LOW-TEMPERATURE GEOTHERMAL ASSESSMENT OF THE SANTA CLARA AND VIRGIN RIVER VALLEYS, WASHINGTON COUNTY, UTAH

By Karin E. Budding and Steven N. Sommer

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
SPECIAL STUDIES 67 **1986**

K.E. BUDDING & S.N. SOMMER, LOW-TEMPERATURE GEOTHERMAL ASSESSMENT OF SANTA CLARA & VIRGIN RIVER VALLEYS, WASHINGTON COUNTY, UT. SPECIAL STUDY 67

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LOW-TEMPERATURE GEOTHERMAL ASSESSMENT OF THE SANTA CLARA AND VIRGIN RIVER VALLEYS, WASHINGTON COUNTY, UTAH

By Karin E. Budding and Steven N. Sommer

ABSTRACT

The low-temperature geothermal assessment of the Santa Clara and Virgin River Valleys and surrounding terrain was funded jointly by the U.S. Department of Energy (grant no. DE-FG07-84ID12543) and the Utah Geological and Mineral Survey (UGMS). Exploration techniques employed included the following: 1) a temperature survey of springs, 2) chemical analyses and calculated geothermometer temperatures of water samples collected from selected springs and wells, 3) chemical analyses and calculated geothermometer temperatures of spring and well water samples in the literature, 4) thermal gradients measured in accessible wells, and 5) geology.

The highest water temperature recorded in the St. George basin is 42°C at Pah Tempe Hot Springs. Additional spring temperatures higher than 20°C are at Veyo Hot Spring, Washington hot pot, and Green Spring. The warmest well water in the study area is 40°C in Middleton Wash. Additional warm well water (higher than 24.5°C) is present north of St. George, north of Washington, southeast of St. George, and in Dameron Valley.

Trilinear plots of common ion analysis of water samples collected resulted in the designation of three types of water. In general, type I waters, (Ca-Na HCO_3-Cl-SO_4) are from aquifers in the Navajo Sandstone and basalt in the northeastern part of the basin, in Snow Canyon, in the Pine Valley Mountains, and near Anderson Junction. Most type II waters (Ca-Na Cl-SO_4-HCO_3) are from shallow alluvial aquifers in the Santa Clara and St. George areas, in addition to water from the Moenkopi Formation in Washington Fields. Type III water (Na-Ca Cl-SO_4-HCO_3 is from the Navajo Sandstone aquifer north of St. George and Washington. Total dissolved solids values in tested water range from 103 ppm ((mg/l) in the recharge area to 9,523 ppm (mg/l) at Pah Tempe Hot Springs. Less than one-third of the samples collected are slightly saline and thirteen samples are moderately saline.

In most instances the Na-K-Ca and chalcedony geothermometers are the appropriate ones to employ in temperature calculations. The majority of the Na-K-Ca calculated reservoir temperatures range between 30° and 50°C. Anomalous geothermometer temperatures were calculated for water from Pah Tempe and a number of locations in St. George and vicinity.

Temperature-depth measurements were made in 17 shallow water wells and in one deep geothermal exploration well. Most gradients calculated are from 0.98° to 1.3°F/100 feet (18° - 24°C/km) although one well is considerably higher with a gradient of 1.85°F/100 feet (33.7°C/km).

In addition to the known thermal areas of Pah Tempe and Veyo Hot Spring, an area north of Washington and St. George is delineated in this study to have possible low-temperature geothermal potential. This area is distinguished on the basis of both anomalous surface and calculated geothermometer temperatures. Further work is needed, however, to define the resource.

INTRODUCTION

The low-temperature geothermal assessment of the Santa Clara and Virgin River Valleys and surrounding terrain was funded jointly by the U.S. Department of Energy (grant no. DE-FG07-84ID12543) and the Utah Geological and Mineral Survey. The boundaries of the study area are taken from the Geothermal Resources of Utah map (Murphy, 1980) which designates the area as being favorable for discovery and development of local sources of low-temperature (less than 90°C) water.

The geothermal study encompasses an area of approximately 250 square miles (650 km^2) in south-central Washington County in southwestern Utah (figure 1). St. George, population 25,000 (1986), is the largest city in the area,

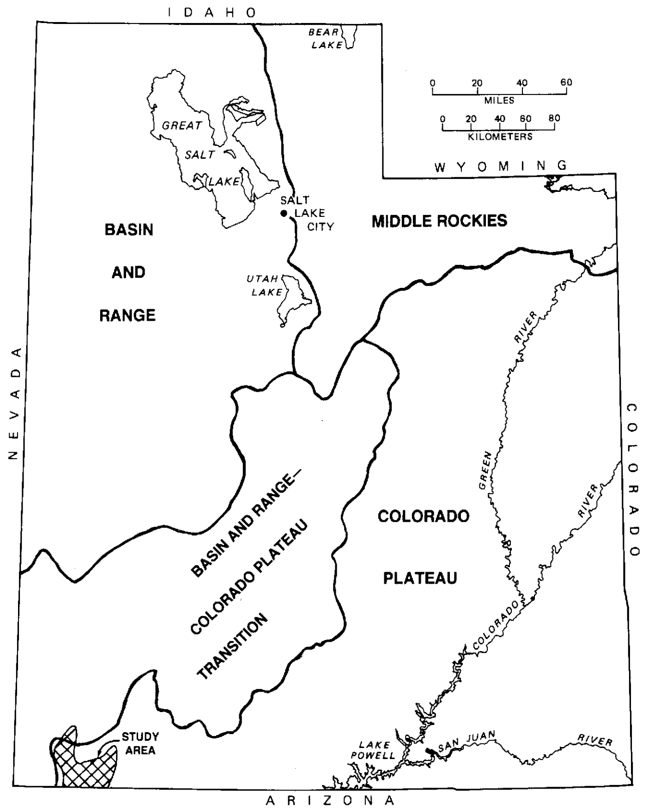


Figure 1. Index map showing the geothermal study area and physiographic provinces.

growing at an annual rate of 12 percent. The metropolitan area of St. George, Bloomington, Santa Clara, and Washington has a combined population of 35,000. Smaller cities include Veyo and Central in the northwest corner of the study area and Hurricane, La Verkin, and Toquerville northeast of St. George.

The geothermal assessment is primarily based on the following: 1) a temperature survey of springs, 2) chemical analyses and calculated geothermometer temperatures of water samples collected from selected springs and wells, 3) chemical analyses and calculated geothermometer temperatures of spring and well water samples in the literature, 4) thermal gradients measured in accessible wells, and 5) geology.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

The majority of the study area lies in the Colorado Plateau physiographic province, immediately south of the Basin and Range-Colorado Plateau transition zone (figure 1). The study area approximately coincides with the boundary for the St. George basin subprovince of Stokes (1977) and in this report will be referred to as the St. George basin. The basin is bordered by the Pine Valley Mountains to the north, the Beaver Dam Mountains to the west, the Hurricane Cliffs to the east, and the Arizona state line to the south. The Virgin River is the largest river in the basin and drains the eastern portion of the area. It enters the study area just south of La Verkin and flows into Arizona southwest of Bloomington. The Santa Clara River has its headwaters in the Pine Valley Mountains and drains the western half of the study area. The confluence of the Santa Clara with the Virgin River is about two miles (3 km) south of St. George.

A structural transition exists within Washington County with flat-lying sedimentary strata, typical of the Colorado Plateau, on the east, and fault blocks of previously folded and thrust-faulted rocks typical of the Basin and Range Province on the west. The St. George basin, although part of the Colorado Plateau, is a transition block with sedimentary rocks moderately folded along northeast axes (Cook, 1960) and is more typical of the Basin and Range-ColoradoPlateau transition zone. The block, bordered on the east by the Hurricane fault and on the west by the Grand Wash fault, has a very gentle regional dip to the northeast (Peterson, 1983).

A sequence of sedimentary rocks over 19,000 feet (5,800 m) thick lies between the Precambrian metamorphic rocks in the Beaver Dam Mountains west of the St. George basin and the Tertiary igneous rocks of the Pine Valley and Bull Valley Mountains north and northwest of the basin (Cook, 1960). Paleozoic sedimentary rocks include the Permian Kaibab Limestone, which is exposed along the crest of the Virgin anticline and with the Permian Toroweap Limestone in the Virgin River gorge west of Hurricane. Descriptions of all the formations are given in the description of map units accompanying plate 1.

Most of the basin is characterized by Mesozoic strata, which include the Triassic Moenkopi, Shinarump, Chinle, Moenave, and Kayenta Formations; the Jurassic Navajo, Carmel, and Entrada Formations; and Cretaceous rocks which include the Dakota, Tropic, Straight Cliffs, Wahweap, and Kaiparowits Formations (Cook, 1960; Hamblin, in press a and b). Sedimentation during the Triassic and Jurassic periods took place during three phases: 1) deposition of fine, largely terrestrial sediments throughout the Triassic, 2) deposition of continental sandstone in Early Jurassic, and 3) shallow marine sedimentation in Late Jurassic.

The Moenkopi Formation and the Navajo Sandstone are the predominant sedimentary units outcropping in the St. George basin. The Moenkopi Formation outcrops south of the Santa Clara River, along the Virgin anticline, and on the east side of the Washington fault. The Navajo Sandstone forms the massive cliffs west of Leeds and north of St. George and is also present in the Sand Mountain area in the southeast portion of the basin. The formation is an important aquifer.

The Tertiary Claron Formation is only present in the northwest corner of the study area; however, it is found along the base of the Pine Valley Mountains where it has been intruded by a laccolith. Cook (1960) refers to this Tertiary quartz monzonite porphyry as among the largest known laccoliths. The Pine Valley laccolith has not been dated; however, the three intrusions, perhaps laccoliths, of the Iron Springs district, approximately 12.5 miles (20 km) west of

Cedar City, are of Miocene age. The Three Peaks, Granite Mountain, and Iron Mountain porphyritic quartz monzonite plutons are about 20 m.y. to 21 m.y. old based partly on K-Ar ages of intrusive rocks (Armstrong, 1970) and largely on field relations between the plutons and dated volcanic rocks (Rowley and Barker, 1978). The nearby quartz monzonite Pine Valley laccolith may be the same age as the plutons in the Iron Springs district.

A late Cenozoic hornblende dacite outcrops approximately one mile (2 km) northeast of the town of Central. It flowed down an ancient valley to the south of Eight Mile Spring. The dacite is composed of a lower, glassy, cliff-forming unit about 50 to 100 feet (15-30 m) thick and an upper, denser porphyritic dacite at least 200 feet (60 m) thick (Cook, 1960). The gray, porphyritic dacite has phenocrysts of hornblende, biotite, plagioclase, and sanidine. As part of this study, a potassium-argon age determination was done on the biotite concentration and an age of 3.1 ± 0.2 m.y. was determined:

> Hornblende dacite (C-39-16) 1dbb; Washington County, Utah
> Analytical data: $K_2O = 7.77\%$; $^{40}Ar = 3.49 \times 10^{-11}$ mol/g; $^{40}Ar/\Sigma\ ^{40}Ar = 0.134$
> K-Ar (biotite) 3.1 ± 0.2. m.y.
> (note: ^{40}Ar refers to radiogenic ^{40}Ar)

Late Cenozoic basaltic flows and cinder cones in the St. George basin provide important data on the tectonic and geomorphic history of the area. Volcanic centers were primarily near the Pine Valley Mountains and the flows traveled southward along stream valleys. After the basalt solidified, the stream channels moved laterally into the less-resistant sedimentary rock and cut new channels. The erosion-resistant basalt flows now cap long, narrow, sinuous ridges called inverted valleys. This process repeated itself with successively younger flows, and the relative ages of the flows can be determined from their height above the present drainage, the older flows lying above the younger basalt. Displacement of the flows by faulting provides time constraints for the periods of recurrent movement along major faults (Hamblin, 1963).

Four stages of basalt flows have been distinguished in the St. George basin on the basis of geomorphic relationships and age determinations (Hamblin, 1970a). The oldest flows (Tb on plate 1) have been classified as Stage I and are those deposited on an erosional surface that is not related to the present drainage system. These basalts are more than 2 m.y. old. Only minor flows of these basalts over 2 m.y. old occur in the basin. Stage I flows on the Shivwits Plateau, south of the St. George basin in Arizona, have been dated at 6 m.y. (Hamblin, 1970b). Stage I flows represent a long time period with intermittent eruption of basalt. Stage II flows (QTb on plate 1) were deposited on an erosional surface which is now 200 to 500 feet (60-150 m) above the present drainage. These flows are approximately 1 m.y. to 2 m.y. old and present throughout the basin. Erosional remnants are usually elongate and parallel to the present drainge as inverted valleys. K-Ar dates for two St. George flows range from 2.24 ± 0.11 m.y. (highest flow) to 1.07 ± 0.04 m.y. (lower flow) (Hamblin and others, 1981). Stage III flows (Qb_1 on plate 1) are those that were deposited on a surface that is 20 to 100 feet (6-30 m) above the present drainage. Incipient inverted valleys are developed on these flows, and the sources and cinder cones associated with the eruptions are preserved. These flows are near Veyo, Central, and Hurricane. Stage III flows are approximately between 1,000 years and 0.25 m.y. old. A flow near Hurricane has an age of 0.293 ± 0.087 m.y. (Hamblin and others, 1981). Stage IV flows (Qb_2 on plate 1) have been deposited on the present erosional surface. Cinder cones are well preserved and most flows are traceable to their source. These basalts, present north of Santa Clara in Snow Canyon, are less than 1,000 years old. Flows in the San Francisco Mountains area near Flagstaff, Arizona, with similar preservation of original flow structures, are dated at 900 years old (Hamblin, in press b).

The St. George basin contains varied types of late Cenozoic lavas (Best and Brimhall, 1970). Basalts are undersaturated in silica (Yoder and Tilley, 1962) and within the alkalic basalt field on the alkalies-silica plot (Macdonald and Katsura, 1964). In the St. George basin the majority of the basalt flows are quartz-bearing basaltic andesite and hawaiite. The basaltic andesite occurs in Stage II and III flows (QTb and Qb_1 on plate 1) in the northeast portion of the basin and near St. George. These lavas are characterized by sparse phenocrysts of olivine and large, cognate crystals of quartz and plagioclase. The hawaiite is found as Stage II and III flows in the eastern part of the basin and as Stage IV flows (Qb_2 on plate 1) north of Santa Clara. The matrix is medium gray and some basalts are aphyric, although olivine phenocrysts are usually present and bytownite and augite appear in many flows (Best and Brimhall, 1974). There are two groups of unconsolidated Quaternary sediments in the area. Older sediments are, largely, coarse gravels that mantle the pediment. These poorly sorted gravels were probably deposited by torrents and mudflows during the Pleistocene (Proctor, 1953). The younger sediments form narrow valleys as well as local deposits of landslide, hillwash, and dune material (Cook, 1960).

STRUCTURAL SETTING

Two structural trends are present in Washington County. Laramide-age structures are seen by northeasterly aligned folds and faults. The second set of structures formed during the Tertiary primarily as north-south-striking faults. Late Cenozoic movements have been influenced by both structural trends. The geologic map presents the major structural features of the St. George basin, including: 1) Virgin anticline, 2) Hurricane fault, 3) Grand Wash fault, and 4) Washington fault (plate 1).

The Virgin anticline cuts the St. George basin in a northeasterly direction for about 16.5 miles (27 km). The feature is a broad, symmetrical fold with maximum flank dips ranging from 25° to 30°. The anticline formed as a result of compression late in the Laramide orogeny, probably in Eocene time (Hamblin personal communication, 1986). The oldest formation exposed along the axis of the anticline is the Permian Kaibab Limestone (Cook, 1960).

Extension and faulting associated with post-Laramide tectonics in early to middle Miocene time produced the north-trending Hurricane, Grand Wash, and Washington faults. The age of initial movement on these faults may be related to relative down-dropping of the eastern Basin and Range Province as a result of collapse of regional upwarping during late Tertiary time (Best and Hamblin, 1978; Earth Sciences Associates, 1982). The upthrown block is to the east on these normal faults.

The Hurricane fault is a major structural feature extending over 186 miles (300 km) from Cedar City, Utah southward into Arizona. It is marked by the west-facing escarpment named the Hurricane Cliffs on the east side of the St. George basin. Approximate displacement on the fault increases northward from 5900 feet (1,800 m) at the state line to 7900 feet (2,400 m) near the town of Hurricane, and a possible 9850 feet (3,000 m) north of Hurricane. The fault is composed of several fault planes in a zone of displacement with a maximum width of one mile (1.6 km) (Hamblin, 1970b). Reverse drag has been formed repeatedly during recurrent movement along the fault (Hamblin, 1965). Eight basalt flows ranging in age from 18 m.y. to a few thousand years erupted across the fault and have been subsequently displaced. Hamblin estimates that the recurrence interval for the Hurricane fault during the last 10 to 15 m.y. is 0.25 m.y. (personal communication, 1986). Based on offset of dated basalt flows, 200 feet (600 m) of movement on the fault has occurred during the last one m.y. Current displacements are judged to be on the order of 1000 to 1650 feet per m.y.(300-500 m/m.y. or 0.03-0.05 cm/yr). Quaternary movement is evidenced by displaced late Pleistocene alluvium (Earth Sciences Associates, 1982).

The Grand Wash fault, also known as the Gunlock/Cedar Pocket Canyon/Veyo fault, can be traced from Gunlock, on the west side of the St. George basin, into northwestern Arizona, a distance of approximately 100 miles (159 km). The structural block between this fault and the Hurricane fault has been uplifted at least 210 feet/m.y. (64 m/m.y.) in late Cenozoic time (Hamblin and others, 1981). Displacement along the Grand Wash fault zone decreases northward. Offset that may be 3 miles (4,880 m) near the mouth of the Grand Canyon, Arizona decreases to less than 1500 feet (460 m) at the state line and to less than 300 feet (90 m) in Utah. Based on the amount of erosion on the Grand Wash Cliffs in Arizona, the main movement of the fault occurred in early Miocene to late Pliocene time. Stage I basalt flows about 6 m.y. old, approximately 34 miles (55 km) south of Utah, have been displaced by the fault, which indicates recurrent movement in that area (Hamblin, 1970b).

The Washington fault is a small-scale version of the Hurricane and Grand Wash faults. The St. George basin is nearly bisected by the Washington fault, which extends southward from the foothills of the Pine Valley Mountains across the Virgin anticline and into Arizona over a distance of about 36 miles (58 km). The fault system follows a conjugate fracture system trending N26°E and N16°W. Similarities in fault patterns between this system and the Hurricane fault suggest origins with similiar stress fields on rocks of closely related composition (Petersen, 1983). Displacement on the Washington fault increases southward. Offset has been estimated at less than 1,000 feet near the Virgin River where the fault breaches the Virgin anticline, increasing to 2495 (760 m) at the Arizona border (Dobbin, 1939). Stage I basalt flows dated at 2.9 m.y. (Best and Hamblin, 1978) are offset by 197 feet (60 m) where they cross the fault indicating an average fault displacement of about 69 feet/m.y. (21 m/m.y.) Drag features, thought to be the result of fault movement, are seen on 2.3 m.y.-old Stage I basalts and suggest recurrent movement during this time span. Woodward and Clyde have found displaced Quaternary alluvial sediment along the Washington fault (Petersen, 1983). Late Quaternary movement along the Washington fault has been documented by Earth Sciences Associates (1982) who believe that fault-related displacements of alluvial materials, seen in exploratory trenches, are likely to have occurred during Holocene time.

SEISMICITY

The Hurricane, Grand Wash, and Washington faults are considered to be seismically active (Earth Sciences Associates, 1982). All three fault zones lie within the Intermountain seismic belt — a major zone of intraplate seismicity in western North America. Two earthquakes of about 5 to 5.5 magnitude and several earthquake swarms have occurred in historic time on the Hurricane fault zone in the Cedar City area. An earthquake of magnitude 5.0 (estimated) that may have been associated with the Washington fault occurred near St. George in 1891. Two other earthquakes of magnitudes 5.0 and 6.3 occurred in 1902 near Pine Valley about 22 miles (35 km) north of St. George (Arabasz and others, 1979; Christenson and Deen, 1983).

HEAT FLOW

Heat flow is the conductive transfer of heat from the earth's interior and, therconditions at depth. Heat flow data within the study area are sparse. The only two measurements are 98 mW/m^2 (milliWatts per square meter) or 2.3 HFU (heat flow units) near Central on the western edge of the Pine Valley intrusion, and 74 mW/m^2 (1.8 HFU) in Snow Canyon State Park, 7.5 miles (12 km) northwest of St. George (Chapman and others, 1978). Figure 2 illustrates heat flow for the entire state (Lachenbruch and Sass, 1980). Representative heat flow for the Utah portion of the Basin and Range Province is 90 ± 10 mW/m^2 (2.2 HFU), significantly above the continental average. Heat flow in the Colorado Plateau is near the average at 49 ± 8 mW/m^2 (1.2 HFU) (Chapman and others, 1978). The high heat flow in regions of extensional tectonics, like the Basin and Range Province, is caused by lithosphere extension and magmatism (Lachenbruch and Sass, 1978). Even though the study area is within the Colorado Plateau, it exhibits heat flow values similar to those measured in the Basin and Range.

HYDROLOGIC SETTING

The central Virgin River basin covers about 1000 square miles (2,590 square km) in Washington and Iron Counties.

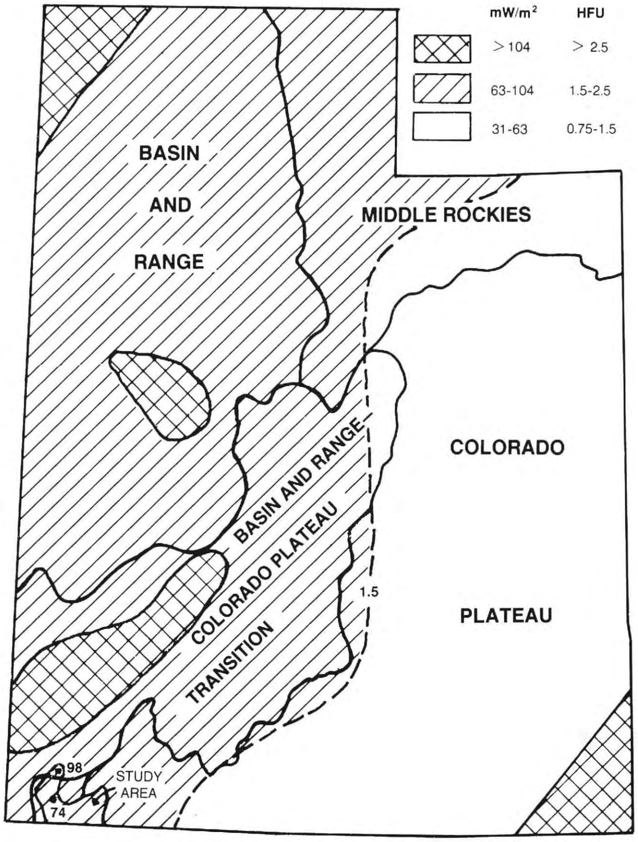


Figure 2. Heat flow map of Utah from Lachenbruch and Sass (1980) showing measurements taken in the George basin from Chapman and others (1978).

This basin includes the study area and additional ground north along the Hurricane fault to Kanarraville, west from there including the Pine Valley and Bull Valley Mountains, and south from there along the crest of the Bull Valley and Beaver Dam Mountains. As the name implies, the area is drained by the Virgin River and its tributaries, part of the Colorado River system. The major tributary within the study area is the Santa Clara River. The Virgin River is perennial and its tributaries are perennial, intermittent, or ephemeral (Cordova and others, 1972).

PRINCIPAL AQUIFERS

Aquifers are present in both unconsolidated and consolidated rocks in the St. George basin. About 25 percent of the basin is covered by unconsolidated alluvial sands and gravels which supply about 80 percent of the water discharged by relatively shallow water wells. Half of the water samples collected for the geothermal assessment were from aquifers in unconsolidated rocks. The thickness of the saturated zone in these aquifers varies but generally is less than 100 feet (30 m); depth to the saturated zone ranges from 10 to 85 feet (3-25 m). Average yield of these wells is less than 250 gpm (16 l/s).

The Moenkopi, Chinle, Moenave, and Kayenta Formations, the Navajo Sandstone, and the Tertiary and Quaternary basalts supply most of the springs in the basin discharging from the consolidated-rock aquifers (generally yielding less than 50 gpm or 3 l/s). Although many wells tap consolidated-rock aquifers, the yield is so low that only about 20 percent of the water withdrawn by wells in the basin comes from consolidated rocks. Water samples in the basin were collected from the Moenkopi, Shinarump, Kayenta Formations, the Navajo Sandstone, the Cretaceous unit, and the basalts. Yield from the aquifers in these units is small to moderate (9.5 to 100 gpm or 0.6-6.3 l/s), with the exception of the Navajo Sandstone and basalt where the flow is moderate to very large (100 to more than 1000 gpm,6.3-63 l/s). This higher yield is due to the larger, more extensive fractures in the hard, brittle rock and, locally, the Navajo Sandstone may contain a significant amount of intergranular openings (Cordova and others, 1972).

RECHARGE, MOVEMENT, AND DISCHARGE

Recharge to the ground-water reservoir in the central Virgin River basin is from the following three sources: 1) infiltration of precipitation primarily in winter — 70,000 acre feet (8,640 km^3) annually; 2) infiltration of stream flow directly from water-ways or irrigated land — 15,000 acre feet (1,850 km^3) annually; 3) subsurface inflow in the upper 500 feet (150 m) of saturated rock from east of the Hurricane Cliffs and from Arizona — 20,000 acre feet (2,470 km^3) annually (Cordova and others, 1972).

The direction of ground-water movement in the St. George basin is toward the Virgin River and its tributaries. Arizona provides flow from east of the Hurricane Cliffs and gains water from beneath and west of the Virgin River valley.

Discharge of ground water in the central Virgin River basin is estimated for 1970 as: 1) seepage into streams — 24,000 acre feet (2,960 km^3); 2) spring and drain discharge from consolidated rocks — 40,000 acre feet (4,930 km^3); 3) evapotranspiration by phreatophytes, mainly in and next to the channels of the Santa Clara and Virgin Rivers — 13,000 acre feet (1,600 km^3); 4) discharge by wells largely from the Santa Clara River valley and Fort Pierce Wash in the St. George basin — 9,100 acre feet (1,120 km^3); and 5) subsurface outflow in the upper 500 feet (150 m) of saturated rock most likely at the Arizona border west of the Virgin River — 2,000 acre feet (250 km^3) (Cordova and others, 1972).

KNOWN GEOTHERMAL AREAS

PAH TEMPE HOT SPRINGS

Pah Tempe Hot Springs, also known as La Verkin and Dixie Hot Springs, is the highest-temperature thermal area within the basin. The springs are located in the Virgin River gorge on the east side of Utah State 17 between Hurricane and La Verkin (plate 1). The springs issue from fractures in the Permian Toroweap Limestone at the base of the cliff and also from the channel of the Virgin River. The majority of the cliffs forming the Virgin River gorge are composed of the overlying Permian Kaibab Limestone. The north-trending Hurricane fault passes just to the west of the springs, but the springs lie within the fault zone. The hot springs are located within 650 feet (200 m) of 1 to 2 m.y.-old basalts (QTb plate 1) and are approximately one-half mile (1 km) from basalt flows that outcrop widely in the vicinity of Hurricane ranging from 1,000 years to 0.25 m.y. old (Qb plate 1).

The recorded temperatures of the hot springs have varied with time from 38° to 56°C (Mundorff, 1970). Measured temperatures between 1960 and 1966 ranged from 38° to 42°C; however, much warmer temperatures of 42° to 56°C (Crook, 1899; Peale, 1886) were reported in the 1800s. It is not known if the original temperature measurements were inaccurate or if the springs have cooled significantly over the past 80 years. A temperature of 42°C was measured in February, 1986. The flow of the springs has also varied with time. Gregory (1950) reports a flow of about 1000 gpm (63 l/s), whereas Mundorff (1970) lists flow measurements taken by the U.S. Geological Survey and Utah State University from 1956 to 1966 to be between 4500 and 5200 gpm (283-328 l/s).

Pah Tempe springs have a very high TDS content. Calculated TDS values on five samples taken between 1940 and 1966 range from 9,390 to 9,760 ppm (mg/l). A slightly lower TDS of 7,214 ppm (mg/l) was found in the sample collected for this study. The source of these dissolved solids is not known (Mundorff, 1970), and the high TDS content of the springs has an adverse effect on the quality of water in the Virgin and Colorado Rivers. Water in the hot springs is probably of meteoric origin. Current development at Pah Tempe consists of a swimming pool and mineral bath spa.

VEYO HOT SPRING

Veyo Hot Spring is located southeast of the town of Veyo along the Santa Clara River which has incised 1 and 2 m.y.-old basalt flows (QTb plate 1). The spring flows into the river at the base of these canyon walls. Holocene and Pleistocene basalt flows (Qb_1 plate 1) surround the hot spring area. The water is probably of meteoric origin. Mundorff (1970) reports temperatures of 32° to 37°C, calculated TDS of 389 to 402 ppm (mg/l), and a discharge of 120 gpm (7.6 l/s) in 1966 and 1967. A temperature of 29.5°C was measured in February 1986, with a calculated TDS of 395 ppm (mg/l). The orifice of the spring has been covered by a swimming pool which is part of a resort open from the end of March through August.

WASHINGTON HOT POT

A warm spring located north of the city of Washington fills a circular depression about 30 feet (9 m) in diameter with a maximum depth of 5 feet (1.5 m). The hot pot is located in the Navajo Sandstone and is a little over one-half mile (1 km) west of the Washington fault. No information on this spring could be found in the literature. A temperature of 24.5°C was measured in February, 1986 with a calculated TDS of 311 ppm (mg/l).

TEMPERATURE SURVEY

Geothermal resources that are below 90° are designated as low temperature. The minimum temperature for a low-temperature geothermal resource has been defined to be 10° above the mean annual air temperature at the surface and should increase by 1.37°F/100 feet (25°/km) with depth (Reed, 1983). The State Climatologist's office in Logan reports the mean temperature in St. George to be 16.6°. In this study, 26°C or warmer water was considered to have low-temperature geothermal potential; water between 20° and 25.9°C may have geothermal potential. The 20° minimum for thermal water has been used in previous studies (Bliss, 1983; Mundorff, 1970).

An attempt was made to locate all springs in the basin that are shown on the USGS 30 x 60 minute St. George quadrangle; however, some springs were not found and others were not flowing. Figure 3 shows the spring and well temperatures that were measured as part of this study, in addition to 22 well and spring temperatures compiled from the literature. The published data were selected because their complete chemical analyses were used in the trilinear diagrams and geothermometer temperature calculations discussed in a later section. Temperatures were measured using a Yellow Springs Instrument (YSI) Model 33 Temperature-Conductivity Meter.

Spring and well temperatures range from a low of 7°C in recharge areas in the Pine Vallley and Bull Valley Mountains to a high of 42°C at Pah Tempe Hot Springs. Spring temperatures of 20° or higher were found at Pah Tempe Hot Springs (42°C), Veyo Hot Spring (29.5°C), and Washington hot pot (24.5°C) as already discussed. Additional thermal water in the basin is evident at Green Spring, about three-fourths mile (1.2 km) west of the Washington hot pot, where a temperature of 23°C was measured (figure 3). Two springs with water temperatures of 20°C are listed in the literature and include West St. George Springs, located near the northwest edge of the city, and an unnamed spring just northwest of Interstate 15 between Washington and Middleton. A temperature of 11.5°C, however, was measured for the West St. George Spring in February, 1986. Washington City Spring, approximately one-half mile (1 km) east of the hot pot, was 19.5°C and a large number of other springs in the basin have water temperatures of 19°C.

Some wells in the basin have water temperatures between 20° and 21.5°C, fewer are between 24.5° and 29°C, and one well measured 40°C. The well temperatures are discussed from northwest to northeast across the basin (figure 3). A temperature of 26.5°C (W16) was measured at Dameron Valley and reportedly the well pipe is warm to the touch during the winter. The St. George City wells in Snow Canyon (W12, W17, W69) range from 18° to 20°C. Sample W31, west of Ivins, measured 20°C, but the well stopped flowing after 15 minutes when the temperature was taken. Water from St. George City Creek Wells no. 1 and 2 (W36, W74, W75), north of St. George, measured 26°C. The warmest well water found in the basin was north of these wells along Middleton Wash where sample W68 measured 40°C. This well was drilled by Terracor for culinary water but was abandoned because of temperature and high TDS. Washington City well (W76), located north of Green Spring and the hot pot, was 29°C. A temperature of 24.5°C was measured southeast of St. George (W49), and southeast of that in Washington Fields two samples (W33 and W41) are 21° and 21.5°C, respectively. South of Berry Springs, two samples (W22 and W23) from Stratton Turf Farm measure 21° and 20°C. Approximately 2-½ miles (4 km) to the east, sample W70 is 21.5°C and sample W35 is 20°C. Sample W35 is from a well drilled by Floratec. Three exploratory wells were drilled at this location in an attempt to establish a geothermally-heated greenhouse operation; drilling did not encounter water of the required temperature. An artesian well approximately 3.5 km southeast of Leeds (W61) has a water temperature of 21.5°C.

WATER CHEMISTRY

Fifty-five spring and well samples were collected as part of this study and 22 samples taken from the literature (figure 4). A Corning-Orion Model 407A/F specific ion meter with an Orion gel-filled Model 91-05 combination pH electrode was used to measure pH. Three readings were taken and averaged. A YSI Model 33 Temperature-Conductivity Meter was used to measure conductivity. The water samples were analyzed at the Earth Science Laboratory of the University of Utah Research Institute (ESL/UURI) and results are presented in table 1.

Sample collection involved filtering the water through a GeoFilter Peristaltic Pump - Model #004 using a 0.45 micron filter paper to fill two 500 ml and one 32 ml polyethylene bottles at each site. The 32 ml bottle was acidified with reagent grade HNO_3 to a final concentration of 20 percent HNO_3 and analyzed for most of the elements and compounds in table 1 by an APL Inductivity Coupled Plasma Quantometer (ICPQ). One 570 ml bottle was acidified with concentrated HCl to a final concentration of one percent HCl and analyzed for SO_4. The water in the remaining bottle was not acidified and analyzed for Cl, F, HCO_3, CO_3, and TDS.

COMMON ION ANALYSES

The chemical analyses were entered into the elemental analyses program ELE at the ESL/UURI that generates trilinear diagrams and calculates geothermometers (Withrow, 1983). Common ion analyses, in percent of total milliequivalents per liter, are plotted on trilinear diagrams in figures 5 through 10. The nomenclature to describe water samples is from Back (1961) and is presented on figure 4. The delineation of type I, Ia, II, IIa, and III waters is arbitrary and was done to aid the discussion of the water chemistry. Samples W43 and W24 are not shown because the percent of error in common ion balance was greater than 3 percent.

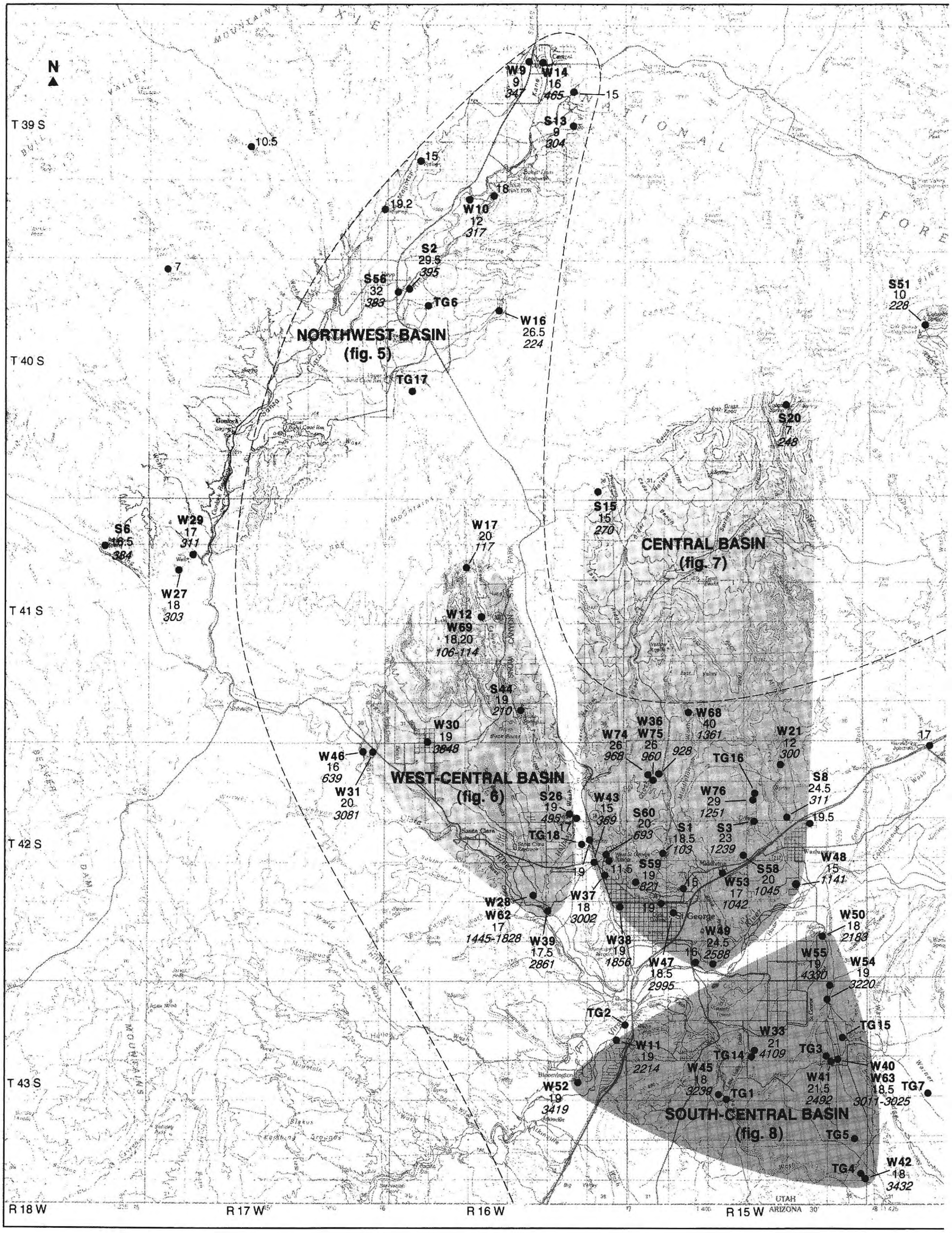
A spring sample was collected for chemical analysis if the water temperature was 20°C or greater. In addition, samples were taken in the Pine Valley Mountains and west of the basin in order to characterize recharge areas. An attempt was made to sample wells that were geographically representative of the basin; however, collection was largely controlled by the presence of water wells, their sampling access, and pumping schedule.

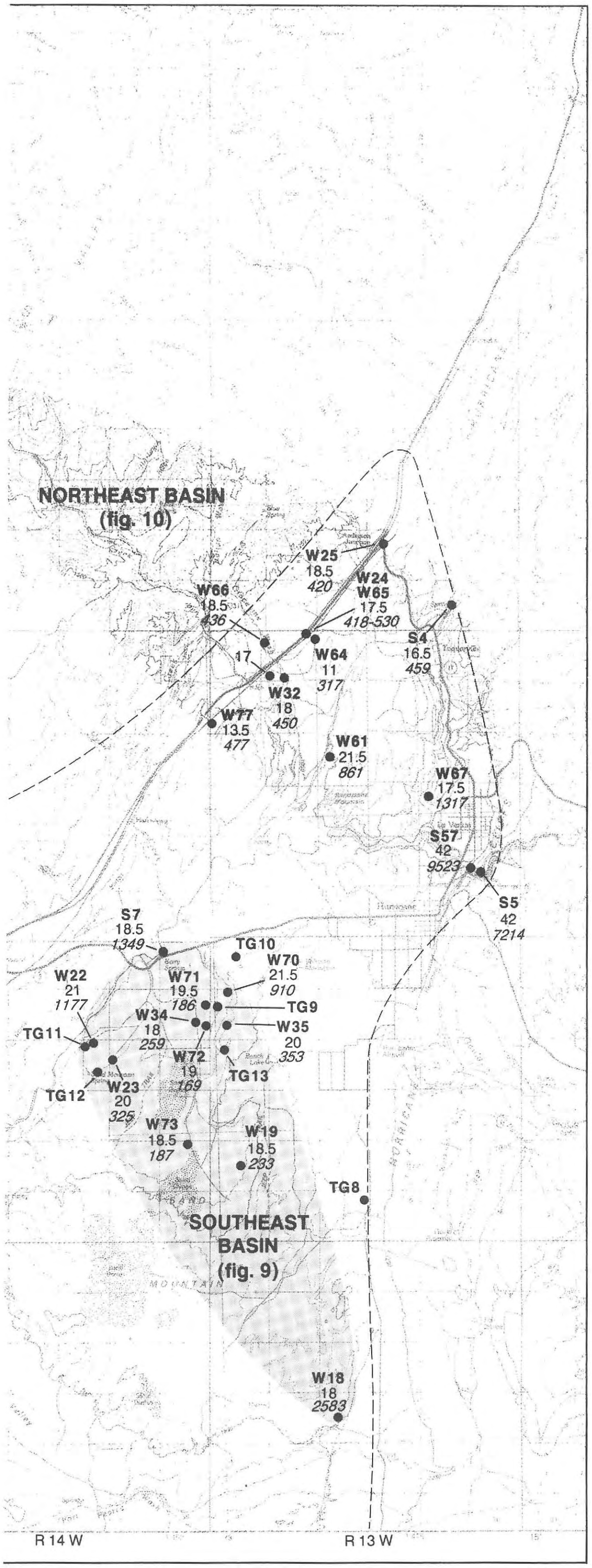
The samples are plotted on six trilinear diagrams grouped on the basis of geography and drainage basins. These groups are indicated on figure 3. Water from the northwest portion of the basin is shown on figure 5. Samples include those taken northwest and southeast of the Santa Clara River and those west of the river, just west of the study area. Sample S6 (Pahcoon Spring) is from a recharge area. Veyo Hot Spring samples are S2 and S56. All the samples in figure 5 are Ca-Na HCO_3-Cl-SO_4 water (type I). The pH varies slightly between 7.3 and 7.7, with the exception of W27 near Gunlock Reservoir with pH 8.0. The well samples in the Veyo area were collected from wells drilled into basalt to depths of approximately 230 feet (70 m); the two wells south of Gunlock Reservoir were drilled into Navajo Sandstone about 560 feet (170 m).

Figure 6 represents those samples in the west-central part of the basin —northeast of the Santa Clara River, south of Red Mountains, and west of West Black Ridge. Well samples from Snow Canyon and Snow Spring are Ca-Na HCO_3-Cl-SO_4 in character (type I) and slightly basic with a pH range of 7.8 - 8.3. The wells in Snow Canyon drilled in Navajo Sandstone are approximately 590 feet (180 m) deep, tapping an aquifer about 215 feet (65 m) below the surface. Water from the shallow wells south of Santa Clara and Miller Spring is Ca-Na Cl-SO_4-HCO_3 in character (type II) with pH range of 7.2 - 7.9. The water sampled in and near Ivins (W30, W31, W46) varies considerably. The Santa Clara and Ivins wells are shallow, about 130 feet (40 m) deep, and are located in alluvium. Aquifers are approximately 30 feet (10 m) below the surface.

Samples from the central part of the basin, the area northwest of the Virgin River and east of West Black Ridge, are plotted on figure 7. This water is slightly basic with pH range 7.1 to 8.4. Sample W49, southeast of Washington, is slightly acidic with a pH of 6.6. Samples S20 from Cougar Spring and S15 from Diamond Valley were collected in the Pine Valley Mountains, a recharge area. Along with the Washington hot pot and a well north of Washington, these four samples are Ca-Mg HCO_3-Cl-SO_4 in character (type Ia). Well W21 is about 660 feet (200 m) deep and is completed in the Navajo Sandstone. The water table is 115 feet (35 m) below the surface. Type III group water is Na-Ca Cl SO_4 HCO_3 in character and was present in springs and wells north of St. George and Washington. The wells are approximately 705 feet (215 m) deep and completed in the Navajo with the exception of well W53, 200 feet deep (60 m). Two aquifers are at depths of 280 feet (85 m) and 560 feet (170 m), respectively. Sample S1 from the St. George City aqueduct, originating south of Cougar Spring, is similar to type Ia water and was collected approximately 12.5 miles (20 km) south of Cougar Spring. Type II water (Ca-Na Cl-SO_4-HCO_3) and type IIa water (Ca-Na Cl) were collected in and southeast of St. George along the Virgin River. Samples represent water from wells (about 65 to 250 feet, 20 - 75 m deep) completed in shallow aquifers.

The south-central portion of the basin (figure 8) is the area southwest of the Virgin River and west of Warner Ridge and Washington Dome; the latter feature is part of the Virgin anticline. The majority of these samples are Ca-Na Cl in character (type IIa) with pH between 7.0 and 7.8. All the water was collected from fairly shallow wells (less than 230 feet or 70 m in depth) primarily drilled into the Moenkopi and tapping


N
T 39 S
T 40 S
T 41 S
T 42 S
T 43 S
R 18 W
R 17 W
R 16 W
R 15 W
UTAH
ARIZONA
NORTHWEST BASIN (fig. 5)
WEST-CENTRAL BASIN (fig. 6)
CENTRAL BASIN (fig. 7)
SOUTH-CENTRAL BASIN (fig. 8)
W9 9 347
W14 16 465
15
S13 9 304
10.5
15
18
19.2
W10 12 317
7
S2 29.5 395
S56 32 383
TG6
W16 26.5 224
S51 10 228
TG17
S20 7 248
S15 15 270
W29 17 311
S6 16.5 384
W27 18 303
W17 20 117
W12 W69 18,20 106-114
S44 19 210
W30 19 3848
W46 16 639
W31 20 3081
W68 40 1361
W36 W75 26 960
W74 26 968
928
W21 12 300
17
TG16
W76 29 1251
S8 24.5 311
19.5
S3 23 1239
S26 19 495
17
W43 15 369
S60 20 693
S1 18.5 103
TG18
19
11.5
S59 19 821
16
S58 20 1045
W53 17 1042
W48 15 1141
W28
W62 17 1445-1828
W37 18 3002
19
W39 17.5 2861
W38 19 1856
W49 24.5 2588
16
W47 18.5 2995
W50 18 2183
W55 19 4330
W54 19 3220
TG2
W11 19 2214
TG15
W33 21 4109
TG14
TG3
W40
W63 18.5 3011-3025
W41 21.5 2492
W45 18 3239
TG1
W52 19 3419
TG7
TG5
TG4
W42 18 3432



EXPLANATION

● W9
Well sample

● S13
Spring sample

● TG6
Temperature-depth logging site

● 10.5
Water temperature, in °C

● *347*
Total dissolved solids (TDS), in ppm

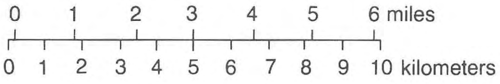


Figure 3. Map showing locations, temperatures (in °C), and calculated TDS values (in ppm) of spring and well samples in the St. George basin, and locations of temperature-depth logging sites and trilinear diagram groups.

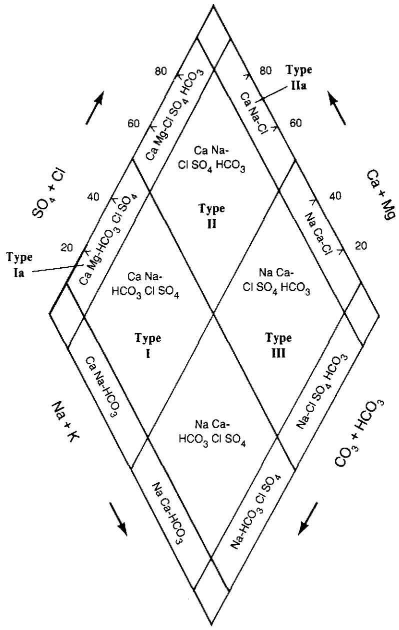


Figure 4. Piper diagram showing nomenclature used to describe water samples from Back (1961) and types of water collected in the St. George basin.

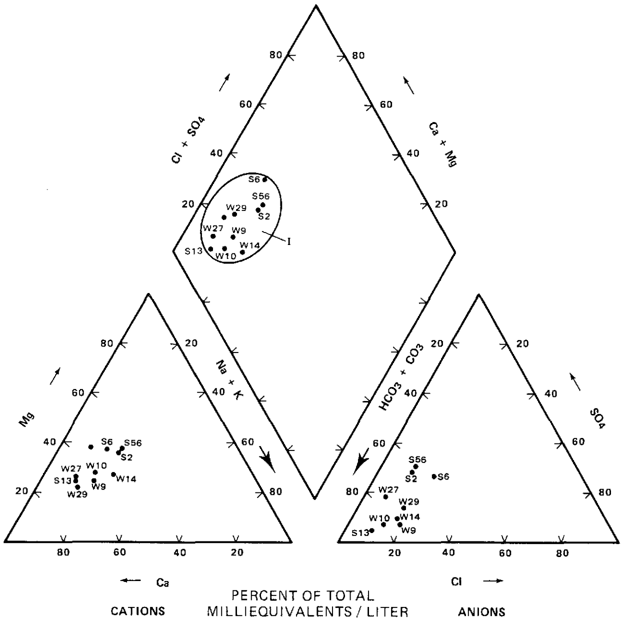


Figure 5. Piper diagram of common ions in samples collected from the northwestern and western portions of the St. George basin.

aquifers that range from 33 to 165 feet (10 - 50 m) below the surface.

Figure 9 depicts water chemistry for the southeast corner of the basin; southeast of the Virgin River and east of Warner Ridge. The water is slightly basic with a pH ranging from 7.5 to 8.2. Most samples are types I and II water (Ca-Na HCO_3-Cl-SO_4 and Ca-Na Cl-SO_4-HCO_3). Three other samples are type II (S7, W22, W70) but have higher SO_4 contents. The wells vary in depth from 148 to 720 feet (45 - 220 m), but all are completed in the Navajo Sandstone aquifer approximately 100 feet (30 m) below the surface. Sample W18 is from a well in the far southeastern corner of the basin that is in the Moenkopi. This water is similar in chemistry to that encountered in the wells drilled in the Moenkopi in the south-central part of the basin (figure 8).

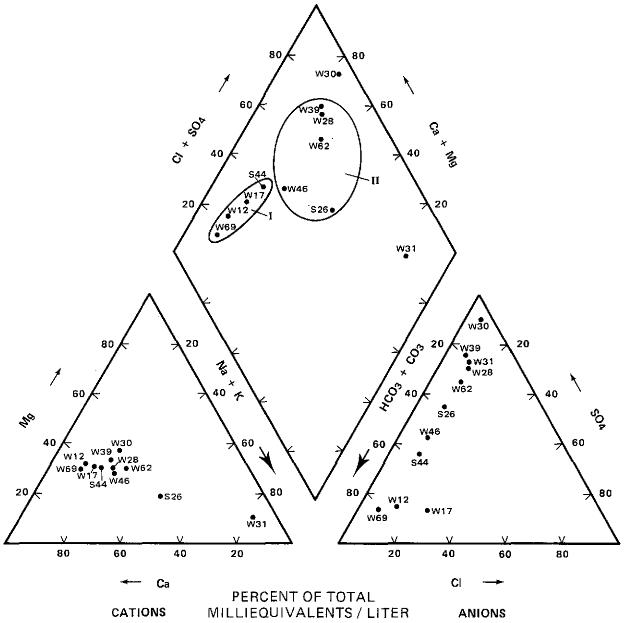


Figure 6. Piper diagram of common ions in samples collected from the west-central portion of the St. George basin.

The samples shown in figure 10 were collected north of the Virgin River in the northeastern corner of the basin. Included is a sample (Columbine Spring) from the recharge area in the Pine Valley Mountains (S51) and two Pah Tempe Hot Springs samples (S5, S57). Most samples range in pH from 7.4 to 8.0; however, Pah Tempe water was 5.9 in March, 1986 and 7.2 in March, 1966. Type I water (Ca-Na HCO_3-Cl-SO_4) is from the vicinity of Anderson Junction, where well water is from the Navajo and the wells are shallow (150 feet - 45 m). The type II water (Ca-Na Cl-SO_4-HCO_3) was collected from much deeper wells to the southeast (1475 feet - 450 m in depth) that result in different water chemistry. Pah Tempe Hot Spring water ranges from Na-Ca Cl to Na-Ca Cl-SO_4-HCO_3 (type III). The recharge sample from Columbine Spring and the water from well W77, down gradient from the spring, is Ca-Mg HCO_3 in character.

In general, type I water (Ca-Na HCO_3-Cl-SO_4) is from aquifers in the Navajo Sandstone and basalt in the northeastern part of the basin, in Snow Canyon, in the Pine Valley Mountains, and near Anderson Junction. Waters from the Sand Mountain area in the Navajo are mostly type II; however some are type I. Most type II waters (Ca-Na Cl-SO_4-HCO_3)

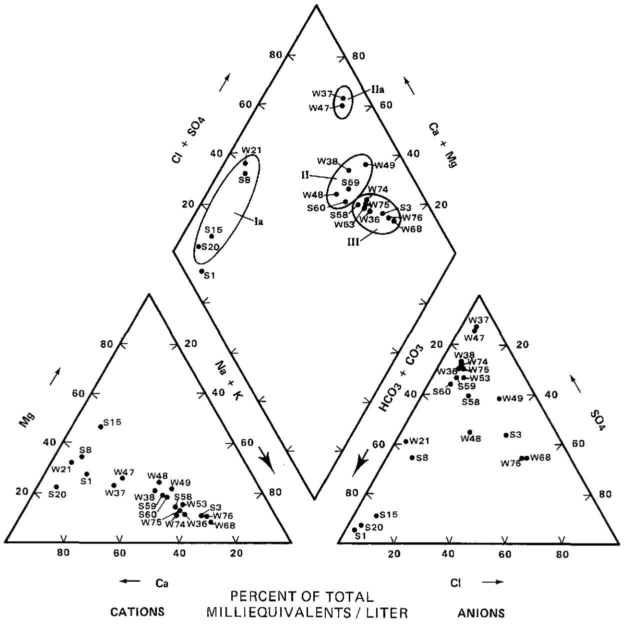


Figure 7. Piper diagram of common ions in samples collected from the central portion of the St. George basin.

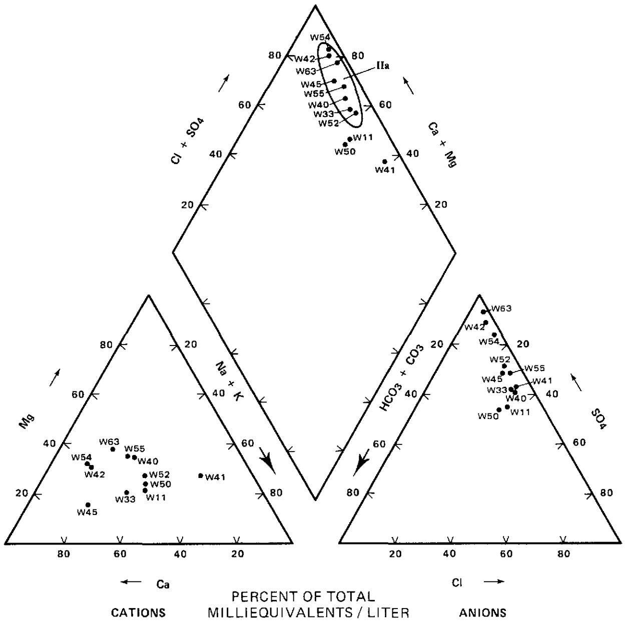


Figure 8. Piper diagram of common ions in samples collected from the south-central portion of the St. George basin.

are from the shallow alluvial aquifers in the Santa Clara and St. George areas, in addition to water from the Moenkopi Formation in Washington Fields. Type III water (Na-Ca Cl-SO_4-HCO_3) is largely from the Navajo Sandstone aquifer north of St. George and Washington.

TOTAL DISSOLVED SOLIDS

Calculated TDS values in table 1 are determined by summing the constituents with bicarbonate mathematically converted to carbonate; the measured TDS values are determined by weighing the residue after heating. With this method, all bicarbonate is measured as carbonate because the bicarbonate converts to carbonate upon heating. Calculated TDS values, known for all the samples, are discussed in this section and plotted on figure 3. All concentrations are in ppm (parts per million; equivalent to mg/l).

The total dissolved-solids concentrations (TDS) vary considerably with each aquifer. Lower TDS values, less than 1,000 ppm (mg/l), are found in water from aquifers in the Navajo Sandstone and basalt, whereas the Moenkopi and Chinle Formations yield water containing greater than 3,000 ppm (mg/l). The TDS values generally increase towards the lower elevations (Cordova and others, 1972).

TDS values range from 103 ppm (mg/l) in the sample from the St. George City aqueduct transporting water from the Pine Valley Mountains to 9,523 ppm (mg/l) at Pah Tempe Hot Springs. The samples collected in recharge areas in the northwest and northeast parts of the basin and from the Sand Mountain area have TDS concentrations in the range of a few hundred ppm and are type I water. These waters are from the Navajo Sandstone, young basalts, and alluvium. Sodium and chloride constitute the major ions contributing to the TDS at Pah Tempe. Approximately 109,000 tons (99,000 metric tons) of dissolved solids flow from the springs annually (Sandberg and Sultz, 1985).

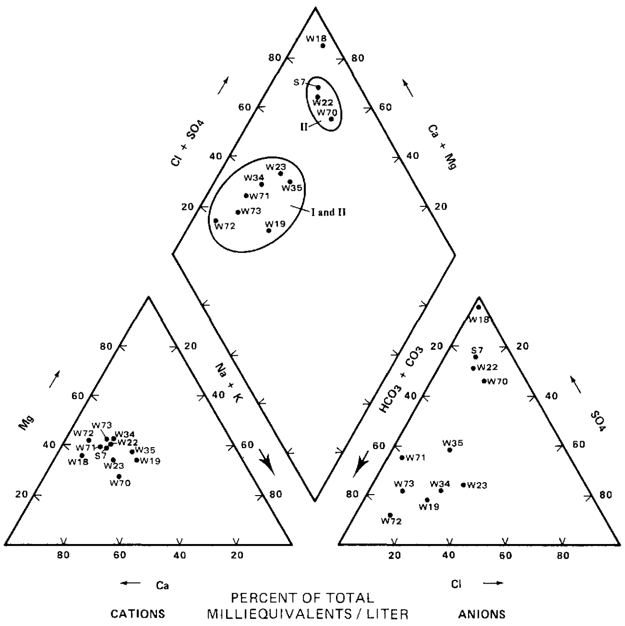


Figure 9. Piper diagram of common ions in samples collected from the southeastern portion of the St. George basin.

Less than one-third of the samples collected are slightly saline (Hem, 1970), with TDS concentrations ranging from

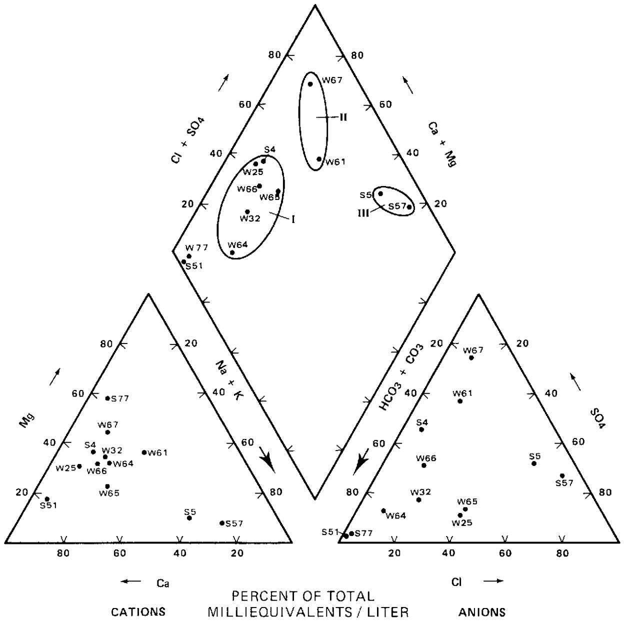


Figure 10. Piper diagram of common ions in samples collected from the northeastern portion of the St. George basin.

1,000 to 3,000 ppm (mg/l). Most of these samples are type II water and are from the central basin between Santa Clara and Washington, although some samples are from Washington Fields. These waters were collected from shallow alluvial wells underlain by the Chinle Formation or wells completed in the Moenkopi Formation.

Thirteen samples are moderately saline with TDS values between 3,000 and 10,000 ppm (mg/l). As discussed, TDS of the Pah Tempe springs water is at the high end of this range —the two samples reported here being 7,214 and 9,523 ppm (mg/l). Most of the moderately saline water, however, has a TDS range from 3,000 to 4,000 ppm (mg/l), is largely from Washington Fields, and is type II. Two of the samples are from the Ivins area and one is from Bloomington. These well waters tap aquifers in the Moenkopi.

OTHER ELEMENTS

Selected elements that are known to be geothermal indicators were plotted against each other in the hopes of distinguishing thermal from non-thermal waters. The plots consisted of Cl vs F, Li vs B, Na vs SiO_2, and calculated TDS vs temperature. Other than the known hot spring samples and certain samples established as anomalous on the basis of other geochemical indicators, no additional anomalous samples were delineated by these plots, thus they are not included.

GEOTHERMOMETRY

Four geothermometers were used to evaluate low-temperature resource potential of the St. George basin: 1) silica-quartz conductive (Fournier, 1981), 2) silica - chalcedony (Fournier, 1981), 3) Na-K-Ca (Fournier and Truesdell, 1974), and 4) Na-K-Ca with Mg correction (Fournier and Potter, 1979). The equations for the geothermometers are given below.

Quartz (conductive):

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

Chalcedony:

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

Na-K-Ca:

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

where: $B = 1/3$ for t greater than 100°C

$B = 4/3$ for t less than 100°C

SiO_2 Na, K, and Ca concentrations are in mg/l

If the temperature calculated by the Na-K-Ca geothermometer is less than 100°C, the silica content of the thermal water is a function of chalcedony and the chalcedony geothermometer should be used; a Na-K-Ca temperature of greater than 100°C indicates that the silica temperature should be calculated assuming the silica content is a function of quartz solubility (Fournier, 1977). The Na-K-Ca geothermometer gives anomalously high results for waters rich in Mg. A Mg-corrected geothermometer should be used when the Na-K-Ca geothermometer calculates a temperature greater than 70°C and R is between 5 and 50, $R = [Mg/(Mg + Ca + K)] \times 100$ using equivalent units of concentration (Fournier and Potter, 1979). A graphical method is used to obtain the temperature; however the ELE program also calculates the temperature.

The geothermometers generally calculate the maximum temperature of the thermal fluids along the water travel path. The reliability of these geothermometers is dependent on five assumptions: 1) temperature-dependent reactions occur at depth; 2) an adequate amount of components are available for the temperature-dependent reactions; 3) water-rock chemical equilibrations occur at the reservoir temperature; 4) only minor equilibration occurs at lower temperatures as the water flows from the reservoir to the surface; and 5) hot water rising from depth does not mix with cooler, shallow ground water (Fournier and others, 1974).

When ascending warm water is diluted by cooler water, a new water-rock chemical equilibrium may or may not be attained after mixing. If equilibrium is not reached, the silica geothermometer will calculate a temperature that is too low and mixing must be accounted for by using mixing models (Fournier, 1981). The effect of dilution on the Na-K-Ca geothermometer is generally negligible if the higher temperature geothermal water is more saline than the diluting water. If the warm water component is 30 percent or less, however, the effects of mixing should be considered. The Mg-corrected Na-K-Ca geothermometer is subject to error from the continued water-rock reaction as ascending water cools (Fournier, 1981).

The calculated geothermometer temperatures for the St. George basin samples are presented in table 2. In most instances the Na-K-Ca and the chalcedony geothermometer temperatures fit the above criteria. Although the majority of the Na-K-Ca calculated reservoir temperatures range between 30° and 50°C, a number of samples have anomalously high geothermometer temperatures relative to the other samples and are discussed below.

The water from Pah Tempe Hot Springs has an average calculated reservoir temperature (quartz and Na-K-Ca Mg corrected) of 80°C. Water at the springs measures 42°C. Two samples collected in Bloomington (W11, W52) have anomalous Na-K-Ca temperatures. Although the chalcedony geothermometer is the other applicable geothermometer, closer agreement is seen with the quartz temperatures. Average reservoir temperature (Na-K-Ca and quartz) is 67°C. The chalcedony temperature average is 29°C. Surface temperatures measured were 19°C.

All other anomalous calculated geothermometer temperatures are for samples collected in St. George and vicinity. Four samples in the Washington/Middleton area include two wells (W53, W76) and two springs (S3, S58). The Na-K-Ca Mg corrected and quartz temperatures correlate well and average 67°C. The chalcedony temperatures vary only slightly and average 32°C. Measured temperatures ranged from 17° to 29°C; the higher temperatures being closer to Washington. Anomalous samples north of St. George include those from City Creek Wells no. 1 and 2 (W74, W75, W36) at 26°C, Miller Spring (S26) at 19°C, and the well in Middleton Wash (W68) that encountered water at 40°C. The quartz geothermometer calculates the most consistent temperatures for these waters at an average 62°C. The applicable Na-K-Ca geothermometer averages a higher temperature of 86°C.

Four out of six samples collected in St. George are anomalous. They include two wells (W38, W47) and two springs on the northern side of the city (S59, S60). Measured temperatures were fairly low (18.5° to 20°C); however, the average calculated reservoir temperature from the quartz and applicable Na-K-Ca geothermometers is 65°C. Southeast of St. George, two wells (W48, W49) have Na-K-Ca temperatures of 88° and 80°C, respectively; other geothermometer temperatures for this area are lower. Measured temperatures were 15°C for W48 located just west of the Washington fault, and 24.5°C for W49.

THERMAL GRADIENTS

Temperature-depth measurements and temperature gradients are useful in exploration for geothermal resources because they can detect thermal anomalies (Laughlin, 1982). Temperature gradients are affected by heat flow and thermal conductivity. For a given heat flow, the temperature gradient is inversely proportional to the thermal conductivity of the material through which the heat is being transmitted by conduction (Kappelmeyer and Haenel, 1974). At shallow depths, temperature gradients are affected by surface conditions such as temperature and precipitation. These effects are eliminated below 65 feet (20 m) in depth (D. Chapman, oral communication, 1986). Temperature measurements are strongly influenced by the movement of ground water (sometimes to depths of thousands of meters), and it should always be recognized that temperature gradients are valid only for conductive heat transfer and that vertical as well as horizontal convection can upset the extrapolation of temperature information (Laughlin, 1982; Lumb, 1981).

Temperature-depth measurements were made in 17 shallow water wells and in one deep geothermal exploration well (1000 feet - 304 m in depth) (figure 3). The shallow wells ranged in depth from 110 to 550 feet (34 - 162 m). Data from well TG-17 (C-40-16) 19aca were not included because the well was blowing air and water was not encountered. A geographic sampling of thermal gradient wells was attempted; however, availability of the wells was the final determining factor. Temperatures were measured with a Fenwal K212E thermistor probe with a nominal resistance of 10,000 ohms at 20°C, power dissipation of 50 mW K^{-1} in still water, and a response time of five seconds. Resistances were measured with a Hewlett-Packard digitial ohm-meter. Measurements were taken at 5-meter (16.4-ft) intervals beginning at the water table, after the temperature had stabilized at each position. Unusual readings were supplemented by additional measurements at 2.5-meter (8.2-ft) intervals. Gradients were calculated using linear regression and the error reported is the standard error of estimate. Table 3 lists the gradients calculated and the depth interval for the calculations. Temperature-depth-profiles for all wells, grouped by proximity, are plotted in figures 11 through 15. The temperature-depth profile data along with the ambient temperatures measured at each site are contained in table 4.

The average thermal gradient for the Colorado Plateau is from 0.82° to 1.09°F/100 feet (15° -20°C/km), in contrast with 1.65° to 2.19°F/100 feet (30° - 40°C/km) for the Basin and Range Province; however, these values are dependent on rock type and associated thermal conductivity (D. Chapman, oral communication, 1986). Gradients were calculated for six of the 17 wells; they ranged from 1.01° to 1.85°F/100 feet (18.5° -33.7°C/km) (table 3). Most gradients are from 0.98° to 1.31°F/ feet (18° - 24°C/km), although well TG12 is considerably higher with a gradient of 1.85°F/100 feet (33.7°C/km).

The density of available wells for temperature-depth measurements was greatest south of Washington Fields. Gradients ranging from 1.06° to 1.31°F/100 feet (19.3° - 23.9°C/km) were calculated for this area for TG1, TG3, TG5, and TG7 (figures 11 and 12). The gradient of 1.19°F/100 feet (21.8°C/km) calculated for TG3 projects back to the surface to a temperature close to the measured ambient temperature of 17°C. The decrease in temperature seen in the four readings near the surface may indicate fractured bedrock within the aquifer. A similar decrease in temperature measured at the bottom of well TG5, gradient 1.22°F/100 feet (22.3°C/km), may reflect a circulation problem at the bottom of the well or perhaps a cold-water aquifer. Although the temperature-depth profile for well TG7 is somewhat irregular, an overall increase in temperature with depth is seen and the calculated

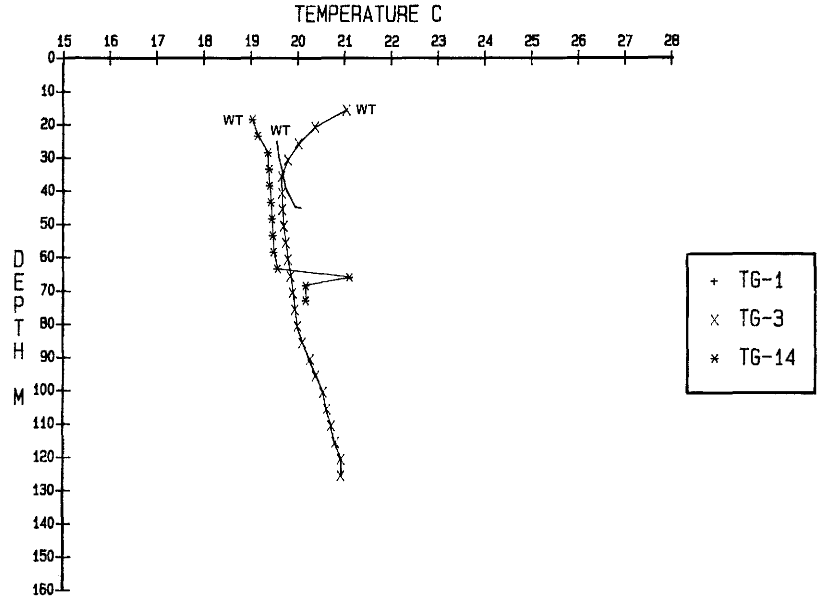


Figure 11.
Temperature-depth profiles TG1, TG3, and TG14 logged south of Washington Fields in the St. George basin.

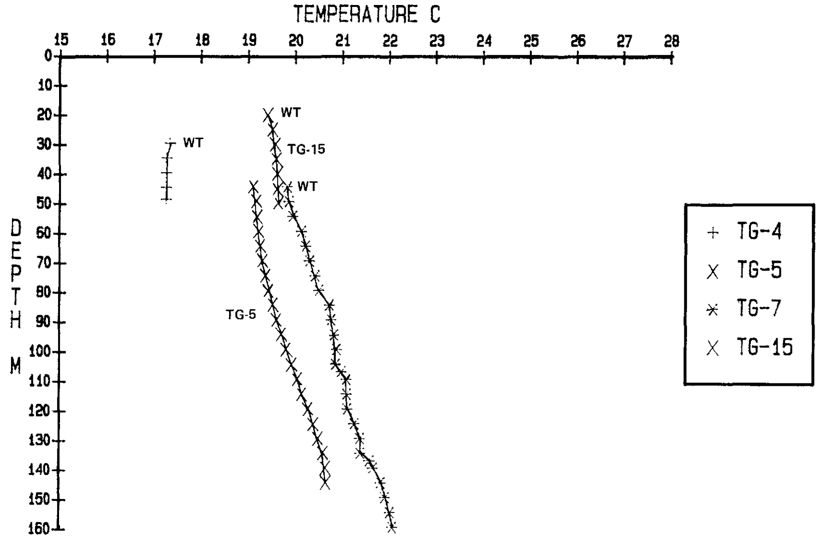


Figure 12.
Temperature-depth profiles TG4, TG5, TG7, and TG15 logged south of Washington Fields in the St. George basin.

gradient is 1.06°F/100 feet (19.3°C/km). Gradients were not calculated for TG4, TG14, and TG15 because the plots are largely isothermal. The higher temperature recorded near the bottom of TG14 may reflect a thin, warm zone and subsequent mixing of the two waters in the intermediate temperatures measured below the aquifer.

Temperature-depth data collected in the eastern part of the basin south of Berry Springs (TG9 - TG13) is plotted on figures 13 and 14. A gradient was only calculated for TG12 which, at 1.85°F/100 feet (33.7°C/km), is the highest gradient determined in the basin. Although the validity of the gradient is uncertain because the well is shallow, the gradient projects back to the surface at close to the mean annual temperature in the basin of 16.5°C. Wells TG9, TG10, TG11, and TG13 are largely isothermal. TG9 was drilled in an unsuccessful attempt to locate warm water to heat a greenhouse. The increase in temperature above the isothermal section in TG10 (from 115 to 210 feet - 35 to 64 m) may reflect surface cooling effects. TG11 and TG13 are very shallow and are affected by variations in surface temperatures as well as convection within the wells.

Figure 14 also includes wells from locations throughout the basin. A gradient of 1.01°F/100 feet (18.5°C/km) was calculated for TG8, approximately 5.6 miles (9 km) south of Hurricane. Although TG16 (north of Washington) is isothermal, the temperature is high (27°C). A water sample

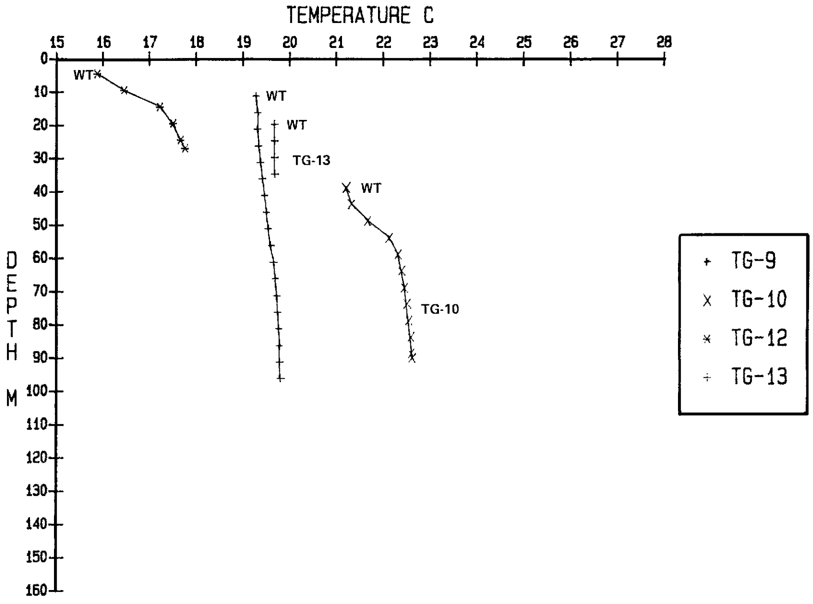


Figure 13.
Temperature-depth profiles TG9 through TG13 logged south of Berry Springs and Washington Fields in the St. George basin.

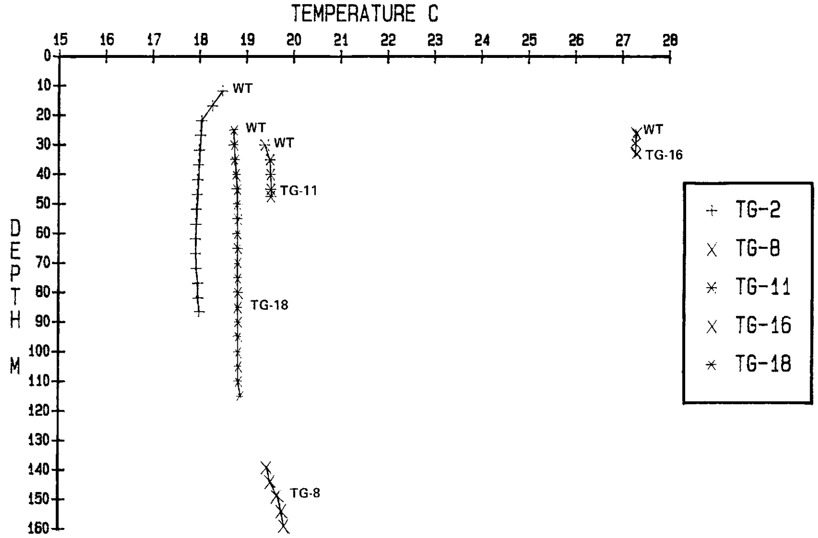


Figure 14.
Temperature-depth profiles TG2, TG8, TG11, TG16, and TG18 logged in scattered locations in the St. George basin.

collected from this well in 1974 is included in this study (W76); a high water temperature of 20°C was reported previously. Isothermal plots for TG2, north of Bloomington, and TG18, northwest of St. George, indicate circulation within these wells. A shallow warm water zone may be causing the higher temperatures from 35 to 65 feet (10 - 20 m) at depth in TG2.

Temperature-depth measurements shown in figure 15 for TG6 were made in a Phillips Petroleum Company deep geothermal exploration well drilled southeast of Veyo. All measurements were in air as water was not encountered. The bottom-hole temperature measured was 69.6°C; however, a gradient could not be calculated because the data may be erroneous due to the convection, particularly in the near-surface.

SUMMARY AND CONCLUSIONS

In addition to the known thermal areas of Pah Tempe and Veyo Hot Springs, an area north of Washington and St. George is delineated in this study to have possible low-temperature geothermal potential. This area is distinguished on the basis of both anomalous surface and calculated geothermometer temperatures. The thermal area at the Washington hot pot can be extended westward to include the area encompassed by samples (north to south) W76, S3, S58, and W53 (figure 3). West of this area and north of St. George, additional high temperatures were found (W36, W74, W75, W68).

The realized or potential low-temperature geothermal resource areas within the St. George basin appear to be related

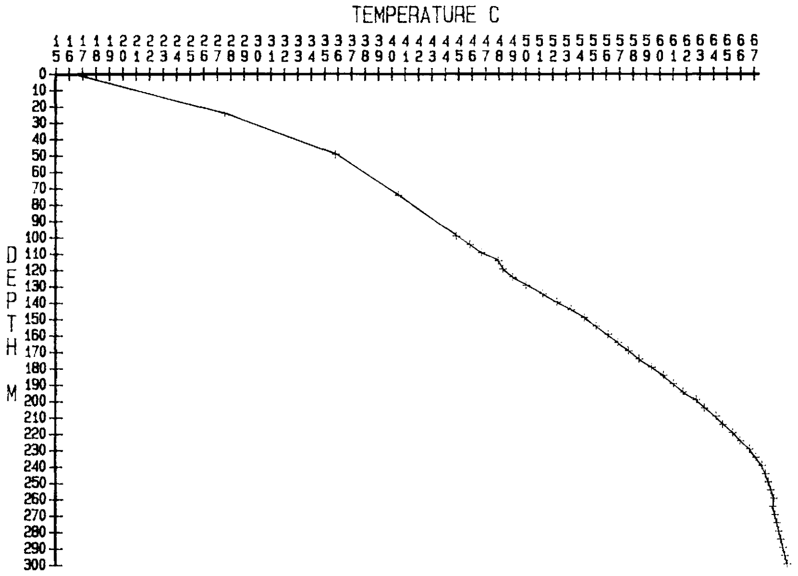


Figure 15.
Temperature-depth profile TG6 logged southeast of Veyo in the St. George basin.

to structure, not to recent igneous activity. Extensive Quaternary and Tertiary basalts in the basin, some less than 1,000 years old, indicate recent volcanism in the area and possibly some associated heat. The basalt probably originated at considerable depth, however, and was erupted at the surface through narrow conduits, thus most heat transferred from the deep heat reservoir was dissipated into the atmosphere as the basalt flow cooled. Feeder dikes for comparative basalt flows in the Grand Canyon are only 3.2 feet (1 m) wide and have no associated wallrock alteration. Basalt erupted on the Uinkaret Plateau in Arizona and its northward extension into Utah locally contains mantle-derived peridotitic inclusions (Best and Hamblin, 1978). The Uinkaret basalt is equivalent to Stage IV flows west of Hurricane in the St. George basin. The dacite northeast of Central, near Veyo Hot Spring, probably originated from a magma body at much shallower depths than the basalt; however, the 3.1 m.y.-old age suggests that the parent body is no longer a local source of heat.

The three major faults in the basin that appear to have some control on the thermal areas (the Hurricane, Gunlock, and Washington faults) are not spatially related to the basalt. The extrusive vents of the basalt are located between the major fault lines and are independent of them. The faults are thought to be listric, thus the shallow faulting probably did not serve as conduits for ascending magma (Best and Hamblin, 1970). The wide-spread basalt that erupted along margins of the Pine Valley Mountains intrusion probably utilized zones of weakness caused by the intrusion. Quaternary movement has been documented along the Hurricane and Washington faults and evidence of late Tertiary movement is found along the Gunlock fault. All three faults are considered to be seismically active and are present in an area of relatively high heat flow.

The Hurricane fault consists of several fault planes in a zone of displacement ranging up to one mile wide (1.6 km) in the gorge of the Virgin River near Hurricane (Hamblin, 1970b). Intense fracturing within the fault zone, in addition to the small horst and graben structures produced from reverse drag on the fault, provide many conduits for the transport of water from depth to feed Pah Tempe Hot Springs at the surface. Near-surface cavernous porosity within the Toroweap Limestone may facilitate high flow rate of the deep-seated water at the springs and the high water pressure may be due to the pressure head from the recharge area. Veyo Hot Springs is not as close to a major fault as is the case with Pah Tempe Springs; however, located 2.8 miles (4.5 km) east of the Gunlock fault, it is within the Gunlock fault zone. The highly fractured basalt provides good conduits for the water that may be heated by the normal geothermal gradient. The known geothermal area north of Washington, and the extension of that area as suggested by the data presented in this study, are probably related to water heated at depth and transported to the surface along the Washington fault. The westernmost limit of this area is approximately 3 miles (5 km) west of the Washington fault. Lateral movement in near-surface aquifers may be involved in producing this thermal anomaly.

Veyo and Pah Tempe Hot Springs are currently developed as swimming pools and mineral baths. The temperature and high flow rate at Pah Tempe suggest that other geothermal applications of the resource may be possible, particularly with the recently developed technology in harnessing this energy. The low-temperature geothermal potential of the area north of Washington and St. George could better be assessed by a study to 1) determine the structural controls on the thermal fluids, 2) delineate the distribution of these fluids in the near surface, and 3) determine the maximum temperature and volume of these fluids.

This low-temperature geothermal assessment is only a reconnaissance appraisal of the geothermal potential of the St. George basin. The lack of evidence for additional geothermal anomalies does not eliminate the possibility that additional resources exist.

ACKNOWLEDGMENTS

The authors are sincerely grateful for the guidance and assistance provided by Robert Klauk, UGMS. We relied heavily on his geothermal expertise. Thanks are also due to Miriam Bugden, UGMS, who painstakingly entered all the geochemical data into the data base. John Hand, UGMS, assisted in computer applications. Don Mabey, UGMS, was consulted on the gravity and aeromagnetic data. Ruth Kroneman and others at ESL/ UURI performed the water analyses and calculated the geothermometers. Dave Chapman, University of Utah, provided the use of his thermal gradient equipment. John Mann, Utah Water Rights, Salt Lake City, helped locate evasive lithologic logs. Thanks are extended to Glen Gubler, City Water Superintendant, St. George; Gerald Stoker, Utah Water Rights, Cedar City; Woody Sandberg, USGS Water Resources, Cedar City; and Jerry Olds, Utah Water Rights, Salt Lake City; for information on well and spring locations and sampling accessibility. Ken Hamblin, BYU, generously offered us the use of his unpublished geologic maps and provided insight on the geology of the field area. Lastly we would like to thank the many people in the St. George basin who graciously allowed us to sample their springs and wells.

WELL AND SPRING NUMBERING-SYSTEMS USED IN UTAH

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number designates a location and describes its position in the land net. The land-survey system divides the state into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by uppercase letters as follows:A, northeast; B, northwest; C, southwest; and D, southeast. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by the three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section-generally 10 acres (4 km2). The quarters of each subdivision are designated by lowercase letters as follows: a, northeast; b, northwest; c, southwest; and d, southeast.

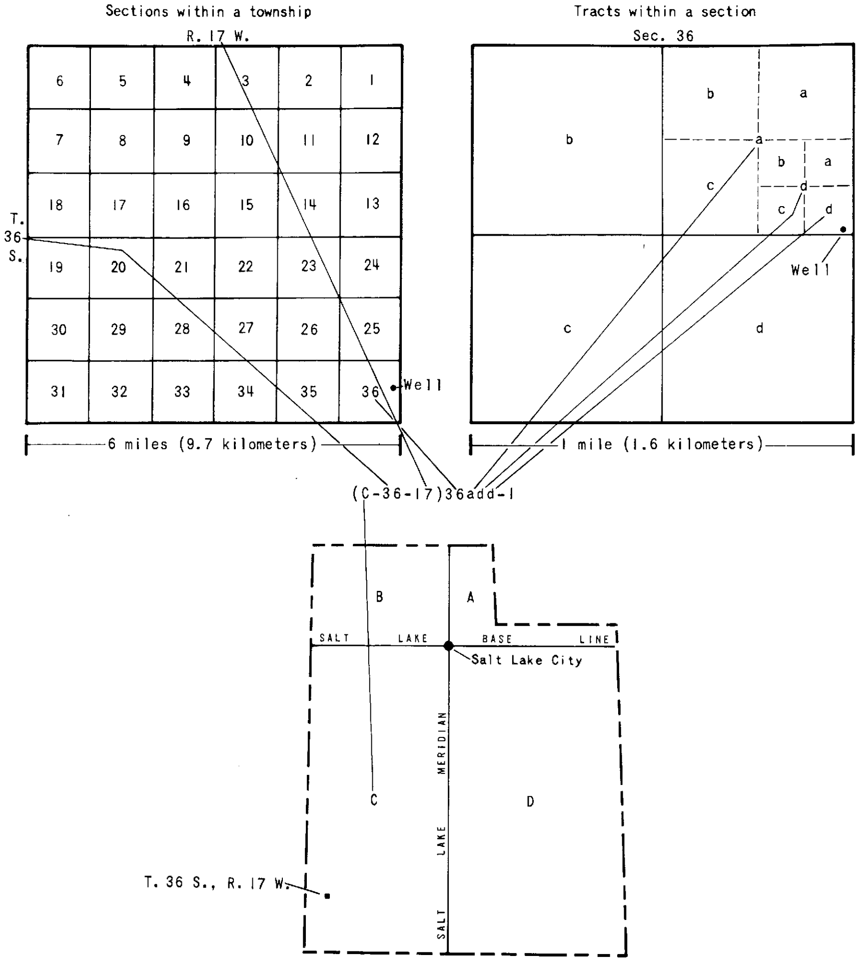


Table 1. Chemical analyses of spring and well water samples collected in the study area and taken from the literature; S preceding sample number denotes spring sample; W preceding sample number denotes well sample; all concentrations in ppm; detection limit (given in parentheses) follows element; ND denotes less than detection limits. Precision of the analytical values, with the exception of TDS, at an order of magnitude greater than the detection limits is approximately ± 2% of the given value at a confidence value of 95%; TDS is approximately ± 5% of the given value. The following elements were analyzed for but were below the detection limit (given in parentheses): Ag (0.05), As (0.61), Au (0.10), Ba (0.61), Be (0.0), Bi (2.44), Cd (0.06), Ce (0.24), Co (0.02), Cr (0.05), Cu (0.06), La (0.12), Mo (1.22), Pb (0.24), Sn (0.12), Sb (0.73), Te (1.22), Th (2.44), Ti (0.12), U (6.10), V (1.22), W (0.12), Zr (0.12), CO_3 (10.00).

Sample #	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Location	**(C-42-15)18ddb**	**(C-40-16)6dbc**	**(C-42-15)15bba**	**(C-40-13)35acd**	**(C-41-13)25cca**	**(C-41-18)2ddc**
Name/Owner	**St. George City Aqueduct**	**Veyo Hot Spring**	**Green Spring**	**Toquerville Spring**	**Pah Tempe Hot Springs**	**Pahcoon Spring**
Reference						
Date	02-04-86	02-05-86	02-06-86	02-06-86	02-06-86	02-07-86
Temp (°C)	18.5	29.5	23	16.5	42	16.5
pH	8.4	7.5	7.0	7.7	5.9	7.5
CalcTDS	103	395	1239	459	7214	386
MeasTDS	108	408	1248	480	7388	107
Na (0.61)	5.25	31.60	274.00	21.00	1587.00	24.90
K (1.22)	ND	3.82	24.10	2.87	120.00	2.19
Ca (0.24)	18.20	56.30	104.00	74.00	740.00	57.00
Mg (0.49)	4.96	28.40	22.70	30.70	130.00	27.00
Fe (0.02)	0.13	ND	ND	ND	ND	ND
Al (0.61)	ND	ND	ND	ND	ND	ND
SiO_2 (0.52)	25.30	38.10	21.80	43.90	27.00	45.20
B (0.12)	ND	ND	0.37	ND	2.40	ND
Li (0.05)	ND	ND	0.28	ND	1.57	0.06
Sr (0.01)	0.10	0.69	1.62	0.80	8.88	1.16
Zn (0.12)	ND	ND	ND	ND	ND	ND
Mn (0.24)	ND	ND	ND	ND	ND	ND
Ni (0.12)	ND	ND	ND	ND	ND	ND
HCO_3 (10.00)	90.00	245.00	234.00	219.00	1104.00	203.00
SO_4 (2.00)	3.00	86.00	404.00	160.00	1802.00	77.00
Cl (2.00)	2.00	29.50	270.00	18.00	2250.00	48.00
PO_4 (1.84)	ND	ND	ND	ND	ND	ND
F (0.10)	ND	0.34	1.29	0.20	2.70	0.62

Sample #	**S7**	**S8**	**W9**	**W10**	**W11**	**W12**
Location	**(C-42-14)1bcb**	**(C-42-15)11ccc**	**(C-39-16)3dcd**	**(C-39-16)28bcd**	**(C-43-16)12adc**	**(C-41-16)16cdb**
Name/Owner	**Berry Spring**	**Washington hot pot**	**Dixie Deer Water Co.**	**Pine Valley Mtn. Farm**	**Bloomington Water Co.**	**St. George City Snow Cyn. #1**
Reference						
Date	02-24-86	02-24-86	02-25-86	02-25-86	02-25-86	02-25-86
Temp (°C)	18.5	24.5	9.0	12.0	19.0	18.00
pH	7.9	7.7	7.4	7.6	7.3	7.8
CalcTDS	1349	311	347	317	2214	114
MeasTDS	1490	338	316	316	2266	142
Na	73.00	9.20	22.00	21.00	298.00	4.30
K	12.00	3.10	3.00	2.00	21.00	2.00
Ca	192.00	62.00	64.00	59.00	288.00	21.70
Mg	97.00	22.00	17.00	18.00	84.00	7.20
Fe	ND	ND	ND	ND	ND	ND
Al	ND	ND	ND	ND	ND	ND
SiO_2	26.00	18.00	58.00	43.00	20.00	12.00
B	0.20	ND	ND	ND	0.50	ND
Li	0.07	ND	ND	ND	0.27	ND
Sr	3.31	0.61	0.31	0.29	4.08	0.80
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND
HCO_3	196.00	189.00	257.00	266.00	314.00	88.00
SO_4	768.00	86.00	19.00	17.00	935.00	13.00
Cl	81.00	17.00	37.00	23.00	408.00	10.00
PO_4	ND	ND	ND	ND	ND	ND
F	0.40	0.30	0.20	0.20	0.40	0.20

Table 1. Continued.

Sample #	S13	W14	S15	W16	W17	W18
Location	(C-39-16)14dab	(C-36-16)3ddd	(C-40-16)36cda	(C-40-16)9adb	(C-41-16)9cbb	(C-43-13)21cca
Name/Owner	Nervine Spring	Central Water Co.	Diamond Valley	Dameron Valley	St.George City Snow Cyn. #3	W. Spendlove
Reference						
Date	02-26-86	02-26-86	02-26-86	02-26-86	02-26-86	02-27-86
Temp (°C)	9.0	16.00	15.00	26.5	20.0	17.0
pH	7.4	7.3	7.5	7.7	8.0	7.6
CalcTDS	304	465	270	224	117	2583
MeasTDS	282	464	258	210	119	2742
Na	14.00	42.00	10.00	9.00	6.00	83.00
K	2.00	7.00	4.00	3.00	2.00	10.00
Ca	62.00	78.00	44.00	41.00	21.00	447.00
Mg	14.00	25.00	27.00	18.00	7.00	170.00
Fe	ND	ND	ND	ND	ND	0.06
Al	ND	ND	ND	ND	ND	ND
SiO_2	53.00	58.00	17.00	25.00	15.00	20.00
B	ND	ND	ND	ND	ND	0.40
Li	ND	0.05	ND	ND	ND	0.12
Sr	0.27	0.48	0.21	0.18	0.10	6.02
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	0.30
Ni	ND	ND	ND	ND	ND	ND
HCO_3	266.00	356.00	261.00	199.00	74.00	96.00
SO_4	7.40	32.00	24.00	17.00	11.00	1768.00
Cl	20.00	47.00	15.00	13.00	18.00	30.00
PO_4	ND	ND	ND	ND	ND	ND
F	0.20	0.70	0.30	0.20	0.20	0.70

Sample #	W19	S20	W21	W22	W23	W24
Location	(C-42-13)30adc	(C-39-15)22dad	(C-42-15)3daa	(C-42-14)15aba	(C-42-14)14bcc	(C-41-13)5aaa
Name/Owner	M. Longley	Cougar Spring	Washington City	Stratton Turf Farm	Stratton Turf Farm	R. Harper
Reference						
Date	02-28-86	02-24-86	02-25-86	02-25-86	02-25-86	02-25-86
Temp (°C)	18.5	7.0	12.0	21.0	20.0	17.5
pH	8.1	8.2	8.2	7.8	8.2	7.8
CalcTDS	233	248	300	1177	325	530
MeasTDS	220	232	296	1284	318	528
Na	27.00	7.00	71.00	71.00	29.00	73.00
K	2.00	ND	2.00	8.00	ND	ND
Ca	31.00	61.00	62.00	161.00	52.00	79.00
Mg	17.00	11.00	19.00	90.00	23.00	23.00
Fe	ND	ND	ND	ND	ND	ND
Al	ND	ND	ND	ND	ND	ND
SiO_2	14.00	27.00	16.00	23.00	15.00	34.00
B	ND	ND	ND	0.20	ND	ND
Li	ND	ND	ND	0.05	ND	ND
Sr	0.14	0.18	0.63	2.50	0.23	0.28
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	0.90
Ni	ND	ND	ND	ND	ND	ND
HCO_3	149.00	246.00	178.00	202.00	154.00	211.00
SO_4	35.00	12.00	99.00	636.00	62.00	76.00
Cl	33.00	8.30	7.00	86.00	68.00	130.00
PO_4	ND	ND	ND	ND	ND	ND
F	0.20	0.10	0.30	0.30	0.30	0.20

Table 1. Continued.

Sample #	**W25**	**S26**	**W27**	**W28**	**W29**	**W30**
Location	**(C-40-13)27bac**	**(C-42-16)11dcb**	**(C-41-17)7dac**	**(C-42-16)22dca**	**(C-41-17)8bca**	**(C-42-16)5bbb**
Name/Owner	**J. Telaroli**	**Miller Spring**	**St.George City Gunlock #3**	**L. Frye**	**St.George City Gunlock #4**	**W. Hafen**
Reference						
Date	02-26-86	02-27-86	02-27-86	02-27-86	02-27-86	02-28-86
Temp (°C)	18.5	19.0	18.0	17.0	17.0	19.0
pH	7.8	7.9	8.0	7.4	7.6	7.2
CalcTDS	420	495	303	1828	311	3848
MeasTDS	430	500	294	1960	306	4182
Na	18.00	77.00	14.00	152.00	17.00	289.00
K	2.00	8.00	2.00	6.00	2.00	8.00
Ca	88.00	57.00	67.00	278.00	69.00	491.00
Mg	27.00	17.00	16.00	101.00	14.00	267.00
Fe	ND	ND	ND	ND	ND	0.03
Al	ND	ND	ND	ND	ND	ND
SiO_2	32.00	18.00	21.00	41.00	31.00	32.00
B	ND	0.20	ND	0.30	ND	1.40
Li	ND	0.13	ND	0.09	ND	0.20
Sr	0.33	0.59	0.39	4.57	0.29	8.71
Zn	ND	ND	ND	ND	ND	0.20
Mn	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND
HCO_3	233.00	170.00	247.00	348.00	229.00	212.00
SO_4	38.00	202.00	45.00	959.00	32.00	2514.00
Cl	100.00	30.00	16.00	115.00	33.00	132.00
PO_4	ND	ND	ND	ND	ND	ND
F	0.20	1.10	0.30	0.40	0.20	0.60

Sample #	**W31**	**W32**	**W33**	**W34**	**W35**	**W36**
Location	**(C-42-17)1aac**	**(C-41-13)5cdd**	**(C-43-15)10cca**	**(C-42-14)12dbd**	**(C-42-13)7cdb**	**(C-42-15)6ddb**
Name/Owner	**W. Hafen**	**L. Lee**	**O. Gregorson**	**E. Graff**	**W. Cooper**	**St.GeorgeCity Creek #2**
Reference						
Date	02-28-86	02-28-86	02-28-86	03-25-86	03-25-86	03-26-86
Temp (°C)	20.0	18.0	21.0	18.0	20.0	26.0
pH	8.0	7.7	7.1	7.9	7.7	7.0
CalcTDS	3081	450	4109	259	353	928
MeasTDS	3140	425	4398	267	382	952
Na	847.00	32.00	484.00	17.00	37.00	176.00
K	21.00	2.00	7.00	2.00	2.00	19.00
Ca	79.00	74.00	637.00	37.00	46.00	90.00
Mg	47.00	31.00	154.00	23.00	27.00	18.00
Fe	0.15	ND	ND	ND	ND	0.06
Al	ND	ND	ND	ND	ND	ND
SiO_2	9.00	36.00	25.00	14.00	15.00	20.00
B	0.90	ND	0.70	0.20	ND	0.50
Li	0.14	ND	0.39	ND	ND	0.21
Sr	1.61	0.51	8.96	0.20	0.38	1.35
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND
HCO_3	536.00	312.00	341.00	141.00	154.00	197.00
SO_4	1640.00	65.00	1930.00	43.00	106.00	462.00
Cl	170.00	56.00	694.00	41.00	44.00	41.00
PO_4	ND	ND	ND	ND	ND	ND
F	1.50	0.30	0.30	0.20	0.30	2.70

Table 1. Continued.

Sample #	W37	W38	W39	W40	W41	W42
Location	(C-42-16)24bdd	(C-42-16)25aab	(C-42-16)26bcb	(C-43-15)12ccd	(C-43-15)12ccc	(C-43-15)25ddd
Name/Owner	St. George City Bluff Park	G. Johnson	R. Mathis	Stucki Farms	Stucki Farms	LDS Church Farm
Reference						
Date	03-27-86	03-27-86	03-27-86	03-24-86	03-24-86	03-24-86
Temp (°C)	18.0	19.0	17.5	18.5	21.5	18.0
pH	7.7	7.0	7.2	7.1	7.8	7.1
CalcTDS	3002	1856	2861	3025	2492	3432
MeasTDS	3226	1940	3096	3226	2646	3758
Na	271.00	261.00	218.00	321.00	501.00	173.00
K	17.00	45.00	11.00	8.00	12.00	14.00
Ca	470.00	220.00	425.00	380.00	155.00	598.00
Mg	123.00	70.00	183.00	200.00	125.00	192.00
Fe	ND	ND	1.34	ND	ND	ND
Al	ND	ND	ND	ND	ND	ND
SiO_2	17.00	24.00	37.00	22.00	17.00	18.00
B	0.70	0.60	0.60	0.60	0.60	0.50
Li	0.26	0.25	0.14	0.21	0.15	ND
Sr	6.31	1.90	7.07	7.96	4.16	9.73
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND
HCO_3	253.00	378.00	501.00	243.00	167.00	149.00
SO_4	1886.00	970.00	1608.00	1439.00	1164.00	2216.00
Cl	85.00	76.00	123.00	526.00	430.00	138.00
PO_4	ND	ND	ND	ND	ND	ND
F	1.70	1.00	0.60	0.60	0.90	0.20

Sample #	W43	S44	W45	W46	W47	W48
Location	(C-42-16)13ccd	(C-41-16)34bda	(C-43-15)16cdc	(C-42-17)1bda	(C-42-15)29bca	(C-42-15)23cba
Name/Owner	J&J Lumber Co.	Snow Spring	J&J Lumber Co.	F. Ence	Dixie College	L. Sorden
Reference						
Date	03-25-86	03-25-86	03-25-86	03-26-86	03-27-86	03-27-86
Temp (°C)	15.0	19.0	18.0	16.0	18.5	15.0
pH	7.7	8.3	7.1	7.6	7.2	7.5
CalcTDS	369	210	3239	639	2995	1141
MeasTDS	362	226	3480	682	3262	1210
Na	15.00	13.00	239.00	58.00	285.00	172.00
K	2.00	3.00	19.0	4.00	26.00	21.00
Ca	80.00	35.00	654.00	102.00	433.00	129.00
Mg	18.00	12.00	89.00	35.00	138.00	51.00
Fe	ND	0.03	ND	ND	0.38	ND
Al	ND	ND	ND	ND	ND	ND
SiO_2	24.00	14.00	20.00	29.00	20.00	29.00
B	ND	0.20	0.40	0.20	1.00	0.30
Li	ND	0.09	0.05	ND	0.39	0.19
Sr	0.39	0.41	8.00	0.95	6.63	1.81
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND
HCO_3	238.00	117.00	254.00	315.00	287.00	359.00
SO_4	77.00	59.00	1651.00	212.00	1857.00	395.00
Cl	35.00	15.00	433.00	43.00	86.00	164.00
PO_4	ND	ND	ND	ND	ND	ND
F	0.30	0.70	0.20	0.30	0.30	0.90

Table 1. Continued.

Sample # **Location** **Name/Owner** **Reference**	**W49** **(C-42-15)33cbc** **P. Foremaster**	**W50** **(C-42-15)26ddd** **E. Harmon**	**S51** **(C-40-14)8cab** **Columbine Spg.**	**W52** **(C-43-16)14ddb** **G. Kemp**	**W53** **(C-42-15)21bca** **N. Howard**	**W54** **(C-43-15)23add** **L. Hancock**
Date	03-27-86	03-27-86	03-27-86	03-27-86	03-28-86	03-28-86
Temp (°C)	24.5	18.00	10.0	19.0	17.0	19.0
pH	6.6	7.0	7.7	7.0	7.3	7.5
CalcTDS	2588	2183	228	3419	1042	3220
MeasTDS	2740	2336	236	3690	1063	3456
Na	442.00	310.00	5.70	429.00	187.00	157.00
K	19.00	12.00	ND	18.00	19.00	9.00
Ca	260.00	294.00	62.00	417.00	97.00	585.00
Mg	102.00	99.00	8.00	171.00	26.00	188.00
Fe	0.38	ND	0.08	9.39	ND	ND
Al	ND	ND	ND	ND	ND	ND
SiO_2	16.00	22.00	27.00	18.00	18.20	21.00
B	0.70	0.60	ND	0.90	0.41	0.30
Li	0.28	0.31	ND	0.34	0.22	0.06
Sr	3.70	3.97	0.10	6.63	1.63	9.48
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	ND
Ni	0.40	ND	ND	ND	ND	ND
HCO_3	380.00	353.00	248.00	222.00	235.00	116.00
SO_4	1138.00	900.00	3.00	1816.00	512.00	1966.00
Cl	416.00	367.00	ND	423.00	63.00	227.00
PO_4	ND	ND	ND	ND	ND	ND
F	2.30	0.30	ND	0.50	1.90	0.40

Sample # **Location** **Name/Owner** **Reference**	**W55** **(C-43-15)2aaa** **G. Andrus**	**S56** **(C-40-16)6cdb** **Veyo Hot Spring** **Mundorff, 1970**	**S57** **(C-41-13)25cbc** **Pah Tempe Hot Springs** **Mundorff, 1970**	**S58** **(C-42-15)16ddd** **Huntington** **Cordova, 1978**	**S59** **(C-42-15)19cba** **Cox** **Cordova, 1978**	**S60** **(C-42-16)13dcb** **WestSt.George Spring** **Cordova, 1978**
Date	03-28-86	04-20-67	03-25-66	01-18-74	11-18-74	01-21-74
Temp (°C)	19.00	32.0	42.0	20.0	19.0	20.0
pH	7.1	7.6	7.2	8.0	7.1	8.1
CalcTDS	4330	383	9523	1045	821	693
MeasTDS	4688	--	--	1050	823	697
Na	416.00	32.00	2530.00	190.00	130.00	120.00
K	11.30	3.60	220.00	18.00	13.00	10.00
Ca	573.00	53.00	643.00	110.00	93.00	78.00
Mg	293.00	28.00	128.00	26.00	28.00	23.00
Fe	ND	0.01	0.01	0.03	0.04	0.04
Al	ND	ND	0.10	ND	ND	ND
SiO_2	21.00	32.00	28.00	20.00	17.00	17.00
B	0.67	0.14	4.80	0.55	0.45	0.47
Li	0.14	0.02	2.00	ND	ND	ND
Sr	10.15	ND	ND	ND	ND	ND
Zn	ND	ND	.002	ND	ND	ND
Mn	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	0.05	ND
HCO_3	253.00	230.00	721.00	249.00	202.00	191.00
SO_4	2251.00	90.00	1990.00	460.00	400.00	320.00
Cl	629.00	30.00	3620.00	96.00	39.00	30.00
PO_4	ND	ND	ND	ND	ND	ND
F	0.60	0.70	2.60	1.50	0.80	0.60

Table 1. Continued.

Sample #	**W61**	**W62**	**W63**	**W64**	**W65**	**W66**
Location	**(C-41-13)16bcd**	**(C-42-16)22dca**	**(C-43-15)12ccd**	**(C-41-13)4bbc**	**(C-41-13)5aaa**	**(C-41-13)5bbc**
Name/Owner	**Utah State Land Board**	**L. Frei**	**S. Stucki**	**H. Ludwig**	**E. Wooten**	**Goddard**
Reference	**Goode, 1978**	**Goode, 1978**	**Goode, 1978**	**Cordova, 1978**	**Cordova, 1978**	**Cordova, 1978**
Date	03-05-70	05-19-67	05-19-67	01-10-75	07-05-74	07-03-74
Temp (°C)	21.5	16.5	19.0	11.0	17.0	18.5
pH	8.0	7.7	7.8	7.7	7.8	7.6
CalcTDS	861	1445	3011	317	418	436
MeasTDS	--	--	--	325	--	--
Na	103.00	148.00	196.00	26.00	42.00	29.00
K	4.50	5.00	10.00	3.30	1.50	2.30
Ca	96.00	204.00	417.00	54.00	78.00	80.00
Mg	60.00	83.00	209.00	21.00	19.00	29.00
Fe	ND	ND	ND	ND	0.01	0.03
Al	ND	ND	ND	ND	ND	ND
SiO_2	24.00	33.00	18.00	36.00	32.00	24.00
B	0.56	ND	ND	0.01	0.09	0.01
Li	ND	ND	ND	ND	ND	ND
Sr.	10.15	ND	ND	ND	ND	ND
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	0.01
Ni	ND	ND	ND	ND	ND	ND
HCO_3	250.00	352.00	100.00	257.00	212.00	248.00
SO_4	375.00	706.00	2050.00	31.00	43.00	110.00
Cl	74.00	92.00	72.00	19.00	98.00	39.00
PO_4	ND	ND	ND	0.39	0.10	0.20
F	0.70	1.10	ND	0.20	0.20	0.20

Sample #	**W67**	**W68**	**W69**	**W70**	**W71**	**W72**
Location	**(C-41-13)23bca**	**(C-41-15)32aca**	**(C-41-16)16cbd**	**(C-42-13)7bba**	**(C-42-14)12ada**	**(C-42-14)12dda**
Name/Owner	**Ash Creek**	**Terracor**	**St. George City Snow Cyn. #1**	**W. Wilson**	**W. Wilson**	**W. Wilson**
Reference	**Cordova, 1978**	**Cordova, 1978**	**Cordova, 1978**	**Cordova, 1978**	**Cordova, 1978**	**Cordova, 1978**
Date	02-05-75	11-15-74	07-19-74	11-17-74	10-23-74	05-21-74
Temp (°C)	17.5	40.0	20.0	21.5	19.5	19.0
pH	7.4	7.3	8.2	7.5	7.8	7.9
CalcTDS	1317	1361	106	910	186	169
MeasTDS	1340	1360	--	916	193	181
Na	64.00	340.00	4.00	90.00	10.00	6.10
K	6.00	29.00	1.80	5.20	1.70	1.70
Ca	180.00	110.00	21.00	140.00	32.00	33.00
Mg	110.00	19.00	6.40	48.00	16.00	17.00
Fe	ND	ND	ND	ND	ND	ND
Al	ND	ND	ND	ND	ND	ND
SiO_2	26.00	20.00	18.00	18.00	15.00	15.00
B	0.58	0.17	ND	0.21	0.05	ND
Li	ND	ND	ND	ND	ND	ND
Sr	ND	ND	ND	ND	ND	ND
Zn	ND	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND
HCO_3	216.00	226.00	81.00	147.00	112.00	137.00
SO_4	750.00	350.00	9.90	440.00	49.00	15.00
Cl	74.00	380.00	5.20	96.00	6.30	14.00
PO_4	0.01	0.01	0.29	0.01	0.01	0.01
F	0.60	1.30	0.20	0.30	0.50	0.20

Table 1. Continued.

Sample #	**W73**	**W74**	**W75**	**W76**	**W77**
Location	**(C-42-14)25abb**	**(C-42-15)6dcc**	**(C-42-15)6dcd**	**(C-42-15)10bcd**	**(C-41-13)7ccb**
Name/Owner	**Terracor #3**	**St. George City Creek #1**	**St. George City Creek #2**	**Washington City**	**L. Sullivan**
Reference	**Cordova, 1978**	**Cordova, 1978**	**Cordova, 1978**	**Cordova, 1978**	**Cordova and others, 1978**
Date	03-19-75	02-14-73	09-18-74	05-18-74	05-05-70
Temp (°C)	18.5	26.0	26.0	29.0	13.5
pH	7.7	7.1	7.0	7.1	7.9
CalcTDS	187	968	960	1251	478
MeasTDS	256	968	962	1250	497
Na	11.00	170.00	170.00	290.00	16.00
K	2.30	20.00	20.00	26.00	2.10
Ca	31.00	100.00	96.00	100.00	68.00
Mg	18.00	17.00	19.00	22.00	65.00
Fe	0.10	0.08	ND	ND	ND
Al	ND	ND	ND	ND	ND
SiO_2	4.40	19.00	19.00	22.00	45.00
B	ND	0.72	0.67	0.52	0.30
Li	ND	ND	ND	ND	ND
Sr	ND	ND	ND	ND	ND
Zn	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND
HCO_3	143.00	197.00	200.00	222.00	522.00
SO_4	34.00	500.00	490.00	330.00	14.00
Cl	16.00	41.00	45.00	350.00	10.00
PO_4	0.06	0.01	0.01	0.01	ND
F	0.02	2.40	2.40	1.10	0.40

Table 2. Calculated chemical geothermometer temperatures and surface temperatures (in °C) for spring and well water samples in the St. George basin. Dash (-) indicates K below detection limit so Na-K-Ca geothermometer cannot be completed; NA indicates Na-K-Ca temperature is less than 70°C so the Mg correction does not apply.

Sample	Measured Temperature	Quartz (Conductive)	Chalcedony	Na-K-Ca	Na-K-Ca (Mg-corrected)
Si	18.5	73	41	--	--
S2 (Veyo HS)	29.5	90	59	38	NA
S3	23	67	35	168	71
S4	16.5	96	65	23	NA
S5 (Pah Tempe HS)	42	75	44	173	83
S6	16.5	97	67	22	NA
S7	18.5	74	42	54	NA
S8 (Washington hot pot)	24.5	60	27	21	NA
W9	9	109	79	27	NA
W10	12	95	64	18	NA
W11	19	63	31	77	66
W12	18	45	13	21	NA
S13	9	105	75	14	NA
W14	16	109	79	50	NA
S15	15	57	25	33	NA
W16	26.5	72	40	26	NA
W17	20	53	21	24	NA
W18	17	63	31	35	NA
W19	18.5	51	18	30	NA
S20	7	75	44	--	--
W21	12	55	23	9	NA
W22	21	69	37	46	NA
W23	20	53	21	--	--
W24	17.5	85	54	--	--
W25	18.5	82	85	11	NA
S26	19	60	27	66	NA

Table 2. Continued.

Sample	Measured Temperature	Quartz (Conductive)	Chalcedony	Na-K-Ca	Na-K-Ca (Mg-corrected)
W27	18	65	33	13	NA
W28	17	93	62	35	NA
W29	17	81	49	14	NA
W30	19	82	51	38	NA
W31	20	36	3	128	25
W32	18	87	56	18	NA
W33	21	72	40	35	NA
W34	18	51	18	24	NA
W35	20	53	21	26	NA
W36	26	63	31	93	80
W37	18	57	25	59	NA
W38	19	70	39	197	51
W39	17.5	88	57	47	NA
W40	18.5	67	35	44	NA
W41	21.5	57	25	77	NA
W42	18	60	27	45	NA
W43	15	70	39	11	NA
S44	19	51	18	32	NA
W45	18	63	31	55	NA
W46	16	78	47	34	NA
W47	18.5	63	31	74	62
W48	15	78	47	88	49
W49	24.5	55	23	80	51
W50	18	67	35	59	NA
S51	10	75	44	--	--
W52	19	60	27	68	NA
W53	17	60	28	92	66
W54	19	65	33	33	NA
W55	19	65	33	48	NA
S56 (Veyo HS)	32	82	51	37	NA
S57(Pah Tempe HS)	42	77	45	191	83
S58	20	63	31	88	73
S59	19	57	25	77	66
S60	20	57	25	71	69
W61	21.5	70	39	43	NA
W62	16.5	83	52	36	NA
W63	19	60	27	44	NA
W64	11	87	56	33	NA
W65	17	82	51	13	NA
W66	18.5	70	39	19	NA
W67	17.5	74	42	35	NA
W68	40	63	31	169	86
W69	20	60	27	19	NA
W70	21.5	60	27	39	NA
W71	19.5	53	21	18	NA
W72	19	53	21	14	NA
W73	18.5	15	-18	26	NA
W74	26	62	29	92	87
W75	26	62	29	93	80
W76	29	67	35	170	71
W77	13.5	97	67	15	NA

Table 3. Geothermal gradient data from St. George basin. Conversions: 1m= 3.2 feet; 18.23 °C/km=1°F/100 feet.

Well	Location	Site Elevation (m)	Depth Interval for Calculated Gradient (m)	Calculated Gradient °C/km
TG1	(C-43-15)16dcc	818	25 - 45.3	23.9 ± 0.2
TG3	(C-43-15)11ddd	845	80.7 - 125.7	21.8 ± 0.4
TG5	(C-43-15)24dcc	875	88.9 - 133.9	22.3 ± 0.4
TG7	(C-43-14)17cdd	925	43.9 - 161.9	19.3 ± 0.7
TG8	(C-42-13)33aad	1035	139 - 161	18.5 ± 0.2
TG12	(C-42-14)15dbd	895	19.5 - 27	33.7 ± 0.2

Table 4. Temperature-depth profile data for TG-1 through TG-16 and TG-18, St. George basin.

Well: TG-1
Location: (C-43-15) 16dcc
Site Elevation: 818 m
Depth Interval for Calculated Gradient: 25-45.3 m
Calculated Gradient: 23.9 ± 0.2°C/km
Ambient Temperature: 17°C

SAMPLE	TEMP °C	DEPTH M
1	19.545	25
2	19.60	30
3	19.685	35
4	19.76	40
5	19.96	45
6	20.075	45.3

Well: TG-2
Location: (C-43-15)7bbb
Site Elevation: 775 m
Ambient Temperature: 9°C

SAMPLE	TEMP °C	DEPTH M
1	18.485	11.8
2	18.27	16.8
3	18.035	21.8
4	18.01	26.8
5	17.99	31.8
6	17.97	36.8
7	17.955	41.8
8	17.94	46.8
9	17.925	51.8
10	17.915	56.8
11	17.91	61.8
12	17.91	66.8
13	17.93	71.8
14	17.96	76.8
15	17.965	81.8
16	17.995	86.5

Well: TG-3
Location: (C-43-15)11ddd
Site Elevation: 845 m
Depth Interval for Calculated Gradient: 80.7-125.7 m
Calculated Gradient: 21.8 ± 0.4°C/km
Ambient Temperature: 17°C

SAMPLE	TEMP °C	DEPTH M
1	21.035	15.7
2	20.365	20.7
3	20.005	25.7
4	19.785	30.7
5	19.655	35.7
6	19.65	40.7
7	19.66	45.7
8	19.965	50.7
9	19.74	55.7
10	19.79	60.7

Table 4. Continued.

11	19.835	65.7
12	19.885	70.7
13	19.935	75.7
14	19.99	80.7
15	20.095	85.7
16	20.255	90.7
17	20.375	95.7
18	20.54	100.7
19	20.62	105.7
20	20.72	110.7
21	20.80	115.7
22	20.92	120.7
23	20.92	125.7

Well: TG-4
Location: (C-43-15)25ddd
Site Elevation: 850 m
Ambient Temperature: 20° C

SAMPLE	TEMP °C	DEPTH M
1	17.335	29.4
2	17.26	34.4
3	17.255	39.4
4	17.255	44.4
5	17.255	48.3

Well: TG-5
Location: (C-43-15)24dcc
Site Elevation: 875 m
Depth Interval for Calculated Gradient: 88.9-133.9 m
Calculated Gradient: 22.3 ± 0.4° C/km
Ambient Temperature: 19°C

SAMPLE	TEMP °C	DEPTH M
1	19.10	43.9
2	19.16	48.9
3	19.185	53.9
4	19.21	58.9
5	19.245	63.9
6	19.29	68.9
7	19.36	73.9
8	19.425	78.9
9	19.525	83.9
10	19.60	88.9
11	19.70	93.9
12	19.80	98.9
13	19.93	103.9
14	20.05	108.9
15	20.15	113.9
16	20.275	118.9
17	20.375	123.9
18	20.485	128.9
19	20.59	133.9
20	20.65	138.9
21	20.65	143.9

Table 4. Continued.

Well: TG-6
Location: (C-40-16)8bbc
Site Elevation: 925 m
Ambient Temperature: 16°C

SAMPLE	TEMP °C	DEPTH M
1	27.52	24
2	35.80	49
3	40.49	74
4	44.79	99
5	45.81	104
6	46.67	109
7	47.92	114
8	48.26	119
9	49.01	124
10	50	129
11	51.25	134
12	52.32	139
13	53.36	144
14	54.35	149
15	55.24	154
16	56.14	159
17	56.88	164
18	57.64	169
19	58.43	174
20	59.38	179
21	60.26	184
22	61	189
23	61.71	194
24	62.71	199
25	63.30	204
26	64.18	209
27	64.68	214
28	65.41	219
29	65.97	224
30	66.66	229
31	67.13	234
32	67.58	239
33	67.82	244
34	68.02	249
35	68.22	254
36	68.45	259
37	68.37	264
38	68.53	269
39	68.69	274
40	68.82	279
41	68.97	284
42	69.13	289
43	69.28	294
44	69.46	299
45	69.60	304

Well: TG-7
Location: (C-43-14)17cdd
Site Elevation: 925 m
Depth Interval for Calculated Gradient: 43.9-161.9 m
Calculated Gradient: 19.3 ± 0.7°C/km
Ambient Temperature: 22°C

SAMPLE	TEMP °C	DEPTH M
1	19.825	43.9
2	19.865	48.9

Table 4. Continued.

3	19.95	53.9
4	20.135	58.9
5	20.225	63.9
6	20.31	68.9
7	20.425	73.9
8	20.51	78.9
9	20.735	83.9
10	20.775	88.9
11	20.83	93.9
12	20.885	98.9
13	20.865	103.9
14	20.99	106.4
15	21.10	108.9
16	21.11	113.9
17	21.12	118.9
18	21.265	123.9
19	21.385	128.9
20	21.395	133.9
21	21.595	136.4
22	21.67	138.9
23	21.835	143.9
24	21.92	148.9
25	22.025	153.9
26	22.08	158.9
27	22.08	161.9

Well: TG-8
Location: (C-42-13)33aad
Site Elevation: 1035 m
Depth Interval for Calculated Gradient: 139-161 m
Calculated Gradient: 18.5 ± 0.2°C/km
Ambient Temperature: 17°C

SAMPLE	TEMP °C	DEPTH M
1	19.43	139
2	19.50	144
3	19.635	149
4	19.745	154
5	19.79	159
6	19.82	161

Well: TG-9
Location: (C-42-13)7bcb
Site Elevation: 900 m
Ambient Temperature: 23°C

SAMPLE	TEMP °C	DEPTH M
1	19.28	11.2
2	19.32	16.2
3	19.305	21.2
4	19.335	26.2
5	19.375	31.2
6	19.415	36.2
7	19.46	41.2
8	19.505	46.2
9	19.55	51.2
10	19.60	56.2
11	19.655	61.2
12	19.70	66.2
13	19.72	71.2

Table 4. Continued.

14	19.735	76.2
15	19.77	81.2
16	19.785	86.2
17	19.785	91.2
18	19.80	96.2

Well: TG-10
Location: (C-42-13)6bdb
Site Elevation: 905 m
Ambient Temperature: 26°C

SAMPLE	TEMP °C	DEPTH M
1	21.21	38.8
2	21.32	43.8
3	21.66	48.8
4	22.125	53.8
5	22.31	58.8
6	22.385	63.8
7	22.45	68.8
8	22.50	73.8
9	22.545	78.8
10	22.58	83.8
11	22.60	88.8
12	22.615	89.9

Well: TG-11
Location: (C-42-14)15aba
Site Elevation: 858 m
Ambient Temperature: 26°C

SAMPLE	TEMP °C	DEPTH M
1	19.39	30
2	19.505	35
3	19.515	40
4	19.52	45
5	19.52	47.5

Well: TG-12
Location: (C-42-14)15dbd
Site Elevation: 895 m
Depth Interval for Calculated Gradient: 19.5-27 m
Calculated Gradient: 33.7 ± 0.2°C/km
Ambient Temperature: 25°C

SAMPLE	TEMP °C	DEPTH M
1	15.88	4.5
2	16.455	9.5
3	17.225	14.5
4	17.51	19.5
5	17.671	24.5
6	17.765	27

Table 4. Continued.

Well: TG-13
Location: (C-42-13)18bbc
Site Elevation: 905 m
Ambient Temperature: 26°C

SAMPLE	TEMP °C	DEPTH M
1	19.675	19.7
2	19.675	24.7
3	19.675	29.7
4	19.685	34.7

Well: TG-14
Location: (C-43-15)10cca
Site Elevation: 820 m
Ambient Temperature: 22°C

SAMPLE	TEMP °C	DEPTH M
1	19.02	18.5
2	19.135	23.5
3	19.36	28.5
4	19.39	33.5
5	19.40	38.5
6	19.42	43.5
7	19.445	48.5
8	19.465	53.5
9	19.485	58.5
10	19.565	63.5
11	21.10	66
12	20.165	68.5
13	20.165	73

Well: TG-15
Location: (C-43-15)12bdd
Site Elevation: 845 m
Ambient Temperature: 19°C

SAMPLE	TEMP °C	DEPTH M
1	19.415	19.6
2	19.51	24.6
3	19.56	29.6
4	19.59	34.6
5	19.61	39.6
6	19.62	44.6
7	19.64	49.3

Well: TG-16
Location: (C-42-15)10bcd
Site Elevation: 925 m
Ambient Temperature: 20°C

SAMPLE	TEMP °C	DEPTH M
1	27.29	24.4
2	27.27	29.4
3	27.26	34.4

Table 4. Continued.

Well: TG-18
Location: (C-42-16)14daa
Site Elevation: 888 m
Ambient Temperature: 16°C

SAMPLE	TEMP °C	DEPTH M
1	18.73	25
2	18.735	30
3	18.75	35
4	18.78	40
5	18.81	45
6	18.81	50
7	18.815	55
8	18.815	60
9	18.815	65
10	18.815	70
11	18.82	75
12	18.82	80
13	18.82	85
14	18.825	90
15	18.825	95
16	18.825	100
17	18.83	105
18	18.83	110
19	18.875	115

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Plate 1

GEOLOGIC MAP OF THE ST. GEORGE BASIN

Modified from Hamblin
(1986; in press a and b)
and Cook (1960)

DESCRIPTION OF MAP UNITS

adapted from Hamblin (1986; in press, a and b)

SEDIMENTARY ROCKS

Qe	Eolian deposits (Holocene)—*Medium- to fine-grained wind blown sand derived largely from erosion of the Navajo Formation*
Ql	Landslide deposits (Holocene)—*Masses of angular unconsolidated poorly sorted debris derived from slumping of basalt ridges or blocks of Navajo Sandstone*
Qa	Alluvium and low-level alluvial terraces (Holocene and late Pleistocene)—*Sand and minor gravels and mud deposited in stream channels, adjacent flood plain, and alluvial fans. Low-level terraces are approximately 23 feet (7 m) above the present drainage*
QTa	High-level alluvial terraces (Pleistocene and Pliocene)—*Gravel and sand preserved in segments of stream terraces up to 197 feet (60 m) above the present stream gradients, as much as 98 feet (30 m) thick; and alluvial gravel and sand capping the highest terraces not obviously associated with present drainage systems*
Tc	Claron (Wasatch) Formation (mostly Eocene and Oligocene, but locally the base may be as old as late Cretaceous or Paleocene)—*Thin- to thick-bedded fluvial and lacustrine sandstone, limestone, conglomerate, and shale (Rowley and Barker, 1978); approximately 476 feet (145 m) thick in the area of the Pine Valley Mountains (Cook, 1960)*
K	Cretaceous undivided—*Interbedded gray sandstone and shale equivalent to the Dakota, Tropic, Straight Cliffs, Wahweap, and Kaiparowits formations. The Upper Cretaceous section in the northwest corner of the study area is approximately 3838 feet (1,170 m) thick (Cook, 1960)*
Je	Entrada Formation—*Friable red chocolate and greenish-white sandstone, maximum thickness 249 feet (76 m) (Cook, 1960)*
Jc	Carmel Formation—*Gray micritic to argillaceous limestone and weak red gypsiferous shale, siltstone, and sandstone; approximately 656 feet (200 m) thick*
JTRn	Navajo Sandstone—*Medium- to fine-grained quartz sandstone with conspicuous large-scale cross bedding. Consists of well-sorted quartz loosely cemented with calcium carbonate and iron oxide. Well developed joint patterns. Thickness ranges from 1968 to 2395 feet (600 m - 730 m)*
TRk	Kayenta Formation—*Lower part is non-resistant slope-forming grayish-red to pale reddish-brown siltstone and silty mudstone, 49 to 492 feet (15 m - 150 m) thick. Upper part consists of massive red sandstone, 328 to 426 feet (100 m - 130 m) thick*
TRo	Moenave Formation—*Reddish-brown to orange siltstone and sandstone. Composed of a non-resistant 230 feet (70 m) thick lower sequence and an upper cliff-forming unit with a maximum thickness of 115 feet (35 m)*
TRc	Chinle Formation—*Variegated hues of red, purple, yellow, and gray shale interstratified with claystone, siltstone, and minor sandstone and conglomerate. A non-resistant unit about 426 feet (130 m) thick*
TRs	Shinarump Conglomerate—*Medium- to coarse-grained sandstone with lenses of conglomerate and shale. Thickness seldom exceeds 98 feet (30 m)*
TRm	Moenkopi Formation-*Includes the following five members: 1) Upper Red Member —426 to 459 feet (130 m - 140 m) of red laminated mudstone, siltstone, and fine- to medium-grained sandstone; 2) Shnabkaib Member — up to 689 feet (210 m) of interbedded white and pink gypsum, olive-gray dolomitic and gypsiferous shale, and red siltstone; 3) Middle Red Member — 164 to 197 feet (50 m - 60 m) of red laminated siltstone, mudstone, and fine-grained sandstone with minor layers of white to gray gypsum; 4) Virgin Limestone Member — 164 to 180 feet (50 m - 55 m) of gray micritic limestone alternating with gray calcareous mudstone; and 5) Lower Red Member — 230 to 344 feet (70 m - 105 m) of red-brown shaly limestone and mudstone with minor beds of sandstone and lenses of gypsum*
Pk	Kaibab Limestone—*A lower unit of gray massive cherty cliff-forming limestone 230 to 328 feet (70 m - 100 m) thick and an upper non-resistant gypsiferous gray to red silty shale 115 to 164 feet (35 m - 50 m) thick*
Pt	Toroweap Limestone—*Gray massive cherty limestone and gypsiferous gray to red silty shale. Consists of three units with total thickness of about 535 feet (163 m)*

IGNEOUS ROCKS

Qb$_2$	Holocene basalts—*Dense black vesicular olivine basalt with sparse olivine phenocrysts in a glassy groundmass. Includes flows less than 1,000 years old*
Qb$_1$	Holocene and Pleistocene basalt—*Medium-grained basalt with ophitic and locally diktytakitic texture. Includes flows between 1,000 years and 0.25 m.y. old*
Qc	Volcanic cinders (Holocene and Pleistocene)—*Basaltic cinder cones*
QTb	Pleistocene and Pliocene basalt—*Black to medium-gray vesicular basalt with gray plagioclase phenocrysts and clear embayed xenocrysts of quartz up to several millimeters in diameter. Includes flows between 1 m.y. and 2 m.y. old*
Tb	Tertiary basalt (Neogene)—*Dense black vesicular basalt. Includes flows older than 2 m.y.*
Td	Tertiary dacite (Pliocene)—*Gray, porphyritic dacite flow northeast of Central with phenocrysts of hornblende, biotite, plagioclase, and sanidine. Flow dated at 3.1 ± 0.2 m.y. old*

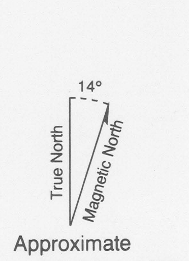
MAP SYMBOLS

Contact

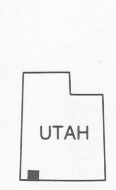
Normal fault — *bar and ball on downthrown side; dashed where approximate; dotted where covered.*

Anticline

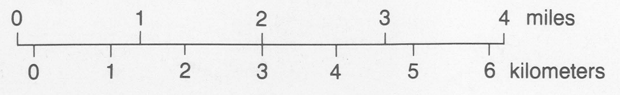
Hot spring



Approximate
mean declination, 1982



Location Map



UTAH GEOLOGICAL AND MINERAL SURVEY

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THE UTAH GEOLOGICAL AND MINERAL SURVEY is one of eight divisions in the Utah Department of Natural Resources. The UGMS inventories the geologic resources of Utah (including metallic, nonmetallic, energy, and ground-water sources); identifies the state's geologic and topographic hazards (including seismic, landslide, mudflow, lake level fluctuations, rockfalls, adverse soil conditions, high groundwater); maps geology and studies the rock formations and their structural habitat; and provides information to decisionmakers at local, state, and federal levels.

THE UGMS is organized into five programs. Administration provides support to the programs. The Economic Geology Program undertakes studies to map mining districts, to monitor the brines of the Great Salt Lake, to identify coal, geothermal, uranium, petroleum and industrial minerals resources, and to develop computerized resource data bases. The Applied Geology Program reponds to requests from local and state governmental entities for site investigations of critical facilities, documents, responds to and seeks to understand geologic hazards, and compiles geologic hazards information. The Geologic Mapping Program maps the bedrock and surficial geology of the state at a regional scale by county and at a more detailed scale by quadrangle.

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