MBMG-80

Final Report

Drilling of Campaqua Geothermal Test Well #1 Hot Springs, Montana

by

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1. INTRODUCTION

This report describes the investigations leading up to the drilling of a geothermal well in the Little Bitterroot geothermal area, as well as the results of drilling of that test well, which was completed in January 1981. Funding for preliminary studies was provided under the Department of Energy State-Coupled Geothermal Resource Assessment Program, RAE Grant #500-800. Funds for drilling, completion, and evaluation of the test well were provided by the Renewable Resources Division of the Montana Department of Natural Resources and Conservation. The primary objectives of the test well were:

1. To tap into the geothermal circulation system beneath a shallow gravel aquifer which underlies the valley;

2. To evaluate flow, temperature, and reservoir characteristics of this hot water system; and

3. To evaluate the geothermal gradient at the test well site.

The siting and drilling approach was as follows:

1. To site the well on a location which would allow maximum penetration of bedrock in the immediate vicinity of the fault(s) along which geothermal water rises from depth.

2. To case through the shallow gravel bed bearing hot (52^{o}C) water (depth from 250 to 300 feet).

3. To drill with air, not mud, for as long as feasible, to minimize damage to the bedrock aquifer and to allow future conversion to a producing geothermal well, if warranted.

2. LOCATION

The Little Bitterroot Valley (Figure 1) is a structural depression, probably bounded by high angle normal or listric normal faults of Tertiary (?) age (Harrison et al., 1980). The valley was infilled by Tertiary sediments and by glacial and post-glacial sediments. The Tertiary sediments are not well exposed and are poorly understood both in character and in thickness distribution. They are thought to be comprised of volcaniclastic sandstones and conglomerates, ash strata, and fluvial sediments. There are several small exposures of these strata along the margins of the valley in its northern part, closer to the Tertiary volcanic center in the Hog Heaven range, but it is not known to what degree Tertiary sediments elsewhere in the valley are similar or what their thickness distribution is. Records for only two wells are available which penetrate the Tertiary sediments: one a 1,400 foot oil test (LB-208) in T. 23 N., R. 23 W., Sec. 11 DCD which penetrates 350 feet of Tertiary and reaches bedrock, reportedly of Belt sediments; the other a deep irrigation well (LB-222) in T. 23 N., R. 23 W., Sec. 34 ADBB, which logged 163 feet of Tertiary and did not reach bedrock. The thickness of Tertiary in the valley probably ranges from 0 to 2,000 or more feet.

Many more wells are drilled into Pleistocene sediments. A permeable gravel bed of an estimated 20 to 60 feet thickness occurs extensively throughout the valley. The top of the bed is very nearly planar and slopes gently from north to south, at an elevation of 2,580 feet in the north to 2,460 feet in the south, at a nearly uniform slope of about 9 feet per mile to the southwest (Figure 2). The gravel is overlain by approximately 200 to 300 feet of homogenous silty clays of Glacial Lake Missoula. Groundwater is confined within the gravel by the lake bed sediments, and water wells completed into the upper five feet of this gravel are used throughout the valley for irrigation, stock watering, and domestic purposes. The aquifer exhibits hydrologic continuity throughout its extent. In the southeastern part of the valley, along the Little Bitterroot River, land surface elevations are below the piezometric level of this aquifer during all or most of the year, and in this area there are a number of flowing wells, many of which are used for irrigation. During the irrigation season (May to September), irrigation withdrawals stress the aquifer and lower static

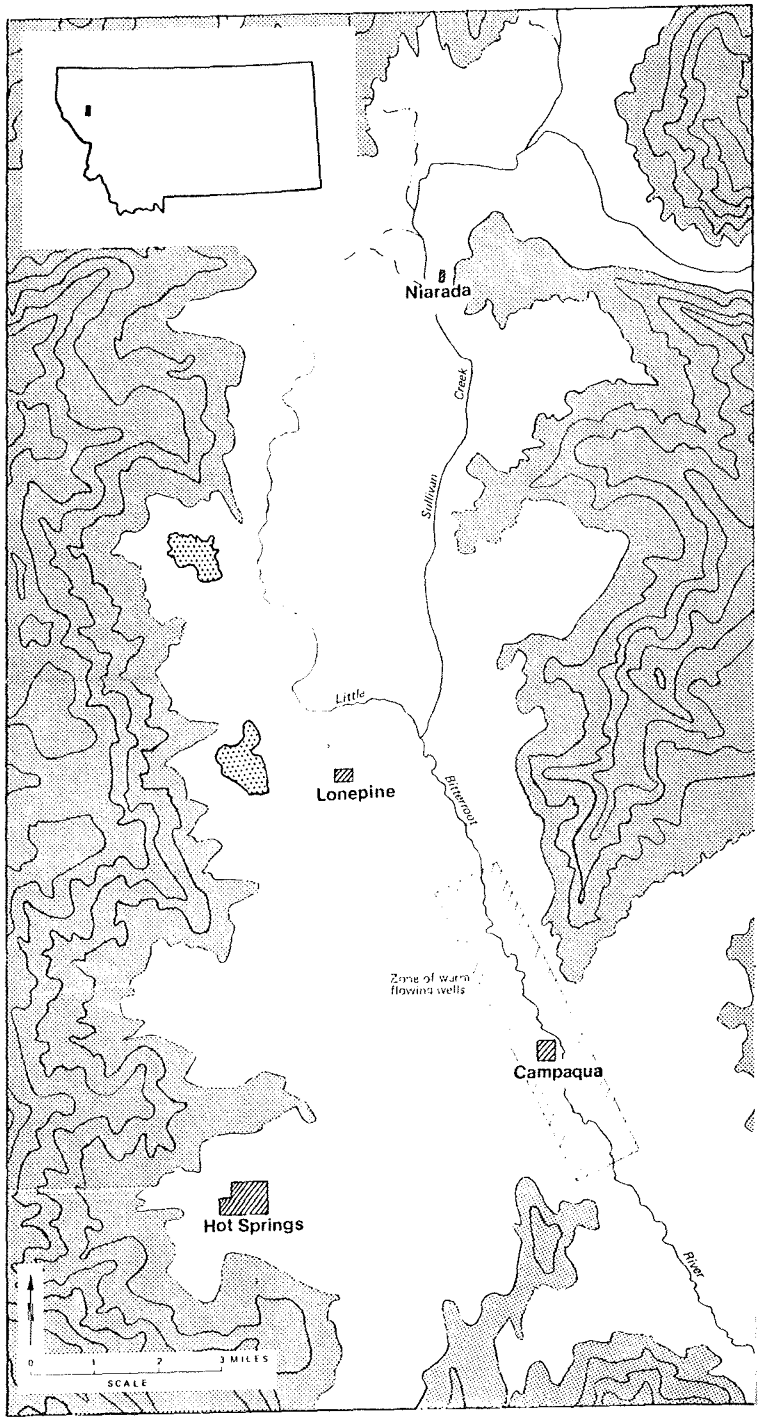

Figure 1. Location map of the Little Bitterroot valley, with geothermal zone in the Campaqua area noted.

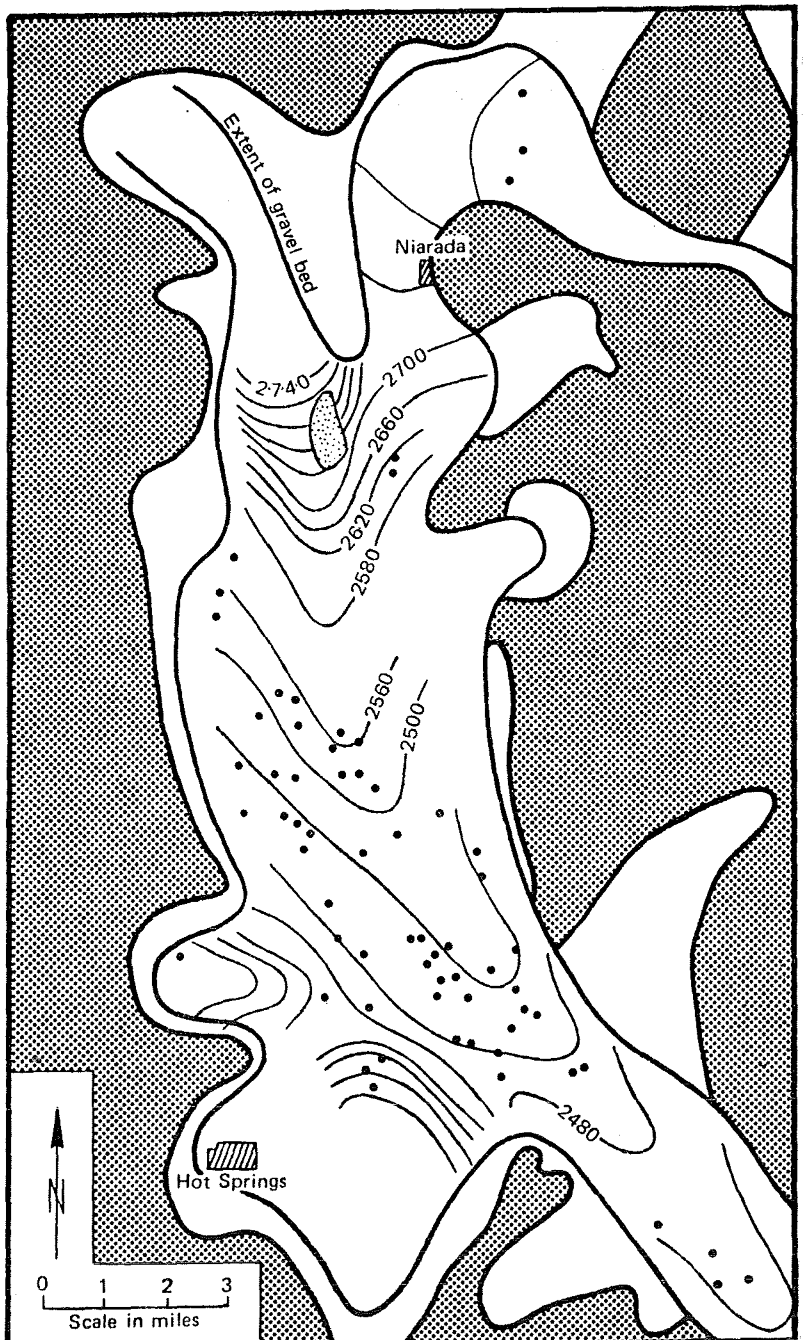

Figure 2. Structure contour map of the top of the Pleistocene gravel bed beneath the Little Bitterroot valley, with elevations in feet ASL. Points represent control from drillers' logs.

water levels throughout the valley confirming the continuity of the aquifer between these wells (Figure 3). As a result of this drawdown, yields of flowing wells decrease considerably as the irrigation season progresses; consequently there is much local sentiment among ranchers in the valley to limit drilling of new wells for additional large-scale withdrawals in the valley, in order not to impose additional stress on the aquifer. With this in mind, it was considered a major objective in the geothermal drilling program to develop, if possible, the resource below the gravel bed in bedrock fractures, in order not to interfere with the local irrigation practices. Also, highest water temperatures probably occur beneath the gravel in the fracture system which leaks hot water into the overlying gravel.

The zone of flowing artesian wells near the Campaqua site is also, by coincidence, the zone of maximum geothermal leakage into the gravel. This zone has been the target of exploration for geothermal resources in this study.

In the town of Hot Springs, along the southwest margin of the valley, geothermal water occurs in springs issuing from thin (<20 feet) valley fill materials and in wells penetrating bedrock fractures. Temperature of this water ranges from 16^{o} to 49^{o} C; flow rates are not high. This water is less mineralized than the geothermal water beneath the Campaqua area. While the deep circulation pattern of this water may be related to the same structural setting at depth as the Campaqua system, this geothermal water is not thought to be in direct hydrologic continuity with the water beneath the Campaqua area.

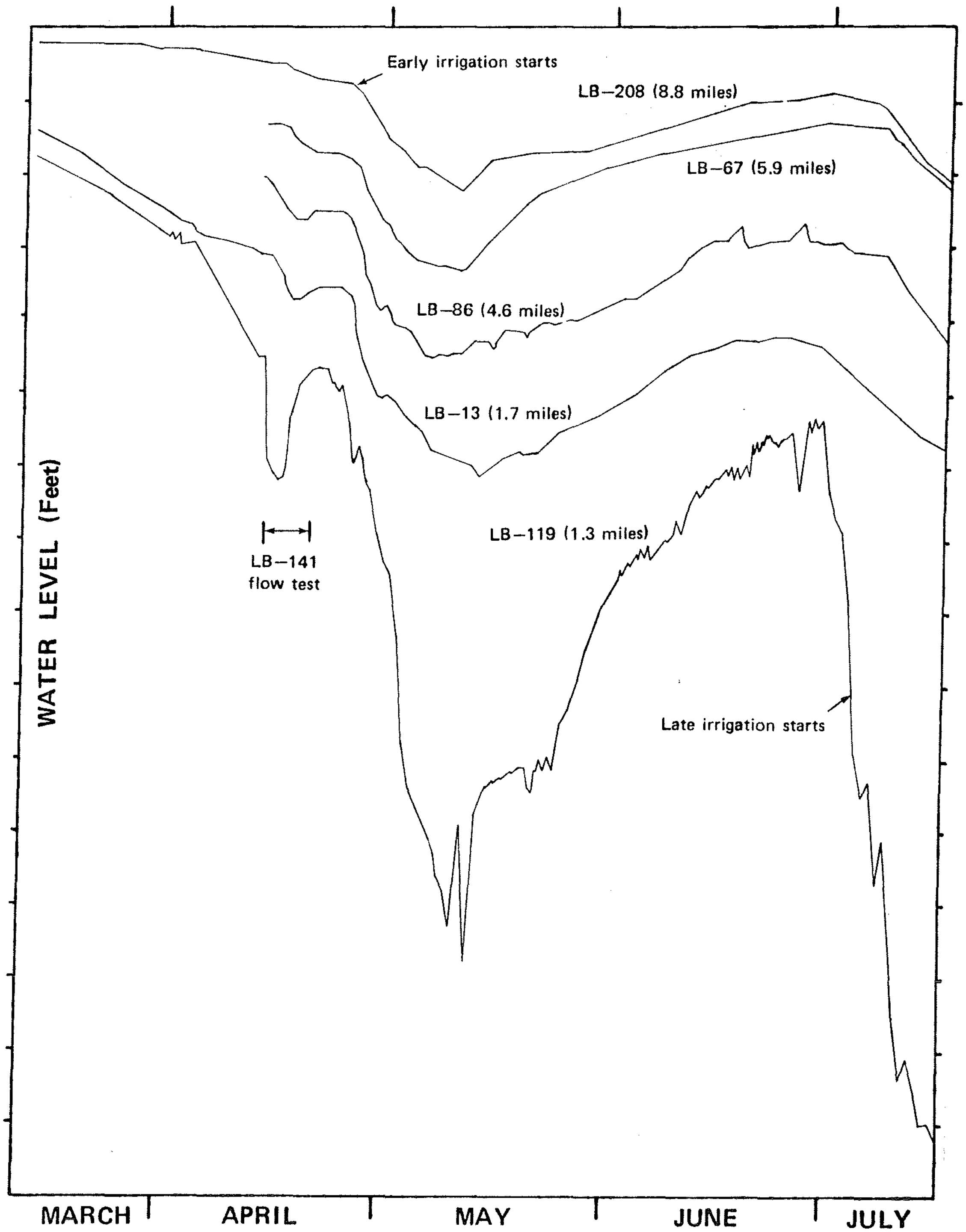

Figure 3. Continuous well records for part of 1981 for five observation wells. Distances are from the test well, LB-141, located approximately in the center of the area of ground-water irrigation. Response of wells is indicated to flow test of LB-141 and to early and late irrigation seasons.

3. PREVIOUS STUDIES

Reconnaissance ground-water data was collected in this area by the U.S. Geological Survey in 1976-78 (Boettcher, 1980). These data include inventories and water quality analyses of selected wells. Earhart (unpublished data, 1977) performed reconnaissance water quality sampling of water wells and springs in the valley. These samples were analyzed for chemical constituents which would allow geothermometer calculations for these waters.

Crosby et al. (1974) and Hawe (1975) performed geophysical investigations in the vicinity of Hot Springs in an effort to locate a shallow heat source of the thermal springs there. They performed detailed gravity, magnetics, electromagnetics, telluric current, and microearthquake studies in the immediate vicinity of the hot springs, but did not extend their study far into the valley and the Campaqua area. Qamar (1976) performed a borehole temperature profile on a 300 foot exploration hole drilled by Confederated Kootenai-Salish tribe near the hot springs in an effort to obtain an estimate of the local geothermal gradient; his study observed very high gradients (120-220° C/km) in the upper part of the hole, but nearly isothermal values at the bottom of the hole, suggesting that a convective warm water zone at the bottom of the well, probably related to the hot springs occurrence, precludes an estimate of the conductive geothermal gradient from a shallow drillhole. Both studies interpreted the hot springs occurrence (and the warm wells in the town) to be related to an eastnortheast-trending boundary fault along the north side of the Hot Springs valley, which they projected to the east towards the Campaqua area.

From 1977-1981, the Montana Bureau of Mines and Geology has been performing a detailed assessment of ground water in the shallow artesian aquifer of the valley. This study has included a comprehensive well inventory, water level monitoring, aquifer evaluation, and water quality. Publication of the final report of this project is anticipated for late 1981.

4. PRELIMINARY HYDROGEOLOGICAL STUDIES

Approximately 200 water wells which produce water from the Pleistocene gravel aquifer at the base of the Lake Missoula sediments were inventoried (Figure 4). Static water levels in these wells respond rapidly (within a few days) throughout the valley to the onset of irrigation withdrawals in the area of flowing wells, experiencing drawdowns of 5 to 15 feet. In the fall, after irrigation ceases, the aquifer recovers rapidly and any cone of depression essentially disappears within two months as the aquifer steadily increases in pressure. In the early spring, when aquifer pressure is generally highest, the piezometric level in the aquifer throughout the valley is from 2,770 to 2,780 feet, with a very slight gradient--probably less than a foot per mile--to the southwest (Figure 5). At the southwest of the valley, where the Little Bitterroot River leaves the basin, the piezometric gradient increases to approximately 10 feet per mile. Ground-water discharge is primarily down the Little Bitterroot Valley towards Ronan to a ground-water discharge area near where the river discharges into the Flathead River at the Big Bend. Irrigation withdrawals probably account for much of the water which otherwise would have discharged out of the valley in the subsurface. Recharge for the aquifer probably occurs in the northern part of the valley, where the Little Bitterroot River flows over permeable valley-bottom gravels thought to be in hydrologic continuity with the artesian gravel aquifer, as well as, to a lesser extent, along the east and west margins of the valley from alluvial drainages leading down from the mountains. This recharge water is cold and not highly mineralized, with total dissolved solids from 150 to 350 mg/L. The gravel bed is, therefore, basically a shallow, cold-water aquifer, hydrogeologically continuous throughout the valley based on observed responses of wells to stress caused by irrigation.

In the zone of flowing artesian wells, however, in the Campaqua area it is apparent that there occurs mixing of geothermal water with the cold water of this aquifer. Temperatures of ground water from wells in this zone range from 17^{o} to 52^{o} C with TDS values ranging from 350 to 600 mg/L. TDS, specific conductance, chloride, $Na^{+}/Ca^{2+}/K^{+}$ ratios, boron, and lithium all increase in some proportion to temperature, suggesting that the geothermal water leaking into the aquifer is enriched in these constituents relative to the cold recharge water.

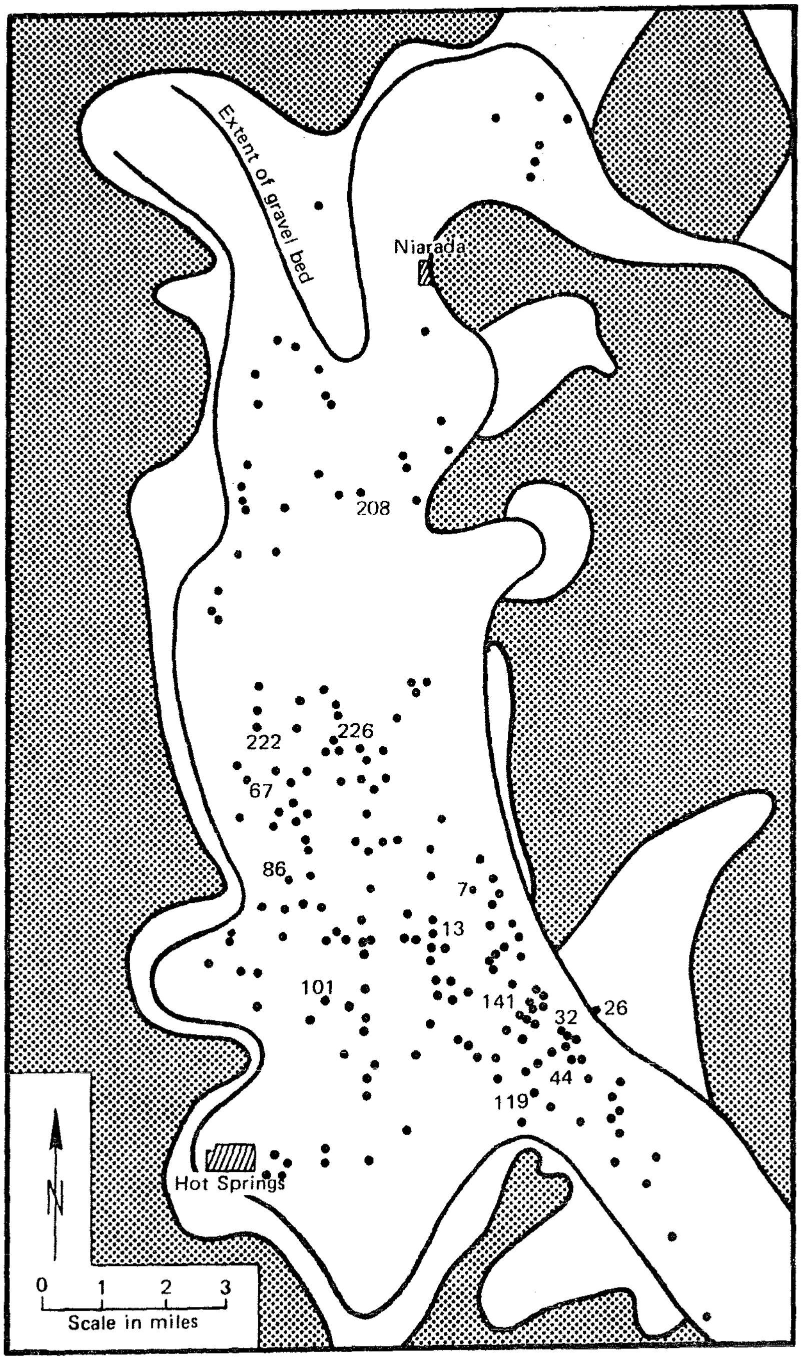

Figure 4. Distribution of water wells tapping the Pleistocene gravel aquifer, with locations for wells referenced in the report.

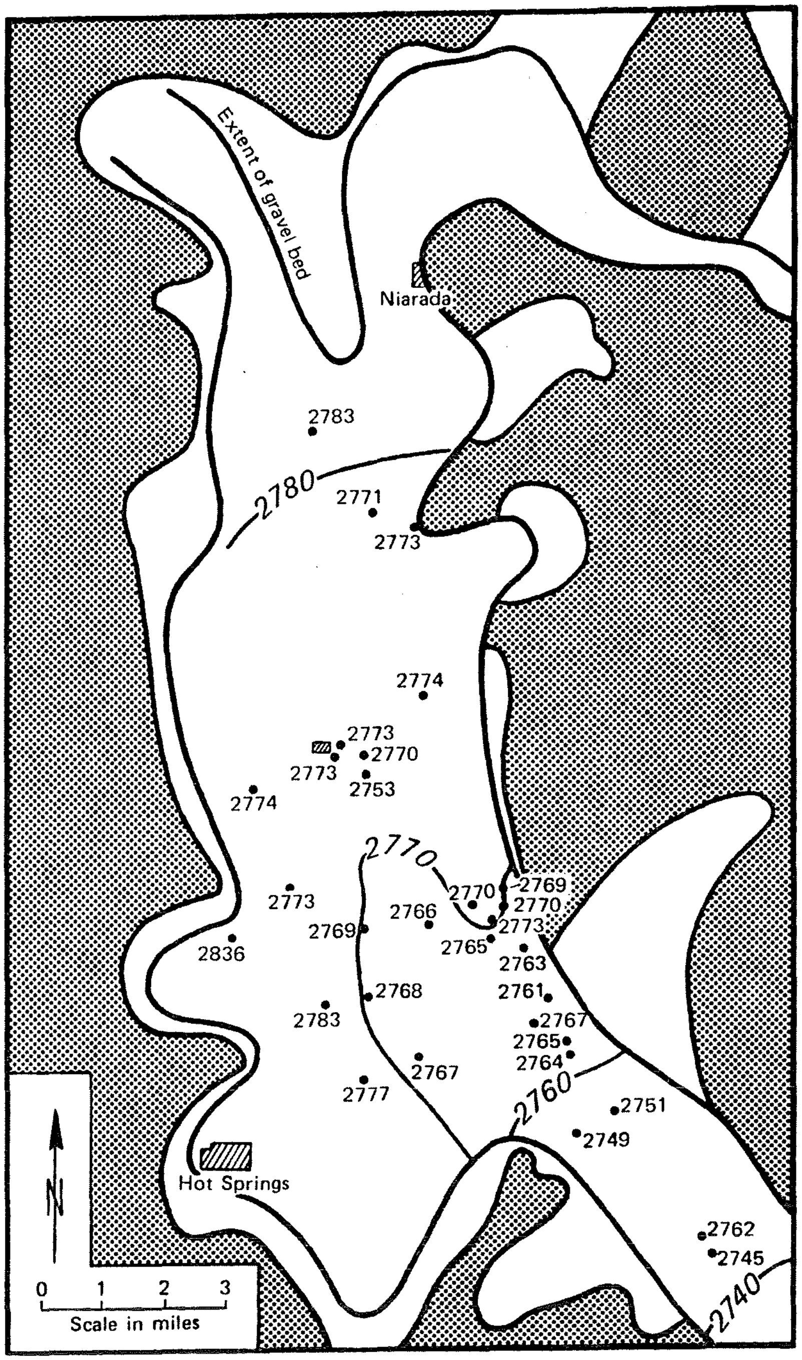

Figure 5. Plezometric surface of ground water in gravel aquifer, March 1981.

The temperature, TDS, and exact chemistry of the hot geothermal water are unknown because the mixing ratio of hot to cold water is also unknown. Chemical geothermometers are also of limited usefulness in estimating this temperature due to mixing, but in general they indicate subsurface temperatures at some depth higher than that of the hottest well in the gravel, 52° C. The cation (Na-Ca-K) geothermometer of Fournier and Rowe (1966) indicates equilibrium subsurface temperatures from 60° to 112° C, not accounting for errors in calculation due to mixing; however, bacterial sulfate reduction activity and accompanying high CO_2 pressures may locally be causing precipitation of calcite in or above the gravel with resulting loss of Ca^{2+} from solution in ground waters of the gravel, invalidating the equilibrium assumption inherent in the geothermometer. Silica concentrations in the mixed water are undersaturated at field temperature with respect to chalcedony, which is thought to be the controlling silica species. The deviation from the chalcedony curve (Figure 6) is attributed to mixing. Due to data scatter and lack of points at higher temperatures, the shape of this mixing trend is uncertain, but it can be projected by an error-bracketed straight line estimate to temperatures at least as high as 70° C and perhaps as high as 90° C. It should be noted, however, that this temperature may reflect equilibrium silica concentrations at the deepest point of circulation not necessarily at shallow depth.

Boron, lithium, and chloride are effective indicators of the location of the zone of leakage of hot water. Each forms a distinctive halo (Figures 7, 8, and 9) indicating the geothermal zone as an elongate, northwest-southeast trend from Campaqua approximately 12 km north to Lonepine. This trend is interpreted as good evidence that the geothermal water is ascending through fractures associated with a normal or listric normal boundary fault along the east side of the valley. Presumably this fault would dip to the west at a somewhat steep angle, or perhaps even be nearly vertical near the surface (Harrison, et al., 1980).

Transmissivity in the gravel has been evaluated for some of the irrigation wells tapping it. Flow recovery tests have been conducted at discharges from 90 to 420 gpm. Discharges below 250 gpm did not produce sufficient stress on the aquifer to produce measurable drawdowns. At higher discharge rates, drawdowns of up to two feet were produced with calculated transmissivities on recovery of 190,000 to 300,000 gpd/ft.

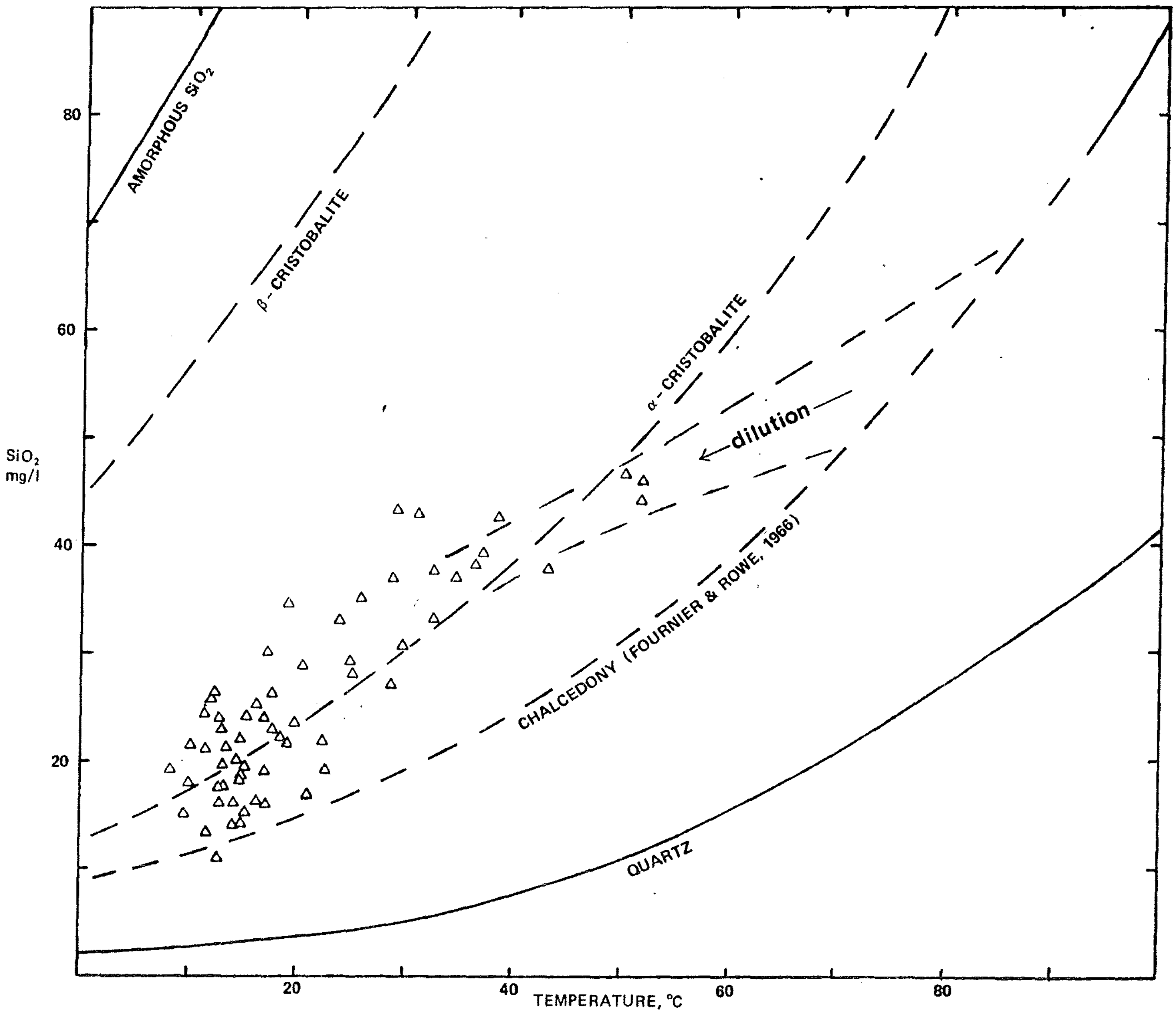

Figure 6. Plot of dissolved silica concentrations vs. observed temperature for water well samples in the Little Bitterroot valley.

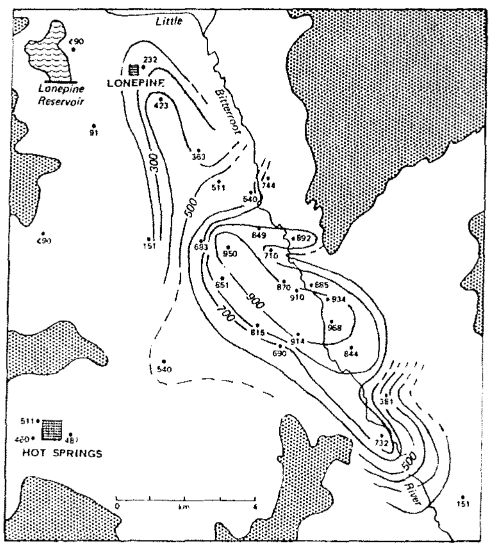

Figure 7. Dissolved Boron concentrations, ppb

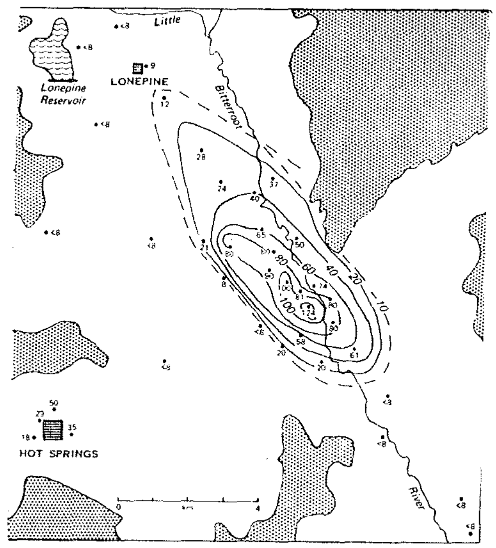

Figure 8. Dissolved Li^+ concentrations, ppb

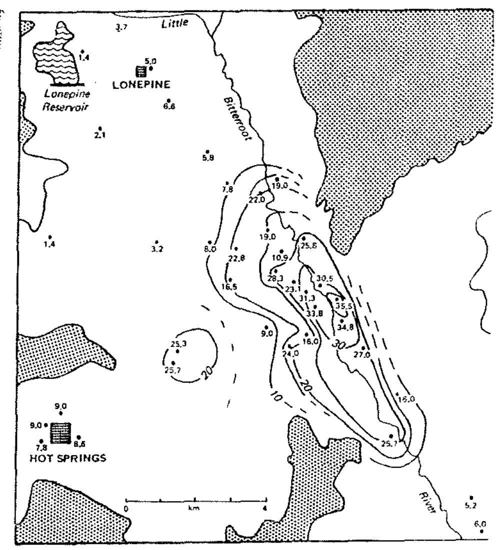

Figure 9. Dissolved Cl^- concentrations, ppm

Due to the relatively small drawdowns produced by yields under 250 gpm, most existing wells are incapable, on an individual basis, of creating sufficient stress to allow accurate determination of parameters for this aquifer.

5. GEOPHYSICAL STUDIES

A reconnaissance gravity survey covering most of the valley (Figure 10) was performed in summer 1978. It was supplemented by seismic refraction lines shot in the geothermal area both with a Texas Instruments DFS-3 seismograph and with a Geometrix Model 1210-F refraction seismograph. The gravity data indicates an anomalous high of about five milligal relief, approximately 1 x 2 miles, located directly beneath the zone of geothermal mixing. This high is interpreted as a fault-bounded upthrown bedrock block, rather than as an intrusive body or as a bedrock formation of anomalously high density. The structural configuration of this block is uncertain. The structure is probably, however, rather complex; the block is in the zone of intersection of the northwest-southeast-trending valley margin fault, outlined by the geochemical haloes for B, Cl, and Li, and one and probably more northeast-southwest-trending cross-valley faults, suggested by the gravity data and discernible as lineaments on high-resolution U-2 aerial photographs for the area. Residents in Garceau Gulch, northeast of Campaqua and at the eastern extent of one of these cross-valley faults, indicate that they experience regular low-magnitude seismic activity in their area. This claim is supported by the history of cold water springs in this area, which have been known to exhibit erratic flow behavior in a way not obviously related to short-term climatic cycles or annual fluctuations. There have also been earth tremors both reported by residents and recorded in this area, including one at magnitude 4.0 (Richter) during an earthquake swarm in 1971 (Stevenson, 1976; Witkind, 1977).

The hypothesis of an uplifted bedrock block at shallow depth beneath the Campaqua area was corroborated by seismic refraction investigations, which were interpreted to indicate bedrock depths in the north half of Section 29 range from 230 to 500 feet. In the profiles, run over deeper valley fill, the seismic layering was as follows: 0 to 200-240 feet, 5,200 feet/second (Lake Missoula sediments; lower velocity gravel at base); 240 feet to bedrock, 8,500 feet/second (Tertiary sediments of unknown characteristics); and Precambrian argillites and quartzites of the Belt Supergroup, 12,000 to 16,000 feet/second. When bedrock is shallower than about 300 feet, no Tertiary (8,500 feet/second) is detected, either because it is absent or because it is too thin to be detected using the geophone spacing (100 feet) on the

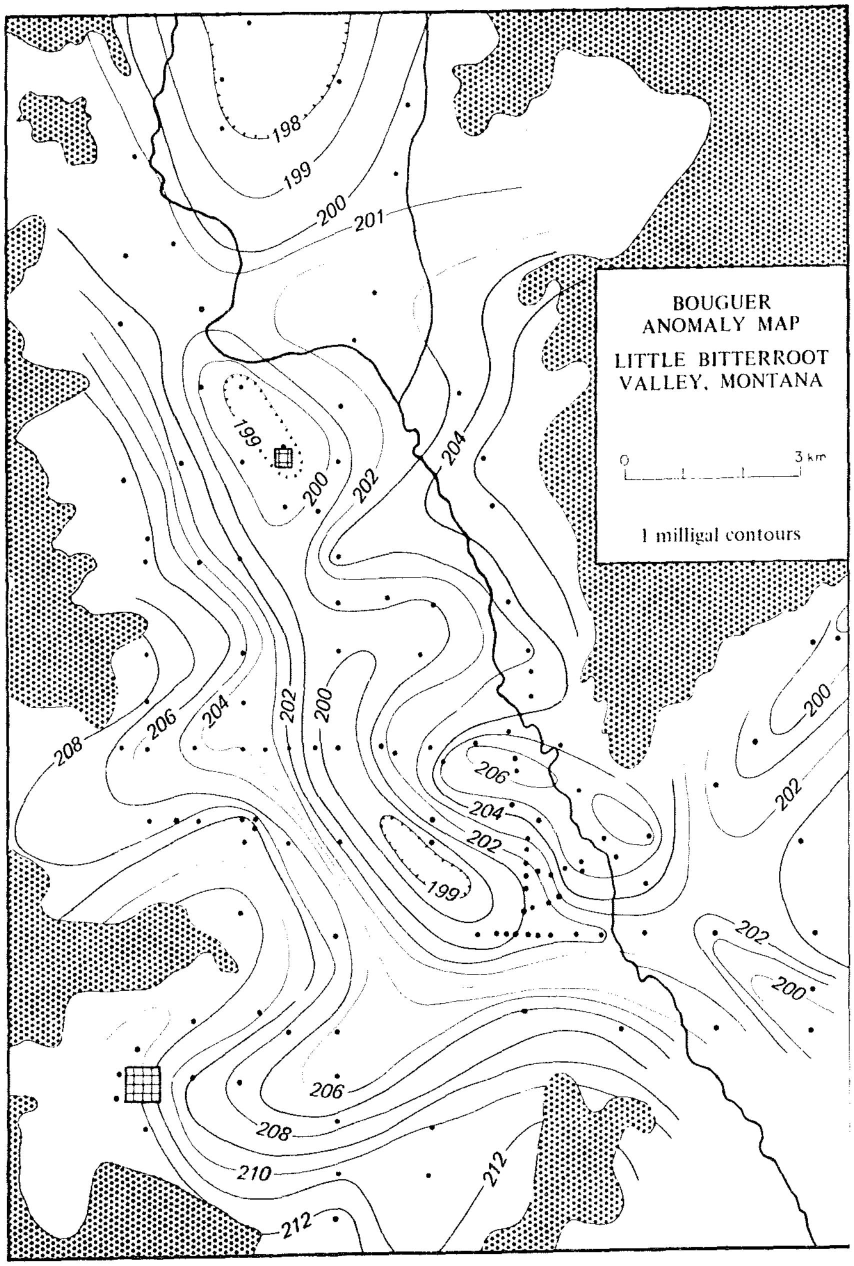

Figure 10. Bouguer gravity map of the Little Bitterroot valley.

refraction line. At the Campaqua site itself, where the hottest existing well producing from the gravel is located, Lake Missoula sediments and gravel were shown by the seismic data to directly overlie bedrock; both west and east of this site, a Tertiary layer was detectable in the profiles.

The refraction data was used to outline an area in the vicinity of Campaqua in which bedrock was shallower than about 400 feet (Figure 11). This bedrock "bench" corresponds to the gravity high of Figure 10 and is essentially devoid of Tertiary sediments.

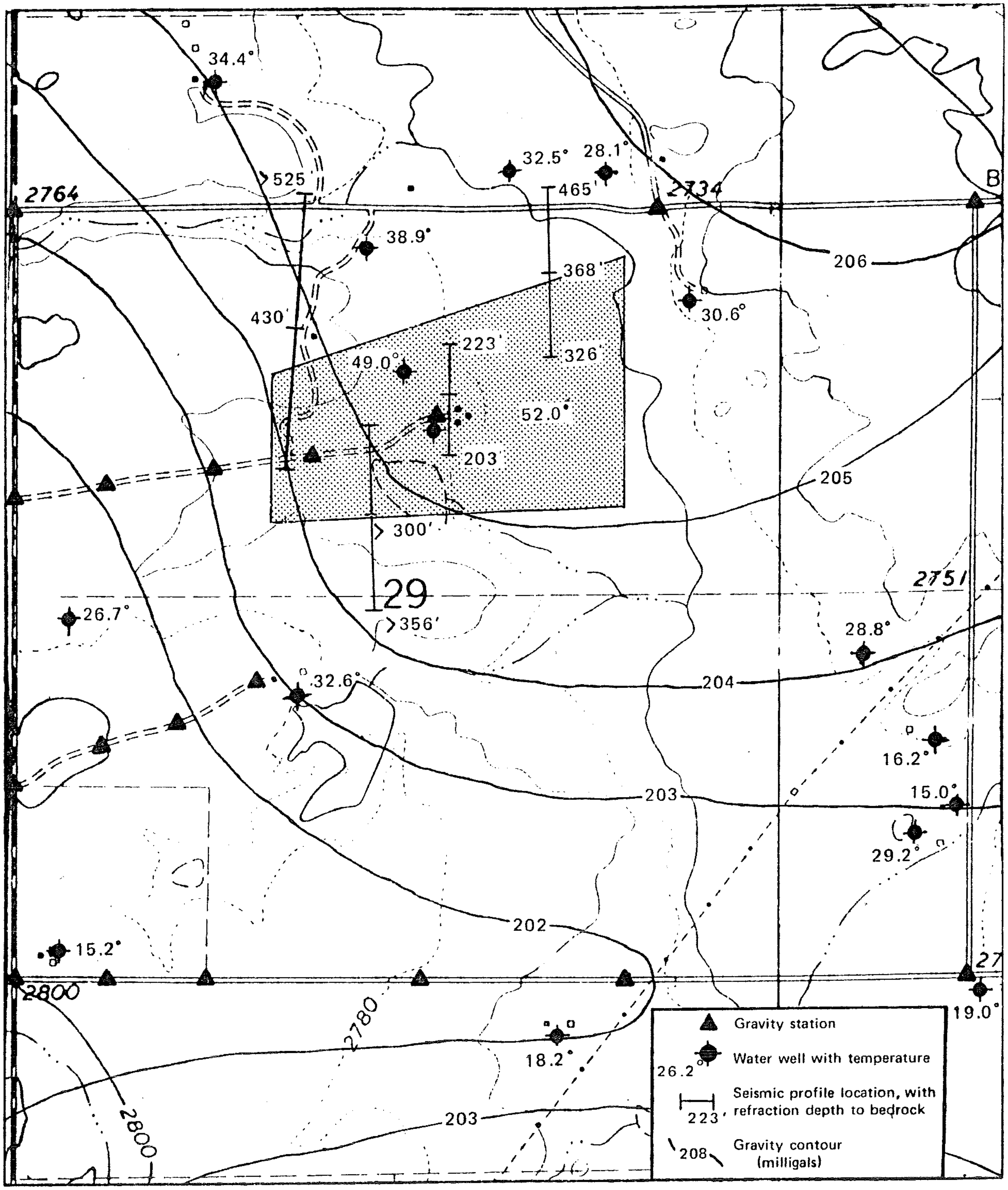

Figure 11. Map showing seismic refraction profile locations and bedrock estimates, gravity stations and contours and approximate location of the shallow bedrock shelf beneath the Campaqua geothermal zone, Section 29, T. 22 N., R. 23 W. Water well locations and temperatures are also noted.

6. TEST WELL SITING

The bedrock "bench" outlined by the refraction and gravity data is interpreted to represent an uplifted fault-bounded block, associated in part with the valley-bounding normal or listric normal fault reflected by the geochemical leakage trend. This fault is assumed to be associated with the circulation of geothermal fluids because of this geochemical evidence, and was, therefore, the exploration target for this hole. It was recognized that there is probably cross-valley faulting which complicates the structural geology; also, the possibility is strong that there may be several high-angle faults occurring en echelon, rather than a single one bounding the valley margin, as is suggested by Harrison et al. (1974) in their interpretive reconnaissance map of the Wallace $1^{o} \times 2^{o}$ sheet. It is assumed, without supporting data, that this fault would be westward-dipping , possibly quite steeply.

With these assumptions, potential drilling sites were chosen based on the following criteria:

a. Location slightly westward of the conjectured normal fault axis, but not so far west as to preclude intersection by a 1,000 foot drillhole.

b. Location over shallow bedrock, to allow as much penetration of water-saturated bedrock fractures as possible within the 1,000 foot drilling budget.

c. Surface conditions suitable to allow adequate drainage of potentially large volumes of water, to preclude risk of property damage or flooding of roads.

d. Location a reasonable distance away from existing wells to minimize risk of mud or air damage to other wells.

The site chosen was in Section 29 BADD, approximately 350 feet northwest of the original Campaqua well (52^{o} C). This site lies slightly west of the interpreted northwest-trending fault axis passing through or east of the Campaqua well. It was anticipated that water in the gravel would be encountered at about the same depth as it was for the Campaqua well (240 feet) and at nearly the same or a slightly lower temperature. It was planned to drive unperforated casing through the gravel into bedrock, shutting off flow from the gravel, and to continue drilling into bedrock with the intention of encountering either the high-angle fault itself or a bedding plane fracture in communication with this system.

The hot-water system ascending through the fractured bedrock was expected to exhibit higher temperature and pressure than the water in the gravel bed. Also, the bedrock aquifer was expected to exhibit significantly lower transmissivity than that of the gravel.

7. TEST WELL RESULTS

7.1 DRILLING ACTIVITIES

Drilling of the test well commenced on December 4, 1980. Standard eight-inch water-well surface casing was set to a depth of 102 feet and cemented in. Drilling continued with a 6-5/8 inch bit to total depth. The gravel was encountered at depth 240 feet, and bedrock directly beneath it at 264 feet. The six-inch casing followed the bit to the latter depth, where it was set and cemented in. All casing joints were arc-welded under dry conditions. Drilling proceeded open hole from 264 feet to a total depth of 1,002 feet, where the well was completed on January 11, 1981. A two-inch sealed (capped, no perforations) steel liner was hung in the well and shut in for logging purposes (temperature, gamma, neutron). A detailed summary of drilling operations is included as Appendix A. The detailed drilling log is included as Appendix B.

Geophysical logs were run in two stages. Immediately after total depth was reached, electric logs (spontaneous potential and resistivity) were run on the uncased portion of the hole from 264 to 667 feet, below which depth the sonde could not penetrate past a sloughing fracture zone. Water was allowed to flow during the logging. After the two-inch liner was set to a depth of 980 feet, natural gamma and temperature logs were run from 0 to 980 feet within the liner. This data is presented in Plate I. No neutron log was run due to the potential for hangup of the radioactive sonde either in the slough zone or in the liner.

The lithology of the upper 240 feet of hole is stratified silts and silty clays of Glacial Lake Missoula (Pleistocene). In surface exposure, faint varve-like laminations are apparent in these sediments; such stratification, if any exists, is undecipherable in highly disturbed rotary cuttings. The clay appeared relatively homogeneous, with no sand interbeds except near the base of these sediments, overlying the gravel aquifer. These sand interbeds probably represent deposition during a period when the glacial ice was still close to the valley and springmelt runoff contributed abundant sediment to the valley. Occasional cobbles or gravel, possible ice-rafted material but also possibly flood-related debris, occur from 130 feet to 240 feet. The color of the clay is light to dark brown from the surface to 180 feet; from 180 to 240 feet, the atmosphere is more reducing and the color becomes increasingly grey with depth. Above the gravel, the color is slate blue, probably reflecting the

7.2 GEOPHYSICAL LOGS

Geophysical logs run on the well include SP, resistivity, and natural gamma, as well as the temperature log (Plate I, Figure12). The electric logs were run on the uncased portion of the well to a depth of 667 feet, where an unpassable obstruction, due to sloughing, was encountered. Gamma and temperature were run from within the two-inch liner.

The gamma log records natural gamma radiation from materials around the wellbore. It records well the transition from unconsolidated materials (low gamma) to bedrock (high gamma). At a depth of about 100 feet in the Glacial Lake Missoula sediments, a slight increase in gamma is noted, which roughly corresponds to the transition in these sediments from brown (oxidized) clay to blue-grey or grey (reduced) clay. The gamma increase is thought to be related to the higher organic content probably responsible for the color change in the clay due to higher natural gamma radiation from these organics. A low gamma defraction at about 226 feet represents sand interstratification in the clay. The gravel (240 feet to 262 feet) exhibits only slightly lower gamma than the interstratified sand in this interval. Within the bedrock portion of the well, high gamma corresponds to argillite, low gamma to quartzite. In addition, some low gamma peaks correspond to zones logged during drilling as fracture zones or as "clay wash" zones, where drilling proceeded rapidly through soft material which yielded very few solid cuttings and a slurry of very fine-grained grey material, probably a mixture of clay, silica, and calcite. In some cases, these low gamma peaks correspond to water-producing zones. They are, in general, not distinguishable from quartzite-rich intervals (viz., 886 feet to 920 feet) without information from the drilling log, with the exception of the very low gamma anomaly at 655 feet to 760 feet which corresponds to a major slough zone and may be a fracture (fault?) zone filled almost completely with secondary minerals.

The SP log was run from a free-hanging sonde, rather than from a bowstring sonde; and, therefore, the data is somewhat erratic and not amenable to straightfoward interpretation over its entire length. Because the wellbore is filled with water of relatively uniform temperature and conductance, rather than drilling mud, potential gradients between fluids in fractures and fluids in the wellbore are probably not well developed. Nonetheless, some bedrock presence of fine-grained iron monosulfide precipitates. Also directly on top of the gravel is a thin (<1 foot) very hard "cap rock," noted by local drillers in wells throughout the valley. While no unusual cuttings were recovered from this hard zone during the drilling, it is thought to be clay indurated with carbonates formed by reaction between Ca^{2+} cations in pore water and CO_2 gas produced by organic decomposition and bacterial activity within the gravel.

The gravel itself is approximately 24 feet thick at this location. Coarse layers in the gravel have well-rounded, smooth, and flat or elongate cobbles up to four inches in length. The provenance of these cobbles and clasts is dominated by argillite and quartzite from Belt rocks (>90%), with minor amounts of highly altered andesitic volcanics (probably from the Hog Heaven complex to the north) and feldspathic gneiss. A bright red shale or claystone, probably another Belt lithology, is also common in the gravel. The roundness of the clasts and the repetitive interbedding of sand and gravel lenses suggest a fluvial, glaciofluvial, or ice contact origin for the sand and gravel, probably deposited during the retreat of late Wisconsinan ice from the north end of the valley.

Water occurs under flowing pressure in the gravel aquifer. In this well, at a shut-in pressure of 10.2 psi, the estimated yield was 300 to 400 gpm from the gravel, with 4½ inch diameter drill steel still in the hole; unobstructed open-hole discharge would have been significantly higher, probably greater than 500 gpm. Temperature in the gravel is hotter at its base (48.6^{o} C) than at its top (46.8^{o} C), supporting the hypothesis that leakage into the gravel is occurring along its base.

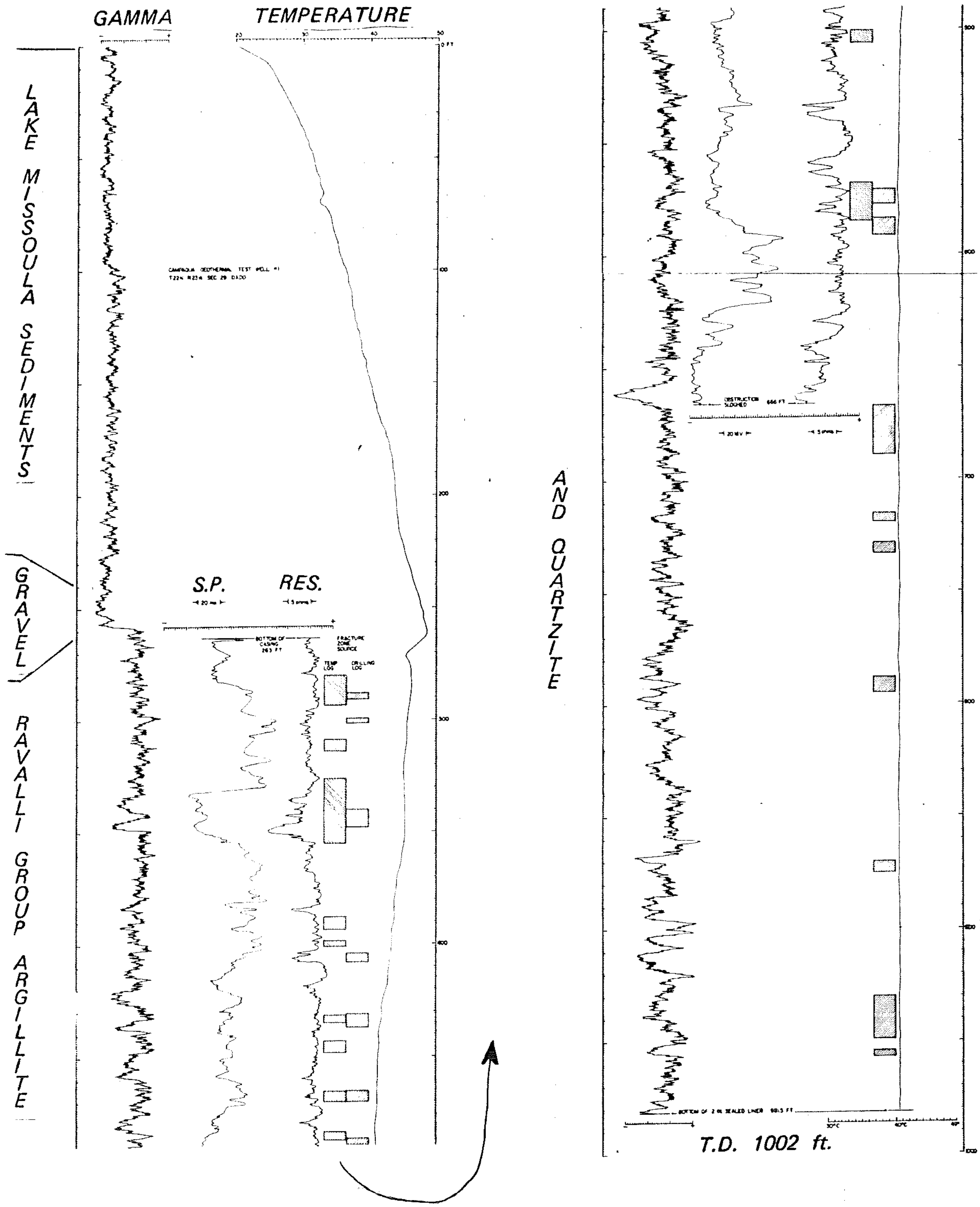

Figure 12. Geophysical and temperature logs (on LB-141, run 1-10-81 through 1-13-81. See Plate I for additional detail.

fractures, apparent as low resistivity kicks, correlate with low-SP deflections. The SP log may be further complicated by zones of pyrite concentration along fractures, which could be contributing to the observed SP baseline wandering.

The resistivity shows pronounced low kicks, which probably correspond to water-filled near-horizontal fractures (vertical or subvertical fractures would probably not appear prominently on the resistivity). Some, but not all, of these conductive intervals may be water producing; others may be highly fractured but nonproductive, although due to the artesian flow in the well all are water-saturated. The pyrite concentrations noted above may also contribute to low resistivity along these fractures.

The temperature log shows a typical near-surface gradient in the upper 240 feet, produced by conductive dissipation of heat from the gravel aquifer to ambient surface temperature (air temperature was about -10° C on January 16, 1981, the date of the log). The upper surface of the gravel is not sharply delineated by the log, probably due to the high thermal conductivity of the well casing. Below the bottom of the casing at the bedrock-gravel contact, temperature drops off sharply, rising again as water-producing zones in bedrock are encountered at greater depth. As noted during the drilling operation, there is an inverse relationship between depth and temperature; the deeper the producing zone, the cooler the water. Intervals on the temperature log over which changes are very slight--less than about 0.01° C per 10 feet--are indicated on Plate I as water producing zones, most of which correspond to zones in which water in highly fractured bedrock was noted to have been encountered during drilling. The detailed temperature log is found in Appendix C. Using this log data and flow measurements taken during drilling, depths and approximate yields of producing zones are summarized in Table 1. Some fractures are apparently highly permeable, yielding 100 to 300 gpm over a zone less than ten feet thick. Other fractures logged as "clay washes" during drilling did not apparently increase water flow during drilling operations and are not apparent as isothermal segments of the temperature log. According to field flow measurements, no additional water-producing zones were encountered below 667 feet, assuming that a six-inch pipe at 10 psi is capable of producing, by Bernoulli's Theorum, up to 3,300 gpm maximum yield.

TABLE 1. WATER PRODUCING ZONES

IN CAMPAQUA TEST WELL #1.

PICKED FROM GEOPHYSICAL TEMPERATURES AND DRILLING LOGS;

TEMPERATURES FROM THERMAL LOG ZONE

DEPTH IN FEET	FLOW (gpm)	TEMPERATURE (^{o}C)
282-295 ft.	12 gpm	46.4^{o}
345-346 ft.	88 gpm	45.3^{o}
406-409 ft.	225 gpm	43.4^{o}
430-440 ft.	40 gpm	41.9^{o}
466-468 ft.	35 gpm	41.4^{o}
488', 529'-538', 570'-578'	350 gpm	40.7^{o}
640'-650', 662'-678' 685'-690'	50 gpm	40.8^{o}

7.3 GEOLOGY OF THE DRILL CUTTINGS

To date the drill cuttings have been subjected to only cursory examination, but the results may have significance for an understanding of the subsurface geology as it relates to the geothermal resources. Since air rotary drilling was used, sample recovery was in the approximate size range 0.1 - 3 mm.Easily washed, finer grains and precipitates were lost during fluid circulation. Occasionally, due to the strongly jointed nature of the brittle Belt sedimentary rocks, larger fragments of rock, from 1 - 10 cm long, reached the surface without being crushed by the bit or drilling string. Eleven of these were selected for thin section examination, to determine primary lithology and to examine secondary fracture-filling phases. Approximately 100 g of cuttings were retained from each five-foot drilling interval and qualitatively examined under a binocular microscope. More detailed petrologic examination of the cuttings including powder diffractometry of mineral unknowns, is pending.

The two primary lithologies of the Ravalli Group rocks are (1) phyllitic shale (argillite), composed of quartz, fine-grained muscovite and sericite, some feldspar, and minor pyrite of apparent diagenetic origin, and (2) well-sorted cemented quartzite and siltite with minor interstitial muscovite. In both lithologies are commonly found fresh, equant porphyroblasts of biotite, which grew in random orientation during the greenschist facies metamorphism. Stratigraphic variations within this section occur in the type of interstratification of these two lithologies, but not in their petrologic character. Drill-hole cuttings were too fine for observation of sedimentary structures.

The Ravalli Group rocks in this hole are cut by fractures filled with a suite of secondary minerals, including very fine-grained silica (chalcedony) of sucrosic texture, calcite, and at least one occurrence of a low-temperature zeolite, either heulandite or clinoptilolite. Mineral unknowns include various sulfides which have been tentatively identified to include covellite and chalcopyrite. In thin section, the sulfides occur in close association with the carbonates, as well as in cross-cutting relationships. This apparently hydrothermal mineralization suite is obviously later than diagenetic, but beyond this no estimate of the age, temperature, or depth and environment of their emplacement can be made at present. It can be speculated that they represent a period of hydrothermal activity that is not recent and may have been associated with the period of Oligocene tectonism and volcanism during which the Hog Heaven extrusive rocks were deposited to the north. The same fracture pathways followed by circulating hydrothermal fluids in Tertiary time could have persisted without being completely sealed to the present, allowing deep circulation of meteoric waters which recharge the modern geothermal system.

7.4 AQUEOUS GEOCHEMISTRY

Water samples were taken from producing zones in the gravel (at 254 feet and 264 feet) and in bedrock (at 324 feet, 362 feet, 423 feet, and 578 feet). The samples from the gravel represent point depths, as the casing was being driven directly behind the bit. The samples from bedrock producing zones were cumulative, as the well was drilled open hole from 264 feet to T.D. and water from all producing zones was mixed in the well.

In the upper gravel at 254 feet, water temperature is slightly higher than in the lower gravel (48.0^{O} versus 48.6^{O} from down-hole measurement). The water chemistry reflects this only slightly, with slightly higher Na^+/K^+ ratio, higher SiO_2 and higher Li^+ and B in the lower gravel sample (see Appendix D). H_2S concentrations were not determined analytically, but were detectable in the field by taste and smell, as in other nearby wells in the gravel.

The water samples from bedrock become increasingly cooler with depth, from 45.4^{O} C at 324 feet to 40.6^{O} C at 578 feet. Water chemistry reflects these cooler water temperatures, with decreasing Na^+/K^+ ratios, Sio_2, B, Li^+, Cl^-, and TDS. Values in Table 2 are calculated water quality data for each producing interval, computed using the assumption that simple mixing, without reaction, occurs in the wellbore and using measured flow rates to calculate mix proportions. H_2S concentrations were undetectable in the field by taste and smell, in contrast to the water in the gravel. Correspondingly, Ca^{2+} and Mg^{2+} concentrations in the bedrock fracture aquifers are somewhat higher (10 to 15 mg/L versus 2 - 5 mg/L) than in the gravel aquifer, since organic matter decomposition is probably not occurring in bedrock and localized zones of calcite precipitation from aqueous solution probably do not occur.

Both the silica and Na-Ca-K geothermometer indicate gradually lower temperatures with depth. Using chalcedony as an equilibrium species, silica temperatures decrease from 56 - 68^{O} C in the gravel to 55 - 60^{O} C in bedrock. These silica concentrations are the product of mixing with cold water and therefore are minimum values. Cation geothermometer calculations show an even more drastic decrease in the bedrock aquifer, from 110^{O} - 128^{O} C to 74^{O} - 80^{O} C, attributable to the loss of Ca^{2+} in the gravel aquifer. Due to this Ca^{2+} loss, the cation geothermometer is probably invalid not only here but elsewhere in the valley for wells tapping the gravel.

TABLE 2. Calculated Water Quality Data from Individual Producing Fracture Zones in LB-141 (see Table 1 for Flow Volumes used in Calculation)

Sample Depth	Major Producing Interval(s)	T°C	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	Mn	SiO_2	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	F^-
324'	282-295'	45.6	10.7	2.1	139.	2.9	0.22	0.027	38.8	348.	35.9	<0.1	.12	4.59
362 '	343-346'	47.2	12.5	2.4	131.	3.5	0.06	0.046	38.5	345.	35.4	<0.1	.096	4.53
423'	406-409'	44.9	12.6	2.4	129.	3.1	0.36	0.008	37.3	344.	35.5	0.1	0.051	4.63
578	430-468' 529-538' 570-578'	43.7	12.7	2.4	125.	3.4	.003	.016	33.5	342.	35.1	0.1	.017	4.05

	S.C.	TDS	B	Cu	Mo	Sr	Ti	Zn	Li	As	Al	Ag	Cd	Cr	Pb	V	Zr	Ni
324'	657	582	0.63	<.002	<.02	0.17	<.001	.006	.050	<.0001	<.03	<.002	<.002	<.002	<.04	< .001	<.004	<.01
362'	651	573	0.62	.003	.02	0.24	<.003	.003	0.60	<.0001	<.03	<002	<.002	< .002	<.04	< .001	<.004	<.01
423'	659	568	0.60	<002	<.02	0.259	<.001	.009	.059	<.0001	<.03	<002	<.002	< .002	<.04	< .001	<.004	<.01
578'	654	559	0.52	<002	<02	0.268	<.001	.014	.059	<.0014	.03	<002	<.002	< .002	<04	< .001	<.004	<.01

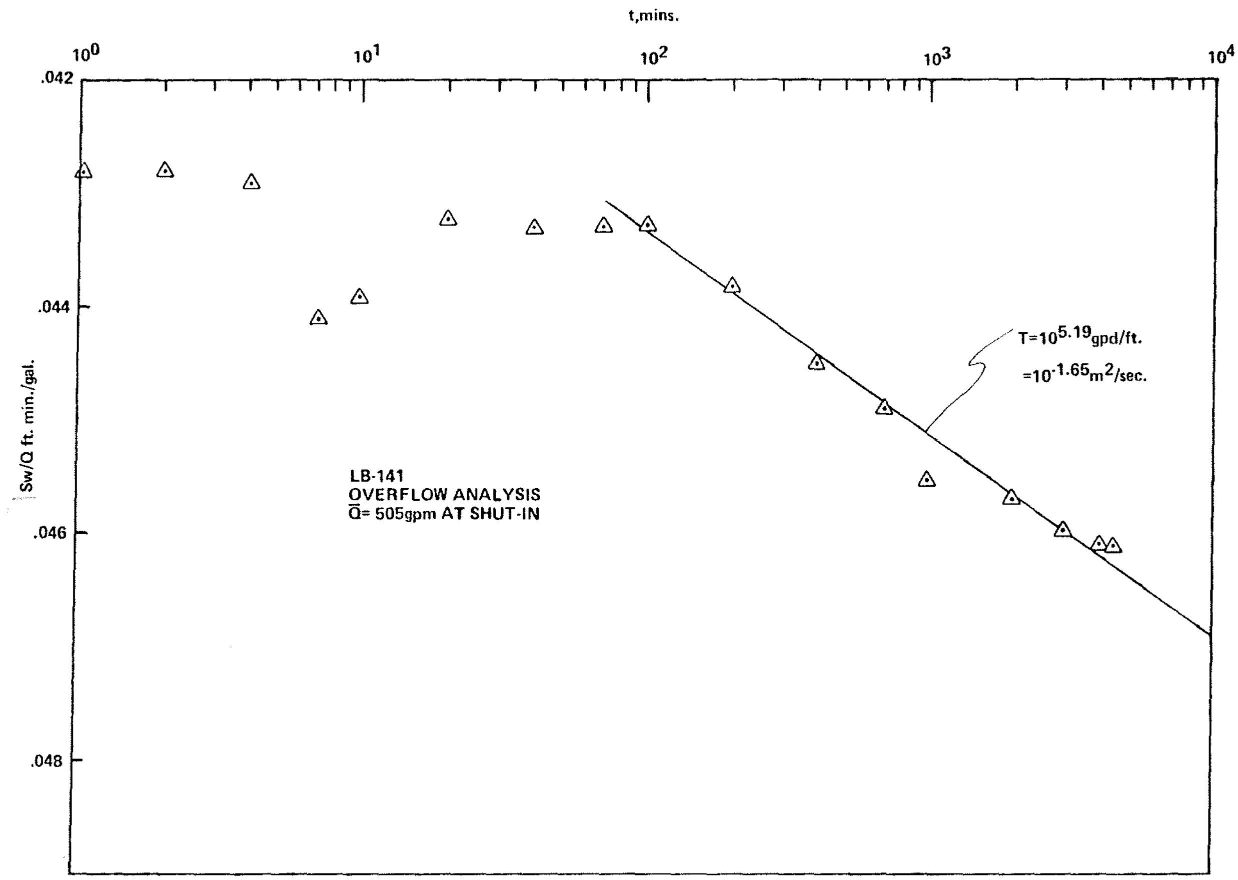

Figure 14. Jacob semi-log plot of time is discharge for flow test of LB-141. Constant drawdown is assumed after the first hour of flow; see Jacob and Lohman (1952).

Table 3. Flow Data
LB - 141 Flow Test
4-14-81 to 4-17-81

Elapsed time (mins)	Mid-flow estimate, gpm	S_w/Q
0.5	543	.0425
1	540	.0428
2	540	.0428
4	539	.0429
7	524	.0441
10	528	.0438
20	535	.0432
40	534	.0433
70	533	.0433
100	533	.0433
200	528	.0438
400	519	.0445
700	514	.0449
1000	508	.0455
2000	505	.0457
3000	502	.0460
4000	501	.0461
4200	501	.0461

Weighted mean = 508.3 gpm

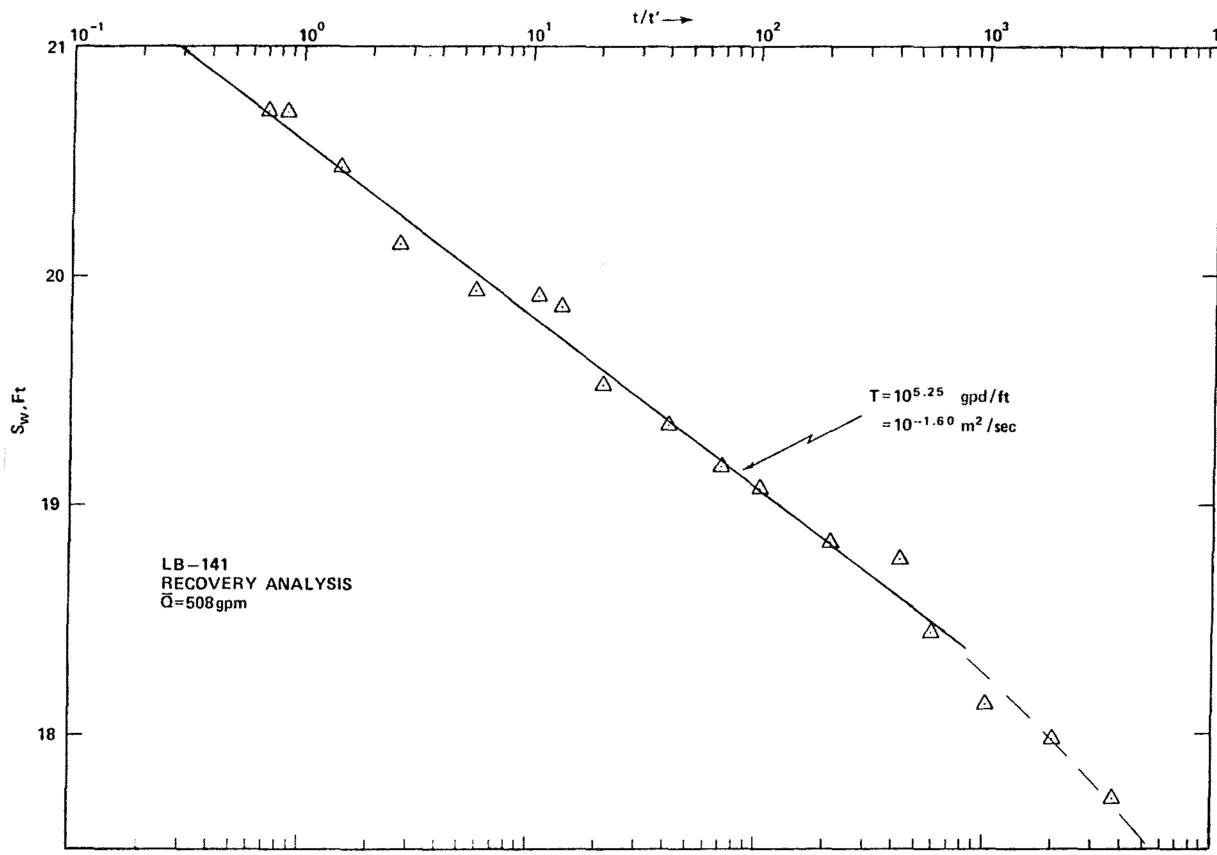

Figure 15. Jacob semi-log plot of recovery for LB-141 flow test.

8. HYDROGEOLOGICAL CHARACTERIZATION OF THE BEDROCK AQUIFER

Previous determinations of transmissivity of the gravel in the valley range from 180,000 to 300,000 gpd/foot, but these determinations were relatively imprecise due to the fact that drawdowns and recoveries were small (less than two feet) for discharges in the range of 90 - 250 gpm. Local variations in gravel thickness might be responsible for variations in transmissivity. The test well was flow-tested and recovery-tested, to determine the hydraulic characteristics of the fractured Belt rocks. In addition, two- and eight-day well recorders were set up on five nonflowing wells in the valley and continuously-recording transducers at two flowing wells to test whether or not the water in bedrock fractures is hydrologically continuous with water in the gravel; also, drawdown data from these wells could be used to obtain a single distance-drawdown estimate of the macroscopic transmissivity of the gravel aquifer as a whole.

From 4/14/81 to 4/17/81, the test well (LB-141) was allowed to flow under its own head for 70 hours. No other irrigation wells in the valley were flowing more than minor amounts (>10 gals/minute). Flow was diverted through a six-inch diameter pipe fitted with a paddle-wheel type flow sensor connected to a continuous recorder. Due to friction along the well casing, flow varied over a period of seconds, exhibiting short-term fluctuations of up to 30 gals/minute. Instantaneous flow estimates were derived from the continuous record at the midpoint of the instantaneous fluctuations. Table 3 shows flow estimates derived for overflow analysis. Flow ranged from an initial 543 gals/minute to 501 gals/minute after 70 hours. A time-weighted mean flow for the test is 508 gals/minute. Using this mean flow estimate and the slope of the line fitted to a Jacob plot of the data (Figure 14), a transmissivity estimate of 155,000 gpd/foot was derived for the bedrock fracture zone from which this well produces water. Recovery data following shut-in of LB-141 (Table 4, Figure 15) yield an estimate of 178,000 gpd/foot, in reasonable agreement with the overflow data.

Observations of water levels at four nonflowing wells (LB-13, LB-86, LB-67, and LB-208) and two flowing wells (LB-32 and LB-7) confirmed that these wells were in hydrologic continuity with LB-141 (Figure 3). One observation well on the valley margin, LB-101, is either silted in and plugged or not in direct continuity with the main gravel bed beneath the valley. The continuity of the other wells confirms that the bedrock fractures from which LB-141 produces warm water are in intimate connection with the gravel bed tapped by the

Table 4. Recovery Data,
LB - 141

Final Q = 505 gpm
Time Flow = 69.5 hrs (4170 mins)
0 - 50 psi; Transducer
Zero = 4 mV.
Scale = 2 mV./psi

Time (mins)	psi	mV	Head, ft.	t/t^1 (t=69.5 hrs)
0.2	7.52	19.03	17.36	20,850
0.5	7.52	19.03	17.36	8,340
0.7	7.53	19.06	17.39	5,957
1.0	7.68	19.35	17.74	4,170
1	7.68	19.35	17.74	4,170
2	7.77	19.54	17.95	2,085
4	7.85	19.70	18.13	1,042
7	7.99	19.98	18.46	596
10	8.12	20.23	18.75	417
20	8.16	20.31	18.84	208.5
40	8.26	20.51	19.07	104.2
70	8.37	20.74	19.33	59.6
100	8.42	20.83	19.44	41.7
200	8.46	20.91	19.53	20.9
300	8.61	21.21	19.88	13.9
400	8.63	21.25	19.92	10.4
700	8.63	21.26	19.94	6.0
1600	8.72	21.44	20.14	2.6
3000	8.87	21.73	20.48	1.39
5000	8.97	21.94	20.72	0.83
5700	8.97	21.94	20.72	0.73

other wells throughout the valley. This directly affects the interpretation of the geothermal flow system and recommendations for future geothermal exploration and development, as will be discussed in greater detail below.

A distance-drawdown plot for the observation wells after 60 hours of flow at LB-141 (Figure 16) yields a straight line transmissivity estimate of 257,000 gpd/foot, based on a fit through observation wells farther away than one mile only. Apparently this line does not intersect LB-32, the well at Campaqua, where drawdown was greater than might have been expected from this transmissivity value. This is interpreted to be due to a slight thinning of the gravel bed over the bedrock high defined by the gravity and seismic data in the Campaqua area. Few wells fully penetrate the gravel beneath the lake beds, and so data is sparse; however, LB-222 at Lonepine penetrated into Tertiary sediments, logging the gravel bed thickness at 56 feet; at LB-44, south of Campaqua, it was logged at 31 - 46 feet thick; at LB-26, east of Campaqua, it was logged as absent; and at LB-141, the test well, it was logged at 23 feet thick. Therefore, the transmissivity of the gravel in the immediate vicinity of Campaqua is probably somewhat less than it is elsewhere in the valley.

With regard to the regional hydrogeology, it is important to note that any wells drilled as geothermal production holes into the gravel bed would be in hydrologic continuity with all the other irrigation wells in the valley, as well as domestic and stock wells; and would, in the Campaqua area, exhibit transmissivities in the range from about 200,000 to 250,000 gals/day/foot of drawdown. With regard to predicting drawdowns on other wells in the area due to utilization of geothermal water, use of the transmissivity estimate derived from the distance-drawdown method (257,000 gals/day/foot) would probably be justifiable.

The producing bedrock zone in the test well is in hydrologic continuity with the overlying gravel bed even though the well is cased through the gravel, and it is apparent that water is leaking downwards into the open-hole portion of the well (deeper than 264 feet) through rather permeable bedrock fractures in the Ravalli Group rocks. The observed transmissivities for drawdown and recovery at the test well are only slightly lower than the transmissivity of the gravel bed determined by distance-drawdown.

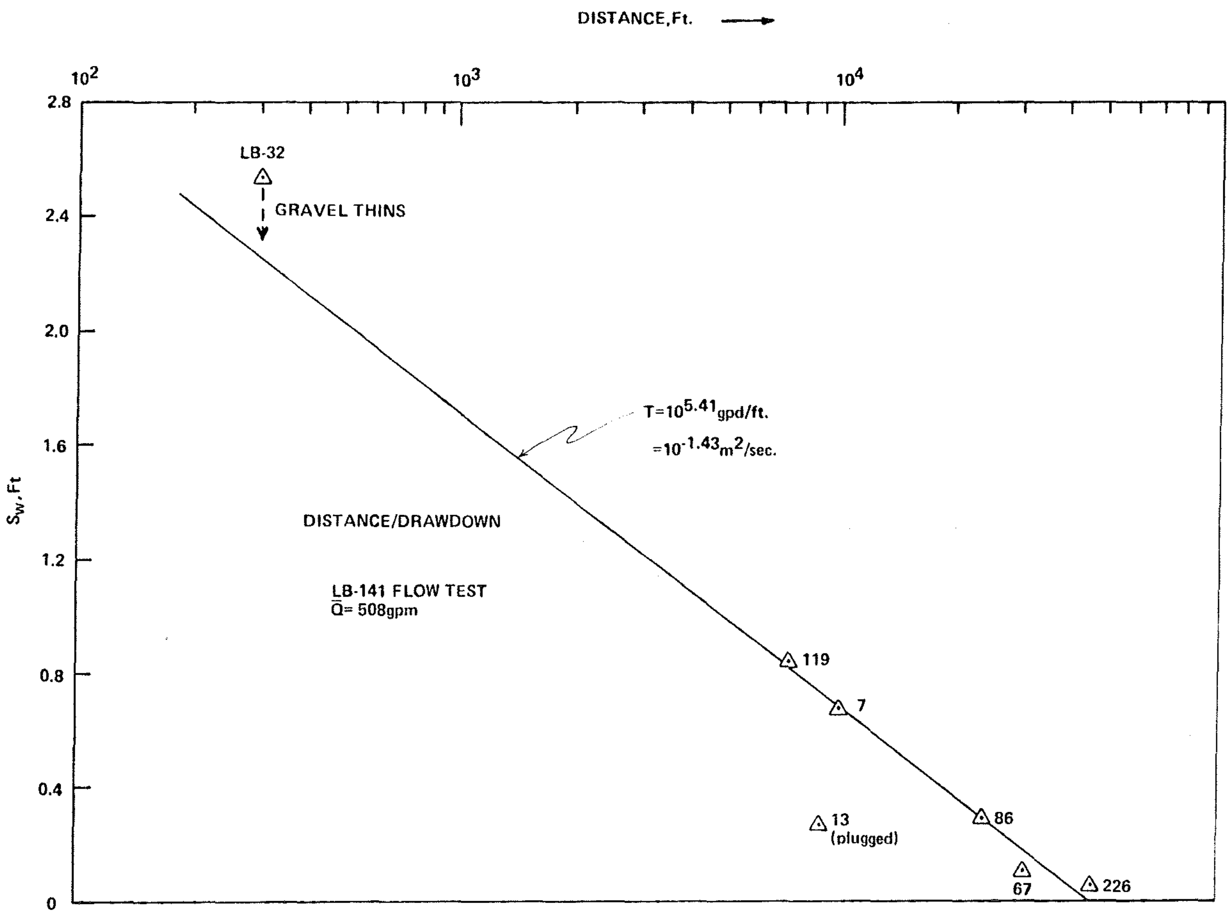

Figure 16. Semi-log plot of distance vs. drawdown for observation wells during LB-141 flow test, at time = 72 hours after beginning of flow test. LB-101 did not show similar response to the stress as the other wells and is assumed to be partially plugged. LB-32 shows slightly greater drawdown than would be expected by the straight-line fit to the other observation wells; this is interpreted as local transmissivity variation, probably thinning of the aquifer.

9. INTERPRETATION OF DRILLING RESULTS

Observations on the test hole can be summarized as follows:

1. Bedrock is overlain directly by Pleistocene glacial gravels; Tertiary sediments were either not deposited on or were eroded away from the bedrock high outlined by the gravity data.

2. The fractures in bedrock yield warm water in hydrologic continuity with the overlying gravel, as confirmed by the flow test.

3. Water-bearing fractures are encountered at various depths in the hole; the deeper the fracture, the cooler the water.

4. Deeper than about 600 feet - below the upper 340 feet of bedrock - no additional water is encountered, even though fractures filled with soft easily-drilled material are encountered repeatedly.

5. Below about 600 feet, the temperature gradient is essentially isothermal.

The fact that water temperature and concentration of chemical geothermal indicators decrease with increasing depth in bedrock strongly suggests that the hot water is transported downward from the gravel through subhorizontal fractures, probably bedding planes, and not from below along the fracture system carrying hot geothermal water from depth. The geophysical logs indicate that permeable bedrock fractures occur every 20 to 50 feet in the upper 400 feet of bedrock. If these were bedding plane fractures dipping towards the east, then they could be transporting water downwards from the gravel bed to the west where water temperatures are progressively cooler (Figure 13).

The deeper the bedrock bedding plane fractures, the farther to the east, away from the drill site the fracture intersects the gravel and the cooler the water temperatures. However, below a depth of about 600 feet fractures are encountered in bedrock, detectable both by low-gamma kicks and by zones of grey wash logged during drilling (Plate I). At some depth, these fractures must cease to be in communication with the gravel in the updip (west) direction, as the bedrock surface slopes off to the west steeply to the west of the drill site and is overlain by a thickness of less permeable Tertiary sediments which probably act as an aquitard between the gravel and bedrock. In the downdip (east) direction, however, there is no discernible leakage of hot water up from the main fault system into the wellbore at any depth, despite the presence of bedding-plane fractures. An interpretation which fits this observation is that the grey mud wash material encountered in deeper bedrock fractures represents fracture-filling minerals of hydrothermal origin which have precipitated from conductivity cooling water peripheral to the main zone of fluid ascent (Figure 17). Hot water must still be rising directly up the fault zone in quantity, as temperatures in the gravel have remained constant over the years since about 1916 and do not exhibit short-term variability during 2 to 4 day flow periods at over 400 gpm. However, apparently the fault zone has been sealed off from lateral communication with bedrock fractures by a halo of hydrothermal mineralization. Therefore, future attempts at intersecting the hot water source may demand drilling immediately above the trace of the main fault system at the base of the gravel. The test well itself did not encounter this major fracture zone because it is probably located too far to the west of the fault to intersect it within the 1,002 feet drilling depth.

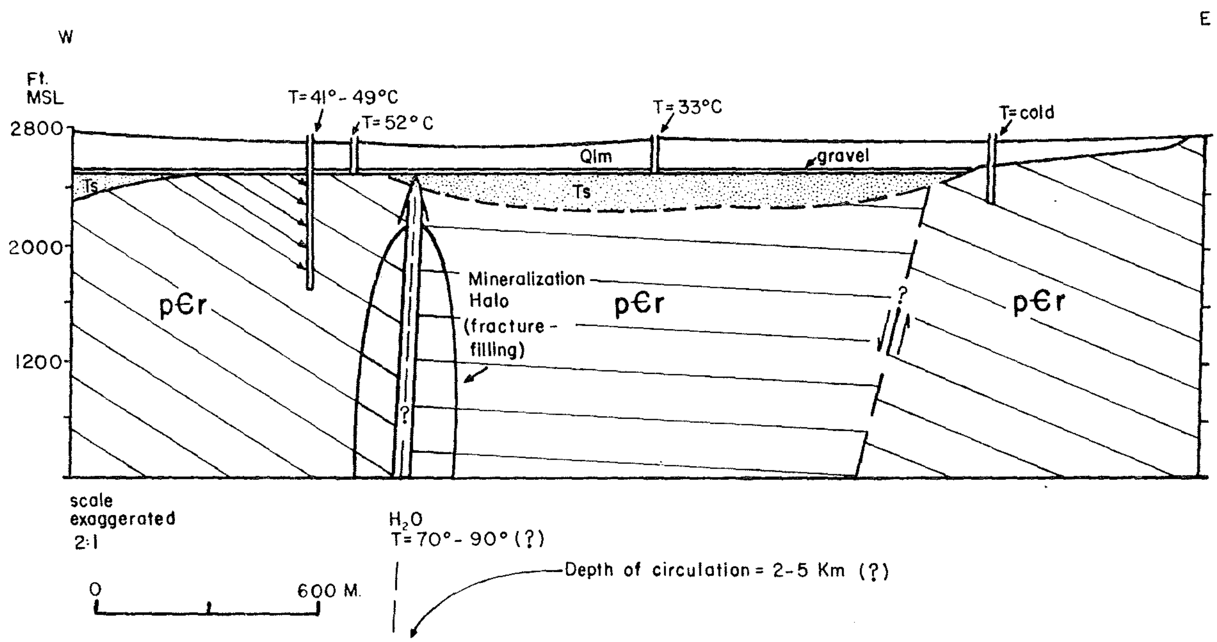

Figure 17. Schematic east-west cross section across Campaqua geothermal zone, showing conjectured ascent path of geothermal fluids, hydrothermal mineralization halo and connectivity of bedrock fractures with overlying gravel.

10. SUMMARY AND CONCLUSIONS

The test well was unsuccessful in its goal of drilling into and evaluating the bedrock fracture system transporting geothermal waters upward into the shallow Little Bitterroot aquifer. It did encounter large volumes of warm water (40.6° to 46.4° C) in bedrock bedding plane fractures, which probably percolates down from the gravel bed overlying bedrock. The thermal regime over most of the depth of the well is dominated by convective heat transport by water; there is no evidence for a shallow heat source beneath the site at depth. In the bottom 200 to 300 feet of the hole, where apparently no water is produced from fracture zones, the temperature gradient is very close to isothermal, about 1.6° C/km, much lower than the "normal" geothermal gradient of about 25° C/km for this area. This suggests that isotherms are nearly vertical and compressed around a hot convective transport system, operating along vertical or sub-vertical fractures. The precise location of the intersection of these fractures with the gravel bed is unknown, but is probably to the east of the test well. These fractures may be very steeply dipping.

The composite temperature of water from all producing zones in bedrock is 43.9° C, making the water suitable for only low temperature applications. The quantity of water available under flowing conditions without assistance of pumping should be between 350 and 600 gpm, depending on pressure in the aquifer, which is transient during and after the irrigation season. This value could be increased about 20 percent by removing the two inch sealed liner from the hole. Production from this well is in direct connection to water in the gravel aquifer, and this well and flowing irrigation wells will interfere with each other during the irrigation season. Possibly, the well could be used for direct heating applications in the winter season without interfering with irrigation usage, as long as the well is not used past mid-April or so in order to allow the aquifer to recover.

The lack of success of this test well does not preclude discovery of a hotter (60 to 90° C) water source in the vicinity of Campaqua; in fact, the isothermal segment at the bottom of the hole suggests that the hot water upwelling along the boundary fault is close enough to affect the thermal gradient in the test well. However, the fault associated with the hot water movement is, in all likelihood, steep or even vertical and another test well should probably not be sited before highly detailed thermal prospecting studies give a very precise indication of the configuration of the fault-related thermal anomaly in the gravel bed in Section 29. A suggested approach for such prospecting would be as follows:

1. Establishment of a sampling grid on approximately 200 foot centers, over the area east of the test well and old Campaqua well on the west side of the river.

2. Surveying of elevations for these stations.

3. Bouguer gravity at these stations.

4. Ground level magnetics at these stations.

5. Drilling of ten foot deep auger holes and installation of sensitive calibrated 0 to 30^{0} C thermistors at the bottom of each hole, in an attempt to localize "hot spots" in the gravel and to estimate temperatures using thermal conductivities from this well.

The above approach should give sufficient information to allow delineation of the intersection of the hot water fracture(s) with the gravel bed. Without such additional information, future drilling into bedrock for hot water (>60^{0} C) would probably be speculative and a poor financial risk.

APPENDIX A

Drilling Summary of

Campaqua Test Well No. 1 (LB-141)

Drilled 12/5/80 to 1/10/81

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WELL OWNER: Jay Gossett
Aurora, Illinois

WELL LOCATION: T. 22 N., R. 23 W., sec. 29 BADD

TOTAL DEPTH: 1002 feet

COMPLETION: +0.5'-104', 8 5/8" casing, no perforations, cemented in with nine sacks cement

+2.5'-264', 6 5/8" casing, no perforations, cemented in with two sacks cement

+2.5'-980', 2 3/8" liner, sealed bottom, no perforations, (for logging tools)

264'-1002', open hole 6 7/8"

T.D. 1002'

CONDENSED WELL LOG:

0-57'	Light to medium brown moist friable silt and silty clay
57'-138'	Dense rubbery medium to dark brown silty clay and clay
138'-140'	Dark brown clay, sharp angular gravel fragements
140'-180'	Dense rubbery medium to dark brown clay
180'-205'	Brown and grey-brown silty clay and clay
205'-239'	Grey to bluish-grey soft rubbery clay, thin sand seams
239'-240'	Thin hard cap rock
240'-264'	Gravel, interbedded sand
264'-1002'	Fine grained grey-green and blue-grey argillite with inter-bedded quartzite; major water-bearing fractures at

282' (5 gpm)
286' (20 gpm)
395' (15 gpm)
345' (90 gpm)
406'-409' (225 gpm)
430'-440' (40 gpm)
466'-468' (35 gpm)
529'-538', 570'-578' (350 gpm)
640'-690' (50 gpm)

SWL on 1/12/81 10.20 psi (+23.6 ft.)

TOTAL YIELD: 750-800 gal/min from bedrock (before 2" liner set) (no perforations in gravel)

500-550 gpm (after 2" liner set)

NOTE: Water producing zones in bedrock are hydrologically connected to the overlying gravel bed.

PUMPING WATER LEVEL: +20.6 ft. after 70 hrs. flow at 500 gpm.

APPENDIX B

Detailed Drilling Log of LB-141

MONTANA BUREAU OF MINES AND GEOLOGY

WELL LOG B4DD

GROUND WATER DIVISION

County SANDERS Location: T. 22N R. 23W Sec. 29 Tract ~~BADD~~ Hole name or number LB-141 CAMPAQUA TEST #1

Hole location

Recorded by JD - AM - PN - RN Date hole started 12/5/80 Date hole completed 1/10/81 Driller Dave Billmayer FRANK CREEK Drilling company Billmayer Water Supply Kalispell, MT

Total well depth (ft.) 1002' Well diameter(s) +3.3' = 104' 8" / +3.3' - 264' 6" Casing diameter(s) and length(s)

Type of casing(s): (A) Steel (black) B. Steel (gal.) C. Plastic D. Open hole E. Wood cribbing F. Other (specify)

Weight or gage of casing

Method-perforated or screened: A. No casing in hole B. Open bottom only C. Slotted with Mill's knife D. Slotted with a torch E. Screened by pulling casing F. Other (specify) OPEN BOTTOM

Interval-perforated or screened: 0-104' 8 5/8" casing, 10' hole/104'-264' 6 5/8 " casing, 6 5/8" hole 264'-1002' 6 5/8" open hole, No perforations -

Has or will well be test pumped? (Yes) No Were material samples taken? (Yes) No 5' intervals Was a water sample(s) taken? (Yes) No at depths 255' - 261', 324', 362', 423', 578',

Remarks

400 gpm
282 - 5gpm
290 - 20gpm
300 - 15gpm
345 - 60gpm
406-420 - 700-50
466 75gpm
510-518 300 gpm

Note:-This log is designed to supplement the well inventory sheet (ABC cards). A well inventory sheet must be filled out to have a complete record for the well. Test pumping data should be recorded on an aquifer form.

DRILLING LOG

From	To	Geological, drilling, and water conditions; remarks and sampling	Gravel c	Gravel f	Sand vc	Sand c	Sand m	Sand f	Sand vf	silt	clay
0'	8'	DRY LT. BROWN TO BUFF SILT AND CLAYEY SILT - FLECKS OF WHITE ALKALI								80	20
8'	37'	VERY LT. BROWN TO LT. BROWN SILTY CLAY AND CLAYEY SILT, MOIST - NO PEBBLES IN CLAY.								30	70
37'	57'	VERY LT. BROWN TO LT. BROWN LOOSE FRIABLE SILTY CLAY, BECOMING DARKER BROWN WITH DEPTH								40	60
57'	88'	DENSE RUBBERY LT. TO MEDIUM BROWN CLAY - CUTTINGS IN SMALL CHUNKS - HARD LAYER @ 57'								40	60
88'	100'	MEDIUM TO DARK BROWN DENSE RUBBERY CLAY, CUTTINGS IN HARD CHUNKS - HARD LAYER @ 96'								40	60
100'	120'	MED. TO DARK BROWN CLAY AND SILTY CLAY, CUTTINGS ½"-1" DIAMETER, NO SAND								40	60
120'	132'	VERY SOFT MEDIUM TO DARK BROWN CLAY, DRILL STRING SINKS UNDER OWN WEIGHT								40	60
132'	140'	MEDIUM TO DARK BROWN CLAY, W/VERY SHARP ANGULAR GRAVEL OR ROCK FRAGMENTS ¼' to 1" DIAMETER (POSS. ICE-RAFTED) -	10							35	55

DRILLING LOG

From	To	Geological, drilling, and water conditions; remarks and sampling	Gravel c	Gravel f	Sand vc	Sand c	Sand m	Sand f	Sand vf	silt	clay
			Estimated composition, %								
140'	180'	MEDIUM TO DARK BROWN CLAY, SILTY CLAY, NO SAND OR GRAVEL - CUTTINGS RECOVERED IN VERY SMALL (<½") CHUNKS								40	60
180'	190'	BROWN TO GREY-BROWN SILTY CLAY AND CLAYEY SILT - NO SAND OR PEBBLES								60	40
190'	200'	MED. BROWN TO GREY-BROWN CLAYEY SILT AND SILTY CLAY - SOME SMALL QUARTZITE FRAGMENTS								60	40
200'	205'	GREY TO GREY-BROWN CLAY AND SILTY CLAY, NO SAND								40	60
205'	215'	MED. GREY TO BLUISH-GREY RUBBERY CLAY, NO SILT - SOME THIN (2%) SAND STREAKS, CASING SINKS VERY EASILY - GOOD CUTTING RECOVERY, CHUNKS UP TO 4" LONG				2	2			10	86
215'	239'	VERY FINE GREY TO BLUE-GREY CLAY, FINE SAND IN THIN STREAKS				CLAY				10	90
						SAND			60	20	20
239'	240	VERY HARD "CAPROCK" - NO CUTTINGS RECOVERED - DRIVE HAMMER REBOUNDS ON IMPACT - MAY BE SULFIDE-INDURATED BLUE CLAY									
240'	244'	BLUE SAND AND GRAVEL, COBBLES UP TO 4" SOME LARGE BOULDERS AT 241'									
		WATER 200-400 gpm									
		TEMP = 120.5°F MEASURED AT DEPTH = 255'									
		PRESSURE = GL + 28'									
244'	258'	SAND AND GRAVEL, COBBLES - WATER									
		COBBLE COMPOSITION - ARGILLITE: 60%	30	15	15	30	10				
		RED CLAYSTONE: 15%									
		QUARTZITE: 20%									
		ANDESITIC VOLCANICS: 3%									
		GNEISS & METAMORPHICS: 2%									
258'	261'	COARSE TO MEDIUM SAND, WELL SORTED - SOME GRAVEL	10	5		35	40	10			
		WATER									

MONTANA BUREAU OF MINES AND GEOLOGY

WELL LOG B4DD

County SANDERS Location: T. 22N R. 23W Sec. 29 Tract ~~BADD~~ Hole name or number LB-141

Hole location 375' NW of CAMPAQUA WELL

Recorded by JD Date hole started 12/5/80 Date hole completed ______ Driller ______ Drilling company ______

Total well depth (ft.) ______ Well diameter(s) ______ Casing diameter(s) and length(s) ______

Type of casing(s): A. Steel (black) B. Steel (gal.) C. Plastic D. Open hole E. Wood cribbing F. Other (specify) ______

Weight or gage of casing ______

Method–perforated or screened: A. No casing in hole B. Open bottom only C. Slotted with Mill's knife D. Slotted with a torch E. Screened by pulling casing F. Other (specify)

Interval–perforated or screened: 0-104' 8 5/8" casing, 10" hole/104'-264' 6 5/8" casing, 6 5/8" hole 264'-1002' 6 5/8" open hole, No perforations

Has or will well be test pumped? Yes No Were material samples taken? Yes No Was a water sample(s) taken? Yes No

Remarks 0-104' cemented in 8 sacks through hole from bottom, poured 3 sacks around casing from top.

Note:–This log is designed to supplement the well inventory sheet (ABC cards). A well inventory sheet must be filled out to have a complete record for the well. Test pumping data should be recorded on an aquifer form.

From	To	DRILLING LOG Geological, drilling, and water conditions; remarks and sampling	Estimated composition, % Gravel c	Gravel f	Sand vc	Sand c	Sand m	Sand f	Sand vf	silt	clay
261'	263'	COARSE GRAVEL AND COBBLES, SOME SAND WATER	30	20	20	20	10				
263'	264'	MUCH FINE TO MEDIUM GRAINED SAND, SOME GRAVEL WATER		10		10	30	40	10		
		@ 264' WATER SAMPLE T = 120.8°F									
		FLOW = 200-400 gpm									
		6" CASING SET TO 254' - DRILLING CONTINUES OPEN HOLE	DRILLING RATE (MIN./FT.)								
264'	276'	FINE-GRAINED GREY-GREEN ARGILLITE INTERBEDDED QUARTZITE, SULFIDES (PYRITE) ALONG BEDDING PLANE CLEARAGE - QUARTZITE IS QUARTZOFELDSPATHIC								1.25	
276'	281'	GREENISH-GREY QUARTZITE ARGILLITE PYRITE ALONG FOLIATIONS, THIN QUARTZITE STREAKS OR VEINS, THEN (<1mm) FINE FRACTURES FILLED WITH SILICA								1.75	
281	285'	GREENISH-GREY QUARTZITE AND ARGILLITE - BIOTITE FLECKS IN QUARTZITE - VERY LITTLE QUARTZITE - FLOW OF WATER FROM THIN FRACTIRES @ 282' (5gpm, pH = 9.44, S.C. = 679, T = 91°F STEEL IN COLOR = ORANGE-BROWN)									
285'	295'	GREENISH-GREY QUARTZITE, ARGILLITE - T = 106°F @ 286' TRIPPED IN WATER @ 290', FLOW = 25 gpm CUMULATIVE.								2.50	
295'	305'	GREENISH-GREY QUARTZITE, ARGILLITE W/PYRITE - TEMP = 109°F @ 295', WATER @ 300' = FLOW = 40 gpm CUMULATIVE									

DRILLING LOG

DRILLING RATE (MIN./FT.)

From	To	Geological, drilling, and water conditions; remarks and sampling	Drilling rate (min./ft.) [Estimated composition, %: Gravel c, f; Sand vc, c, m, f, vf; silt; clay]
305'	324'	GREENISH-GREY ARGILLITE INTERBEDDED QUARTZITE - PYRITE IN FRACTURES	2.50
		@ 310' T = 113°F (TRIPPED IN)	
		@ 315' T = 114°F (TRIPPED IN)	
		@ 320' T = 113°F (TRIPPED IN)	
		@ 324' T = 114°F (TRIPPED IN)	
		@ 324' T = 114.0°F (TRIPPED OUT)	
		WATER SAMPLE @ 324' FLOW = 12 gpm (NO AIR)	
		BOTTOM HOLE TEMP - 47.2°C (117.0°F)	
		pH = 7.82 S.C. = 666	
324'	370'	GREENISH-GREY ARGILLITE INTERBEDDED QUARTZITE, FINE-GRAINED FRESH FLECKS OF PYRITE -	2.50
		@ 345' WATER FLOW = 100 gpm TOTAL	
		WATER SAMPLE @ 362' pH 7.74 TEMP 117.0°F S.C. 668	
370'	406'	FINE-GRAINED GREENISH-GREY ARGILLITE, INTERBEDDED QUARTZITE	4.50
406'	420'	HIGHLY FRACTUREY GREEN-GREY ARGILLITE, GREY WASH OF CLAY FROM FRACTURES, MUCH WATER	3.50
		WATER @ 406'-409'	
		@ 420 FLOW = 300-350 gpm	
		WATER SAMPLE pH - 7.96 S.C. = 667 TEMP = 112.8°	
420'	427'	ARGILLITE, INTERBEDDED QUARTZITE	18.0
427'	440'	DENSE GREEN ARGILLITE, SEEMS OF SOFT SILICA	11.0
		WATER @ 430'-440'	

MONTANA BUREAU OF MINES AND GEOLOGY

WELL LOG

GROUND WATER DIVISION

County ______ Location: T. ______ R. ______ Sec. ______ Tract ______ Hole name or number ______

Hole location ______

Recorded by ______ Date hole started ______ Date hole completed ______ Driller ______ Drilling company ______

Total well depth (ft.) ______ Well diameter(s) ______ Casing diameter(s) and length(s) ______

Type of casing(s): A. Steel (black) B. Steel (gal.) C. Plastic D. Open hole E. Wood cribbing F. Other (specify) ______

Weight or gage of casing ______

Method—perforated or screened: A. No casing in hole B. Open bottom only C. Slotted with Mill's knife D. Slotted with a torch E. Screened by pulling casing F. Other (specify)

Interval—perforated or screened: ______

Has or will well be test pumped? Yes No Were material samples taken? Yes No Was a water sample(s) taken? Yes No

Remarks PRODUCING ZONES: 283-291, 298-301, 309-314, 333-351, 399-409 (200 gpm), 431-436, 464-470, 482-486, 570-585 (300 gpm), 640-650, 660-680, 685-690,

Note:—This log is designed to supplement the well inventory sheet (ABC cards). A well inventory sheet must be filled out to have a complete record for the well. Test pumping data should be recorded on an aquifer form.

From	To	DRILLING LOG — Geological, drilling, and water conditions; remarks and sampling	Estimated composition, % (Gravel c f; Sand vc c m f vf; silt; cl) — DRILLING RATE (MIN./FT.)
440'	475'	SAME AS ABOVE, GREEN-GREY FRACTURED ARGILLITE	11.0
		WATER AT 466'-468'	
		T = 112.5°F pH = 7.54 S.C. = 642 FLOW = 400 gpm	
475'	520'	GREENISH-GREY ARGILLITE, INTERBEDDED QUARTZITE, BIOTITE FLECKS,	5.0
		FRACTURES, BROWN CLAY WASH @ 488'	
520'	578'	GREENISH-GREY ARGILLITE, INTERBEDDED QUARTZITE, BIOTITE FLECKS,	5.0
		BIOTITE FLECKS, FRACTURES, BROWN CLAY WASH @ 570-578'	
		WATER @ 570'=578'	
		TRIPPED OUT 578' - FLOW = 750 gal/min TEMP = 110.6°	
		pH = 7.99 S.C. - 691	
		SHUT-IN PRESSURE = 10.50 psi, BUDDING TO 11.20 psi	
		WITHIN 2 HOURS	
578'	600'	GREY ARGILLITE - FLOW OF WATER OF GREY CLAY FROM 584'-592'	2.0
600'	675' 655?	FINE-GRAINED GREY ARGILLITE, INTERBEDDED WHITE AND GREY-WHITE	5.0
		QUARTZITE, FLECKS OF BIOTITE - SOME FINE-GRAINED FRESH PYRITE	
675' 655?	~~685'~~ 668	SOFT, HIGHLY FRACTURED QUARTZITE AND ARGILLITE, GREY CLAY WASH	3.0
		FROM FRACTURES	

DRILLING LOG

DRILLING RATE (MIN./FT.)

From	To	Geological, drilling, and water conditions; remarks and sampling	Drilling rate (min./ft.)
668	712'	DARK GREY QUARTZITE AND GREY-GREEN ARGILLITE, DENSE, NO FRACTURES EVIDENT - SOME CHALCEDONY, PYRITE, FLUORITE(?) IN CUTTINGS	6.0
		700' = TRIPPED OUT psi = 10.1 BUILDING TO 11.3	
		FLOW = 750-800 gpm	
		T = 111.4°F	
612'	733'	SOFT FRACTURED ARGILLITE, INTERBEDDED QUARTZITE - VERY SOFT FROM 716'-724' AND 728'-733' (HAD TO HOLD BACK BIT)	2-2.5
733'	788'	VERY DENSE INTERBEDDED QUARTZITE, BOTH DARK GREY AND WHITE, MICA FLAKES, INTERMITTENT SOFT WEATHERED ZONES EVERY ≈ 15'	8.0
788'	796'	SOFT GREY ARGILLITE, BLAST OF GREY CLAY	3.0
796'	890'	INTERBEDDED ARGILLITE AND QUARTZITE, SOFT ZONE AT 870'-875'	6.0
890'	910'	VERY HARD DENSE, INTERBEDDED GREY AND WHITE QUARTZITE, NO SOFT ZONES	12.0
910'	930'	INTERBEDDED GREY QUARTZITE, WHITE QUARTZITE AND GREY ARGILLITE	
930'	948'	VERY SOFT FRIABLE GREY QUARTZITE, GRUS-LIKE TEXTURE, INTERBEDDED WITH MEDIUM GREY ARGILLITE, LARGE CHUNKS OF FINE-GRAINED PYRITE - VERY SOFT FROM 935'-940'	0.5-2.0
948'	960'	DENSE GREY-BLUR AND GREY ARGILLITE, INTERBEDDED QUARTZITE; SOFT FRACTURED ZONE FROM 956'-957'	5.0
960'	980'	VERY FRIABLE DARK GREY ARGILLITE, LITTLE OR NO QUARTZITE	1.5
980'	996'	INTERBEDDED DENSE GREY ARGILLITE AND GREY QUARTZITE	8.0
996'	1002'	SOFT GREY ARGILLITE, FRACTURED	2.0
		T.D. 1002	
		WELL LEFT OPEN-HOLE FROM 263'-1002'	
		WELL PRODUCES 750'-800' gpm AT 11.0 psi	

APPENDIX C

Detailed Version of

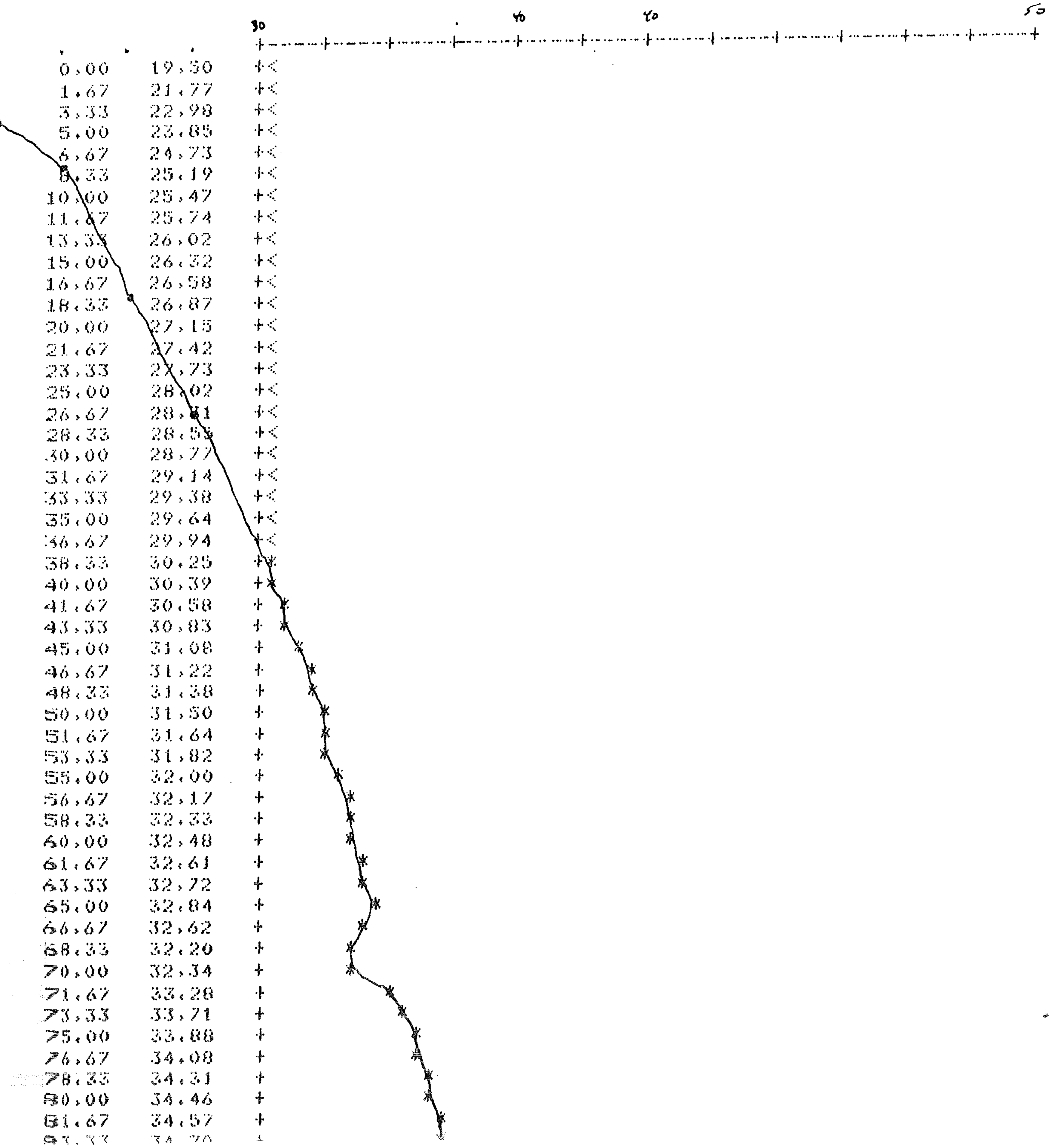
Downhole Temperature Log, LB-141,

Run 1/13/81

Surface Air Temperature = $-4^{o}C$

*
Ready

RUNGRAD
30.
50.



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11.67	25.74
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15.00	26.32
16.67	26.58
18.33	26.87
20.00	27.15
21.67	27.42
23.33	27.73
25.00	28.02
26.67	28.31
28.33	28.55
30.00	28.77
31.67	29.14
33.33	29.38
35.00	29.64
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41.67	30.58
43.33	30.83
45.00	31.08
46.67	31.22
48.33	31.38
50.00	31.50
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55.00	32.00
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60.00	32.48
61.67	32.61
63.33	32.72
65.00	32.84
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68.33	32.20
70.00	32.34
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73.33	33.71
75.00	33.88
76.67	34.08
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80.00	34.46
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140.00	39.22	+
141.67	39.36	+
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151.67	40.22	+
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156.67	40.63	+
158.33	40.79	+
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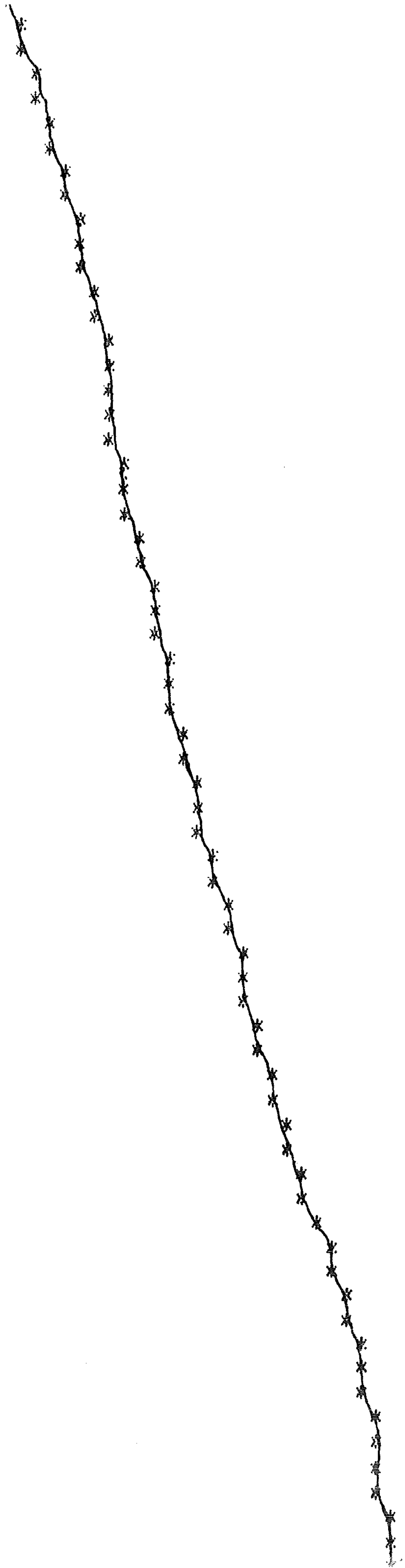

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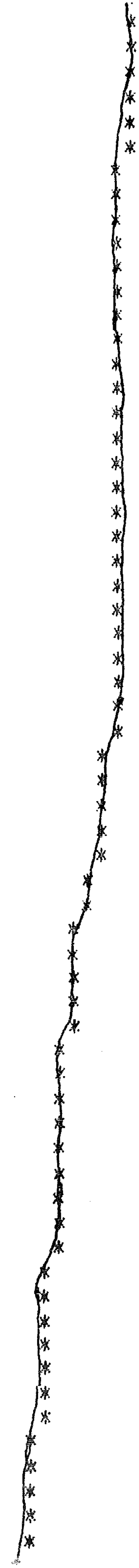

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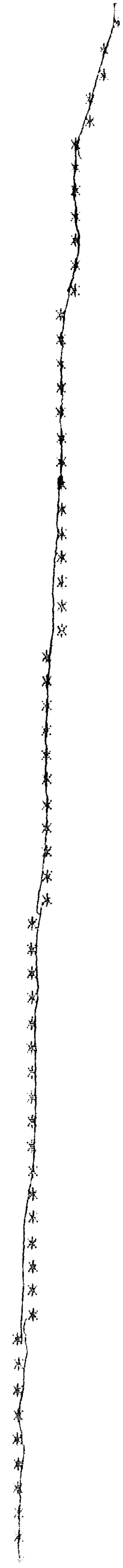

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625,00	40,71	+
626.67	40,71	+
628,33	40,71	+
630.00	40,71	+
631,67	40,71	+

638.33	40.72	+	*
640.00	40.73	+	*
641.67	40.73	+	*
643.33	40.75	+	*
645.00	40.77	+	*
646.67	40.78	+	*
648.33	40.78	+	*
650.00	40.76	+	*
651.67	40.76	+	*
653.33	40.75	+	*
655.00	40.74	+	*
656.67	40.74	+	*
658.33	40.75	+	*
660.00	40.76	+	*
661.67	40.76	+	*
663.33	40.76	+	*
665.00	40.77	+	*
666.67	40.76	+	*
668.33	40.77	+	*
670.00	40.78	+	*
671.67	40.78	+	*
673.33	40.77	+	*
675.00	40.78	+	*
676.67	40.78	+	*
678.33	40.78	+	*
680.00	40.78	+	*
681.67	40.76	+	*
683.33	40.77	+	*
685.00	40.77	+	*
686.67	40.78	+	*
688.33	40.80	+	*
690.00	40.79	+	*
691.67	40.79	+	*
693.33	40.79	+	*
695.00	40.78	+	*
696.67	40.78	+	*
698.33	40.78	+	*
700.00	40.78	+	*
701.67	40.78	+	*
703.33	40.78	+	*
705.00	40.78	+	*
706.67	40.78	+	*
708.33	40.78	+	*
710.00	40.78	+	*
711.67	40.78	+	*
713.33	40.78	+	*
715.00	40.78	+	*
716.67	40.78	+	*
718.33	40.78	+	*
720.00	40.78	+	*
721.67	40.78	+	*
723.33	40.78	+	*
725.00	40.78	+	*
726.67	40.78	+	*
728.33	40.78	+	*
730.00	40.75	+	*
731.67	40.73	+	*
733.33	40.74	+	*
735.00	40.74	+	*
736.67	40.74	+	*
738.33	40.74	+	*
740.00	40.74	+	*
741.67	40.74	+	*

748,33	40,74	+	*
750,00	40,74	+	*
751,67	40,74	+	*
753,33	40,74	+	*
755,00	40,74	+	*
756,67	40,74	+	*
758,33	40,74	+	*
760,00	40,74	+	*
761,67	40,74	+	*
763,33	40,74	+	*
765,00	40,74	+	*
766,67	40,74	+	*
768,33	40,73	+	*
770,00	40,73	+	*
771,67	40,73	+	*
773,33	40,73	+	*
775,00	40,74	+	*
776,67	40,74	+	*
778,33	40,74	+	*
780,00	40,74	+	*
781,67	40,74	+	*
783,33	40,74	+	*
785,00	40,74	+	*
786,67	40,74	+	*
788,33	40,74	+	*
790,00	40,74	+	*
791,67	40,74	+	*
793,33	40,74	+	*
795,00	40,74	+	*
796,67	40,74	+	*
798,33	40,74	+	*
800,00	40,74	+	*
801,67	40,74	+	*
803,33	40,74	+	*
805,00	40,73	+	*
806,67	40,73	+	*
808,33	40,73	+	*
810,00	40,73	+	*
811,67	40,73	+	*
813,33	40,73	+	*
815,00	40,72	+	*
816,67	40,72	+	*
818,33	40,72	+	*
820,00	40,72	+	*
821,67	40,72	+	*
823,33	40,72	+	*
825,00	40,72	+	*
826,67	40,72	+	*
828,33	40,72	+	*
830,00	40,72	+	*
831,67	40,72	+	*
833,33	40,72	+	*
835,00	40,72	+	*
836,67	40,72	+	*
838,33	40,72	+	*
840,00	40,72	+	*
841,67	40,72	+	*
843,33	40,72	+	*
845,00	40,73	+	*
846,67	40,73	+	*
848,33	40,73	+	*
850,00	40,73	+	*
851,67	40,73	+	*

858.33	40.74	+	*
860.00	40.74	+	*
861.67	40.74	+	*
863.33	40.74	+	*
865.00	40.74	+	*
866.67	40.74	+	*
868.33	40.74	+	*
870.00	40.74	+	*
871.67	40.74	+	*
873.33	40.74	+	*
875.00	40.74	+	*
876.67	40.75	+	*
878.33	40.75	+	*
880.00	40.75	+	*
881.67	40.76	+	*
883.33	40.76	+	*
885.00	40.76	+	*
886.67	40.76	+	*
888.33	40.76	+	*
890.00	40.76	+	*
891.67	40.76	+	*
893.33	40.76	+	*
895.00	40.76	+	*
896.67	40.76	+	*
898.33	40.76	+	*
900.00	40.76	+	*
901.67	40.76	+	*
903.33	40.76	+	*
905.00	40.76	+	*
906.67	40.76	+	*
908.33	40.76	+	*
910.00	40.76	+	*
911.67	40.76	+	*
913.33	40.76	+	*
915.00	40.76	+	*
916.67	40.76	+	*
918.33	40.76	+	*
920.00	40.77	+	*
921.67	40.77	+	*
923.33	40.77	+	*
925.00	40.77	+	*
926.67	40.77	+	*
928.33	40.77	+	*
930.00	40.77	+	*
931.67	40.77	+	*
933.33	40.77	+	*
935.00	40.77	+	*
936.67	40.77	+	*
938.33	40.77	+	*
940.00	40.77	+	*
941.67	40.77	+	*
943.33	40.77	+	*
945.00	40.78	+	*
946.67	40.78	+	*
948.33	40.78	+	*
950.00	40.78	+	*
951.67	40.78	+	*
953.33	40.78	+	*
955.00	40.78	+	*
956.67	40.78	+	*
958.33	40.78	+	*
960.00	40.79	+	*
961.67	40.79	+	*

```
  968.33    40.79   +                                *
  970.00    40.79   +                                *
  971.67    40.79   +                                *
  973.33    40.79   +                                *
  975.00    40.80   +                                *
  976.67    40.80   +                                *
  978.33    40.80   +                                *
  980.00    40.80   +                                *
                    +----+----+----+----+----+----+----+----+----+----+----+----+



STOP --

Ready
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APPENDIX D

Water Analyses

From LB-141 and LB-32

MONTANA BUREAU OF MINES AND GEOLOGY — WATER QUALITY ANALYSIS
BUTTE, MONTANA 59701 (406)496-4101 — LAB NO. 8002812

STATE	MONTANA	COUNTY	LAKE
LATITUDE-LONGITUDE	47038'32"N 114034'17"W	SITE LOCATION	22N 23W 29 BAUD
UTM COORDINATES	Z11 N5288750 E681985	MBMG SITE	
TOPOGRAPHIC MAP	HOT SPRINGS NE 7 1/2'	STATION ID	473832114341701
GEOLOGIC SOURCE	112GRAV* *	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	PL	LAND SURFACE ALTITUDE	2758. FT < 10
AGENCY + SAMPLER	MBMG*JJD	SUSTAINED YIELD	225. GPM
BOTTLE NUMBER	LBTEST1	YIELD MEAS METHOD	BUCKET/STOPWATCH
DATE SAMPLED	11-DEC-80	TOTAL DEPTH OF WELL	254. FT (M)
TIME SAMPLED	13:00 HOURS	SWL ABOVE(-) OR BELOW GS	31.6 FT (M)
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	6 IN (M)
DATE ANALYZED	14-JAN-81	CASING TYPE	STEEL
SAMPLE HANDLING	3120	COMPLETION TYPE	01*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	
WATER USE	RESEARCH		

SAMPLING SITE MBMG GEO. TEST WELL #1 * CAMPAQUA AREA
GEOLOGIC SOURCE

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	4.2	0.21	BICARBONATE (HCO3)	339.	5.56
MAGNESIUM (MG)	1.2	0.10	CARBONATE (CO3)	11.0	0.37
SODIUM (NA)	156.	6.79	CHLORIDE (CL)	36.1	1.02
POTASSIUM (K)	3.4	0.09	SULFATE (SO4)	.1	0.00
IRON (FE)	1.65	0.09	NITRATE (AS N)	.56	0.04
MANGANESE (MN)	.070	0.00	FLUORIDE (F)	5.2	0.27
SILICA (SIO2)	50.6		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		7.27	TOTAL ANIONS		7.26

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) -0.08

LABORATORY PH	8.71	TOTAL HARDNESS AS CACO3	15.43
FIELD WATER TEMPERATURE	49.2 F	TOTAL ALKALINITY AS CACO3	296.38
CALCULATED DISSOLVED SOLIDS	437.08	SODIUM ADSORPTION RATIO	17.28
SUM OF DISS. CONSTITUENT	609.08	RYZNAR STABILITY INDEX	8.10
LAB SPEC.COND.(MICROMHOS/CM)	693.2	LANGLIER SATURATION INDEX	0.31

PARAMETER	VALUE	PARAMETER	VALUE
TEMPERATURE, AIR (C)	-2.	ALUMINUM, DISS (MG/L-AL)	1.56
STRONTIUM,DISS (MG/L-SR)	.10	SILVER,DISS (MG/L AS AG)	<.002
TITANIUM DIS(MG/L AS TI)	.011	BORON ,DISS (MG/L AS B)	.66
VANADIUM,DISS(MG/L AS V)	<.001	CADMIUM,DISS(MG/L AS CD)	.004
ZINC,DISS (MG/L AS ZN)	.015	CHROMIUM, DISS (MG/L-CR)	<.002
ZIRCONIUM DIS(MG/L ZR)	<.004	COPPER,DISS (MG/L AS CU)	<.002
LITHIUM,DISS(MG/L AS LI)	.085	MOLYBDENUM,DISS(MG/L-MO)	<.02
NICKEL,DISS (MG/L AS NI)	<.01	LEAD,DISS (MG/L AS PB)	.04
ARSENIC,DISS(UG/L AS AS)	.8		

REMARKS: WATER DEGASSES VERY RAPIDLY - CLOUDY WITH GAS * H2S ODOR AND TASTE * LITTLE BITTERROOT GEOTHERMAL AREA * SAMPLE GRABBED FROM FREE FLOW WITH OPEN BOTTOM WHEN CASING WAS DRIVEN TO 254 FT *
LAB: BR NOT DETECTED IN CHROMATOGRAM *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

QW WA S2 WT OW PW AT OTHER
OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: — COST:
LAST EDIT DATE: 24-FEB-81 — BY: TP *CLG
PROCESSING PROGRAM: F1730P V2 (8/9/80) — PRINTED: 07-AUG-81

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3
2	1	93	1	14	0	76

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002812

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002813

STATE	MONTANA	COUNTY	LAKE
LATITUDE-LONGITUDE	47038'32"N 114034'17"W	SITE LOCATION	22N 23W 29 BADD
UTM COORDINATES	Z11 N5288750 E681985	MBMG SITE	LBTEST2
TOPOGRAPHIC MAP	HOT SPRINGS NE 7 1/2'	STATION ID	473832114341701
GEOLOGIC SOURCE	112GRAV* *	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	PL	LAND SURFACE ALTITUDE	2758. FT < 10
AGENCY + SAMPLER	MBMG*JJD	SUSTAINED YIELD	225. GPM
BOTTLE NUMBER	LBTEST2	YIELD MEAS METHOD	BUCKET/STOPWATCH
DATE SAMPLED	11-DEC-80	TOTAL DEPTH OF WELL	264. FT (M)
TIME SAMPLED	16:00 HOURS	SWL ABOVE(-) OR BELOW GS	31.6 FT (M)
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	6 IN (M)
DATE ANALYZED	14-JAN-81	CASING TYPE	STEEL
SAMPLE HANDLING	3120	COMPLETION TYPE	01*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	
WATER USE	RESEARCH		

SAMPLING SITE MBMG GEO. TEST WELL * CAMPAQUA AREA
GEOLOGIC SOURCE

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	3.4	0.17	BICARBONATE (HCO3)	341.	5.59
MAGNESIUM (MG)	.3	0.02	CARBONATE (CO3)	10.1	0.34
SODIUM (NA)	159.	6.92	CHLORIDE (CL)	35.8	1.01
POTASSIUM (K)	3.2	0.08	SULFATE (SO4)	0.4	0.01
IRON (FE)	.23	0.01	NITRATE (AS N)	.26	0.02
MANGANESE (MN)	.022	0.00	FLUORIDE (F)	5.2	0.27
SILICA (SIO2)	45.9		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		7.21	TOTAL ANIONS		7.24

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.14

LABORATORY PH	8.72	TOTAL HARDNESS AS CACO3	9.72
FIELD WATER TEMPERATURE	49.3 F	TOTAL ALKALINITY AS CACO3	296.52
CALCULATED DISSOLVED SOLIDS	431.79	SODIUM ADSORPTION RATIO	22.19
SUM OF DISS. CONSTITUENT	604.81	RYZNAR STABILITY INDEX	8.27
LAB SPEC.COND.(MICROMHOS/CM)	694.0	LANGLIER SATURATION INDEX	0.22

PARAMETER	VALUE	PARAMETER	VALUE
TEMPERATURE, AIR (C)	-5.	ALUMINUM, DISS (MG/L-AL)	.10
STRONTIUM,DISS (MG/L-SR)	.064	SILVER,DISS (MG/L AS AG)	<.002
TITANIUM DIS(MG/L AS TI)	.004	BORON ,DISS (MG/L AS B)	.64
VANADIUM,DISS(MG/L AS V)	.003	CADMIUM,DISS(MG/L AS CD)	<.002
ZINC,DISS (MG/L AS ZN)	.009	CHROMIUM, DISS (MG/L-CR)	<.002
ZIRCONIUM DIS(MG/L ZR)	.006	COPPER,DISS (MG/L AS CU)	<.002
LITHIUM,DISS(MG/L AS LI)	.083	MOLYBDENUM,DISS(MG/L-MO)	<.02
NICKEL,DISS (MG/L AS NI)	<.01	LEAD,DISS (MG/L AS PB)	
ARSENIC,DISS(UG/L AS AS)	.5		

REMARKS: WATER DEGASSES VERY RAPIDLY - CLOUDY WITH GAS * H2S ODOR AND TASTE * LITTLE BITTERROOT GEOTHERMAL TEST AREA * SAMPLE GRABBED FROM FREE FLOW WITH OPEN BOTTOM WHEN CASING WAS DRIVEN TO 264 FT *
LAB: BR NOT DETECTED IN CHROMATOGRAM *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

QW WA S2 WI OW PW AT OTHER

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 24-FEB-81
PROCESSING PROGRAM: F1730P V2 (8/9/80)

COST:
BY: TP *CLG
PRINTED: 07-AUG-81

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3
2	0	95	1	13	0	77

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002813

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002827

STATE	MONTANA	COUNTY	LAKE
LATITUDE-LONGITUDE	47D38'32"N 114034'17"W	SITE LOCATION	22N 23W 29 BADD
UTM COORDINATES	Z11 N5288750 E681985	MBMG SITE	LB-141
TOPOGRAPHIC MAP	HOT SPRINGS NE 7 1/2'	STATION ID	473832114341701
GEOLOGIC SOURCE	400PRCD*112GRAV*	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	PL	LAND SURFACE ALTITUDE	2758. FT < 10
AGENCY + SAMPLER	MBMG*JJD	SUSTAINED YIELD	12. GPM
BOTTLE NUMBER	LBTEST3	YIELD MEAS METHOD	BUCKET/STOPWATCH
DATE SAMPLED	15-DEC-80	TOTAL DEPTH OF WELL	324. FT (M)
TIME SAMPLED	22:00 HOURS	SWL ABOVE(-) OR BELOW OS	FLOWING
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	6 IN (M)
DATE ANALYZED	20-JAN-81	CASING TYPE	STEEL
SAMPLE HANDLING	3120	COMPLETION TYPE	10*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	261 TO 324 FT
WATER USE	RESEARCH		

SAMPLING SITE MBMG GEO. TEST WELL #1 * CAMPAQUA AREA
GEOLOGIC SOURCE PRICHARD FORMATION OR SLATE

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	10.7	0.53	BICARBONATE (HCO3)	348.	5.70
MAGNESIUM (MG)	2.1	0.17	CARBONATE (CO3)	0.	
SODIUM (NA)	139.	6.05	CHLORIDE (CL)	35.9	1.01
POTASSIUM (K)	2.9	0.07	SULFATE (SO4)	<.1	
IRON (FE)	.22	0.01	NITRATE (AS N)	.12	0.01
MANGANESE (MN)	.027	0.00	FLUORIDE (F)	4.59	0.24
SILICA (SIO2)	38.8		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		6.84	TOTAL ANIONS		6.97

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.61

LABORATORY PH	8.18	TOTAL HARDNESS AS CACO3	35.36
FIELD WATER TEMPERATURE	45.6 C	TOTAL ALKALINITY AS CACO3	285.42
CALCULATED DISSOLVED SOLIDS	405.79	SODIUM ADSORPTION RATIO	10.17
SUM OF DISS. CONSTITUENT	582.36	RYZNAR STABILITY INDEX	7.85
LAB SPEC.COND.(MICROMHOS/CM)	656.6	LANGLIER SATURATION INDEX	0.16

PARAMETER	VALUE	PARAMETER	VALUE
TEMPERATURE, AIR (C)	10.	CNDUCTVY,FIELD MICROMHOS	653.
FIELD PH	7.82	ALKALINITY,FLD(AS CACO3)	327.6
ALUMINUM, DISS (MG/L-AL)	<.03	STRONTIUM,DISS (MG/L-SR)	.17
SILVER,DISS (MG/L AS AG)	<.002	TITANIUM DIS(MG/L AS TI)	<.001
BORON ,DISS (MG/L AS B)	.63	VANADIUM,DISS(MG/L AS V)	<.001
CADMIUM,DISS(MG/L AS CD)	<.002	ZINC,DISS (MG/L AS ZN)	.006
CHROMIUM, DISS (MG/L-CR)	<.002	ZIRCONIUM DIS(MG/L ZR)	<.004
COPPER,DISS (MG/L AS CU)	<.002	LITHIUM,DISS(MG/L AS LI)	.050
MOLYBDENUM,DISS(MG/L-MO)	<.02	NICKEL,DISS (MG/L AS NI)	<.01
LEAD,DISS (MG/L AS PB)	<.04	ARSENIC,DISS(UG/L AS AS)	<.1

REMARKS: PH RISES VERY RAPIDLY ON WITHDRAWL * NO H2S SMELL OR TASTE *
LITTLE BITTERROOT GEOTHERMAL AREA * CASING DRIVEN TO 261 FT *
OPEN HOLE AND PRODUCING INTERVAL 261-224 FT WITH MAJOR ZONES AT 283,
LAB: 290, 305, T AT BOTTOM = 47.8 C *
LAB: FU NA OF 141 MG/L GIVES .182 SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

QW WA S2 WI OW PW AT OTHER

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 23-FEB-81
PROCESSING PROGRAM: FI730P V2 (8/9/80)

COST:
BY: TP *CLG
PRINTED: 07-AUG-81

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3
7	2	88	1	14	0	81

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002827

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002826

STATE	MONTANA	COUNTY	LAKE
LATITUDE-LONGITUDE	47D38'32"N 114D34'17"W	SITE LOCATION	22N 23W 29 BADD
UTM COORDINATES	Z11 N5288750 E681985	MBMG SITE	LB-141
TOPOGRAPHIC MAP	HOT SPRINGS NE 7 1/2'	STATION ID	473832114341701
GEOLOGIC SOURCE	400PRCD*112GRAV*	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	FL	LAND SURFACE ALTITUDE	2758. FT < 10
AGENCY + SAMPLER	MBMG*JJD	SUSTAINED YIELD	100. GPM
BOTTLE NUMBER	LBTEST4	YIELD MEAS METHOD	BUCKET/STOPWATCH
DATE SAMPLED	16-DEC-80	TOTAL DEPTH OF WELL	362. FT (M)
TIME SAMPLED	04:00 HOURS	SWL ABOVE(-) OR BELOW GS	FLOWING
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	6 IN (M)
DATE ANALYZED	20-JAN-81	CASING TYPE	STEEL
SAMPLE HANDLING	3120	COMPLETION TYPE	10*
METHOD SAMPLED		PERFORATION INTERVAL	261 TO 362 FT
WATER USE	RESEARCH		

SAMPLING SITE MBMG GEO. TEST WELL #1 * CAMPAQUA AREA
GEOLOGIC SOURCE PRICHARD FORMATION OR SLATE

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	12.3	0.61	BICARBONATE (HCO3)	345.	5.65
MAGNESIUM (MG)	2.4	0.20	CARBONATE (CO3)	0.	
SODIUM (NA)	132.	5.74	CHLORIDE (CL)	35.5	1.00
POTASSIUM (K)	3.4	0.09	SULFATE (SO4)	.1	0.00
IRON (FE)	.081	0.00	NITRATE (AS N)	.099	0.01
MANGANESE (MN)	.044	0.00	FLUORIDE (F)	4.54	0.24
SILICA (SIO2)	38.5		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		6.65	TOTAL ANIONS		6.90

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 1.26

LABORATORY PH	8.21	TOTAL HARDNESS AS CACO3	40.59
FIELD WATER TEMPERATURE	47.2 C	TOTAL ALKALINITY AS CACO3	282.96
CALCULATED DISSOLVED SOLIDS	398.91	SODIUM ADSORPTION RATIO	9.02
SUM OF DISS. CONSTITUENT	573.96	RYZNAR STABILITY INDEX	7.71
LAB SPEC.COND.(MICROMHOS/CM)	651.5	LANGLIER SATURATION INDEX	0.25

PARAMETER	VALUE	PARAMETER	VALUE
TEMPERATURE, AIR (C)	-5.	CNDUCTVY,FIELD MICROMHOS	644.
FIELD PH	7.74	ALUMINUM, DISS (MG/L-AL)	<.03
STRONTIUM,DISS (MG/L-SR)	.23	SILVER,DISS (MG/L AS AG)	<.002
TITANIUM DIS(MG/L AS TI)	.003	BORON ,DISS (MG/L AS B)	.57
VANADIUM,DISS(MG/L AS V)	<.001	CADMIUM,DISS(MG/L AS CD)	<.002
ZINC,DISS (MG/L AS ZN)	<.003	CHROMIUM, DISS (MG/L-CR)	<.002
ZIRCONIUM DIS(MG/L ZR)	<.004	COPPER,DISS (MG/L AS CU)	.003
LITHIUM,DISS(MG/L AS LI)	.059	MOLYBDENUM,DISS(MG/L-MO)	.02
NICKEL,DISS (MG/L AS NI)	<.01	LEAD,DISS (MG/L AS PB)	<.04
ARSENIC,DISS(UG/L AS AS)	<.1		

REMARKS: PH RISES RAPIDLY ON WITHDRAWL * NO H2S SMELL OR TASTE *
LITTLE BITTERROOT GEOTHERMAL AREA * OPEN HOLE PROD ZONE 261-362 FT *
PRIMARY FLOWS AT 283, 290, 305, 345 *
LAB: FU NA OF 136 MG/L GIVES .390 SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

QW WA S2 WI OW PW AT OTHER

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: COST:
LAST EDIT DATE: 23-FEB-81 BY: TP *CLG
PROCESSING PROGRAM: FI730P V2 (8/9/80) PRINTED: 07-AUG-81

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3
9	2	86	1	14	0	81

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002826

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002825

STATE	MONTANA	COUNTY	LAKE
LATITUDE-LONGITUDE	47D38'32"N 114D34'17"W	SITE LOCATION	22N 23W 29 BADD
UTM COORDINATES	Z11 N5288750 E681985	MBMG SITE	LB-141
TOPOGRAPHIC MAP	HOT SPRINGS NE 7 1/2'	STATION ID	473832114341701
GEOLOGIC SOURCE	400PRCD*112GRAV*	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	PL	LAND SURFACE ALTITUDE	2758. FT < 10
AGENCY + SAMPLER	MBMG*JJM	SUSTAINED YIELD	350. GPM
BOTTLE NUMBER	LBTEST5	YIELD MEAS METHOD	BUCKET/STOPWATCH
DATE SAMPLED	16-DEC-80	TOTAL DEPTH OF WELL	423. FT (M)
TIME SAMPLED	08:30 HOURS	SWL ABOVE(-) OR BELOW GS	FLOWING
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	6 IN (M)
DATE ANALYZED	20-JAN-81	CASING TYPE	STEEL
SAMPLE HANDLING	3120	COMPLETION TYPE	10*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	261 TO 423 FT
WATER USE	RESEARCH		

SAMPLING SITE MBMG GEO. TEST WELL #1 * CAMPAQUA AREA
GEOLOGIC SOURCE PRICHARD FORMATION OR SLATE

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	12.5	0.62	BICARBONATE (HCO3)	344.	5.64
MAGNESIUM (MG)	2.4	0.20	CARBONATE (CO3)	0.	
SODIUM (NA)	130.	5.65	CHLORIDE (CL)	35.5	1.00
POTASSIUM (K)	3.2	0.08	SULFATE (SO4)	.1	0.00
IRON (FE)	.25	0.01	NITRATE (AS N)	.066	0.00
MANGANESE (MN)	.019	0.00	FLUORIDE (F)	4.6	0.24
SILICA (SIO2)	37.7		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		6.57	TOTAL ANIONS		6.89

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 1.55

LABORATORY PH	8.26	TOTAL HARDNESS AS CACO3	41.09
FIELD WATER TEMPERATURE	44.9 C	TOTAL ALKALINITY AS CACO3	282.14
CALCULATED DISSOLVED SOLIDS	395.79	SODIUM ADSORPTION RATIO	8.83
SUM OF DISS. CONSTITUENT	570.34	RYZNAR STABILITY INDEX	7.65
LAB SPEC.COND.(MICROMHOS/CM)	657.0	LANGLIER SATURATION INDEX	0.31

PARAMETER	VALUE	PARAMETER	VALUE
TEMPERATURE, AIR (C)	-3.	CNDUCTVY,FIELD MICROMHOS	667.
FIELD PH	7.96	ALKALINITY,FLD(AS CACO3)	310.4
ALUMINUM, DISS (MG/L-AL)	<.03	STRONTIUM,DISS (MG/L-SR)	.25
SILVER,DISS (MG/L AS AG)	<.002	TITANIUM DIS(MG/L AS TI)	<.001
BORON ,DISS (MG/L AS B)	.59	VANADIUM,DISS(MG/L AS V)	<.001
CADMIUM,DISS(MG/L AS CD)	.004	ZINC,DISS (MG/L AS ZN)	.007
CHROMIUM, DISS (MG/L-CR)	<.002	ZIRCONIUM DIS(MG/L ZR)	<.004
COPPER,DISS (MG/L AS CU)	<.002	LITHIUM,DISS(MG/L AS LI)	.059
MOLYBDENUM,DISS(MG/L-MO)	<.02	NICKEL,DISS (MG/L AS NI)	<.01
LEAD,DISS (MG/L AS PB)	<.04	ARSENIC,DISS(UG/L AS AS)	<.1

REMARKS: PH RISES RAPIDLY ON WITHDRAWL * NO H2S TASTE OR SMELL *
LITTLE BITTERROOT GEOTHERMAL AREA * OPEN HOLE PROD ZONE 261-423 FT
PRIMARY FLOWS AT 283, 290, 305, 345, 406-409 FT * MAIN FLOW 406-409FT*
LAB: FU NA OF 135 MG/L GIVES .466 SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

QW WA S2 WI OW PW AT OTHER
OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: COST:
LAST EDIT DATE: 25-FEB-81 BY: TP *CLG
PROCESSING PROGRAM: F1730P V2 (8/9/80) PRINTED: 07-AUG-81

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3
9	3	86	1	14	0	81

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002825

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002824

STATE	MONTANA	COUNTY	LAKE
LATTITUDE-LONGITUDE	47038'32"N 114034'17"W	SITE LOCATION	22N 23W 29 BADD
UTM COORDINATES	Z11 N5288750 E681985	MBMG SITE	LB-141
TOPOGRAPHIC MAP	HOT SPRINGS NE 7 1/2'	STATION ID	473832114341701
GEOLOGIC SOURCE	400PRCD*112GRAV*	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	PL	LAND SURFACE ALTITUDE	2758. FT < 10
AGENCY + SAMPLER	MBMG*JJD	SUSTAINED YIELD	750.0 GPM
BOTTLE NUMBER	LBTEST6	YIELD MEAS METHOD	BUCKET/STOPWATCH
DATE SAMPLED	18-DEC-80	TOTAL DEPTH OF WELL	578. FT (M)
TIME SAMPLED	13:00 HOURS	SWL ABOVE(-) OR BELOW GS	FLOWING
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	6 IN (M)
DATE ANALYZED	15-JAN-81	CASING TYPE	STEEL
SAMPLE HANDLING	3120	COMPLETION TYPE	10*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	216 TO 578 FT
WATER USE	RESEARCH		

SAMPLING SITE MBMG GEO. TEST WELL #1 * CAMPAQUA AREA
GEOLOGIC SOURCE PRICHARD FORMATION OR SLATE

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	12.6	0.63	BICARBONATE (HCO3)	343.	5.62
MAGNESIUM (MG)	2.4	0.20	CARBONATE (CO3)	0.	
SODIUM (NA)	127.	5.52	CHLORIDE (CL)	35.3	1.00
POTASSIUM (K)	3.3	0.08	SULFATE (SO4)	.7	0.01
IRON (FE)	.11	0.01	NITRATE (AS N)	.038	0.00
MANGANESE (MN)	.017	0.00	FLUORIDE (F)	4.29	0.23
SILICA (SIO2)	35.3		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		6.44	TOTAL ANIONS		6.86

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 2.06

LABORATORY PH	8.21	TOTAL HARDNESS AS CACO3	41.34
FIELD WATER TEMPERATURE	43.7 C	TOTAL ALKALINITY AS CACO3	281.32
CALCULATED DISSOLVED SOLIDS	390.02	SODIUM ADSORPTION RATIO	8.60
SUM OF DISS. CONSTITUENT	564.05	RYZNAR STABILITY INDEX	7.69
LAB SPEC.COND.(MICROMHOS/CM)	655.6	LANGLIER SATURATION INDEX	0.26

PARAMETER	VALUE	PARAMETER	VALUE
TEMPERATURE, AIR (C)	10.0	CNDUCTVY,FIELD MICROMHOS	633.
FIELD PH	7.99	ALKALINITY,FLD(AS CACO3)	296.0
ALUMINUM, DISS (MG/L-AL)	<.03	STRONTIUM,DISS (MG/L-SR)	.26
SILVER,DISS (MG/L AS AG)	<.002	TITANIUM DIS(MG/L AS TI)	<.001
BORON ,DISS (MG/L AS B)	.55	VANADIUM,DISS(MG/L AS V)	<.001
CADMIUM,DISS(MG/L AS CD)	<.002	ZINC,DISS (MG/L AS ZN)	.011
CHROMIUM, DISS (MG/L-CR)	<.002	ZIRCONIUM DIS(MG/L ZR)	<.004
COPPER,DISS (MG/L AS CU)	<.002	LITHIUM,DISS(MG/L AS LI)	.059
MOLYBDENUM,DISS(MG/L-MO)	<.02	NICKEL,DISS (MG/L AS NI)	<.01
LEAD,DISS (MG/L AS PB)	<.04	ARSENIC,DISS(UG/L AS AS)	.8

REMARKS: PH RISES RAPIDLY ON WITHDRAWL * NO H2S SMELL OR TASTE *
LITTLE BITTERROOT GEOTHERMAL AREA * DRAW HOLE PROD ZONE 261-578 FT
PRIMARY ZONES AT 283, 290, 305, 345, 406-409, 570-578 *
LAB: FU NA OF 134 MG/L GIVES .543 SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

QW WA S2 WI OW PW AT OTHER

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: COST:
BY: TP *CLG
LAST EDIT DATE: 23-FEB-81
PROCESSING PROGRAM: F1730P V2 (8/9/80) PRINTED: 07-AUG-81

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3
9	3	85	1	14	0	81

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002824

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8100010

STATE	MONTANA	COUNTY	SANDERS
LATITUDE-LONGITUDE	47D38'05"N 114D33'43"W	SITE LOCATION	22N 23W 29 DADD
UTM COORDINATES	Z11 N5280750 E651985	MBMG SITE	
TOPOGRAPHIC MAP	HOT SPRINGS NE 7 1/2'	STATION ID	473805114334301
GEOLOGIC SOURCE	400PRCD*112GRAV*	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	PL	LAND SURFACE ALTITUDE	2758. FT < 10
AGENCY + SAMPLER	MBMG*JJD	SUSTAINED YIELD	800. GPM
BOTTLE NUMBER	LBTEST	YIELD MEAS METHOD	BUCKET/STOPWATCH
DATE SAMPLED	15-JAN-81	TOTAL DEPTH OF WELL	1002. FT (M)
TIME SAMPLED	16:00 HOURS	SWL ABOVE(-) OR BELOW GS	-26.6 FT (M)
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	6 IN (M)
DATE ANALYZED	16-APR-81	CASING TYPE	STEEL
SAMPLE HANDLING	3120	COMPLETION TYPE	10*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	265 TO 1002 FT
WATER USE	RESEARCH		

SAMPLING SITE MBMG GEOTHERMAL TEST WELL #1*CAMPAQUA AREA
GEOLOGIC SOURCE PRICHARD FORMATION OR SLATE

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	15.5	0.77	BICARBONATE (HCO3)	321.	5.26
MAGNESIUM (MG)	2.8	0.23	CARBONATE (CO3)	0.	
SODIUM (NA)	129.	5.61	CHLORIDE (CL)	34.8	0.98
POTASSIUM (K)	3.8	0.10	SULFATE (SO4)	21.5	0.45
IRON (FE)	.16	0.01	NITRATE (AS N)	.05	0.00
MANGANESE (MN)	.050	0.00	FLUORIDE (F)	3.13	0.16
SILICA (SIO2)	36.8		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		6.72	TOTAL ANIONS		6.86

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.66

LABORATORY PH	8.32	TOTAL HARDNESS AS CACO3	50.23
FIELD WATER TEMPERATURE	42.7 C	TOTAL ALKALINITY AS CACO3	263.27
CALCULATED DISSOLVED SOLIDS	405.72	SODIUM ADSORPTION RATIO	7.92
SUM OF DISS. CONSTITUENT	568.59	RYZNAR STABILITY INDEX	7.46
MBMB SPEC.COND.(MICROMHOS/CM)	663.9	LANGLIER SATURATION INDEX	0.43

PARAMETER	VALUE	PARAMETER	VALUE
TEMPERATURE, AIR (C)	-5.	FIELD PH	7.75
ALKALINITY,FLD(AS CACO3)	277.2	ALUMINUM, DISS (MG/L-AL)	<.03
NICKEL,DISS (MG/L AS NI)	.01	SILVER,DISS (MG/L AS AG)	<.002
LEAD,DISS (MG/L AS PB)	<.04	BORON ,DISS (MG/L AS B)	.50
STRONTIUM,DISS (MG/L-SR)	.35	CADMIUM,DISS(MG/L AS CD)	.007
TITANIUM DIS(MG/L AS TI)	<.001	CHROMIUM, DISS (MG/L-CR)	<.002
VANADIUM,DISS(MG/L AS V)	<.001	COPPER,DISS (MG/L AS CU)	<.002
ZINC,DISS (MG/L AS ZN)	.034	LITHIUM,DISS(MG/L AS LI)	.073
ZIRCONIUM DIS(MG/L ZR)	<.004	MOLYBDENUM,DISS(MG/L-MO)	<.02
ARSENIC,DISS(UG/L AS AS)	2.6		

REMARKS: CLEAR WATER - ODORLESS - TASTELESS *
SAMPLE COMPOSITE FROM ALL PRODUCING ZONES IN TEST WELL *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

QW WA S2 WI OW PW AT OTHER

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: COST:
LAST EDIT DATE: 05-MAY-81 BY: TP *CLG
PROCESSING PROGRAM: F1730P V2 (8/9/80) PRINTED: 05-MAY-81

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3
11	3	83	1	14	6	76

IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8100010

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002723

STATE MONTANA
ITUDE-LONGITUDE 47D38'28"N 114D34'16"W
UTM COORDINATES Z11 N5279405 E682590
TOPOGRAPHIC MAP HOT SPRINGS NE 7 1/2'
GEOLOGIC SOURCE 112GRAV*400PRCD*
DRAIN. BASIN PL
AGENCY + SAMPLER MBMG*JJD
BOTTLE NUMBER LB-32B
DATE SAMPLED 22-OCT-80
TIME SAMPLED 17:30 HOURS
LAB + ANALYST MBMG*ENA
DATE ANALYZED 06-FEB-81
SAMPLE HANDLING 3120
METHOD SAMPLED GRAB
WATER USE RECREATIONAL

COUNTY SANDERS
SITE LOCATION 22N 23W 29 ACBB
MBMG SITE LB-32
STATION ID 473828114341601
* SAMPLE SOURCE WELL
LAND SURFACE ALTITUDE 2743. FT < 10
SUSTAINED YIELD 116. GPM
YIELD MEAS METHOD WEIR
TOTAL DEPTH OF WELL 244. FT (R)
SWL ABOVE(-) OR BELOW GS 35.4 FT (M)
CASING DIAMETER 4 IN (R)
CASING TYPE STEEL
COMPLETION TYPE 01*
PERFORATION INTERVAL

SAMPLING SITE CAMPAQUA HOT WELL * HOT SPRINGS MT
GEOLOGIC SOURCE

		MG/L	MEQ/L			MG/L	MEQ/L
CALCIUM	(CA)	3.2	0.16	BICARBONATE	(HCO3)	361.	5.92
MAGNESIUM	(MG)	.3	0.02	CARBONATE	(CO3)	0.	
SODIUM	(NA)	152.	6.61	CHLORIDE	(CL)	32.5	0.92
POTASSIUM	(K)	4.0	0.10	SULFATE	(SO4)	4.1	0.09
IRON	(FE)	.17	0.01	NITRATE	(AS N)	.01	0.00
MANGANESE	(MN)	.010	0.00	FLUORIDE	(F)	3.9	0.21
SILICA	(SIO2)	42.2		PHOSPHATE TOT	(AS P)		

TOTAL CATIONS 6.91 TOTAL ANIONS 7.12

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 1.04

LABORATORY PH	8.65	TOTAL HARDNESS AS CACO3	9.23
FIELD WATER TEMPERATURE	52.0 C	TOTAL ALKALINITY AS CACO3	296.08
CULATED DISSOLVED SOLIDS	420.22	SODIUM ADSORPTION RATIO	21.78
SUM OF DISS. CONSTITUENT	603.39	RYZNAR STABILITY INDEX	8.40
SPEC.COND.(MICROMHOS/CM)	695.0	LANGLIER SATURATION INDEX	0.13

PARAMETER	VALUE	PARAMETER	VALUE
TEMPERATURE, AIR (C)	12.	FIELD PH	8.44
ALKALINITY,FLD(AS CACO3)	292.8	ALUMINUM, DISS (MG/L-AL)	.09
STRONTIUM,DISS (MG/L-SR)	.10	SILVER,DISS (MG/L AS AG)	.012
TITANIUM DIS(MG/L AS TI)	.007	BORON ,DISS (MG/L AS B)	.64
VANADIUM,DISS(MG/L AS V)	.008	CADMIUM,DISS(MG/L AS CD)	<.002
ZINC,DISS (MG/L AS ZN)	<.004	CHROMIUM, DISS (MG/L-CR)	.006
ZIRCONIUM DIS(MG/L ZR)	.014	COPPER,DISS (MG/L AS CU)	.011
LITHIUM,DISS(MG/L AS LI)	.087	MOLYBDENUM,DISS(MG/L-MO)	.03
NICKEL,DISS (MG/L AS NI)	.03	LEAD,DISS (MG/L AS PB)	.11
ARSENIC,TR (UG/L AS AS)	<.1		

REMARKS: WATER DEGASSES VIOLENTLY UPON SAMPLING * EST. 5% BY VOLUME GAS *
WATER HAS H2S AND IRON TASTE *
FLOW TEST 6.5 HOURS AFTER VALVE OPENED *
LAB: BROMINE NOT DETECTED *

XPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L =
ILLIEQUIVELENTS PER LITER, FT = FEET, MT = METERS. (M) = MEASURED, (E) =
STIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

QW WA S? WI OW PW AT OTHER
THER AVAILABLE DATA
THER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 06-APR-81
ROCESSING PROGRAM: F1730P V2 (8/9/80)

COST:
BY: TP *CLG
PRINTED: 06-APR-81

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3
2	0	95	1	12	1	83

OTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002723