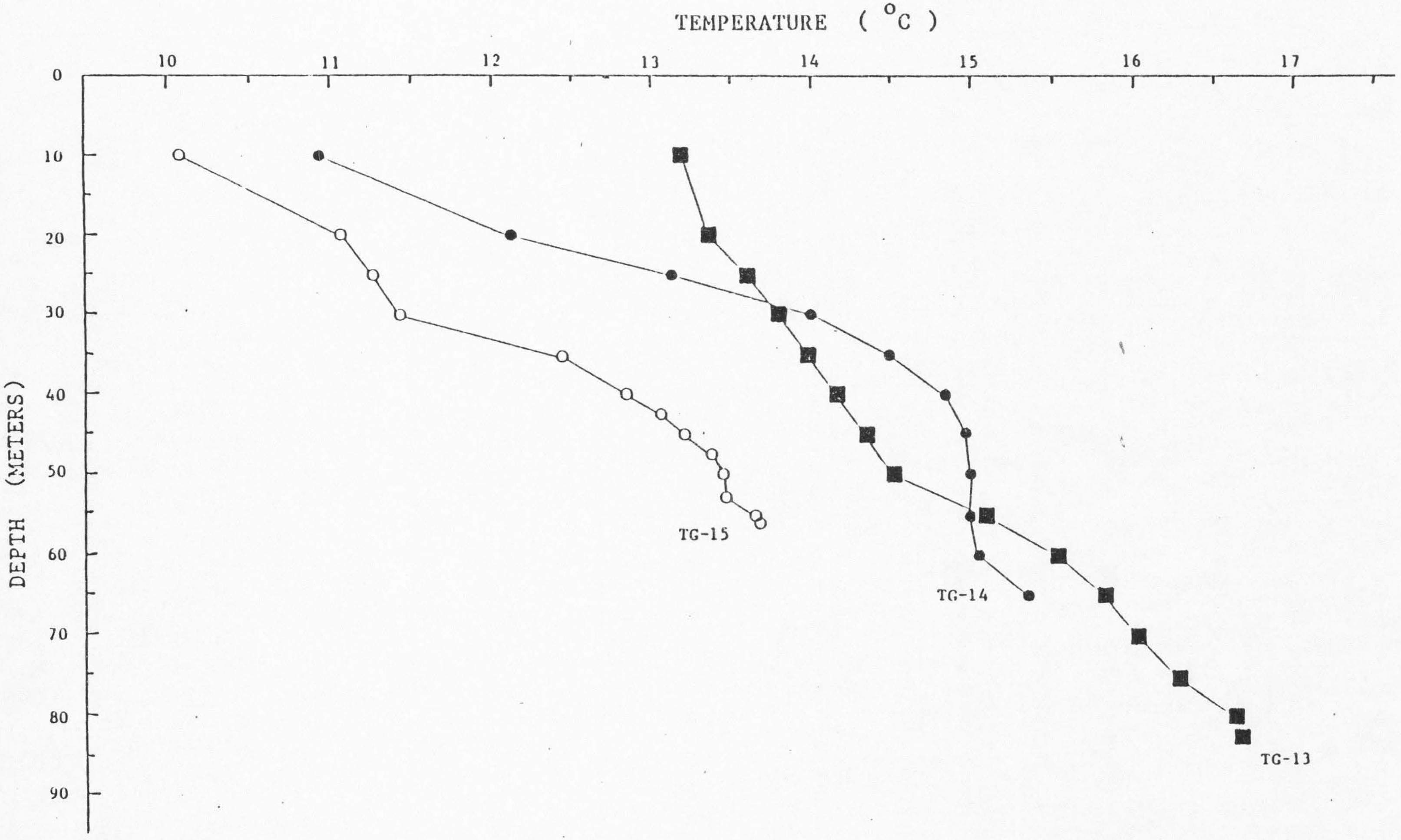

Figure 10. Temperature-depth profiles of wells logged in Area I (Plate 4) in north-central Box Elder County, Utah.

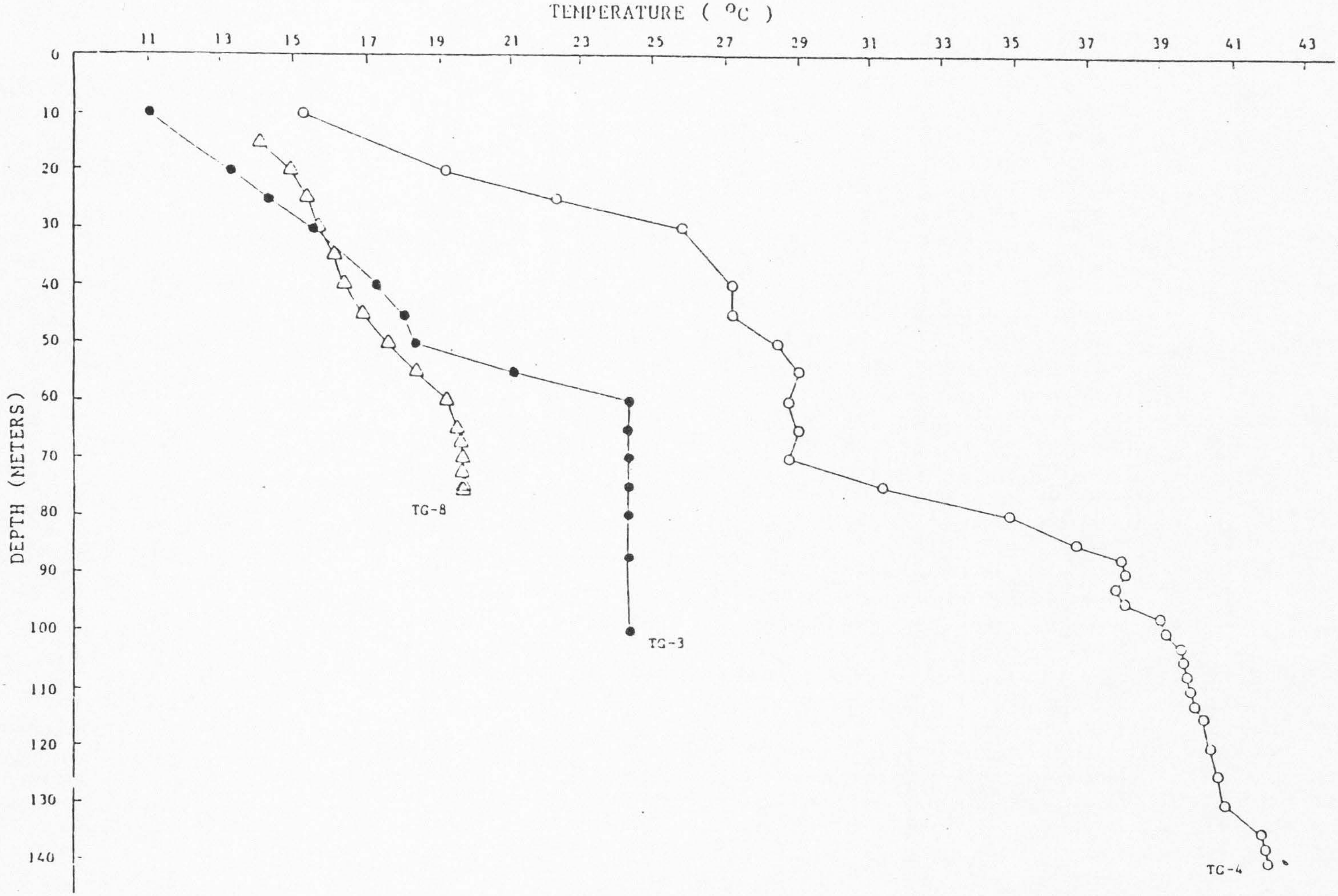

Figure 11. Temperature-depth profiles of wells logged in Area II (Plate 4) in north-central Box Elder County, Utah.

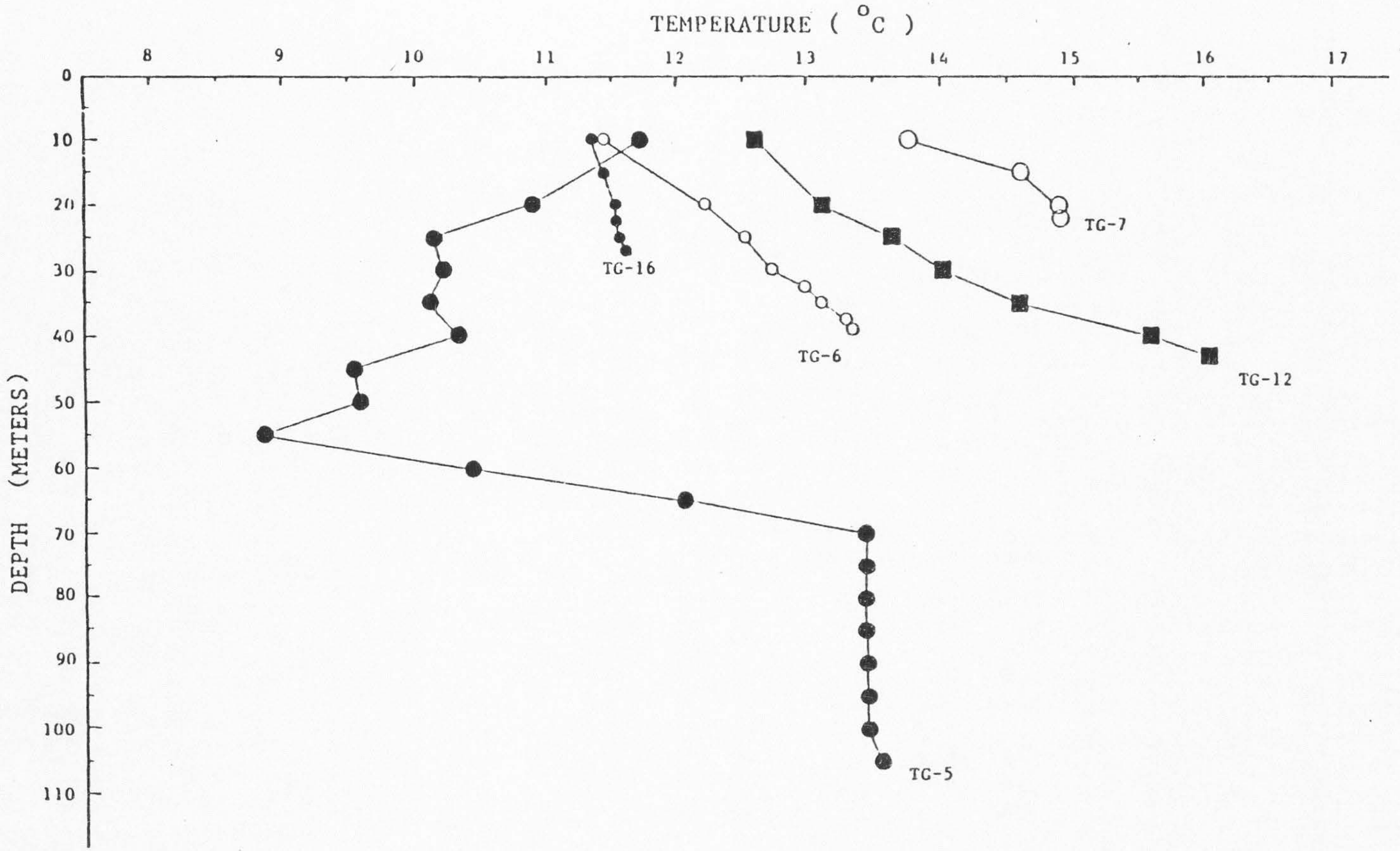

Figure 12. Temperature-depth profiles of wells logged in Area II (Plate 4) in north-central Box Elder County, Utah.

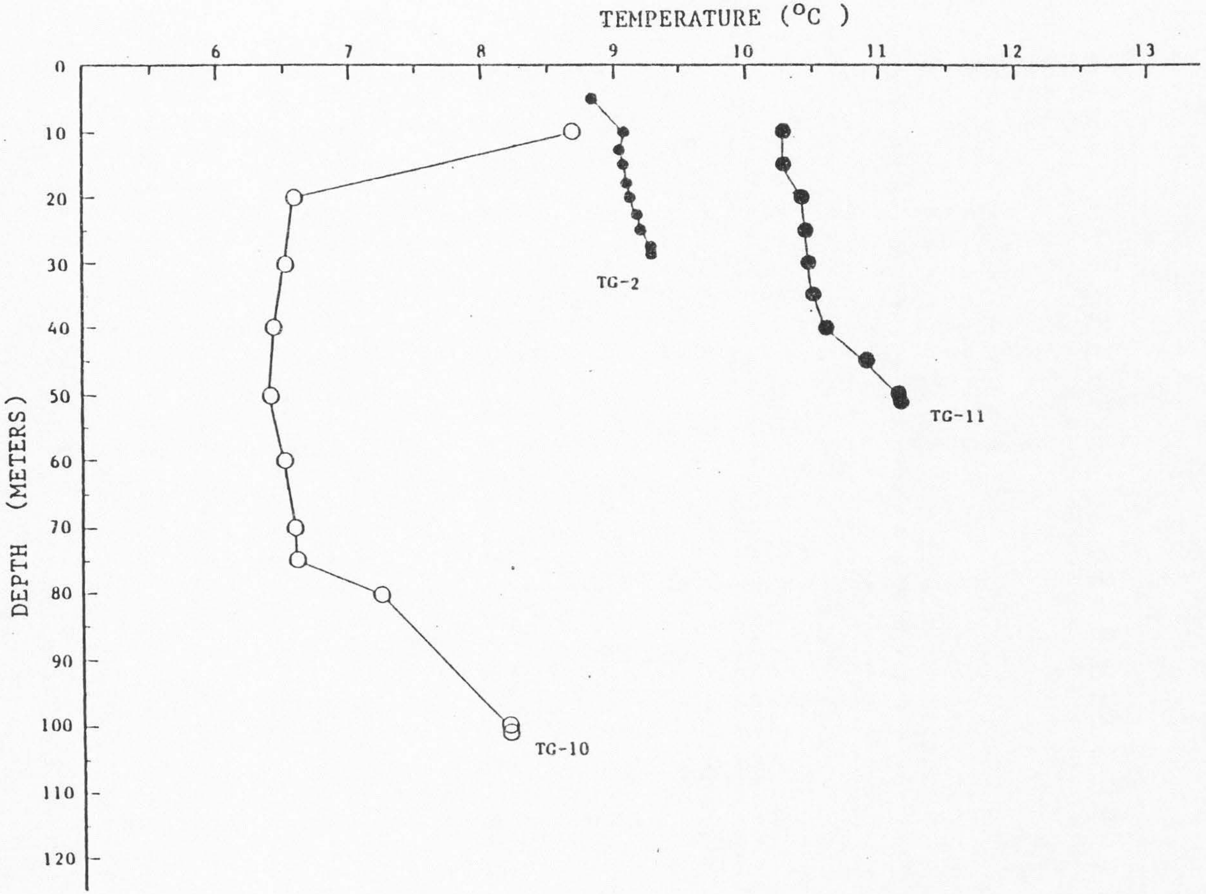

Figure 13. Temperature-depth profiles of wells logged in Area III (Plate 4) in north-central Box Elder County, Utah.

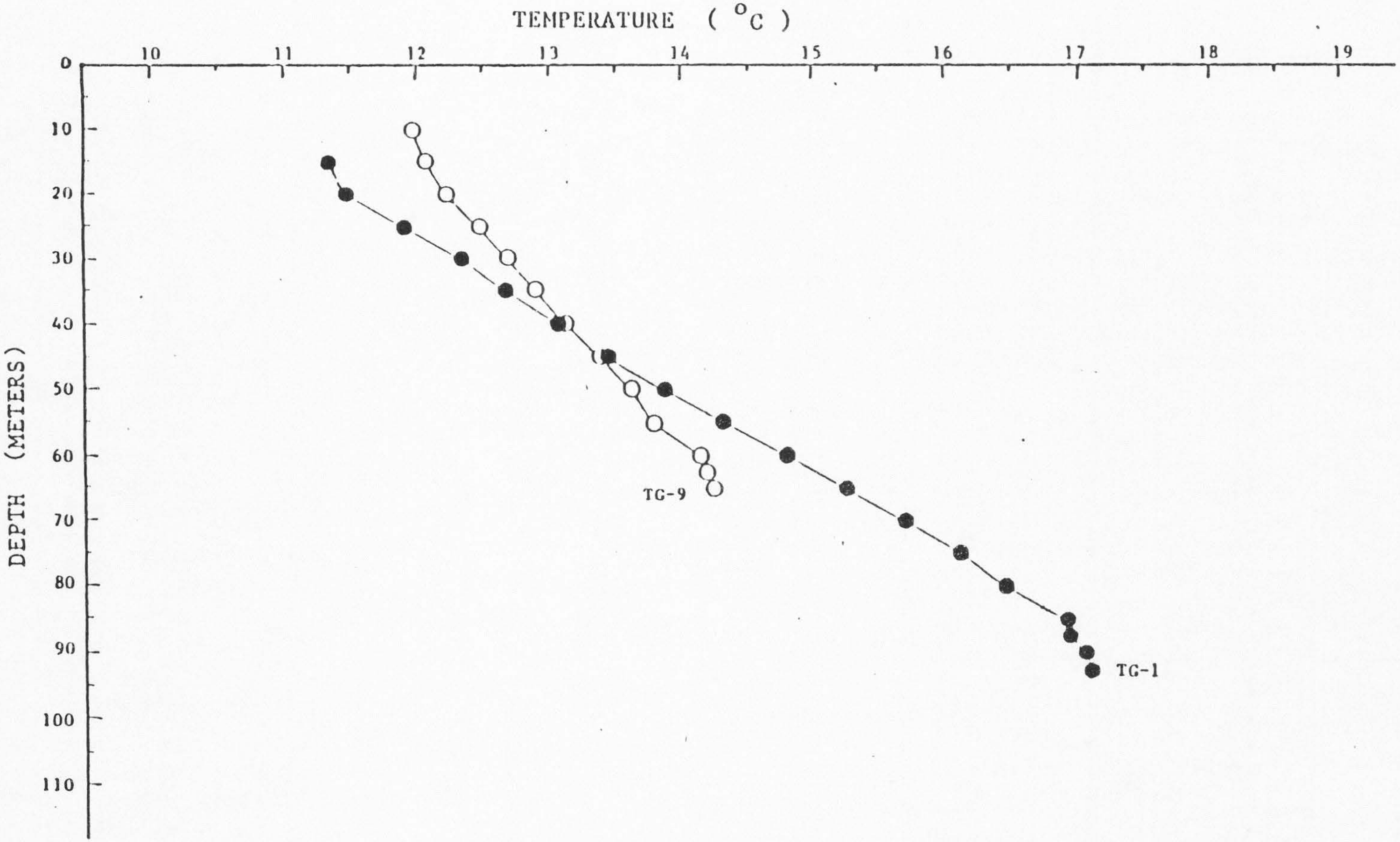

Figure 14. Temperature-depth profiles of wells logged in Area IV (Plate 4) in north-central Box Elder County, Utah.

TABLE 5. GEOTHERMAL GRADIENT DATA LOGGED IN NORTH-CENTRAL BOX ELDER COUNTY, UTAH.

Site	North Latitude	West Longitude	Surface Elevation (m)	Depth Interval for Calc. Gradient (m)[a]	Calc. Gradient (°C/km)[b]
TG-1	41°49'46"	112°35'24"	1485	30-92.5	86 ± 3
TG-2	41°59'14"	112°42'10"	1386	20-28.5	18 ± 1
TG-3	41°58'22"	112°49'54"	1347	30-60	267 ± 37
TG-4	41°59'56"	112°52'08"	1359	75-132.5	182 ± 7
TG-5	41°56'59"	112°58'38"	1363	--	isothermal
TG-6	41°51'50"	112°56'48"	1323	30-39	65 ± 3
TG-7	41°48'19"	112°57'46"	1313	15-22	44 ± 6
TG-8	41°58'18"	112°52'53"	1342	30-75	119± 26
TG-9	41°50'38"	112°37'29"	1458	20-65	46 ± 3
TG-10	41°53'09"	112°49'08"	1386	50-101	39± 29
TG-11	41°55'19"	112°45'49"	1384	35-50	44 ± 6
TG-12	41°58'49"	112°47'38"	1376	25-43	135 ± 23
TG-13	41°51'52"	113°05'27"	1366	30-82	59 ± 14
TG-14	41°47'43"	113°06'45"	1310	25-65	44 ± 11
TG-15	41°47'43"	113°07'25"	1315	30-56	75 ± 24
TG-16	41°57'37"	112°50'37"	1343	20-27	11 ± 2

[a] Interval was choosen as representative of entire hole.

[b] Errors were calculated from standard deviations of linear regressions.

two areas of high gradients exist.

The first of these two areas is located in the northeast portion of Area II (Plate 4) west from the Showell Hills to the R.9 W./ R.10 W. border. Four temperature-depth measurements (TG-3, TG-4, TG-8, and TG-12) resulted in gradients over 100°C/km. The gradient calculated for TG-3 was the highest in the study area at 267°C/km. The thermal gradient for this well becomes isothermal several meters below the water level, which may be due to the abnormally high gradient forcing convection of the water within the well (Sestini, 1970). Some convection may also occur in TG-8 and TG-4, but their gradients are still probably anomalously high for the study area. The temperature-depth measurements from TG-4 produced the highest temperature within the project area, with 41.87°C at the bottom of the well.

A second area with gradients noticeably higher than background is located on the east side of Hansel Valley. A gradient of 86°C/km was calculated from TG-1. Thermal gradient TG-9 on the west side of the valley was only half as great as TG-1. This lower gradient correlates positively with cold water found at well depths which are similar to those of warm water wells on the east side of the valley where the gradient is higher.

Another area of possibly elevated thermal gradients is in the southern portion of Area I (Plate 4) where a 75°C/km gradient was measured at TG-15. The area between the Wildcat Hills and Cedar Hill recorded a gradient of 65°C/km (TG-6) and is also suspected of having higher than average gradients. Both of these areas need additional measurements to confirm the actual presence of anomalously high thermal gradients.

Unusual temperature-depth profiles were calculated for TG-10 and TG-5 (Plate 6). From TG-10, a temperature of 6.5°C was recorded at 50 meters and the temperature gradually increased from that depth to the dry bottom at 101 meters (Fig. 13). The reason for temperatures below 7.5°C (the mean annual air temperature) is not clear. One explanation may be evaporative cooling from a perched body of water intercepted by an uncased or perforated portion of the well, or possibly the intersection of an ice tunnel similar to those found in the Ice Caves area of Idaho to the north. TG-5 may have a high gradient, but is isothermal from a depth of 72 meters to 105 meters, and showed many fluctuations in temperature readings with depth probably due to the convecting conditions (Fig. 12). More gradient data are needed to accurately determine the conductive heat flow for these and other areas within north-central Box Elder County, Utah.

SUMMARY AND CONCLUSIONS

From the initial reconnaissance techniques used to evaluate the geothermal potential in north-central Box Elder County, Utah, two areas have been identified as possibly having low-to-moderate temperature geothermal resources. These areas are presented on Plate 9 and will be referred to as Areas A and B. Other areas of possible interest include the area approximately 8 to 16 kilometers north of the Wildcat Hills, the western edge of the North Promontory Mountains west of Snowville, and along the Hansel Mountains in T. 13 N., R. 8 W. and T. 12 N., R. 8 W. (Plate 7). Conclusions were based on temperature surveys, water chemistry, and temperature-depth measurements, in addition to their relationship to the geology and hydrology within the study area. Therefore, a summary of the techniques used to help identify these areas, and models to explain warm water occurrences, will be discussed.

Recorded water temperatures for the project area ranged from 5°C to 31°C. Each of the above mentioned proposed anomalous areas contained at least one well of over 25°C. Because any well, if deep enough, can give warm temperatures even with a relatively low geothermal gradient, well depths had to be considered before determining whether the sampled water was actually unusually warm or not.

The calculated temperature-depth profile of an area plays a major role in the occurrence of warm water. The conductive heat flow within a region can be determined from temperature gradient and thermal conductivity measurements. The calculated gradients ranged from $11^{\circ}C/km$ to $267^{\circ}C/km$, with an estimated background for the study area slightly above the $35^{\circ}C/km$ Basin and Range average.

The water chemistry of collected samples was used extensively in the evaluation of geothermal potential within the report area and was broken-down into several cateogories, including: total dissolved solid concentrations, common ion analysis, the presence of trace elements, and geothermometry. When using water chemistry interpretations, several factors had to be considered. These factors include: the different lithologic units within the flow systems; the variability in length of groundwater residence times; the mixing of waters, especially if from different source areas; and the influences of seasonal variations.

Several geothermal models are proposed to explain the occurrence of warm water within the study area. Model 1 involves meteoric water that has migrated to depth, being warmed by the normal thermal gradient. This water then rises along a permeable fault zone and eventually mixes with near-surface cold water recharge, causing dilution from depth (Fig. 15). In Model 2, water warmed by the normal thermal gradient migrates up a permeable fault zone and infiltrates a fractured bedrock gravity high. After passing through the secondary permeability of the bedrock, the hot water mixes with cooler near-surface water before intercepted by a well (Fig. 16). Model 3 once again involves warmed meteoric water travelling up a permeable conduit such as a fault zone. The water

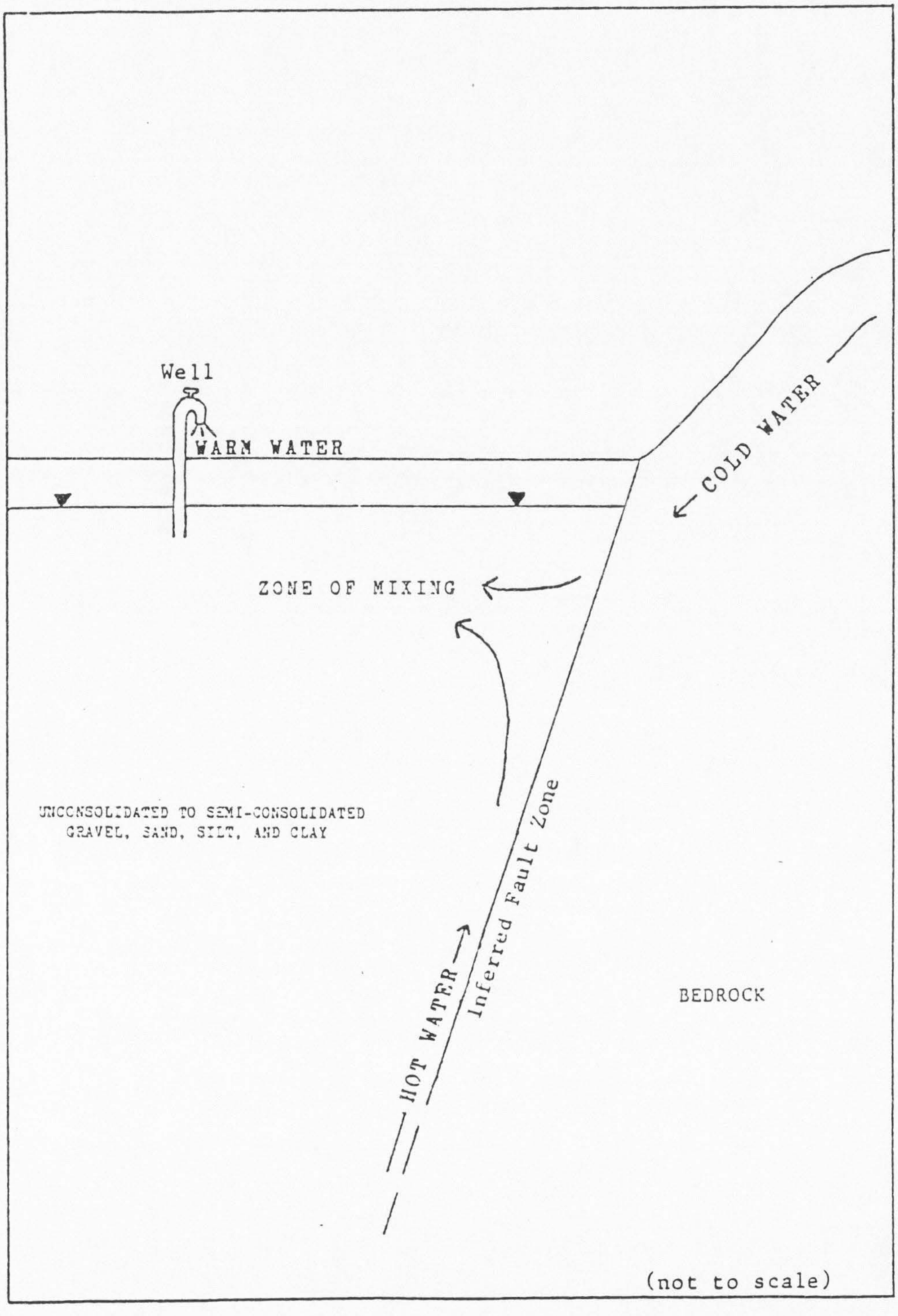

Figure 15. Model 1 proposed for the geothermal anomalies in north-central Box Elder County, Utah.

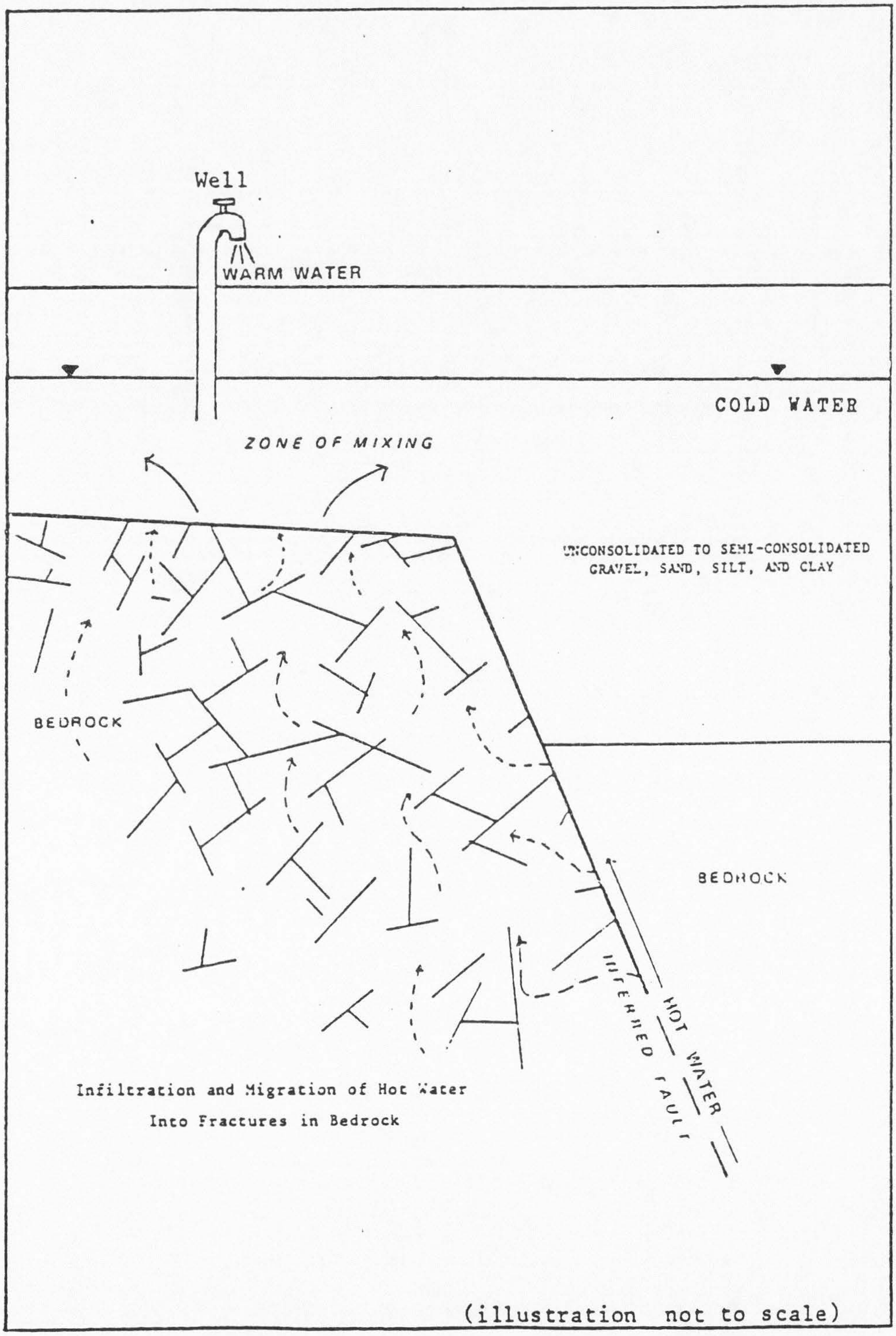

Figure 16. Model 2 proposed for the geothermal anomalies in north-central Box Elder County, Utah.

from depth mixes with cooler water migrating down gradient. The mixed water within a flow system encounters a less permeable bedrock gravity high which forces the warmed water closer to the surface (Fig. 17). A final model, Model 4, is similar to the previously mentioned geothermal model. In Model 4, heated water does not need to come from a fault zone but instead water migrates to depth in a deep basin, being warmed by the normal thermal gradient in the area. The water travels down gradient through the basin until forced nearer to the surface by a less permeable bedrock high (Fig. 18). Combinations of these models can also be used to explain the cooling of hot water in the proposed areas of geothermal interest.

Area A

Area A includes sample locations C-36, C-41, C-43, C-44, C-45, C-46, C-52, and C-53, with water temperatures ranging from 17°C to 25°C (Plate 7). Four temperature-depth holes were logged in this area (TG-8, TG-12, TG-4, and TG-3) resulting in calculated gradients ranging from 119°C/km to 267°C/km. The water at the bottom (132.5 meters) of TG-4 was 41.8°C/km which is similar to a reported temperature of 41.5°C for a near-by unused well of the same depth (Charles Taylor, personal communication).

The chemical analysis of waters from Area A indicates all but one (C-44) are Type II in character. C-44 is an isolated occurrence of Type III water and is high (>75%) in sodium and chloride. The concentrations of total dissolved solids in Area A ranged from 846 to 5,168 mg/l. Only C-53 has a TDS less than 1,000 mg/l, which may

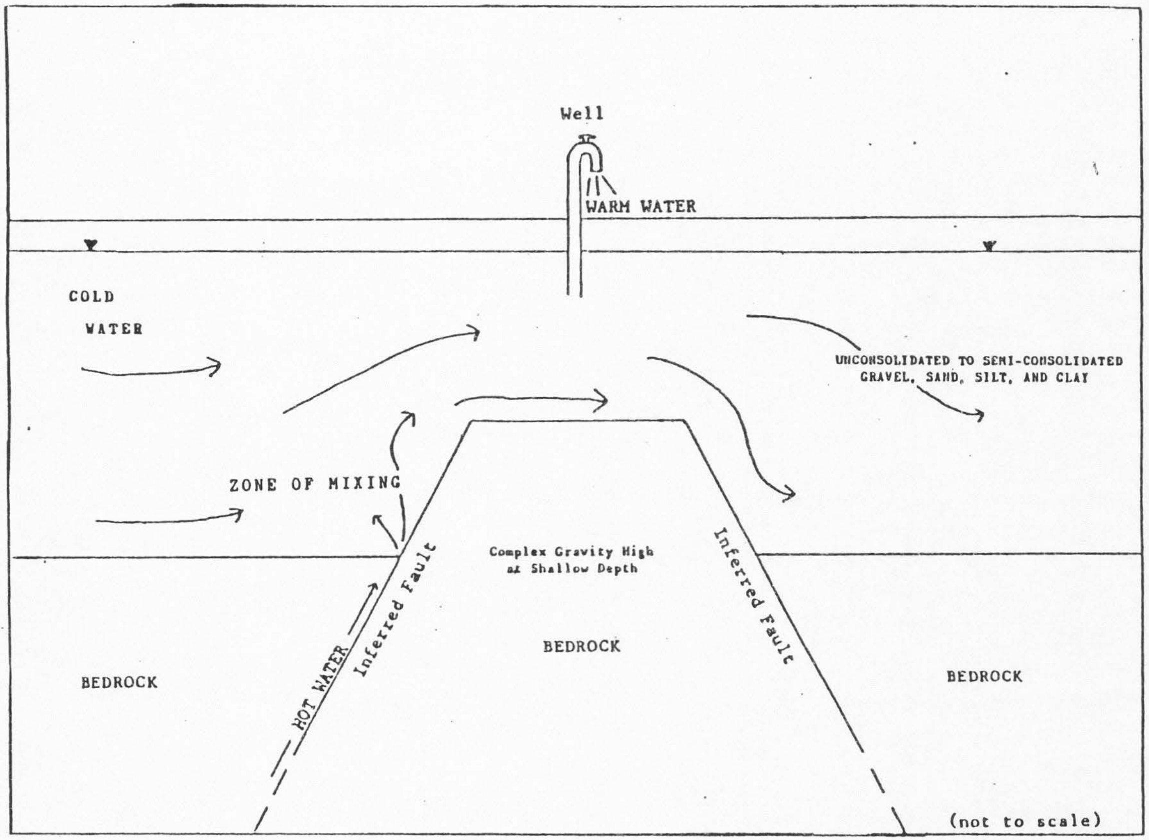

Figure 17. Model 3 proposed for the regions of possible geothermal interest in north-central Box Elder County, Utah.

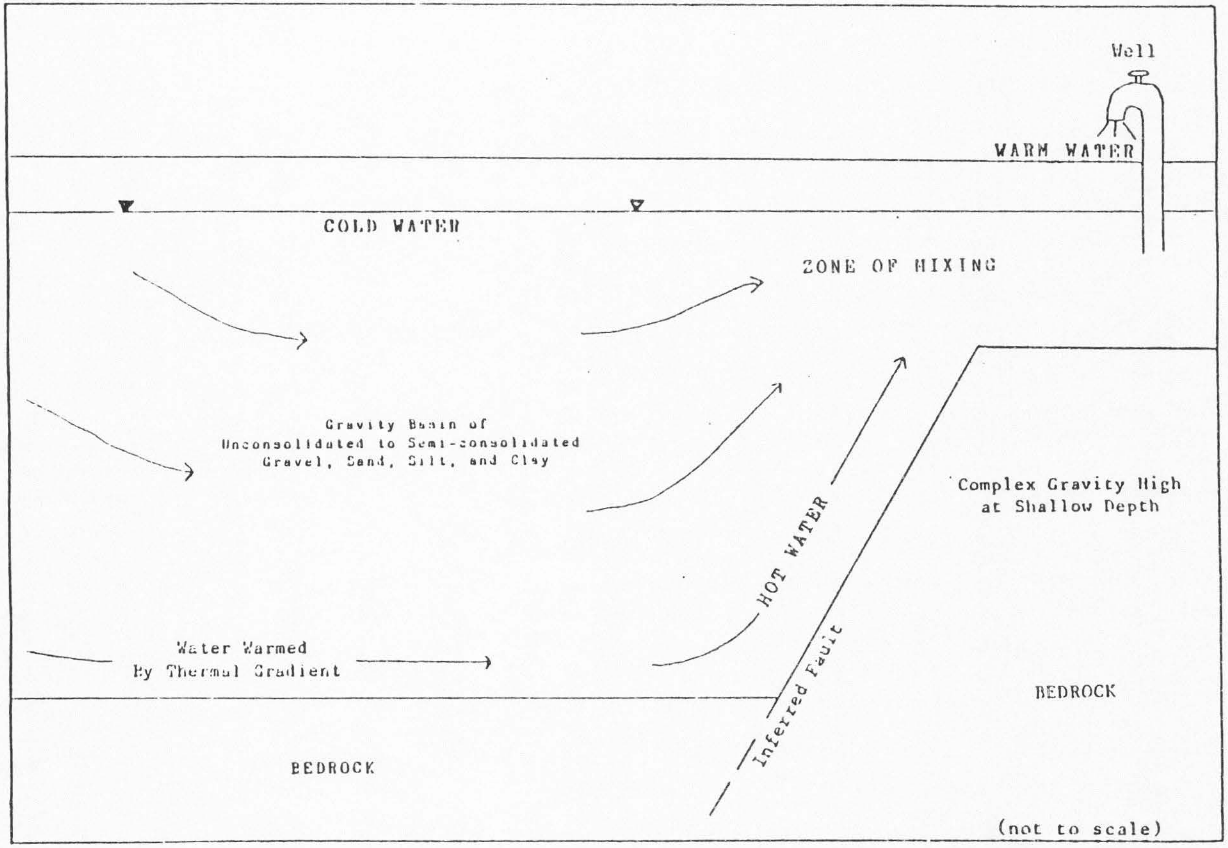

Figure 18. Model 4 proposed for the regions of possible geothermal interest in north-central Box Elder County, Utah.

be indicative of shorter residence time or the precipitation and/or dilution of dissolved solids due to mixing with cold, more dilute waters. A summary of the water chemistry in Area A is presented in Table 6.

Estimated reservoir temperatures ranged from 43°C to 60°C for the Na-K-Ca-Mg geothermometer and 37°C to 98°C for the chalcedony geothermometer. The Na-K-Ca geothermometer without the Mg correction indicated a reservoir temperature of over 100°C for C-43, C-44, C-45, and C-46. These temperatures are also indicated by applying the mixing model (Truesdell and Fournier, 1977) to the warm water wells. The model could not be applied to most of the samples from the study area because of inconsistent silica concentrations in the warm and cold waters analysed. The variations in silica concentrations may be due to the dissolution of amorphous silica by cold waters. Silica geothermometer temperatures for samples C-45 and C-44 were corrected for the hot water component, resulting in estimated reservoir temperatures of 198°C and 104°C, respectively. Both sample sites were calculated to have over 80% cold water component within its mixture.

A model for the apparent low temperature geothermal anomaly in Area A is depicted by Model 2 (Fig. 16). Deep circulation ($\geq$ 1km) of meteoric water is warmed by the thermal gradient and migrates up the north- by northeast-trending normal fault mapped in the region (Plate 2). Concealed north-south trending normal faults are suspected in the area and could also serve as conduits. During its

TABLE 6. SUMMARY OF THE WATER CHEMISTRY AND QUALITATIVE CHEMICAL INDICATORS OF THERMAL RESERVOIRS AVERAGED IN AREA A, AREA B, AND ENTIRE STUDY AREA. CONCENTRATIONS ARE GIVEN IN mg/l.

	Average Values within Entire Study	Average Values within Area A	Average Values within Area B
TDS	1641	2089	1115
Ca	141	203	87
HCO_3	284	262	236
Mg/Ca	.37	.30	.36
Na/Ca	1.61	1.74	3.05
Cl/HCO_3	2.73	3.87	1.33
Cl/F	1123	1729	420
B	.12	.03	.15
Li	.02	.09	.06

upward migration, the warmed water infiltrates the fractured bedrock which underlies the area. The water continues to pass through the bedrock, finally mixing with cooler water in near-surface aquifers before interception by wells in the area. A second model depicted in Figure 15 may apply to locations where water wells are located in slightly thicker unconsolidated to semi-consolidated material. Water warmed by the thermal gradient migrates up a permeable fault zone, eventually mixing with cooler water in near-surface aquifers. A combination of these models (Figures 15 and 16) may also be applicable to the warm water occurrences in Area A.

Area B

Area B is located along the eastern side of Hansel Valley and includes sample locations H-2, H-3, H-5, and H-15 (Plate 7). The water temperatures recorded from these wells were 30, 22, 21, and 17oC, respectively. Much warmer water temperatures were recorded in Area B than were recorded across the valley to the west, even though well depths are similar. The differences in sub-surface conditions between the east and west sides of the valley are noticeable by comparing the temperature-depth measurements. A thermal gradient of 86oC/km was calculated in Area B at TG-1, but to the west, outside this area, TG-9 produced a gradient of only 46oC/km.

The chemical analyses of Area B characterized H-3, H-5, and H-15 as Type II water and H-2 as Type III water. H-2 had higher (>75%) sodium and chloride concentrations, which is characteristic of Type III water, than the other three water samples. The three water samples that were Type II in character showed no chemical resemblances to each other except for similar proportions of Na + K and Ca. The concentrations of dissolved solids are variable between water samples in Area B. H-2 had a TDS concentration of 2,264 mg/l whereas the other three samples had less than 1,000 mg/l. This difference in TDS concentrations may be due to the residence time of the water intercepted by each well and the solubility of the rock through which the water flows. The elevated water temperature of H-2 also gives the water greater capacity to dissolve solids, such as the alkali-metal chlorides. This synopsis fits the results of the chemical analyses, which found H-2 to be high (>75%) in Na + K and chloride concentrations (Fig. 5). A summary of the water chemistry in Area B is presented in Table 6.

Reservoir temperatures ranging from 30°C to 66°C using the Na-K-Ca-Mg geothermometer and 42°C to 103°C using the chalcedony geothermometer were calculated. The mixing model (Truesdell and Fournier, 1977) was applied to H-2 using the mean annual temperature (7.5°C) and the silica concentration of H-7 and H-8 (14 mg/l) as the cold water components of the mixing equation. A reservoir temperature of 121°C, with an 80% cold water mixture at the surface, was estimated by this method. This temperature is just under the calculated Na-K-Ca temperature of 137°C for H-2.

Model 1 (Fig. 15) is used to explain the occurrence of warm water in Area B. From this model, water which has migrated to depth, is warmed by the normal thermal gradient, after which it rises along one of the permeable Basin and Range fault zones located along the valley margin and/or concealed within the valley (Plate 2). This heated water mixes with near-surface cold recharge water before being intercepted by wells in the area. Some confined conditions have been found locally present within the valley. Under these conditions, rising hot water and/or mixed water may be forced to flow horizontally, during which time gradual cooling occurs before well interception (Fig. 19). The close relationship between well zones and the wells in the area was demonstrated after the 1964 earthquake in Hansel Valley. Well H-3 had to be drilled 15 meters deeper after the earthquake because of an apparent shift in the aquifer layer and/or a drop in the water table.

Other Areas of Interest

Other areas may also be of possible geothermal interest, but they lack sufficient data with which to accurately estimate their potential. Conclusions drawn from these areas should be viewed as preliminary.

One of these areas is located approximately 8 to 16 kilometers north of the Wildcat Hills, in the vicinity of Coyote Spring (Plate 7). This area contained only one spring (C-10) and one water well (C-34). C-10 had a water temperature of 29°C and the adjacent well, C-34, recorded a temperature of 14°C. In a previous study by Baker (1974) on the hydrology of Curlew Valley, C-10 was reported to be (43.5°C) but three temperature measurements one month apart were made for this study and a maximum temperature of 29°C was recorded.

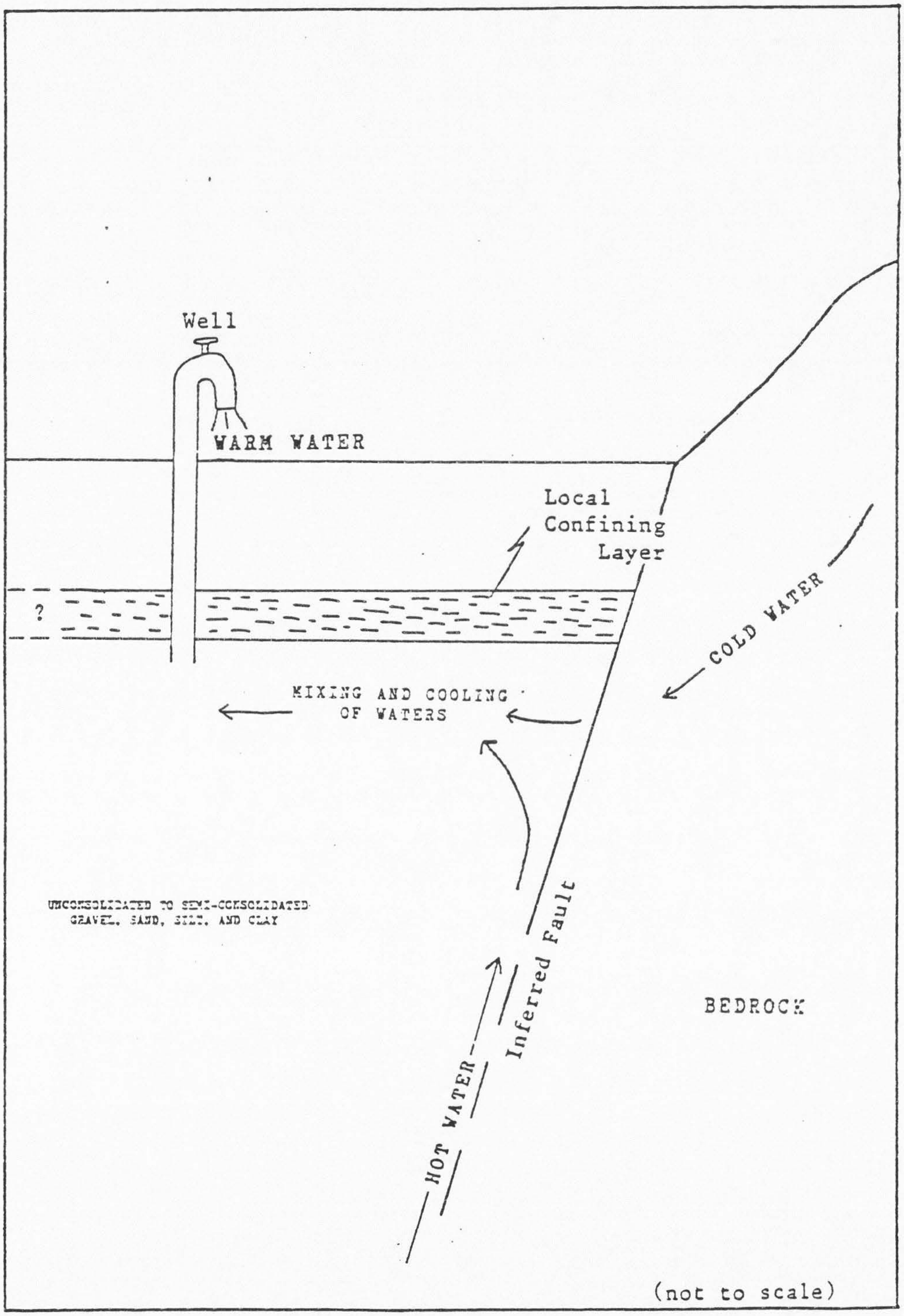

Figure 19. Proposed model to explain the occurrence of warm water under locally confined conditions.

This difference may be accounted for by seasonal fluctuations. The above average precipitation just prior to and during the sample collection for this study may have caused more dilution than normal of the hot water component. No abandoned holes were available for temperature-depth measurements in the area, but a temperature-depth measurement in a shallow well to the southeast (TG-6) had a gradient of 65°C/km while a well north of this area (TG-5) was isothermal. Water wells farther north were not included with C-10 and C-34 because of large differences in TDS concentrations (Plate 5), trace elements, and calculated temperatures (Table 3).

The two water samples from this area were Type III in character but separate from the main clustering of Type III water (Fig. 7) in that proportionally more Na + K and less Ca is present. Both samples in this area had nearly identical TDS concentrations with 3,168 mg/l in C-10 and 3,166 mg/l in C-34. In addition, lithium and boron concentrations were anonamalously high. Li and B concentrations of 1.25 mg/l and 1.0 mg/l were found in C-10 and 0.96 mg/l and 1.1 mg/l in C-34, respectively. These high concentrations, compared to a background of less than 0.02 mg/l Li and 0.12 mg/l B, are suggestive of warm water occurrences. Mixing appears to have taken place in the area because of the similarity in relatively conservative element ratios despite a 15°C difference in water temperature.

The project area's highest estimated reservoir temperatures from the cation geothermometers were determined from C-10 and C-34.

area. From Plate 2, a fault is shown to exist between the two sample sites in this area. Water heated by the normal thermal gradient in the area may rise along this fault as well as infiltrate the fractured bedrock high. This warmed water mixes with near-surface water as it exits the fault conduit and as it passes through the fractured bedrock into the unconsolidated material in the vicinity of C-10 and C-34.

Another area of interest is located near the southern extent of the Hansel Mountains in the upper half of T. 12 N., R. 8 W. and the lower half of T. 13 N., R. 8 W. (Plate 7). Wells C-19 and C-23 are included in this area with water temperatures of 24°C and 31°C, respectively. Well C-20 is located a few kilometers north of C-23 and had a temperature of 12°C at a similar depth. Well C-20 appears to be intercepting cooler, fresher recharge water that because of the local groundwater flow paths, by-passes C-23. Temperature-depth measurements could not be taken in the area, but the warm temperatures at relatively shallow (>110 m) well depths suggest the possibility of elevated gradients in the area. The water in this area is Type III in character, high (<75%) in chloride and sodium concentrations. Although located in the southern portion of the project area where TDS concentrations are normally high (<2,000 mg/l), the water from C-23 had over 3,000 mg/l more dissolved solids than two wells just a few kilometers to the north. The Na-K-Ca-Mg geothermometer gave an estimated reservoir temperature very close to the measured water temperature (Table 3). Using the water temperature and silica concentration of C-20, the mixing model produced a reservoir temperature of 117°C for C-23. The mixing model (Truesdell and Fournier, 1977) was also applied to C-19 using an adjacent cold water well (C-21) for the cold water component of the equation. The corrected reservoir temperature was estimated to be 161°C.

Both C-19 and C-23 are located in areas of thin alluvial cover. Model 2 and Model 1 can be applied to this area, in which water warmed by the normal thermal gradient migrates up along one of the faults located in the area (Plate 2). The rising hot water also infiltrates the fractured bedrock underlying the region. As the hot water passes through the bedrock and also continues to travel along a permeable fault zone, it eventually mixes with cooler near-surface waters before meeting the perforated sections of wells C-19 and C-23 (Figures 15 and 16).

A third area of possible low temperature geothermal potential is located along the western edge of the North Promontory Mountains, north of Highway U. S. 80 N. Three warm springs (C-26, C-38, and C-39) and one warm well (C-40) were measured in this area (Plate 7). These waters are Type II in character and, generally, had low concentrations of TDS, ranging from 764 to 1,148 mg/l. Associated with these low TDS concentrations, the silica concentrations were all less than 20 mg/l, which, when employing the chalcedony geothermometer, gave estimated reservoir temperatures equal to or slightly above the measured water temperatures (Table 3). From the mixing model, calculated reservoir temperatures ranged from 92°C to

104°C using the mean annual temperature (7.5°C) and the silica concentration of cold spring H-7 (14 mg/l) as the cold water components. The cold water component was calculated to be approximately 83% of the mixture.

Model 1 (Fig. 15) can be used to explain the warm water in this area. After meteoric water has migrated to depth ($\leq$ 1km), and being warmed by the normal thermal gradient, it rises in the permeable fault zone located along the western extent of the North Promontory Mountains. The rising water mixes with cooler near-surface recharge water and/or a cold water aquifer, both of which reduce the temperature of the hot water component.

In conclusion, the areas of warm water occurrences, previously described as Areas A and B, have possible low-to-moderate temperature geothermal potential. Other areas within the study also may be of interest but lack sufficient data at this time. High TDS concentrations in several wells within the regions (C-10, C-23, C-34, C-45, and H-2) may discourage any geothermal development, but high (<100°C/km) thermal gradients especially in Area A, and relatively shallow reservoir depths are promising. The aquifers found in the project area are, generally, permeable and the valley sediments and fractured bedrock have a fairly high storage capacity necessary for water movement within a geothermal reservoir. The recharge rate to Area B and possibly Area A may not be adequate to properly recharge the reservoir in the event of climatic changes and/or heavy pumping.

FURTHER STUDY

Based on initial exploration techniques used in this study, the area along U.S. 80 N. west of Snowville (Area A), and the eastern half of Hansel Valley (Area B) indicate low-to-moderate temperature geothermal anomalies. To help explain these areas, as well as other areas of possible interest more thoroughly, additional temperature-depth measurements should be made. More research is also needed in these areas to determine the source of the thermal waters and their maximum temperatures.

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APPENDICES

Appendix A. Well- and Spring-Numbering System

Well-and spring numbering system

The system of numbering wells and springs in Utah is used in this report. The numbering system is based on the cadastral land-survey system of the Federal Government. The number identifies the well or spring and locates its position to the nearest 4 hm2 tract in the land net. By this system the State is divided into four quadants by the Salt Lake base line and meridian. These quadrants are designated by the uppercase letters A, B, C, and D for the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range, in that order, follow the quadrant letter, and the three are enclosed in parentheses. The number after the parentheses designates the section, the quarter-quarter section, and the quarter-quarter-quarter section; the letters a,b,c, and d indicate the northeast, northwest, southwest, and southeast quarters, respectively, of each subdivision. The number after the letters is the serial number of the well or spring within its 4hm2 tract; the letter S preceding this number denotes a spring. The numbering system is illustrated in Figure 20.

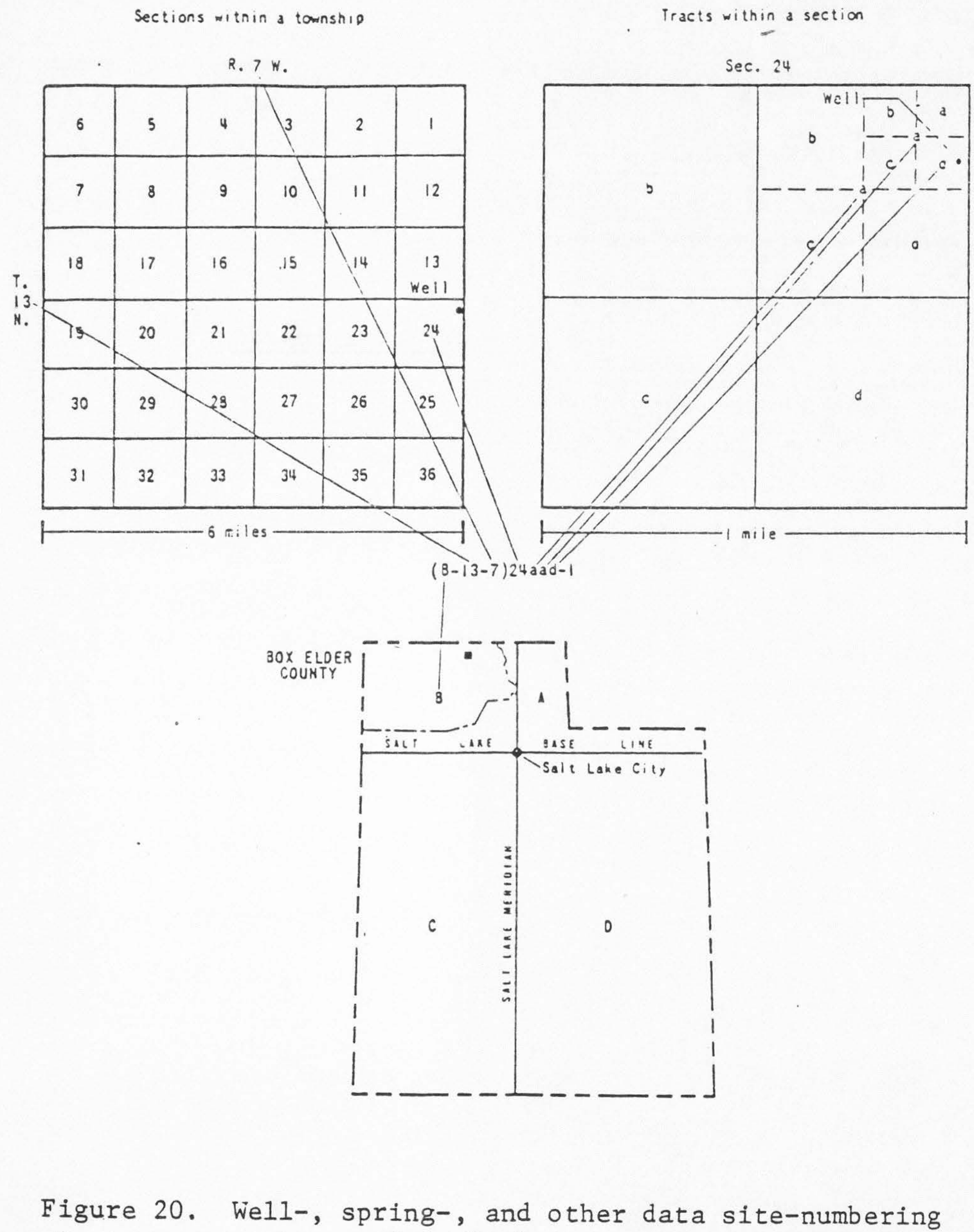


Figure 20. Well-, spring-, and other data site-numbering system used in Utah.

Appendix B. Well and Spring Data

Water Analysis Data

Concentrations within parentheses were obtained from analytical methods performed at Utah State University.

u denotes elements not present or not in detectable concentrations.

Water analysis from wells and springs in North-central Box Elder County, Utah.

Sample #		C-1	C-2	C-3	C-4	C-5	C-6	C-7
Location		(B-14-10)1dca 41°58'10" 112°55'39"	(B-14-9)6add 41°58'27" 112°54'08"	(B-14-9)11bcb 41°57'35" 112°50'27"	(B-14-9)1ccc 41°58'06" 112°48'13"	(B-14-8)2bbb 41°58'47" 112°43'30"	(B-14-8)1ccc 41°57'54" 112°42'15"	(B-15-8)36bac 41°59'34" 112°42'01"
Temp.	°C	14	5	14	15	11	6	9
pH		7.32	7.04	7.2	7.1	6.95	7.26	6.9
Na	mg/l	34 (32)	37 (37)	180 (178)	142 (144)	440 (438)	223 (221)	289 (292)
K	mg/l	7 (7)	11 (11)	11 (11)	12 (11)	15 (15)	9 (9)	36 (37)
Ca	mg/l	66 (65)	76 (75)	94 (93)	103 (105)	222 (220)	80 (81)	186 (188)
Mg	mg/l	16 (16)	18 (18)	44 (43)	42 (42)	77 (76)	30 (32)	88 (87)
SiO_2	mg/l	62 (63)	69 (71)	52 (53)	54 (54)	42 (42)	40 (41)	72 (72)
Fe	mg/l	u (u)	u (u)	u (u)	u (u)	0.07 (u)	u (u)	0.04 (u)
Sr	mg/l	0.36	0.49	2.13	1.07	2.04	1.20	2.15
Mn	mg/l	u	u	u	u	u	u	u
Zn	mg/l	u	0.2	0.1	0.2	0.8	0.3	0.4
Li	mg/l	u	u	0.08	0.06	0.08	0.06	0.22
B	mg/l	u	u	u	u	0.3	u	0.5
Ba	mg/l	u	u	u	u	u	u	u
Al	mg/l	u	u	u	u	u	u	u
Pb	mg/l	u	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u	u
F	mg/l	0.3 (.3)	0.3 (.3)	0.3 (.3)	0.4 (.4)	0.5 (.5)	0.8 (.7)	0.8 (.8)
Cl	mg/l	81 (80)	118 (117)	287 (283)	233 (234)	511 (509)	324 (324)	509 (511)
SO_4	mg/l	19 (20)	13 (13)	76 (74)	53 (52)	639 (643)	43 (44)	397 (399)
HCO_3	mg/l	217	225	376	367	384	275	351
TDS	mg/l	346 (361)	402 (410)	870 (864)	790 (794)	2072 (2055)	850 (843)	1766 (1735)

(Continued)

Sample #		C-8	C-9	C-10	C-11	C-12	C-13	C-14
Location		(B-13-8)18abc 41°51'39" 112°47'39"	(B-14-11)S13bdd 41°56'44" 113°02'56"	(B-14-10)S33bcc 41°54'02" 112°59'56"	(B-14-11)1cdb 41°57'59" 113°03'06"	(B-15-11)26cdd 41°59'35" 113°04'08"	(B-15-11)36ccc 41°58'49" 113°03'29"	(B-15-11)32ccc 41°58'46" 113°08'06"
Temp.	°C	12	15	29	9	14	16	11
pH		7.40	7.28	7.05	7.24	7.11	7.10	7.40
Na	mg/l	1758 (1759)	39 (39)	1111 (1109)	45 (45)	31 (31)	46 (45)	77 (77)
K	mg/l	78 (78)	3 (3)	73 (74)	1 (u)	u (u)	2 (2)	8 (8)
Ca	mg/l	194 (196)	68 (69)	82 (82)	62 (63)	62 (63)	63 (64)	89 (91)
Mg	mg/l	103 (104)	24 (24)	17 (17)	20 (20)	17 (17)	21 (22)	34 (35)
SiO_2	mg/l	48 (48)	17 (17)	33 (35)	14 (14)	13 (13)	14 (13)	59 (59)
Fe	mg/l	u (u)	u (u)	u (u)	u (u)	u (u)	u (u)	u (u)
Sr	mg/l	6.01	0.53	2.87	0.43	0.31	0.44	0.73
Mn	mg/l	u	u	u	u	u	u	u
Zn	mg/l	0.2	u	u	u	u	u	u
Li	mg/l	0.55	u	0.87	u	u	u	u
B	mg/l	0.4	u	1	u	u	u	u
Ba	mg/l	u	u	u	u	u	u	u
Al	mg/l	u	u	u	u	u	u	u
Pb	mg/l	u	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u	u
F	mg/l	0.6 (.6)	0.2 (.2)	2.4 (2.7)	0.2 (.2)	0.2 (.2)	0.2 (.2)	0.4 (.4)
Cl	mg/l	3190 (3186)	83 (82)	1660 (1664)	95 (96)	63 (64)	94 (96)	198 (201)
SO_4	mg/l	151 (154)	20 (21)	63 (63)	21 (21)	19 (19)	20 (21)	34 (34)
HCO_3	mg/l	234	242	351	250	242	225	217
TDS	mg/l	5684 (5655)	352 (354)	3168 (3165)	382 (382)	342 (344)	362 (359)	628 (634)

(Continued)

Sample #		C-15	C-16	C-17	C-18	C-19	C-20	C-21
Location		(B-14-12)12ada 41°57'31" 113°09'29"	(B-14-11)S31cba 41°55'58" 113°10'14"	(B-14-11)S31cba 41°53'46" 113°09'08"	(B-14-8)28aba 41°55'17" 112°45'03"	(B-13-8)21dcd 41°50'09" 112°45'00"	(B-13-8)35bbb 41°49'08" 112°43'28"	(B-13-8)10dcd 41°51'55" 112°44'02"
Temp.	°C	15	13	11	12	24	12	8
pH		7.12	-	7.14	6.60	6.70	6.40	6.60
Na	mg/l	82 (83)	-	65 (65)	229 (227)	740 (743)	348	272 (273)
K	mg/l	12 (13)	-	3 (3)	14 (13)	26 (26)	14	14 (14)
Ca	mg/l	142 (139)	-	73 (72)	124 (124)	180 (181)	169	204 (205)
Mg	mg/l	47 (47)	-	32 (33)	71 (70)	70 (70)	58	68 (68)
SiO_2	mg/l	32 (32)	-	27 (27)	41 (39)	49 (49)	32	30 (31)
Fe	mg/l	1.25 (1.13)	-	u (u)	u (u)	u (u)	0.03	u (u)
Sr	mg/l	0.70	-	0.31	1.82	3.90	2.64	1.83
Mn	mg/l	u	-	u	u	u	u	u
Zn	mg/l	0.6	-	u	0.3	u	0.6	1.5
Li	mg/l	u	-	u	0.11	0.20	0.12	0.11
B	mg/l	0.1	-	u	u	0.2	0.2	0.2
Ba	mg/l	u	-	u	u	u	u	u
Al	mg/l	u	-	u	u	u	u	u
Pb	mg/l	u	-	u	u	u	u	u
P	mg/l	u	-	u	u	u	u	u
Ce	mg/l	u	-	u	u	u	u	u
F	mg/l	0.3 (.3)	-	0.2	0.3	0.4	0.6	0.2
Cl	mg/l	375 (377)	-	109	407	1460	766	797
SO_4	mg/l	61 (62)	-	29	246	83	77	13
HCO_3	mg/l	200	-	301	301	217	217	175
TDS	mg/l	975 (982)	477	462	1238	2744	1644	1670

(Continued)

Sample #		C-22	C-23	C-24	C-25	C-26	C-27	C-28
Location		(B-12-9)2bcc 41°47'20" 112°50'28"	(B-12-8)10bcc 41°47'03" 112°44'32"	(B-14-8)32aaa 41°54'21" 112°45'56"	(B-14-8)2aba 41°58'47" 112°42'41"	(B-15-7)S32dca 41°58'53" 112°39'09"	(B-15-8)36aaa 41°59'39" 112°41'15"	(B-15-8)25cdc 41°59'43" 112°42'02"
Temp.	°C	19	30	18	12	24	9	7
pH		6.90	6.50	6.60	6.95	7.10	6.90	7.30
Na	mg/l	1204	1527	278 (279)	214 (213)	179 (181)	478	211 (210)
K	mg/l	52	82	20 (21)	9 (9)	5 (5)	23	22 (22)
Ca	mg/l	127	160	102 (102)	71 (69)	78 (79)	177	140 (138)
Mg	mg/l	73	76	53 (53)	28 (29)	34 (34)	87	44 (44)
SiO_2	mg/l	43	37	63 (65)	38 (38)	17 (17)	60	44 (43)
Fe	mg/l	u	u	u (u)	u (u)	u (u)	0.21	u (u)
Sr	mg/l	3.29	3.39	1.84	0.96	1.52	3.54	1.05
Mn	mg/l	u	u	u	u	u	0.5	u
Zn	mg/l	0.9	0.4	u	0.2	u	1.6	0.2
Li	mg/l	0.39	0.50	0.11	0.06	u	0.11	0.14
B	mg/l	0.14	0.60	u	u	u	0.20	0.20
Ba	mg/l	u	u	u	u	u	u	u
Al	mg/l	u	u	u	u	u	u	u
Pb	mg/l	u	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u	u
F	mg/l	0.7	1.4	0.5 (.5)	0.8 (.9)	0.9	1.4	1.3
Cl	mg/l	1950	2460	481 (481)	291 (289)	311	849	314
SO_4	mg/l	180	327	106 (108)	54 (55)	37	114	84
HCO_3	mg/l	234	376	209	301	275	438	480
TDS	mg/l	3738	4724	1140 (1138)	804 (802)	774	1948	1096

(Continued)

Sample #		C-29	C-30	C-31	C-32	C-33	C-34	C-35
Location		(B-15-8)36bbd 41°59'12" 112°42'08"	(B-15-8)36daa 41°59'15" 112°41'16"	(B-13-9)1adc 41°53'09" 112°48'28"	(B-12-9)6ada 41°47'58" 112°54'00"	(B-13-10)25ddd 41°49'12" 112°55'18"	(B-14-10)bbb 41°54'23" 112°58'44"	(B-14-8)29bbb 41°55'18" 112°54'05"
Temp.	°C	9	9	15	17	17	14	18
pH		6.80	6.80	7.20	7.20	7.10	7.00	6.50
Na	mg/l	509 (507)	509 (510)	935 (931)	830 (834)	532 (534)	1155 (1149)	308
K	mg/l	20 (20)	29 (29)	40 (41)	26 (25)	21 (22)	74 (74)	26
Ca	mg/l	60 (62)	125 (123)	116 (114)	138 (137)	156 (156)	98 (96)	199
Mg	mg/l	35 (35)	82 82	50 (52)	62 (62)	56 (56)	16 (16)	56
SiO_2	mg/l	65 (65)	66 (65)	44 (44)	34 (34)	42 (42)	33 (34)	70
Fe	mg/l	u (u)	u (u)	u (u)	u (u)	u (u)	u (u)	u
Sr	mg/l	1.19	3.57	2.49	4.00	2.78	2.85	1.56
Mn	mg/l	u	u	u	u	u	u	u
Zn	mg/l	0.4	u	u	0.2	0.6	0.5	0.3
Li	mg/l	0.08	0.14	0.30	0.21	0.13	0.96	0.10
B	mg/l	0.7	0.2	0.3	0.2	u	1.1	u
Ba	mg/l	u	u	u	u	u	u	u
Al	mg/l	u	u	u	u	u	u	u
Pb	mg/l	u	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u	u
F	mg/l	1.7	2.0	1.1 (1.0)	0.5 (.5)	2.4	3.0	0.5
Cl	mg/l	466	863	1460 (1464)	1441 (1438)	947	1640	796
SO_4	mg/l	207	142	151 (149)	106 (105)	87	68	57
HCO_3	mg/l	584	459	301	284	284	384	275
TDS	mg/l	1526	2082	2963 (3011)	2876 (2854)	2076	3166	1906

(Continued)

Sample #		C-36	C-37	C-38	C-39	C-40	C-41	C-42
Location		(B-14-8)5bda 41°58'33" 112°46'35"	(B-14-8)3ccc 41°58'00" 112°44'29"	(B-14-7)S5dab 41°58'20" 112°39'03"	(B-14-7)S5adb 41°58'30" 112°39'07"	(B-15-7)32dba 41°59'08" 112°39'10"	(B-14-8)5dcc 41°58'01" 112°46'27"	(B-12-11)6abb 41°48'10" 112°08'32"
Temp.	°C	19	17	20	24	25	18	16
pH		7.10	7.00	6.80	7.10	6.80	7.10	6.80
Na	mg/l	229 (227)	453 (454)	279 (282)	236	159 (162)	201 (199)	150
K	mg/l	14 (14)	14 (14)	10 (10)	9	5 (5)	14 (14)	8
Ca	mg/l	111 (109)	191 (195)	124 (125)	198	76 (77)	127 (126)	89
Mg	mg/l	36 (36)	60 (59)	43 (43)	48	33 (33)	47 (47)	25
SiO_2	mg/l	25 (25)	32 (33)	17 (18)	19	19 (19)	44 (44)	31
Fe	mg/l	u (u)	0.06 (u)	0.12 (u)	0.22	u (u)	u (u)	u
Sr	mg/l	1.83	1.83	2.62	2.60	1.48	1.84	0.51
Mn	mg/l	u	u	u	u	u	u	u
Zn	mg/l	0.6	1.9	2.8	5.6	0.2	0.4	u
Li	mg/l	0.09	0.09	0.07	0.06	u	0.07	0.05
B	mg/l	u	0.4	u	u	u	u	0.2
Ba	mg/l	u	u	u	u	u	u	u
Al	mg/l	u	u	u	0.7	u	u	u
Pb	mg/l	u	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	0.3	u	u
F	mg/l	0.7 (.7)	0.5 (.5)	1.3 (1.4)	1.3	1.2	0.6 (.6)	0.5
Cl	mg/l	425 (422)	453 (450)	513 (515)	483	303	449 (452)	136
SO_4	mg/l	49 (49)	620 (618)	44 (44)	52	44	84	42
HCO_3	mg/l	275	459	217	225	326	326	242
TDS	mg/l	1064 (1067)	2056 (1998	1148 (1154)	1034	764	1228	484

(Continued)

Sample #		C-43	C-44	C-45	C-46	C-47	C-48	C-49
Location		(B-14-9)4ccc 41°58'00" 112°52'53"	(B-15-9)35abb 41°59'43" 112°49'57"	(B-15-9)28cbc 41°59'55" 112°52'53"	(B-14-9)4bbb 41°58'47" 112°52'52"	(B-14-9)5bbb 41°58'47" 112°54'04"	(B-14-9)7bbb 41°57'54" 112°55'14"	(B-14-9)18bdd 41°56'38" 112°54'43"
Temp.	°C	21	25	24	17	16	20	16
pH		7.00	6.90	6.70	6.70	6.80	6.70	6.70
Na	mg/l	503	509 (511)	610 (609)	453	136 (139)	48	126 (124)
K	mg/l	29	9 (9)	40 (39)	32	16 (16)	13	17 (17)
Ca	mg/l	269	69 (71)	503 (507)	374	212 (209)	117	136 (137)
Mg	mg/l	68	28 (27)	132 (133)	100	48 (48)	24	41 (41)
SiO_2	mg/l	76	25 (25)	81 (81)	70	64 (64)	73	69 (68)
Fe	mg/l	u	0.69 (u)	u (u)	0.03	0.58 (u)	u	0.75 (u)
Sr	mg/l	2.06	2.10	4.82	2.74	0.92	0.66	1.04
Mn	mg/l	u	u	u	u	u	u	u
Zn	mg/l	1.1	1.5	u	0.6	1.0	1.1	u
Li	mg/l	0.11	0.23	0.12	0.09	u	u	0.06
B	mg/l	u	0.2	u	u	u	u	u
Ba	mg/l	u	u	0.7	u	u	u	u
Al	mg/l	u	u	u	u	u	u	u
Pb	mg/l	0.5	u	u	u	u	u	u
P	mg/l	1.8	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u	u
F	mg/l	1.0	0.4 (.5)	0.9 (.8)	0.5	0.3	0.3	0.3 (.3)
Cl	mg/l	876	793 (795)	1980 (2001)	1280	303	172	430 (433)
SO_4	mg/l	315	54 (55)	56 (55)	225	357	23	32
HCO_3	mg/l	301	225	192	225	234	209	217
TDS	mg/l	2434	1638 (1642)	5168 (5237)	3596	1292	603	1278

(Continued)

Sample #		C-50	C-51	C-52	C-53	C-54	C-55	C-56
Location		(B-14-9)19bbb 41°56'10" 112°55'14"	(B-14-10)acd 41°56'40" 112°56'45"	(B-15-9)36cad 41°59'09" 112°48'51"	(B-15-8)31ccc 41°58'51" 112°48'12"	(B-12-11)5bba 41°48'10" 113°07'46"	(B-12-11)5bdc 41°47'51" 113°07'42"	(B-14-11)10bad 41°57'36" 113°05'17"
Temp.	°C	15	18	19	21	17	17	17
pH		6.80	6.90	6.60	6.80	6.80	6.90	6.80
Na	mg/l	70	46	185	138 (139)	99 (101)	136	35
K	mg/l	13	11	5	4 (4)	11 (11)	17	3
Ca	mg/l	103	61	78	97 (95)	227 (228)	230	70
Mg	mg/l	30	21	37	41 (40)	63 (64)	87	29
SiO_2	mg/l	69	76	23	23 (23)	28 (28)	34	20
Fe	mg/l	0.09	u	u	u (u)	0.04 (u)	u	u
Sr	mg/l	0.67	0.57	1.53	1.85	1.16	1.63	0.52
Mn	mg/l	u	u	u	u	u	u	u
Zn	mg/l	u	u	0.2	u	0.9	0.3	0.2
Li	mg/l	u	u	u	u	u	0.08	u
B	mg/l	u	u	u	u	u	u	u
Ba	mg/l	u	u	u	u	u	u	u
Al	mg/l	u	u	u	u	u	u	u
Pb	mg/l	u	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u	u
F	mg/l	0.3	0.4	0.2	0.2	0.2 (.2)	0.3	0.3
Cl	mg/l	216	114	338	359	481 (484)	644	137
SO_4	mg/l	44	50	36	35	619 (623)	68	20
HCO_3	mg/l	250	217	284	267	242	242	225
TDS	mg/l	740	386	738	846	1378 (1359)	1636	412

(Continued)

Sample #		C-57	C-58	C-59	C-60	C-61	C-62	C-63
Location		(B-14-10)5bba 41°58'43" 113°00'57"	(B-15-10)34ccc 41°58'47" 112°58'44"	(B-14-10)14bbc 41°56'55" 112°57'34"	(B-14-10)23bbb 41°56'09" 112°57'34"	(B-14-10)15ccc 41°56'11" 112°58'41"	(B-14-10)1bbb 41°58'46" 112°56'22"	(B-15-10)36bbb 41°59'39" 112°56'22"
Temp.	°C	15	15	20	15	23	18	17
pH		6.90	6.60	6.60	6.65	6.70	6.75	6.80
Na	mg/l	45	45 (45)	133 (135)	233	253	31	20 (22)
K	mg/l	1	3 (3)	14 (15)	16	16	8	9 (9)
Ca	mg/l	67	32 (33)	84 (86)	80	63	89	84 (85)
Mg	mg/l	23	21 (20)	34 (35)	35	17	18	14 (14)
SiO_2	mg/l	13	66 (67)	71 (73)	51	47	73	74 (75)
Fe	mg/l	0.04	u (u)	0.06 (u)	u	0.04	0.07	0.06 (u)
Sr	mg/l	0.42	0.44	1.12	1.38	0.95	0.50	0.35
Mn	mg/l	u	u	u	u	u	u	u
Zn	mg/l	u	u	1.2	0.1	0.8	0.6	0.6
Li	mg/l	u	u	0.07	0.14	0.17	u	u
B	mg/l	u	u	0.2	0.2	0.2	u	u
Ba	mg/l	u	u	u	u	u	u	u
Al	mg/l	u	u	1.5	u	u	u	u
Pb	mg/l	u	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u	u
F	mg/l	0.2	0.8 (.9)	0.4	0.4	0.7	0.4	0.3
Cl	mg/l	97	67 (68)	289	424	305	73	58
SO_4	mg/l	27	26 (27)	44	36	37	24	18
HCO_3	mg/l	200	200	275	284	284	242	234
TDS	mg/l	346	402 (409)	870	790	2072	850	1766

(Continued)

Sample #		H-1	H-2	H-3	H-4	H-5	H-6
Location		(B-13-7)14aaa 41°51'52" 112°36'34"	(B-13-6)7ccc 41°51'54" 112°35'22"	(B-13-6)17ccc 41°51'01" 112°34'12"	(B-13-7)24aad 41°50'51" 112°35'26"	(B-13-6)30cdc 41°49'39" 112°35'26"	(B-13-7)S4caa 41°53'14" 112°39'26"
Temp.	°C	14	30	22	16	21	12
pH		7.28	7.42	7.20	7.10	7.15	7.12
Na	mg/l	50	614	106	99	102	171
K	mg/l	10	21	13	13	12	10
Ca	mg/l	85	95	50	128	85	157
Mg	mg/l	19	39	27	32	25	34
SiO_2	mg/l	72	26	89	77	87	53
Fe	mg/l	u	u	u	u	u	u
Sr	mg/l	0.53	3.38	0.80	0.75	0.65	0.71
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	0.3	0.2	0.2	0.5	0.2	u
Li	mg/l	u	0.18	u	u	u	u
B	mg/l	u	0.3	0.2	0.2	0.2	0.2
Ba	mg/l	u	u	u	u	u	u
Al	mg/l	u	u	u	u	u	u
Pb	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u
F	mg/l	0.3	1.4	0.8	0.3	0.4	0.4
Cl	mg/l	145	752	62	215	223	305
SO_4	mg/l	21	60	111	177	47	90
HCO_3	mg/l	184	250	242	184	167	351
TDS	mg/l	592	2264	614	890	774	1234

(Continued)

Sample #		H-7	H-8	H-9	H-10	H-11	H-12
Location		(B-14-7)S27bac 41°55'18" 112°38'29"	(B-14-7)27abb 41°55'27" 112°38'08"	(B-12-8)S27ccc 41°43'59" 112°44'30"	(B-12-8)S23ddc 41°44'54" 112°42'34"	(B-12-7)21dbc 41°45'12" 112°39'27"	(B-15-8)S36bac 41°45'13" 112°39'34"
Temp.	°C	17	15	18	12	17	19
pH		7.30	7.26	7.10	7.00	6.80	7.05
Na	mg/l	58	58 (57)	3824	3335	1290	1451
K	mg/l	1	u (u)	149	108	42	47
Ca	mg/l	61	56 (57)	269	232	107	130
Mg	mg/l	16	16 (16)	97	31	39	44
SiO_2	mg/l	14	14 (14)	43	31	25	25
Fe	mg/l	u	u (u)	u	u	0.04	0.04
Sr	mg/l	0.28	0.27	10.83	9.54	4.07	4.56
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	0.4	0.2	u	u	0.2	0.7
Li	mg/l	u	u	1.45	1.19	0.42	0.48
B	mg/l	u	u	0.9	0.8	0.4	0.5
Ba	mg/l	u	u	u	u	u	u
Al	mg/l	u	u	u	u	u	u
Pb	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u
F	mg/l	0.2	0.3 (.3)	1.3	1.3	1.4	1.4
Cl	mg/l	94	95 (97)	6460	5720	2000	2320
SO_4	mg/l	29	32 (33)	232	210	99	108
HCO_3	mg/l	209	217	326	334	259	292
TDS	mg/l	384	348 (351)	11590	10310	3732	4122

(Continued)

Sample #		H-13	H-14	H-15	H-16
Location		(B-12-7)S21bca 41°45'29" 112°39'50"	(B-13-7)34bad 41°49'09" 112°38'28"	(B-13-6)19coc 41°50'08" 112°35'23"	(B-14-6)31baa 41°54'32" 112°34'54"
Temp.	°C	18	14	17	17
pH		7.15	6.80	6.80	7.20
Na	mg/l	2627	108	155	52
K	mg/l	88	9	15	9
Ca	mg/l	165	155	93	176
Mg	mg/l	59	43	26	36
SiO_2	mg/l	24	64	62	64
Fe	mg/l	u	u	u	u
Sr	mg/l	7.32	0.99	0.57	0.77
Mn	mg/l	u	u	u	u
Zn	mg/l	u	u	0.8	3.1
Li	mg/l	0.92	0.07	0.07	u
B	mg/l	0.7	u	0.1	u
Ba	mg/l	u	u	u	u
Al	mg/l	u	u	u	u
Pb	mg/l	u	u	u	u
P	mg/l	u	u	u	u
Ce	mg/l	u	u	u	u
F	mg/l	1.4	0.4	0.4	0.3
Cl	mg/l	4320	303	223	200
SO_4	mg/l	154	159	133	73
HCO_3	mg/l	309	275	284	284
TDS	mg/l	7742	1002	808	844

(Continued)

Sample #		L-1	L-2	L-3	L-4	L-5	L-6
Location		(B-12-10)S36cab 41°43'27" 112°55'55"	(B-12-10)S36dcc 41°43'05" 112°55'31"	(B-11-10)S1adc 41°42'37" 112°55'15"	(B-11-10)S12aac 41°41'56" 112°55'16"	(B-11-9)S6cdc 41°42'13" 112°54'41"	(B-11-9)S5cca 41°42'15" 112°53'41"
Temp.	°C	13	16	16	15	16	18
pH		7.60	7.55	7.30	7.00	6.90	6.80
Na	mg/l	829 (831)	560 (558)	947 (951)	1145	1054	1244
K	mg/l	57 (58)	31 (31)	38 (39)	53	42	59
Ca	mg/l	132 (130)	131 (132)	156 (160)	101	147	103
Mg	mg/l	68 (69)	64 (66)	71 (71)	59	65	63
SiO_2	mg/l	46 (46)	64 (64)	41 (41)	34	36	36
Fe	mg/l	u (u)	u (u)	0.10 (u)	u	0.08	u
Sr	mg/l	3.61	2.82	4.09	3.24	3.86	3.03
Mn	mg/l	u	u	u	u	u	u
Zn	mg/l	u	0.2	1.9	u	1.5	u
Li	mg/l	0.41	0.19	0.27	0.37	0.32	0.42
B	mg/l	0.3	0.2	0.3	0.3	0.2	0.4
Ba	mg/l	u	u	u	u	u	u
Al	mg/l	u	u	u	u	u	u
Pb	mg/l	u	u	u	u	u	u
P	mg/l	u	u	u	u	u	u
Ce	mg/l	u	u	u	u	u	u
F	mg/l	0.6 (.6)	0.4 (.4)	0.4	0.5	0.7	0.8
Cl	mg/l	1490 (1488)	1110 (1106)	1670	1910	1789	2000
SO_4	mg/l	166 (168)	95 (97)	129	145	143	158
HCO_3	mg/l	225	217	209	225	234	275
TDS	mg/l	2976 (2983)	2232 (2237)	3224	3591	3450	3898

Appendix C. Thermal Gradient Data

Area	North-central Box Elder Co., Utah		
Location	T13N/R6W/S30bbc		
Site Name	Hansel Valley TG-1		
Latitude	41° 49' 46" N.	Depth to Water	85m ± 2.5m
Longitude	112° 35' 24" W.	Depth Range	30-92.5m
Elevation	1485 ± 0.7m	Gradient	86° ± 3°C/km

Thermal Logging Date: 5-27-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--	55	14.32
10	10.66	60	14.79
15	11.35	65	15.26
20	11.47	70	15.69
25	11.90	75	16.12
30	12.35	80	16.46
35	12.67	85	16.93
40	13.08	87.5	16.94
45	13.45	90	17.06
50	13.88	92.5	17.10

Area	North-central Box Elder Co., Utah		
Location	T15N/R8W/S36cba		
Site Name	Curlew Valley TG-2		
Latitude	41° 59' 14" N.	Depth to Water	8m ± 2.5m
Longitude	112° 42' 10" W.	Depth Range	20-28.5m
Elevation	1386 ± 0.7m	Gradient	18° ± 1°C/km

Thermal Logging Date: 6-7-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
5	9.84		
10	10.08		
13	10.05		
15	10.07		
18	10.10		
20	10.13		
22.5	10.17		
25	10.19		
27.5	10.28		
28.5	10.29		

Area	North-central Box Elder Co., Utah		
Location	T14N/R9W/S2dbb		
Site Name	Curlew Valley TG-3		
Latitude	41° 58' 22" N.	Depth to Water	58m ± 2.5m
Longitude	112° 49' 54" W.	Depth Range	30-60m
Elevation	1347 ± 0.7m	Gradient	267° ± 37°C/km

Thermal Logging Date: 6-9-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--	63	24.35
10	11.03	65	24.34
20	13.30	70	24.35
25	14.29	75	24.35
30	15.65	80	24.34
40	17.29	90	24.35
45	17.99	100	24.35
50	18.34		
55	21.15		
60	24.35		

Area	North-central Box Elder Co., Utah		
Location	T15N/R9W/S28dbd		
Site Name	Curlew Valley TG-4		
Latitude	41° 59' 56" N.	Depth to Water	78m ± 2.5m
Longitude	112° 52' 08" W.	Depth Range	75-132.5m
Elevation	1359 ± 0.7m	Gradient	182° ± 7°C/km

Thermal Logging Date: 6-9-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--	90	38.05
10	15.29	92.5	37.61
20	19.19	95	38.12
25	22.30	97.5	39.03
30	25.79	100	39.22
40	27.15	102.5	39.61
45	27.14	105	39.74
50	28.38	107.5	39.81
55	29.02	110	39.86
60	28.70	112.5	39.91
65	29.04	115	40.22
70	28.66	120	40.40
75	31.41	125	40.61
80	34.92	130	41.81
85	36.73	132.5	41.86
87.5	37.98	133.5	41.87

Area	North-central Box Elder Co., Utah		
Location	T14N/R10W/S15bbb		
Site Name	Curlew Valley TG-5		
Latitude	41° 56' 59" N.	Depth to Water	64m ± 2.5m
Longitude	112° 58' 38" W.	Depth Range	--
Elevation	1363 ± 0.7m	Gradient	Isothermal

Thermal Logging Date: 6-12-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--	75	13.45
10	11.73	80	13.45
20	10.90	85	13.45
25	10.14	90	13.46
30	10.23	95	13.48
35	10.12	100	13.47
40	10.33	105	13.56
45	9.55		
50	9.60		
55	8.86		
60	10.45		
65	12.07		
70	13.44		

Area	North-central Box Elder Co., Utah		
Location	T13N/R10W/S11dcd		
Site Name	Curlew Valley TG-6		
Latitude	41° 51' 50" N.	Depth to Water	35m ± 2.5m
Longitude	112° 56' 48" W.	Depth Range	30-39m
Elevation	1323 ± 0.7m	Gradient	65° ± 3°C/km

Thermal Logging Date: 6-7-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	11.45		
20	12.23		
25	12.54		
30	12.76		
32.5	12.99		
35	13.12		
37.5	13.30		
39	13.36		

Area	North-central Box Elder Co., Utah		
Location	T13N/R10W/S34ddc		
Site Name	Curlew Valley TG-7		
Latitude	41° 48' 19" N.	Depth to Water	None
Longitude	112° 57' 46" W.	Depth Range	15-22m
Elevation	1313 ± 0.7m	Gradient	44° ± 6°C/km

Thermal Logging Date: 6-11-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	13.77		
15	14.62		
20	14.90		
22	14.91		

Area	North-central Box Elder Co., Utah		
Location	T14N/R9W/S4cbb		
Site Name	Curlew Valley TG-8		
Latitude	41° 58' 18" N.	Depth to Water	64m ± 2.5m
Longitude	112° 52' 53" W.	Depth Range	30-75m
Elevation	1342 ± 0.7m	Gradient	119° ± 26°C/km

Thermal Logging Date: 6-13-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--	70	19.66
15	14.12	72.5	19.98
20	14.99	75	19.69
25	15.43	76	19.69
30	15.74		
35	16.10		
40	16.38		
45	16.92		
50	17.56		
55	18.33		
60	19.30		
65	19.52		
67.5	19.59		

Area	North-central Box Elder Co., Utah		
Location	T13N/R7W/S23bcd		
Site Name	Hansel Valley TG-9		
Latitude	41° 50' 38" N.	Depth to Water	48m ± 2.5m
Longitude	112° 37' 29" W.	Depth Range	20-65m
Elevation	1458 ± 0.7m	Gradient	46° ± 3°C/km

Thermal Logging Date: 6-15-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	11.96		
15	12.07		
20	12.23		
25	12.47		
30	12.68		
35	12.89		
40	13.13		
45	13.38		
50	13.62		
55	13.78		
60	14.14		
62.5	14.19		
65	14.25		

Area	North-central Box Elder Co., Utah		
Location	T13N/R9W/S1bdc		
Site Name	Curlew Valley TG-10		
Latitude	41° 53' 09" N.	Depth to Water	None
Longitude	112° 49' 08" W.	Depth Range	50-101m
Elevation	1386 ± 0.7m	Gradient	39° ± 29°C/km

Thermal Logging Date: 6-15-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	8.69		
20	6.59		
30	6.51		
40	6.43		
50	6.40		
60	6.51		
70	6.59		
75	6.60		
80	7.24		
100	8.19		
101	8.19		

Area	North-central Box Elder Co., Utah		
Location	T14N/R8W/S28bbb		
Site Name	Curlew Valley TG-11		
Latitude	41° 55' 19" N.	Depth to Water	44m ± 2.5m
Longitude	112° 45' 49" W.	Depth Range	35-50m
Elevation	1384 ± 0.7m	Gradient	44° ± 6°C/km

Thermal Logging Date: 6-16-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	10.28		
15	10.29		
20	10.42		
25	10.44		
30	10.47		
35	10.50		
40	10.60		
45	10.89		
50	11.14		
51	11.15		

Area	North-central Box Elder Co., Utah		
Location	T14N/R8W/S6abb		
Site Name	Curlew Valley TG-12		
Latitude	41° 58' 49" N.	Depth to Water	None
Longitude	112° 47' 38" W.	Depth Range	25-43m
Elevation	1376 ± 0.7m	Gradient	135° ± 23°C/km

Thermal Logging Date: 6-16-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	12.63		
20	13.12		
25	13.64		
30	14.03		
35	14.61		
40	15.61		
43	16.04		

Area	North-central Box Elder Co., Utah		
Location	T13N/R11W/S10cdc		
Site Name	Curlew Valley TG-13		
Latitude	41° 51' 52" N.	Depth to Water	None
Longitude	113° 05' 27" W.	Depth Range	30-82m
Elevation	1366 ± 0.7m	Gradient	59° ± 14°C/km

Thermal Logging Date: 6-16-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	13.20		
20	13.38		
25	13.61		
30	13.80		
35	13.99		
40	14.17		
45	14.35		
50	14.51		
55	15.09		
60	15.52		
65	15.81		
70	16.03		
75	16.28		
80	16.63		
82	16.64		

Area	North-central Box Elder Co., Utah		
Location	T11N/R12W/S4cbc		
Site Name	Curlew Valley TG-14		
Latitude	41° 47' 43" N.	Depth to Water	38m ± 2.5m
Longitude	113° 06' 45" W.	Depth Range	25-65m
Elevation	1310 ± 0.7m	Gradient	44° ± 11°C/km

Thermal Logging Date: 6-17-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	10.94		
20	12.13		
25	13.13		
30	14.00		
35	14.50		
40	14.85		
42.5	14.93		
45	14.98		
47.5	14.99		
50	14.99		
55	15.00		
60	15.05		
65	15.33		

Area	North-central Box Elder Co., Utah		
Location	T11N/R12W/S5dbb		
Site Name	Curlew Valley TG-15		
Latitude	41° 47' 43" N.	Depth to Water	30m ± 2.5m
Longitude	113° 07' 25" W.	Depth Range	30-56m
Elevation	1315 ± 0.7m	Gradient	75° ± 24°C/km

Thermal Logging Date: 6-17-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	10.08		
20	11.08		
25	11.28		
30	11.43		
35	12.48		
40	12.84		
42.5	13.04		
45	13.21		
47.5	13.37		
50	13.45		
52.5	13.46		
55	13.65		
56	13.66		

Area	North-central Box Elder Co., Utah		
Location	T14N/R9W/S10ada		
Site Name	Curlew Valley TG-16		
Latitude	41° 57' 37" N.	Depth to Water	None
Longitude	112° 50' 37" W.	Depth Range	20-27m
Elevation	1343 ± 0.7m	Gradient	11° ± 2°C/km

Thermal Logging Date: 6-17-83

Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
0	--		
10	11.36		
15	11.43		
20	11.54		
22.5	11.55		
25	11.57		
27	11.62		

PLATE NO. I

LITHOLOGIC MAP OF NORTH-CENTRAL BOX ELDER COUNTY, UTAH

EXPLANATION:

--QUATERNARY--

☐ Sediments; Alluvium, Colluvium, and Lake Bed Deposits, Undifferentiated.

--TERTIARY--

⁘ Volcanic Rocks; Basalts, Felsic Tuffs, and Ignimbrites, Undifferentiated

▨ Salt Lake Formation – Sedimentary Rocks.

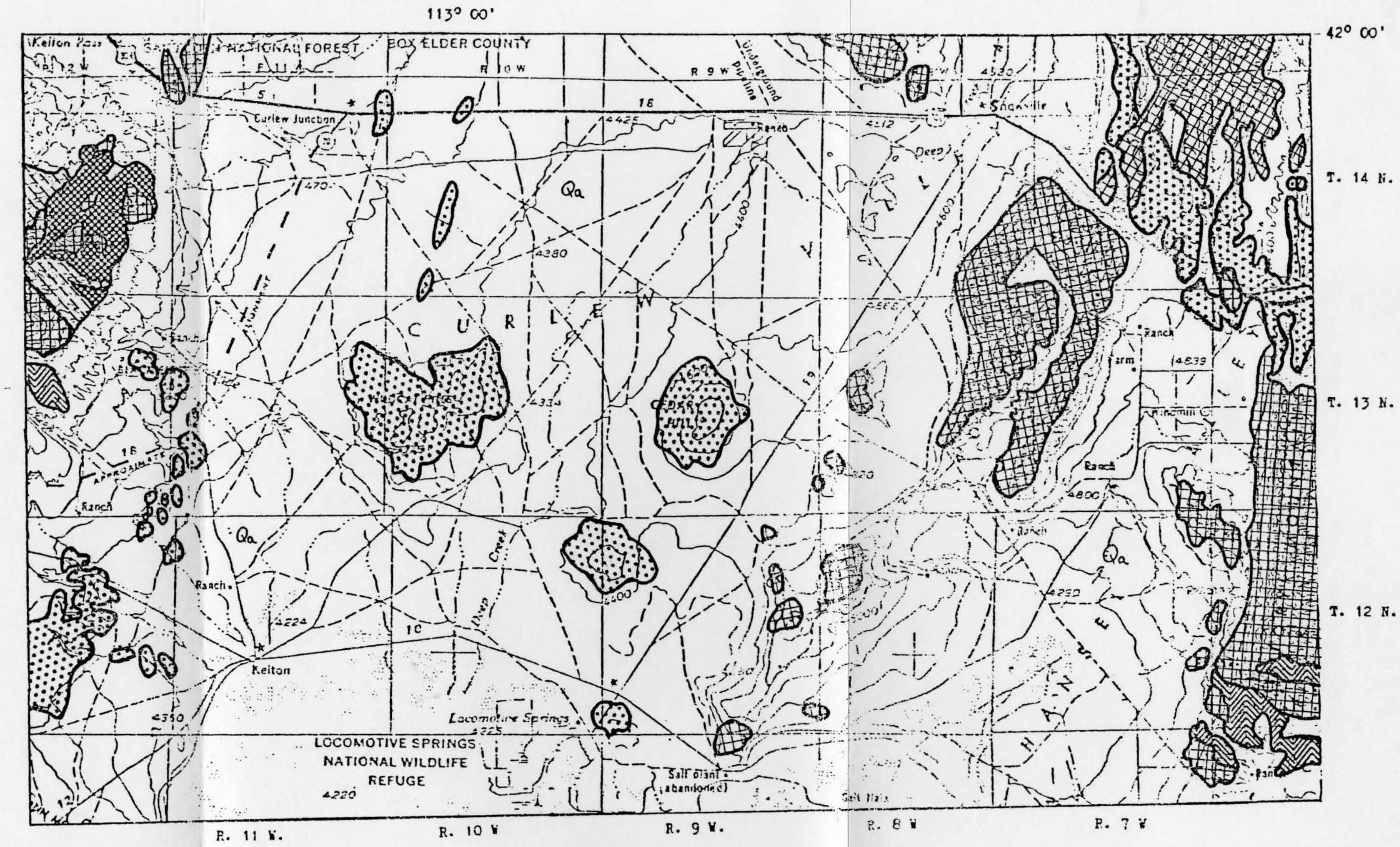
--PALEOZOIC--

▦ Pennsylvanian-Permian Oquirrh Fm. and Mississippian-Pennsylvanian Manning Canyon Fm., Undifferentiated

▩ Paleozoic Rocks, Undifferentiated.

--PRECAMBRIAN--

▧ Precambrian Rocks, Undifferentiated.



SOURCES: Adams, 1962
Howes, 1972
Stokes, 1963
Hintze, 1980

SCALE 1:250,000

5 0 5 10 Miles

5 0 5 10 Kilometers

Contour Interval 200 Feet

Base from U.S. Geological Survey, Brigham City, 1970

COMPLETE BOUGER GRAVITY AND FAULT MAP OF NORTH-CENTRAL BOX ELDER COUNTY, UTAH

PLATE NO. 2

EXPLANATION:

Fault Exposed ———

Fault Inferred – – – – –

Thrust Fault- Barbs On Upper Plate ▲▲▲▲

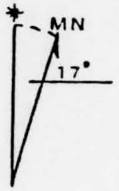
Concealed Fault - Inferred From Gravity Studies - Dots On Down-Thrown Side ⊥ ⊥ ⊥

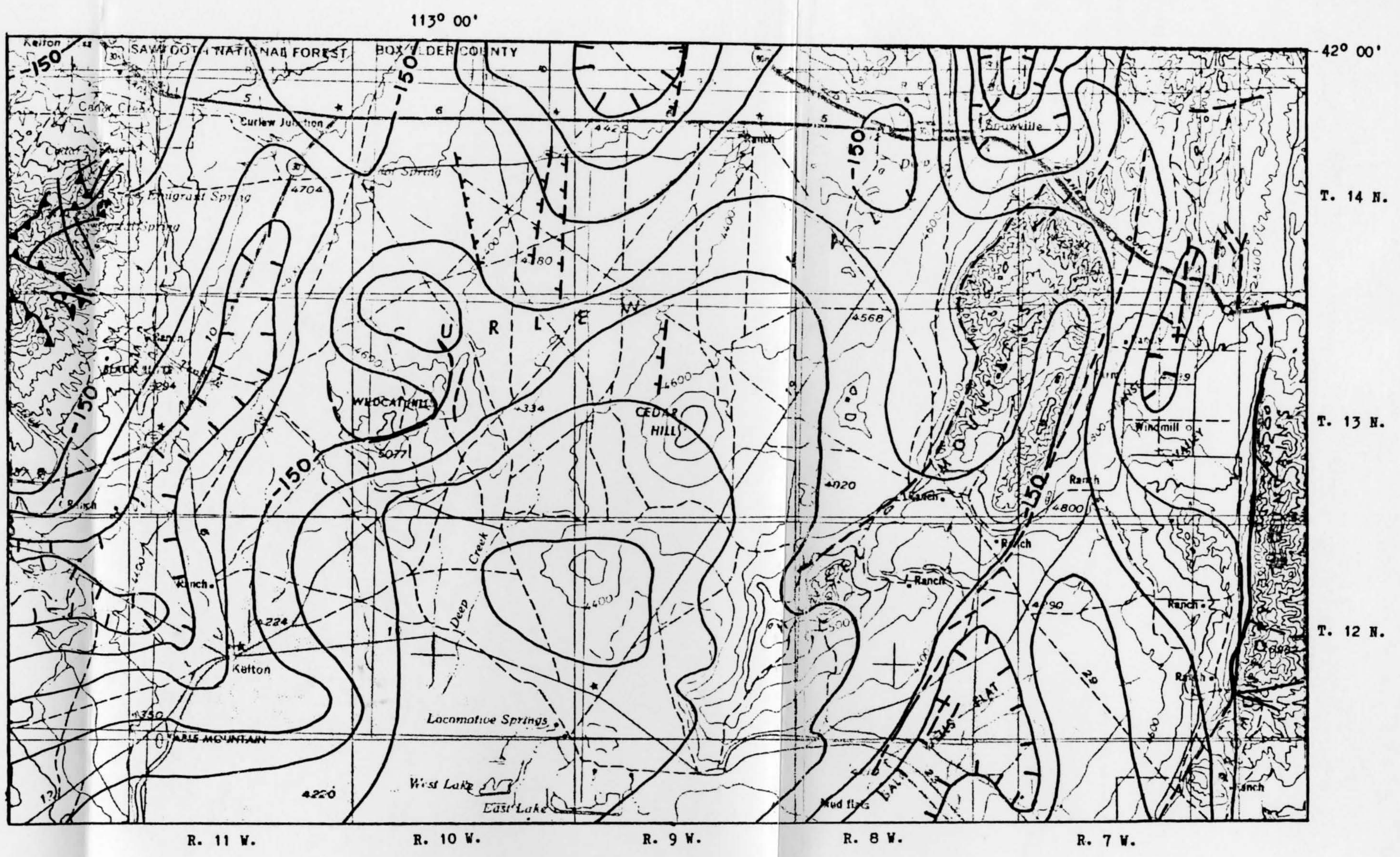
150

Bouguer Gravity- In Milligals

Hachured To Indicate Closed Areas Of Lower Gravity

Gravity Contour Interval - 2 Milligals





SOURCE: Adams, 1962; Hintze, 1980
Howes, 1972; Stokes, 1963
Peterson, 1974; Cook, 1964

Base from U.S. Geological Survey, Brigham City, 1970

SCALE 1:250,000

5 0 5 10 Miles

5 0 5 10 Kilometers

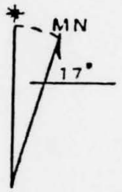
Contour Interval 200 Feet

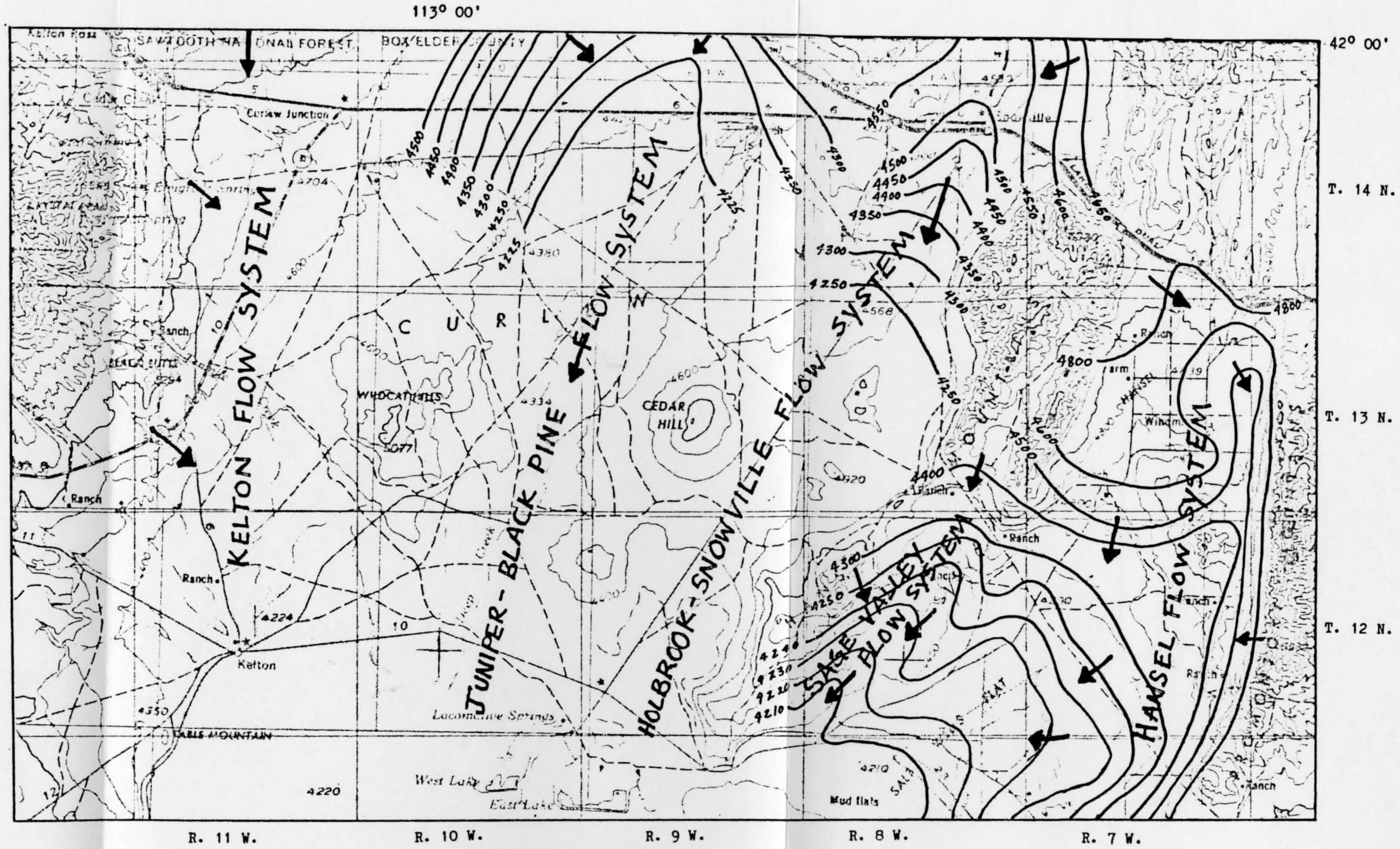
POTENTIOMETRIC SURFACE CONTOUR MAP OF NORTH-CENTRAL BOX ELDER COUNTY, UTAH

EXPLANATION:

Water-level Contour In Feet

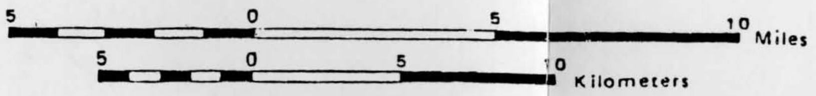
Shows Altitude Of Water-Level; Dashed Where Approximate Or Inferred; Contour Interval 10, 50, 100, and 200 Feet; Datum Is Mean Sea Level; Arrow Indicates Direction Of Ground Water Movement.





SOURCES: Bolke and Price, 1969
Hood, 1971

SCALE 1:250,000



Contour Interval 200 Feet

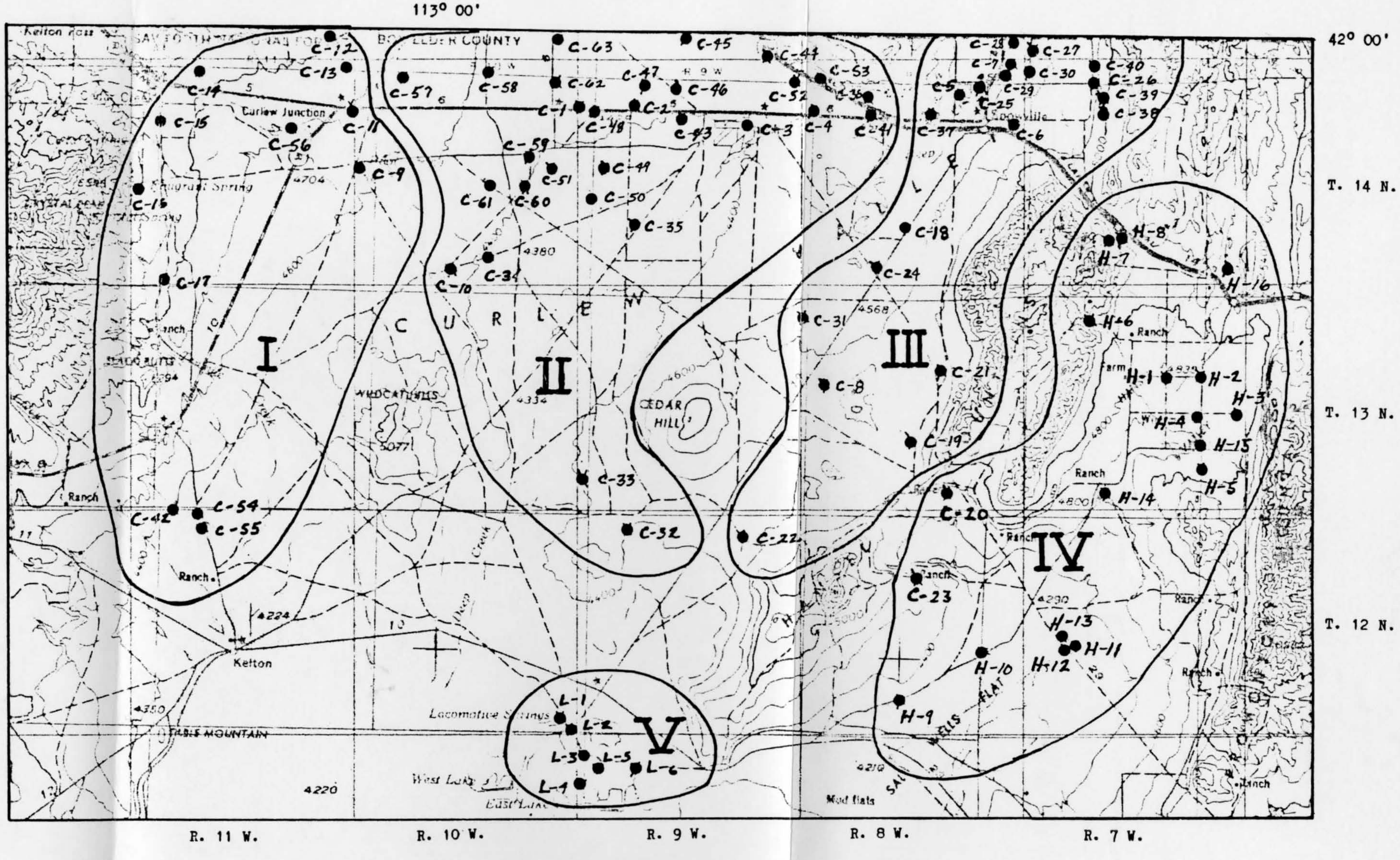
Base from U.S. Geological Survey, Brigham City, 1970

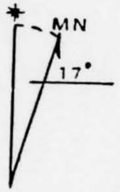
WELL AND SPRING SAMPLE LOCATIONS IN NORTH-CENTRAL BOX ELDER COUNTY, UTAH

EXPLANATION:

● Well and Spring Locations

(IV) Area and Area Numbers Of Grouped Samples





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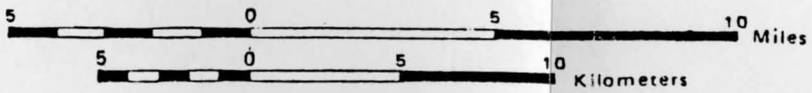


Contour Interval 200 Feet

Base from U.S. Geological Survey, Brigham City, 1970

GROUNDWATER TEMPERATURE MAP AND TOTAL DISSOLVED SOLIDS IN NORTH-CENTRAL BOX ELDER COUNTY, UTAH

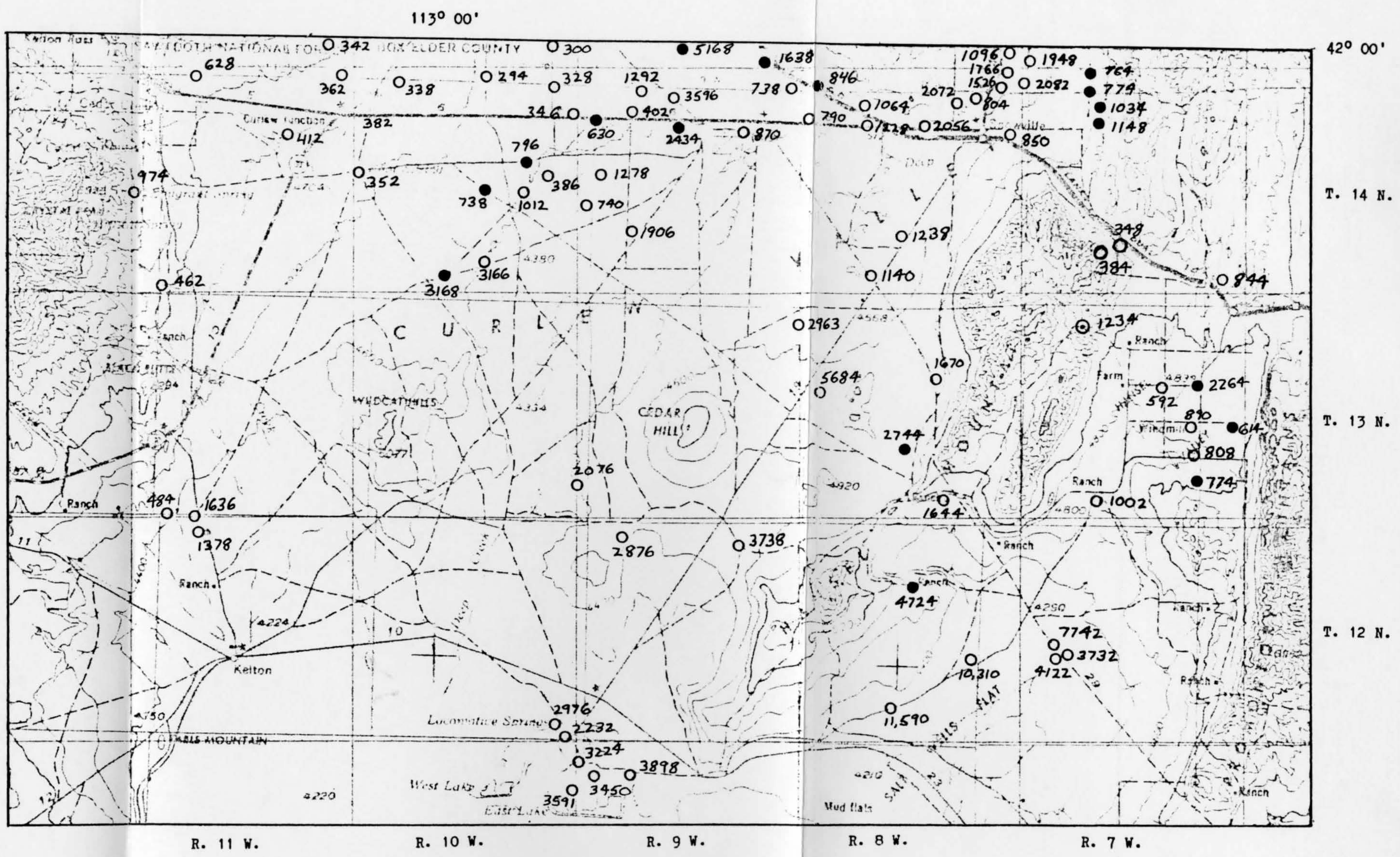
PLATE NO. 5

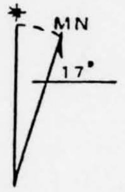
EXPLANATION:

○ Temperature < 20°C

● Temperature ≥ 20°C

○ TDS Location Values In Milligrams per Liter





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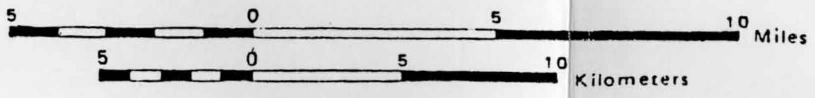


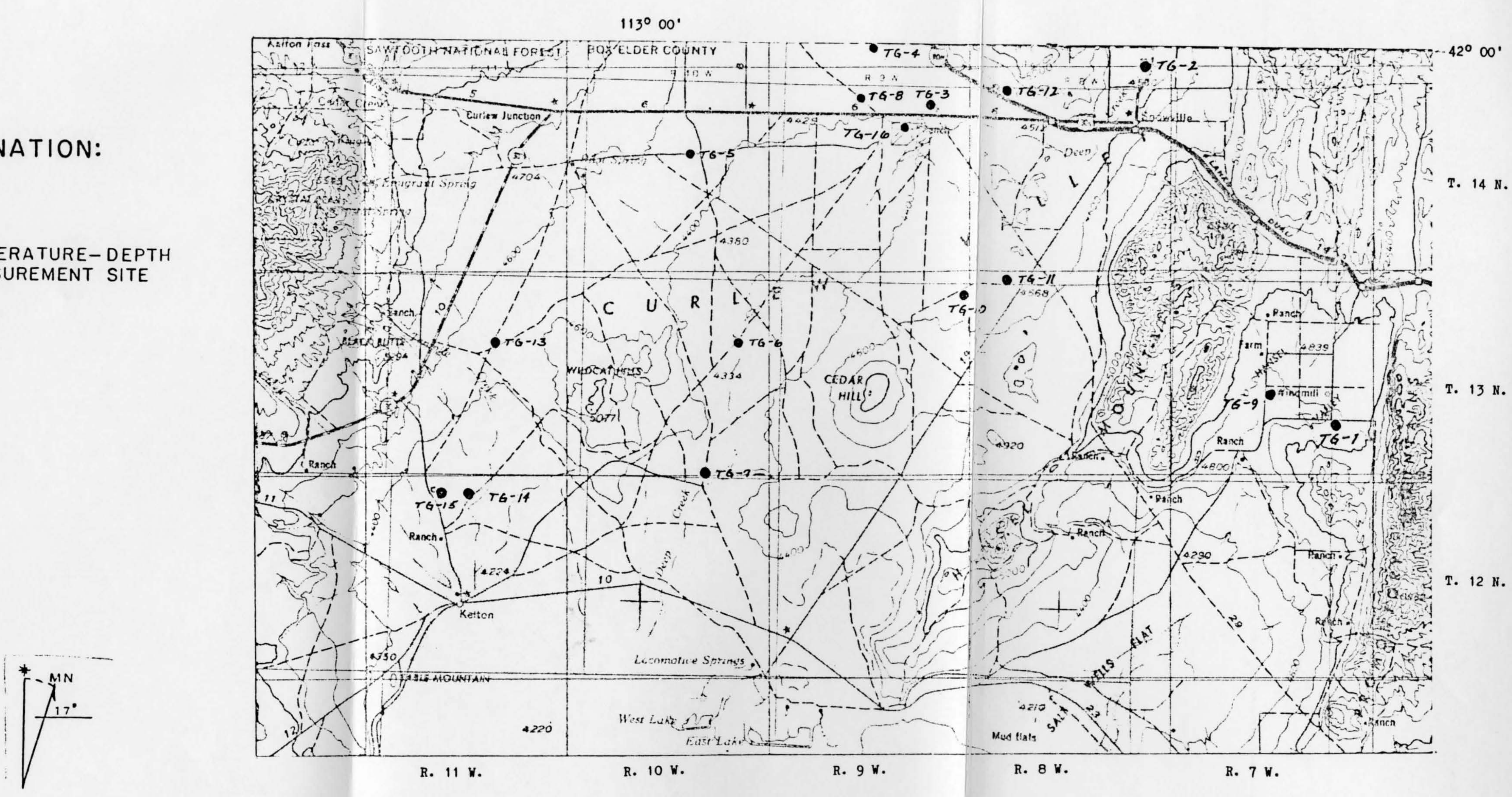
Contour Interval 200 Feet

Base from U.S. Geological Survey, Brigham City, 1970

LOCATION OF TEMPERATURE DEPTH MEASUREMENTS IN NORTH-CENTRAL BOX ELDER COUNTY, UTAH

EXPLANATION:

● TEMPERATURE-DEPTH MEASUREMENT SITE



SCALE 1:250,000

5 0 5 10 Miles

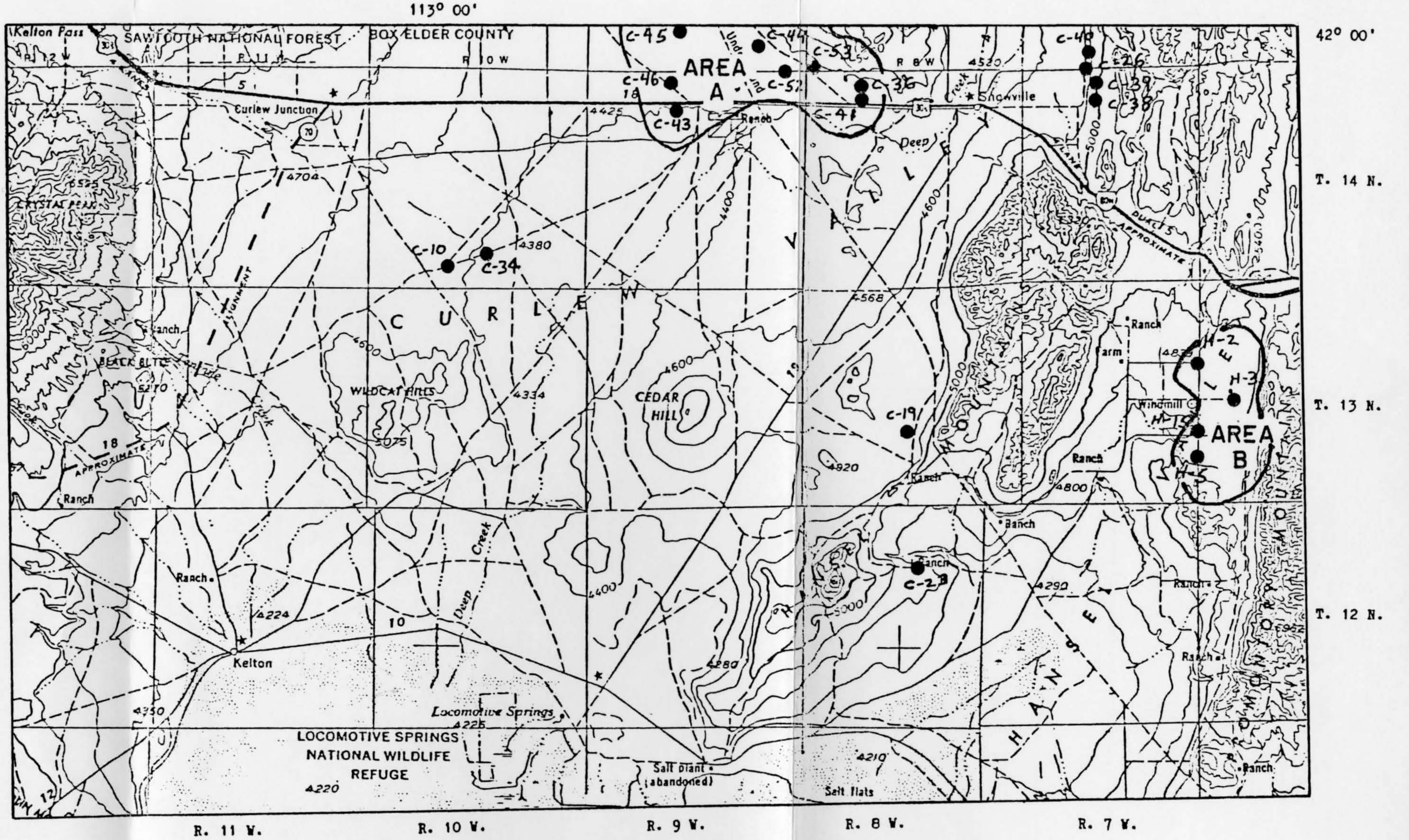
5 0 5 10 Kilometers

Contour Interval 200 Feet

Base from U.S. Geological Survey, Brigham City, 1970

PROPOSED REGIONS OF GEOTHERMAL INTEREST IN NORTH-CENTRAL BOX ELDER COUNTY, UTAH

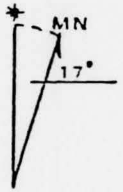
PLATE NO. 7



EXPLANATION:

AREA A — Proposed Regions Of Geothermal Interest

● SITES OF GEOTHERMAL INTEREST



SCALE 1:250,000

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5 0 5 10 Kilometers

Contour Interval 200 Feet

Base from U.S. Geological Survey, Brigham City, 1970