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FINAL TECHNICAL REPORT FOR THE GEOTHERMAL-RESERVOIR ASSESSMENT AND CONFIRMATION PROGRAM FOR DIRECT-HEAT APPLICATIONS IN COLORADO

by
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COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
Denver, Colorado

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RICHARD HOWARD PEARL
PROJECT COORDINATOR

PROJECT DESCRIPTION

This is a reservoir assessment and confirmation program leading to the development of the low- and moderate-temperature geothermal reservoirs in Colorado for direct-heat applications.

The Colorado Geological Survey is responsible for the preparation of reports summarizing the distribution and quality of geothermal reservoirs that appear suitable for direct-heat applications. This is accomplished through a synthesis of available geological, geochemical, geophysical and hydrogeological data. Data obtained through this effort is also provided to the U.S. Geological Survey for incorporation into the GEOTHERM data file.

INTRODUCTION

This report summarizes activities of the project from its inception, June 27, 1977 to its completion March 31, 1983. The contract, DE-AS07-77ET-28365 (initially numbered EG-77-07-1678) was ammended several times. Following is a history of the various ammendments.

	Amount	Period
Original contract:	$154,130	6/27/77 - 6/26/78
Modification A001:	164,621	6/27/78 - 12/31/78
Modification A002:	100,000	1/ 1/79 - 12/31/79
Modification A003:	100,000	no time
Modification A004:	0	1/ 1/80 - 2/28/80
Modification A005:	199,995	3/ 1/80 - 2/28/81
Modification A006:	5,000	no time
Modification A007:	173,676	3/ 1/81 - 2/28/82
Modification A008:	0	3/ 1/82 - 8/31/82
Modification A009:	0	9 /1/82 - 12/31/82
Modification A010:	0	1/ 1/83 - 3/31/83

REQUIRED RESEARCH TO BE PERFORMED UNDER THE CONTRACT

Following is a summary of all the contractual research requirements. In several instances identical or nearly identical research requirements were listed in several years. Where this occurred these requirements have been combined below. At the end of each research requirements is noted the number of the report, or reports, which describes that particular project.

1. Prepare a preliminary synthesis of data presently available concerning the distribution of low and moderate temperature geothermal reservoirs in Colorado potentially suitable for direct heat applications. Data generated during this review will be provided to the U.S.G.S. GEOTHERM data base. For results see report no. 15.

2. In cooperation with U.S. Geological Survey, U.S. Forest Service, and representives of U.S. ERDA-Division of Geothermal Energy, select individual sites for detailed site assessment studies. Studies may include: (A) Geological and hydrological mapping; (B) Geophysical investigations; (C) Heat flow drilling and measurements. Areas initially chosen were Pagosa Springs and Glenwood Springs. For results see reports no. 6, 8, 9 and 14.

3. Subcontract for preliminary environmental assessments and reports on non-Forest Service land as required by ERDA-DGE Environmental Reporting Procedures. For results see report no. 9.

4. Recommend sites for confirmation during follow-on work. For results see reports no. 14 and 18.

5. Complete the testing and analysis of the Pagosa Springs Well. Work to be coordinated with Coury and Associates and the City of Pagosa Springs. This task was not done because the city of Pagosa Springs took it over.

6. Cooperate with the U.S. Geological Survey in geophysical investigations of the San Luis Valley and/or other areas of Colorado with geothermal potential. The work in the San Luis Valley should include site specific geological, geophysical and hydrological studies in the Alamosa Area. For results see report no. 4.

7. Conduct evaluation of the geothermal resources of select areas in Colorado where geothermal interest exists. Evaluation program to include, but is not limited to: Geophysical and geochemical surveys, geological and hydrogeological mapping, drilling of gradient holes, and drilling of reservoir confirmation test holes. These areas may include, but are not limited to: Ouray, the Animas Valley north of Durango, Pagosa Springs, San Luis Valley, Wagon Wheel Gap Hot Springs, Waunita Hot Springs, Ranger-Cement Creek Warm Springs, Canon City area, Hartsel Hot Springs, Idaho Springs, Glenwood Springs, Hot Sulphur Springs, and Steamboat-Routt Hot Springs. Prepare reports detailing findings. This item is a combination of 3 or 4 separate work elements. See reports no. 1, 2, 4, 5, 6, 7, 8, 11, 12, 13, 21, 22, 23, 26, 27, 28, 30, 31, 32 and 33 for results of investigations.

8. Conduct an electrical resistivity survey and a seismic survey in the Shaw Warm Spring area, San Luis Valley. Collect all available geophysical information concerning the northern portion of the San Luis Valley. Report detailing findings will be prepared. See reports no. 1,2,4, and 32.

9. Acquire available thermal gradient measurements from existing wells. Report no. 24 details findings.

10. Make a state-wide assessment of the groundwater temperatures. Obtain bottom hole temperatures from water and oil and gas wells in eastern Colorado. Prepare a map showing temperatures. For results see reports no. 24 and 25.

11. Acquire and interpret any available geophysical data, on an as-available basis. For results see report no. 29 and 30.

12. Provide assistance to NOAA in preparation of a state wide geothermal map. Also provide information to U.S.G.S. for inclusion in the GEOTHERM file. See report no. 16 results.

13. Prepare a heat-flow, ground-water temperature, and temperature gradient maps of Colorado. Reports no. 24, 25, and 29 report findings.

14. Measure geothermal gradients in holes of opportunity. See report no. 24.

15. Evaluate thermal waters in selected mining districts. Prepare a report detailing findings. Report no. 10 detailis findings.

16. Provide advice and assistance to private citizens, companies, governmental agencies and any others regarding geothermal resources of Colorado. See reports no. 3, 17, 19, 20, and 21 for results of efforts.

PROJECT PERSONNEL

1. The following personnel worked full time on the project.
   a. Richard H. Pearl, Project Coordinator.
   b. Jay Dick, Geologist
   c. Michael Galloway, Hydrogeologist
   d. Kevin McCarthy, Hydrogeologist
   e. Frank Repplier, Geologist
   f. Chuck Ringrose, Hydrogeologist
   g. Ted Zacharakis, Geophysicist

2. Personnel who worked part time on project
   a. Becky Andrews, word processor operator
   b. Cheryl Brchan, draftsperson
   c. Shirley Denzler, word processor operator
   d. Etta Norwood, draftsperson
   e. Mark Persichetti, draftsperson
   f. Neil Sherry, draftsperson
   g. Debbie Stafford, secretary

3. Field assistants who worked on the project during summer months only.
   a. John Bradbury, soil mercury
   b. Kevin Columbia, temperature measurements.
   c. Carol Gerlitz, soil mercury
   d. Mike Glaze, soil mercury
   e. Robert Fargo, geophysics
   f. Jay Jones, geophysics
   g. John Memmi, geophysics
   h. Mike Relf, temperature measurements
   i. James Ross, soil mercury
   j. Brad Strong, geophysics
   k. Charles Treska, geophysics
   l. Deborah Wester, soil mercury

REPORTS AND PUBLICATIONS

The following reports were either prepared by project staff personnel or for the project by consultants in support of research requirements. A brief summary of the paper is presented.

1. Applegate, J.K., 1981, SEIMIC REFLECTION SURVEY IN THE VICINITY OF CANON CITY, COLORADO, AND A REVIEW OF SEISMIC DATA GATHERED IN THE SAN LUIS VALLEY; Final Report to Geophysics Fund Inc.: Colorado School Mines, Exploration Research Laboratory, Unpub. report to the Colorado Geological Survey.

   The seismic data in the Canon City study was acquired east of Canon City and north of Florence. The study was along a line approximately three miles in length near which additional geophysical data were acquired in the past and orthogonal to the trend of the postulated Brush Hollow anticline.

   The Colorado School of Mines has conducted a field camp for their geophysics students in the San Luis Valley for several years. In addition, several petroleum companies have undertaken seismic surveys in the valley. The Colorado Geological Survey is particularly interested in utilizing the seimic method in the vicinity of Shaw Springs area to map structural controls that may provide conduits for hot water circulation. The purpose of this report is to review the methodology used to acquire seimic data in the Shaw Springs area, contrast it to seismic data acquired in other parts of the valley and postulate the reasons for data quality variations and speculate on seismic methodology, if any, that is applicable to solving the problem. (From the Introduction).

2. Bond, M.A., 1981, AN INTEGRATED GEOPHYSICAL STUDY OF THE SHAW WARM SPRING AREA, SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO: Unpub. Master of Science thesis, Dept. of Geophysics, Colorado School Mines.

   An integrated geophysical study of the Shaw Warm Spring area located on the western edge of the San Luis Valley, a down-faulted structural depression, was undertaken to determine the nature of the geothermal system. The geophysical methods employed in the study included: time-domain electrogmagnetic soundings, D.C. resistivity, audiomagnetotelluric and telluric surveys, seismic reflection and refraction surveys, and gravity surveys. (From Abstract).

3. Burroughs, R.L., 1981, A SUMMARY OF THE GEOLOGY OF THE SAN LUIS BASIN, COLORADO - NEW MEXICO WITH EMPHASIS ON THE GEOTHERMAL POTENTIAL FOR THE MONTE VISTA GRABEN: Colorado Geol. Survey Spec. Pub. 17 and U.S. Dept. of Energy DOE/ET/28365-10, 30 p.

   The objective of this report is to review the known geologic data of the San Luis Basin and to relate it to an understanding of the hydrothermal potential of the Alamosa-Monte Vista area. The report reviews the physiographic setting of the region; the structural framework of the basin and its influence on the stratigraphic makeup of the rock sequence, which in turn control the occurrence of potential deep water reservoirs. Attention is also given to high heat flow along the Rio Grande Rift and to the geothermal gradient of the San Luis Basin. The "confined" aquifer is then considered in respect to its hydrogeology, water quality, and as to the legal aspects of the system. (From the Introduction).

4. Christopherson, K.R., Nervick, K.H., Heran, W.D. and Pringle, Laurel, 1981, AUDIO-MAGNETOTELLURIC AND TELLURIC PROFILING STUDIES IN THE SHAW WARM SPRINGS REGION, COLORADO: U.S. Geol. Survey Open-File Report 81-958.

   During 1980, the U.S. Geological Survey conducted geophysical studies in the region of Shaw Warm Springs, Colorado. The work was done to help assess the geothermal potential of the region in a cooperative effort with the Colorado Geological Survey. The geophysical methods used were audio-magnetotellurics (AMT) and E-field ratio telluric profiles. (From the paper).

5. Christopherson, K.R., Nervick, K.H. and Heran, W.D., 1981, TELLURIC PROFILING STUDIES IN THE PENROSE AREA, COLORADO: U.S. Geol. Survey Open File Report 81-461.

   Three E-field ratio telluric profiles were made approximately 13 kilometers east of Canon City, and 3 kilometers southwest of Penrose, Colorado. The traverses were between 5 and 13 kilometers in length and trended west-northwest to west. The purpose of the traverses was to locate major north-trending faults that displace the Precambrian bedrock but have little or no surficial expression. These faults could provide channels for the upflow of geothermal waters. Warm water (25°C) has been found in several wells drilled in the region. (From the report).

6. Galloway, M.J., 1980, HYDROGEOLOGICAL AND GEOTHERMAL INVESTIGATIONS OF PAGOSA SPRINGS, COLORADO, WITH A SECTION ON MINERALOGICAL AND PETROGRAPHIC INVESTIGATIONS OF SAMPLES FROM GEOTHERMAL WELLS 0-1 and P-1, PAGOSA SPRINGS, COLORADO by W.W. Atkinson, Jr.; Colorado Geol. Survey Sp. Pub. 10, and U.S. Dept. of Energy DOE/ET/28365-5, 95 p. and plates.

   Pagosa Springs, Colorado was selected for study because of possible subsurface geothermal resource potential and community interest. Adequate subsurface temperature and measured surface flows justified further reservoir investigation. The reservoir assessment and confirmation study was to be used by the local school district for a planned new high school. The program consisted of reconnaissance geological and hydrogeological mapping, drilling of gradient holes and drilling and testing of two wells.

7. Gwinn, Cindy, 1981, HEAT FLOW MEASUREMENTS IN THE SAN LUIS VALLEY AND CANON CITY AREAS, COLORADO: Unpub. report, Dept. of Geological Sciences, Southern Methodist University, Dallas Texas, (Findings summarized in reports on San Luis Valley by Zacharakis and others, 1983 and Canon City Area by Zacharakis and Pearl, 1982).

   Heat flow, geothermal gradient and lithological data are presented for 16 drill holes in the San Luis Valley and 10 drill holes in the Canon City area of Colorado. These holes were drilled by the Colorado Geological Survey in 1979-1980 as part of a study to assess the geothermal potential of the state. During the summer of 1981, temperature as a function of depth was measured for each hole, and thermal conductivity determinations were made in the laboratory on cuttings samples. From these data, heat flow values were calculated as the product of interval geothermal gradient and average thermal conductivity. (From the Introduction).

8. Keller, G.V., 1978, GEOPHYSICAL SURVEYS AT PAGOSA SPRINGS AND GLENWOOD SPRINGS, COLORADO: Unpub. report by Dept. of Geophysics, Colorado School of Mines for the Colorado Geological Survey, 18 p. and plates.

   The Geophysics Department of the Colorado School of Mines has carried out surveys in the vicinity of Glenwood Springs and Pagosa Springs to assist in locating test wells to evaluate the geothermal potential. At Pagosa Springs, a seismic reflection survey indicates that the main springs issue along a fault that bounds an anticline with closure of approximately 500 feet. Electrical resistivity surveys indicate anomalously low values over an area of several square miles extending northeastward from the main hot springs. This area is also characterized by a slightly higher content of mercury in the soil than is present in surrounding areas.

At Glenwood Springs, only electrical resistivity surveys were carried out. An area of anomalously low resistivity was mapped along the Colorado River but centered beneath Lookout Mountain which lies two miles east of Glenwood Springs. The resistivity surveys show progressively better potential for the presence of a geothermal reservoir as one goes from the west end to the east end of the anomaly. (Abstract).

9. Koulet, K.G. and Armstrong, J.A., 1978, AN ENVIRONMENTAL REPORT ON THE DRILLING AND PRODUCTION TESTING OF AN EXPLORATORY GEOTHERMAL WELL IN PAGOSA SPRINGS, COLORADO: Unpub. report prepared for Colorado Geol. Survey by Denver Research Institute, University of Denver, 69 p.

Pagosa Springs, Colorado, is a small town of less than 1,500 people located in the southwestern part of the state. Because of the occurrence of hot springs within and adjacent to Pagosa Springs, a likely geothermal reservoir exists that has the potential of providing the town with geothermal energy for years to come.

The Colorado Geological Survey is currently conducting preliminary geological and geophysical work needed to ascertain the characteristics of the geothermal reservoir or reservoirs below the town. Temperatures of the town's Big Spring are around 50°C and the likelihood of encountering higher temperatures at greater depths is expected. If the Colorado Geological Survey is able to tap an extensive geothermal reservoir below the town, then this water could initially be used to heat a recreation-complex and proposed school and then be distributed elsewhere.

Currently the State is assessing the most promising site to drill a well that will help to determine if the resource is capable of supporting a space-heating system. This environmental report assesses the impact of drilling and testing the well. (From the Introduction).

10. McCarthy, K.P., 1982, GEOTHERMAL IMPLICATIONS OF WARM MINE WATER DRAINAGE AT LAKE CITY AND CRIPPLE CREEK, COLORADO: Colorado Geol. Survey Open-File Report 82-5 and U.S. Dept. of Energy DOE/ET/28365-20, 15 p.

During 1981 warm waters draining from mines near Lake City and Cripple Creek were sampled. The most interesting result of this work was the discovery of several "hot" mines near Cripple Creek. Strong cases can be made for both exothermic reactions, and geothermal phenomena providing the heat at Lake City. Geothermal gradients may be higher than normal at this site.

Several clues provided indirectly by water and air problems at Cripple Creek suggest sulphide oxidation may cause the high temperatures in the mines.

11. McCarthy, K.P., Been, Josh, Reimer, G.M., Bowles, C.G., and Murrey, D.G., 1982, HELIUM AND GROUND TEMPERATURE SURVEYS AT STEAMBOAT SPRINGS, COLORADO: Colorado Geol. Survey Spec. Pub. 21, and U.S. Dept. of Energy DOE/ET/28365-21, 12 p. Also published in the Sept., 1982 issue of Geothermal Energy Magazine, pp. 13-16.

As demonstrated in Steamboat Springs, Colorado, helium and shallow temperature surveys are quick, inexpensive exploration methods that can be used together with excellent results in an urban environment. A shallow temperature survey was conducted in the city to determine the usefulness of this method to to delineate a low temperature resource. Several extraneous factors influencing shallow temperature measurements were delt with by field technique or subsequent analysis. A helium survey was conducted to compare with temperature results. Sixty-two soil helium samples were taken, using an interval of .0 to .2 km (.06 to .12 mi), twice the density of the 18 temperature probe stations. The contoured data from each method correlate well spatially and indicate that two faults control the resource in Steamboat Springs. (From the Abstract).

12. McCarthy, K.P., Zachrakis, T.G., and Pearl, R.H., 1982, GEOTHERMAL RESOURCE ASSESSMENT OF HARTSEL, COLORADO: Colorado Geol. Survey Res. Ser. 18, and U.S. Dept. of Energy DOE/ET/28365-19, 86 p.

Two unused hot springs of moderate temperature issue from the Morrison Formation at Hartsel, Colorado, in South Park. Exploration activities by the Colorado Geological Survey around these springs included soil mercury and electrical resistivity surveys and shallow temperature measurements.

Results of the exploration suggest that the Santa Maria fault which passes through Hartsel serves as the conduit for warm water coming from the east. Hot water from depth may be forced upward due to an impermeable horst block adjacent to the fault. Other data indicates that warm water exists in the thick Paleozoic sediments to the west, but this is probably a seperate system. Any further exploration should focus upon the Santa Maria Fault, the Dakota Sandstone aquifer, or the Precambrian rocks beneath Glendiver Dome to the east. (From the Abstract).

13. McCarthy, K.P., Zacharakis, T.G., and Ringrose, C.D., 1982, GEOTHERMAL RESOURCE ASSESSMENT OF THE ANIMAS VALLEY, COLORADO: Colorado Geol. Survey Res. Ser. 17 and U.S. Dept. of Energy DOE/ET/28365-17, 60 p.

In the Animas River Valley, north of Durango, Colorado, in south-western Colorado, two groups of thermal springs exist: Pinkerton Springs to the north, and Tripp-Trimble-Stratten Springs about 5 miles (8.1 km) south of Pinkerton. Temperatures range from 28 to 44°C (82 to 111°F), and the discharge ranges from 1 gpm to 50 gpm (0.6 to 3.15 l/s).

During the summer of 1980, the geothermal resources of the Animas Valley were studied. Due to terraine problems in the narrow valley, a soil mercury survey was conducted only at Tripp-Trimble-Statten, while an electrical D.C. resistivity survey was limited to the vicinity of Pinkerton.

The geothermal resources in the Animas Valley are fault controlled. Pinkerton and Tripp-Trimble-Stratten are probably not directly connected systems, but may have the same source at distance. Recharge to the geothermal systems comes from the Needle and La Plata Mountains, and the latter may also be a heat source. Movement of the thermal water is probably primarily horizontal, via the Leadville Limestone aquifer. Further shallow drilling in the valley may produce moderate temperature fluids in great quantity, but deep drilling may not be as successful.

14. Pearl, R.H., 1978, 1977-78 YEAR END REPORT FOR GEOTHERMAL RESERVOIR ASSESSMENT AND CONFIRMATION PROGRAM FOR DIRECT HEAT APPLICATIONS IN COLORADO: U.S. DEPT. OF ENERGY DOE/ET/1678-3.

    Describes activities of project during period June, 1977 to December 31, 1978.

15. Pearl, R.H., 1979, COLORADO'S HYDROTHERMAL RESOURCE BASE--AN ASSESSMENT: Colorado Geol. Survey Resource Series 6 and DOE/ET/28365-4, 144 p.

    As part of its effort to more accurately describe the nations geothermal resource potential, the U.S. Dept. of Energy/Division of Geothermal Energy contracted with the Colorado Geological Survey to appraise the hydrothermal (hot water) resources of Colorado. Part of this effort required that the amount of energy possibly contained in the various hydrothermal systems in Colorado be estimated. This publication presents the findings of that assesment. 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 x 1015 BTU's to 13.2386 x 1015 BTU's. (From the Abstract).

16. Pearl, R.H., 1980, GEOTHERMAL RESOURCES OF COLORADO: Colorado Geol. Survey Map Series 14, Scale 1:500,000.

Colorado's geothermal resources are varied in character and scattered in the western half of the State. In recent years most geothermal exploration has been directed toward high temperature (>150°C) resources and has tended to ignore the intermediate-temperature (90-150°C) and low-temperature (<90°C) systems. Three high-temperature areas are now being evaluated, at Mount Princeton Hot Springs, Poncha Hot Springs, and Cebolla Hot Springs. Numerous intermediate - and low-temperature resource areas can be exploited for varied significant uses and are expected to supply a large part of the State's energy needs in years to come.

There are approximately 130 thermal springs and wells in 58 areas of western Colorado. The temperature range is generally from 20°C (68°F) in some areas to a high of 83°C (181°F) at Hortense Hot Spring (Mount Princeton). Discharge rates are less than four L/min (liters per minute) at Trimble Hot Spring and Browns Canyon Warm Spring to more than 8300 L/min at Glenwood Springs. Dissolved mineral matter ranges from 84 mg/L (milligrams per liter) at Eldorado Warm Springs to a high of over 21,000 mg/L at Glenwood Springs. (From the paper).

17. Pearl, R.H., 1981, HYDROTHERMAL RESOURCES OF WESTERN COLORADO: in R.C. Epis and J.F. Callender (eds) Western Slope Colorado, Guidebook, New Mexico Geological Society Thirty-second Field Conference, pp. 333-335.

In Colorado west of the Continental Divide there are 34 thermal areas contining approximately 103 thermal springs and wells. The surface temperatures of the waters in these areas range from a low of 23°C to a high of 80°C. The temperatures, discharge, total dissolved solids and estimated reservoir temperatures of the thermal systems in Colorado are summarized in a table.

With the exception of Routt Hot Springs, north of Steamboat Springs, all thermal areas in western Colorado are geologically associated with sedimentary rocks. The geological conditions of the thermal areas vary from relatively simple structural conditions to highly complex structural environments. Evaluation of the geological conditions of each thermal area has shown that all thermal waters are associated with faults and in several instances the springs are located at the intersection of two faults. (Summary of the Introduction).

18. Pearl, R.H., 1981, REVISED 1979 YEAR END REPORT FOR GEOTHERMAL RESERVOIR ASSESSMENT AND CONFIRMATION PROGRAM FOR DIRECT HEAT APPLICATIONS IN COLORADO: U.S. Dept. of Energy DOE/ET/28365-11, 42 p.

Describes activities of project during period January 1, 1979 to February 28, 1980.

19. Pearl, R.H., 1982, DESCRIPTION OF THE DRILL CUTTINGS FROM A DEEP GEOTHERMAL WELL DRILLED AT ALAMOSA, COLORADO: Colorado Geol. Survey Informal Report and U.S. Dept. of Energy DOE/ET/28365-16.

In late 1981 the City of Alamosa, Colorado drilled a deep (7,125 ft. 2.17 km) geothermal well. Due to the depth of the well and the rocks encountered, Energy Services Inc., Idaho Falls, ID., consultants to the city of Alamosa supplied the Colorado Geol. Survey with a set of drill cuttings. This report describes those cuttings.

20. Pearl, R.H. and Coe, B.A., 1980, POTENTIAL FOR GEOTHERMAL ENERGY DEVELOPMENT IN COLORADO, in H.C. Kent and K.W. Porter (eds) Colorado Geology: Rocky Mountain Assoc. of Geologists, Denver, CO, pp. 247-249.

Colorado's geothermal energy resources are predominantly low to moderate temperature wells and springs. Presently, there are known in the State only three thermal resource areas capable of generating electrical power. The majority of the thermal areas occur in association with the San Juan and La Plata Mountains of southwestern Colorado, and the San Luis-Upper Arkansas Valleys which constitute a northern extension of the Rio Grande Rift Zone of New Mexico. Geologically, the thermal resources occur in both normal stratigraphic sequences and highly complex structural and stratigraphic settings. Widely diverse uses for low and moderate temperature thermal energy exist, principally space and water heating. Constraints on development of the resource are (1) acquisition of leases on Federal and private lands (2) necessary large capital investment, and (3) general public unfamilarity with thermal energy as a resource. (From the Abstract).

21. Pearl, R.H., Galloway, M.J., and Dick, J.D., 1978, THE PAGOSA SPRINGS PROJECT--THE FIRST PERMITTED GEOTHERMAL WELLS IN COLORADO; in Geothermal Energy: A Novelty Becomes Resource; Transactions Geothermal Resources Council Annual Meetings, Hilo, Hawaii: Geothermal Resources Council, v. 2, pp. 517-519.

The geothermal resources of two areas in Colorado-Pagosa Springs and Glenwood Springs-are being explored and developed for direct application uses. At Pagosa Springs any thermal waters developed will primarily be used to heat a new high school complex. Geological, hydrogeological, geophysical, and geothermometer studies were done in the region to fully delineate the reservoir. It was determined that the reservoir encompasses some 4 sq. kilometers and may have a temperature of 125°C.

Before drilling commences it was necessary to apply for permits from the Colorado Oil and Gas Conservation Commission, Water Quality Control Commission, and Air Quality Control Commission. All permits have been issued. To test the aquifer and to determine what legal hydrological conditions the thermal waters are occurring under, a 2-3 day aquifer test will be run. (From the Abstract).

22. Pearl, R.H., Zacharakis, T.G., and Ringrose, C.D., 1982, GEOTHERMAL RESOURCE ASSESSMENT OF HOT SULPHUR SPRINGS, COLORADO: Colorado Geol Survey Res. Ser. 23, and U.S. Dept. of Energy DOE/ET/28365-23, 50 p.

Approximately 10 thermal springs whose waters are used for recreation, steam baths and laundry purposes are located at Hot Sulphur Springs, approximately 97 mi (156 km) west of Denver.

Estimated heat-flow at Hot Sulphur Springs is approximately 100 mW/m^2, which is about normal for western Colorado. Recent work tends to show that surface and reduced heat flow in the mountains of northern Colorado could be high.

The thermal waters have an estimated discharge of 50 gpm, a temperature that ranges from 104°F (40°C) to a high of 111°F (44°C), and a total dissolved solid content of 1,200 mg/l. the waters are a sodium bicarbonate type with a large concentration of sulphate. It is estimated that the most likely reservoir temperature of this system ranges from 167°F (75°C) to 302°F (150°C) and that the areal extent of the system could could encompass 1.35 sq mi (3.50 sq km) and could contain 0.698 Q's (10^{15} B.T.U.'s) of heat energy.

To aid in the evaluation of this system, soil mercury and electrical resistivity surveys were conducted.

While no deep hydrogeological information is available, it appears that the Hot Sulphur Springs thermal waters represent deep circulation of meteroric waters along numerous faults and fractures in an area of above normal heat flow. Recharge to the system probably occurs on the high ground to the east.

It is not possible to make any accurate predictions concerning required circulation depths due to the thick sequence of insulating Pierre shale found in the area. Due to the presence of this unit it is possible that low-to moderate-temperature waters 158°F-212°F, (70°C-100°C) could be found at its base. (Summary of Abstract).

23. Pearl, R.H., Zacharakis, T.G., and Ringrose, C.D., 1983, GEOTHERMAL RESOURCE ASSESSMENT OF STEAMBOAT SPRINGS, COLORADO: Colorado Geol. Survey Res. Ser. 22, and U.S. Dept. of Energy DOE/ET/28365-24.

An assessment of the geothermal resources of the Steamboat-Routt Hot Springs region in northwest Colorado was initiated and carried out in 1980 and 1981. The program consisted of dipole-dipole, Audio-magnetotelluric, telluric, self potential and gravity geophysical surveys, soil mercury and soil helium geochemical surveys: shallow temperature measurements; and preparation of geological maps.

The investigation showed that all the thermal springs appear to be fault controlled. Based on chemical composition of the thermal waters it appears that Heart Spring, in Steamboat Springs, is hydrologically related to the Routt Hot Springs. This relationship was further confirmed when it was reported that thermal waters were encountered during the construction of a new high school in Strawberry Park on the north side of Steamboat Springs. Geological mapping has determined that a major fault extends from the Routt Hot Springs area into Strawberry Park.

It is estimated that the Steamboat Springs system could have an areal extent of .52 sq. miles (.84 sq. Km) and contain .0487 Q's of heat energy. The Routt Hot Springs system's minimum extent could be .50 - .75 sq mi (.8 - 1.2 sq km) and contain .1663 Q's of heat energy. It was not assumed that the two systems are hydrologically connected. If they are then the estimates given are minimum estimates.

24. Repplier, F. N. and Fargo, R.L., 1981, GEOTHERMAL GRADIENT MAP OF COLORADO: Colorado Geol. Survey Map Series 20, and U.S. Dept. of Energy DOE/ET/28365-13, Scale 1:1,000,000.

Reported bottom hole temperatures (BHT) were taken from 12,000 Oil and Gas wells provided by the Colorado Oil and Gas Conservation Commission files. Average annual surface temperatures were subtracted from the BHT and then divided by the depth to give a gradient. To elimiate as many sources of error as possible, the gradient values were averaged for each township and contoured. Geothermal gradients in Colorado range from a low of less than 25°C/km to over 45°C/km.

25. Repplier, F.N., Relf, M.M. and Columbia, R.K., 1981, GROUNDWATER TEMPERATURE MAP OF COLORADO: Colorado Geol. Survey Map Series 21, and U.S. Dept. of Energy DOE/ET/28365-15, Scale 1:1,000,000.

This map was prepared using published and unpublished ground-water temperature data throughout Colorado. Excluding the temperatues of known thermal waters, the temperatues of the ground waters in eastern Colorado range from a low of approximately 12°C to a high of 17°C. In western Colorado the temperatures range from a low of less than 10°C to a high of just over 20°C.

26. Repplier, F.N., Zacharakis, T.G., and Ringrose, C.D., 1982, GEOTHERMAL RESOURCE ASSESSMENT OF IDAHO SPRINGS, COLORADO: Colorado Geol. Survey Res. Series 16 and U.S. Dept. of Energy DOE/ET/28365-17, 50 p.

Located in Idaho Springs, approximately 30 miles west of Denver are a series of thermal springs and wells. The temperature of these waters ranges from a low of 68°F (20°C) to a high of 127°F (53°C).

An investigation consisting of an electrical resistivity survey, soil mercury geochemical surveys, and reconnaissance geological and hydrogeolgical investigations was made in 1980 to define the hydrothermal conditions of the Idaho Springs region. Due to topographical and cultural restrictions, the investigation was limited to the immediate area surrounding the thermal springs at the Indian Springs Resort.

The investigation showed that the thermal waters are most likely fault controlled and the thermal area does not have a large areal extent.

27. Ringrose, C.D. 1980, TEMPERATURE--DEPTH PROFILES IN THE SAN LUIS VALLEY AND CANON CITY AREA, COLORADO: Colorado Geol. Survey Open-File Report 80-12, and U.S. Dept. of Energy DOE/ET/28365-6.

During the winter of 1979-80, 11 gradient holes were drilled in the Canon City area and 16 gradient holes were drilled in the San Luis Valley. All the holes were approximately 100 m deep except for one in the Canon City area which was 520 m deep. Measured gradients ranged from 28.2°C/km to a high of 89.7°C/km in the Canon City area. In the San Luis Valley the gradients ranged from a low of 29.6°C/km to a high of 71.5°C/km.

28. Zacharakis, T.G. (ed), 1981, GEOTHERMAL RESOURCE ASSESSMENT OF WAUNITA HOT SPRINGS, COLORADO: Colorado Geol. Survey Spec. Pub. 16 and U.S. Dept. of Energy DOE/ET/28365-14.

The investigations reported in this publication were prepared for AMAX Exploration, Inc. and their venture partner on the project, Austral Oil Co., by consultants and AMAX company personnel or by Colorado Geological Survey personnel. Upon conclusion of their resource evaluation program AMAX and Austral Oil Company dropped their leases to the Waunita Hot Springs and released the results of their resource assessment efforts to the general public. Realizing the value of this information the Colorado Geological Survey approached AMAX Exploration Inc. concerning the possibility of publishing the data. They graciously granted permission.

The publication contains reports on the geological, geophysical, heat flow, temperature and gradient and hydrogeochemical conditions of the area. In addition there is a chapter describing the results of the Colorado Geologcial Survey's soil mercury surveys in the area.

29. Zacharakis, T.G., 1981, REVISED HEAT FLOW MAP OF COLORADO: Colorado Geol. Survey Map Series 18 and U.S. Dept. of Energy DOE/ET/28365-12. Scale 1:1,000,000.

This map represents an update of an earlier published heat-flow map of Colorado. It is based on published and unpublished data. As shown measured heat flow in Colorado varies from a low of 60 mW/m2 to a high of 240 mW/m2. The most promising areas are the San Luis Valley and the Ouray-Gunnison trend in the southwest central part of the state.

30. Zacharakis, T.G., and Pearl, R.H., 1982, GEOTHERMAL RESOURCE ASSESSMENT OF CANON CITY, COLORADO AREA: Colorado Geol. Survey Res. Series 20 and U.S. Dept. of Energy DOE/ET/28365-22, 79 p.

In 1979 a program was initiated to fully define the geothermal conditions of an area east of Canon City, Colorado. In this area there are a number of thermal springs and wells in two distinct groups. The eastern group consists of 5 thermal artesian wells. The western group, located in and adjacent to Canon City consists of one thermal spring and three thermal wells.

The thermal waters of the Canon City embayment, are a calcium-bicarbonate type and range in temperature from 70°F (26°C) to a high of 108°F (42°C). The total combined discharge of all the thermal waters in the study area is in excess of 523 acre feet (A.F.) per year.

Gradients in 11 temperature gradient holes ranged from 2.17°F/100 ft (21.8°C/km) to a high of 4.92°F/100 ft (89.7°C/km). The regional heat flow map of Colorado shows that the study area has a heat flow of 90mW/m2, about normal for the Colorado Front Range.

During the course of this investigation the following geophysical investigations were conducted: Electrial resistivity; telluric; audio-magnetotelluric; and seismic. The electrical resistivity surveys were effective in delineating the near surface parts of the Canon City Hot Springs reservoir. These surveys were less than satisfactory in the deeper eastern artesian thermal well area. The telluric surveys were useful in further defining the structural conditions of the Brush Hollow Anticline (horst?). The audiomagnetotelluric survey indicated two possible geothermal systems, one in the vicinity of Canon City and the other in the Penrose area. The seismic surveys turned up evidence of a a deep geological structure. It was suggested that this stucture could be of several origins: an overthrust with subsequent movement; a sub-basement reflection within the basement; or a deep geothermal front.

Due to unfavorable geological conditions and contamination of the surface by the activities of man, the soil mercury geochemical sampling program was unsatisfactory in defining the geothermal conditions of the study area.

Examination of geological and hydrogeological data suggests that the origin of the thermal waters is due to a combination of favorable geological conditions plus decay of radioactive minerals. The thermal ground waters of the study area contain large amounts of radioactive mineral deposits. Overlying these aquifers is a thick sequence of Pierre Shale, a good insulating blanket. This unit traps and retains the heat given off by decaying radioactive minerals which then heats the recharging ground waters.

The thermal resources of the Canon City area appear to be large. It is calculated that in excess of 532 Acre Feet (A.F.)/year of thermal waters are currently being discharged to the surface. In addition it is estimated that there are approximately 264,000 A.F. of thermal waters that could be recovered in the study area. While these resources are large their development will be limited by the depth at which they are found. (From the Abstract).

31. Zacharakis, T.G. and Pearl, R.H., 1983, GEOTHERMAL RESOURCE ASSESSMENT OF RANGER WARM SPRINGS: Colorado Geol. Survey Res. Series 24 and U.S. Dept. of Energy DOE/ET/28365-26,

During 1980 and 1981 geothermal resource assessment efforts were conducted in the Cement Creek Valley south of Crested Butte. In this valley are two warm springs, Cement Creek and Ranger, about 4 mi (6.4 km) apart. The temperature of both both springs is 77-79°F (25-26°C) and the discharge ranges from 60 to 195 gallons per minute. Due to access problems no work was conducted in the Cement Creek Warm Springs area. At Ranger Warm Springs electrical resistivity and soil mercury surveys were conducted.

The electrical resistivity survey indicated that the waters of Ranger Warm Springs are moving up along a buried fault which parallels Cement Creek.

The areal extent of the Ranger Warm Springs thermal system has been estimated to encompass between 0.30 sq. mi (1.01 sq km) and 0.88 sq mi (2.28 sq km) depending upon how much of the faulting is included. It has also been estimated that the energy contained in the system could range from 0.0021 Q's to 0.0062 Q's (10^{15} BTU's) at an average temperature of 113°F (45°C). (Summary of Abstract).

32. Zacharakis, T.G., Pearl, R.H., and Ringrose, C.D., 1983, GEOTHERMAL RESOURCE ASSESSMENT OF WESTERN SAN LUIS VALLEY, COLORADO: Colorado Geol. Survey Res. Ser. 19, and U.S. Dept. of Energy DOE/ET/28365-25, 71 p.

The program initiated and carried out to fully assess the geothermal resource potential of the western San Luis Valley during 1979 and 1980 was a fully integrated program. The San Luis Valley is a large intermontane basin located in south-central Colorado. While thermal springs and wells are found throughout the Valley, the only thermal waters found along the western part of the Valley are found at Shaw Warm Springs, which is a relatively unused spring located approximately 6 miles (9.66 km) north of Del Norte, Colorado. The waters at Shaws Warm Spring have a temperature of 86°F (30°C), a discharge of 40 gallons per minute and contain approximately 408 mg/l of total dissolved solids.

The assessment program consisted of: soil mercury geochemical surveys; geothermal gradient drilling; and dipole-dipole electrical resistivity traverses, Schlumberger soundings, audio-magnetotelluric surveys, telluric surveys, and time-domain electro-magnetic soundings and seismic surveys.

Shaw Warm Springs appears to be the only source of thermal waters along the western side of the Valley. From the various investigations conducted the springs appear to be fault controlled and is very limited in extent.

Based on best evidence presently available estimates are presented on the size and extent of Shaw Warm Springs thermal system. It is estimated that this system could have an areal extent of 0.63 sq. miles (1.62 sq. km) and contain 0.0148 Q's of heat energy.

33. Zacharakis, T.G., Ringrose, C.D., and Pearl, R.H., 1981, GEOTHERMAL RESOURCE ASSESSMENT OF OURAY, COLORADO: Colorado Geol. Survey Res. Series 15, and U.S. Dept. of Energy DOE/ET/28365-9, 70 p.

Resource assessment efforts carried out in the Ouray area by the Colorado Geol. Survey consisted of geological mapping, soil mercury geochemical surveys and resistivity geophysical surveys.

The soil mercury survey obtained inconclusive results, with the Box Canyon area indicating a few anomalous values. These values are questionable and probably are due to to hot spring activity and mineralization within the Leadille limestone rock.

The electrical resistivity survey indicated several areas of low resisitivity zones above the Box Canyon area, the power station aera and Wiesbaden Motel area. From these low zones it is surmised that the springs are related to a complex fault system which serves as a conduit for the deep circulation of ground water through the system. (From the Abstract).

PROBLEMS AND RECOMMENDATIONS

For the most part very few major problems were encountered during this project and the ones that did develop were very easily solved. As all the problems have been discussed in depth, either in previous yearly technical reports or in the site specific reports, a brief discussion will be made of some of the more serious problems encountered and proposed solutions.

1). Urban environment. Unfortunately, many of the low to moderate temperature geothermal resource areas in Colorado are located in urban environments. As we found out, this makes exploration efforts very difficult. The soil mercury and electrical and seismic geophysical surveys in a number of instances proved less than satisfactory. Very late in the project we employed two methods which seemed to work very well in urban areas. These were shallow temperature measurements and soil helium surveys. Where employed in the same area these two methods gave supporting evidence for the location of the geothermal resources. It is recommended that more research into the applicability of these two methods be undertaken. They appear to offer great promise for the evaluation of geothermal resources in an urban environemt.

2). Soil mercury surveys. We experienced mixed results with this exploration method. This was primarily due to several causes: A) Trying to collect samples in an urban environment, where the soil had become contiminated by the activities of man, B) Low temperature and depth of Colorado's geothermal resources, especially in the Canon City area. It is believed that this exploration method should be judiciously applied. If we had to do it over again, I would not employ this method.

3). Geophysics. As so many of the thermal areas in Colorado are located in an urban environment we did not acquire consistently good geophysical data. In addition, the seismic method proved less than satisfactory in the San Luis Valley where the volcanic rocks are close to the surface. From my limited knowledge of the subject, the reason for the failure is not apparent. To overcome this it is believed that a whole suite of geophysical methods should be employed rather than just the one or two employed during this project.

TABLE 1. SUMMARY OF RESOURCE ASSESSMENT EFFORTS IN COLORADO AND AN ESTIMATE OF FUTURE WORK ELEMENTS
(See attached map for location of areas)

THERMAL AREA*	GEOLOGY		HYDROGEOLOGY**		GEOTHER-*** MOMETRY	GEO PHYSICS
	RECON.	DETAILED	RECON.	DETAILED		
1. Juniper		x	n		x	n
2. Craig		x	n		x	n
3. Routt		x	x		x	x
4. Steamboat		x	x		x	x
5. Brand's Ranch		x	n		x	n
6. Hot Sulphur		x	x		x	x
7. Haystack Butte	x	x	n		x	n
8. Eldorado Springs		x	n		x	n
9. Idaho Springs		x	x		x	x
10. Dotsero		x	n		x	n
11. Glenwood		x	x		x	x
12. South Canyon		x	n		x	n
13. Penny		x	n		x	n
14. Col. Chinn		x	n		x	n
15. Conundrum		x	n		x	n
16. Cement Creek	x	x	x		x	x
17. Ranger	x	x	x		x	x
18. Rhodes		x	n		x	n
19. Hartsel		x	x		x	x
20. Cottonwood Creek		x	x		x	x
21. Chalk Creek		x	x		x	x
22. Brown's Canyon		x	n		x	x
23. Poncha Springs		x	n		x	n
24. Wellsville		x	n		x	n
25. Swissvale		x	n		x	n
26. Canon City		x	x		x	x
27. Fremont		x	x		x	x
28. Florence		x	x		x	x
29. Don K Ranch	x		n		x	n
30. Clark		x	n		x	n
31. Mineral		x	x		x	x
32. Valley View	x		n		x	n
33. Shaws		x	x		x	x
34. Sand Dunes	n		n		x	n
35. Splashland	x		x		x	n
36. Dexter-McIntyre	x		n		x	n
38. Stinking Springs		x	n		x	n
39. Dutch Crowley		x	n		x	n
40. Eoff Artesian						
41. Pagosa Springs		x		x	x	x
42. Rainbow	x		n		x	n
43. Wagon Wheel Gap		x	n		x	n
44. Antelope and						
45 Birdsie	x		n		x	n
46. Waunita		x	x		x	x
47. Cebolla	x		n		x	n

THERMAL AREA*	GEOLOGY		HYDROGEOLOGY**		GEOTHER-***	GEO
	RECON.	DETAILED	RECON.	DETAILED	MOMETRY	PHYSICS
48. Orvis	x		n		x	n
49. Ouray		x	n		x	n
50. Lemon		x	n		x	n
51. Dunton		x	n		x	n
52. Geyser		x	n		x	n
53. Paradise	n		n		x	n
54 Rico		x			x	n
55 Pinkerton	x		x		x	x
56 Tripp-Trimble	x		x		x	x
57. Stratton	x		x		n	n
58. Piedra	n		n		n	n

* Areas are presented here in the same order that they are presented in C.G.S. Bull 39 and Resource Series 6.

** Hydrogeological appraisal is assumed to be detailed only if the C.G.S. drills and test wells like was done at Pagosa Springs.

*** Geothemometer estimates were done and published in C.G.S. Bull. 39.

x = done
n = never

TABLE 1 CONT.

THERMAL AREA	GRADIENT	SOIL MERCURY	AREAL EXTENT OF RESERVOIR ESTIMATED****	PRIORITY FOR DEVELOPMENT (1=high, 5=low)
Juniper	n	n	x	5
Craig	n	n	x	5
Routt	n	x	x	completed
Steamboat	n	x	x	completed
Brand's Ranch	n	?	x	3
Hot Sulphur	n	x	x	completed
Haystack Butte	?	n	x	4
Eldorado Springs	n	n	x	4
Idaho Springs	n	x	x	completed
Dotsero	n	n	x	5
Glenwood	n	x*****	x	1
South Canyon	n	n	x	5
Penny	n	n	x	3
Col. Chinn	n	n	x	4
Conundrum	n	n	x	-
Cement Creek	n	x	x	completed
Ranger	n	x	x	completed
Rhodes	n	n	x	5
Hartsel	n	x	x	completed
Cottonwood Creek	n	n	x	5
Chalk Creek	n	n	x	completed
Brown's Canyon	n	n	x	3
Poncha Springs	n	n	x	5
Wellsville	n	n	x	3
Swissvale	n	n	x	3
Canon City	x	x	x	completed
Fremont	x	x	x	completed
Florence	x	x	x	completed
Don K Ranch	n	n	x	5
Clark	n	n	x	5
Mineral	n	n	x	2-3
Valley View	n	n	x	5
Shaws	n	x	x	completed
Sand Dunes	n	n	x	5
Dexter-McIntyre	n	n	x	5
Stinking Springs	n	n	x	4
Eoff Artesian	n	n	x	4
Dutch Crowley	n	n	x	4
Pagosa Springs	x	x	x	completed
Rainbow	n	n	x	-
Wagon Wheel Gap	n	n	x	1-2
Antelope and Birdsie	n	n	x	3-4
Waunita	x	x	x	completed
Cebolla	n	n	x	-
Orvis	n	n	x	3-4
Ouray	n	x	x	completed
Lemon	n	n	x	2-3
Dunton	n	n	x	3-4

THERMAL AREA	GRADIENT	SOIL MERCURY	AREAL EXTENT OF RESERVOIR ESTIMATED****	PRIORITY FOR DEVELOPMENT (1=high, 5=low)
Geyser	n	n	x	3-4
Paradise	n	n	x	3-4
Rico	n	n	x	3-4
Pinkerton	n	x	x	completed
Tripp-Trimble	n	x	x	completed
Stratton	n	n	x	4
Piedra River	n	n	x	5

San Luis Valley — More geophysical and heat flow drilling needed.
Eastern Colo. — Completed

****Areal extent of the individual reservoirs were estimated and published in C.G.S. Resource Series 6, Hydrothermal Resource Base of Colorado--An Assessment.

*****All soil mercury determinations were made by the C.G.S. with the exception of Glenwood Springs which was done and published by Ron Klusman, Colo. School of Mines.

x = done
n = never

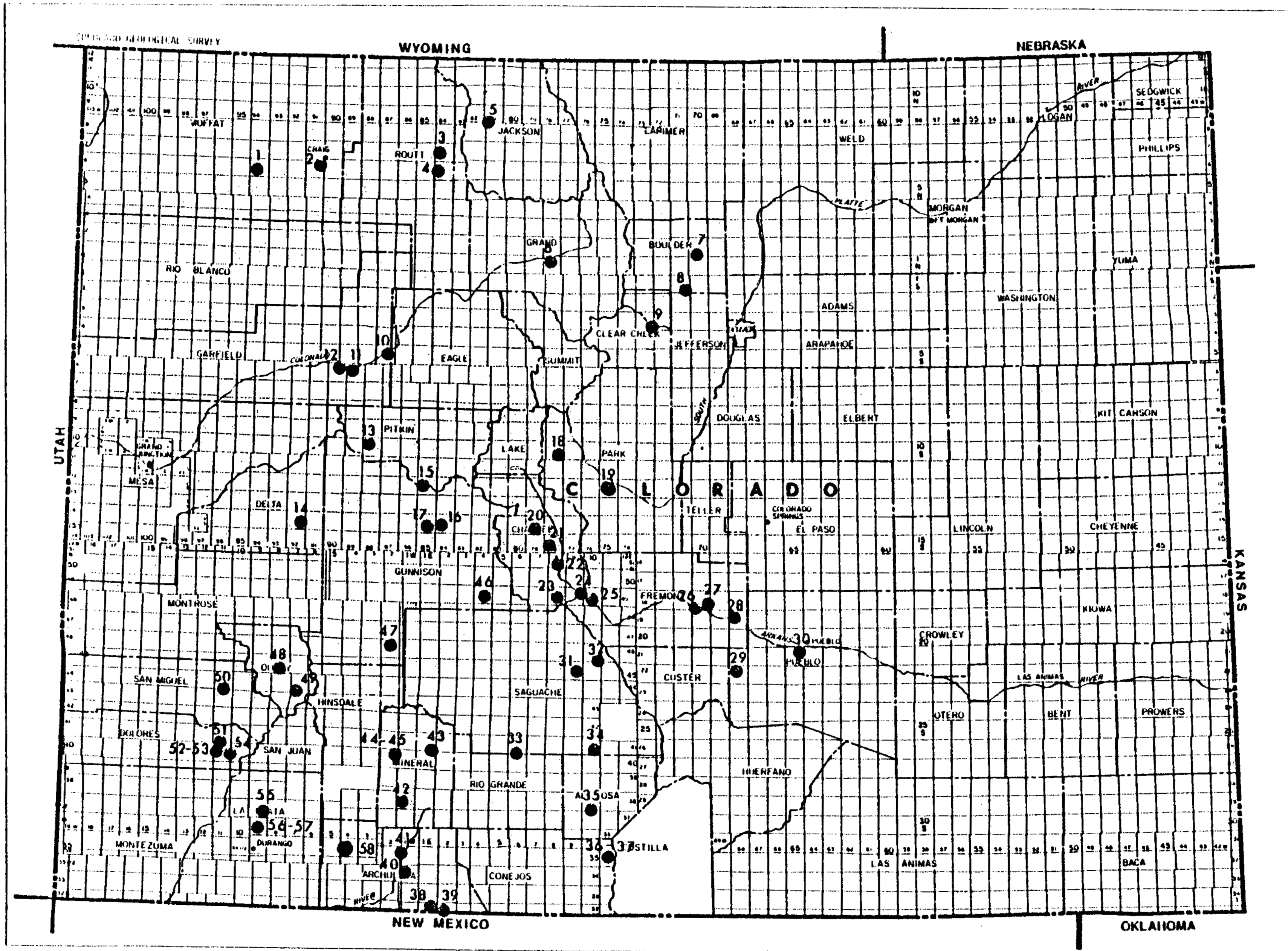

Figure 1. Location of thermal springs and wells in Colorado. Numbers identify thermal areas.