Geothermal Resources Council, TRANSACTIONS, Vol. 13, October 1989

AN ASSESSMENT OF GEOTHERMAL RESOURCES AT NEWCASTLE, UTAH

by

Robert E. Blackett(1) Michael A. Shubat(1) David S. Chapman(2)
Craig B. Forster(2) Charles M. Schlinger(2)

(1) Utah Geological and Mineral Survey (UGMS), Salt Lake City, Utah
(2) University of Utah, Department of Geology and Geophysics (UUGG)
Salt Lake City, Utah

ABSTRACT

Integrated geology, geophysics, and geochemistry studies in the Newcastle area of southwest Utah are used to develop a conceptual geologic model of a blind, moderate-temperature hydrothermal system. Studies using 12 existing and 12 new, thermal gradient test holes, in addition to geologic mapping, gravity surveys, and other investigations have helped define the thermal regime. Preliminary results indicate that the up-flow region is located near the west-facing escarpment of an adjacent mountain range, probably related to the bounding range-front fault. Chemical geothermometers suggest equilibration temperatures ranging from 140°C to 170°C. The highest temperature recorded in the system is 130°C from an exploration well drilled by the Unocal Corporation. Presently, geothermal fluid, at temperatures approaching 100°C, is used in three, commercial greenhouse complexes.

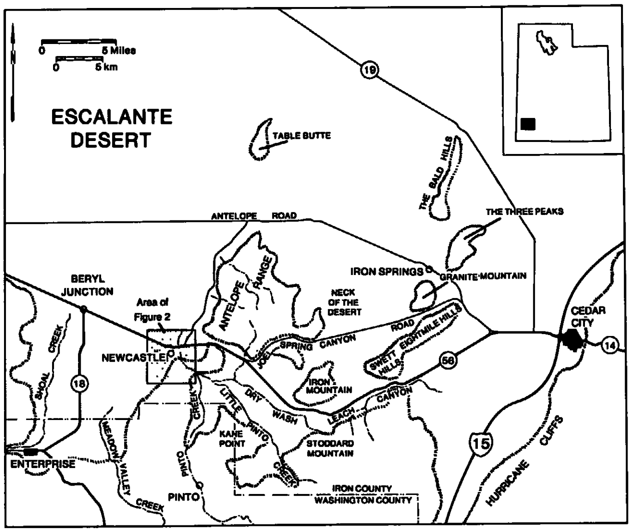

Figure 1: Location map.

INTRODUCTION

Newcastle is a rural farming community situated roughly 30 miles west of Cedar City, Utah (Figure 1) where thermal water was discovered in 1975 during test pumping of an irrigation well owned by Christensen Brothers (Rush, 1983). The discovery well encountered a hot-water aquifer with a maximum temperature of 108°C between depths of 85 and 95 meters. This was the first record of geothermal activity at Newcastle, although local residents have described an incident during the early settlement history of the valley when settlers, hand-digging a water well, were forced to abandon the endeavor because of heat in the well (B. Christensen, personal communication).

Since the discovery well was drilled, several workers have studied the system. Denton (1976) conducted a helium-gas survey across the area and detected a broad helium anomaly around the discovery well and along the nearby range-front fault. Rush (1977) compiled temperature-gradient data for the Escalante Valley and other areas in Utah, and reported the results. Pe and Cook (1980) conducted a gravity survey in the region and defined a large, northeast-trending gravity low centered northwest of the town of Newcastle, which they interpreted as representing a deep graben. Chapman and others (1981) calculated the thermal power loss of 13 megawatts from an area of 9.4 sq km (3.6 sq mi), assuming a water temperature of 110°C (230°F) and a discharge rate of 32 l/s (507 gpm). Rush (1983), using chemical geothermometry, estimated a reservoir temperature of 140°C to 170°C (284°F to 338°F) and published a chemical analysis of the Newcastle thermal water, temperature profile of the Christensen Brother's well, potentiometric map of the area, temperature map at a depth of 100 m (328 ft), and a heat flow map of the principal hot water aquifer. Hoover (1987) reported the results of eight audiomagnetotelluric soundings in the Newcastle area, with the lowest resistivity values measured at a station east of the Christensen Brother's well. Mabey and Budding (1987) compiled available data on the Newcastle system and presented a geothermal model suggesting that hot water rising along a fault zone near the base of the hills southeast of Newcastle discharges into an aquifer in unconsolidated Quaternary sediments.

The objective of our project is to develop a conceptual model of this blind (no surface expression) hydrothermal system. It involves an integrated program of geology, geochemistry, and geophysics and includes (1) mapping of Quaternary surficial units and structures; (2) mapping of bedrock units and structural analysis in the adjacent mountain range; (3) a ground-based gravity survey; (4) sampling and analyses of available water sources; (5) sampling of soil for determination of mercury content; and (6) drilling and completing a number of shallow, temperature gradient monitoring holes, and monitoring their temperature profiles over a period of several months.

LOCATION AND REGIONAL SETTING

The Sevier thermal area was defined by Mabey and Budding (1987) to include a large area of western Utah where young igneous rocks, complex geologic structure, high regional heat flow, and seven high- and moderate-temperature geothermal systems are present. The Escalante Desert, part of the Sevier thermal area, is an elliptical depression extending over an area measuring approximately 44 x 28 mi (70 x 45 km) and surrounded by mountain ranges and hills composed dominantly of Tertiary ash-flow tuff units ranging in age from 32 to 19 million years ago (Ma), and rhyolite and dacite flows and domes ranging in age from 13 to 8.5 Ma.

GEOLOGY

Stratigraphy

Bedrock units at Newcastle range in age from Upper Cretaceous to upper Miocene, and consist of older sedimentary rocks overlain by a series of middle Tertiary ash-flow tuffs and capped by rhyolite and dacite flows. The oldest exposed unit is the Eocene to Oligocene Claron Formation, which unconformably overlies the Iron Springs Formation, and consist of fluvial and lacustrine sandstone and limestone, with lesser interbedded shale and conglomerate. The minimum thickness of the unit is 430 feet (130 m). The Oligocene Isom Formation overlies the Claron Formation and consists of two densely-welded, crystal-poor, ash-flow tuff members of regional extent; the lower Baldhills and upper Hole-in-the-Wall Tuff Members. The minimum thickness of the Isom Formation is 1340 feet (408 m) and its age is approximately 26 Ma (Rowley and others, 1979).

Three regional ash-flow tuffs of the Quichapa Group overlie the Isom Formation. The moderately-welded Leach Canyon Tuff is 580 feet (177 m) thick and approximately 25 Ma (Rowley and others, 1979). The Bauers Tuff of the Condor Canyon Formation is crystal-poor, densely-welded, approximately 23 Ma (Rowley and others, 1979), and about 430 feet (130 m) thick. The Harmony Hills Tuff is a distinctive, crystal-rich, moderately-welded tuff dated at about 21 Ma (Rowley and others, 1979) and is 480 feet (146 m) thick. An unnamed aerially-extensive volcaniclastic unit, approximately 130 feet (40 m) thick, overlies Harmony Hills Tuff and contains abundant clasts and crystal fragment of Harmony Hills Tuff as well as andesite cobbles.

The Racer Canyon Tuff overlies the Quichapa Group rocks and is the youngest regional ash-flow tuff present at Newcastle. The tuff is crystal-rich, poorly to moderately welded, greater than 490 feet (150 m) thick, and is approximately 19 Ma. The volcaniclastic rocks of Newcastle Reservoir overlie the Racer Canyon tuff and are greater than 980 feet (300 m) thick. The unit is correlative with the mine series of Siders (1985), which has a minimum age of 11.6 Ma, and consists of intercalated lenses of conglomerate, mudflow breccia, and sandstone. Rhyolite and dacite lava flows and domes overlie and intrude Racer Canyon Tuff in the northeast corner of the map area. These informally named units, the Rhyolite of Silver Peak and Dacite of Bullion Canyon, yielded K-Ar ages of 8.4 and 8.5 Ma, respectively. (Shubat and Siders, 1988).

Figure 2 shows a simplified version of the Quaternary to upper Tertiary unconsolidated deposits mapped by Siders and others (in press). The oldest unit is lower Pleistocene in age, poorly consolidated, contains pedogenic beds of calcium carbonate, and consists of boulder, cobble, and pebble conglomerate and sandstone. This material and older, moderately-consolidated basin-fill deposits probably underlie much of the Escalante Desert near Newcastle. Sediments of middle to late Pleistocene age consist of piedmont-slope alluvium, alluvial-fan deposits, and stream-terrace alluvium. The youngest unconsolidated deposits are late Pleistocene to Holocene in age and consist of alluvium in modern channels, stream-terrace alluvium, piedmont-slope alluvium, alluvial-fan and distal alluvial-fan deposits, colluvium, and talus. Sediments that produce hot water in the Newcastle geothermal area are likely Pliocene to lower Pleistocene in age, moderately consolidated, and consist of gravelly alluvial-fan (both fluvial and debris flow) deposits.

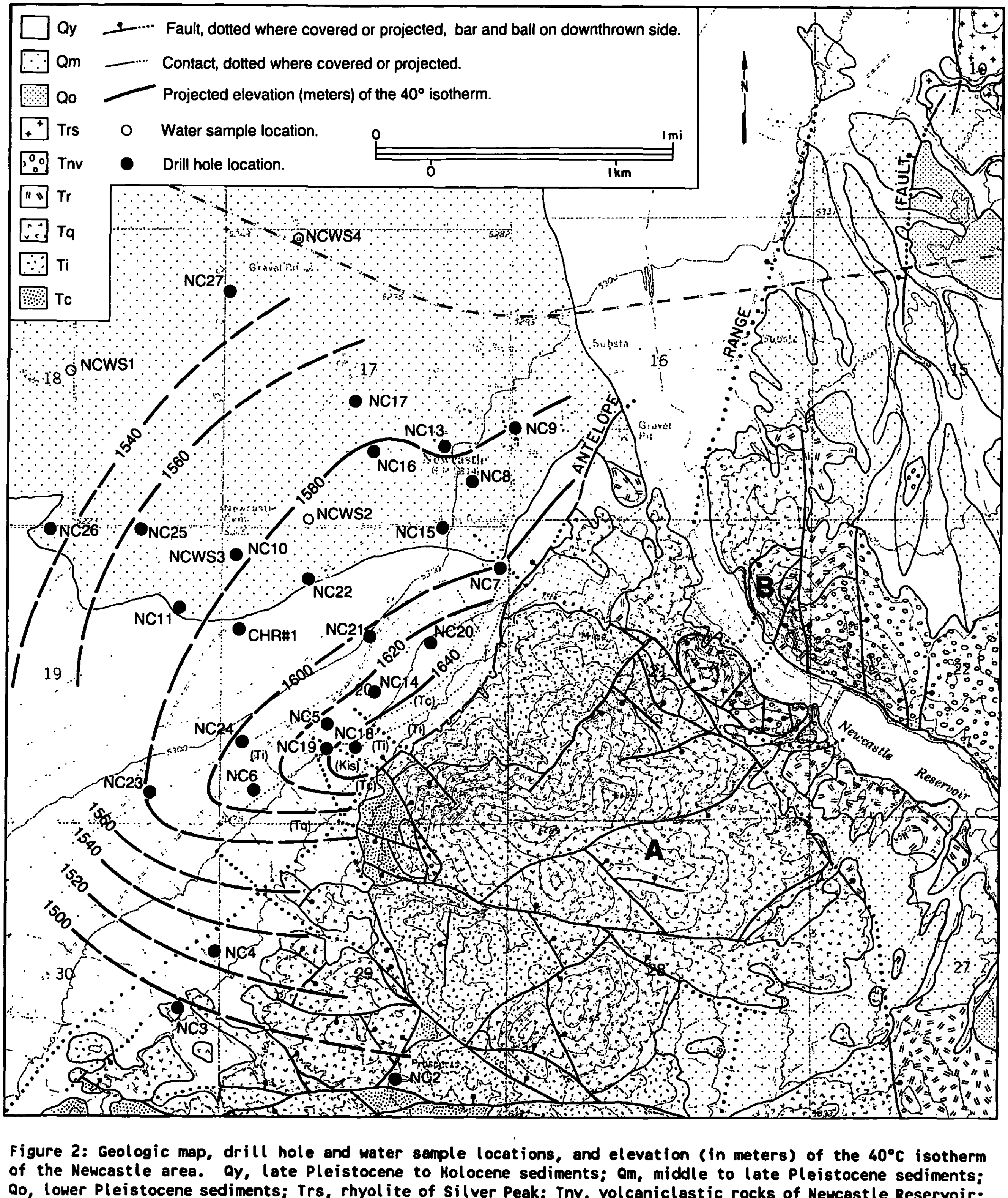

Figure 2: Geologic map, drill hole and water sample locations, and elevation (in meters) of the 40°C isotherm of the Newcastle area. Qy, late Pleistocene to Holocene sediments; Qm, middle to late Pleistocene sediments; Qo, lower Pleistocene sediments; Trs, rhyolite of Silver Peak; Tnv, volcaniclastic rocks of Newcastle Reservoir; Tr, Racer Canyon Tuff; Tq, Quichapa Group; Ti, Isom Formation; Tc, Claron Formation; Kis, Iron Springs Formation. Symbols in parentheses refer to buried bedrock units on the footwall of the Antelope Range fault.

Structure

Structural investigations at Newcastle included mapping of bedrock structures, Quaternary structures, and measurement of slip directions of minor faults from four sites near Newcastle. The goal of these studies was to document the structures that may localize the geothermal system.

Antelope Range Fault

The Antelope Range fault, as defined by Quaternary fault scarps, is a north-northeast striking normal fault that extends from Newcastle at its southwestern end to the northern tip of the Antelope Range, spanning a distance of 16 miles (26 km). At Newcastle, the fault separates the Escalante Valley to the northwest, from the uplifted bedrock of the Antelope Range to the southeast. Although not marked by scarps, the fault probably continues an additional 9 miles (14 km) to the southwest, terminating near Mountain Meadow. As mapped by Siders and others (in press), the fault breaks into three right-stepping en echelon strands east of Newcastle (Figure 2). Anderson and Christenson (in press) assign a middle to late Pleistocene age for the last surface-rupturing event, based on scarp morphology. G.E. Christenson (oral communication., 1989) noted that the scarps northeast of Newcastle are multiple-event scarps. Without additional information, it is not possible to determine if the southwestern limit of Quaternary scarps marking the fault represents the southwestern tip of the most recent surface-rupturing events or if scarps were simply not preserved southwest of Newcastle. We did not observe hydrothermal alteration along the trace of the Antelope Range fault.

Gravity data indicate that the Antelope Range fault marks the southeastern margin of a northeast-tending, alluvium-filled graben named the Newcastle graben by Pe and Cook (1980). This graben, centered approximately 2.3 miles (3.7 km) northwest of Newcastle, contains as much as 9,800 feet (3000 m) of alluvium (Pe and Cook, 1980), which is one estimate of the minimum normal separation across the Antelope Range fault. Modeling of detailed gravity data collected during our work (in progress) should refine our knowledge of the subsurface geometry of the fault. A preliminary examination of these data, however, indicates that the dip of the Antelope Range fault is steep (approximately 70°) and that the Newcastle graben contains at least 6,500 feet (2,000 m) of alluvium.

Bedrock Faults

Geologic mapping of the range south and east of Newcastle revealed a complex pattern of steeply- to moderately-dipping faults that strike in all directions (Figure 2). Most faults show apparent normal separation, as determined by stratigraphic separation and dips from three-point solutions. However, the dominant displacement on map-scale faults, if similar to minor faults, may be strike-slip, as shown by the dominantly sub-horizontal rakes of minor fault striae measured from two sites near Newcastle. Because of the absence of piercing points, we could not determine the net slip for any of the map-scale faults. Stratigraphic separation appears to be the greatest (2,000 to 3,000 feet; 610 to 910 m) and the most variable along northwest-striking faults and fault zones. One of these faults contains a very coarse breccia body (megabreccia) lying between two splays located in the northeast 1/4 of section 29, T36S, R15W. This is a steep reverse fault and in the subsurface it projects northwesterly toward the center of the thermal anomaly (near hole NC-18, Figure 2). Figure 2 shows the map-view projection of this and other faults and contacts onto the footwall of the Antelope Range fault, assuming that it dips 70° toward the valley and strikes parallel to its surface trace.

Fault Slip Analysis

We undertook a fault slip study at Newcastle in order to better understand the chronology of deformational events by collecting data from rocks of different ages. Fault slip analysis involves the fitting of a mean stress tensor to a population of fault slip measurements. Angelier (1979; 1984), Angelier and others (1985), and Reches (1987) developed the methods used in this study. To apply this technique, we measured many minor fault orientations from outcrop-scale areas and for each fault recorded the strike, dip, rake, and sense of slip. We collected data from three sites, two of which lie within the area of Figure 2 (sites A and B). Faults at these two sites cut the 21 Ma Harmony Hills Tuff. The third site is 4,000 feet (1,200 m) northeast of Figure 2 and faults at this site cut 8.5 Ma rhyolite and dacite. The number of faults measured for sites A, B, and C are 108, 134, and 20, respectively. We performed the analysis using software generously provided by Z. Reches.

Table 1 lists the results of the analysis. We rotated the orientations of fault slip data for sites A and B to restore bedding to horizontal (rotation about the line of strike), and for all data sets we performed a step wise removal of statistical outliers by examining histograms of the misfit angles between individual measurements and the solution tensor. Misfit results for site A showed a distinct bimodal distribution that allowed us to separate these data into two subsets, listed as sites A1 and A2 in Table 1.

The very similar results obtained for

sites A1 and B suggest that the same tectonic event (T1) produced these faults. Likewise, the similar results obtained for sites A2 and C suggest that a separate tectonic event (T2) produced these faults. The dominance of the T1 event in the fault population from site A, the high density of minor faults associated with the T1 event (sites A and B), and the absence of expression of the T1 event at site C argue that the T1 event occurred prior to the eruption of the 8.5 Ma rhyolite at site C and that the T2 event occurred after this eruption. From our data, we bracket the T1 event between 21 and 8.5 Ma and associate it with regional 15-8 Ma, southwest-directed extension recognized by many workers (Angelier and others, 1985; Anderson, 1987) in southeastern Nevada and southwestern Utah. At Newcastle, this event probably produced most (if not all) of the faults exposed in the range south and east of Newcastle. We associate the T2 event with the formation of the Antelope Range fault and the Newcastle graben and interpret these structures to be less than 8.5 Ma. From this interpretation we note that of the faults produced during the T1 event, relatively few were reactivated during the T2 event and that the T2 event generated only sparse new faults near the footwall of the Antelope Range fault, apparently contributing little to the fault and fracture permeability of the bedrock.

THERMAL GRADIENT STUDIES

Thermal studies performed at Newcastle are reported by Chapman and others (1981) and Rush (1977 and 1983). The temperature profile in the original discovery well (NC-10) shows high initial gradient to the top of a thermal aquifer, a maximum temperature of 107.8°C achieved between 85 and 95 meters, and a temperature decline to 103.7°C at total depth. Temperature profiles in Newcastle drill holes exhibit a number of characteristics, described by Chapman and others (1981) such as downward curvature, sub-normal gradients, temperature reversals, and isothermal sections, that are typical of hydrothermal systems where heat is transferred laterally and vertically by moving fluid (Figures 3 and 4).

Unocal Corporation investigated the Newcastle area by drilling a 3,000 ft (914 m)-deep geothermal test well, located a few hundred feet south from the site of the original discovery well. Similarly, temperature increased rapidly within the first three hundred feet, achieved a maximum value of 266°F (130°C) at 346 ft (105 m), decreased gradually with depth to 1820 ft (555 m), and then increased to 238°F (114.4°C) at total depth (CHR-1, on Figure 3). The maximum temperature measured (266°F) in the Union well is the highest recorded temperature within the system.

Twelve shallow (< 70 ft) temperature gradient test holes, numbered NC-16 through NC-27, were drilled in the alluvial valley-fill to define the shape of the thermal anomaly (Figures 5 and 6). The holes were drilled with standard rotary drilling equipment and completed by installing 1.25-inch PVC pipe and back-filling. The pipes were filled with water and allowed to achieve temperature equilibrium with the surrounding material. Temperature profiles were made over a period of nine months using calibrated thermistor probes and digital volt-ohm meters. Three holes drilled by local individuals and previously unrecorded, were also available for temperature profiling (NC-13, NC-14, and NC-15 on Figure 3).

The observed distribution of near-surface temperatures in the Newcastle area, based upon temperature profiles obtained during this study is illustrated on Figure 2 as an elevation projection of the 40°C (104°F) isotherm. The shape of the 40°C isotherm suggests that thermal fluid moves upward within a flow zone near the base of the mountain range, fans out into permeable horizons within the valley-fill material, probably mixing with cool groundwater. The location of the up-flow zone with respect to the range front fault suggest that fluid is rising along associated fractures.

WATER ANALYSES AND SOIL-MERCURY SURVEY

Common Ion Analyses

							sigma 1		sigma 2		sigma 3	
Site	n	%	C	princ	slip	phi	plunge	trend	plunge	trend	plunge	trend
A1	62	79	.31	22.95	15.99	.77	9	352	80	187	2	82
A2	23		.40	37.77	24.09	.55	83	207	6	39	1	309
B	93	69	.21	28.89	18.36	.53	7	352	82	166	0	82
C	13	65	.40	26.08	13.49	.05	81	358	6	218	5	127

Table 1: Results of fault slip analysis, Newcastle geothermal area. Site locations described in text. n = number of faults, % = percent of original data retained, C = cohesion, princ = mean principal axes misfit angle, slip = mean slip axis misfit angle, phi = (sigma 2-sigma 3)/(sigma 1-sigma 3).

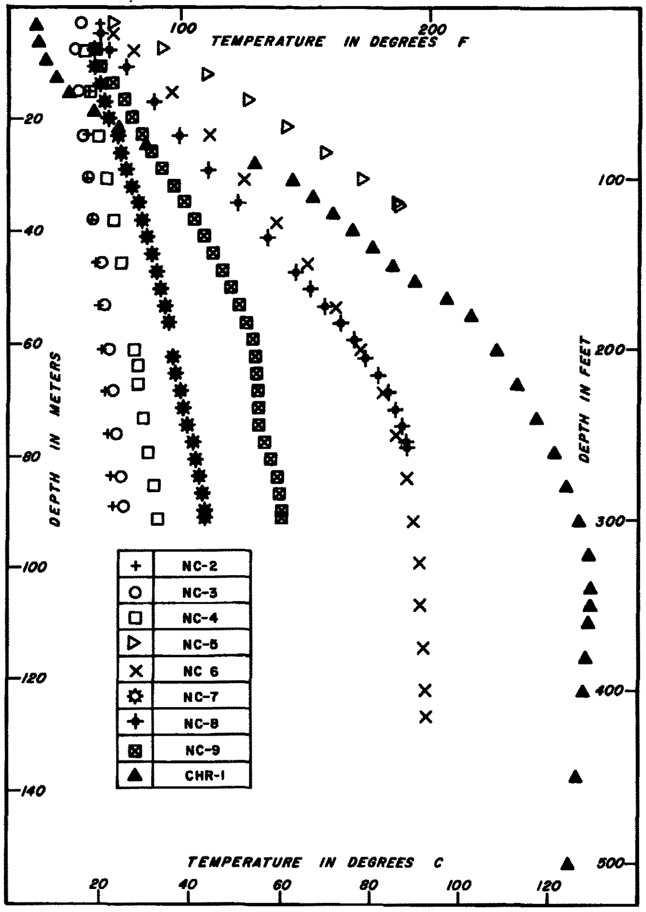

Figure 3: Temperature-depth profiles of geothermal test holes NC-2 through NC-9 and the Christiansen #1 well. Data from Unocal Geothermal Division, Rush (1977), and Chapman and others (1981).

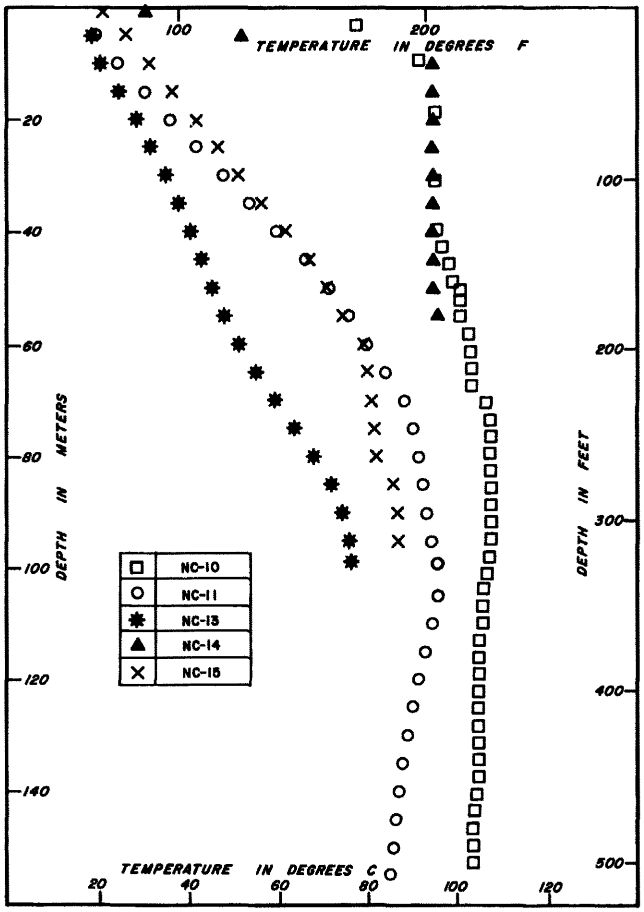

Figure 4: Temperature-depth profiles of geothermal test holes NC-10 through NC-15. Data from Rush (1977) (NC-10) and this study.

Four water samples collected from pumped wells in the immediate area were analyzed for major elements (Table 2). Two samples (2 and 3) were taken from supply wells for commercial greenhouses. Sample 1 was collected from a cold water irrigation well located away from the thermal area, and sample 4 was taken from a warm well on the periphery of the system. Samples 2 and 3 are of Na Ca-Cl type, while 4, although near this composition, is classified as Na Ca-Cl SO4 HCO3 type. Sample 1 is Ca Na-Cl SO4 HCO3 type.

Rush (1983) reported analytical values for sodium, potassium, calcium, magnesium, and silica (Table 2). Using various chemical geothermometers, Rush computed reservoir temperatures and estimated a temperature range between 140°C and 170°C for the system. Geothermometers applied to samples collected for this study show somewhat lower estimates than those of Rush, and could be a reflection of seasonal and annual fluctuations within the system that affect fluid mixing. The maximum recorded temperature in the system to date (130°C) plus chemical geothermometry suggest equilibration temperatures are within the range estimated by Rush.

Oxygen and Hydrogen Isotopes

Water samples, from two thermal wells, one cold well and four cold springs, were collected for determinations of oxygen-18 and deuterium. The results of the analyses, expressed in standard per mil notation relative to V-SMOW, are shown plotted with reference to the global meteoric water line in Figure 7. All samples plot on or near the meteoric water line. Samples from the two geothermal wells (NC-10 and Hildebrand) are slightly enriched in oxygen-18.

Soil-Mercury Studies

A soil-mercury survey was performed at Newcastle across the location of suspected

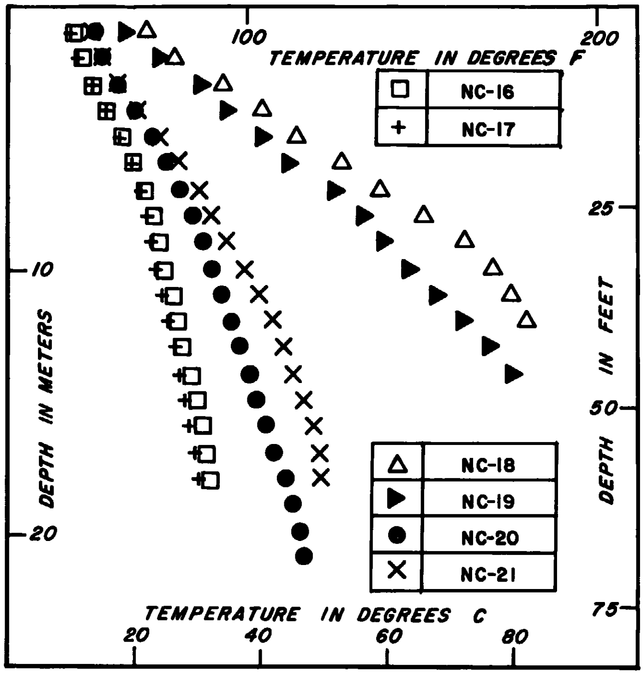

Figure 5: Temperature-depth profiles of geothermal test holes NC-16 through NC-21.

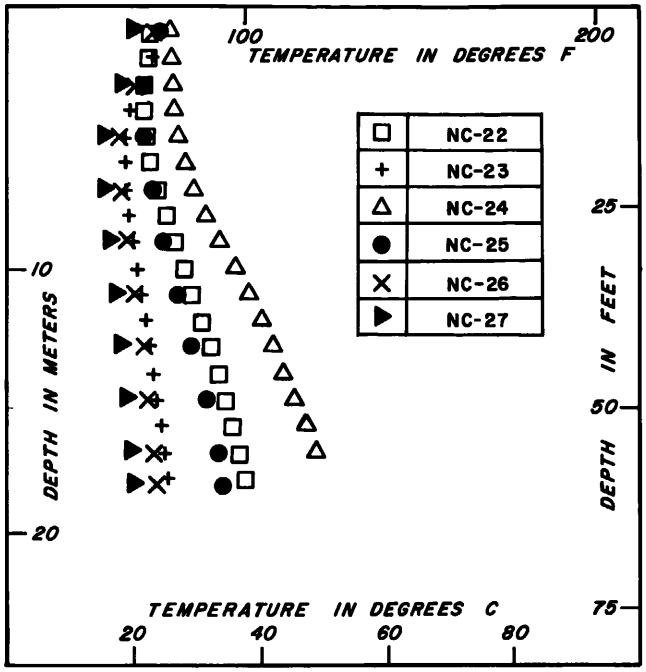

Figure 6: Temperature-depth profiles of geothermal test holes NC-22 through NC-27.

geothermal up-flow. Some 110 soil samples were taken on a sample grid of 200 feet by 500 feet and analyzed using gold-film detection. The mean and standard deviation for the sample set, reported in parts per billion, are 30.2 and 10.3 respectively. The general distribution of sample points falling within the 4th quartile forms an irregular pattern in two areas near the range front. One area is within the vicinity of drill holes NC-18 and NC-19 (on Figure 2) and the other a short distance to the northeast.

Sample	1	2	3	4	Rush
		(concentration in ppm)			(1983)
Na	24.58	273.28	290.24	249.61	270
K	2.76	15.24	16.97	11.74	21
Ca	54.05	64.57	78.68	64.36	58
Mg	25.57	0.75	0.69	5.51	0.4
Fe	N.D.	N.D.	N.D.	N.D.	-
Al	N.D.	N.D.	N.D.	N.D.	-
SiO2	42.12	79.19	69.37	63.24	99
B	N.D.	0.34	N.D.	0.62	-
Li	0.50	0.52	0.60	0.33	-
Sr	N.D.	1.3	1.56	0.36	-
HCO3	181.00	58.00	44.00	104.00	-
CO3	N.D.	N.D.	N.D.	N.D.	-
Cl	48.00	69.00	104.00	76.00	-
F	0.30	7.30	6.30	4.70	-
SO4	82.00	569.00	637.00	478.00	-
TDS	364.00	1154.00	1236.00	1016.00	-
pH(lab)	7.74	8.03	7.98	7.89	-

Table 2. Analytical data for Newcastle water samples. Sample 2 = Hildebrand greenhouses; Sample 3 = Troy Hygro greenhouses (NC-10); Sample 4 = Dan Tullis well (Figure 2).

SUMMARY

Understanding the "blind" geothermal system at Newcastle is important in the context of undiscovered hydrothermal systems in the Basin and Range province of western Utah. Work completed to date suggests that the location and shape of the up-flow zone is controlled, at least in part, by the range-front fault and structures that cross-cut its footwall. Fluids apparently migrate upward from 2 kilometers, or more, along these intersecting structures and flow out beneath the valley floor within unconsolidated material.

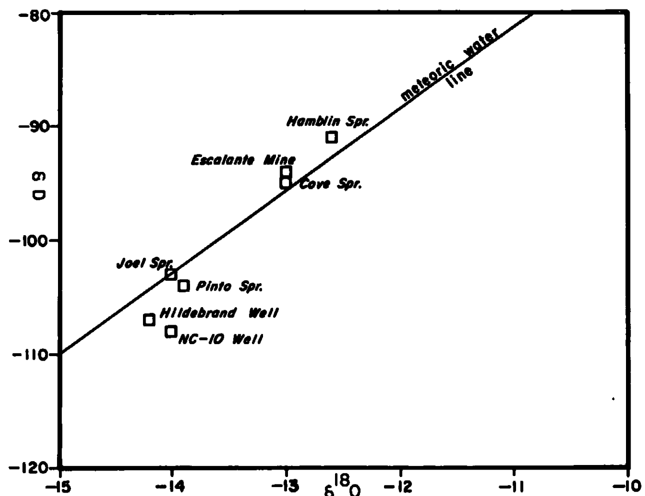

Figure 7: Oxygen-18 and Deuterium compositions of seven water samples near Newcastle.

The Utah Geological and Mineral Survey and the University of Utah are continuing a study of the Newcastle area with the intent of defining and modeling the hydrology of the system. Additional activities scheduled include a dipole-dipole survey and a radon study. Upon completion of the project, a comprehensive, detailed report (UGMS, 1989) will describe all work completed at Newcastle and present a conceptual geo-hydrologic model of the system.

ACKNOWLEDGMENTS

Funding for this work was provided in large part by the U.S. Department of Energy (grant no. DE-FG07-88ID12756). The Unocal Geothermal Division of the Unocal Corporation provided temperature and other geophysical data from their Christiansen #1 Well. We wish to express our thanks to Boyd Christensen, Carroll Tullis, Dan Tullis, Steven Christensen, George Becham, and other residents of Newcastle for their assistance. We also thank M. Siders, P. Rowley, G. Christenson, and G. Galyardt for permission to use unpublished mapping and Z. Reches for the use of his stess tensor programs.

REFERENCES

Anderson, R.E., 1987, Neogene geologic history of the Nevada-Utah border area at and near latitude 37°30'N.: Geological Society of America Abstracts with Programs, V. 19, No. 7, p. 572.

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features, Cedar City 1°x2° quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication, in press, scale 1:250,000.

Angelier, Jacques, 1979, Determination of the mean principal directions of stress for a given fault population: Tectonophysics, V. 156, p. T17-T26.

Angelier, Jacques, 1984, Tectonic analysis of fault slip data sets: Journal of Geophysical Research, V. 89, No. B7, p. 5835-5848.

Angelier, Jacques, Colletta, Bernard, and Anderson, R.E., 1985, Neogene paleostress changes in the Basin and Range: A case study at Hoover Dam, Nevada-Arizona: Geological Society of America Bulletin, V. 96, p. 347-361.

Chapman, D.S., Clement, M.D., and Mase, C.W., 1981, Thermal regime of the Escalante Desert, Utah, with an analysis of the Newcastle geothermal system: Journal of Geophysical Research, V. 86, No. B12, p. 11,735-11,746

Denton, E.H., 1976, Helium sniffer test, Newcastle, Utah 10-26 March 1976: U.S. Geol. Survey Open-File Rept. 76-421, 4 p.

Hoover, D.B., and Pierce, H.A., 1987, Audio-magnetotelluric data release for the Newcastle, Utah geothermal area: U.S. Geol. Survey Open-File Report 87-69, 6 p.

Mabey, D.R., and Budding, K.E., 1987, High-temperature geothermal resources of Utah: Utah Geological and Mineral Survey Bulletin 123, 64 p.

Pe, Win, and Cook, K.L., 1980, Gravity survey of the Escalante Desert and Vicinity, in Iron and Washington Counties, Utah: Earth Science Laboratory/University of Utah Research Institute Rept. No. DOE/ID/12079-14, 169 p.

Reches, Ze'ev, 1987, Determination of the tectonic stress tensor from slip along faults that obey the Coulomb yield condition: Tectonics, V. 6, No. 6, p. 849-861.

Rowley, P.D., Steven, T.A., Anderson, J.J., and Cunningham, C.G., 1979, Cenozoic stratigraphic and structural framework of southwestern Utah: U.S. Geol. Survey Prof. Paper 1149, 22 p.

Rush, F.E., 1977, Subsurface-temperature data for some wells in western Utah: U.S. Geol. Survey Open-File Rept. 77-132, 36p.

Rush, F.E., 1983, Reconnaissance of the hydrothermal resources of Utah: U.S. Geol. Survey Prof. Paper 1044-H, p. H1-H49.

Shubat, M.A., and Siders, M.A., 1988, Geologic map of the Silver Peak quadrangle, Iron County, Utah: Utah Geological and Mineral Survey Map 108, 13 p., scale 1:24,000.

Siders, M.A., 1985, Geologic map of the Beryl Junction quadrangle, Iron County, Utah, Utah Geological and Mineral Survey Map 85, 11 p., scale 1:24,000.

Siders, M.A., Rowley, P.D., Shubat, M.A., Christenson, G.E., and Galyardt, G.L., 1989, Geologic map of the Newcastle quadrangle, Iron County, Utah: U.S. Geol. Survey Quadrangle Map, in press, scale 1:24,000.

Utah Geological and Mineral Survey, 1989, A geothermal resource assessment at Newcastle, Iron County, Utah: a report prepared for the U.S. Department of Energy (in prep.).