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THE HYDROTHERMAL GEOLOGY

OF THE

VALLES CALDERA, JEMEZ MOUNTAINS

NEW MEXICO

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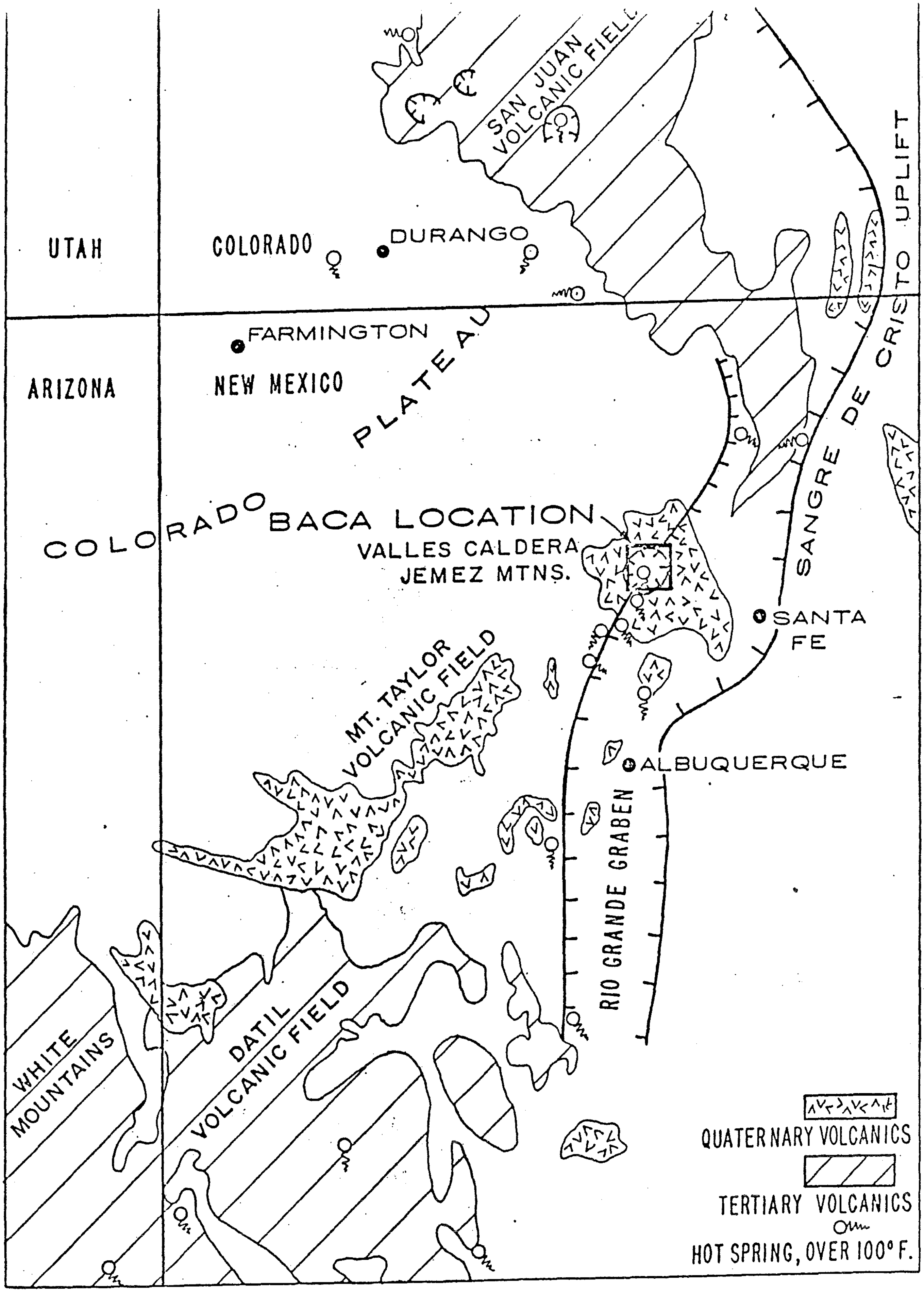


FIGURE I. REGIONAL GEOLOGIC SETTING OF VALLES CALDERA, JEMEZ MOUNTAINS, NEW MEXICO.

I. SUMMARY

The Valles Caldera, sometimes called Jemez Caldera, is located in the Jemez Mountains, a complex volcanic highland of Pliocene and Pleistocene age, about 55 miles north of Albuquerque in north-central New Mexico. The caldera is circular in shape, 12 to 15 miles in diameter, and 500 to 2000 feet deep. The caldera is a relatively young structure, originating about 1.1 million years ago following an enormous eruption of rhyolitic ash and pumice. The caldera is currently in a stage of hot spring activity, although the periodicity of rhyolitic volcanism does not preclude future eruptions.

Hot springs and warm water wells are generally distributed over several hundred square miles in the Jemez Mountains, indicating a geothermal anomaly of regional scope. The geothermal anomaly culminates in the Valles Caldera, most obviously in the western half, where a maximum temperature of 532°F. has been measured in the Baca #4 geothermal well. Because the structure of the caldera is analogous to a pot on a stove, high sub-surface temperatures are probably available everywhere within the 150 square mile caldera, and certainly everywhere within the central 100 square miles.

The deep groundwater system underlying the Valles Caldera is essentially a single unit which can be described simply as the deep flow of water from the San Pedro and Jemez Mountains into the Rio Grande drainage basin. In addition to subsurface pressure measurements, ionic and isotopic characteristics of the hydrothermal waters can be used to trace water flow in the hydrothermal system. The potentiometric surface of the deep groundwater system is near the surface in the northern half of the caldera and over a thousand feet below the surface in the center of the caldera.

Knowing the subsurface pressure-temperature relationships, a tentative model of the Valles Caldera hydrothermal system is proposed: Relatively cool water enters the very hot caldera from the north. As the water flows

through the subsurface the enthalpy increases, and near the center of the caldera boiling begins. In the vicinity of the Baca #4 well, boiling of the deep water has led to formation of a vapor-dominated reservoir about 2500 feet thick. South of the Baca #4 location, given a continuing addition of calories, the vapor-dominated reservoir should be thicker.

The above considerations lead to the conclusion that about 40 square miles in the southern half of the Valles Caldera are prospective for dry-steam production. Liquid-phase reservoirs with temperatures at least as high as the vapor-dominated reservoirs may be prospected for in the northern half of the caldera where the water table is near the surface. Surface manifestations (hot springs, altered rock) of the hydrothermal system are absent in the eastern half of the Valles Caldera and in the adjoining Toledo Caldera. The lack of surficial expression is due to topography and near-surface geology. At depth, the Toledo Caldera, and eastern Valles Caldera are fully as prospective as the western Valles Caldera.

II. INTRODUCTION

The primary purpose of this report is to summarize the presently available knowledge of the Valles Caldera hydrothermal system and, secondarily, to present a very tentative model of the hydrothermal system for use as a basis for geothermal exploration. Over a series of years, many man-hours of study have been devoted to the Valles Caldera, which is one of the worlds' truly impressive volcanic collapse structures. The studies have ranged from the academic pursuits of the United States Geological Survey to private attempts to win commercial geothermal resources. This report is simply an attempt to bring together the pertinent, but scattered data generated by other workers. With the exception of the proposed model, there is little original work in this report.

The sources of data for this report are published geological reports, unpublished United States Geological Survey information from the files of the Baca Land and Cattle Company, drilling reports and geological reports of the geothermal wells, and geologic excursions in the Jemez Mountains.

I have purposely not elaborated in the topics of stratigraphy and structure. Those subjects are well covered by the U.S.G.S. map of the Jemez Mountains by Smith, Bailey and Ross. The enclosed copy of that map should be considered an integral part of this report.

Every attempt has been made to utilize reliable data. During the course of data collection, however, some information, particularly downhole data from geothermal tests, had to be disregarded. The accuracy and completeness of the included data, therefore, cannot be guaranteed.

III. GEOLOGIC SETTING (Largely from Doell, et al, 1968 and Smith and Bailey, 1968.)

A. REGIONAL GEOLOGY AND GEOGRAPHY (Figure 1)

The Valles Caldera, sometimes called the Jemez Caldera, is located in the Jemez Mountains, a complex volcanic highland of Pliocene and Pleistocene age, about 55 miles north of Albuquerque in north-central New Mexico. The Jemez Mountains are situated at the intersection of two major geologic features. One is the southeastern rim of the Colorado Plateau, including the chain of volcanic fields that have developed along the rim: White Mountains, Datil, Mt. Taylor, Jemez, and San Juan. The other regional geologic structure is the western margin of the Rio Grande Graben, a trough that extends several hundred miles through New Mexico and Colorado. Geophysical evidence (Joesting, et al, 1961) indicates approximately 19,000 feet of differential elevation between Pre-Cambrian rocks east and west of the graben and Pre-Cambrian rocks buried in the center of the graben.

West of the graben fault zone, the volcanic rocks of the Jemez Mountains overlie Pre-Cambrian granite, and Paleozoic-Mesozoic sediments. East of the fault zone, the volcanic rocks rest on Tertiary epiclastic sediments that fill the graben. The principal focus of volcanic activity is clearly within the graben; of the 154 known volcanic vents in the Jemez Mountains, only 18 are located on the uplifted block west of the graben. (Smith, et al, 1970.)

Most of the hot springs in New Mexico are associated with the chain of volcanic fields around the rim of the Colorado Plateau or with the western edge of the Rio Grande Graben (Summers, 1965). It is apparent that the hydrothermal activity in the Valles Caldera is not an isolated spurious occurrence, but is part of a regional, deep-seated thermal anomaly.

Geographically, the Jemez Mountain highland is formed by a central, eroded mountainous mass composed mainly of basalt, andesite, and dacite, and surrounded by more youthfully dissected plateaus composed mainly of rhyolitic ash flows. Valles Caldera is a sub-circular depression in the center of the Jemez Mountains. The caldera is 12 to 15 miles in diameter and 500 to 2000 feet deep. In the center of the caldera is a broad structural dome (Redondo Peak), which rises 3000 feet above the caldera floor and has an elevation of 11,254 feet. Several smaller mountains, rhyolite domes, surround Redondo Peak.

B. GEOLOGIC HISTORY OF THE VALLES CALDERA (Map I)

The volcanism, which has led to the present stage of development of the Jemez Mountains, began in late Miocene, or early Pliocene time with an eruption of a basalt-rhyolite sequence, followed by two complex basalt-andesite-dacite-rhyolite sequences that were erupted over a period of about 10 million years. The Valles Caldera is a relatively young structure; its history can be considered as a series of stages:

a) Regional doming of the Jemez volcanic highland with formation of a ring-fracture system over a shallow magma chamber.

b) Two gigantic pyroclastic eruptions, 1.4 and 1.1 million years ago, which produced the Bandelier Tuff, a deposit of rhyolitic ash and pumice, widespread in the Jemez Mountains. Each outburst yielded about 50 cubic miles of volcanic debris.

   The eruptions were followed by collapse along ring-fracture systems, producing first the Toledo Caldera, and, some 300,000 years later, the Valles Caldera. The collapse structure of the Valles Caldera truncates the southwestern part of the Toledo Caldera.

c) Formation of a caldera lake and eruption and deposition of rhyolitic lavas and pyroclastics on the lower parts of the caldera floor. During this stage the caldera was filled with about 2000 feet of assorted lacustrine, landslide and volcanic rocks.

d) Uplift of the central dome (Redondo Peak), accompanied by radial fracturing and formation of a longitudinal graben across the dome (Redondo and Jaramillo Creeks). Simultaneously with doming, rhyolitic lava erupted within the graben and the northwestern part of the ring-fracture system. During this stage, the lake, pushed to higher levels as the dome emerged, eventually overflowed the caldera rim on the southwest side. The concentration of water flow caused erosion and formation of Cañon de San Diego, and the localization of the Jemez river which now drains Valles Caldera.

e) Eruption of rhyolite along the ring-fracture zone around the central dome forming a chain of cones, flows and domes. Ten major vent areas and at least 18 separate eruptions spanning 900,000 years are recognized. The youngest eruption, El Cajete, is less than 100,000 years old.

f) Hot-spring and solfataric activity in the western half of the caldera. The Valles Caldera is in this stage now, and may have been in this stage for the last 100,000 years. This stage is of much more than academic interest, for the probable long duration of the solfataric stage in large epi-continental cauldrons suggests major ore-forming potential and long-lived hydrothermal systems.

IV. HYDROTHERMAL GEOLOGY

A. VOLCANIC SETTING

The Valles Caldera is favorably situated in space, time and type of volcanism for development of a large hydrothermal system. The caldera is situated in the center of the Jemez volcanic field of over 700 square miles, active more or less continuously for the last 10 million years.

The geologic history of the caldera during the last 1.5 million years of doming-rhyolite eruption-collapse-resurgent doming-rhyolite eruption, indicates the caldera is directly over the shallowest portion of the magma chamber supplying lava to the Jemez volcanic field (Smith and Bailey, 1968). The association of large hydrothermal systems with rhyolite volcanoes or granite intrusives is well documented. The Salton Sea and Long Valley hydrothermal fields in California, Yellowstone National Park, and Wairakei, New Zealand, are but four of many examples. This association has been observed in other countries and is ascribed to the probability that rhyolite magma chambers are shallower than basalt sources and are therefore better able to heat circulating groundwater (McNitt, 1970).

B. TEMPERATURE DISTRIBUTION

1. Springs and Water Wells

Abnormal earth temperature is certainly the most readily sensed parameter of a hydrothermal system, and hot springs are the most obvious manifestations of subsurface temperature. Because low-density hot water can percolate up permeable fracture zones large distances above normally heated aquifers, hot springs, in themselves, are not necessarily evidence of abnormally hot hydrothermal systems.

The occurrence of hot springs must be examined with respect to the regional geology. Map I shows that hot springs occur in the Jemez Mountains over a distance of sixty miles in association with major faults which are projected through the western portion of the Valles Caldera. Nowhere else along the boundary faults of the Rio Grande graben are hot springs so numerous. The concentration of hot springs in the Jemez Mountains is therefore an indication of a widespread hydrothermal system in the region surrounding Valles Caldera.

Water wells are another source of subsurface temperature. Wells in four areas are pertinent; two inside Valles Caldera, and two outside are shown on Map I. Twenty-five miles south-west of the caldera, water with a temperature of 130°F. flows from an abandoned oil test 2000 feet deep. (Summers, 1965a) Summers reports the average temperature of near surface water in this area is 52°F. The depth of the water-producing formation is unknown, but in any event, the geothermal gradient must be at least 3°F per 100 feet, about twice normal.

Griggs, et al (1964), reports on several water wells in Guaje Canton, 15 miles east of Valles Caldera, near the center of the Rio Grande graben. Five wells, each 2000 feet deep, produce water up to 85°F in composite flow from many water-bearing zones between 300 feet and 1800 feet. Assuming the average flow comes from a depth of 1000 feet, the geothermal gradient is about 3.3F° per 100 feet, about twice normal. The abandoned oil test and the Guaje Canyon water wells prove abnormal subsurface temperatures are available throughout the entire Jemez Mountains region.

Water supply investigation wells were drilled by the United States Geological Survey in two of the valleys within the Valles Caldera, Valle Grande and Valle Toledo, on the eastern side of the caldera, about six miles from hot-spring activity. (Conover, et al, 1963; Griggs, 1964.) The location of two pertinent wells are shown on Map I.

In the authors' concept, rainwater enters the alluviated valleys by downflow through the blocky crusts of the flanking rhyolite domes and emerges in springs to feed the Jemez River and San Antonio Creek. The annual through-put of water is estimated at 2200 acre-feet in Valle Grande and 1600 acre-feet in Valle Toledo. Under conditions of dynamic flow, detailed interpretation of shallow ground temperatures is hazardous, but the generalized picture is very informative.

In the Valle Grande, artesian well water from approximately 450 feet deep is 64°F., and the ground temperature nearby at 100 feet is 45°F. The indicated gradient is 5.4F° per 100 feet.

In Valle Toledo, artesian well water from a zone 400 feet deep is 64°F, while water from a nearby 97-foot well is 50°F. The indicated gradient is 4.6F° per 100 feet. The geothermal gradients in both intra-caldera valleys are significantly above normal, and may be lower than the geothermal gradient at a depth of a few thousand feet if near-surface waters are flushing calories down stream.

To summarize, the distribution of hot springs and high geothermal gradients over an area of at least 1300 square miles indicates the presence of an extensive hydrothermal system which is approximately coincident with Jemez Mountains volcanic field.

2. <u>Temperature Observation Holes (Figure 2)</u>

During the summer of 1970 about 50 temperature observation holes were drilled in various parts of the Valles Caldera. Most of the holes were 100 feet deep, an easily attainable depth below the limit of significant annual variation. Three were drilled to 300 feet to obtain gradient data. The purpose of the survey was to determine the general pattern of near-surface temperature distribution to aid in the selection of a site for a deep geothermal test.

The results generally corroborate the hot-spring pattern and regional geology: the western half of the Valles Caldera has a higher near-surface temperature than the eastern half. With few exceptions the temperature at a depth of 100 feet in Valle Grande and Valle Toledo are in the range 44°-48°F. In the western half of the caldera however, only one temperature was recorded below 50°F., and the maximum temperature at 100 feet was 106°F.

Temperatures measured in the zone of active surface acid alteration are surprisingly low, generally 70°-90°F., and suggest the alteration is caused by escaping gases from the deep hydrothermal system, rather than by circulating waters, and that near-surface water flow is not connected hydraulically to the deep system. This is but one of the indications of an under-pressured hydrothermal system, conducive to the production of dry steam.

Three holes in Valle Grande were anomalous; the maximum temperature at 100 feet was 60°F. A deeper hole, drilled next to one of the anomalous shallow holes had a temperature of 72°F. at 300 feet, noticeably warmer than water from a depth of 450 feet in the artesian well 1-1/2 miles to the east. The indicated gradient at this location is 10F° per 100 feet, about six times normal. If the gradient continues with depth, temperatures in the range of 450°F.-550°F. would be available at depths of 4000-5000 feet. Rex (1970) points out that successful steam wells have been drilled in the Salton Sea field, California, at sites where the near-surface geothermal gradient is only 6.3F° per 100 feet.

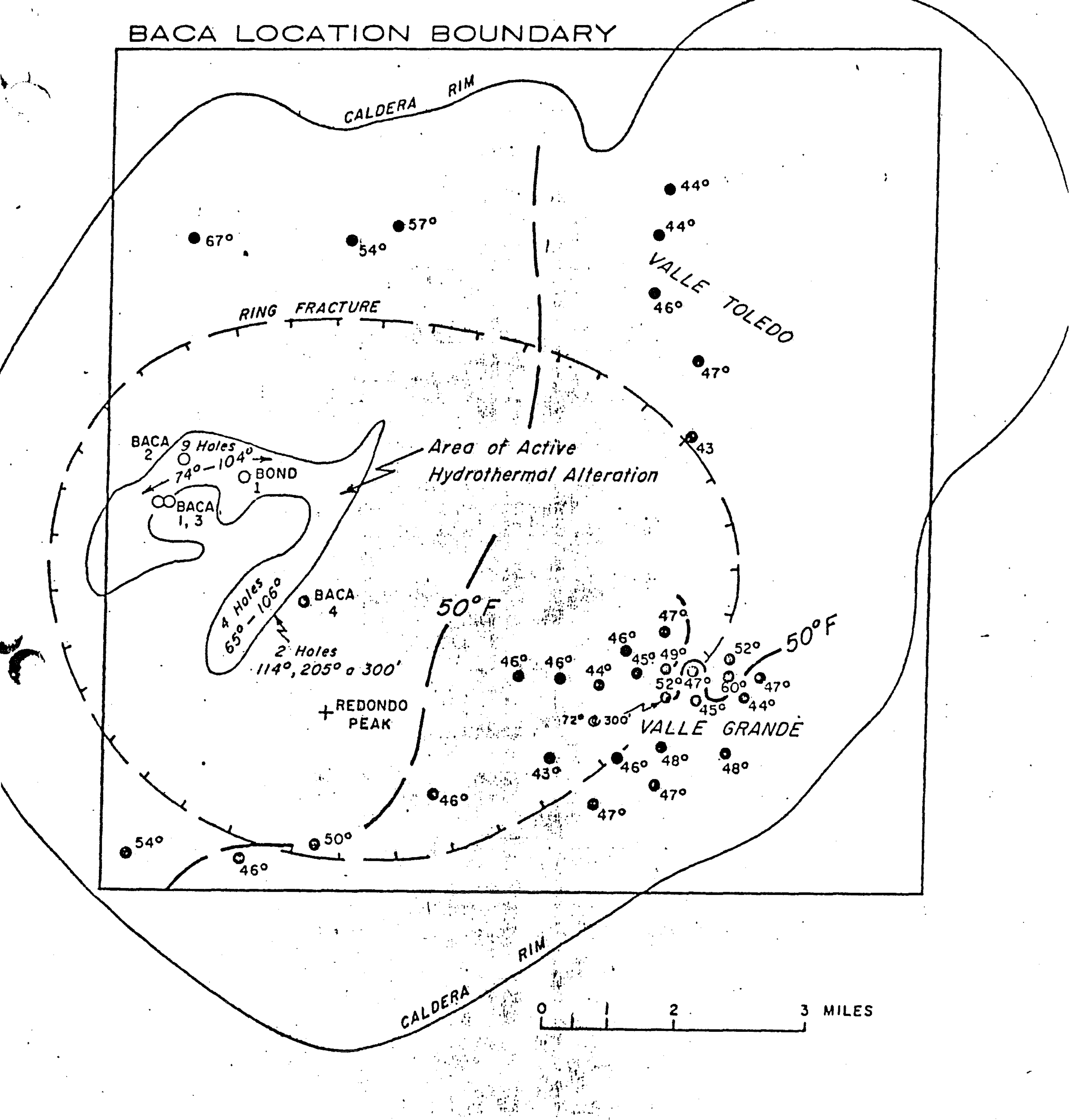


FIGURE 2 SUMMARY OF SHALLOW TEMP. SURVEY

BACA LOCATION, NEW MEXICO

SURVEY DATE: JULY 1970

DEPTH DATUM: 100 FEET

3. Geothermal Wells

(Detailed temperature data for the deep geothermal test wells is recorded in the Concise Well Summaries in the Appendix of this report. Only the most pertinent data is presented here.)

The Baca #4 well is the only deep well with reasonably good temperature data. Typical observed formation temperatures at depth are 300°F. at 2000 feet, 404°F. at 2625 feet, and 532°F. at 4820 feet. Above a depth of 2000 feet, the Baca #4 well has an average geothermal gradient of no more than 12.5F° per 100 feet, not dissimilar to the gradient in Valle Grande. The low, near-surface gradient is because of the low reservoir pressure of the deep hydrothermal system, and an impermeable layer of altered tuff which extends from the surface to a depth of about 1600 feet in the Baca #4 well. Below a depth of 2000 feet, temperatures increase rapidly with depth at a rate approximating the normal boiling-point-depth curve (Figure 3). Temperature observations in the Baca #4 well indicate higher temperatures are available below the bottom of the well.

Although the data are sketchy, temperature information from the Baca #2 well, T.D. 5658 feet, indicates downhole temperatures are as high, and possibly higher, than in the Baca #4 well. The following is pertinent:

a) Below a depth of 3000 feet, the mudflow line temperature averaged about 160°F. and the suction line about 130°F., an increase of 30°F. during a round trip of the circulating mud. The temperature increase is similar to those observed in the Imperial Valley, California, where reservoir temperatures are in excess of 600°F.

b) After drilling to total depth, the well was cooled by circulating water prior to Schlumberger temperature logging. At a depth of 2500 feet, a zone drilled over a month before, the temperature rebounded from 255°F. at 2 hours static to 330°F. at 9 hours static. Such a rebound performance is typical of the very hot reservoirs in the Imperial Valley.

c) There are unconfirmed reports that temperature-sensitive paint strips lowered into the well near total depth indicated temperatures over 500°F.

d) Long term static temperatures of about 400°F. at 2000 feet, and 350°F. at 1200 feet have actually been measured. If formation temperatures increase with depth along the boiling point-depth curve, the probable bottom temperature in the Baca #2 well exceeds 600°F.

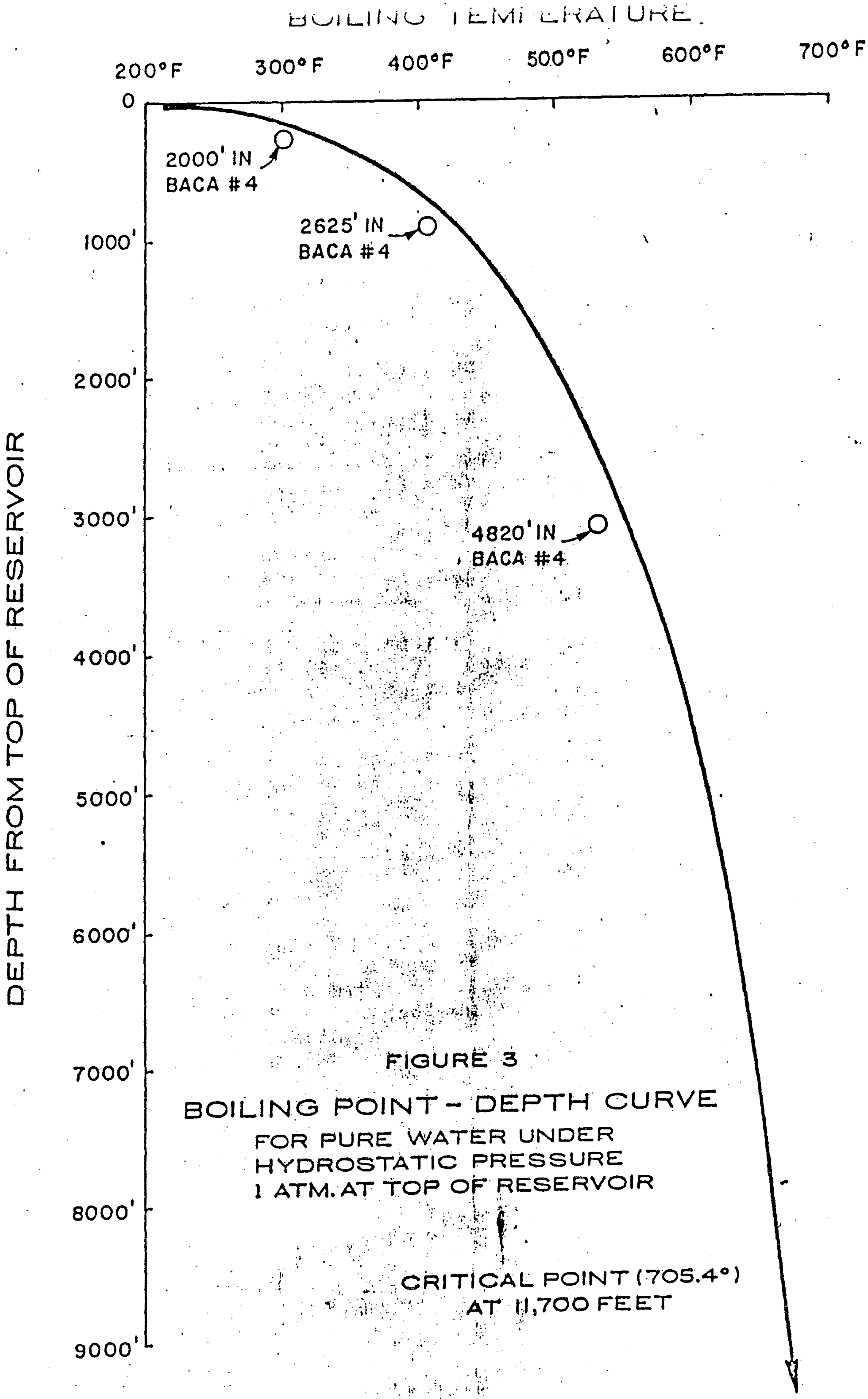


FIGURE 3

BOILING POINT - DEPTH CURVE

FOR PURE WATER UNDER HYDROSTATIC PRESSURE 1 ATM. AT TOP OF RESERVOIR

Baca #1 and Baca #3 wells are only 2560 feet and 2200 feet deep respectively, and do not have adequate static temperature data. One temperature survey measured 390°F. at 1800 feet in the Baca #3 well, and it is likely that the temperature regime at the Baca #1 and #3 location is similar to the Baca #2 location.

The Bond #1 well, T.D. 3675 feet, similarly has meager temperature data. Poor data indicate a formation temperature of 270°F. at 1400 feet, and this well may have a low near-surface gradient similar to the Baca #4 well. A non-equilibrium temperature of 391°F. was observed at 2400 feet which proves, at least, that the well is not "cold" at depth, but may be cooler than the other wells.

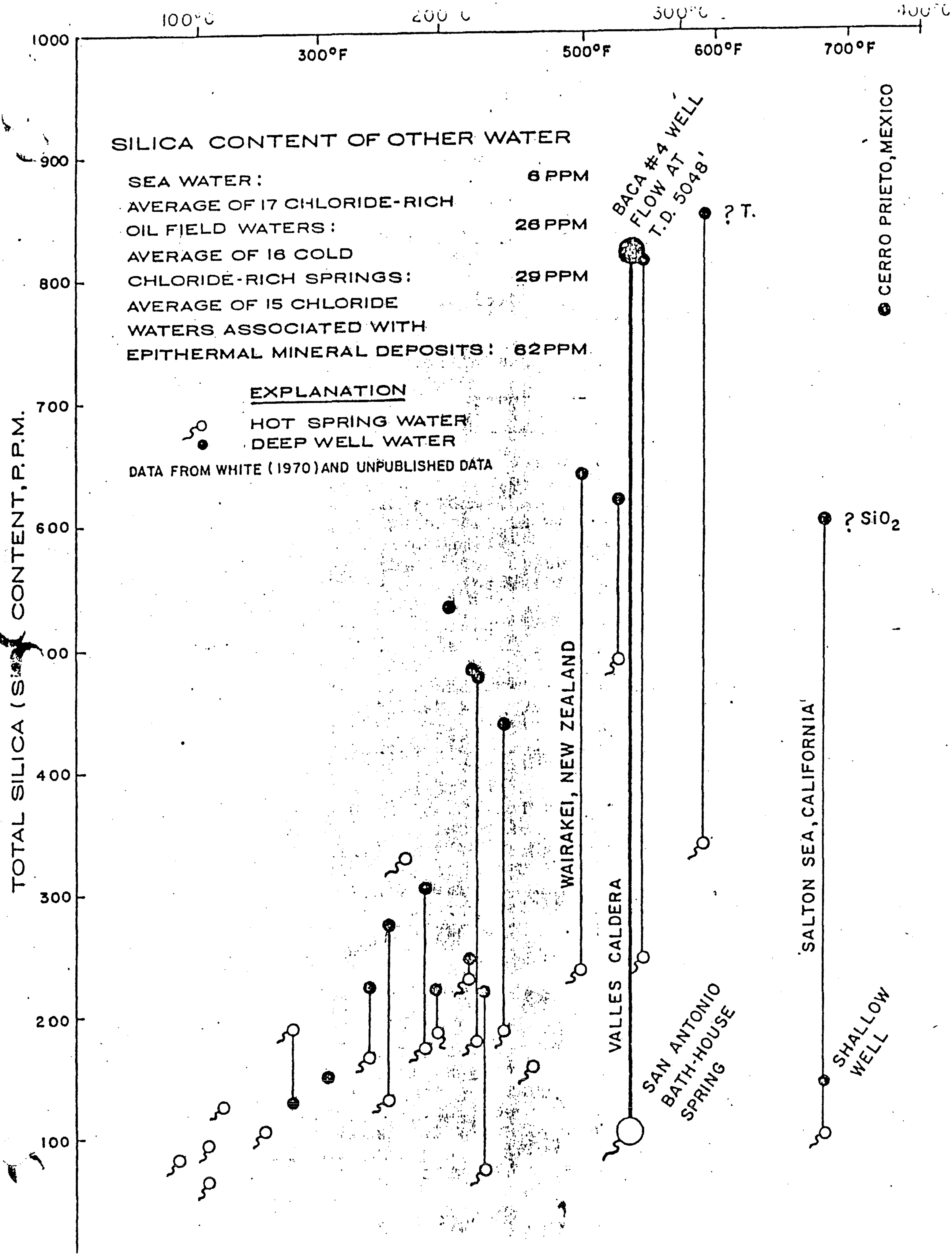
4. Geochemical Evidence For Temperatures Higher Than Observed in the Baca #4 Well

White (1970) reports extensively on the use of geochemical indicators to estimate the base temperature in hydrothermal systems. White states that dissolved silica, and the ratio of sodium to potassium in water are the best measures of the maximum temperature of interreacting rock and water. In a general way, higher temperatures favor the increased dissolution of silica and of potassium relative to sodium.

Data for many hydrothermal systems are shown in Figures 4 and 5. I have added data from chemical analyses of water from the Baca #4 well. It is seen that the silica content of the deep water from the Baca #4 well is appropriate for the observed temperature at depth, about 530°F. The sodium-potassium ratio, however, indicates equilibrium with rock temperature of about 660°F. (350°C.). White (personal communication) believes the equilibration time is much faster for silica than sodium-potassium, so that the silica may measure the producing formation temperature while sodium-potassium may reflect higher temperatures from a deeper part of a circulating hydrothermal system. Although geochemical temperature indicators are not yet fully calibrated, it does appear highly possible that temperatures of about 650°F. are available in the Valles Caldera. At the Baca #4 well location, such temperatures should be found at a depth of about 8700 feet.

5. Areal Distribution of Temperature

Because the structure of the caldera is analogous to a pot sitting on a stove, there is every reason, at this writing, to expect that the high temperatures observed in the geothermal wells are probably available at depth everywhere within the caldera, and certainly within the ring-fracture system. I strongly recommend that a detailed shallow-gradient survey be performed to rapidly evaluate the true area extent of the subsurface hydrothermal system.



100°C
200°C
300°C
400°C
300°F
500°F
600°F
700°F
1000
900
800
700
600
400
300
200
100
TOTAL SILICA (SiO2) CONTENT, P.P.M.
SILICA CONTENT OF OTHER WATER
SEA WATER: 6 PPM
AVERAGE OF 17 CHLORIDE-RICH OIL FIELD WATERS: 26 PPM
AVERAGE OF 16 COLD CHLORIDE-RICH SPRINGS: 29 PPM
AVERAGE OF 15 CHLORIDE WATERS ASSOCIATED WITH EPITHERMAL MINERAL DEPOSITS: 62 PPM
EXPLANATION
HOT SPRING WATER
DEEP WELL WATER
DATA FROM WHITE (1970) AND UNPUBLISHED DATA
BACA #4 WELL FLOW AT T.D. 5048'
? T.
CERRO PRIETO, MEXICO
? SiO2
WAIRAKEI, NEW ZEALAND
VALLES CALDERA
SAN ANTONIO BATH-HOUSE SPRING
SALTON SEA, CALIFORNIA
SHALLOW WELL

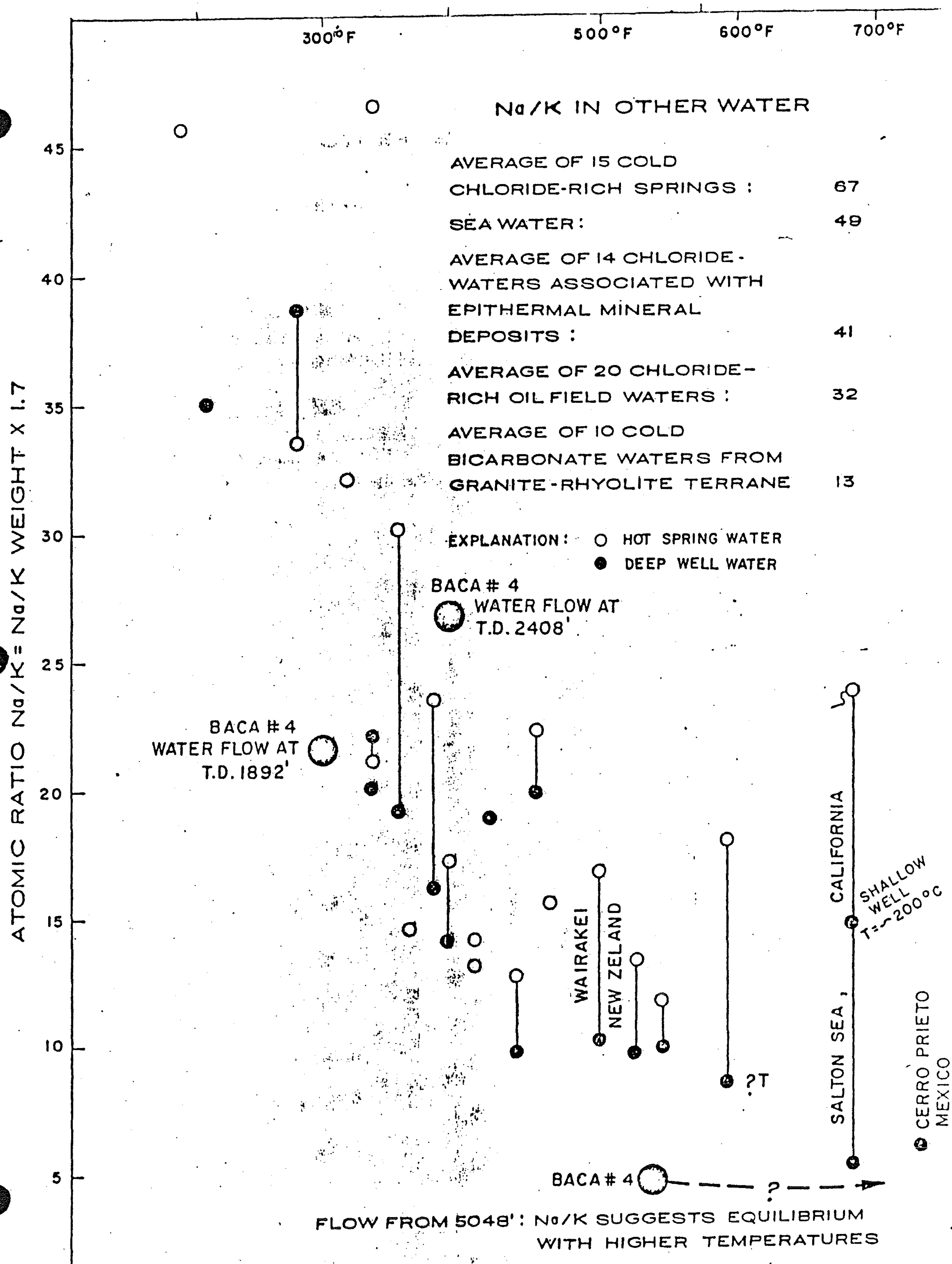


FIG 5 — SODIUM/POTASSIUM CONTENT OF THERMAL WATER

C. FLUID PRESSURE DISTRIBUTION AND GROUNDWATER FLOW PATTERN (MAP II)

1. General

Although abnormal temperature is easily sensed, subsurface fluid pressure distribution is equally important in the description of a hydrothermal system. Knowledge of subsurface fluid pressure distribution is pertinent to definition of reservoir capacity and performance, water supply and recharge, direction of groundwater flow, and waste water disposal areas. The combination of subsurface temperature and pressure largely defines the physical state (vapor or liquid) of the water in the hydrothermal system. Combined knowledge of subsurface pressure and temperature distribution therefore allows the delineation of areas where dry steam or wet steam production can be expected.

Subsurface pressure data comes from two principal sources: springs, which because of temperature or mineral content can be deduced to be connected to deep or shallow ground water bodies, and drilled wells, primarily those drilled for water or steam. Oil tests are also very informative if a detailed history of the well is available.

The subsurface fluid pressure distribution is directly due to topography, stratigraphy, and geologic structure. In a geothermal region, heat flow is also an important factor. In general, the subsurface pressure distribution can be related to one of two groundwater zones: a near-surface zone of low-chloride water with a potentiometric surface closely related to local topography, and a deep zone of chloride-bearing water with a potentiometric surface related to regional topography and geology. In the Jemez Mountains, there are many separate bodies of near-surface water. The deep groundwater system is essentially a single unit which can be described simply as the deep flow of water from the San Pedro and Jemez Mountains into the Rio Grande drainage basin.

2. Springs and Water Wells

A spring is the intersection of a groundwater table with the topographic surface. The elevation of the spring, therefore, is approximately equivalent to the elevation of the potentiometric surface of the groundwater system at that point. The potentiometric surface of the deep groundwater system under the Jemez Mountains can be measured at the many hot, chloride-bearing springs located along the Jemez River, within the Valles Caldera, and at Aqua Caliente spring on the north flank of the Jemez Mountains. The many cold, chloride-free springs in the Jemez Mountains, such as those in Valle Toledo and Valle Grande, are clearly not flowing from the deep groundwater system and their elevations do not represent the potentiometric surface of the deep groundwater system. Sulphur Hot Springs, in the western part of Valles Caldera at an elevation of about 8300 feet, are gassy, acid, low volume, hot springs with a pH of 2, and with a negligible chloride content. The hot springs are caused by hot gases from the deep hydrothermal system escaping into a shallow perched water table. The elevation of the springs is not equivalent to the deep potentiometric surface.

Deep water wells near Los Alamos produce warm water from depths to 2000 feet. (Griggs, 1964.) Although the chloride content is low, the stratigraphy indicates the water is part of the deep Rio Grande system and the reported pressure data from the wells can be used to determine the shape of the deep potentiometric surface under the Jemez Mountains. The low chloride content of the water probably means that the Los Alamos area is over the cooler east flank of the hydrothermal system.

Artesian wells, producing from aquifers to 600 feet deep in Valle Grande and Valle Toledo, have a head a few feet above ground level at the well sites, an elevation of about 8500 feet. (Conover, et al, 1963.) They report that the head of the deeper aquifers in Valle Grande is less than the shallow aquifers, so that some downward movement of water is possible, but probably not very rapid through the clayey near-surface sediments. The artesian waters are cold and essentially chloride free, and tend to flow downward; these waters are therefore not considered an upwelling of the deep hydrothermal system. Conover, et al, consider Valle Grande to be a near static basin of groundwater in which recharge from the flanking hills does not enter the deep valley aquifers, but emerges in a series of springs along the edge of the valley. (Isotope evidence reported in another section of this report, proves the concept.) Because of the near static nature of the groundwater in Valle Grande, some faith can be placed in high temperature gradients reported in a previous section of this report.

3. Geothermal Test Wells (Detailed Data in Appendix)

Pressure measurements in the deep geothermal wells clearly show that the deep hydrothermal system is a separate water body from the shallow water in Valle Grande and Valle Toledo, and from the shallow hot waters at Sulphur Springs. As measured in four wells, Baca #2, #3 and #4, and Bond #1, the top of the deep hydrothermal system is at an elevation of about 7500 feet, deepest at Baca #4, shallowest at Baca #2.

4. Summary of Pressure Observations

Consideration of the regionally distributed data from springs and wells (Map II) reveals that the deep water system is very simply related to the superposition of the Jemez Mountains topography upon the normal subsurface water flow in the Rio Grande graben. Deep water flow from the San Pedro and Jemez Mountains radiates north, east and south into the Rio Grande drainage area. Most of the subsurface water passing across Valles Caldera enters from the higher mountains north and northwest of the caldera. A limited amount of flow enters from the caldera rim to the west, south and east, and a certain amount of near-surface water, such as in Valle Grande, must percolate downwards to enter the deep system. Hydrologically, the Valles Caldera is a "flat" zone; the normal north-to-south flow is impeded by the lack of topographic drainage relief, the abundant rhyolite plugs and the localized non-regional flow patterns caused by the caldera rim.

D. WATER CHEMISTRY

1. Solution Chemistry

The chemistry of the dissolved solids in waters of the Jemez Mountains permits a very tentative five-fold subdivision: deep thermal water, saturated steam, shallow thermal water, shallow perched thermal water, and water from outside the hydrothermal system. Typical analyses (from many available analyses, chiefly in Summers, 1965, a, b; Conover et al, 1963; and Griggs, 1964), are presented in the appendix. Only the general characteristics are discussed below.

a) Deep thermal water. The Baca #4 produces from dry steam zones between 3468 feet and 4995 feet, and from a water zone at about 5000 feet. The sample of the deep water zone is a wellhead flowline sample of the liquid effluent while the well was flowing from all zones between 3468 feet and 5048 feet, total depth. As sampled, the deep thermal water is a chloride water with dissolved solids of about 7000 ppm. (Analytical results are not adjusted for concentration during flashing in the well bore, because thermodynamic calculations indicate about as much dry steam is condensed to lift the water as is evaporated during flashing. In the future, an attempt should be made to obtain unflashed samples.) The water is very high in fluorine (38 ppm) but relatively low in boron (15 ppm) for water with an initial temperature over 500°F. The high fluorine and low boron appear to reflect passage of the water through dominantly volcanic rocks rather than sediments (Hem, 1970; Goldschmidt, 1954; Heide and Theile, 1957). The analysis shows no calcium or magnesium, however a small amount of calcium could have been precipitated during flashing. Low calcium content is common in waters of high temperature, calcite decreasing in solubility with increasing temperature (White, 1970; Hem, 1970). The low calcium content may also reflect the low calcium content of the reservoir rock. The reservoir rock in the Baca #4 well is a rhyolitic tuff which contains 0.24% of CaO compared with 1.2% for the average rhyolite (Daly, 1933). The high silica content (820 ppm) of the deep thermal water, and the low ratio of sodium to potassium (4.5, atomic ratio) are typical of water with a very high reservoir temperature (White, 1970).

Water of similar chemistry to the deep chloride water, occurs in the Baca #3 well (T.D. 1944 feet when sampled), Soda Dam Hot Springs, Jemez Hot Springs, and San Ysidro Indian Hot Spring, the latter about 15 miles south of Valles Caldera. The available analysis of the water from Baca #3 is barely useful; the silica analysis is obviously in error and no analyses were made for fluorine or boron. However, the high dissolved-solids (5712 ppm), the low calcium (16 ppm), and the low sodium-potasium ratio (11.1) indicate that water is part of the deep thermal water. The hot springs along the Jemez River differ from the deep well water by a lower silica content, and a higher calcium and bicarbonate content. I believe that much of the hot spring water has flowed southward from the high temperature caldera regime into the cooler rocks surrounding the caldera. Along the course of flow the cooling water has lost much of the initial silica and gained calcium bicarbonate from the Paleozoic limestones in Jemez Canyon.

b) Saturated steam. Saturated or dry steam occurs in the Baca #4 well between the depths of about 2500 feet to 5000 feet. No condensate samples were taken of this steam for chemical analysis.

c) Shallow thermal water. A chloride-bicarbonate-sulfate water, with dissolved solids of about 2000 ppm, quite distinct from the deep chloride water has been sampled from depths of about 1700 feet to 2500 feet in the Baca #4 well, and from about 1300 feet to 1500 feet in the Baca #1 well. The shallow thermal water has a high content of bicarbonate and sulfate due to the dissociation of carbon dioxide and oxidation hydrogen sulfide, both gases escaping from the deep hydrothermal system. The shallow thermal water contains about 200 ppm silica, reflecting a lower temperature environment than the deep chloride water, and apparently contains no boron.

In the Baca #4 well, this water overlies a vapor phase reservoir. Presence of this water may indicate the existance of a deeper vapor phase, through which carbon dioxide and hydrogen sulfide may pass to the exclusion of chloride ion.

d) Shallow perched thermal water. A very localized type of thermal water is associated with Sulphur Hot Springs in the west central part of the Valles Caldera. The springs are about 150°F. with a pH of 2, and a relatively low flow. Bicarbonate content is nil and chloride content is very low (3.5 ppm). The water is clearly perched, heated by conductive heat flow and by escaping gases. The acidity and high sulfate content are caused by near surface oxidation of H_2S to H_2SO_4. This type of spring is clearly not in fluid communication with deep chloride waters and is indicative of underlying vapor phase reservoirs (White, 1970, 1971).

e) Water outside the hydrothermal system. Water from outside the hydrothermal system is a dilute (100 - 200 ppm dissolved solids) bicarbonate water with minor sulfate and very low chloride content. Fluoride is high for dilute waters (about 1.5 ppm, and boron is nil, both characteristics typical of water from a rhyolitic volcanic environment. The dilute bicarbonate water is typical of the artesian wells in Valle Grande and Valle Toledo, and the water wells near Los Alamos.

A variety of this water is found in the warm springs around the rim of Valles Caldera: San Antonio Bath-House, McCauley, and Bathtub Springs. The warm springs have a slightly higher silica content than the typical cold, bicarbonate water, an indication the water has percolated at least through the edges of the major hydrothermal system. Except for silica content the warm springs are identical chemically to typical cold water. I believe the warm springs represent areas where normally cold ground water is heated near the edges of the deep hydrothermal system. The warm springs thus may indicate areas where the deep hydrothermal system is totally in the liquid phase, possibly with hydrostatic pressures to the surface. Such areas would be ideal for production of wet steam and for hot water. The area around San Antonio Bath House is suggested as a prospective area which could combine high subsurface temperature, good reservoir beds, hydrostatic pressure, and low-salinity fluids.

2. Isotope Chemistry

It has been known for some time that the isotopes of the lighter elements are fractionated by chemical and physical processes in natural systems. The stable isotope of oxygen, O^{18}, has been particularly useful to hydrologists because of the abundance of oxygen in water and rocks. The basic geochemistry of O^{18} is quite simple. Assume the ocean as a large mass of water with a fixed ratio of O^{18} to O^{16} atoms. This ratio is about one O^{18} atom per 250 O^{16} atoms. During oceanic evaporation, the lighter O^{16} atoms tend to leave the ocean easier than the heavier O^{18} atoms. Rainfall is thus depleted in O^{18} relative to ocean water. Rocks contain a proportionately higher amount of O^{18} than ocean water. As the O^{18} depleted rainwater percolates through the earth, O^{16} from the water is exchanged for O^{18} from rocks. The exchange process is very slow at low temperatures, but increases rapidly with increasing temperature. The principal utility of O^{18}/O^{16} measurements in geothermics is as an indicator of the relative length of time water has been in a hydrothermal environment.

Analytical results are usually presented as per mil (per cent x 10) variation from a Standard known as Standard Mean Ocean Water (SMOW). Thus water with O^{18} analysis of -7.6‰ would be depleted in O^{18} relative to seawater to the extent of having a O^{18}/O^{16} value 7.6‰ (0.76%) lower than sea water.

Tritium (H^3), a radioactive isotope of hydrogen, occurs as a natural constituent of the atmosphere through the reaction of cosmic-ray-produced neutrons with nitrogen atoms:

$$N^{14} + n^1 \longrightarrow C^{12} + H^3 + \text{ENERGY}$$

$$\text{or} \quad N^{14} + n^1 \longrightarrow 3He^4 + H^3 + \text{ENERGY}$$

(Kaufman & Libby, 1954)

The natural frequency of tritium atoms is very low; rainwater contains about five naturally occurring tritium atoms for every 10^{18} hydrogen atoms. Because of the low activity, a convenient unit of measurement called a Tritium Unit, has been defined:

$$1 \text{ T.U.} = \frac{\text{Number of tritium atoms}}{\text{Number of hydrogen atoms}} \times 10^{18}$$

Artificial tritium, generated by thermonuclear explosions, has been introduced into the atmosphere in considerable amounts since 1954. In 1963, the tritium content of some rains in North America was over 10,000 T.U.

The half-life of tritium, 12.5 years, furnishes the hydrologist with a short-range dating tool. The large slugs of artificial tritium, produced since 1954, also provide an excellent natural tracer. For example, groundwater which originated as rainfall over 50 years ago, now has a tritium content of less than 0.5 T.U., below the limit of routine commercial analysis. Groundwater samples containing tritium between 1 T.U. and 2 T.U. contain some water "younger" than 50 years, and samples with excess of 5 T.U. clearly have some water originating as rain since 1954.

The O^{18} and tritium values for some waters from the Jemez Mountains, sampled in October, 1970, are:

Sample Locality	(O^{18}) ‰ SMOW	T.U.
Artesian Well, Valle Grande 64°F., flow from 450'.	-12.0	3.6
San Antonio Bath-House Spring, 100°F.	-12.7	4.4
Soda Dam Spring, 104°F.	-11.5	6.8
Sulphur Spring, 150°F.	-12.5	54.4
Baca #4 Well, T.D. 1892'	-11.3	N.D.
Baca #4 Well, T.D. 5048' Flow line water from well producing from dry steam zones from 3468'-4995' and water zone about 5000'.	- 7.4	5.1

The O^{18} content of water from the Valle Grande artesian well is probably representative of Jemez Mountain water which has never been in a hydrothermal system. The tritium content of the artesian well water is neither abnormally high or low. The tritium content of pre-1954 rain has decayed to about 2 T.U. in 1970. 1954 rainfall has decayed to probably no less than 10 T.U. Thus, the artesian water is probably mostly pre-1954 water with a small admixture of post-1954 water.

The water from San Antonio Bath-House spring is warm, with a meteoric value for O^{18} and a relatively low tritium content for a spring. Most springs I am acquainted with have tritium contents of over 10 T.U. Evidently the water has been in the ground for several years, but has only recently entered the hydrothermal system.

The water from Soda Dam Springs is an interesting contrast to the San Antonio Bath-House water. The water at Soda Dam has had some exchange of O^{18} with hot rocks, and contains about 100 times as much chloride ion as the Bath-House Spring, indicating the water has definitely passed through part of the deep hydrothermal system. The tritium content of the Soda Dam water is significantly higher than the Bath-House water, probably the result of near-surface contamination.

Isotopic composition of the water from Sulphur Springs proves that water to be very young, near-surface water, heated by escaping hot gases. Evaporation could concentrate tritium, but it would also concentrate O^{18}. Sulphur Spring water has an O^{18} deficiency similar to recent rain water, and shows no effects of exchange or evaporation.

The O^{18} value for water from 1892 feet in the Baca #4 well reveals some exchange with hot rock, but the subsurface history of the water is probably so complex (the formation water may be a combination of saturated steam condensate and near-surface ground water) that further discussion is not warranted.

Interpretation of the thermal water from Baca #4 well, from 5000 feet deep, is slightly confounded by the flashing which takes place in the well bore as the water is produced. The extent of concentration of heavier isotopes during flashing is quantitatively unknown. Nevertheless, the limiting values are of great significance.

The deep water has had a significant amount of O^{18} exchange with hot rock. The difference between the O^{18} values for surface water and exchanged-hydrothermal water is known as the "oxygen shift." The oxygen shift has been measured in many hydrothermal systems (White, 1970). The apparent shift in the deep Baca #4 water is:

Valle Grande Well		Baca #4		
-12‰	-	(-7.4‰)	=	-4.6‰

The actual shift is possibly less because of the concentration of O^{18} during flashing. A shift of 4.6‰ is somewhat intermediate compared to other hydrothermal systems of similar depth and temperature. The Salton Sea hydrothermal system has a O^{18} shift of at least 13‰. Wairakei, New Zealand has an O^{18} shift of only 1‰. The explanation proposed for Wairakei is that so much water has passed through the system (recharge) that the reservoir rocks are now in equilibrium with the circulating meteoric water supply (White, 1970). The low oxygen shift in the Baca #4 water suggests a similar high throughput of water may be present in the Valles Caldera.

The tritium content of the deep water from the Baca #4 well is high for water from an unproduced reservoir 5000 feet deep, although some concentration, up to 38%, by flashing is possible. The important fact is that any tritium was detected at all. Assuming perfect separation during flashing (impossible) and no condensation of the dry-steam production (unlikely), the deep thermal water contains a minimum of 3.5 T.U. The tritium content of 1954 pre-bomb rainwater has decayed to about 2 T.U. in 1970. Therefore we can conclude that the deep thermal water in Valles Caldera does include a component of post-1954 rainwater, which has traveled through the earth at least one mile vertically in sixteen years. The deep water flow at the Baca #4 well location is apparently much more rapid than the near-surface ground water flow in Valle Grande. Evidence for rapid movement of hydrothermal water is becoming more common, although little data has been published. White (personal communication) recently has found tritium in "presumed" ancient waters at Yellowstone National Park.

E. HYDROTHERMAL ALTERATION

1. Near-Surface Alteration (Map I)

A zone of active hydrothermal alteration covering over 12 square miles has been mapped by the U.S. Geological Survey (unpublished) in the western part of Valles Caldera. Active alteration is most conspicuous near Sulphur Spring, a low pH, low volume, sulfate-rich hot spring. The rocks surrounding the spring area are mostly caldera-fill clastics, tuffs, and rhyolite lavas which have been bleached and leached to a light-gray, porous, siliceous residue, with common native sulphur, sulfate minerals, and clay, probably kaolinite. Vegetation is sparse or absent in the hot spring area, but over most of the active-alteration area, plant-free areas are only sporadic. Surface heat flow is obvious only in the hot spring area, manifested by hot springs, steam vents, and numerous gas seeps; however, the shallow temperature survey revealed that the entire area is underlain by rocks with a very high geothermal gradient.

Hydrogen sulfide, escaping from the deep hydrothermal system is the primary agent responsible for the active rock alteration. Near the surface hydrogen sulfide reacts with atmospheric oxygen to form sulfuric acid, accounting for the high sulfate and low pH of the hot spring waters. The acid attacks the rocks, removing most of the cations and leaving a siliceous, clayey residue. This type of hot spring and alteration activity contrasts markedly with near-neutral chloride springs, and is becoming a classic indicator of vapor-dominated hydrothermal systems. (White, et al, 1971.)

The active area of alteration is superimposed on a much larger area of more subtle, though, pervasive hydrothermal alteration (Doell, et al, 1968.) The exposed altered rocks cover an area of about 70 square miles, and include all the rock units within the caldera except for most of the late rhyolite domes. The late rhyolite domes and recent valley fill unquestionably cover large areas of older hydrothermal alteration. I estimate the total extent of altered rocks to be considerably over 100 square miles.

Away from the active areas of acid-leaching, the alteration is predominately mild silicification and oxidation (Doell, et al, 1968.) Locally, seams of chalcedony or coarser quartz are common, as are opaline deposits in cavities and fractures. The late rhyolite domes are generally free of alteration except for partial hydration of their glassy facies. Doell notes an exception is the rhyolite dome near San Antonio Bath-House Spring, which shows considerable veining with quartz, chalcedony, and opal. The widespread hydrothermal alteration appears to be associated with subaqueous hot springs that rose under the lakes formed in the caldera immediately after collapse, about one million years ago. The late rhyolite domes probably stood above the lake level, escaping alteration. The Bath-House dome has a wave-cut terrace on top, proving its subaqueous history.

It is concluded that a major hydrothermal system, evidenced by near-surface hot spring activity has been present at the Valles Caldera for at least one million years. The preceding statement is quite different than noting that volcanism has been active at Valles Caldera for over one million years. There are notable occurrences of large igneous masses which have been emplaced without concomitant hydrothermal systems. Marysville Buttes, California, is a good example. The Buttes are a Pliocene andesite-rhyolite volcanic complex, over ten miles in diameter, intruded through Cretaceous and Tertiary sediments. Not only is there no evidence of associated hydrothermal fluids, prolific natural gas production has been established in the adjacent sediments. Extensive near-surface hydrothermal alteration, then, is better evidence of deep, long-lived hydrothermal systems than is voluminous volcanic activity.

2. Bland Mining District

The small Bland Mining District, five miles southeast of the Valles Caldera, provides interesting evidence that hydrothermal systems have been associated with igneous activity in the Jemez Mountains for a period far in excess of one million years. The host rocks in the Bland District are Eocene (?) or Oligocene (?) volcanic flows and tuff breccias intruded by small stocks, dikes and sills of granodiorite. The rocks are pervasively chloritized, and locally argillized and silicified (Smith, et al, 1970, Elston, 1961). The mineralogy is characteristic of shallow hydrothermal alteration, such as that presently operating at the Salton Sea Geothermal Field (Muffler and White, 1969). Gold and silver occur in the Bland District in low grade quartz veins; the Albemarle Mine produced over $1,300,000 of gold and silver during operations between 1894 and 1948 (Elston, 1961).

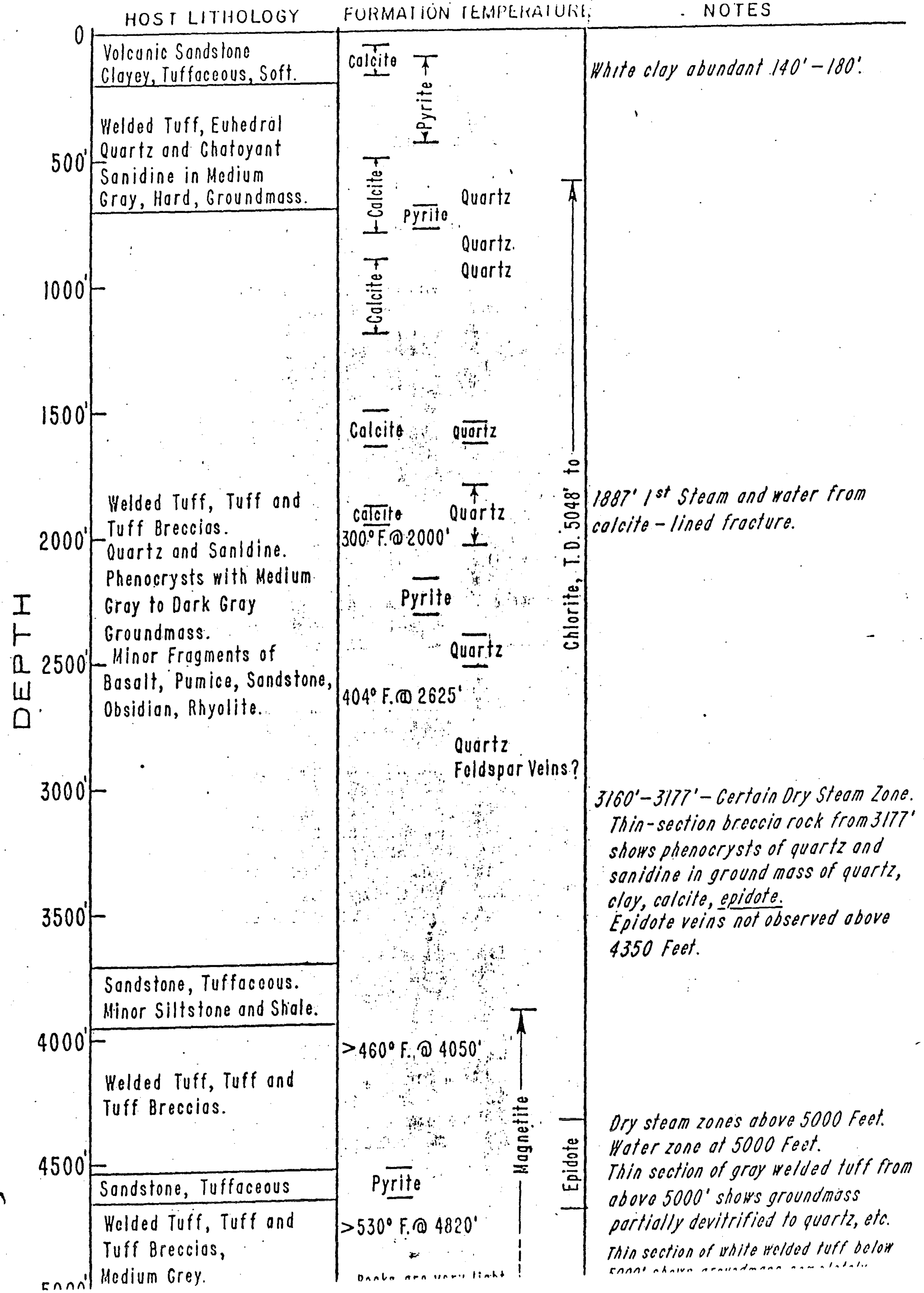
3. Geothermal Wells

The rocks penetrated during the drilling of the five deep geothermal test wells have all been modified extensively by the hydrothermal waters. My knowledge of the stratigraphy and mineralogy of the Bond #1 well and Baca wells #1, #2, and #3 is from cuttings descriptions by U.S.G.S. personnel. More extensive, though still incomplete, data is available from the Baca #4 well. Therefore, except for a cursory description, this section will primarily deal with lithologic observations in the Baca #4 well.

The host rocks in the Bond #1 and Baca #1 and #3 wells are intra-caldera tuffs and tuffaceous sediments. The only well to penetrate pre-caldera rocks is the Baca #2 well (T.D. 5660 feet) which cut, in addition to intra-caldera rocks, a succession of Tertiary sandstone, Paleozoic sandstone, shale and limestone, and Pre-Cambrian granite. Of the wells drilled solely in intra-caldera rocks, the Bond #1 well is the deepest with a total depth of 3675 feet. Baca #1 and Baca #3 are 2560 feet and 2200 (?) feet deep respectively. The sample log from the Bond #1 well describes pyrite throughout the well with calcite above a depth of 1000 feet and frequent mention of silicified zones below 1000 feet. Chloritization is noted at 1200 feet and recrystallized secondary feldspar described at 2600 feet to 3675 feet. Sample logs from the Baca #1 and #3 wells are similar with the exception that secondary feldspar was not noted in the shallower wells. The deep Baca #2 well contains ubiguitous pyrite, shallow secondary calcite and several silicified zones above 2200 feet, approximately the base of the intra-caldera rocks. Sample descriptions of the Tertiary and Paleozoic sediments mention only pyrite, although the well is known to be very hot and many mineralogic changes should occur in the Paleozoic carbonate rocks. The Pre-Cambrian granite is described as containing chlorite, sericite, and epidote, common minerals in the heart of a hydrothermal system. However, the age of the mineralization in the Pre-Cambrian rocks is not available from the sample descriptions.

The rocks penetrated in the Baca #4, T.D. 5048 feet, well consist almost entirely of rhyolite ash-flow tuffs, both welded and non-welded (Figure 6). A few hundred feet of tuffaceous sandstone is also present, interbedded with the tuffs. Smith (personal communication, text in appendix) tentatively identifies the tuff as Bandelier Tuff, a widespread rhyolitic tuff blown out of Toledo and Valle Calderas at the time of initial caldera formation.

The Valles Caldera hydrothermal system has extensively altered the host rocks both physically and mineralogically. Investigations for this report consisted of binocular microscope examination of well cuttings, and thin-section analysis, chemical analysis, and porosity and permeability determinations on selected large pieces of rock ejected from the well during production tests. The original depth of the large pieces thrown from the well was determined by correlation with cuttings and drilling characteristics. The data are summarized in Figure 6.



HOST LITHOLOGY
FORMATION TEMPERATURE
NOTES
DEPTH
0
500'
1000'
1500'
2000'
2500'
3000'
3500'
4000'
4500'
Volcanic Sandstone Clayey, Tuffaceous, Soft.
Welded Tuff, Euhedral Quartz and Chatoyant Sanidine in Medium Gray, Hard, Groundmass.
Welded Tuff, Tuff and Tuff Breccias. Quartz and Sanidine. Phenocrysts with Medium Gray to Dark Gray Groundmass. Minor Fragments of Basalt, Pumice, Sandstone, Obsidian, Rhyolite.
Sandstone, Tuffaceous. Minor Siltstone and Shale.
Welded Tuff, Tuff and Tuff Breccias.
Sandstone, Tuffaceous
Welded Tuff, Tuff and Tuff Breccias, Medium Grey.
Calcite
Pyrite
Calcite
Pyrite
Quartz
Quartz
Quartz
Calcite
Calcite
quartz
calcite
Quartz
300° F.@ 2000'
Pyrite
Quartz
404° F.@ 2625'
Quartz
Feldspar Veins?
>460° F.@ 4050'
Pyrite
>530° F.@ 4820'
Chlorite, T.D. 5048' to
Magnetite
Epidote
White clay abundant 140' – 180'.
1887' 1st Steam and water from calcite – lined fracture.
3160' – 3177' – Certain Dry Steam Zone. Thin-section breccia rock from 3177' shows phenocrysts of quartz and sanidine in ground mass of quartz, clay, calcite, epidote.
Epidote veins not observed above 4350 Feet.
Dry steam zones above 5000 Feet.
Water zone at 5000 Feet.
Thin section of gray welded tuff from above 5000' shows groundmass partially devitrified to quartz, etc.
Thin section of white welded tuff below

The general pattern of secondary mineralization as a result of the hydrothermal environment follows the pattern well documented on the Salton Sea geothermal field, California (Muffler and White, 1969): calcite and quartz veins in the near-surface, low temperature environment (300°F. @ 2000 feet), changing to epidote and probable potash-feldspar with increasing depth and temperature (530°F. @ 4820 feet). A general proposed reaction (Muffler and White) is:

Muscovite + Calcite + Quartz + Iron + Oxygen

$$\longrightarrow$$

Epidote + K-feldspar + Carbon Dioxide + Water

This reaction is believed to account for the abundance of CO_2 generally associated with the shallow parts of hydrothermal systems. Epidote is first observed as veins at a depth of 4300 feet, however thin sections of rock from no deeper than 3177 feet show epidote formation as a ground mass alteration product in a rhyolitic tuff breccia. Below a depth of about 500 feet, the groundmass of the tuff is patchily chloritized, and some hornblende (?) crystals are completely replaced by chlorite. Magnetite is an extremely common mineral below a depth of 3900 feet. It appears to be present as a powdery fracture filling, for although the drillsite and equipment were covered with black, magnetic dust, discrete grains of magnetite were rare in washed samples of cuttings.

A very interesting and probably important lithologic change occurs at a depth of about 5000 feet. During drilling of the well, several dry steam zones were encountered between 2600 feet and 5000 feet. At approximately 5000 feet, a water bearing zone was penetrated. The change from steam-bearing-zones to water-bearing-zones is concomitant with a color change in welded tuff from medium gray to very light gray. Thin-section analysis (details in appendix) revealed that the welded tuff above 5000 feet consist of quartz and sanidine phenocrysts set in a glassy groundmass partially devitrified to quartz. The approximate abundance of rock components is quartz 40%, glass shards 30%, sanidine 20%, and minor clay, pyrite, epidote, and plagioclase. The ground mass of the welded tuff below 5000 feet has been replaced almost entirely by quartz, the abundance of rock components is quartz 80%, sanidine 10%, glass 5%, plus minor components. The nearly white color of the deeper rocks is a result of the intensive, very fine-grained silicification. The intensive silicification below 5000 feet is probably due to the high chemical activity of silica in the formation water, over 800 p.p.m. Ionic migration and rock alteration is impeded in the rocks above 5000 feet which contain vapour-phase water, a very poor solute. The relatively sharp lithologic and vapour-liquid phase contacts at 5000 feet imply a long-lived equilibrium between heat flow and water flow.

Chemical analyses of the welded tuffs above and below 5000 feet were obtained. Dr. Robert Smith of the U.S.G.S. kindly supplied two chemical analyses of outcrop specimens of Bandelier Tuff for comparison. The analyses are:

	Bandelier	Bandelier	Baca #4 Above 5000'	Baca #4 Below 5000'
S_1O_2	77.4%	74.2%	77.6%	73.9%
Al_2O_3	12.1	12.0	11.4	11.1
Fe_2O_3	1.1	0.9	1.5	1.3
MgO	0.0	0.1	0.2	0.2
CaO	0.3	0.4	0.4	0.2
Na_2O	4.1	3.7	4.2	3.5
K_2O	4.3	4.8	4.1	4.1
T_1O_2	0.1	0.1	0.1	0.1
P_2O_5	0.0	0.0	0.1	0.1
MnO	0.1	0.1	0.1	0.1
	99.5	96.3	99.7	94.5

Except for variations which could be due to analytical differences, the bulk chemistry of the Baca #4 welded tuffs is identical to the unaltered outcrop samples of Bandelier. The hydrothermal alteration consists largely of rearrangement of rock material, rather than enrichment and leaching of various components.

Nine pieces of rock from the Baca #4 well were analyzed for porosity and permeability. The results are:

Depth-Feet	Rock Type	Porosity-Percent	Permeability-Millidarcies
3177'	Tuff Breccia	4.8	0.09
"	" "	5.1	0.18
"	" "	6.7	0.07
4900'-5000'	Welded Tuff	10.4	0.33
"	" "	8.7	0.16
"	" "	8.1	0.14
Below 5000'	Welded Tuff	10.9	0.18
"	" "	8.8	0.19
"	Sandstone	16.9	1.82

Smith (1960) and Smith and Bailey (1966) report that outcrop specimens of the Bandelier Tuff have a porosity range of 10% to 40%, and porosity is commonly about 30%. The welded tuffs from the Baca #4 well have a porosity of about 10%. The difference in porosity between outcrop and subsurface samples is the result of load compaction and hydrothermal silicification. The porosity of the sandstone sample is probably similar to most of the sandstones interbedded with the tuffs.

The permeability of the sample rocks is low, but as noted by White, Muffler, and Truesdell (1971), vapor dominated systems, such as The Geysers, California, require low initial permeability for separation of the liquid-vapour phases. Commercial production of steam usually comes from a few permeable fractures, rather than from the bulk rock. The low measured permeabilities are, therefore, not considered detrimental.

V. GEOPHYSICAL SURVEYS

A. GRAVITY SURVEY (Figure 7)

The gravity map (Figure 7) is generalized from an unpublished gravity survey of the Jemez Mountains by the United States Geological Survey. The station density is about one data point per three square miles. Gravity data are responsive to the distribution of rock density. In areas where the stratigraphy is well known, petroleum provinces for example, fairly detailed structural interpretations from gravity data are possible. In hydrothermal areas, however, large variations in bulk density can result from many causes, such as: intrusions, buried lava flows, hydrothermal alteration, dense brines, and low-density steam. Gravity interpretations in hydrothermal areas are always somewhat ambiguous.

The Valles Toledo Caldera is a negative gravity anomaly quite obviously related to the caldera depression, filled with volcanic tuffs and intra-caldera sediments less dense than the surrounding volcanic flows, Tertiary-Paleozoic sediments and Pre-Cambrian granite. The negative anomaly is greatest near the projected intersection of the Valles Caldera and Toledo Caldera, presumably the area of greatest substance, and thickest low density fill. The slope of the gravity-contour-surface within the Valles Caldera is least steep inside the ring-fracture system. This area is thus a positive anomaly, for a simple basin of subsidence should have gravity contours which exactly parallel the basin boundaries. The anomaly is most noticeable in the vicinity of the Baca #4 well and the gravity contours east of the well which actually are convex into the principal negative anomaly. Smith, et al (1970) have unquestionably used the gravity data, and in their cross-section B - B' appear to explain the positive anomaly by structural doming. The reader will recall that the Baca #2 well penetrated a succession of caldera fill, Tertiary sediments, Paleozoic sediments, and Pre-Cambrian granite. The doming hypothesis calls for the Baca #2 stratigraphy to be found at higher elevations at the Baca #4 location. Instead, the Baca #4 well, whose surface elevation is only 800 feet above the Baca #2 well, penetrated over 5000 feet of Bandelier Tuff. The actual stratigraphy suggests two alternative explanations for the positive gravity anomaly: a very near surface magma chamber, dense in contrast to the Bandelier Tuff; or widespread hydrothermal alteration of the Bandelier Tuff by silicification, generally increasing bulk density. Most positive gravity anomalies in the Imperial Valley, California are directly related to metamorphism of sediments in hydrothermal systems. (Rex, 1970.) Porosity of Bandelier Tuff from three deep zones in the Baca #4 well was about 10%, indicating a density of 2.1 - 2.3 gms / cc^3, considerably more than the average density of Bandlier Tuff outcrops. Considerable ambiguity exists, but it is at least possible that the positive gravity anomaly defines the area of most intense hydrothermal activity.

B. MAGNETIC SURVEY (Figure 8)

Figure 8 is a generalized aeromagnetic map from unpublished U.S.G.S. data. The flight lines are on east-west courses at one-mile intervals. Magnetic variations are a result of the variable distribution of magnetite, Fe_3O_4, in rocks. In general, igneous rocks contain much more magnetite than sediments. Among volcanic rocks, basalt and andesite usually contain more magnetite than rhyolite. In the Jemez Mountains, many rocks contain abundant magnetite which occurs as a primary mineral in the volcanic flows and as a secondary mineral of hydrothermal origin.

The aeromagnetic map of the Valles Caldera shows a series of positive magnetic anomalies around the edge of the caldera that are associated with the thick pre-caldera volcanic rocks along the caldera rim. Within the caldera an extensive negative anomaly, in the southern and eastern part of the caldera, approximately coincides with the negative gravity anomaly. The negative anomalies are directly over large masses of rhyolite, indicating that positive anomalies in other parts of the caldera are not a response to the abundant surficial masses of rhyolite.

The major magnetic feature of the Valles Caldera is a complex area of positive anomalies in the western part of the caldera. The general area is, in part, coincident with the positive gravity anomaly, but also extends farther west and northeast than the gravity anomaly. Some of the magnetic anomalies may be due to patches of outcropping pre-caldera andesite ("Tpa" on the geologic map). However, the Baca #4 well is situated on a distinct positive anomaly generated by large amounts of hydrothermal magnetite deposited in Bandelier Tuff. Thus, the aeromagnetic survey, like the gravity survey, may be very useful in determining the extent of the Valles hydrothermal system.

C. SEISMIC NOISE (Figure 9)

A seismic noise survey maps the distribution of very low frequency (1-10 cycles per second) noise which has been found to emanate ubiguitously from the earth. There appears to be some relation between seismic noise variability and hydrothermal systems (Clacy, 1968), but the relation is extremely unclear. The Geysers, California geothermal field is an abnormally "quiet" area. The Salton Sea geothermal field is abnormally "noisy". Dry steam is produced at The Geysers while the Salton Sea field is a liquid reservoir. To further confuse interpretation, bedrock terrane is generally quiet, and alluviated valleys are noisy.

The seismic noise map of the Valles Caldera is presented in Figure 9. Noisy areas coincide with thick deposits of valley fill, as interpreted from topographic, geologic, gravimetric, and magnetic maps. The quiet zone surrounding the Baca #4 well generally coincides with the hydrothermally generated gravity and magnetic anomalies.

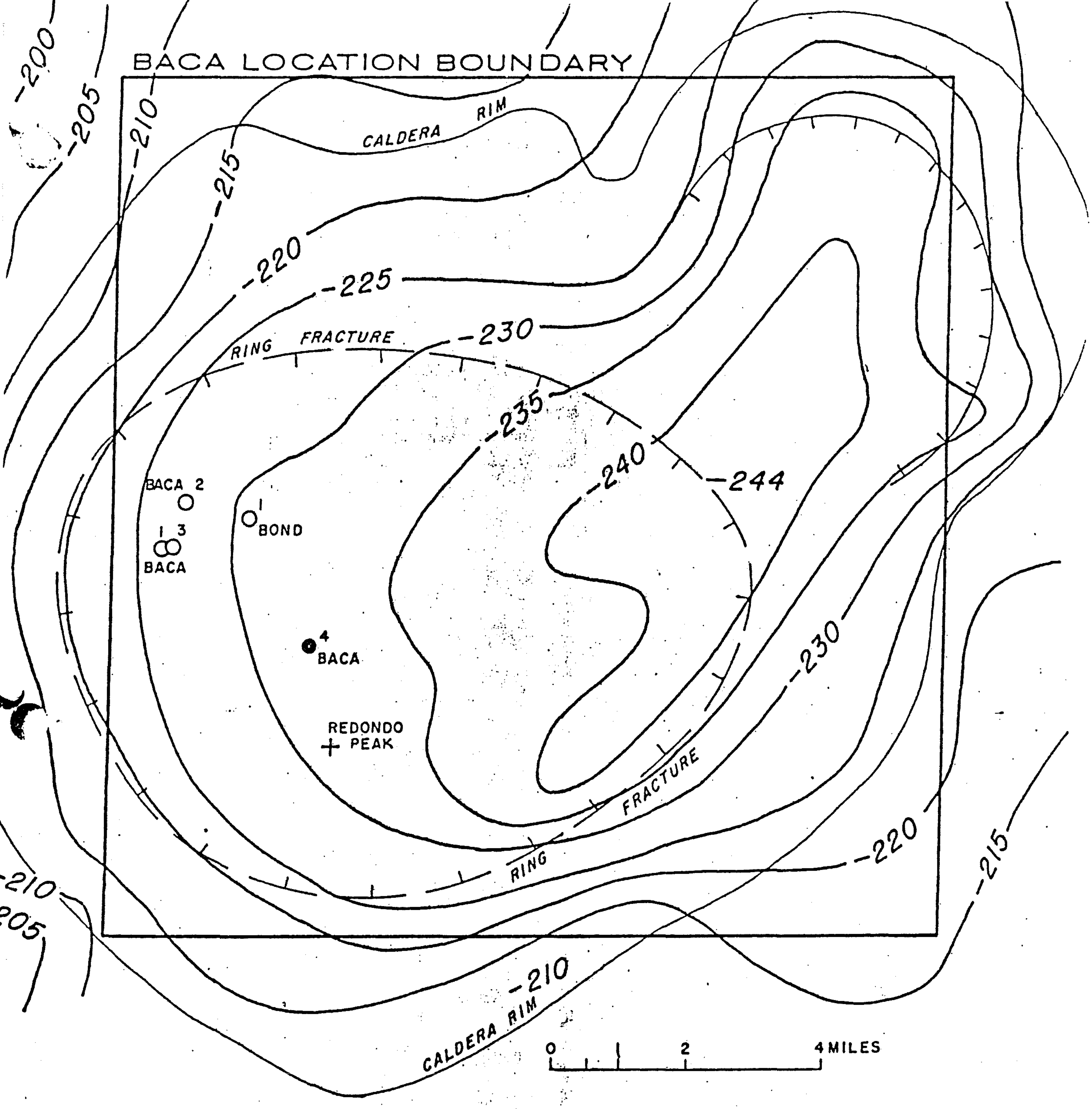


FIGURE 7 GRAVITY MAP, BACA LOCATION, NEW MEXICO
COMPLETE BOUGUER ANOMALY, INCLUDES
TERRAIN CORRECTION
CONTOUR INTERVAL : 5 MGALS.
SOURCE : UNPUBLISHED U.S.G.S. MAP

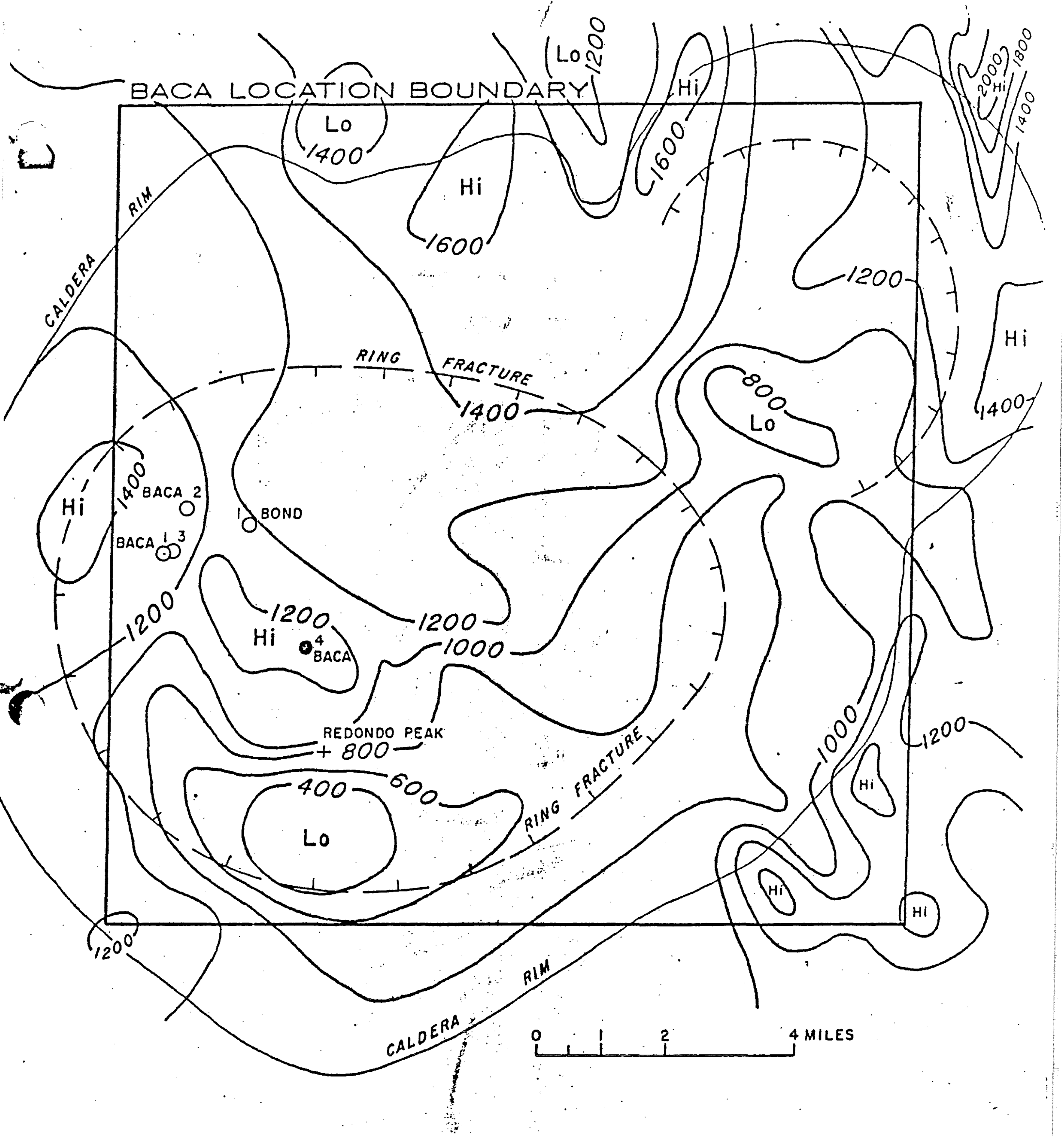


FIGURE 8 AEROMAGNETIC MAP, BACA LOCATION, NEW MEXICO
CONTOUR INTERVAL: 200 GAMMA
FLIGHT LINE SPACING : ONE MILE
SOURCE : UNPUBLISHED U.S.G.S. MAP

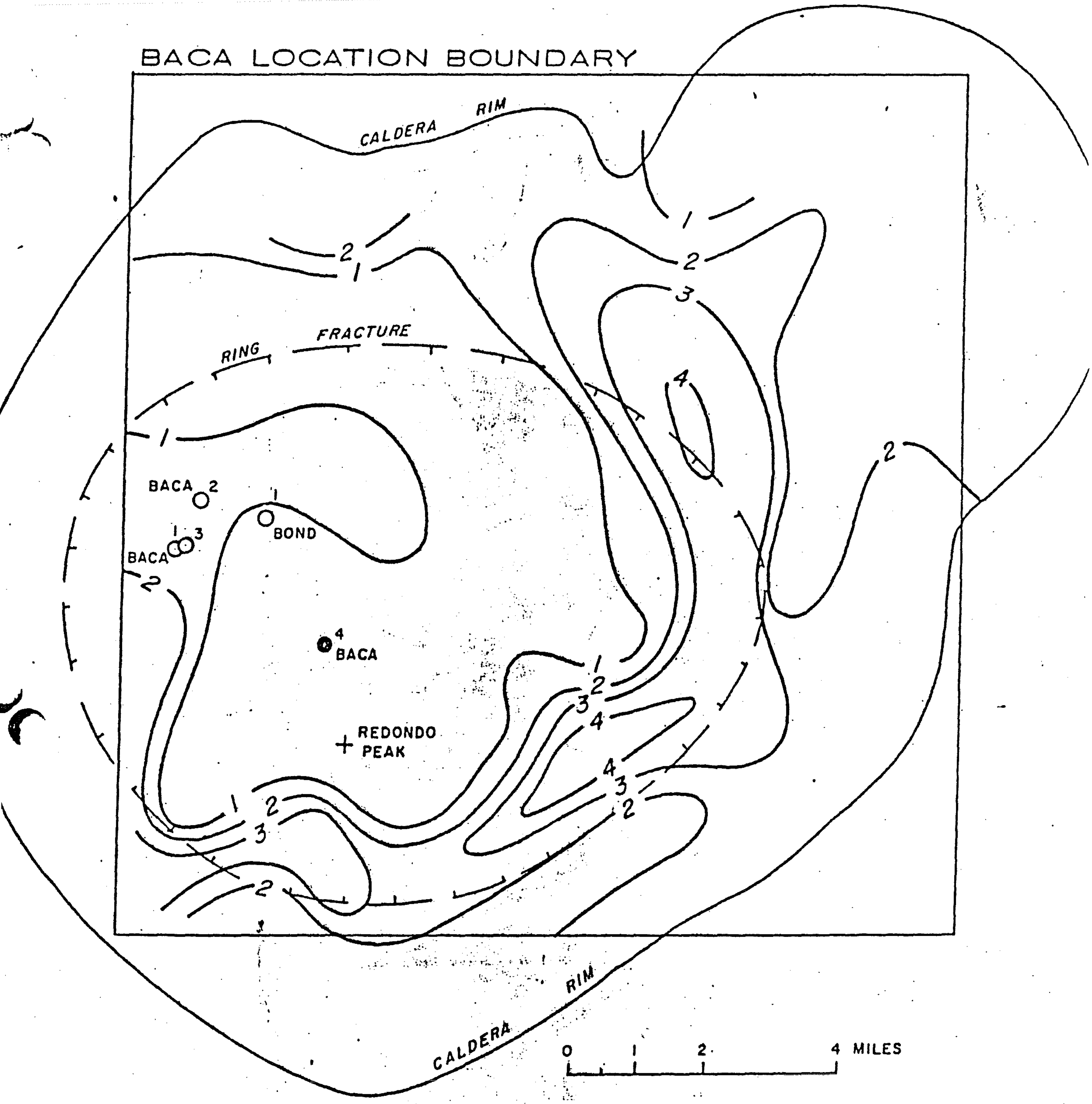


FIGURE 9 SEISMIC NOISE, BACA LOCATION, NEW MEXICO
RELATIVE TOTAL AMPLITUDE, 1-10 HZ.

VI. GEOTHERMAL ENERGY POTENTIAL OF THE VALLES CALDERA

A. GENERAL STATEMENT

The preceding section of this report was devoted primarily to a tabulation of facts with as little speculative material as possible. With the exception of well data, this section is more interpretive and leads to a generalized model of the Valles Caldera hydrothermal system. The general conclusion proposed is that the Valles Caldera is an excellent prospect for geothermal development including the production from vapor-dominated, and liquid-dominated reservoirs. The general model consists of a high heat flow area, the caldera, situated in the path of a deep ground-water system tending to flow from north to south across the caldera. Heat flow near the center of the caldera is sufficient to cause boiling and separation of vapor-phase water. This area is prospective for the production of dry steam. The most likely area for production from a liquid phase reservoir, which requires a potentiometric surface near the earth's surface, and a porous and permeable reservoir, is immediately north of the vapor phase prospective area.

B. SUMMARY OF WELLS DRILLED TO DATE

1. Bond #1, T.D. 3675 feet
(More complete descriptions of all wells are in the Appendix)

Of the five deep wells within the Valles Caldera, four were drilled as geothermal tests. The earliest well, the Westates-Bond #1, was drilled in 1960 as a petroleum test. Drilled largely with mud, the Bond #1 well furnished the first evidence of a high-temperature, low pressure hydrothermal system in the Valles Caldera. Lost circulation zones were encountered at depths of 1204 feet, 1338 feet, and 3650 feet, the latter so serious that the mud system was converted to air. The well was abandoned at a depth of 3675 feet because the air supply could not keep the hole unloaded. During drilling, high mud flow line temperatures were observed: 170°F. at 1698 feet increasing to 194°F. (boiling at wellhead elevation) at 2966 feet.

In 1967, the well was cleaned out to 1920 feet, at which time it flowed surges of steam and water. Downhole temperature and pressure measurements indicated a liquid water phase in the lost circulation zone at 1338 feet. The formation pressure, about 100 psig, is considerably below a hydrostatic column extending to the surface. The formation temperature is about 250°F., below the temperature at equivalent depths in other wells.

Deeper permeable zones apparently are also liquid filled, for the temperature surveys show that some of the test fluid was coming from below 2900 feet, but pressures appear too high and temperatures too low to allow a vapor-phase separation.

It is concluded that the rocks penetrated by the Bond #1 well contain liquid water at elevated temperature, and significantly less than hydrostatic pressure.

2. Baca #1, T.D. 2560 feet
Baca #3, T.D. 2200(?) feet

The Baca #1 well is the first well in Valles Caldera drilled to establish geothermal steam production. With 13-3/8 inch casing emplaced to 461 feet, the well encountered steam zones at 1441 - 1500 feet. As measured by Rogers Engineering Company, the zones flowed 85,000 pounds of steam per hour with less than 5% liquid water content. Their estimate of reservoir conditions was 310° - 320°F. and 65 psig reservoir pressure, a saturated steam zone. Rogers' estimate of the formation temperature is in good agreement with the temperature calculated from the sodium-potassium content of the effluent water: 338°F. The well was deepened to 2560 feet and the hole was lost while attempting to run casing.

The Baca #3 well, a twin to the Baca #1, was drilled to re-establish production from the steam zones discovered in the Baca #1 well. At a total depth of 1983 feet, with 1179 feet of 9-5/8 inch casing, the well had a flow of 11% steam and 89% water, chiefly from zones below 1900 feet. The water zone apparently was depleted rapidly, for one day later the well was flowing 50% steam. After tests, 7 inch casing was hung from 1000 feet to 1983 feet and the well was drilled to total depth, about 2200 feet. A down-hole temperature survey recorded a maximum temperature of 390°F. at 1800 feet and a water level between 800 feet and 900 feet.

The Baca #1 and #3 wells establish that low pressure-high temperature conditions are available in the Valles Caldera suitable for formation of saturated steam reservoirs. Although the wells, as drilled, did not discover commercial production, data from the Baca #4 well indicates the Baca #1 - #3 location is probably on the fringe of a saturated steam reservoir and may be prospective for dry steam production from greater depths.

3. Baca #2, T.D. 5658 feet

The Baca #2 well is the deepest geothermal test in the Valles Caldera, and is the only well to penetrate Paleozoic sediments and Pre-Cambrian granite. The well was drilled with mud to a depth of 3445 feet with lost circulation while drilling at 1163 feet and 3332 feet. After setting 9-5/8 inch casing at 3445 feet and converting to air, the well was drilled through Paleozoic sediments to 4726 feet. Some steam flow was encountered in the Paleozoic section for the drilling reports cite:

9-20-63 Increase in volume noted between 3780' and 3809'

9-21-63 Depth 4446', flow line temp. 204°F., wellhead pressure 31#.

Evidently the flow diminished, for a 7 inch liner was hung from 3397 feet to 4726 feet, and the well was drilled to total depth, 5658 feet. Drilling reports indicate that no permeable zones were encountered between 4726 feet and 5658 feet. After drilling to total depth, many zones between 1300 feet and 3100 feet were perforated, resulting in many flows of hot water.

Although no adequate down-hole temperature-pressure data are available below 2274 feet, drilling records((see Appendix and previous discussions of temperature distribution) below that depth, and shallower temperature measurements prove the well is extremely hot, possibly over 600°F. at total depth. The maximum observed temperature in the well was 428°F. at 1400 feet. At that time the well had been static for several months with a plug at 2288 feet and perforations from 1750 feet to 2288 feet. The fluid level was at a depth of 860 feet. Assuming the existence of a permeable zone at the highest perforations, 1750 feet, down hole pressure-temperature surveys (300 psig and 408°F. at 1750 feet) indicate liquid-phase water in the reservoir.

The Baca #2 well further confirms the existence of a very high temperature-low pressure hydrothermal system in the Valles Caldera.

4. Baca #4, T.D. 5048 feet

The Baca #4 well was drilled with mud to 1442 feet and from 1442 feet to total depth with air. Water-bearing zones were encountered between 1887 feet and approximately 2600 feet. Zones producing dry steam at the surface were cut between 2600 feet and approximately 5000 feet. At approximately 5000 feet a liquid water-bearing zone was penetrated. The existence of a boiling water feed-zone below vapor-dominated steam reservoirs has been speculated on (White, et al, 1971, and others), but the Baca #4 well is believed to be the first geothermal well to clearly penetrate such a water zone.

Pressure temperature surveys indicate a low-pressure, high-temperature hydrothermal system at the Baca #4 location. The potentiometric surface of the deep water zone is approximately 2000 feet deep. The above-sea elevation of the potential water table is about 300 feet lower than the potential surface in the Baca #2 well, showing that subsurface water tends to flow from the Baca #2 location towards the Baca #4 location, and proves that the deep hydrothermal system operates independently of the near-surface drainage effects of Redondo Peak, the dominant topographic factor in Valles Caldera.

Observed downhole temperatures are comparatively very high, over 532°F. at 4820 feet. White (1971) reports that of about 100 hydrothermal systems explored by drilling, only about 10 demonstrably exceed 480°F. (250°C).

Little data are available on the formation pressure of the major dry-steam producing zones. On one occasion during shut-in, the wellhead shut-in pressure rose to over 500 psig, indicating a formation pressure of over 500 psig at the highest permeable zone open to the well bore. That zone is at a depth of 3468 feet and the zone produces dry steam. (The temperature of the zone is therefore greater than 465°F.) Assuming that the deeper, hotter dry-steam producing zones contain saturated steam, the reservoir pressure at a depth of 4900 feet (in excess of 530°F.) is about 885 psig.

Because of the influx of deep water, no good data are available concerning the potential flow of dry steam above the water-zone. The well flow, on the basis of visual observation, appeared to be in the order of 100,000 pounds of steam per hour.

The Baca #4 well proves the existence of an areally large, very hot, under-pressured hydrothermal system in the Valles Caldera. Temperatures in Baca #4 well and Baca #2 well, about three miles apart, are about the same on an above-sea elevation basis. The well also proves the existence of a vapor-dominated reservoir conducive to the production of dry steam. The areal extent and commercial utility of the vapor-dominated reservoir will be determined by future drilling.

Data from the Baca #4 well also proves that the pressure regime of the deep hydrothermal system is related to the deep groundwater flow of the regional Rio Grande drainage basin, and is largely independent of local topography.

C. MODEL OF THE VALLES CALDERA HYDROTHERMAL SYSTEM (Map III)

The proposed model of the Valles Caldera hydrothermal system, presented diagramatically as Cross-Section A-A on Map III, is analogous to a stream of water flowing slowly over a tilted hot plate or griddle. Dilute subsurface water, flowing normally away from the heart of the Jemez Mountains to the Rio Grande basin, passes over the high heat flow area of the Valles Caldera. The water is warmed while passing across the caldera; boiling and separation of vapor-phase water occurs in the southern half of the caldera. Evaporation of water from the declining deep water table, and leaching of mineral matter from rocks, concentrates dissolved salts in the residual liquid. The concentrated liquid leaves the hydrothermal system on the south side of the caldera, manifesting itself in several chloride-rich hot springs along the Jemez River.

Let us review the factual bases for the proposed model. The regional pattern of deep ground-water flow is well documented by the occurrence of chloride-bearing thermal springs, deep water-observation wells, and fluid-level determinations in geothermal wells. A widespread temperature anomaly in the Valles Caldera is shown by hot springs, shallow temperature and temperature-gradient wells, and temperatures measured in geothermal wells.

The water from San Antonio Bath-House hot spring is water which has relatively recently entered the hydrothermal system. Chemically the water is similar to fresh, cold water of the Jemez Mountains, such as water in Valle Grande. The tritium content of the water is quite low, proving a long history of subsurface flow. The water, however, is warm and contains an abnormal amount of dissolved silica, indicating the water has circulated through the fringes of the hydrothermal system.

The liquid-phase water travels for several miles before boiling occurs. Water underlying the Baca #2 well location appears to be entirely in the liquid-phase, although very hot. Some saturated steam was encountered in the Baca #1 well, indicating that boiling begins somewhere between the Baca #2 and Baca #1 wells. The thickness of the vapor-phase reservoir is unknown at the Baca #2 location, but at the Baca #4 location, the vapor-dominated reservoir is over 2400 feet thick.

The vapor-dominated reservoir was once filled with liquid water. The extensive hydrothermal alteration of the tuffaceous rocks probably could not have been accomplished with saturated steam, a poor solute, as the dominant reservoir fluid. According to White, et al, (1971):

"Vapor dominated systems require relatively potent heat supplies and low initial permeability. After an early hot-water stage, a system becomes vapor-dominated when net discharge starts to exceed recharge."

At least two mechanisms in the Valles Caldera are acting to lower rock permeability and thus to lower the recharge capacity of the system. Calcium carbonate and calcium sulphate decrease in solubility with increasing temperature. As cold water enters the hydrothermal system, deposition of calcite and gypsum takes place in the flow channels, thus decreasing permeability. The deposition of calcite near the edges of the hydrothermal system is clearly demonstrated in the geothermal wells in the Valles Caldera. In all the wells, calcite is common as a hydrothermal mineral only in the upper, cooler portions of the wells. At depth, calcite becomes much less common. Deposition of calcite tends to form a caprock preventing vertical intrusion of surface water into the reservoir. Presumably, calcite deposition also takes place on the northern flanks of the system, impeding deep recharge.

A second mechanism, probably the dominant mechanism in the Valles Caldera, is the silicification of tuffaceous rocks. In the Baca #4 well, for example, the Bandelier Tuff reservoir rocks are intensively silicified with a porosity of about 10% and negligible permeability. Outcrop specimens of Bandelier commonly have a porosity over 30%, and presumably some permeability. The Baca #4 reservoir rocks had a near-surface origin (proven by interbedded sandstones) and, therefore, reasonably good initial permeability. The decrease of permeability due to silicification has resulted in an imbalance between heat flow and water flow leading to boiling and generation of a vapor-dominated reservoir.

At the Baca #4 location, the vapor-liquid interface has declined to a level about 5000 feet deep. With the liquid-water table at that depth, an equilibrium between heat flow and water flow appears to have been established. The very distinct change in degree of alteration at the vapor-liquid interface could not have developed rapidly, and certainly does not indicate an actively declining liquid-water table. The tritium content of the liquid water shows that active recharge of the hydrothermal system is significant. Because the water recharge is not quenching and filling the vapor-phase reservoir, we can assume the water recharge is balanced by heat flow from below the caldera. Evidence of a high continuing heat flow comes from the periodicity of rhyolitic volcanism over the last million years, which as Doell (1968) points out does not preclude future eruptions.

South of the Baca #4 location, the steam-water interface will be found at greater depths in response to the addition of heat as the water moves across the caldera. Near the caldera edge however, the vapor-dominated reservoir will terminate due to decreased heat flow beyond the ring-fracture complex. Some surface water from the caldera rim may also enter the hydrothermal system south of the ring-fracture system, further tending to condense the vapor-phase reservoir.

The chloride-rich hot springs along the Jemez River represent the outflow of water from the Valles Caldera. The solution chemistry of the springs is similar to the deep water in the Baca #4 well, and the isotope chemistry proves a long subsurface residence in a hydrothermal system. Some evidence of decreased flow through the caldera is given by Soda Dam Hot Springs. The springs are named for an enormous deposit of travertine which forms a dam across the Jemez River. The springs must have been much more active in the past, because under present spring flow the travertine dam is being actively eroded.

Map III also shows the areal distribution of land believed prospective for geothermal resources. The speculative nature of the map must be emphasized. The optimum conditions for production of dry-steam are a deep water table, high heat flow, and relatively impermeable reservoir rocks. These conditions are best met in the area underlain by silicified Bandelier Tuff in the southern half of the caldera within the ring-fracture system.

Production from a liquid-phase reservoir is best accomplished where the water table approaches the surface, and the reservoir rocks are porous and permeable, and filled with relatively fresh water. The area immediately north of the vapor-phase reservoir is suggested as a likely prospect area. High reservoir temperatures, similar to those found in the Baca #2 well, should be generally available just north of the zone of incipient boiling. The potentiometric surface of the hydrothermal system intersects the surface at San Antonio Bath-House hot springs and should be relatively close to the surface in the common valleys between San Antonio Creek and the flanks of Redondo Peak. The reservoir fluid may consist largely of relatively fresh water just entering the hydrothermal system. Some consideration will have to be given to the distribution of potential reservoir rocks. The history of the Baca #2 well indicates that the Paleozoic sediments are not good reservoir rocks. The outcrops of pre-caldera Tertiary volcanic rocks a few miles east of the Baca #2 well, suggest that Tertiary sandstones may be present in the subsurface over much of the northern half of the caldera within the ring-fracture system. Outcrop samples of the Tertiary sandstones appear to have adequate reservoir characteristics, and could be logical targets for geothermal tests.

A small fringe area on the south side of the caldera where the deep thermal water leaves the caldera may be prospected for production from liquid-phase reservoirs. Although good reservoir rocks are not generally distributed through this area, and water chemistry may be deleterious, subsurface temperatures should be very high and hydrostatic pressures may extend nearly to the earth's surface.

The dashed line trending northeast-southwest through the prospective areas on Map III, represents the projection of major pre-caldera faults through the Valles and Toledo Calderas. At this date the subsurface geology east of the projected fault zone is very poorly known. Lack of knowledge is the sole reason for classifying the Toledo Caldera and the eastern half of the Valles Caldera as lower quality than the western Valles Caldera. If the near-surface temperature gradients in Valle Grande and Valle Toledo continue with depth, subsurface temperatures equivalent to those in the Baca #2 and Baca #4 wells will be found at similar above-sea elevations in the eastern valleys. Structural considerations argue in favor of a very thick section of Tertiary reservoir rocks underlying the Toledo Caldera and eastern Valles Caldera. The principal difference between the western and eastern prospect areas may simply be surface topography. In the western part of the Valles Caldera, hydrothermal fluids, including hot gases, are free to migrate up fractures in consolidated bedrock, and the alteration effects of the fluids are exposed by erosion. In the eastern prospect area alteration areas may be hidden by recent alluvial deposits and the escape of hydrothermal fluids is impeded by thick, soft valley clays and near-surface cold water masses which may actually tend to flow into the deep thermal reservoir.

Richard F. Dondanville

VII

APPENDIX A

REFERENCES

REFERENCES

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APPENDIX B

CHEMICAL ANALYSES

OF SELECTED WATER

RICHLOND 5-0411 FORM C-4 1-68

SMITH-EMERY COMPANY

CHEMISTS • TESTING • INSPECTION • ENGINEERS

701 EAST WASHINGTON BOULEVARD

LOS ANGELES 21, CALIFORNIA

FILE NO.: 9596-70
CLIENT: BACA LAND & CATTLE
ADDRESS: P. O. BOX 872
LOS ALAMOS, NEW MEXICO
ATTENTION: MR. J. HARRELL

DATE RECEIVED: OCT. 30, 1970
REPORTED: NOV. 16, 1970
SAMPLE: WATER
SUBMITTED BY: CLIENT
LABORATORY NO.: C-554907
MARKED: "FLASHED WATER, BACA #4, TD 5048"

REPORT OF WATER ANALYSIS

ANALYSIS OF DISSOLVED SOLIDS	PARTS PER MILLION	HYPOTHETICAL COMBINATIONS	PARTS PER MILLION
SILICA (SiO_2)	12.0 *	SILICA SiO_2	12.0
ALUMINUM OXIDE (Al_2O_3)	TRACE	ALUMINUM OXIDE Al_2O_3	TRACE
IRON OXIDE (Fe_2O_3)	TRACE	IRON OXIDE Fe_2O_3	TRACE
CALCIUM (CA)	NONE	CALCIUM BICARBONATE $Ca(HCO_3)_2$	NONE
MAGNESIUM (MG)	NONE	CALCIUM SULFATE $CaSO_4$	NONE
SODIUM (NA)	2100.0	CALCIUM CHLORIDE $CaCl_2$	NONE
SULFATE (SO_4)	65.8	MAGNESIUM BICARBONATE $Mg(HCO_3)_2$	NONE
CHLORIDE (CL)	3618.3	MAGNESIUM SULFATE $MgSO_4$	NONE
CARBONATE (CO_3)	36.0	MAGNESIUM CHLORIDE $MgCl_2$	NONE
BICARBONATE (HCO_3)	286.8	SODIUM BICARBONATE $NaHCO_3$	394.9
NITRATE (NO_3)	N.D.	SODIUM CARBONATE Na_2CO_3	63.6
NITRITE (NO_2)	N.D.	SODIUM SULFATE Na_2SO_4	97.3
BORATE (B_4O_7)	135.9	SODIUM CHLORIDE NACL	4818.6
POTASSIUM --- (K) ---------	777.0	SODIUM NITRATE $NaNO_3$	N.D.
		SODIUM NITRITE $NaNO_2$	N.D.
		POT. CHLORIDE ---(KCL) --	1469.8
		SOD. BORATE ----($Na_2B_4O_7$)	[illegible]
TOTAL SOLIDS	7031.8	TOTAL SOLIDS	7031.8
TOTAL NON-VOLATILE SOLIDS	6886.0	TOTAL HARDNESS AS $CaCO_3$	NONE

*Silica redone = 820 ppm

DETERMINATIONS

SPECIFIC CONDUCTANCE MICROMHOS/CM	10000	TURBIDITY	NONE
HYDROGEN ION CONCENTRATION (PH)	9.0	COLOR	6
BORON (B) IN PPM	37.9	ODOR	NONE
FLUORIDE (F) IN PPM	15.0	TASTE	N.D.
LANGELIER INDEX	N.D.	SUSPENDED MATTER	NONE

AMMONIUM ---------- LESS THAN 0.1 PPM
SILVER ----------- LESS THAN 0.1 PPM
ARSENIC ---------- 6.0 PPM
MERCURY ---------- LESS THAN 0.01 PPM
BROMINE ---------- LESS THAN 0.1 PPM
LITHIUM ---------- LESS THAN 1.0 PPM

RESPECTFULLY SUBMITTED
SMITH-EMERY COMPANY

BY [signature]

3 - ADDRESSEE
CH-

RICHMOND 9-2411

SMITH-EMERY COMPANY

CHEMISTS • TESTING • INSPECTION • ENGINEERS

701 EAST WASHINGTON BOULEVARD

LOS ANGELES 21, CALIFORNIA

FORM C-4 1-62 LC

FILE NO.: 9596-70
CLIENT: BACA LAND & CATTLE

ADDRESS: P. O. BOX 872
LOS ALAMOS, NEW MEXICO
ATTENTION: MR. J. HARRELL

DATE RECEIVED: OCT. 30, 1970
REPORTED: NOV. 16, 1970
SAMPLE: WATER
SUBMITTED BY: CLIENT
LABORATORY NO.: C-554906
MARKED: "SODA SPRING" IN JEMEZ CANYON

REPORT OF WATER ANALYSIS

ANALYSIS OF DISSOLVED SOLIDS	PARTS PER MILLION	HYPOTHETICAL COMBINATIONS	PARTS PER MILLION
SILICA (SiO_2)	10.0 *	SILICA SiO_2	10.0
ALUMINUM OXIDE (Al_2O_3)	TRACE	ALUMINUM OXIDE Al_2O_3	TRACE
IRON OXIDE (Fe_2O_3)	TRACE	IRON OXIDE Fe_2O_3	TRACE
CALCIUM (CA)	67.3	CALCIUM BICARBONATE $Ca(HCO_3)_2$	272.4
MAGNESIUM (MG)	8.3	CALCIUM SULFATE $CaSO_4$	NONE
SODIUM (NA)	1200.0	CALCIUM CHLORIDE $CaCl_2$	NONE
SULFATE (SO_4)	37.0	MAGNESIUM BICARBONATE $Mg(HCO_3)_2$	49.7
CHLORIDE (CL)	1452.6	MAGNESIUM SULFATE $MgSO_4$	NONE
CARBONATE (CO_3)	NONE	MAGNESIUM CHLORIDE $MgCl_2$	NONE
BICARBONATE (HCO_3)	1441.9	SODIUM BICARBONATE $NaHCO_3$	1646.0
NITRATE (NO_3)	N.D.	SODIUM CARBONATE Na_2CO_3	NONE
NITRITE (NO_2)	N.D.	SODIUM SULFATE Na_2SO_4	54.7
BORATE (B_4O_7)	175.5	SODIUM CHLORIDE NACL	1728.3
POTASSIUM ---- (K) ----------	456.0	SODIUM NITRATE $NaNO_3$	N.D.
		SODIUM NITRITE $NaNO_2$	N.D.
		POT. CHLORIDE -- (KCL) ---	870.1
		SOD. BORATE --- ($Na_2B_4O_7$)	[illegible]
TOTAL SOLIDS	4858.6	TOTAL SOLIDS	4858.6
TOTAL NON VOLATILE SOLIDS	4125.8	TOTAL HARDNESS AS $CaCO_3$	202.0

Silica redone = 35 ppm

DETERMINATIONS

SPECIFIC CONDUCTANCE MICROMHOS/CM	6060	TURBIDITY	NONE
HYDROGEN ION CONCENTRATION PH	6.8	COLOR	6
BORON (B) IN PPM	49.0	ODOR	NONE
FLUORINE (F) IN PPM	N.D.	TASTE	N.D.
LANGELIER INDEX	N.D.	SUSPENDED MATTER	NONE

RESPECTFULLY SUBMITTED
SMITH-EMERY COMPANY

BY [signature]
P.E. [illegible]

3 - ADDRESSEE
CH

RICHMOND 9-3411

SMITH-EMERY COMPANY

CHEMISTS • TESTING • INSPECTION • ENGINEERS

781 EAST WASHINGTON BOULEVARD

LOS ANGELES 21, CALIFORNIA

FORM C-4 1-62 LC

FILE NO.: 9596-70
CLIENT: BACA LAND & CATTLE COMPANY

ADDRESS: P. O. BOX 872
LOS ALAMOS, NEW MEXICO
ATTENTION: MR. JOE HARRELL

DATE RECEIVED: OCTOBER 15, 1970
REPORTED: OCTOBER 21, 1970
SAMPLE: WATER
SUBMITTED BY: CLIENT
LABORATORY NO.: C-554695
MARKED: "GROPCO BACA #4 WATER FLOW AT T.D. 2408'

REPORT OF WATER ANALYSIS

ANALYSIS OF DISSOLVED SOLIDS	PARTS PER MILLION	HYPOTHETICAL COMBINATIONS	PARTS PER MILLION
SILICA (SiO_2)	28.0*	SILICA SiO_2	28.0
ALUMINUM OXIDE (Al_2O_3)	TRACE	ALUMINUM OXIDE Al_2O_3	TRACE
IRON OXIDE (Fe_2O_3)	TRACE	IRON OXIDE Fe_2O_3	TRACE
CALCIUM (CA)	NONE	CALCIUM BICARBONATE $Ca(HCO_3)_2$	NONE
MAGNESIUM (MG)	NONE	CALCIUM SULFATE $CaSO_4$	NONE
SODIUM (NA)	917.0	CALCIUM CHLORIDE $CaCl_2$	NONE
SULFATE (SO_4)	255.1	MAGNESIUM BICARBONATE $Mg(HCO_3)_2$	NONE
CHLORIDE (CL)	800.0	MAGNESIUM SULFATE $MgSO_4$	NONE
CARBONATE (CO_3)	111.0	MAGNESIUM CHLORIDE $MgCl_2$	NONE
BICARBONATE (HCO_3)	598.0	SODIUM BICARBONATE $NaHCO_3$	823.4
NITRATE (NO_3)	N.D.	SODIUM CARBONATE Na_2CO_3	196.1
NITRITE (NO_2)	N.D.	SODIUM SULFATE Na_2SO_4	377.2
BORATE (B_4O_7)	NONE	SODIUM CHLORIDE NACL	1232.1
POTASSIUM ---- (K) ----------	58.0	SODIUM NITRATE $NaNO_3$	N.D.
		SODIUM NITRITE $NaNO_2$	N.D.
		POTASSIUM CHLORIDE (K CL)	110.3
TOTAL SOLIDS	2767.1	TOTAL SOLIDS	2767.1
TOTAL NON VOLATILE SOLIDS	2463.2	TOTAL HARDNESS AS $CaCO_3$	NONE

*Silica Redone = 242 ppm

DETERMINATIONS

SPECIFIC CONDUCTANCE MICROMHOS/CM	4160	TURBIDITY	NONE
HYDROGEN ION CONCENTRATION pH	9.2	COLOR	6
BORON (B) IN PPM LESS THAN --	0.08	ODOR	NONE
FLUORIDE (F) IN PPM	N.D.	TASTE	N.D.
LANGELIER INDEX	N.D.	SUSPENDED MATTER	NONE

RESPECTFULLY SUBMITTED
SMITH-EMERY COMPANY

BY Kenneth Drennon
KENNETH DRENNON

2 - ADDRESSEE
1 - RICHARD DONDANVILLE
CH vr

AGRICULTURE
CHEMICAL ANALYSIS
PETROLEUM

BC LABORATORIES
J. J. EGLIN, REG. CHEM. ENGR.
3016 UNION AVE. BAKERSFIELD, CALIFORNIA 93305 PHONE 325-7475

Baca Land & Cattle Company
P. O. Box 1641
Abilene, Texas 79604

Date Reported: 1/8/71
Date Received: 1/4/71
Laboratory No.: 1268

Attention: Mr. Joe Harrell, Jr.

Submitted by: Mr. R. F. Dondanville

Sample Description: Baca #4, 2408'

Sample: Water

Total Silica as SiO_2	---	242 ppm
Soluble SiO_2	---	165 ppm
Fluoride	---	8 ppm
Lithium	---	10 ppm
Arsenic	---	1.21 ppm

B C LABORATORIES

BY J. J. Eglin
J. J. Eglin

ch

1-Mr. Dondanville

RICHMOND 9-3411

SMITH-EMERY COMPANY

CHEMISTS • TESTING • INSPECTION • ENGINEERS

781 EAST WASHINGTON BOULEVARD

LOS ANGELES 21, CALIFORNIA

FORM C-4 1-62 LC

FILE NO.: 9596-70
CLIENT: BACA LAND & CATTLE COMPANY

ADDRESS: P. O. BOX 872
LOS ALAMOS, NEW MEXICO
ATTENTION: MR. JOE HARRELL

DATE RECEIVED: OCTOBER 15, 1970
REPORTED: OCTOBER 21, 1970
SAMPLE: WATER
SUBMITTED BY: CLIENT
LABORATORY NO.: C-554696
MARKED: BACA #4 AT T.D. 1892'

REPORT OF WATER ANALYSIS

ANALYSIS OF DISSOLVED SOLIDS	PARTS PER MILLION	HYPOTHETICAL COMBINATIONS	PARTS PER MILLION
SILICA (SiO_2)	24.0 *	SILICA SiO_2	24.0
ALUMINUM OXIDE (Al_2O_3)	TRACE	ALUMINUM OXIDE Al_2O_3	TRACE
IRON OXIDE (Fe_2O_3)	TRACE	IRON OXIDE Fe_2O_3	TRACE
CALCIUM (CA)	NONE	CALCIUM BICARBONATE $Ca(HCO_3)_2$	NONE
MAGNESIUM (MG)	NONE	CALCIUM SULFATE $CaSO_4$	NONE
SODIUM (NA)	632.9	CALCIUM CHLORIDE $CaCl_2$	NONE
SULFATE (SO_4)	189.3	MAGNESIUM BICARBONATE $Mg(HCO_3)_2$	NONE
CHLORIDE (CL)	530.0	MAGNESIUM SULFATE $MgSO_4$	NONE
CARBONATE (CO_3)	90.0	MAGNESIUM CHLORIDE $MgCl_2$	NONE
BICARBONATE (HCO_3)	422.3	SODIUM BICARBONATE $NaHCO_3$	581.4
NITRATE (NO_3)	N.D.	SODIUM CARBONATE Na_2CO_3	159.0
NITRITE (NO_2)	N.D.	SODIUM SULFATE Na_2SO_4	279.9
BORATE (B_4O_7)	NONE	SODIUM CHLORIDE NACL	798.8
POTASSIUM (K)	50.0	SODIUM NITRATE $NaNO_3$	N.D.
		SODIUM NITRITE $NaNO_2$	N.D.
		POTASSIUM CHLORIDE (KCL)	95.4
TOTAL SOLIDS	1938.5	TOTAL SOLIDS	1938.5
TOTAL NON VOLATILE SOLIDS	1723.9	TOTAL HARDNESS AS $CaCO_3$	NONE

* Silica Analysis Too Low

DETERMINATIONS

SPECIFIC CONDUCTANCE MICROMHOS/CM	3030	TURBIDITY	110
HYDROGEN ION CONCENTRATION pH	9.2	COLOR	7
BORON (B) IN PPM LESS THAN	0.08	ODOR	NONE
FLUORIDE (F) IN PPM	N.D.	TASTE	N.D.
LANGELIER INDEX	N.D.	SUSPENDED MATTER	TRACE

RESPECTFULLY SUBMITTED
SMITH-EMERY COMPANY

BY Kenneth [signature]

2 - ADDRESSEE
1 - RICHARD DONDANVILLE
CH 2

SMITH-EMERY COMPANY

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701 EAST WASHINGTON BOULEVARD

LOS ANGELES 21, CALIFORNIA

FILE NO.: 9596-70
LABORATORY NO.: C-554905

RECEIVED: OCTOBER 30, 1970
REPORTED: NOVEMBER 16, 1970

BACA LAND & CATTLE
P. O. BOX 872
LOS ALAMOS, NEW MEXICO

MARKED: ~~BATHHOUSE SPRING"~~ Sulphur Spring

ATTENTION: MR. J. HARRELL

REPORT OF WATER ANALYSIS

SAMPLE SUBMITTED FOR WATER ANALYSIS BUT CONTAINS A CONSIDERABLE QUANTITY OF FREE ACID (H_2SO_4) AND METALS IN SOLUTION. RESULTS ARE REPORTED BELOW:

ION	PPM	HYPOTHETICAL COMBINATIONS	PPM
SILICA, SiO_2	20.0 *	SILICA, SiO_2	20.0
IRON, FE	44.0	CALCIUM SULFATE, $CaSO_4$	421.4
ALUMINUM, AL	119.0	MAGNESIUM SULFATE $MgSO_4$	288.3
SODIUM, NA	9.0	SODIUM SULFATE, Na_2SO_4	27.7
POTASSIUM, K	10.0	POTASSIUM SULFATE, K_2SO_4	22.7
CALCIUM, CA	124.1	IRON SULFATE, $Fe_2(SO_4)_3$	157.3
MAGNESIUM, MG	58.3	ALUMINUM SULFATE, $Al_2(SO_4)_3$	745.5
SULFATE, SO_4	1522.6	SULFURIC ACID, H_2SO_4	224.1
TOTAL	1907.0		1907.0
PH VALUE	2.2		

*Silica redone = 220 ppm

RESPECTFULLY SUBMITTED,

SMITH-EMERY COMPANY

BY [signature]

P. E. MATHENY

3 - ADDRESSEE
CH 12

RICHMOND 9-3411

SMITH-EMERY COMPANY

FORM C-4 1-62 LC

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701 EAST WASHINGTON BOULEVARD

LOS ANGELES 21, CALIFORNIA

FILE NO.: 9596-70
CLIENT: BACA LAND & CATTLE

ADDRESS: P. O. BOX 872
LOS ALAMOS, NEW MEXICO
ATTENTION: MR. J. HARRELL

DATE RECEIVED: OCT. 30, 1970
REPORTED: NOV. 16, 1970
SAMPLE: WATER
SUBMITTED BY: CLIENT
LABORATORY NO.: C-554903
MARKED: ~~"SULFUR SPRINGS"~~ Bathouse Springs San Antonio Creek

REPORT OF WATER ANALYSIS

ANALYSIS OF DISSOLVED SOLIDS	PARTS PER MILLION	HYPOTHETICAL COMBINATIONS	PARTS PER MILLION
SILICA (SiO_2)	28.0*	SILICA SiO_2	28.0
ALUMINUM OXIDE (Al_2O_3)	TRACE	ALUMINUM OXIDE Al_2O_3	TRACE
IRON OXIDE (Fe_2O_3)	TRACE	IRON OXIDE Fe_2O_3	TRACE
CALCIUM (CA)	TRACE	CALCIUM BICARBONATE $Ca(HCO_3)_2$	NONE
MAGNESIUM (MG)	TRACE	CALCIUM SULFATE $CaSO_4$	NONE
SODIUM (NA)	15.0	CALCIUM CHLORIDE $CaCl_2$	NONE
SULFATE (SO_4)	NONE	MAGNESIUM BICARBONATE $Mg(HCO_3)_2$	NONE
CHLORIDE (CL)	NONE	MAGNESIUM SULFATE $MgSO_4$	NONE
CARBONATE (CO_3)	NONE	MAGNESIUM CHLORIDE $MgCl_2$	NONE
BICARBONATE (HCO_3)	48.2	SODIUM BICARBONATE $NaHCO_3$	54.7
NITRATE (NO_3)	N.D.	SODIUM CARBONATE Na_2CO_3	NONE
NITRITE (NO_2)	N.D.	SODIUM SULFATE Na_2SO_4	NONE
BORATE (B_4O_7)	NONE	SODIUM CHLORIDE NACL	NONE
POTASSIUM --- (K)	5.5	SODIUM NITRATE $NaNO_3$	N.D.
		SODIUM NITRITE $NaNO_2$	N.D.
		POT. BICARBONATE, ($KHCO_3$)	14.0
TOTAL SOLIDS	96.7	TOTAL SOLIDS	96.7
TOTAL NON VOLATILE SOLIDS	72.2	TOTAL HARDNESS AS $CaCO_3$	NONE

* Silica redone = 93 ppm

DETERMINATIONS

SPECIFIC CONDUCTANCE MICROMHOS/CM	91	TURBIDITY	NONE
HYDROGEN ION CONCENTRATION PH	7.5	COLOR	5
BORON (B) IN PPM	LESS THAN 0.08	ODOR	NONE
FLUORIDE (F) IN PPM	N.D.	TASTE	N.D.
LANGELIER INDEX	N.D.	SUSPENDED MATTER	NONE

RESPECTFULLY SUBMITTED
SMITH-EMERY COMPANY

BY [signature]
P. E. MATHEWS

3 - ADDRESSEE
CH

RICHMOND 9-3411

FORM C-4 1-62 LC

SMITH-EMERY COMPANY

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781 EAST WASHINGTON BOULEVARD

LOS ANGELES 21, CALIFORNIA

FILE NO.: 9596-70
CLIENT: BACA LAND & CATTLE

ADDRESS: P. O. BOX 872
LOS ALAMOS, NEW MEXICO
ATTENTION: MR. J. HARRELL

DATE RECEIVED: OCT. 30, 1970
REPORTED: NOV. 16, 1970
SAMPLE: WATER
SUBMITTED BY: CLIENT
LABORATORY NO.: C-554904
MARKED: "ARTESIAN WELL"
VALLE GRANDE

REPORT OF WATER ANALYSIS

ANALYSIS OF DISSOLVED SOLIDS	PARTS PER MILLION	HYPOTHETICAL COMBINATIONS	PARTS PER MILLION
SILICA (SiO_2)	24.0 *	SILICA SiO_2	24.0
ALUMINUM OXIDE (Al_2O_3)	TRACE	ALUMINUM OXIDE Al_2O_3	TRACE
IRON OXIDE (Fe_2O_3)	TRACE	IRON OXIDE Fe_2O_3	TRACE
CALCIUM (CA)	TRACE	CALCIUM BICARBONATE $Ca(HCO_3)_2$	TRACE
MAGNESIUM (MG)	TRACE	CALCIUM SULFATE $CaSO_4$	NONE
SODIUM (NA)	29.0	CALCIUM CHLORIDE $CaCl_2$	NONE
SULFATE (SO_4)	NONE	MAGNESIUM BICARBONATE $Mg(HCO_3)_2$	NONE
CHLORIDE (CL)	NONE	MAGNESIUM SULFATE $MgSO_4$	NONE
CARBONATE (CO_3)	NONE	MAGNESIUM CHLORIDE $MgCl_2$	NONE
BICARBONATE (HCO_3)	85.4	SODIUM BICARBONATE $NaHCO_3$	105.9
NITRATE (NO_3)	N.D.	SODIUM CARBONATE Na_2CO_3	NONE
NITRITE (NO_2)	N.D.	SODIUM SULFATE Na_2SO_4	NONE
BORATE (B_4O_7)	NONE	SODIUM CHLORIDE NACL	NONE
POTASSIUM ---- (K)	5.5	SODIUM NITRATE $NaNO_3$	N.D.
		SODIUM NITRITE $NaNO_2$	N.D.
		POT. BICARBONATE ($KHCO_3$)	14.0
TOTAL SOLIDS	143.9	TOTAL SOLIDS	143.9
TOTAL NON VOLATILE SOLIDS	100.5	TOTAL HARDNESS AS $CaCO_3$	NONE

* Silica redone = 80 ppm

DETERMINATIONS

SPECIFIC CONDUCTANCE MICROMHOS/CM	160	TURBIDITY	NONE
HYDROGEN ION CONCENTRATION PH	8.0	COLOR	5
BORON (B) IN PPM LESS THAN	0.08	ODOR	NONE
FLUORINE (F) IN PPM	N.D.	TASTE	N.D.
LANGELIER INDEX	N.D.	SUSPENDED MATTER	NONE

RESPECTFULLY SUBMITTED
SMITH-EMERY COMPANY

BY [signature]
P. E. [illegible]

3 - ADDRESSEE
CH

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LOS ANGELES 21, CALIFORNIA

FILE NO.: 9596-70
LABORATORY NO.: C-554903-07-ADD

DATE: DECEMBER 8, 1970

BACA LAND & CATTLE
P.O. BOX 872
LOS ALAMOS, NEW MEXICO

RE: "WATER SAMPLES"

REPORT OF DETERMINATIONS

SAMPLE IDENTIFICATION	TOTAL SILICA (SiO_2)
SULFUR SPRINGS ------------------	220.0 PPM
ARTESIAN WELL ------------------	80.0 PPM
BATHHOUSE SPRINGS -------------	92.5 PPM
SODA SPRINGS -------------------	35.0 PPM
FLASHED WATER BACA NO. 4 TD 5048 ----------------------	820.0 PPM

RESPECTFULLY SUBMITTED,

SMITH - EMERY COMPANY

BY Kenneth Drennon
KENNETH DRENNON

3 - BACA LAND & CATTLE
ATTN: MR. DONDANVILLE

CH

UV

ISOTOPES
A TELEDYNE COMPANY

Westwood Laboratories

50 Van Buren Ave., Westwood, New Jersey 07675
Phone: 201-664-7070 TWX: 710-990-7503

REPORT OF ANALYSIS

CUSTOMER NAME: Mr. Joe Harrell
Baca Land and Cattle Company
P. O. Box 872
Los Alamos, New Mexico 87544

ISOTOPES NO. 3-2884-132

PAGE 1 OF 1 PAGES

CUSTOMER PURCHASE ORDER NO. letter

TYPE OF ANALYSIS O^{18}/O^{16}

CUSTOMER SAMPLE NO. AND/OR IDENTIFICATION	$\delta_c(O^{18})$‰ SMOW				
Baca #4 T.D.5048'	- 7.4				
Baca #4 T.D.1892'	- 11.3				
Sulphur Spring	- 12.5				
Soda Spring	- 11.5				
Valle Grande	- 12.0				
Bathouse Spring	- 12.7				

$\delta_c(O^{18})$‰ SMOW is relative to SMOW and is corrected for the factors discussed by Craig (Geochimica et Cosmochimica Acta, 1957, v. 12, p. 133-149)

cc: Mr. Richard F. Dondanville, 1378 Plaza Pacifica, Santa Barbara, California 93103

DATE November 25, 1970

APPROVED BY [signature]
Ronald G. Senechal

ISOTOPES
A TELEDYNE COMPANY

Westwood Laboratories
50 Van Buren Ave., Westwood, New Jersey 07675
Phone: 201-664-7070 TWX: 710-990-7503

REPORT OF ANALYSIS

CUSTOMER NAME Mr. Joe Harrell
Baca Land and Cattle Company
P. O. Box 872
Los Alamos, New Mexico, 87544

ISOTOPES NO. 3-2881-122

PAGE 1 OF 1 PAGES

CUSTOMER PURCHASE ORDER NO. letter

TYPE OF ANALYSIS Enrichment and Tritium - Gas Counting

CUSTOMER SAMPLE NO. AND/OR IDENTIFICATION	ISOTOPES Sample No.	TU ASSAY			
Baca #4 T.D.5048'	TC3800E	5.1 ± 0.4			
Bathouse Spring	TC3801E	4.4 ± 0.4			
Soda Spring	TC3802E	6.8 ± 0.5			
Sulphur Spring	TC3803E	54.4 ± 3.2			
Valle Grande					
Artesian Well	TC3804E	3.6 ± 0.3			

Mr. Richard F. Dondanville, 1378 Plaza Pacifica, Santa Barbara, California 93103

December 11, 1970

APPROVED BY Eugene R. French
Eugene R. French
Task Supervisor

APPENDIX C

CHEMICAL AND PHYSICAL ANALYSES OF ROCKS FROM THE BACA #4 WELL

United States Department of the Interior

GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

November 12, 1970

Mr. Richard F. Dondanville
1378 Plaza Pacifica
Santa Barbara, California 93103

Dear Mr. Dondanville:

The samples from Baca #4 well arrived last week. The corner of the box was torn open and one of the three bags was hanging out. Fortunately nothing was lost.

I have taken the liberty to sacrifice one chip from each bag for thin section. The sections have not yet been completed but rather than wait on them I have decided to send you my comments, based on hand lens and binocular microscope examination, of all the chips.

Thin section examination will not change the fact that all three samples are rhyolitic welded tuffs and they are something of a surprise to us. Two chips from the light gray fraction 5000-5043 appear to be sand but as near as I can tell the sand grains are derived from the same materials that make up the tuff fragments.

All fragments from all three levels are pervasively altered by the hot waters. They contain pyrite, chlorite, and/or clay minerals, and introduced silica as alteration products. The original phenocrysts are quartz and alkali feldspar and the rocks look like Bandelier tuff. They are not part of the andesite or dacite section as we know it.

In all probability they are from the Otowi member of the Bandelier but out of context with the cuttings from the entire hole, it would be presumptuous of me to try to interpret the samples and their structural and stratigraphic implications at this time. If they are from the lower part of a continuous, thick Bandelier section, they probably represent an intracaldera facies we've never seen before. At least 4 or 5 alternative explanations occur to me including the possibility that the rocks are not Bandelier. Much depends on what, if any, other rock types occur at higher levels.

Needless to say we are extremely interested in the problem. I would like to keep the samples at least until I see the thin sections, and then return them to you. If you have no further use for them now, or in the future, we would be happy to have all or any part of them for our Jemez study collections. Some of the feldspars appear only weakly altered and it may be that we can learn something from their composition.

I'm sure you understand the potential complexity of the structure and stratigraphy in Redondo Creek, and for that matter, in the entire caldera area. The Baca #4 site may be a delightful spot for steam, but it is one of the last places I would choose to drill a hole for stratigraphic information, but maybe we will be lucky.

I will try to answer any other specific questions that may occur to you.

Sincerely yours,

Robert L. Smith

Robert L. Smith
Field Geochemistry and
Petrology Branch

United States Department of the Interior

GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

January 7, 1971

Mr. Richard Dondanville
1378 Plaza Pacifica
Santa Barbara, California 93103

Dear Mr. Dondanville:

I have been trying to use up some accrued annual leave which I would otherwise have forfeited at the end of the year, hence my late reply to your letter.

Many thanks for the analyses of the Baca samples. They are remarkably similar to facies of the Bandelier. I enclose two unpublished analyses of Bandelier surface samples for you to make comparison.

I have, of course, tried to make the comparison myself and for rocks as close chemically as are the Baca samples and the Bandelier, a meaningful comparison is difficult if not impossible, because the analyses were done in different labs by different methods. If one accepts the numbers at face value the Baca samples are enough different from all known Bandelier chemistry to make me suspect that they are not Bandelier as we know it. The differences show up in P_2O_5, TiO_2, MgO, Al_2O_3, and in certain element ratios.

However, the differences could be analytical. The Baca samples are hydrothermally altered, but the chemistry suggests that there has been little, if any, bulk chemical change and if the differences are due to alteration I don't understand the process that would release alumina, but not silica and at the same time add P_2O_5, TiO_2, and MgO. The lower silica in one of the Baca samples is probably related to the fact that the summation is only 94.52 and H_2O is not reported. Assuming that H_2O makes the difference, and recalculating the analysis H_2O Free and to 100%, SiO_2 is raised to about 78% and in line with the other analysis.

If the Baca samples are from a chemically slightly different facies of the Bandelier than heretofore known, and if the analyses are good, I would expect the Baca samples to plot on Bandelier variation trends. They do not, largely because of the various odd ratios among the elements mentioned above and other major elements.

I am left with the feeling that the rocks are probably Bandelier and the small differences in chemistry are analytical but it would take very little hard stratigraphic information to make me change my mind.

Thanks again for your letter and the chemical data.

Sincerely yours,

R. L. Smith

Robert L. Smith
Field Geochemistry and
Petrology Branch

Enc.

	JS49-2	BM49-1
SiO_2	77.38	74.16
Al_2O_3	12.10	12.02
Fe_2O_3	1.08	0.93
FeO	0.27	0.38
MgO	0.02	0.08
CaO	0.30	0.35
Na_2O	4.08	3.73
K_2O	4.31	4.77
H_2O^+	0.25	2.92
H_2O^-	0.01	0.19
TiO_2	0.08	0.07
P_2O_5	0.01	0.02
MnO	0.06	0.05
CO_2	0.01	0.00
	99.96	99.67

Rocky Mountain Geochemical Corporation

P. O. BOX 2217
SALT LAKE CITY, UTAH 84110

Phone 322-2396
Area Code: 801

CERTIFICATE OF ANALYSIS

Date November 18, 1970

Client Richard F. Dondanville
1378 Plaza Pacifica
Santa Barbara, California 93103

Report on: 2 samples

Submitted by: R. F. Dondanville

Date Received: October 27, 1970

Analysis: Silicate analysis

Remarks: P_2O_5 & TiO_2 analyses determined colorimetrically. All other analyses determined by atomic absorption.
Job No. 70-40-6SL

cc: Enc.
File (2)

LRR:pba

Sample No.	% P_2O_5	% TiO_2	% K_2O	% Na_2O	% Al_2O_3	% SiO_2	% CaO	% MgO	% Fe_2O_3	% MnO
ACA #4 4900'	.06	.14	4.1	4.2	11.4	77.6	.36	.24	1.46	.052
ACA #4 5000'	.06	.12	4.1	3.5	11.1	73.9	.24	.19	1.27	.044
...G. RHYOLITE ...OLY, Ia. K.+ ...ths of the EARTH, ...33	0.10	.29	4.6	3.3	13.3	72.7	1.2	0.38	1.40	0.07

By Lawrence R. Reid
Lawrence R. Reid

ND = None Detected 1 ppm = 0.0001% 1 Troy oz/ton = 34.28 ppm % Mo x 1.6683 = % MoS_2

CHEMICAL ANALYSIS
PETROLEUM

B C LABORATORIES
J. J. EGLIN, REG. CHEM. ENGR.
3016 UNION AVE. BAKERSFIELD, CALIFORNIA 93305 PHONE 325-7475

NO. 1183

FIELD

DATE 12/7/70

WELL Baca #4

CLIENT Baca Land & Cattle Company
P. O. Box 1641
Abilene, Texas 79604

Attention: Mr. J. B. Harrell

Core Analysis

COUNTY

STATE

DEPTH FEET	POROSITY PERCENT	HORIZ. PERMEABILITY MILLIDARCYS	VERT. PERMEABILITY MILLIDARCYS	OIL-WATER RATIO	RESIDUAL LIQUID SATURATION PERCENT OF PORE SPACE OIL	RESIDUAL LIQUID SATURATION PERCENT OF PORE SPACE WATER	SALINITY OF CORE WATER GRAINS PER GALLON SODIUM CHLORIDE	REMARK
3177	4.8	0.09						
3177	5.1	0.18						
3177	6.7	0.07						
4900	10.4	0.33						
4900	8.7	0.16						
4900	8.1	0.14						
5000	10.9	0.18						
5000	8.8	0.19						
5000	16.9	1.82						

B C LABORATORIES

BY [signature]
J. J. Eglin

ch

THIN-SECTION DESCRIPTIONS OF ROCKS FROM THE BACA #4 WELL

ANALYST: Ralph Higgins, Graduate Student, University of California, Santa Barbara. Sample Notes by R.F. Dondanville.

SAMPLE: Baca #4, T.D. 3177'. The bulk sample consists of rocks up to 2 inches diameter thrown from well during a flow test. A steam-bearing zone which caved badly during drilling is believed to be the source of most of the rocks.

ROCK NAME: Rhyolitic Breccia.

MINERALS IDENTIFIED: As phenocrysts: Quartz, sanidine.
In Groundmass: Quartz, clay, sericite, calcite, epidote, pyrite.

DISCUSSION: The sample is extensively altered, the groundmass replaced by quartz and minor amounts of epidote and calcite. Alteration has destroyed any textural features which could be used to further classify the breccia. However, the presence of sanidine as euhedral crystals suggests they were originally phenocrysts in the matrix of this rock. Sanidine is most often found in volcanic rocks. Therefore its presence is suggestive of a volcanic origin for this rock, but not conclusive.

Alteration products (clay, epidote and sericite) are present which differ texturally and mineralogically from normal devitrification. Therefore, the sample is thought to have gone through two stages of alteration: one, the normal devitrification of glass to quartz and feldspar, and hydrothermal alteration of the original minerals, particularly the feldspars.

* * *

SAMPLE: Baca #4, T.D. 5048 feet, sample from 4900 to 5000 feet. Between 4900 feet and 5048 feet the drill cuttings changed color from medium gray to very light gray, the most conspicuous change being near 5000 feet. Rocks caught during a flow test were separated into light gray and darker gray rocks. For the thin-section analysis the two rock groups were labelled "4900 feet" and "below 5000 feet". The latter sample is almost certainly from below 5000 feet, the original depth of the former sample is more uncertain.

ROCK NAME: Rhyolitic Welded Tuff.

MINERALS: Phenocrysts: Quartz, euhedral to anhedral, Sanidine, subhedral to anhedral.
Groundmass: Quartz, clay, epidote, plagioclase, pyrite.

OTHER CONSTITUENTS: Glass Shards.

APPROX. FREQUENCY:

Glass shards	30%
Quartz	40%
Sanidine	20%
Clay	2%
Pyrite	2%
Epidote	1%
Plagioclase	1%

DISCUSSION: Feldspar is present as sanidine phenocrysts, and a minor amount of plagioclase. The sanidine is moderately altered to clay minerals, probably Kaolin. The glass is partially devitrified to quartz. The glass is present as shards. Even though devitrification is strong (50% of the shards altered to quartz), the original texture of the glass matrix is preserved. A large part of the glass is altered to clay minerals. The rock was pyroclastic judging from the glass shards. Enough heat was present to keep the shards plastic; they are flattened and bent around the phenocrysts, rather than broken. Emplacement by airfall or water would not allow the glass to remain plastic while cooling. The sample is from an ash flow tuff. The degree of welding is not possible to determine due to the degree of devitrification and alteration.

* * *

SAMPLE: Baca #4, T.D. 5048 feet, sample from below 5000 feet.

ROCK NAME: Rhyolite Welded Tuff.

MINERALS: Phenocrysts: Quartz, euhedral to subhedral Sanidine, subhedral to anhedral.
Groundmass: Quartz, sericite, plagioclase, epidote, pyrite.

OTHER CONSTITUENTS: Glass shards.

APPROX. FREQUENCY:

Quartz	80%
Sanidine	10%
Glass	5%
Plagioclase	1%
Pyrite	1%
Clay & Sericite	1%
Epidote	1%

DISCUSSION: The sanidine is less altered to clay and sericite than the 4900-foot sample. The glass is almost completely devitrified. However, the original texture of the glass matrix is preserved indicating a pyroclastic origin. The shards are bent and deformed around phenocrysts indicating the plastic nature of the shards at the time of deposition. This sample is from an ash flow, but the degree of welding is impossible to determine.

APPENDIX D

CONCISE GEOTHERMAL WELL SUMMARIES

WESTATES - BOND #1

ELEVATION: 8697'
T.D.: 3675'
DRILLED: MAY-JULY, 1960
DRILLED WITH MUD 0-3650'
" " " AIR 3650-3675

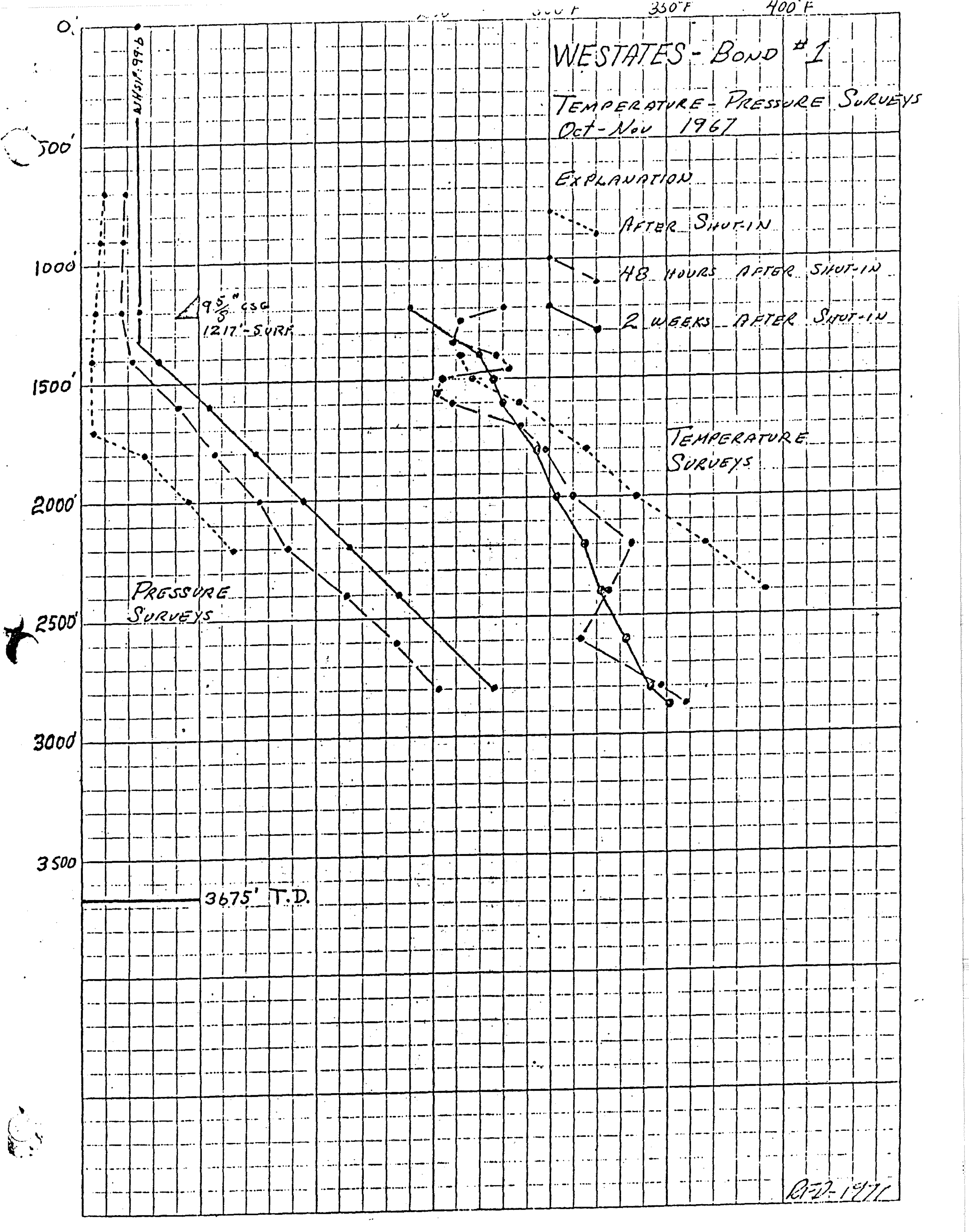
0' – 1000'	CALDERA FILL: SANDS, TUFFS, GRAVELS	13 3/8" CSG. 404' - SURF.	
1000' – 2500'	RHYOLITIC WELDED TUFF, MINOR TUFFACEOUS SANDS. Silicified, pyritic, chloritized	9 5/8" CSG. 1217' - SURF. Set at T.D. 3650' WITH 100 SX. CEM.	LOST SOME MUD AT T.D. 1204'. LOST CIRCULATION AT T.D. 1338'. MUD TEMP: 170°F @ 1698'. MUD TEMP: 180°F @ 1864'. MUD TEMP: 180°F @ 2150'
2500' – 3675'	TUFFACEOUS SAND, SILICIFIED WITH SECONDARY FELDSPAR, pyrite	T.D. 3675'	MUD TEMP: 188°F @ 2871'. MUD TEMP: 194°F @ 2966'. LOST CIRCULATION @ T.D. 3650'

0' — 500' — 1000' — 1500' — 2000' — 2500' — 3000' — 3500'

LOST CIRCULATION @ T.D. 3650'
PIPE STUCK, WELL TRYING TO BLOW. FISHED FOR PIPE WITH BLOWING STEAM OR LOST CIRCULATION. CONVERTED TO AIR AND FISHED WITH CONTINUING STEAM BLOW. RAN 9 5/8 csg to 1217'.
CLEANED OUT HOLE: WATER AND STEAM BLOW. DRILLED WITH AIR TO 3675'. COULD NOT KEEP HOLE UNLOADED. ABANDONED.

1967 - CLEANED OUT TO 1920'
FLOW THRU 5 1/2" SWAGE = 4 psig @ 212°F WITH HEADS TO 262°F @ 30 psig
T & P logs run.

RFD - 1971



350°F
400°F
WESTATES - BOND #1
TEMPERATURE - PRESSURE SURVEYS
Oct - Nov 1967
EXPLANATION
AFTER SHUT-IN
48 HOURS AFTER SHUT-IN
2 WEEKS AFTER SHUT-IN
TEMPERATURE SURVEYS
PRESSURE SURVEYS
9 5/8" CSG
1217' - SURF
0'
500'
1000'
1500'
2000'
2500'
3000'
3500
3675' T.D.
RFD-1971

BACA LAND AND CATTLE CO.
BACA #1

ELEVATION: 8350'
T.D. 2560'
DRILLED: SUMMER 1963
DRILLED WITH AIR

	TUFFACEOUS SAND	13 3/8" CSG. 461' - SURF.
500'	POMICEOUS TUFF	
1000'	TUFFACEOUS SAND	STEAM ZONE 1441'-1500'
1500'	VOLCANIC SANDS + GRAVELS	
2000'		
2500'		2560' T.D.

ROGER'S ENGINEERING TEST: 85,000 #/HR STEAM @ 10 # FLOWING PRESSURE WITH LESS THAN 5% WATER

ESTIMATED FORMATION CONDITIONS: 310°-320°F @ 65 # pressure

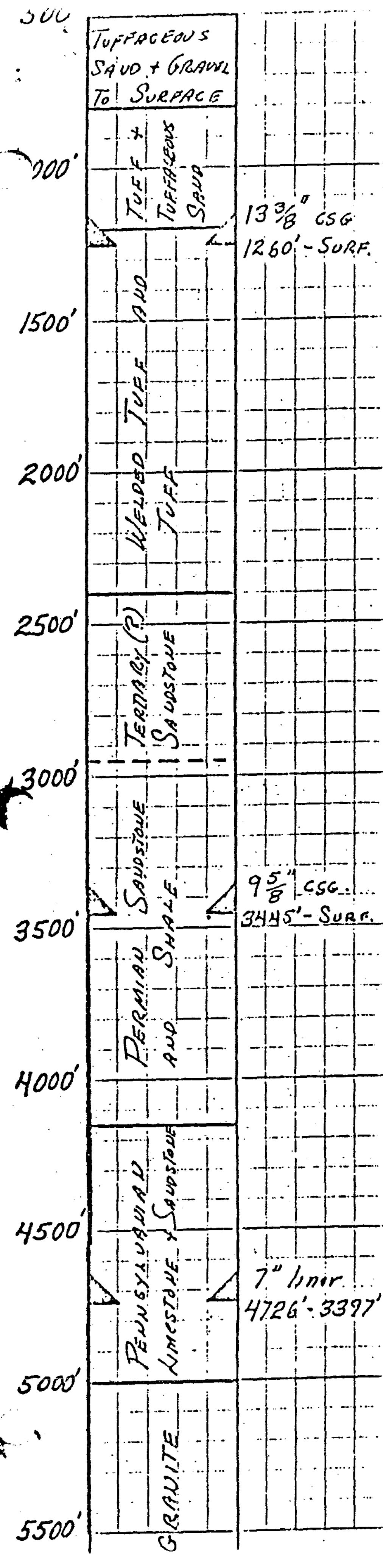
Na/K IN PRODUCED WATER = 18.2 INDICATING EQUILIBRIUM @ 338°F

2560' T.D. LOST HOLE ATTEMPTING TO RUN CASING

R.F.O 1971

BACA LAND AND CATTLE CO.- BACA #2

ELEVATION: 8500'
T.D: 5658'
DRILLED: JULY - OCTOBER, 1964



SUMMARY

DRILLED WITH MUD TO 3445'
LOST CIRCULATION @ 1163' + 3332'

DRILLED WITH AIR 3445'-4726'
T.D. 4446': F.L.T 204°F @ 31 psig
T.D. 4725' F.L.T 140° while circulating

SET 7" liner 4726'-3397'

DRILLED WITH AIR TO T.D. 5658'
DUSTING, LOW TEMP. returns

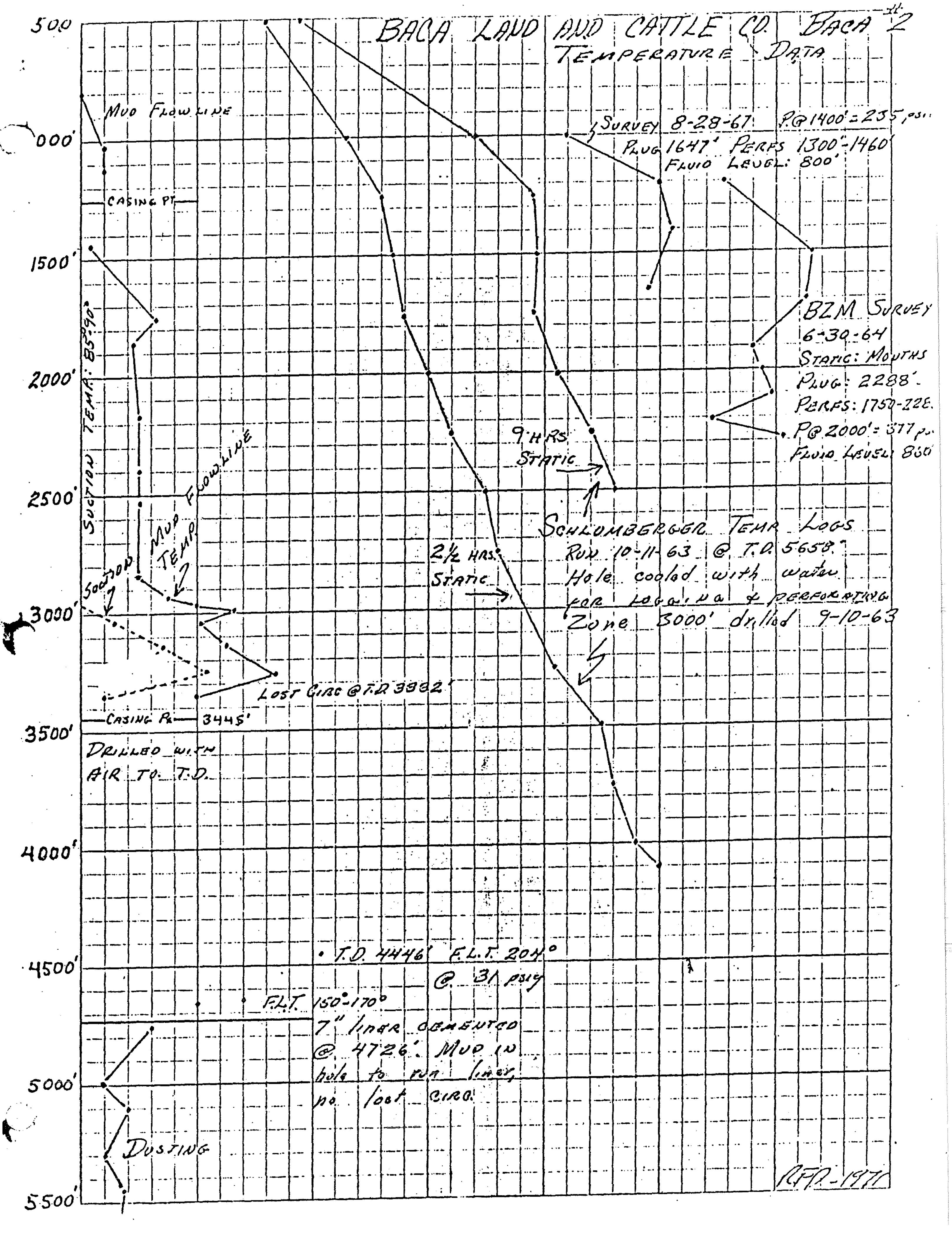
SET PLUG AT 4658'
COOLED WELL WITH WATER, logged well - Temp, GAMMA-NEUTRON
PERFORATED MANY ZONES 2400'-3100'
WELL FLOWED 100 gal/min. water @ 195° F. = 60,000 #/hr.

SET PLUG AT 2288'
PERFORATED 1750'-2300' (??)
FLOWED HOT WATER
RIG RELEASED 10-25-63

6-30-64 TEMPERATURE SURVEY in STATIC Well

SET PLUG 1647', PERFORATE 1300'-1460'
FLOWED HOT WATER

RFD-1971



BACA LAND AND CATTLE CO. BACA #2
TEMPERATURE DATA
500
1000'
1500'
2000'
2500'
3000'
3500'
4000'
4500'
5000'
5500'
MUD FLOWLINE
CASING PT.
SUCTION TEMP: 85-90°
MUD FLOWLINE TEMP
SUCTION
LOST CIRC @ T.D. 3332'
CASING PT. 3445'
DRILLED WITH AIR TO T.D.
SURVEY 8-28-67 P@1400' = 235 psi
PLUG 1647' PERFS 1300'-1460'
FLUID LEVEL: 800'
BZM SURVEY
6-30-64
STATIC: MONTHS
PLUG: 2288'
PERFS: 1750-228
P@2000' = 377 p
FLUID LEVEL 860
9 HRS STATIC
SCHLUMBERGER TEMP LOGS
RUN 10-11-63 @ T.D. 5658'
Hole cooled with water
for logging & perforating
Zone 3000' drilled 9-10-63
2½ HRS. STATIC
• T.D. 4446' F.L.T. 204°
@ 31 psig
F.L.T. 150°-170°
7" liner cemented
@ 4726'. Mud in
hole to run liner,
no lost circ.
DUSTING
RFD-1971

BACA LAND AND CATTLE CO.
BACA #3 (TWIN TO BACA #1)

ELEVATION: 8350'
T.D.: 2200' (?)
DRILLED WITH AIR, SUMMER, 1964

500'	TUFFACEOUS SAND & GRAVEL	13 3/8" CSG 506' - SURF
	TUFF	
1000'	VOLCANIC SAND & GRAVEL	9 5/8" CSG 1179' - SURF
1500'	VOLCANIC GRAVEL	7" liner 1983' - 1000'
2000'		2200' T.D. ?

T.D. 1555' WHSIP 32 psig

T.D. 1944' WHSIP 130 psig

T.D. 1983' W.HSIP 99 psig @ 306°F
6/27/64 ROGERS ENG. CALORIMETER TEST INDICATES 10.6% STEAM
6/28/64 CALORIMETER IND. 50% STEAM

AFTER TESTS, 7" liner hung 1000' - 1983', WELL driller to T.D.

7/4/64 BZM TEMPERATURE SURVEY

DEPTH	TEMP	
500'	220° F	
800'	250°	← LOG NOTES TOP-OF-H_2O
900'	342°	
1800'	390°	
2000'	380°	

PERFORATE 1880'-1936' FLOW STEAM & WATER
" 1780-1840 " " " "

Na/K in produced WATER = 11:1
INDICATES EQUILIBRIUM WITH 410°-428°F

RFD 1971

BACA LAND AND CATTLE CO-
BACA #4

ELEVATION: 9318' G.L.
T.D.: 5048'
DRILLED: SEPT-OCT 1970

0

VOLCANIC SANDSTONE

WELDED RHYOLITIC TUFF

500'

TUFF

1000'

1290' - FRACS ?

13 3/8" CSG
1442' - SURF.

1500'

WELDED AND ALL RHYOLITIC

1887' - FRACS, ST. + WTR.
1988' - " " "

2000'

2117' - " ST. INC.
2226' - "
2347' - "
2490' - " ST. INC.

2500'

TUFF, NON-WELDED, TUFF BRECCIA.

2626' - FRACS-DRY STEAM
2875' - FRACS-ST. INC.
2940' - FRACS

3000'

9 5/8" CSG 3050', 3090' - FRACS
3182' - SURF.
3160'-3177' LARGE FRACS, DRY STEAM
3468' - FRACS-DRY ST.

3500'

3690' - FRACS
3710'-3730' FRACS ST. INC., DRY

TUFFACEOUS SANDSTONE

4000'

WELDED TUFF, TUFF, TUFF BRECCIA

4080' - FRACS

4500'

TUFFACEOUS SANDSTONE

4610'-4618' FRACS, LARGE ST. INC., DRY

WELDED TUFF, TUFF, TUFF BRECCIA, MINOR SAND

4975' LARGE ST. INC. DRY
4991' LARGE ST. INC. DRY

5000'

SUMMARY:

DRILLED WITH MUD TO 1442'
MINOR LOST CIRC AT T.D. SET CASING

DRILLED WITH AIR TO 3177'
STEAM AND WATER FLOW FROM SEVERAL ZONES, 1887' to 2490'.
WATER CHEMISTRY AND STEAM FLOW INDICATES VAPOR-DOMINATED ZONES 2625' TO 3177'.
AT T.D. 2835', thru 4" orifice: 10 psig @ 221°F
Almost dry, small trickle of water
AT T.D. 3177', FLOW dry, VISUALLY SEVERAL TIMES FLOW AT T.D. 2835

CONVERTED TO MUD, MAJOR LOST CIRCULATION, SET AND DRILLED CEMENT PLUGS, SET CASING

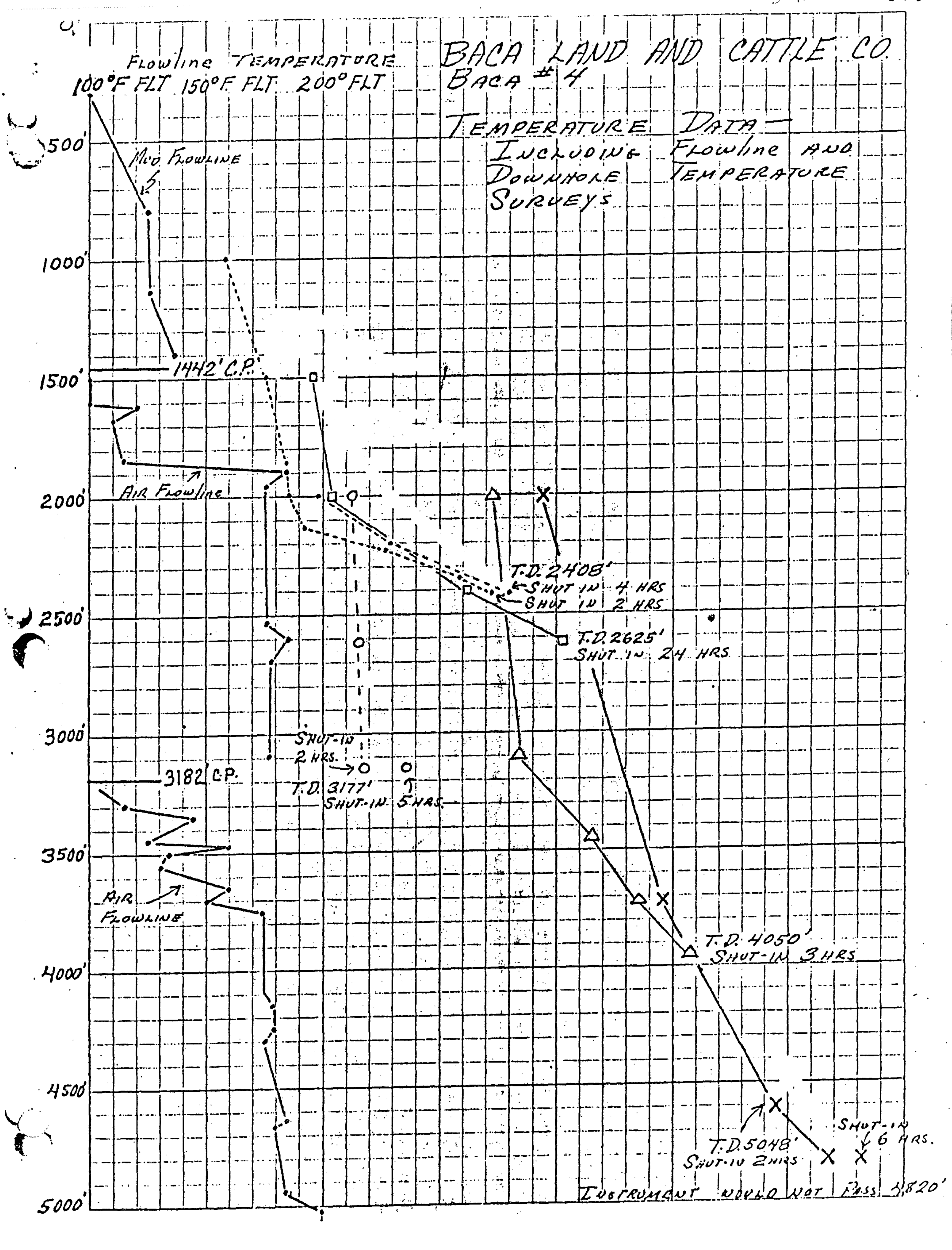
DRILLED WITH AIR TO 5048'
DRY STEAM PRODUCTION FROM SEVERAL ZONES, 3468' to 4991'.
AT T.D. 4685' FLOW THRU 8" ORIFICE: 1 psig @ 230°F, DRY.
MUCH BRIDGING ABOVE MAJOR STEAM ZONE AT 4610 NOTED WHEN RE-ENTERING HOLE.

VERY LARGE DRY STEAM INCREASES AT 4975' AND 4991'.

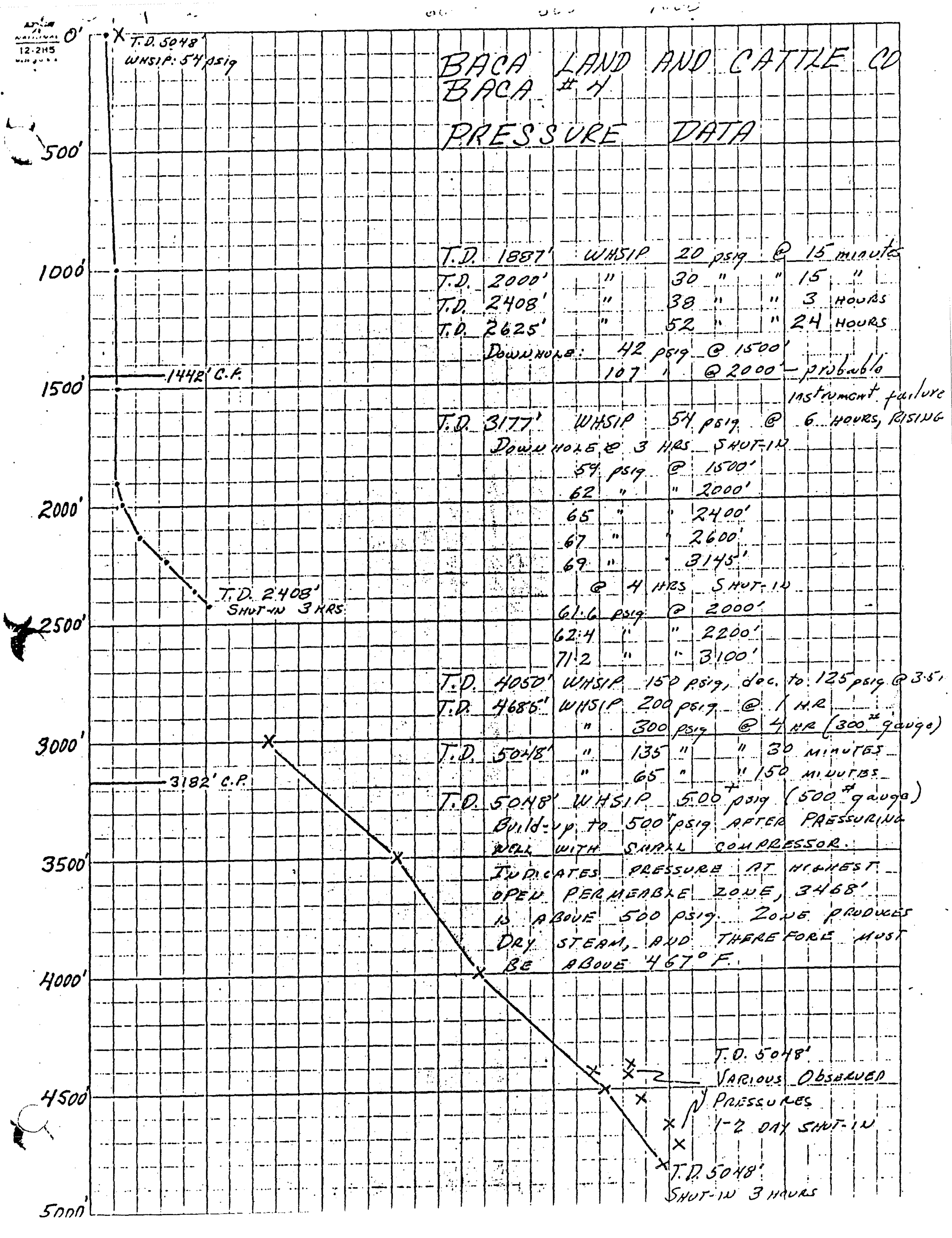
WATER ENTRY IN REGION 5000'-5010'

STABLE FLOWS:
NO ORIFICE: 4 psig @ 204°F, 18 gpm WATER
8" ORIFICE: 12 psig @ 226° + WATER
4 1/2" ORIFICE: 58 psig @ 288° + 21 gpm WATER.

RFD-1971



BACA LAND AND CATTLE CO.
BACA #4
TEMPERATURE DATA—
INCLUDING FLOWLINE AND
DOWNHOLE TEMPERATURE
SURVEYS
FLOWLINE TEMPERATURE
100°F FLT 150°F FLT 200°F FLT
0'
500'
1000'
1500'
2000'
2500'
3000'
3500'
4000'
4500'
5000'
MUD FLOWLINE
1442' C.P.
AIR FLOWLINE
T.D. 2408'
SHUT IN 4 HRS
SHUT IN 2 HRS
T.D. 2625'
SHUT-IN 24 HRS.
SHUT-IN
2 HRS.
T.D. 3177'
SHUT-IN 5 HRS.
3182' C.P.
AIR
FLOWLINE
T.D. 4050'
SHUT-IN 3 HRS
T.D. 5048'
SHUT-IN 2 HRS
SHUT-IN
6 HRS.
INSTRUMENT WOULD NOT PASS 4820'



BACA LAND AND CATTLE CO
BACA #4
PRESSURE DATA
T.D. 5048'
WHSIP: 54 psig
T.D. 1887' WHSIP 20 psig @ 15 minutes
T.D. 2000' " 30 " " 15 "
T.D. 2408' " 38 " " 3 HOURS
T.D. 2625' " 52 " " 24 HOURS
Downhole: 42 psig @ 1500'
107 " @ 2000' - probable instrument failure
T.D. 3177' WHSIP 54 psig @ 6 HOURS, RISING
Down hole @ 3 HRS SHUT-IN
54 psig @ 1500'
62 " " 2000'
65 " " 2400'
67 " " 2600'
69 " " 3145'
@ 4 HRS SHUT-IN
61.6 psig @ 2000'
62.4 " " 2200'
71.2 " " 3100'
T.D. 4050' WHSIP 150 psig, dec. to 125 psig @ 3.5 [illegible]
T.D. 4686' WHSIP 200 psig @ 1 HR
" 300 psig @ 4 HR (300# gauge)
T.D. 5048' " 135 " " 30 MINUTES
" 65 " " 150 MINUTES
T.D. 5048' WHSIP 500+ psig (500# gauge)
Build-up to 500+ psig AFTER PRESSURING WELL WITH SMALL COMPRESSOR.
INDICATES PRESSURE AT HIGHEST OPEN PERMEABLE ZONE, 3468' IS ABOVE 500 psig. ZONE PRODUCES DRY STEAM, AND THEREFORE MUST BE ABOVE 467° F.
0'
500'
1000'
1442' C.P.
1500'
2000'
T.D. 2408'
SHUT-IN 3 HRS
2500'
3000'
3182' C.P.
3500'
4000'
T.D. 5048'
VARIOUS OBSERVED PRESSURES
1-2 DAY SHUT-IN
4500'
T.D. 5048'
SHUT-IN 3 HOURS
5000'

Well History subsequent to releasing drilling rig.

Closed well in at 4:30 A.M. on 10-12-70 and released drilling rig.

10-17-70 Pressured well up with air to 380 PSI. Left closed in 45 minutes. Opened master gate. Pressure bled down to nearly zero. Surfaced some water for 5 minutes and then kicked off. In 10 minutes had 55 PSI through blooie line on 8" orifice and 290°F. At end of 15 minutes, 70# and 310°. In 35 minutes, 30# and 260°. 50 minutes, 25# and 250°. (This was at 12:20 P.M. 10-17-70) At 6:00 P.M., 15# and 232°.

10-18-70	7:30 A.M.	13#	230°	
	6:00 P.M.	13#	230°	
10-19-70	7:30 A.M.	12#	228°	
	6:00 P.M.	12#	228°	
10-20-70	7:30 A.M.	12#	228°	
	1:30 P.M.	12#	226°	

Closed well in at 1:30 P.M. 15 minutes SIP 160#. Pulled 8" orifice and opened well back up with no orifice @ 1:50 P.M.

	2:45 P.M.	5#	207°	
	6:00 P.M.	5#	207°	
10-21-70	7:30 A.M.	4#	204°	

Measured free water at end of blooie line in tub. Water calculated to be 18 gallons per minutes.

10-22-70	11:00 A.M.	4#	204°	Plus 18 gals. water per minute.
10-23-70		4#	204°	16 gals. water per minute
10-24-70		4#	204°	18 1/2 gals. water per min.
10-25-70		4#	204°	18 gals. water per min.
10-26-70		4#	204°	17 gals. water per min.

Took water samples for chemical analysis at end of blooie line.

10-27-70		4#	204°	20 gals. per min.

Noticed small amount of material surfacing through blooie line.

10-28-70		4#	204°	18 gals water
10-29-70		4#	204°	
10-30-70		4#	204°	

Closed in at 11:10 A.M. 25 minute SIP 165#. Opened well through 4 1/2" orifice @ 11:45 A.M.

	12:10 P.M.	75#	306°	
10-31-70		53#	287°	25 gals water per min.
11-1-70		53#	288°	25 gals water
11-2-70		54#	289°	22 gals water.

Closed well in at 9:50 A.M. for temperature and pressure surveys.

11-2-70 Ran 900 PSI pressure bomb to 4500'. Did not mark on the chart. Pulled lubricator of bomb. With bomb in hole, well blew down through 2" connection and killed itself in approximately 3 hours. Ran temperature bomb to 5048 (bomb did not go to this depth but set down at some depth above this). Maximum extension on chart showed temperature of 505° while pulling bomb out of hole. Line straightened at 1900' and pulled up in lubricator.

11-3-70 Cut line off and ran pressure bomb to 4444'. Clock did not run. Maximum extension on chart indicated pressure to be 933#. Ran temperature bomb to 4444'. Clock did not run. Maximum extension indicated temperature of 491°.

11-5-70 Ran other pressure bomb to determine depth to which bomb was setting down. Pressure at 4444' was 870. At 4544, 956. At 4644, 1013. At 4744, 1026. Data indicates bomb stopping at approximately 4600'. Ran temperature bomb to 4600 and left 15 minutes. Clock did not run. Chart extension indicated temperature of 508°. Ran temperature bomb with new clock to 4600. Temperature at 4444 was 499. Temperature at 4600 was 507.

11-6-70 Ran pressure bomb (2394N) to 4400'. Clock did not run. Chart extension indicated pressure of 938#. Ran temperature bomb (KT6681) to 4600'. Clock did not run. Extension indicated temperature of 508°.

11-7-70 Moved in small air compressor and started pressuring well up at 4:00 P.M.

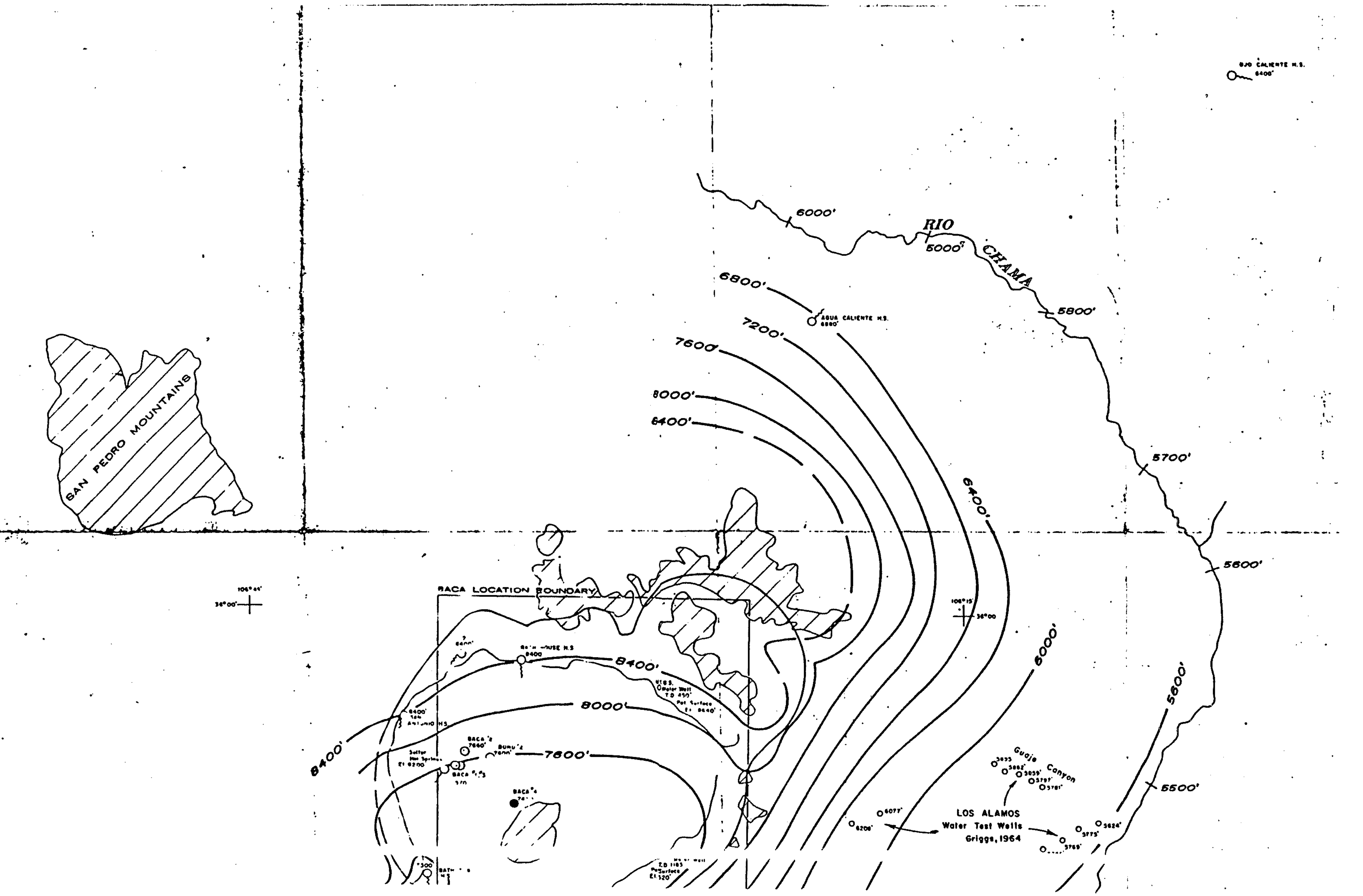
11-8-70 Found compressor dead. Apparently had not run over one hour. Restarted compressor.

11-9-70 Found compressor dead and 500 PSI pressure gauge on well head was over-ranged against the peg. Well had something over 500# pressure.

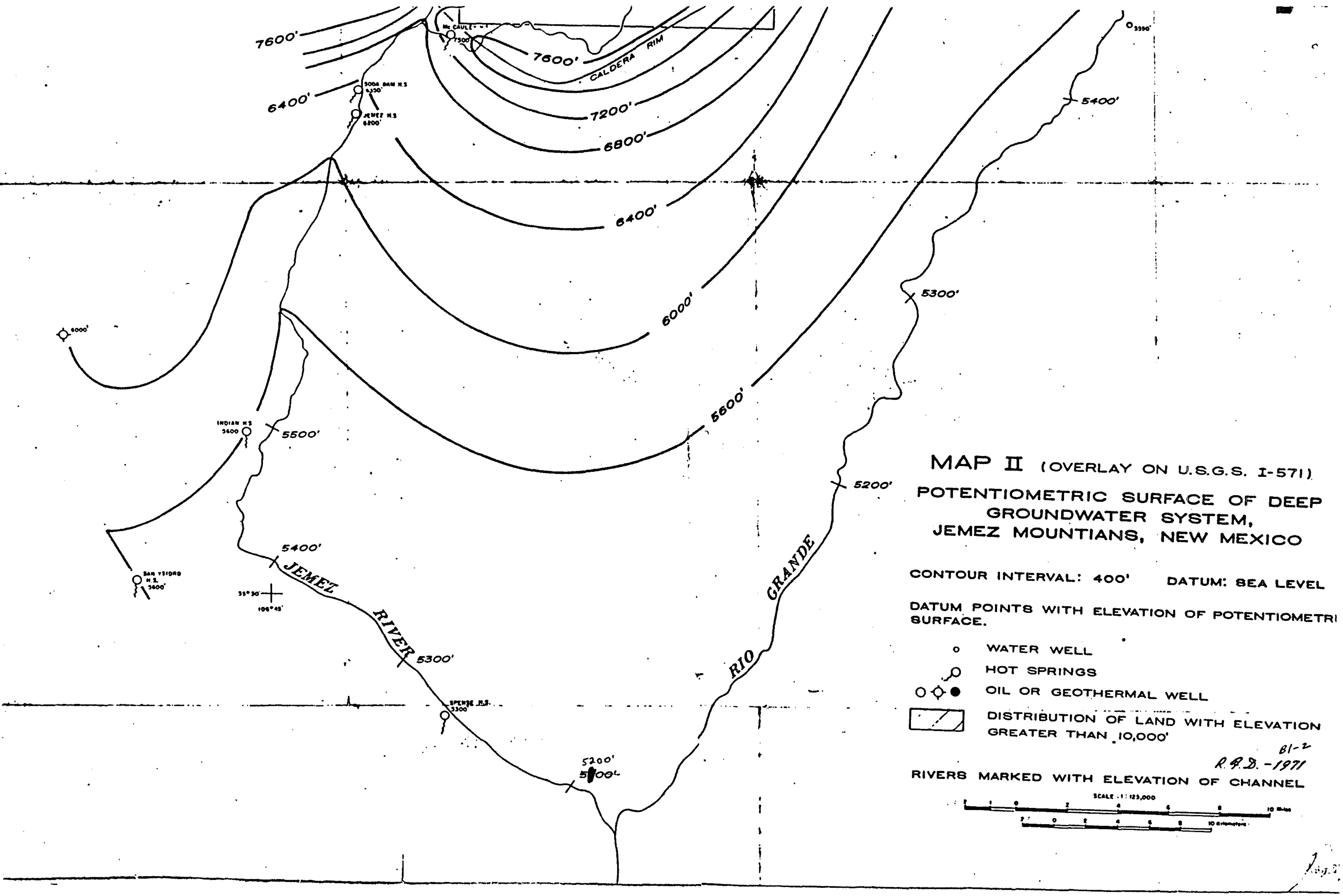
11-10-70 Pressure on well had decreased to 200 PSI. Opened well up at 12:00 Noon with no orifice in the blooie line. Well kicked off.

11-11-70 9:45 A.M. 7#, 206°. Closed well in and installed 4 1/2" orifice plate. Opened well up at 10:15 A.M. At 10:45 A.M. had 64# and 296°.

11-12-70	11:00 A.M.	56#	290°	
	1:00 P.M.	58#	290°	
11-16-70	12:00 Noon	57#	289°	
11-19-70	4:00 P.M.	58#	288°	20 gals. water per minute
11-20-70	8:00 A.M.	58#	288°	21 gals water per minute



SAN PEDRO MOUNTAINS
RIO
CHAMA
6000'
5000'
5800'
5700'
5600'
5500'
OJO CALIENTE H.S.
AGUA CALIENTE H.S.
6800'
7200'
7600'
8000'
8400'
6400'
6000'
5600'
BACA LOCATION BOUNDARY
8400'
8000'
7600'
8400'
Guaje Canyon
LOS ALAMOS
Water Test Wells
Griggs, 1964



MAP II (OVERLAY ON U.S.G.S. I-571)

POTENTIOMETRIC SURFACE OF DEEP GROUNDWATER SYSTEM, JEMEZ MOUNTAINS, NEW MEXICO

CONTOUR INTERVAL: 400'   DATUM: SEA LEVEL

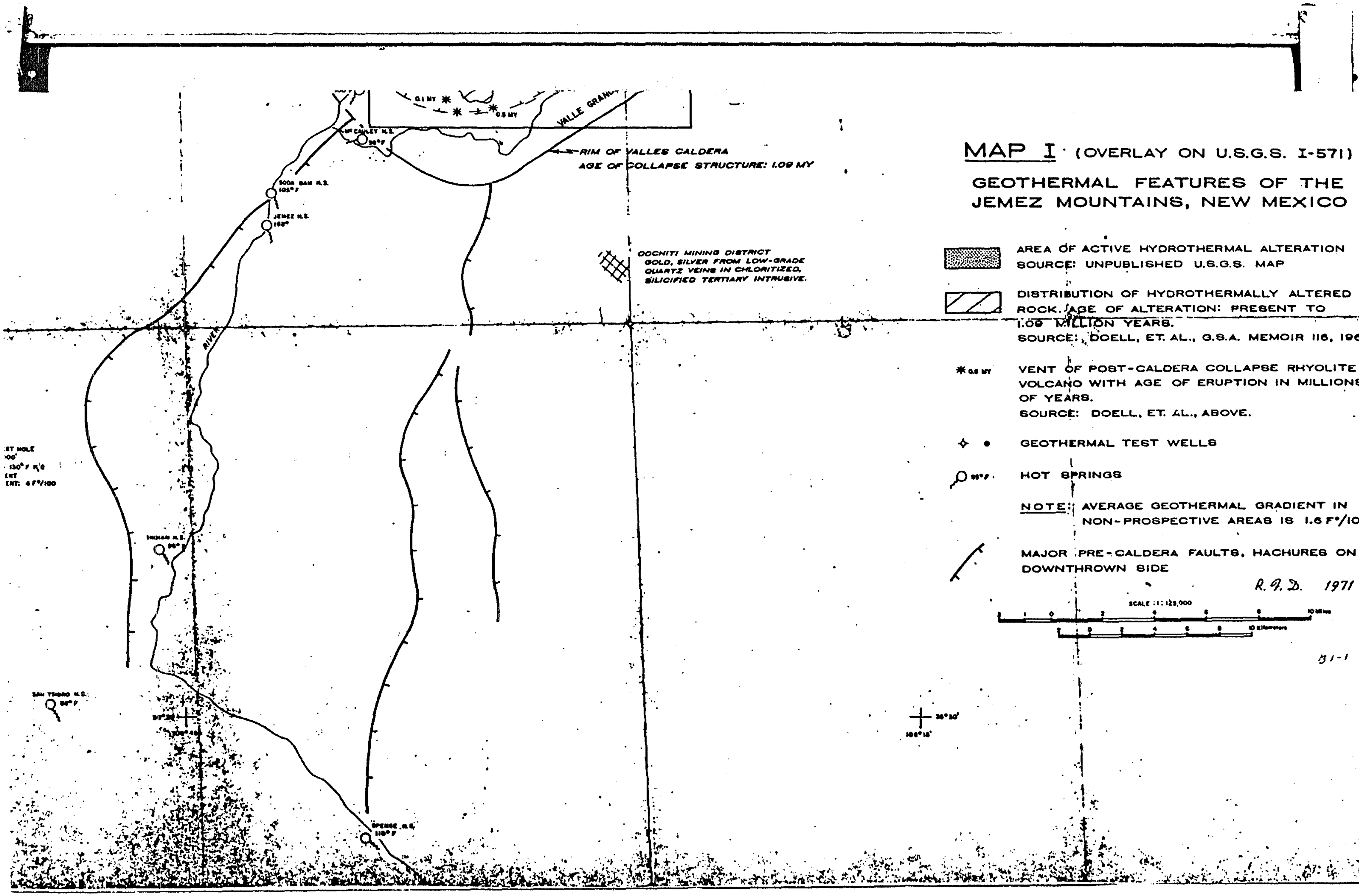
DATUM POINTS WITH ELEVATION OF POTENTIOMETRI SURFACE.

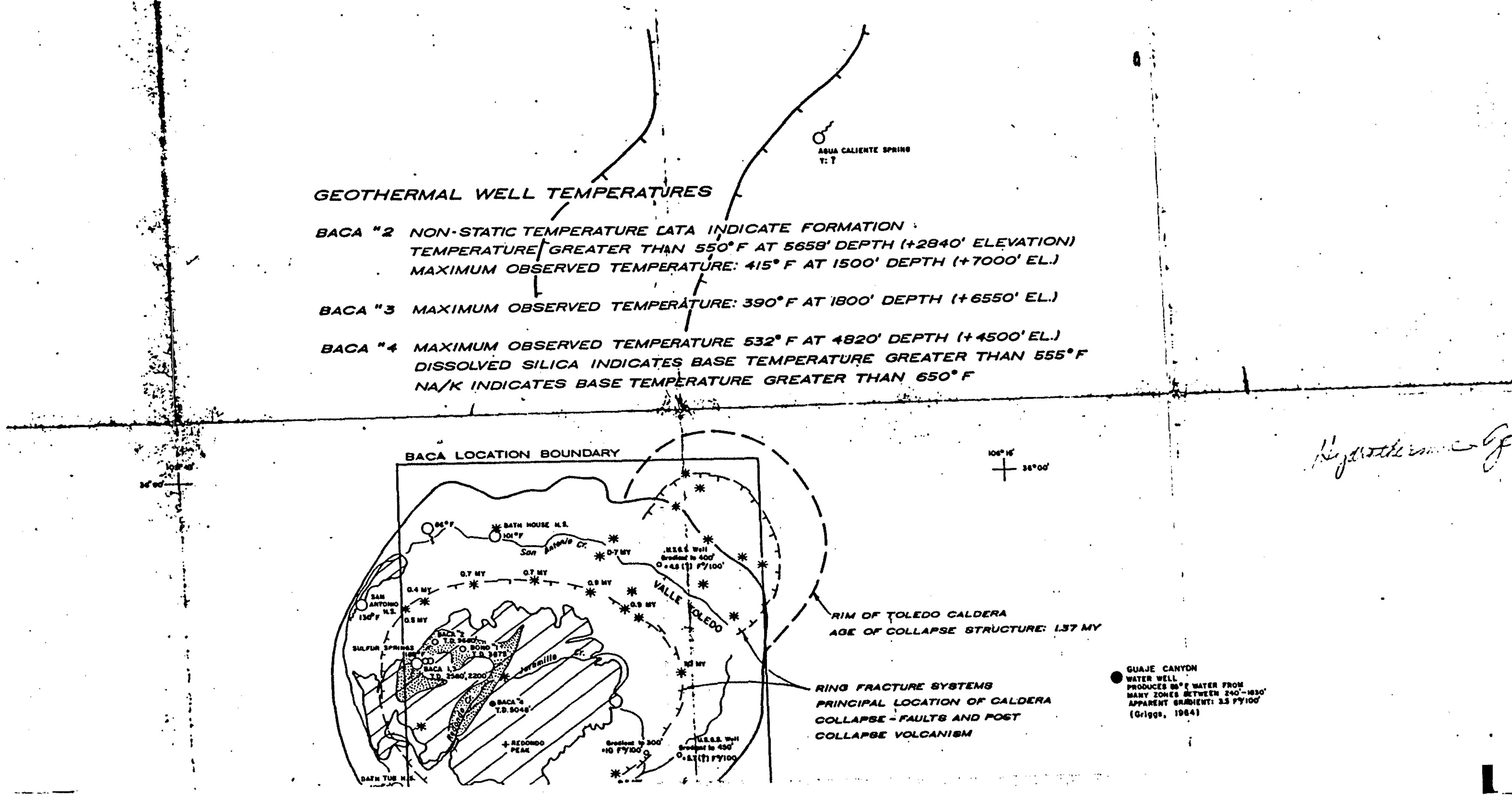
- WATER WELL
- HOT SPRINGS
- OIL OR GEOTHERMAL WELL
- DISTRIBUTION OF LAND WITH ELEVATION GREATER THAN 10,000'

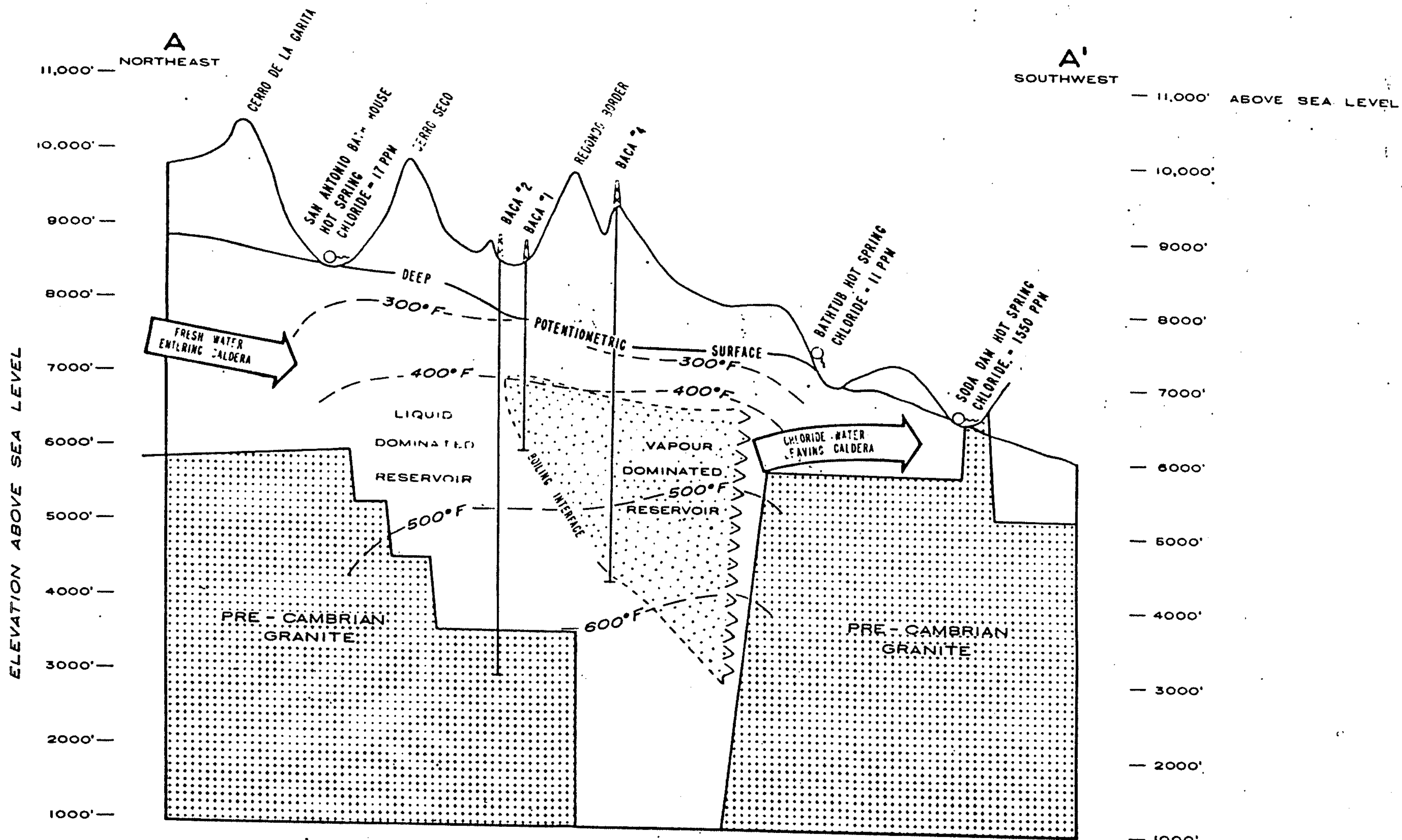
81-2
R.P.D. -1971

RIVERS MARKED WITH ELEVATION OF CHANNEL

SCALE 1:125,000

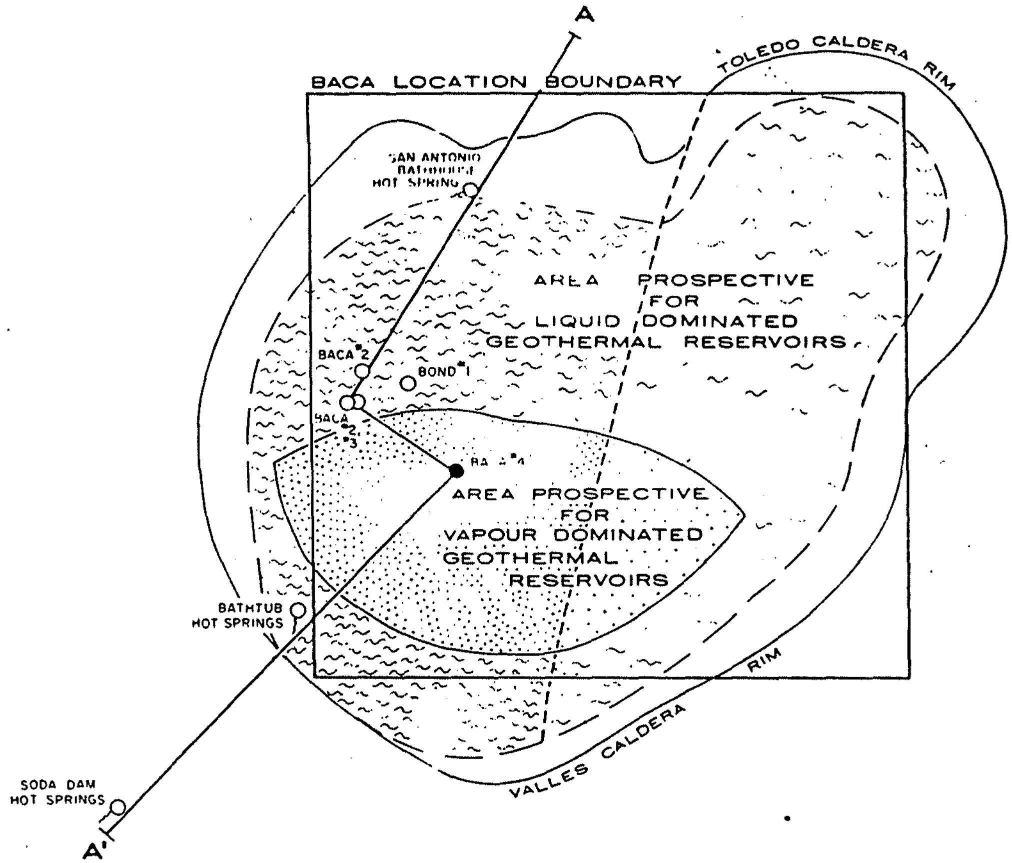

MAP I (OVERLAY ON U.S.G.S. I-571)
GEOTHERMAL FEATURES OF THE JEMEZ MOUNTAINS, NEW MEXICO
AREA OF ACTIVE HYDROTHERMAL ALTERATION
SOURCE: UNPUBLISHED U.S.G.S. MAP
DISTRIBUTION OF HYDROTHERMALLY ALTERED ROCK. AGE OF ALTERATION: PRESENT TO 1.09 MILLION YEARS.
SOURCE: DOELL, ET. AL., G.S.A. MEMOIR 116, 196
VENT OF POST-CALDERA COLLAPSE RHYOLITE VOLCANO WITH AGE OF ERUPTION IN MILLIONS OF YEARS.
SOURCE: DOELL, ET. AL., ABOVE.
GEOTHERMAL TEST WELLS
HOT SPRINGS
NOTE: AVERAGE GEOTHERMAL GRADIENT IN NON-PROSPECTIVE AREAS IS 1.6 F°/10
MAJOR PRE-CALDERA FAULTS, HACHURES ON DOWNTHROWN SIDE
R. J. D. 1971
RIM OF VALLES CALDERA
AGE OF COLLAPSE STRUCTURE: 1.09 MY
VALLE GRANDE
COCHITI MINING DISTRICT
GOLD, SILVER FROM LOW-GRADE QUARTZ VEINS IN CHLORITIZED, SILICIFIED TERTIARY INTRUSIVE.
SODA DAM H.S.
JEMEZ H.S.
INDIAN H.S.
SAN YSIDRO H.S.
SPENCE H.S.
RIVER


AGUA CALIENTE SPRING
T: ?
GEOTHERMAL WELL TEMPERATURES
BACA #2 NON-STATIC TEMPERATURE DATA INDICATE FORMATION
TEMPERATURE GREATER THAN 550° F AT 5658' DEPTH (+2840' ELEVATION)
MAXIMUM OBSERVED TEMPERATURE: 415° F AT 1500' DEPTH (+7000' EL.)
BACA #3 MAXIMUM OBSERVED TEMPERATURE: 390° F AT 1800' DEPTH (+6550' EL.)
BACA #4 MAXIMUM OBSERVED TEMPERATURE 532° F AT 4820' DEPTH (+4500' EL.)
DISSOLVED SILICA INDICATES BASE TEMPERATURE GREATER THAN 555° F
NA/K INDICATES BASE TEMPERATURE GREATER THAN 650° F
BACA LOCATION BOUNDARY
BATH HOUSE H.S.
101° F
San Antonio Cr.
0.7 MY
0.7 MY
0.7 MY
0.9 MY
0.4 MY
0.5 MY
0.9 MY
SAN ANTONIO H.S.
130° F
SULFUR SPRINGS
BACA #2
BONO #1
BACA 1, 3
BACA #4
Jaramillo Cr.
Redondo Cr.
REDONDO PEAK
VALLE TOLEDO
U.S.G.S. Well
BATH TUB H.S.
RIM OF TOLEDO CALDERA
AGE OF COLLAPSE STRUCTURE: 1.37 MY
RING FRACTURE SYSTEMS
PRINCIPAL LOCATION OF CALDERA
COLLAPSE - FAULTS AND POST
COLLAPSE VOLCANISM
GUAJE CANYON
WATER WELL



CROSS SECTION A-A'

(NOTE EXAGGERATED VERTICAL SCALE)

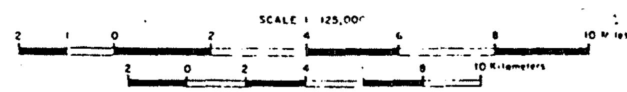


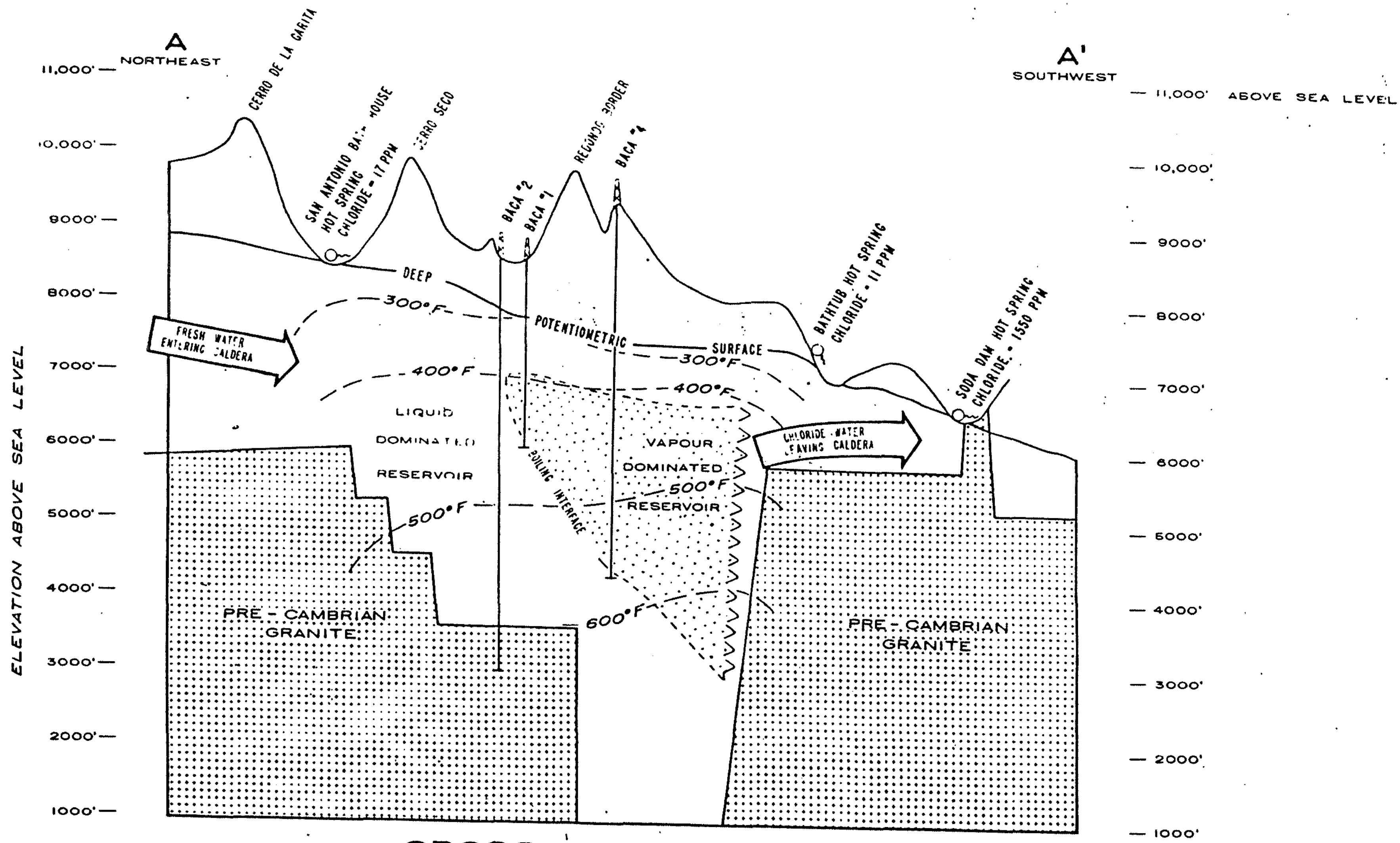
MAP III

AREAS PROSPECTIVE FOR GEOTHERM
ENERGY IN VALLES AND TOLEDO
CALDERAS INCLUDING CROSS-SECT
OF PROPOSED MODEL OF VALLES
CALDERA HYDROTHERMAL SYSTEM

AREA HIGHLY PROSPECTIVE FOR LIQUID
VAPOUR-DOMINATED RESERVOIRS

AREA PROSPECTIVE FOR LIQUID OR VAPC
DOMINATED RESERVOIRS BUT MORE
SPECULATIVE THAN ABOVE BECAUSE OF
LACK OF DEEP SUBSURFACE INFORMAT





CROSS SECTION A-A'

(NOTE EXAGGERATED VERTICAL SCALE)