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DESERT PEAK: A GEOTHERMAL FIELD IN CHURCHILL COUNTY, NEVADA

K. P. Goyal, W. R. Benoit, J. P. Maas, and J. R. Rosser

Phillips Petroleum Company
655 East 4500 South
Salt Lake City, Utah 84107

ABSTRACT

The 400°F liquid dominated Desert Peak geothermal reservoir produces from fractures associated with intersecting north-northeast and east-northeast trending normal faults. Fractures occur in intrusive basement rocks, pre-Tertiary metasedimentary and metavolcanic rocks, and Tertiary volcanic rocks. Static temperature surveys from six deep wells indicate that the reservoir has both recharge and discharge in the vicinity of wells B21-1 and 86-21.

Interference data, from a 30-day flow test of 86-21 show high reservoir connectivity. The calculated transmissivity is an order of magnitude higher in a north-south direction than in an east-west direction. A reservoir thickness on the order of thousands of feet and disturbed reserves in excess of 7 billion barrels are estimated.

A conceptual model of the Desert Peak system contains meteoric water derived from the Carson and Fernley Sinks. Heated at depth, water rises up along normal faults into highly fractured rocks between the depths of 3000 and 9000 feet, forming a geothermal reservoir. The thermal water naturally rises or leaks out of the reservoir up normal faults to within a few hundred feet of the surface until it has reached hydrostatic equilibrium or is blocked by discontinuous impermeable lacustrine sedimentary rocks. In the latter case it spreads out laterally creating a huge near surface thermal anomaly.

INTRODUCTION

The Desert Peak geothermal field is located approximately 50 miles east-northeast of Reno, Nevada in northwestern Churchill County (Fig. 1). It underlies the northern part of the Hot Springs Mountains which form part of the northwestern margin of the Carson Sink. To date six deep wells and numerous shallow and intermediate depth temperature-gradient holes have been drilled at Desert Peak. Only one of these wells has not intersected the geothermal reservoir. These wells have discovered a liquid dominated reservoir with an average temperature of 400°F. The wells produce from depths between 3000 and 9000 feet. The produced fluid is a sodium chloride water with a total dissolved solids content of 6700 mg/l. The dissolved gas content is between .02 and .04% by weight. The Desert Peak geothermal field is blind in that there is very little geological evidence exposed on the surface to indicate its presence (Benoit et al., 1982). At the present time, the proposed field development by Phillips Petroleum Company calls for a 9 MW demonstration power plant to be built and operating by 1985.

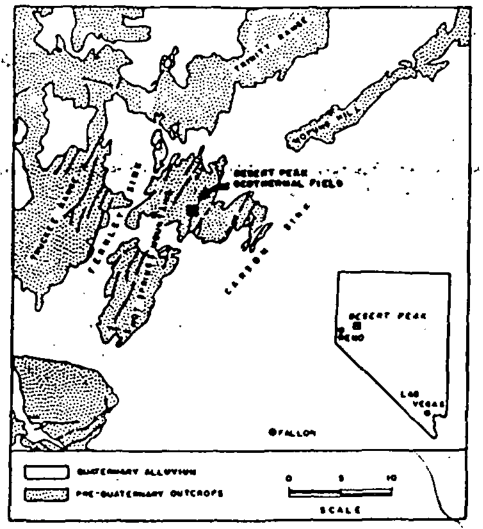


Figure 1. The Location Map.

GEOLOGY AND GEOPHYSICS

The Hot Springs Mountains are a low relief, highly fragmented horst block. In the northern half of the range, the general stratigraphy consists of intrusive rocks ranging from hornblendite to granite in composition below depths of 7000 feet. These have intruded and contact metamorphosed a Mesozoic (?) sequence of marine metasedimentary and metavolcanic rocks which lie between depths of 3000 and 7000 feet. Argillite, quartzite and phyllite are the dominant lithologies with lesser limestone and metavolcanic rocks also being present. Tertiary volcanic rocks overlie the pre-Tertiary section. This volcanic section can be broken into a lower rhyolitic unit composed primarily of ash flow tuffs and an upper basaltic unit known as the Chloropagus Formation. The combined thickness of this volcanic unit is between 2500 and 3000 feet. Overlying these volcanic rocks is a sequence of lacustrine sedimentary rocks known as the Truckee Formation which is up to 600 feet thick in the vicinity of the wells. Lastly, Quaternary alluvium and a thin veneer of windblown sand cover most of the area in the immediate vicinity of the wells.

Structurally, the northern Hot Springs Mountains have been broken into numerous rhombohedral blocks by intersecting north-northeast and east-northeast trending normal faults. Recent mapping and drilling indicates that drape folds overlie many of these normal faults in the vicinity of the deep wells. These drape folds can be exposed where well-bedded Tertiary sedimentary rocks have been preserved above an elevation of about 4500 feet. In the immediate vicinity of the wells the sedimentary rocks are either eroded or are poorly exposed so the drape folds are much more difficult to recognize. The locations of the deep wells and the faults inferred on the basis of a drape folding interpretation are shown in Fig. 2. The locations of these faults are different than those presented earlier (Benoit et al., 1982; Hiner, 1979).

Self-potential and ground magnetic surveys have been used at Desert Peak to help in locating possible hydrothermally active buried faults. The trends of both geologically and geophysically interpreted faults, as shown in Fig. 2, are similar. The elevation contours of the 400°F temperature, also shown in this figure, depict a dome with its peak around well B21-1. This indicates that the hot liquid rises up along normal faults in the vicinity of this well. Earlier reports (Benoit et al., 1982) have demonstrated that near the surface this thermal water

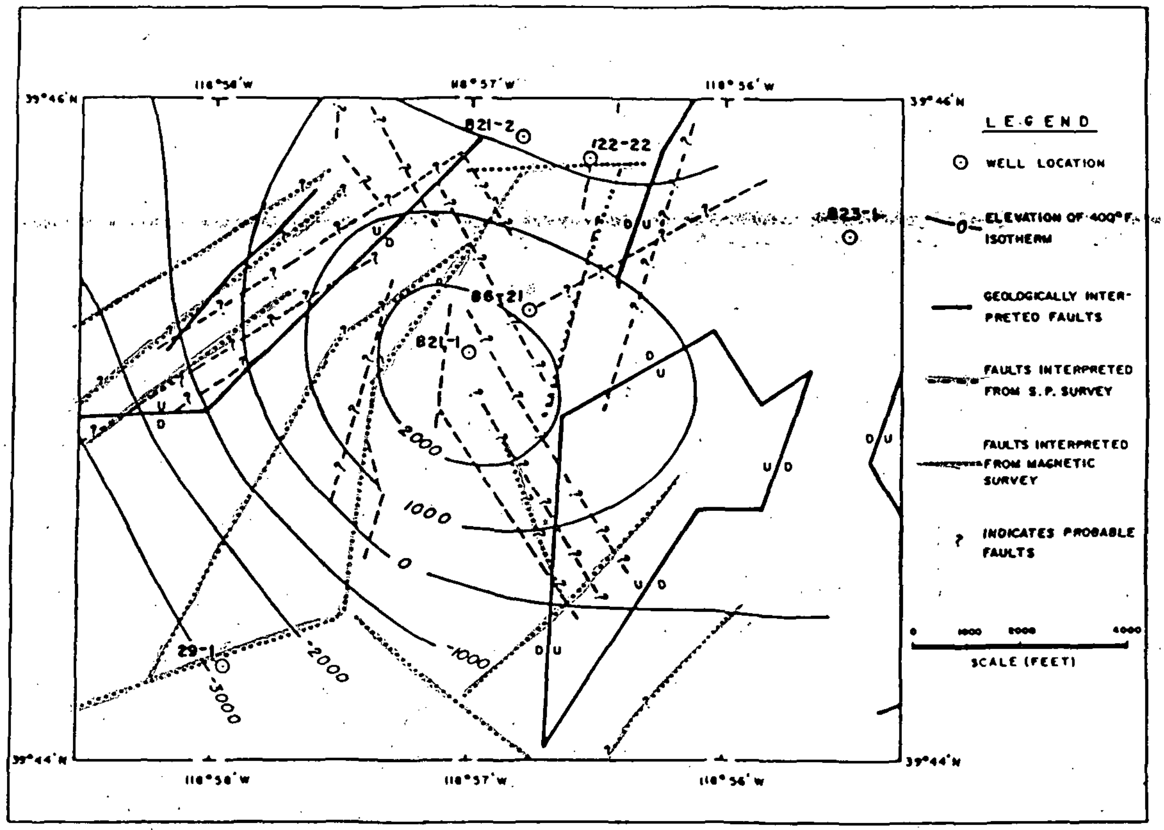
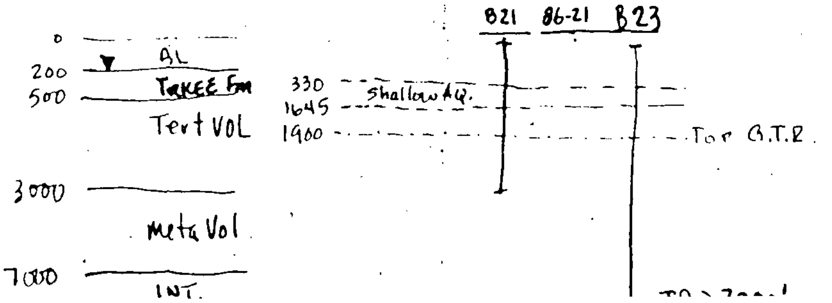


Figure 2. Inferred faults, well locations and evaluation contours of 400°F temperature in Desert Peak.



moves laterally down gradient through available permeability.

A plot of static formation temperatures versus elevation in all the Desert Peak wells is shown in Fig. 3. In a broad sense, these temperature profiles are of three types. **First, wells B21-1 and 86-21 are the hottest** wells at the shallowest depths with continuously decreasing temperature gradients. These wells are believed to be closer to a hot discharge zone of the system than the other wells in the field. A comparison of the deep isothermal temperatures in the wells suggests that wells B21-1 and 86-21 are also closer to the recharge source of the system than well B21-2. The isothermal temperature in B21-1 and 86-21 is 406°F compared to that of 392°F in B21-2.

The second type of profiles are those measured in wells B23-1 and 22-22.

The temperatures at shallow depths in these wells are lower than those obtained in B21-1 ✓ **and 86-21, but are similar at greater depths.** The profiles of the third type are the reversible temperature profiles measured in wells B21-2 and 29-1. The main difference between these two wells is that the well **B21-2 intersected the geothermal reservoir while the well 29-1 is located outside the reservoir.** The high **temperature gradients at shallow depths** in these two wells appear to have been **caused by lateral flow of hot water.** The reversal in 29-1 is caused by hot water originating in the vicinity of **wells B21-1 and 86-21 flowing outward over colder local waters.** The cause of the reversal in B21-2 needs further study.

The production zones defined from well logs and drilling reports are also shown in Fig. 3. **It is believed that the well B23-1 intersects two different hot water aquifers,** however only one is shown in this figure. **Based on successive temperature surveys, Urban and Diment (1982) delineated a shallow aquifer between 330 and 1645 foot elevation (2950 and 4265 foot depth), as shown in Fig. 3. Well B23-1 apparently produces from below the 7000 foot depth, indicating a deeper reservoir extending below this depth.** The geothermal reservoir, as presently known, in the Desert Peak area lies below an elevation of 1900 feet.

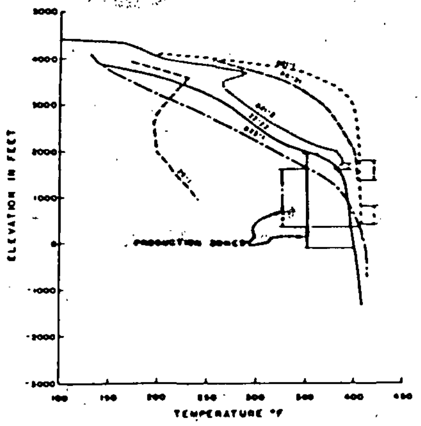


Figure 3. Static temperatures in Desert Peak Wells.

INTERFERENCE TESTING

Well 86-21 was flow tested for 30 days in the fall of 1982. It produced about 550,000 lbm/hr at an average wellhead pressure and temperature of 85 psig and 325°F respectively. A total of 1.3 million barrels of fluids was produced during this test. Wells B21-1 and B21-2, located respectively 1315 feet southwest and 3190 feet north from 86-21, were monitored for the interference data (Fig. 2).

The observation wells were equipped with downhole pressure chambers connected to high accuracy Heise gauges by capillary tubing. The monitoring system was pressurized with nitrogen to minimize response time. An hourly reading of the interference data was taken during the test. It was noticed that the wells B21-1 and B21-2 responded within 8 and 12 hours, respectively, to the flowing of 86-21. This indicates that the wells in this reservoir are well connected.

A log-log plot of drawdown versus time is shown in Fig. 4 for both wells. A maximum pressure drop of about 34 psi was noted in well B21-1 and that of about 12.5 psi in well B21-2. The line source solution match of the field data and the nondimensional coordinates of the matched point are also shown in this figure.

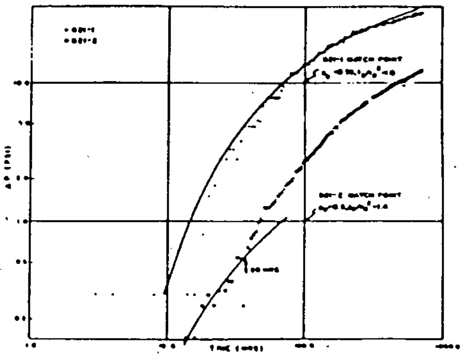


Figure 4. Drawdown-type curve match for Wells B21-1 and B21-2.

The Horner buildup plots of both wells are presented in Fig. 5. The data of the well B21-1, shown in Figs. 4 and 5, do not point toward the existence of a permeability barrier. However, the plots of the well B21-2 do display the existence of a discontinuity after 55 hours during drawdown and 142 hours during buildup.

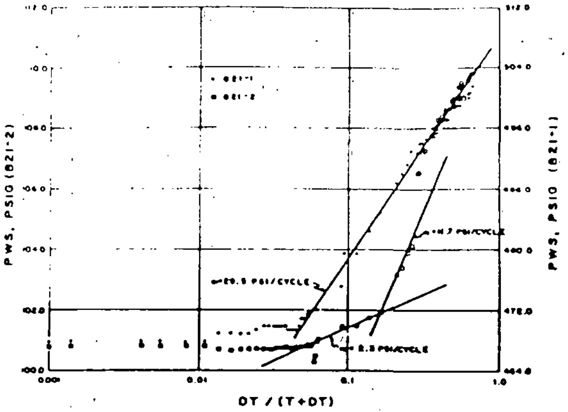


Figure 5. Horner buildup plots for wells B21-1 and B21-2.

For an average production rate of 550,000 lbm/hr and a reservoir temperature of 405°F, the following reservoir parameters may be obtained from Figs. 4 and 5 (Earlougher, 1977).

Observation Well B21-1

Drawdown: $kh = 33{,}000$ md-ft
$\phi C_t h = 37 \times 10^{-4}$ ft/psi

Buildup: $kh = 33{,}000$ md-ft
$\phi C_t h = 27 \times 10^{-4}$ ft/psi

Observation Well B21-2

Drawdown: $kh = 423{,}200$ md-ft
$\phi C_t h = 57 \times 10^{-4}$ ft/psi
distance to the discontinuity 5600 feet

Buildup: $kh = 423{,}800$ md-ft
$\phi C_t h = 70 \times 10^{-4}$ ft/psi
distance to the discontinuity 8150 feet

These results imply that the thickness of the reservoir is in thousands of feet rather than hundreds of feet. Based on the interference data, the reserves disturbed during the 30-day flow exceed 7 billion barrels. Northeast-southwest trending faults located north of well 22-22 may be interpreted as possible permeability barriers.

CONCEPTUAL MODEL

A conceptual model of the Desert Peak geothermal field is shown in Fig. 6. The depths of the upper mantle in the Basin and Range province varies from 15 to 20 miles (Stauber, 1983). Previously discussed stratigraphy and the thicknesses of various formations encountered in this field are also shown in this figure.

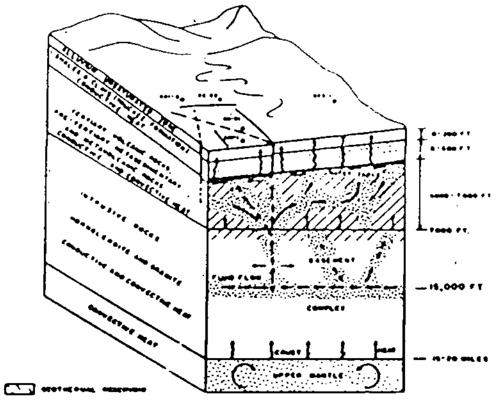


Figure 6. Conceptual Model of Desert Peak Geothermal Field.

The fractures in hard basement rocks which result from normal faulting are expected to increase vertical permeability much more than the horizontal permeability. The heat transfer mechanism in the basement complex is expected to be controlled by convection in open fractures and by conduction in low permeability rocks. Well B23-1 is believed to produce from the granite below 7000 feet.

Wells B21-1 and B21-2 produce from the pre-Tertiary section. Well 86-21 produces from rhyolite near the bottom of the Tertiary volcanic section where both vertical and horizontal water flow has been observed. In the Tertiary volcanic section, heat transfer is primarily by convection. It is presumed that heat transfer in the pre-Tertiary metasedimentary and metavolcanic rocks is by both convection and conduction depending upon the presence or absence of fluid movement. The known geothermal reservoir is shown schematically by hatched lines in Fig. 6.

Fine grained lacustrine sedimentary rocks of the Truckee Formation overlie Tertiary volcanic rocks and act as local caps for near surface horizontal movement of thermal water. However, in many areas the water table is several hundred feet deep. This means that often the relatively thin Truckee Formation does not have a chance to act as a cap rock because it is completely above the water table. At this time, it is not known whether or not an effective cap exists for the Desert Peak reservoir.

The uppermost layer in Fig. 6 consists of alluvium to a maximum depth of 200 feet. This layer is almost always above the water table.

The reservoir is highly fractured with faults concentrated in northeasterly and northwesterly directions, as shown in Fig. 2. Faults shown in Fig. 6 are schematic, but do represent the reservoir concept as known to date.

In summary, the vertical as well as horizontal permeability in the basement and in the geothermal reservoir is mostly due to fractures. The major source of fluids in the Desert Peak area is thought to be seepage from the Carson and Fernley Sinks, which are located respectively to the east and west of the Hot Springs Mountains (Fig. 1). It is postulated that this water percolates gradually into the sediments and basement rock over an area considerably larger than the Desert Peak anomaly. Heated at depth by an as yet undefined source, the liquid rises into the high permeability fractured fault zones, convecting energy toward the surface. The ascending hot water charges the highly fractured main geothermal reservoir which is believed to exist between 3000 feet and 9000 feet depth. The thermal water either continues to rise or leaks out of the reservoir to within a few hundred feet of the surface until it has reached hydrostatic equilibrium or it is blocked by impermeable lacustrine sedimentary rocks. In the latter case, it flows laterally down gradient along available flow path permeability between depths of 200 to 1000 feet. This lateral hot water flow has created a huge, intense near-surface thermal anomaly which obscures the location of the smaller actual produceable reservoir (Fig. 3). It is believed that the three shallowest producing wells (B21-1, B21-2 and 86-21) produce from normal faults concealed by overlying drape folds.

CONCLUSIONS

Geological and well testing data indicate that the fractured geothermal reservoir lies in various rock types. The fractures, at least in the immediate vicinity of wells B21-1, B21-2 and 86-21, display a strong north-south trend. The interference data indicates that the wells intersect a highly permeable reservoir. The north-south transmissivity is an order of magnitude higher than that in east-west direction. This agrees well with the fault orientation in the field. The transmissivity and storativity calculations indicate that the thickness of the Desert Peak reservoir is on the order of thousands of feet. This agrees well with the interpretation that the fracture zones are associated with steeply dipping normal faults. A conceptual model, involving deep circulation of meteoric water through normal faults, explains various features associated with the Desert Peak geothermal reservoir.

REFERENCES

1. Benoit, W. R., J. E. Hiner and R. T. Forest (1982) "Discovery and Geology of the Desert Peak Geothermal Field: A Case History", Nevada Bureau of Mines and Geology, University of Nevada, Reno, Bulletin 97, p. 82. ✓

2. Earlougher, Jr., R. C. (1977) "Advances in Well Test Analysis", Monograph volume 5, Henry L. Doherty Series, Society of Petroleum Engineers of AIME, New York, p. 264.

3. Hiner, J. E. (1979) "Geology of the Desert Peak Geothermal Anomaly, Churchill County, Nevada": Masters Thesis, Univeristy of Nevada, Reno, p. 84. obtain

4. Stauber, D. A. (1983) "Crustal Structure of North Central Nevada from Seismic Refraction, Gravity and Surface Wave Data", in Abstracts of the Symposium on the Role of Heat in the Development of Energy and Mineral Resources in the Northern Basin and Range Province. Geothermal Resources Council, p. 26.

5. Urban, T. C. and W. H. Diment (1982) "An Interpretation of Precision Temperature Logs in a Deep Geothermal Well near Desert Peak, Churchill County, Nevada", Transactions, Geothermal Resources Council, v.6, pp 317-320.

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A REVIEW OF HIGH-TEMPERATURE GEOTHERMAL DEVELOPMENTS IN THE NORTHERN BASIN AND RANGE PROVINCE

Walter R. Benoit
Phillips Petroleum Company

Robert W. Butler
Chevron Resources Company

ABSTRACT

Intensive geothermal exploration in the northern Basin and Range province has resulted in the the discovery of nine high-temperature (>200°C) geothermal reservoirs:

1) Roosevelt Hot Springs, Utah
2) Beowawe, Nevada
3) Humboldt House, Nevada
4) Brady's Hot Springs, Nevada
5) Desert Peak, Nevada
6) Northern Dixie Valley, Nevada
7) Soda Lake, Nevada
8) Steamboat Springs, Nevada
9) Coso, California

In addition, there is geological, geophysical, and geochemical evidence to indicate an undiscovered reservoir in the Long Valley caldera, California. Delays in Federal leasing are the main reason this reservoir has not yet been located.

Four of these areas occur along the east or west margins of the province and are spatially associated with Quaternary or Recent siliceous volcanic centers. Five are in or near the Carson Basin in northwestern Nevada and lack evidence for magmatic heating. The Beowawe reservoir has a unique occurrence near the east-west center of the province. Most reservoirs are closely associated with known or suspected Basin and Range normal faults.

With the exceptions of the localized shallow steam production at Coso and bicarbonate-rich water at Beowawe, the known reservoir waters have a dilute sodium chloride composition. Reservoir temperatures typically range from 200 to 220°C. The maximum reported temperature in the northern Basin and Range province is 271°C at Roosevelt Hot Springs.

The most thoroughly evaluated reservoirs are Roosevelt Hot Springs and northern Dixie Valley with 13 and 10 deep wells respectively. The most limited data are from the Soda Lake, Steamboat Springs, Humboldt House, and Long Valley prospects where only two or three deep wells per prospect have been drilled. Depths of the producing intervals vary from about 300 to 3000 m, but production is often from less than 1200 m.

Only one high-temperature, geothermal power plant at Roosevelt Hot Springs is under construction in the province. Extensive negotiations between developers and utilities have taken place regarding the Beowawe, Dixie Valley, and Desert Peak reservoirs.

INTRODUCTION

During the past ten years there has been a major effort by private industry, government agencies, research organizations, and universities to locate and study geothermal resources capable of generating electrical power. This has resulted in hundreds of published papers covering many geothermal areas in the northern Basin and Range province in a wide variety of scientific journals, plus a great amount of unpublished data generated by private industry. It is impossible to know how many potential high-temperature areas have been considered as prospects but the number must exceed 100. A complete exploration history of the northern Basin and Range province would be incomplete and sporadic at best. Therefore, this paper will briefly review the history and geology of ten areas where exploration for high-temperature (>200°C) geothermal reservoirs has been successful.

Exploration for high-temperature geothermal reservoirs in the northern Basin and Range province started in 1950 with the drilling of the Rodeo well at Steamboat Springs, Nevada specifically searching for steam to generate electricity (White, 1983). In the 33 years since this little-noticed beginning, several hundred million dollars and untold man years have been spent in exploration. At least 171 wells intended to produce high-temperature geothermal fluids have been drilled by many different entities to depths from 28 to 3854 m. The net result has been the discovery of nine high-temperature reservoirs in eight widely separated areas (Fig. 1). The total industry cost per discovery in the northern Basin and Range province is estimated at $20 million (Edmiston, 1982). Of these nine discoveries, one power plant is presently under construction. Four additional power plants have been seriously discussed.

There was little exploration activity after the unsuccessful Rodeo well until 1959, when Magma Power Company began a major drilling program in search of dry-steam reservoirs. By late 1962, Magma ceased this initial exploration program after drilling 48

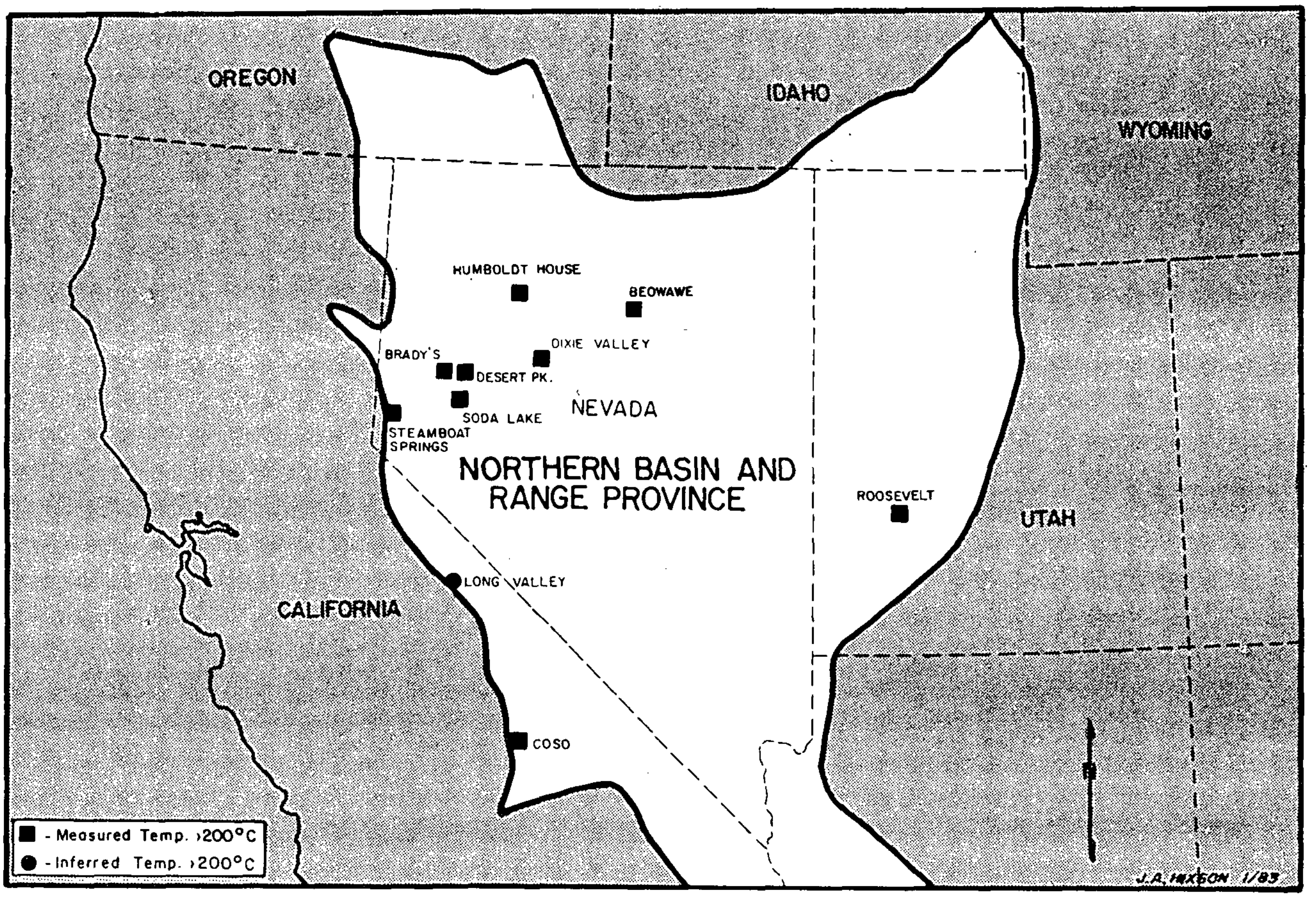

Figure 1. Locations of High-Temperature Geothermal Reservoirs in the Northern Basin and Range Province (modified from Edmiston, 1982).

wells in the immediate vicinity of 15 thermal springs. This activity proved to Magma that the high-temperature reservoirs, if present in the Basin and Range province, would not be dry-steam systems like the Geysers in California. In retrospect, Magma was at a further disadvantage in their exploration because they were limited to privately owned, hot spring properties. Until 1974, Federal lands were unavailable for geothermal leasing.

Between 1962 and 1973 geothermal exploration proceeded slowly. The main exploration thrust was deeper drilling, generally in the more promising areas drilled by Magma. Additional companies joined in the search during this time, including some not cited in this report, but no major new successes resulted. At least 76 wells were drilled prior to 1974 resulting in measured temperatures greater than 200°C at Beowawe and Brady's Hot Springs. In the early 1970's geothermal exploration in the Basin and Range province began to revive for several reasons. The Geothermal Steam Act of 1970 permitted future leasing and development on Federal lands. The true potential of the Geysers in California was becoming evident, proving that geothermal power could be generated at competitive prices and in sufficient quantity to interest large corporations. The early 1970's were dominated by OPEC policies--dramatic oil-price increases, embargoes, and energy shortages--that shook America's complacency regarding energy supplies. Finally, geothermal had enhanced environmental benefits when compared to coal, nuclear, oil, and new large scale hydroelectric power. These factors encouraged large energy companies to commit substantial sums of money, derived primarily from oil production, to geothermal exploration. In addition, the Federal government committed tens of millions of dollars to geothermal exploration, research and development, and managing leasing activities in the province. The commitment of funds reached an initial high point in 1975 (Edmiston, 1982) when private industry first obtained enough Federal leases and completed enough preliminary exploration to warrant drilling 12 large-diameter production wells. Drilling peaked in 1979 at 19 wells, many partially funded by the U. S. Department of Energy's Industry-Coupled Geothermal Reservoir Assessment Program (Fiore, 1980). A large share of the Basin and Range geothermal literature resulted from this program. Between the enactment of the Geothermal Steam Act in 1974 and May, 1983, 95 large-diameter exploratory or production wells were drilled.

ROOSEVELT HOT SPRINGS

The Roosevelt Hot Springs geothermal reservoir is located in southwestern Utah near the east margin of the province (Fig. 1) along the western side of the Mineral Mountains about 19 km northeast of Milford, Utah (Fig. 2).

Roosevelt Hot Springs is the only known high-temperature geothermal reservoir in the eastern half of the province. It is also the hottest known reservoir in the province with a maximum publicly reported temperature of 271°C (Rudisill, 1976). The discovery well, 3-1, was the second drilled by Phillips Petroleum Company in 1975, following a comprehensive three-year exploration program (Lenzer et al., 1977). The high reservoir temperature and relatively early discovery date, which coincided with abundant grant money made available by the U. S. Department of Energy, has made Roosevelt Hot Springs the site of extensive geological, geophysical, and geochemical research performed primarily by the University of Utah Research Institute. This extensive data base has been integrated into a comprehensive case study by Ross et al. (1982). An older, more extensive bibliography was prepared by McKinney (1978).

The Roosevelt Hot Springs geothermal system was classified as a Known Geothermal Resource Area (KGRA) by the U. S. Geological Survey in 1972, mainly because of its encouraging surficial features which include 190°F thermal springs, siliceous sinter, mercury deposits, nearby young obsidian flows, and an 82-m deep "steam" well which was drilled in 1967 and 1968. The well flowed for six weeks before being plugged. The Federal lands were leased in July, 1974 at one of the earliest KGRA sales. Since that sale, 13 exploration and production wells (Appendix 1) and eight deep temperature-gradient holes have been drilled (Fig. 2.), making it the most thoroughly drilled reservoir in the province and outlining a productive area of almost 14 km^2.

The Roosevelt Hot Springs geothermal reservoir is a fractured complex of competent Tertiary granitic and Precambrian metamorphic rocks. It underlies an area 2.4 km wide by 3.7 km long between the Dome Fault on the west and the irregular front of the Mineral Range on the east (Peterson, 1975; Ross et al., 1982). The reservoir is elongate in a north-northeast direction and coincides closely with a series of range-bounding normal faults as suggested by seismic-refraction data (Ross et al., 1982).

A line of rhyolite domes dated at .5 to .8 my occur along the crest of the Mineral Range both north and south of the reservoir. These domes indicate the possibility of magma in the vicinity of the reservoir and may explain the substantially higher than normal temperature of this Basin and

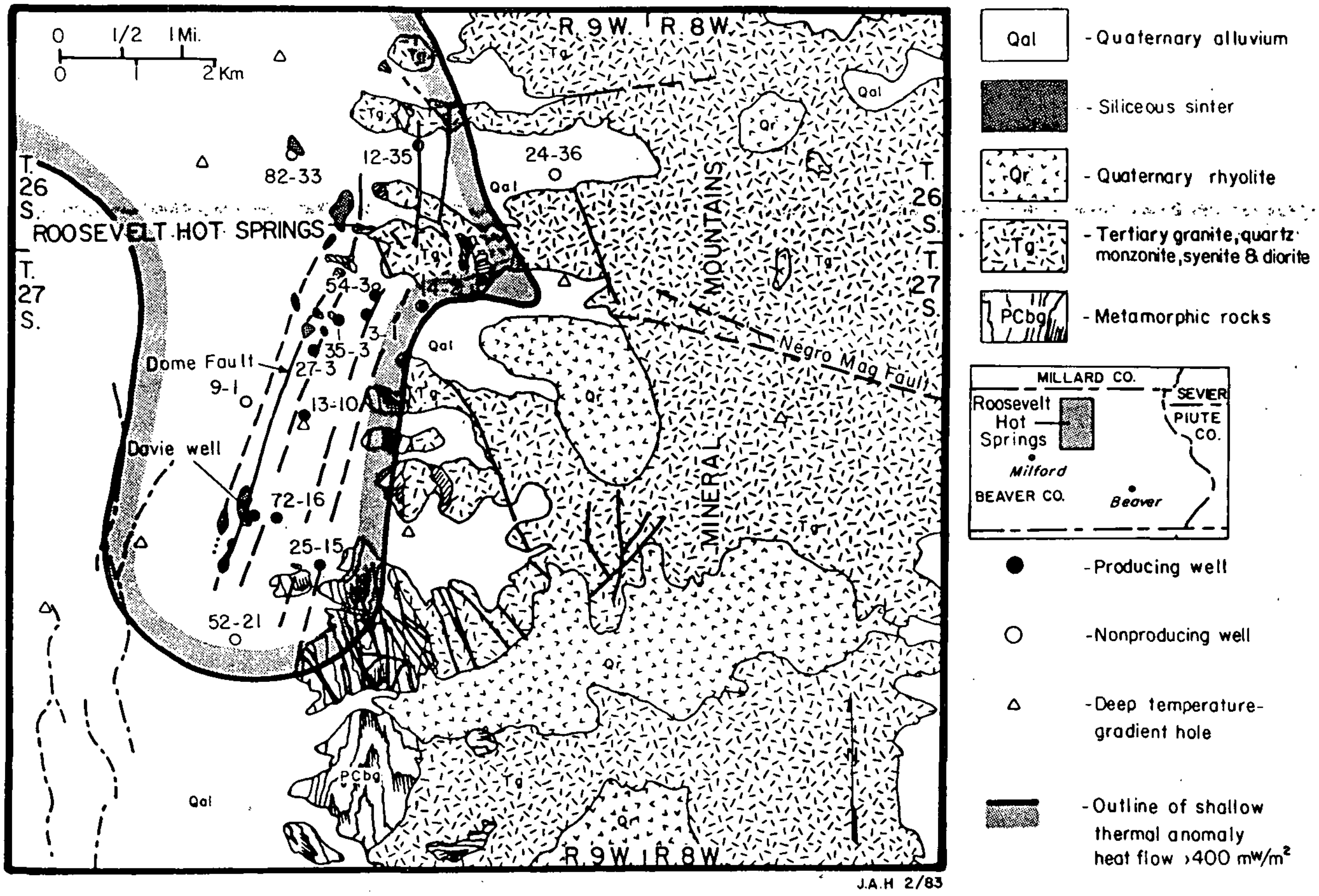

Figure 2. Map of the Roosevelt Hot Springs, Utah Area (modified from Ross et al., 1982).

Range reservoir.

Production wells at Roosevelt Hot Springs produce a sodium chloride water with a total dissolved solids content of about 7000 mg/l. These wells are somewhat unique in the Basin and Range province because the abnormally high temperature has created a reservoir pressure greater than the hydrostatic pressure, requiring no stimulation to begin flow. Mass-flow rates for the Roosevelt wells are variable but can be very high. Wells 27-3 and 35-3 have respective flow rates of 454,000 and 635,000 kg/hr, making them among the most prolific hot-water geothermal producers in North America (National Geothermal Service, 1983).

Negotiations for a heat-sales agreement with Utah Power and Light began in 1977. In September, 1980, a contract was signed for the construction of a 20-mw, single-flash demonstration plant to be followed by two additional 50-mw units contingent upon the success of the first plant. The 20-mw power plant is currently under construction and is expected to be operational early in 1984.

The Roosevelt Hot Springs area was the site of a one-mw helical-screw expander that generated the first electricity produced from a geothermal resource in the province during a long-term flow test of well 54-3 in March, 1978. In April, 1983 a 1.6-mw Biphase rotary-separator turbine completed a six-month endurance test, again powered by fluid from well 54-3.

BEOWAWE

The Beowawe geothermal area is located in north-central Nevada, 32 km southeast of the town of Battle Mountain near the center of the province (Fig. 3). It has some of the most spectacular surface manifestations of any area within the province, including a 75-m high sinter terrace made up almost exclusively of opal. In addition, there are boiling springs, fumaroles, steaming ground, geysers, mud pots, and abundant hydrothermally altered rock and ground. Thus it is no surprise that in 1960, Beowawe was the first high-temperature geothermal reservoir to be discovered in the Basin and Range province.

The geothermal literature on Beowawe is extensive. The local geology is discussed by Struhsacker (1980) who also included a very thorough bibliography. The regional setting of Beowawe is emphasized in papers by Stewart et al. (1975), and Zoback and Thompson (1978). Geophysical studies have been published by Smith (1979), Smith et al. (1979), Swift (1979), and Zoback (1979). Reservoir-engineering studies have been prepared by Middleton (1961) and Epperson (1982).

The basement geology at Beowawe is intensely deformed, thrust-faulted Paleozoic carbonate and clastic sedimentary rocks. Overlying the Paleozoic section is a gently dipping cap of basaltic-andesite and dacite flows with minor tuffs, related to a north-northwest-striking, mid-Miocene rift just a few km west of the sinter terrace. The rift at Beowawe is part of a 700-km long belt of extensional faulting and volcanic centers with associated dike swarms and graben-filling volcanic rocks, extending from central Oregon to central Nevada (Stewart et al., 1975; Zoback and Thompson, 1978). The Beowawe reservoir is located along an east-northeast-striking, Basin and Range normal fault, the Malpais fault, in the Paleozoic sedimentary and Tertiary volcanic rocks.

Geothermal exploration at Beowawe started in 1959 with shallow well drilling by Magma and Sierra Pacific Power Companies (Appendix 1). By 1965 they had completed 12 wells and discovered a resource

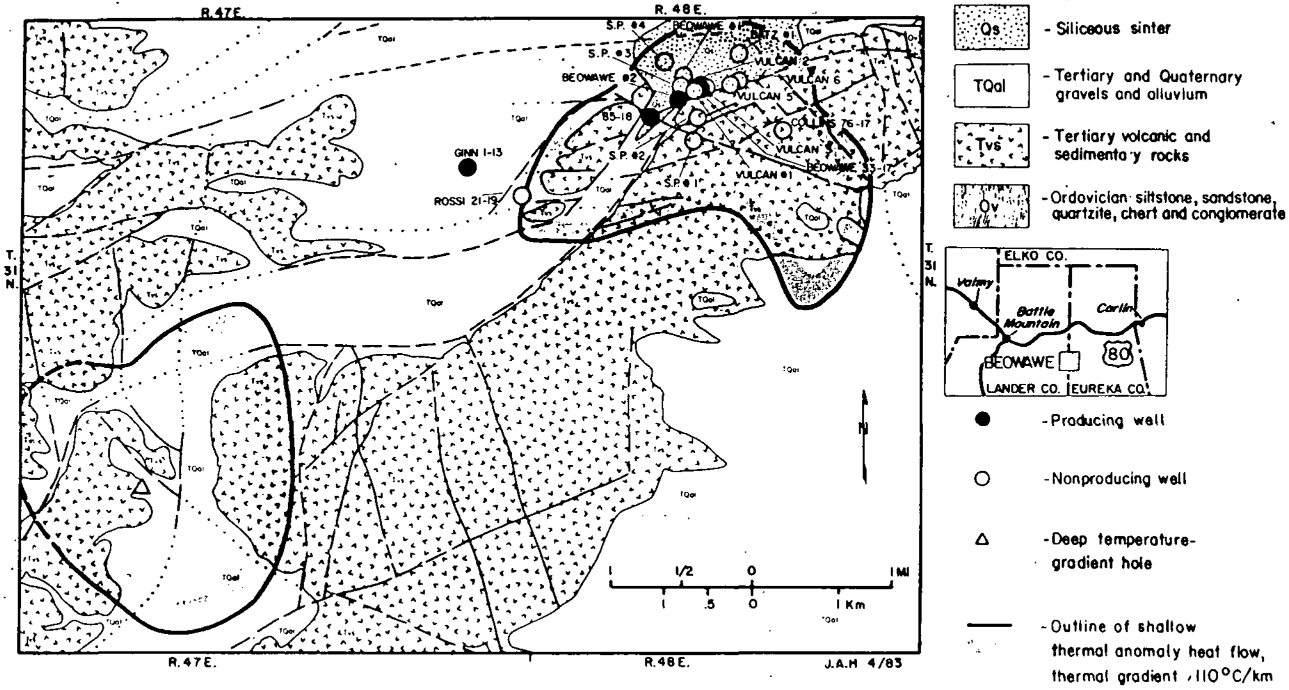

Figure 3. Map of the Beowawe, Nevada Area (modified from Struhsacker, 1980)

> 200°C at depths of 215 to 245 m (Garside, 1974; Garside and Schilling, 1979). Vulcan wells 1, 2, and 3 had flow rates of 680,000 kg/hr at wellhead pressures of 7.5 bars ± (Middleton, 1961). However, temperature and flow-rate decreases led to the conclusion that the reservoir was depleting and being invaded by cold water (Epperson, 1982). Activity then ceased until the early 1970's.

Exploration resumed in the early 1970's when Chevron drilled the Ginn 1-13. This 2911-m test, the deepest in the province at the time (1974), encountered a 216°C reservoir within fractured Paleozoic quartzites along the Malpais fault. The Rossi 21-19 was next drilled closer to the Malpais fault, but lacks sufficient permeability. In 1975 exploration drilling returned to the sinter terrace. However, the Batz #1 well at the east end of the terrace was the final disappointment for Magma. Chevron later drilled two producing wells on the terrace, 85-18 and 33-17. The most recent well, the Collins No. 1, was drilled by Getty Oil Company in 1981 on the back side of the terrace, and was unsuccessful.

The current interpretation of the Beowawe reservoir is that there is a shallow 185°C ± producing interval in the terrace area within the Tertiary volcanic section. There is also deeper and hotter fracture production between 2500 and 3000 m with a temperature of 216°C ± in Paleozoic rocks along the Malpais fault. Interference tests indicate a high degree of continuity between all wells. Pressure responses are observed in less than one hour for wells up to 2 km apart, even for those completed in different geologic units (Epperson, 1982).

The productivity of the recently tested wells is around 185,000 kg/hr total mass flow. Epperson (1982) believes the lower flow rates compared to those of Middleton (1961), are due primarily to mechanical completion restrictions. A more conventional casing program would allow the Ginn 1-13 to flow two-phase brine at 450,000 kg/hr with a pressure of 9.3 kg/cm^2 ±.

The water produced at Beowawe is a dilute sodium bicarbonate water with a dissolved solids content of 1200 mg/l. This is the only high-temperature resource in the province which is not a typical sodium chloride water, possibly indicating a deeper reservoir in Paleozoic carbonate rocks.

Between 1979 and 1982, Chevron and a consortium of utilities known as NORNEV (Keilman, 1982) negotiated to build a 13-mw (gross) binary-power plant at Beowawe. Currently Chevron is negotiating with a field-development partner for a joint-venture, 10 to 20-mw power plant to be built by a third-party manufacturer. A power-sales contract would be negotiated with Sierra Pacific Power Company.

BRADY'S HOT SPRINGS - DESERT PEAK

The Brady's Hot Springs-Desert Peak area is located in the northern part of the Hot Springs Mountains, 32 km northeast of Fernley, Nevada (Fig. 4). Brady's Hot Springs and Desert Peak are apparently separate, high-temperature geothermal systems located about six km apart.

A lengthy case history and bibliography of these two areas has recently been published by Benoit et al

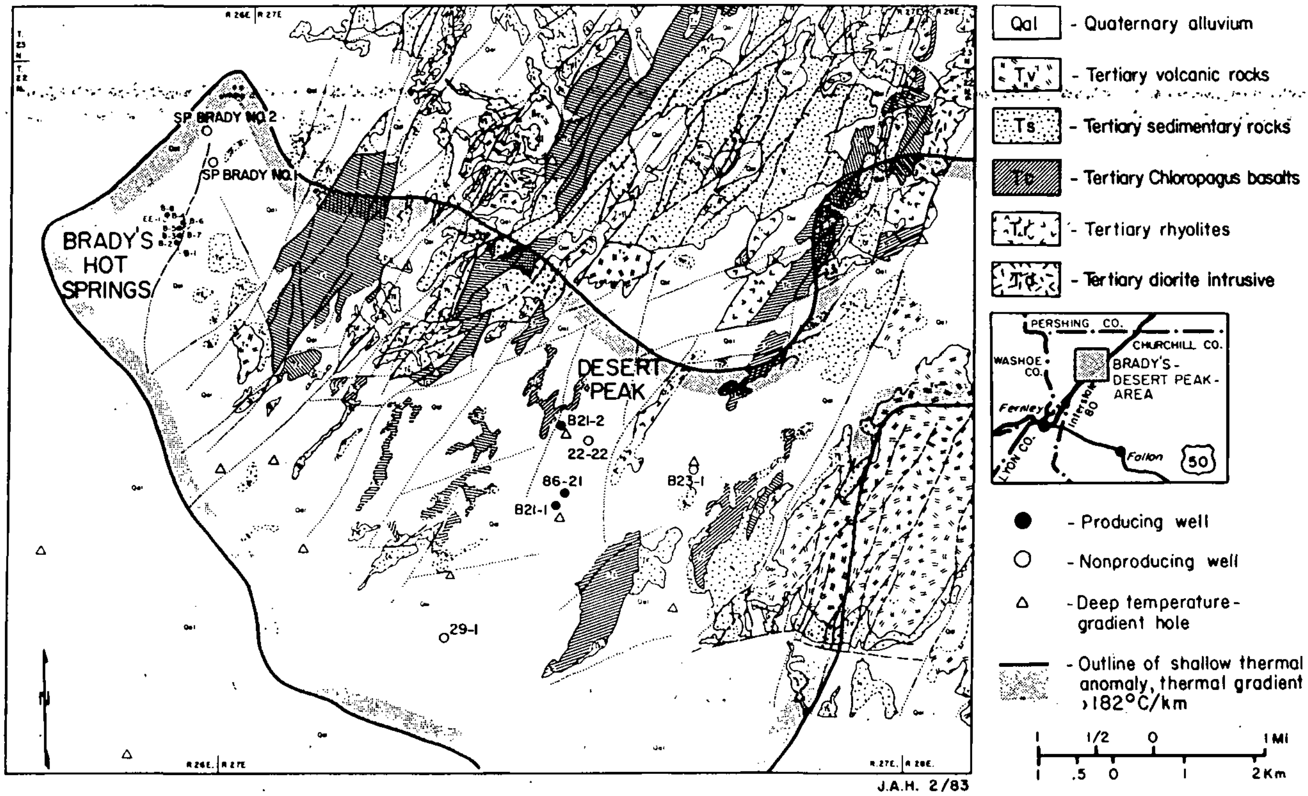

Figure 4. Map of the Brady's Hot Springs-Desert Peak, Nevada Area (after Benoit et al., 1982)

(1982). A more recently published work on Desert Peak is a temperature study of well B23-1 by Urban and Diment (1982).

The Desert Peak geothermal system is significant in two aspects. It was the first blind geothermal discovery in the province with minor surface manifestations to indicate the presence of this reservoir. Second, the near-surface thermal anomaly associated with the Desert Peak reservoir is the largest and most intense in the province. An area of approximately 195 km^2 has temperature gradients in excess of 110°C/km. The local surficial geology consists of Tertiary volcanic and sedimentary rocks that are drape folded over numerous, seldom-exposed, north-northeast and east-northeast-striking normal faults.

Geothermal exploration began in 1959 at Brady's Hot Springs solely because of the once-impressive surficial thermal features. Magma Power Company initially drilled six shallow wells, several of which produced large volumes of sodium chloride water with temperatures over 160°C (Appendix 1) and dissolved solids contents near 3500 mg/l after steam separation. In 1964 Earth Energy drilled the first deep well, encountered 212°C temperatures but failed to produce significant amounts of fluid. The last major exploration at Brady's Hot Springs occurred in 1974 and 1975 when two unsuccessful deep wells confirmed the small size of this reservoir. This does not mean that Brady's Hot Springs is an insignificant resource. The world's only commercial geothermal food-processing plant has been in operation since 1978 at Brady's Hot Springs. This plant is the largest commercial geothermal operation in the Basin and Range province and will remain so until the 20-mw power plant at Roosevelt Hot Springs comes on line in 1984.

Geothermal exploration at Desert Peak began in 1973 as a result of a shallow temperature-gradient hole program centered on Brady's Hot Springs. The Desert Peak reservoir was discovered solely by shallow and deep temperature-gradient drilling, a technique which was successful primarily because the Desert Peak thermal anomaly is so large. This large size is a result of subsurface thermal-water discharge into subhorizontal aquifers at shallow depths. Phillips Petroleum Company's second deep exploratory well, B21-1, discovered the Desert Peak reservoir in November, 1976. To date, six production wells and 12 deep temperature-gradient holes have been drilled. The first three producing wells at Desert Peak suggested the reservoir was areally extensive and confined to pre-Tertiary metasedimentary, metavolcanic and granitic rocks. In 1982, wells 86-21 and 22-22 confirmed that discrete north-northeast-and east-northeast-striking faults provide the shallow permeability and proved production from the Tertiary volcanic rocks. Well 86-21 is currently the largest producer at Desert Peak with a maximum flow rate between 340,000 and 410,000 kg/hr. The sodium chloride reservoir water at Desert Peak is about twice as saline as the Brady's water with a dissolved solids content of 6700 mg/l.

Calcium carbonate scaling in the wellbore during production is a problem at Desert Peak as it is in most, or possibly all, of the high-tempererature Basin and Range reservoirs. A 30-day, scale-inhibition test by EFP Systems Inc. on well B21-2 was successful in alleviating this problem. They used recycled carbon dioxide as a gas-lift pump to increase the wellhead pressure and lower the pH of the geothermal fluid from 7.0 to 5.6, thus preventing scaling during flashing in the wellbore (Kuwada, 1982).

Negotiations are underway between Sierra Pacific Power Company and Phillips Petroleum which will hopefully result in the construction of a 10-mw demonstration power plant. The ultimate potential of this large and promising prospect has yet to be determined.

HUMBOLDT HOUSE

The Humboldt House geothermal reservoir is located in northwestern Nevada midway between the towns of Lovelock and Winnemucca (Fig. 5) and underlies a series of coalescing alluvial fans descending from the west flank of the Humboldt Range. This prospect has been characterized by initial success followed by increasing frustration in exploration. Geothermal literature on this prospect is quite limited. The regional geology is described by Johnson (1977) and the local geology has been mapped by Silberling and Wallace (1967). Some geothermal history and information is briefly presented by Desormier (1979). Data and interpretations from the most recent exploratory well, Campbell E-2, have been published by Phillips Petroleum Company (1979), and Sibbitt and Glenn (1981).

The geothermal potential of the Humboldt House area was recognized during a regional shallow temperature-gradient-hole drilling program. As the near-surface thermal anomaly was being outlined, recently extinct, siliceous and calcareous spring deposits were noted (Garside and Schilling, 1979) and a small volume of 75°C water was discovered leaking from an old shallow mineral-exploration hole. The Na-K-Ca geothermometer predicts a subsurface temperature of 260°C for this water. This may be the highest predicted subsurface temperature in Nevada, but no drill hole at Humboldt House has yet come close to this temperature (Appendix 1).

The first production well, Campbell E-1, was drilled by Phillips Petroleum Company in November, 1977 and is capable of producing about 363,000 kg/hr of fluid with a maximum subsurface temperature of 183°C. The produced fluid is a dilute sodium chlorid water with a total dissolved solids content of about 5000 mg/l, and is chemically very similar to the thermal water from the old shallow mineral-exploration hole well 6.6 km to the north-northwest. The Campbell E-1 well is believed to produce from an unconsolidate zone of alluvial limestone boulders at depths between 546 and 559 m (Desormier, 1982). This is the only known geothermal well in Nevada with a high shut-in pressure, 10.5 kg/cm^2.

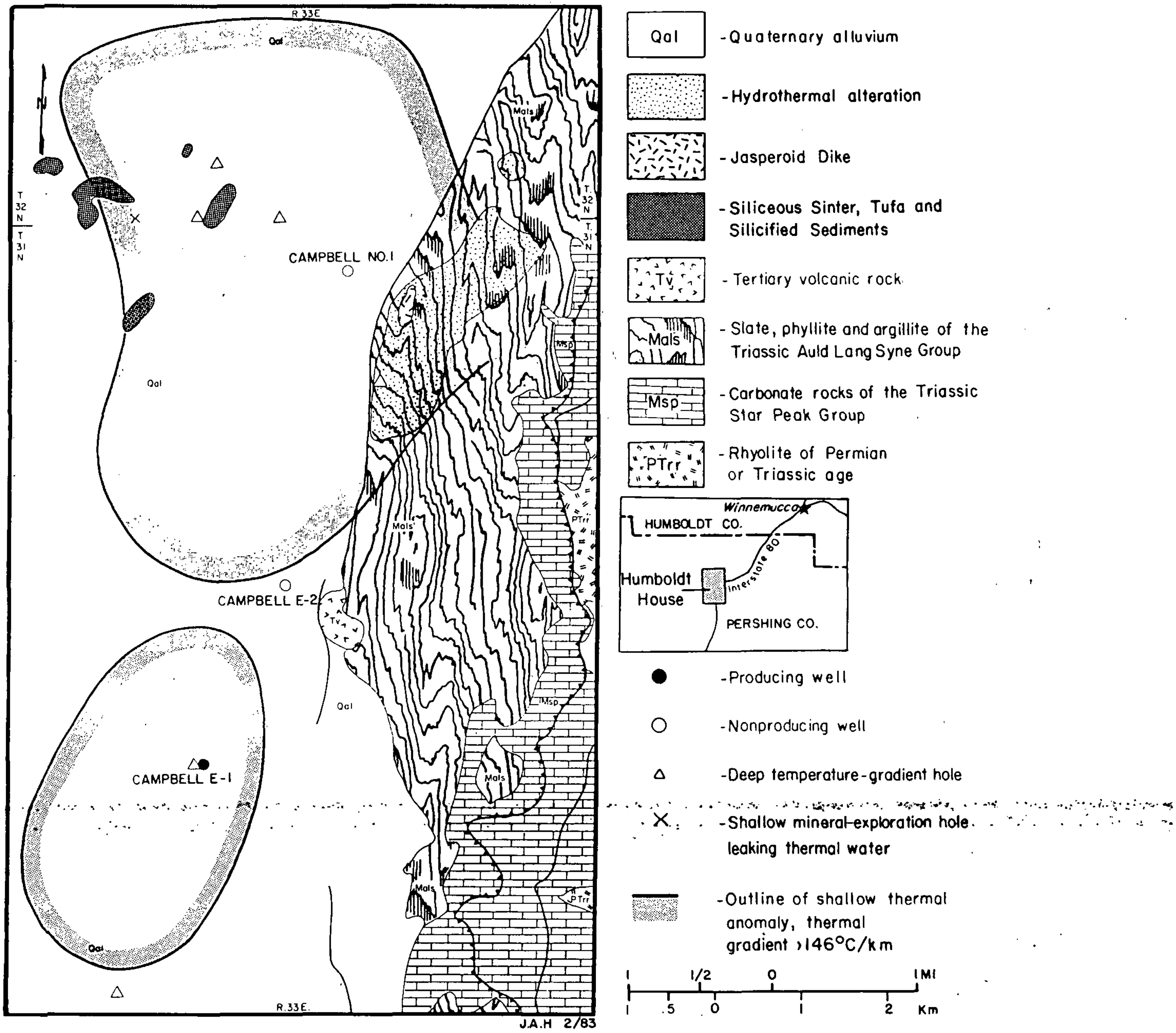

Figure 5. Map of the Humboldt House, Nevada Area (geology after Silberling and Wallace, 1967).

Two other dry exploratory wells were drilled in 1978 and 1979 (Appendix 1). Union Oil Company's Campbell No. 1 well has the maximum measured temperature at Humboldt House (205°C) but produced only about 10 Lpm of brine. These two wells encountered thick sections of the Triassic Auld Lang Syne Group--shales, slates and phyllites which appear too incompetent to maintain fracture permeability. The lack of permeability in the Auld Lang Syne Group has also been a problem at other geothermal prospects in northwestern Nevada. Thick sequences of siliceous sinter have been found interbedded within the Quaternary alluvium and underlying Tertiary lacustrine sedimentary rocks in both wells and deep temperature-gradient holes, indicating a long history of geothermal activity at Humboldt House.

No drilling has occurred on this prospect since 1979. Additional drilling is needed to confirm the reservoir, possibly one of the hottest in Nevada, but the major problem remains an apparent inability to locate successful wells.

NORTHERN DIXIE VALLEY

The Northern Dixie Valley geothermal area in west-central Nevada is about 95 km northeast of Fallon (Fig. 6). This is the second most developed area in the province, with 10 deep wells. Actually, there are several prospective, high-temperature areas in Dixie Valley, but only the area of the potentially commercial SUNEDCO development near Senator fumaroles will be discussed.

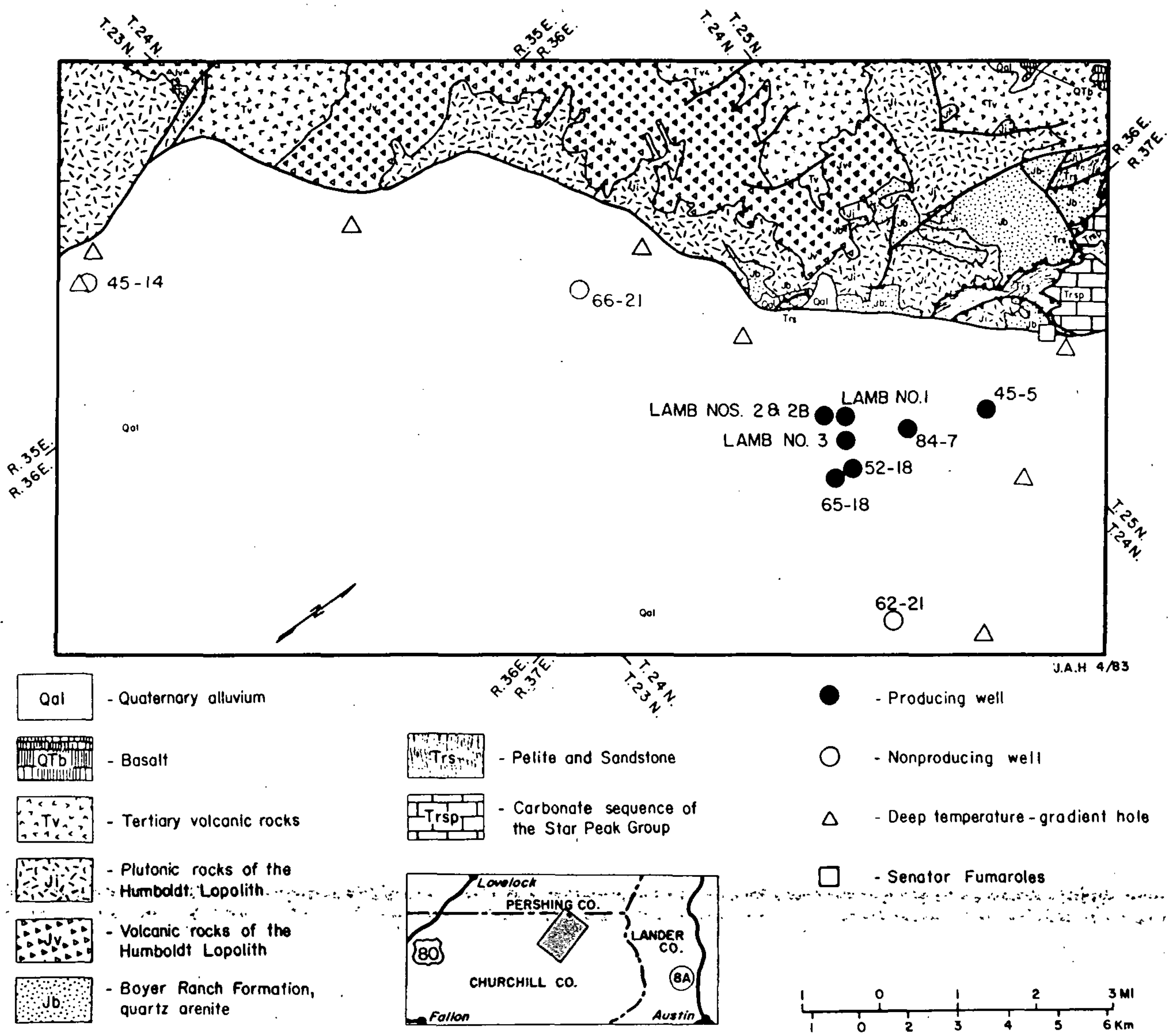

Figure 6. Map of the Dixie Valley, Nevada Area (modified from Speed, 1976).

SUNEDCO has released few results of their exploration. Therefore, the geothermal literature on Dixie Valley is mostly regional studies or discussions of data from the two wells drilled by Thermal Power Company and Southland Royalty Company as part of the Industry-Coupled Program (Fiore, 1980; Denton et al., 1980). A compilation of published literature and data can be found in the June, 1981 Geothermal Resources Council Bulletin. The most recent report summarizing SUNEDCO's exploration activities is by Parchman and Knox (1981). Geothermal developments in the southern part of Dixie Valley are reported by Waibel (1983).

Dixie Valley is a typical Basin and Range graben with a northeasterly strike and interior drainage into the Humboldt Salt Marsh. The geothermal reservoir is associated with the major normal fault(s) separating Dixie Valley from the Stillwater Range to the west. The Stillwater Range is a structurally complex block of Mesozoic sedimentary and igneous rocks overlain by a thick and variable Tertiary volcanic sequence (Willden and Speed, 1974; Speed, 1976; Waibel, 1983). Similar geology has been penetrated by the wells in Dixie Valley (Bard, 1980). Dixie Valley is known primarily for the 6.8-magnitude, 1954 Dixie Valley-Fairview Peak earthquake and associated swarms that produced fault scarps as high as 6 m (Slemmons, 1957). A spreading rate of 1 mm/yr for the past 12,000 yrs has been estimated by Thompson and Burke (1974).

Surface thermal manifestations in northern Dixie Valley are obvious and abundant at the base of the east scarp of the Stillwater Range. They include Dixie and Sou Hot Springs, Senator and other unnamed fumaroles, and several hydrothermally altered and mineralized areas. Although the predicted subsurface temperatures based on the standard chemical geothermometers from the thermal springs were low, SUNEDCO continued exploration because silica-mixing models at Dixie Hot Springs and temperature-gradient data indicated an estimated 180-210°C reservoir at depth (Parchman and Knox, 1981).

SUNEDCO's first well, Lamb #1, was the discovery well (Appendix 1). Completed at 2211 m in 1978 about 4-1/2 km southeast of the Senator Fumaroles, this well produces from fractured Tertiary volcanic rocks and possibly the underlying Mesozoic intrusive and volcanic rocks (Bard, 1980). SUNEDCO has subsequently drilled seven stepout or delineation wells, six of which are producers. The only nonproducer, Federal 62-21, is the deepest test to date and the furthest from the range-front fault. As all the producing wells are between 2211 and 3005 m deep, Dixie Valley is the deepest geothermal reservoir yet discovered in the province. SUNEDCO has not released temperature data but a bottomhole temperature of the SUNEDCO development in excess of 238°C has been published (Keilman, 1982).

Two additional deep wells were drilled along the range front southwest of SUNEDCO's wells in 1979 by Thermal Power Company. Although both of these wells are hot, neither is productive. Bard (1980) reports that the Thermal Power Company wells encountered the same general lithology as the Lamb #1. However, he believes the reason the permeability is reduced is because of a "missing" red clay-layer cap overlying the volcanic sequence, and the absence of a sizeable intrusive body.

The limited fluids produced from the Thermal Power wells are sodium chloride in composition and have a total dissolved solids content ranging from 1600 to 5400 mg/ml (Bohm et al., 1980). The SUNEDCO wells produce a similar low-salinity water.

The SUNEDCO flow rates have not been released, but they are considered favorable for potential electric-power development. SUNEDCO has talked to a number utilities about developing Dixie Valley and at the present time, the next likely step is a small demonstration plant.

SODA LAKE

The Soda Lake geothermal area is located in the southwestern part of the Carson Sink, some 10 km northwest of Fallon, Nevada (Fig. 7). This prospect is relatively unknown as industry exploration results to date have not been widely publicized, and the surficial geology largely conceals the active geothermal manifestations.

The geothermal potential of the Soda Lake area was first indicated in 1903, when water well drilling at an extinct hot spring hit boiling water at 18 m (Garside and Schilling, 1979). This well furnished steam for a bathhouse as late as 1964. Morrison (1964) mapped the area as part of a larger study of Lake Lahontan and the southern Carson Desert. Olmsted et al. (1975) studied the hydrology plus outlined and interpreted the large near-surface thermal anomaly. Industry began exploratory work in 1973. Hill et al. (1979) presented a brief

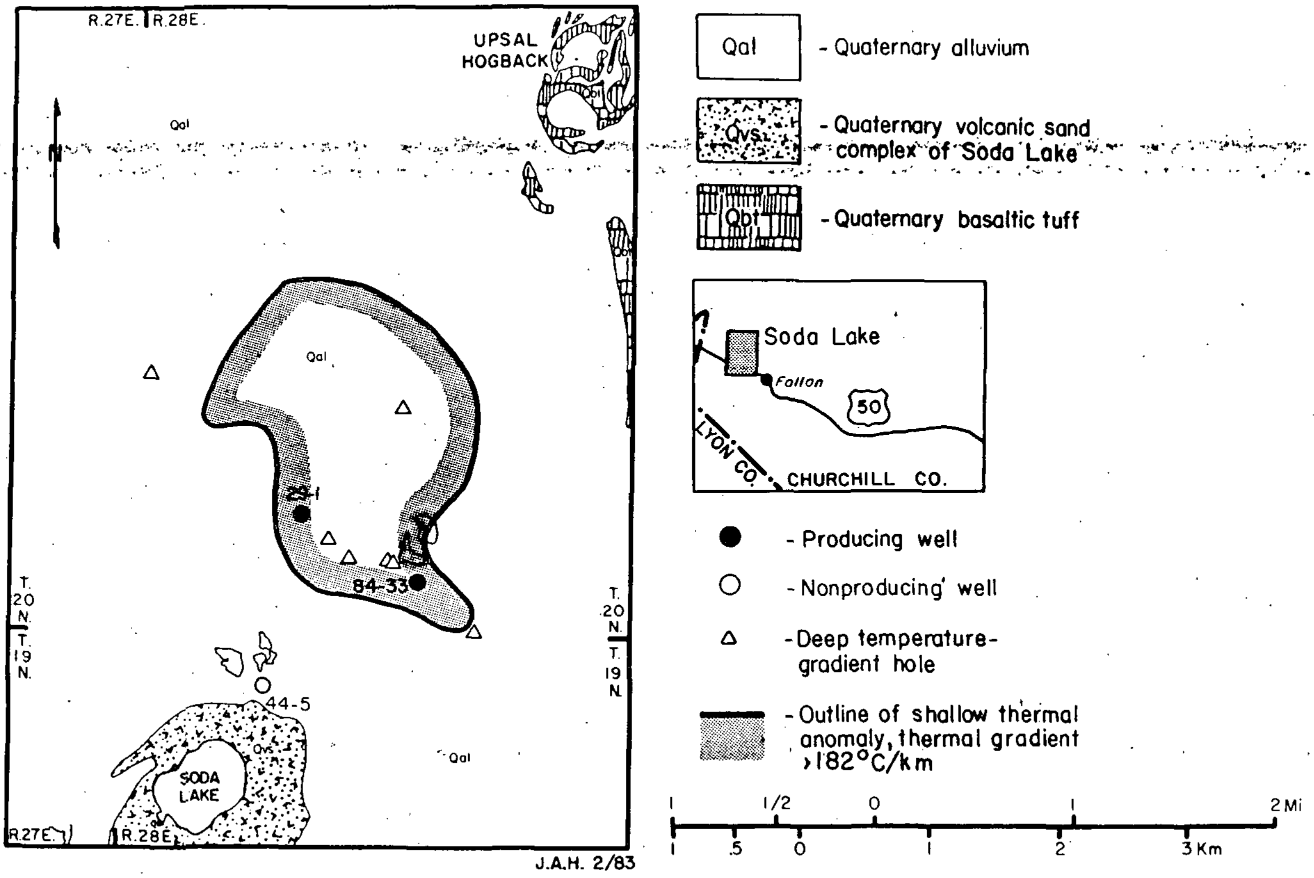

Figure 7. Map of the Soda Lake, Nevada Area (geology modified from Morrison, 1964).

exploration history and geothermal interpretation. Detailed lithologic logs from several of the intermediate-depth and deep wells in the area are presented by Sibbett (1979).

The Soda Lake geothermal area is the only proven high-temperature Basin and Range geothermal prospect not adjacent to range-bounding, frontal-fault systems or located within an exposed small-relief horst block. It is located in the southern Carson Sink, about 18 km from pre-Quaternary bedrock exposures. The Carson Sink is the major drainage sump of the northwestern Great Basin and is one of the largest and deepest basins in northern Nevada. The surficial geology is almost entirely late Pleistocene lacustrine and aeolian sediments. The flat, monotonous sedimentary surficial cover is broken by two volcanic-related deposits. Soda Lake and Little Soda Lake occupy phreatic explosion craters within cones of Quaternary sand and basaltic lapilli ejecta about 30 m high. These explosive craters are believed to have been active as recently as 10,000 yrs ago and hot-spring activity apparently is present near the center of Soda Lake (Breese, 1968). Quaternary magmatic activity at Upsal Hogback, about 9 km northeast of Soda Lake, has produced from four to seven overlapping cones of subaerially deposited basaltic tuff. The alignment of these volcanic and hydrothermal features provides evidence for a major northeast-striking structure controlling the geothermal system. Hill et al. (1979) have interpreted this structure from seismic data as a narrow graben.

There is gravity and magnetic evidence for other interesting, and as yet poorly understood, features beneath the surficial cover. A 6-mgal, arcuate Bouguer gravity high with a diameter of about 10 km is approximately centered on Soda Lake. A magnetic low correlates with the central gravity low. Directly beneath Soda Lake a small positive gravity residual may indicate an intrusive plug.

The Soda Lake resource is largely defined by temperature-gradient holes. Three large-diameter wells and six intermediate-depth temperature-gradient holes have helped define the thermal regime at depth. However, stratigraphic correlations between these holes, especially in the pre-Quaternary rocks, have met with limited success to date.

The first deep exploratory well, 1-29, (Appendix 1) was drilled in 1974 just west of the old steam well. Production was found at 238 m in unconsolidated alluvium with a maximum temperature of 172°C. The 44-5 well was unsuccessfully drilled in 1978 on a resistivity anomaly near the south margin of the shallow thermal anomaly (Hill et al., 1979). Although 188°C has been measured as shallow as 610 m, the hottest measured temperature to date is 204°C in the 84-33 well. A short-term flow test of well 84-33 has indicated potential for commercial production. It produced 115,000 kg/hr total-mass flow through 75 m of perforated casing completed in the Tertiary volcanic section. The reservoir fluid is a low-salinity, 5000 mg/l, sodium chloride water.

Soda Lake is not yet a commercial success and no power plants have been proposed, but the results to date are encouraging. Additional drilling, testing and evaluation are required before the potential of this reservoir can be determined.

STEAMBOAT SPRINGS

Steamboat Springs is located about 16 km south of downtown Reno, Nevada (Fig. 8). Systematic research on the Steamboat Springs geothermal system began in 1945, making it the first such system to be extensively studied in the Basin and Range province (Thompson and White, 1964; White et al., 1964; White, 1968). This early work, along with the impressive thermal features, has made Steamboat Springs known to geothermal and economic geologists worldwide. The water geochemistry has been studied by Bateman and Scheibach (1975), and Nehring (1979, 1980). White et al. (1974) have studied the geochemical processes which created the extensive areas of acid-leached and hydrothermally altered rock at Steamboat Springs. Geophysical data have been presented by Hoover et al. (1975a, 1975b), Long and Brigham (1975), and Peterson (1975). The most recent geological paper has been on the duration of hydrothermal activity (Silberman et al., 1979). The only published information on the recent geothermal exploration is by Desormier (1983).

Steamboat Springs has a wide variety of geothermal features covering an area of about 10 km^2, making it one of the most obvious and interesting geothermal exploration targets in the province. The thermal springs are located at the northeast end of Steamboat Hills, a small northeast-striking range transverse to the dominant regional trends. The Steamboat Hills consist of granodiorite and metamorphosed sedimentary and volcanic rocks partially buried by Tertiary volcanic rocks and Quaternary volcanic and sedimentary rocks. A north-east-striking line of four Quaternary rhyolite domes (Thompson and White, 1964) indicates a possible magmatic heat source. The area is highly faulted and these faults appear to control the location of the known reservoir (Desormier, 1983). Steamboat Springs has a long documented history of geothermal activity.It has been intermittently active for at least 2.5 million years (Silberman et al., 1979).

Geothermal exploration at Steamboat Springs began about 1920 when a local resort owner drilled shallow wells to supply a spa. In 1950 the Rodeo well (Appendix 1) was the first well to be drilled at Steamboat Springs, and probably the first in the Basin and Range province, specifically searching for steam for generating electricity (White, 1983). The initial intermediate-depth exploratory well was drilled in 1959 by Nevada Thermal Power Company (Magma) to 558 m (White, 1968). Five other wells soon followed with the maximum measured temperature of 186°C in Nevada Thermal Power well 4. No production or deep exploratory wells were drilled at Steamboat Springs between 1962 and 1979.

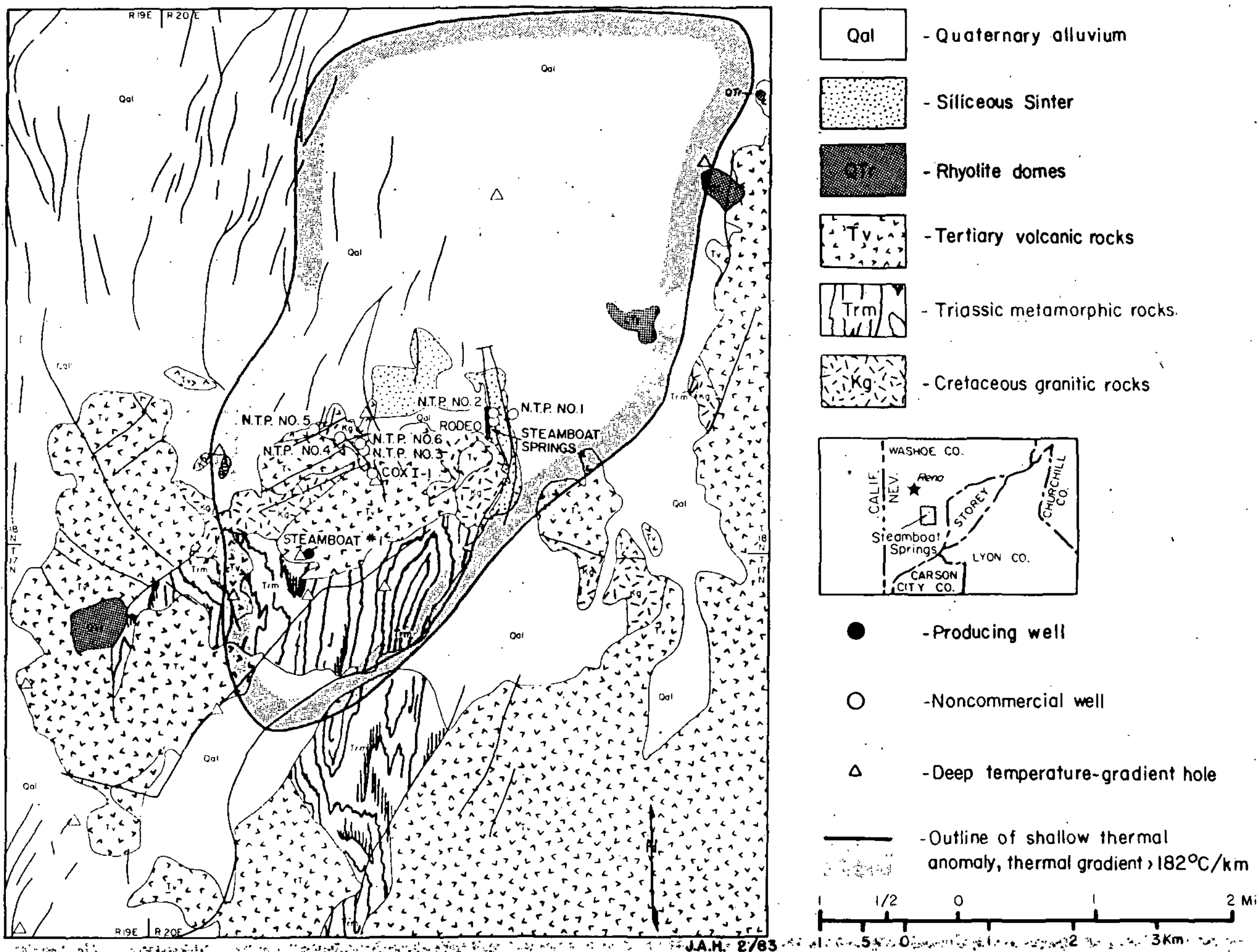

Figure 8. Map of the Steamboat Springs, Nevada Area (modified from Silberman et al., 1979)

In the mid 1970's private industry resumed exploration at Steamboat Springs in anticipation of the September, 1975 KGRA sale. Phillips Petroleum conducted an integrated exploration program between 1975 and 1979 which resulted in drilling five intermediate-depth, temperature-gradient holes. Data from these holes were used to locate Steamboat #1, the discovery well (Desormier, 1983).

Steamboat #1 was drilled to a depth of 930 m in the summer of 1979 and is capable of producing 272,000 kg/hr of fluid from fractured granodiorite and metamorphic rocks. The maximum measured subsurface temperature is 228°C. The chemical geothermometers indicate subsurface temperatures near 220°C (Nehring, 1979). The produced sodium chloride water is chemically similar to the hot springs water with a salinity of 2200 mg/l.

Steamboat #1 appears to have an unusual location, on top of the Steamboat Hills, almost three km southwest of the main thermal springs. However, Steamboat #1 has demonstrated that this area is a deeper source for the Steamboat Springs thermal water which flows laterally to the northeast from beneath Steamboat Hills.

Nine intermediate-depth temperature-gradient holes and one other non-commercial production well, the Cox I-1, have been drilled since 1979. These have confirmed the Steamboat Springs geothermal reservoir underlies the higher parts of the Steamboat Hills. Between 1981 and 1983 there was no drilling activity because one of the major lease holders was liquidating their position. This was accomplished early in 1983 so a second attempt at a confirmation well is now feasable.

COSO

The Coso geothermal field is located in the Coso Mountains of southern California about 55 km north of the town of Ridgecrest and mostly within the borders of the China Lake Naval Weapons Center (Fig. 9).

Coso lies a short distance east of the scenic eastern scarp of the Sierra Nevada Range amid a spectacular cluster of Quaternary rhyolite domes.

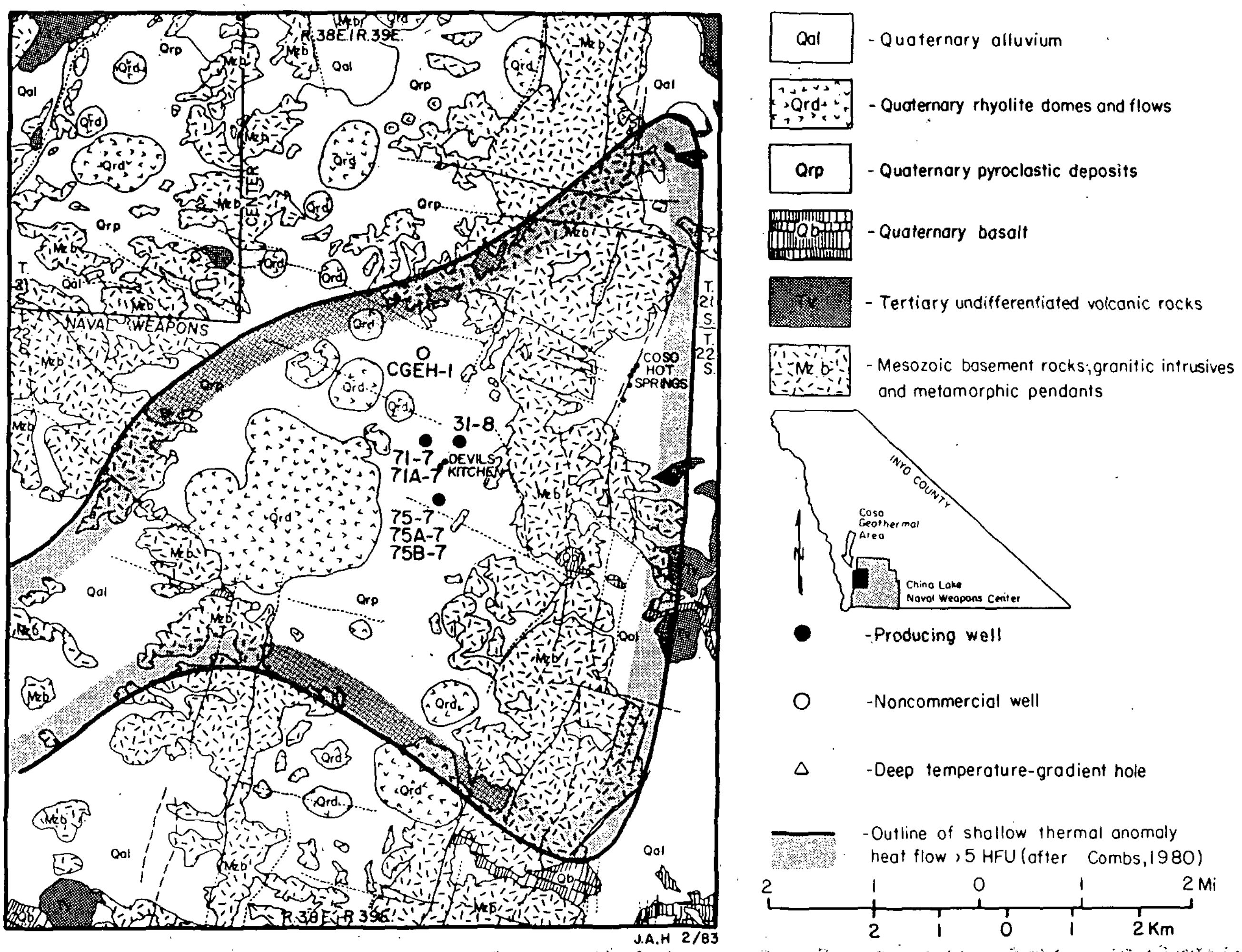

Figure 9. Map of the Coso, California Area (modified from Duffield and Bacon, 1981).

These domes, together with the Coso thermal springs and the Devil's Kitchen fumaroles, clearly indicate high geothermal potential. Coso has been intensively studied by the U. S. Geological Survey, University of Utah Research Insitute, U. S. Navy, the U. S. Department of Energy, and private industry.

The literature on Coso is extensive. The collection of papers in the Journal of Geophysical Research (1980) examine many facets of Coso. More recent contributions are a geologic map (Duffield and Bacon, 1981) and recent production-drilling results near the Devil's Kitchen (Moore et al., 1982).

Numerous geophysical studies were conducted at Coso prior to drilling the first large-diameter exploratory well, CGEH-1 late in 1977 (Galbraith, 1978). CGEH-1 was drilled by the U. S. Department of Energy in search of hot dry rock. CGEH-1 has a maximum temperature of 195°C (Appendix 1) and during drilling produced 27,000 kg/hr of sodium chloride water with a total dissolved solids content near 4,500 mg/l. The chloride water has been interpreted to indicate a hot-water reservoir (Fournier et al., 1980).

After the drilling and testing of CGEH-1 there was no additional drilling until late 1981. During this time, legal and political problems requiring congressional and U. S. Navy action to permit private development within the Naval Weapons Center were resolved. In December, 1979, almost six years after the Geothermal Steam Act was enacted, California Energy Company contracted with the U. S. Navy to explore for and develop geothermal resources on an initial 3000-ac tract. This arrangement is unique because the U. S. Navy has retained title to the geothermal resource. In September, 1981 the remaining Federal KGRA lands outside the Naval Weapons Center were offered for lease. The Los Angeles Dept. of Water and Power bid $1262 and $1012 per acre for two parcels which are by far the highest KGRA bonus bids in the province.

In December, 1981, California Energy drilled well 75-7 (Appendix 1) near the Devil's Kitchen to a depth of 405 m and encountered dry steam with a temperature of 213°C and a pressure of 17.9 kg/cm^2. The 75-7 well is capable of a sustained steam-flow rate well in excess of 45,000 kg/hr (Moore et al., 1982; The Oil and Gas Journal, 1982). The dry steam was largely a surprise because of the chloride water present in CGEH-1. Moore et al. (1982) believe the steam results from a local zone of vigorous flashing rather than from an extensive steam cap. Fournier (pers comm.) interprets the dry steam to result from the partial obstruction of hot water flow along a fault which was intersected by the 75-7 wellbore. He believes that there also is no steam cap, but that the steam only forms as the pressure is decreased above the obstruction. The reservoir at Coso apparently consists of north-south striking fractures in Mesozoic granitic rocks and variable high-grade metamorphic rocks of uncertain age.

California Energy has drilled five additional wells, all of which are reported to be capable of commercial flow rates and produce two-phase fluids (National Geothermal Service, 1982). The drilling strategy to date at Coso has varied from most other Basin and Range prospects. Temperature-gradient holes deeper than 150 m are conspicuously absent.

The maximum reported temperature at Coso is 213°C in well 75-7. Temperatures as high as 245°C in the deeper chloride-water part of the reservoir are possible based on geochemical evidence (Fournier et al., 1980). As all of the wells to date at Coso have been relatively shallow, deeper drilling may encounter these higher indicated temperatures.

California Energy Company has announced that they intend to be generating a substantial amount of electrical power by the end of 1984. If this schedule is met, the elapsed time between the first commercial well and power production will be only 3 years. This would be the most rapid commercial geothermal-power development in the United States.

LONG VALLEY

The Long Valley caldera is located at the base of the eastern scarp of the Sierra Nevada, 50 km north of the town of Bishop. The scenic resort town of Mammoth Lakes is nestled within its southwest quadrant (Fig. 10). The caldera is located directly along the western margin of the Basin and Range province and may be more closely related to the province boundary than the province proper. However, the 450 km^2 Quaternary caldera has all the geological pre-requisites to contain the largest

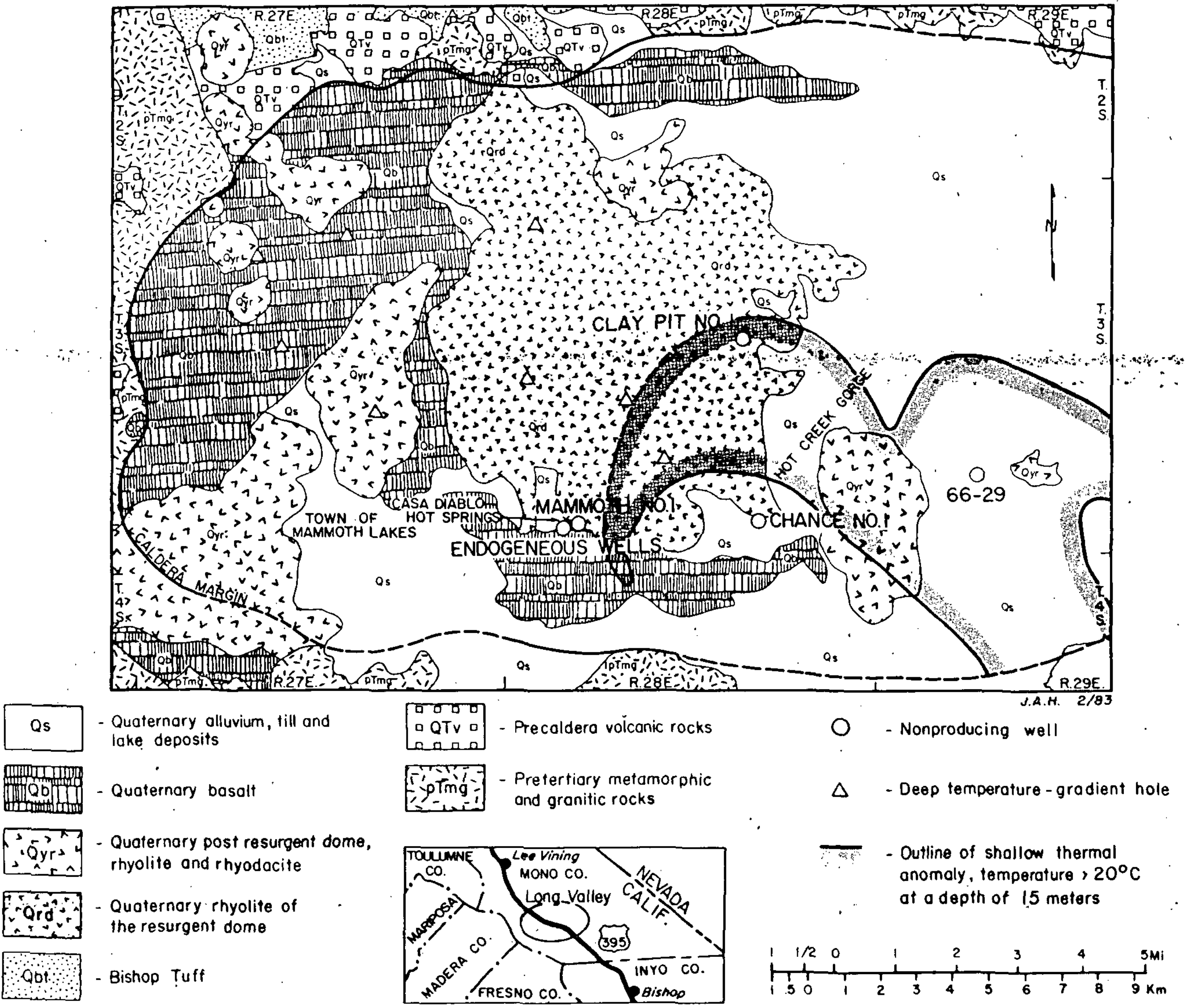

Figure 10. Map of the Long Valley, California Area (modified from Sorey et al., 1978).

geothermal reservoir in the Basin and Range province. Recent obsidian flows, along with gravity, seismic refraction, and P-wave delay data indicate a magmatic heat source underlies the western portion of the caldera. The hot springs in Hot Creek Gorge are the largest volume boiling springs in the province and the chemical geothermometers when applied to these waters indicate a reservoir temperature between 200 and 282°C. Large areas of intense hydrothermal alteration are present at Casa Diablo, Hot Creek, and the Clay Pit. Fairly intense seismic activity, probably related to magma movement, is presumably maintaining or enhancing reservoir permeability. On the other hand, this activity has initiated a volcano-watch designation by the U. S. Geological Survey. In spite of these favorable geological characteristics, no large reservoir has yet been discovered. The main reason for this is U. S. Forest Service delays in leasing Federal land within this most scenic of the high-temperature geothermal prospects.

The literature on Long Valley is very extensive. The U. S. Geological Survey's Long Valley Symposium (Journal of Geophysical Research, 1976) is a very comprehensive collection of papers on geology, geochemistry, geophysics and hydrology. A complete integration of the hydrothermal system of Long Valley has been presented by Sorey et al (1978). Diment et al (1980) have studied the shallow thermal regime.

Geothermal exploration at Long Valley began in 1959 at Casa Diablo Hot Springs on private lands. Nine shallow production holes were drilled by Magma Power Company and Endogeneous Power Company to a maximum depth of 324 m (Appendix 1). A maximum temperature of 178°C was measured and the maximum-reported flow rate was 246,000 kg/hr (McNitt, 1963). After this initial burst of activity which lasted through 1962, little happened until the U. S. Geological Survey began a comprehensive program in 1971 to study Long Valley as its type hot-water geothermal system. Some of the interpretations from this study, made without any deep drill holes, have since proven to be almost prophetic.

The first deep well in the Long Valley caldera was drilled in 1976 by Republic Geothermal to a depth of 2109 m in the southeastern quadrant (Smith and Rex, 1977). Well 66-29 is located on land leased at the first KGRA sale in January 1974. This apparently had much to do with the location. Well 66-29 turned out to be surprisingly cold with a maximum unstabilized temperature of 72°C, obtained 90 hrs after last circulation.

Between 1976 and 1979 no deep wells were drilled in the caldera. This was not because of the discouraging results of the Republic well, but because the U. S. Forest Service was not making Federal lands in the central and western parts of the caldera available for lease. In 1979, the U. S. Forest Service, together with the Bureau of Land Management and U. S. Geological Survey, proposed a lease sale in the central part of the caldera. However, the special stipulations attached to the leases included such items as forced unitization, a commitment to drill three wells at least four km apart within two years of unitization, and phased leasing. Industry felt it could not effectively operate under these requirements and filed an appeal. The Chief of the U. S. Forest Service mitigated these problems in March 1981.

In preparation for this sale Union Oil Company drilled two unsuccessful deep production wells in the summer of 1979. Union verbally presented data from these wells to the geothermal industry prior to the rescheduled KGRA sale at a Bay Area section meeting of the Geothermal Resources Council. Some of this material has later appeared in print (Gambill, 1981).

The Union Mammoth No. 1 well has a double temperature reversal with a 60°C temperature decrease below the reversal. The Clay Pit well was also quite discouraging with a bottomhole temperature of 147°C at 1846 m. More importantly, these two wells demonstrated that a high-temperature geothermal reservoir is not present beneath two of the most impressive surficial manifestations in the caldera. The three deep wells within the caldera have demonstrated that much of the caldera is not underlain by a geothermal reservoir. Consequently the exploration focus has shifted to the unexplored western third of the caldera.

The lease sale for the central part of the caldera was held in October, 1981, after the appeal had run its course. A final lease sale was later scheduled for September 1982, to include most of the western third of the caldera. This lease sale was delayed due to appeals by environmental factions to July, 1983.

Long Valley has been the site of the most friction between the geothermal industry, government, and environmental factions in the province. However, additional deep exploratory wells will be drilled in the caldera and hopefully this elusive reservoir will be discovered in the near future.

THE FUTURE

Currently geothermal exploration for high-temperature reservoirs is stagnant (Edmiston, 1982), a result of the modest decline in the price of the principal forms of energy. Most known reservoirs in the Basin and Range province have marginal temperatures under present economic conditions. Any significant additional decline in energy prices could render most and possibly all of these reservoirs noncompetitive. A collapse of OPEC could create such a decline. Until energy prices stabilize or increase, geothermal exploration for undiscovered reservoirs will continue at a low level with fewer than four wildcat wells being drilled in the province each year.

There could still be significant development drilling activity on the discovered reservoirs. It is crucial that the geothermal industry prove as soon as possible, that at least one of the discovered reservoirs in the temperature range of 200-220°C is capable of power generation. In all likelihood the first power plants on each reservoir will be demonstration facilities of 10 or 20 mw. At this time it is not possible to predict when or how many of the reservoirs will be developed.

Long-term exploration for new reservoirs will continue, although at a much slower pace than in the past decade. Most future discoveries will either have to be blind, like Desert Peak; deep, like Dixie Valley; or reinterpretations of some already drilled areas. Thermal systems with boiling springs and large exposed siliceous-sinter deposits such as Beowawe, Roosevelt Hot Springs, Steamboat Springs, and Brady's Hot Springs have been drilled. Temperatures of new discoveries generally will not exceed 220°C as there is no evidence to expect any new discoveries, other than Long Valley and possibly the Mono Craters, to be closely associated with shallow silicic-magma chambers.

In spite of all the exploration to date in the northern Basin and Range province, many areas in excess of 200 km^2 do not contain even a single shallow temperature-gradient hole. There has not been a deep well drilled in any of the major, high-relief mountain ranges. The same may generally be said for deep temperature-gradient holes. Similarly, the areas of Recent mafic volcanism such as Lunar Crater or the Owens Valley have also been virtually ignored. It is not likely that all the high-temperature reservoirs have been discovered. Future discoveries will probably be concentrated along the east or west margins of the province, or in the vicinity of the Carson Sink.

ACKNOWLEDGEMENTS

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BIBLIOGRAPHY

Bard, T. R., 1980, Petrologic alteration studies in Geothermal Reservoir Assessment Case Study--Northern Dixie Valley, Nevada: Southland Royalty Company, U. S. Dept. of Energy Contract No. DE-AC08-79 ET27006, p. 88-158.

Bateman, R. L., and Scheibach, R. B., 1975, Evaluation of geothermal activity in the Truckee Meadows, Washoe County, Nevada: Nevada Bur. of Mines and Geol. Report 25, 38 p.

Benoit, W. R., Hiner, J. E., and Forest, R. T., 1982, Discovery and geology of the Desert Peak geothermal field: A case history: Nevada Bur. of Mines and Geol. Bull. 97, 82 p.

Bohn, B. W., Jacobson, R. L., Campana, M. E., and Ingraham, N. L., 1980, Hydrology and hydrochemistry in Geothermal Reservoir Assessment Case Study-- Northern Dixie Valley, Nevada: Southland Royalty Company, U. S. Dept. of Energy Contract No. DE-AC08-79ET27006, p. 159-186.

Breese, C. R. Jr., 1968, A general limnological study of Big Soda Lake: M. S. thesis, Univ. of Nevada, Reno, 83 p.

Combs, J., 1980, Heat flow in the Coso geothermal area, Inyo County, California: Jour. of Geophys. Res. Vol. 85, No. B5, p. 2411-2424.

Denton, J. M., Bell, E. J., and Jodry, R. L., 1980, Geothermal reservoir assessment case study--Northern Dixie Valley, Nevada: Southland Royalty Company, U. S. Dept. of Energy Contract No. DE-AC08-79ET27006, 223 p.

Desormier, W. L., 1979, Desert Peak to Humboldt House and Winnemucca, in Lane, M. A., (ed.) Nevada Geothermal Areas: Desert Peak, Humboldt House, Beowawe: Guidebook for Field Trips#6 Geothermal Resources Council 1979 Annual Meeting, p. 9-18.

_____, 1982, Humboldt House lease evaluation and preliminary development plan Pershing County, Nevada: unpublished report for Phillips Petroleum Company, 15 p.

_____, 1983, Steamboat Springs Geothermal Project: Geothermal Resources Council Field Trip Guidebook for the Role of Heat in the Development of Energy and Mineral Resources in the Northern Basin and Range Province, 7 p.

Diment, W. H., Urban, T. C., and Nathenson, M., 1980, Notes on the shallow thermal regime of the Long Valley caldera, Mono County, Calif- Vol. 4, p. 37-40.

Duffield, W. A., and Bacon, C. R., 1981, Geologic map of the Coso volcanic field and adjacent areas, Inyo County, California: U. S. Geol. Surv. Misc. Invest. Map I-1200.

Edmiston, R. C., 1982, A review and analysis of geothermal exploratory drilling results in the Northern Basin and Range geologic province of the USA from 1974 through 1981: Geothermal Resources Council Trans. Vol. 6, p. 11-14.

Edmiston, R. C., 1982, Lets face the facts about geothermal power development in the U. S.: Geothermal Resources Council Bull. Vol. 11, No. 11, p. 19-20.

Epperson, I. J., 1982, Beowawe, Nevada, well testing: history and results: Geothermal Resources Council Trans., vol. 6, p. 257-260.

Fiore, J. N., 1980, Overview and status of the U. S. Department of Energy's Industry-Coupled Geothermal Reservoir Assessment Program: Geothermal Resources Council Trans. Vol. 4, p. 201-204.

Fournier, R. O., Thompson, J. M., and Austin, C. F., 1980, Interpretation of chemical analyses of waters collected from two geothermal wells at Coso, California: Jour. of Geophys. Res., Vol. 85, p. 2405-2410.

Galbraith, R. M., 1978, Geological and geophysical analysis of Coso geothermal exploration hole no. 1 (CGEG-1), Coso Hot Springs KGRA, California: Univ. of Utah Research Inst., Earth Science Lab. Report, 39 p.

Gambill, D. T., 1981, Preliminary hot dry rock geothermal evaluation of Long Valley caldera, California: Los Alamos National Laboratory, LA-8710-HDR, 22 p.

Garside, L. J., 1974, Geothermal exploration and development in Nevada through 1973: Nevada Bureau of Mines and Geology Report 21, 12 p.

Garside, L. J., and Schilling, J. H., 1979, Thermal Waters of Nevada: Nevada Bur. of Mines and Geology Bull. 91, 163 p.

Hill, D. G., Layman, E. B., Swift, C. M., and Yungul, S. H., 1979, Soda Lake, Nevada, thermal anomaly: Geothermal Resources Council Trans. Vol. 3, p. 305-308.

Hoover, D. B., O'Donnell, J. O., Batzle, M., and Rodriguez, R., 1975, Map of telluric profiles, Steamboat Hills, Nevada: U. S. Geol. Survey Open-File Report 75-445.

Hoover, D. B., Batzle, M., and Rodriguez, R., 1975b, Self-potential map, Steamboat Hills, Nevada: U. S. Geol. Survey Open-File Report 75-446.

Johnson, M. G., 1977, Geology and mineral deposits of Pershing County, Nevada: Nevada Bur. Mines and Geol. Bull. 89, 115 p.

Journal of Geophysical Research, 1976, Vol. 81, No. 5, p. 721-860. Long Valley Papers

_____, 1980, Vol. 85, p. 2379-2516.
Coso Papers

Keilman, L., 1982, Beowawe #1 - a 10 mw geothermal unit in northern Nevada: Geothermal Resources Council Trans. Vol. 6, p. 351-353.

Kuwada, J. T., 1982, Field demonstration of the EFP system for carbonate scale control: Geothermal Resources Council Bull. Vol. 11, No. 9, p. 3-9.

Lenzer, R. C., Crosby, C. W., and Berge, C. W., 1977, Recent developments at the Roosevelt Hot Springs KGRA: Trans. Am. Nuclear Soc. Topical Mtg., Golden, Colo., April 12-14, p. 60-67.

Long, C. L., and Brigham, R. H., 1975, Audio-magnetotelluric data log for Steamboat Hills, Nevada: U. S. Geol. Survey Open-File Report 75-447, 7 p.

McKinney, D. B., 1978, Annotated bibliography of the geology of the Roosevelt Hot Springs known geothermal resource area and the adjacent Mineral Mountains, March 1978: Univ. of Utah Research Inst., Earth Science Lab Report, 15 p.

McNitt, J. R., 1963, Exploration and development of geothermal power in California: California Div. of Mines and Geol: Spec. Report 75, 45 p.

Middleton, W. M., 1961, Report on Beowawe, Nevada Geothermal Steam Wells: prepared for Magma - Vulcan Thermal Power Project (unpublished).

Moore, J. L., Austin, C. F., and Prostka, H. J., in press, Geology and geothermal energy development at the Coso KGRA: in Energy Resources of the Pacific Region, Proceedings 1982 Circum-pacific Conference, Amer. Assoc. of Petrol. Geol.

Morrison, R. B., 1964, Lake Lahontan: Geology of southern Carson Desert, Nevada: U. S. Geol. Survey Prof. Paper 401, 156 p.

National Geothermal Service, 1982, Vol. 4, No. 13.

_____, 1983, Vol. 5, No. 21.

Nehring, N. L., 1979, Reservoir temperature, flow, and recharge at Steamboat Springs, Nevada: Geothermal Resources Council Trans. Vol. 3, p. 481-483.

_____, 1980, Geochemistry of Steamboat Springs: U. S. Geol. Survey Open-File Report 80-887, 66 p.

Oil and Gas Journal, 1982, Geothermal strike drilled on Navy's China Lake land: Vol. 80, No. 6, p. 66.

Olmsted, F. H., Glancy, P. A., Harrill, J. R., Rush, F. E., and VanDenburgh, A. S., 1975, preliminary hydrologic appraisal of selected geothermal systems in northern and central Nevada: U. S. Geol. Survey Open-File Report 76-76, 274 p.

Parchman, W. L., and Knox, J. W., 1981, Exploration for geothermal resources in Dixie Valley, Nevada a case history: Geothermal Resources Council Bull. Vol. 10, No. 5, p. 3-6.

Peterson, C. A., 1975, Geology of the Roosevelt Hot Springs area, Beaver County, Utah: Utah Geology, Vol. 2, No. 2, p. 109-116.

Peterson, D. L., 1975, Principal facts for gravity stations in Steamboat Hills and Wabuska, Nevada: U. S. Geol. Survey Open-File Report 75-443, 8 p.

Phillips Petroleum Company, 1979, Geothermal reservoir assessment case study, northern Basin and Range province: U. S. Dept. of Energy, Division of Geothermal Energy Report DOE/ET/27099-1, 38 p.

Ross, H. P., Nielson, D. L., Moore, J. N., 1982, Roosevelt Hot Springs Geothermal System, Utah-Case study: Amer. Assoc. of Petrol. Geol. Bull. Vol. 66, No. 7, p. 879-902.

Rudisell, J. M., 1976, Geothermal well Utah State 14-2, 48-hour flow test, Nov. 16, 1976 to Nov. 18, 1976: released by U. S. Dept. of Energy under contract No. EG-77-C-08-1525, 15 p.

Schoen, R., White, D. E., and Hemley, J. J., 1974, Argillization by descending acid at Steamboat Springs, Nevada: Clays and Clay Minerals, Vol. 22, p. 1-22.

Sibbett, B. S., 1979, Geology of the Soda lake geothermal area: Univ. of Utah Research Inst., Earth Science Lab. Report, 14 p.

Sibbett, B. S., and Glenn, W. E., 1981, Lithology and well log study of Campbell "E-2" geothermal test well, Humboldt House geothermal prospect, Pershing County, Nevada: Univ. Utah Research Inst., Earth Science Lab Report 53, 17 p.

Silberling, N. J., and Wallace, R. E., 1967, Geologic map of the Imlay quadrangle, Pershing County, Nevada: U. S. Geol. Survey map GQ-666.

Silberman, M. L., White, D. E., Keith, T. E. C., and Dockter, R. D., 1979, Duration of hydrothermal activity at Steamboat Springs, Nevada, from ages of spatially associated volcanic rocks: U. S. Geological Survey Prof. Paper 458-D, 14 p.

Slemmons, D. B., 1957, Geological effects of the Dixie Valley - Fairview Peak, Nevada, earthquakes of December 16, 1954: Seis Soc. America Bull. 47, No. 4, p. 353-375.

Smith, J. L. and Rex, R. W., 1977, Drilling results from the eastern Long Valley caldera: Am. Nuclear Soc. Mtg. on Energy and Mineral Recovery Research, Golden, Colo., April 12-14, p. 529-540.

Smith, C., 1979, Interpretation of electrical resistivity and shallow seismic reflection profiles, Whirlwind Valley and Horse Heaven areas, Beowawe KGRA, Nevada: Earth Science Lab Report 25, 43 p.

Smith, C., Struhsacker, E. M., and Struhsacker, D. W., 1979, Structural inferences from geologic and geophysical data at Beowawe KGRA, north-central Nevada: Geothermal Resources Council Trans. Vol. 3, p. 659-662.

Sorey, M. L., Lewis, R. E., and Olmsted, F. H., 1978, The hydrothermal system of Long Valley caldera, California: U. S. Geol. Surv. Prof. Paper 1044-A, 60 p.

Speed, R. C., 1976, Geologic map of the Humboldt Lopolith and surrounding terrain, Nevada: Geol. Soc. America Map MC-14, 4 p.

Stewart, J. H., Walker, G. W., and Kleinhampl, F. J., 1975, Oregon-Nevada lineament: Geology, Vol. 3, p. 265-268.

Struhsacker, E. M., 1980, The geology of the Beowawe geothermal system, Eureka and Lander Counties, Nevada: Earth Science Lab Report 37, 78 p.

Swift, C. M., 1979, Geophysical data, Beowawe geothermal area, Nevada: Geothermal Resources Council Trans. Vol. 13, p. 701-703.

Thompson, G. A., and White, D. E., 1964, Regional geology of the Steamboat Springs area, Washoe County, Nevada: U. S. Geological Survey Prof. Paper 458-A, 52 p.

Thompson, G. A., and Burke, D. B., 1974, Regional Geophysics of the Basin and Range Province: Ann. Rev. Earth and Planetary Sci., Vol. 2, p. 213-238.

Urban, T. C., and Diment, W. H., 1982, An interpretation of precision temperature logs in a deep geothermal well near Desert Peak, Churchill County, Nevada: Geothermal Resources Council Trans. Vol. 6, p. 317-320.

Waibel, A. F., 1983, Field Trip #1 Reno, NV. to Dixie Valley, NV. 15 May 1983: Geothermal Resources Council Field Trip Guidebook for the Role of Heat in the Development of Energy and Mineral Resources in the Northern Basin and Range Province, 24 p.

White, D. E., 1968, Hydrology, activity and heat flow of the Steamboat Springs thermal system, Washoe County, Nevada: U. S. Geological Survey Prof. Paper 458-C, 109 p.

_____, 1983, Summary of Steamboat Springs Geothermal Area, Nevada, with attached road-log commentary: Geothermal Resources Council Field Trip Guidebook for the Role of Heat in the Development of Energy and Mineral Resources in the Northern Basin and Range Province, 20 p.

White, D. E., Thompson, G. A., and Sandberg, C.H., 1964, Rocks, structure, and geologic history of Steamboat Springs thermal area, Washoe County, Nevada: U. S. Geol. Survey Prof. Paper 458-B, 63p.

Willden, R., and Speed, R. C., 1974, Geology and Mineral Deposits of Churchill County, Nevada: Nevada Bureau of Mines and Geology Bull. 83, 95 p.

Zoback, M. L., 1979, A geological and geophysical investigation of the Beowawe geothermal area, north-central Nevada: Stanford University Publication, Geological Sciences, Vol. 16, 79 p.

Zoback, M. L., and Thompson, G. A., 1978, Basin and Range rifting in northern Nevada: Clues from a mid-Miocene rift and its subsequent offsets: Geology, Vol. 6, p. 111-116.

DESERT PEAK KGRA, NEVADA

Geophysical Data Base

The geophysical data base transmitted with the Phillips Petroleum Company data package included summary apparent resistivity and apparent conductance maps resulting from a roving dipole survey, interpreted resistivity slice maps from a magnetotelluric survey and a local gravity survey with some interpreted gravity linears and structures. Benoit et al. (1982) note that these data did not play a major role in understanding the subsurface geology of the area and are not, in general, consistent with drilling results. We tend to concur with the observations of Benoit et al. (1982) and offer the following additional comments.

The roving dipole resistivity data are difficult to interpret in detail, and the large transmitter length and transmitter-receiver separations do tend to give large area bulk resistivities, perhaps explaining the small range of resistivity values. The data are not sufficiently detailed for comparison with the drill results. The magnetotelluric (MT) data should also be considered a reconnaissance scale data base. The MT slice maps are probably the contoured representation of one-dimensional data inversions in a three-dimensional geologic area dominated by low resistivity basin fill and volcanics. The gravity data appear to have an adequate data density but suffer from relatively inaccurate elevation control (± 1.0 feet) and are limited to the immediate Desert Peak area. These gravity data provide important verification of the northwest-trending structure also indicated by temperature data and topography, which is interpreted as a southwestern limit to the reservoir area.

Benoit et al. (1982) also indicate linear features (possible structures) interpreted from self-potential and ground magnetic traverses. We cannot evaluate these interpretations without a detailed review of the data, but would tend to believe that near surface, possibly local, structures are responsible for these observations.

The most significant data base is the temperature data which is described and interpreted in detail by Benoit et al. (1982). Our brief reading of their paper and review of the maps and sections indicates their evaluations and interpretations are consistent with the data and geology. We therefore agree with the near surface hydrologic and structural interpretations they present.

We have inspected regional aeromagnetic (Nevada Bureau of Mines, 1977) and gravity data (Erwin and Berg, 1977) for the Reno 1:250,000 quadrangle from ESL files, and found that these data are too coarse in the area of interest to substantially modify any structural or hydrologic interpretations.

Induced Seismicity

An important element that must be addressed in an Environmental Impact Assessment for Desert Peak geothermal production is the topic of induced seismicity. The principal considerations include historic seismicity for the region, geologic structures which may be affected by production and injection activities, the baseline seismicity record at the production site, and potential impacts on natural features and constructed objects. Induced seismicity was not addressed in any of the Phillips Petroleum Company's technical papers or documents which we reviewed.

Slemmons et al. (1964) have published a review of the major earthquakes with Nevada epicenters for the historic period up to 1961. Churchill County has been the locus of several major (Richter magnitude $\geq$ 5.0) earthquakes since 1940 and the 118° Meridian Seismic Zone is ranked as one of the country's most active seismic zones (Slemmons et al., 1964). The Desert Peak area is relatively remote from population centers and low magnitude (m $\leq$ 4.0) induced seismicity should present no problems to the nearest population centers at Lovelock, Fernley and Fallon. More likely to be affected are the nearby Southern Pacific railroad, Interstate 80 highways, and perhaps the production of geothermal fluids from nearby Brady's Hot Springs. A detailed evaluation of these potential impacts should be developed.

References

Benoit, W. R., Hiner, J. E., and Forest, R. T., 1982, Discovery and geology of the Desert Peak geothermal field: a case history: Nevada Bureau of Mines and Geology (NBMG) Bull. 97.

Erwin, J. W., and Berg, J. C., 1977, Bouguer gravity map of Nevada, Reno sheet: NBMG Map 58.

Nevada Bureau of Mines and Geology, 1977, Aeromagnetic map of Nevada, Reno sheet: NBMG Map 54.

Slemmons, D. B., Gimlett, J. I., Jones, A. E., Greensfelder, R., and Koenig, J., 1964, Earthquake epicenter map of Nevada: NBM Map 29.

NEVADA BUREAU OF MINES AND GEOLOGY

BULLETIN 97

DISCOVERY AND GEOLOGY OF THE DESERT PEAK GEOTHERMAL FIELD: A CASE HISTORY

Walter R. Benoit, John E. Hiner, and Robert T. Forest

A case history of the exploration, development (through 1980), and geology of the Desert Peak geothermal field. Contains sections on geochemistry, geophysics, and temperature-gradient drilling.

UNIVERSITY OF NEVADA • RENO
1982

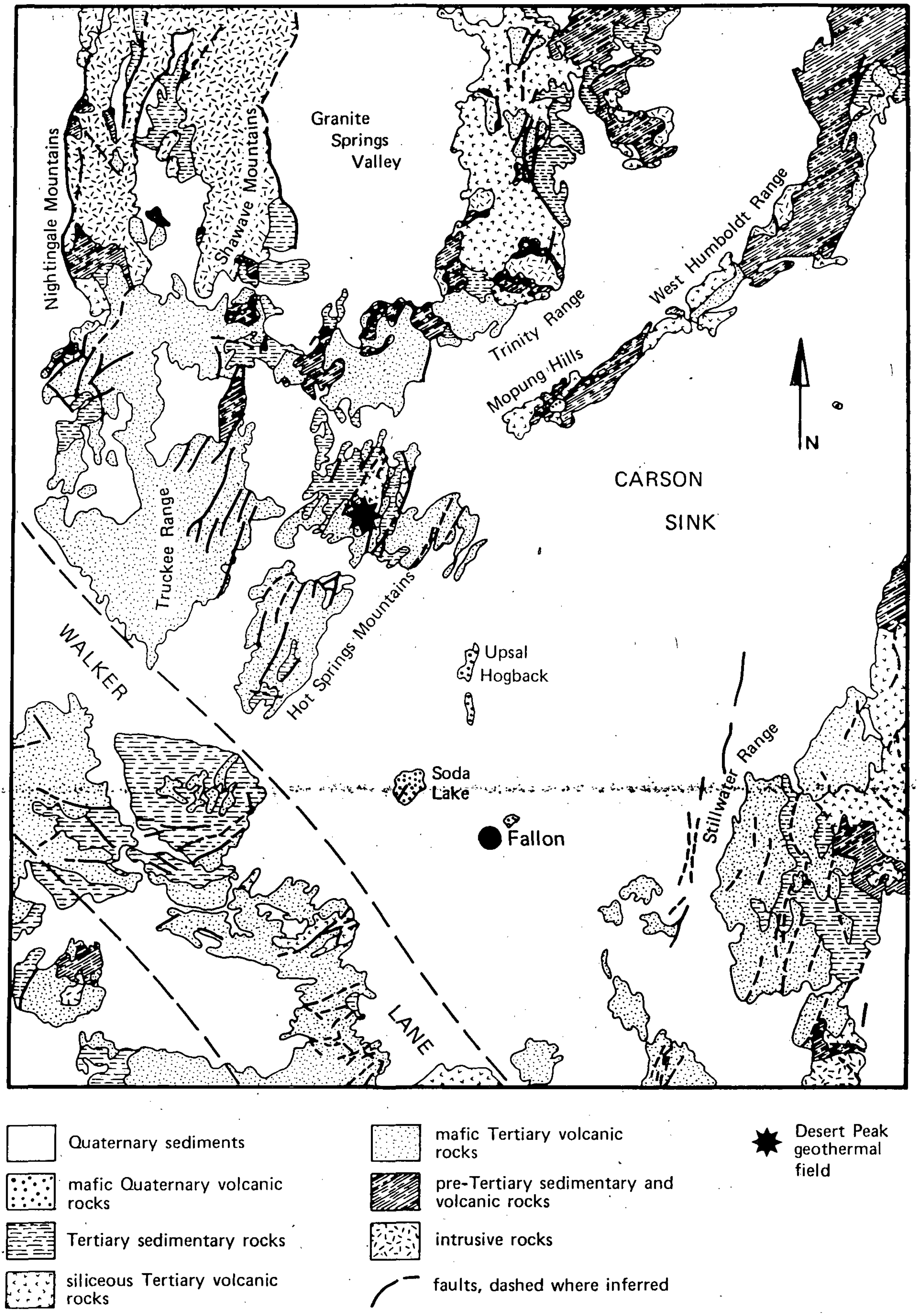


FIGURE 2. Simplified regional geology map of Desert Peak geothermal field, Churchill County, Nevada (from Stewart and Carlson, 1978).

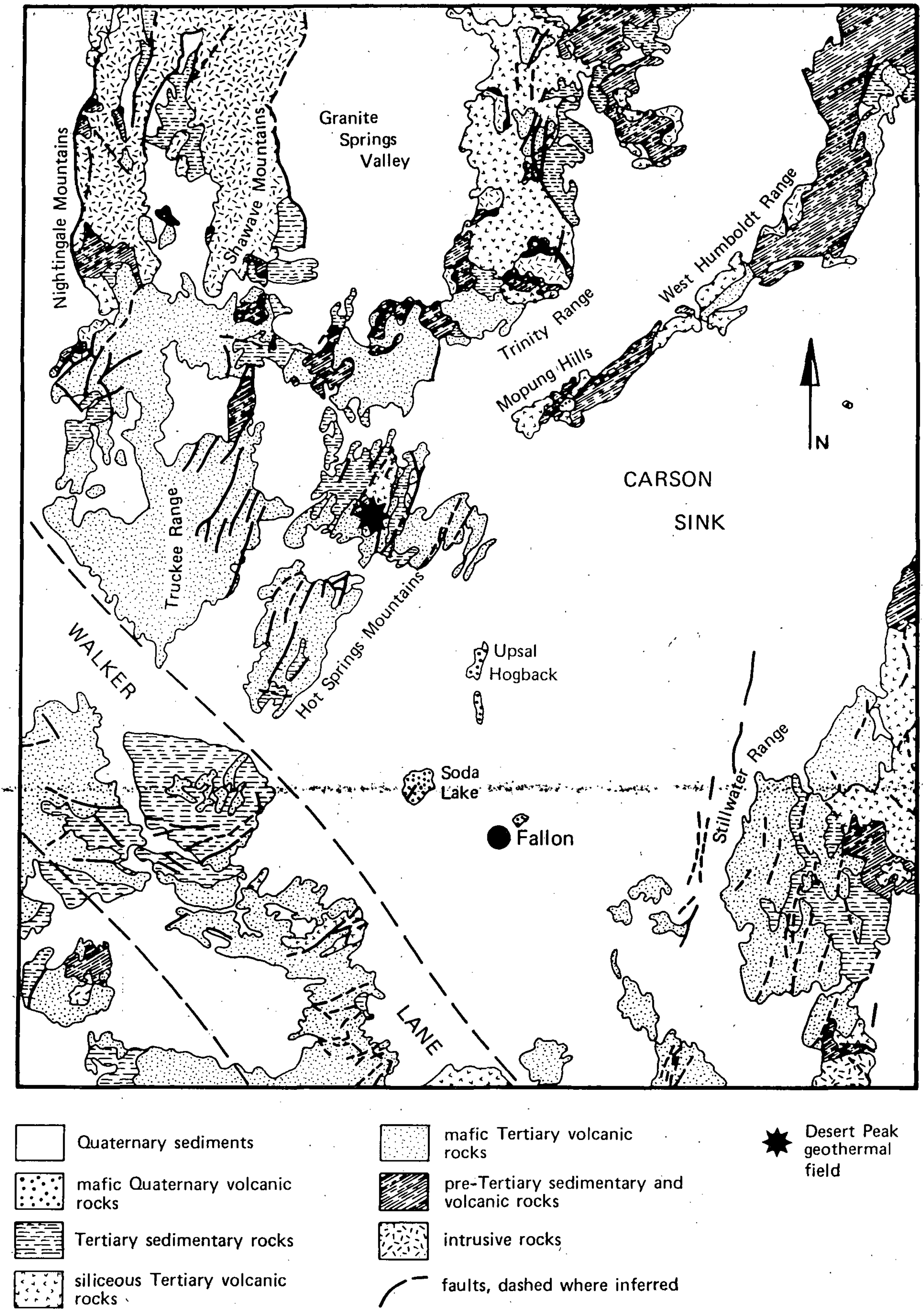
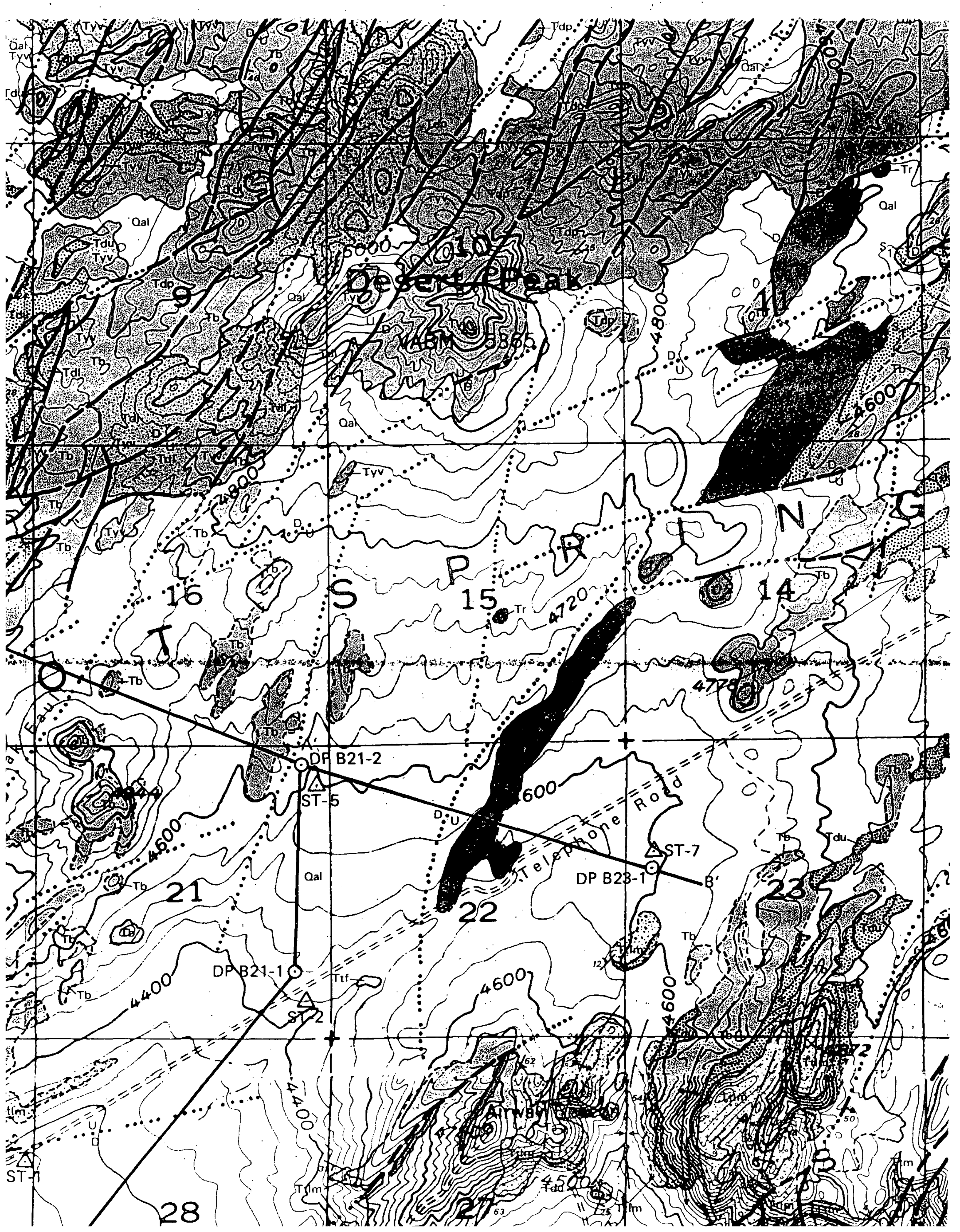


FIGURE 2. Simplified regional geology map of Desert Peak geothermal field, Churchill County, Nevada (from Stewart and Carlson, 1978).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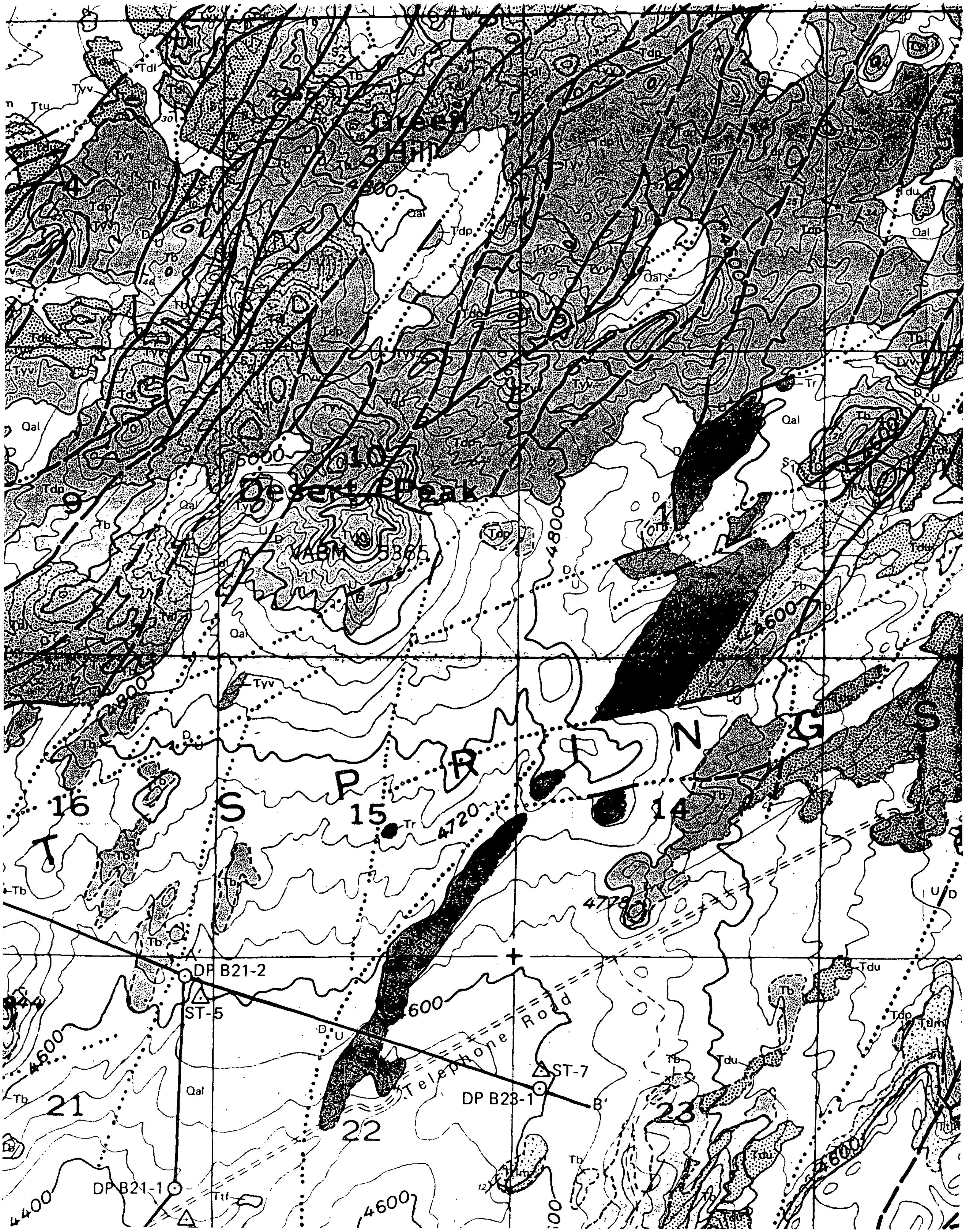

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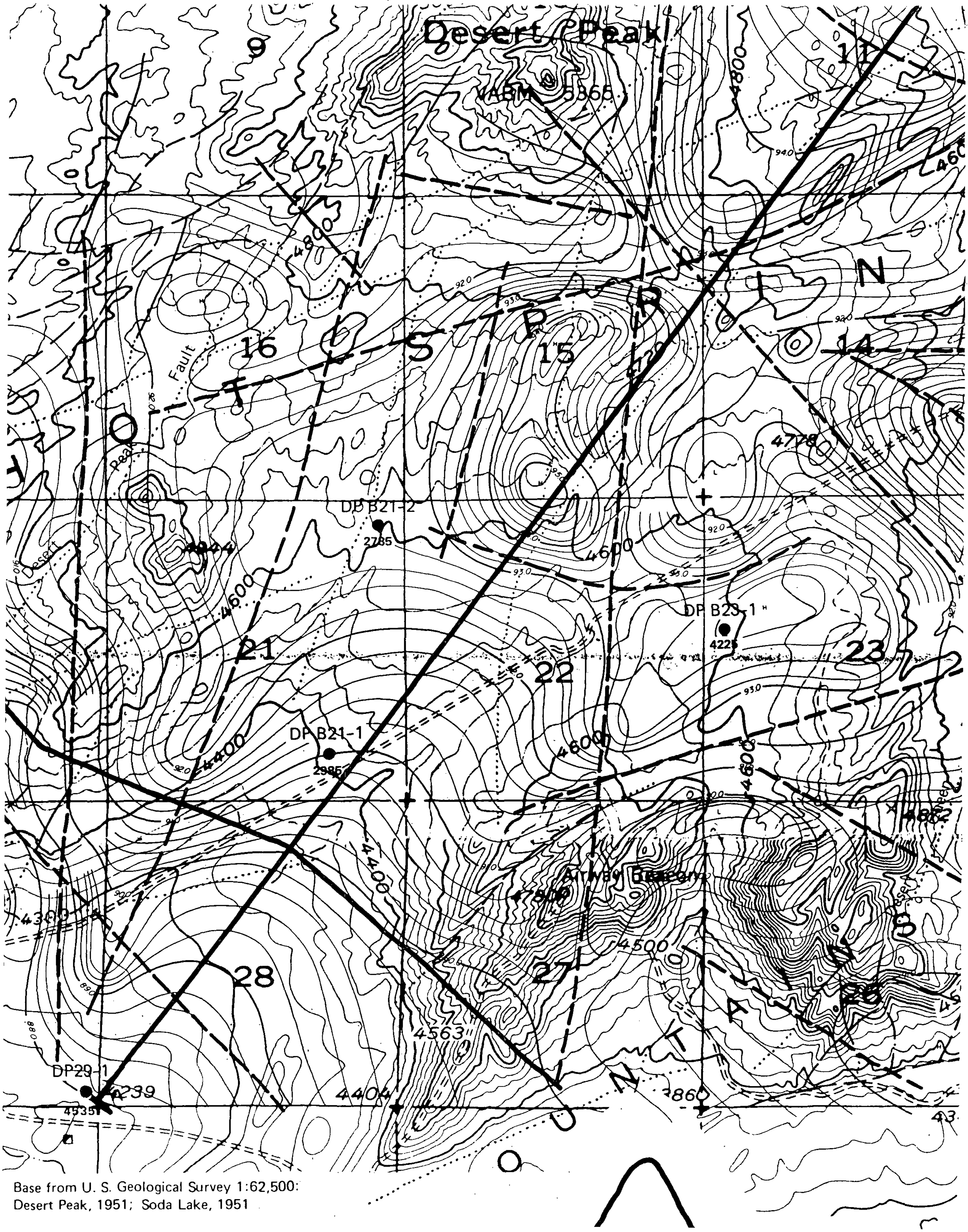

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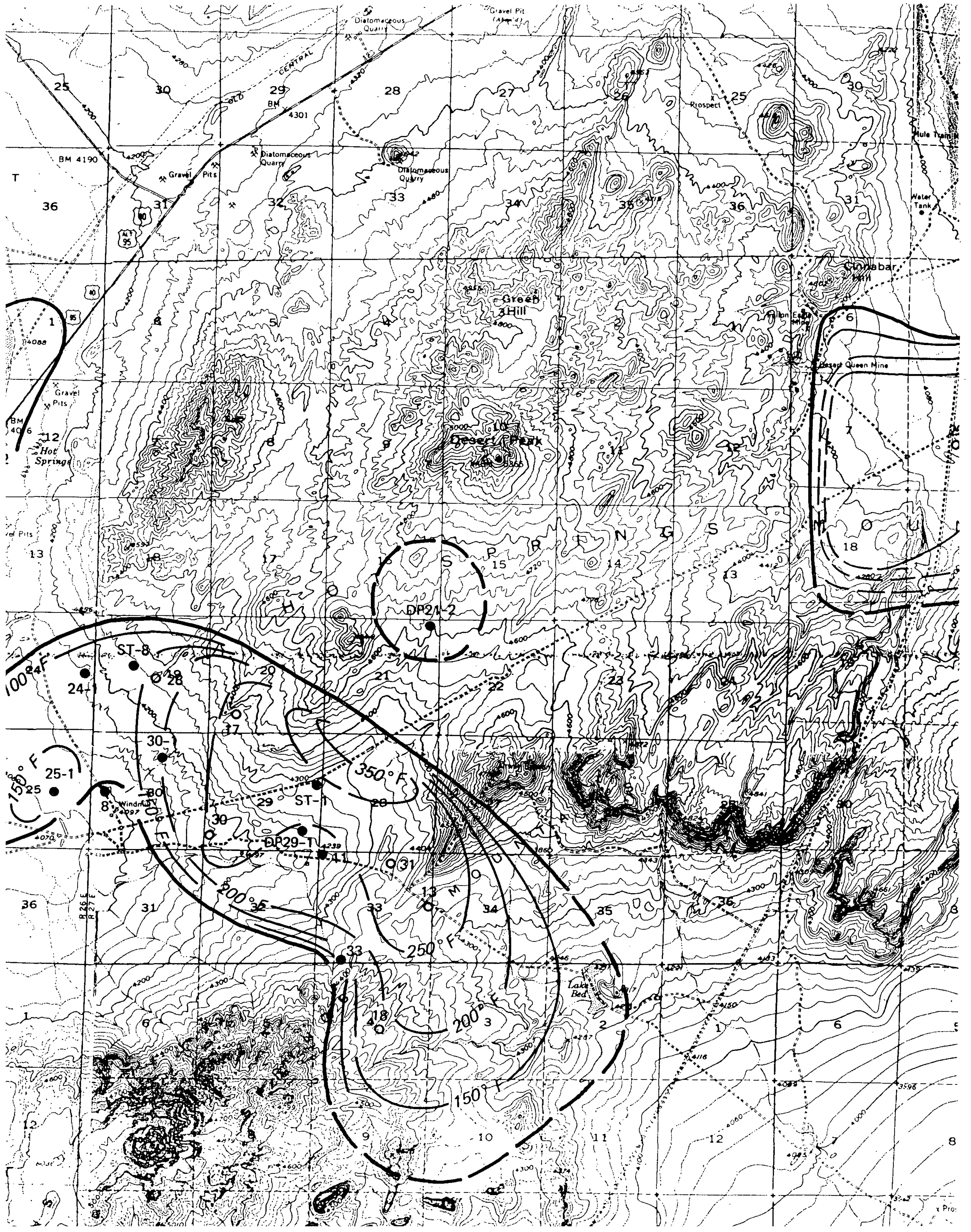
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Cinnabar Hill
Green Hill
Desert Queen Mine
Desert Peak
Hot Springs
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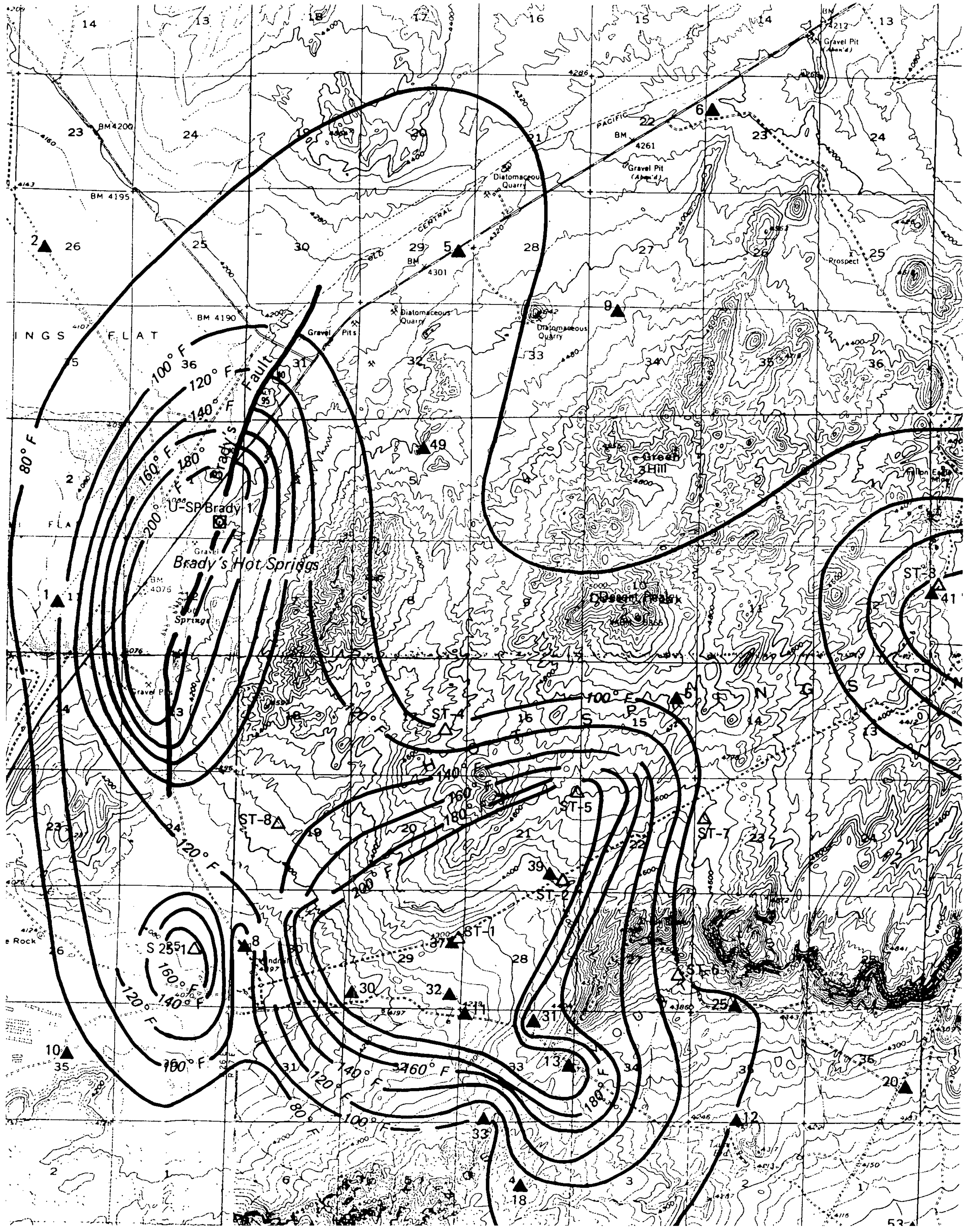
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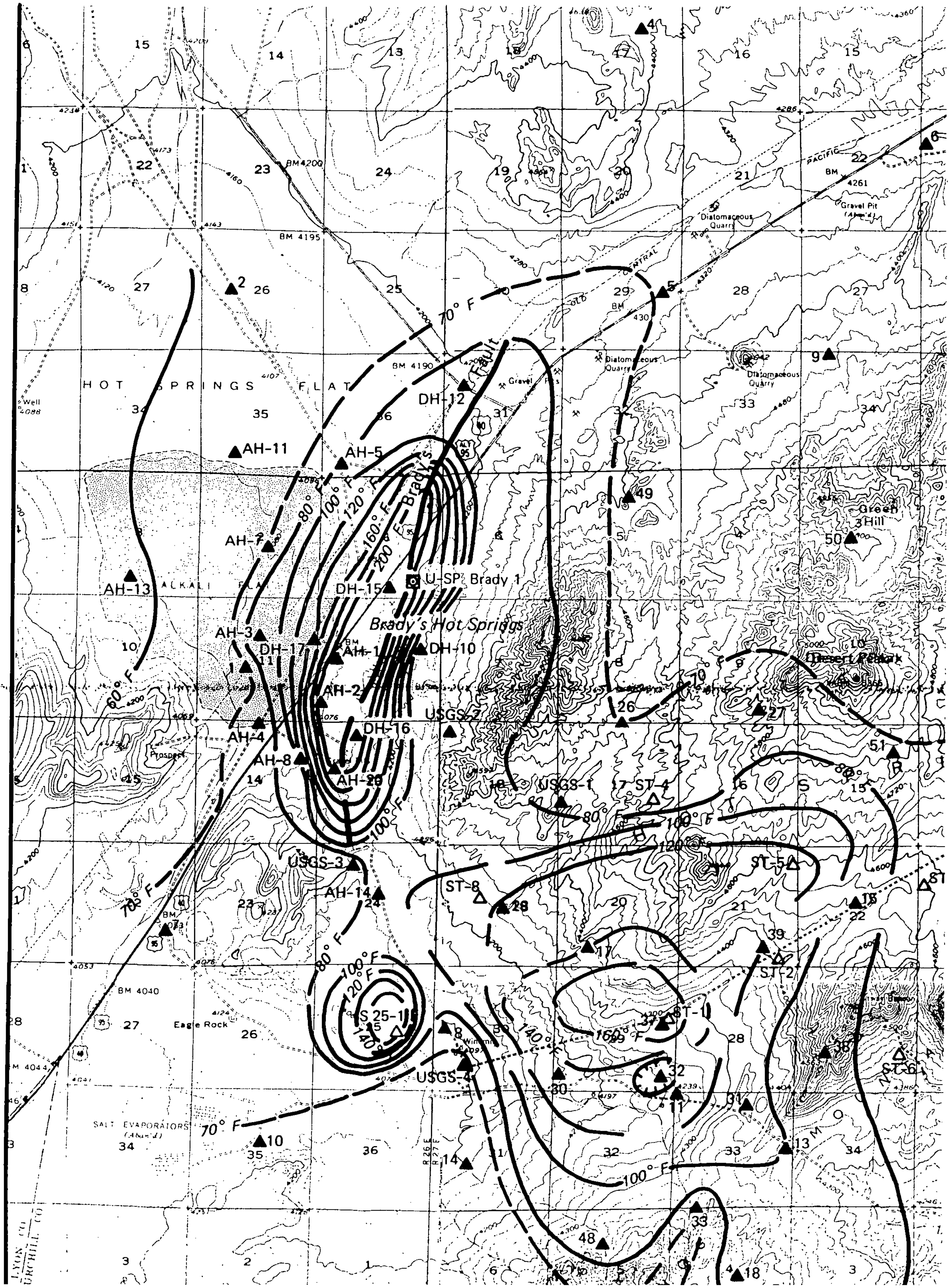

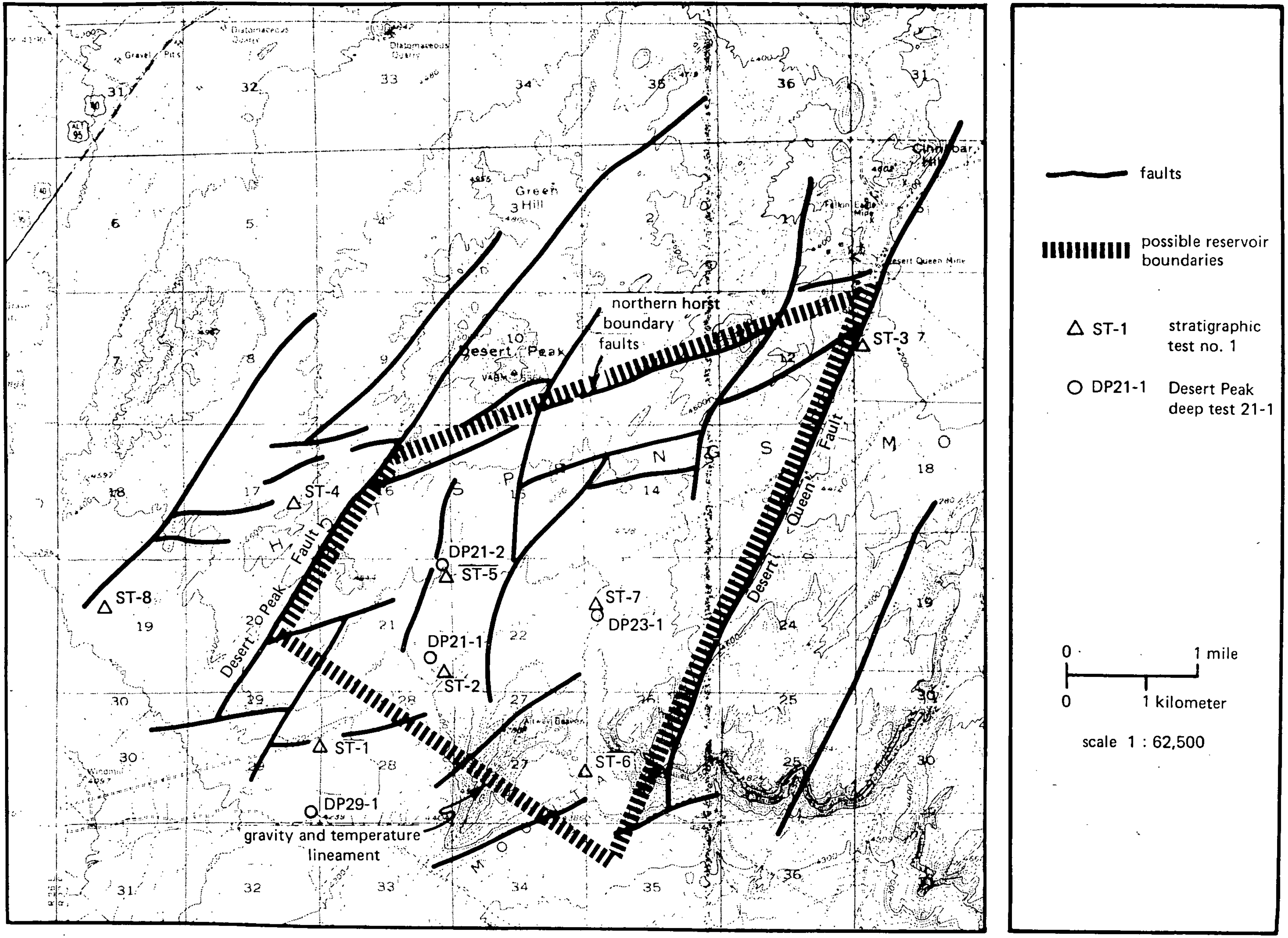

FIGURE 38. Map showing possible reservoir boundaries.

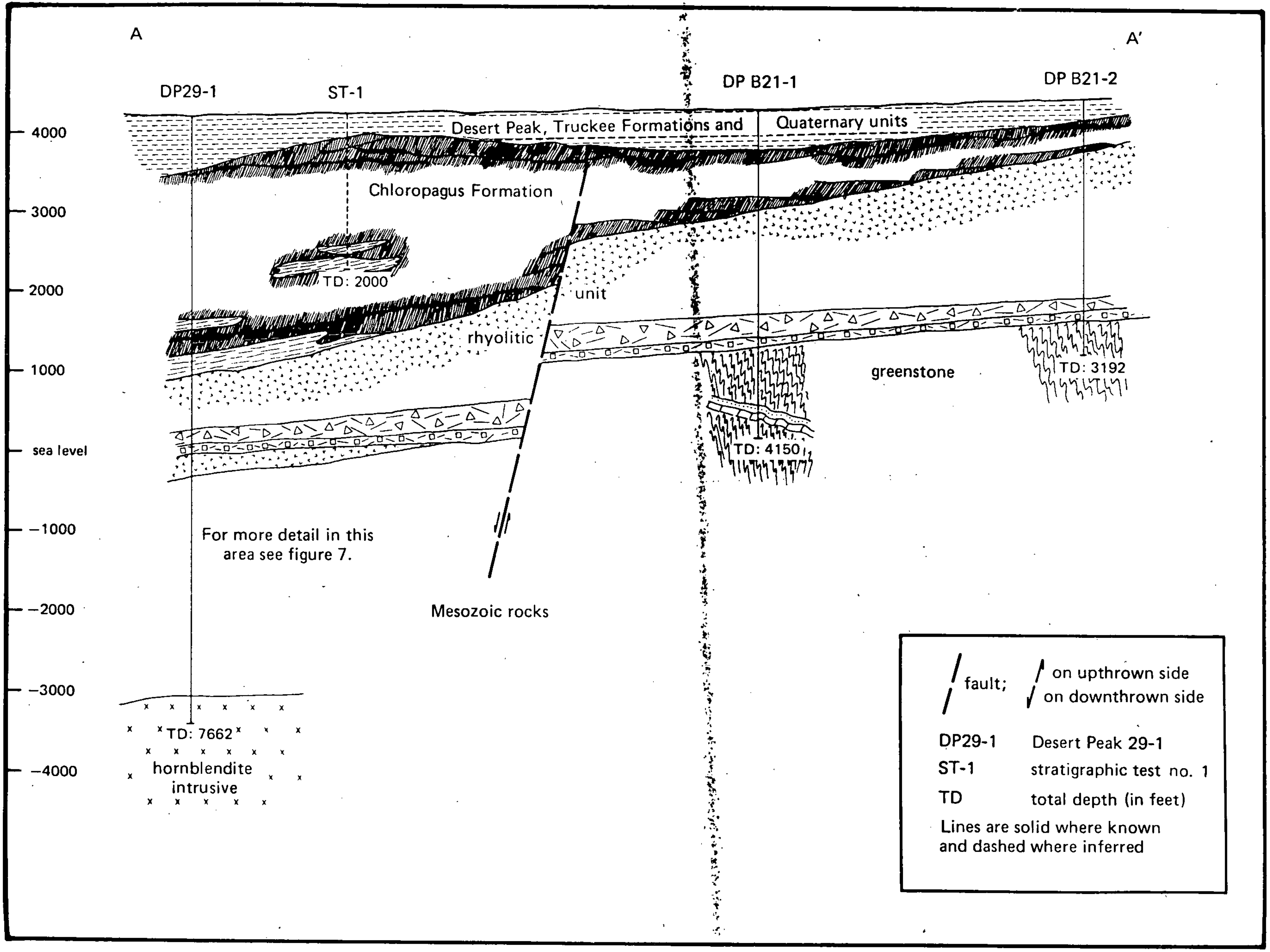

FIGURE 33. Geologic cross section A-A′ (see plates 12 and 13 for location of A-A′).

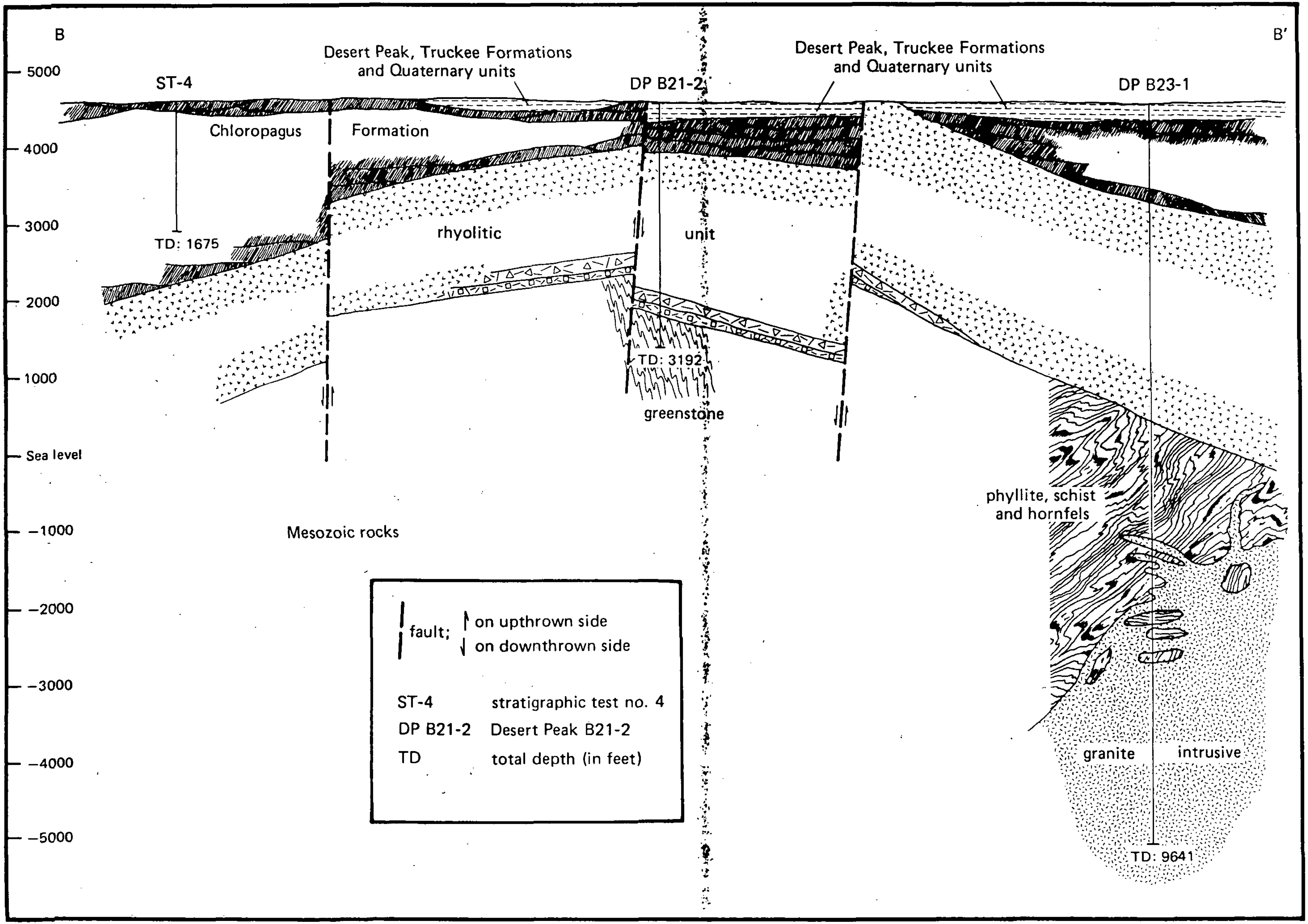

FIGURE 36. Geologic cross section B-B′ (see plate 13 for location of B-B′).

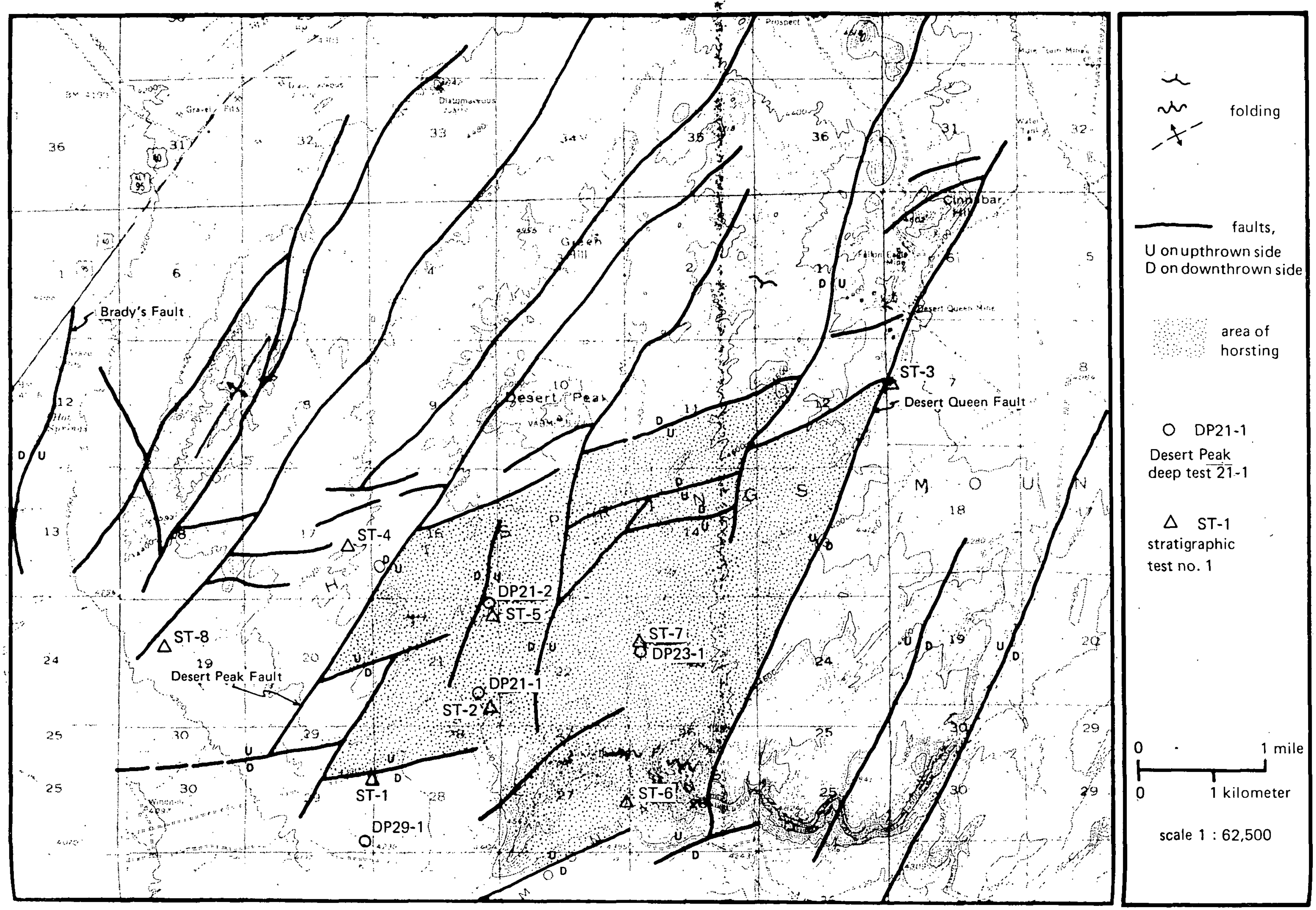

FIGURE 35. Simplified structure map of the Desert Peak area.

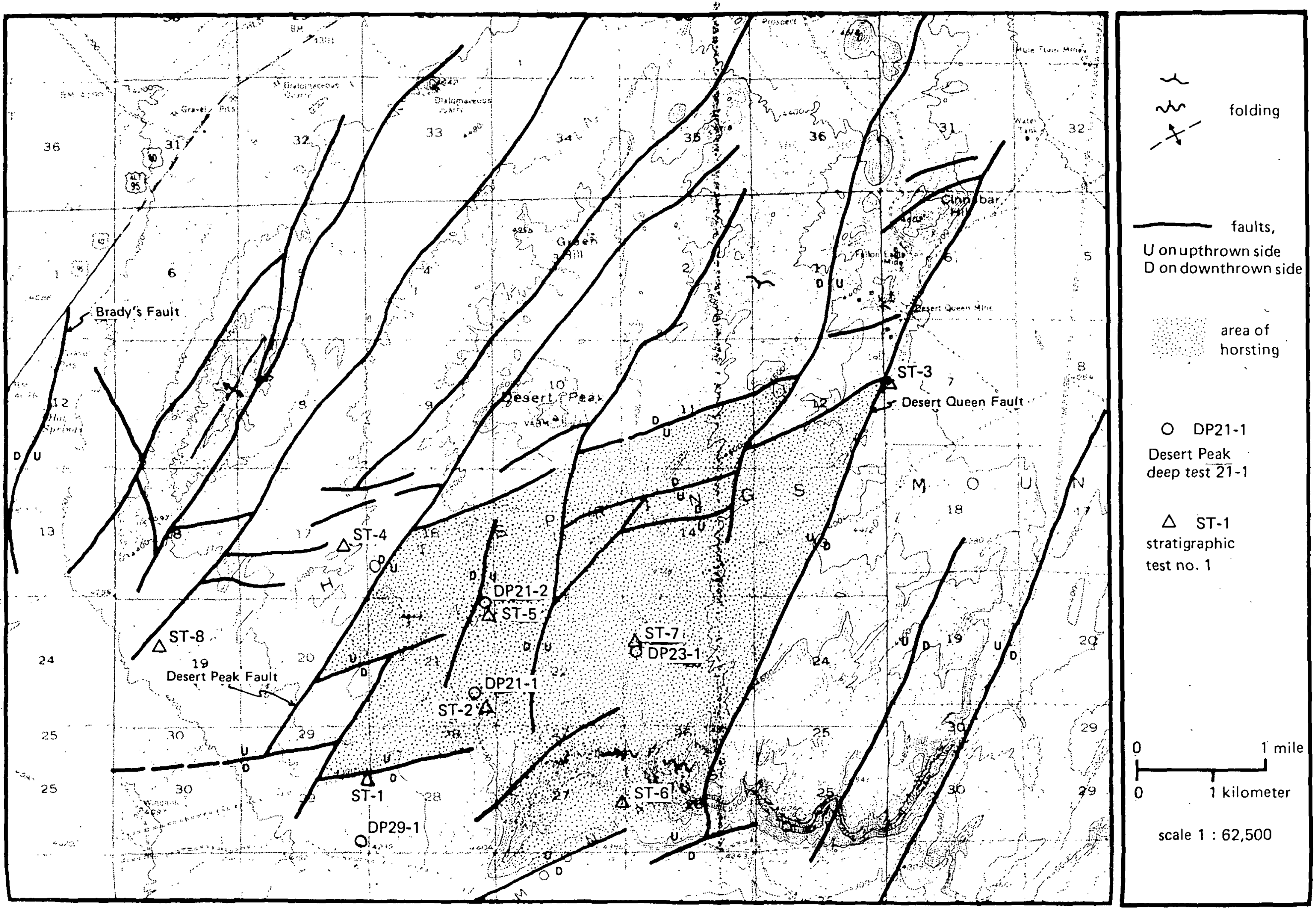

FIGURE 35. Simplified structure map of the Desert Peak area.