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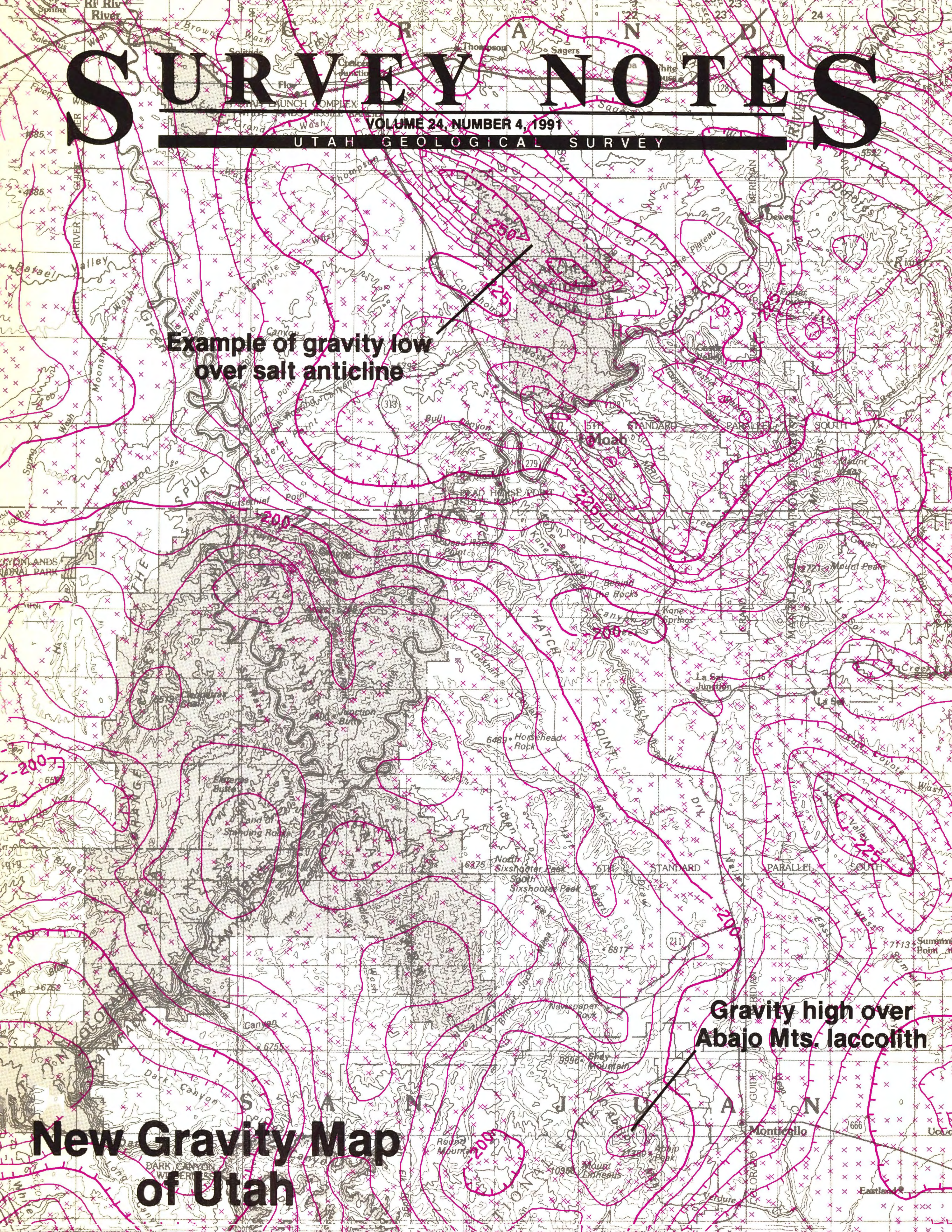

New Gravity Map of Utah

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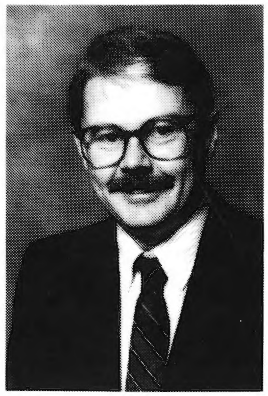
Cover: Portion of UGS Map 122, Complete Bouguer Gravity Anomaly Map of Utah.



THE DIRECTOR'S PERSPECTIVE *by M. Lee Allison*

A NEW NAME, A NEW HOME

On April 30, 1991, the Utah Geological and Mineral Survey became, simply, the Utah Geological Survey (UGS). And as this issue of *Survey Notes* goes to press, we are finishing moving our offices and labs into a new building two miles south of our location of the last 15 years in Research Park.

Our name change is something that many, both inside and outside of the survey, had long felt was needed. The word "Mineral" was redundant, often dropped (particularly by the media) and made a real mouthful in describing who we were. But the attendant costs of passing legislation, changing letterhead, business cards, logos and other signs kept us from seriously considering the change. However, when it became clear that we would be moving into new offices, the name change could be accomplished at no extra cost. Utah Senator Lyle W. Hillyard and Representative Fred R. Hunsaker introduced the necessary bill in the last legislature and it easily passed.

The new UGS offices are in the former First Continental Life building at 2363 Foothill Boulevard, just north of Interstate 80. Two considerations prompted our move. The renewal of our lease in Research Park was initially proposed to include a 30% rent increase escalating to over 60% during the five-year period. In addition, growth of the survey through the 1980s meant that the facilities were inadequate in size and capabilities.

The weak commercial real estate market in Salt Lake City allowed us to negotiate an excellent deal. Because we will be paying a lower dollar per square foot rate than at present, we leased sorely needed additional space. The extra couple of thousand square feet of space is allocated mostly to library and public data areas, sales room, project work areas, and reproduction/editorial facilities. Working with the building owners, the UGS staff was fully involved in designing the layout of the new space to optimize productivity and accessibility. All of the cost of the renovations and remodeling are being borne by the owner, who also provided additional funds to pay for the entire cost of the move.

Location of the new offices keeps us in proximity to our colleagues at the University of Utah and in other government and private geology operations which are centered on the east side of town in and around Research Park. It also significantly reduces travel time between our sister agencies in the Department of Natural Resources and the new location.

The "new" building is actually about 40 years old but a structural examination indicated that it was extremely well built and likely to withstand a strong earthquake. That is a critical concern if the UGS is to function in an emergency. All in all, we are excited about the move. The elimination of cramped quarters, overworked heating and cooling systems, and occasionally flooded offices will be greatly welcomed. We invite you to stop by and see us in the new location. We think it will substantially improve our ability to provide our services to the citizens of Utah.

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THE NEWCASTLE GEOTHERMAL AREA

(A STUDY OF A CONCEALED HYDROTHERMAL SYSTEM)

by Robert Blackett

INTRODUCTION

Although many hydrothermal-geothermal systems are known in the Basin and Range province of the western United States, Brook and others (1979, p. 35) believe that only about one fifth of the total accessible hydrothermal resource base (to a depth of 3 kilometers) has been identified. The remaining four fifths is contained within extensions of known hydrothermal systems and within isolated, concealed hydrothermal systems. Concealed hydrothermal systems -- having no surface expression of hydrothermal activity such as thermal springs, sinter mounds, or surface alteration -- are usually discovered by chance as a result of water well or exploratory drilling. Such a hydrothermal system exists at Newcastle Utah.

Newcastle is a rural farming community located in southwestern Utah's Iron County (figure 1) where, in 1975 during test pumping of a newly drilled irrigation well, the Christensen brothers unexpectedly produced boiling thermal water (Rush, 1983, p. 19). The discovery well encountered a hot-water aquifer with a maximum temperature of 226° F (108°C) beween depths of 245 and 310 feet (75 and 95 m). This was the first record of geothermal activity at Newcastle although early settlers were apparently forced to stop hand digging a water well because of excessive heat (Boyd Christensen, personal communication, 1988). Other developed geothermal systems in Utah include (1) the Roosevelt Hot Springs area where Utah Power and Light Company produces 23 megawatts electric (MWe) from its Blundel power plant, (2) Cove Fort/Sulphurdale where the Utah Municipal Power Agency and the City of Provo have recently expanded generating capacity to 13.5 MWe, and (3) Crystal Hot Springs, in Salt Lake County, where Utah Roses, Inc. and the Utah State Prison use thermal water directly for space heating.

Since the discovery, geothermal-related studies at Newcastle have included a helium-gas survey (Denton, 1976), temperature gradient and heat flow studies (Rush, 1977 and 1983; Clement, 1981; Chapman and others, 1981; and Mower, 1982), and geophysical investigations (Pe and Cook, 1980; and Hoover and Pierce, 1987). In addition, Mabey and Budding (1987) compiled available data on the Newcastle system and presented a geothermal model suggesting that hot water rising

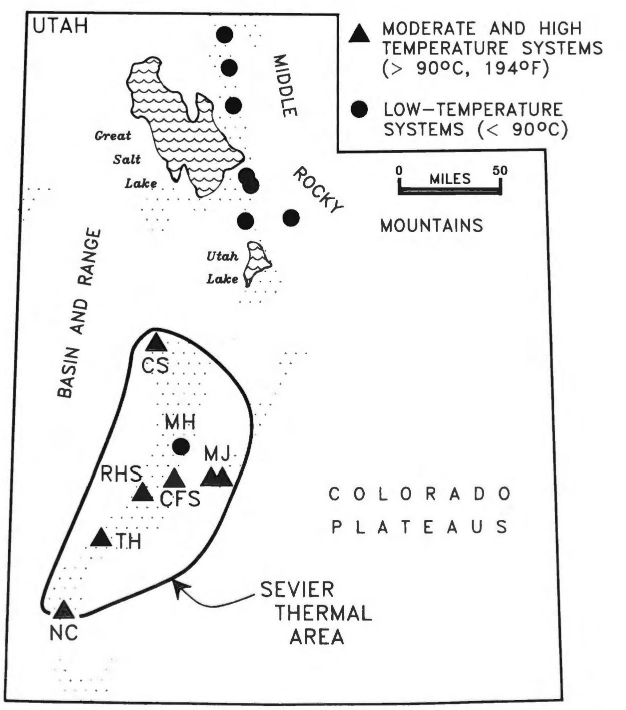

Figure 1. Location of the Newcastle geothermal area(NC) with respect o physiographic regions and other geothermal systems within the Sevier Thermal area. Geothermal areas include CS-Crater Springs; MH-Meadow/Hatton; MJ-Monroe/Joseph; RHS-Roosevelt Hot Springs; CFS-Cove Fort /Sulphurdale; TH-Thermo Hot Springs.

Figure 2. View looking to the northwest across the Escalante Valley. Commercial greenhouses using geothermal fluid for space heating are seen in the foreground.

along a fault zone near the base of the hills southeast of Newcastle discharges into an aquifer in unconsolidated Quaternary sediments. Mabey and Budding believed the Newcastle area to be the least understood of Utah's significant geothermal systems. Presently, two commercial greenhouse complexes use thermal water for space heating (figure 2).

A proposal for a cost-share geothermal research project at Newcastle was submitted to the U.S. Department of Energy (DOE) in 1987. The proposed research, a joint effort between the UGS and the University of Utah Department of Geology and Geophysics, was awarded funding as part of DOE's State Geothermal Research and Development program (U.S. DOE grant no. DE-FG07- 88ID12756). Work ranged from shallow temperature gradient drilling and geochemical studies to geologic mapping and geophysical surveys. The purpose of the activities was to characterize the Newcastle system and to develop a conceptual model.

REGIONAL GEOLOGY

Within the region, widespread mid- to late-Tertiary rhyolite and andesite volcanic flows and domes, and intrusive bodies, have erupted onto or intruded into folded and thrust-faulted Paleozoic and Mesozoic marine sedimentary rocks. The Newcastle geothermal area is located along the southeast margin of the Escalante Valley, an elliptical depression in southwest Utah measuring roughly 44 miles long by 28 miles wide (70 by 45 km). Two broad, east-west belts of Tertiary intrusive centers and metallic mineralization -- the Pioche-Marysvale and the Delamar-Iron Springs belts -- are present in the region. These belts, which roughly bracket the Escalante Valley to the north and south respectively, provide

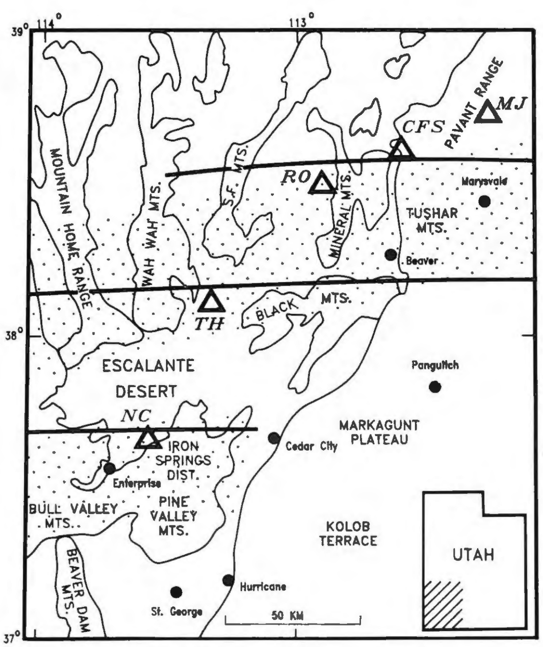

Figure 3. Physiography of southwest Utah. Stipple pattern denotes Pioche-Marysvale and Delamar-Iron Springs igneous belts (north and south, respectively). East-west lines denote (top to bottom) the Black Rock, Blue Ribbon, and Timpahute lineaments (after Rowley and others, 1979). Triangles denote geothermal areas: NC-Newcastle, TH-Thermo Hot Springs, RO-Roosevelt Hot Springs, CFS-Cove Fort/Sulphurdale, MJ-Monroe/Joseph.

evidence of past hydrothermal activity (figure 3). Later volcanic products include Quaternary rhyolite domes and basaltic flows. Basin and Range extension, active over the past several million years, has produced many north-south normal faults and less obvious oblique structural zones. This network of structures represents several episodes of tectonism. The region is still undergoing tectonism as evidenced by earthquakes generated within the Intermountain seismic belt (Smith and Sbar, 1974) and greater than normal heat flow (Chapman and others, 1981).

Bedrock Units

Exposed bedrock units at Newcastle (described in detail by Siders and others, 1990) 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 of regional extent, capped by local rhyolite and dacite flows (figure 4). The oldest unit exposed is the Upper Cretaceous Iron Springs Formation. It is mostly light-colored, thin- to thick-bedded sandstone and lesser shale, conglomerate, limestone, and carbonaceous shale, and is over 1400 feet (430 m) thick southeast of the study area. It is of fluvial, alluvial-plain, and paludal material from the eroded Sevier orogenic highlands to the west. The Claron Formation of Eocene to Oligocene age unconformably overlies the Iron Springs Formation. It consists of fluvial and lacustrine shale, sandstone, limestone, siltstone and conglomerate with a total thickness of about 700 feet (210 m).

The Isom Formation, which has an Oligocene age of 26 Ma (Rowley and others, 1979), overlies the Claron Formation. It consists of two densely welded, crystal-poor, ash-flow tuffs -- the lower Baldhills Tuff Member and the upper Hole-in-the-Wall Tuff Member. Both contain sparse phenocrysts of plagioclase, clinopyroxene, and magnetite and range from dark brown to black. Extreme welding produced flattened pumice clasts as much as 2 feet (0.6 m) in length, and secondary flowage produced stretched vesicles as much as 1 foot (0.3 m) in length. Intercalated with densely welded tuff near the base of the Baldhills Tuff Member are probable andesite flows marked by autobrecciation and flow-top scoria, and thin beds of volcanic sandstone. The Bald Hills Tuff Member has a minimum thickness of 1080 feet (330 m). The Hole-in-the-Wall Tuff Member consists of a single cooling unit that is about 260 feet (80 m) thick. The concealed source caldera or vent for the Isom Formation probably lies beneath the southern margin of Hamblin Valley or the northern margin of the Escalante Desert (Best, 1987), approximately 22 miles (35 km) northwest of Newcastle.

Three regional rhyodacite to dacite ash-flow tuffs of the Quichapa Group overlie the Isom Formation and were probably erupted from sources in the Caliente caldera complex (Williams, 1967). The rhyodacitic, moderately welded Leach Canyon Tuff (25 Ma, Rowley and others, 1979) is about 580 feet (177 m) thick and consists of several cooling units. It contains 20 to 30 percent phenocrysts of plagioclase, quartz, sanidine, and biotite and reddish lithic fragments. The Bauers Tuff (23 Ma, Rowley and others, 1979) is rhyodacitic, crystal-poor, densely welded, and about 430 feet (130 m) thick. This unit contains phenocrysts of plagioclase, sanidine, and bronze biotite and abundant highly flattened pumice clasts. The Bauers Tuff apparently erupted from the Clover Creek

SERIES	FORMATION		SYMBOL	AGE (yrs x 10^6)
Miocene	Rhyolite of Silver Peak		–	8.5
Miocene	Volcaniclastic Rocks Newcastle Reservoir		–	>11.6
Miocene	Racer Canyon Tuff			19
Miocene	Volcaniclastic Rocks			–
Miocene	Quichapa Group	Harmony Hills Tuff		21
Miocene	Quichapa Group	Bauers Tuff		23
Oligocene	Quichapa Group	Leach Canyon Tuff		25
Oligocene	Isom	Hole-in-the-Wall Tuff Member		26
Oligocene	Isom	Baldhills Tuff Member		26
Eocene	Claron			–
Upper Cretaceous	Iron Springs		–	–

Figure 4. Stratigraphic diagram for bedrock units in the Newcastle area.

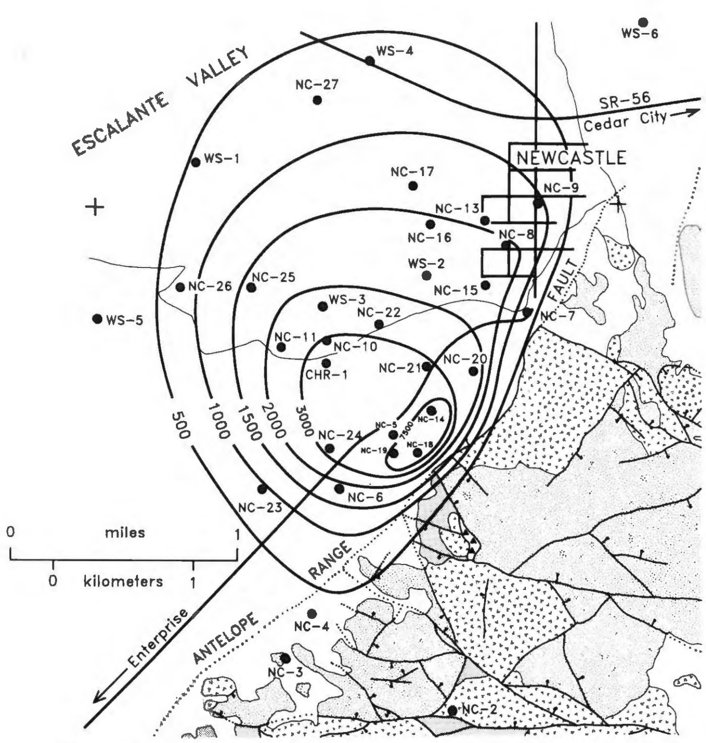

Figure 5. Geologic map, temperature gradient holes (NC prefix), fluid sample locations (WS prefix), and heat flow contours (values in milliwatts per m^2). Qy, late Pleistocene to Holocene sediments; Qm, middle to late Pleistocene sediments. Bedrock units correspond to the patterns indicated on figure 4.

caldera located in Lincoln County, Nevada (Rowley and Siders, 1988). The Harmony Hills Tuff (21 Ma, Rowley and others, 1979) is a distinctive crystal-rich, dacitic, moderately welded tuff. It consists of nearly 50 percent crystals of plagioclase, biotite, hornblende, quartz, and pyroxene and is 480 feet (146 m) thick.

Although it is combined with the Quichapa Group for illustrative purposes on figure 5, an unnamed, aerially extensive volcaniclastic unit, approximately 130 feet (40 m) thick, overlies Harmony Hills Tuff. It contains abundant clasts and crystal fragments of Harmony Hills Tuff as well as andesite cobbles. This northward-thickening unit is probably a distal debris-flow deposit shed from an andesite highland to the north. The Racer Canyon Tuff overlies the rocks of the Quichapa Group and volcaniclastic rocks.

The Racer Canyon Tuff is the youngest regional ash-flow tuff present at Newcastle. The tuff is crystal- rich, rhyodacitic, poorly to moderately welded, and is greater than 490 feet (150 m) thick. Southeast of the map area the Racer Canyon Tuff consists of at least 3 cooling units and its age is approximately 19 Ma (Siders and others, 1990). An informally named unit, the Volcaniclastic Rocks of Newcastle Reservoir, overlies the Racer Canyon tuff and is greater than 980 feet (299 m) thick. These volcaniclastic rocks are correlative with the informally named "mine series" of Siders (1985), which has a minimum age of 11.6 Ma. Overall, the unit consists of intercalated lenses of conglomerate, mudflow breccia, and sandstone, and most clasts are volcanic rocks. Rhyolite and dacite lava flows and domes overlie and intrude Racer Canyon Tuff in the northeast part of the 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).

QUATERNARY UNITS

A variety of unconsolidated to semi-consolidated deposits, described in detail by Siders and others, (1990), overlie the bedrock units. These unconsolidated units include upper Miocene to Pliocene moderately consolidated, coarse fluvial material deposited at the margin of the Escalante Valley, and Pliocene to lower Pleistocene piedmont-slope alluvium. Unconsolidated deposits of Pleistocene age include (1) stream-terrace alluvium deposited in stream channels and flood plains at an elevation approximately 50 to 80 feet (15 to 24 m) above modern channels; (2) piedmont-slope alluvium forming dissected remnants of a surface in mountain front re-entrants that are older and higher than the modern surface; and (3) alluvial-fan deposits that form from dissected remnants of older and higher alluvial-fan deposits in the Escalante Valley. The youngest unconsolidated deposits consist of sand, silt, gravel, and clay divided on the basis of depositional environment and geomorphic expression. They include alluvial-fan and stream-terrace deposits, colluvium, and talus.

STRUCTURE

Pleistocene and Holocene geologic units of the Escalante Valley that comprise the valley fill generally terminate at the Antelope Range fault (figure 5). The fault is a major north-northeast-trending, range-bounding normal fault which defines the southeast side of the Newcastle graben, a feature first suggested by the regional gravity work of Pe and Cook (1980). The northwest side of the graben is represented at the surface by a subtle scarp, located a few thousand feet northwest from the range front at Newcastle, which cuts unconsolidated units and faces opposite the Antelope Range fault. Scarp morphology along the Antelope Range fault indicates a middle to late-Pleistocene age for the last surface-rupturing event.

Geologic mapping of bedrock units within the northwest extension of the Pine Valley Mountains, by geologists from the UGS and the U.S. Geological Survey (Siders and others, 1990; Shubat and Siders, 1988), provided many insights about the structural history of the area. Oligocene and Miocene ash-flow tuffs, debris flows, and rhyolite flows provided good stratigraphic markers for determining fault locations, displacements, and attitudes. Additional detailed mapping by Mike Shubat of the UGS, as part of our project, revealed a complex network of faults and fracture zones within the range. Greatest stratigraphic separation (2000 to 3000 feet or 610-915 m) occurs along northwest-striking faults and fault zones (Blackett and others, 1989; 1990).

In addition, fault slip studies by Mike Shubat involved collection of fault-slip data from bedrock terrain at six sites in and around Newcastle. Computer analysis of these data suggested that two principal tectonic events were responsible for the fault and fracture systems seen in the study area (Angelier, 1979, 1984; Angelier and others, 1985; and Reches, 1987). An older event occurred between 21 and 8.5 million years ago, associated with regional southwest-directed extension, and produced the dominantly northwest-trending faults mapped in bedrock. A second event, active between 8.5 million years ago and the present, apparently produced only minor faults. The fault-slip data were unable to uniquely define an event associated with displacement on the Antelope Range fault. Of the faults produced during the older event, few were reactivated during the younger event. The younger event appears to have generated relatively few new faults away from the Antelope Range fault, and therefore probably contributed little to the fracture permeability of bedrock.

A subtle, discontinuous trend of gravity lows including the Newcastle graben (Pe and Cook, 1980) is oriented in a northwesterly fashion across the Escalante Valley and intersects the dominant northeast- trending gravity gradient, associated with the Antelope Range fault, near Newcastle. Northwest-trending gravity lows may represent unconsolidated material filling isolated basins caused by regional scale, southwest-directed extension. These isolated basins were possibly later dismembered by Basin and Range extension which produced the dominant northeast-trending set of gravity lows. Alignment of these presumed regions of enhanced permeability in northwest-southeast and northeast-southwest directions could provide preferred pathways for ground-water flow in bedrock. The complex network of faults within the range east of Newcastle may reflect this postulated, broad northwest-trending structural zone.

STUDIES

HEAT FLOW STUDIES

One purpose of the study was to increase the understanding of the subsurface thermal regime and to review previous estimates of heat loss from the geothermal system. Ideally a series of deep (400 feet or deeper; 122 m), temperature gradient (T/G) holes would be required to collect the necessary information. Unhappily, the limited funding available for the overall project would not permit deep drilling.

Using existing data, however, David Chapman and Craig Forster of the University of Utah were able to design an innovative drilling plan by noting that the temperature profiles obtained by Rush (1977), exhibited some features typical of hydrothermal systems (figure 6). The holes drilled deep enough to penetrate the geothermal aquifer displayed steep temperature gradients initially, and became isothermal or showed temperature reversals within the geothermal aquifer between about 245 and 328 feet (75 and 100 m). Chapman and Forster also noted that only eight to ten T/G holes would be needed to constrain the system, particularly to the south. They argued that much shallower holes, on the order of 50 to 65 feet (15 to 20 m) deep could be drilled at much less cost and still establish the linear temperature gradient within the conductive region above the geothermal aquifer. New estimates of heat flow from the system could then be made using the new thermal gradient information in combination with thermal conductivities determined from drill cuttings. A depth of 60 feet (18 m) was selected as the drill depth for additional T/G holes. This was sufficiently deep to avoid "noise" from annual surface temperature variations while still the minimum depth required to reveal the signature of the geothermal system.

With this drill depth, we were able to complete 12 new, shallow T/G holes (NC-16 through NC-27). All holes were completed by inserting a bottom-capped 1.25" ID schedule 40 PVC pipe, filling the pipe with water and back-filling the annulus between the pipe and the borehole with drill cuttings.

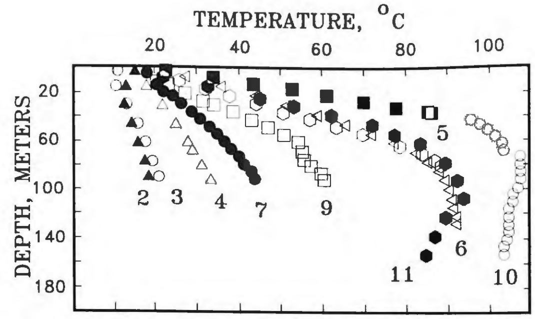

Figure 6. Temperature-depth profiles for Newcastle drill holes NC-2 through NC-12 (after Chapman and others, 1980).

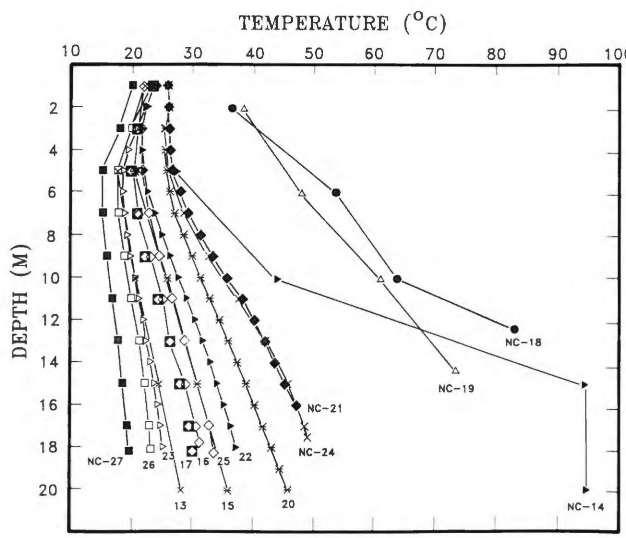

Figure 7. Temperature-depth profiles for Newcastle drill holes NC-13 through NC-27 (after Blackett and others, 1990).

Table 1. Summary of temperature gradient, thermal conductivity, and heat flow data for thermal monitoring wells NC-2 through NC-27.

NC Well	Depth Interval (meters)	Thermal Gradient (°C/km)	Thermal Conduct. (W/m°C)	Heat Flow (mW/m)
2	46 to 89	89	2.27	200
3	46 to 89	116	1.70	200
4	8 to 40	220	1.70	370
5	8 to 20	1998	1.70	3400
6	5 to 38	1065	1.73	1840
7	8 to 47	370	1.70	630
8	17 to 41	1028	1.70	1750
9	8 to 56	710	1.70	1210
10	0 to 40	1833	1.76	3230
11	15 to 46	1292	1.74	2250
12	49 to 118	21	1.70	40
13	5 to 20	729	1.70	1240
14	0 to 14	>5000	1.72	>8600
15	5 to 40	1010	1.68	1700
16	5 to 18	931	1.80	1680
17	5 to 18	847	1.67	1410
18	0 to 13	5737	1.83	10500
19	0 to 14	4615	1.83	8450
20	5 to 20	1409	1.70	2400
21	5 to 18	1943	1.64	3190
22	5 to 18	1267	1.57	1990
23	5 to 18	582	1.80	1050
24	5 to 17	1914	1.55	2970
25	5 to 18	982	1.72	1690
26	7 to 18	521	1.54	800
27	5 to 18	412	1.60	660

Table 2. Results of chemical analyses and geothermometry of groundwater samples from the Newcastle area. Sample locations (WS-1 through WS-6) are shown on figure 4.

SPECIES	Concentration in (PPM) WS-1	WS-2	WS-3	WS-4	WS-5	WS-6
Na	24.58	273.28	290.24	249.61	63.98	104.80
K	2.76	15.24	16.97	11.74	2.64	5.05
Ca	54.05	64.57	78.68	64.36	63.82	62.34
Mg	25.57	0.75	0.69	5.51	25.59	13.32
Fe	ND	ND	ND	ND	ND	ND
Al	ND	ND	ND	ND	ND	ND
SiO2	42.12	79.19	69.37	63.24	31.89	46.80
B	ND	0.34	ND	0.62	0.15	0.19
Li	0.50	0.52	0.60	0.33	ND	0.09
Sr	ND	1.30	1.56	0.36	0.55	0.35
HCO3	181.00	58.00	44.00	104.00	182.00	228.00
CO3	ND	ND	ND	ND	ND	ND
Cl	48.00	69.00	104.00	76.00	44.00	82.00
F	0.30	7.30	6.30	4.70	0.48	1.03
SO4	82.00	569.00	637.00	478.00	208.00	115.00
TDS						
meas. (m)	364.00	1154.00	1236.00	1016.00	530.00	545.00
calc. (c)	368.88	1109.01	1227.03	1005.60	530.59	543.00
100 – (m/c)	98.68	104.06	100.73	101.03	99.89	100.37
pH	7.74	8.03	7.98	7.89	7.48	7.60

GEOTHERMOMETER (Reference)	Estimated Reservoir Temperatures (°C) WS-1	WS-2	WS-3	WS-4	WS-5	WS-6
Chalcedony (1)	64	97	89	84	51	69
Na-K-Ca (2)	28	99	99	89	32	54
Na-L (3)	63	115	120	92	32	69
K-Mg (4)	30	110	114	7	30	48

Temperatures were then measured, using high-precision thermistor probes and digital ohm-meters, at depth intervals of 1, 3, or 5 meters to the bottom of the borehole. Temperature measurements were made most efficiently in drill holes filled with water because of the short equilibration time for the probe. Temperature measurements made in air, above the water table in unsealed holes, required reading every few seconds over periods of several minutes to provide an extrapolation to equilibrium temperatures (Blackett and others, 1990, p. 53). In addition to the newly drilled holes, three holes drilled by local residents were also available for temperature logging (NC-13, NC-14, and NC-15).

Temperature profiles from the new T/G holes exhibited gradients typical of hydrothermal systems and similar to previous holes (figure 7, table 1). Temperature profiles for three holes (NC- 14, NC-18, and NC-19) drilled on an alluvial fan southeast of Newcastle, however, displayed very steep geothermal gradients, indicating that the hottest part of the geothermal system is close to the surface trace of the Antelope Range fault. This suggests a much more direct role for the fault in controlling leakage of fluids than previously thought.

Using the revised heat flow map (figure 5) and integrating the anomalous heat flux, Chapman, Forster, and B.J. MacPherson, a graduate student, calculated a new heat loss estimate for the Newcastle system. The revised estimate for anomalous heat loss above the background heat flow of 100 mW/m^2 (milliwatt per square meter), and contained within the 500 mW/m^2 contour, was 12.4 megawatts thermal (MWt). The calculated revised fluid discharge rate, based upon the new heat loss estimates, was 0.031 m^3/s (cubic meters per second, or 490 gpm) (Blackett and others, 1990, p. 58). Because of better constraints on the system, this value is slightly less than the previous estimate of 12.8 MWt computed by Chapman and others (1981).

WATER ANALYSES

Water samples collected from six wells (figure 5) and analyzed for major ions (table 2), indicate that the geothermal fluid has moderate TDS and mixes to varying degrees with cool, shallow ground water of low TDS. Geothermal water, after entering the shallow aquifer, disperses to the north and west into the Escalante Valley becoming cooler and increasingly mixed with shallow ground water. Samples WS-2, WS-3, and WS-4 are similar in chemistry and are of SO_4-Cl-HCO_3 type. Sample WS-1 has much lower TDS and is classified as HCO_3-SO_4-Cl type. The difference in water chemistry between samples indicates that the out-flowing plume of thermal water moves generally northward within valley-fill deposits.

Chemical geothermometers are experimentally derived formulas applied to the results of water analyses in order to estimate geothermal reservoir temperatures. Geothermometers applied to the Newcastle water analyses (table 2) indicate that, overall, computed equilibration temperatures are low. The sample from the Hygro well (WS-3) yielded the highest calculated temperature at 248° F (120° C), with samples from wells WS-1, WS-5, and WS-6 yielding temperatures too low to be applicable for geothermometry. A maximum measured temperature of 266° F (130° C) measured in Unocal well CHR-1 at a depth of 346 feet (105 m) suggests that the fluid chemistry in the sampled wells may be more representative of conditions within the shallow out-flow portion of the hydrothermal system. Qualitatively, samples WS-3, WS-2, WS-4, and WS-1 indicate a progression of increasingly mixed fluid. Samples WS-2 and WS-3 are estimated to be about 90% of the original hydrothermal fluid, while WS-4 is about 40% of original, and WS-1 is about 5% of original (Blackett and others, 1990, p. 63).

Fluid samples for isotopic studies from wells and springs suggest that the geothermal fluid has undergone little isotopic exchange with reservoir rocks and that the water is of local meteoric origin. The most likely candidate area for recharge is in the Pine Valley Mountains located to the southeast.

GEOPHYSICAL STUDIES

Geophysical investigations at Newcastle included detailed gravity studies, a limited magnetic survey which yielded little useful information due to interference by power transmission lines, a resistivity survey, and a self-potential (SP) survey. Gravity and magnetic studies were carried out in an effort to help determine depth to bedrock beneath the Escalante Valley sediments and to estimate the attitude of the Antelope Range fault. Resistivity and SP studies, performed in cooperation with researchers from the University of Utah Research Institute, were used to help define the position of up-flowing geothermal fluid and the dispersion of the out-flow plume with respect to heat flow distribution.

GRAVITY SURVEY

Detailed gravity studies, consisting of nearly 400 close-spaced gravity stations, were performed by Charles M. Schlinger, formerly of the University of Utah Department of Geology and Geophysics with the assistance of U of U geoscience students. After compiling and applying routine reductions to the data, Dr. Schlinger and his students performed a forward modelling procedure described in Blackett and others (1990, p. 29). The procedure, which uses constant density horizontal prisms (polygonal cross-sections) with strike lengths of 20 kilometers (12.5 miles), provided a rough, non-unique interpretation of the subsurface geometry along a northwest-southeast-trending gravity profile normal to the Antelope Range fault (figure 8). The interpretation shows the northwest extension of the Pine Valley Mountains separated from the Escalante Valley by the Antelope Range fault. Prisms with densities of 2.400 g/cm^3 (grams per cubic centimeter) represent Cretaceous and lower Tertiary sedimentary rocks, and Tertiary volcanic units. These units are exposed in the mountains in the southeast portion of the study area and are present in the subsurface beneath the Escalante Valley. Prisms of densities ranging from 1.900 g/cm^3 to 2.125 g/cm^3 represent alluvial, fluvial, and lacustrine deposits of the Newcastle graben and the Pinto graben. The model depicts the Antelope Range fault dipping at an angle of 65 degrees (±5 degrees) to the northwest.

RESISTIVITY AND SP SURVEYS

To analyze the subsurface electrical expression in the hydrothermal system, Howard Ross and Claron Mackelprang of the University of Utah Research Institute directed electrical resistivity and SP surveys with the assistance of UGS geologists (Ross and others, 1990). Although the temperature anomaly thought to result from up-flowing thermal fluids had been roughly defined, none of the new T/G holes penetrated deep enough to encounter thermal water. Therefore, the position of the main conduit along a 4000-foot-length (1220 m) of the Antelope Range fault remained uncertain. Electrical geophysical methods are very useful for mapping geothermal systems because hydrothermal fluids often contain higher concentrations of ions in solution than normal ground water, and thereby have lower electrical resistivity with respect to the surrounding environment. Within the area of suspected up-flowing thermal fluid, near the surface trace of the Antelope Range fault, the resistivity and SP surveys showed well defined electrical responses.

Two-dimensional numerical modelling of the resistivity data (figure 9) from resistivity lines oriented northwest-southeast across the Antelope Range fault (figure 10) indicates two low resistivity zones. A deep, near-vertical zone, or conduit, extends to depths of 985 feet (300 m) adjacent to the Antelope Range fault, and a quasi horizontal zone, or outflow plume, 300 to 450 feet thick (100 - 150 m), lies within alluvium at depths of 130 to 180 feet (45 - 60 m) northwest of the fault.

Self-potential, or SP surveys (sometimes called spontaneous polarization) are often used in exploration for high-temperature geothermal resources. The relatively simple and inexpensive method often can detect the presence of thermal fluids. SP responses occur as a variety of amplitudes, shapes,

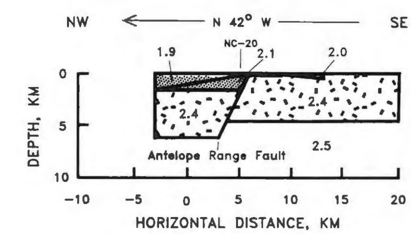

Figure 8. Subsurface forward model of a detailed gravity profile oriented northwest to southeast and normal to the range-front at Newcastle (after Blackett and others, 1990).

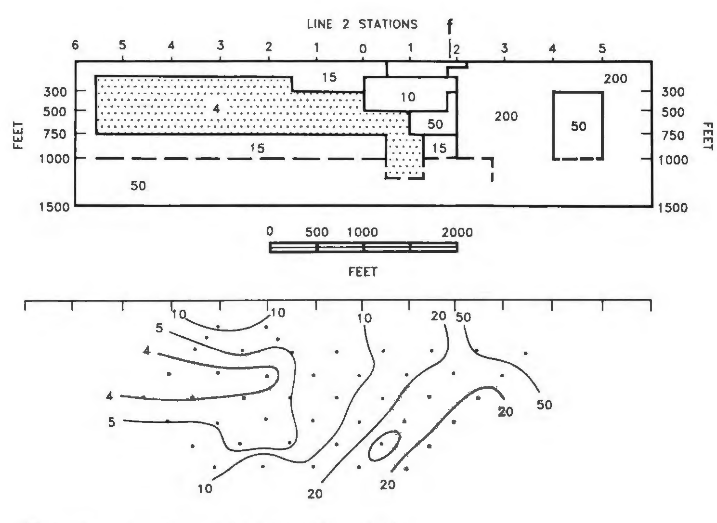

Figure 9. Numerical model solution for line L-2. The low-resistivity bodies (shaded) are interpreted as the up-flow source and outflow plume (after Ross and others, 1990).

multiple anomalies, and may be positive or negative in polarity (Ross and others, 1990, p. 1534). The SP survey at Newcastle, shown on figure 11, identified a near circular, 500-foot diameter (152 m), -108 mV low nearly coincident with an area of low resistivity and the center of our mapped thermal anomaly. A smaller, -30 mV SP anomaly is offset approximately 1970 feet (600 m) to the southwest. The positions of the low resistivity zones, negative SP anomaly, thermal anomaly, and fault relationships suggests that hot fluid moves upward along narrow, open channelways associated with intersections of major bedrock faults with the Antelope Range fault. Additional minor leakage of thermal fluid may be occurring along a 4900-foot segment (1.5 km) of the Antelope Range fault.

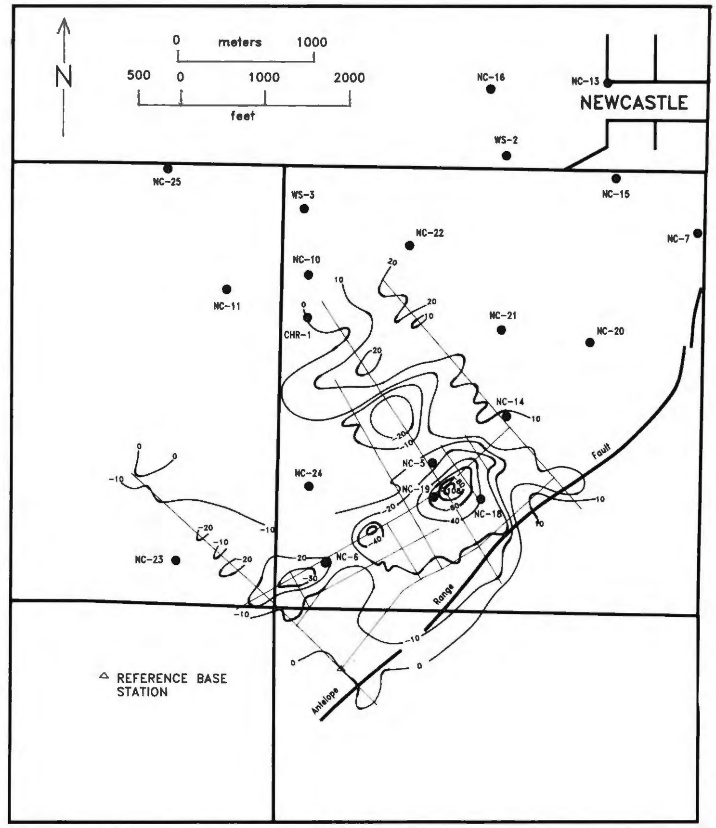

Figure 11. Self-potential map for the Newcastle geothermal area. Contour values are shown in millivolts. Locations of selected drill holes and the surface trace of the Antelope Range fault are shown for reference (after Ross and others, 1990).

CONCEPTUAL MODEL

The variety of analytical techniques used at Newcastle helped formulate a general model for the hydrothermal system. Recharge in the Pine Valley Mountains moves downward along faults and fractures to depths of up to 3 miles (5 km) and continues to the northwest within a postulated broad structural zone. The fluid becomes heated by the earth's geothermal gradient. The northeast-trending Antelope Range fault and its intersection with the postulated northwest-trending structural zone may provide preferred pathways for localizing discharge of geothermal fluid at the basin fill/bedrock contact along the southeast margin of the Escalante Valley. A low-permeability barrier might be formed by fine-grained alluvial material adjacent to the Antelope Range fault, or by fault gouge adjacent to fractured rock. This barrier then forces the thermal fluid, which is under increased hydraulic pressure, to move upward along or adjacent to the Antelope Range fault. Siliceous or carbonate precipitates formed at the interface between thermal and non-thermal water in the basin fill could possibly form a low-permeability "seal" and also force fluid upward. We believe that thermal fluid issues from a throat-like source or "up-flow" zone within a few hundred feet of the ground surface at a temperature of 266° F (130° C) or greater as recorded in well CHR-1. This geothermal source spills into alluvium of the Escalante Valley and forms an out-flowing plume of thermal water which moves northward and westward within an unconfined alluvial aquifer. The aquifer probably consists of permeable zones within piedmont-slope alluvium generally at depths between 245 and 328 feet (75 - 100 m). Thermal fluid within the out-flow plume gradually mixes with shallow ground water and becomes cooler in the distal parts of the system.

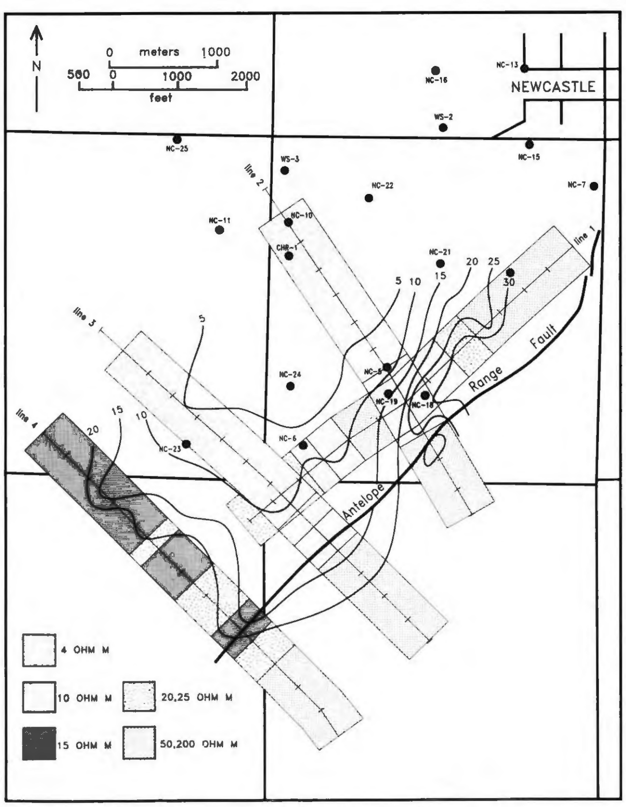

Figure 10. Contoured apparent resistivity and modeled intrinsic resistivity for the depth interval 300 to 500 feet (91-152 m, third separation). Locations of selected drill holes and the surface trace of the Antelope Range fault are shown for reference (after Ross and others, 1990).

CONCLUSIONS

The results of the Newcastle geothermal project illustrate the practicality of employing a variety of geological, geophysical, and geochemical techniques for analyzing moderate-temperature hydrothermal systems in the Great Basin. The methods used and the approach taken during the study were determined by considering the type and coverage of existing data, and by realizing the level of funding available for the project. Detailed geologic mapping revealed the structural framework within the adjacent mountain range and guided us to several bedrock faults that may exert control on the location of the system along the Antelope Range fault. Placement of additional shallow thermal gradient test holes permitted us to complete the mapping of heat flow and confine the location of the hottest part of the system to a relatively small area near the range-front. Detailed gravity investigations aided us in estimating the geometry of the range-bounding fault zone and the thickness of valley-fill units in the adjacent Newcastle graben. Electrical resistivity and self-potential (SP) surveys across the thermal anomaly allowed us to determine the suspected location of the geothermal source, although this source remains untested by deeper drilling. The success of the SP survey at Newcastle in detecting the postulated source of geothermal fluids, surveys which are relatively simple and inexpensive to perform, suggests that the SP method would be useful in the exploration of many other moderate-temperature geothermal systems. The characteristics that we observed in the Newcastle system will be useful for developing an analog for other undiscovered geothermal systems in the Great Basin. Also, the new resource information will help in management of the Newcastle geothermal reservoir as development of direct-use applications, such as greenhouses and space heating, and possible development of binary electric power generation continues.

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Earthquake Activity in the Utah Region

January 1 — March 31, 1991

Susan J. Nava
University of Utah Seismograph Stations
Department of Geology and Geophysics

During the three-month period January 1 through March 31, 1991, the University of Utah Seismograph Stations located 205 earthquakes within the Utah region (see accompanying epicenter map). The total includes nine earthquakes in the magnitude 3 range, specifically labeled on the epicenter map, and 88 in the magnitude 2 range. (Note: Magnitude indicated here is either local magnitude, M_L, or coda magnitude, M_C. All times indicated here are local time, which was Mountain Standard Time.)

Larger and/or Felt Earthquakes

M_L 3.3	January 26	2:49 p.m.	11 miles ESE of Escalante
M_L 3.1	January 28	5:40 a.m.	9 miles ESE of Snowville
M_L 3.1	February 6	6:46 a.m.	4 miles W of Hiawatha; felt at the U.S. Fuel Company Gentry Mtn. mine
M_L 3.4	February 21	4:23 a.m.	3 miles W of Salina; felt in Axtell, Redmond, and Salina (MMI IV), and at Aurora and Centerfield (MMI III)
M_C 3.1	February 23	2:23 a.m.	32 miles SW of Enterprise
M_L 3.3	March 2	1:41 a.m.	25 miles SSE of Vernal
M_L 3.0	March 15	1:33 p.m.	11 miles NW of Orangeville; felt at the Utah Power & Light Huntington mine
M_L 3.1	March 22	7:59 a.m.	4 miles NNE of Enoch; felt in Enoch
M_L 3.2	March 26	11:42 a.m.	10 miles NNW of Springdale; felt in Zion National Park, Virgin, Hurricane, and St. George

Significant Clusters of Earthquakes

Southwest of Price (coal-mining related): Three clusters of earthquakes make up 30% of the shocks that occurred in the Utah region during the report period.

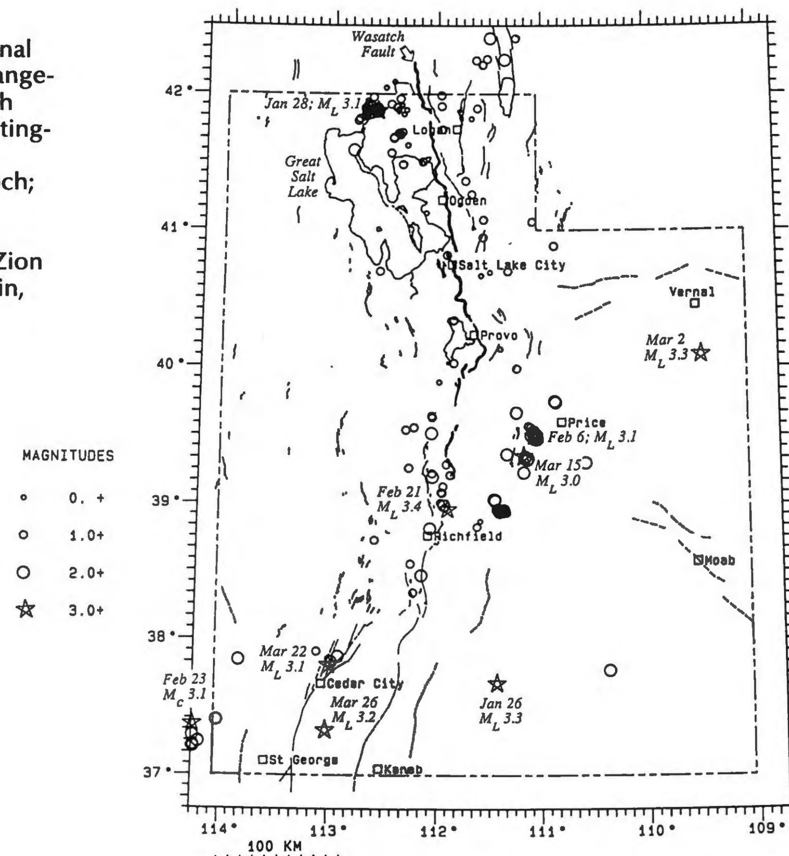
— 30 earthquakes, magnitude 1.9 to 3.1, occurred in the vicinity of the U.S. Fuel Company Gentry Mountain mine complex;

— 6 earthquakes, magnitude 2.0 to 3.0, occurred in the vicinity of the Utah Power & Light Huntington mine complex; and

— 27 earthquakes, magnitude 1.5 to 2.7, occurred in the vicinity of the Southern Utah Fuel Company Confusion Canyon mine complex.

North of the Great Salt Lake: A series of 45 earthquakes occurred NE of the northern arm of the Great Salt Lake (65 km WNW of Logan), ranging in magnitude from 1.0 to 2.6. This is one of the most seismically active regions of Utah, and the observed activity is not unusual.

Additional information on earthquakes within the Utah region is available from the University of Utah Seismograph Stations.



New Publications of the Utah Geological Survey

Quaternary geology of the Black Rock Desert, Millard County, Utah, by C.G. Oviatt, 23 p., 1 pl., 1:100,000, 1991, Special Study 73 **$6.00**

Paleoseismology of Utah Volume 1: Fault behavior and earthquake recurrence on the Provo segment of the Wasatch fault zone at Mapleton, Utah County, Utah, by W.R. Lund, D.P. Schwartz, W.E. Mulvey, K.E. Budding, and B.D. Black, 41 p., 1991, Special Study 75 **$7.00**

Paleoseismology of Utah Volume 2: Paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah and the Pole Patch trench site, Pleasant View, Utah, by S.F. Personius, 39 p., 1991, Special Study 76 **$6.00**

Geologic map of the Mount Escalante quadrangle, Iron County, Utah, by M.A. Siders, 9 p., 2 pl., 1:24,000, 1990, Map 131 **$5.00**

Landslide map of Utah, by K.M. Harty, 28 p., 2 sheets, 1:500,000, Map 133 **$7.00**

The industrial rock and mineral industry in Utah, 1990, by B.T. Tripp, 31 p., 1991, Circular 82 **$5.00**

A guide to reducing losses from future earthquakes in Utah - consensus document, edited by W.J. Arabasz, 30 p., April 1991, Miscellaneous Publication 91-1 **$5.00**

Characteristics of acid-sulfate alteration in the Marysvale-Pioche mineral belt: a guide to gold mineralization, by A.J.B. Thompson, 29 p., April 1991, Miscellaneous Publication 91-2 **$5.00**

Soils as a tool for applied Quaternary geology, by P.W. Birkeland, M.N. Machette, and K.M. Haller, 63 p., April 1991, Miscellaneous Publication 91-3 **$6.50**

Wood Ranch thermal anomaly, Iron County, Utah, by H.P. Ross, R.E. Blackett, and M.A. Shubat, 28 p., June 1991, Miscellaneous Publication 91-4 **$5.50**

Petrology, age, geochemistry, and correlation of the Tertiary volcanic rocks of the Awapa Plateau, Garfield, Piute, and Wayne Counties, Utah, by S.R. Mattox, 46 p., 1 pl., 1:100,000, June 1991, Miscellaneous Publication 91-5 **$6.25**

Geology and scenery of the central Wasatch Range, Salt Lake and Summit Counties, by Miriam Bugden, 17 p., 1991, Public Information Series 9 **$6.00**

Earthquake awareness and risk reduction in Utah, by Utah State University, 24-minute videotape, May 1991, Public Information Series 10 **$6.00**

Earthquake fault map of a portion of Utah County, Utah, by UGS staff, 1 p., May 1991, Public Information Series 11, **free**

Permitted mine locations and mineral processing plants in Utah, compiled by Roger Lee Bon, 1 pl., 1:750,000, July 1991, Public Information Series 12 **$1.50**

Geologic map of the Pilot Peak quadrangle, Box Elder County, Utah and Elko County, Nevada, by D.M. Miller and A.P. Lush, 59 p., 2 pl, scale 1:24,000, March 1991, Open-File Report 208 **$7.80**

Geologic map of the Copper Creek Benches quadrangle, Garfield County, Utah, by M.D. Jackson and J.S. Noller, 44 p., 2 pl., 1:24,000, March 1991, Open-File Report 209 **$5.50**

Zeolite minerals in Utah, by B.H. Mayes and B.T. Tripp, 170 p., 1 pl., 1:750,000, May 1991, Open-File Report 210 **$15.00**

Places with hazards; a teacher's handbook on natural hazards in Utah: The earthquake hazard in Utah, by S.N. Eldredge, 83 p., June 1991, Open-File Report 211A **$6.80**
Part II - slide set for 211A; 40 slides, 6 p. **$15.00**

Places with hazards; a teacher's handbook on natural hazards in Utah: Slope failures in Utah, by S.N. Eldredge, 45 p., June 1991, Open-File Report 211B **$3.70**
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Places with hazards; a teacher's handbook on natural hazards in Utah: Problem soil and rock in Utah, by S.N. Eldredge and W.E. Mulvey, 21 p., June 1991, Open-File Report 211C **$1.75**
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April 1991 Publications List with update is still available on request to UGS Sales at our new address.

The New Gravity Map of Utah--An Overview of Its Usefulness for Geologic Studies

By

[1]Kenneth L. Cook, [2]Don R. Mabey and [3]Viki Bankey

Gravity, defined as the attraction that acts between two bodies because of their mass, is continually experienced by everyone and generally accepted as one of the constants in our lives. But the attraction exerted upon us by the earth is not constant. It varies with our location upon the earth and to a much smaller amount with time. These variations can provide information on the geology and resources buried beneath the surface of the earth. For nearly a century, measurements of gravity have been made in Utah to define gravity variations over the state and determine their geological significance. These measurements have been used to compile a gravity map of Utah, which was recently published by the Utah Geological Survey.

EARLY STUDIES OF GRAVITY

Our understanding of gravity begins with Galileo (1564-1642), who discovered the laws of freely falling bodies and of pendular motion. He demonstrated that two cannon balls, one large and one small, released simultaneously would be subjected to the same gravitational acceleration and hit the ground simultaneously irrespective of their masses. This experimental result was contrary to the philosophy of Aristotle (384-322 B.C.) being taught in Galileo's time, which asserted that heavy bodies fall faster than lighter ones. Sir Isaac Newton (1642-1727), using the contributions of Galileo and Johannes Kepler's (1571-1630) three laws of planetary motion about the sun, formulated the law of universal gravitation: the force of attraction between two bodies depends upon the mass (or amount of matter) of each body and the distance between their centers of mass.

All early measurements of gravity were made with the pendulum. Galileo discovered the law of pendular motion in 1584, and Christian Huyghens (1629-1695) first used pendulums in clocks in 1657. In 1672, Jean Richer observed that his astronomical pendulum clock ran slower in Cayenne, French Guiana than in Paris, France. Newton, in his *Mathematica Principia,* published in 1687, explained that this observed effect was caused by a difference of the earth's gravity at these two locations and also must be due to the departure of the earth from spherical form. Pierre Bouguer (1698-1759) led an expedition to Peru for the French Academy of Sciences during the years 1735-1743 principally to measure a meridian of arc, by geodetic means, to demonstrate that the earth is shaped like an oblate spheroid, as Newton had foretold; but Bouguer also made measurements of gravity in Peru, using pendulums (Eckhardt, 1949). His name is perpetuated in the designation of "Bouguer corrections" and "Bouguer anomalies" which are used in processing and geological interpretation of gravity data.

By measuring the period of swing of a pendulum, the absolute value of the gravitational acceleration at the location of the pendulum can be determined. Gravity measurements using pendulums are time-consuming because to obtain the desired accuracy it is necessary to allow the pendulums to swing for several hours to determine the average period. Measurements of gravity differences were greatly accelerated by the advent of the gravity meter, or gravimeter, during the 1930s. By the mid-1940s, nearly all measurements of gravity differences were made with gravity meters which measure differences of gravity and not the absolute value of gravity. Their basic principle involves the measurement of the change in the length of a spring on which a mass is suspended; and the change in position of the mass is proportional to changes in gravity. Millions of gravity measurements have been made worldwide with these gravity meters.

UNIT OF ACCELERATION

In most gravity studies, the unit of acceleration is designated the "Gal," in honor of Galileo, and is defined as "one centimeter per second per second" (1 cm/sec/sec). In Utah, a freely falling body has an acceleration of approximately 980 Gals, or 980 cm/sec/sec, which is equal to about 32 feet per second per second. The measured value of gravity at U.S. Coast and Geodetic Survey (USC&GS) pendulum station 49, located in the Temple Grounds in Salt Lake City and established in 1894, is 979.806 Gals. A body falling freely from rest in the downtown Salt Lake City area would be falling at an approximate speed of 980 cm/sec (or about 32 ft/sec) at the end of the first second; 1,960 cm/sec (or 64 ft/sec) at the end of the second second; 2,940 cm/sec (or 96 ft/sec) at the end of the third second, and so on.

Differences in gravity caused by geological features are much smaller than 1 Gal. Consequently the unit of acceleration commonly used in geologic investigations is the "milliGal" (abbreviated "mGal"), which is defined as one-thousandth of a Gal.

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VARIATIONS IN THE EARTH'S GRAVITY

Over the surface of the earth, the major variations of the earth's gravity are the result of changes in elevation or latitude, or both. The gravity change associated with the difference in elevation between two observation sites is the result of two effects. The "free-air effect" measured from a balloon suspended above the earth is a decrease of gravity of about 0.09 mGal for each foot increase in elevation. Thus gravity is about 9 mGal less 100 feet above the ground than at a point on the ground directly below. However, if the gravity observation is made on top of an extensive 100-foot-thick slab of rock rather than in a balloon, the slab of rock exerts its own gravity attraction that increases the measured gravity attraction, and this effect is named the "Bouguer effect", in honor of Pierre Bouguer. If the slab is as dense as the average rock in the earth's crust, the attraction will be about 0.03 mGal for each foot of thickness or about 3 mGal for the 100-foot slab. In summary, the gravity measured on top of the slab will be 9 mGal less because of the increased elevation but 3 mGal more because of the attraction of the slab giving a net decrease of 6 mGal (0.06 mGal per foot of elevation increase) relative to a measurement made at the elevation of the base of the slab. In Utah, because the total difference between the lowest and highest elevation in the state is about 10,000 feet, the corresponding maximum variation in gravity due to the two effects is about 10,000 feet times 0.06 mGal/foot, or about 600 mGal.

The gravity change associated with the difference of latitude between two observation sites is the result of (1) the oblate spheroidal shape of the earth and (2) the centrifugal acceleration due to the earth's rotation on its axis. In Utah, this latitude effect causes an increase of gravity of about 1 mGal per mile from south to north. The total latitude effect between the Utah-Arizona border and the Utah-Idaho border is about 442 mGal.

Gravity also varies a small amount with time as a result of tidal attraction of the moon and sun upon the earth, with an approximate 12.5-hour cycle. In Utah, this tidal effect can reach about 0.3 mGal at spring tides and a lesser amount at neap tides.

Variations in the earth's gravity caused by these effects--namely the latitude effect, the two effects related to changes in elevation, and the tidal effect--can be accurately computed. Measured gravity values are adjusted for these effects, and adjusted gravity values are compared with each other to examine variations related to geology.

The total acceleration of gravity in Utah is about 980,000 mGal, while the largest variations of gravity in Utah due to the latitude effect is about 442 mGal and due to the total or combined elevation correction effect is about 600 mGal, or about 0.045 percent and 0.061 percent, respectively, of the total observed gravity value.

Weight is proportional to mass and acceleration. Thus the weight of the object will change according to changes in gravity at various locations of latitude and elevation in Utah. The difference for a 200-pound person would be a little more than 2 ounces between the top of Navajo Mountain near the Utah-Arizona border and the valley floors on the Utah-Idaho border.

Superimposed on the variations in the earth's gravity related to elevation and latitude changes are much smaller variations caused by differences in the density of the material in the earth underlying the observation sites. When the effects of variations in latitude and elevation and some smaller effects such as irregularities in the land surface (terrain corrections) are computed and removed from a network of gravity measurements, the remaining differences in the measured gravity are used to infer variations in the mass of rocks underlying the observation sites (gravity stations) and thus the geology of the subsurface. Variations of gravity related to geology, usually called gravity anomalies, can identify features as small as the thickness of sand and gravel in a stream channel or as large as the thickness and composition of the earth's crust.

Figure 1. Making a gravity measurement in Utah with a Worden gravity meter; operator Stephen R. Gray, 1967.

GRAVITY STUDIES IN UTAH

The first measurements of gravity in Utah were three made by the U.S. Coast and Geodetic Survey (USC&GS) in 1894. They were part of a profile of 26 gravity stations extending across the United States east of Salt Lake City and were designed to determine the significance of variations in gravity that were detected using a newly developed pendulum. The uncertainty of the gravity measurement was about one thousand times that of present-day gravity-measuring instruments. The USC&GS did not establish any additional gravity stations in Utah until 1948.

The Department of Geophysics at the University of Utah obtained its first gravity meter in 1950. Since then the staff and students have made tens of thousands of gravity measurements in Utah. The U.S. Geological Survey (USGS) began a series of gravity surveys in Utah in the 1950s that have provided regional gravity coverage over large parts of the state. The Utah Geological Survey (UGS) supported several gravity surveys as part of investigations of geothermal resources. The Department of Defense has made widely-spaced gravity observations over Utah and more detailed surveys in

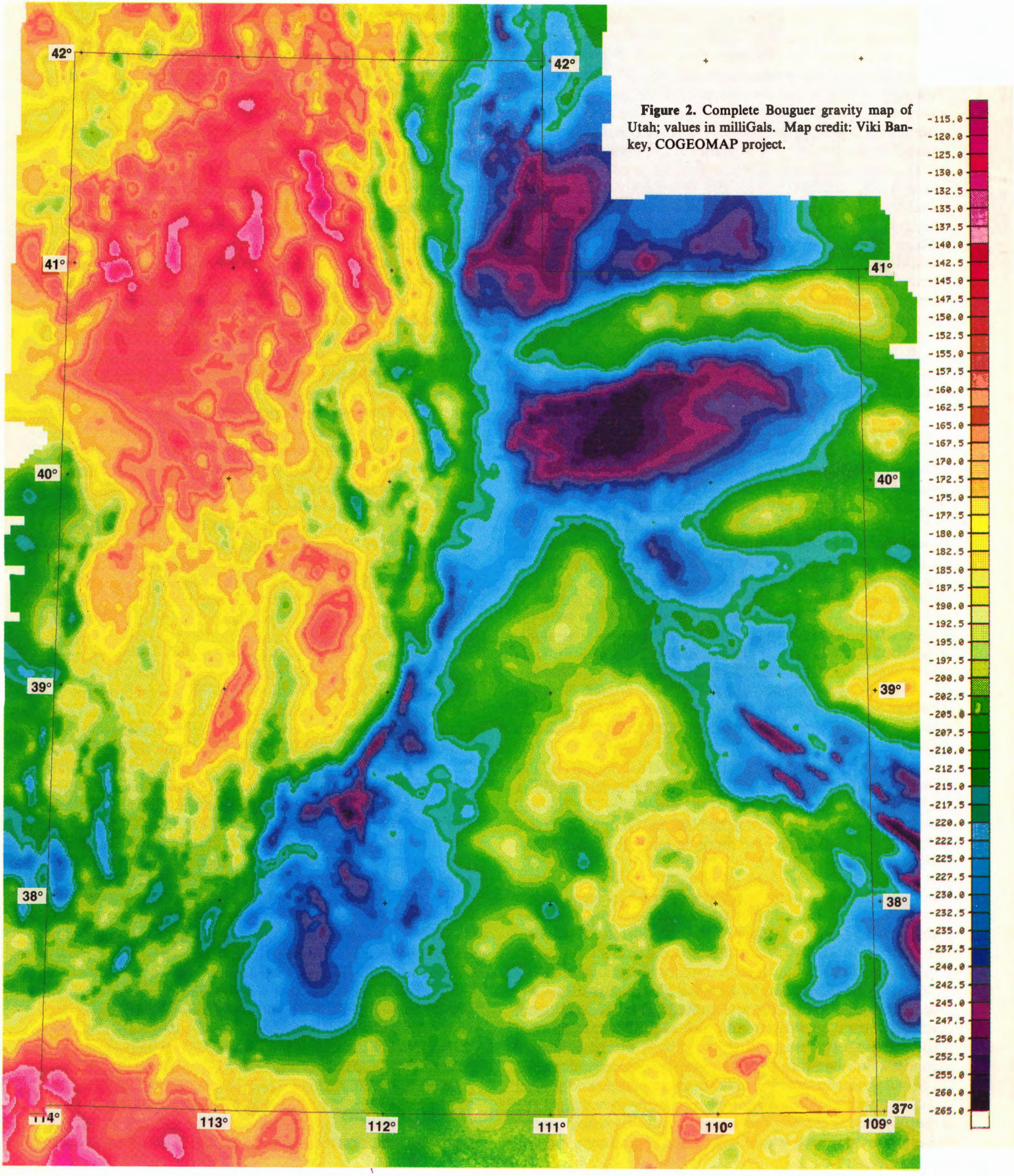

Figure 2. Complete Bouguer gravity map of Utah; values in milliGals. Map credit: Viki Bankey, COGEOMAP project.

areas that were considered for the location of MX missiles. Essentially all of these gravity measurements along with smaller data sets obtained by other sources are available to the public from the National Geophysical Data Center (NGDC) of the National Oceanographic and Atmospheric Administration (NOAA), in Boulder, Colorado. In addition, many more gravity observations have been made by or for companies exploring for energy and mineral resources, but most of these data are not available to the public.

The first published gravity map of Utah based on 27,000 stations was produced at a scale of 1:1,000,000 (Cook and others, 1975). Although this map was a major contribution, the lack of terrain corrections limited its usefulness in areas of high topographic relief. The data set upon which the map was based was not released to the public at that time because permission had not yet been obtained from several petroleum companies for the publication of the principal facts of their gravity data that had been used in the map compilation.

The need for a complete Bouguer gravity anomaly map of Utah (which includes terrain corrections) and a supporting digital data set was recognized by the University of Utah, the UGS and the USGS. In 1985, a cooperative program was begun whereby: 1) Cook would compile the gravity data in the University of Utah files, 2) the USGS would combine these with data in the USGS and NGDC files to produce a complete Bouguer gravity anomaly map of Utah and digital data set (this became the responsibility of Viki Bankey of the USGS), 3) Cook and Don R. Mabey (UGS) would edit the map and data set, 4) the UGS would publish the map, and 5) the USGS would make the data set available to the public. The scale of 1:500,000 was selected for the map because that is the scale of the geology map of Utah published by the UGS. Michael DePangher assisted Cook in the compilation and editing.

The 1989 gravity map has been published as UGS Map 122 (Cook and others, 1989); and the digital data set is available from the U. S. Geological Survey, EROS Data Center, Data Services Officer, Sioux Falls, South Dakota 57198, as *Principal Facts of Gravity Stations Used for the Complete Bouguer Gravity Anomaly Map of Utah,* by Kenneth L. Cook, Viki Bankey, Don R. Mabey and Michael DePangher (Cook and others, 1990).

About 42,000 gravity stations were used to compile the new gravity map and are contained in the digital data set. About 33,500 stations were from files of the University of Utah and about 8,500 stations were from the National Geophysical Data Center and the USGS. The merging and processing of the data were done by Bankey.

COMPLETE BOUGUER GRAVITY ANOMALY VALUES

Gravity measurements -- Relative gravity measurements are commonly made to 0.01 mGal. With great care and detail relative Bouguer gravity anomaly values as small as 0.1 mGal can be defined and analyzed. Most gravity surveys that have been incorporated into the Utah gravity map were designed to define anomalies several milliGals in amplitude and several miles in extent. To obtain an absolute gravity value of the accuracy used in the map, each measurement is referenced to a base gravity station where the value of absolute gravity is known from previous observations. A Utah network of gravity base stations was established in 1967 by the Gravity Division of the Army Topographic Command (TOPO-COM), formerly Army Map Service, in cooperation with the Department of Geophysics of the University of Utah. The network consists of 46 stations referenced to an international datum. Descriptions of the base stations and the absolute gravity value at each station were published by the UGS (Cook and others, 1971).

To obtain an observed gravity value at each station, the measured gravity value is adjusted for the computed or measured effects of the attraction of the moon and sun at the time and location of the measurement (tidal corrections) and any drift in the instrument due to temperature changes or other effects.

Computation of the complete Bouguer gravity anomaly values -- Computing the complete Bouguer gravity anomaly values calculates and removes the effects of large variations due to the different latitudes and elevations of the gravity stations. The location and elevation of each station must be determined as well as the topography within 100 miles (166.7 km) to compute the terrain correction at the map scale. Reduced gravity values are then compared to determine "gravity anomalies," or "departures from the norm". These resulting gravity anomalies are caused by density contrasts related to geologic features.

The standard method of computing complete Bouguer gravity anomaly values involves a series of steps that reduce the gravity values for each station to a common datum or level, sea level in our compilation. First, the observed absolute gravity value of the field station is obtained by measuring the difference between the field station and one of the base stations in the Utah network, and calculating and removing a correction for the tidal effect and instrument drift during the time between the two measurements. Second, the resulting observed absolute gravity value of the field station is corrected for the latitude effect, which is based on an international gravity formula that gives the theoretical gravity at sea level for any given value of latitude. Third, corrections for the "free-air effect" and "Bouguer effect," caused by the elevation of the station above sea level, are made to reduce the gravity data to a mean sea-level datum (a correction for the effect of the earth's curvature is also included). In our calculation for the gravity map of Utah, a density of 2.67 grams per cubic centimeter was assumed for the material between sea level and the station. Gravity values resulting from this third step are designated "simple Bouguer gravity anomaly values". Fourth, the terrain corrections for each station, computed for a total radial distance of 100 miles (166.7 km) from each station, are added algebraically to give the complete Bouguer gravity anomaly value. Until the advent of digital computers, and the compilation of digital topography for Utah used to compute the terrain corrections, these computations took several hours for each gravity station.

Causes of gravity anomalies -- The complete Bouguer gravity anomaly value at a station is most affected by masses near and below the station. A small mass buried a short distance below the station has the same effect on the measured gravity anomaly as a larger mass buried more deeply. By using gravity observations alone, a unique solution for the disturbing mass producing a gravity anomaly cannot be obtained. However, if a profile or grid of observations is made, some conclusions can be drawn as to the size, shape, and depth of burial of a mass that is producing a gravity effect; therefore, gravity anomaly values are usually used as a map of contoured values or as a profile of values. The geologic interpretation of gravity anomalies usually involves determining a geologic model that is reasonable, consistent with all other available information, and capable of producing the measured gravity anomaly. The more geologic information available, the more useful the interpretation is likely to be.

UTAH GRAVITY MAP

About 42,000 gravity stations were used to prepare the gravity map of Utah averaging about one station per two square miles. The gravity stations are not uniformly distributed over the state, and the gravity anomalies are not uniformly defined. Coverage is most detailed in areas where local gravity anomalies of particular interest exist. The published map shows each gravity station location and contours of the complete Bouguer gravity anomaly values at a 5-milliGal contour interval. A color version of the complete Bouguer gravity anomaly map was prepared by Viki Bankey for this report (figure 2). The use of color provides an excellent presentation of the changes in level of complete Bouguer gravity anomaly values across Utah. The color map has about 55 separate colors with a color contour interval of 2.5 mGal. However, the top and bottom 3-4 colors on the scale are not linear; that is, the contour interval changes to 5 mGal, which is double that on the rest of the map. The highest gravity values are red; the lowest are violet.

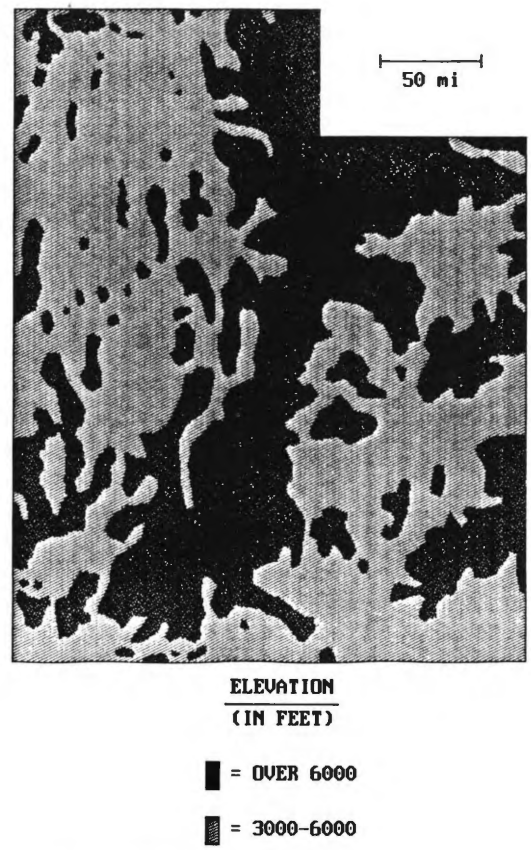

Figure 3. Regional topography of Utah.

Regional Features

Isostatic features -- All of the complete Bouguer gravity anomaly values in Utah are negative: the values range from a high of minus 120 mGal on the Promontory Mountains north of Great Salt Lake to lows of less than minus 255 mGal in several areas of the state. A comparison of the gravity map and a regional topographic map (figure 3) shows the general inverse correlation between Bouguer anomaly values and regional topography.

The highest gravity values correspond to the topographic low in northwestern Utah containing the Great Salt Lake basin and in the topographic low in the Virgin River drainage in the southwest corner of the state. Low values occur over the high plateaus and the area east of the Wasatch Front. This inverse correlation between Bouguer anomaly values and regional topography reflects isostasy.

Isostasy is defined as the state of equilibrium in the earth's crust wherein large blocks of the rigid surface crust appear to float on a more dense fluid layer. Extensive areas of high-surface elevation are underlain and buoyed up by compensating mass deficiencies about equal to the mass of rock constituting the topography. Northwestern Utah provides an impressive illustration of the functioning of isostasy. The variations in elevation of the shorelines produced by Lake Bonneville show that when the lake filled with about 1000 feet of water, the lake basin subsided as much as 240 feet due to the weight of the water depressing the rigid crust into the fluid layer. With the water gone, the basin rebounded to its current elevation.

The complete Bouguer gravity anomaly values have been corrected for the elevation of each gravity station and the attraction of the material between the station and sea level but not for the negative compensating mass lying below sea level that is supporting the material lying above sea level. Thus in a region of Utah in approximate isostatic equilibrium, the general level of the complete Bouguer gravity anomaly values will be negative by an amount equal to the effect of the compensating mass lying below sea level. This is illustrated by the Bouguer anomaly values in northwest Utah. The average elevation around Great Salt Lake and the Great Salt Lake Desert is about 4500 feet above sea level. The gravity anomaly produced by a slab of material 4500 feet thick having an average density of the upper earth's crust of 2.67 g/cc is 150 mGal. The average Bouguer gravity anomaly value in the area is about minus 150 mGal, indicating a compensating mass deficiency exists at depth below sea level that is about equal to the mass of the material between the surface and sea level.

Free-air and isostatic anomaly values, which do not reflect regional topography as strongly as do Bouguer anomaly values, are useful in some investigations. The free-air anomaly does not include a correction for the mass between the gravity station and sea level, and, if this mass is compensated by an equivalent mass deficiency below sea level, the free-air anomaly value will be near zero. Free-air anomalies have a strong correlation with local variations in elevation that are not in isostatic equilibrium, and in most of Utah are not an effective tool in geologic studies. Isostatic anomalies are computed by assuming a model of isostatic equilibrium and using the surface topography to compute the gravity effect of the model. The isostatic anomaly value at a station is obtained by adding the computed gravity effect of the model

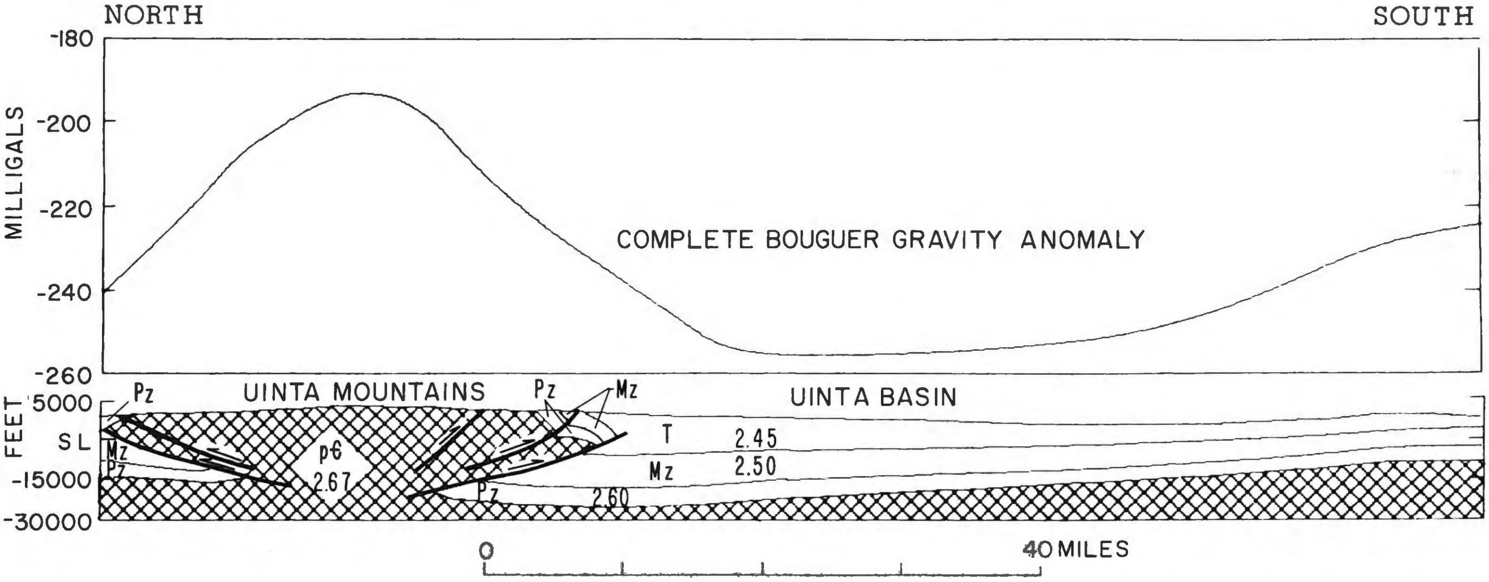

Figure 4. Complete Bouguer gravity anomaly and generalized geologic profile across the Uinta Mountains and Uinta Basin, Utah. Geologic section modified from Gries (1983) and Smith and Cook (1985). T, Tertiary; Mz, Mesozoic; Pz, Paleozoic; pC, Precambrian. Assumed densities are in g/cc.

(designated the "isostatic correction") to the complete Bouguer gravity anomaly value. The isostatic anomaly values can reflect both departures from isostatic equilibrium and departures from the assumed model.

Only broad topographic features are in isostatic balance; narrow topographic features are not locally compensated but are supported by the strength of the earth's crust. The size of the mass that can be supported varies with the strength of the crust. The crust in the Basin and Range province of western Utah is relatively weak. Here, loads the width of the average mountain ranges are supported by the strength of the crust, but topographic features several times as wide are not. The crust in the Colorado Plateau is stronger, and topographic features as large as the Uinta Basin (over 50 miles wide) are not in local isostatic equilibrium. Detailed analysis of the relation between regional topography and complete Bouguer gravity anomalies in Utah promises to provide important information on the earth's crust.

Regional gravity anomalies -- Several large gravity anomalies in Utah reflect relief on the Precambrian basement rock that is generally more dense than the overlying sedimentary rock. The two most prominent anomalies are the gravity low over the Uinta Basin and the companion gravity high over the uplifted Precambrian rocks of the Uinta Mountains (figure 4). The 60-mGal low over the Uinta Basin is produced by over 30,000 feet of less dense sedimentary rocks filling the basin (Smith and Cook, 1985). Two gravity highs that appear to be associated with basement topographic highs are shown on a gravity profile that extends east-southeastward across Utah and passes through the Gunnison area at approximately latitude 39° N (figure 5). A gravity high on the western edge of the Pavant Range and Canyon Mountains lies partly over the consolidated rocks of the two ranges and partly over the unconsolidated rocks of the basin area to the west and thus cannot be explained by the surface geology. A regional seismic-reflection profile across the anomaly defines a broad structural high approximately coincident with the gravity high. Another large gravity high reflects uplifted basement rocks under the San Rafael Swell. In eastern Utah, a few gravity anomalies appear to be produced by mass anomalies within the Precambrian basement. In western Utah, similar anomalies reflecting intrabasement mass anomalies may exist but are difficult to identify because of the complex anomalies associated with younger, shallower rocks and structures.

In western Utah, the gravity expression of structures related to the Sevier orogeny and metamorphic core complexes are not well defined by the generally sparse data in the ranges and are difficult to isolate from the larger Basin and Range structures in the valleys. Some of the overthrust faults juxtapose rocks of significantly different densities, and the cur-

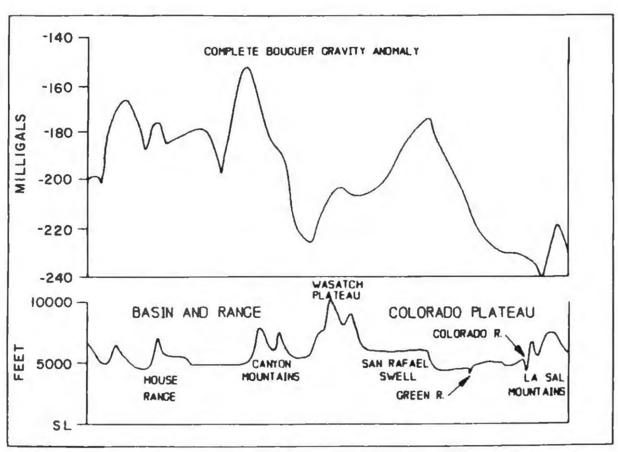

Figure 5. Complete Bouguer gravity anomaly and topography along an east-southeastward-trending profile across Utah that extends through the Gunnison area at approximately latitude 39° N.

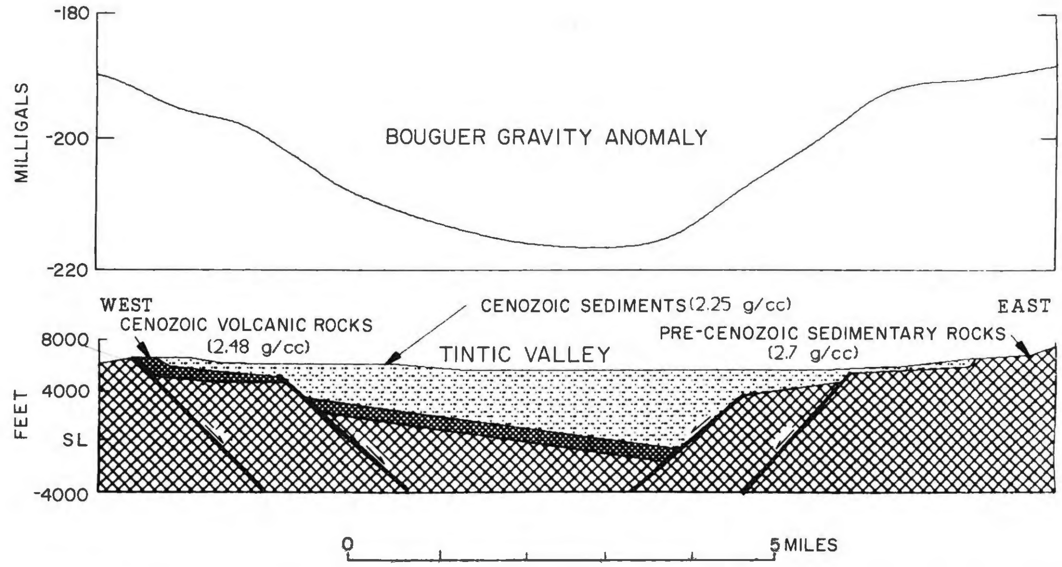

Figure 6. Bouguer gravity anomaly and interpretive geologic cross section across Tintic Valley, Utah. Modified from Mabey and Morris (1967).

rent configuration of the faults is partly controlled by underlying structures that have gravity expression. Tertiary intrusions into metamorphic complexes produce gravity lows, and the detachment or denudation faults associated with the complexes produce a variety of gravity anomalies. Detailed analysis of the gravity data can contribute to studies of the overthrust belt and of the metamorphic core complexes.

Local Features

Numerous gravity anomalies of small areal extent occur in Utah. These anomalies reflect mass anomalies in the upper crust and often can be interpreted in terms of geologic features of direct interest to resource investigations and other geologic studies.

Basin and Range features -- Over the Basin and Range province of western Utah, the dominant local gravity anomalies are generally north-trending highs and lows. The anomalies are produced by the density contrast between the relatively low-density, unconsolidated or poorly consolidated, sedimentary rocks of Cenozoic age, commonly called "valley fill," that underlie the valleys and the more dense consolidated rocks, commonly called "bedrock," that form most of the ranges. The amplitude of the gravity anomaly from the crest of the high to the trough of the low is often over 20 mGal and some are more than 40 mGal. The most important factor determining the amplitude of the gravity anomaly produced by the low-density sedimentary rocks is the total negative mass anomaly represented by the valley fill. Thus, a small thickness of valley fill of very low density will produce the same gravity low as a greater thickness of valley fill of higher density. Many of the valleys are grabens or half-grabens bounded on one or both sides by normal faults across which the sediments thicken abruptly. These faults are reflected by steepened gravity gradients in linear zones parallel to the axes of the valleys.

Qualitative interpretation of the Basin and Range gravity lows usually involves the following: 1) inferring the relative thickness of the valley fill from the relative amplitude of the gravity low, 2) inferring the location of the thickest valley fill and the general configuration of the bedrock under the valley from the location of the axis of the gravity low and the general form of the anomaly, 3) identifying buried bedrock ridges within the valleys as indicated by relative gravity highs within the valley low, and 4) inferring the approximate location of normal faults from the location of the steep, gravity gradients that form linear patterns.

Quantitative interpretation of the gravity lows over the Basin and Range valleys involves three basic steps: 1) isolating the gravity low caused by basin fill from other unrelated gravity anomalies, 2) determining or assuming the densities of the basin fill and the bedrock (which result in a "density contrast" or density difference between the fill and bedrock) to develop a density model, 3) determining one or more models of the basin fill that has a density configuration that will produce the measured anomaly, fits any constraints imposed by information about the subsurface from drill-hole or other geophysical data, and is geologically reasonable. Isolating the anomaly is commonly accomplished by assuming that the gravity variation not related to the basin fill is more extensive than that produced by the valley and removing a simple regional gravity surface suggested by the gravity anomaly values measured on bedrock in the ranges surrounding the valley. Occasionally, the source of the broader anomalies can be geologically inferred (thickening of the crust, for example) and the total gravity anomaly analyzed by modelling the larger source as well as the valley.

The primary limitation on the interpretation of the Basin and Range gravity lows is the complex and largely unknown density of the valley fill. The major Cenozoic basins in western Utah have a complex history that has produced a complex distribution of sedimentary and volcanic rocks having a wide range of densities. The coarse, poorly sorted sediments near the range fronts are more dense than the finer, commonly lacustrine, sediments in the central part of the basin. Density also usually increases with depth as the sediments become more compacted and indurated. In some basins, relatively dense volcanic rocks are interbedded with the sediments of the basin fill. In none of the large basins in western Utah is enough information available on the density of the basin fill to define the density distribution within the sedimentary fill. The simplest quantitative interpretations assume a single density contrast between the valley fill and the bedrock. This density contrast may be based on experience in similar basins, information from drill holes on the density of the fill, or a computed density based on a known thickness of fill at one or more points within the basin. More sophisticated interpretations attempt to model systematic density variations within the fill related to increasing depth and degree of sorting.

Modeling of the gravity anomaly may be either three-dimensional by modeling the entire anomaly or two-dimensional by modeling a profile. Because many gravity lows are elongated parallel to the trend of Basin and Range structure, two-dimensional modeling of a profile normal to this trend is often effective in inferring basin structure. The location of faults can often be more effectively determined along a profile than with more complex models developed with three-dimensional modeling. A refinement of two-dimensional modeling includes an assumption of the extent of the body normal to the profile (2-1/2 dimensional modeling). Gravity surveys of Basin and Range valleys often consist of stations along profiles normal to the axis of the valley to provide data for profile analysis. An interpreted profile across Tintic Valley (figure 6) shows an example of a two-dimensional analysis of the gravity anomaly in a typical Basin and Range valley.

Figure 7 shows (1) a partially terrain-corrected Bouguer gravity anomaly (for which the terrain corrections were made out to a radial distance of 8.44 km (5.3 miles) from each station), (2) assumed regional gravity, (3) residual gravity, and (4) an interpretive geologic cross section across the Wasatch rift along a profile that extends eastward from Little Mountain South, to eastern Ogden Canyon in the Wasatch Range. To model near-surface geologic features along the profile, the assumed regional gravity (caused by deeper, regional density contrasts within the crust and/or upper mantle) was subtracted from the terrain-corrected Bouguer gravity anomaly values, and the resulting residual gravity was plotted and used in the model. For the interpretive geologic cross section, three computed gravity values are shown on the residual gravity curve based on an assumed density contrast between the valley fill of Cenozoic age and the bedrock along each of the three assumed bedrock surfaces of 0.4, 0.5, or 0.6 g/cc. The total gravity relief due to the graben is about 44 mGal. Although the geologic structures shown are reasonable, it must be emphasized that instead of the few faults which are postulated, a series of smaller step faults will give similar results for the computed gravity. The thickness of the valley fill calculated by using the largest assumed average density contrast (0.6 g/cc) between the bedrock and valley fill is about 7600 feet (i.e., bedrock surface is about 3400 feet below sea level). Two independent reflection seismic surveys in the general area of this profile indicated that the depth to the basement rock (i.e., thickness of the valley fill) might be "as much as 6000 feet" and "about 6200 feet;" these estimated depths were based on the deepest reflector horizon observed in each of the seismic surveys. Low compressional seismic velocities that extend to considerable depth indicate that the assumed average density contrast of 0.6 g/cc could be too low. If so, the estimated thickness of the valley fill from this model (7600 feet) would be too great. On the other hand, if the deepest seismic reflections obtained in both reflection seismic surveys came from a possible (but not proven) basalt layer of Cenozoic age, the valley fill of Cenozoic age might be much deeper than the estimates of 6000 or 6200 feet. The location of the two western faults of the graben were indicated by one seismic survey, but the inferred amount of throw of each fault is based on the gravity data.

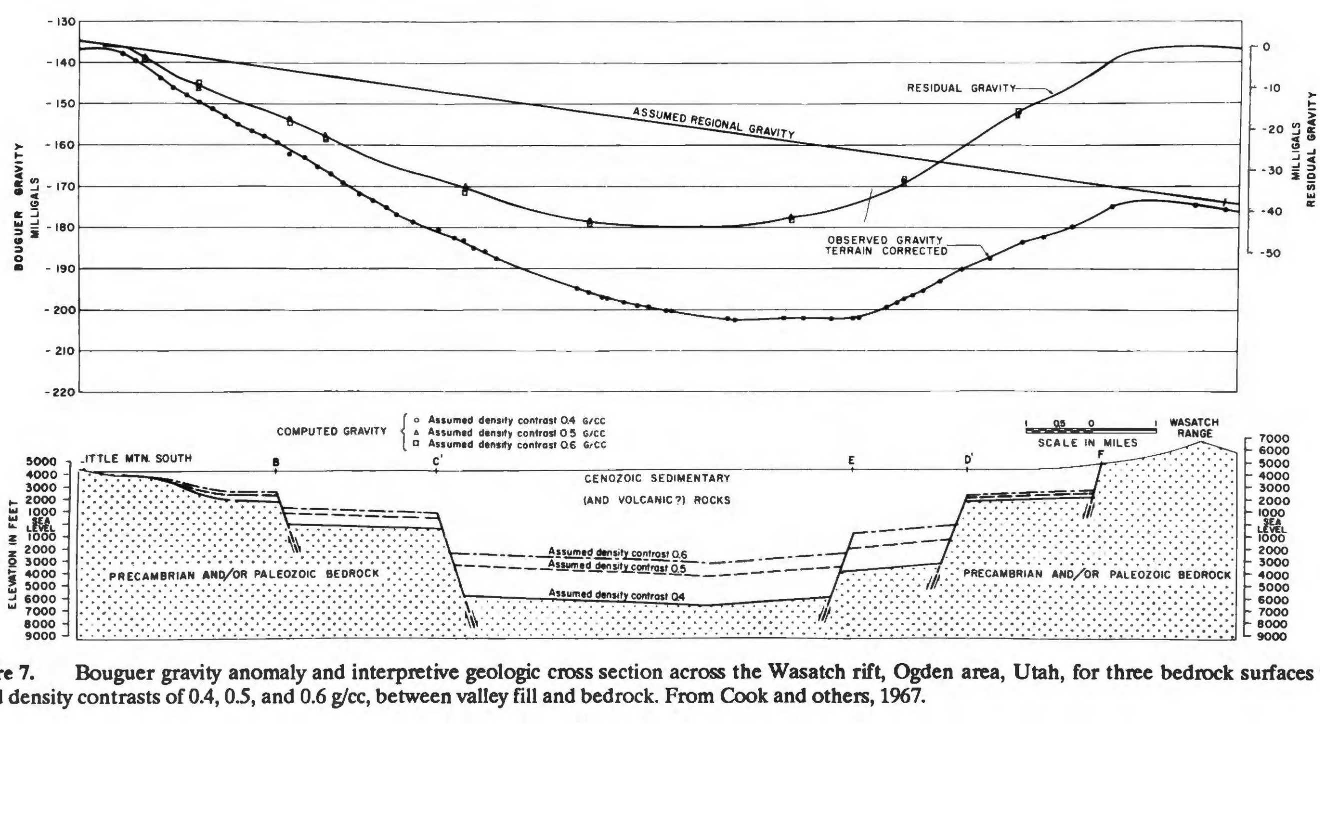

Figure 7. Bouguer gravity anomaly and interpretive geologic cross section across the Wasatch rift, Ogden area, Utah, for three bedrock surfaces with assumed density contrasts of 0.4, 0.5, and 0.6 g/cc, between valley fill and bedrock. From Cook and others, 1967.

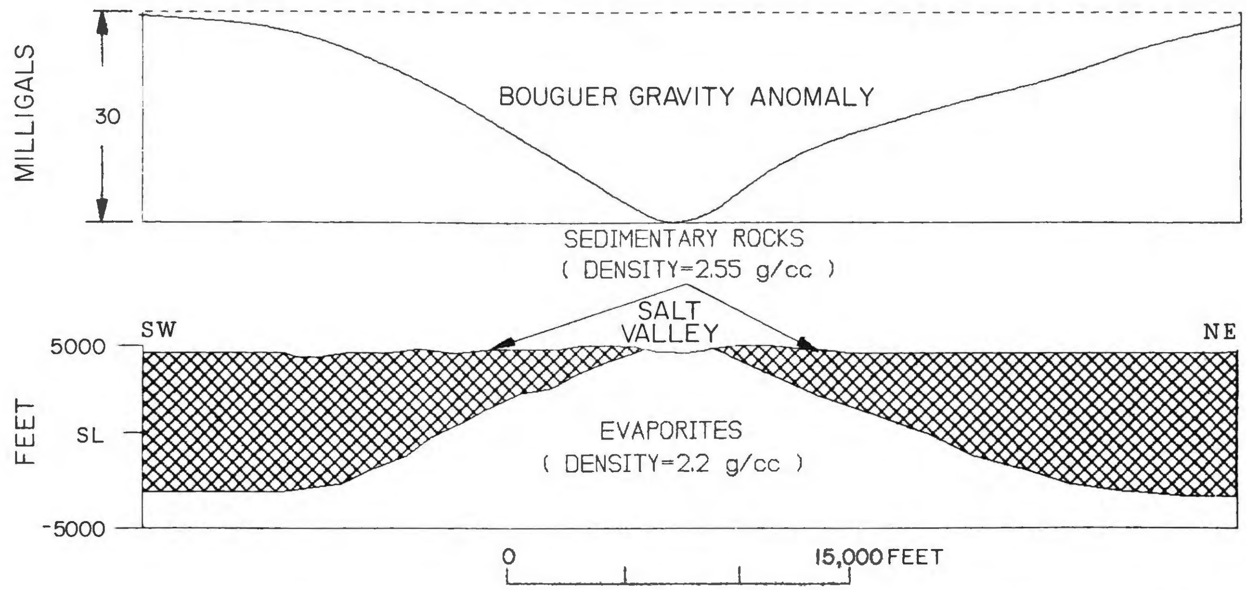

Figure 8. Bouguer gravity anomaly and interpretive geologic cross section across salt anticline, Salt Valley, Arches National Park, Utah. Modified from Case and Joesting (1972).

Salt structures -- The Paradox basin in southeastern Utah contains a sequence of Pennsylvanian evaporites. These evaporites are less dense than the enclosing sedimentary rocks and have risen to form large domes and anticlines. The most prominent of these are several large anticlines trending northwest that later collapsed, forming prominent valleys where ground water dissolved part of the salt. Large gravity lows are produced by the salt remaining in these structures. These lows are the most prominent local anomalies in southeastern Utah. A profile across Salt Valley, in Arches National Park, illustrates a typical gravity anomaly associated with one of these salt structures (figure 8).

In central and northern Utah, the gravity expression of structures related to Middle Jurassic and Tertiary evaporites are less obvious, partly because many of the anomalies are smaller and partly because they are interspersed with anomalies associated with Basin and Range and overthrust structures and are more difficult to identify. Local thickening of salt may produce significant gravity lows in this part of Utah.

Tertiary igneous features -- In southeastern and western Utah, gravity anomalies are produced by intrusive and extrusive Tertiary igneous rocks. The gravity map shows small gravity highs that are associated with three laccolithic mountains of southeastern Utah (the La Sal, Henry, and Abajo Mountains), but no data are available over Navajo Mountain. In southwestern Utah, an elongated gravity high overlies the three northeast-trending outcrops of Iron Mountain, Granite Mountains, and The Three Peaks--laccolith mountains comprising quartz monzonite masses known to be continuous at depth. The contribution of igneous rocks to these anomalies over the laccoliths is difficult to isolate. Tertiary plutons of western Utah are generally slightly less dense than the average density for the Paleozoic sedimentary rocks into which they are commonly intruded. In the ranges where these plutons are exposed, the gravity anomalies are not well defined, but several plutons appear to produce gravity lows. The largest anomaly is a 15-mGal residual gravity low over the batholith in the central part of the Mineral Mountains west of Beaver.

Three west-trending belts of Tertiary volcanic rocks extend across western Utah. The density of these rocks is generally less than that of the Paleozoic rocks exposed in the ranges but greater than that of the Cenozoic sediments that fill the valleys. Some gravity lows can be attributed primarily to the volcanic rocks, and in the volcanic belts these rocks augment the gravity lows in the valleys. Gravity lows are produced by the volcanic rocks filling several of the complex calderas in these belts. The anomalies produced by the caldera fill are usually difficult to isolate from the superimposed Basin and Range structures and underlying plutons.

For a more detailed discussion of both regional and local features shown on the gravity map, the reader is referred to an expanded abstract by Cook and others (1990).

USE OF GRAVITY DATA SET

The published 1:500,000-scale gravity map of Utah can be used with the state geologic map in the quantitative study of the regional geology of the state. The digital data set can be used to produce contour maps at other scales and contour intervals.

The standards of accuracy used in compiling the data set allow the compilation of maps at scales as small as 1:24,000 and contour intervals as small as 2 mGal.

With proper software and a computer, quantitative interpretations can be made of anomalies defined by the data set. Numerous factors are involved in the quantitative interpretation of gravity data, and those not skilled in these interpretations should use caution in attempting them. The data set can be used with other data in a wide variety of studies. Used alone the gravity data cannot provide unique geologic models; however, to be valid, any geologic model must be consistent with the gravity data.

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Staff Changes

Kent Brown, Senior Cartographer and long-time member of the Editorial Staff, begins his new position in Mapping section as Senior Geotech in charge of the plotter and several databases. He finally gets to play with computers as much as he wants.

Suzanne Hecker has left the Applied section to accept a position with the U.S. Geological Survey in Menlo Park, California, She will be missed. But we'll be coming after her if she doesn't finish the Quaternary Tectonics map (see Survey Notes vol. 24 no. 3).

Alex Keith will leave the Survey to pursue career and educational goals in mining engineering. Alec has been in charge of the NCRDS coal program as well as other major programs in the Ecnomic section for many years. Best of luck!

Dr. Milton E. Wadsworth, Dean of the College of Mines at the University of Utah, and a member of the UGS Board, was recently elected president of the American Institute of Mining, Metallurgical and Petroleum Engineers. He will step down as Dean in July.

Patricia Speranza is the new Senior Cartographer for Editorial. Her 6-plus years of map production by hand have given her a renewed interest in computer applications, an area we hope to expand.

Adolph Yonkee, with the Mapping section for a year, has just accepted a teaching position at Weber State University's Department of Geology and will leave us at the start of the school year.

The Economic section has installed two new section chiefs. *Mike Shubat* will head Minerals, while *Tom Chidsey* will have Energy. Congratulations!

The UGS bids farewell to our first Visiting Scientist, *John Hubert,* professor of stratigraphy and sedimentology at the University of Massachusetts. John did field work in central Utah for 6 months. We also welcome our second Visiting Scientist, *Guimei Ai,* a geological engineer, here for 6 months on behalf of China National Petroleum Corporation. She will be learning U.S. technology as well as helping our petroleum people on several projects including the gas atlas project and Duchesne field horizontal drilling study.

SUMMARY OF OIL AND GAS DRILLING IN UTAH, 1989

by

Thomas C. Chidsey, Utah Geological Survey

Michael D. Laine, Utah Division of Oil, Gas and Mining

THIS REPORT IS A SHORT VERSION OF UGS CIRCULAR 83, DUE OUT THIS AUGUST. IT WILL BE THE FIRST OF AN ANNUAL SERIES OF OIL AND GAS SUMMARIES, AND REPRESENTS INVALUABLE HELP FROM STAFF OF THE UTAH DIVISION OF OIL, GAS AND MINING PLUS WELL DATA FROM MANY INDIVIDUALS AND COMPANIES.

In 1989, a total of 87 oil and gas exploration and development wells were completed in Utah. The Uinta and Paradox Basins were the most active areas, resulting in a number of significant wildcat discoveries and field extensions (outposts). Interest continues to be high in these areas and 1990 should show even greater activity. A brief summary of the exploration and development wells for 1989 is given below:

	Exploratory Wells (all types)	Development Wells
Successful Wells -Oil	4	36
Successful Wells - Gas	7	18
Dry Holes	18	4
TOTALS	29	58
Percent successful	37.9%	93.1%

Twenty-nine exploratory wells were completed in Utah during 1989 (see figure 1 and table 1 for well locations). Drilling activity was reported in 7 of Utah's 29 counties in 1989. The most active counties were San Juan with 33 wells, followed by Duchesne and Uintah, each with 19 wells.

Although some of the wildcat and outpost wells were drilled along previously recognized trends or structures, many appear to have been drilled to test new plays or exploration concepts. For example, the unsuccessful Skull Valley Federal 26-3, NE 1/4 NW 1/4 section 26, T. 3 S., R. 9 W., Tooele County (figure 1 and table 1, well 24), tested a Paleozoic "high" buried and sealed by valley- fill deposits in the Skull Valley graben. While over 11 million barrels of oil have been produced from similar targets in Nevada, this exploration play remains relatively untested in the Utah portion of the Basin and Range province. Many regions in Utah are currently being evaluated for other exciting new plays including Precambrian oil, coalbed methane and improved field development using state-of-the-art horizontal drilling techniques.

EXPLORATION ACTIVITY

Well permits for the first quarter of 1990 increased significantly over the first quarter of 1989, particularly within the Paradox Basin. This increase can be attributed, in part, to discoveries in 1989. Descriptions of individual wells, drilling rationales and results are discussed below.

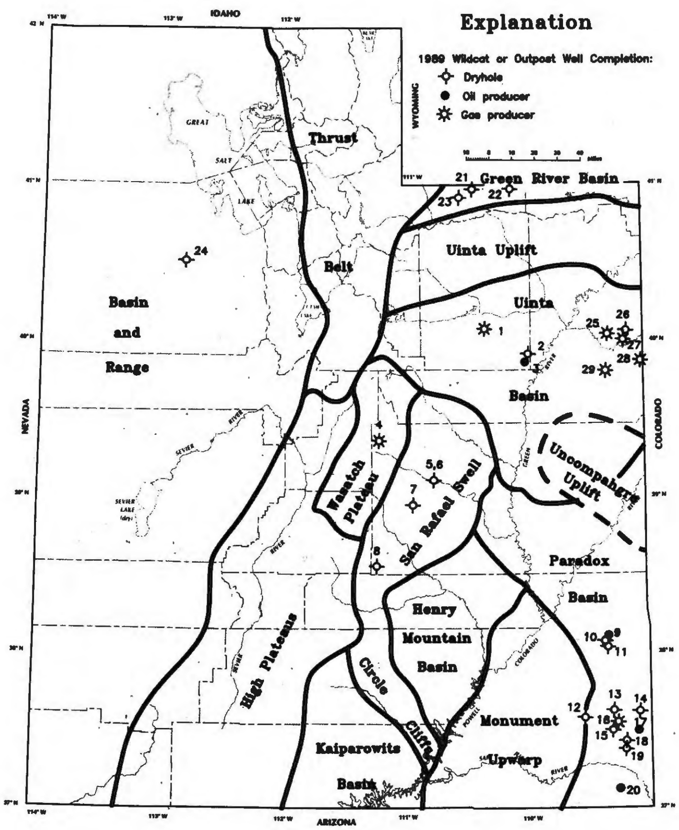

Figure 1. Major physiographic divisions of Utah and location of exploratory wells (wildcats and outposts) drilled in 1989. Numbers refer to well numbers in the text.

NEW FIELD DISCOVERIES

The Chuska Energy Company 1 Sahgzie, NE 1/4 NW 1/4 section 5, T. 42 S., R 24 E., San Juan County (figure 1, table 1, well 20 and figure 2) in the southern Paradox Basin, was the most significant 1989 Utah discovery. This well is the first in a unique and ambitious drilling program being conducted on Navajo Indian lands by Chuska Energy Company in joint venture partnership with six Australian companies. The Sahgzie wildcat was drilled to test an algal mound in the Desert Creek zone of the Pennsylvanian Paradox Formation along the southern end of the giant Aneth field.

Algal mounds within the Desert Creek and Ismay zones of the Paradox Formation are buildups of bioclastic debris supported by carbonate mud; they represented the main drilling targets for the Sahgzie prospect and other wildcats in the basin. The hydrocarbon entrapment is controlled by both primary and secondary porosity; primary porosity is present within the algal mound or the surrounding fossil hash. Porosity may be enhanced by secondary leaching of oolites and dolomitization. The 6411-foot discovery well was completed in November, 1989, with two Desert Creek zone intervals commingled flowing at a daily rate as high as 5000 bbls of oil (Western Oil, 1990). The Sahgzie discovery was quickly followed by five additional discoveries drilled by Chuska during the first half of 1990.

The Marathon Lightning Draw 1, NW 1/4 NE 1/4 section 35, T. 30 S., R. 23 E., San Juan County (figure 1 and table 1, well 9), was a 5282-foot rank wildcat drilled to extend the Ismay zone algal mound play of the Paradox Formation northward into the Paradox fold and fault belt. Algal mounds were identified in an anhydritic "fairway" separate from that in the southern part of the basin. Completed in January, 1989, the well was perforated from 5182 to 5186 feet and 5190 to 5200 feet, and flowed 11 bbls of oil, 43 MCF of gas, and 12 bbls of water daily from the Ismay zone. The relatively thin productive interval is a dolomite which may represent a few algal mats rather than a mound.

The Samedan Oil Corporation Shane Federal 1, NE 1/4 SW 1/4 section 7, T. 37 S., R. 24 E., San Juan County (figure 1 and table 1, well 16), was another 1989 Ismay zone discovery. The well was drilled to a depth of 6482 feet and the Ismay zone perforated from 6227 to 6240 feet initially flowed 3 bbls of oil, 979 MCF of gas, and 5 bbls of water daily.

The Celsius Energy Company Cedar 1, NE 1/4 SE 1/4 section 34, T. 37 S., R. 25 E., San Juan County (figure 1 and table 1, well 17), was drilled as a Desert Creek prospect in a trend that produces primarily from the overlying Ismay zone. The 5873-foot well was located on a northeast porosity pinchout (defined by previous wells) within a Desert Creek zone algal mound complex. The Desert Creek zone was completed at a daily rate of 43 bbls of oil, 113 MCF of gas, and 53 bbls of water.

In the Uinta Basin, the Cochrane Resources Wilkens Ridge 22-29, NW 1/4 SW 1/4 section 29, T. 10 S., R. 17 E., Duchesne County (figure 1 and table 1, well 3), was a re-entry into the Exxon 1 Wilkens Ridge Unit to test an unevaluated section of the lower Green River Formation (Eocene). The 5125-foot Cochrane Wilkens Ridge 22-29 was completed in the basal limestone unit of the lower Green River Formation for 29 bbls of oil and 15 MCF of gas daily.

The Meridian Oil Company East Mountain Federal 32-23, SW 1/4 NE 1/4 section 23, T. 16 S., R. 6 E., Emery County (figure 1 and table 1, well 4), re-evaluated the potential of the abandoned Flat Canyon field on the Wasatch Plateau about 24 miles southwest of Price, Utah. The three-well field, discovered in 1953, produced 1.44 BCF of gas from the Cretaceous Ferron and Dakota formations before being plugged and abandoned in 1969. Meridian Oil Company believed the field was abandoned due to low gas prices rather than depletion of the reservoir. The East Mountain Federal 32-23 was staked near the crest of the northeast- trending Flat Canyon anticline and was completed in the Ferron Formation for 1.22 MMCF of gas per day.

SIGNIFICANT UNSUCCESSFUL WILDCATS

Fourteen unsuccessful wildcat wells were completed in Utah during 1989. Six dry holes were drilled in the Paradox Basin (San Juan County). These unsuccessful exploratory tests were targeted for algal mounds, porosity pinchouts, and oolite banks within the Desert Creek and Ismay zones of the Pennsylvanian Paradox Formation (figure 1 and table 1, wells 10-13, 18 and 19). Eight other 1989 wildcats were completed in Tooele, Emery and Summit counties (figure 1 and table 1, wells 5-8 and 21-24) and represent rank wildcats which tested new exploration concepts or trends. Six wells are discussed.

The Celsius Energy Company Federal 8-1, NW 1/4 NE 1/4 section 8, T. 21 S., R. 9 E., Emery County (figure 1 and table 1, well 7), located on the western flank of the San Rafael Swell, tested a regional stratigraphic trap. This regional trap is represented by a porosity pinchout in the Permian Kaibab Formation from porous bioclastic dolomite on the west flank to low porosity, impermeable micritic dolomite eastward (Kiser, 1976). The Federal 8-1 was spudded in November, 1989 and drilled to a total depth of 3226 feet in the Permian Elephant Canyon Formation. Some shows were encountered in the Kaibab Formation, but log analysis generally indicated low porosity values and high water saturation.

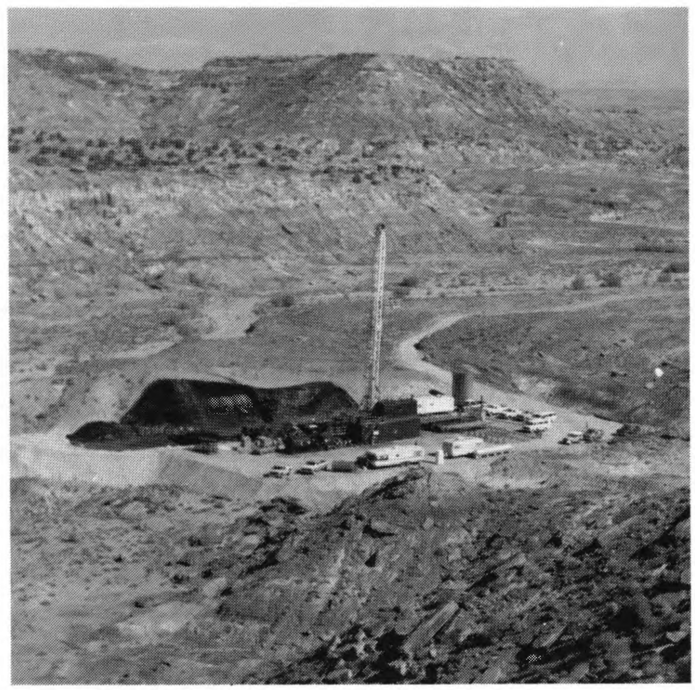

Figure 2. The Chuska Energy Company 1 Sahgzie discovery well, NE 1/4 NW 1/4 section 5, T. 42 S., R. 24 E., San Juan County, Utah. Photo courtesy of Brad Morrison, Chuska Energy Company.

The Diversified Operating Corporation Federal Rockwash 13-35, SW 1/4 SW 1/4 section 35, T. 25 S., R. 6 E., Emery County (figure 1 and table 1, well 8), was drilled to re-evaluate the Last Chance field based on hydrodynamic considerations. Analysis of subsurface pressure data from wells in the field indicated the presence of a strong north-dipping potentiometric surface, which may have shifted any hydrocarbons off the axis of the anticline to the north (Kiser, 1976). For example, the Upper Valley field (in Garfield County) has produced over 22 million bbls of hydrodynamically displaced oil, which suggests that additional hydrocarbon accumulations may exist adjacent to known geologic structures. The Federal Rockwash 13-35 was drilled about one mile north of the Last Chance anticline on the northeast flank (off-axis). The primary target of the well, the Kaibab Formation, was penetrated at 3210 feet with a strong show of black oil staining and yellow fluorescence. A drillstem test of the formation recovered only 300 feet of slightly oil-cut mud and 1093 feet of water. The completion of the well as a dry hole indicates no significant hydrodynamic trapping of hydrocarbons has occurred in the immediate Last Chance field area.

Three 16,500 foot wildcats (one a re-entry) were drilled in the southernmost Green River Basin along a projected continuation of the Moxa arch. The target was the Cretaceous Dakota Formation which is highly productive in the Lucky Ditch field just north of the Utah-Wyoming border and the focus of much exploration activity. Fluvial sandstones of the Dakota Formation generally trend in a northwest direction over subsidiary structures along the Moxa arch creating combination structural/stratigraphic traps. The Chevron Federal 1-25, SE 1/4 SW 1/4 section 25, T. 3 N., R 13 E.; Blue Diamond Gregory 44-21-P, SE 1/4 SE 1/4 section 21, T. 3 N., R. 16 E.; and Texaco Steel Creek 1, SE 1/4 SW 1/4 section 11, T. 2 N., R. 12 E., all in Summit County (figure 1 and table 1, wells 21, 22 and 23), were unsuccessful attempts to extend this trend into Utah although some results were encouraging.

The Andy Pierce Skull Valley Federal 26-3, NE 1/4 NW 1/4 section 26, T. 3 S., R. 9 W., Tooele County (figure 1 and table 1, well 24), was the most remote wildcat drilled in Utah during 1989. The wellsite was selected using close-spaced gravity data that indicated the presence of an eroded hill or mound of Paleozoic rocks lying beneath the Tertiary alluvium of Skull Valley. Surprisingly, the Pennsylvanian-Permian Oquirrh Formation was penetrated at a depth of 211 feet, indicating that the alluvium was much thinner than anticipated. Although live oil shows were encountered in the lower part of the Mississippian Manning Canyon Shale, no drillstem tests were performed, and the well was completed as a dry hole at a depth of 2108 feet.

FIELD EXTENSIONS AND DEVELOPMENT ACTIVITIES (OUTPOSTS)

In 1989, nine outpost wells were completed in Utah to extend the productive limits of proven fields (figure 1 and table 1, wells 1, 2, 14, 15 and 25-29). Five were successful for gas and four were classified as dry holes. Successful wells were completed in the Duchesne, Hell's Hole Canyon, Devil's Playground, Natural Buttes and Rock House field areas (figure 1 and table 1, wells 1, 25, and 27-29 respectively), which are all located in the Uinta Basin. A new reservoir in the Jurassic Morrison Formation was also added to the Hell's Hole Canyon field (productive primarily from the Dakota Formation). A total of 58 development wells were completed in Utah during 1989. Thirty-six were completed as oil wells, 18 as gas wells, and 4 were dry holes for a success rate of 93.1 percent. As for the past several years, development activity continued to be high in the Uinta Basin at Duchesne, Altamont-Bluebell, Monument Butte and Horseshoe Bend fields. Other traditionally active areas where numerous development wells were completed in 1989 included the Greater Cisco and San Arroyo fields along the Uncompahgre uplift, the Mexican Hat field on the east flank of the Monument upwarp, and the Greater Aneth field in the southern Paradox Basin. It is anticipated that activity in these fields will continue for many more years.

CONCLUSIONS

Seven new exploratory trends or types of drilling targets may develop in the future as the result of wildcats completed in 1989 or concepts they were designed to test:

1. Desert Creek zone algal mound trends south and east of the Greater Aneth field area (Chuska Energy Company 1 Sahgzie).
2. Ismay zone algal mound targets in the northern Paradox Basin within an anhydritic "fairway" separate from that of the southern part of the basin (Marathon Lightning Draw 1).
3. Erosional "highs" beneath the Tertiary unconformity, buried and sealed by valley-fill deposits in the Basin and Range province (Andy Pierce Skull Valley Federal 26-3).
4. Kaibab Formation updip porosity pinchouts and truncations against the impermeable basal Moenkopi Formation along the west flank of the San Rafael Swell (Celsius Federal 8-1).
5. Hydrodynamically displaced oil in the Kaibab Formation and other Paleozoic reservoirs throughout the Colorado Plateau (Diversified Federal Rockwash 13-35).
6. Dakota fluvial sandstones crossing subsidiary structures on the continuation of the Wyoming Moxa arch trend into Utah (Texaco Steel Creek 1).
7. Ferron Formation stratigraphic and structural targets in the Wasatch Plateau (Meridian East Mountain Federal 32-23).

In 1989, Utah ranked tenth nationally in production of oil and natural gas liquids and fifteenth in production of natural gas. Oil and gas were produced from 117 fields and 38 undesignated field areas in nine counties. Production from the 4115 active wells in Utah totaled 28,415,680 bbls of oil and 277,811,296 MCF of gas during the year (Utah Division of Oil, Gas and Mining, 1989). Estimated recoverable reserves for the state are 260 million bbls of crude oil, 290 million bbls of natural gas liquids, and 2 TCF of natural gas (oral communication, Jeff Burks, Utah Division of Energy). Utah promises to continue as a leading producer of oil and gas. New trends, drilling techniques, and ideas will contribute significantly to the discovery of additional hydrocarbon reserves especially in a time when the nation is importing 50 percent of its oil needs.

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Kiser, L.C., 1976, Stratigraphy and petroleum potential of the Permian Kaibab Beta Member, east-central Utah, in Hill, G.J., editor, Symposium on the Geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists 1976 Guidebook, p. 161-172.

Utah Division of Oil, Gas and Mining, Monthly Oil and Gas Production Report, December, 1989.

Western Oil World, 1990, CHAP plows into Paradox Basin: v. 47, no. 1, p. 25.

Table 1. List of all exploratory wells (wildcats and outposts) completed in Utah, 1989.

REFERENCE NUMBER	County	Location (Sec. - T & R)	Operator and Well Name	Field or Area	Spud Date	Completion Date	Formation at Total Depth	Total Depth (feet)	Tested Formations/Zones	Initial Production	Status
1 *	Duchesne	NWNE 20-04S-04W	Coors Ute Tribal 1-20D	Duchesne Outpost	08-30-89	11-10-89	Wasatch	7903	Green River	13 BOPD 351 MCFGPD 4 BWPD	PGW
2	Duchesne	NWSW 09-10S-17E	Cochrane Resouces Wilkens Ridge II Unit 13-9	Eight Mile Flat Outpost	07-29-89	08-20-89	Wasatch	5341	Green River	None Wasatch	P&A
3	Duchesne	SENW 29-10S-17E	Cochrane Resources Wilkens Ridge 22-29	Unnamed Discovery (re-entry)	10-19-89	12-4-89	Green River	5125	Green River	29 BOPD 15 MCFGPD	POW
4 *	Emery	SWNE 23-16S-06E	Meridian East Mountain Fed. 32-23	Unnamed Discovery	09-16-89	10-27-89	Mancos (Tununk)	7476	Ferron	1220 MCFGPD	PGW
5	Emery	NWSE 23-19S-10E	William G. Bush Bush 1	Wildcat (re-entry)	12-04-89	12-05-89	Navajo	210	None	None	P&A
6	Emery	NWSE 23-19S-10E	William G. Bush	Wildcat	12-08-89	12-14-89 Bush 1-A	Moenkopi	1500	None	None	P&A
7 *	Emery	NWNE 08-21S-09E	Celsius Energy Co. Celsius Federal 8-1	Wildcat	11-06-89	11-22-89	Elephant Canyon	3226	Moenkopi/Sinbad Kaibab	None	P&A
8	Emery	SWSW 35-25S-06E	Diversified Oper. Corp. Federal Rockwash 13-35	Wildcat	12-01-89	12-17-89	White Rim	3398	Kaibab	None	P&A
9	San Juan	NWNE 35-30S-23E	Marathon Oil Co. Lightning Draw 1	Unnamed Discovery	05-28-88	01-08-89	Paradox (salt)	5282	Lower Ismay	11 BOPD 43 MCFGPD 12 BWPD	POW
10	San Juan	NWSE 04-31S-23E	Marathon Oil Co. Sugarloaf 4-1	Wildcat	07-09-89	07-25-89	Paradox (Akah)	5730	None	None	P&A
11	San Juan	SWNE 22-31S-23E	CNG Producing Co. Major Martin Fed. 1	Wildcat	12-06-89	12-19-89	Paradox (salt)	5248	LaSal Desert Creek	None	P&A
12 *	San Juan	NWSW 35-36S-21E	Coastal Oil & Gas Corp.	Wildcat	07-18-89	08-06-89 COGC Fed. 1-35-36-21	Paradox (salt)	6049	Ismay Desert Creek	None	P&A
13 *	San Juan	NWSW 13-36S-23E	Samedan Oil Corp. Big Pony 1-13	Wildcat	08-30-89	09-13-89	Paradox (salt)	6300	None	None	P&A
14	San Juan	NWNW 12-36S-25E	BTA Oil Producers 8822 JV-P Cedar Point 1	Bug Outpost	09-16-89	10-12-89	Paradox (Akah)	6015	Desert Creek	None	P&A
15	San Juan	SWNE 35-37S-23E	Celsius Energy Co. Chouinard 1	Unnamed Outpost	04-28-89	05-12-89	Paradox (salt)	6390	None	None	P&A

16	San Juan	NESW 07-37S-24E	Samedan Oil Corp. Shane Federal 1	Unnamed Discovery	07-11-89	07-31-89	Paradox (Akah)	6482	Ismay	3 BOPD 979 MCFGPD 5 BWPD	PGW
17	San Juan	NESE 34-37S-25E	Celsius Energy Co. Cedar 1	Unnamed Discovery	12-27-88	02-18-89	Paradox (Akah)	5873	Ismay Desert Creek	43 BOPD 113 MCFGPD 53 BWPD (Desert Creek)	P&A
18	San Juan	SWNE 25-38S-24E	Axem Resources Inc. Black Steer Fed. 7-25	Wildcat	01-19-89	02-01-89	Paradox (salt)	6170	Ismay Desert Creek	None	P&A
19	San Juan	SENW 11-39S-24E	BTA Oil Producers McCracken 1	Wildcat	01-19-89	02-04-89	Paradox (Akah)	6325	Ismay Desert Creek	None	P&A
20	San Juan	NENW 05-42S-24E	Chuska Energy Co. 1 Sahgzie	Wildcat	10-02-89	11-02-89	Paradox	6411	Desert Creek	1226 BOPD 433 MCFGPD	POW
21	Summit	SESW 25-03N-13E	Chevron USA Inc. Chevron Fed. 1-25	Wildcat	11-20-88	06-10-89	Morrison	16520	Fort Union Dakota Cedar Mountain	None	P&A
22	Summit	SESE 21-03N-16E	Blue Diamond Oil Corp. Gregory 44-21-P	Wildcat (re-entry)	11-18-88	06-24-89	Morrison	16670	Dakota	None	TA
23 *	Summit	SESW 11-02N-12E	Texaco Inc. Steel Creek 1	Wildcat	11-26-88	04-18-89	Morrison	16458	Dakota	None	P&A
24	Tooele	NENW 26-03S-09W	Andy Pierce Skull Valley Fed. 26-3	Wildcat	09-30-89	10-30-89	Manning Canyon	2108	NA	None	P&A
25	Uintah	SENW 31-08S-23E	Quintana Petroleum Corp. Badlands Federal 1-31	Natural Buttes Outpost	12-04-88	03-01-89	Mesaverde Group	7900	Mesaverde	1700 MCFGPD	SIGW
26 *	Uintah	NWSE 27-08S-23E	Gilmore O&G Exxon Federal 27-1	Unnamed Outpost	03-15-89	03-24-89	Wasatch	4100	None	None	P&A
27	Uintah	NESE 04-09S-24E	Quintana Petroleum Corp. Little Bonanza Federal 1-4	Devil's Playground Outpost	10-09-88	02-11-89 Group	Mesaverde	6700	Wasatch	2790 MCFGPD 391 BWPD	SIGW
28	Uintah	SWSW 36-10S-25E	Mitchell Energy Corp. H. H. State 2-36-10-25	Hell's Hole Canyon Outpost	09-01-89	10-13-89	Morrison	7310	Morrison	Tr Oil 723 MCFGPD Tr Wtr	PGW
29	Uintah	SESE 18-11S-23E	TXO Production Corp. Marble Mansion Unit 1	Rock House Outpost	06-21-89	11-01-89	Mesaverde Group	6603 Wasatch	Mesaverde (Wasatch)	1900 MCFGPD	SIGW

Explanation: POW = producing oil well; PGW = producing gas well; SIGW = shut-in gas well; P&A = plugged and abandoned; TA = temporarily abandoned; BOPD = barrels of oil per day; MCFGPD = thousand cubic of gas per day; BWPD = barrels of water per day; Tr = trace; NA = none available; * = samples available in Utah Geological Survey Sample Library.

Teacher's Corner

by Sandra N. Eldredge

Field Trips for Teachers

The Utah Geological Survey offers field trips for teachers upon request. A casual, no-cost field trip is scheduled for Saturday, October 26. Topics include: 1) glaciation events and resulting landforms, 2) Lake Bonneville landforms, 3) the Wasatch fault, and 4) mountain building. Discover the processes of erosion and deposition, and identify different landforms created over time. **Activities** involve sketching Lake Bonneville shorelines and the Wasatch fault, and collecting sedimentary, metamorphic, and igneous rocks. Printed materials provided consist of 8.5 x 11 generalized earthquake fault maps and background information. Please fill out the form below and return to UGS by October 18.

NEW PUBLICATIONS

For publications mentioned, refer to "New Publications of the UGS" in this issue of *Survey Notes*.

Places with hazards; a teachers' handbook on natural hazards in Utah, is now available at UGS. The four geologic hazards included so far are earthquakes, slope failures, problem soil and rock, and radon gas. The four sections can be purchased separately, as can the 35mm slide sets accompanying each section. Contained in several of the text portions are classroom activities, master sheets for overheads or copying, glossaries, and resources. The publication is referred to as UGS Open-File Report 211.

Earthquake fault map of a portion of Utah County, Utah is available for free. The generalized map (UGS Public Information Series 11) has the same format as the earthquake fault maps for Davis, Weber, and Salt Lake Counties.

Earthquake awareness and risk reduction in Utah is a 24-minute videotape that will be available at each school district in the fall of this year. This videotape can also be purchased at UGS (UGS Public Information Series 10).

WASATCH FRONT FIELD TRIP

Please complete this form and return, by October 18, to Sandy Eldredge, Utah Geological Survey. We will contact those of you who indicate interest to finalize the day and times of the field trip. Make sure you include your phone number.

WASATCH FRONT FIELD TRIP
Saturday, October 26, 1991
9:a.m. - 2:00 p.m.

Name:______________________________

Grade level you teach:______________________________

School:______________________________

School district:______________________________

Phone number:__________ School:__________ Home:__________

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YEAR	VOL/NO	AUTHOR	TITLE OF ARTICLE
1980	14-1	W.W. Hambleton	Resources & Public Policy
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	14-3	UGMS	Mt. St. Helens
	14-4	UGMS	Geothermal Test Well Yields 1000 G.P.M.
1981	15-1	H.R. Ritzma	Thrust Belt Only The Beginning
	15-2	UGMS	Director Retires
		UGMS	4.7 Million for Antelope Island
		UGMS	Petrographic Microscope to Aid Coal Studies
	15-3	UGMS	Landslide Derails Mail Train
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		UGMS	Executive Changes at DNR
1982	16-1	H.H. Doelling and A.D. Smith	Utah's Fertile Coal Crescent
		UGMS	1982 Symposium on Geol. of Rocky Mtn. Coal
	16-2	G. Atwood & H.H. Doelling	History of Paradox Salt Deformation
	16-3	W.R. Lund	Liquid Waste Disposal Problems in Utah
		Editor	Survey Notes Get New Look
	16-4	R. Klauk	Geothermal Energy
1983	17-1	H.H.Doelling	Mineral Resources of Utah
	17-2	B.N. Kaliser	Geologic Hazards of 1983
	17-3	F.D. Davis	Wasatch Front Mapping Project
	17-4	R. Kerns	Utah Tar Sands
1984	18-1	J.W. Gwynn	The Great Salt Lake Incremental Sampling Program
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	18-2	P. James	The Tintic Mining District
		L. Chenoweth	Early Uranium-Vanadium Mining in Monument Valley
	18-3	K.W. Brown	Petroleum Activities in Utah 1972-82
		UGMS	The Alta Conference
		L. Bruhn	Structure and Composition of the Crust
		R. Currey	Dating Geological Materials in Utah
		W. Fleming	Geologic Hazards
	18-4	D.R. Mabey	Earthquake Hazards in Utah
		L. Stokes	Looking Backward
1985	19-1	H.H. Doelling	Utah's Geologic Mapping Program
			Geologic Projects in Utah Conducted in Summer
	19-2	A.D. Smith	Methane and Coal Mining
		G.E. Christenson	Wasatch Front County Hazards Geologists
	19-3	B.T. Tripp	Industrial Commodities in Utah
		D.R. Mabey	Volcanic Hazards
	19-4	M.R. Smith	Information Program at the UGMS
		H.E. Gill	Excavation Inspection Program
1986	20-1	G.E. Christenson	Utah's Geologic Hazards
		S.N. Eldredge	UGMS Workshop on Landslide Inventories
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		D.R. Mabey	Notes on Historic High Level of Great Salt Lake
	20-3	M.A. Shubat	Mining District Studies
	20-4	L.F. Hintze	CUSMAP-Minerals Appraisal
		H.H. Doelling	Utah Quadrangle Mapping
1987	21-1	G.E.Christenson, M.V. Lowe, C.V. Nelson, R.M. Robinson	Geologic Hazards and Land-Use Planning, Wasatch Front
		W.F. Case	Big Cottonwood Canyon Flume Damaged by Rockfall
	21-2,3	G. Oviatt & F.D. Davis	Cooperative Geological Mapping
		M.A. Shubat	Parapierrotite Discovered
		D.R. Mabey	End of the Wet Cycle
	21-4	C.J. Brandt, M.A. Shubat	UGMS Sample Library Scandium-bearing Aluminum Phosphate
1988	22-1,2	G. Atwood	Status of the Utah Geological and Mineral Survey
		H.H. Doelling	Rockfall in Hackberry Canyon
		W.F. Case	Geologic Effects of the Emery County Earthquakes
		S.J. Nava, J.C. Pechmann & W.J. Arabasz	The Magnitude 5.3 San Rafael Swell Earthquake, a Preliminary Seismological Summary
		J. Tingey & F. May	CEM ALERT Report Summary of August 14, 1988 Earthquake in Emery County
	22-3	W.R. Lund	The Wasatch Fault Zone, G.K. Gilbert to the Present
		UGMS	UGMS Projects
	22-4	D.A. Sprinkel	Assessing the Radon Hazard in Utah
		D.A. Sprinkel	Mineral Lease Special Projects Program
1989	23-1	H.H. Doelling	Antelope Island State Park
		M.L. Ross	Contributors to Geologic Mapping (Charles Hunt)
		M.E. Jensen	New Geologic Databases for Utah
		G.C. Willis	Wanted: High Quality Geologic Mappers
		G.C. Willis	AAPG Cross Section of Utah
		G.C. Willis	Update to Geologic Mapping by the UGMS
	23-2	UGMS	Highlights of the 88/89 Fiscal Year
		K.M. Harty & C.M. Wilkerson	Emigration Canyon Debris Flood, June 9, 1989
		K.M. Harty	Cedar Canyon Landslide
		C.B. Hunt & A.A. Baker	Pre-Jeep Fieldwork by the UGMS
	23-3	B.T. Tripp & B.H. Mayes	Zeolite Occurrences of Utah
		R.H. Woody	Allison Named UGMS Director
		M. Shubat & B. Tripp	The Tooele 1x2 degree Mineral Occurrence Map
		R.W. Gloyn	UGMS Industrial Minerals Publications
		J.W. Gwynn	Saline Resources of Utah
		UGMS	The Last Map Ceremonies
	23-4	K.M. Harty	Landslide Mapping, Hazards, & Historical Landslides in Utah
		G.E. Christenson	The October 17, 1989 Ms 7.1 Earthquake Near San Francisco
		B.J. Solomon	The Tooele County Geologic Hazards Project
		M.N. Machette, A.R. Nelson & S.F. Personius	Surficial Geologic Maps of the Wasatch Fault Zone, Utah
		B.J. Solomon	Geology and Sanitary Landfills in Sevier County, Utah
		W.E. Mulvey	Wastewater Disposal in Rock, Duchesne County
1990	24-1	L.F. Hintze & F.D. Davis	Focus on Millard County
		H.H. Doelling	Contributor to Geologic Mapping; William Lee Stokes
		H.H. Doelling	Geologic Projects in Utah
	24-2	M. Bugden	UGMS Information Section Public Inquiries 1988-89
		M. Bugden	Information Geology-Related Mineral Lease Contracts
		D.A. Sprinkel	Information Geology — Its Role in the UGMS
		P.F. MaGann	Showcasing Resource Opportunities at Industry Shows
		S.N. Eldredge	Cool Off! Wasatch Mountain Glaciers
		S.J. Nava	Earthquake Activity in the Utah Region
		W.F. Case	The UGMS Computer System
1991	24-3	G.E. Christenson	Utah's Earthquake Problem
		G.E. Christenson	Earthquake Hazards of Utah
		S.N. Eldredge	Great Salt Lake Trivia
		S. Hecker	Quaternary Tectonics of Utah
		S.J. Nava	Earthquake Activity in the Utah Region
		S.S. Olig	Earthquake Ground Shaking in Utah
		G.E. Christenson	Earthquake Legislation
		B. Everitt	Stratigraphy of Eastern Farmington Bay

Upcoming Events

October 6-9: 25th Annual Meeting of Association of Earth Science Editors, Troy, New York. Contact Jim Stringfellow, Utah Geological Survey, (801) 467-7970.

October 21-24: Geological Society of America Annual Meeting, San Diego, California. Contact GSA (303) 447-2020.

October 30: First Annual Conference of the Utah Geographic Information Council, Salt Lake City, Utah. Contact Bill Lund, Utah Geological Survey, (801) 467-7970.

October 31-Nov. 1: Fourth Annual Conference of the Southwest ARC/INFO User Group, Salt Lake City, Utah. Contact Riki Darling, Automated Geographic Reference Center (801) 538-3159.

February 24-27: Society for Mining, Metallurgy, and Exploration (SME) 1992 Annual Meeting, Phoenix, Arizona. Contact Meetings Dept. SME, (303) 973-9550, P.O. Box 625002, Littleton, CO 80162.

Books and Papers

Studies of geology and hydrology in the Basin and Range Province, Southwestern United States, for isolation of high-level radioactive waste; characterization of the Bonneville region, Utah and Nevada, edited M.S. Bedinger, K.A. Sargent and W.H. Langer. Prepared in cooperation with the states of Arizona, California, Idaho, Nevada, New Mexico, Texas, and Utah. 1990. p. G1-G-38. 7 plates in pocket. Supercedes Open-File Report 84-744. U.S.G.S. Professional Paper 1370-G.

Studies of geology and hydrology in the Basin and Range Province, Southwestern United States, for isolation high-level radioactive waste; evaluation of the regions, by M.S. Bedinger, K.A. Sargent and W.H. Langer. Prepared in consultation with the states of Arizona, California, Idaho, Nevada, New Mexico, Texas, and Utah. 1990. p. H1-H61. 7 plates in pocket. U.S.G.S. Professional Paper 1370-H.

Bibliography of the geology of the Green River Formation, Colorado, Utah, and Wyoming to July 1, 1990, by M.C. Smith. 1990. One 3½ inch diskette. U.S.G.S. Open-File Report 90-0486.

Stratigraphic framework, coal zone correlations, and depositional environment of the Upper Cretaceous Blackhawk Formation and Star Point Sandstone in the Scofield and Beaver Creek areas, Nephi 30′ x 60′ Quadrangle, Wasatch Plateau coal field, Carbon County, Utah, by J.D. Sanchez. 1990. Two sheets. Scale 1:24,000. U.S.G.S. Coal Investigation Map C-0128-B.

Map showing distribution of silver in the nonmagnetic fraction of heavy-mineral concentrates, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J. B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field Studies Map MF-2137-B.

Map showing distribution of barium in stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field Study Map MF-2138-A.

Map showing distribution of bismuth and cadmium in the stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field Study Map MF-2138-B.

Map showing distribution of gold in stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field Study Map MF-2138-D.

Composite aeromagnetic map of the Richfield 1° x 2° Quadrangle, Utah, by J.L. Plesha. 1990. 1 over-size sheet, scale 1:250,000. U.S.G.S. Open-File Report OF 90-0228.

Mineral resources of the San Rafael Wilderness Study Areas, including Muddy Creek, Crack Canyon, San Rafael Reef, Mexican Mountain, and Sids Mountain Wilderness Study Areas, Emery County, Utah, by Susan Bartsch-Winkler, R. P. Dickerson, H.N. Barton, A.E. McCafferty, V.J.S. Grauch, Hayai Koyuncu, Kennan Lee, J.S. Duval, U.S. Geological Survey; S.R. Munts, D.A. Benjamin, T.J. Close, D.A. Lipton, T.R. Neumann, and S.L. Willett, U.S. Bureau of Mines. 1990. 56 p. 1 plate in pocket. U.S.G.S. Bulletin B 1752.

Map showing distribution of lead in stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field Study Map MF-2138-E.

Map showing distribution of molybdenum in stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field Study Map MF-2138-F.

Map showing distribution of silver in the stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field Study Map MF-2138-G.

Map showing distribution of thorium in stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field study Map MF-2138-H.

Map showing distribution of tin in stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. 1990. Scale 1:250,000. U.S.G.S. Miscellaneous Field Study Map MF-2138-I.

Map showing distribution of uranium in stream-sediment samples, Richfield 1° x 2° Quadrangle, Utah, by W.R. Miller, J.M. Motooka and J.B. McHugh. Scale 1:250,000. U.S.G.S. Miscellaneous Field Study Map MF-2138-J.

Hydrogeology of the San Jose, Nacimiento, and Animas formations in the San Juan structural basin, New Mexico, Colorado, Arizona, and Utah, by G.W. Levings, S.D. Craigg, W.L. Dam, J.M. Kernodle and C.R. Thorn. 1990. Two sheets, full color. Scale 1:1,000,000. U.S.G.S. Hydrologic Investigation HA-0720-A.

Hydrogeology of the Kirtland Shale and Fruitland Formation in the San Juan structural basin, New Mexico, Colorado, Arizona, and Utah, by J.M. Kernodle, C.R. Thorn, G.W. Levings, S.D. Craigg and W.L. Dam. 1990. Two sheets, full color. Scale 1:1,000,000. U.S.G.S. Hydrologic Investigaiton HA-0720-C.

Hydrogeology of the Cliff House Sandstone in the San Juan structural basin, New Mexico, Colorado, Arizona, and Utah, by C.R. Thorn, G.W. Levings, S.D. Craigg, W.L. Dam and J.M. Kernodle. 1990. Two sheets, full color. Scale 1:1,000,000. U.S.G.S. Hydrologic Investigation HA-0720-E.

Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah; Volume IV, edited by P.L. Gori, 1990. 455 p., U.S.G.S. Open-File Report 90-0225.

Genesis of the tabular-type vanadium-uranium deposits of the Henry Basin, Utah; Part II, Mechanisms of ore and gangue mineral formation at the interface between brine and meteoric water, by M.B. Goldhaber, R.L. Reynolds, J.A. Campbell, R.B. Wanty, R.I. Grauch and H.R. Northrop. Economic Geology and the Bulletin of the Society of Economic Geologists, v. 85, no. 2. April 1990. p. 236-250. OP-37.

Mineral resources of the Deep Creek Mountains Wilderness study Area, Juab and Tooele counties, Utah, by C.J. Nutt, D.R. Zimbelman, D.L. Campbell, J.S. Duval, U.S. Geological Survey; and B.J. Hannigan, U.S. Bureau of Mines. 1990. U.S.G.S. Bulletin B 1745-C. p. C1-C40. 1 plate in pocket.

(Books and Papers, continued...)

K-Ar ages of Jurassic to Tertiary plutonic and metamorphic rocks, northwestern Utah and northeastern Nevada, by D.M. Miller, J.K. Nakata and L.L. Glick. 1990. U.S.G.S. Bulletin

Peak-flow characteristics of small urban drainages along the Wasatch Front, Utah, by K.L. Lindskov and K.R. Thompson, prepared in cooperation with the Utah Department of Transportation. 1989. 38 p. U.S.G.S. Water Resource Investigation Report WRI 89-4095.

Magmatic history of the East Tintic Mountains, Utah, by J.L. Hannah and Alec Macbeth. 1990. 24 p., 1 over-size sheet. Scale 1:24,000. U.S.G.S. Open-File Report OF 90-0095.

Analytical results and sample locality map of stream-sediment samples from the Delta 1° x 2° Quadrangle, Tooele, Juab, Millard, and Utah counties, Utah, by B.F. Arbogast, D.R. Zimbelman and H.A. Whitney. 1990. 46 p. 1 over-size sheet. Scale 1:250,000. U.S.G.S. Open File Report OF 90-0222.

Geologic map of the Newcastle Quadrangle, Iron County, Utah, by M.A. Siders, P.D. Rowley, M.A. Shubat, G.E. Christenson and G.L. Galyardt. 1990. Scale 1:24,000 (Supercedes Open-file Report 89-449). U.S.G.S GQ-1690

Stratigraphic framework, coal zone correlations, and depositional environment of the Upper Cretaceous Blackhawk Formation and Star Point Sandstone in the Candland Mountain and Wattis areas, Nephi 30' x 60' Quadrangle, Wasatch Plateau coal field, Carbon and Emery counties, Utah, by J.D. Sanchez and E.G. Ellis. 1990. Scale 1:24,000. U.S.G.S. Coal Investigation Map C-0128-A.

Fluid inclusion, $\delta^{18}O$, and Sr/^{86}Sr evidence for the origin of fault-controlled copper mineralization, Lisbon Valley, Utah and Slick Rock District, Colorado, by G.N. Breit and Jean-Dominique Meunier. Economic Geology and the Bulletin of the Society of Economic Geologists, v. 85, no. 4. July 1990. p. 884-891.

Analytical results and sample locality map of heavy-mineral-concentrate samples from the Delta 1° x 2° Quadrangle, Tooele, Juab, Millard, and Utah counties, Utah, by B.F. Arbogast, H.A. Folger and D.R. Zimbelman. 1990. 39 p., 1 over-size sheet. Scale 1:250,000. U.S.G.S. Open-File Report OF 90-0264.

Geologic map of the Circleville Canyon area, southern Tushar Mountains and northern Markagunt Plateau, Beaver, Garfield, Iron, and Piute counties, Utah, by J.J. Anderson, P.D. Rowley, J.T. Blackman, H.H. Mehnert and T.C. Grant. 1990. Scale 1:50,000. U.S.G.S. Miscellaneous Investigation Series Map I-2000.

Hydrogeology of the Menefee Formation in the San Juan structural basin, New Mexico, Colorado, Arizona, and Utah, by G.W. Levings, S.D. Craigg, W.L. Dam, J.M. Kernodle and C.R. Thorn. 1990. Two sheets. Scale 1:1,000,000. U.S.G.S. Hydrologic Investigation HA-0720-F.

Geohydrology and water quality in the vicinity of the Silver Creek tailings site, Summit County, Utah, *in* J.L. Mason, Geology and hydrology of hazardous-waste, mining-waste, waste-water, and repository sites in Utah; 1989 symposium and field conference. Utah Geological Association Publication 17.

Genesis of the tabular-type vanadium-uranium deposits of the Henry Basin, Utah; Part I, Geochemical and mineralogical evidence for the sources of ore-forming fluids, by H.R. Northrop, M.B. Goldhaber, G.P. Landis and J.W. Unruh. Economicc Geology and the Bulletin of the Society of Economic Geologists, v. 85, no. 2, April 1990. p. 215-236.

Genesis of the tabular-type vanadium-uranium deposits of the Henry Basin, Utah; Part III, Evidence from the mineralogy and geochemistry of clay minerals, by H.R. Northrop, M.B. Goldhaber, Gene Whitney, G.P. Landis and R.O. Rye. Economic Geology and the Bulletin of the Society of Economic Geologists, v. 85, no. 2, April 1990. p. 250-265.

Geophysical applications in mineral-resource assessment. Cedar City 1°x 2° Quadrangle, southwestern Utah, by H.R. Blank. ***Preliminary assessment of the mineral resources of the Cedar City 1°x 2° Quadrangle, Utah,*** by T.M. Cookro, M.A. Shubat, and J.L. Jones. ***Basin evolution and petroleum studies in the U.S. eastern Great Basin; relevance to mineral investigations,*** by C.J. Potter, J.A. Grow, C.H. Thoman, H.E. Cook, and J.A. Peterson. These three papers are in *U.S.G.S. Research on Mineral Resources, 1991, Program and Abstracts,* U.S.G.S. Circular 1062, 1991, 99 p.

Mineral resources of the Cougar Canyon/Tunnel Spring Wilderness Study Area, Washington County, Utah, and Lincoln County, Nevada, by J.E. Conrad, H.D. King, H.R. Blank, Jr., G.P. Murphy and G.S. Ryan. Prepared by the U.S. Geological Survey and U.S. Bureau of Mines, for the U.S. Bureau of Land Management. 1990. 17 p. U.S.G.S. Open-File Report OF 90-0331.

Mineral resources of the Mount Ellen-Blue Hills (Addition) Wilderness Study Area, Wayne County, Utah, by R.F. Dubiel and D.D. Gese. 1990. 17 p. U.S.G.S. Open-File Report OF 90-0335.

Mineral resources of the Paria-Hackberry Wilderness Study Area, Kane County, Utah, by Henry Bell, III, A.L. Bush, R.L. Turner, J.W. Cady, S.D. Brown, B.J. Hannigan and J.R. Thompson. 1990. 28 p., 1 over-size sheet. Scale 1:100,000. U.S.G.S. Open-File Report OF 90-0453.

Geologic map of the Salt Lake City 30' x 60' Quadrangle, north-central Utah, and Uinta County, Wyoming, by Bruce Bryant, *with a section on* Palynologic data from Cretaceous and lower Tertiary rocks in the Salt Lake City 30' x 60' Quadrangle, by D.J. Nichols and Bruce Bryant. 1990. Two sheets, scale 1:100,000. U.S.G.S. Miscellaneous Investigation Map I-1944.

Geologic map of the Fourmile Bench Quadrangle, Kane County, Utah, by W.E. Bowers, 1991. U.S.G.S. Coal Investigation Map C-0140.

Mineral resources of the Mill Creek Canyon Wilderness Study Area, Grand County, Utah, by M.F. Diggles, J.E. Case, H.N. Barton and J.S. Duval. Prepared by the U.S. Geological Survey and the U.S. Bureau of Mines, for the U.S. Bureau of Land Management. 1990. 29 p. U.S.G.S. Open-File Report OF 90-0516.

Mineral resources of the Marble Canyon Wilderness Study Area, White Pine County, Nevada, and Millard County, Utah, by M.F. Diggles, G.A. Nowland, H.R. Blank, Jr., S.M. Marcus and R.F. Kness. Prepared by the U.S. Geological Survey and the U.S. Bureau of Mines, for the U.S. Bureau of Land Management. 1990. 34 p. U.S.G.S. Open-File Report 90-0522.

Geological map of the Nevershine Hollow area, eastern Black Mountains, southern Tushar Mountains, and northern Markagunt Plateau, Beaver and Iron counties, Utah, by J.J. Anderson, P.D. Rowley, M.N. Machette, S.H. Decatur

(Books and Papers, continued...)

and H.H. Mehnert. 1990. Scale 1:50,000. U.S.G.S. Miscellaneous Investigation Map I-1999.

Seismicity map of the State of Utah, by C.W. Stover, B.G. Reagor and S.T. Algermissen. Scale 1:1,000,000 U.S.G.S. Miscellaneous Field Study Map MF-1856. (Reprint).

National Earthquake Hazards Reduction Program, summaries of technical reports; Volume XXX, compiled by M.L. Jacobson. Prepared by participants in National Earthquake Hazards Reduction Program. 1990. 654 p. U.S.G.S. Open-File Report OF 90-0334.

Mineral resources of the Desolation Canyon, Turtle Canyon, and Floy Canyon Wilderness Study Areas, Carbon, Emery, and Grand counties, Utah, by W.B. Cashion, J.E. Kilburn, H.N. Barton, K.D. Kelley, D.M. Kulik, U.S. Geological Survey; and J.R. McDonnell, Jr., U.S. Bureau of Mines. 1990. p. B1-B34. 1 plate in pocket. U.S.G.S. Bulletin 1753-B.

Gold in the Tintic mining district, Utah, by H.T. Morris, U.S. Geological Survey. p. F1-F11, in U.S.G.S. Bulletin 1857-F.

Analytical results and sample locality maps of stream-sediment, heavy-mineral-concentrate, and rock samples from the Negro Bill Canyon and the Mill Creek Canyon Wilderness study Areas, Grand County, Utah, by J.H. Bullock, Jr., H.N. Barton, T.A. Roemer, P.L. Hageman and D.L. Fey. 1990. 16 p., 1 over-size sheet, scale 1:24,000. U.S.G.S. Open-File Report OF 90-0464.

Analyses of rock samples from the Central mining and intrusive area, Marysvale, Utah, by J.B. McHugh, R.T. Hopkins, W.R. Miller and R.E. Tucker. 1990. 22 p. U.S.G.S. Open-File Report OF 90-0529.

Geologic map of Bryce Canyon National Park and vicinity, southwestern Utah, by W.E. Bowers. 1990. Scale 1:24,000. Accompanied by 17-page text. U.S.G.S. Miscellaneous Investigation Map I-2108.

Items of Interest

• The Mapping Section of UGS has been awarded $28,000 for COGEOMAP projects for the coming year. This cooperative project is between UGS and the U.S. Geological Survey. Past contracts have mapped extensive areas in western Utah and resulted in several UGS publications: *Quaternary geology of part of the Sevier Desert, Millard County, Utah,* (Special Study 70), *Quaternary geology of the Black Rock Desert, Millard County, Utah,* (Special Study 73), and *Quaternary geology of Fish Springs Flat, Juab County, Utah* (Special Study 77), all authored by C.G. Oviatt.

• The UGS has been awarded a contract for $63,424 with the Utah Bureau of Radiation Control from the Environmental Protection Agency as part of the State Indoor Radon Grants program. Barry Solomon of the Applied Section will head the project. This is the second year Barry has received funding.

• The Utah Division of Energy has awarded UGS a contract for $49,000 for a horizontal drilling study in the Duchesne field in the Unita Basin. This is a co-op with the University of Utah Research Institute and Coors Energy. Schlumberger is contributing computer analyses, and Mobil Oil may participate, as well.

• The Gas Research Institute (GRI), a non-profit industry group, has awarded a two-year, $1 million contract to the four Rocky Mountain state surveys (Utah, New Mexico, Colorado and Wyoming) to produce an atlas of natural gas reservoirs in the Rockies. This is the first such cooperative effort by the surveys and the first gas atlas in the country not awarded to the Texas Bureau of Economic Geology, which has worked on three.

• Union Pacific Railroad has given UGS a $15,000 grant to fund a cooperative study of the gold potential of the Farmington Canyon Complex and nearby areas in northern Utah.

UTAH GEOLOGICAL SURVEY
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Salt Lake City, Utah 84109-1491

Address correction requested
Survey Notes

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