

COLORADO'S HYDROTHERMAL RESOURCE BASE- AN ASSESSMENT

by Richard Howard Pearl

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
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Cover: Photo taken during drilling of Pagosa Springs geothermal well, photo by Michael Galloway.

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ABSTRACT

As part of its effort to more accurately describe the nation's geothermal resource potential, the U.S. Department of Energy/Division of Geothermal Energy contracted with the Colorado Geological Survey to appraise the hydrothermal (hot water) geothermal resources of Colorado. Part of this effort required that the amount of energy that could possibly be contained in the various hydrothermal systems in Colorado be estimated.

This publication presents the findings of that assessment. To make these estimates the geothermometer reservoir temperatures estimated by Barrett and Pearl (1978) were used. In addition, the possible reservoir size and extent were estimated and used. This assessment shows that the total energy content of the thermal systems in Colorado could range from 4.872×10^{15} BTU's to 13.2386×10^{15} BTU's.

INTRODUCTION

As part of its effort to more accurately describe the nation's geothermal resource potential, the U.S. Dept. of Energy/Division of Geothermal Energy (DOE/DGE) has contracted with representatives in each of the western states to appraise the low temperature (less than 200°C) geothermal resources in their respective state. In July, 1977, under DOE/DGE contract No. EG-77-S-07-1678, the Colorado Geological Survey began a 2 1/2 year assessment of the low temperature geothermal resource potential of Colorado and reservoir confirmation program. This publication reports the findings of the resource assessment phase of the contract.

In most instances the thermal waters of Colorado are unused, although small amounts of thermal waters are used for recreation, space heating, domestic, and miscellaneous agricultural purposes. Although many energy companies have expressed interest in the geothermal resources of the state and have acquired leases to federal, state and private lands, no large scale development has occurred.

The geothermal resources of Colorado appear to be ideally suited for processes requiring low to moderate temperature hot water. In 1978 Barrett and Pearl calculated the estimated reservoir temperatures of all the thermal systems in Colorado. Their calculations showed that the reservoir temperatures range from a low of 20°C to over 200°C, with most of the temperatures being in the range of 50°C to 150°C.

Colorado's geothermal resource potential is expressed in the numerous thermal springs and wells found throughout the western one-half of the state (Fig. 1). These springs and wells, numbering over 120, have been described by numerous authors. The first and most comprehensive inventory of the thermal springs and wells was published in 1920 by R. D. George and others. Since then summaries have been published by Barrett and Pearl (1978), Lewis (1966), Mallory and Barnett (1973), Pearl (1972), and Waring (1965).

Various authors have attempted to define those thermal areas of Colorado that might have potential for containing geothermal resources or the amount of heat contained in them. In 1971 Goodwin and

others, published a comprehensive analysis of lands in the western United States that might contain geothermal resources. Their report showed that there are approximately 32 areas in Colorado that have the potential for containing geothermal resources. Brook and others in 1979, Renner and others in 1975 and Sammel, 1979 made a tentative appraisal of Colorado's geothermal resource potential, and calculated the amount of heat contained in those reservoir having estimated reservoir temperatures above certain temperatures.

In 1978 Barrett and Pearl published a comprehensive appraisal of Colorado's geothermal resources. In addition to locating 127 thermal springs and wells having a temperature above 20°C (68°F) and making such field measurements as discharge, pH, conductivity, and temperature they made a general appraisal of the hydrogeological conditions, recharge areas, and reservoir temperatures surrounding each thermal area. A geothermometer determination of the estimated reservoir temperature was made for all the thermal areas in the State. The four major geothermometer models they used were: 1) Silica, 2) Mixing Models I and II, 3) Sodium-Potassium, and 4) Sodium-Potassium-Calcium. In order to clarify the use of these models, a detailed explanation of each was presented.

Barrett and Pearl (1978) determined the location of the spring or well to the nearest degree, minute and second of latitude and longitude by the use of either 7.5-minute or 15-minute U.S. Geological Survey topographic quadrangle maps. The land grid location was also determined if the township, range, and section had been determined and printed on the topographic map. To avoid confusion by the use of varying ambient air temperatures throughout western Colorado, Barrett and Pearl (1978) assumed an ambient air temperature of 60°F (15.6°C). A base thermal temperature of 20°C (68°F) was then used. Evaluation of their data shows that there are 56 distinct thermal areas within the State, consisting of one or more groups of springs or wells (Barrett and Pearl, 1978). More recent work has shown that there are at least 58 thermal areas in Colorado.

This current investigation by the Colorado Geological Survey attempts to refine those earlier estimates of Colorado's geothermal resources. In making this effort the author, with the aid of Mr. Jay Dick, drew heavily and freely upon conclusions and findings published in papers by Barrett and Pearl (1976 and 1978). Most of the text in this publication is an abridged version of Barrett's and Pearl's 1978 report. For a complete description of their findings and conclusions the reader is referred to their paper. The author, using geological maps published by Barrett and Pearl (1978) plus his knowledge of the geological and hydrogeological conditions of each thermal area, attempted to draw boundaries around what he felt

was the limits of the reservoir. It should be remembered that with the exception of very few sites no geological, hydrogeological, or geophysical surveys have been done in or adjacent to these thermal areas. Therefore all estimates of the reservoir sizes, depths, and heat contained in them should be viewed with caution until supported or refuted with exploration data.

Figure 1 shows the location of the thermal springs or wells in Colorado. The numbers in the figure correspond to the order in which the springs and wells are discussed in the text.

Table 1 is an alphabetical listing of all the thermal springs and wells in Colorado.

RESOURCE ASSESSMENT PROCEDURE

With the exception of a few of the thermal systems in Colorado, most of the thermal systems' depth, size and hydrogeological conditions are unknown. Therefore, before calculating the energy contained in each system, it was necessary to estimate those parameters. It cannot be stressed strongly enough that these parameters are estimates and that until definitive test drilling or geophysical surveys which will more accurately portray the thermal systems are done, all conclusions should be viewed with these limitations in mind. The estimates are presented in Table 2.

In making this assessment the following procedure was followed.

1. The areal extent of the reservoir, based on an assessment of the regional geological conditions, was estimated. In several instances two estimates of the reservoir size were made, a conservative estimate and an optimistic estimate.

2. Reservoir thickness. Of all the estimates made this was the most difficult. The reservoir was first estimated to be a fractured or a stratigraphic reservoir. If the reservoir was estimated to to be a stratigraphic reservoir, it was then determined which formation would most logically be the reservoir. In some instances this was not possible, and a generalized approach was taken. After the reservoir type had been estimated the total thickness of the reservoir was estimated. If the reservoir was believed to be a fractured reservoir, an arbitrary thickness of 1,000 ft was assigned. If the reservoir type was unknown, a

thickness of 500 ft was assigned. Thickness of the stratigraphic reservoir was based on the thickness of the assumed water bearing unit.

3. The usable reservoir temperature (Δt) is the difference between the temperatures as presented by Barrett and Pearl (1978) and 20°C.

4. The heat content in British Thermal Units (BTU's) in each system was calculated using the following formula.

$$\text{BTU's} = \frac{(\text{mi}^2 \times 2.59 \times 10^{10})(\text{Thick/ft} \times 30.48)(.6)(\Delta t)}{252}$$

The heat content of a system is reported in Quad's (Q's) (1,000,000,000,000 or 10^{15} Btu's). For example the heat content of Juniper Hot Springs is estimated to be .10616 Q's, this is $.10611 \times 10^{15}$ BTU's.

5. For those systems where two different reservoir sizes had been estimated, two estimates of the total BTU's in the ground were calculated.

6. In many instances the amount of heat contained in each system will differ from those estimates made earlier by Brook and others (1979) and Brook and others (1975) and Sammel (1979). This is due to the author attempting to define each system individually rather than assume set reservoir parameters. For a complete description of how Brook and others (1979), Renner and others (1975), and Sammel (1979) made their determinations the reader is referred to their papers.

GEOOTHERMOMETER MODELS—THEORY AND EXAMPLES

Research by Fournier (1973, and 1977), Fournier and Rowe (1966), Fournier and Truesdell (1972, 1973, and 1974), Fournier and others (1974), Truesdell and Fournier (1975), and White (1972) on the relationship between the concentration of ions in thermal waters and reservoir temperatures has

led to the development of a number of geothermometer models that can be used to estimate the subsurface reservoir temperature. The most frequently used geothermometers are related to the silica, sodium, potassium, and calcium content of thermal waters.

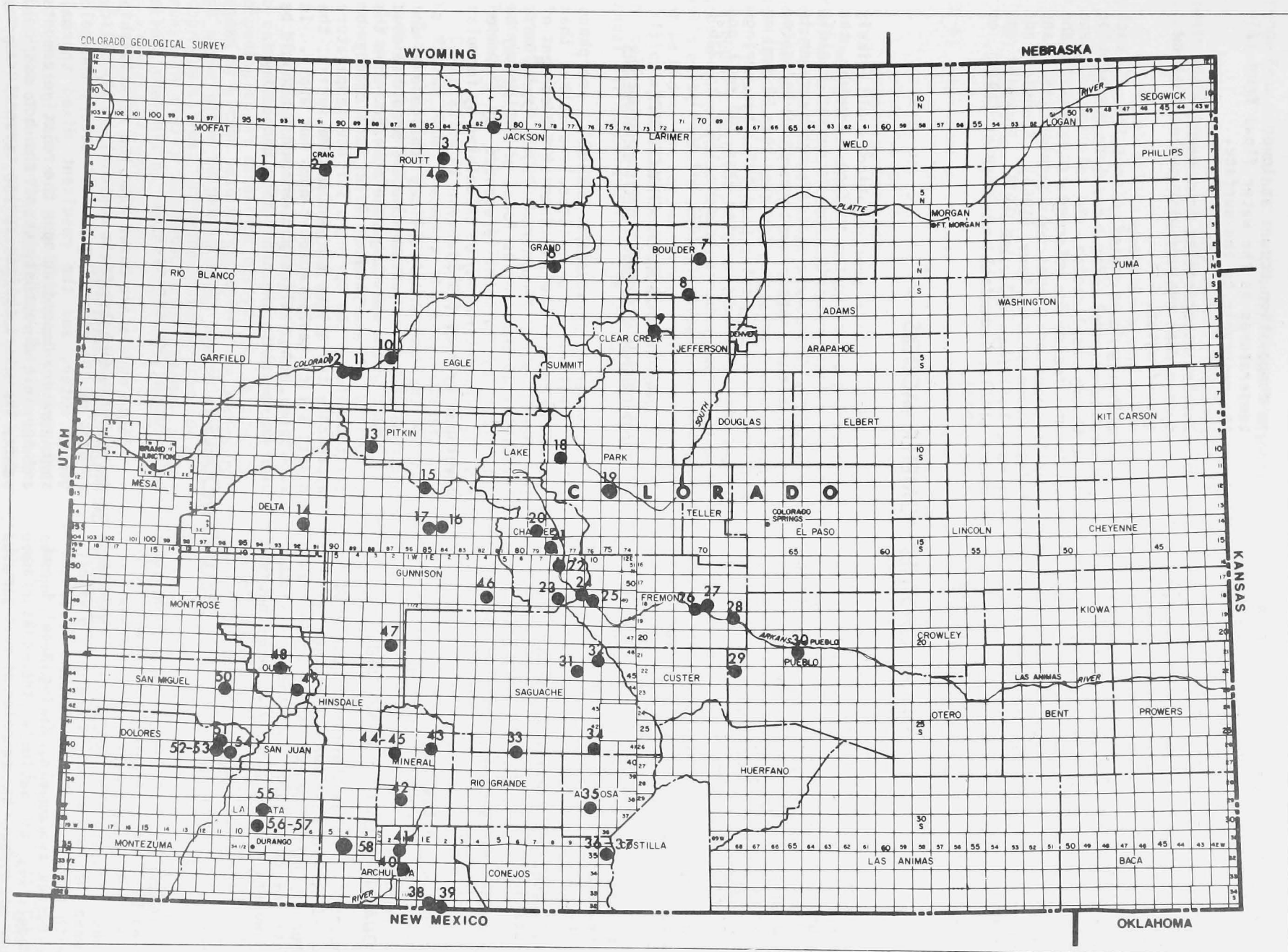


Figure 1.--Location of thermal springs and wells in Colorado. Numbers identify thermal areas. Thermal areas are discussed in numerical sequence beginning on page 9.

The following assumptions are inherent in all geothermometer models (Fournier and others, 1974). Violation of any of these assumptions may cause erroneous subsurface temperature estimates:

- 1) Temperature-dependent reactions occur at depth.
- 2) All constituents involved in a temperature dependent reaction are sufficiently abundant (i.e., supply is not a limiting factor).
- 3) Water-rock equilibration occurs at the reservoir temperature.
- 4) Little or no re-equilibration or change

in composition occurs at lower temperatures as the water flows from the reservoir to the surface.

- 5) The hot water coming from deep in the system does not mix with cooler shallow ground water.

Following is a brief discussion of each geothermometer model. For a complete description of the theory, application, and solution of these models the reader is referred to Barrett's and Pearl's paper or papers by Fournier (1973 and 1974), Fournier and Rowe (1966), Fournier and Truesdell (1972, 1973, and 1974), Fournier and others (1974), Truesdell and Fournier (1975), or White (1972).

SILICA GEOTHERMOMETER MODELS

The silica geothermometer is derived from the experimentally determined relationship between silica solubility, temperature and pressure (Fournier, 1973). Dissolved silica found in thermal waters may be supplied by temperature-dependent reactions between the thermal water and either quartz, chalcedony, amorphous silica or cristobalite.

Application of the various silica geothermometer models is restricted by four assumptions:

- 1) No mixing occurs between ascending thermal waters and shallow ground water.
- 2) Silica does not precipitate from the solution.
- 3) Steam does not separate from the thermal water during ascent to the surface.
- 4) The chemical activity of the thermal water is not greatly diminished.

QUARTZ-SILICA GEOTHERMOMETER

The quartz-silica geothermometer is based on temperature-dependent equilibration between quartz and the thermal fluid. Quartz is the predominant source of silica above 150°C. If the deep-seated geothermal waters were originally at temperatures

above 225°C, silica precipitation would likely occur during ascent to the surface. However, the rate of silica precipitation decreases rapidly below 180°C. The quartz silica geothermometer is most reliable as a subsurface temperature indicator in moderately discharging (greater than 50 gpm) or high temperature (greater than 50°C) hot springs with a silica content greater than 100 mg/l and subsurface temperatures between 150°C to 225°C (Fournier and Truesdell, 1972 and 1974).

AMORPHOUS SILICA, CHALCEDONY, AND CRISTOBALITE SILICA GEOTHERMOMETERS

At water temperatures below 150°C, amorphous silica, chalcedony, or cristobalite rather than quartz may control the dissolved silica content of the thermal water (Fournier, 1973). Approximate solubility of the various forms of silica may be calculated by formulas presented by Fournier (1973). Temperatures may be calculated by formulas developed by Reed (1975).

The amorphous silica, chalcedony and cristobalite silica geothermometers should be used as a check on the quartz geothermometer. When the solubility of amorphous silica, chalcedony or cristobalite at the spring's surface temperature approaches the silica content of the spring, the quartz silica geothermometer does not apply. In such cases, other silica geothermometers should be used to calculate the subsurface temperature.

MIXING MODELS

Assumption No. 1 of the silica geothermometer model states that the ascending thermal waters do not mix with the shallow ground waters. However, in many, if not most, geothermal systems mixing does occur between the thermal waters and ground water. To deal with this problem Fournier and Truesdell (1974) developed two models, Mixing Model I and Mixing Model II, to estimate the subsurface temperature and compute the fraction of cold ground

water in the hot spring.

These models are based upon the relationship between the enthalpy (heat content) and the silica content of the ascending thermal water, the cold ground water, and the resultant mixed thermal spring water. Depending upon the relative amounts and the initial enthalpies of the hot and cold water, the mixed surface spring temperatures may

range from cool to boiling (Fournier and Truesdell, 1974).

The use of mixing models involves four additional assumptions to those discussed for the silica geothermometers.

- 1) Initial silica content is controlled by temperature-dependent reactions between the deep thermal water and quartz.
- 2) Additional silica is not dissolved or deposited after mixing.
- 3) Enthalpy is not lost by conductive cooling or steam loss before mixing.
- 4) The temperature and silica content of cold springs are similar to the temperature and silica content of the ground water that mixes with the ascending hot water.

Analysis of subsurface temperatures using the Mixing Model requires knowledge of the surface temperatures and silica contents of the thermal and nonthermal waters in the area. As many cold springs or wells as possible should be sampled in the vicinity of the hot spring to insure an adequate representation of the regional ground-water conditions. If no cold springs or wells exist in the area, the following assumptions can be made: The cold water can be assumed to have a silica content of 25 mg/l, and the temperature of the cold water may be assumed to equal the mean annual air temperature of the region.

MIXING MODEL NO. I

Subsurface reservoir temperatures may be estimated by Mixing Model I either by graphical techniques or by use of a computer program (Truesdell and others, 1973).

Calculation of subsurface temperatures using the Mixing Model requires the knowledge of the surface temperatures and silica contents of the thermal and nonthermal waters in the area. If no cold springs or wells exist in the area, the above assumptions have to be made.

MIXING MODEL NO. II

For some thermal systems, it is not possible to calculate the temperature, or the calculated temperatures are unrealistically high. This may be caused by either loss of steam from the ascending hot water prior to mixing or by the solution of amorphous silica. For those systems, Fournier and Truesdell (1974) developed a geothermal model called the Mixing Model II. This model is

applicable to those thermal systems where steam vents or fumaroles are present at the surface and the solution of amorphous silica is not significant (Fournier and Truesdell, 1974). If amorphous silica is supplying silica ions to the thermal water, then Mixing Model I provides excessive subsurface temperature estimates. If amorphous silica is not supplying any silica to the system, then steam separation is likely.

Mixing Model II should only be used when mixing model assumption 3 is violated, i.e., when steam is lost from the ascending hot water before mixing. In this case the enthalpy and silica content of the hot water at depth are greater than the enthalpy and silica content of the hot water after steam separation. The amount of steam fractionation and the resultant silica enrichment are estimated by assuming steam loss at atmospheric pressure for the hot springs elevation (Fournier and Truesdell, 1974).

OTHER MIXING MODELS

At temperatures below 150°C amorphous silica, chalcedony, or cristobalite rather than quartz may control the dissolved silica content of the hot spring (Fournier, 1973). Temperature-dependent equilibration between the thermal water and solid silica phases other than quartz will cause the mixing model estimates of subsurface temperature and cold water fraction to be too high (Assumption No. 1). If the silica concentration of the thermal water approaches the theoretical solubility of amorphous silica, chalcedony or cristobalite at the spring's surface temperature, then mixing models based on amorphous silica, chalcedony, or cristobalite should be used.

These models are identical to Mixing Model I in all respects except for the assumption that amorphous silica, chalcedony, or cristobalite rather than quartz is the source of silica in the thermal water.

SUMMARY

Mixing Models I and II yield maximum and minimum subsurface temperature estimates, respectively (Fournier and Truesdell, 1974). They are best suited for the analysis of moderately discharging (greater than 50 gpm) hot springs with silica concentrations above 75 to 100 mg/l. These models should provide similar subsurface temperature estimates for multiple hot spring systems where each spring contains different proportions of cold water or for spring areas where mixing fluctuates seasonally. Even if the mixing model results should vary widely, the data obtained can be useful for evaluating the accuracy of the assumptions involved in geothermometer analysis.

ENTHALPY—CHLORIDE GEOTHERMOMETER

Mixing Models I and II are useful for the prediction of subsurface temperature from mixed hot springs. However, neither geothermometer model

commonly predicts temperatures in excess of 200°C even in thermal systems where higher temperatures have been substantiated by deep drilling (Truesdell

and Fournier, 1975).

To solve this problem, Truesdell and Fournier (1975) developed a mixing model in which chloride rather than silica ions are used in the calculation. This model, called enthalpy-chloride mixing model, was designed to calculate subsurface temperatures and hot water fractions for groups of mixed springs that issue at the boiling point. The derivation of this model is based upon the relationship between the enthalpies and chloride contents of the ascending hot water, the cold ground waters, and the resultant mixed warm spring waters.

The enthalpy-chloride geothermometer model is based on the following four assumptions (Truesdell and Fournier 1975):

1) An unmixed hot water sample is available.

- 2) Silica is not precipitated during ascent of the mixed water. Precipitation of silica after mixing will lower the enthalpy of the thermal solution, thus causing the estimated subsurface temperatures to be too low.
- 3) No change in enthalpy occurs before or after mixing. Enthalpy loss during ascent reduces the estimated subsurface temperature.
- 4) Quartz re-equilibration occurs after mixing. Hot water mixing with cold water usually creates a solution that is supersaturated in silica. If precipitation of silica does not occur, then the enthalpy of the solution will be too high. This results in an excessive subsurface temperature estimate.

SODIUM—POTASSIUM—CALCIUM GEOTHERMOMETER MODEL

The Na-K-Ca geothermometer model developed by Fournier and Truesdell (1973) is based on an empirical relationship between the molar concentrations of sodium, potassium and calcium ions and water temperature. This relationship is interpreted by Fournier and Truesdell (1973) as representing the temperature-dependent chemical equilibration between sodium, potassium, and calcium-bearing minerals and water.

Use of the Na-K-Ca geothermometer requires three assumptions:

1) No mixing occurs between the ascending thermal water and shallow ground water. If the calcium content of the undiluted thermal water is high (greater than 50 to 100 mg/l), then mixing with dilute ground water will cause the subsurface subsurface temperature estimate to be too low.

- 2) Sodium potassium and calcium concentrations in the thermal water are controlled by temperature dependent equilibration with albite, potassium feldspar and calcium-bearing minerals.
- 3) Little or no re-equilibration occurs during ascent. Changes in the sodium-potassium-calcium ratios in thermal waters may be great or negligible depending upon the rate of ascent and the relative reactivity of the rocks and minerals along the flow path. Low calcium-content thermal waters generally yield low subsurface temperature reactions during ascent (increased aqueous calcium ion concentration). High calcium content waters, however, may yield excessive geothermometer temperature estimates because of calcium carbonate deposition.

SODIUM—POTASSIUM GEOTHERMOMETER MODEL

The Na-K geothermometer model is based on a relationship between the molar concentrations of sodium and potassium and water temperature. This model is based on the same assumptions as the sodium-potassium-calcium geothermometer model.

SUMMARY

The Na-K and Na-K-Ca geothermometer models should only be used for spring waters in which other evidence of high subsurface temperatures are present (i.e. springs with high surface temperatures and high silica content). Subsurface

temperatures estimates greater than 100°C should be treated skeptically for moderately discharging springs (15 gpm) unless the results are substantiated by other geothermometers. Both geothermometers are intended for the analysis of low magnesium (below 5 mg/l) and of near-neutral and alkaline waters that do not deposit travertine. Travertine and calcium carbonate-depositing springs yield excessive Na-K and Na-K-Ca geothermometer subsurface temperature estimates. On the other hand, excessive solution of calcium carbonate will lower the Na-K-Ca geothermometer estimate (Fournier and Truesdell, 1973).

DESCRIPTION OF INDIVIDUAL THERMAL AREAS

Following is a description of the individual thermal areas in Colorado. For this report, a thermal area is defined as an area consisting of one or more springs or groups of springs. For example, Orvis Hot Spring, consisting of only one spring, is considered a thermal area, while the Chalk Creek area on the south flank of Mount Princeton, which contains numerous hot springs and wells, is also considered a thermal area.

Each thermal area is numbered on the index map (Fig. 1). For example, Area #1, in the northwest corner of the map, is Juniper Hot Springs. In the following discussion the thermal areas will be described in numerical, rather than alphabetical order so that all the thermal areas in the same region can be discussed together.

Each spring or group of springs is discussed in the following manner:

1. The location of the spring or springs is presented in several ways:
 - a) latitude and longitude.
 - b) township, range and section (Fig. 2).
 - c) county
 - d) the topographic quadrangle map in which the area is located.

2. Directions are given to the area from the nearest town or other prominent geographic feature. Any other pertinent facts about the area, where available, are given.

3. The hydrology and geological conditions of the area are discussed. Reported are such measured hydrological parameters as: temperature, pH, concentration elemental ions if determined, the measured conductance values, and water type. For most thermal areas a geological map was prepared. In many instances, these maps were adopted from previously published geologic maps of the area by reconnaissance geologic mapping.

4. The subsurface temperature of each spring or spring area was determined utilizing the Silica, Mixing Model, Sodium-Potassium (Na-K), and Sodium-Potassium-Calcium (Na-K-Ca) geothermometer models. Before applying the silica and mixing model geothermometers it was determined from silica solubility and temperature relationships which form of silica was controlling the silica found in the waters.

5. Resource assessment. The estimated energy contained in each system was calculated using the method described earlier.

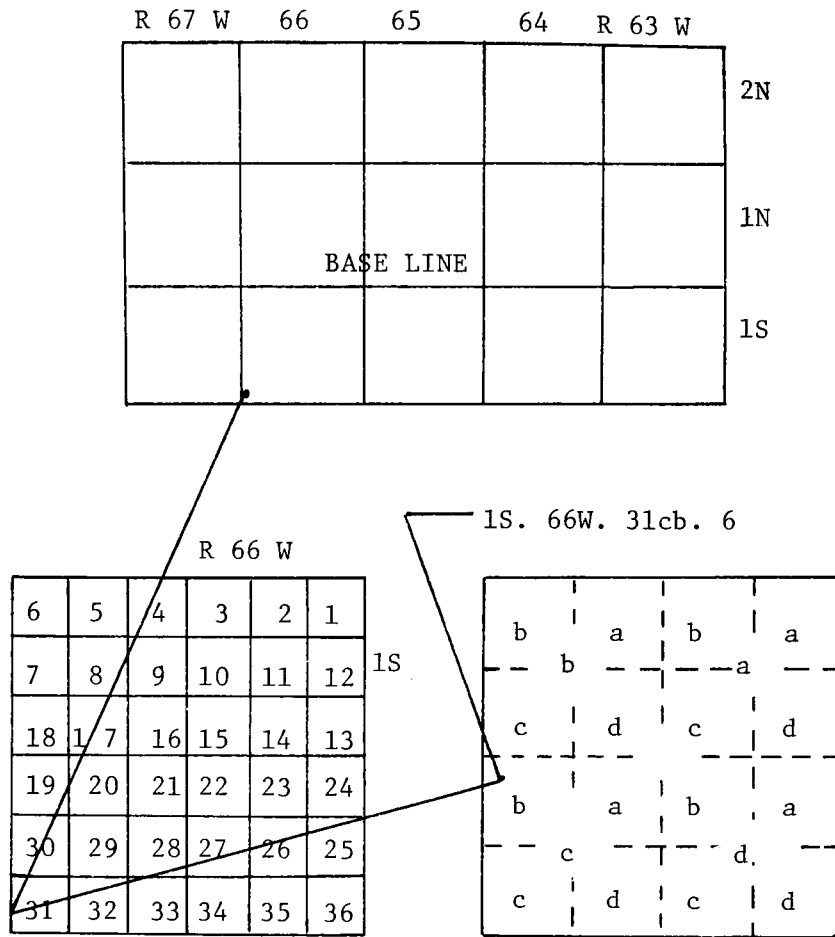


Figure 2: Spring Location numbering system used in Colorado

The well numbering system used in this report is based on the U.S. Bureau of Land Management system of land subdivision, and shows the location of the spring or well by township, range, section, and position within the section. In this report all lands are referenced to the 6th Principal Meridian or the New Mexico Principal Meridian. The first two segments of the number designate the township and range, the third number designates the section. The letters following the section number locate the feature within the section. The first letter denotes the quarter section, the second the quarter-quarter section. These letters are assigned within the section in a counter-clockwise direction beginning with "a" in the northeast quarter. Letters are assigned within each quarter section and within each quarter-quarter section in the same manner. In the example above the spring is located in the NW 1/4, SW 1/4, Sec. 31, T. 1 S., R. 66 W., 6th Principal Meridian.

#1 JUNIPER HOT SPRINGS

LOCATION: Latitude: 40°28'01"N.; Longitude: 107°57'10"W.; T. 6 N., R. 94 W., Sec. 16 cd, 6th P.M.; Moffat County; Juniper Hot Springs 7 1/2-minute topographic quadrangle map.

GENERAL: These springs are located on the south bank of the Yampa River in northwest Colorado, approximately 27 miles south and west of Craig, Colorado. The waters from the springs are used in the swimming pool and for hot baths at the Juniper Hot Springs Lodge.

GEOLOGY AND HYDROLOGY: The springs emerge into the hot bath pools; therefore, it was not possible to obtain an accurate measurement of their temperature or discharge. Field measurements of these values throughout a year's time were: Temperature: 33°C to 38°C; Discharge: 13 to 18 gpm; and total dissolved solids: 1,150 mg/l. The waters are a sodium bicarbonate type.

Sears (1924) shows the Juniper Hot Springs occurring at a point of transition from the flanks of a southeasterly plunging syncline to the southeast flank of Juniper Mountain to the west. Sears has shown that the strike of the Cretaceous sedimentary formations change in the immediate vicinity of Juniper Springs from generally southeast to northeast. Tweto (1975) states that a small section of undifferentiated Mesozoic sedimentary rocks is overlain by Cretaceous Mancos Shale at the site of the springs (Fig. 3). If this is the case, then a fault must lie in the immediate vicinity of the springs. If present, this fault could be the conduit along which the waters move up from depth. It is believed that the waters come from the Dakota Formation and migrate up faults associated with Juniper Mountain to the west.

GEOOTHERMOMETER ANALYSES: Analysis shows that chalcedony may control the silica content of the hot springs (Barrett and Pearl, 1978). The chalcedony-silica geothermometer model gave an estimated subsurface temperature ranging from 47°C

to 53°C, based on varying silica content throughout the year's time. This estimate may be close to the actual temperature at depth because the theoretical chalcedony-induced silica solubility (26 mg/l) at the surface temperature of the spring (42°C) is near the silica content of the spring (29 to 33 mg/l).

Chalcedony mixing model analysis yields a subsurface temperature estimate of 73°C to 81°C with a cold water fraction of 55 to 61 percent of the spring flow (Table 3).

Calculations by Barrett and Pearl (1978), show that the Na-K and Na-K-C geothermometers yield subsurface temperature estimates of 67°C to 75°C and 76°C to 80°C, respectively (Table 3). The close agreement of these results with the other geothermometer estimates suggests they represent the actual temperature at depth.

Conclusion: Geothermometer models must be used with caution when applied to Juniper Hot Springs because samples of the thermal water were taken from large, quiescent pools. Such sampling situations may exaggerate the effects of the surface conditions on the thermal water, allowing evaporative concentration of the silica content and other re-equilibration reactions to occur.

In light of the agreement between the geothermometer estimates, the subsurface temperature in this area is probably between 50°C and 75°C (Table 3).

RESOURCE ASSESSMENT: Barrett and Pearl (1978) conjectured that an unmapped fault might exist in the vicinity of this spring could be controlling its occurrence. In drawing the postulated boundaries of the system, the author attempted to draw the area big enough to include all of the supposed faulted area. It is therefore estimated that this area may encompass an area of 1.0 sq mi, and contain .0163 Q's (0.0163×10^{15} B.T.U's) of heat energy at an average temp. of 63°C (Table 2).

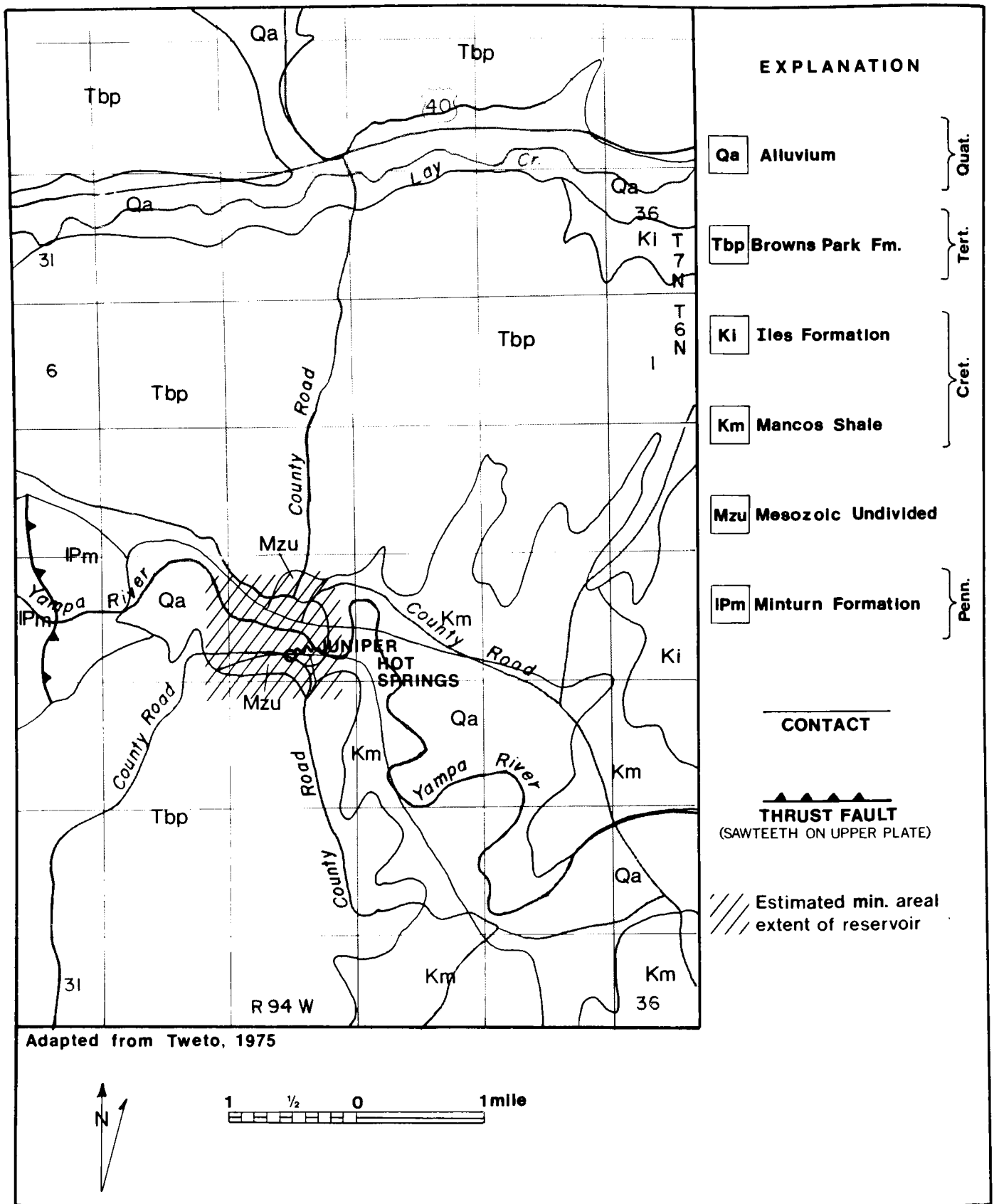


Figure 3.--Geologic map of Juniper Hot Springs area and extent of estimated geothermal reservoir.

#2 CRAIG WARM WATER WELL

LOCATION: Latitude: 40°30'06"N.; Longitude: 107°33'04"W.; T. 6 N., R. 91 W., Sec. 1 dcb, 6th P.M.; Moffat County; Craig 7 1/2-minute topographic quadrangle map.

GENERAL: The well, an oil test well, is reported to be 1,400 ft deep. The well is located 0.75 mile south of Craig near Colorado highways 13/789. From these roads, one turns east on a dirt road, about 0.25 mile north of the bridge over the Yampa River. The well is along the dirt road approximately 300 ft north of the farmhouse.

GEOLOGY AND HYDROLOGY: The surface temperature of this well is 39°C with a discharge of 24 gpm. The waters contain 896 mg/l of total dissolved solids (Barrett and Pearl, 1976). The bedrock of the area is the Lewis Shale of Late Cretaceous age. As shown on the geologic map (Fig. 4), although no major structural features lie in the immediate vicinity of the well an east-west trending fault is located approximately 2 miles to the west.

Since the exact depth or construction of this well is not known, it is not possible to state with any degree of certainty from what formations the waters come from or their recharge area.

GEOOTHERMOMETER ANALYSES: Analysis shows that chalcedony or quartz may control the silica content of the artesian well (Barrett and Pearl, 1978). The quartz-silica geothermometer yields a subsurface temperature estimate of 58°C (Table 3). This appears to be the most reliable estimate. The chalcedony-silica geothermometer subsurface temperature estimate (30°C), is below the surface temperature of the thermal water (39°C).

Both quartz and chalcedony mixing models are applicable. The quartz mixing model yields a

subsurface temperature estimate of 70°C with a cold water fraction of 50 percent. These estimates are probably excessive because the silica content and the flow rate of the artesian well are below the minimum conditions specified for the reliable application of this geothermometer.

The chalcedony mixing model yields a subsurface temperature estimate of 35°C with a cold water fraction of 20 percent of the total flow. Although the subsurface temperature estimate is below the surface temperature of the well (39°C), it is within the expected margin of error.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 100°C and 104°C, respectively (Table 3). Both of these estimates are too high because calcium carbonate is being deposited at the surface of the artesian well.

Conclusion: The subsurface temperature in this area is best represented by the chalcedony and quartz mixing models. Therefore, the temperature at depth is probably between 40°C and 60°C (Table 3).

RESOURCE ASSESSMENT: As seen on Fig. 4, the well is located on the lower flank of an unnamed anticline. An outcrop of Tertiary age intrusive rocks is located approximately 3 1/2 miles to the east. It is believed that the entire anticline should be considered as having potential for geothermal resources. The areal extent of the reservoir is estimated to either 1.3 or 12.0 sq mi. Calculations show that there may be between .0329 Q's ($.0329 \times 10^{15}$ B.T.U.'s) and .395 Q's ($.395 \times 10^{15}$ B.T.U.'s) of energy contained in the system (Table 2).

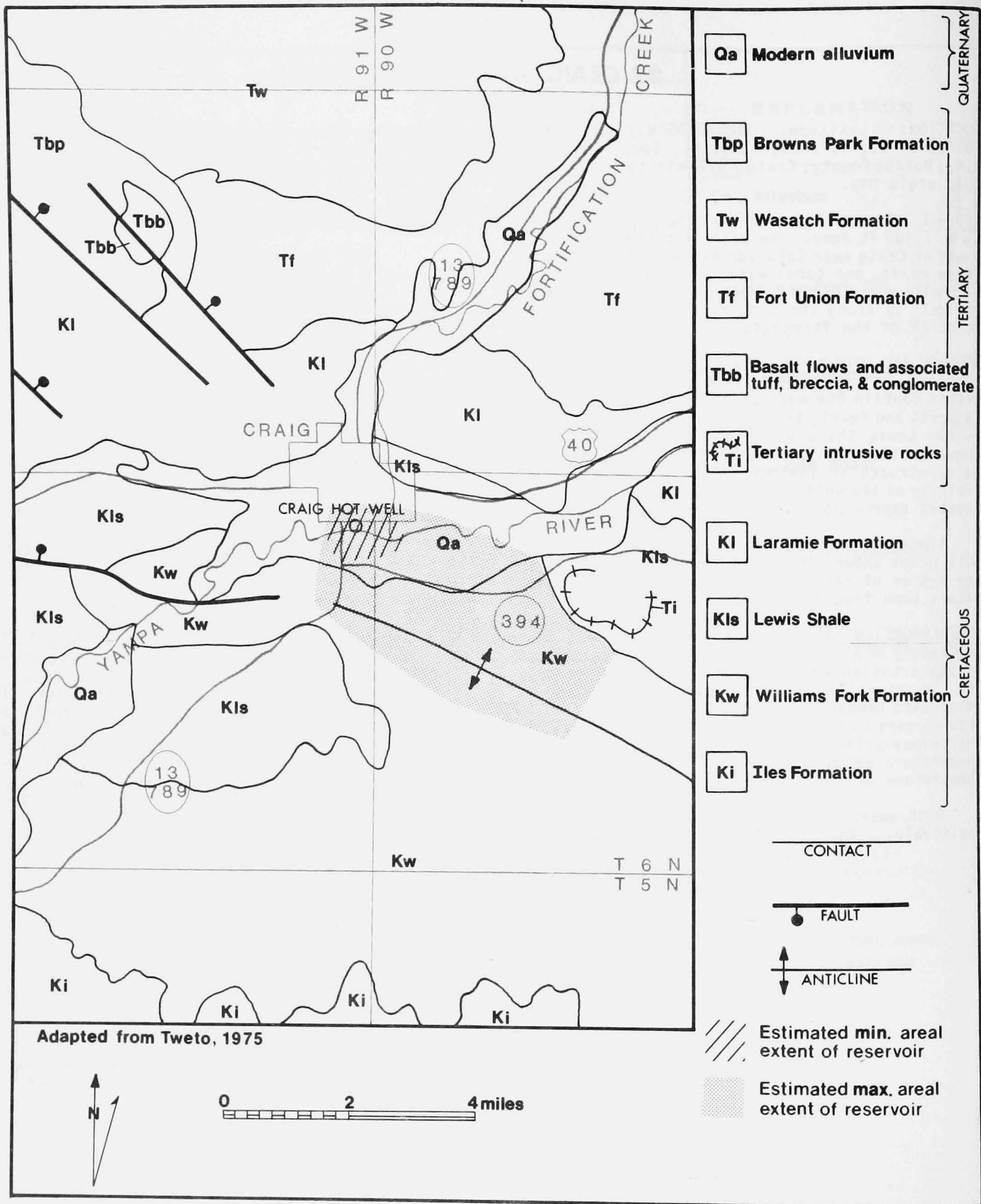


Figure 4.--Map showing geology surrounding Craig Warm Water Well and extent of estimated geothermal reservoir.

#3 ROUTT HOT SPRINGS

LOCATION: Latitude: 40°33'34"N.; Longitude: 106°51'00"W.; T. 7 N., R. 84 W., Sec. 18 dc, 6th P.M.; Routt County; Rocky Peak 7 1/2-minute topographic quadrangle map.

GENERAL: This group of 5 unused springs is located approximately 8 miles north of Steamboat Springs on Hot Spring Creek. Access is north on 7th Street in Steamboat Springs past the hospital to Park Road, then north on this road to the springs.

GEOLOGY AND HYDROLOGY: The following springs were measured.

Spring A: Located approximately 100 ft up the hillside on the south side of the creek; Temperature: 64°C; Discharge: 25 to 50 gpm; Total Dissolved Solids: 518-552 mg/l; Water Type: sodium chloride-bicarbonate.

Spring B: Biggest spring on north bank of creek, approximately 5 ft above the creek; Temperature: 62°C; Discharge: 30 gpm; Total Dissolved Solids: 539 mg/l; Water Type: sodium chloride-bicarbonate.

Spring C: Not sampled; Located 50 ft east of Spring A; Temperature: 54°C; Discharge: Est. 2 gpm; Conductance: 830 micromhos.

Spring D: Not sampled; Located approximately 40 ft southeast of Spring C; Temperature: 51°C; Discharge: Est. 2 gpm; Conductance: 830 micromhos.

No detailed geologic reports or maps have been prepared or published on this area. As shown by Tweto (1975), the springs issue from northwest-trending fracture zones within faulted Precambrian metamorphic rocks (Fig. 5).

Recharge of these springs may occur along the western edge of the Park Range to the east with deep circulation of the waters along fault zones in an area of above-normal heat flow.

GEOOTHERMOMETER ANALYSIS: Calculations by Barrett and Pearl determined the following estimated subsurface temperatures: Quartz-silica geothermometer model yielded an estimated temperature of 125°C to 136°C (Table 3); Quartz mixing model yielded an estimated subsurface temperature of 192°C to 231°C with a cold water fraction of 71 to 78 percent; the Na-K and Na-K-Ca geothermometers yielded subsurface temperature estimates of 165°C to 170°C and 154°C to 159°C, respectively (Table 3). The high surface temperature (64°C), rapid flow (100 gpm) and close agreement with the mixing model results suggest that these are reasonable estimates.

Conclusion: The fluctuation of the various geothermometer estimates is within the range of values that could result from normal analytical error. The close agreement between the mixing model and the Na-K-Ca model estimates suggests that these geothermometers adequately reflect the temperature at depth. Therefore, these results and the precision of the geothermometers suggest temperatures at depth between 125°C and 175°C (Table 3).

RESOURCE ASSESSMENT: Due to the uncertainty of the reservoir size and extent, two estimates of reservoir extent were made. One estimate was based on the reservoir being restricted to the northwest trending fault zone (Fig. 5). This reservoir is estimated to have an areal extent of .5 sq mi and contained .1110 Q's of energy (Table 3).

During the summer of 1978, in an attempt to define this system, personnel from the U.S. Geological Survey ran several electrical geophysical surveys across the area. Preliminary analysis of the data shows that the thermal system is fault-controlled and restricted to an area of approximately .50 - .75 sq mi around the spring (Karen Christopherson, personal communication, 1978). This area could contain .1663 Q's of heat energy at an average maximum temperature of 138°C (Table 2).

#4 STEAMBOAT SPRINGS

LOCATION:

(Heart Spring): Latitude: 40°28'58"N.; Longitude: 106°49'37"W.; T. 6 N., R. 84 W., Sec. 17 abd, 6th P.M.; Routt County; Steamboat Springs 7 1/2-minute topographic quadrangle map.

GENERAL: With the exception of the Heart Spring, which is located at the southeast end of the town, all the springs are unused at the present time. Waters from the Heart Spring are used in the large community swimming pool. The spring is located just to the northwest of the pool.

At the northwest end of town are several springs spread over a large area. Most of these springs are cold, but the original Steamboat Spring is warm. This spring is located on the west bank of the Yampa River along the railroad tracks, just to the west of the little City Park.

The other thermal spring, Sulphur Cave Spring, is located 1,100 ft northwest of the rodeo grounds and approximately 80 ft above the level of the river.

GEOLOGY AND HYDROLOGY: The Heart Spring has a temperature of 39°C with a discharge of 140 gpm. The total dissolved mineral matter in the waters is 903 mg/l, and the waters are a sodium-chloride type with a strong concentration of sulfate.

Steamboat Spring has a temperature of 26°C with a discharge of 20 gpm. The waters are a sodium-bicarbonate type and contained 6,170 mg/l of dissolved mineral matter.

The waters of the Sulphur Cave Spring had a temperature of 20°C with a discharge of 10 gpm. The waters are a sodium chloride type and contain 4,530 mg/l of dissolved mineral matter.

As shown on Figure 5, these springs are situated on or just off of a major north-south trending fault paralleling the western front of the Park Range. This fault has brought sandstones of the Cretaceous Dakota Formation into contact with the Tertiary Brown's Park Formation. The Dakota Formation, primarily a sandstone unit, contains large amounts of sulfur-rich black shales. The Brown's Park Formation is a consolidated to semiconsolidated, coarse-grained sandstone that contains some shale and clay beds.

While no values of heat flow have been determined for this part of Colorado, it is believed to be above normal. The occurrence of these thermal waters may be due to deep circulation of ground waters along some of the many faults found in the region.

GEO THERMOMETER ANALYSES: Barrett and Pearl (1978) stated that the low surface temperature and flow of Steamboat and Sulphur Cave spring renders geothermometer analysis unreliable; therefore, they only calculated the estimated reservoir temperatures for Heart Hot Spring.

The quartz-silica geothermometer model yields a maximum subsurface temperature estimate of 101°C (Table 3) (Barrett and Pearl, 1978). Quartz-silica mixing model analysis yields a subsurface temperature estimate of 179°C with a cold-water fraction of 81 percent of the spring flow. The low silica content of this spring casts doubts upon the reliability of these estimates.

The Na-K and Na-K-Ca geothermometer estimates of subsurface temperature are 148°C and 141°C, respectively (Table 3). Although precipitation of calcium carbonate does not occur at the present time at this site, extensive travertine deposits exist in the western half of section 17, T. 6 N., R.84 W. If these deposits represent current conditions at depth for Heart Hot Spring, then the Na-K and Na-K-Ca geothermometer estimates are too high.

Conclusion: It is difficult to make a precise prediction of subsurface temperature for this area because of the wide range of geothermometer results and the unknown effects of the chemical additives on the water chemistry of the hot spring. However, the Na-K and Na-K-Ca geothermometer estimates are substantiated by the analysis of the Routt Hot Spring group 5 miles northwest of this spring (see preceding section on Routt Hot Springs). The best estimate of subsurface temperature for this area is between 125°C and 130°C (Table 3).

RESOURCE ASSESSMENT: A number of major faults have been mapped in the vicinity of Steamboat Springs (Fig. 5). However, these springs appear to be located on the trace of an unmapped northwest trending fault (Karen Christopherson, personal communication, 1978). During the summer of 1978, Ms. Christopherson, as part of the field work for her M.S. thesis requirements at the University of Colorado, ran several electrical geophysical surveys in the Routt-Steamboat Springs area. Because of cultural interference, she was not able to get as a complete definition of the reservoir at Steamboat Springs as at Routt Hot Springs. Analysis of her data shows that there is an unmapped fault trending northwest through the springs. Therefore, until proven otherwise, it will be assumed that the reservoir is fault controlled and extends only along the northwest fault. It is estimated that this reservoir has an areal extent of .52 sq mi and contains .0487 Q's of heat energy at an average maximum temperature of 70°C (Table 2).

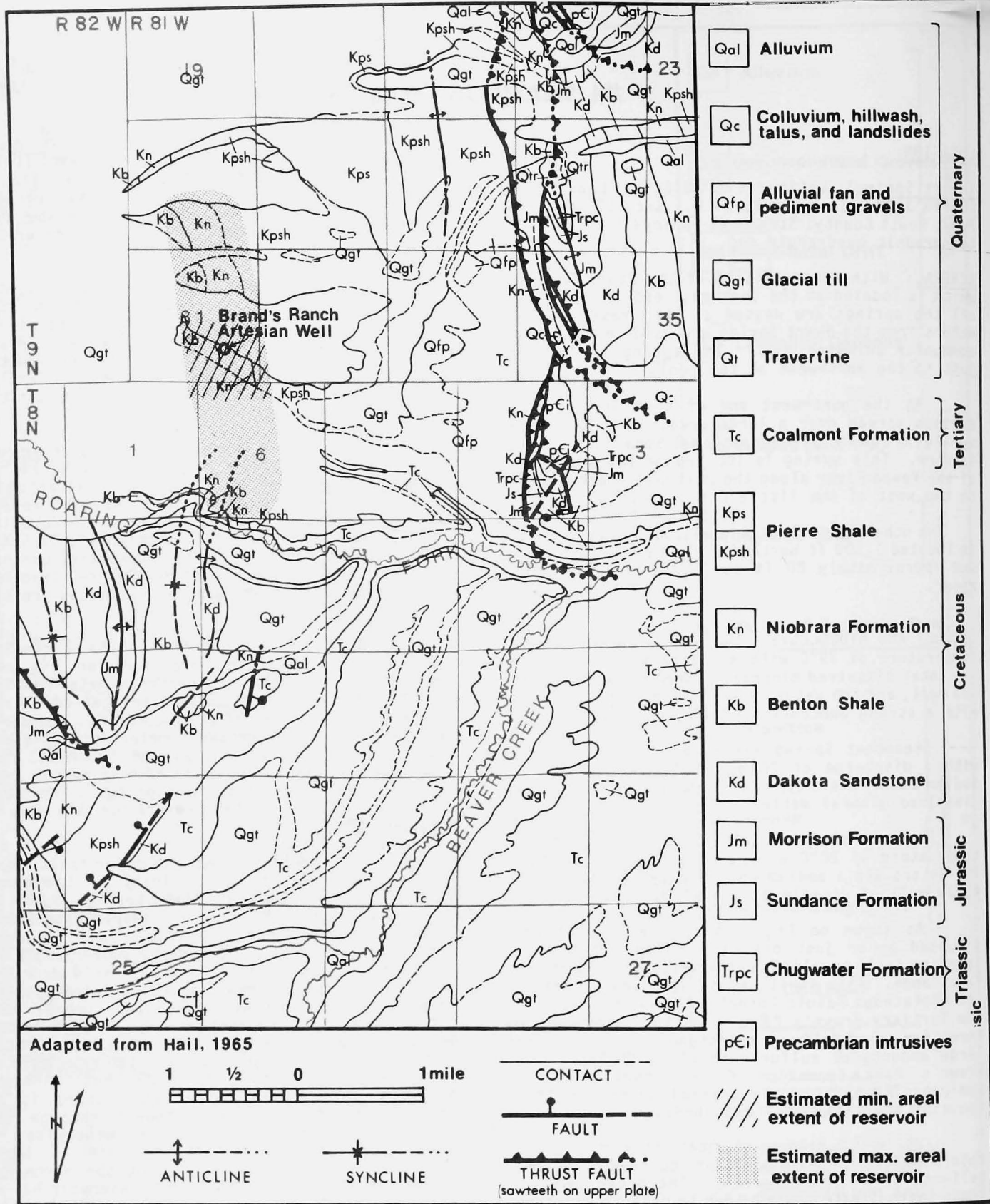


Figure 6.--Geology map of Brands Ranch Artesian Well and extent of estimated geothermal reservoir.

#5 BRAND'S RANCH ARTESIAN WELL

LOCATION: Latitude: 40°42'17" N.; Longitude: 106°32'05" W.; T. 9 N., R. 81 W., Sec. 31 dcd, 6th. P.M.: Jackson County; Pitchpine Mountain 7 1/2-minute topographic quadrangle map.

GENERAL: This unused well is located west of Walden, Colorado, and may be reached by going 7.7 miles west of Walden on a paved county road to the North Platte River, cross the river and go 2.6 miles to an intersection. Turn right at the intersection and proceed 0.6 mile to an intersection near South Delaney Lake. Turn left on the dirt road and go west 3.8 miles to Brand's Ranch, a group of abandoned buildings. Go 0.2 miles west of the ranch and cross twin irrigation ditches. Turn right immediately west of the ditches and go 0.7 mile north on the dirt road along the west side of the ditches. Park at the locked gate and walk 0.3 mile east of the gate to a small foot bridge. The well is about 300 ft south of the foot bridge in a swampy area in a pasture.

GEOLOGY AND HYDROLOGY: This artesian well, an old oil test well 800 ft deep, has an estimated discharge of 80 gpm at a temperature of 42°C. The conductance of the water is 405 micromhos with a pH of 6.0

This well is located on the west side of North Park, a large intermontane basin in northwest Colorado. The geology of the area has been discussed in detail by Hail (1965). As shown on the geologic map (Fig. 6), the well is located on the outcrop of the Niobrara Formation, and no major faults have been mapped in the immediate vicinity of the well. It is postulated that the waters come from the Dakota, Sundance, or Chugwater Formations.

Recharge to the well probably occurs along the east flank of the Park Range to the west.

GEOOTHERMOMETER ANALYSES: Analysis by Barrett and Pearl (1978) of silica solubility and temperature relationships suggest that the chalcedony silica geothermometer should be used. The chalcedony-silica geothermometer subsurface temperature estimate is 42°C (Table 3), which is the same as the surface temperature of the hot well.

Chalcedony mixing model yields a subsurface temperature estimate of 43°C with a cold-water fraction of 1 percent of the total flow.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 199°C and 171°C, respectively. Although no calcium carbonate deposits were noticed near the artesian well, large travertine deposits (800 ft x 2000 ft x 25 ft thick) occur in section 27, T. 9 N., R. 81 W. approximately 2.5 miles northeast of the artesian well (Fig. 6). Hail (1965) states that the spring waters responsible for this deposit ascend along a large reverse fault from unknown depth and surface at the junction of the fault and an anticlinal axis. Field data for one of these springs follows (Barrett, unpublished field data):

Temperature	18°C
Conductance	3500 micromhos
pH	7.0
Discharge	less than 2 gpm

If the spring and thermal artesian well waters are of similar origin, then the travertine deposits around the springs may indicate similar conditions occurring at depth within the artesian well. If calcium carbonate is deposited within the artesian well, then the Na-K and Na-K-Ca geothermometer estimates are too high (199°C and 171°C, respectively).

Conclusion: The rapid flow of the well, the excellent agreement between the silica and mixing models with the temperature and silica content of the thermal water imply that the subsurface temperature is near the surface temperature of the artesian well. The temperature at depth in this area, therefore, is probably 42°C to 55°C (Table 3).

RESOURCE ASSESSMENT: Two estimates of the reservoir's extent were made. One estimate showed that the reservoir may contain 0.36 sq mi and be restricted to an area just around the well. The other estimate showed that the reservoir may extend to the projected faults south and approximately 1.3 miles north of the well. This system may encompass an area of 1.5 sq mi. The amount of energy estimated to be contained within this system varied from .0039 Q's to .0164 Q's at a temperature of 49°C (Table 2).

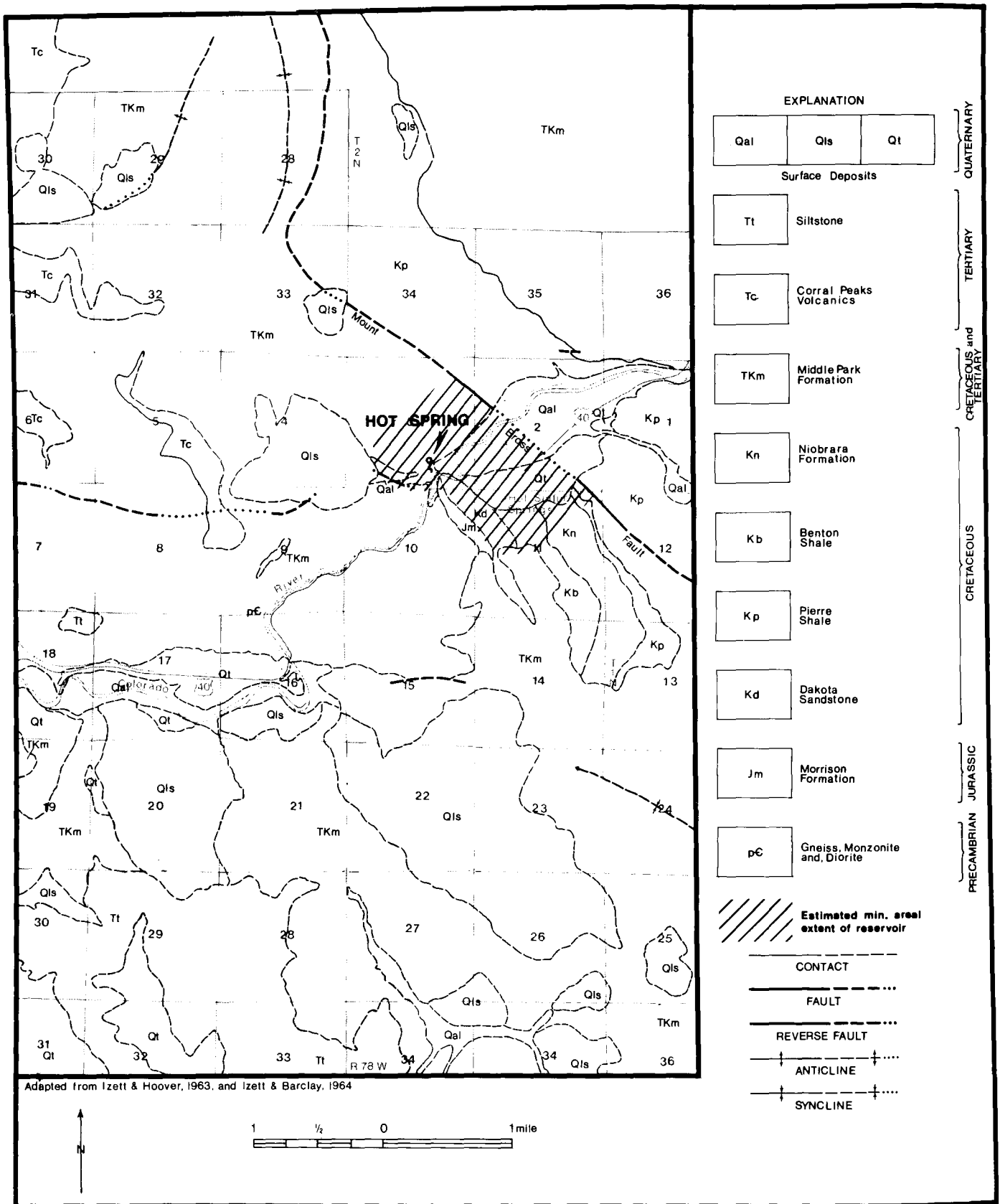


Figure 7.--Map showing geologic conditions surrounding Hot Sulphur Springs and extent of estimated geothermal reservoir.

#6 HOT SULPHUR SPRINGS

LOCATION: Latitude: 40°04'33"N.; Longitude 106°06'43"W.; T. 1 N., R. 78 W., Sec. 3 dc, 6th P.M.; Grand County; Hot Sulphur Springs 15-minute topographic quadrangle map.

GENERAL: This group of springs is located immediately to the northwest of Hot Sulphur Springs on the north side of the Colorado River. Due to the modifications of the springs discharge points, it was not possible to accurately determine the number of springs; however, 5 to 10 springs appear to be present. Waters from the largest springs are piped to the various buildings on the property where the waters are used for swimming, steam baths, and laundry purposes.

GEOLOGY AND HYDROLOGY: The waters are a sodium bicarbonate type with a large concentration of sulfate. The total dissolved solids of the water is 1,200 mg/l, and the temperature ranges from 40°C to 44°C. While the discharge of the various springs ranges from 1 to 23 gpm, the total discharge of all the springs is approximately 50 gpm. A large travertine deposit surrounds the spring. The waters come from the Dakota Sandstone, the underlying bedrock formation.

The geology of the surrounding area has been discussed in detail by Izett (1968). The accompanying geologic map (Fig. 7), taken from Izett and Hoover (1963) and Izett and Barclay (1964), shows that Precambrian igneous and metamorphic rocks are exposed less than one mile southwest of Hot Sulphur Springs in Byers Canyon. Unconformably overlying these rocks and dipping to the northeast is a sequence of sedimentary

sandstones, siltstones, shales, and limestones, belonging in ascending order to the Morrison, Dakota, Benton, Niobrara Formations and Pierre Shale. Overlying these formations is the Tertiary Middle Park Formation consisting of lava flows and associated rocks, siltstones and sandstones.

The Mount Brass Fault, a major northwest-trending thrust fault, occurs less than one half mile to the northeast of the springs. This fault may not control the occurrence of the springs since they are located on a small north trending normal fault. The thermal waters may be ascending along this fault zone.

The occurrence of the thermal waters may be due to deep circulation of ground water along fault zones in an area having above normal geothermal gradients. Reiter (1975) has shown this area to have a heat flow of approximately 2.3 heat flow units.

GOTHERMOMETER ANALYSES: Most geothermometer techniques yield unreliable estimates when applied to Hot Sulphur Springs because many of the assumptions inherent in their use are violated (Barrett and Pearl, 1978). The best geothermometer subsurface temperature estimate for this spring group is between 75° and 150°C (Table 3).

RESOURCE ASSESSMENT: For resource assessment purposes the reservoir is estimated to extend from the Mount Brass Fault on the northwest to the small fault southwest of the springs. If this estimate of the reservoir extent (1.35 sq mi) is correct, it could contain .0698 Q's of energy at a temperature of 40°C (Table 2).

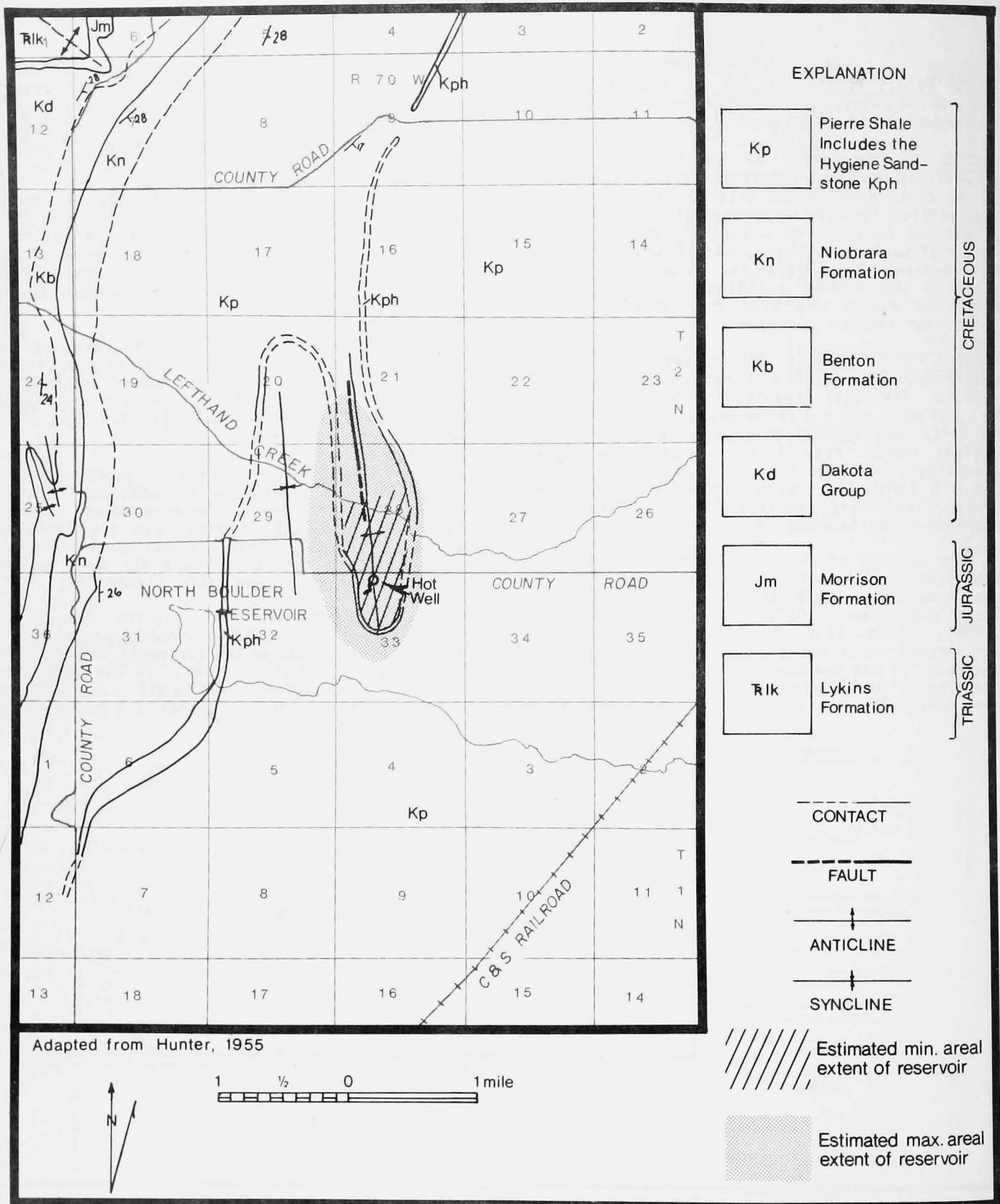


Figure 8.--Geology of Haystack Butte area and estimated areal extent of the geothermal reservoir.

#7 HAYSTACK BUTTE WARM WATER WELL

LOCATION: Latitude: 40°05'48"N; Longitude: 105°14'16"W.; T. 2 N., R. 70 W., Sec. 33 ba, 6th P.M.; Boulder County; Niwot 7 1/2-minute topographic quadrangle map.

GENERAL: This unused oil test hole is located approximately halfway between Boulder and Longmont. Access is northeast from Boulder on State Highway 119. The well is 650 ft south and 1,550 ft east of the northwest corner of sec. 33.

Another unused well was located in 1977. This well is located 1,100 ft south and 1,850 ft east of the northwest corner of sec. 33. The well has a temperature of 32°C with a discharge of approximately 5 gpm.

The Haystack Butte Warm Water well was drilled in 1920 to a total depth of 2,932 ft. The well was abandoned due to the large amount of water encountered.

GEOLOGY AND HYDROLOGY: The discharge of this well, which is just seeping around all the material that has been thrown in the well in attempt to plug it, is approximately 4 gpm. The waters have a temperature of 28°C, with 1,200 mg/l of dissolved solids. The waters are a sodium-bicarbonate type.

As shown on Figure 8, the well is located on the south end of a faulted anticline. While the

fault does not extend as far south as the well, the well is on strike with the fault. The bedrock of the area is the Pierre Shale and with the reported depth of the well, 2,932 ft, it is believed that the waters come from the Dakota Formation, which outcrops a few miles to the west. Recharge probably occurs along the front of the mountains to the west. The source of the heat is unknown; however, a number of Tertiary igneous features dot the mountain front north from Golden (Ralson Butte, Valmont Dike, etc.). These rocks may be too old to supply the needed heat.

GEOOTHERMOMETER ANALYSES: Most geothermometers are unreliable when applied to the Haystack Butte Warm Water Well because most of the assumptions inherent in their use are violated. The best estimate of the temperature at depth in this area is probably near 50°C.

RESOURCE ASSESSMENT: Two estimates of the total energy contained in the reservoir were made. Two different sizes of the reservoir were assumed, one restricted to the crest of the anticline and one encompassing the total anticline (Fig. 8). The small area is estimated to be approximately 0.54 sq mi in size and contain .0061 Q's of energy. The larger area is estimated to encompass most of the anticline. This area is estimated to encompass an area of 1.5 sq mi and contain .0169 Q's of heat energy (Table 2).

FIGURE 9 HERE GEOLOGIC MAP OF ELDORADO SPRINGS

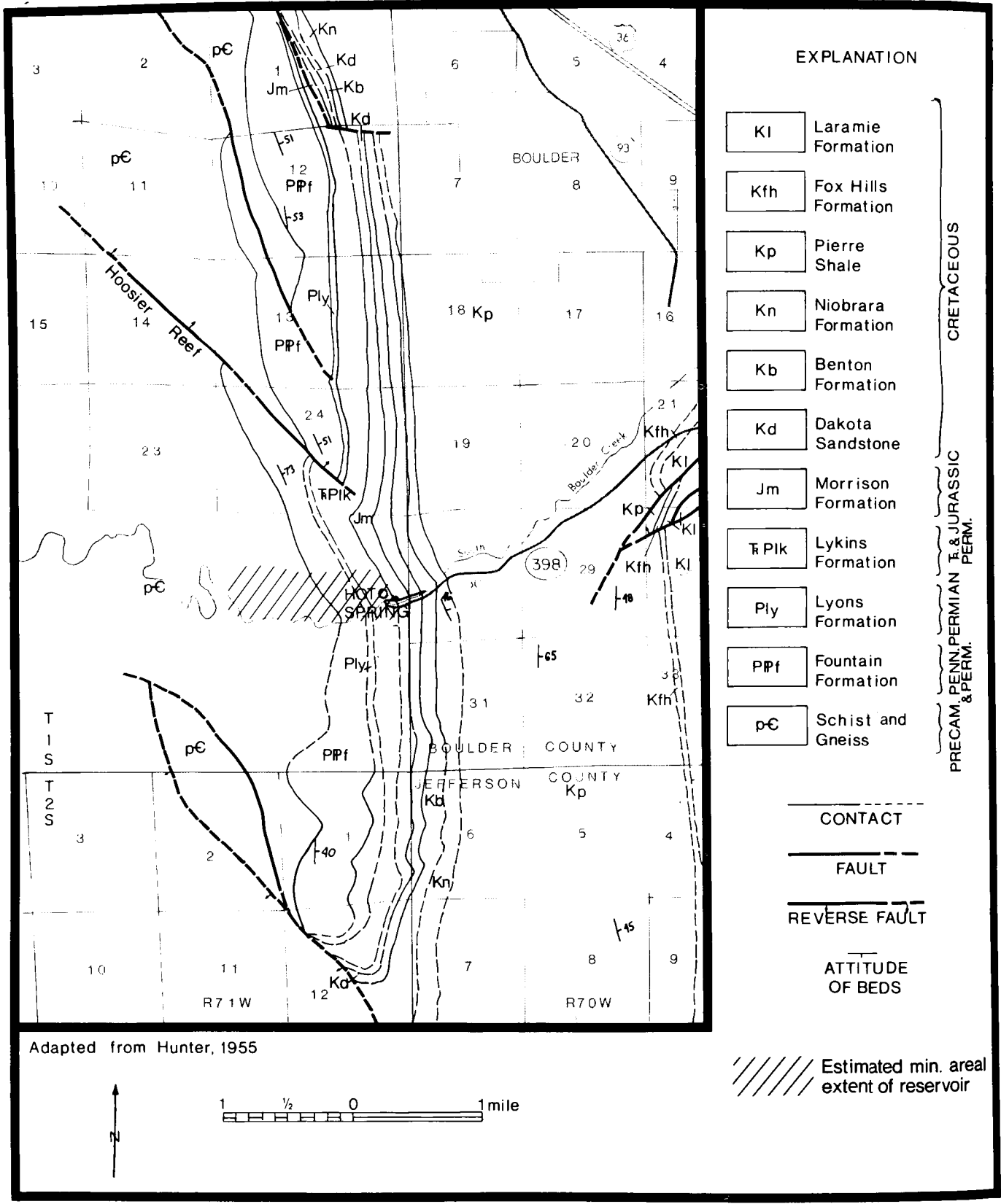


Figure 9.--Map showing the estimated areal extent of the geothermal reservoir and the geologic conditions surrounding Eldorado Springs.

#8 ELDORADO WARM SPRINGS

LOCATION: Latitude: 39°55'52" N.; Longitude: 105°16'46" W.; T. 1 S., R. 71 W., Sec 25 da, 6th P.M.; Boulder County; Eldorado Springs 7 1/2-minute topographic quadrangle map.

GENERAL: These springs are located approximately 10 miles south of Boulder at the eastern edge of the Front Range. The springs are reached by State Highway 93 from Boulder, then west on State Highway 398.

The springs, which are actually three wells and one spring, are located on both sides of South Boulder Creek. The spring is located in the basement of the large rock and cement building on the north side of the creek west of the swimming pool. The waters from these wells and spring are used in the swimming pool and are bottled and sold commercially.

GEOLOGY AND HYDROLOGY: Throughout the year's time, the temperature of the water ranged from 24°C to 26°C, and the total dissolved solids ranged from 84 to 101 mg/l. Due to the physical layout of the water collection system, it was not possible to measure the discharge of these wells and spring. The waters are a calcium sulfate type.

The waters emerge from South Boulder Creek alluvium, which overlies steeply easterly dipping

sandstones of the Fountain and Lyons Formations (Fig. 9). While there are no major faults mapped in the region, it is believed that the waters originated by deep circulation through fault and fracture zones in the underlying basement rocks of the mountains a few miles to the west.

GEOOTHERMOMETER ANALYSES: Geothermometer analysis of the subsurface temperatures by Barrett and Pearl (1978) determined the following: Chalcedony silica 21°C to 23°C; Chalcedony mixing model, 26°C to 27°C with a cold water fraction of 1 to 19 percent of the spring flow; Na-K, 254°C to 320°C; Na-K-Ca, 43°C to 57°C (Table 3). The Na-K estimate is too high because one of the conditions of the model was violated.

The mixing model and silica geothermometer provide a minimum subsurface temperature estimate while the Na-K-Ca geothermometer estimate is probably a maximum value of subsurface temperature. Therefore, the subsurface temperature in this area is probably between 26°C and 40°C (Table 3).

RESOURCE ASSESSMENT: Based on the above assessment of the geologic conditions of the area, it is assumed that the reservoir extends to the west of the spring and encompasses an area of approximately .50 sq mi and contained .0147 Q's of energy (Table 2).

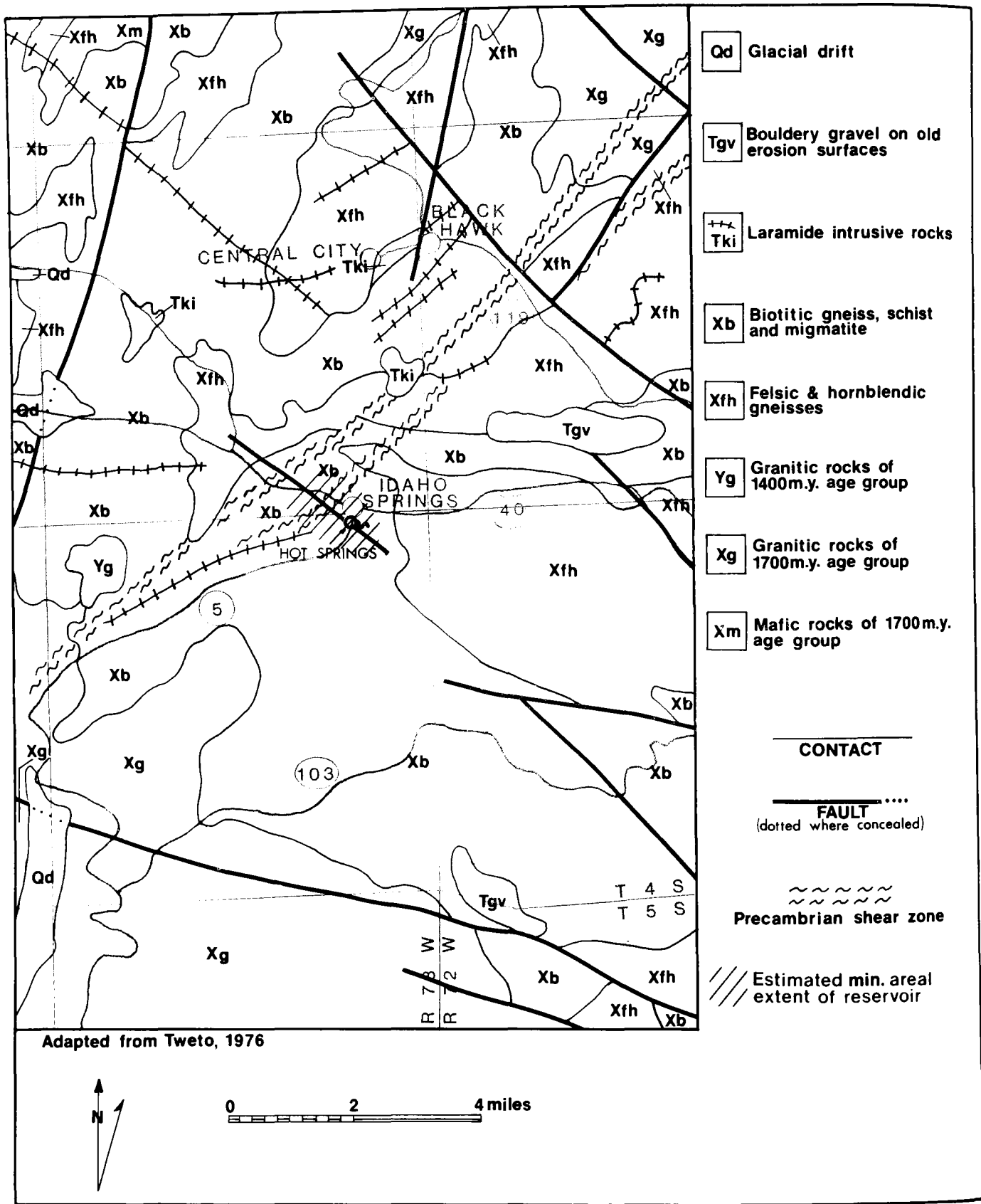


Figure 10.--Geology surrounding Idaho Springs and estimated geothermal reservoirs extent.

#9 IDAHO HOT SPRINGS

LOCATION: Latitude: 39°44'20"N.; Longitude: 105°30'43"W.; T. 4 S., R. 73 W., Sec 1 ba, 6th P.M.; Clear Creek County; Idaho Springs 7 1/2-minute topographic quadrangle map.

GENERAL: This group of three thermal springs and one well are located along Soda Creek at the Indian Springs Lodge on the south side of the town of Idaho Springs. The waters from the springs and well are used for baths and swimming purposes.

GEOLOGY AND HYDROLOGY: The temperatures of the waters range from a low of 20°C to a high of 46°C. The discharge varies from 1 gpm to 30 gpm.

Spring A: located in a tunnel 75 ft south of the lodge, and east of the creek. During the year the temperature of the water ranged from 40°C to 45°C. The spring had a discharge of 21 gpm and total dissolved solids in the water varied from 1,940 to 2,110 mg/l. The waters are a sodium-bicarbonate type.

Spring B: This spring is located 50 ft east of the southeast corner of the lodge in a tunnel in the cliff face. The spring has a temperature of 24°C, a discharge of less than one gpm and the total dissolved solids in the water is 1,070 mg/l of a sodium-bicarbonate type.

Spring C: This spring is located in a tunnel 100 ft south of the lodge. When measured, the spring had a temperature of 20°C, a discharge of one gpm, and total dissolved mineral matter of 1,070 mg/l in waters of a sodium-bicarbonate type.

Lodge Hot Water Well: This well, located at the south end of the swimming pool at the north end of the lodge, has a temperature of 46°C and a discharge of 30 gpm. The water contains 2,070 mg/l of total dissolved solids and is a sodium-bicarbonate type.

The following brief description of the geological history of the Idaho Springs region is taken from Harrison and Wells (1959), Lovering and Goddard (1950), and Moench and Drake (1966).

The Idaho Hot Springs are located within the Colorado Mineral Belt. The Mineral Belt is a northeast-trending zone of intrusive rocks and

hydrothermal veins of early Tertiary age. The bedrock of the area is composed largely of layered Precambrian gneissic rocks, the Idaho Springs Formation, and small bodies of granite and pegmatite.

Unfortunately, none of the various reports published on the Idaho Springs area describes in any detail the geological conditions surrounding the hot springs. As noted on Figure 10, the hot springs are located on the trace of a northwest-trending fault cutting Precambrian metamorphic rocks of the Idaho Springs Formation.

The origin of the hot springs is unclear, but they are believed to be due to deep circulation of ground waters through fracture and fault zones within the basement complex. Reiter (1975) has shown Idaho Springs to have a heat flow of 2.0 heat flow units.

GEOOTHERMOMETER ANALYSES

Conclusion: Geothermometer models should be used with caution when applied to the Idaho Hot Springs because most of the assumptions inherent in their use are violated.

Due to the extensive modification of the natural springs for bathing purposes, the following geothermometer analysis will be based on data from the Lodge Hot Water Well. Cristobalite silica geothermometer yields a estimated temperature of 59°C; Cristobalite Mixing Model yielded a temperature estimate of 81°C with a cold-water fraction of 48 percent; and Na-K and Na-K-Ca geothermometer yielded estimated temperatures of 231°C and 210°C respectively (Table 3) (Barrett and Pearl, 1978).

The estimation of subsurface temperature for this area is unreliable due to the ambiguous geochemistry of the thermal waters.

RESOURCE ASSESSMENT: Since Barrett and Pearl (1978) postulated that the springs were associated with fault and fracture zones the boundaries of the reservoir area were drawn to include those zones (Fig. 10). It is estimated that the areal extent of the reservoir includes 1.52 sq mi. Calculations show that this system could contain .1714 Q's of energy at a maximum temp. of 80°C (Table 2).

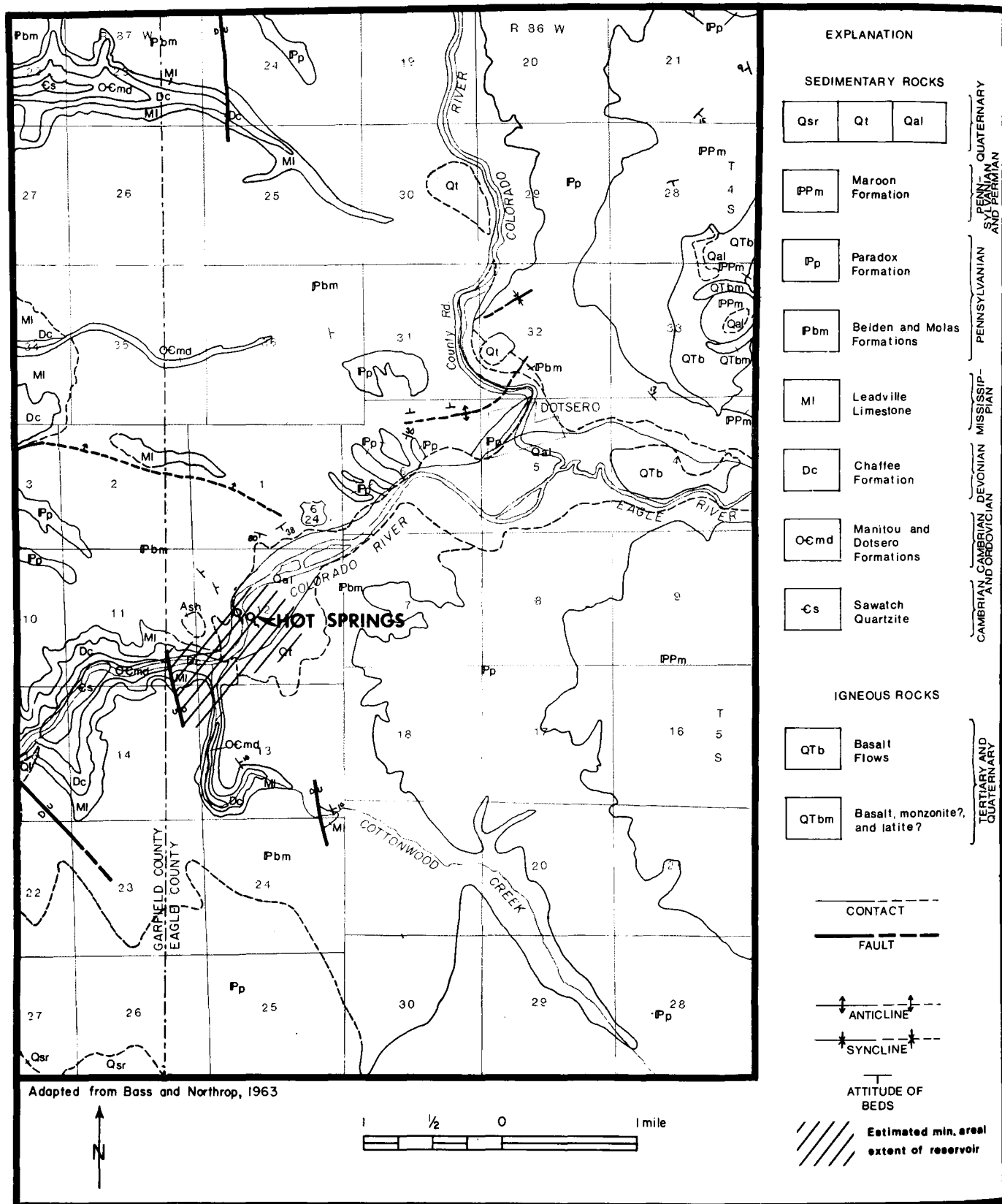


Figure 11.--Map showing estimated areal extent of the geothermal reservoir and geologic conditions surrounding Dotsero Hot Springs.

#10 DOTSERO WARM SPRINGS

LOCATION: Latitude: 39°37'39"N.; Longitude: 107°06'22"; T. 5 S., R. 87 W., Sec. 12 bd, 6th P.M.; Eagle County; Glenwood Springs 15-minute topographic quadrangle map.

GENERAL: This group of unused springs is located on both sides and in the Colorado River approximately 0.5 mile upstream from where the river bends before entering Glenwood Canyon and approximately 3 miles downstream from the confluence of the Colorado and Eagle Rivers. The springs on the west side of the river are located approximately 150 yd north of the house and flow out from under U.S. Highways 6 and 24 at the level of the Colorado River. About 5 springs comprise the group.

The springs on the south side of the river are located at the bend of the river. Access to these springs is either by a bridge a couple miles down the river or by a foot bridge several miles upriver.

GEOLOGY AND HYDROLOGY: Due to the spring's high flow, and the near submergence of the springs by the river, one cannot accurately measure the discharge of either groups of springs. Depending upon the time of year, the discharge of the springs on the west side varies between 500 and 800 gpm. The discharge of the springs on the southeast side of the river was estimated to be 1,000 gpm. Waters from both groups contained approximately 10,000 mg/l of dissolved solids, and the waters are a sodium-chloride type. The temperature of both spring groups was 32°C (Barrett and Pearl, 1978).

While the springs emerge from the Colorado River alluvium, which overlies the Belden shale (Fig. 11), it is believed that the waters actually come from the nearby Leadville Limestone. These springs may be fault controlled, for just to the north of the springs there is an abrupt change in direction of dip from northeast to southwest. If the fault which occurs south of the spring were to be continuous in the subsurface to the north it would pass close to the spring and the area where the dips reverse.

Recharge probably occurs where the Leadville Limestone crops out to the north and west along the flanks of the White River Uplift. The source of heat is unknown but may be related to the volcanic

rocks capping the White River Uplift. Thermal waters found around the White River Uplift at Glenwood Springs, Dotsero, Yampa (reported hot-water well), Steamboat Springs and Routt Springs, leads one to postulate that a residual heat source remains in association with the White River Uplift. Volcanic rocks that were erupted approximately 4,000 years ago are found approximately one mile east of the confluence of the Colorado River and the Eagle River (Grose, 1974). Another possible source of the heat could be elevated geothermal gradients in the area (Barrett and Pearl, 1978).

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978) stated that analysis suggests that quartz or chalcedony may control the silica content of the warm springs. The chalcedony-silica geothermometer yields a subsurface temperature estimate of 16°C, which is obviously incorrect because it is below the surface temperature of the warm springs (31°C to 32°C) (Table 3). The quartz-silica geothermometer estimate of subsurface temperature is 45°C to 47°C. The chalcedony mixing model yields a temperature estimate of 27°C-29°C with a cold-water fraction of 26 to 36 percent of the spring flow. The quartz mixing model yields a subsurface temperature estimate of 74°C to 76°C with a cold-water fraction of 65 to 67 percent of the spring flow. The reliability of both the quartz and chalcedony mixing models is questionable because the silica contents of the warm springs are well below the minimum conditions specified for the application of this geothermometer.

Calculations by Barrett and Pearl (1978) showed that the Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 102°C to 135°C and 109°C to 144°C, respectively.

Conclusion: The extremely high flow (greater than 1,500 gpm) of this group suggests very little difference between the surface temperature of these springs and the temperature at depth. Therefore, the likely subsurface temperature in this area is between 32°C and 45°C (Table 3).

RESOURCE ASSESSMENT: The reservoir is estimated to extend from the small fault southwest of the spring and to the area of the projected fault to the north. This area encompasses approximately 0.5 sq mi and may contain .0045 Q's of heat energy at an average temperature of 39°C (Table 2).

#11 GLENWOOD HOT SPRINGS

LOCATION: Latitude: 39°32'59"N; Longitude: 107°19'18"W.; T. 6 S., R. 89 W., Sec. 9 ad, 6th P.M.; Garfield County; Glenwood Springs 7 1/2-minute topographic quadrangle map.

GENERAL: The 12 to 15 springs collectively known as Glenwood Springs are located in and adjacent to the community of Glenwood Springs along the Colorado River on Interstate Highway 70 in western Colorado. These springs are located along both banks of and in the Colorado River from a point approximately 0.5 to 0.75 mile east of the canyon mouth to the west edge of Glenwood Springs. The waters from the springs are used for swimming and medicinal purposes.

South Side of River from East to West

Railroad Spring: Located approximately 0.75 mile west of the westernmost tunnel on the railroad, approximately 0.5 to 0.75 mile east of the canyon mouth. The spring, which is located just at the water line of the river, has a discharge of 75 gpm, a temperature of 51°C, and contains 18,400 mg/l of total dissolved solids.

Spring D: Located approximately 250 ft east of the siphon pipes crossing the river below the cliffs. This spring has a discharge of 74 gpm, a temperature of 50°C, and contains 18,000 mg/l of total dissolved solids.

Spring C: Located 170 ft east of the siphon pipe. This spring has a discharge of 2 to 3 gpm, a temperature of 46°C. The spring was not sampled for dissolved mineral matter.

Spring B: Located 27 ft west of the siphon, this spring has a discharge ranging from 75 to 110 gpm with a temperature of 49°C and contains 17,700 to 18,400 mg/l of total dissolved solids.

Spring A: This spring is located 480 ft west of siphon and has a discharge of 2 to 3 gpm with a temperature of 44°C and contains 17,600 mg/l of total dissolved solids.

River Springs: Located about 50 ft out into the Colorado River, directly north of Spring A, are two large boulders of Leadville Limestone. Hot Springs issue from these boulders with discharges of about 10 gpm and 50 gpm. The temperature of the springs nearest to the shore were 50°C. These springs were not sampled for dissolved mineral matter.

North Side of River, from East to West

The Vapor Caves Springs are located at the canyon mouth in the Vapor Caves building. The discharge of the spring in the men's side was estimated at 5 gpm, the temperature was 50°C, and the total dissolved solids were 18,000 mg/l. A strong sulfur dioxide gas content in the spring is apparent for it takes your breath away when you enter the tunnel.

Big Spring (also called Yampa Spring) is located approximately 75 yd to the east of the swimming pool. The waters from this spring are used in the swimming pool. The spring has a discharge of 2,263 gpm with a temperature of 50°C and contains 20,200 mg/l of total dissolved solids.

Drinking Spring: Located approximately 100 ft east of the swimming pool. The spring has a discharge of 140 to 161 gpm with a temperature of 50°C to 51°C, and contains 18,800 to 20,500 mg/l of total dissolved solids.

Graves Spring is located at 0281 164 Road in T. 6 S., R. 89 W., Sec. 9 bb, 6th P.M. south and west of the State Highway buildings. This spring is located under the front porch of Dr. Charles Graves' chiropractic office. The discharge of this spring is 5 gpm with a temperature of 46°C and contains 21,500 mg/l of total dissolved solids. A number of other hot springs in the immediate vicinity were not sampled.

All of the above springs are a sodium-chloride type with a high concentration of sulfate.

While all the springs issue from alluvial deposits along the Colorado River, it is believed that the waters migrate up from depth through the underlying Leadville Limestone. The Leadville Limestone is very porous and permeable as evidenced by the large solution caves present at the canyon mouth on the south side.

Glenwood Springs are located at the west end of Glenwood Canyon and on the south flank of the White River Uplift. Rocks from Precambrian to Mississippian in age are exposed in the canyon just a few miles to the east. As shown on Fig. 12, the area to the north and east of the springs is cut by many faults.

One of the major faults that may control the occurrence of the hot springs is the northwest-trending Storm King Fault. Although it has not been proven that this fault actually extends as far east as the hot springs, Bass and Northrop (1963) have projected it to the spring area. While this fault may be the controlling factor for this thermal spring, Galloway (personal communication, 1978) has shown, based on evidence presented by Bass and Northrop (1963), that the ascending Leadville limestone intersects the surface at the site of the springs. According to Galloway's hypothesis, the springs result from deep circulation and up dip flow of heated waters in the Leadville limestone and that the recharge area is probably somewhere to the southwest.

One of the unexplained circumstances regarding this group of springs is the origin of the sulfate ions found in the water. The Leadville Limestone and underlying formations consist of limestones, sandstones, and some thin shale units. If the thermal waters moved only through these formations, no sulfate minerals would be dissolved since these

units do not contain any large amounts of sulfate-bearing minerals. Overlying the Leadville Formation are the red beds of the Maroon Formation and its lateral equivalents, the Eagle Valley Evaporite. These units do contain large amounts of sulfate-bearing minerals. Therefore, from the mineralogy of the thermal waters, it appears that at some point they contact the Maroon Formation. The hydrology of this system appears to be quite complex and must be studied in further detail.

GEOTHERMOMETER ANALYSES: Silica solubility and temperature relationships suggest that temperature-dependent equilibration between the thermal water and chalcedony may control the silica content of the hot springs (Table 3) (Barrett and Pearl, 1978). The chalcedony-silica geothermometer estimate of subsurface temperature is 44°C to 51°C, which is nearly identical to the surface temperature of the hot springs in this area (46°C to 51°C). Chalcedony mixing model analysis yields a subsurface temperature estimate of 49°C to 77°C, with a cold-water fraction of 0 to 46 percent of the spring flow.

Barrett and Pearl (1978) stated that the presence of extensive travertine deposits in the vicinity (T. 6 S., R. 89 W., Sections 3, 4, 5, 9, 10) and travertine-depositing springs (Springs B and D, Railroad Hot Springs and others) suggest that the Na-K and Na-K-Ca geothermometer estimates (129°C to 168°C and 143°C to 186°C, respectively) are too high. In addition, the extremely high sodium, chloride, calcium, magnesium, and sulfate contents of the hot springs suggest that the ascending thermal water encounters the Eagle Valley

Evaporite at depth (Bass and Northrop, 1963), further raising the geothermometer estimates.

Conclusion: The extremely high flow (3000 gpm), and excellent agreement between the chalcedony-silica and the mixing models with the silica content and surface temperature of the hot springs suggest that the temperature at depth is probably not much higher than the surface temperature of the hot springs. However, the geochemistry of these thermal waters is too complex for accurate prediction of subsurface temperature.

RESOURCE ASSESSMENT: Galloway (personal communication, 1978) has shown that the source of the heat may be due to deep circulation within the Leadville Limestone. Bass and Northrop (1963) have shown that the Leadville Limestone dips steeply to the southwest and reaches a depth in excess of 20,000 ft within 4 miles of Glenwood Springs. If this is the case, then the spring's occurrence is due to up dip flow of hot water in the Leadville Limestone and reaches the surface at its present location. Faulting may be a secondary controlling factor.

As there is a possibility that the waters could be coming from one of two directions, two estimates of the reservoir extent were made. One estimate considered that the waters could be related to the faulting north of town and the other estimate that the waters are moving up dip from the south-southwest. The northern reservoir has an estimated areal extent of 1.32 sq mi and contains .0279 Q's of energy. The southern reservoir has an estimated areal extent of approximately 0.50 sq mi and contains .0106 Q's of energy (Table 2).

#12 SOUTH CANYON HOT SPRINGS

LOCATION: Latitude: 39°33'16"N.; Longitude: 107°23'53"W.; T. 6 S., R. 90 W., Sec. 2 cd, 6th P.M.; Garfield County; Storm King Mountain 7 1/2-minute topographic quadrangle map.

GENERAL: This small group of unused springs is located 0.5 mile south of Interstate Highway 70 in South Canyon west of Glenwood Springs.

There are three distinct springs or seeps in this group. Spring A, which is the largest, is actually the discharge of three small springs that flow together. Spring B lies approximately 75 ft east of A, and Spring C is located 5 ft upstream from the footbridge crossing the creek. Waters from A and B are piped to the pool for bathing purposes. Waters from Spring C are unused.

GEOLOGY AND HYDROLOGY:

Spring A: Temperature: 48°C; Discharge 7 to 17 gpm; Total dissolved solids: 772-800 mg/l; Water type: sodium-bicarbonate.

Spring B: Temperature: 48°C; Discharge est.: 1 gpm; Total dissolved solids: 757 mg/l; Water type: sodium-bicarbonate.

Spring C: Temperature: 49°C; Discharge: 6 gpm.

These waters discharge from the Dakota Formation along the Grand Hogback. As shown on the geologic map (Fig. 13). The occurrence of these thermal springs is peculiar because there are no nearby faults or folds. The springs probably represent deep circulation through the Dakota Formation in an area of high geothermal gradient.

GEOOTHERMOMETER ANALYSES: Geothermometer model analysis yields the following subsurface temperatures: Chalcedony silica 60°C to 67°C; Mixing model 103°C to 127°C with a cold water fraction of 60 to 80 percent; and Na-K, and Na-K-Ca model 137°C to 140°C and 135°C to 137°C, respectively (Table 3) (Barrett and Pearl, 1978).

Considering the precision of the geothermometer models suggests that reservoir temperatures in this area are between 100°C and 130°C.

RESOURCE ASSESSMENT: The areal extent of the reservoir is estimated to be 0.1 sq mi (Fig. 13). A reservoir of this size could contain .0021 Q's of heat energy at an average maximum temperature of 75°C (Table 2).

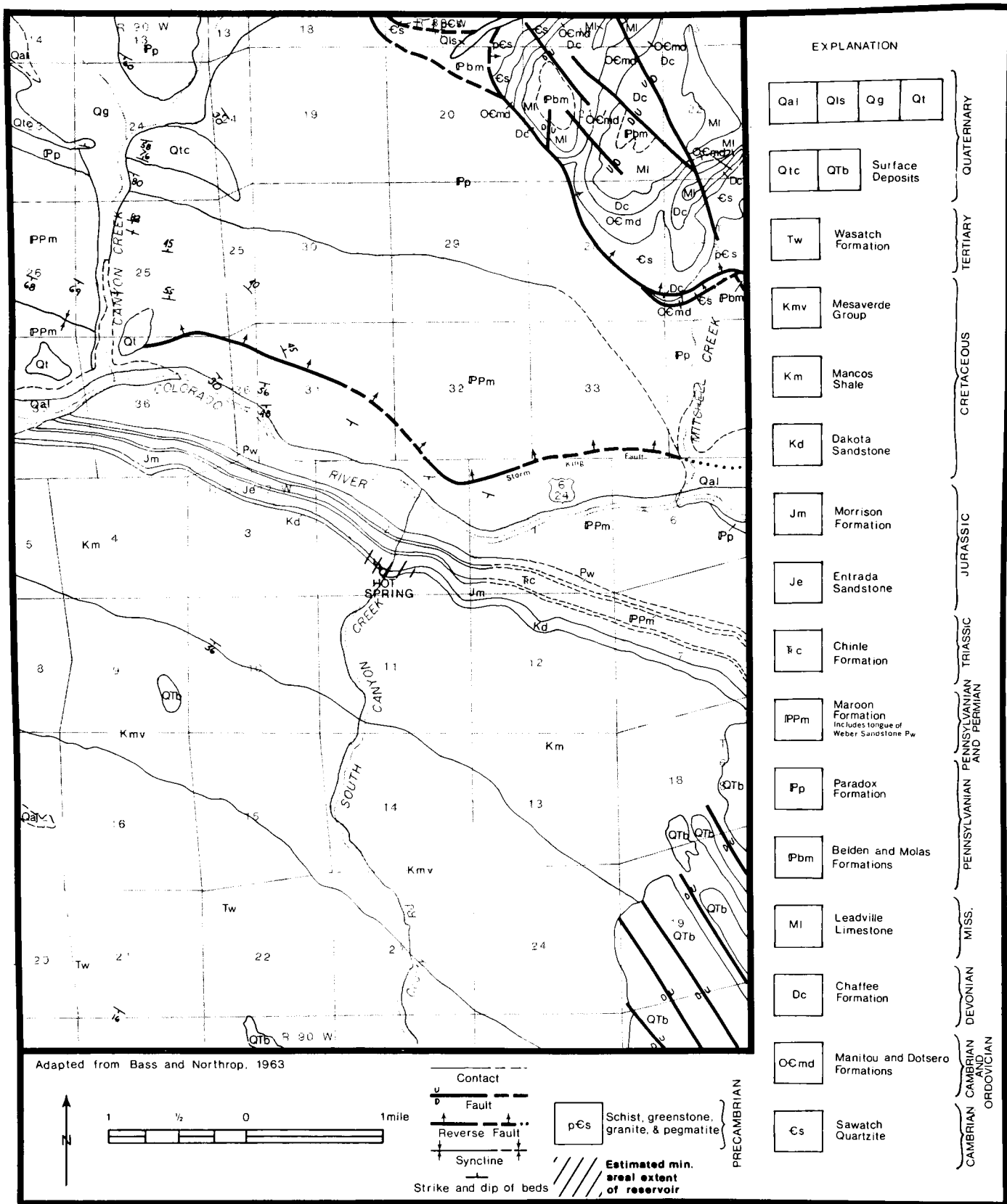


Figure 13.--Map showing estimated extent of the South Canyon Hot Springs geothermal reservoir and the surrounding geologic conditions.

#13 PENNY HOT SPRINGS

(AVALANCHE HOT SPRINGS)

LOCATION: Latitude: 39°13'33"N.; Longitude: 107°13'28"W.; T. 10 S., R. 88 W., Sec. 4 ba, 6th P.M.; Pitkin County; Redstone 7 1/2-minute topographic quadrangle map.

GENERAL: This large group of hot springs extends for over 0.5 mile along both banks of the Crystal River approximately 3 miles north of Redstone and 13.5 miles south of Carbondale on State Highway 133. With the exception of one small spring, which is used in a small greenhouse, the thermal waters are unused.

GEOLOGY AND HYDROLOGY: Only two springs, the Penny and the Granges Springs, were sampled and measured. The temperature of Penny Hot Springs, which is located on the south side of the river, varied from 40°C to 46°C throughout a year's time, while its discharge remained constant at 10 gpm. The waters contained 2,750 to 2,820 mg/l of dissolved solids and are a mixed calcium-sodium sulfate type.

Granges Spring, located on the north side of the river, has a discharge of 12 gpm, a temperature of 56°C, total dissolved solids of 2,960 mg/l, and the waters are a calcium-sodium sulfate type. This spring was sampled during a period of low river flow, and the samples were collected from the edge of the spring pool. The Penny Spring sampling point is 50 ft south of a wooden fence-like structure in the field.

The geologic map (Fig. 14) of the Penny Hot Springs area shows that the waters ascend through Crystal River alluvium overlying the Pennsylvanian Maroon Formation. While the upper springs are associated with the Maroon Formation, the lower springs may be associated with a large Tertiary intrusive. It is believed that waters from all

springs are associated with the intrusive body. While no faults are shown on the geologic map, the intrusive body is cut by numerous faults and fractures. These features do not continue into the overlying sedimentary formations. It is believed that the waters ascend from depth along these faults and fractures. Recharge probably occurs in the high area to the northwest with the waters moving downdip in the sedimentary formations and then up the fractures in the intrusive.

GEOOTHERMOMETER ANALYSES: When applied to Penny Hot Springs, most of the assumptions inherent in the use of the geothermometer models are violated. Therefore, they must be used with caution. Amorphous silica geothermometer yields an estimated reservoir temperature of 3°C to 39°C; the Amorphous Silica Mixing Model yields a temperature estimate of 35°C to 45°C with a cold water fraction of 2 to 50 percent. The Na-K and Na-K-Ca geothermometers yield subsurface temperatures of 197°C and 202°C and 89°C to 93°C, respectively (Table 3) (Barrett and Pearl, 1978).

The Na-K-Ca geothermometer and the Amorphous Silica Mixing Model provide maximum and minimum estimated subsurface temperatures, respectively. The reservoir temperature in this area is probably between 60°C and 90°C (Table 3).

RESOURCE ASSESSMENT: The areal extent of the reservoir was estimated to include all of the intrusive rock body plus some of the adjoining rocks. Since there is another intrusive rock body approximately 1 mile to the northwest (Fig. 14) the reservoir boundaries were drawn to include this area also. The Penny Hot Spring fractured reservoir is estimated to contain between .1664 Q's and .486 Q's.

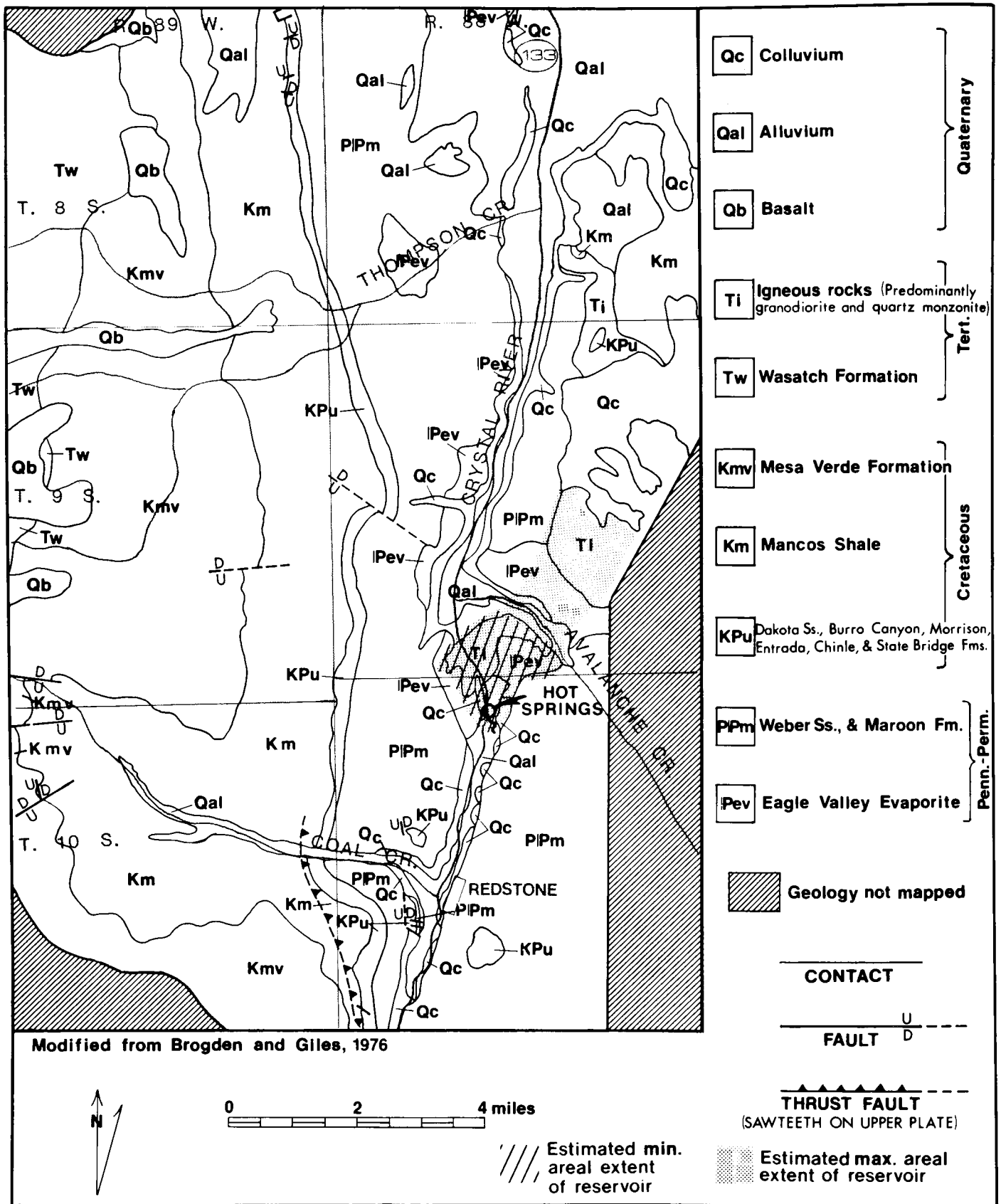


Figure 14.--Penny Hot Springs, geology and estimated areal extent of the reservoir.

#14 COLONEL CHINN HOT WATER WELL

LOCATION: Latitude: 38°52'23"N.; Longitude: 107°38'04"W.; T. 14 S., R. 92 W., Sec. 14 add, 6th P.M.; Delta County; Paonia 7 1/2-minute topographic quadrangle map.

GENERAL: This well is located southwest of Paonia, Colorado, on Stewart's Mesa. The well is approximately 2.25 miles from Paonia on a paved county road and 0.25 mile south of the curve in the road where the road tops the mesa and heads due south.

GEOLOGY AND HYDROLOGY: The well is reported to be 4,499 ft deep, and the waters have a surface temperature of 42°C. While the total dissolved solids were not determined, the conductance was 3,560 micromhos.

As noted on Figure 15 the geological conditions of the area appear very simple. Stewart's Mesa is an erosional geomorphic feature capped with alluvial sand and gravel deposits. The bedrock of the area is the black shale of the Mancos Formation. The thermal waters may come from the Dakota Formation which underlies the Mancos shale. Hail (1972) mapped the Dakota Sandstone as having uniform north dip from the outcrop area approximately 9 miles south of the well. It is believed that the waters found in this well are being recharged at the outcrop area along the Smith Fork and then migrate downdip to the north. Their elevated temperatures probably arise from high geothermal gradients in the area due to a Tertiary intrusive located 5 miles to the Southeast.

GEOOTHERMOMETER ANALYSES: Calculation of the silica solubility and temperature relationships shows that the chalcedony-silica geothermometer is applicable (Barrett and Pearl, 1978). This model yields a subsurface temperature estimate of 41°C. Chalcedony mixing model analysis yields a subsurface temperature estimate of 43°C with a cold water fraction of 1 percent of the total flow (Table 3).

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 183°C and 170°C, respectively. These results are unreliable due to the low discharge (5 gpm) and low temperature (42°C) of the artesian well. Moreover, the high magnesium content of the thermal waters further reduces the reliability of these models (Barrett and Pearl, 1978).

Conclusion: The mixing model and the silica geothermometers imply that the temperature at depth is near the surface temperature of the artesian well. However, the ambiguous nature of the geochemistry of these waters is such that no reliable subsurface temperature estimates are possible.

RESOURCE ASSESSMENT: In light of the uncertainty regarding the areal extent of the reservoir it was estimated to be restricted to an area of 1.55 sq mi around the well. If this estimate is correct, the reservoir could contain .0181 Q's of heat energy with an average temperature of 51°C (Table 2).

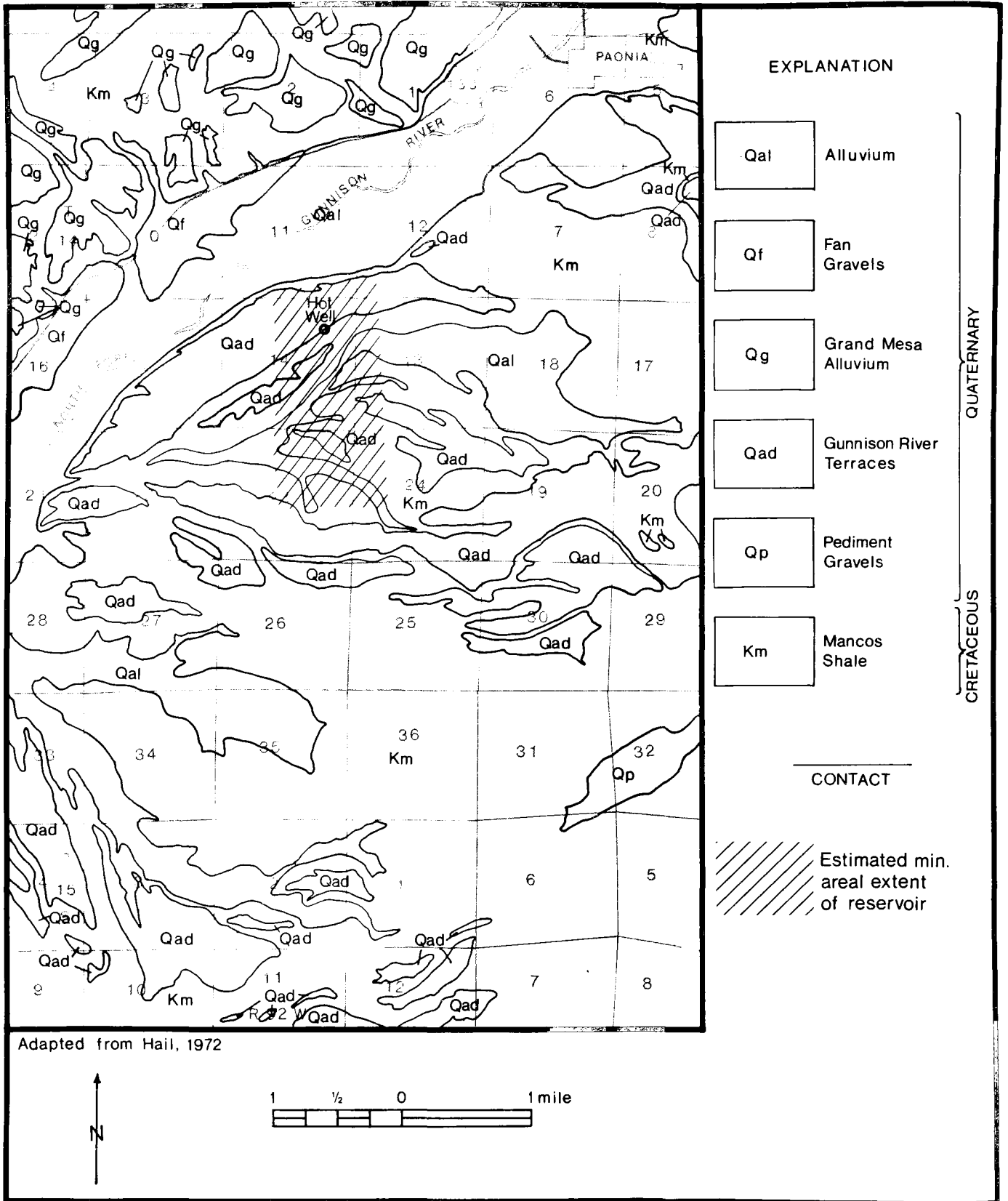


Figure 15.--Map showing geologic conditions surrounding Colonel Chinn Water Well and estimated areal extent of reservoir.

#15 CONUNDRUM HOT SPRINGS

LOCATION: Latitude: 39°00'44"N; Longitude: 106°53'26"W.; T. 12 S., R. 85 W., Sec. 16, 6th P.M.; Pitkin County; Maroon Bells 7 1/2-minute topographic quadrangle map.

GENERAL: This group of two unused springs is located at an elevation of 11,200 ft in the Maroon Bells-Snowmass Wilderness area. Access is from Aspen, up Castle Creek along the county road for 6.0 miles to Conundrum Creek, along the jeep trail up Conundrum Creek until it ends, and then along the hiking trail to the springs. The springs are approximately 15.5 miles south of Aspen.

GEOLOGY AND HYDROLOGY: The upper spring (approximately 100 ft south of the lower spring) has a discharge of approximately 10 gpm, with a temperature of 32°C. The lower spring has an estimated discharge of 50 gpm with a temperature of 38°C. The calcium sulfate waters of the spring contain 1,910 mg/l of dissolved solids.

The springs issue from the Pennsylvanian Maroon Formation (Fig. 16). The origin and occurrence of this spring is very anomalous. The springs are near the top of the drainage divide between the Roaring Fork and Gunnison Rivers in a sedimentary sequence that dips to the northeast.

While no faults are mapped in the immediate vicinity, several normal faults are located approximately 0.25 mile to the west. As shown on the geologic map (Fig. 16), the sedimentary formations of the area have been intruded by Tertiary granodiorite. The author believes that the waters enter the Maroon Formation on the outcrop area to the south of the divide. As they migrate down dip, they become heated.

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978) have shown that the moderate flow rate (50 gpm) and the excellent agreement between the theoretical cristobalite-induced silica solubility and the silica content of the springs suggest the subsurface temperature is not much greater than the surface temperature of the hot springs. Therefore, the temperature at depth in this area is probably between 40°C and 50°C (Table 3).

RESOURCE ASSESSMENT: If Barrett's and Pearl's (1978) theory of the origin of these waters is correct, and assuming the nearby by faulting plays some part in their occurrence, the areal extent of the reservoir could be as much as 0.45 sq mi. A reservoir of this size with an average temperature of 45°C could contain .0042 Q's of heat energy (Table 2).

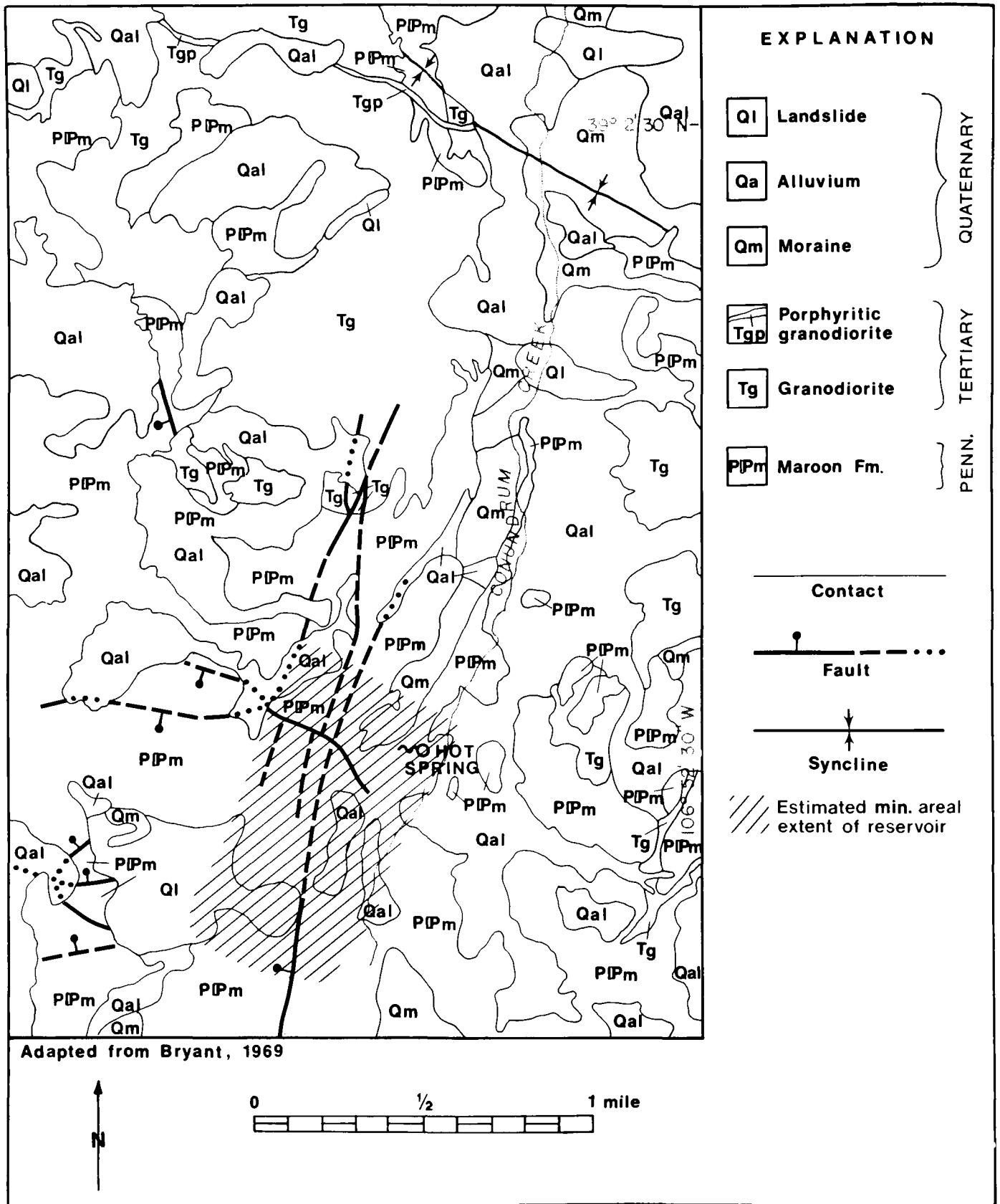


Figure 16.--Map showing estimated areal extent of the Conundrum Hot Springs reservoir and surrounding geologic conditions.

#16 CEMENT CREEK WARM SPRING

LOCATION: Latitude: 38°50'06"N.; Longitude: 106°49'34"W.; T. 14 S.; R. 84 W.; Sec. 18 cac., 6th P.M.; Gunnison County; Cement Mtn. 7 1/2-minute topographic quadrangle map.

GENERAL: This small spring is located approximately 11.5 miles southeast of Crested Butte, Colorado, on Cement Creek. The spring is used for swimming and for the domestic water supply at the Cement Creek Ranch.

GEOLOGY AND HYDROLOGY: The spring emerges from colluvium at the base of the hill across the road from the ranch buildings. The ranch buildings are located on a large travertine mound approximately 15 to 20 ft high and several hundred ft in diameter.

The spring has a discharge that varied throughout the year's time from 60 to 80 gpm with a temperature of 25°C. The waters are a calcium-carbonate type with total dissolved solids of approximately 390 mg/l.

The geology of the Cement Creek Valley and surrounding area has been described in detail by McFarlan (1961). As shown on the accompanying geologic map (Fig. 17), the thermal waters come from undifferentiated Precambrian granitic rocks.

While no fault zones are shown on the map, the waters come from fracture zones within these rocks.

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978) reported that the chalcedony-silica geothermometer model yielded an estimated subsurface temperature of 25°C to 30°C. They noted that chalcedony mixing model analysis yields a subsurface temperature estimate of 27°C to 53°C with a cold-water fraction of 0 to 61 percent of the spring flow. The Na-K geothermometer model gave a very high estimate (225°C to 238°C) while the Na-K-Ca geothermometer model gave an estimated temperature of 45°C to 49°C.

Conclusion: The good agreement between the mixing model and the silica and Na-K-Ca geothermometers suggests a subsurface temperature between 30°C and 60°C (Table 3).

RESOURCE ASSESSMENT: Since there is a possibility that these waters could be associated with the large fault approximately 0.75 miles to the west, two estimates of reservoir extent were made (Fig. 17). The more conservative estimate contained approximately 0.28 sq mi around the spring. The second showed the area to extend from the fault to just east of the spring, this area was estimated to contain 1.40 sq mi. The amount of heat estimated to be contained within this system at an average temp. of 45°C ranges from .0132 Q's to .0658 Q's (Table 2).

#17 RANGER WARM SPRING

LOCATION: Latitude: 38°48'57"N.; Longitude: 106°52'28"W.; T. 14 S., R. 85 W., Sec. 22 dc., 6th P.M.; Gunnison County; Cement Mtn. 7 1/2-minute topographic quadrangle map.

GENERAL: The spring is on the south side of Cement Creek, 7 miles from Crested Butte. Waters from the spring are unused.

GEOLOGY AND HYDROLOGY: The temperature of the spring remained fairly constant throughout the year's time at 26 to 27°C. The discharge varied from 132 to an estimated 250 gpm. The waters contain approximately 465 mg/l of dissolved solids and are a sodium-bicarbonate type.

As noted on Figure 17 the springs emerge from undifferentiated sedimentary rocks of Cambrian-Mississippian age. These formations are an alternating sequence of sandstones and limestones with some thin shale units. Due to the scale of the geologic map, it was not possible to show all the fault zones. McFarlan (1961) has projected an east-west fault passing very near or through this spring along the valley floor. Tweto and others (1976) show one major north-south trending fault in the vicinity. While the thermal waters may be moving along fault zones, for resource assessment it was assumed that the reservoir is a stratigraphic reservoir 150' thick. No appraisal was made of which stratigraphic unit the waters may be coming from.

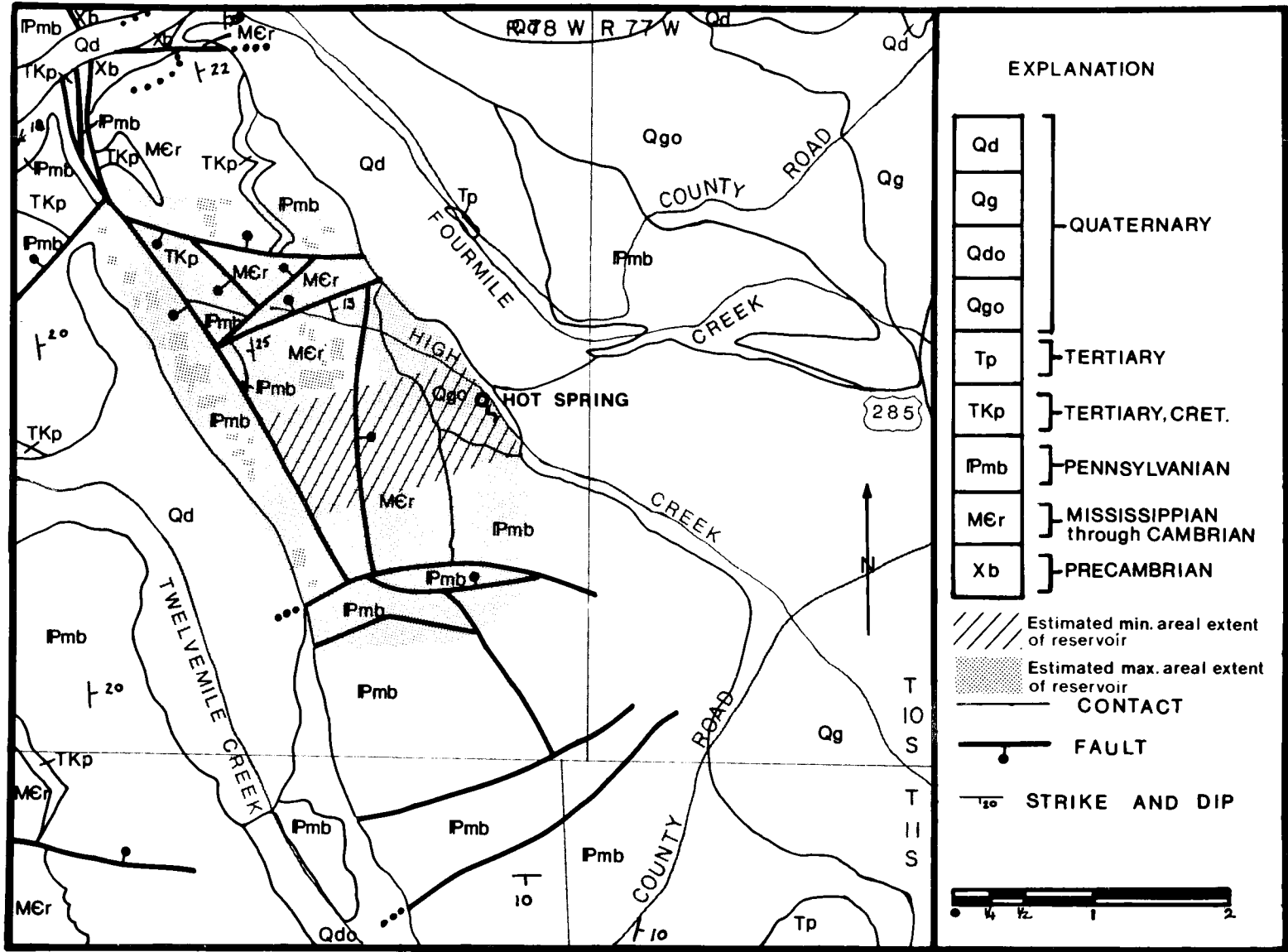
GEOOTHERMOMETER ANALYSES: The chalcedony-silica geothermometer model is the most applicable to estimate the subsurface temperature (Barrett and

Pearl, 1978). This model yields an estimate of 28°C to 32°C (Table 3). The chalcedony mixing model yields an estimated reservoir temperature ranging from 29°C to 67°C with a cold-water fraction of 1 to 71 percent of the spring flow (Table 3). The Na-K and Na-K-Ca geothermometer models yield estimated reservoir temperatures ranging from 56°C to 218°C (Table 3), depending upon the time of year the sample was taken. Since travertine deposits surrounds the spring and if calcium carbonate deposition still occurs, both the Na-K and Na-K-Ca geothermometer estimates will be too high (Barrett and Pearl, 1978).

Conclusion: The good agreement between the mixing model and the silica and Na-K-Ca geothermometers suggests subsurface temperatures between 30°C and 60°C (Table 3).

RESOURCE ASSESSMENT: As shown on Fig. 17, the stratigraphic units in the vicinity of the springs are Precambrian-Mississippian undivided. With the exception of the Precambrian age rock, all the others are predominately carbonates, normally good aquifers.

Due to the occurrence of major faults in the area, two estimates were made of the areal extent of the reservoir (Fig. 17). The more conservative estimate contains 0.30 sq mi, and the other which was drawn to include more of the faulting, is estimated to contain approximately 0.88 sq mi. The amount of energy estimated to be contained in this system at an average temperature of 45°C ranges from .0021 Q's to .0062 Q' (Table 2).



Adapted from Tweto and others, 1976

Figure 18.--Rhodes Warm Spring, geology of surrounding area and estimated areal extent of the geothermal reservoir.

#18 RHODES WARM SPRING

LOCATION: Latitude: 30°09'49"N.; Longitude: 106°03'53"W.; T. 10 S., R. 78 W., Sec. 24 cd, 6th P.M.; Park County; Fairplay West 7 1/2-minute topographic quadrangle map.

GENERAL: This unused spring is reached by going south on U.S. 285 from Fairplay for approximately 4.0 miles, or 0.3 mile south of the bridge over Fourmile Creek and then west on a dirt trail for approximately 3.75 miles.

GEOLOGY AND HYDROLOGY: The spring has a temperature of 24°C and a discharge of 200 gpm. The waters contain approximately 190 mg/l of dissolved solids and are a calcium bicarbonate type.

Rhodes Warm Spring is located on the west side of South Park, a large intermountain basin. Very little has been written on the geology of this part of South Park. DeVoto (1971) described in general the Cenozoic history of South Park. Knepper and Grose (1976) have described South Park as a complexly faulted Laramide structural basin that was excavated in late Cenozoic time. Chronic (1964) has described the stratigraphy along the west side of the basin.

As shown on Figure 18, the area around the warm springs is cut by numerous faults. While the waters are shown as issuing from Quaternary gravels and colluvial deposits overlying the Pennsylvanian

Maroon Formation, it is believed that they are fault controlled. Recharge probably occurs along the Tenmile Range to the west. Reiter (1975) indicates that this area has a heat flow of 2.5 heat flow units.

GEOOTHERMOMETER ANALYSES: While the estimated subsurface temperatures may be calculated by use of the various geothermometer models, these models should be used with caution when applied to Rhodes Warm Spring because many of the assumptions inherent in their use do not apply (Barrett and Pearl, 1978). The high flow rate (approximately 200 gpm) and low surface temperature of this spring (25°C) suggest that the subsurface temperature is not much greater than the surface temperature of the warm water. Therefore, the subsurface temperature in this area is probably between 25°C and 35°C (Table 3).

RESOURCE ASSESSMENT: Since Barrett and Pearl (1978) estimated that the occurrence of this spring to be fault controlled, two estimates of the reservoirs areal extent were made (Fig. 18). One estimate extends the reservoir from the springs to the west to the fault zone. This reservoir is estimated to contain .0432 Q's of heat energy. The other estimate of reservoir extent is much more optimistic. It contains 7.1 sq mi and encompassed practically all of the faults in the immediate area. This reservoir is estimated to contain .2003 Q's of heat energy (Table 2).

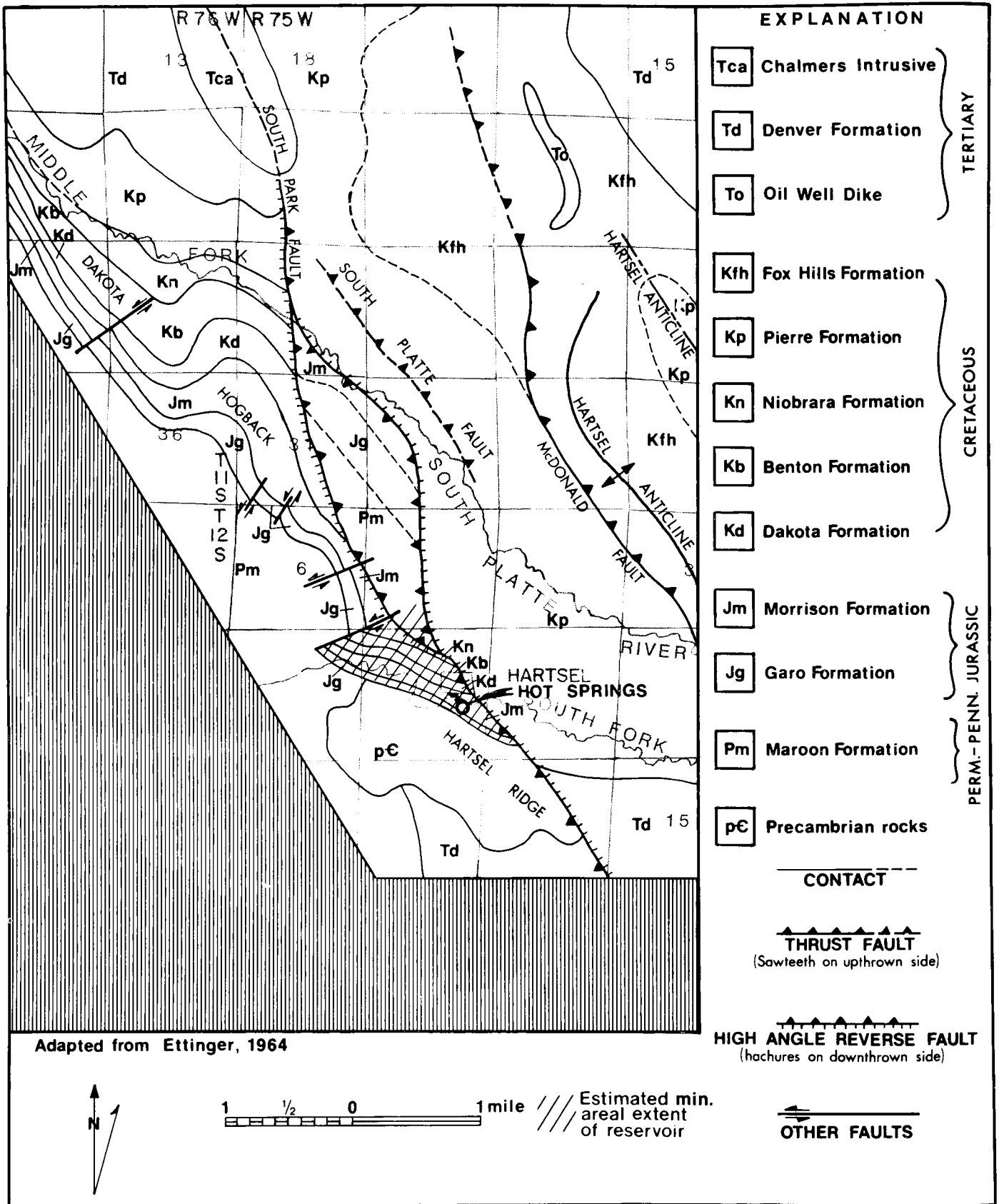


Figure 19.--Map showing estimated areal extent of the HartseI Hot Springs geothermal reservoir and geology of surrounding area.

#19 HARTSEL HOT SPRING

LOCATION: Latitude: 39°01'05"N; Longitude: 105°47'40"W.; T. 12 S., R. 75 W., Sec. 8 da, 6th P.M.; Park County; Hartsel 7 1/2-minute topographic quadrangle map.

GENERAL: The Hartsel Hot Springs are located in South Park on U. S. Highway 24 just south of the town of Hartsel. Both springs are presently unused.

GEOLOGY AND HYDROLOGY: These springs have a combined discharge of 107 gpm. The western spring has a discharge of approximately 57 gpm and the eastern spring a discharge of 50 gpm. Water of both springs are a sodium-chloride type. Throughout a year's time the temperature of the springs ranged from 45°C to 52°C, with the total dissolved solids content varying from 2,140 mg/l to 2,330 mg/l (Barrett and Pearl, 1978).

These springs are located in the south-central part of South Park, a large intermontane basin bounded by the Mosquito Mountains on the west, the Continental Divide on the north, and the Front Range on the east. Several large north-south faults traverse the basin. One of these, the South Park Fault, is within 0.5 mile of the Hot Springs (Fig. 19). The springs emerge from the Morrison Formation, which overlies a large outcrop of Precambrian granitic rocks. Not shown on the geologic map (Fig. 19) are, to the south and east, the extensive outcrops of Tertiary volcanic rocks. The distribution, age, and mode of occurrence of these volcanic rocks have been discussed in detail by Epis and Chapin (1968).

The origin of these hot springs has not been determined, but they may be related to the South Park Fault and the volcanic rocks to the south and east. Reiter (1975) states that this area has a heat flow of 2.4 heat flow units.

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978), in describing geothermometer analysis of Hartsel Hot Spring, showed that the chalcedony-silica geothermometer model yields a subsurface temperature estimate of 55°C to 63°C. Chalcedony mixing model analysis yields a subsurface estimate of 73°C to 87°C with a cold water fraction of 33 to 53 percent of the spring flow, and the Na-K and Na-K-Ca geothermometers estimated subsurface temperatures of 163°C and 153°C respectively (Table 3).

Conclusion: The insignificant variation in flow, mineral content, surface temperature and geothermometer temperature estimates of these hot springs suggests that they are not materially affected by seasonal meteorological conditions. Moreover, the fluctuation of the various geothermometer temperature estimates is well within the range of values that could result from normal analytical error. The geochemistry of these waters is such that no reliable subsurface temperature estimate is possible (Barrett and Pearl, 1978).

RESOURCE ASSESSMENT: The areal extent of the reservoir was drawn to include all the faulting in the area plus some of the Precambrian age rocks. The reservoir extent is estimated to be 1.00 sq mi and contain .0470 Q's of heat energy at an average temp. of 70°C (Table 2).

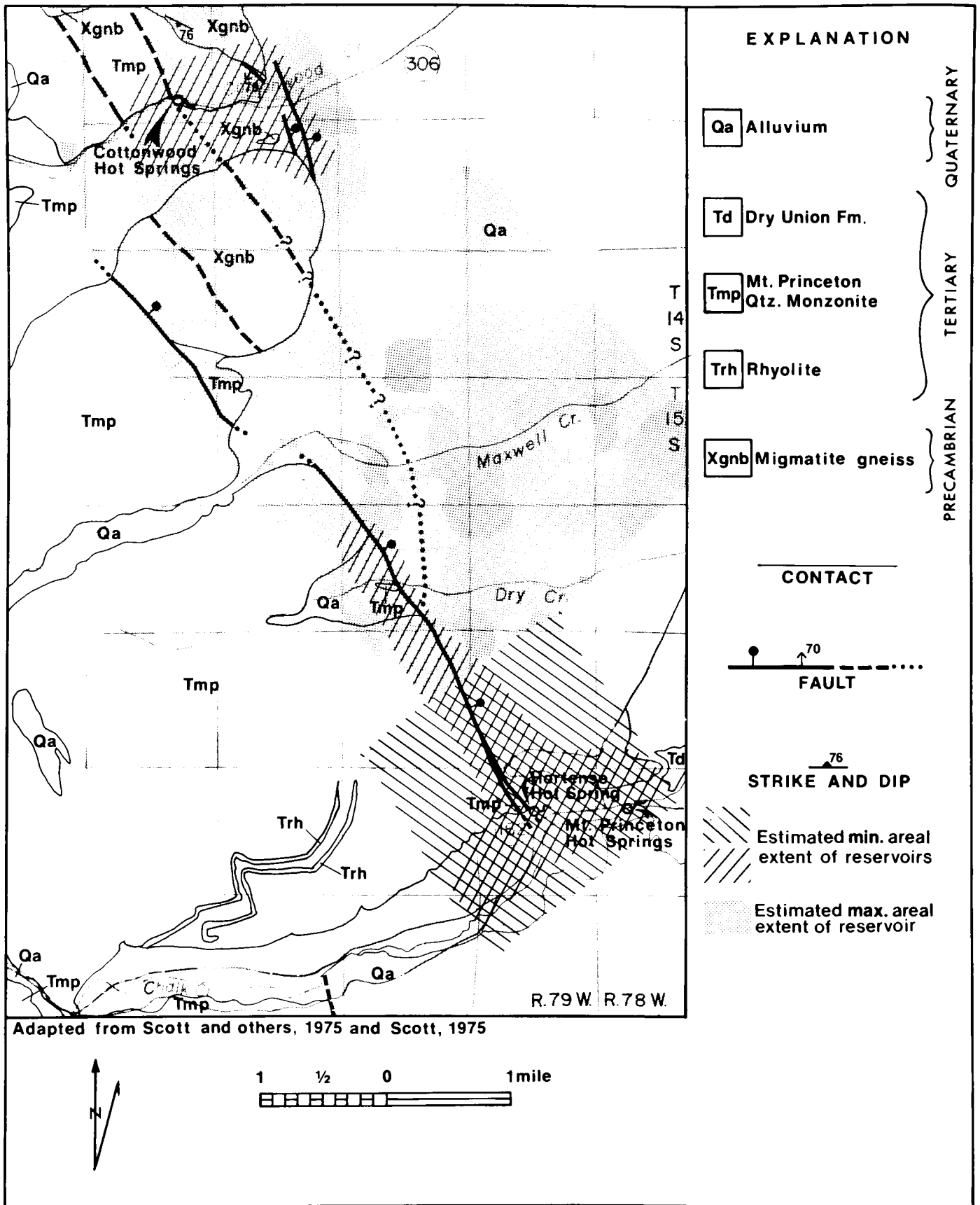


Figure 20.--Geologic map of region surrounding Cottonwood Creek and Chalk Creek Valleys and estimated areal extent of the geothermal reservoirs.

#20 COTTONWOOD CREEK

(COTTONWOOD AND JUMP—STEADY HOT SPRINGS)

LOCATION: Latitude: 38°48'48"N.; Longitude: 106°13'21"W.; T. 14 S., R. 79 W., Sec. 21 dca and ddb, 6th P.M.; Chaffee County; Buena Vista 15-minute topographic quadrangle map.

GENERAL: The Cottonwood Hot Springs are located approximately 5.6 miles west of Buena Vista along Colorado Highway 306 on the banks of Cottonwood Creek on the north side of Mt. Princeton. Modifications of the topography by the highway and the users of the springs make it impossible to accurately determine the number of springs in this group. The Jump-Steady resort, 0.5 mile east of the springs, uses the waters from another spring a short distance east of the Cottonwood Hot Springs for space heating and domestic purposes.

Mr. and Mrs. Merrifield, who live approximately 0.75 mile south of Cottonwood Creek, have a 115-ft-deep-hot-water well. The waters from this well are used in their greenhouse and swimming pool, and for space heating.

GEOLOGY AND HYDROLOGY: The temperatures of these springs and one well range from a low of 46°C to a high of 58°C. The waters are a sodium-bicarbonate type and contain between 300 and 370 mg/l of dissolved solids.

Although the waters issue from alluvium and coluvium covering the Mount Princeton quartz monzonite, they are related to the faulting and fracturing of that rock body. The accompanying geologic map (Fig. 20) shows that the Cottonwood Hot Springs are located on a major northwest-trending fault bordering the east side of Mount Princeton. In addition to this fault, other factors may control the occurrence of these springs because the rock types change from Precambrian migmatitic gneiss on the south side of Cottonwood Creek to the Mt. Princeton Quartz Monzonite on the north side of Cottonwood Creek. Scott (1975) did not map any faults in this area; however, some workers have postulated that a fault does follow Cottonwood Creek (Robert Kirkham, 1977, oral communication).

One possible recharge area for these springs is the Arkansas River to the east, where the waters enter the thick valley-fill sequence (Zohdy and others, 1971), move to the west, and then up the fault zones. The other possible source is the high country along the Continental Divide just to the west where the waters enter and migrate downward along fault zones, and then up the faults to the Cottonwood Hot Springs.

Romero and Fawcett (1978), in attempting to relate the geothermal resources of the upper Arkansas and San Luis Valleys to the ground-water resources of those areas, had detailed electrical geophysical surveys run of the area from just south of Mineral Hot Springs in the San Luis Valley to a

point approximately 4 miles north of Cottonwood Hot Springs in the upper Arkansas Valley. These surveys determined that a series of resistivity lows and highs exist from Mineral Hot Springs to Cottonwood Hot Springs. The lows clearly define the shape and extent of the Rio Grande Rift.

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978) pointed out that because these springs lie within the boundaries of the Mt. Princeton quartz monzonite batholith (Scott, 1975), quartz, not cristobalite, is probably the most abundant solid silica phase. The quartz silica geothermometer estimate of subsurface temperature is 105°C to 182°C (Table 3). Mixing model analysis of Cottonwood and Jump-Steady Hot Springs yields a subsurface temperature estimate of 174°C to 182°C with a cold water fraction of 70 to 74 percent of the spring flow.

The Na-K and Na-K-Ca geothermometers estimates of subsurface temperature are 131°C to 135°C and 79°C to 85°C, respectively. The Na-K geothermometer estimates appear reasonable for both springs. They are substantiated by the silica geothermometer and mixing model results, but the Na-K-Ca geothermometer estimates are too low. This may be caused by temperature-dependent equilibration between the thermal water and the relatively potassium-deficient quartz monzonite.

Conclusion: The most realistic geothermometer estimates of subsurface temperature range from 105°C to 182°C (Table 3).

RESOURCE ASSESSMENT: To fully appraise the resource potential of this area, two estimates of the faulted reservoirs areal extent were made. One estimate showed the maximum possible extent of the reservoir. The boundaries of this area were drawn to include an area that would encompass most of the faulting found along the mountain front plus some of the faulted area to the east. This area was estimated to contain approximately 4.14 sq mi and contain 1.1672 Q's of heat energy.

The other area, less extensive in size, includes only the area around the spring plus the immediate mountain front. This area is approximately 1.38 sq mi in extent and is estimated to contain .3894 Q's of energy at a temp. of 170°C. (Table 2).

In the vicinity of Cottonwood Hot Springs, Romero and Fawcett (1978) determined that a resistivity low exists east of the mountain front and extends from Cottonwood Creek south almost all the way to Chalk Creek. This low encompasses an area of approximately 6 sq mi. Using the following criteria, Romero and Fawcett (1978) calculated that the system contained 15.48 Q's of energy: depth to top of reservoir, 2,500 ft; depth to base of

reservoir, 1.86 miles; areal extent of the reservoir, 8.5 sq mi; average maximum temperature, 129°C. Because the parameters they used were

different, the amount of heat calculated is considerably higher than that calculated by the author (1.1682 Q's).

#21 CHALK CREEK AREA

The following thermal springs and wells are located in the Chalk Creek Valley on the south flank of Mount Princeton: Mount Princeton Hot Springs, Hortense Hot Spring and Well, Woolmington Hot Water Well, Wright Hot Water Wells, and Young Life Hot Water Well.

These springs are located on the south side of Mount Princeton southwest of Buena Vista in the Chalk Creek Valley within 1 or 2 miles of each other along Colorado Rt. 162 approximately 4.5 miles west of U.S. Highway 285 (Fig. 20).

GEOLOGY: The geological conditions surrounding the thermal springs and wells in the Chalk Creek Valley are nearly identical. The springs lie on the south side of Mount Princeton on the west side of the Upper Arkansas Valley graben. Southwest of Buena Vista the graben is asymmetrical with the east side downdropped more than the west side. Geophysical work by Zohdy and others (1971) has revealed as much as 4,600 ft of valley-fill sediments near Buena Vista. All the thermal waters are associated with faults and fractures within the Mount Princeton Quartz Monzonite batholith. The

accompanying geological map (Fig. 20) does not show the numerous faults and fractures in the Chalk Cliffs. The whole Upper Arkansas Valley is cut by numerous faults; however, Scott and others (1975) show only one major northwest trending fault in the southern Mount Princeton area. This fault lies along the east face of Mount Princeton and terminates at the Hortense Hot Spring. Other workers have postulated that a major fault trends northeast along the Chalk Creek Valley (Robert Kirkham, 1977, oral communication).

The possible recharge areas are either the Arkansas River to the east or the high country to the west.

As explained earlier (see Cottonwood Hot Springs), Romero and Fawcett (1978) did a geophysical appraisal of the geothermal conditions in the upper Arkansas Valley. Their work showed that no clear cut resistivity low exists in the immediate vicinity of the Mount Princeton Hot Springs. They did show the presence of a resistivity low northeast of the springs.

#21 MOUNT PRINCETON HOT SPRING

LOCATION: Latitude: 38°43'58"N.; Longitude: 106°09'40"W.; T. 15 S., R. 78 W., Sec. 19 bca, 6th P.M.; Chaffee County; Poncha Springs 15-minute topographic quadrangle.

GENERAL: The Mount Princeton Hot Springs are the largest group of springs in the Chalk Creek Valley. The springs are located in and along the north bank of Chalk Creek extending from immediately west of the big wooden building by the swimming pool to just east of the swimming pool. Some of the waters

are piped uphill and used to heat the swimming pool and cabins north of Colorado 162.

HYDROLOGY: All of the springs in this group have temperatures ranging between 44°C and 56°C. The waters contain approximately 250 mg/l of dissolved solids and are a mixed sodium sulfate-bicarbonate type. The combined flow of all the springs, as measured by a Parshall Flume, was 175 gpm. This value may be low due to any pumping of thermal waters that might have been occurring.

#21 WRIGHT HOT WATER WELLS (EAST AND WEST)

LOCATION: East Well: Latitude: 38°44'00"N.; Longitude: 106°10'00"W.; T. 15 S., R. 79 W.; Sec. 24 ca, 6th P.M.; Chaffee County; Poncha Springs 15-minute topographic quadrangle map.

West Well: Latitude: 38°43'58"N.; Longitude: 106°10'25"W.; T. 15 S., R. 79 W.; Sec. 24 ac, 6th P.M.; Chaffee County; Poncha Springs 15-minute topographic quadrangle map.

GENERAL: Approximately one mile west of the Mount Princeton Hot Springs are two thermal wells owned by William Wright. Waters from these two wells are

used to heat greenhouses. In addition, waters from the east well are used for heating two houses immediately to the south. The east well is located in the greenhouse situated just south of Highway 162. The west well is located in the greenhouse located approximately 0.5 mile west and 0.25 mile north of the east greenhouse.

HYDROLOGY: The east well is 40 ft deep, and the waters have a temperature of 67°C with 234 mg/l of dissolved solids. The waters are a mixed sodium sulfate-bicarbonate type. Waters from the west well have a temperature of 72°C with 313 mg/l of dissolved solids. Unlike the waters from the east well, these waters are a sodium-bicarbonate type.

#21 HORTENSE HOT SPRING AND WELL, AND YOUNG LIFE HOT WATER WELL

LOCATION: Hortense Hot Spring: Latitude: 38°43'59"N.; Longitude: 106°10'26"W.; T. 15 S., R. 79 W.; Sec. 24 bd, 6th P.M.; Chaffee County; Poncha Springs 15-minute topographic quadrangle map.

Hortense Hot Water Well: Latitude: 38°43'58"N.; Longitude: 106°10'27"W.; T. 15 S., R. 79 W., Sec. 24 bd; Chaffee County; Poncha Springs 15-minute topographic quadrangle map.

Young Life Hot Water Well: Latitude: 38°43'57"N.; Longitude: 106°10'27"W.; T. 15 S., R. 79 W.; Sec. 4b; Chaffee County; Poncha Springs 15-minute topographic quadrangle map.

GENERAL: Just to the north and to the west of the West Wright Hot Water Well are two wells and one spring. The Hortense Hot Spring is located approximately from this spring, which are the

hottest in the State, are piped to the Young Life Camps and used for recreational purposes. The Hortense Hot Water Well is located to the west of the Wright Greenhouse. Waters from this well, approximately 180 ft deep, are also used in the Young Life Camp for domestic purposes. The Young Life Hot Water Well is located approximately 200 yd to the west of the Hortense Hot Water Well. Waters from this well are also piped to the Young Life Camp.

HYDROLOGY: Both the Hortense Hot Water Well and Spring have temperatures of 82°C. The discharge of the spring is 18 gpm. The total dissolved solids content of the spring is approximately 340 mg/l, and the well was 318 mg/l. The Young Life Well has a dissolved mineral content of 259 mg/l. Waters from all three are a mixed sodium sulfate-bicarbonate type.

#21 WOOLMINGTON HOT WATER WELL

LOCATION: Latitude: 38°43'24"N.; Longitude: 106°10'38"W.; T. 15 S., R. 79 W.; Sec. 24 db, 6th P.M.; Chaffee County; Poncha Springs 15-minute topographic quadrangle map.

GENERAL: This well, which is the westernmost thermal water found in the Chalk Creek Valley, is located approximately 0.75 mile west of the Young Life Camp and 100 yd south of the highway. At the

time Barrett and Pearl (1978) visited the well (Fall, 1975), the waters were unused.

HYDROLOGY: The temperature of the waters is 39°C and the total dissolved solids content is 143 mg/l. The waters are a sodium-bicarbonate type. The waters come from the alluvial and colluvial deposits north of Chalk Creek.

GEOOTHERMOMETER ANALYSES OF CHALK CREEK AREA: While analysis of silica solubility and temperature relationships suggest that temperature-dependent equilibration between the thermal water and chalcedony controls the silica content of the hot springs and wells chalcedony is not likely to be abundant because this thermal area is located well within the boundaries of the Mount Princeton Batholith (Scott and others, 1975 and Barrett and Pearl, 1978). The most abundant solid silica phase in this area is probably quartz suggesting that the quartz-silica geothermometer and the quartz mixing models are applicable.

The quartz-silica geothermometer estimate of subsurface temperature is 105°C to 127°C for Mount Princeton Hot Springs and 116°C to 129°C for Hortense Hot Springs (Barrett and Pearl, 1978). Sharp (1970) noted that boulders near Hortense Hot Spring are coated with a mixture of calcite, opal and phillipsite. If deposition of silica occurs at depth, then the silica geothermometer and mixing model estimates are too low.

Mixing model analysis yields a subsurface temperature estimate of 186°C to 236°C with a cold-water fraction of 77 to 81 percent for Mount

Princeton Hot Springs and a subsurface temperature estimate of 156°C to 186°C with a cold-water fraction of 54 to 61 percent for Hortense Hot Spring (Table 3). These estimates may be too high, however, because steam fumaroles occur near Hortense Hot Spring (Jay Dick, 1976, personal communication).

Since steam vents are associated with these waters, Mixing Model II may be applied. This model yields a subsurface temperature estimate of 131°C to 150°C with a hot water fraction of 43% to 52% for Mount Princeton Hot Springs and a subsurface temperature estimate of 120°C to 131°C with a hot-water fraction of 9 to 12 percent for Hortense Hot Spring. These estimates may be too low, with the actual subsurface temperature probably lying between the Mixing Model I and Mixing Model II estimates.

The enthalpy-chloride geothermometer can be applied to this thermal area because the surface temperature of Hortense Hot Spring (83°C) is near the boiling point for the elevation. This geothermometer yields a subsurface temperature estimate of 160°C. A plot of the field data (temperature and silica content) of the hot springs

superimposed on the quartz silica geothermometer yields 153°C.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 148°C to 151°C and 51°C to 59°C, respectively, for Mount Princeton Hot Springs and 141°C to 146°C and 93°C to 97°C, respectively, for Hortense Hot Spring (Table 3). The Na-K geothermometer estimates for both springs groups appear reasonable, and they are substantiated by the silica geothermometer and mixing model results. On the other hand, the Na-K-Ca geothermometer estimates seem to be too low.

The low Na-K-Ca geothermometer estimates may be caused by temperature-dependent equilibration between the ascending thermal water and the relatively potassium-deficient quartz monzonite. In addition, the hot spring waters are supersaturated with respect to albite, calcite, laumontite, and quartz (Limbach, 1975). Supersaturation of the thermal waters with respect to calcite would cause the Na-K-Ca geothermometer estimates to be too low.

Conclusion: The most realistic geothermometer estimates of subsurface temperature range from 150°C to 200°C (Table 3). These results are in close agreement with the formation temperature of laumontite (hydrated leonhardite) 145°C to 220°C, reported by Combs (Sharp, 1970).

RESOURCE ASSESSMENT: Based on geological and geophysical surveys, three estimates of this systems areal extent were made. Romero and Fawcett (1978) have shown that a geophysical anomaly exists along the front of Mt. Princeton. Therefore, the boundaries of one of the estimates were drawn to include this large area. This area was estimated to cover 10.0 sq mi and contain 2.6314 Q's of energy at an average temperature of 160°C (Table 2). The boundaries of the intermediate size area (4.0 sq mi) were drawn on the assumption that the reservoir was restricted to an area immediately around the spring. The boundaries of the most conservative case were drawn to cover an area following closely the major NW-SE trending fault along the mountain front (Fig. 20). This area was estimated to be 3.14 sq mi in extent and contain 1.0623 Q's of energy at a temperature of 200°C (Table 2).

Romero and Fawcett (1978) in attempting to evaluate the heat content of this system calculated that it would contain as much as 53.17 Q's an estimate much greater than that presented above. The reason for the greater values is the reservoir parameters used: reservoir thickness, 7,321 ft; areal extent of the reservoir, 27 sq mi; and average maximum temperature of 139°C. The total amount of heat contained in the Cottonwood-Mount Princeton system was estimated by Romero and Fawcett (1978) to be 68.6 Q's, while the author estimated that the system could contain a maximum of 3.81 Q's.

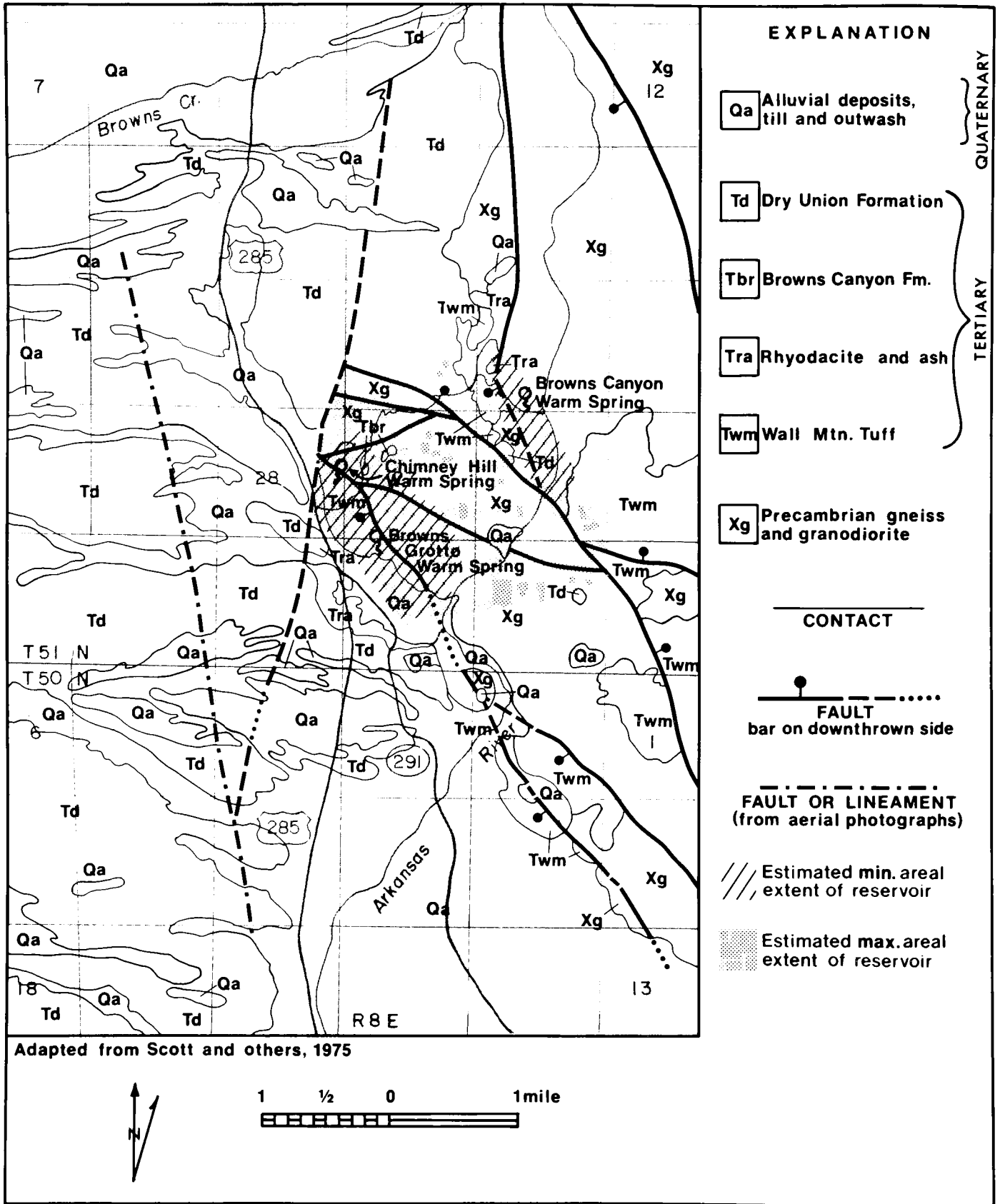


Figure 21.--Map showing estimated areal extent of the Browns Canyon geothermal reservoir and geology of surrounding area.

#22 BROWNS CANYON THERMAL AREA

Located in Browns Canyon, approximately 12 miles north and west of Salida, Colorado, are two unused springs and one unused well.

GEOLOGY OF BROWN'S CANYON: As shown on Figure 21, the springs and wells in Brown's Canyon are situated in a geologically complex region. Brown's Canyon is located on the east side of the Upper Arkansas Valley, a structural extension of the Rio Grande Rift zone. The bedrock of the area consists of Precambrian granitic and metamorphic rocks that make up the Arkansas Hills, on the east side of

valley. In fault contact with these rocks is a middle Tertiary age complex assemblage of lava flows, ash beds, sandstones and shales of the Dry Union Formation, and alluvial deposits.

All the thermal waters in the region appear to be fault controlled, especially Brown's Grotto Warm Spring and Chimney Hill Warm Water Well. Reiter (1975) has shown that this area has a heat flow in excess of 2.5 heat flow units. The thermal waters probably represent deep circulation of ground water through fault zones in an area of high heat flow.

#22 BROWNS CANYON WARM SPRING

LOCATION: Latitude: 38°39'13"N.; Longitude: 106°03'11"W.; T. 51 N., R. 8 E., Sec. 23 cdb, N.M.P.M.; Chaffee County; Poncha Springs 15 minute topographic quadrangle map.

approximately 2.4 miles to an old stone cabin. The spring is in an open area approximately 550 ft north of the cabin.

GENERAL: This unused spring may be located by going northwest from Salida on State Highway 291 to U.S. 285. One half mile north of this intersection turn east on county road 194 and proceed northeast for

HYDROLOGY: The spring has a discharge estimated at 1 gpm with a temperature of 25°C. The waters of the spring were not sampled for determination of dissolved mineral matter. Field measurement of specific conductance is 7,877 micromhos, and the pH is 8.0.

#22 BROWNS GROTTO WARM SPRING

LOCATION: Latitude: 38°38'13"N.; Longitude: 106°04'26"W.; T. 51 N., R. 8 E., Sec. 27 ccd, N.M.P.M.; Chaffee County; Poncha Springs 15 minute topographic quadrangle map.

0.5 mile to the spring. The spring is on the east side of the small gulch.

GENERAL: This unused spring may be reached by turning off U.S. 285 on Chaffee County 194. After going 0.2 mile turn south and drive approximately

HYDROLOGY: When sampled, this spring had an estimated discharge of 5 gpm with a temperature of 23°C. The waters contain 494 mg/l of dissolved mineral matter and are a mixed sodium sulfate-bicarbonate type.

#22 CHIMNEY HILL WARM WATER WELL

LOCATION: Latitude: 38°38'40"N.; Longitude: 106°04'41"W.; T. 51 N., R. 9 E., Sec. 28 add, N.M.P.M.; Chaffee County; Poncha Springs 15-minute topographic map.

may be used for drainage purposes at the abandoned Chimney Hill Mine. The well is capped but may be sampled by opening a valve on top of the casing.

GENERAL: This well was located by J.D. Dick (1976) in 1975. This well is approximately 0.25 mile north from the junction of U.S. 285 and Chaffee County 194. The depth of the well is unknown, and the waters are unused. Dick believes that the well

HYDROLOGY: According to Dick (1976), the waters have a temperature of 27°C. The discharge of the well was not measured. Dick (1976) determined that the waters contain 170 mg/l of sodium, 2.7 mg/l of potassium, 7 mg/l of calcium and 47 mg/l of silica.

GEOOTHERMOMETER ANALYSES OF BROWN'S CANYON: Cristobalite appears to be controlling the silica content of Brown's Grotto Warm Springs (Barrett and Pearl, 1978). This geothermometer yields an estimated temperature of 49°C (Table 3). However,

this estimate may be too high because the theoretical cristobalite-induced silica content (24 mg/l) at the springs surface temperature (22°C) is well below the silica content of the warm spring (47 mg/l).

The cristobalite mixing model analysis yields a subsurface temperature estimate of 129°C with a cold water fraction of 87 percent for Brown's Grotto Warm Spring and an estimated temperature of 95°C with a cold-water fraction of 86 percent for the spring in fluorspar mine.

These estimates should be treated skeptically because the flow rate and silica contents of these springs are well below the minimum conditions specified for reliable mixing model results and, in addition, associated minerals complicate the mixing model analysis (Barrett and Pearl, 1978).

Chimney Hill Warm Water Well has a calculated reservoir temperature of 287°C with a cold water fraction of 95 percent (Dick, 1976).

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 123°C and 89°C, respectively, for Brown's Grotto Warm Spring (Table 3), and 142°C and 131°C for the spring within the fluorspar mine. It should be noted that the Na-K geothermometer estimates for both of these springs are too high since because the conditions of the model are violated (Barrett and Pearl, 1978). Dick (1976) calculated the Chimney Hill Warm Water Well subsurface temperature with this model to be 85°C.

Conclusion: Geothermometer models should be used with caution when applied to Brown's Grotto Warm

Spring since most of the assumptions inherent in their use are violated.

Opal deposits at depth within the nearby fluorspar mine (Van Alstine and Cox, 1969) suggests temperatures at depth below 100°C. However, the extensive fluorspar deposits indicate subsurface temperatures between 119°C and 168°C. At any rate, these considerations probably pertain to historical rather than present-day subsurface conditions. The best estimated temperature possible for this area ranges from 50°C to 100°C (Table 3).

RESOURCE ASSESSMENT OF BROWN'S CANYON: As shown on Figure 21, two of the three springs are associated with faults. Barrett and Pearl (1978) stated that they believe all three springs are fault controlled; therefore, the boundaries of this area were drawn to include most of the faulting in the area. As drawn, the area encompasses approximately 3.23 sq mi and contains approximately .4856 Q's of energy at a maximum average temperature of 100°C (Table 2). If these springs are part of one large system, the reservoir may be too deep to be reached economically; therefore, estimates were made based on the assumption that each area would be developed separately. This analysis was based on the assumption that the individual reservoirs had an areal extent of 0.50 sq mi each and contained .2256 Q's of thermal energy at a maximum average temperature of 100°C.

#23 PONCHA HOT SPRINGS

Located several hundred ft above the Arkansas River at the southern end of the Upper Arkansas River Valley is a large group of hot springs known as Poncha Hot Springs.

LOCATION: Five springs were located by Barrett & Pearl (1978) during the course of their investigation at or near: Latitude: 38°29'49"N.; Longitude: 106°04'37"W.; T. 49 N., R. 8 E., Sec. 15 cb, N.M.P.M.; Chaffee County; Bonanza 15-minute topographic quadrangle map.

GENERAL: This large group of springs is located approximately one mile south of the town of Poncha Springs and just east of U.S. Highway 285. Access is via a dirt road from U.S. 285, 1,000 ft south of the bridge crossing the South Arkansas River.

The springs are contained in two distinct groups. The south group, Springs A & B, just uphill from a group of buildings, is the main spring area. Another group of three unused springs lies over the ridge line and down in a small valley north of the main spring area. The main spring area is characterized by a large travertine apron extending over the entire hillside. At one time up to 40 springs issued on this hillside, but at the present time no thermal waters flow to the surface because of collection by buried pipelines. Most of the waters are piped approximately 5 miles to Salida where they are used in the municipal swimming pool. During the summer some of the waters are used in a swimming pool at the hot springs area. Some of the waters are also used to heat the caretaker's house at the hot springs. In the main spring area only two springs were found that could be sampled, Springs A and B. Both of these "springs" flow from buried pipelines leading into concrete-lined junction boxes where the waters are collected and piped to Salida.

Springs C, D, and E are located in a separate area approximately 500 ft northeast of the main spring area. These three springs are small and unused.

GEOLOGY AND HYDROLOGY:

Spring A: Temperature: 50°C-71°C; Discharge: 200 gpm; Total Dissolved Solids: 654 to 697 mg/l; Water Type: sodium bicarbonate-sulfate. Spring A, which is a concrete-lined junction box, is located approximately half the way uphill and on the south side of the travertine apron.

Spring B: Temperature: 66°C; Discharge: Estimated 30 gpm; Total Dissolved Solids: 655 mg/l; Water Type: sodium bicarbonate-sulfate. Spring B is located approximately 140 ft northeast of A and approximately 50 ft higher uphill.

Spring C: Temperature: 62°C; Discharge: 2 to 4 gpm; Total Dissolved Solids: 655 to 685 mg/l; Water Type: sodium sulfate-bicarbonate type. Spring C is the easternmost spring.

Spring D: Temperature: 56°C; Discharge: 2 gpm est.; Conductance: 1,000 micromhos. Spring D is located approximately 40 ft northwest of C.

Spring E: Temperature: 60°C; Discharge: 2 gpm est.; Conductance: 950 micromhos. Spring E is located approximately 20 ft southwest of Spring D.

The Poncha Hot Springs, which issue from colluvial deposits overlying the Dry Union Formation, are located at the southern end of the Upper Arkansas River Valley and on the northwest side of the Sangre de Cristo Horst (Knepper, 1976). The geology of the region has been described in detail by a number of authors. Chapin (1971), Knepper (1976), and Van Alstine (1970 and 1974) have all presented excellent summaries of the geology in the immediate vicinity. Chapin (1971) presents a general discussion of the structural development of the Rio Grande Rift Zone. Knepper (1976) presents a detailed discussion of the structural development of the Upper San Luis Valley and the Upper Arkansas River Valley. Knepper (1976) states that the hot springs are located on the northwest end of the Sangre de Cristo Horst, a structurally high area between the two valleys. Van Alstine (1970) states that this part of the horst consists of, in part, blocks of allochthonous Paleozoic rocks that originated to the west in the Sawatch Range. Chapin (1971), Knepper (1976), and Van Alstine (1970) all state that the area around the hot springs is structurally complex (Fig. 22). In describing the geologic history of the region, Van Alstine (1970) states that in Late Tertiary time the Upper Arkansas Valley was connected to the San Luis Valley by a trough along the west edge of the Sangre de Cristo Horst. Chapin (1971) and Knepper (1976) state that faulting began in the region sometime after the close of Oligocene time, for Oligocene rocks along the margins of the valleys have been offset at least 5,000 ft by faulting.

Romero and Fawcett (1978) showed the presence of a resistivity low extending from the Salida area to about 5 miles west of Poncha Springs. This low extends in a north-south direction north over 6 miles from the spring area.

Due to the complexity of the structure in this region, it is difficult to ascertain the origin of the hot springs. The springs are probably fault controlled. Although the area of recharge is not known, the Arkansas River may be the source of the waters. Recharge may also be occurring along the Collegiate and Sawatch Ranges to the west.

GOTHERMOMETER ANALYSIS: Calculations by Barrett and Pearl (1978) determined that the quartz-silica geothermometer model yields an estimated subsurface temperature of 119°C to 137°C. The quartz mixing model yields an estimated subsurface temperature of 157°C to 209°C with a cold water fraction of 60 to 73 percent of the spring flow (Table 3).

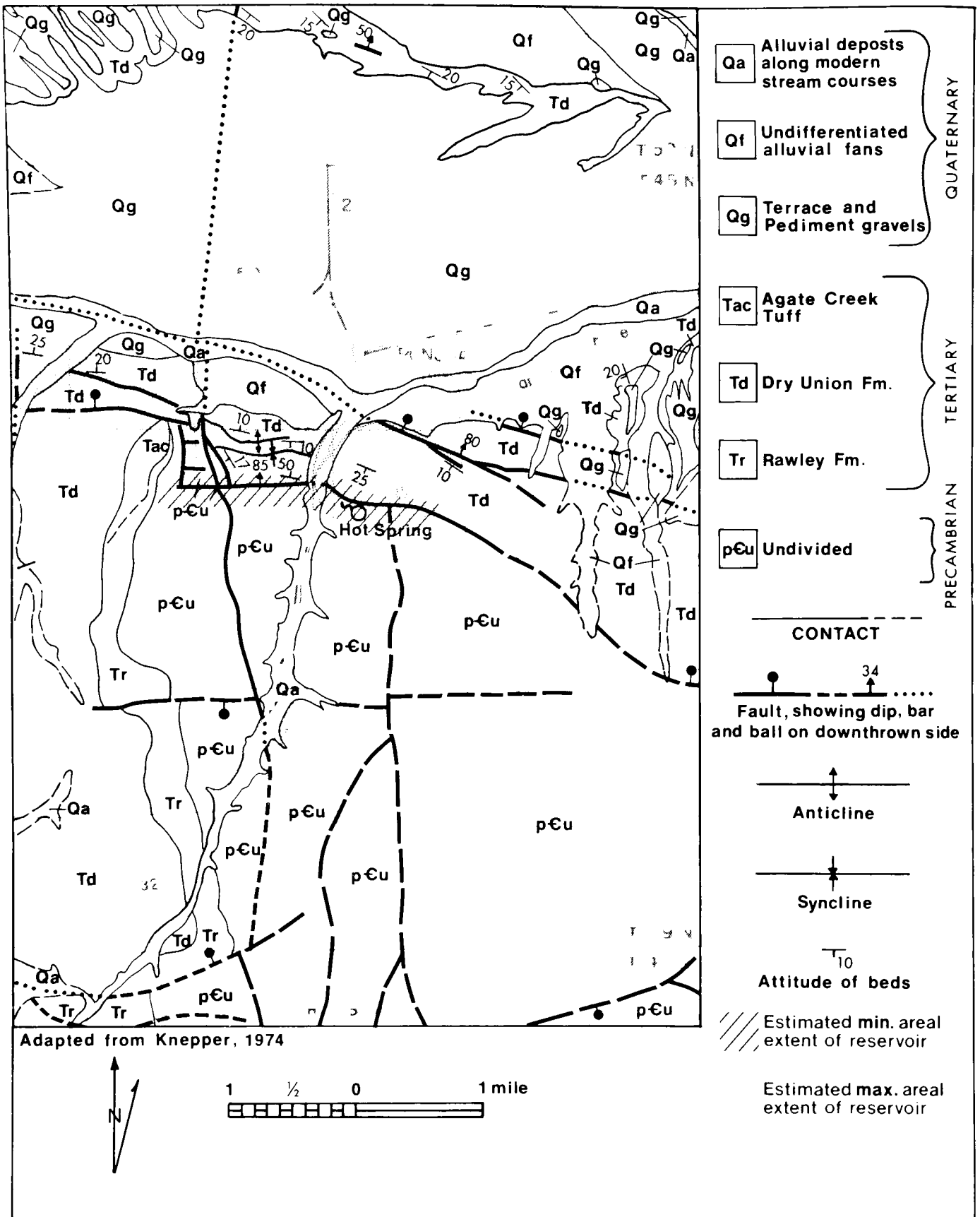


Figure 22.--Map showing geologic conditions surrounding Poncha Hot Springs and estimated extent of the geothermal reservoir.

Barrett and Pearl (1978), also determined that the Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 154°C to 159°C and 96°C to 145°C, respectively. It was noted that extensive travertine deposits occur in the vicinity of these hot springs, and Spring A is currently depositing calcium carbonate within the collection box. Therefore, Barrett and Pearl (1978) felt that the Na-K and Na-K-Ca geothermometer estimates were too high.

Conclusion: The best approximation of subsurface temperature is provided by the cristobalite mixing model, and the Na-K-Ca geothermometer which yields a maximum estimate of temperature. Therefore, the temperature at depth in this area is probably within the range of 115°C to 145°C (Table 3).

RESOURCE ASSESSMENT: Due to the complexity of this region and that the reservoir could extend some distance to the west, two estimates of the reservoirs extent were made. The conservative

estimate included not only the area around the spring but extended as far west at the fault block area. Included in this area are some reported warm mud pots west of Poncha Creek. This area is approximately 0.6 sq mi in extent and may contain .1410 Q's of energy at an average maximum temperature of 145°C in a faulted reservoir (Table 2).

The second area includes all of the first area plus an additional 4.47 sq mi. This area extends the reservoir boundaries up the South Fork of the Arkansas River to the west. It is estimated that this reservoir contains 1.1911 Q's of energy at a maximum average temperature of 145°C.

Romero and Fawcett (1978) estimated that this system could contain as much as 38.10 Q's of heat energy, considerably more than here estimated. This is because their estimates were based on different parameters than those used by the author.

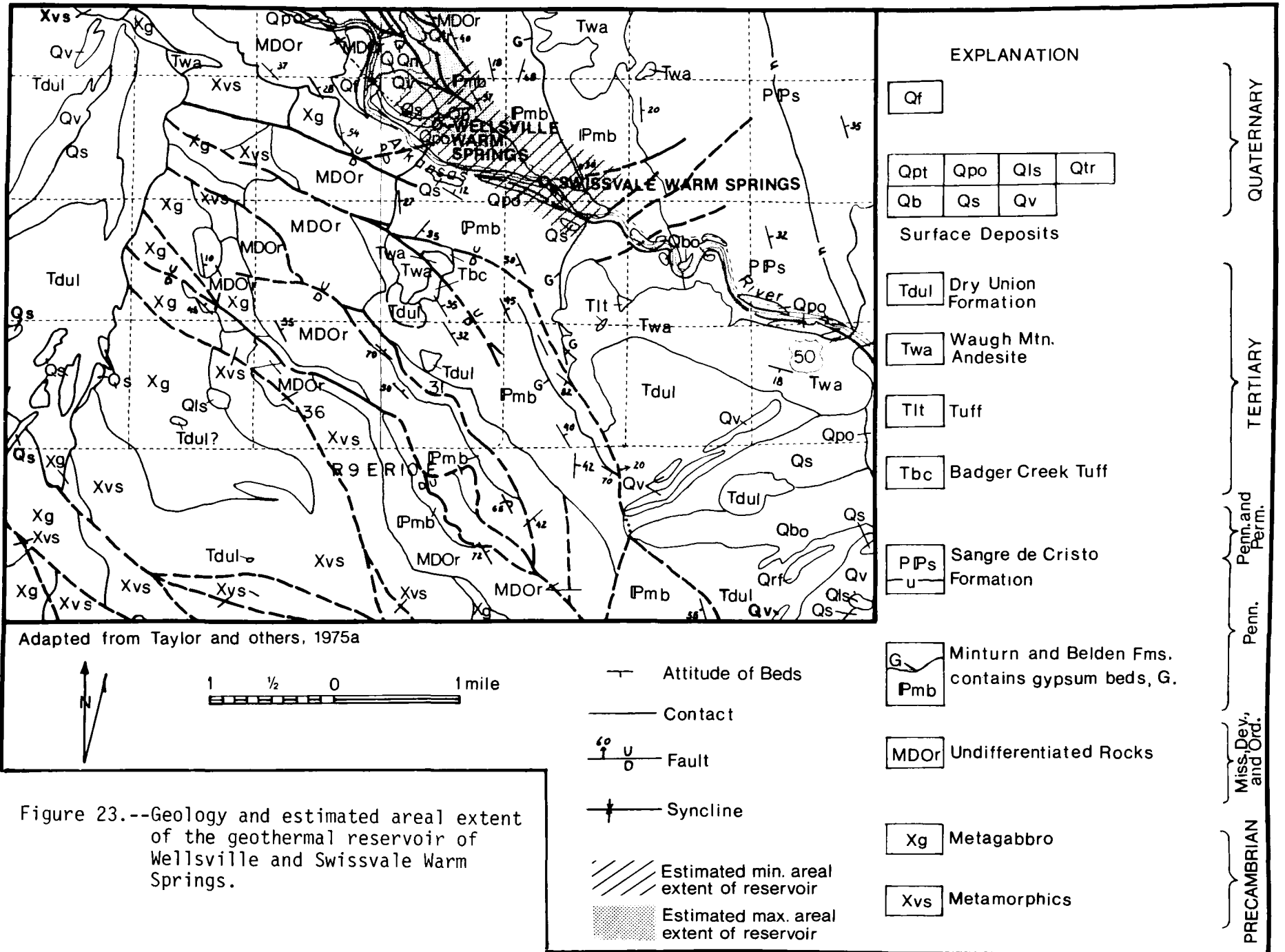


Figure 23.--Geology and estimated areal extent of the geothermal reservoir of Wellsville and Swissvale Warm Springs.

#24 WELLSVILLE WARM SPRING

LOCATION: Latitude: 38°29'07"N; Longitude: 105°54'36"W.; T. 49 N., R. 10 E., Sec. 18 -, N.M.P.M.; Chaffee County; Howard 15-minute topographic quadrangle map.

GENERAL: Barrett and Pearl (1978), stated that this large warm spring is located on the north bank of the Arkansas River approximately 6 miles east of Salida. Waters from the spring are used in tropical fish-rearing ponds. Algae and tropical plants are also grown commercially in some of the ponds.

GEOLOGY AND HYDROLOGY: The temperature of the waters ranged from 28°C to 33°C in a year's time. The discharge varied from 160 to 200 gpm. The total dissolved solids content range from 470 mg/l to 484 mg/l. The waters are a calcium bicarbonate type.

As shown on the accompanying geologic map (Fig. 23), the Wellsville Warm Spring is located on a small northeast-trending fault. While the bedrock has been mapped as undivided Mississippian, Devonian, and Ordovician sedimentary formations, the waters come from the Leadville Limestone. Due to the erosional history of the Arkansas River and faulting, only a small remnant of Leadville Limestone is present.

No attempt was made to decipher the hydrogeological conditions surrounding this spring, but the waters may be recharged from the high ground either to the north or to the south. The

springs are located on the extreme edge of the Rio Grande rift zone. Reiter (1975), states that the area has a heat flow of just below 2.0 H.F.U. The origin of the heat is unknown.

GEOOTHERMOMETER ANALYSES: Calculations determined that cristobalite controls the silica content of the warm spring (Barrett and Pearl, 1978). The cristobalite-silica geothermometer model yields a temperature of 30°C to 31°C (Table 3) which is the same as the surface temperature of the warm spring. Analysis suggests that this geothermometer estimate is close to the actual temperature at depth (Barrett and Pearl, 1978).

Cristobalite mixing model analysis yields a subsurface temperature estimate of 33°C with a cold water fraction of 2 to 15 percent of the spring flow.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 213°C to 216°C and 48°C to 50°C, respectively (Table 3) which are probably high.

Conclusion: The high flow, and excellent agreement between the silica geothermometer and mixing models with the silica content and temperature of the warm spring suggest that the temperature at depth is near the surface temperature of the warm spring. Therefore, the subsurface temperature is near 35°C and certainly between 35°C to 50°C (Table 3).

RESOURCE ASSESSMENT: See Resource Assessment of Swissavle Warm Springs.

#25 SWISSVALE WARM SPRINGS

LOCATION: Latitude: 38°28'49"N.; Longitude: 105°53'25"W; T. 49 N., R. 10 E., Sec. 20 cda, N.M.P.M.; Fremont County; Howard 15-minute topographic quadrangle map.

GENERAL: This group of nine unused springs is located along the north bank of the Arkansas River approximately 6.5 miles east of Salida. Field measurements were made at the two largest springs in the group. Spring A, the largest and easternmost spring, is located 30 ft south of a U.S. Bureau of Land Management cadastral survey marker. Spring F is located approximately 350 ft west of Spring A and about 20 ft above the river bank.

GEOLOGY AND HYDROLOGY: Spring A has a temperature of 28°C, a discharge of 125 gpm with a conductance of 880 micromhos. Spring F has a temperature of 20°C, a discharge estimated at 20 gallons per minute, and a specific conductance of 775 micromhos. Total discharge of all springs is approximately 200 gpm.

As shown on Figure 23, the waters come from the Pennsylvanian Maroon and Belden Formations. These formations dip to the northeast and are cut by a north-northeast trending fault less than 1 mile to the east. Taylor and others (1976) mapped numerous major southeast-trending faults to the south, southwest, and northwest of the spring. None were projected into the spring area; however, one north-trending fault was mapped less than 1 mile east of the springs. The thermal waters may migrate up one of these faults into the fracture zones within the Maroon Formation.

GEOOTHERMOMETER ANALYSES: The cristobalite-silica geothermometer model yields a subsurface

temperature estimate of 32°C, which is near the surface temperature of the warm springs (28°C). The cristobalite mixing model yields a subsurface temperature estimate of 35°C to 47°C with a cold-water fraction of 22 percent to 69 percent of the spring flow (Table 3).

Na-K and Na-K-Ca Geothermometers: The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 214°C and 44°C to 48°C, respectively (Table 3).

Conclusion: The high flow and the excellent agreement between the silica geothermometer and mixing model estimates suggest that the temperature at depth is near the surface temperature of the warm springs. Therefore, the subsurface temperature in this area is probably near 35°C and certainly between 35°C and 50°C (Table 3).

RESOURCE ASSESSMENT OF WELLSVILLE-SWISSVALE WARM SPRINGS: Since the geologic conditions surrounding the Wellsville and Swissvale Springs are nearly identical, they are here considered as one reservoir unit for resource assessment purposes. Upon appraising the regional geologic conditions of the area, it appears that the areal extent of the reservoir could include 0.94 sq mi. The faulted area to the west of Wellsville (Fig. 23) might have some controlling influence on the occurrence of the springs. If this area is included in the areal extent of the reservoir it would include 1.66 sq mi. The reservoir is estimated to be within sedimentary rocks, with the waters probably associated with the Leadville Limestone or one of the older carbonate rocks. The energy content of the system is estimated to range from .0085 Q's to .0150 Q's at an average maximum temperature of 40°C (Table 2).

#26 CANON CITY HOT SPRINGS

LOCATION: Latitude: 38°25'57"N.; Longitude: 105°15'46"W.; T. 18S., R.70 W., Sec. 31 d, 6th P.M.; Fremont County; Royal Gorge 7 1/2-minute topographic quadrangle map.

GENERAL: The spring is located in the front yard of the house at 1400 Riverside Drive in Canon City. The spring, located at the southeast corner of the abandoned swimming pool, is cased with a 6-in. diameter pipe to a depth of 50 ft.

In the summer of 1979 two other artesian thermal wells were located in the Canon City area. Other than measuring the water temperature no effort was made at that time to sample the waters for contained mineral matter or measure the discharge accurately. These thermal wells are described in Table 6 at the end of the paper.

GEOLOGY AND HYDROLOGY: This unused spring has a discharge estimated to be 5 gpm with a temperature of 40°C. The total dissolved solids content of the water is 1,230 mg/l.

The spring is located at the contact between the Leadville Limestone and the overlying Fountain Formation (Fig. 24). No faults have been mapped in the vicinity of the spring, and none are apparent on the surface. Therefore, the waters must ascend through the Leadville Limestone. The recharge area for this spring is probably to the north and east along the northern flanks of the Canon City Embayment.

GEOTHERMOMETER ANALYSES: Geothermometer models are not reliable when applied to the Canon City Hot

Springs because many of the assumptions inherent in their use are violated. Barrett and Pearl (1978) did however, calculate the subsurface temperatures. The chalcedony-silica geothermometer yielded a subsurface temperature estimate of 34°C to 35°C, which is below the surface temperature of the thermal spring (40°C). This low temperature estimate may be caused by mixing of the ascending thermal water and dilute ground water.

The chalcedony mixing model yields a subsurface temperature estimate of 38°C to 40°C with a cold-water fraction of 3 to 12 percent of the total flow (Barrett and Pearl, 1978). These estimates are well within the range of values that could result from normal analytical error.

The Na-K and Na-K-Ca geothermometers estimates are 187°C and 68°C to 72°C, respectively. These estimates are too high because calcium carbonate is deposited on the well casing.

Barrett and Pearl (1978) noted that upon analysis of the data it appears that no reliable estimate of the subsurface temperature is possible.

RESOURCE ASSESSMENT: It is estimated that this sedimentary reservoir is restricted to an area of approximately .50 sq mi, primarily to the east of the spring. Calculations based on a reservoir of this size with an average maximum temperature of 50°C shows that there maybe .0028 Q's of heat energy contained in the system (Table 2).

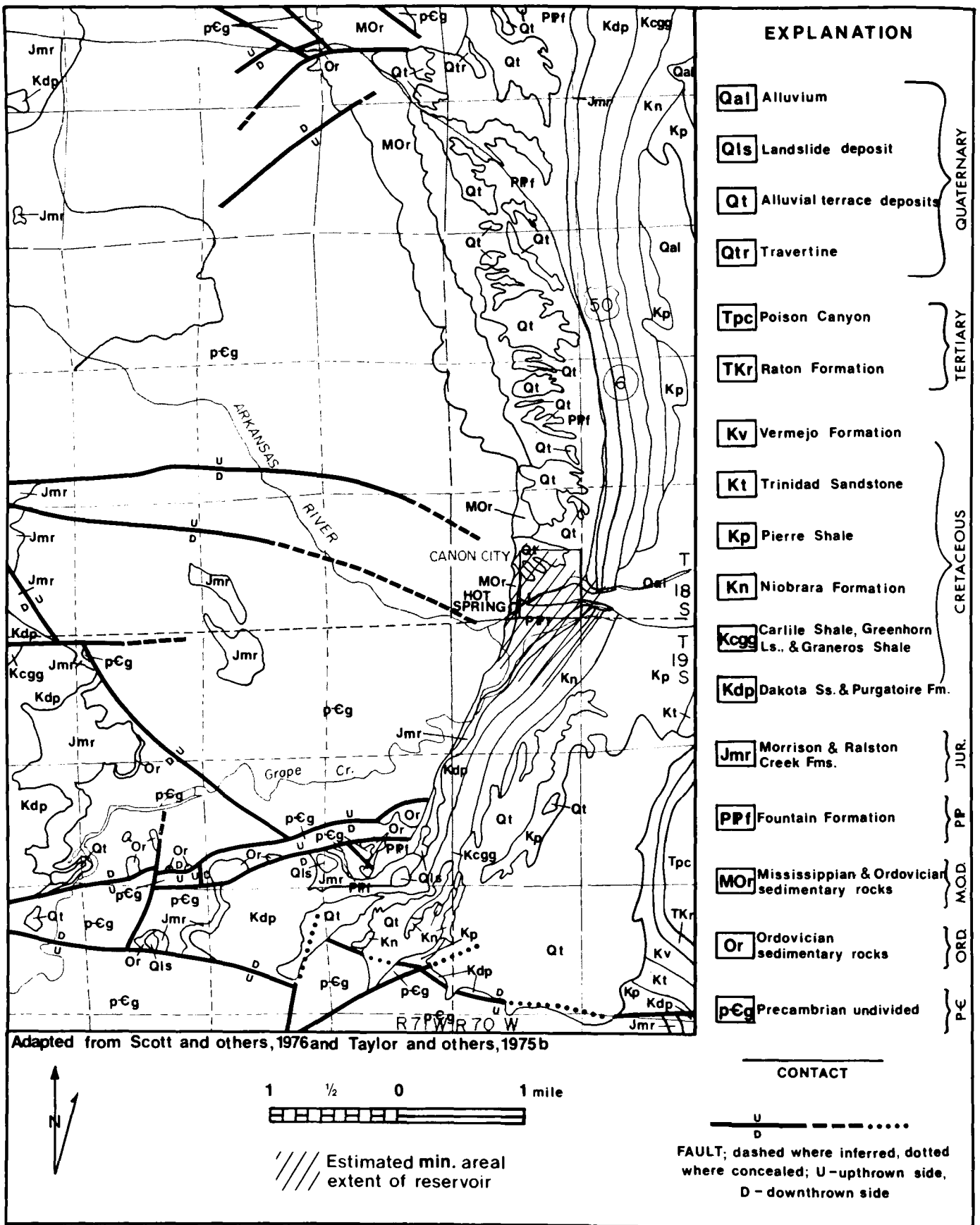


Figure 24.--Geology of Canon City region and estimated areal extent of the geothermal reservoir.

#27 FREEMONT NATATORIUM WELL

LOCATION: Latitude: 38°27'38"N.; Longitude: 105°11'46"W.; T. 18 S., R. 70 W., Sec. 26 bbb, 6th P.M.; Fremont County; Canon City 7 1/2-minute topographic quadrangle map.

GENERAL: This 1,800-ft-deep artesian well is located at 3095 Central Avenue in northeast Canon City (Barrett and Pearl, 1978). The well, which supplied waters to the pool at the natatorium, is just behind the unused swimming pool north of the bend in the road.

As noted earlier several other existing wells in the Canon City area were located in the Canon City area during the summer of 1979. For a description of these wells see table 6.

GEOLOGY AND HYDROLOGY: Barrett and Pearl (1978) noted that the temperature of the waters is 35°C with a discharge of 20 gpm. The total dissolved solids content varied from 1,300 mg/l to a high of 1,370 mg/l throughout a year's time.

This well is located on the west side of the Canon City Embayment and the bedrock of the area is the Cretaceous Pierre Shale. As noted on the geologic map (Fig. 25), no faults or folds occur in the immediate vicinity of this well.

The depth of the well suggests that the waters come from the Dakota Formation, which is the principal aquifer in the Canon City Embayment. Recharge probably occurs to the north around the flanks of the embayment with the heating of the waters caused by decay of radioactive minerals. The Dakota Formation in western portions of the

Canon City Embayment contains above-normal concentrations of radioactive minerals (Richard Gamewell, 1975, oral communication, and Vinickier, 1978).

GEOOTHERMOMETER ANALYSES: Calculations by Barrett and Pearl (1978) determined the following subsurface temperatures: Quartz-silica, 50°C, Chalcedony-silica, 23°C, Quartz mixing model, 78°C to 88°C with a cold water fraction of 63 to 69 percent. These estimates are probably too high because both the silica content and the flow rate of the artesian well are below the minimum conditions specified for the reliable application of this geothermometer. Other geothermometer estimates of the subsurface temperature are: Chalcedony mixing model, 32°C with a cold water fraction of 23 percent of the total flow, and Na-K and Na-K-Ca, 174°C and 73°C, respectively. Both of these estimates are too high because calcium carbonate is being deposited around the well.

The subsurface temperature in this area is probably between the surface temperature of the artesian well and the quartz silica geothermometer estimate, namely 35°C to 50°C (Table 3).

RESOURCE ASSESSMENT: Due to the uncertainty of the geologic control of these thermal waters it was assumed that the waters are coming from the Dakota Formation and are restricted to an area of approximately 1.0 sq mi around the well. The calculated amount of heat energy contained in this system is .0095 Q's at an average maximum temperature of 43°C (Table 2).

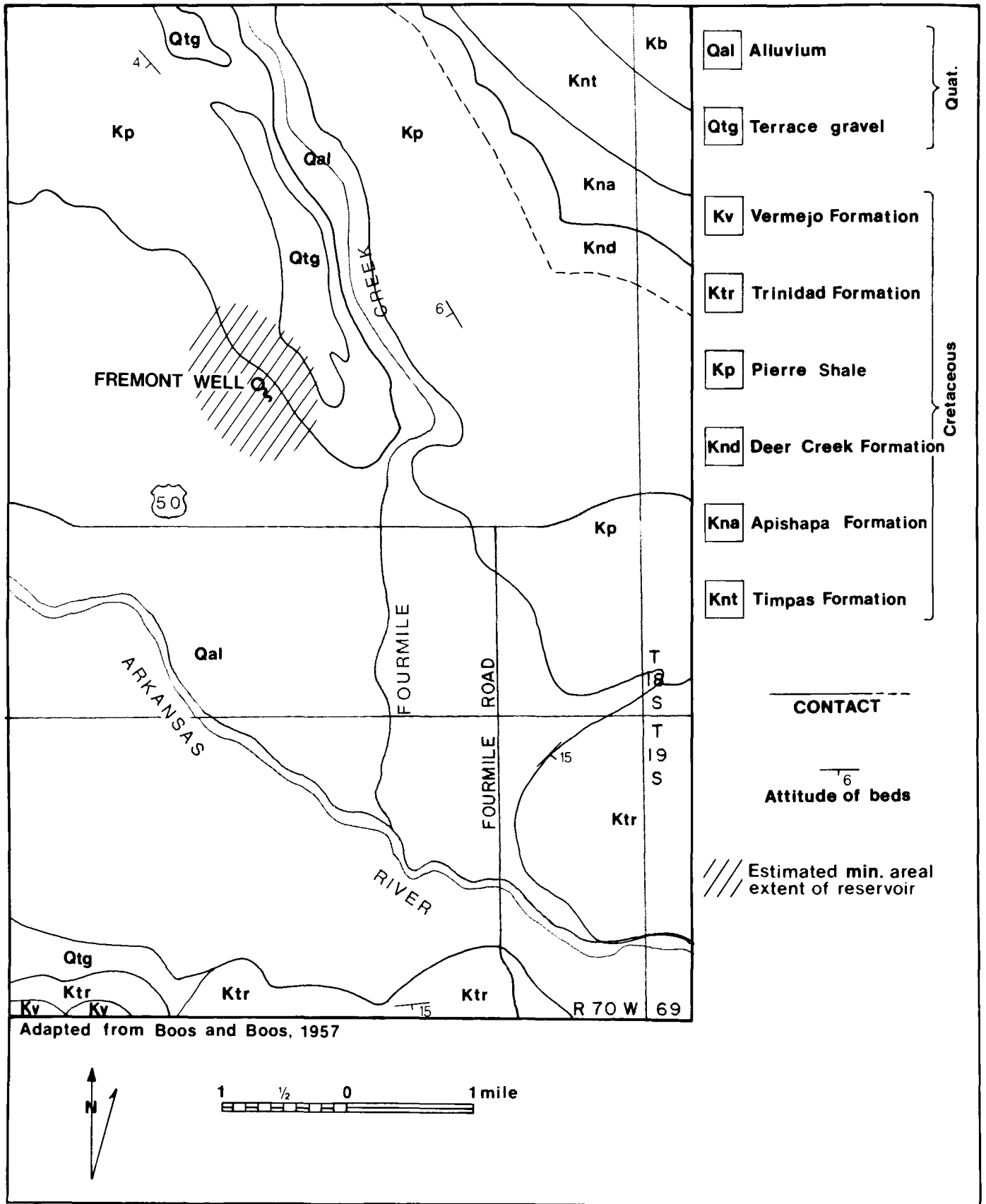


Figure 25.--Map showing estimated areal extent of the Fremont Natatorium geothermal reservoir and surrounding geologic conditions.

28 PENROSE ARTESIAN WELL

(FORMERLY FLORENCE ARTESIAN WELL)

LOCATION: Latitude: 38°24'53"N.; Longitude: 105°02'43"W.; T. 19 S., R. 68 W., Sec. 7 bac; 6th P.M.; Fremont County; Florence 7 1/2-minute topographic quadrangle map.

GENERAL: Barrett and Pearl (1978) mislocated and misnamed this well in their report. To correct that error the well is here renamed the Penrose Artesian Well. This unused well of unknown depth is located approximately 1,800 ft southwest of the junction of U.S. 50 and Colorado 115 south of Penrose. The well is located on the east side of Colorado 115 and southwest of an abandoned farm building.

During the summer of 1979 two other artesian thermal wells were located in the Penrose area and one in the Florence area. No attempt was made at that time to either accurately measure the discharge of the wells or have the waters analyzed for contained mineral matter. These wells are described in Table 6 at the end of the paper.

GEOLOGY AND HYDROLOGY: The waters have a surface temperature of 28°C, with a discharge of 130 gpm. The waters contain 1,480 mg/l of dissolved solids, and the waters are a sodium-bicarbonate type (Barrett and Pearl, 1978).

This well is located in the Canyon City Embayment. The bedrock of the area is the Niobrara Fm., and no major structural features are present in the area (Fig. 26). The depth of the well is unknown, but the waters probably come from the Dakota Formation, which is the main aquifer in the Canyon City Embayment. The origin of the heat is unknown but may be related to decay of radioactive minerals in the Dakota Formation (see Clark Artesian Well discussion).

GEOTHERMOMETER ANALYSES: Calculations show that chalcedony controls the silica content of the artesian well. The chalcedony-silica geothermometer model gave an estimated subsurface temperature of 34°C.

Chalcedony mixing model analysis yields a subsurface temperature estimate of 41°C with a cold water fraction of 40 percent of the total flow (Barrett and Pearl, 1978).

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 212°C and 178°C, respectively. The Na-K geothermometer estimate is too high because the conditions of the model are violated. Moreover, the high magnesium content (78 mg/l) of the waters makes geothermometers unreliable.

Most geothermometers are not reliable when applied to Florence Artesian Well because many of the assumptions inherent in their use are violated. Therefore, the most likely subsurface temperature in this area is between 34°C and 50°C (Table 3).

RESOURCE ASSESSMENT: Vinckier (1978) has shown the occurrence of faulting in the vicinity of this well. Therefore, even though it is estimated that the reservoir is a stratigraphic reservoir two estimates of the reservoirs areal extent were made based on the occurrence of the faults. One was a conservative estimate of 1.0 sq mi and included only the area around the spring. The other estimate, of 5.2 sq mi in extent, was drawn to try to include some of the faulting. Calculated heat energy contained in this system varied from .0083 Q's to .0430 Q's at an average maximum temperature of 43°C (Table 2).

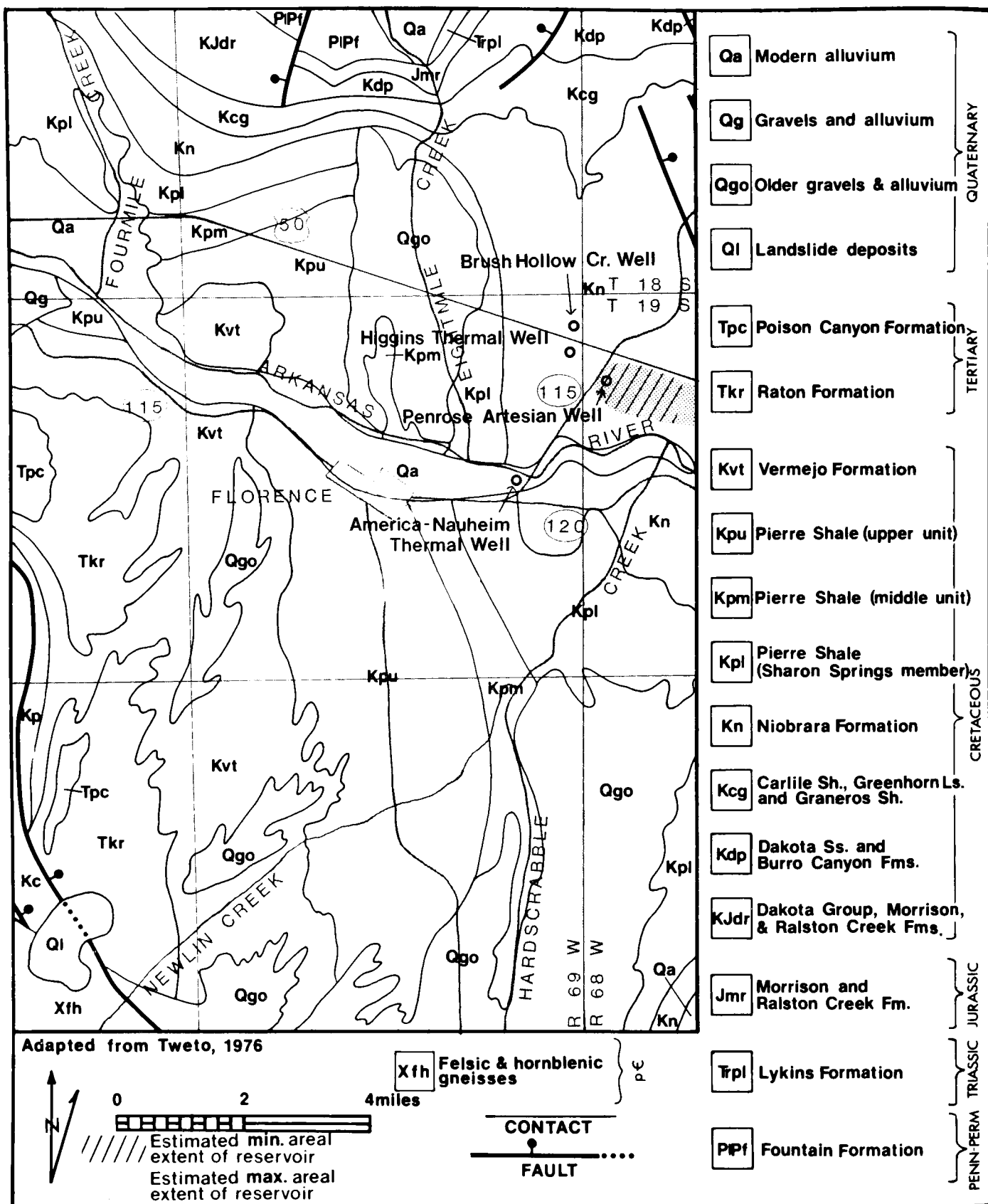


Figure 26.--Geology of the Florence area and estimated areal extent of the Penrose Artesian Well geothermal reservoir.

#29 DON K RANCH ARTESIAN WELL

LOCATION: Latitude: 38°10'20"N.; Longitude: 105°00'32"W.; T. 22 S., R. 68 W., Sec. 5 a, 6th P.M.; Fremont County; Wetmore 7 1/2-minute topographic quadrangle map.

GENERAL: This unused well, of unknown depth, may be reached by going west from Pueblo for approximately 19.5 miles on State Highway 96 to the community of Siloam. At Siloam turn left on a dirt road, called Siloam Road, and go approximately 4.75 miles to the turnout to the Don K. Ranch. Follow this road for approximately one mile to the ranch house.

GEOLOGY AND HYDROLOGY: The waters of this well have a surface temperature of 28°C and a discharge of 25 gpm. The total dissolved solids of the waters are 1,710 mg/l, and the waters are a sodium bicarbonate type.

The well is located down on the northeast flank of the Red Anticline (Fig. 27). The bedrock of the area is the Pennsylvanian Fountain Formation. Taylor and Scott (1973) mapped no faults in the area. On the crest of the anticline, approximately one mile to the southwest, Precambrian biotite gneiss crops out. No attempt was made to determine the origin of the thermal waters or the heat source; however, a cursory appraisal suggests that heat lensing occurs within the Precambrian metamorphic rocks. Dr. Trobe Grose (1977, oral communication) states that "heat lensing" can occur when a granitic or metamorphic rock body is overlain by a sedimentary sequence. Because sedimentary rocks have lower specific heat content than the granitic or metamorphic rocks, the heat is drawn to and concentrated in the metamorphic and granitic rocks.

GEOOTHERMOMETER ANALYSES: The silica content of this artesian well does not approach the solubility of amorphous silica, chalcedony, cristobalite or quartz; therefore, application of any of these silica geothermometers yields questionable results (Barrett and Pearl, 1978).

The cristobalite-silica geothermometer model yielded an estimated subsurface temperature of 42°C. However, this estimate is probably too high because the theoretical cristobalite solubility (29 mg/l) at the surface temperature of the well (28°C) is below the silica content of the thermal water (40 mg/l).

Mixing model analysis is unreliable when applied to the thermal waters in this well because the temperature and flow of well are below the minimum conditions specified for the reliable use of this model. The amorphous silica mixing model yields a subsurface temperature estimate of 23°C with a cold-water fraction of 47 percent of the artesian flow. The cristobalite mixing model yields a subsurface temperature estimate of 63°C with a cold water content of 61 percent.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 219°C and 190°C, respectively. Both of these estimates are too high because calcium bicarbonate is deposited on the well casing.

Conclusion: Geothermometer analysis for this area is not reliable because most of the assumptions do not apply.

RESOURCE ASSESSMENT: The occurrence of this thermal water is not fully understood and should probably be classified as unknown. However, to try to estimate the areal extent of the reservoir, it was hypothesized that faulting to the west may play some part in the occurrence of the thermal waters. Therefore, it was assumed that the waters are moving up from depth along the fault then down dip in some sedimentary formation. Thus, the reservoir was estimated to extend east from the fault for a distance of over 2 miles and encompassed an area of approximately 1.5 sq mi (Fig. 27). If this estimate is correct, the reservoir could contain .0353 Q's of energy at an average maximum temperature of 40°C (Table 2).

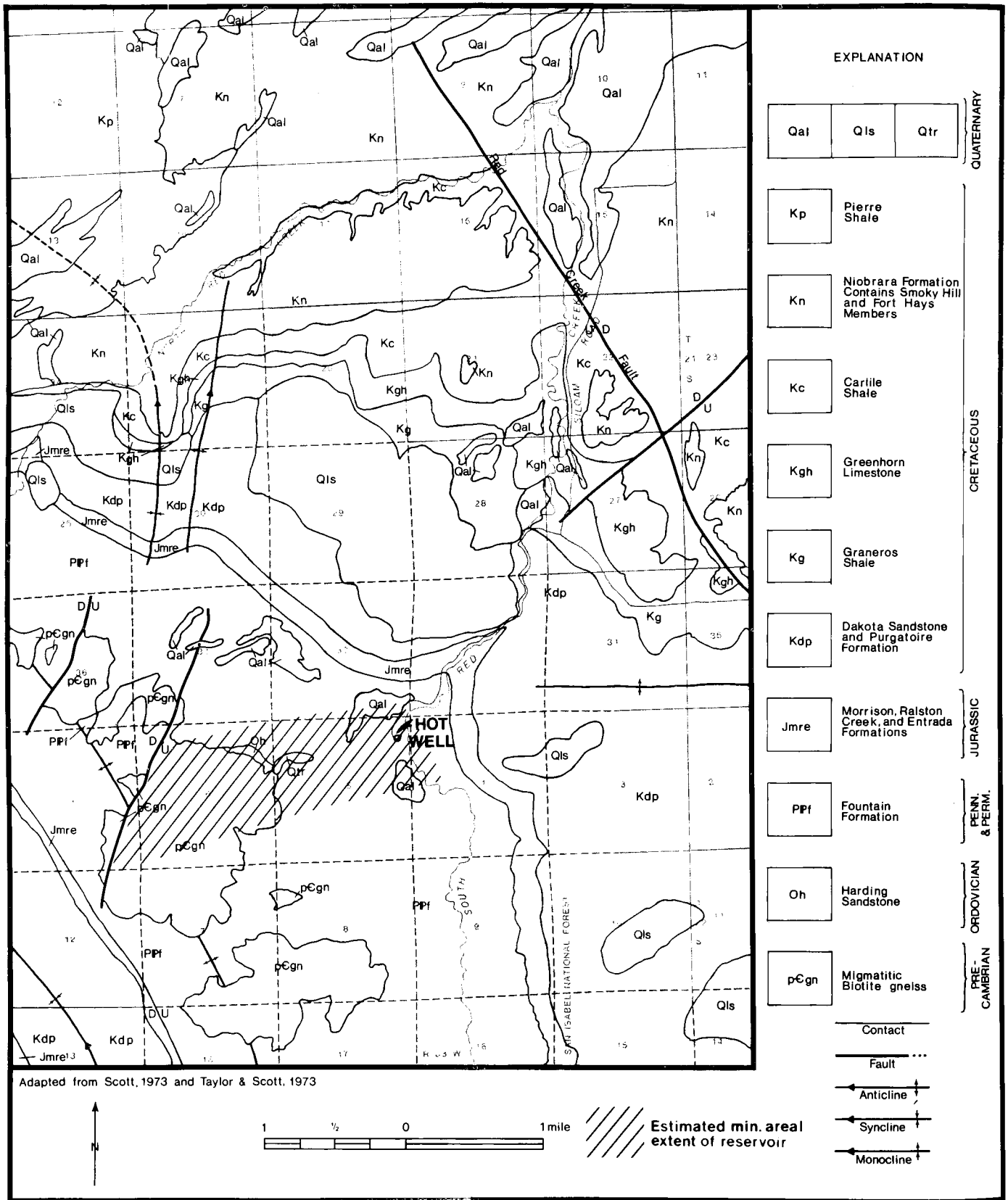


Figure 27.--Don K Ranch area, geology and estimated areal extent of the geothermal reservoir.

#30 CLARK ARTESIAN WELL

(CLARK SPRING WARM WATER WELL)

LOCATION: Latitude: 38°15'29"N.; Longitude: 104°36'35"W.; T. 21 S., R. 65 W.; Sec. 1 aab, 6th P.M.; Pueblo County; NE Pueblo 7 1/2-minute topographic quadrangle map.

GENERAL: This well is located inside the Clark Spring Water Company building on the north corner of Clark and B Streets in Pueblo, Colorado. The waters are bottled and sold commercially by the Clark Spring Water Company.

GEOLOGY AND HYDROLOGY: This well is 1,412 ft deep. The waters, which issue at the surface with a temperature of 25°C, contain 1,210 mg/l of dissolved mineral matter and are a sodium sulfate type.

As shown on Figure 28, the well is located on the southwest flank of an unnamed syncline. The origin of the thermal waters is unknown but may be caused by decay of radioactive minerals in the Dakota Formation. Richard Gamewell (1977, oral communication), a radiological specialist for the Colorado Department of Health, and Vinickier (1978) have reported elevated levels of radioactivity in the Pueblo area associated with ground waters from the Dakota and other Cretaceous formations.

Recharge to the Dakota Formation occurs primarily along the flanks of the Canon City Embayment to the west of Pueblo.

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978) noted that most geothermometer models are not reliable for estimating the Clark Artesian Well

reservoir temperature because many of the assumptions inherent in their use are violated. The quartz-silica geothermometer model yielded a subsurface temperature of 40°C.

The quartz mixing model yielded a subsurface temperature estimate of 61°C with a cold water fraction of 65 percent of the total flow. Any estimates of subsurface temperatures with this model are unreliable because the silica content (11 mg/l) and the flow of this well are below the minimum conditions specified for the reliable application of this geothermometer (Barrett and Pearl, 1978).

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 280°C and 159°C, respectively. The high magnesium content (45 mg/l), low surface temperature and flow of this well and the lack of substantiation of such high subsurface temperatures by the other geothermometers render these estimates unreliable.

Conclusion: From analysis of all the data, it appears that the most likely subsurface temperature in this area is between 25°C and 50°C (Table 3).

RESOURCE ASSESSMENT: Because of the uncertainty concerning the origin and geological controls of this hot water, the boundaries of the reservoir were drawn to include only a small area around the well. As drawn the reservoir encompasses some 1.1 sq mi and contains .0083 Q's of heat energy at an average temperature of 40°C (Table 3).

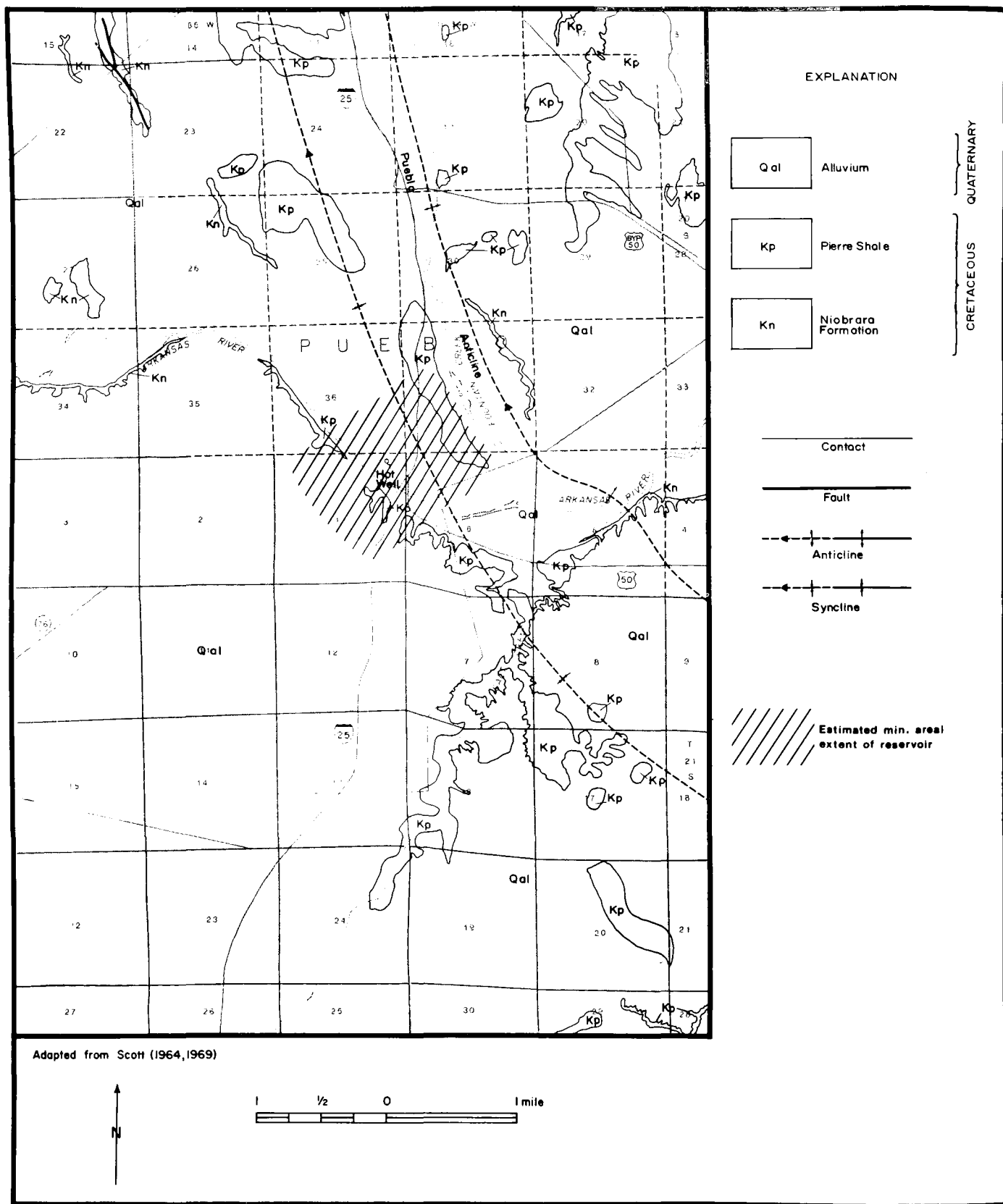


Figure 28.--Map showing estimated areal extent of the Clark Artesian Well geothermal reservoir and surrounding geologic conditions.

#31 MINERAL HOT HOT SPRINGS

LOCATION: Latitude: 38°10'08"N.; Longitude: 105°55'05"W.; T. 45 N., R. 9 E., Sec. 12 ad, N.M.P.M.; Saguache County; Villa Grove 7 1/2-minute topographic quadrangle map.

GENERAL: The Mineral Hot Springs consists of a number of unused springs scattered over approximately 80 acres just east of Colorado 17, 6.5 miles south of Villa Grove in the northern San Luis Valley.

These unused springs are located in three groups--an eastern group of two springs and one well, a central group of one spring, and one seep in a western group. Development of the area has reduced the many springs around the travertine mound to just one seep and the main spring, which flows into a concrete-lined cistern (Barrett and Pearl, 1978).

GEOLOGY AND HYDROLOGY: The waters of all the springs are quite similar. The temperature of the springs is 60°C, and the total dissolved solids content is approximately 650 mg/l (varies slightly throughout the year's time). The waters are a sodium bicarbonate type.

Spring A, which is actually a well, has the largest discharge of all the springs. Its discharge ranges between 70 and 167 gpm throughout the year. Spring A comprises almost all of the discharge of the easternmost group of three springs. The other two are seeps having a discharge of 1 to 2 gpm. Spring D, which is the large spring flowing into the concrete-lined cistern in the center group, has an estimated discharge of 5 gpm.

The Mineral Hot Springs are located in the northern end of the San Luis Valley, a part of the Rio Grande rift zone. There are no surface expressions of any fault systems crossing this area. However, several authors have projected one and possibly two faults in the vicinity of the springs (Fig. 29). It has been postulated that a northwest-trending fault extends from the Bonanza area as far east as the Mineral Hot Springs area. This theory was confirmed by students from the Department of Geophysical Engineering, Colorado School of Mines, who conducted a geophysical investigation in this area during the summer of 1977. Their work showed that the springs are located at the intersection of two fault zones (Dr. George Keller, 1977, oral communication). During the course of their investigation a small-diameter hole, located almost due west of Spring A and due north of Spring D, was drilled to a depth of 320 ft. This well encountered ground waters under artesian conditions. The flow of the well established at 2 to 5 gpm, and the waters had a temperature of 38°C. The thermal waters appear to be narrowly restricted because less than 1/2 mile to the east of the Spring A there is a cold ground-water well.

The area is underlain by thick valley-fill alluvium. Dr. George Keller (1977, oral communication) reported that the 1977 geophysical investigations showed up to 5,000 ft of alluvium just a few hundred ft north of the springs. At Spring D the bedrock is very close to the surface, thus implying a rapid southwest elevation of the bedrock surface or a large normal fault.

In addition to the geophysical investigations by the Colorado School of Mines in 1977, the Colorado Division of Water Resources did extensive geophysical and test drilling in the vicinity of Mineral and Valley View Hot Springs during the winter and summer of 1976 (Romero and Fawcett, 1978). This investigation showed that the valley floor is approximately 5,000 ft deep in the vicinity of Mineral and Valley View Hot Springs and is cut by numerous high angle normal faults.

It is believed that the Mineral Hot Springs represent deep circulation of ground waters through fault zones in a region of above-normal heat flow (Reiter, 1975). Another possible explanation for this thermal spring is the upward welling of ground waters along a fault zone that blocks the normal south-southeast flow in a region of above-normal heat flow.

GEOOTHERMOMETER ANALYSES: Chalcedony-silica geothermometer yielded a temperature estimate of 67°C to 72°C (Barrett and Pearl, 1978). Chalcedony mixing model analysis yields a subsurface temperature estimate of 79°C to 93°C with a cold water fraction of 30 to 43 percent of the total flow. The cold-water data used in this calculation (T: 11°C, SiO₂: 19 mg/l) may not reflect the actual ground water conditions at depth. Klein (1976) states that ground water in the San Luis Valley area has an exceedingly high silica content. If this is true and the assumed silica in the ground water is below the actual concentration, then the subsurface temperature and cold-water-fraction estimates are too high. The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 195°C to 206°C and 87°C to 92°C, respectively. The Na-K geothermometer estimate is too high because one of the assumptions of the model were violated. Large travertine mounds and calcium carbonate-depositing springs suggest that both the Na-K and Na-K-Ca geothermometer estimates are too high.

Conclusion: The mixing model and the silica and Na-K-Ca geothermometers predict that the temperature at depth in this area is between 70°C and 90°C (Table 3).

RESOURCE ASSESSMENT: Romero & Fawcett (1978) have shown the presence of a resistivity low extending northwest up the valley from the general area of Mineral Hot Springs. They have also shown that the valley floor northwest of the hot spring has been cut by numerous faults.

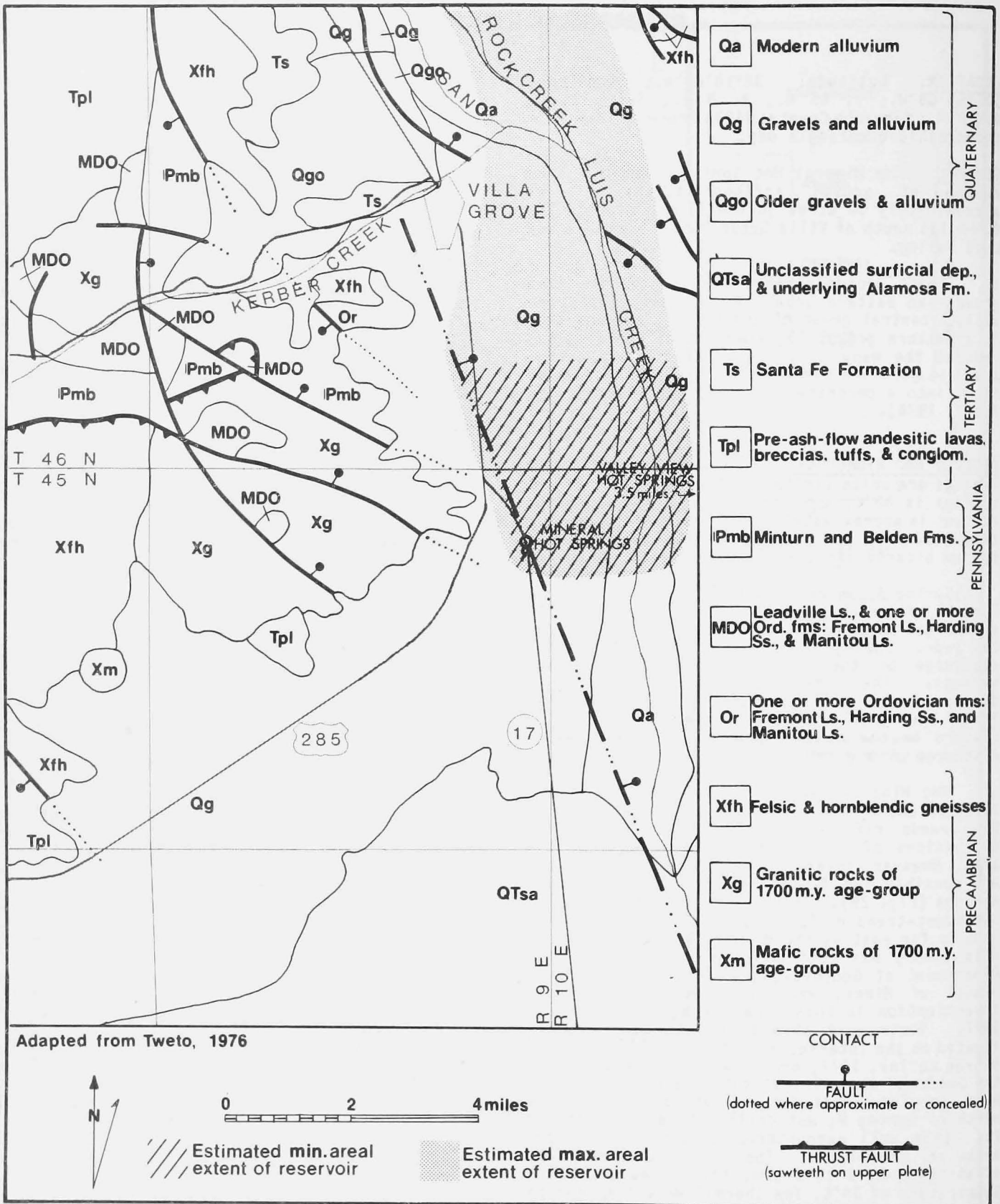


Figure 29.--Map of geologic conditions surrounding Mineral Hot Springs and estimated areal extent of the geothermal reservoir.

In making this assessment, using Romero & Fawcetts (1978) data, the author made two estimates of the heat contained in the system. The more conservative estimate restricted the reservoir to an area of approximately 10.1 sq mi north of the spring. This area was calculated to contain .9492 Q's of energy at an average maximum temperature of 70°C. The other estimate extended the reservoir up the valley for a distance of 32 sq mi, encompassing the resistivity low of Romero & Fawcett (1978). This area was calculated to contain 3.007 Q's of energy (Table 2). The difference in temperature

estimates can be explained by the methods presented by the estimates of Romero & Fawcett (1978) and this report. Romero & Fawcett (1978), in calculating the temperature of the reservoir, used the average of all four geothermal temperatures (155°C) presented by Barrett & Pearl. Barrett & Pearl (1978) stated that the most likely temperature of this reservoir is 70-90°C. The author in his calculation used a reservoir temperature of 70°C. Whereas, Romero & Fawcett (1978) assumed that the reservoir had a thickness of 6,821 ft, the author assumed that the reservoir only had a thickness of 1,000 ft.

#32 VALLEY VIEW HOT SPRINGS

(ORIENT HOT SPRINGS)

LOCATION: Latitude: 38°11'32"N.; Longitude: 105°48'49"W; T. 46 N., R. 10 E Sec. 36 db, N.M.P.M.; Saguache County; Valley View Hot Springs 7 1/2-minute topographic quadrangle map.

GENERAL: The Valley View Hot Springs, also known as the Orient Hot Springs, are located on the east side of the San Luis Valley approximately 12 miles southeast of Villa Grove. The area around these thermal springs is relatively undeveloped, with the waters being used for bathing purposes by those camping in the area.

The springs are found in two groups--a lower group consisting of three springs, and an upper group of one spring. Waters from the largest spring in the lower group were once piped to a large swimming pool. After this pool collapsed in 1974 or 1975, a crude dirt-embankment swimming pool was constructed over Spring A. Spring B, in the lower group and located approximately 50 yd south of A, is a small rock-ringed pool. Spring C is located several yards south of B on a hillside.

Spring D, the upper spring, is several hundred ft in elevation above Spring A and is reached by a 0.5-mile walk along a well-marked trail leading southeast from Spring A.

GEOLOGY AND HYDROLOGY:

Spring A: Temperature of this spring varied throughout the year's time from 35°C to 37°C. The discharge of the spring was estimated at 60 gpm. The total dissolved solids in the water are 234 mg/l to 252 mg/l. The waters are a calcium bicarbonate-sulfate type.

Spring B: This spring has a temperature of 32°C and the discharge was not determined. The total dissolved solids in the water are 234 mg/l, and the waters are a calcium bicarbonate type.

Spring C: Not sampled.

Spring D: The temperature of this spring varied throughout the year from 34°C to 36°C. The discharge also varied from 75 to 120 gpm. The total dissolved solids in the water varied from 223 mg/l to 247 mg/l. The waters are a calcium-bicarbonate type.

The waters are associated with the Valley View Fault zone which traverses the east side of the valley in this location (Fig. 30). The bedrock of the area is the Pennsylvanian Minturn and Belden Formations. As shown on Figure 30, these formations are truncated at the Valley View Springs by the Valley View Fault zone along the west side of the Sangre de Cristo Range.

Recent work by Romero and Fawcett (1978) has showed that the bedrock floor of the valley here

is extensively cut by high-angle normal faults, one of which is the Valley View Fault. Reiter (1975) showed the San Luis Valley to have a heat flow in excess of 2.0 heat flow units. Recharge to these springs is probably normal ground waters of the valley that enter the fault zone and then circulate deeply.

GEOOTHERMOMETER ANALYSES: Analysis showed that chalcedony controls the silica content of the hot springs. The chalcedony-silica geothermometer gave an estimated subsurface temperature of 25°C to 34°C (Barrett and Pearl, 1978) (Table 3). Although this estimate is below the surface temperature of the springs (34°C-37°C) it is within the margin of error inherent in the geothermometer technique. Chalcedony mixing model analysis yields a subsurface temperature estimate of 29°C to 37°C, with a cold water fraction of 4 to 33 percent of the spring flow (Table 3). The cold-water data used in these calculations (Temp.: 6°C; SiO₂: 15 mg/l) may not reflect the actual ground water conditions at depth. Klein (1976) states that ground waters in the San Luis Valley area have exceedingly high silica content. If the assumed silica content of the cold ground waters is below the actual concentration, then the subsurface temperature and cold water-fraction estimates will be too high.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 338°C to 389°C and 10°C to 16°C, respectively. The Na-K-Ca geothermometer estimate is obviously incorrect since it is below the surface temperature of the warm springs. This result may be due to the excessive solution of calcium carbonate by the thermal waters during ascent through numerous caliche zones recently discovered by Romero and Fawcett, 1978).

Conclusion: The high flow rate (250 gpm) and the excellent agreement between the theoretical chalcedony-induced solubility and the silica content of the springs suggest that the temperature at depth in this area is not much greater than the surface temperature. Therefore, the temperature at depth in this area is probably between 40°C and 50°C (Table 3).

RESOURCE ASSESSMENT: In assessing the possible areal extent of this reservoir, the author felt that it was restricted to the Valley View Fault zone (Fig. 30) and only had an areal extent of approximately 1 sq mi. It was estimated that this reservoir is 1,000 ft thick, has a maximum temperature of 50°C, and contains .0564 Q's of heat energy.

Romero and Fawcett (1978), using the same criteria as they used for Mineral Hot Springs, calculated that this area contains 265.5 Q's of heat energy.

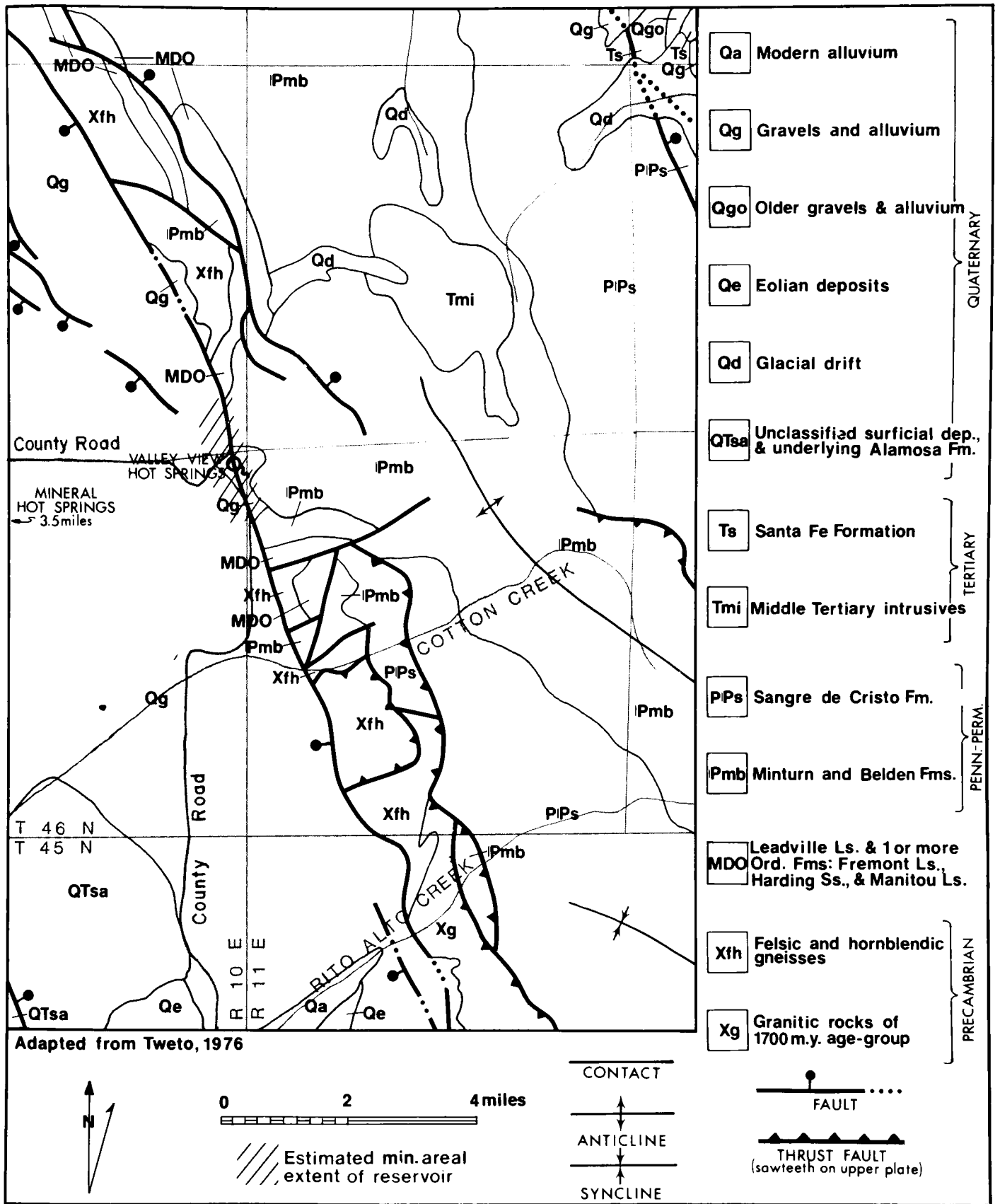


Figure 30.--Valley View Hot Springs area, geology and estimated extent of the geothermal reservoir.

#33 SHAWS WARM SPRING

LOCATION: Latitude: 37°45'01"N.; Longitude: 106°19'01"W.; T. 41 N., R. 6 E., Sec. 33 dd, N.M.P.M.; Saguache County; Twins Mnts. SE 7 1/2-minute topographic quadrangle map.

GENERAL: This spring is located approximately 6 miles north of Del Norte. The waters are used in a private swimming pool.

GEOLOGY AND HYDROLOGY: Temperature: 30°C; Discharge: 34 to 50 gpm; Total dissolved solids range from 398 to 424 mg/l; Water is a sodium-bicarbonate type.

This spring is located on the west side of the San Luis Valley and the Rio Grande Rift zone. As shown on the accompanying geologic map (Fig. 31), the bedrock of the area is a complex assemblage of volcanic rocks related to the Summer Coon Volcano and other centers of volcanic activity in the area. All the rocks erupted from the Summer Coon Volcano have been included in the Conejos Formation by Lipman and others (1970).

The geology of the region has been described in detail by Lipman (1968) and Mertzman (1971). As described by these two authors, the spring is located well down on the lower southeast flank of the Summer Coon Volcano.

The bedrock of the area is an assemblage of volcanic rocks, tuffaceous sandstones, and conglomerates (Fig. 31). Mertzman (1971) noted that the Summer Coon Volcano was active 31.1 to 34.7 million years ago (late Paleocene) and that the volcano became extinct by the time the Rio Grande depression began in early Miocene time.

One fault exists approximately 0.5 mile to the northeast of the spring site, but probably has not affected the occurrence of the spring. It is believed that the waters move down dip through permeable interflow units until they emerge at this site. Recharge probably occurs in the higher

ground to the west, and the heat source is probably residual Tertiary volcanic activity in the area.

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978) showed that amorphous silica may control the silica content of the warm spring. The amorphous silica geothermometer subsurface temperature estimate is 2°C to 17°C, which is well below the surface temperature of the warm spring (30°C). This low temperature estimate may be caused by mixing of ascending thermal water and dilute ground water or silica precipitation at depth.

Amorphous silica mixing model analysis yields a subsurface temperature estimate of 26°C to 28°C with a cold-water fraction of 19 to 32 percent of the spring flow (Table 3).

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 98°C to 101°C and 83°C to 104°C, respectively. These results are unreliable because the low discharge (45 gpm) and surface temperature (30°C) of this spring are well below the minimum conditions specified for the application of these geothermometers.

Conclusion: Geothermometers should be used with caution when applied to Shaw's Warm Spring because most of the assumptions inherent in their use are violated. From review of all data it is believed that the most likely subsurface temperature in this area is between 30°C and 60°C (Table 3).

RESOURCE ASSESSMENT: Barrett & Pearl (1978) postulated that the occurrence of this spring was due to a down dip flow of waters through permeable inter-volcanic units. The thickness of these units is unknown; therefore, a thickness of 500 ft was assigned. It was estimated that the reservoir is a sedimentary reservoir and encompasses an area of approximately 0.63 sq mi and has an average maximum temperature of 45°C. Calculations show that a reservoir of this size could contain 0.0148 Q's of heat energy (Table 2).

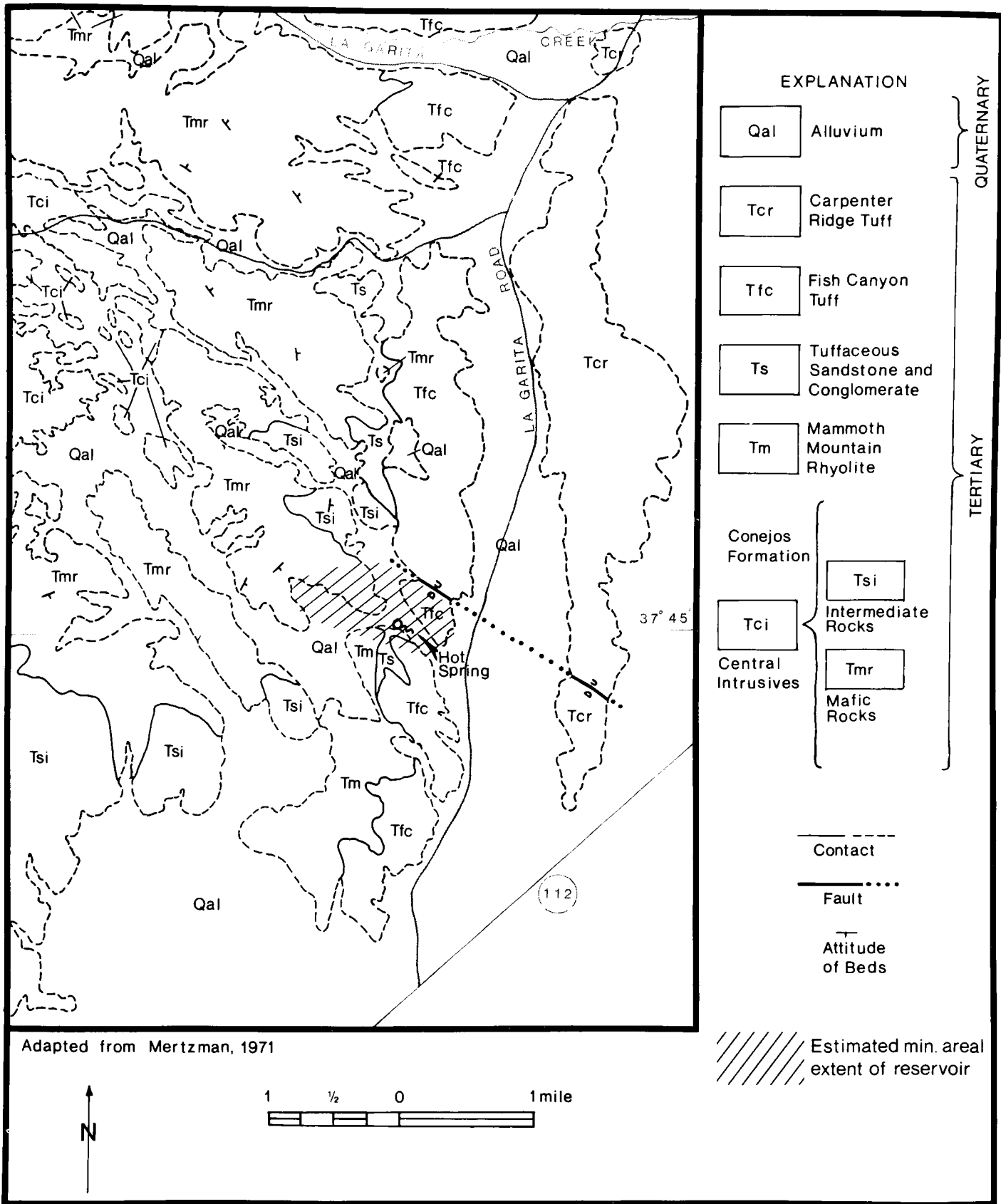


Figure 31.--Geology and estimated areal extent of the geothermal reservoir, Shaws Warm Spring.

#34 SAND DUNES SWIMMING POOL HOT WATER WELL

LOCATION: Latitude: 37°46'42"N.; Longitude: 105°51'20"W.; T. 41 N., R. 10 E., Sec. 27 aa, N.M.P.M.; Alamosa County; Deadman Camp 7 1/2-minute topographic quadrangle map.

GENERAL: This 4,400-ft-deep well is located 3 miles northeast of Hooper in the San Luis Valley. Of the two wells present, the north well is hot and the south well is cold. The hot well was sampled at the discharge pipe by the pump.

GEOLOGY AND HYDROLOGY: The temperature of the thermal waters was 44°C, with a total dissolved solids of 334 mg/l. The waters are a sodium bicarbonate type with a high silica content.

Chapin (1971), Emery (1971), Emery and others (1971), and Stoughton (1977) have presented detailed discussions of the geology and hydrology of the San Luis Valley and the Rio Grande Rift zone. As shown by Gacia and Karig (1966) and Stoughton (1977) this well is approximately located over the deepest part of the San Luis Valley. Gacia and Karig (1966) showed that the deepest part of the basin contained up to 30,000 ft of valley-fill sediments. Later work by Stoughton (1977) has revised this figure to a maximum of approximately 20,000 ft of valley fill sediments. A deep oil well test was drilled in 1974 in T. 40 N., R. 12 E., Sec. 32, bd, N.M.P.M. by Mapco and Amoco. This well was drilled to a depth of 9,480 ft and had a bottom-hole temperature of 128°C. The geothermal gradient in the well was 38.8°C/km (3.1°F/100 ft). Reiter (1975) has determined that

this part of the San Luis Valley has a heat flow of 2.4 heat flow units.

From analysis of all published data it is believed that these thermal waters occur as a result of normal movement of ground water from west to east in the San Luis Valley in an area of above-normal heat flow. While no faults have been mapped in the vicinity, it is believed that the waters are fault controlled.

GEOTHERMOMETER ANALYSES: When analyzing the estimated subsurface temperatures of this system, Barrett and Pearl (1978) noted that the geothermometer models yield questionable results because most of the assumptions inherent in their use are violated. However, they did calculate the subsurface temperatures. Their results were: Amorphous-silica, 26°C.; Amorphous-silica mixing model, 39°C with a cold-water fraction of 19 percent; Na-K and Na-K-Ca, 205°C and 187°C, respectively (Table 3).

Conclusion: The complex geochemistry of this well does not allow an accurate estimation of the subsurface temperature (Barrett and Pearl, 1978).

RESOURCE ASSESSMENT: Although there is uncertainty regarding the occurrence of this reservoir, the author estimated that it this is a sedimentary reservoir that encompasses an area of 1.5 sq mi around the well. With a maximum temperature of 75°C it could contain 0.1551 Q's of heat energy (Table 2).

#35 SPLASHLAND HOT WATER WELL

LOCATION: Latitude: 37°29'19"N.; Longitude: 105°51'27"W.; T. 38 N., R. 10 E., Sec. 34 dd, N.M.P.M.; Alamosa County; Alamosa East 7 1/2-minute topographic quadrangle map.

GENERAL: This 2,000-ft-deep well is located approximately 200 yds southwest of the Splashland Swimming Pool, 1 mile north of Alamosa on State Highway 17. The waters are used for recreational purposes in the swimming pool.

GEOLOGY AND HYDROLOGY: The waters have a temperature of 40°C and contain 311 mg/l of dissolved elemental mineral matter. The waters are a sodium bicarbonate type. The waters are associated with the valley-fill sediments of the San Luis Valley. Recharge occurs along the west side of the valley with the waters migrating to the east in the subsurface in an area of above-normal geothermal gradients (Reiter, 1975).

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978) determined that geothermometer analysis yielded questionable results when applied to this thermal well because most of the assumptions inherent in their use are violated. They did, however, solve the various geothermometer models. The amorphous-silica geothermometer model yielded a subsurface temperature estimate of 22°C (Table 3). The Amorphous Silica Mixing Model analysis yields a

subsurface temperature estimate of 35°C with a cold water fraction of 23 percent of the spring flow (Table 3). The cold water data used in these calculations (T: 6°C, SiO₂: 25 mg/l) may not reflect the actual ground-water conditions at depth. Klein (1976) states that ground water in the San Luis Valley has an exceedingly high silica content. If the assumed silica content of the cold ground water is below the actual concentration, then the subsurface temperature and cold water-fraction estimates are too high. The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 221°C and 197°C, respectively (Table 3).

Conclusion: Geothermometer models yield questionable results when applied to this thermal well because most of the assumptions inherent in their use are violated. From review of all data it appears that the subsurface temperature in this area is probably between 40°C and 100°C (Table 3).

RESOURCE ASSESSMENT: These thermal waters are thought to be contained in the valley fill sediments (Barrett & Pearl, 1978). As the subsurface geologic conditions are unknown, for assessment of the resource it was assumed that the reservoir could encompass an area of 1.5 sq mi. Calculations show that it could contain 0.1551 Q's of heat energy (Table 2).

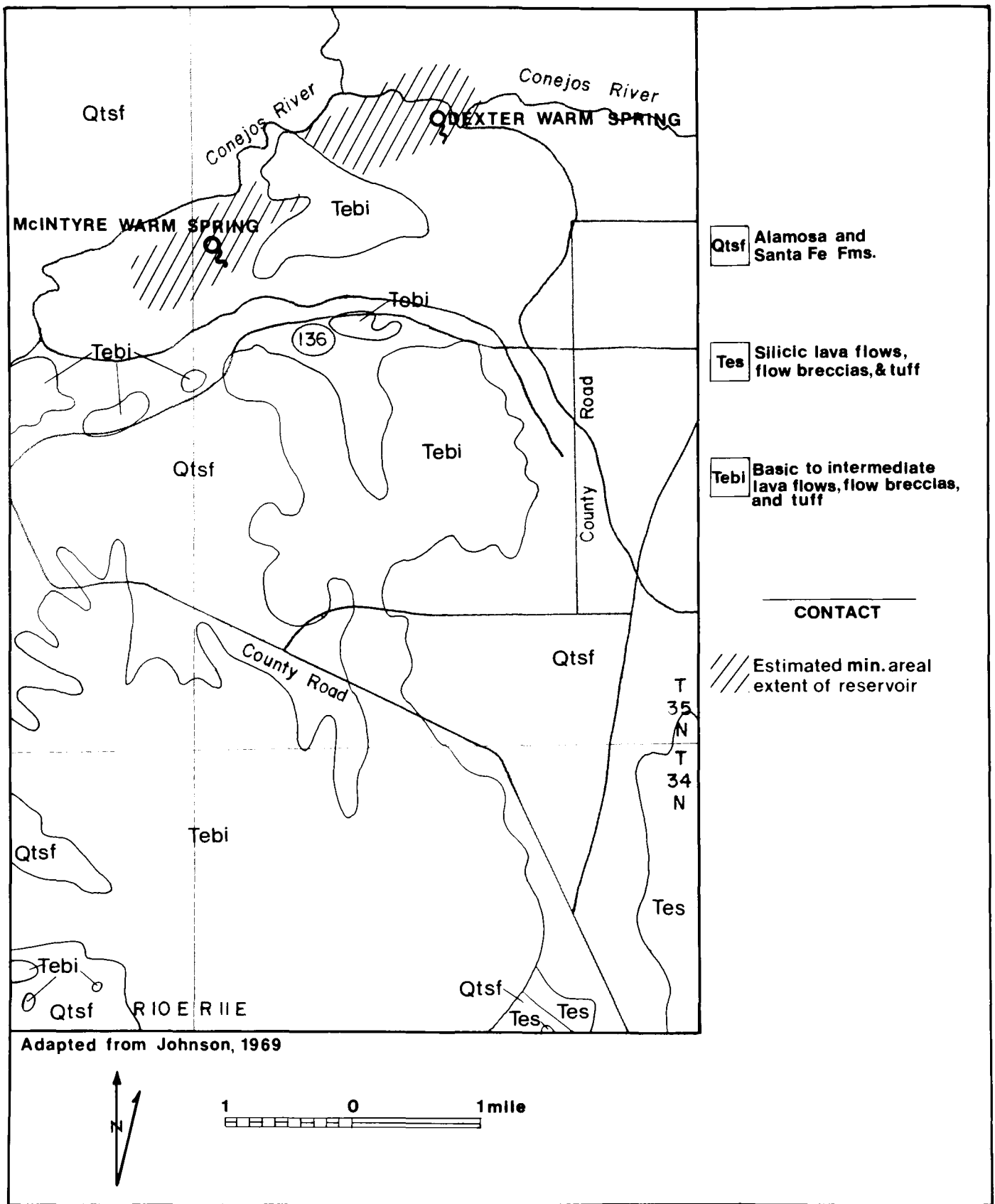


Figure 32.--Map showing estimated areal extent of the Dexter and McIntyre Warm Springs geothermal reservoir and surrounding geologic conditions.

DEXTER AND McINTYRE WARM SPRINGS

Located on the north side of the San Luis Hills in the southern end of the San Luis Valley are two springs, Dexter and McIntyre, whose

occurrence and characteristics are nearly identical. As these springs appear so nearly identical, they will be discussed together.

#36 DEXTER WARM SPRING

Location: Latitude: 37°17'41"N.; Longitude: 105°47'05"W.; T. 35 N., R. 11 E., Sec. 8 ada; Conejos County; Pikes Stockade 7 1/2-minute topographic quadrangle map.

Conejos River. The springs are reached by going east from Sanford on Colorado Highway 142 for 7.1 miles to a dirt road. Turn north on this road and go approximately 1.75 miles to the springs.

GENERAL: This group of several unused springs and seeps is located in a marshy area on the north side of the San Luis Hills and on the south side of the

The springs have a temperature of 20°C with a combined discharge of just over 5 gpm. The waters contain 195 mg/l of dissolved solids and are a sodium-bicarbonate type.

#37 McINTYRE WARM SPRING

LOCATION: Latitude: 37°16'48"N.; Longitude: 105°49'07"W.; T. 35 N., R. 11 E., Sec. 18 bcb, N.M.P.M.; Conejos County; Pikes Stockade 7 1/2-minute topographic quadrangle map.

While the temperature of these springs (10 to 14°C) is below the minimum temperature used during this investigation, these springs were sampled and measured because of their association with the nearby Dexter Warm Springs. Due to the amount of surface water flowing through the area, it was not possible to measure the discharge of the springs, but it appears to be large. The waters contain 165 mg/l of dissolved solids and are a calcium-bicarbonate type.

GENERAL: These 10 to 15 unused springs are located on the south bank of the Conejos River south of Alamosa in the San Luis Valley. Access is via a paved county road for 5.3 miles east from Sanford, Colorado, then north and east on a dirt trail for approximately 1 mile.

GEOLOGY AND HYDROLOGY OF DEXTER AND McINTYRE WARM SPRINGS: As the geological and hydrogeological conditions surrounding each spring are nearly identical, they will be discussed together. The springs are located on the north side of the San Luis Hills and emerge from sediments of the Santa Fe Group (Fig. 32). The San Luis Hills consist of a series of middle to late Tertiary lava flows that rise prominently above the flat surface of the San Luis Valley. The geology of this area has been described in detail by Burroughs (1971). While no faults are shown on the geologic map (Fig. 32), it appears from Burroughs' description that the springs are probably associated with faulting on the north side of the hills.

The origin of the heat for the thermal waters is in doubt but appears to be related to the Pliocene volcanic activity that took place in this area (Burroughs, 1971). Reiter (1975) has mapped the San Luis Valley as having heat flow above 2.5 heat flow units. The origin of the springs is probably due to deep circulation of ground waters in the San Luis Valley ascending through fault zones in an area of above-normal geothermal gradients.

GEOOTHERMOMETER ANALYSES FOR DEXTER AND McINTYRE WARM SPRINGS: The silica content of these springs does not approach the solubilities of amorphous silica, chalcedony, cristobalite or quartz. Therefore, application of any of these silica geothermometers will yield unreliable results. The amorphous-silica mixing model yields subsurface temperature estimates of 15°C to 19°C, with cold water fractions of 33 to 35 percent of the spring flow. The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 273°C to 333°C and 50°C to 91°C, respectively. The Na-K geothermometer results are too high because one of the assumptions of the model is violated. The low surface temperature of the warm springs and the lack of substantiation of such high temperatures at depth by the other geothermometers suggest that both the Na-K and Na-K-Ca results are unreliable.

Conclusion: Geothermometer models must be used with caution when applied to McIntyre and Dexter warm springs because most of the assumptions inherent in their use are violated. Any geothermometer estimate for this area is unreliable at best. However, it appears that the temperature at depth is probably between 20°C and 50°C (Table 3).

RESOURCE ASSESSMENT: No definitive work has been published on the subsurface geologic conditions of the reservoir (Barrett & Pearl, 1978). Therefore, the reservoir's areal extent was estimated to

extended in a NE-SW direction along the front of the San Luis Hills and encompassed an area of 1.2 sq mi. Estimates show that the reservoir contains .0339 Q's of heat energy at an maximum temperature of 35°C (Table 2).

#38 STINKING SPRINGS

LOCATION: Latitude: 37°02'05"N.; Longitude: 106°48'25"W.; T. 32 N., R. 1 E., Sec. 2 dd, N.M.P.M.; Archuleta County; Chromo 15-minute topographic quadrangle map.

GENERAL: These unused springs are located approximately 2 miles east of Chromo. Although marshy areas exist near these springs, only one with any distinct flow was located approximately 100 yd south of the road.

GEOLOGY AND HYDROLOGY: The spring had a temperature of 27°C with a discharge of 24 gpm. The total dissolved mineral matter solids contained in the waters are 899 mg/l, and the waters area a calcium-sulfate type.

As shown on Figure 33, the springs are located on the crest of the Chromo Anticline on the trace of a small northwest trending fault. The bedrock of the area, Mancos Shale, dips to the southwest off of the Continental Divide, which bounds the basin on the east side. It is believed that recharge to this spring occurs along the eastern flank of the San Juan Basin where the waters move downdip until they intersect a fault. They then migrate upward along the fault to the surface. Heating of the waters occurs because this area has above normal heat flow (Reiter, 1975).

GEOOTHERMOMETER ANALYSES: Using the following geothermometer models the following subsurface temperatures were calculated (Barrett and Pearl, 1978): Chalcedony-silica geothermometer, 39°C, Chalcedony silica mixing model 59°C with a cold water fraction of 61 percent, Na-K geothermometer, 39°C, and the Na-K-Ca geothermometer, 41°C. The Na-K estimate is too high because one of the requirements of the model was violated (Barrett and Pearl, 1978).

Conclusion: Geothermometer models must be used with caution when applied to Stinking Springs because most of the assumptions inherent in their use are violated. Moreover, samples of the thermal water had to be taken from a large, quiescent pool where evaporative concentration of silica and other re-equilibration reactions may have occurred.

In light of the excellent agreement between the mixing model and the silica and Na-K-Ca geothermometers the subsurface temperature in this area is probably between 40°C and 60°C (Table 3).

RESOURCE ASSESSMENT OF STINKING SPRINGS AND DUTCH CROWLEY ARTESIAN WELL: Even though Barrett & Pearl (1978) described the origin of Stinking Springs as due to faulting for resource assessment purposes, the author considers the reservoir to be a sedimentary reservoir. This is due to the fact that there are no faults mapped in the vicinity of this spring (Fig. 33). This does not preclude the possibility that the waters could be moving up a fault and into a sedimentary formation. For the same reason it was assumed that the Dutch Crowley Artesian well is drawing its water from a sedimentary reservoir.

Two estimates of the reservoir areal extent were made. In one case it was assumed that the reservoir encompassed some 3.66 sq mi along the crest of the anticline and included both thermal water orifices. In the other case it was assumed that the reservoir was restricted to a net area of 1.52 sq mi around both thermal water orifices (Fig. 33).

The amount of energy estimated to be contained in the system ranges from .0257 to .0620 Q's at an average maximum temperature of 65°C (Table 2).

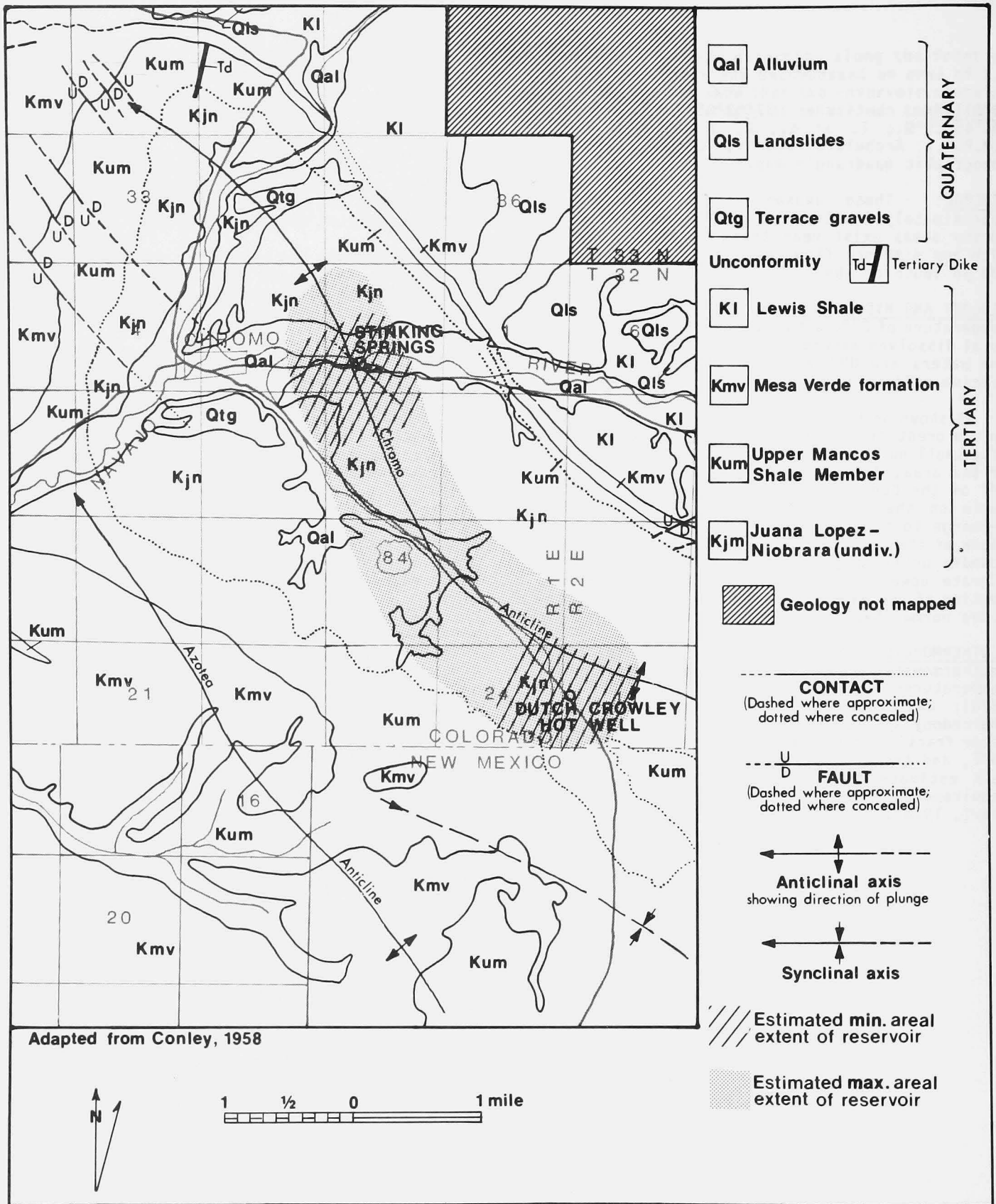


Figure 33.--Map of Stinking Springs and Dutch Crowley Artesian Well region showing geology and estimated areal extent of the geothermal reservoirs.

#39 DUTCH CROWLEY ARTESIAN WELL

LOCATION: Latitude: 37°00'01"N.; Longitude: 106°47'03"W.; T. 32 N., R. 2 E., Sec. 18 bbb, N.M.P.M.; Archuleta County; Chromo 15-minute topographic quadrangle map.

GENERAL: This artesian well, which is an old oil well test hole 1,725 ft deep, is located south of Chromo, Colorado, on the Colorado-New Mexico border. Access is via U.S. 84 south from Pagosa Springs to two miles south of Chromo where a dirt trail leads to the east. Turn left on this trail and proceed approximately 1.3 miles until the trail turns south. The well is 0.2 mile south of this turn and approximately 1,000 ft east of the road. The well is used for irrigation purposes.

GEOLOGY AND HYDROLOGY: The waters that flow from the well with a temperature of 70°C are a sodium bicarbonate type and contain 101 mg/l of dissolved solids.

As shown of Figure 33, the well is located on the lower northeast side of the Chromo Anticline. The bedrock of the area is the Juana Lopez Member of the Mancos Shale, and other than minor faulting mapped less than one mile east of the well, no other major structural features have been mapped in the vicinity.

The general dip of the formations in this part of the San Juan basin is to the southwest off the Continental Divide, which bounds the basin on the east. Due to the depth of the well, 1,725 ft, it is believed that the waters come from the underlying Dakota Sandstone. Recharge occurs along the flanks of the Continental Divide where the waters move down dip to the southwest in an area where the heat flow is between 2.0 and 2.5 H.F.U. (Reiter, 1975).

GEOOTHERMOMETER ANALYSES: Silica solubility and temperature relationships suggest that temperature-dependent equilibration between the thermal water and chalcedony may control the silica content of the artesian well. Therefore, the chalcedony-silica geothermometer yields the most reliable temperature estimate.

The chalcedony-silica geothermometer estimate of subsurface temperature is 63°C (Table 3). Although this estimate is below the surface temperature of the artesian water (70°C), it is

within the margin of error inherent in the geothermometer technique.

Since temperature-dependent equilibration between the thermal water and chalcedony apparently controls the silica content of the artesian well, the chalcedony mixing model is applicable. Mixing model analysis yields a subsurface temperature estimate of 65°C with a cold water fraction of 7 percent of the artesian flow (Table 3).

The mixing model should predict a cold-water fraction of 0 percent because of very little opportunity for shallow ground water percolation into a 1,741 ft deep cased well. In addition, the subsurface temperature estimate should equal or exceed the surface temperature of the artesian water (70°C).

Based on the expected analytical precision, the silica content of this artesian well (41 mg/l) should vary from 36.9 to 45.1 mg/l (Table 3). If the maximum value of silica (45.1 mg/l) is inserted into the mixing model calculation, the results are 70°C and 0 percent. Therefore, the apparent discrepancy between the expected and actual mixing model results is probably due to analytical error in determining the silica content of the thermal water.

The Na-K and Na-K-Ca geothermometers yield questionable results. The Na-K geothermometer estimate of 271°C is too high because one of the basic requirements of the model is violated. The Na-K-Ca geothermometer estimate of 16°C is obviously wrong since it is below the surface temperature of the artesian well. This result may be due to the excessive solution of calcium carbonate by the thermal water during ascent through the anhydrite deposits of the Todilto Limestone.

Conclusion: The rapid flow rate (75 gpm) and the excellent agreement between the mixing model and silica geothermometer suggests that the subsurface temperature is near the surface temperature of the artesian well. Therefore, the temperature at depth in this area is probably between 70°C and 80°C (Table 3).

RESOURCE ASSESSMENT: See Stinking Springs Resource Assessment.

#40 EOFF ARTESIAN WELL

LOCATION: Latitude: 37°11'26"N; Longitude: 106°59'36" W.; T. 34 N., R. 1 W.; Sec. 7 cdc, N.M.P.M.; Archuleta County; Chromo 15-minute topographic quadrangle map.

GENERAL: This unused, 2,998-ft-deep oil-well test hole is located south of Pagosa Springs. Access is via U.S. Highway 84 south from Pagosa Springs for 5.8 miles, then west on a gravel road for 0.5 mile to a farmhouse. The well is 3.5 miles west of the house along Squaw Canyon.

GEOLOGY AND HYDROLOGY: The waters from this well have a temperature of 39°C and an estimated discharge of 50 gpm. The waters were not sampled for complete analysis of contained mineral matter, but the field measurement of the conductance was 2,500 micromohs, with a pH of 7.0

This well is located on the east side of the San Juan Basin. The Colorado portion of the basin is bounded on the north and east by the San Juan Mountains and on the south by the Colorado-New Mexico state line. While the central portion of the basin consists of sedimentary formations dipping into the basin, the San Juan Mountains consist of a complex assemblage of varying volcanic rock types. Very little has been published on the geology of the eastern portion of the San Juan Basin. However, while not directly referring to the geologic history or conditions of the San Juan Basin, Lipman (1975) and Steven and Ratte (1960) have discussed in detail the geologic history, especially the volcanic history, of the southeastern San Juan Mountains.

Because this well is approximately 3,000 ft deep, a surface geologic map would not accurately portray the factors controlling the occurrence of the thermal waters. Therefore, no geologic map was prepared for this area.

The bedrock of the area is the Cretaceous Mancos Shale. Formations underlying the Mancos Shale from which the thermal waters could possibly come are, in descending order: Dakota Sandstone, Burro Canyon Formation and the Morrison Formation. It is believed that these thermal waters just represent circulation of ground waters in either the Burro Canyon or some of the sandstone units in the Morrison Formation in an area having above-normal geothermal gradients. Reiter (1975) has shown this area to have a heat flow of between 2.0 and 2.5 heat flow units.

GEOOTHERMOMETER ANALYSES: Cristobalite-silica geothermometer model yielded a subsurface temperature estimate of 47°C (Barrett and Pearl, 1978). Cristobalite mixing model analysis yields a subsurface temperature estimate of 59°C with a cold water fraction of 38 percent of the total flow. Barrett and Pearl (1978) determined that the Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 221°C and 56°C, respectively. The Na-K geothermometer estimate is too high because the basic requirement of the model is violated (Fournier and Turesdell, 1973). The Na-K-Ca geothermometer estimate is in good agreement with the mixing model results.

Conclusion: The rapid discharge of this well suggests that the temperature at depth is not much higher than the surface temperature of the thermal water (39°C). However, the mixing model and the Na-K-Ca geothermometer suggest a temperature of about 60°C. Therefore, the subsurface temperature in this area is probably between 40°C and 60°C (Table 3).

RESOURCE ASSESSMENT: As noted above, no geologic map was prepared for this area. It was estimated that the reservoir could have an areal extent of approximately 1.5 sq mi and contain .0169 Q's of heat energy (Table 2).

#41 PAGOSA SPRINGS

LOCATION: Latitude: 37°15'52"N.; Longitude: 107°00'37"W.; T. 35 N., R. 2 W.; Sec. 13 cd, N.M.P.M.; Archuleta County; Pagosa Springs 7 1/2-minute topographic quadrangle map.

GENERAL: This group of several springs and wells, collectively known as Pagosa Springs, are located throughout the downtown area of the town by the same name on U.S Highway 160 and 84, in the southwest part of Colorado. The major spring, Big Spring (Fig. 34), is located across from the downtown area on the south bank of the San Juan River by the Spring Inn Motel. This spring is the second largest spring in the State of Colorado.

At the present time at least five producing wells and several abandoned wells are located throughout the downtown area. Thermal waters are used throughout the city for the following: recreational purposes in the swimming pool at the Spa Motel; space heating of the courthouse building, the Spring Inn Motel, the Methodist Church, the Texaco and Standard Oil gas stations west of the courthouse; and for partial space heating of the Rexall Drug store on Main Street, and the Adobe Inn.

GEOLOGY AND HYDROLOGY: Waters from the Big Spring and two wells were sampled and analyzed. Samples were collected from the edge of the Big Spring. This spring had a temperature that ranged throughout the year's time from 54°C to 58°C. The discharge varied from a low of 226 gpm to a high of 265 gpm. Due to the diversion of some of the spring water, it was necessary to measure the discharge at several points and then combine them. The main flow was measured in a ditch approximately 200 ft south of the spring, while other flows were measured down along the river below the motel. The waters contain between 3,040 to 3,310 mg/l of dissolved mineral matter and are a sodium-sulfate type.

Waters from the Spa Motel's 500-ft-deep well, which were sampled at the wellhead, have a temperature of 53°C and contain 3,320 mg/l of dissolved solids. These waters are a sodium-sulfate type.

The Courthouse well, located behind the courthouse, was sampled at the point of outfall from the building. This well has a discharge of 30 gpm, with a temperature of 56°C. The waters contain 3,300 mg/l of dissolved solids and are a sodium-sulfate type.

As shown on Figure 34, the bedrock of the area is the Mancos Shale. Although a major fault lies approximately 1.5 mile southwest of the spring, no obvious controlling structural feature for the occurrence of this spring can be seen. Precipitation of the minerals from the waters has formed a large travertine mound around the Big Spring. The mineral matter found in the thermal waters is derived from the Mancos Shale. Based on

conversations with various well owners, plus interperation of the geologic conditions of the area, it appears that the thermal waters are coming from the Dakota Formation.

GEOTHERMOMETER ANALYSIS: The chalcedony-silica geothermometer yielded an estimated reservoir temperature of 76°C to 81°C (Barrett and Pearl, 1978). The chalcedony mixing model yields a subsurface temperature estimate of 113°C to 134°C with a cold water fraction of 54 to 66 percent of the spring flow.

The seasonal fluctuation of the subsurface temperature estimates suggests that the assumed cold-water analysis and percent-mixing estimates do not adequately represent the hydrological conditions at depth. However, no certain conclusions can be made from these estimates because they are within the range of values that could result from normal analytical error.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 207°C to 211°C and 191°C to 195°C, respectively (Barrett and Pearl, 1978) (Table 3). Extensive travertine deposits occur throughout this area, and the Big Spring currently deposits travertine along the south bank of the San Juan River. The presence of these deposits indicates that the Na-K and the Na-K-Ca geothermometers are too high.

Conclusion: The insignificant variation in surface temperature, mineral content, and geothermometer estimates of these hot springs suggests that they are not substantially affected by seasonal meteorological conditions. The fluctuations of the various geothermometer estimates are well within the range of values that could result from normal analytical error. Consideration of the various geothermometer estimates (Table 3) and the precision of the geothermometers suggests a temperature at depth between 80°C and 150°C (Table 3).

RESOURCE ASSESSMENT: As noted above, Barrett & Pearl (1978) stated that no controlling structural feature for this spring could be seen. During the summer of 1978 the Colorado Geological Survey drilled two wells behind the courthouse across the San Juan River from the spring. The first well was drilled to a depth of 780 ft before the hole was abandoned because of caving. The second well was drilled to a depth of 1,483 ft and bottomed in Precambrian (?) granite and metamorphic rocks.

In both of these wells, hot waters (56°C) were encountered in the Mancos Shale and the Dakota Formation. Below the Dakota aquifer the temperature of the water dropped to 45°C. While all the rock units encountered carried at least some water, the hottest waters were restricted to the Dakota and Mancos Formations. The author believes that the Mancos is really a secondary aquifer and that the primary shallow aquifer in

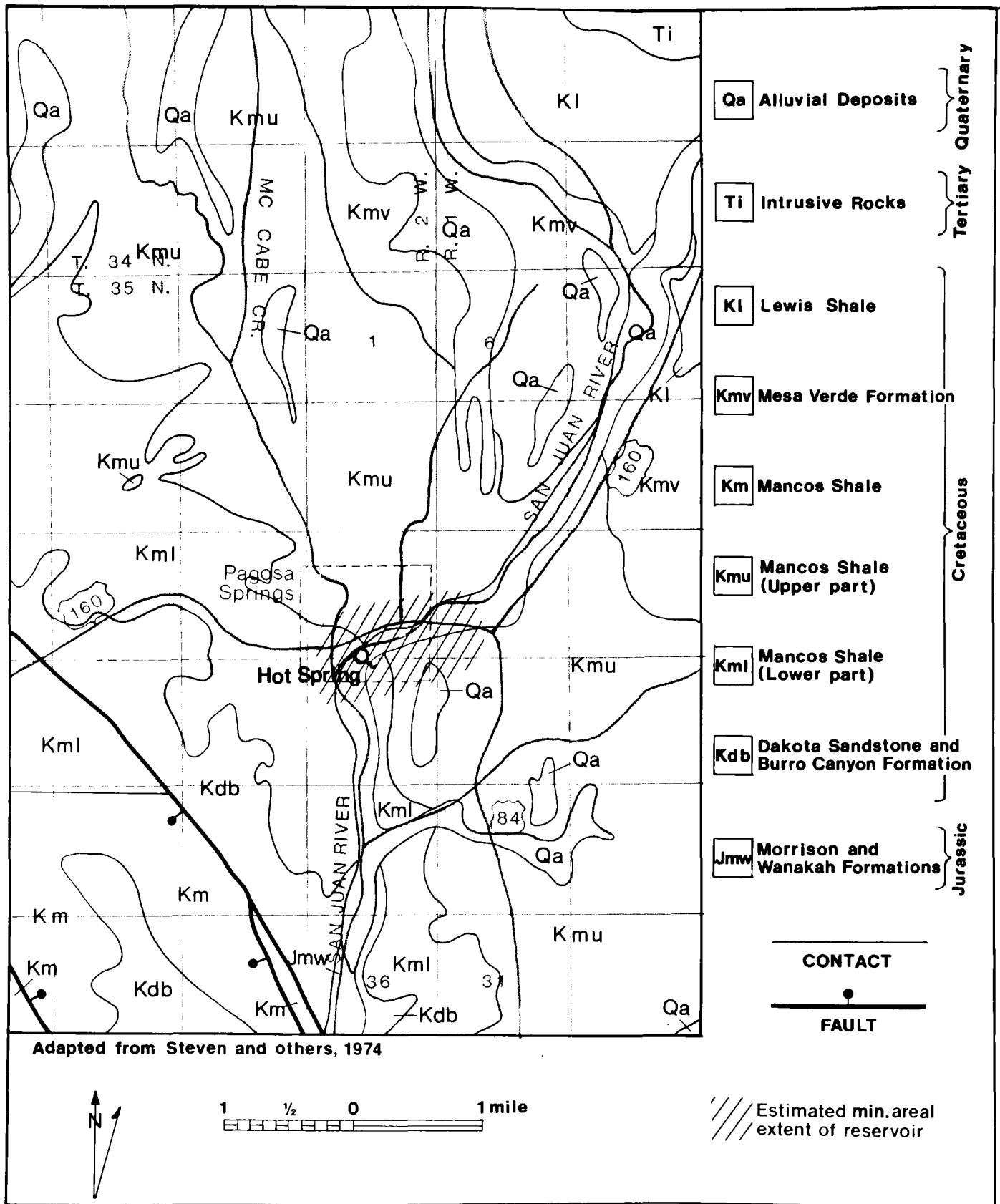


Figure 34.--Pagosa Springs, geology and estimated areal extent of the geothermal reservoir.

this area is the Dakota Formation. All the units encountered were highly fractured but did not appear to be faulted. Therefore, it is postulated that the waters are moving up from depths along fracture zones and into the Dakota Formation. For a complete description of the Pagosa Springs project the reader is referred to Galloway, 1979

For resource assessment purposes it was assumed that the Dakota reservoir has an areal extent of 1.0 sq mi and contains .0226 Q's of energy (Table 2). It is possible that the primary reservoir is fractured Precambrian age rocks. As the size of this reservoir is not known at the present no estimate of its heat content were here made.

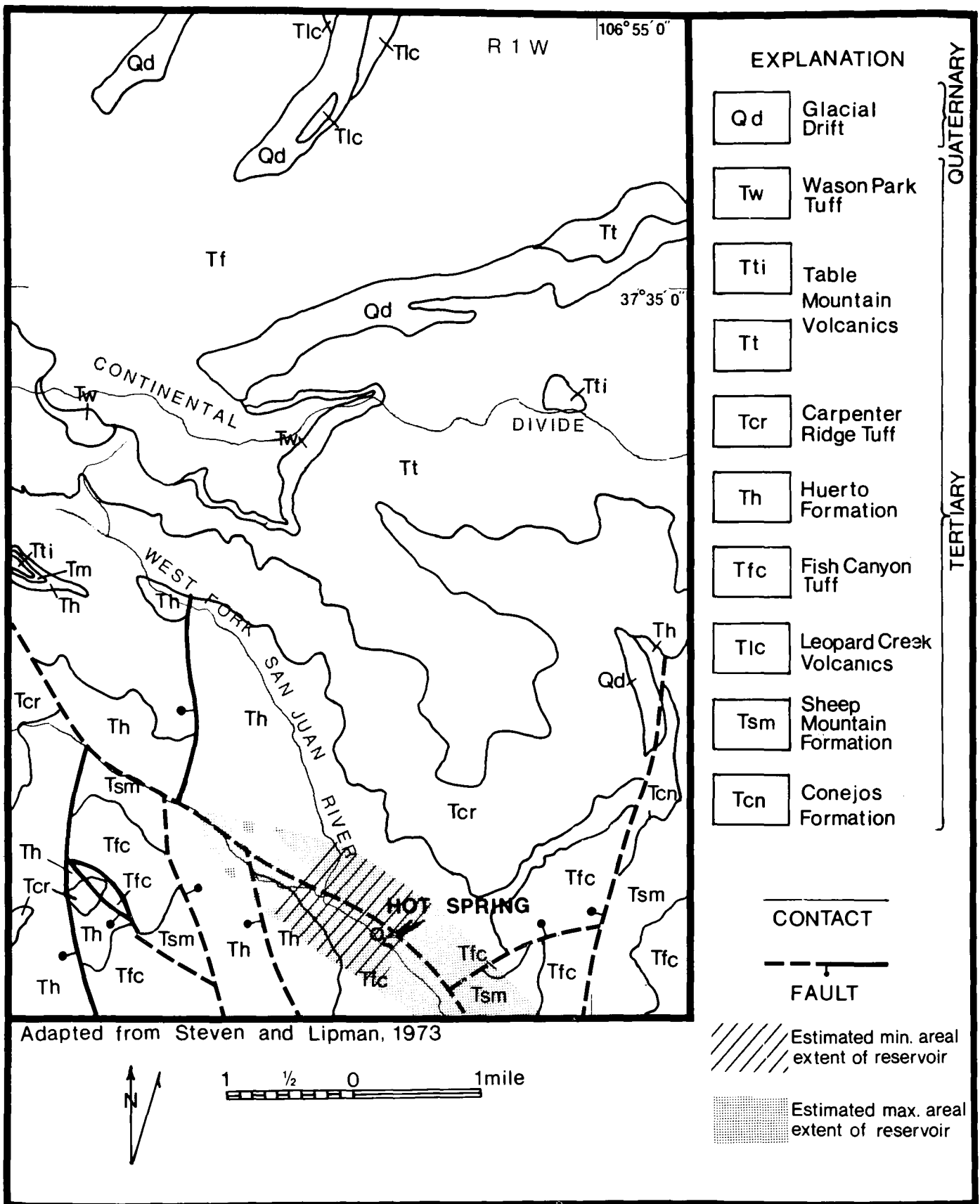


Figure 35.--Rainbow Hot Springs, geology and estimated areal extent of the geothermal reservoir.

#42 RAINBOW HOT SPRING

LOCATION: Latitude: 37°30'34"N.; Longitude: 106°56'52"W.; T. 38 N., R. 1 W., Sec. 9, N.M.P.M.; Mineral County; Spar City 15-minute topographic quadrangle map.

GENERAL: This unused spring is reached by walking approximately 6 miles up the West Fork of the San Juan River. Access is via a dirt road at the base of Wolf Creek Pass that turns from U.S. 160 to the West Fork Campground. Continue past the campground to the end of the road at the Borns Lake cabin area. Near this cabin area a marked foot trail leads to the spring.

GEOLOGY AND HYDROLOGY: When sampled in September, 1975, the spring had a temperature of 40°C, a discharge of 45 gpm, contained 161 mg/l of dissolved mineral matter, and was a sodium-bicarbonate type.

As mapped by Steven and Lipman (1973) (Fig. 35), the thermal waters emerge along a southeast-trending normal fault that closely follows the valley of Cimarron Creek and the West Fork of the San Juan River. It is believed that recharge to the spring is via deep circulation along fault zones in an area of above-normal geothermal gradients that are probably related to the Oligocene volcanic activity that occurred in this region.

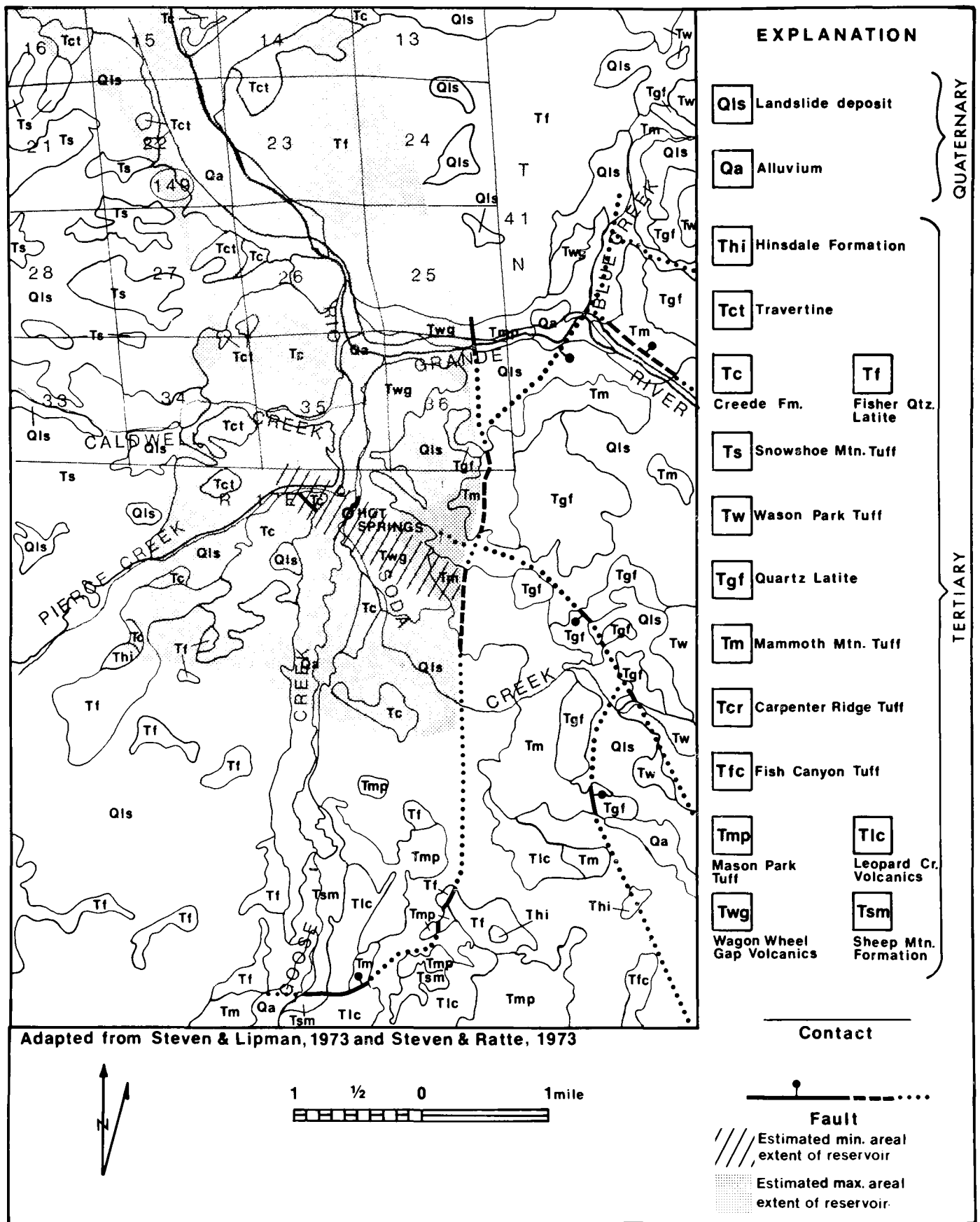
GEOOTHERMOMETER ANALYSES: The cristobalite-silica geothermometer yielded an estimated subsurface temperature of 41°C, which is very close to the surface temperature of the hot spring (40°C) (Barrett and Pearl, 1978). Cristobalite mixing model analysis yielded a subsurface temperature estimate of 41°C with no shallow, cold ground water contained within the hot spring flow (Table 3). According to Barrett and Pearl (1978), the Na-K and

Na-K-Ca geothermometers yield subsurface temperature estimates of 68°C and 22°C, respectively (Table 3). The Na-K geothermometer estimate is too high because the basic assumption of the model was violated (Fournier and Truesdell, 1973). The Na-K-Ca geothermometer estimate is obviously incorrect because it is below the surface temperature of the hot spring. This low estimate may be due to temperature-dependent equilibration between the ascending thermal fluid and the potassium-deficient Fish Canyon Tuff, a quartz-laticite ash flow tuff.

Conclusion: The rapid flow rate and close agreement between the silica geothermometer and mixing model results suggest that the subsurface temperature is not much higher than the surface temperature in this area. Therefore, the subsurface temperature in this area is probably between 40°C and 50°C (Table 3).

RESOURCE ASSESSMENT: The occurrence of this spring is associated with the major faults in the area (Fig. 35). In assessing the extent of the reservoir, two estimates of its extent were made. As shown on Figure 35, the smaller area extending mainly to the west of the spring encompasses an area of approximately 1 sq mi. The other area is much larger, 2.0 sq mi, and extends along the fault zone from a point approximately 1.75 miles west of the spring to a point southeast of the spring. This area also encompasses the intersection of another major fault with the fault Rainbow Springs is located on.

It is estimated that this fault controlled reservoir contains between .0470 Q's and .0940 Q's of heat energy, at an average maximum temperature of 45°C (Table 2).



#43 WAGON WHEEL GAP HOT SPRINGS

LOCATION: Latitude: 37°41'06"N.; Longitude: 106°49'47"W.; T. 41 N., R. 1 E.; Sec. 35 dd, N.M.P.M.; Mineral County; Spar City 7 1/2-minute topographic quadrangle map.

GENERAL: This group of two springs is located approximately 10 miles southeast of Creede. Access is via a dirt road from State Highway 149 approximately 0.5 mile west of the community of Wagon Wheel Gap and along the west side of Goose Creek.

Although these two springs are named for the community of Wagon Wheel Gap, they actually lie over 1 mile south of town along both sides of Goose Creek. One spring, the 4UR, is located on the 4UR Ranch, which is called the Wagon Wheel Gap Ranch on the topographic map. The other spring, here named the CFI Spring, is located on the east bank of Goose Creek approximately 200 yd south of the 4UR Spring. This unused spring is just south of the CFI Mine.

The spring on the 4UR Ranch is located at the south end of the compound and west-southwest of the old bathroom building. The spring emerges into a large concrete-lined pool. Several springs flow into the pool, although the exact number is indeterminable. Since all of these springs are mixed, it was not possible to sample them individually. The waters are used in a new outdoor swimming pool and in a sauna bath.

GEOLOGY AND HYDROLOGY:

4UR Spring: The temperature of the spring varied from 55°C to 57°C throughout the year. The discharge of the spring was an estimated 30 gpm. The total dissolved mineral matter in the water also varied from 1,550 mg/l to 1,620 mg/l. The water is a sodium-bicarbonate type.

CFI Spring: The temperature of the spring varied from 48°C to 51°C throughout the year. The discharge also varied from a low of 48 gpm to 51 gpm. The dissolved elemental mineral matter varied throughout the years time from 1,470 mg/l to 1,540 mg/l. The waters are a sodium-bicarbonate type.

The Wagon Wheel Gap Hot Springs are located on the southeast side of the central part of the Creede Caldera in the San Juan volcanic field. The geology of the Creede Caldera has been discussed in detail by Steven and Ratte (1973), Steven and Lipman (1973), and others. The authors have shown that this area was the center of extensive volcanic activity in Oligocene time and has had a long and varied geologic history.

Barrett and Pearl (1978) made no attempt to describe the hydrogeological conditions of the area in detail. They believed that the springs are recharged in the immediate vicinity where the waters move down through fault zones. The waters may be stored in some of the more permeable intervolcanic beds.

At one time the Creede Caldera may have been quite thermally active. Steven and Ratte (1973) mapped extensive travertine deposits extending from the 4UR Spring northward to the Rio Grande River, west up the river to the vicinity of Creede, then southwest to the edge of the Creede quadrangle (Fig. 36). None of these deposits were mapped in the Spar City quadrangle; however, it is believed that from the nature of their occurrence in the Creede quadrangle that they may also extend into the Spar City quadrangle. Steven (1969b) described these deposits to be of cold-water origin. White (1967) on the other hand believes that they were formed by thermal waters.

As shown on the accompanying geologic map (Fig. 36), the waters of both springs emerge through alluvial deposits overlying the Creede Formation which consists of stream, lake, and pyroclastic deposits (Steven and Lipman, 1973). As shown on the geologic map, no faults were mapped in the vicinity of the CFI spring; however, one of the few faults in the area lies within a few hundred yards of the 4UR spring.

GEOOTHERMOMETER ANALYSES: Emmons and Larson (1913) reported siliceous sinter and opaline silica east of the hot springs (Barrett and Pearl, 1978). If silica deposition still occurs at depth, then both the silica geothermometers and mixing model results are too low. The opaline silica suggests subsurface temperatures below 100°C. However, the extensive fluorspar deposits indicate temperatures at depth between 119°C and 168°C. If deposition of these minerals still occurs, then the subsurface temperature is probably between 100°C and 168°C. At any rate, the geochemistry of these springs is too complex for a reliable subsurface temperature estimate.

As the silica content of these springs does not approach the solubility of amorphous silica, chalcedony, cristobalite, or quartz, the application of the silica geothermometers will yield questionable results. However, the amorphous silica geothermometer yields a maximum subsurface temperature estimate of 12°C, which is well below the surface temperature of the warm springs (48°C to 51°C). The cristobalite-silica geothermometer subsurface temperature estimate is 66°C to 81°C (Table 3). However, this estimate is probably too high because the theoretical cristobalite solubility (50 mg/l) at the spring's surface temperature is well below the silica content of the thermal water (67 mg/l to 90 mg/l) (Barrett and Pearl, 1978).

According to Barrett and Pearl (1978), Amorphous Mixing Model yielded a subsurface temperature estimate of 43°C with a cold-water fraction of 40 percent. This temperature estimate is also below the surface temperature of the spring, suggesting that amorphous silica probably does not control the silica content of the thermal water.

The cristobalite mixing model yields a subsurface temperature estimate that ranges from 99°C to 157°C with a cold-water fraction of 56 percent to 76 percent of the spring flow. For the same reason given above, the estimates are probably too high (Barrett and Pearl, 1978).

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 200°C to 206°C and 181°C to 194°C, respectively. Although none of the springs deposit calcium carbonate, considerable calcium carbonate occurs in association with nearby fluorspar and barite deposits. If deposition occurs at depth, then both the Na-K and Na-K-Ca geothermometer estimates are too high.

RESOURCE ASSESSMENT: In assessing the possible extent of this thermal system, consideration was given to the fact that it occurs within the Creede Caldera and that there are extensive travertine deposits in the area. Even though some doubt exists regarding the origin of these travertine deposits (see Barrett and Pearl, 1978), the boundaries of the area were drawn to include them (Fig. 36).

In trying to assess this area, it was recognized that this thermal system could be very narrowly restricted to a small area around the springs. Therefore, two estimates were made. One estimate restricted the reservoir to an area running from the possible major fault to the east to just west of the small fault west of the spring. Alternatively, it was postulated that this small fault might extend to the southeast and intersect the major fault. If this fault did, it then could be the conduit along which the waters are moving up from depth. The area could encompass approximately .7 sq mi and contain .0625 Q's of heat energy at an average maximum temperature of 115°C (Table 2).

The other area is by necessity much larger (Fig. 36) and includes all the travertine deposits in the area. It is believed that until proven otherwise, this area should be considered to contain a geothermal resource. This area as drawn encompasses some 16.0 sq mi and could contain 1.4285 Q's of heat energy at an average temperature of 115°C (Table 2).

ANTELOPE AND BIRDSIE WARM SPRINGS

Located in the upper reaches of the Rio Grande River Valley west of Creede, Colorado, are two

small springs whose characteristics and mode of occurrence are nearly identical.

#44 ANTELOPE WARM SPRING

LOCATION: Latitude: 37°44'36"N.; Longitude: 107°02'14"W.; T. 40 N., R. 2 W., Sec. 1 dd, N.M.P.M.; Mineral County; Workman 7 1/2-minute topographic quadrangle map.

GENERAL: Antelope warm spring is located behind a large log building approximately 1 mile north of Colorado 149 and approximately 12 miles west of

Creede, Colorado. This unused spring is at the base of a small concrete-lined cistern.

HYDROLOGY: The spring has a discharge estimated to be 3 gpm with a temperature of 32°C. The total dissolved mineral matter in the waters is 150 mg/l, and the waters are a sodium-bicarbonate type.

#45 BIRDSIE WARM SPRING

LOCATION: Latitude: 37°43'42"N.; Longitude: 107°00'44"W.; T. 40 N., R. 2 W., Sec. 14 abc, N.M.P.M.; Mineral County; Workman 7 1/2-minute topographic quadrangle map.

GENERAL: This unused spring is located along

Colorado 149 approximately 14 miles west of Creede, Colorado.

HYDROLOGY: The discharge of this spring was measured at 15 gpm with a temperature of 30°C. The waters had a conductance of 200 micromhos and a pH of 8.6.

GEOLOGY OF ANTELOPE AND BIRDSIE WARM SPRINGS: These springs are located on the west side of the Creede Caldera, an area of extensive middle Tertiary volcanic activity. The geology of the area has been described in detail by Steven and Ratte (1973).

The geologic map (Fig. 37), based in part on Steven and Ratte (1973), shows that Antelope Spring emerges from glacial drift which overlies volcanic rocks. Birdsie Warm Spring emerges from Tertiary volcanic rocks. These springs do not appear to be fault controlled, for few faults are mapped the vicinity of the springs (Fig. 37). No attempt was made during this investigation to accurately determine the hydrogeological conditions surrounding these springs. However, the spring may originate from southward down-gradient flow of groundwaters through permeable intravolcanic zones that dip into the center of the caldera, an area with above-normal heat flow. Reiter (1975) has shown the upper Rio Grande River valley to have a heat flow in excess of 2.5 heat flow units.

GEOOTHERMOMETER ANALYSES OF ANTELOPE AND BIRDSIE SPRINGS: Analysis suggests that cristobalite controls the silica content of the warm springs. The cristobalite-silica geothermometer yields a subsurface temperature estimate of 43°C for Antelope Warm Spring and 52°C for Birdsie Warm Spring (Table 3).

Since temperature-dependent equilibration between the thermal water and cristobalite

apparently controls the silica content of the warm springs, the Cristobalite Mixing Model is applicable (Barrett and Pearl, 1978). Mixing Model analysis of Antelope Warm Spring yields a subsurface temperature estimate of 55°C with a cold water fraction of 44 percent of the spring flow. The Mixing Model estimate for Birdsie Warm Spring is 91°C with a cold-water fraction of 70 percent. These estimates are within the range of values that could result from normal analytical error.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 83°C to 102°C and 35°C to 36°C, respectively (Table 3). The Na-K geothermometer estimate is too high as the basic assumption of the model is violated (Fournier and Truesdell, 1973).

Conclusion: Most geothermometer techniques are not reliable when applied to Antelope and Birdsie Warm Springs because many of the assumptions inherent in their use are violated. The close agreement between the Cristobalite-Silica and the Na-K-Ca geothermometers suggests subsurface temperatures between 35°C to 52°C (Table 3).

RESOURCE ASSESSMENT: As noted earlier, the reasons for the occurrence of these springs is imperfectly understood. They may occur due to the flow of hot waters through permeable inter volcanic zones or they might be associated with unmapped fault zones. Steven (1967) has shown that faulting may exist a few miles north of each springs (Fig. 37). These faults could be extended southward into the

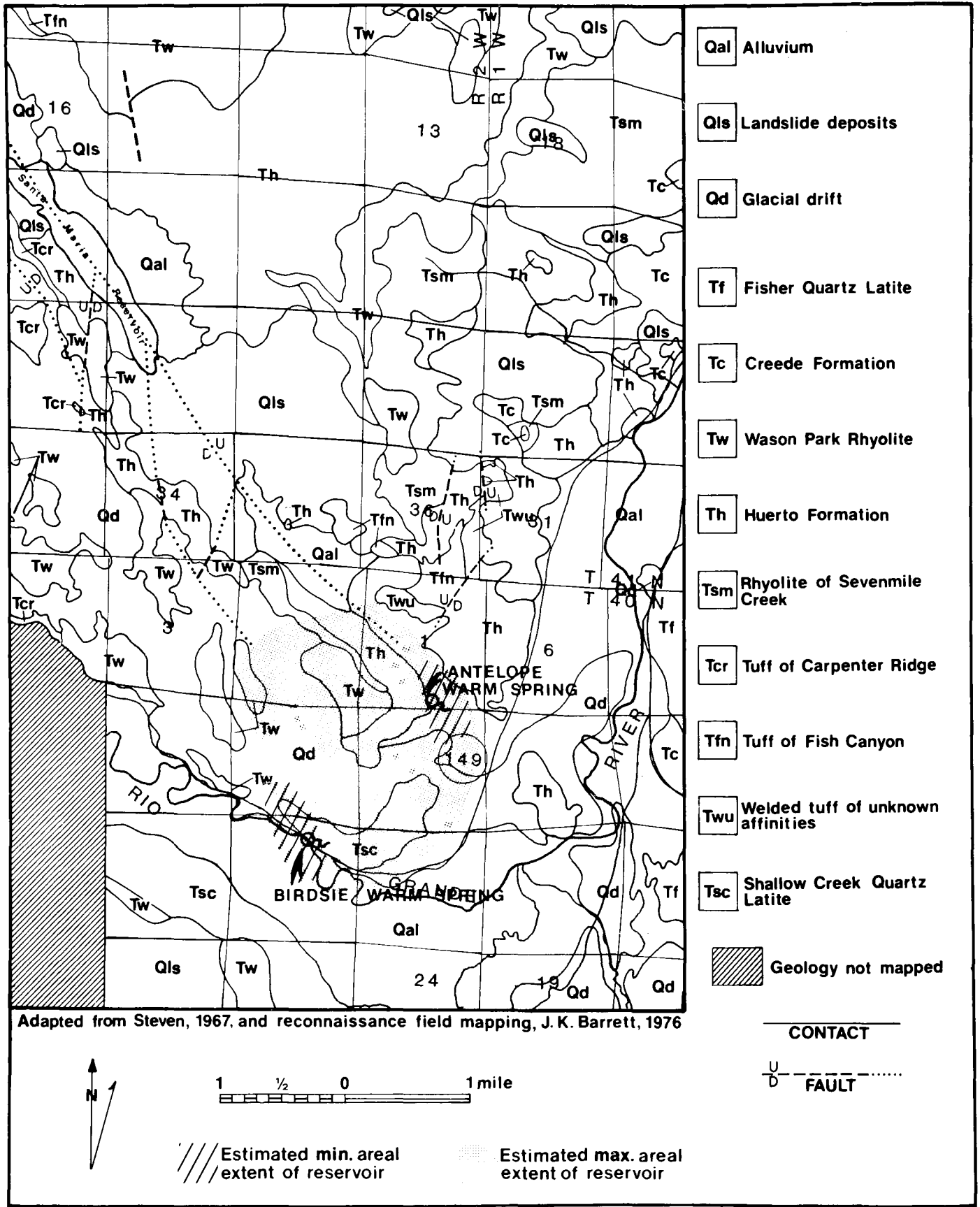


Figure 37.--Map of Antelope and Birdsie Warm Springs region showing geology and estimated areal extent of the geothermal reservoir.

vicinity of the springs with very little difficulty. If this is the case then the springs are partly fault controlled.

In assessing the extent of these systems, the above parameters were taken into consideration. In the conservative case, it was felt that the reservoirs were restricted to a small area around each spring. In this estimate, the combined extent of the reservoirs encompassed an area of .50 sq mi

and contained .0113 Q's of energy at a temperature of 44°C.

For the other estimate it was assumed that both springs were part of one large system (Fig. 37) that contained part of the postulated faults. This area was estimated to contain approximately 3.90 sq mi and contain .0880 Q's of energy (Table 2). The extent of this system is difficult to estimate, for it could be restricted to a small area around each spring or it could encompass a much larger area.

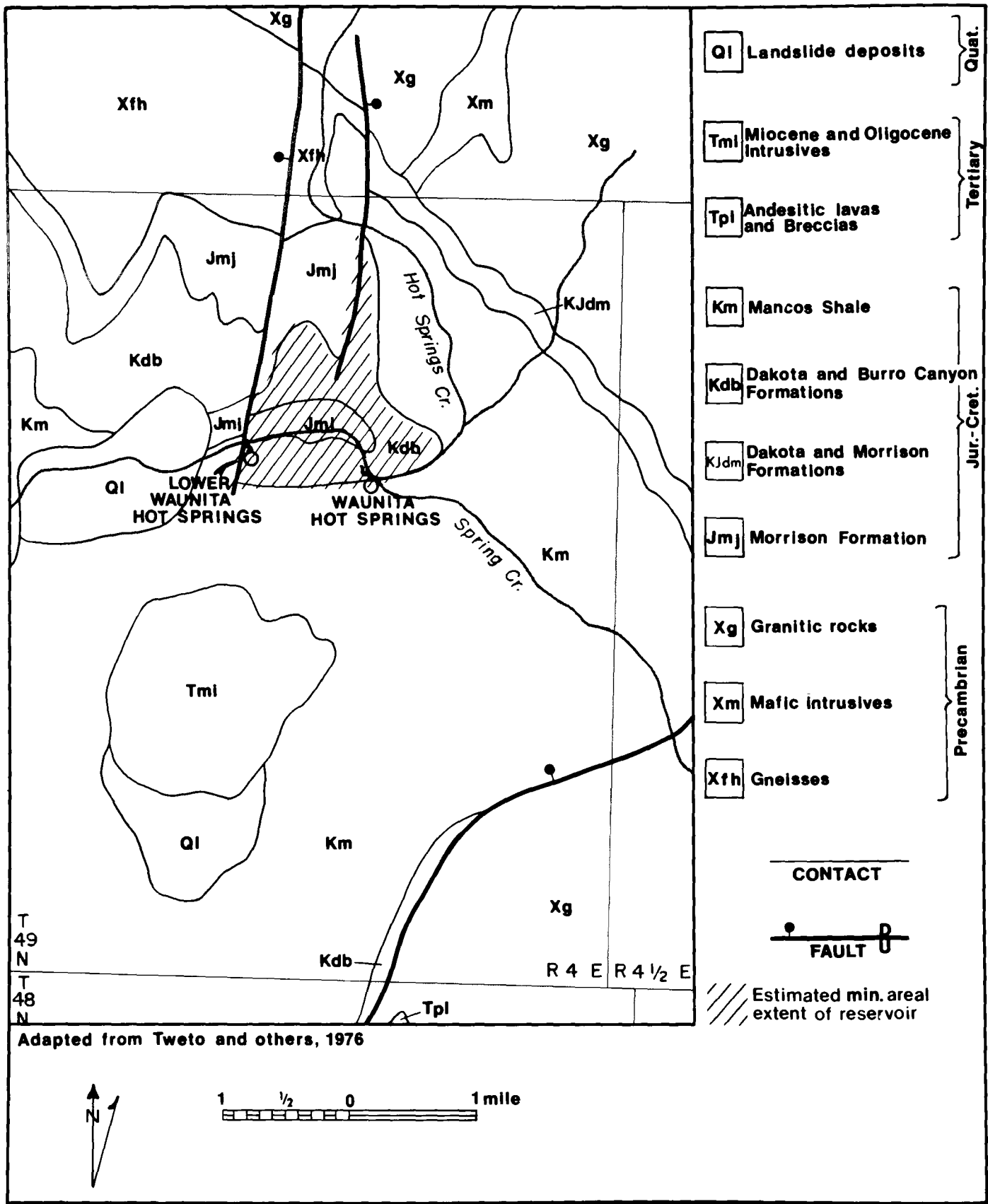


Figure 38.--Map showing estimated areal extent of the Waunita Hot Springs geothermal reservoir and surrounding geologic conditions.

#46 UPPER AND LOWER WAUNITA HOT SPRINGS

#46 UPPER WAUNITA HOT SPRINGS

LOCATION: Latitude: 38°30'50"N.; Longitude: 106°30'27"W.; T. 49 N., R. 4 E., Sec. 11 cc, N.M.P.M.; Gunnison County; Pitkin 7 1/2-minute topographic quadrangle map.

GENERAL: This group of four springs is reached by traveling east from Gunnison, Colorado, on U.S. Highway 50 for 19 miles, and north on a well marked county road for approximately 8 miles. The springs are located on the southeast side of the ranch headquarters building. Waters from the springs are used for swimming, drinking, and heating the headquarters building. All the springs are located in front of the ranch headquarters building along Hot Springs Creek.

Spring A, the hottest spring, is located in a gazebo-like structure. This spring is extensively developed with the waters being pumped to the buildings. It was not possible to obtain a sample of the waters for analysis because an iron grill prohibited access.

Spring B is located approximately 75 ft south of A on the same side of the creek. The discharge

of this spring was not large and it was not possible to measure it.

Spring C and D are located on the opposite side of Hot Springs Creek from Springs A and B. Spring C, the largest spring, is located south of the old swimming pool. Spring D flows into the old swimming pool, and due to severe leaking, a discharge measurement could not be obtained. A sample of the water was obtained from the east end of the pool.

GEOLOGY AND HYDROLOGY:

Spring A: Temperature: 76°C; Discharge: not determined; Conductance: 750 micromhos.

Spring B: Temperature: 78°C; Discharge: not determined; Conductance: 720 micromhos.

Spring C: Temperature: 77 to 80°C; Discharge varied throughout the year, measured from 30 gpm to 55 gpm. The total dissolved solids during the period varied from 557 mg/l to 613 mg/l; the water is a sodium-sulfate type.

#46 LOWER WAUNITA HOT SPRINGS

LOCATION: Latitude: 38°31'00"N.; Longitude: 106°30'55"W.; T. 49 N., R. 4 E., Sec. 10 bc, N.M.P.M.; Gunnison County; Pitkin 7 1/2-minute topographic quadrangle map.

GENERAL: This large group of unused springs is located approximately 0.5 mile to the west down Hot Springs Creek from the Waunita Hot Springs resort. Access is along a dirt trail from the Waunita Hot Springs resort buildings.

The Lower Waunita Hot Springs consists of three separate groups of springs extending over several hundred yd in length. The major spring in each group was selected for measurements.

The northern group (Group A) was named Spring A, the biggest spring on the east side of the group. Group B contains a cistern-like structure and several seeps. Springs in Group C emerge from the old abandoned rock buildings at the south end

of the area. Spring C emerges from beneath the old steambath building. Group D is located around the old gazebo along the creek. Spring D is the spring in the gazebo.

HYDROLOGY:

Spring A: Temperature: 75°C; Discharge: estimated at 75 gpm; Conductance: 765 micromhos.

Spring B: Temperature: 70°C; Discharge: estimated at 20 gpm; Total Dissolved Solids: Varied from 528 mg/l to 544 mg/l; Water Type: sodium sulfate-bicarbonate.

Spring C: Temperature: 70°C; Discharge: 8 gpm; Conductance: 780 micromhos.

Spring D: Temperature: 62°C; Discharge: not determined; Total Dissolved Solids: 535 mg/l; Water Type: sodium sulfate-bicarbonate.

GEOLOGY OF UPPER AND LOWER WAUNITA HOT SPRINGS: The Waunita Hot Springs are located on the north side of the Tomichi Dome, a Tertiary intrusive that has arched the overlying Mancos Shale. Very little has been written on the geology of this part of Colorado. The one article describing the geology

of the area (Stark and Behre, 1936) describes the Tomichi Dome.

The accompanying geologic map (Fig. 38), taken from Tweto and others (1976), shows that the upper springs are situated on the contact between the

Dakota Sandstone and the overlying Mancos Shale. The lower springs are located along a fault zone. It is believed that the upper spring waters migrate up from depth along the contact between the Dakota and Mancos.

GEOOTHERMOMETER ANALYSES OF UPPER AND LOWER WAUNITA HOT SPRINGS: The quartz-silica geothermometer estimate of the subsurface temperature is 143°C to 157°C for Waunita Hot Springs and 123°C to 130°C for Lower Waunita Hot Springs (Table 3) (Barrett and Pearl, 1978). Mixing model analysis yields a subsurface temperature estimate of 209°C to 291°C with a cold-water fraction of 64 to 83 percent for Waunita Hot Springs and a subsurface temperature estimate of 181°C to 208°C with a cold water fraction of 64 to 73 percent for Lower Waunita Hot Springs (Table 3).

According to Barrett and Pearl (1978), Waunita Hot Spring D and Lower Waunita Hot Spring D are the least suitable springs for mixing model analysis, but yield the highest subsurface temperature estimates of the group (291°C and 208°C, respectively). Waunita Hot Spring D was sampled from a large, quiescent pool. Lower Waunita Hot Spring D appears to be partially flooded by a nearby stream. Excluding these two springs, the subsurface temperature estimates range from 209°C to 247°C for Waunita Hot Springs and 181°C to 197°C for Lower Waunita Hot Springs.

The seasonal fluctuation of the subsurface temperature estimates suggests that the assumed cold water analysis and the percent-mixing

estimates do not adequately represent the hydrological condition at depth. However, no certain conclusions can be made from these estimates because they are within the range of values that could result from normal analytical error.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 174°C to 179°C and 159°C to 167°C, respectively, for both hot springs groups. The high surface temperature (70°C to 80°C), flow (100 to 200 gpm), and close agreement with the mixing model results suggest that the Na-K and Na-K-Ca geothermometer models provide reasonable estimates for this area.

Conclusion: The close agreement between the Mixing model and the Na-K-Ca model estimates suggests that these geothermometers adequately reflect the temperature at depth. Therefore, consideration of these results and the precision of the geothermometers suggests temperatures at depth between 175°C and 225°C (Table 3).

RESOURCE ASSESSMENT: In estimating the size of this reservoir, the geologic conditions of the area were taken into consideration. It was noted that the springs are either associated with the Dakota Formation or faults. Therefore, the boundaries of the area were drawn along the contacts of the Dakota Formation and parts of the fault zones (Fig. 38). As drawn, the areal extent of the system encompasses some 1.4 sq mi and contains approximately .0606 Q's of heat energy having an average maximum temperature of 135°C (Table 2).

#47 CEBOLLA HOT SPRINGS

(FORMERLY KNOWN AS POWDERHORN HOT SPRINGS)

LOCATION: Latitude: 30°16'26"N.; Longitude: 107°05'54"W.; T. 46 N., R. 2W., Sec 4 ab, N.M.P.M.; Gunnison County; Powderhorn 7 1/2-minute topographic quadrangle map.

GENERAL: This group of three fairly large springs is located approximately 30 miles southwest of Gunnison, Colorado, just off Highway 149 along Cebolla Creek. At one time these springs were extensively developed and used, but today all the old buildings and the swimming pool are gone and all that remains are two small wooden buildings.

The springs are used today for bathing purposes. Two springs emerge into a large cistern-like structure in the southernmost building and the other spring is located in the large building approximately 75 ft to the northwest.

GEOLOGY AND HYDROLOGY: Due to modifications of the area around the springs, it was not possible to accurately measure the discharge. However, a fairly reliable discharge of 3 gpm was obtained for one of the two springs in the southern building. All three springs have a temperature of 38°C to 40°C (depending on time of year when measured) with total dissolved mineral matter of 1,450 mg/l. The waters are a sodium-bicarbonate type.

As mapped by Hedlund and Olson (1975) (Fig. 39), these springs are located 300 ft from the southeast trending Cimarron Fault. The bedrock of the area consists of complex assemblages of Precambrian metamorphic rocks, Cambrian and Ordovician intrusives, and Oligocene volcanic-derived rocks. It appears that that thermal activity in the geologic past was very extensive in this area, for indicators of such activity have been mapped by Hedlund and Olson (1975) along the Cimarron Fault west of the Cebolla Hot Springs.

As the Precambrian rock types are not good aquifers, the springs probably originate from deep circulation along the Cimarron Fault system in an area of elevated geothermal gradients. Reiter (1975) has determined that the Cebolla Hot Springs area has a heat flow of just over 2.5 heat flow units.

GEOOTHERMOMETER ANALYSIS: Geothermometer models must be used with caution when applied to Cebolla Hot Springs since most of the assumptions inherent in their use are violated. Moreover, samples of the thermal water had to be taken from large, quiescent pools. Such sampling conditions may exaggerate the effects of the surface conditions on the thermal water, allowing evaporative

concentration of the silica content and other reequilibration reactions to occur.

Analysis of silica solubility and temperature relationships suggest that cristobalite may control the silica content of the hot springs. Therefore, the cristobalite-silica geothermometer was used to determine the most reliable subsurface temperature estimate (Barrett and Pearl, 1978).

The cristobalite-silica geothermometer estimate of subsurface temperature is 65°C to 82°C. This estimate is probably too high because the theoretical cristobalite-induced silica solubility (39 mg/l) at the surface temperature of the springs (38°C to 41°C) is well below the silica content of the springs (77 to 92 mg/l).

Cristobalite mixing model analysis yields subsurface temperature estimates of 105°C to 185°C with a cold water fraction of 66 to 83 percent of the spring flow (Table 3).

Cristobalite mixing model estimated temperatures based on the January and April, 1976 samples range from 163° to 185°C with a cold-water fraction of 80 to 83 percent of the spring flow (Table 3). normal analytical error.

The Na-K and Na-K-Ca geothermometers estimates of 238°C to 278°C and 209°C to 220°C, respectively. Travertine deposits mapped in sections 33 and 34, T. 47 N., R. 2 W. and sections 2, 3, 11, 12, T. 46 N., R. 2 W. by Hedlund and Olson (1975) (not shown on Fig. 39) suggest that both the Na-K and the Na-K-Ca geothermometer estimates are too high. In addition, the geothermometers may yield erroneous results when applied to the high magnesium waters of these springs.

Conclusion: The geochemistry of these waters is too complex for an accurate estimation of the temperature at depth.

RESOURCE ASSESSMENT: Barrett & Pearl (1978) stated that they believed the occurrence of these thermal waters is due to deep circulation of waters along the Cimarron Fault. Hedlund and Olson (1975) mapped extensive sinter and travertine deposits northwest of the spring along Cebolla Creek.

As no clear cut controlling feature is available, reservoir boundaries were drawn (Fig. 39) to include many of the sinter and travertine deposits of Hedlund & Olson (1975). The area is estimated to be 1.28 sq mi in extent and contain approximately .0481 Q's of heat energy (Table 2).

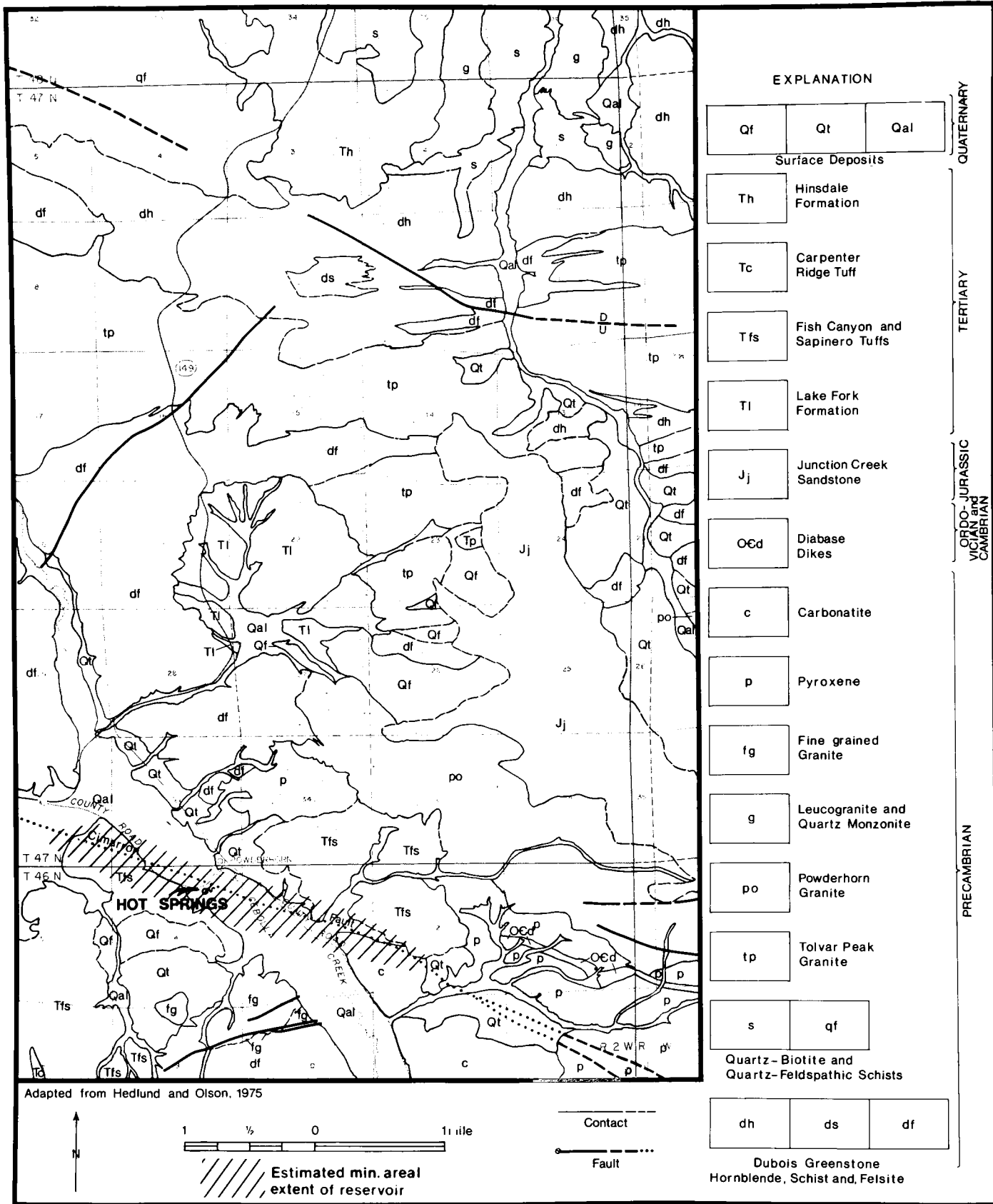


Figure 39.--Geology surrounding Cebolla Hot Springs and estimated areal extent of the geothermal reservoir.

#48 ORVIS HOT SPRING

LOCATION: Latitude: 38°07'59"N.; Longitude 107°44'01"W.; T. 45 N., R. 8 W., Sec. 22 cd, N.M.P.M.; Ouray County; Dallas 7 1/2-minute topographic quadrangle map.

GENERAL: This spring is located on the west side of U.S. Highway 550 approximately 9 miles north of Ouray. Waters from the spring are diverted and piped approximately 200 yd to the north to a building for use in hydrotherapy.

GEOLOGY AND HYDROLOGY: No water issues from the spring today due to the waters being diverted to the nearby buildings. The spring has a temperature of 52°C and contains approximately 2,300 mg/l of dissolved mineral matter. The waters are a sodium sulfate type with a high concentration of iron.

Although the waters ascend through the alluvial and colluvial deposits of the valley floor, they are associated with the underlying red beds of the Morrison Formation. While geologic mapping (Fig. 40) does not show any possible origin for this spring, it is believed that the waters must move up fracture systems related to the San Juan and La Plata Mountains to the south, for geologic mapping to the west on Dallas Divide (Bush and others, 1956) has shown an extensive network of faults and folds. It is believed that water ascends some fractures that must be present in the vicinity of Orvis Hot Springs. Recharge to this system probably occurs to the south along the flanks of the San Juan Mountains. Reiter (1975) has shown Ouray to be an area of high heat flow (greater than 2.5), and presumably the origin of the heat for the Orvis Hot Springs is related to this high heat flow.

GEOOTHERMOMETER ANALYSES: Barrett and Pearl (1978) calculated the following subsurface temperatures: 75°C to 82°C with chalcedony silica geothermometer, 99°C to 127°C with a cold water fraction of 54 to 66 percent with the chalcedony mixing model, 179°C to 187°C with the Na-K geothermometer, which is definitely too high because the conditions of the model has been violated, and 93°C to 97°C with the Na-K-Ca geothermometer model. Extensive travertine deposits, calcium carbonate-cemented gravels, and calcium-depositing seeps near the hot spring suggest that both the Na-K and Na-K-Ca geothermometer estimates are too high.

Conclusion: Geothermometer models must be used with caution when applied to Orvis Hot Spring since most of the assumptions inherent in their use are violated. Samples of the thermal water had to be taken from a large, quiescent pool. Such sampling conditions may exaggerate the effects of the surface conditions on the thermal water, allowing evaporative concentration of the silica content and other re-equilibration reactions to occur.

RESOURCE ASSESSMENT: In order to make sure that the full possible extent of the system would be included, two estimates of the systems extent were made. The smaller estimate restricted the reservoir to an area of .55 sq mi around the spring. The other area was estimated to be much larger, 2.53 sq mi. Since no real geologic reasoning was used in selecting these two extents other than it was felt that these areas would encompass much of the Morrison Formation, the supposed reservoir.

Calculations show that the energy contained in this system ranges from 0.0284 Q's to 0.1308 Q's at an average maximum temperature of 75°C (Table 2).

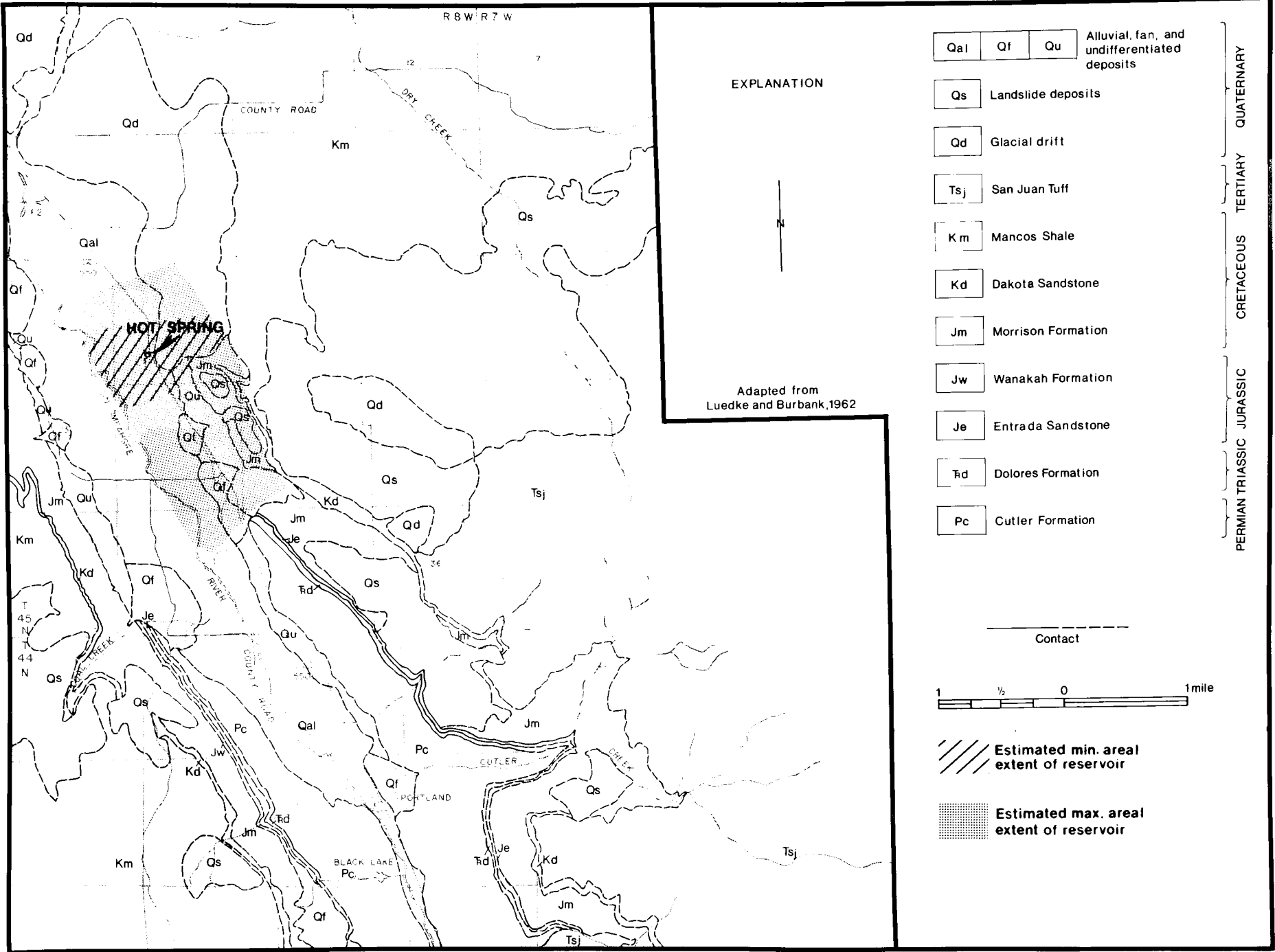


Figure 40.--Orvis Hot Spring, geology and estimated areal extent of the geothermal reservoir.

#49 OURAY HOT SPRINGS

In and adjacent to the City of Ouray are a number of hot springs, most of which have small discharges, usually less than 5 gpm. However, the largest and hottest of the springs, the Pool Spring, has a discharge that varies throughout the year from a low of 69 gpm to a high of 200 gpm. This spring is located at the upper reaches of Box Canyon.

LOCATION OF THERMAL SPRINGS LOCATED AND MEASURED:

Pool Spring: Latitude: 38°01'00"N.; Longitude: 107°40'41"W.; T. 44 N., R. 7 W., Sec. 31, N.M.P.M.; Ouray County; Ouray 7 1/2-minute topographic quadrangle map.

Uncompahgre Hot Spring: Latitude: 38°01'06"N.; Longitude: 107°40'34"W.; T. 44 N., R. 7 W., Sec. 31, N.M.P.M.; Ouray County; Ouray 7 1/2-minute topographic quadrangle map.

Wiesbaden Vapor Caves and Motel Hot Springs: Located in basement of the Wiesbaden motel at the corner of 6th Avenue and 5th Street are three springs. Latitude: 38°01'15"N.; Longitude: 107°40'03"W.; T. 44 N., R. 7 W., Sec. 31, N.M.P.M.; Ouray County; Ouray 7 1/2 minute topographic quadrangle map.

GENERAL: With the exception of the Uncompahgre Hot Spring, several seeps in Box Canyon, and the springs at the rear of Box Canon Motel, all the thermal waters in the Ouray vicinity are used. The waters from the Pool Hot Spring are piped from Box Canyon to the swimming pool on the north end of town. Waters from the Wiesbaden Springs are used for the motel's mineral baths, swimming pool, and space heating.

GEOLOGY AND HYDROLOGY: As stated earlier, the discharge of the Pool Spring varies throughout the year from a low of 60 gpm to a high of 200 gpm. The temperature of the waters is a very consistent, 67°C to 69°C. The waters contain approximately 1,650 mg/l of dissolved solids and are a calcium-sulfate type. The concentration of radiochemical elements, Radium²²⁶ and Radium²²⁸, in the Pool Spring exceeds the U.S. Environmental Protection Agency Protection Agency limits for drinking water supplies (Barrett and Pearl, 1978). Due to the alterations at both the swimming pool and the spring site, it was only possible to obtain water samples when the pipeline dumps into a concrete cistern near Oak Creek.

The Uncompahgre Hot Spring has a discharge of 5 gpm with a temperature of 49°C. The waters contain 1,570 mg/l of dissolved solids and are a calcium sulfate type. The spring was sampled on the Uncompahgre River, below a sheer cliff approximately 100 yd upstream from the 3d Ave. bridge.

The Wiesbaden Motel Hot Springs are located in vapor caves beneath the motel at the corner of 6th

Ave. and 5th St. Spring A has a temperature of 53°C and contains 910 mg/l of dissolved solids. The waters are a calcium-sulfate type. This spring was sampled from the cistern just to the left inside the cave entrance. Spring B was sampled at the back of the cave from a ledge about 8 ft above the floor. The spring has an estimated discharge of 2 gpm. The waters contain 410 mg/l of dissolved solids and are a calcium sulfate type. Spring C, located in the furthest corner of the cave, has a discharge which varies between one gpm and 30 gpm throughout the year. The waters from this spring contain approximately 800 mg/l of dissolved solids and are a calcium-sulfate type.

Due to the complexity of the geological conditions in the area, no definitive statements can be made regarding the geological conditions controlling the occurrence of these springs (Fig. 41). All the springs appear to be associated with one or more fault systems, and they apparently represent deep circulation of ground water through the fault systems of the region.

Thermal springs have been reported to the south in the Red Mountain Pass area (Kevin McCarthy, 1977, oral communication). These springs have not been located or sampled yet.

GEOOTHERMOMETER ANALYSES: Due to the extensive modifications made to most of the hot springs for recreation and space heating, only data from Pool Hot Spring will be discussed in the following sections. Geothermometer results for Pool Hot Spring and the other hot springs in this area are listed in Table 3.

According to Barrett and Pearl (1978), the chalcedony-silicageothermometry yields a subsurface temperature of 69°C to 71°C, which is very near the surface temperature of the spring (67°C to 69°C).

Chalcedony mixing model analysis yields a subsurface temperature estimate of 77°C to 79°C with a cold water fraction of 15 to 16 percent of the spring flow (Barrett and Pearl, 1978).

The Na-K and Na-K-Ca geothermometers yields a subsurface temperature estimate of 184°C to 192°C and 39°C, respectively (Table 3). The Na-K geothermometer estimate is definitely too high because the basic assumption of the model is violated (Barrett and Pearl, 1978). The Na-K-Ca geothermometer estimate is incorrect because the result is below the surface temperature of the hot spring.

Conclusion: The high flow (approximately 175 gpm) of this hot spring and close agreement between the silica geothermometer and mixing model estimates suggests temperatures at depth between 70°C and 90°C (Table 3).

RESOURCE ASSESSMENT: The geologic conditions of this area are very complex (Barrett & Pearl, 1978). Therefore, it is very difficult to draw the

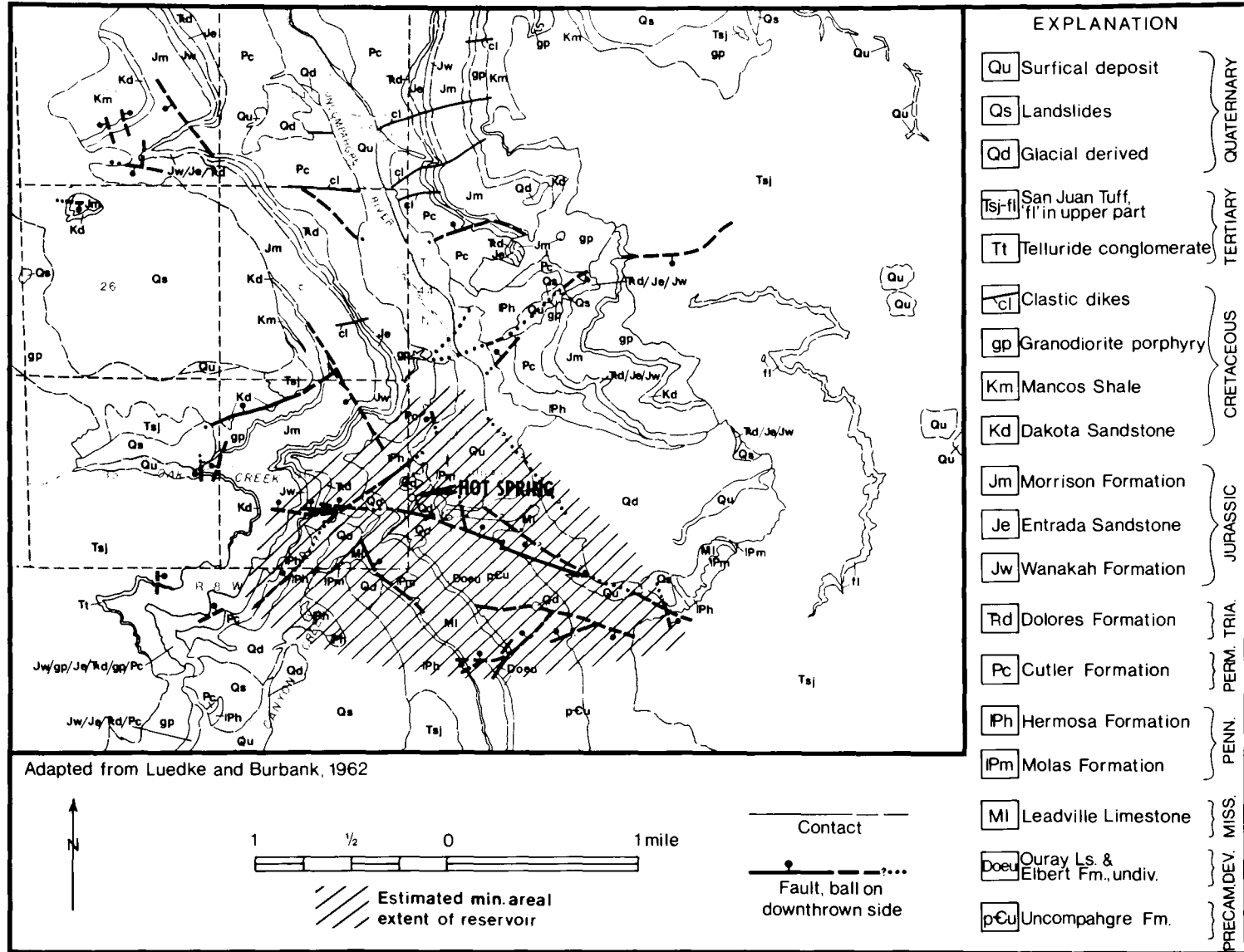


Figure 41.--Map of Ouray area showing geology and estimated areal extent of the geothermal reservoir.

boundaries of this system with any degree of confidence. Barrett & Pearl (1978) stated that they believed the waters were associated with one or more of the faults found in the region. The boundaries were drawn to try and include as much of the faulting as possible. Also, as unconfirmed thermal springs have been reported to the south in

the Red Mountain Pass Region the southern boundary was drawn to extend in that direction.

It is estimated that this areal extent of the system could encompass approximately 2.00 sq mi and contain .2256 Q's of heat energy at an average maximum temperature of 80°C (Table 2).

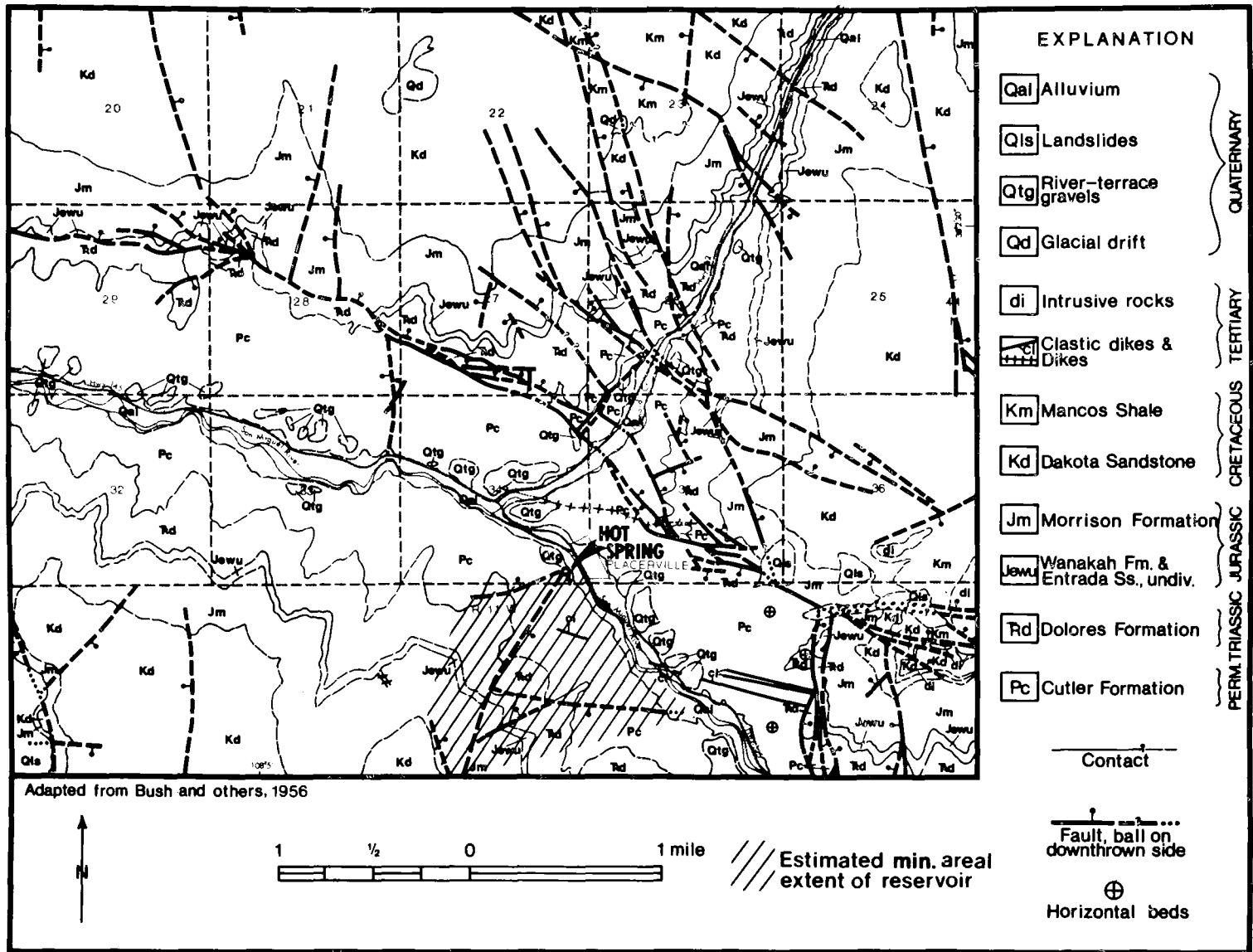


Figure 42.--Map of Lemon Hot Springs area showing geology and estimated areal extent of the geothermal reservoir.

#50 LEMON HOT SPRING

LOCATION: Latitude: 38°51'00"N.; Longitude: 108°03'11"W.; T. 44 N., R. 11 W., Sec. 34 dd, N.M.P.M.; San Miguel County; Placerville 7 1/2-minute topographic quadrangle map.

GENERAL: This unused spring is located in a tunnel driven into the Dolores Formation on the west bank of the San Miguel River in the community of Placerville 17 miles northwest of Telluride on Highway 145.

GEOLOGY AND HYDROLOGY: Barrett and Pearl (1978) reported that the spring has a discharge of 8 to 10 gpm at a temperature of 31 to 33°C. The waters contain from 2,740 to 2,810 mg/l of dissolved solids and are a mixed sodium bicarbonate-sulfate type. The surrounding area is geologically very complex, for the area is a transition zone between the Uncompahgre Plateau to the north and the La Plata Mountains to the south. A number of large north-trending fault zones and grabens intersect northwest-trending fault zones paralleling the San Miguel River. These north-south structures die out at the San Miguel River. Although none of these structures are mapped on the south side of the river (Fig. 42), one of them, the Sheep Draw Graben and associated faults, are on trend with the Lemon Warm Spring. The spring itself is located at the intersection and termination of one small and one large fault. Even though these faults are not apparent within the tunnel at the spring site, it is believed that they control the origin of the spring. It is believed that the waters migrate up these faults from depth. The waters come from the red beds of the Triassic Dolores Formation (Fig. 42). Recharge is probably to the south and west along the flanks of the La Plata Mountains.

GEOOTHERMOMETER ANALYSES: Analysis by Barrett and Pearl (1978) showed that the amorphous-silica

geothermometer should yield the most reliable subsurface temperature estimate. The amorphous-silica geothermometer estimate of subsurface temperature is 14°C to 17°C, which is below the surface temperature of the hot spring (31°C to 33°C). This low estimate may be caused by dilution of the ascending thermal water by shallow ground water.

The amorphous-silica mixing model analysis yields a subsurface temperature estimate of 29°C to 31°C with a cold-water fraction of 15 to 17 percent of the spring flow. Although the subsurface temperature estimate is below the surface temperature of the hot spring (33°C), it is well within the expected margin of error (Barrett and Pearl, 1978).

According to Barrett and Pearl's (1978) calculations the Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 203°C to 210°C and 192°C to 198°C, respectively. The nearby occurrence of travertine deposits, calcium carbonate-cemented river gravels and the lack of substantiation of such high temperature estimates by the other geothermometers suggest that these estimates are excessive.

Conclusion: The low surface temperature and flow of this hot spring renders geothermometer analysis unreliable.

RESOURCE ASSESSMENT: The boundaries of this system were drawn to include most of the faulting at the south side of the San Miguel River (Fig. 42). As drawn, the system encompasses an area of approximately .80 sq mi. Calculations show that it could contain .0149 Q's of energy at an average maximum temperature of 43°C (Table 2).

#51 DUNTON HOT SPRING

LOCATION: Latitude: 37°46'18"N.; Longitude 108°05'38"W.; T. 41 N., R. 11 W.; Sec. 32, N.M.P.M.; Dolores County; Dolores Peak 7 1/2-minute topographic quadrangle map.

GENERAL: This spring is located at the old mining town of Dunton, which is now a resort area northwest of Rico. Access is via a dirt road which turns off of Colorado 145 approximately 2 miles north of Rico or alternatively via a dirt county road up the West Dolores River starting a few miles west of Stoner. The spring is located at the base of the hill east of the main buildings. The waters are piped approximately 30 yd to a building where they empty into a large pool and are used for bathing. The waters are drained from this pool to the West Dolores River.

GEOLOGY AND HYDROLOGY: The waters of these springs are a calcium bicarbonate type with a strong concentration of iron (up to 2,300 mg/l) and manganese (average concentration of 1,800 mg/l). The temperature of the spring is 42°C with a discharge of 25 gpm. The surrounding bedrock are the red sandstones, siltstones, and shales of the Dolores Formation. The red color and high iron content of the spring water confirm that the waters are associated with the Dolores Formation.

The surface of the ground is mantled with a veneer of red sandstones and shales which makes difficult the determination of the true geologic conditions of the area. As shown on the accompanying geologic map (Fig. 43), several major north-northwest trending faults, with major displacement, pass through or are located only a short distance from Dunton. The fault on which the Dunton Hot Spring is located has dropped the Morrison Formation down into contact with the Entrada and Dolores Formations.

The recharge area of these springs is unknown but is probably to the south with the spring resulting from deep circulation along fault zones in an area of high geothermal gradients.

In 1922, E. Bastin visited the Emma Mine (approximately 0.5 mile south of Dunton Hot Spring) and reported a warm spring (Temp. 82°F) located in the mine, 3000 ft from the main portal.

GEOOTHERMOMETER ANALYSES: The various geothermometer calculated subsurface temperatures are (Barrett and Pearl, 1978): 51°C to 54°C by the chalcedony-silica geothermometer, 65°C to 69°C with a cold-water fraction of 39 to 43 percent by the mixing model, 328°C to 342°C with the Na-K model. This estimate is too high because one of the basic assumptions of the model has been violated (Barrett and Pearl, 1978). The Na-K-Ca geothermometer model yields a temperature of 47°C to 52°C (Table 3).

Conclusion: The subsurface temperature in this area is probably between 50°C and 70°C (Table 3).

RESOURCE ASSESSMENT OF DUNTON, PARADISE, AND GEYSER HOT SPRINGS AREAS: While not proven, it is speculated that these three systems may be part of a larger system. Numerous faults have been mapped in the vicinity of these three springs (Fig. 43). Barrett & Pearl (1978) speculated that the springs are probably fault controlled and the waters may also be associated with the Triassic Dolores Formation. Therefore, the boundaries of the system were drawn to include as many of these features as possible. It is estimated that this system may encompass an area of 1.20 sq mi and contains .0271 Q's of heat energy (Table 2).

RESOURCE ASSESSMENT OF DUNTON HOT SPRING: While it is hypothesized that all three springs in this area could be part of one large system, it may be that this system lies at such a extreme depth that it would be economically unfeasible to develop it. Therefore, estimates will be made of the possible areal extent of each individual thermal system.

The Dunton Hot Spring is located on the trace of a north trending fault. It is conjectured that the extent of the reservoir around the fault would encompass an area of approximately .03 sq mi and contain .0068 Q's of heat energy (Table 2).

#52 GEYSER WARM SPRING

LOCATION: Latitude: 37°44'48"N; Longitude: 108°07'02"; T. 40 N., R. 11 W., Sec. 6 N.M.P.M.; Dolores County; Rico 7 1/2-minute topographic quadrangle map.

GENERAL: This spring, as implied by its name, is a true geyser, the only true geyser in the State of Colorado. Although the frequency of the eruption varies, 30 minute intervals are most common. The geyser action is slight and boils only 12 to 15 in. above the quiescent level of the spring (Barrett and Pearl, 1978).

The spring is reached via a 2-mile foot trail that starts approximately 1.5 miles south of Dunton and approximately 0.5 mile north of the Paradise Ranch buildings. The trail crosses the West Dolores River and runs east.

GEOLOGY AND HYDROLOGY: Due to the physical make up of the area around the spring and the geyser action, it was not possible to accurately measure the spring's discharge, but it is estimated to be 25 to 200 gpm. The temperature of the spring is 28°C, and the waters are a sodium-bicarbonate type. The waters contain 1,620 mg/l of dissolved solids (Barrett and Pearl, 1978).

Bush and Bromfield (1966) have mapped the location of this spring near the intersection of two faults (Fig. 43), a postulated northeast-trending fault and a postulated northwest-trending fault. The waters emerge from the Dolores Formation, which overlies the Pennsylvanian Cutler Formation. The Dolores Formation consists of red siltstones, sandstone, shale, and a few limestone-pebble conglomerate beds (Bush and Bromfield, 1966). The intense faulting

in the area makes reliable predictions of the recharge areas difficult.

GEOTHERMOMETER ANALYSES: Calculations by Barrett and Pearl (1978) show that the chalcedony-silica geothermometer yields a subsurface temperature estimate of 58°C, the cristobalite mixing model an estimate of 113°C with a cold water fraction of 80 percent of the spring flow, the Na-K geothermometer a temperature of 183°C, and the Na-K-Ca geothermometer a temperature of 160°C (Table 3). Travertine deposits near the warm spring and the lack of substantiation of such high temperatures by the other geothermometers suggest that the Na-K and Na-K-Ca estimates are too high.

Conclusion: The mixing model and silica geothermometers yield the most reliable estimates of subsurface temperature for Geyser Warm Spring. The subsurface temperature suggested by these geothermometers is between 60°C and 120°C (Table 3).

RESOURCE ASSESSMENT: This spring is located at the intersection of two faults (Fig. 43). It is postulated that this reservoir could extend for a short distance along both faults. If it does, it could encompass an area of approximately .03 sq mi. Calculations show that an area of this size having an average maximum temperature of 50°C could contain .0068 Q's of heat energy (Table 2).

It was also postulated that this spring could be part of a much larger system that also included the Dunton Hot Spring and the Paradise Hot Spring. For an analysis of this system see the Resource Assessment for Dunton Hot Springs section.

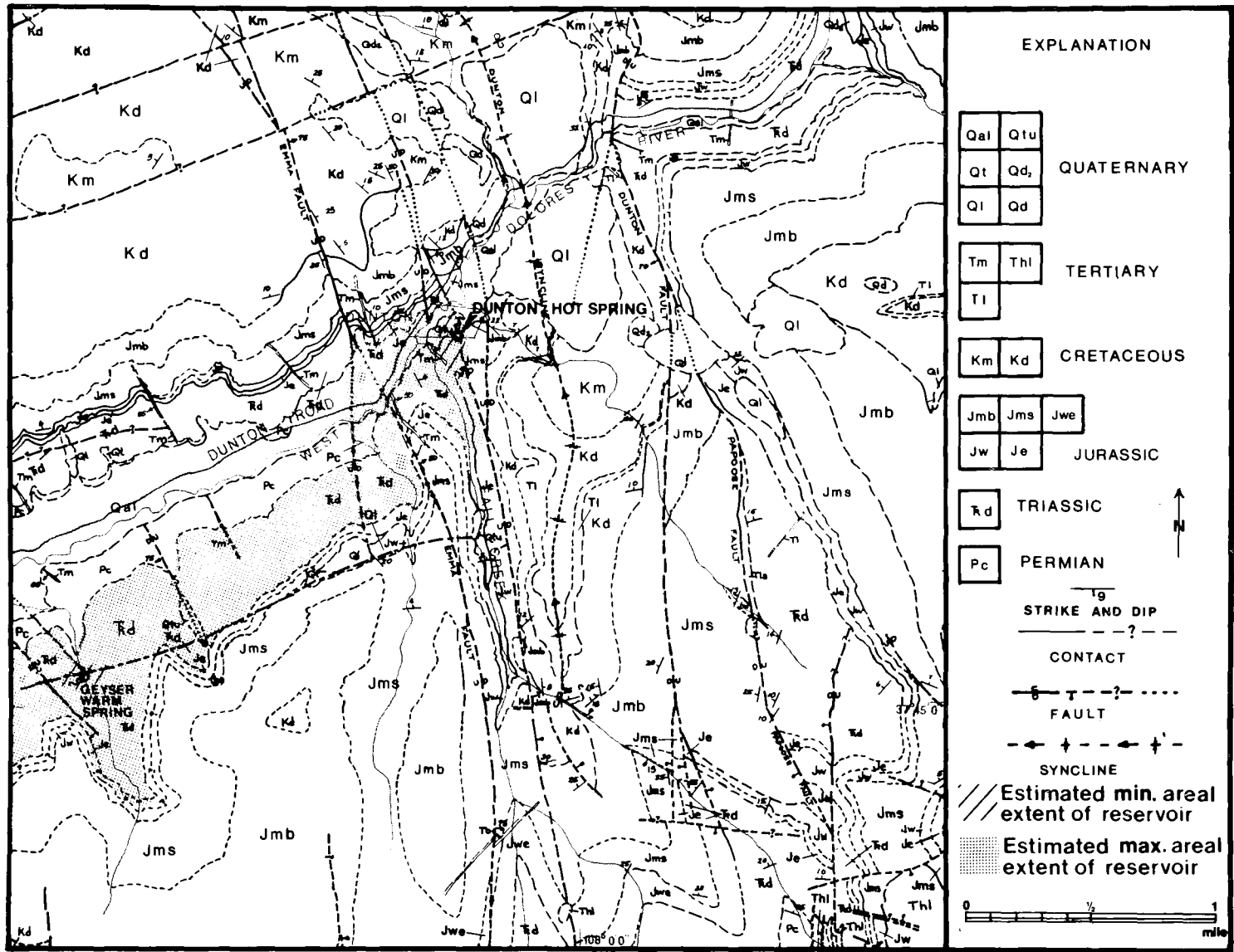


Figure 43.--Map of Dunton and Geysir Hot Springs area showing geology and estimated areal extent of the geothermal reservoirs.

#53 PARADISE WARM SPRING

LOCATION: Latitude: 37°45'15"N.; Longitude: 108°07'53"W.; T. 40 N., R. 12 W., Sec. 1, N.M.P.M.; Dolores County; Groundhog Mountain 7 1/2- minute topographic quadrangle map.

GENERAL: This spring is located approximately 2.6 miles south of Dunton, Colorado on the northeast bank of the West Dolores River. Access is via the paved and dirt county road from State Highway 145 along the West Dolores River. The main spring is located in the large log building at the ranch headquarters. Several seeps are reported in the pasture between the buildings and the river, but they were not located. The spring in the building flows into a large concrete cistern and is used privately by the owners for mineral baths. Evidently the thermal waters were used in the past to heat the large swimming pool just south of the log building.

GEOLOGY AND HYDROLOGY: The waters of this spring have a temperature that ranges throughout the year from 40°C to 46°C. The total dissolved solids varied from a low of 6,070 mg/l to a high of 6,530 mg/l. The waters are a sodium chloride type with a discharge of 26 to 34 gpm. When it was possible to gain access to the building, the spring was sampled from the edge of the cistern. Other times it was sampled from the outfall discharge pipe on the south side of the building.

Since no previously published geologic map exists for this area, no geologic map was prepared for this report. Detailed geologic mapping has not been done near this spring, but one can assume that some of the faults mapped in the quadrangle to the north (see Dunton Hot Spring, No. 51) extend into the vicinity of this spring. The waters emerge through West Dolores River alluvium which overlies the red sandstones, shales, and siltstones of the Dolores Formation.

GEOOTHERMOMETER ANALYSES: Computation of the silica solubility and temperature relationships for this

spring suggest that amorphous silica may control the silica content of the warm waters. The amorphous silica geothermometer gave an estimated subsurface temperature of 39°C to 56°C (Table 3) (Barrett and Pearl, 1978).

According to Barrett and Pearl (1978), amorphous silica mixing model analysis yields a subsurface temperature estimate of 43°C to 45°C with a cold water fraction of 1 to 4 percent of the spring flow (Table 3).

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 245°C to 247°C and 248°C to 252°C, respectively. These estimates should be treated skeptically for the magnesium content (30 mg/l) of the spring may be effecting the geothermometers.

Conclusion: Geothermometer models must be used with caution when applied to Paradise Warm Spring because most of the assumptions inherent in their use are violated. The ambiguous nature of the geochemistry precludes any reliable subsurface temperature estimates.

RESOURCE ASSESSMENT: As described earlier (see Resource Assessment of Dunton Hot Spring, Geyser Warm Spring and Paradise Warm Spring under Dunton Hot Spring) this spring might be part of a much larger system. However, because it was recognized that it may not an estimate of its areal extent was made.

This area is not shown on any geologic map; therefore, it was not possible to make any estimate of the reservoirs areal extent. Based on the authors knowledge of the area, it is estimated that the reservoir could encompass an area of 1.0 sq mi. If this is so, then this area could contain approximately .0226 Q's of heat energy at an average maximum temperature of 50°C (Table 2).

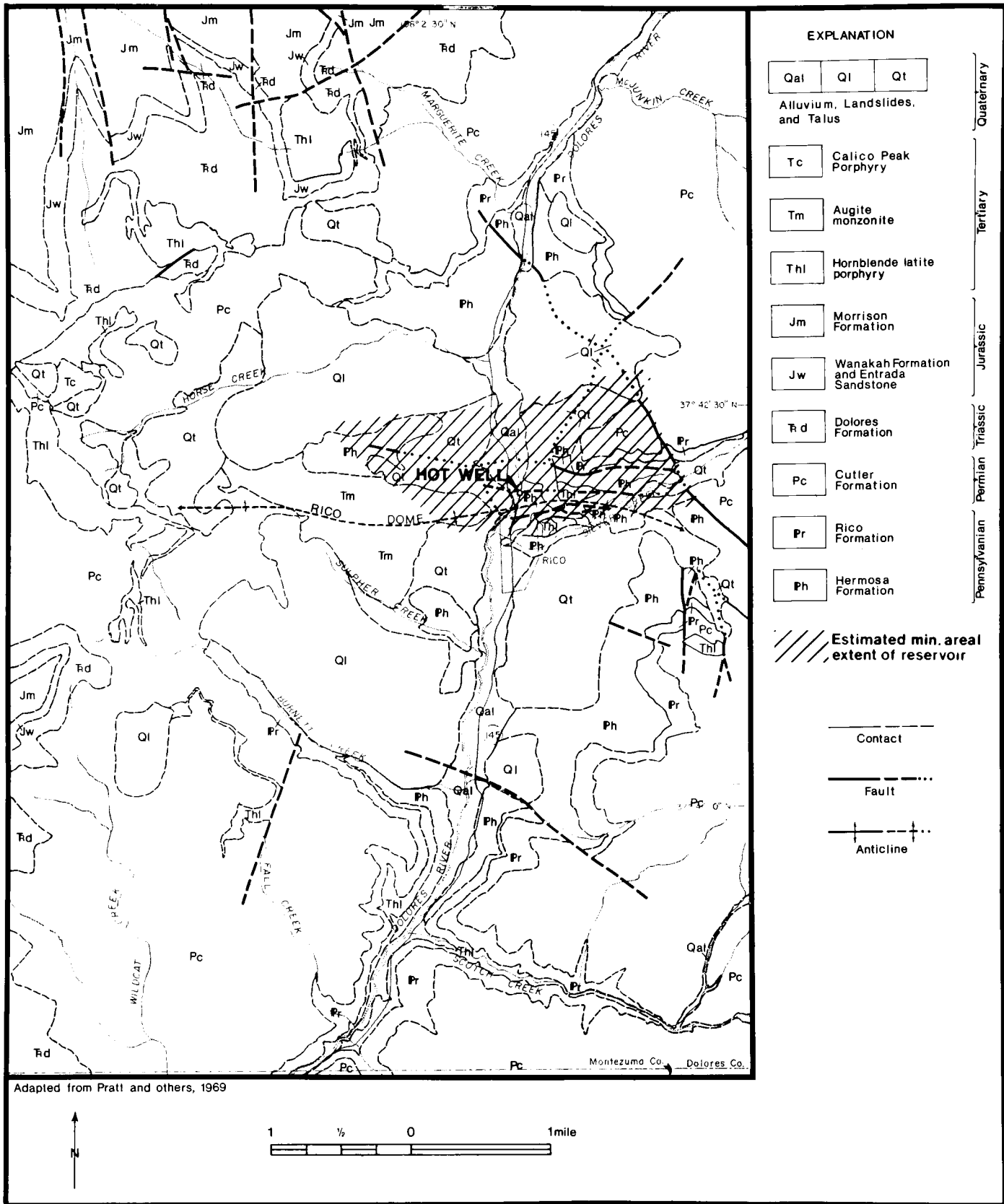


Figure 44.--Rico area, geology and estimated areal extent of the geothermal reservoir.

#54 RICO

Just to the north of Rico, Colorado, along the east bank of the Dolores River are, or were, four core-drill holes that have been described as springs (Barrett and Pearl, 1978). These holes and their locations are as follows:

LOCATION:

Diamond Drill Hole: Latitude: 37°42'05"N.; Longitude: 108°01'45"W.; T. 40 N., R. 11 W., Sec. -, N.M.P.M.; Dolores County; Rico 7 1/2-minute topographic quadrangle map.

Big Geyser Warm Spring: Latitude: 37°42'00"N.; Longitude: 108°01'44"W.; T. 40 N., R. 11 W., Sec. -, N.M.P.M.; Dolores County; Rico 7 1/2-minute topographic quadrangle map.

Geyser Warm Spring: Latitude: 37°42'02"N.; Longitude: 108°01'44"W.; T. 40 N., R. 11 W., Sec. -, N.M.P.M.; Dolores County; Rico 7 1/2-minute topographic quadrangle map.

Little Spring: Latitude: 37°42'04"N.; Longitude: 108°01'44"W.; T. 40 N., R. 11 W., Sec. -, N.M.P.M.; Dolores County; Rico 7 1/2-minute topographic quadrangle map.

GENERAL: All the above thermal waters are located along the east side of the dirt road leading into the Argentine Mine on the east side of the Dolores River 0.2 to 0.3 mile above the bridge across the Dolores River. While these are called "springs", they are actually drill holes. Two of the springs have geyser action, the waters from the Big Geyser attaining the greatest height of approximately 6 ft. These features may no longer exist by the time this report is published because of plans to plug the wells. All the thermal waters are within 200 yd of each other, and the waters are unused. The depths of these wells are unknown.

GEOLOGY AND HYDROLOGY:

Diamond Drill Hole: Temperature: 44°C; Discharge: 15 gpm; Total Dissolved Solids: 2,250 mg/l; and the waters are a calcium bicarbonate-sulfate type with a large concentration of manganese.

Big Geyser Warm Spring: Temperature: 34 to 36°C; Discharge: 8-12 gpm; Total Dissolved Solids: 2,750 mg/l; and the waters are a calcium-bicarbonate type with large concentrations of iron and manganese.

Geyser Warm Spring: Temperature: 38°C; Discharge: 14 gpm; Total Dissolved Solids: 2,790 mg/l; and the waters are a calcium-bicarbonate type with large concentrations of iron and manganese.

Little Spring: Temperature: 38°C; Discharge: 13 to 15 gpm; Total Dissolved Solids: 2,745 mg/l average; and the waters are a calcium bicarbonate-sulfate type with large concentrations of iron and manganese.

Geyser Warm Spring contained 38 picocuries/liter of Radium²²⁶, the highest of any thermal waters in Colorado, and 11 picocuries/liter of Radium²²⁸, the highest in Colorado.

The geological conditions in the Rico area are very complex for the area is cut by numerous faults and fractures (Fig. 44). The bedrock varies from Precambrian metamorphic rocks to Mississippian and younger sedimentary rocks. The hot water wells are located on the crest of the Rico Dome, a large anticlinal-type feature that extends from several miles west of Rico to the east of Rico.

No complete appraisal of the hydrogeological conditions of the area was possible, but the waters may represent deep circulation along some of the various fault systems in the area with the heating resulting from radioactive disintegration and residual heat from the magma chamber that supplied the Tertiary volcanic rocks.

Due to a high carbon dioxide content, the waters have a frothy appearance. This gas drives the water and gives the geyserlike activity to the waters.

GEOOTHERMOMETER ANALYSES: Geothermometer models should be used with caution when applied to the Rico area because most of the assumptions inherent in their use are violated. Any geothermometer estimate for this group of springs is at best unreliable due to the ambiguous geochemistry of the waters (Barrett Pearl, 1978).

Silica solubility and temperature relationships suggest that temperature-dependent equilibration between the thermal water and amorphous silica controls the silica content of the thermal water. The amorphous silica geothermometer gives an estimated subsurface temperature of 22°C to 35°C (Table 3) which is below the surface temperature of the thermal water (36°C to 44°C). This low estimate may be caused by shallow ground water dilution of the ascending thermal water.

The amorphous-silica mixing model yield a subsurface temperature estimate of 31°C to 39°C with a cold-water fraction of 1 to 19 percent of the total flow (Table 3) (Barrett and Pearl, 1978). Although the subsurface temperature estimate is below the surface temperature of the thermal water (36°C to 44°C), it is within the expected margin of error.

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 185°C to 315°C and 17°C to 59°C respectively, (Table 3). The Na-K geothermometer estimate is too high because the basic assumption of the model has been violated (Barrett and Pearl, 1978). Excluding the September 16, 1975, analysis of Rico Little Spring, the Na-K-Ca geothermometer yield temperature estimates of 56°C to 59°C. The high magnesium content of the springs renders these results unreliable.

RESOURCE ASSESSMENT: As shown on Figure 44, these thermal waters are located in an area of intense faulting on the Rico Dome. It has been postulated that this system is fault controlled (Barrett & Pearl, 1978). In drawing the boundaries of this system as much of the faulting in the area as

possible was included. Therefore, the system as drawn is estimated to encompass an area approximately 2.15 sq mi and contains .1738 Q's of heat energy at a maximum average temperature of 63°C (Table 2).

#55 PINKERTON HOT SPRINGS

Located approximately 14 miles north of Durango along U.S. Highway 550 are a group of springs known as the Pinkerton Hot Springs (Barrett and Pearl, 1978).

LOCATION: The location of the following springs were determined:

Spring A: Latitude: 37°26'50"N.; Longitude: 107°48'17"W.; T. 37 N., R. 9 W., Sec. 25 ab, N.M.P.M.; La Plata County; Hermosa 7-1/2 minute topographic quadrangle map.

Spring B: Latitude: 37°27'58"N.; Longitude: 107°48'18"W.; T. 37 N., R. 9 W., Sec. 25 a, N.M.P.M.; La Plata County; Hermosa 7-1/2 minute topographic quadrangle map.

Mound Spring: Latitude: 37°27'07"N.; Longitude: 107°48'20"W.; T. 37 N., R. 9 W., Sec. 25 ba, N.M.P.M.; La Plata County; Hermosa 7-1/2 minute topographic quadrangle map.

Little Mound Spring: Latitude: 37°27'09"N.; Longitude: 107°48'21"W.; T. 37 N., R. 9 W., Sec. 25 ba, N.M.P.M.; La Plata County; Hermosa 7-1/2 minute topographic quadrangle map.

General: Spring A is located just east of the highway right-of-way and to the south of the resort buildings. Spring B was located 900 to 1,200 ft west of Spring A in the trees and bushes. Mound Spring is located approximately 1,500 ft northwest of Spring A. As the name implies, Mound Spring flows from the top of a large mound approximately 100 ft above the road. Little Mound Spring is located several hundred ft north of Mound Spring. The new section of U.S. 550 passes the base of Mound and Little Mound Springs. The construction of this new section of road has destroyed Spring B.

Geology and Hydrology: Spring A was sampled in the fall of 1975, January, 1976, and April 1976. The temperature remained a constant 32°C, and its discharge was 54 gpm. The dissolved solids of the waters varied from a low of 3,700 mg/l to a high of 3,990 mg/l, and the waters are a mixed sodium-calcium, chloride-bicarbonate type with a high concentration of iron.

Spring B was sampled only once. Its temperature was 33°C with a discharge of 20 gpm. The dissolved solids was not determined, but the field measurement of conductance was 6,000 micromhos. The waters are a sodium-bicarbonate type with a very high concentration of iron (Barrett and Pearl, 1978).

Mound Warm Spring: The waters of this spring have a temperature of 32°C and the discharge of the spring is 54 gpm. The waters contain approximately 3,800 mg/l of dissolved solids with a high iron content.

Little Mound Spring: The waters of this spring were not sampled for complete chemical analysis of dissolved solids. Field measurements showed that the spring had a temperature of 26°C, an estimated discharge of 2 gpm, a pH of 7.0, and a conductance of 5,500 micromhos.

Surrounding all four springs are large aprons of iron-rich sediments.

These springs are located on the south side of the La Plata Mountains and Coal Bank Hill, a pass in the La Plata Mountains. The waters emerge from colluvial and alluvial deposits overlying the Mississippian Leadville Limestone.

The La Plata Mountains and the San Juan Mountains, immediately to the east, were centers of extensive volcanic activity in middle Tertiary time. Although no volcanic rocks are found near these springs, they occur only a few miles to the north. While not shown on the accompanying geologic map (Fig. 45), the Leadville Limestone appears to be faulted in the vicinity of the springs. Moyer and others (1961) state that the waters emerge from a fault transverse to the valley. Any explanation of the occurrence of these thermal waters must explain the high concentration of dissolved iron and evaporite mineral matter in the waters. Kilgore and Clark (1961, p. 235) have shown that a thin section of early Paleozoic limestones and sandstones underlies the Pinkerton Hot Springs, none of which contain large amounts of readily soluble minerals, especially iron. However, the overlying red sandstones, shales, siltstones of the Hermosa Group do. In addition, formations within the Hermosa group contain large amounts of evaporite minerals. Contact of the thermal waters with these units would explain the origin of the mineral matter in the thermal waters.

Reiter (1975) has shown this part of western Colorado to have a heat flow between 2.0 and 2.5 heat flow units. The source of the heat is unknown but may be related to the volcanic rocks found in the La Plata and San Juan Mountains. Recharge of the thermal water is believed to occur via deep circulation along fault zones from the La Plata Mountains.

GEOTHERMOMETER ANALYSIS: Quartz-silica geothermometer yields an estimated temperature of 78°C for Spring A and Mound Spring (Barrett and Pearl, 1978). The quartz mixing model yields an estimated subsurface temperature of 127°C to 133°C with a cold-water fraction of 81 to 82 percent. A temperature of 139°C with a cold-water fraction of 84 percent was determined for Mound Spring (Table 3). These values are within the range of values that could result from normal analytical error. The Na-K geothermometer yields a subsurface temperature estimate of 231°C to 234°C for Spring A, and 234°C to 235°C for Mound Spring. The Na-K-Ca geothermometer yields an estimated

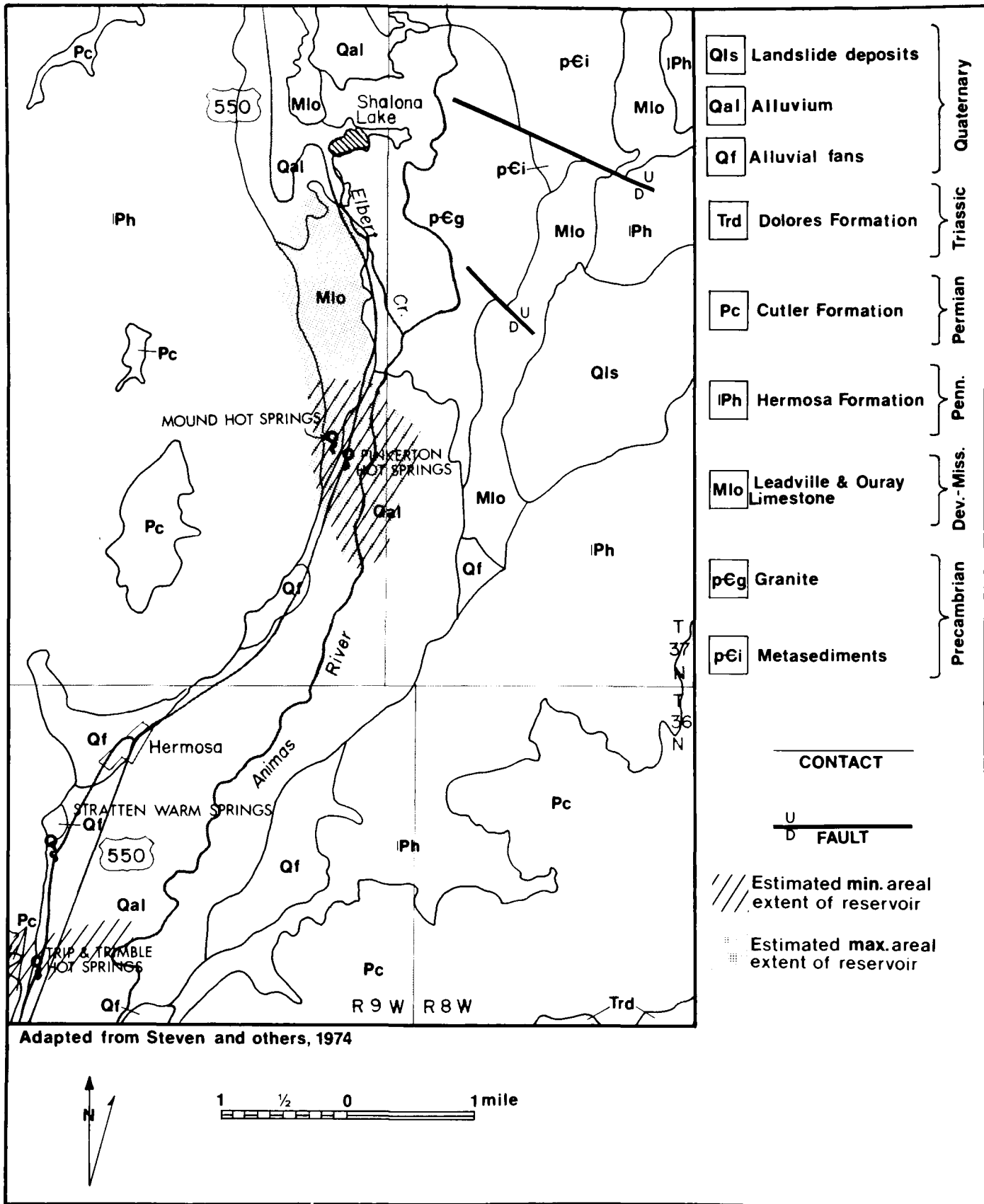


Figure 45.--Pinkerton, Mound, Tripp, Tribble and Stratten Springs area, geology and estimated areal extent of the geothermal reservoirs.

temperature of 202°C to 206°C for Spring A and 206°C to 207°C for Mound Spring. Barrett and Pearl (1978) noted that the Na-K estimated temperature is too high because the basic assumption of the model was violated. The large travertine and calcium carbonate deposits near the hot springs suggest that both the Na-K and Na-K-Ca geothermometer estimates are too high (Barrett and Pearl, 1978).

Conclusion: Consideration of the mixing model and silica geothermometer results and mixing model precision suggests subsurface temperatures between 75° and 125°C (Table 3).

RESOURCE ASSESSMENT: Barrett & Pearl (1978) noted

that these springs are associated with faulted Leadville Limestone. As the Leadville Limestone is a permeable cavernous unit and appears to contain large amounts of water, the boundaries of this system were purposely drawn to include a large area to the south and east of the springs. A second estimate of the reservoirs extent was made. This estimate extended the reservoir to the north and included all the Leadville outcrop to the south of the spring (Figure 45).

The estimated size of the system varied from less than 1.0 sq mi to just over 2 sq mi. The energy contained in the system varied from .0099 Q's to .0209 Q's at an average maximum temperature of 50°C (Table 2).

#56 TRIPP AND TRIMBLE WARM SPRINGS

#56 TRIMBLE HOT SPRING

LOCATION: Latitude: 37°23'28"N.; Longitude: 107°50'52"W.; T. 36 N., R. 9 W., Sec. 15 bb, N.M.P.M.; La Plata County; Hermosa 7 1/2-minute topographic quadrangle map.

GENERAL: Trimble Hot Spring is located approximately 9.25 miles north of Durango just off U.S. Highway 550. At the present time the spring is unused and just barely flows. In the past this spring fed the large swimming pool located to the south. The spring is inside a small rock house.

GEOLOGY AND HYDROLOGY: This spring had a temperature of 36°C and a discharge of less than one gpm. The waters contained 3,340 mg/l of

dissolved mineral matter and are a calcium sulfate type.

The waters, although issuing from colluvial deposits at the base of the cliff, are associated with the underlying red beds of the Paradox Formation (Fig. 45).

Moyer and others (1961) have described a northeast-trending fault, downthrown on the northwest side, crossing the valley near the springs. They state that the springs emerge along this fault zone. Kilgore and Clark (1961) show this and other faults in the vicinity reaching to basement rocks. The origin of these thermal waters is unknown but may result from deep circulation and updip flow along faults in the San Juan basin.

#56 TRIPP HOT SPRING

LOCATION: Latitude: 37°23'30"N.; Longitude: 107°50'52"W.; T. 36 N., R. 9 W., Sec. 10 cc, N.M.P.M.; La Plata County; Hermosa 7 1/2-minute topographic quadrangle map.

GENERAL: This spring is located less than 200 ft north of the Trimble Hot Spring, approximately 9.25 miles north of Durango off U.S. Highway 550. The spring is located in the big tin building behind

the house. The spring was sampled from a concrete-lined trough in the metal building.

GEOLOGY AND HYDROLOGY: Temperature: 44°C; Discharge: not determined; Total Dissolved Solids: 3,240 mg/l; Calcium-sodium sulfate type.

Like the Trimble Hot Spring waters, these waters come from colluvial deposits overlying the red beds of the Paradox Formation.

GEOOTHERMOMETER ANALYSES: Geothermometer models must be used with caution when applied to Tripp and Trimble warm springs because most of the assumptions inherent in their use are violated. However, the subsurface temperature is probably between 45°C and 70°C (Table 3) (Barrett and Pearl, 1978).

The silica content of these springs does not approach the solubilities of amorphous silica, chalcedony, cristobalite, or quartz. Therefore, application of any of these silica geothermometers will yield unreliable results. The amorphous silica solubility at the warm springs surface temperature (36°C to 44°C), 143 to 164 mg/l, is much higher than the silica content of the thermal water (69 to 72 mg/l). This discrepancy may be caused by mixing of the thermal water and relatively dilute groundwater.

The amorphous-silica mixing model yields a subsurface temperature estimate of 30°C to 40°C with a cold-water fraction of 39 to 47 percent of the spring flow (Table 3).

The Na-K and Na-K-Ca geothermometers yield subsurface temperature estimates of 197°C to 198°C and 97°C to 99°C, respectively (Table 3). The Na-K geothermometer estimate is too high because the basic assumption of the model has been violated (Barrett and Pearl, 1978). The low surface temperature and flow (less than 1 gpm) and the lack of substantiation of such high subsurface temperatures by the other geothermometers suggest that both the Na-K and Na-K-Ca estimates are unreliable.

RESOURCE ASSESSMENT: Barrett & Pearl (1978) in describing the geologic controls of this spring, reported that the springs are located on an unmapped northeast trending fault. They also stated that the waters are associated with the red sedimentary Cutler Formation.

In attempting to draw the boundaries of this system, the boundaries were drawn to try and encompass the northeast trending fault (Fig. 45). As drawn, the area encompasses approximately 1.0 sq mi. If this is accurate, the system could contain some .0357 Q's of heat energy at an average temperature of 58°C (Table 2).

#57 STRATTEN WARM SPRING

LOCATION: Latitude: 37°24'23"N.; Longitude; 107°50'37"W.; T. 36 N., R. 9 W. Sec 10 bab, N.M.P.M.; La Plata County, Hermosa 7 1/2 minute topographic quadrangle map.

GENERAL: This unused spring is located approximately one mile north of Tripp Warm Spring on the west side of the road at the base of the hill.

GEOLOGY AND HYDROLOGY: The spring has a temperature of 28°C and a discharge of approximately 10 gpm. The waters have a pH of 6.8 and a conductivity of 1950 micromohs. This spring was located in the fall of 1978 and has not yet been sampled or the water analyzed for contained mineral matter.

A complete geologic appraisal of this area has not yet been done. While the waters, issue from colluvial deposits at the base of the cliff they are associated with the underlying red beds of the Paradox Formation (Fig. 45).

GEOOTHERMOMETER ANALYSIS: As these waters have not yet been analyzed for contained mineral matter it was not possible to calculate the estimated reservoir temperatures.

RESOURCE ASSESSMENT: No attempt was made to estimate the amount of energy contained in this system.

#58 PIEDRA RIVER SPRING

LOCATION: Latitude: 37°18'14"N.; Longitude: Unsurveyed T. 35 N., R. 4 W. Sec. 19, N.M.P.M., Archuleta County, Devil Mountain 7 1/2 minute topographic quadrangle map.

GENERAL: These unused springs extend north approximately 30 yd along the east bank of the Piedra River from Coffee Creek. The springs may be reached from U.S. 160 by the dirt road that runs along the east side of the Piedra River. Go approximately 6.7 miles to the intersection of Monument Park Road and Sheep Creek Trail. Take the trail downward to the river and follow the trail along the east bank for approximately one mile to Coffee Creek. At this point the valley floor widens into a little meadow. The springs are located along the river. If the river is at high stage the springs may not be visible for they are located along the side of the river channel.

GEOLOGY AND HYDROLOGY: These springs have not yet been sampled and analyzed for contained mineral

matter. Field measurements in the fall of 1978 determined that the spring waters have a pH of 6.5, a conductivity of 2650 micromhos, and a temperature of 42°C, and a discharge of approximately 50 gpm.

No complete geologic appraisal of the area surrounding these springs has yet been made by the author. Reconnaissance mapping shows that the springs emerge from alluvial deposits overlying the Leadville Limestone. The area is structurally complex and Tertiary age extrusive volcanic rocks are found a few miles to the north.

GEO THERMOMETER ANALYSIS: As the dissolved mineral matter contained in these waters has not yet been determined no attempt has been made to determine the estimated reservoir temperatures.

RESOURCE ASSESSMENT: The author has not yet attempted to determine the amount of energy contained in this system.

OTHER AREAS

Not shown on Figure 1 are a number of supposedly thermal springs and wells which have been called to the authors attention. As they have not yet been located or measured by representatives

from the Colorado Geological Survey they will not be described here. Information about these springs and wells, which are described in Tables 4 and 5 is here presented for informational purposes only.

SUMMARY

Colorado's geothermal resource potential is expressed in the over 160 thermal springs and wells (temperatures in excess of 20°C) found throughout the western one-half of the state. While these springs and wells are found in a variety of geological environments, the majority of them are associated with the Rio Grande Rift of the San Luis Valley and Upper Arkansas Valleys, and with the San Juan and La Plata Mountains of southwestern Colorado.

To aid in appraising the hydrothermal resources of Colorado, geothermometer models were utilized to estimate the subsurface reservoir temperatures of the various thermal areas. The

models used were: Silica, Mixing Model I and II, Na-K, and Na-K-Ca. Probable subsurface temperatures range from a low of 20°C at Dexter Warm Spring in the southern San Luis Valley to high of over 200°C at both Cottonwood Hot Springs and Mount Princeton Hot Springs areas.

Using data presented by Barrett and Pearl (1978), the areal extent of each thermal system was estimated and the amount of heat contained in the system calculated. These estimates showed that the total amount of heat contained in the hydrothermal systems in Colorado ranged from 4.8782 Quads to 13.2386 Quads.

TABLE 1

ALPHABETICAL LIST OF THERMAL SPRINGS AND WELLS IN COLORADO

	<u>Spring Number in Report</u>	<u>County</u>
Antelope Hot Spring	44	Mineral
Birdsie Warm Spring	45	Mineral
Brands Ranch Artesian Well	5	Jackson
Brown's Canyon Warm Spring	22	Chaffee
Brown's Canyon Grotto Warm Spring	22	Chaffee
Canon City Warm Spring	26	Fremont
Cebolla Hot Springs	47	Gunnison
Cement Creek Warm Spring	16	Gunnison
Chimney Hill Warm Water Well	22	Chaffee
Clark Artesian Well	30	Pueblo
Colonel Chinn Hot Water Well	14	Delta
Conundrum Hot Springs	15	Pitkin
Cottonwood Hot Springs	20	Chaffee
Craig Warm Water Well	2	Moffat
Dexter Warm Spring	36	Conejos
Don K Ranch Artesian Well	29	Pueblo
Dotsero Warm Spring	10	Eagle
Dunton Hot Spring	51	Dolores
Dutch Crowley Artesian Well	39	Archuleta
Eldorado Springs	8	Boulder
Eoff Artesian Well	40	Archuleta
Fremont Natatorium Hot Spring	27	Fremont
Geyser Warm Spring	52	Dolores
Glenwood Springs	11	Garfield
Hartsel Hot Springs	19	Park
Haystack Butte Warm Water Well	7	Boulder
Hortense Hot Spring	21	Chaffee
Hortense Hot Water Well	21	Chaffee
Hot Sulphur Springs	6	Grand
Idaho Hot Springs	9	Clear Creek
Juniper Hot Springs	1	Moffat
Jump-Steady Hot Spring	20	Chaffee
Lemon Hot Spring	50	San Miguel
Little Mound Spring	55	La Plata
McIntyre	37	Conejos
Merrifield Hot Water Well	20	Chaffee
Mineral Hot Spring	31	Saguache
Mound Hot Spring	55	La Plata
Mt. Princeton Hot Springs	21	Chaffee
Orvis Hot Spring	48	Ouray
Ouray Hot Spring	49	Ouray
Pagosa Springs	41	Archuleta
Paradise Hot Spring	53	Dolores
Penny Hot Springs	13	Pitkin
Penrose Artesian Well	28	Fremont
Piedra River Springs	58	Archuleta
Pinkerton Hot Springs	55	La Plata
Poncha Hot Springs	23	Chaffee
Rainbow Hot Spring	42	Mineral
Ranger Hot Spring	17	Gunnison
Rhodes Warm Spring	18	Park
Rico	54	Dolores
Routt Hot Springs	3	Routt
Sand Dunes Swimming Pool, Hot Water Well	34	Saguache

TABLE 1 (Cont.)

	<u>in Report</u>	<u>County</u>
Shaws Warm Spring	33	Saguache
South Canyon Hot Spring	12	Garfield
Splashland Hot Water Well	35	Alamosa
Steamboat Springs	4	Routt
Stinking Springs	38	Archuleta
Stratten Warm Spring	57	La Plata
Swissvale Warm Spring	25	Fremont
Trimble Hot Spring	56	La Plata
Tripp Hot Spring	56	La Plata
Valley View Hot Springs	32	Saguache
Wagon Wheel Gap Hot Springs	43	Mineral
Waunita Hot Springs, Upper and Lower	46	Gunnison
Wellsville Warm Spring	24	Fremont
Woolmington Warm Water Well	21	Chaffee
Wright Water Wells	21	Chaffee
Young Life Hot Water Well	21	Chaffee

TABLE 2

ASSESSMENT OF HYDROTHERMAL RESOURCES IN COLORADO

(Adapted from Coe, 1978)

Thermal Spring Areas		Areal Extent (mi ²)	Thickness (ft.)	Temp. (°C)	Estimated Total Btu's	
					Probable (10 ¹⁵)	Feasible (10 ¹⁵)
Juniper	1	1.00	200(S)	63	.0163	.0163
Craig	2	1.00	500(U)	55	.0329	----
		12.0	500(U)	55	----	.395
Routt	3	0.5	1000(F)	138	.1110	----
		0.75	1000(F)	138	----	.1663
Steamboat	4	0.52	1000 (F)	70	.0487	.0487
Brand's Ranch	5	0.36	200(S)	49	.0039	----
		1.5	200(S)	49	----	.0164
Hot Sulphur	6	1.35	500(U)	75	.0698	.0698
Haystack Butte	7	0.54	300(S)	40	.0061	----
		1.50	300(S)	40	----	.0169
Eldorado	8	0.52	1000(F)	35	.0147	.0147
Idaho	9	1.52	1000(F)	80	.1714	.1714
Dotsero	10	0.50	250(S)	39	.0045	.0045
Glenwood	11	1.32	250(S)	65	.0279	.0279
		0.50	250(S)	65	(.0106)	(.0106)
South Canyon	12	0.1	200(S)	75	.0021	.0021
Penny	13	1.61	1000(F)	75	.1664	----
		4.7	1000(F)	75	----	.486
Colonel Chinn	14	1.55	200(S)	51	.0181	.0181
Conundrum	15	0.45	200(S)	45	.0042	.0042
Cement Creek	16	0.28	1000(F)	45	.0132	----
		1.40	1000(F)	45	----	.0658
Ranger	17	0.30	150(S)	45	.0021	----
		0.88	150(S)	45	----	.0062
Rhodes	18	1.53	1000(F)	35	.0432	----
		7.1	1000(F)	35	----	.2003
Hartsel	19	1.00	500(U)	70	.0470	.0470
Cottonwood Creek	20	1.38	1000(F)	170	.3894	----
		4.14	1000(F)	170	----	1.1672

TABLE 2 (Cont.)

Thermal Spring Areas	Area Extent (mi ²)	Thickness (ft.)	Temp. (°C)	Estimated Total Btu's	
				Probable (10 ¹⁵)	Feasible (10 ¹⁵)
Mt. Princeton 21	3.14	1000(F)	200	1.0623	----
	4.0	1000(F)	200	----	(1.3544)
	10.0	1000(S)	160	----	2.6314
Browns Canyon 22	1.50	1000(F)	100	.2256	----
	3.23	1000(F)	100	----	.4856
Poncha 23	0.60	1000(F)	145	.1410	----
	5.07	1000(F)	145	----	1.1911
Wellsville/Swissvale 24/25	0.94	240(S)	40	.0085	----
	1.66	240(S)	40	----	.0150
Canon City 26	0.50	100(S)	50	.0028	.0028
Freemont Natatorium 27	1.0	220(S)	43	.0095	.0095
Florence 28	1.0	200(S)	42	.0083	----
	5.2	200(S)	42	----	.0430
Don K. Ranch 29	1.5	500(U)	45	.0353	.0353
Clark Well 30	1.1	200(S)	40	.0083	.0083
Mineral 31	10.1	1000(F)	70	.9492	----
	32.0	1000(F)	70	----	3.007
Valley View 32	1.0	1000(F)	50	.0564	.0564
Shaw's 33	0.63	500(U)	45	.0148	.0148
Sand Dunes 34	1.5	1000(S)	75	.1551	.1551
Splashland 35	1.5	1000(S)	75	.1551	.1551
Dexter/McIntyre 36/37	1.2	1000(F)	35	.0339	.0339
Stinking/Dutch Crowley 38/39	1.52	200(S)	65	.0257	----
	3.66	200(S)	65	----	.0620
Eoff Well 40	1.5	200(S)	50	.0169	.0169
Pagosa 41	1.00	200(S)	80	.0226	.0226
Rainbow 42	1.00	1000(F)	45	.0470	----
	2.0	1000(F)	45	----	.0940
Wagonwheel Gap 43	0.70	500(U)	115	.0625	----
	16.00	500(U)	115	----	1.4285
Antelope/Birdsie 44/45	0.50	500(U)	44	.0113	----
	3.90	500(U)	44	----	.0880
Waunita 46	1.4	200(S)	135	.0606	.0606
Cebolla 47	1.28	500(U)	60	.0481	.0481

TABLE 2 (Cont.)

Thermal Spring Areas		Areal Extent (mi ²)	Thickness (ft.)	Temp. (°C)	Estimated Total Btu's	
					Probable (10 ¹⁵)	Feasible (10 ¹⁵)
Orvis	48	0.55	500(S)	75	.0284	----
		2.53	500(S)	75	----	.1308
Ouray	49	2.00	1000(F)	80	.2256	.2256
Lemon	50	0.80	425(S&F)	43	.0149	.0149
Dunton/Geyser/Paradise 51/52/53		1.20	400(S&F)	50	----	.0271
Dunton	51	0.30	400(S&F)	50	.0068	----
Geyser	52	0.30	400(S&F)	50	.0068	----
Paradise	53	1.00	400(S&F)	50	.0226	----
Rico	54	2.15	1000(F)	63	.1738	.1738
Pinkerton/Mound	55	0.98	180(S&F)	50	.0099	----
		2.06	180(S&F)	50	----	.0209
Tripp/Trimble	56	1.0	500(F&S)	58	.0357	.0357
Total					4.8782	13.2386

(S) Stratigraphic reservoir
(F) Fracture reservoir
(U) Unknown

TABLE 3

ESTIMATED RESERVOIR TEMPERATURES (°C) AND GEOCHEMICAL DATA

(Adapted from Barrett and Pearl, 1978)

Geothermometer Models
 q = quartz c = chalcedony
 a = amorphous cr = cristobalite

Hot Spring	Spring Number	Date Sampled	Silica G.T.	Mixing Model		Na-K G.T.	Na-K-Ca G.T.	Most Likely Sub. Temp.	Discharge gpm.	T.D.S. mg/l
				T.	%					
<u>Antelope W.S.</u>	44	8/75							3E	151
		10/75	41	49	36 cr	83	35	35-52	3E	150
<u>Birdsie W.S.</u>	45	8/76	52 cr	91	70 cr	102	36	35-52	15	168
<u>Brands Ranch</u>	5	7/76	42 c	43	1 c	199	171	42-55	80E	262
<u>Brown's Grotto W.S.</u>	22	6/76	49 cr	129	87 cr	123	89	50-100	3E	494
<u>Canon City H.S.</u>	26	9/75	35 c	40	3 c	187	70	--	5	1,230
		1/76	34 c	38	12 c	187	68		1	1,220
		4/76	34 c	38	12 c	188	72		2	1,210

<u>Cebolla Hot Springs</u>										
Spring "A"	47	7/75	71 cr	125	72 cr	278	216	--	--	1,450
		10/75	65 cr	105	66 cr	248	215		3	1,440
		1/76	78 cr	163	80 cr	238	209		3	1,470
		4/76	82 cr	185	83 cr	252	220		3	1,450
Spring "B"	47	7/75	73 cr	145	78 cr	249	217		--	1,460
Spring "C"	47	7/75	74 cr	143	76 cr	250	217	--	--	1,460

<u>Cement Ck. W.S.</u>	16	7/75	30 c	53	61 c	232	45	30-60	--	401
		10/75	25 c	27	0 c	225	48		80	389
		1/76	25 c	27	0 c	225	46		60	398
		4/76	28 c	29	6 c	238	49		60	382

<u>Chalk Creek H.S. Area:</u>										
Mt. Princeton H.S. "A"	21	7/75	110 q	194	78 q	149	56	150-200	--	245
		10/75	108 q	190	77 q	148	58		18	248
		1/76	105 q	186	77 q	151	58		20	244
		4/76	127 q	236	81 q	150	59		23	248
H.S. "F"	21	7/75	107 q	201	81 q	150	51	150-200	12	229
Hortense H.S.	21	7/75	118 q	164	57 q	146	94	150-200	--	340
		10/75	116 q	156	54 q	144	93		18	336
		1/76	120 q	164	56 q	141	97		18	351
		4/76	129 q	186	61 q	145	93		17	341
Hortense Hot Water Well	21	7/75	118 q	164	56 q	144	80	150-200	--	318
Woolmington Hot Water Well	21	8/75	--	---	--	156	47	150-200	--	143
Wright Hot Well(E.)	21	8/75	103 q	152	62 q	148	62	150--200	--	234
Wright Hot Well(W.)	21	7/75	116 q	172	64 q	145	77	150-200	--	313

TABLE 3 (Cont.)

Hot Spring	Spring Number	Date Sampled	Silica G.T.	Mixing Model		Na-K G.T.	Na-K-Ca G.T.	Most Likely Sub. Temp.	Discharge gpm.	T.D.S. mg/l
				T.	%					
<u>Chalk Creek Area Cont.</u>										
Young Life Hot Well	21	7/75	116 q	188	71 q	135	68	150-200	--	259
Clark Artesian Well	30	9/75	40 q	61	65 q	280	159	25-50	12	1,210
<u>Colonel Chinn Hot Water Well</u>	14	4/76	41 c	43	1 c	183	170	--	--	
Conundrum H.S.	15	9/75	40 cr	41	6 cr	187	4	40-50	50	1,910
<u>Cottonwood H.S. Area:</u>										
Cottonwood H.S.	20	6/75	110 q	174	70 q	132	84	105-182	10E	370
Jumpsteady H.S.	20	6/75	108 q	180	74 q	133	79	105-182	--	356
		10/75	105 q	174	74 q	131	85		90	364
		1/76	109 q	182	74 q	131	83		50	368
		4/76	--	---	--	135	83		50	302
Merrifield Hot Water Well	20	6/75	97 q	174	77 q	141	68	105-182	--	301
<u>Craig Warm Water Well</u>	2	1/76	58 q	70	50 q	100	104	40-70	24	896
				35	20 c					
Dexter W.S.	36	4/76	--	19	36 a	278	91	20-50	50E	--
<u>Don K. Ranch Artesian Well</u>	29	9/75	42 cr	63	61 cr	219	190	--	25	1,700
Dotsero W.S.	10	9/75	--	--	--	104	113	32-45	500E	--
		1/76	16 c	27	36 c	135	144		525E	10,400
		4/76	16 c	29	26 c	104	112		800E	9,940
S. Dotsero W.S.	10	12/75	16 c	29	26 c	102	109	32-45	1,000E	9,040
Dunton H.S.	51	9/75	54 c	69	40 c	329	50	50-70	26	1,260
		1/76	51 c	65	39 c	328	47		25	1,340
		4/76	53 c	69	43 c	342	52		25	1,300
<u>Dutch Crowley Artesian Well</u>	39	8/76	63 c	65	7 c	271	16	70-80	75E	--
<u>Eldorado Springs Spring "A"</u>	8	9/75	23 c	27	8. c	314	43	26-40	--	101
Spring "B"	8	9/75	21 c	26	10 c	320	45	26-40	--	84
		2/76	21 c	26	19 c	254	57		--	91
		4/76	21 c	26	1 c	311	46		--	84
Eoff Artesian Well	40	8/76	47 cr	59	38 cr	221	56	40-60	50E	--
<u>Florence Artesian Well (Penrose)</u>	28	9/75	34 c	41	40 c	212	178	34-50	130	1,480
<u>Freemont Natatorium H.S.</u>	27	9/75	23 c	32	23 c	172	72	35-50	20	1,370
		1/76	21 c	32	23 c	174	73		20	1,300
		4/76	21 c	32	23 c	171	71		18	1,330
Geyser W.S.	52	9/75	58 c	113	80 c	183	160	60-120	25-200E	1,620

TABLE 3 (Cont.)

Hot Spring	Spring Number	Date Sampled	Silica G.T.	Mixing Model		Na-K G.T.	Na-K-Ca G.T.	Most Likely Sub. Temp.	Discharge gpm.	T.D.S. mg/l
				T.	%					
<u>Glenwood Springs Area:</u>										
Big Spring	11	7/75	51 c	59	18 c	133	148	--	2,263	20,200
Drinking Spring	11	7/75	51 c	59	18 c	133	147	--	--	20,300
		10/75	47 c	49	3 c	131	145	--	--	20,200
		1/76	48 c	51	0 c	168	186		161	20,500
		4/76	48 c	51	0 c	135	149		140	18,800
Vapor Caves, Men's H.S.	11	9/75	45 c	49	3 c	129	143	--	5E	18,000
Graves Spring	11	9/75	51 c	77	46 c	133	144	--	5	21,500
Spring "A"	11	7/75	48 c	73	46 c	134	149	--	2-3E	17,600
Spring "B"	11	7/75	48 c	51	0 c	135	149	--	75	18,300
		10/75	44 c	47	9 c	131	145		75	18,400
		1/76	45 c	49	6 c	133	165		100	17,700
		4/76	45 c	49	6 c	135	151		110	17,800
Spring "D"	11	7/75	48 c	51	2 c	133	147	--	74	18,000
Railroad Spring	11	1/76	47 c	49	6 c	143	158	--	75	18,400
		4/76	47 c	49	6 c	138	152		75	18,200

<u>Hartsel Hot Springs</u>										
Spring "A"	19	6/75	63 c	85	44 c	162	152		--	2,280
Spring "B"	19	6/75	59 c	73	33 c	163	152		--	2,140
		10/75	55 c	79	46 c	163	153		40	2,260
		1/76	56 c	83	51 c	161	152		48	2,310
		4/76	58 c	87	53 c	163	153		50	2,330

<u>Haystack Butte</u>										
Warm Water Well	7	9/75	47 c	57	53 c	52	62	50	4E	1,200

<u>Hot Sulphur Springs</u>										
Spring "A"	6	7/75	86 q	109	63 q	169	171	75-150	--	1,200
		10/75	81 q	97	59 q	166	166		12	1,210
		1/76	81 q	97	59 q	165	165		12	1,220
		4/76	84 q	103	64 q	169	168		13	1,160
Spring "B"	6	7/75	86 q	113	67 q	169	169	75-150	1	1,200
Spring "C"	6	7/75	86 q	115	69 qr	170	170	75-150	3	1,210
		10/75	81 q	99	64 q	165	164		15	1,190
Spring "D"	6	10/75	80 q	97	63 q	167	166	75-150	23	1,190

<u>Idaho Hot Springs</u>										
Spring "A"	9	7/75	66 cr	109	64 cr	231	210	--	21	2,020
		10/75	59 cr	95	63 cr	231	210		--	2,110
		2/76	71 cr	141	76 cr	225	204		--	1,950
		4/76	78 cr	171	81 cr	228	207		--	1,940
Spring "B"	9	7/75	66 cr	--	--	230	210	--	--	2,070
Spring "C"	9	7/75	47 cr	--	--	235	206	--	1	1,070
Lodge Well	9	10/75	59 cr	81	48 cr	231	210	--	30	2,070

TABLE 3 (Cont.)

Hot Spring	Spring Number	Date Sampled	Silica G.T.	Mixing Model		Na-K G.T.	Na-K-Ca G.T.	Most Likely Sub. Temp.	Discharge gpm.	T.D.S. mg/l
				T.	%					
<u>Juniper H.S.</u>	1	7/75	53 c	81	59 c	75	80	50-75	13	1,150
		10/75	47 c	73	61 c	67	76		14	1,160
		1/76	50 c	73	55 c	70	78		13	1,160
		4/76	51 c	81	61 c	69	78		18	1,150
<u>Lemon H.S.</u>	50	9/75	15 a	29	17 a	210	198	--	8	2,760
		1/76	17 a	31	15 a	203	192		10	2,810
		4/76	14 a	29	25 a	207	195		10	2,740
<u>McIntyre W.S.</u>	37	4/76	--	15	33 a	333	50	20-50	5E	---
<u>Mineral Hot Springs Spring "A"</u>	31	6/75	70 c	87	38 c	206	90	70-90	100	643
		10/75	67 c	79	30 c	202	90		167	663
		1/76	69 c	83	34 c	199	89		70	658
		4/76	69 c	83	34 c	202	90		95	639
Spring "C"	31	6/75	72 c	93	43 c	197	91	70-90	--	723
Spring "D"	31	6/75	70 c	89	41 c	202	92	70-90	--	665
		10/75	67 c	79	30 c	198	91		--	690
		1/76	68 c	81	32 c	195	87		5E	657
		4/76	69 c	83	34 c	202	90		--	648
<u>Orvis H.S.</u>	48	9/75	73 c	99	54 c	179	93	--	-1	2,270
		1/76	82 c	127	66 c	183	97		-1	2,490
		4/76	75 c	107	54 c	187	93		-1	2,270
<u>Ouray Hot Springs</u>										
Wiesbaden Vapor Caves "A"	49	9/75	61 c	51	4 c	196	32	70-90	--	1,580
Wiesbaden Vapor Caves "B"	49	9/75	47 c	111	75 c	198	32	70-90	2E	695
Wiesbaden Vapor Caves "C"	49	9/75	60 c	99	56 c	299	28	70--90	1E	1,380
		1/76	60 c	161	83 c	190	41		30E	1,430
		4/76	60 c	93	51 c	192	43		5E	1,390
Pool H.S.	49	9/75	69 c	77	16 c	191	39	70-90	125	1,650
		1/76	71 c	79	15 c	184	39		60	1,660
		4/76	71 c	79	15 c	192	39		200	1,640
Uncompahgre H.S.	49	4/76	66 c	109	58 c	192	40	70-90	5	1,570
<u>Pagosa Spgs.</u>										
Big Spg	41	8/75	76 c	113	54 c	209	194	80-150	265	3,200
		10/75	--	--	--	209	194		226	--
		1/76	80 c	133	64 c	207	191		241	3,310
		4/76	81 c	139	66 c	210	193		260	3,040
Courthouse hot water well	41	8/75	74 c	113	56 c	210	193	75-125	30	3,300
Spa Hot Water Well	41	8/75	73 c	117	60 c	211	195	75-125	--	3,320
<u>Paradise Hot Spring</u>	53	9/75	39 a	45	4 a	247	252	--	26	6,070
		1/76	56 a	53	7 a	247	248		34	6,530
		4/76	39 a	43	1 a	245	250		30	6,180

TABLE 3 (Cont.)

Hot Spring	Spring Number	Date Sampled	Silica G.T.	Mixing Model		Na-K G.T.	Na-K-Ca G.T.	Most Likely Sub. Temp.	Discharge gpm.	T.D.S. mg/l
				T.	%					
<u>Penny Hot Springs</u>	13	9/75	15 a	35	25 a	199	93	60-90	10	2,820
		1/76	3 a	35	48 a	197	89		10	2,820
		4/76	39 a	45	2 a	202	92		10	2,750
Granges Spring	13	1/76	7 a	41	50 a	198	90	60-90	12	2,960

<u>Pinkerton H.S. Area:</u>										
Spring "A"	55	9/75	78 q	127	81 q	231	205	75-125	54	3,990
		1/76	78 q	127	81 q	231	202		54	3,880
		4/76	78 q	133	82 q	234	206		54	3,770
Spring "B"	55	9/75	--	--	--	234	206	75-125	20	----
Mound Spring	55	9/75	79 q	139	84 q	234	206	75-125	8E	3,940
		1/76	78 q	137	85 q	235	206		5E	3,880
		4/76	78 q	137	85 q	235	207		5E	3,840

<u>Poncha Hot Springs</u>										
Spring "A"	23	6/75	126 q	173	63 q	155	99	115-145	--	667
		10/75	119 q	157	60 q	154	140		--	678
		1/76	137 q	201	69 q	154	141		--	697
		4/76	137 q	201	69 q	159	145		200	654
Spring "B"	23	6/75	127 q	183	68 q	154	139	115-145	30E	655
Spring "C"	23	6/75	126 q	185	70 q	157	96	115-145	2	670
		10/75	119 q	169	68 q	156	142		3	660
		1/76	130 q	195	72 q	154	141		2	685
		4/76	136 q	209	73 q	158	144		4	655

<u>Rainbow Hot Spring</u>	42	9/75	41 cr	41	0 cr	68	22	40-50	45	161
<u>Ranger Warm Spring</u>	17	7/75	32 c	67	71 c	214	56	30-60	132	461
		10/75	28 c	29	1 c	216	66		250E	465
		1/76	30 c	45	49 c	218	60		225E	466
		4/76	30 c	45	49 c	217	60		175E	474

<u>Rhodes W.S.</u>	18	6/75	10 c	21	65 c	240	2	25-35	--	186
		10/75	13 c	23	41 c	222	10		200	194

<u>Rico</u>										
Diamond Drill Hole	54	1/76	26 a	39	18 a	307	56	--	15	2,250
Big Geyser W.S.	54	9/75	22 a	31	19 a	297	57	--	8	2,750
		4/76	35 a	37	1 a	315	56		12	2,740
Geyser W.S.	54	9/75	22 a	35	15 a	301	59	--	14	2,790
Little Spring	54	9/75	26 a	35	15 a	305	58	--	13	2,790
		1/76	26 a	37	10 a	185	17		15	2,700

<u>Routt Hot Springs</u>										
Spring "A"	3	7/75	136 q	225	75 q	170	154	125-175	33	552
		10/75	125 q	199	71 q	165	154		50	518
		1/76	129 q	209	73 q	167	155		25	521
		4/76	131 q	213	73 q	169	157		35	527
Spring "B"	3	7/75	136 q	231	76 q	170	159	125-175	30	539

<u>Sand Dunes Hot Well</u>	34	8/75	26 a	39	19 a	205	187	--	--	334

TABLE 3 (Cont.)

Hot Spring	Spring Number	Date Sampled	Silica G.T.	Mixing Model		Na-K G.T.	Na-K-Ca G.T.	Most Likely Sub. Temp.	Discharge gpm.	T.D.S. mg/l
				T.	%					
<u>Shaws W.S.</u>	33	8/75	8 a	26	32 a	101	103	30-60	34	406
		10/75	2 a	26	32 a	98	104		34	402
		1/76	17 a	28	19 a	101	83		52	424
		4/76	4 a	26	32 a	100	102		40	398

<u>South Canyon H. S.</u>										
Spring "A"	12	7/75	66 c	123	67 c	138	137	100-130	12	794
		10/75	60 c	103	60 c	137	135		7	800
		1/76	67 c	127	68 c	140	137		9	783
		4/76	63 c	115	65 c	140	137		17	772
Spring "B"	12	7/75	65 c	119	66 c	139	137	100-130	1E	757
<u>Splashland Hot Well</u>	35		22 a	35	23 a	221	197	40-100	--	311

<u>Steamboat Springs</u>										
Heart Spring	4	4/76	101 q	179	81 q	148	141	125-130	140	903
Sulphur Cave	4	4/76	60 q	79	79 q	181	188	125-130	10	4,530
Steamboat Spring	4	4/76	66 q	93	76 q	176	187	125-130	20	6,170
<u>Stinking Springs</u>	38	9/75	39 c	59	61 c	339	41	40-60	24	899

<u>Swissvale Warm Spgs.</u>										
Spring "A"	25	6/76	32 cr	35	22 cr	214	48	35-50	125	--
Spring "F"	25	6/76	31 cr	47	69 cr	2	44	35-50	20	--
<u>Trimble H.S.</u>	56	9/75	--	34	47 a	197	97	45-70	1E	3,340
<u>Tripp H.S.</u>		9/75	--	30	39 a	198	99	45-70	--	3,240

<u>Valley View Hot Spgs.</u>										
Spring "A"	32	6/75	34 c	37	4 c	356	12	40-50	--	252
		10/75	32 c	35	9 c	356	14		60E	249
		1/76	32 c	35	5 c	352	15		--	243
		4/76	32 c	35	9 c	375	15		--	234
Spring "B"	32	6/75	30 c	31	12 c	338	11	40-50	--	234
Spring "D"	32	10/75	25 c	29	33 c	360	11	40-50	120E	229
		1/76	28 c	31	25 c	346	16		75E	247
		4/76	28 c	31	29 c	389	10		75E	223

<u>Wagon Wheel Gap</u>										
4UR Spring	43	10/75	75 cr	113	56 cr	206	194	--	30E	1,580
		1/76	81 cr	137	66 cr	204	191		30E	1,550
		4/76	77 cr	119	59 cr	200	188		28E	1,620
CF & I Spring	43	8/75	71 cr	117	64 cr	205	181	--	30	1,510
		10/75	66 cr	99	56 cr	203	184		50	1,520
		1/76	80 cr	157	76 cr	203	175		30	1,540
		4/76	66 cr	99	57 cr	206	181		32	1,470

<u>Waunita Hot Springs</u>										
Spring "C"	46	7/75	143 q	213	66 q	179	163	175-225	--	557
		10/75	143 q	209	64 q	176	166		30	579
		1/76	157 q	247	71 q	174	159		55	613
		4/76	148 q	225	68 q	178	167		50	575
Spring "D"	46	7/75	153 q	291	83 q	175	165	175-225	--	594

TABLE 3 (Cont.)

<u>Hot Spring</u>	<u>Spring Number</u>	<u>Date Sampled</u>	<u>Silica G.T.</u>	<u>Mixing Model</u>		<u>Na-K G.T.</u>	<u>Na-K-Ca G.T.</u>	<u>Most Likely Sub. Temp.</u>	<u>Discharge gpm.</u>	<u>T.D.S. mg/l</u>
				<u>T.</u>	<u>%</u>					
<u>Lower Waunita H.S.</u>	46	7/75	130 q	197	67 q	178	165	110-160	--	544
Spring "B"		10/75	123 q	181	64 q	176	163		20E	549
		4/76	129 q	195	67 q	179	165		25E	528
<u>Lower Waunita H.S.</u>	46	7/75	129 q	209	73 q	179	166	110-160	--	535
Spring "D"										
<u>Wellsville W.S.</u>	24	6/75	32 cr	33	2 cr	213	49	35-50	--	470
		10/75	30 cr	33	7 cr	214	49		160	484
		1/76	31 cr	33	15 cr	216	48		175	482
		4/76	31 cr	33	15 cr	213	50		200	482

TABLE 4

REPORT BUT UNCONFIRMED HOT SPRINGS OR WELLS

The following sources of thermal water have been brought to the author's attention. These sources have not yet been field checked or located.

1. Burgener Spring, T. 49 N., R. 9 E., Sec. ?, N.M.P.M., Howard quadrangle, Chaffee County. Reported by Mrs. John Burgener, 1978. A small spring located on their property along Bear Creek.

2. Radium Warm Spring, T. 5 S., R. 90 W., Sec. 34 da, Storm King Mountain quadrangle, Garfield County. Reported by Chenn and Associates. A small unused spring located on the south bank of the Colorado River.

TABLE 5

WELLS IN THE SAN LUIS VALLEY HAVING MEASURED TEMPERATURES ABOVE 20°

(Adapted from Emery, Snipes and Dumeyer, 1972)

Location	Depth (ft)	Temperature (°C)	County
T. 37 N., R. 9 E, Sec. 15 ddc	1632	28	Alamosa
T. 37 N., R. 9 E, Sec. 28 ccb2	2640	24	Alamosa
T. 37 N., R. 10 E, Sec. 5 dbb	3080	40	Alamosa
T. 37 N., R. 10 E, Sec. 11 ccc	1500	27	Alamosa
T. 37 N., R. 10 E, Sec. 32 cdc2	1721	24	Alamosa
T. 37 N., R. 11 E, Sec. 9 cbb	1156	23	Alamosa
T. 37 N., R. 11 E, Sec. 22 ccc1	2062	33	Alamosa
T. 38 N., R. 9 E, Sec. 1 ada	----	21	Alamosa
T. 38 N., R. 9 E, Sec. 22 cbc	1840	23	Alamosa
T. 38 N., R. 10 E, Sec. 11 acc	1500	31	Alamosa
T. 38 N., R. 10 E, Sec. 24 aaa	----	21	Alamosa
T. 38 N., R. 10 E, Sec. 36 ccc	----	22	Alamosa
T. 38 N., R. 11 E, Sec. 9 cdb	----	24	Alamosa
T. 39 N., R. 10 E, Sec. 3 ccd	600	21	Alamosa
T. 39 N., R. 10 E, Sec. 6 bbb	1991	31	Alamosa
T. 39 N., R. 10 E, Sec. 13 bbb	2096	36	Alamosa
T. 39 N., R. 11 E, Sec. 5 cdd	----	23	Alamosa
T. 40 N., R. 9 E, Sec. 11 bcc3	600	21	Alamosa
T. 40 N., R. 10 E, Sec. 22 bbb	2063	31	Alamosa
T. 40 N., R. 10 E, Sec. 34 abc	2034	30	Alamosa
T. 35 N., R. 11 E, Sec. 5 cac	937	24	Conejos
T. 36 N., R. 11 E, Sec. 30 dba	800	26	Conejos
T. 36 N., R. 11 E, Sec. 34 ccc	318	24	Conejos
T. 31 N., R. 75 W, Sec. 23 dda	345	22	Costilla <i>in New Mexico</i>
T. 41 N., R. 9 E, Sec. 25 ccc	1425	27	Saguache
T. 41 N., R. 10 E, Sec. 27 aaa	4200	45	Saguache
T. 41 N., R. 11 E, Sec. 2 bc	----	20	Saguache
T. 42 N., R. 11 E, Sec. 36 cd	----	20	Saguache
T. 43 N., R. 8 E, Sec. 7 aaa	----	20	Saguache
T. 43 N., R. 10 E, Sec. 10 cad	----	20	Saguache
T. 43 N., R. 11 E, Sec. 32 cd	----	21	Saguache
T. 45 N., R. 10 E, Sec. 7 bcb	354	60	Saguache

TABLE 6

NEWLY LOCATED THERMAL WELLS IN THE CANON CITY AREA

1. Valle Cuatro Millas Artesian Well, Latitude 38° 28' 29" N., Longitude 105° 11' 30" W, T. 18 S., R. 70 W., Sec. 23 ba, 6th P.M., Fremont County, Canon City, 7 1/2 minute topographic quadrangle map.

This well, which is reported to be between 2200 and 2900 feet deep, is located just south of the golf clubhouse west of the dirt road along Four Mile Creek. The water, which has a temperature of 26°C, is used for domestic purposes at the ranch house approximately one-half mile to the south and on the golf course grounds (Fig 25).

2. Four Mile Creek Artesian Thermal Well. Latitude: 38° 31' 13" N.; Longitude: 105°12'52"W., T. 17 S., R. 70 W., Sec. 34 cc 6th P.M. Fremont County, Cooper Mountain 7 1/2 minute topographic quadrangle map.

3. Brush Hollow Creek Thermal Artesian Well. Latitude: 38°25'26"N; Longitude: 105°3'15"W; T. 19 S., R. 69 W., Sec. 1 daa 6th P.M. Fremont County, Florence 7 1/2 minute topographic quadrangle map.

This unused well, which has a temperature of 32°C, is located along the banks of Brush Hollow Creek approximately 100 yards north of U.S. 50. The casing, which extends up above ground level for approximately 10 feet, is encased in mineral matter. The well has an estimated discharge of 100 gpm (Fig. 26).

4. Higgins Artesian Thermal Well. Latitude: 38°25'07"N; Longitude: 105°03'28"W; T. 19 S., R. 69 W., Sec. 1 dcd. The waters from this reported 1875 ft deep well which have a temperature of 42°C, are used to heat a house and in a swimming pool. According to Ms. Hazel Higgins, the well was drilled in 1924.

To reach the well go approximately 0.7 mi west of the junction of U.S. 50 and Colo. 115 to a dirt road leading to the south. Take this road and go to the house approximately 0.4 miles (Fig. 26).

5. American Nauheim Artesian Thermal Well. Latitude 38°23'23"N; Longitude: 105°04'26"W.; T. 19 S., R. 69 W., Sec. 14 ddc, 6th P.M.; Fremont County, Florence 7 1/2 minute topographic quadrangle map.

The waters from this unused well have a temperature of 27°C. The depth of the well is reported by Mr. George Goodwin to be approx. 1400 ft. The well is located on the west side of the old swimming pool approximately 1/4 mile north of the intersection of Colo. 115 and Colo. 120 (Fig. 26).

At one time, according to Mr. Goodwin, the well had a discharge of 200 gpm, but is much less than that now.

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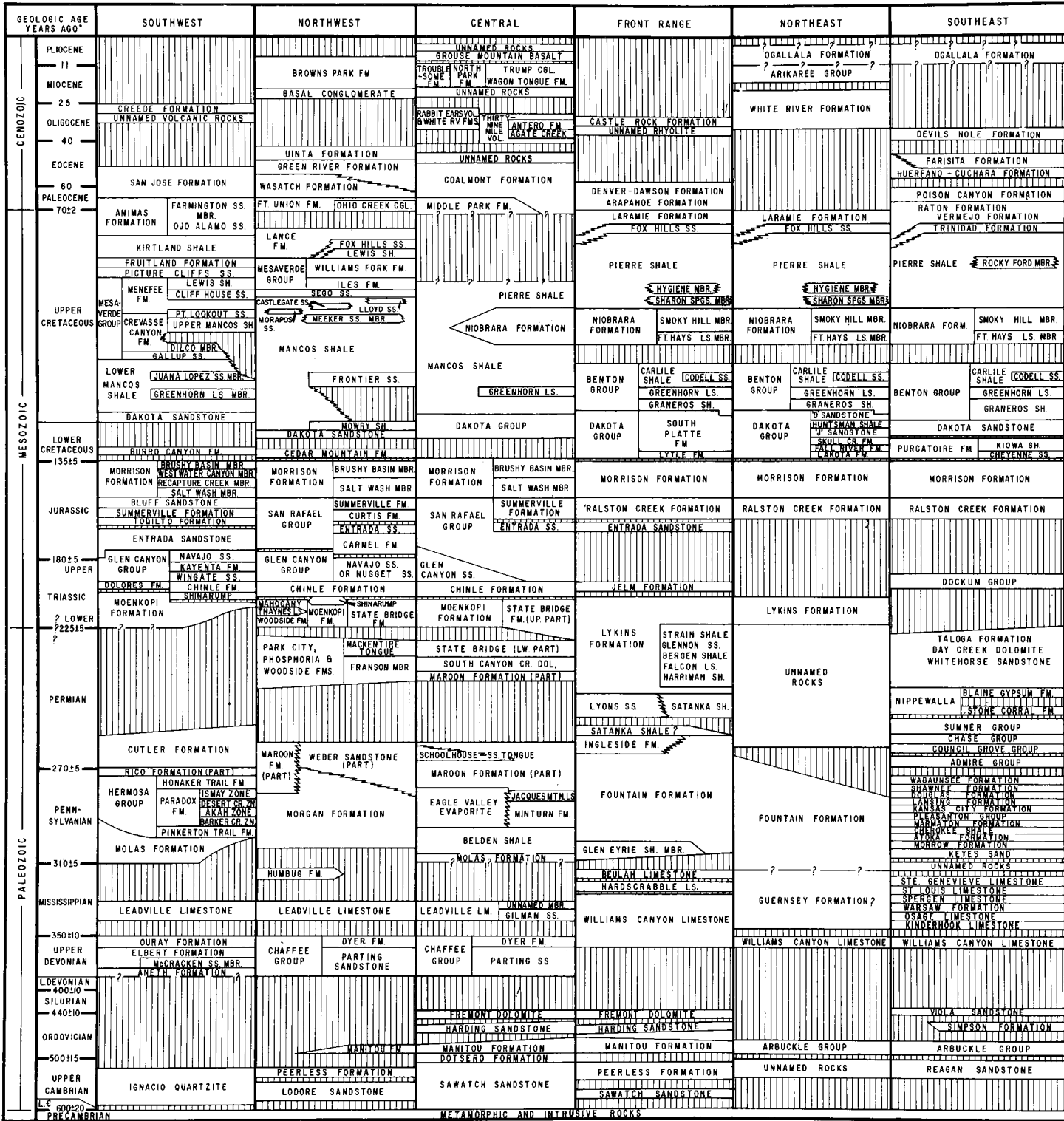
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COLORADO STRATIGRAPHIC CORRELATION CHART

COLORADO GEOLOGICAL SURVEY



Compiled by Richard Howard Pearl and D. Keith Murray (August 1974).
 *Millions of years before present (Source: Geochron Laboratories, Inc.)

Source of data: Geologic Atlas of the Rocky Mountain Region (RMAG, 1972) and other publications. Reviewed by selected members of the RMAG.

ENERGY-RELATED PUBLICATIONS OF THE COLORADO GEOLOGICAL SURVEY

GEOHERMAL ENERGY AND GROUNDWATER

- BULLETIN 33 -- Bibliography of Hydrogeologic Reports in Colorado, by R. H. Pearl, 1971, 39 p., \$1.00.
- BULLETIN 35 -- Proceedings of a Symposium on Geothermal Energy in Colorado, by R. H. Pearl, ed., 1974, 102 p., \$3.00.
- BULLETIN 36 -- Geologic Control of Supply and Quality of Water in the Mountainous Part of Jefferson County, Colorado, by W. E. Hofstra and D. C. Hall, 1975, 51 p., \$3.00.
- BULLETIN 39 -- An Appraisal of Colorado's Geothermal Resources, by J. K. Barrett and R. H. Pearl, 1978, 223 p., \$7.00.
- SPECIAL PUBLICATION 2 -- Geothermal Resources of Colorado, by R. H. Pearl, 1972, 54 p., \$1.00.
- SPECIAL PUBLICATION 4 -- Geology of Ground Water Resources in Colorado--An Introduction, by R. H. Pearl, 1974, 47 p., \$1.50.
- INFORMATION SERIES 4 -- Map Showing Thermal Springs, Wells and Heat-Flow Contours in Colorado, by J. K. Barrett, R. H. Pearl, and A. J. Pennington, 1976, 1 pl., scale 1:1,000,000, \$1.50.
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URANIUM

- BULLETIN 40 -- Radioactive Mineral Occurrences of Colorado, and Bibliography, including maps, by J. L. Nelson-Moore, D. Bishop Collins, and A. L. Hornbaker, 1978, 1,055 p., over-the-counter, \$37.00, mailed \$40.00.
- MAP SERIES 11 -- Uranium-Vanadium Mining Activity Map of Colorado with Directory, J. Collier, A. L. Hornbaker, and W. Chenoweth, 1978, scale 1:500,000, incl. Uranium Mineral Area 1:100,000, \$4.00.

GENERAL

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- MAP MF-788 -- Preliminary Geologic Map of Colorado, compiled by Ogden Tweto, published by U.S. Geological Survey, 1976, 2 sheets, black and white, scale 1:500,000, \$1.50.
- MAP I-1039 -- Energy Resources Map of Colorado, compiled by U.S. Geological Survey and Colorado Geological Survey, 1 sheet, multi-color, scale 1:500,000, \$2.00.
- MAP SERIES 1 -- Geologic, Energy and Mineral Resources Maps of Routt County, Colorado, by A. E. Miller, 1975, 2 maps, scale 1:126,720, \$5.00.
- MAP SERIES 3 -- Geology of Moffat County, by A. E. Miller, 1977, scale 1:126,720, \$8.00.
- MAP SERIES 13 -- State Lands Status Map, Lands and Minerals Administered by Agencies of the Colorado Department of Natural Resources, 1979, scale 1:500,000, \$3.00.
- OPEN-FILE REPORT -- Mineral Resources Maps of Moffat County, Colorado, by C. S. Robinson and Associates, 1975, 3 sheets, \$5.00, (reproducibles also available at Moffat County Planning Commission Office, Craig, Colorado).
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