NMSU CAMPUS GEOTHERMAL DEMONSTRATION PROJECT

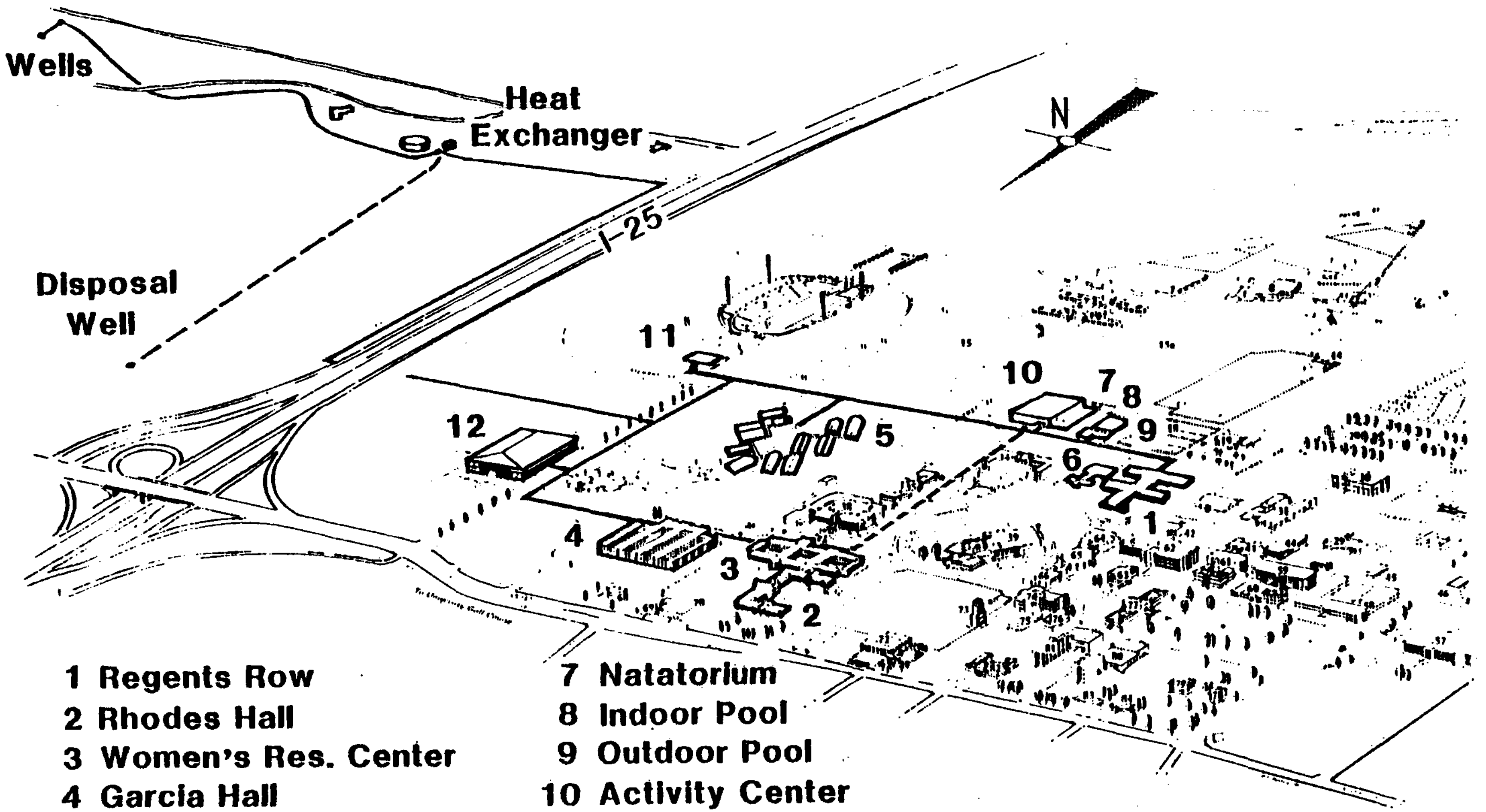
Roy A. Cunniff
Project Engineer
Box 3-PSL
Las Cruces, NM 88003
Telephone: (505) 522-9349

- Demonstrate Major Geothermal System
    - 140°F geothermal water (850 - 950 Ft. Well)
    - Two wells with combined flow rates of 550-600 gpm (200 gpm to be used for initial phase)
- Provide service to <u>Eleven</u> Buildings and Outdoor Pool
    - 5 Dorms; 2908 Students
    - Health Center; 102 Students per day
    - Indoor Pool; 204 Students, 8 classes per week
    - Activity Center; 1200 Students, 57 classes per week
    - Natatorium
    - Pan Am Center
    - Stadium Complex

  (Natatorium, Pan Am Center, Stadium Complex:) Used heavily by students; Geothermal system also will displace natural gas
- Save 78,000 mcf/year of natural gas
- Save $330,000/year (1980 costs)
- 4-6 year payoff
- System Overview
    - Three miles of pipeline
    - Heat exchangers and equipment building
    - Pumps and instrumentation
    - Building retrofit
    - Disposal system
    - Target completion date: 28 February 1982
- Cost Summary

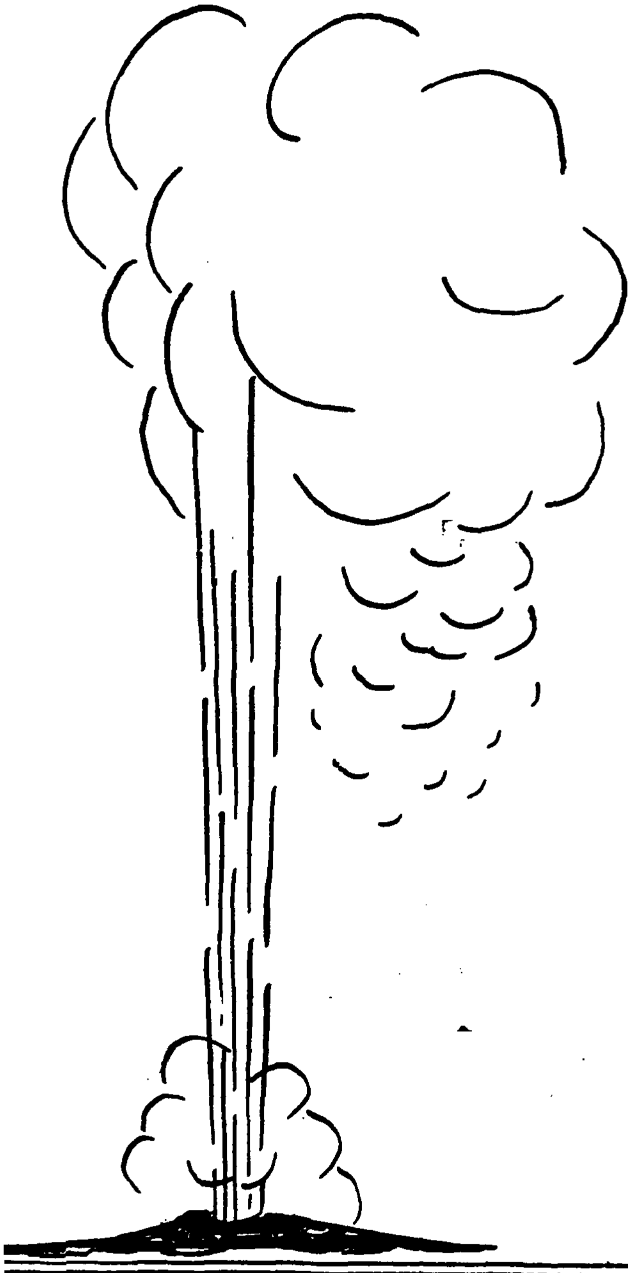
DOE	$ 336,000
NM	954,000
TOTAL	$1,290,000

NMSU CAMPUS GEOTHERMAL PROJECT



1 Regents Row
2 Rhodes Hall
3 Women's Res. Center
4 Garcia Hall
5 Alumni Ave. Res. Center
6 Health Center
7 Natatorium
8 Indoor Pool
9 Outdoor Pool
10 Activity Center
11 Stadium Facilities
12 Pan Am Center

DOE/ID/12099-1.1



THE COMMERCIAL PROSPECTS FOR GEOTHERMAL DIRECT HEAT: A Summary of the Economic Performance of Several DOE Demonstrations

Presentation to

U.S. Department of Energy's
Rocky Mountain Basin and Range
State Commercialization Teams
Custer State Park, South Dakota

William F. Hederman, Jr.
Laura A. Cohen

September 9, 1981

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for the
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ICF Incorporated
Washington, D.C.

U. S. DEPARTMENT OF ENERGY

Geothermal Energy

PREFACE

This one of a series of presentations based upon ICF's preliminary analysis of geothermal direct heat applications for the Idaho Operations Office of the U.S. Department of Energy. This analysis is reported in an interim topical report, Economic Assessment of Geothermal Direct Heat Technology: A Review of Five DOE Demonstration Projects, DOE/ID/12099-1. The results are being presented to government officials, project staffs, and others concerned with geothermal development.

INTRODUCTION

ICF has recently completed a preliminary economic assessment of five of the Program Opportunity Notice (PON) demonstration projects funded by the DOE Geothermal Direct Heat Applications Program.[1] In this presentation, we summarize the results of that analysis.

The economic performance of geothermal direct heat technology is assessed by comparing the costs of supplying geothermal direct heat energy to the costs of equivalent quantities of conventional fuels. To assure that the geothermal cost estimates would be accurate, only projects that had achieved operational status or advanced close to that stage were considered. The five projects reviewed in the first assessment were:

- Diamond Ring Ranch, which uses geothermal water from a previously existing well to heat several small buildings and to dry grain on a private ranch in South Dakota. (Operational: 1979)

- Klamath YMCA, which uses geothermal energy to heat a swimming pool and to provide space and water heating to a YMCA Building in Klamath Falls, Oregon. (Operational: 1980)

- Pagosa Springs, Colorado, where the local government is developing a near-the-surface geothermal resource to provide district heating for at least 127 businesses, residences, and public facilities. (Operation planned: 1981)

- Philip, South Dakota, where a local government has developed a small district heating system to heat five school buildings and at least eight businesses. (Operational: 1980)

- St. Mary's Hospital, which provides space heating and hot water preheating to a hospital in South Dakota. (Operational: 1980)

Table 1 summarizes key characteristics of these projects.

The results of our analysis indicate that for each of these projects geothermal resources offer a source of direct heat energy economically superior to conventional fossil fuels. In the remainder of this presentation, we describe the economic assessment. First, the analytic approach used is described. Next, we present the base case results, which are followed by a

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[1] ICF, Economic Assessment of Geothermal Direct Heat Technology: A Review of Five DOE Demonstration Projects, Interim Topical Report, prepared for U.S. DOE, Idaho Operations Office, DOE/ID/12099-1, June 1981.

TABLE 1

PROJECT DATA SUMMARY

Project (Sponsor Status)	Application	Well Depth (feet)	Fluid Temperature (°F)	Start-up of Operations	Planned Project Life a/ (years)	Capital Cost (1980 Dollars)	O&M Cost (1980 Dollars)	Annual Energy Delivered (109 Btu)
Diamond Ring Ranch (private firm)	grain drying; space & water heating	4100	152°F	1979	20	$ 489,000 b/	$ 5,000	7.9
Klamath YMCA (private, non-profit)	institutional space & water heating	1400	147	1980	25	285,000	2,100	7.0
Pagosa Springs (local government)	district heating	275 300	131 148	1981 c/	30	1,462,000	50,400	56.7
Philip, S.D. (local government)	district heating	4300	157	1980	30	1,188,000	4,000	14.8 d/
St. Mary's Hospital (non-profit, tax-exempt bonds)	institutional space & water heating	2200	106	1980	30	769,000	10,800	11.4

a/ Period prior to major capital re-investment.

b/ Adjusted to include cost of building new well and exclude costs of extending pipeline to existing well site.

c/ Planned.

d/ Data not available from project; estimated from energy displacement data.

sensitivity analysis. The presentation ends with a discussion of the general implications of the findings and identifies the next steps of the continuing economic analysis.

ANALYTIC APPROACH

We used a discounted cash flow (DCF) analysis to compare the costs of supplying equivalent quantities of geothermal direct heat energy and conventional fossil fuels for the life of the geothermal direct heat applications reviewed. The analysis employed an Unconventional Energy Supply Financial Model developed by ICF for DOE's Office of Finance and Tax Policy to properly account for the effects of taxation and inflation. The DCF results are presented in terms of the real levelized unit costs (dollars per million Btu) of providing the energy supplies for each project.[2]

The use of unit cost figures has two important advantages:

- project costs are translated into terms familiar to energy users

- project costs can be compared for projects of different sizes or of different project lifetimes.

Other factors requiring special attention to assure a consistent comparison of energy supplies included the following:

- project capital structure and cost of capital
- cost elements included in supply estimates
- inflation
- tax and royalty treatment
- measurement of energy supplied
- relevant alternatives to geothermal energy and price projections for these alternatives.[3]

BASE CASE RESULTS

The first set of economic comparisons used the cost and performance estimates for the five projects, adjusted for any special circumstances,[4] to analyze the economic attractiveness of geothermal energy for each of three investor types:

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[2] The real levelized unit cost represents the constant dollar figure that, when applied to a project's energy production stream, yields a discounted present value equal to the discounted present value of a supply's actual net cost stream.

[3] See Chapter II of ICF, Economic Assessment of Geothermal Direct Heat Technology for a detailed discussion of these factors.

[4] For instance, Diamond Ring Ranch had an existing well, but we added the cost of a new well to this project and adjusted the pipeline costs for a new well location.

- private, for-profit firms
- non-profit organizations that cannot issue tax-exempt bonds, and
- local governments (and non-profit organizations with tax-exempt bond authority).

Each of these categories is considered separately because each faces significantly different direct project costs and project discount rates due to differences in the tax payments and benefits incurred and the tax treatment of equity and debt instruments. Table 2 summarizes these potential investor category distinctions.

TABLE 2

INVESTOR CHARACTERISTICS

Potential Investor Category	Tax Status	Financial Status
Private, for-profit firm	• Subject to federal income taxes and property taxes • Bonds taxed	• Initial D/E of 50/50 • Return on equity: 9.5% real • Interest on debt: 3% (real)
Non-profit organization[1]	• No income or property taxes • Bonds taxes	• 100% debt financing • Interest on debt: 3% (real)
Local government[2]	• No income or property taxes • Tax-exempt bonds	• 100% debt financing • Interest on debt: 75% of nominal corporate interest rate

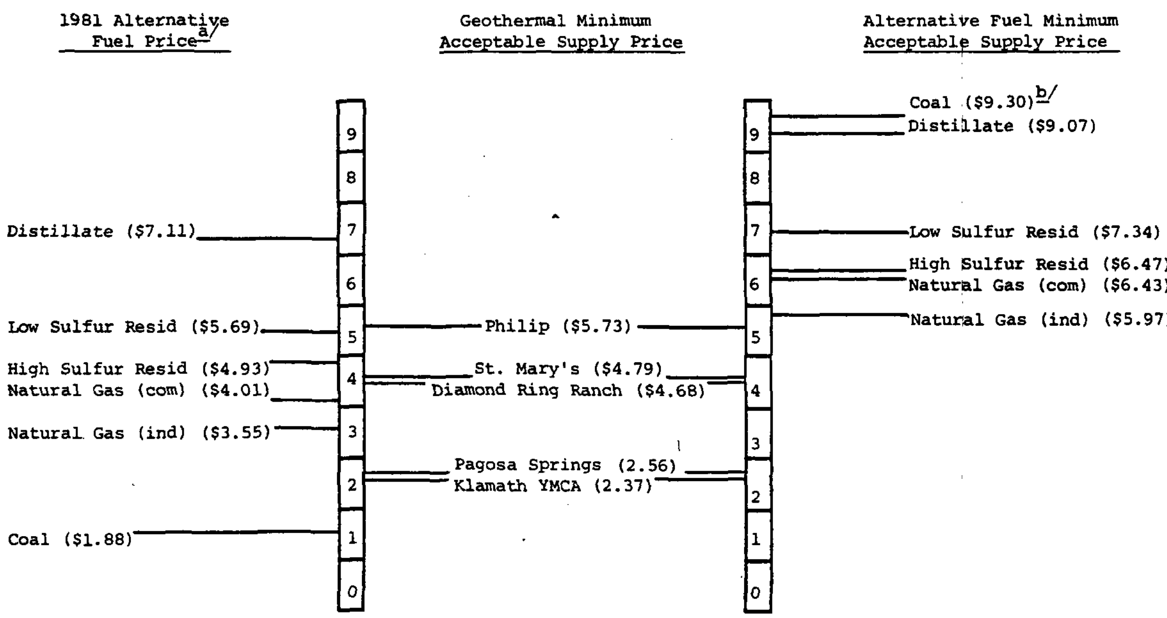
1 Without tax-exempt bond authority.

2 Including non-profit organizations with tax-exempt bond authority.

The results of the cost comparisons show that for each sponsor category geothermal energy is less expensive than distillate fuel oil, residual fuel oil, natural gas, or an alternative investment in a coal system. Figure 1 illustrates these results for the private, for-profit firm category.

FIGURE 1

BASE CASE COMPARISON OF
GEOTHERMAL AND CONVENTIONAL ENERGY COSTS
(1980 Dollars per Million Btu)



a/ Fuel only.
b/ Capital, O&M, and fuel costs.

The comparative economics of geothermal direct heat energy versus conventional fuels are even more favorable for geothermal when project sponsors are non-profit organizations or local governments. This results from (i) the avoidance of taxes, and (ii) the lower relevant discount rates. Despite some tax advantages the overall effect of taxation leads to net costs for the private firm. The lower discount rates increase the importance of the future benefits of geothermal direct heat applications. Table 3 presents these economic comparisons.

Before proceeding to examine the sensitivity of geothermal energy's projected economic advantages to the base case conditions, two other points are worth noting. These points relate to the differences in geothermal supply costs among projects and to an alternative measure of project economic performance, the internal rate of return.

TABLE 3

COMPARATIVE ENERGY COST ESTIMATES OF
GEOTHERMAL AND CONVENTIONAL FUELS
(1980 dollars per million Btus)

Project	Geothermal[1]	Distillate	High-Sulfur Residual	Natural Gas (Commercial)	Coal
NON-PROFIT ORGANIZATION					
Diamond Ring Ranch[2]	N/A	N/A	N/A	N/A	N/A
Klamath YMCA	1.77	9.57	6.87	6.88	5.49
Pagosa[2]	N/A	N/A	N/A	N/A	N/A
Philip	3.68	10.12	7.25	7.17	7.28
St. Mary's	4.17	10.11	7.29	7.16	5.41
LOCAL GOVERNMENT					
Diamond Ring Ranch[2]	N/A	N/A	N/A	N/A	N/A
Klamath YMCA	1.34	9.90	7.13	7.11	4.94
Pagosa	1.33	10.79	7.83	7.66	4.35
Philip	2.65	10.61	7.68	7.48	6.48
St. Mary's	2.28	10.60	7.67	7.47	4.85

[1] Excludes any exploration costs required to identify the geothermal resource and assess its suitability for the project.

[2] Listed as not applicable because the sponsor category is unlikely to invest in such a project.

Within each of the three investor classes just examined, the unit costs of the geothermal energy projects do vary. The highest unit costs are 2.0 to 2.4 times the lowest unit costs. Five projects do not provide an adequate data base for a definitive evaluation of the cause of geothermal cost variations. A review of the cost data and the project characteristics, however, suggests that well depth is quite important to geothermal energy project costs. Other factors that appear likely to influence costs are the temperature of the geothermal fluid, the rate at which the fluid flows from the well, and the extent to which the full capacity of each geothermal well is used.

The Base Case analysis just described presents the levelized unit cost for geothermal projects, given an assumed cost of capital to project sponsors. An alternative way of examining the competitive advantage of geothermal energy is to calculate the after tax internal rate of return which could be earned by a project when the value of the geothermal energy used is set equal to the cost of the fuel replaced. Table 4 shows the real internal rates of return which result when geothermal energy is valued at the same unit price as commercial natural gas, the least costly of the fossil fuels examined. These internal rates of return vary from 17 percent (real) for Philip, the project with the highest unit energy cost, to 34 percent (real) for Pagosa Springs, which has the lowest unit geothermal cost.

TABLE 4

INTERNAL RATES OF RETURN FOR GEOTHERMAL PROJECTS
(Geothermal energy value set equal to the price of natural gas delivered to commercial users)

Project	Internal Rate of Return (real)
Diamond Ring Ranch	20%
Klamath YMCA	31%
Pagosa Springs	34%
Philip	17%
St. Mary's	20%

SENSITIVITY ANALYSIS

Some of the conditions and assumptions about geothermal project costs, tax treatment, project financing conditions, and conventional fuel prices may not apply to all future projects. Variations could result from several sources, including:

- tax policy
- technological uncertainty
- alternative financing arrangements
- conventional fuel price escalation.

The sensitivity analysis sought to identify circumstances where the geothermal projects reviewed could become more costly than conventional alternatives. For this reason, the private, for-profit case of the Philip project was used for the analysis. This case was chosen because it represented the highest cost geothermal energy supply reviewed.

Although this approach "biased" the analysis against geothermal by using a high-cost project, geothermal energy remained economically superior to distillate fuel oil for all cases examined and superior to natural gas in many cases. Under the gas price assumptions used for this analysis, however, natural gas would be more economical than geothermal energy for the Philip project if the required real return on equity increased by 25 percent, the inital equity share grew to 75 percent, capital costs increased substantially (perhaps to provide an injection well), or the energy tax credit were removed. Table 5 lists the levelized unit costs of the Philip geothermal project and of distillate fuel oil and commercial natural gas for selected sensitivity analysis cases.

CONCLUSIONS

The results of our assessment indicate that geothermal energy can provide an economical alternative to conventional fossil fuels in low temperature heating applications. The cost estimates developed should be applicable to similar projects when the geothermal resource to be used is known to resemble the resources used in the projects examined. Consequently, potential investors in geothermal direct heat applications can use the results of this study to evaluate the economic attractiveness of proposed projects for some specific options.

The generally favorable preliminary findings in this report indicate the need for additional analysis along two avenues of inquiry. First, the preliminary findings based on projects using known geothermal resources should be further verified. Second, the economic assessment must expand its scope of analysis to include the costs associated with exploration to identify and confirm the presence of a useful geothermal resource.

TABLE 5

SELECTED SENSITIVITY ANALYSIS RESULTS

Parameter	Parameter Change	Philip Geothermal MASP b/ ($/million Btu)	Minimum Acceptable Supply Price a/ Distillate ($/million Btu)	Natural Gas (Commercial) ($/million Btu)
Capital Cost	25% Increase	$7.10	$9.07	$6.43
	25% Decrease	4.35	9.07	6.43
Yearly Production Rate	Declining to 1/2 initial Rate c/	6.40	8.78	6.22
	Declining to 0 c/	7.26	8.42	5.96
Debt/Equity Ratio	25/75	7.22	9.07	6.43
	75/25	4.23	9.07	6.43
Real Return on Equity	25% increase	6.80	8.79	6.20
	25% decrease	4.72	9.40	6.68
Tax Treatment	Remove energy tax credit	7.19	9.07	6.43
	"10-5-3" accelerated depreciation	3.88	9.07	6.43
Royalties	Remove royalty charge	5.15	9.07	6.43
Project Sponsor Status	Private, not-for-profit (no tax-exempt debt)	3.68	10.12	7.17
	Local government (tax-exempt debt)	2.65	10.61	7.48

a/ Conventional fuel prices are levelized assuming the same energy quantities and applying the same discount rate as the corresponding geothermal project costs.

b/ Minimum acceptable supply price.

c/ Linear decline beginning year 6.

The validity of the study's results would be enhanced by improving both the geothermal and the conventional energy cost estimates. The geothermal cost estimates can be improved by expanding the geothermal direct heat project data base with data from additional projects. For conventional fuel costs, future work should review fuel price escalation rates in greater detail.

The identification of a geothermal resource and the confirmation of its quality requires an analysis of the costs and risks of such activities and the means to finance them. The act of identifying and confirming the quality of a geothermal reserve may or may not lead to an exploitable resource. Future work on the economics of geothermal direct heat applications should estimate the costs of geological and geophysical exploration and the risks at each stage that a resource could prove unusable. Means of reducing the effective costs of such activity through full use of the tax advantages available and through creative financing approaches will also be examined.

On the basis of the preliminary evidence, it appears that the commercial prospects for geothermal direct heat technology are favorable. Our future work will seek to provide more information about the range of opportunities for economic exploitation of geothermal direct heat energy.

THE COMMERCIAL PROSPECTS FOR GEOTHERMAL DIRECT HEAT: A SUMMARY OF DOE DEMONSTRATION PERFORMANCE

SEPTEMBER 9, 1981

ICF INCORPORATED

PRESENTATION OUTLINE

- o BACKGROUND OF THE ANALYSIS
- o ANALYTIC APPROACH
- o BASE CASE RESULTS
- o SENSITIVITY ANALYSIS
- o CONCLUSIONS

BACKGROUND

- ECONOMIC ANALYSIS OF PON PROJECT PERFORMANCE, SUPPORTED BY DOE IDAHO
- 5 ADVANCED PROJECTS REVIEWED

PROJECTS REVIEWED

PROJECT	APPLICATION	STATUS
DIAMOND RING RANCH	SPACE HEATING, GRAIN DRYING	OPERATIONAL (1979)
KLAMATH YMCA	SPACE AND WATER HEATING	OPERATIONAL (1980)
PAGOSA SPRINGS	DISTRICT HEATING	EXPECTED STARTUP (1981)
PHILIP	DISTRICT HEATING	OPERATIONAL (1980)
ST. MARY'S HOSPITAL	SPACE AND WATER HEATING	OPERATIONAL (1980)

ANALYTIC APPROACH

- ECONOMIC ANALYSIS COMPARES ENERGY SUPPLY COSTS ON A DISCOUNTED CASH FLOW BASIS.
- FINANCING PROVISIONS ARE INCORPORATED.
- ECONOMIC, FINANCIAL, AND TECHNICAL FACTORS ARE TREATED CONSISTENTLY AMONG ENERGY SUPPLIES.
- COMPARISONS ARE MADE WITH SEVERAL CONVENTIONAL ENERGY SOURCES (E.G., DISTILLATE, RESIDUAL FUEL OIL, NATURAL GAS, AND COAL).

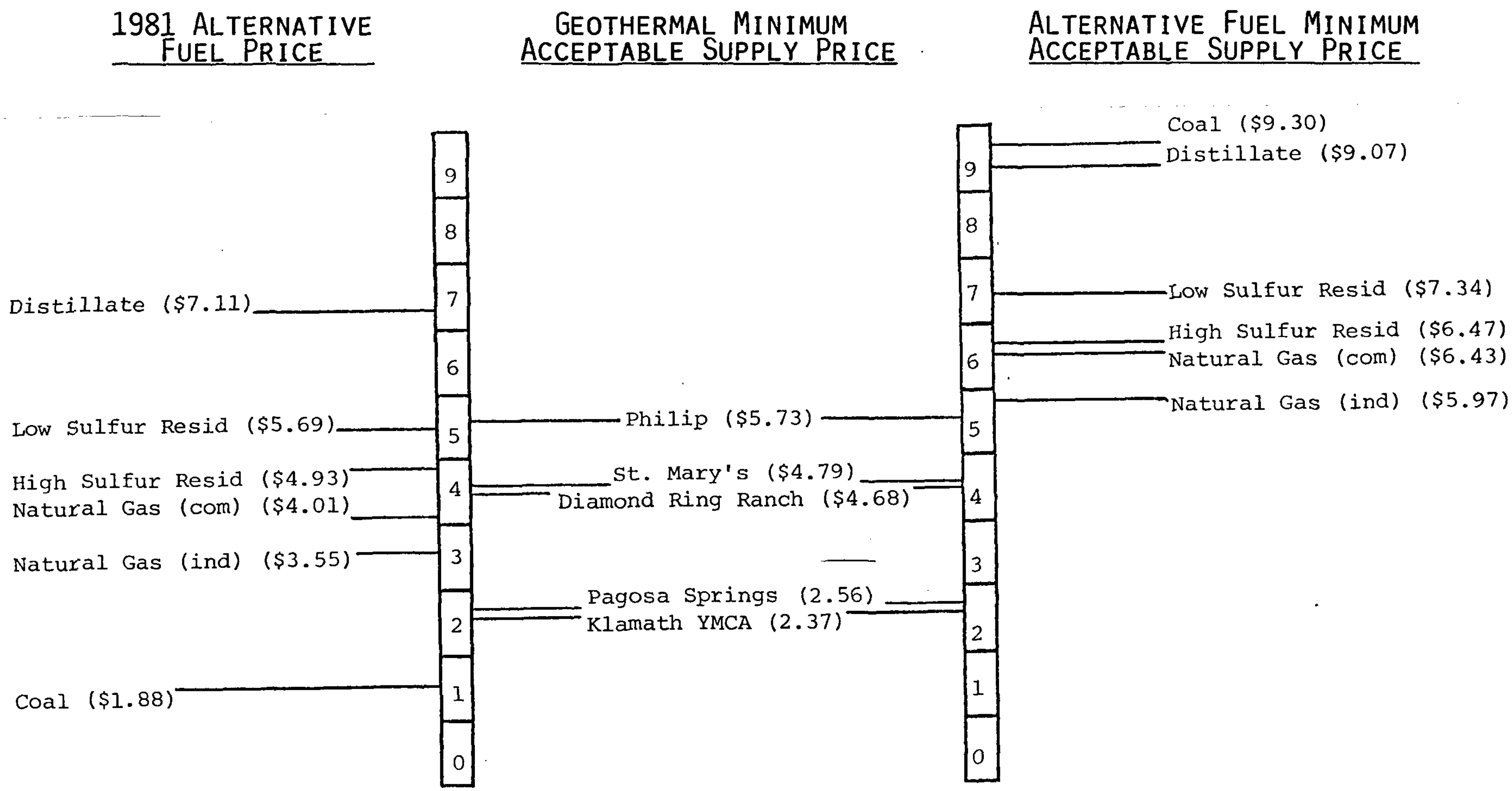
BASE CASE ANALYSIS

- ACTUAL COST (CAPITAL AND O&M) AND PRODUCTION DATA ARE USED TO THE MAXIMUM EXTENT FEASIBLE.
- SOME DATA ARE ADJUSTED TO ENHANCE VALUE OF RESULTS TO POTENTIAL INVESTORS.
- 3 POTENTIAL INVESTOR TYPES EXAMINED
  - PRIVATE, FOR-PROFIT
  - NON-PROFIT
  - LOCAL GOVERNMENT

INVESTOR TYPES HAVE IMPORTANT DIFFERENCES IN FINANCIAL CHARACTERISTICS

INVESTOR CATEGORY	TAX STATUS	FINANCIAL STATUS
PRIVATE, FOR-PROFIT FIRM	o SUBJECT TO FEDERAL INCOME TAXES AND PROPERTY TAXES o BONDS TAXED	o INITIAL D/E OF 50/50 o RETURN ON EQUITY: 9.5% REAL o INTEREST ON DEBT: 3% (REAL)
NON-PROFIT ORGANIZATION	o NO INCOME OR PROPERTY TAXES o BONDS TAXED	o 100% DEBT FINANCING o INTEREST ON DEBT: 3% (REAL)
LOCAL GOVERNMENT	o NO INCOME OR PROPERTY TAXES o TAX-EXEMPT BONDS	o 100% DEBT FINANCING o INTEREST ON DEBT: 75% OF NOMINAL CORPORATE INTEREST RATE

BASE CASE RESULTS
(PRIVATE, FOR-PROFIT FIRM)



THE ANALYSIS EXAMINED THE SENSITIVITY OF THE RESULTS TO SEVERAL INPUTS

- SENSITIVITY ANALYSIS PROBED THE POTENTIAL EFFECTS OF
  - TAX POLICY
  - TECHNOLOGICAL UNCERTAINTY
  - ALTERNATIVE FINANCIAL ARRANGEMENTS
- THE RELATIVELY HIGH COST PHILIP PROJECT SERVED AS THE BASIS FOR THE COMPARISONS

GEOTHERMAL DIRECT HEAT APPEARS LIKELY TO REMAIN ATTRACTIVE IN THE ABSENCE OF MAJOR PROBLEMS

- FOR ALL THE CASES EXAMINED, GEOTHERMAL REMAINS LESS COSTLY THAN DISTILLATE FUEL OIL.

- GEOTHERMAL REMAINS LESS COSTLY THAN NATURAL GAS, EXCEPT IN THE CASE OF:

  - SUBSTANTIAL COST OVERRUNS (+25%)
  - HIGH EQUITY SHARES (75%) OR RATE OF RETURN (12% REAL)
  - NO ENERGY TAX CREDIT

CONCLUSIONS

- o GEOTHERMAL DIRECT HEAT TECHNOLOGY HAS DEMONSTRATED A CAPABILITY TO PROVIDE ECONOMIC ENERGY SUPPLIES.
- o NEXT ANALYTIC STEPS SHOULD
  - -- EXPAND THE SCOPE OF THE ANALYSIS TO INCLUDE COSTS FOR EXPLORATION OF POTENTIAL RESOURCES
  - -- INCREASE THE NUMBER OF PROJECTS INCLUDED IN THE ANALYSIS (INCLUDING NON-FEDERALLY FUNDED ACTIVITY, WHERE APPROPRIATE)
  - -- EXPLORE THE EFFECTS OF ALTERNATIVE CONVENTIONAL FUEL PRICE SCENARIOS.

GEOTHERMAL

DIRECT HEAT APPLICATIONS

PROGRAM SUMMARY

NOVEMBER 1980

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

GEOTHERMAL

DIRECT HEAT APPLICATIONS

PROGRAM SUMMARY

PRESENTED

AT THE

SEMI-ANNUAL REVIEW MEETING

LAS VEGAS, NEVADA

NOVEMBER 20-21, 1980

U.S. DEPARTMENT OF ENERGY

GEOTHERMAL ENERGY DIVISION

ACKNOWLEDGMENTS

The project descriptions contained in this summary were prepared by the Project Teams of each of the twenty direct heat application projects currently in progress throughout the United States. The Department of Energy gratefully acknowledges their assistance in providing this information which will assist other potential users in assessing the economic and technical viability of the direct use of geothermal energy. Additional copies of this summary can be obtained through the Department of Energy Offices listed on page 7.

At this review, the project presentations are organized according to the phase the project is in: reservoir confirmation, drilling and testing; financial and institutional concerns; system design; and system construction and operation.

TABLE OF CONTENTS

GEOTHERMAL DIRECT HEAT APPLICATIONS
SEMI-ANNUAL REVIEW MEETING

AGENDA

Thursday, April 15, 1980

8:00 - 9:00	Registration
9:00 - 9:10	Welcome Mahlon Gates, Manager Nevada Operations Office
9:10 - 10:15	DOE Geothermal Programs Overview Eric Peterson, Program Manager Direct Heat Applications Programs DOE, Washington, D.C. Title VI - Energy Security Act Hilary Sullivan, Program Coordinator DOE, San Francisco Operations Office ICF Study on Direct Heat Application Projects William C. Stitt, President ECF Incorporated Materials Testing Marshal Conover Radian Corporation
10:15 - 10:30	Coffee Break

Session I

Reservoir Confirmation, Drilling and Testing

10:30 - 11:00	Madison County (ID) Food Processing Roger C. Stoker, Manager Geological Engineering Energy Services, Inc.

11:00 - 11:30	Elko (NV) Space and Process Heating Sheldon Gordon, Project Engineer Chilton Engineering
11:30 - 12:00	Pagosa Springs (CO) Heating Kenneth Goring, Project Engineer Coury & Associates
12:00 - 1:30	Lunch Speaker: Phil Edwardes City of Susanville
1:30 - 2:00	Holly Sugar (CA) Jay Seidman, Project Manager TRW Energy Systems Group
2:00 - 2:30	Warm Springs (MT) State Mental Hospital Karen Barclay, Project Manager Montana Energy and MHD R & D Institute, Inc.
2:30 - 3:00	Utah Roses Dr. Jay Kunze, General Manager Energy Services, Inc.
3:00 - 3:15	Coffee Break
3:15 - 3:45	Utah State Prison Jeff Burks, Project Engineer Utah Energy Office
3:45 - 4:45	Susanville (CA) District Heating Phil Edwardes, Principal Investigator City of Susanville
4:45 - 5:15	Reservoir Management for District Heating Systems Harold Derrah, Assistant City Manager Klamath Falls, Oregon
5:30 - 6:30	Social Hour

Friday, November 21, 1980

SESSION II

Financial and Institutional

8:30 - 9:00 **Boise (ID) District Heating**

Nathan Little, Project Manager
CH2M Hill - Boise

9:00 - 9:30 **Moana, Reno (NV) Apartment Complex Heating**

Dr. David J. Atkinson, President
Hydrothermal Energy Corporation

9:30 - 10:00 **El Centro (CA) Space Heating and Cooling**

Georgy Parker, City Manager
City of El Centro, California

10:00 - 10:15 **Coffee Break**

10:15 - 10:45 **Municipal Bonding Outlook**

Harold Derrah, Assistant City Manager
Klamath Falls, Oregon

SESSION III

System Design

10:45 - 11:15 **Kelly Hot Springs (CA) Agricultural Center**

Alfred B. Longyear
Lahontan, Inc.

11:15 - 11:45 **Navarro College and Memorial Hospital (TX)**
Ron Keeney, Project Engineer
Radian Corporation

11:45 - 1:00 **Lunch**

1:00 - 1:30	Klamath Falls (OR) District Heating James K. Balzhiser, Hubbard and Associates
1:30 - 2:00	Torbett-Hutchings-Smith Memorial Hospital (TX) Marshall Conover, Project Engineer Radian Corporation

SESSION IV

System Construction and Operation

2:00 - 2:30	Philip (SD) Schools Dick Berg, Project Engineer Hengal, Berg & Associates
2:30 - 3:00	Diamond Ring Ranch (SD) Dr. Stanley M. Howard Professor of Metallurgical Engineering South Dakota School of Mines and Technology
3:00 - 3:15	Coffee Break
3:15 - 3:45	St. Mary's Hospital (SD) James Russel, Administrator St. Mary's Hospital
3:45 - 4:15	YMCA of Klamath County (OR) Brian FitzGerald, General Director Klamath County YMCA
4:15 - 4:45	Aquafarms (CA) Becky Broughton Aquafarms International, Inc.

DIRECT HEAT APPLICATION PROJECTS

The use of geothermal energy for direct heat purposes by the private sector within the United States has been quite limited to date. However, there is a large potential market for thermal energy in such areas as industrial processing, agribusiness, and space/water heating of commercial and residential buildings. Technical and economic information is needed to assist in identifying prospective direct heat users and to match their energy needs to specific geothermal reservoirs. Technological uncertainties and associated economic risks can influence the user's perception of profitability to the point of limiting private investment in geothermal direct applications.

To stimulate development in the direct heat area, the Department of Energy, Division of Geothermal Energy, issued two Program Opportunity Notices (PON's). These solicitations are part of DOE's national geothermal energy program plan, which has as its goal the near-term commercialization by the private sector of hydrothermal resources. Encouragement is being given to the private sector by DOE cost-sharing a portion of the front-end financial risk in a limited number of demonstration projects.

The twenty-two projects summarized herein are direct results of the PON solicitations. These projects will provide (1) visible evidence of the profitability of various direct heat applications in a number of geographical regions, (2) technical, economic, institutional, and environmental data under field operating conditions that will facilitate decisions on the utilization of geothermal energy by prospective developers and users, and (3) demonstration of a variety of types of applications.

DOE PROJECT OFFICES

Three Department of Energy Operations Offices are responsible for the management of the direct heat application projects. The offices and their respective projects are:

OFFICE	PROJECTS
Idaho Operations Office 550 Second Street Idaho Falls, Idaho 83401 Contact: Mike Tucker Project Coordinator (208) 526-3180 Technical Support: Ed DiBello EG&G Idaho, Inc. Idaho Falls, ID 83401 (208) 526-9521	Boise Diamond Ring Ranch Elko Heating Madison County Pagosa Springs Philip Schools St. Mary's Hospital Utah Roses Utah State Prison Warm Springs State Hospital
Nevada Operations Office P.O. Box 14100 Las Vegas, Nevada 89114 Contact: Conway Grayson Engineering Branch (702) 734-3424	Navarro College T-H-S Hospital
San Francisco Operations Office 1333 Broadway Oakland, California 94612 Contact: Hilary Sullivan Program Coordinator (415) 273-7943 Technical Support: George Budney Project Manager Energy Technology Engineering Center Canoga Park, CA 91304 (213) 341-1000	Aquafarms International El Centro Holly Sugar Kelley Hot Springs Klamath County YMCA Klamath Falls Moana, Reno Susanville

DIRECT HEAT APPLICATIONS

PROJECT DESCRIPTIONS

PROJECT TITLE: Madison County Geothermal Project

PRINCIPAL INVESTIGATOR: Dr. J. Kent Marlor, Chairman
Madison County
Energy Commission (208) 356-3431

PROJECT TEAM: Madison County
American Potato Company
Energy Services, Inc.

PROJECT OBJECTIVE: To demonstrate the economics and feasibility of using a low-temperature geothermal resource for food processing and space heating application.

LOCATION DESCRIPTION: Rexburg, Madison County, Idaho
25 miles (40 km) northeast of Idaho Falls, Idaho
Population: 10,773 (Rexburg)
Area Activities: Potato Processing, agriculture and trade center.

RESOURCE DATA:

Well Depth: 3950 ft (1204 m)

Date Complete: 7/4/80 (rig dismissed, well not completed)

Completion Technique: Open Hole

Wellhead Temperature: 68°F (20°C)

Flowrate: 600 - 700 gpm (38-44 ℓ/s)

Summary: Madison County is at the edge of the Snake River Plain, an area that has been characterized as a young volcanic rift. Northeast trending faults, concentrated along the plain boundaries, are the source of many hot springs. The Madison County well intersected a fault at 3,000 ft (914 m). But the very porous formation has made it impossible to sample the formation fluid temperatures below 2400 ft, just below the casing.

Madison County (Continued)

SYSTEM FEATURES:

Application: Potato processing and district heating were originally proposed.

Heatload (Design): 25×10^6 Btu/hr potato processing (proposed)
60×10^6 Btu/hr space heat (proposed)

Yearly Utilization (Maximum): Geothermal resource not confirmed to date.

Energy to be Replaced: 1.8×10^{11} Btu/yr potato processing and 4.5×10^{11} Btu/yr space heat. (proposed)

Facility Description: Nine public buildings, residences and the American Potato plant were originally proposed.

Disposal Method: One injection well was originally proposed.

Summary: The Madison County project was originally proposed as a combination district heating and industrial process system. A deep well was to supply 250°F (121°C) water to the American Potato Company for use in blanching and drying equipment. An additional well supplemented by the geothermal water discharged from the potato plant was to be used in a district heating system for the Rexburg business district.

STATUS: Drilling below the 3150 ft level, using water as the drilling fluid, proceeded without returns. Severe lost circulation, at a number of known depths. Bridging occurred at several locations, and the hole has never been logged below 3480 ft. Drilled to 3950 ft, when it was decided to stop drilling because cuttings were not being adequately lifted. Air lifted (pumped) well for 3 days at about 600 gpm. No drawndown and no change in wellhead temperature (68°F). Well is cased to 2304 ft. Rig was dismissed. Well is bridged at 2800 ft. Flow meter logging revealed a 40 gpm natural flow into well at 2400 ft, flowing down. It is therefore, concluded that the cold water production at 2400 ft must be sealed off before anything definitive can be determined about the formation water temperatures below this depth.

CURRENT ESTIMATED PROJECT COSTS:

Total: $3,422,500

DOE Share: $1,677,025 (49%) Participant Share: $1,745,475 (51%)

Expenditures to date: $660,000

Madison County (Continued)

LESSONS LEARNED:

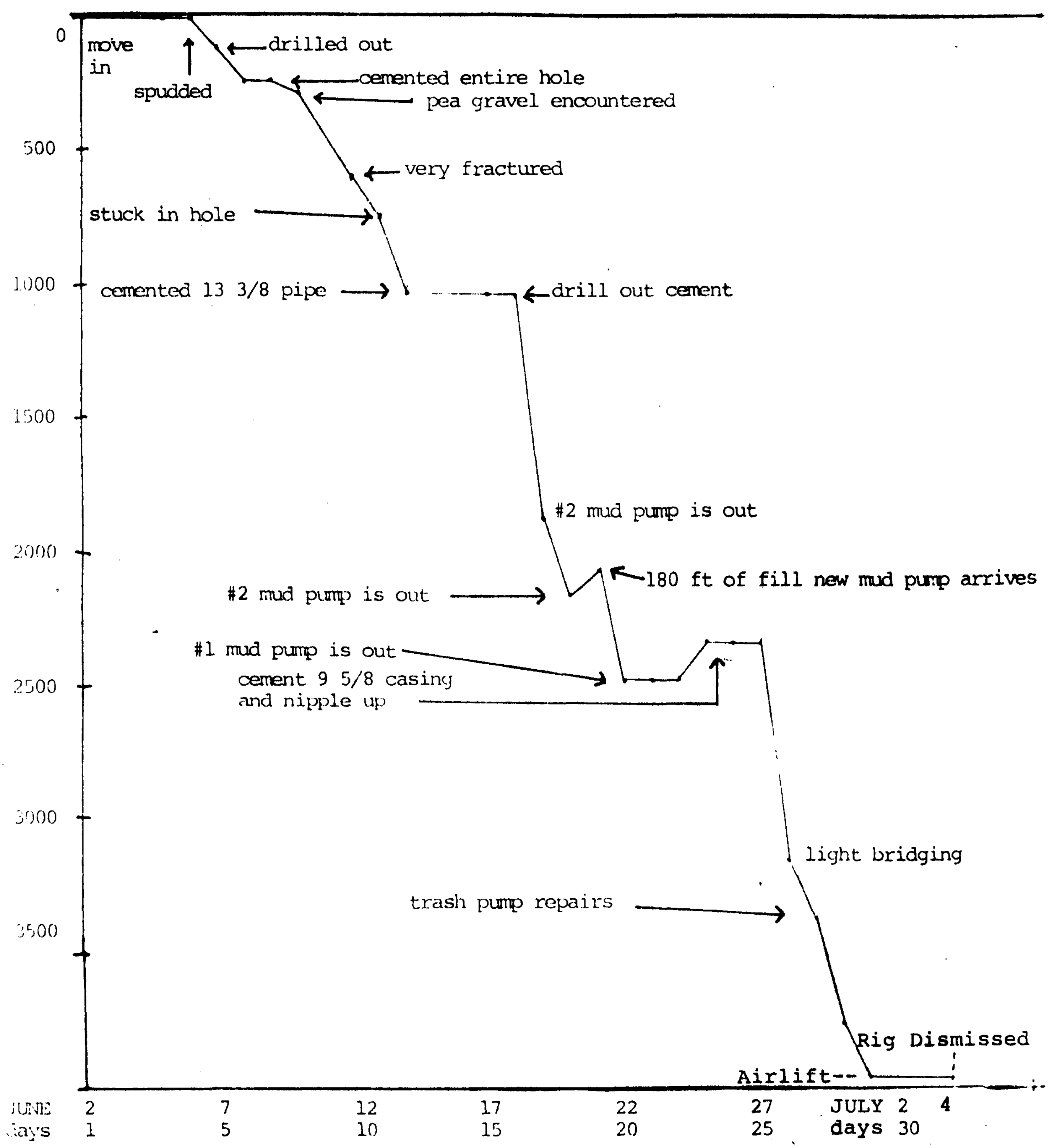
The $6,000 perday expense of the rig dictated that it be dismissed. Now there is pending remedial action with a workover rig. However, had it been known that downward flow in the well was masking the formation temperatures, liner could have been ordered in advanced, along with smaller diameter drill pipe to work within the liner using the rig that was then over the hole. Also, with half of the budgeted drilling funds uncommitted, there was the option of this being the reinjection hole, and drilling another well for production.

In retrospect, the choice of dismissing the large rig in favor of a workover rig was the least expensive option in pursuit of true formation water temperatures near the bottom of the hole. However, if much deeper drilling is to be done (as a result of encouraging bottom hole temperatures), the overall effect will be greater expense then had the large rig been kept over the hole on standby.

Currently, the project is awaiting authorization to proceed with a workover rig, to install a 7 in. liner from 2,300 ft (casing bottom) to top of fill at 3,700 ft. A cement plug will be spotted at 3,700 ft, and it and the fill drilled out to 3,950 ft.

7/23/80

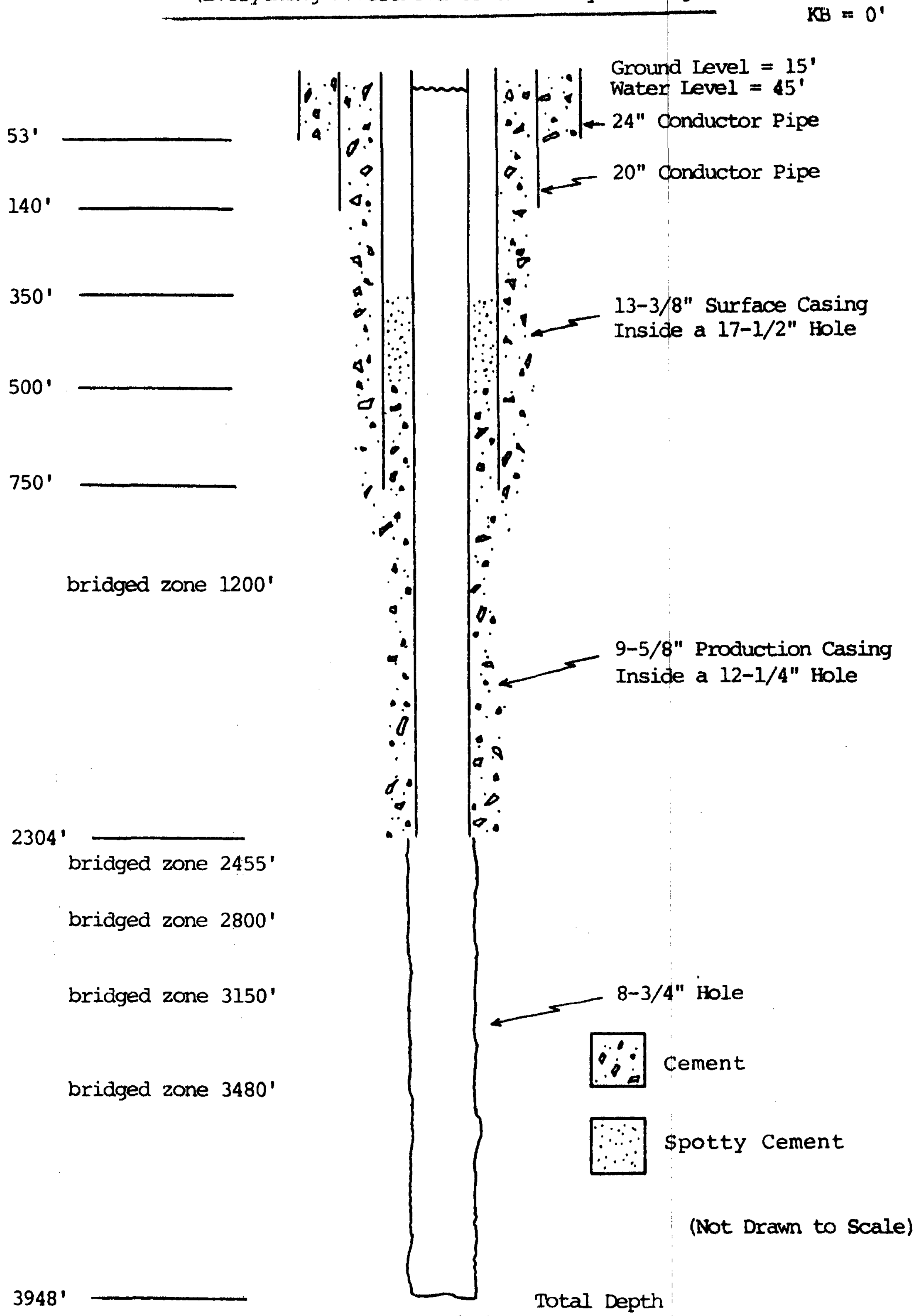
MADISON COUNTY GEOTHERMAL WELL #1



MADISON COUNTY WELL PROFILE 7/23/80

GEOTHERMAL WELL #1

(Everything Referenced to the Kelly Bushing " KB ")



PROJECT SUMMARY

Project Title:

Field Experiments for Direct Uses of Geothermal Energy
Elko Heat Company, Elko, Nevada

Location:

City of Elko, NV

Principal Investigator:

Mr. Ira S. Rackley, P.E., Project Manager
Chilton Engineering, 702-738-3108

Project Team:

- Elko Heat Company, Elko, NV - Mr. Jim Meeks, President
- Chilton Engineering, Elko, NV - Mr. Ira S. Rackley, P.E. Project Manager and Mr. Sheldon S. Gordon, P.E., Project Engineer

Project Objectives:

This project was selected to demonstrate the technical and economic feasibility of the direct use of geothermal brines from the Elko KGRA for the purpose of providing space, water, and process heat. In a more general sense, it is the aim of the project to generate information and approaches that will enable the proposers to develop the Elko resource as a viable alternative to the consumption of primary fuels for space, water and process heating in Elko.

Objectives related to this overall goal are:

- Develop adequate resource information to allow for the design of the geothermal process system.
- Use of this resource information to generate a plan for the continued development and use of this resource after the period of government support.
- Displace a significant portion of the primary fuel consumption in Elko for identified energy markets with geothermal energy.
- Determine the economics of the required investment and characterize the economics of a variety of applications of the resource.

Resource Data:

A gradient hole drilling program was initiated in April, 1980 with two holes being drilled within the business district of Elko. The location of the test holes was determined by the surface thermal survey conducted by Geothermal Surveys, Inc.

In September, 1980, two additional gradient holes were drilled on the western edge of the Elko Business District in an effort to gather more data on the complex faulting which seems to be controlling the heat flow from the Elko resource. A summary of the results of this drilling program is as follows:

Test Well EHC No. 1

Water Temperature @ 100'	15.4°C
Average Temperature Gradient	3.73°C/100'
BHT @ 995'	48.8°C
Maximum Temperature Gradient observed	5.8°C/100'
Water Quality	Good

Test Well EHC No. 2

Water Temperature @ 100'	14.5°C
BHT @ 900'	36.4°C
Average Temperature Gradient	2.74°C/100'
Maximum Temperature Gradient observed	2.8°C/100'
Water Quality	Good

Test Well ECH No. 3

Water Temperature @ 100'	61.9°C
BHT @ 565'	71.2°C
Average Temperature Gradient	2.97°C/100'
Maximum Temperature Gradient observed	2.97°C/100'
Water Quality	TDS - 694 mg/ℓ Silica - 56 mg/ℓ

Test Well EHC No. 4

Water Temperature @ 100'	15.1°C
BHT @ 625'	29.0°C
Average Temperature Gradient	2.65°C/100'
Maximum Temperature Gradient observed	2.65°C/100'
Water Quality	unknown

The lithology of the gradient holes as similar, consisting of some brown sands and silts in the upper sections, lighter volcanic sands in the middle, and altered volcanics to intermixed clay lenses in the bottom.

It is theorized that test holes No. 1 and 3 are on the down thrust side of a controlling northeast-southwest fault line. Also, there appears to be cross faulting in the vicinity of test hole No. 3.

It should be noted that the resource temperature is estimated to be 115°C based upon silica geothermemetry.

Design:

The project team has recently started conceptual design work for the project. Due to parallel scheduling of work tasks relating to the confirmation of the geothermal resource (i.e., gradient hole drilling) the present effort of the design team has been directed primarily towards the preparation of an inventory and detailed description of the existing mechanical systems in the three selected buildings.

This effort is the first step in a system design and modeling effort which we feel is somewhat unique. The three selected buildings will be computer modeled using DOE-2, a detailed building loads and system simulation model used to certify compliance to Title 24 of the California Administrative Code - Energy Conservation Standards. The building and process loads description generated by that modeling effort will then be used to drive a modified TRYNSYS simulation of the geothermal distribution system. This modeling effort will allow the design team to look at a number of options for the configuration of the geothermal distribution system and to design a system which may be expanded to meet future geothermal development needs of the community. The modeling tool will also have general applicability to the problems of design and performance estimation for geothermal district and process heating systems. The design team feels that a design tool of this nature will be particularly useful in the evaluation of system economics.

The buildings selected for retrofit to the geothermal source provide a wide variety of system types and configurations. These are described in more detail below. While the diversity of systems has posed a number of problems for the design team, it has also provided the opportunity for the project team to design and operationally test systems for a variety of retrofit applications. This experience will be useful in the effort at continued development of the resource.

Building Systems and Load Summary:

1. Henderson Bank Building

The fifty year old Henderson Bank Building is a four-story, 21,000 sq.ft., brick or stone faced concrete building. The first floor (bank lobby) rises the equivalent of two stories. A mezzanine covers approximately one-third of the floor area and serves as bank office space. The second through fourth floors are office rental spaces. The basement is an unconditioned space and houses the primary energy conversion equipment.

The primary energy conversion equipment applicable to geothermal retrofit is a 200 HP hot water boiler. The boiler is coupled to a perimeter radiation distribution system. Cast iron radiators are located normally at each window. Each radiator is controlled by a thermostatically actuated modulating valve.

2. Vogue Laundry

The Vogue Laundry is a 17,300 sq.ft. building. The building construction is tilt-up concrete walls with a 25 ft. high beamed dome, which houses the dry cleaning and laundry facilities. A single story office space fronts the domed building.

Process loads make up the majority of the building energy demand. Internal gains from these process loads supply, in large part, the heat necessary to meet building loads. The primary energy conversion equipment are two 250 HP 125 PSIG steam boilers in parallel. Normally, only one boiler is fired at a time. The 125 PSIG steam is utilized directly by two commercial flat irons. A hot water generator converts the steam into 175°F hot water which is stored in a 5,000 gallon holding tank. This 175°F hot water is used by six commercial washing machines of a combined capacity totalling 3,130 lbs. Discharged waste water from the washers is run through a heat recovery system to preheat makeup water into the hot water storage tank. The geothermal retrofit will be utilized to heat hot water for the washers.

3. Stockmen's Motor Hotel

The Stockmen's consists of several building components. First is the original motor court building. This is a two-wing, three-story, motel-type building with a heated swimming pool located in the court yard.

Attached to the motor court is the two-story casino/restaurant. The first floor houses the casino/restaurant. The second floor houses air handling equipment and operates as a return plenum. In 1965 a two-story addition was built on top of the casino/restaurant section. These two floors consist of hotel rooms with a large glass-covered atrium court yard in the middle. Another addition was built off the casino/restaurant section in 1973. This two-story addition consists of a showroom, storage area, and four banquet rooms. Underneath the entire building is a basement/garage, which is used as office space, storage, parking, and to house mechanical equipment.

The primary energy conversion heating equipment consists of two 250 HP 60 PSIG steam boilers. Again, these boilers are piped in parallel with usually only one boiler on line at a time. The 60 PSIG steam is used as the main heat transfer medium to the steam coils or hot water generators.

There are several types of distribution systems which corresponds to the various building components. The original motor court is serviced by a modified, two-pipe hot/chilled water system, with individual terminal room fan coil convertors. 180°F hot water is supplied to the system from a steam fired hot water generator. The heated swimming pool utilizes 100°F hot water, again from a hot water generator.

The casino/restaurant is serviced by three air distribution systems and an outside air preheat system. The four systems utilize steam coils for heating. 60 PSIG supply steam is pressure reduced to 10 PSIG at each coil.

The two floors of hotel rooms overhead of the casino/restaurant is serviced by a four-pipe hot/chilled water system. Again, individual terminal room fan coil convertors are utilized. 180°F hot water is supplied from a steam fired hot water generator.

The showroom addition has three types of systems. The majority of space conditioning is supplied by six air handlers. These air handlers are equipped with steam coils which utilize pressure reduced 10 PSIG steam. Two 30 PSIG unit heaters service the storage area. Lastly, a 30 PSIG baseboard system is used to heat a small portion of the addition.

Finally, three air handlers service the underground parking area and mechanical room. These air handlers are equipped with steam coils which utilize either 60 or 30 PSIG steam.

Cooling is accomplished by utilizing two centrifugal water chillers supplying chilled water to the various systems noted above. The feasibility of retrofitting the Stockmen's heating systems will be two-fold. First, all hot water systems will simply be tied into the geothermal source via heat exchangers. Secondly, all steam boilers, distribution piping, and coils will be retrofitting to hot water and connected to the geothermal source. This will be a major undertaking and requires extensive repiping.

PROJECT TITLE: Pagosa Springs Geothermal Heating and Distribution System

PRINCIPAL INVESTIGATOR: Fred A. Ebeling, Planning Administrator
(303) 264-5851

PROJECT TEAM: Town of Pagosa Springs
Archuleta County
School District #50-Joint
Coury and Associates, Inc.

PROJECT OBJECTIVE: To provide the community with a means of using its natural hydrothermal resource for space heating.

LOCATION DESCRIPTION: Pagosa Springs, Colorado
60 miles (97 km) east of Durango, CO
Population: 1500
Area Activities: Ranching, Lumbering, & Tourism/Recreation

RESOURCE DATA:

	PS-3	PS-5
Well Depth:	300 ft. (91 m.)	275 ft. (84 m.)
Date Complete:	7/2/80	7/31/80
Completion Technique:	Open hole	Open hole
Wellhead Temperature:	131°F. (55°C.)	148°F. (64° C.)
Flowrate:	600 gpm (38 ℓ/s) for 12 hr test	1200 gpm (76 ℓ/s) for 12 hr test

Summary: The geothermal resource in Pagosa Springs has been used since the early 1900's. Nearly 30 wells have been drilled for heating and recreation purposes. These wells are drilled to depths of less than 500 feet (152 m) and produce waters ranging in temperature from 130°-170°F. (54°-77°C.). The hydrothermal fluids are produced from a Dakota Sandstone acquifer.

SYSTEM FEATURES:

Application: District Heating

Heatload (Design): 27×10^6 BTU/hr (7.9 MW)

Yearly Utilization (Maximum): 28.6×10^9 BTU/yr (.96 MW-yr)

Energy Replaced: Natural gas - 40.8×10^6 cu.ft.

Facility Description: 10 public buildings, 54 businesses, and 63 residences

Disposal Method: The State of Colorado has agreed to discharge of the geothermal fluid to the San Juan River.

Summary: The district system will provide heating for users located along U.S. Highway 160. For the proposed closed distribution system, two independent loops have been designed. The initial system will utilize 900 gpm (57 ℓ/s) but will be capable of expansion to 1800 gpm, (113 ℓ/s).

STATUS:

Technical Scope

The objective of this project is to demonstrate the engineering and economic feasibility of the utilization of a moderate temperature geothermal resource for space heating.

For the proposed closed distribution system, two independent loops have been designed, one for the east side of town and the other for the west side, to provide a safety factor in the event of a pipeline breakage. The east loop is designed to carry 1350 gpm. The west loop has been designed for 1000 gpm; however, initially it will carry only 500 gpm. This is to permit future expansion of the distribution system into the growth areas of Pagosa Springs. A schematic diagram of the overall design is shown on Figure 1. Briefly, the system will operate as follows:

1) Clean city water will be heated with the geothermal fluid using two plate heat exchangers. The geothermal fluid leaving the plate heat exchangers is then discharged to the San Juan River.

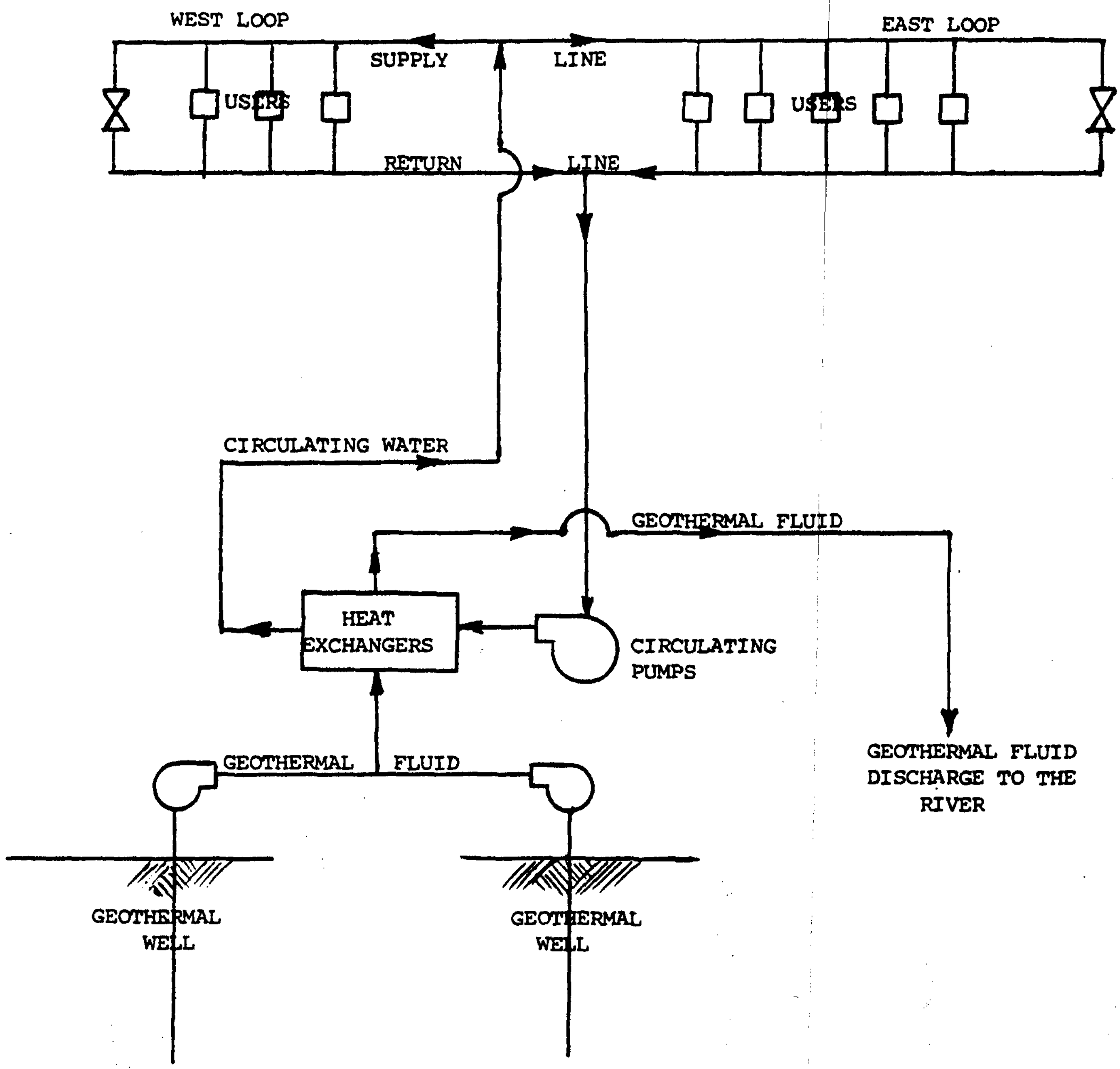
2) The clean heated city water will be circulated in each of two closed loops by means of one to four pumps, depending on user demand. Each of the loops consists of large diameter concrete asbestos pipes, 6 inches to 10 inches, referred to as trunklines, and smaller dismeter service pipes carrying the water to the individual users. Two parallel trunklines are in each loop. An insulated supply trunkline carries the heated circulating water, and an uninsulated return trunkline directs the cooled circulating water back to the heat exchangers.

3) At the terminal point of the supply line, in each loop, there will be flow control valves to ensure a minimal amount of hot water being circulated at all times.

4) The circulating water is collected in the return trunkline and then routed to the heat exchangers where the entire process is repeated.

SCHEDULE:

The wells required for the project were completed earlier this summer. Based on results from the well drilling program, the final design was completed in October and has been reviewed by DOE. Recommendations coming from this review are currently being incorporated into the design and bid documents. The major milestones for the remainder of the project are now scheduled as follows.



SCHEMATIC DIAGRAM OF THE TOWN GEOTHERMAL HEATING SYSTEM

FIGURE #1

1. Send out bid documents — Mid-November 1980
2. Construction contracts — January 1981
3. Construction — March - July 1981
4. System testing — August 1981
5. System operation — September 1981

CURRENT ESTIMATED PROJECT COST

Total	1,364,280	
DOE share	1,111,000	81%
Participant share	253,280 *	19%

* Includes $115,500 of existing facility credits. Also, Partiipant has agreed to pay back $60,000 from revenues after the system becomes operative.

LESSONS LEARNED

1. With the rapidly escalating costs of materials and labor, an appropriate contingency factor should be included in all cost estimates and should be acknowledged and accepted by grantor agencies. A good portion of our cost overrun from original agreement estimates made over two years ago are because of inflationary cost escalation during that time.

2. Keeping the public informed of project progress is important for successful acceptance, and to minimize erroneous information and rumors. Interviews by media reporters frequently result in partial, misleading information being published or broadcast. Carefully written news releases are best but even then the media space or time limitations result in editing which often changes the context. If at all possible a person should be designated to communicate with the media and the public on a regular basis.

3. Predicting the existence of geothermal fluid underground, and especially quantification, is not reliable even in close proximity to existing wells. It seems the only dependable way to determine the existence of, and to quantify, geothermal sources is by means of test holes.

In our project a new well located only 30 feet from a previously drilled test well produced fluid 10°F cooler than had been obtained from the test well at comparable depth. A second new well located 350 feet southwest of the first one did not produce fluid quantity or temperature comparable to the first new well nor as expected from geological analysis of the sub-strata. The well could not be used and was cemented up. A third new well located 180 feet east of the first one and about 30 feet south of an existing old well produced much greater quantity of fluid than either of them and 17°F hotter and at a depth considerable less than predicted by geological analysis of the sub-strata.

4. Drilling geothermal wells, particularly artesian wells, presents problems and situations not encountered in usual water well drilling. This applies not only to the temperatures and pressures involved but also to the subsurface strata which may have been affected by the geothermal conditions. Anomalies from usual geologic situations should be expected.

5. Keeping state agencies and local government bodies informed on the progress of the project and particularly about well drilling is of great value in assisting various permitting and approval requirements.

HOLLY SUGAR

PROJECT TITLE: Holly Sugar/TRW Geothermal Project

PRINCIPAL INVESTIGATOR: Louis P. Orleans, Holly
Jay Seidman, TRW

PROJECT TEAM: Holly Sugar Corporation
TRW Energy Systems Group

PROJECT DESCRIPTION: This project is the second phase of an industry/DOE program to exploit geothermal energy at a sugar beet processing plant in Brawley, California. The program intends to capitalize on the geothermal energy potentially available from a company-owned resource and apply the energy directly to the processing of sugar beets in the company facility. At its completion, and assuming the resource is adequate in composition, temperature and flow rate, the available geothermal energy will replace over 225,000 equivalent barrels of fuel oil per year through a technically straightforward, economically sound and environmentally acceptable geothermal application.

PROJECT LOCATION: The well site is located on Holly Sugar property, roughly half way between the cities of Brawley and El Centro in the Imperial Valley in California.

RESOURCE DATA:

Well Depth:	8758 feet MD 8500 vertical depth
Completion Date:	February, 1981
Completion Technique:	Slotted liner/liner
Well Diameter:	20" conductor, 13 3/8" casing, 9 5/8" casing, 7" liner (Figure 1)
Wellhead Temperature:	350°F (typical)
Flow Rate:	500 gpm (typical)
TDS:	25,000 ppm (typical)

SYSTEM FEATURES: Application: Energy from the geothermal well will be used to heat air to directly replace gas-heated air in the drying of sugar beet pulp. If the temperature is high

SYSTEM FEATURES:
(Continued)

enough, and if there is a large enough flow, some steam will be generated for general plant application.

Heat Load and Yearly Utilization: For the pilot plant, the heat load will vary with the temperature of the resource. With a minimum acceptable temperature of 292°F the heat load is approximately 3.8 x 10^8 Btu/hr or an equivalent of 182,500 Bbl of oil for the duration of the campaign.

If the resource comes in at higher temperatures an added amount of oil can be replaced by supplying heat to other users in addition to the low pressure steam and the pulp drying; potentially upwards of 300,000 Bbl of oil/year.

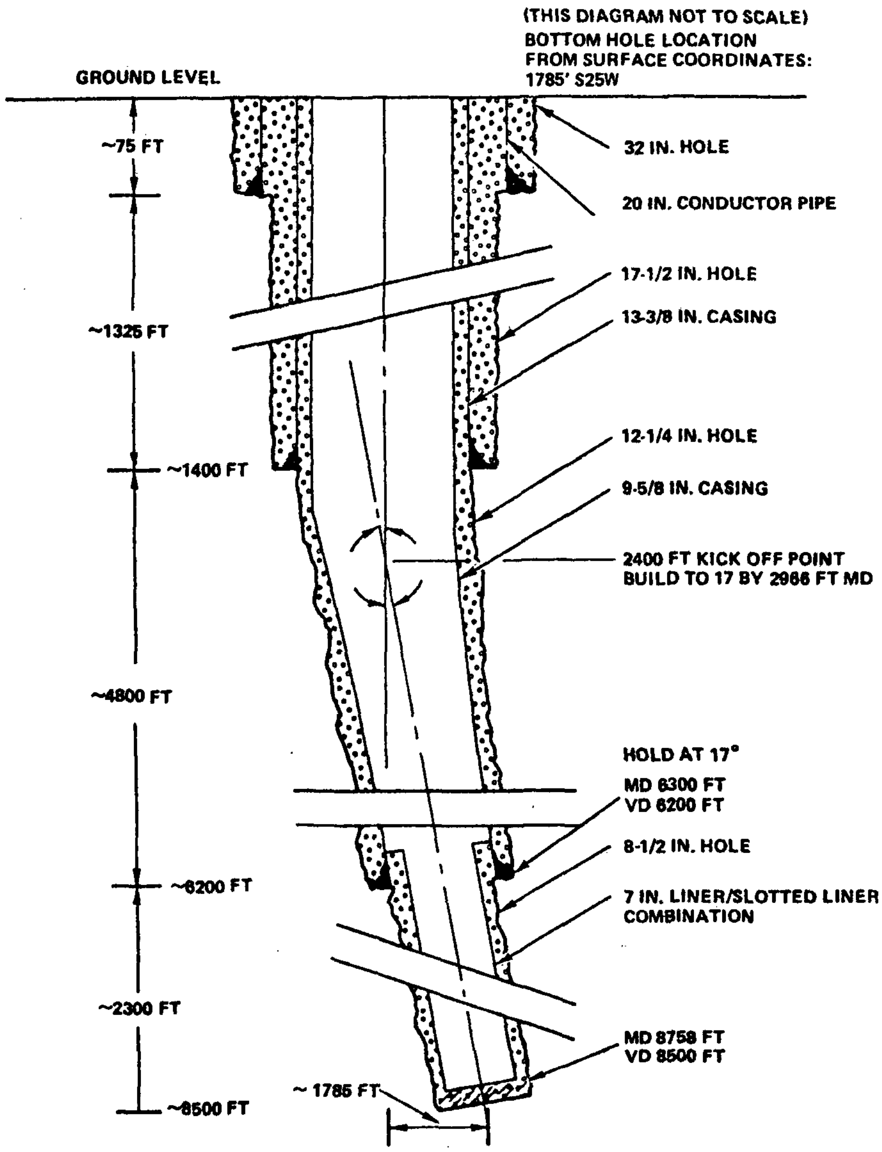
Energy Displaced: Approximately 300,000 barrels of oil equivalent.

Facility: During the pilot plant operation, the geothermal energy will be used to completely replace the gas used for the beet pulp dryer, and depending on the quality and quantity of the resource, some of the make-up steam for auxiliary plant operations. In the final configuration, the geothermal energy will be used to make up steam for beet processing, electrical generation, mechanical drivers, refrigeration and drying. (The dryers use approximately 45 percent of the total energy used by the plant).

Disposal Method: During the test operation, waste brine will be disposed of in approved sumps. During the pilot plant and subsequent operation, the waste brine will be reinjected into a different strata at the well site.

STATUS:	Preliminary siting and obtaining of permits have been completed. Roads and well pad have been constructed. Cellar has been installed around 75 foot conductor. Subcontractors and suppliers have been selected for the production and injection well casing, the casing inspection, casing slotting, the mud program, well head, cementing, drilling, direction drilling, logging and permeability tests. We anticipate drilling will start January 2, 1981.
COSTS:	Pilot Plant Facility: $ 3,266,795 Total Program: $ 4,000,000 Total Contract Amount to Date: $ 3,783,895*
LESSONS LEARNED:	Shortages in supply; particularly casing, poor quality casing, and accelerating costs.

* $3,546,897--DOE
$ 236,998--Holly Sugar


(THIS DIAGRAM NOT TO SCALE)
BOTTOM HOLE LOCATION
FROM SURFACE COORDINATES:
1785' S25W
GROUND LEVEL
~75 FT
~1325 FT
~1400 FT
~4800 FT
~6200 FT
~2300 FT
~8500 FT
~ 1785 FT
32 IN. HOLE
20 IN. CONDUCTOR PIPE
17-1/2 IN. HOLE
13-3/8 IN. CASING
12-1/4 IN. HOLE
9-5/8 IN. CASING
2400 FT KICK OFF POINT
BUILD TO 17 BY 2966 FT MD
HOLD AT 17°
MD 6300 FT
VD 6200 FT
8-1/2 IN. HOLE
7 IN. LINER/SLOTTED LINER
COMBINATION
MD 8758 FT
VD 8500 FT

PROJECT TITLE: Geothermal Heating of Warm Springs State Hospital

PRINCIPAL INVESTIGATOR: Karen L. Barclay, Montana Energy Research and Development Institute, (406) 494-6246

PROJECT TEAM: State of Montana
MERDI, Inc.
Energy Services, Inc.
CH2M Hill, Inc.

PROJECT OBJECTIVE: To develop the geothermal resource at Warm Springs for domestic water and space heating.

LOCATION DESCRIPTION: Warm Springs State Hospital, Deer Lodge County, Montana
15 miles (24 km) south of Deer Lodge
Population: 10,700 (Deer Lodge County)
Area Activities: Mining, state hospitals, and agriculture

RESOURCE DATA:

Well Depth: 1498 ft (457 m)

Date Complete: 12/5/79

Completion Technique: Slotted Liner

Wellhead Temperature: 171°F (77°C)

Flowrate: 250-300 gpm (15.8-18.9 ℓ/s) required for system design

Summary: Warm Springs is located adjacent to the State Hospital and discharges 171°F (77°C) water with a dissolved solids content of 1250 mg/ℓ. The source of the geothermal fluid is attributed to deep circulation in fault zones.

SYSTEM FEATURES:

Application: Space and water heating

Heatload (Design): 6.6×10^6 Btu/hr (1.93 MW) estimated

Yearly Utilization (Maximum): 26.0×10^9 Btu/yr (.87 MW-Yr) estimated

Energy Replaced: Natural gas - 7.5×10^7 cu. ft.

Facility Description: 2 buildings out of 9 at the complex will be served with geothermal water.

Disposal Method: Surface discharge to migratory waterfowl wetlands.

Summary: Two plate-type counterflow heat exchangers will provide space and domestic water heating to the Warren and Food Service buildings. A geothermal side ΔT of 100°F will be achieved by placing these heat exchangers in series.

STATUS:

The Warm Springs State Hospital project was initiated in February, 1979 with an environmental assessment being done of what impact the project would have on the surrounding area. This assessment addressed both human and natural environment factors with respect to development of the geothermal resource. Concurrent with this assessment a legal/statutory review was conducted to determine those legal requirements having to be met prior to, during, and after development of the resource.

Resource evaluation also commenced in the same time frame with the primary objective being the selection of the most favorable geological location for siting of the geothermal well.

All readily available data (reports, maps, surveys, and studies) were evaluated in regard to the nature of the geothermal resource. The Montana Bureau of Mines and Geology also conducted a gravity and resistivity survey within the immediate area of Warm Springs' existing surface manifestation (hot spring mound). The resistivity survey indicated a low in the area of the mound and main buildings. The gravity data indicated that a northwest trending linear exists ≈1300 feet northeast of the mound and a gravity high is located on the south side of this linear just east of the mound.

Two independent structure studies were made of the Deer Lodge valley which resulted in the mapping of a number of features with identifiable surface expression and three questionable faults running northeast to southwest and north to south.

Taking into consideration all the geophysical and geological information, the Warm Springs State Hospital production well was sited (see Figure 1) northeast of the mound in the area of the facility's heating plant.

The well was spudded in at 12:25 p.m. October 12, 1979. A 17-1/2 inch hole was drilled to 900 ft. where 12-3/4 inch casing was set and cemented in place on November 6, 1979. Drilling resumed, with an 11 inch hole from 900 to 1500 feet where temperature and geophysical logs were run on November 17. An 8-5/8 inch liner was suspended from 850 feet to 1498 feet. The slotted section of the liner extended from 1040 to 1370 feet with 16 slots per foot. The well was prepared for pump testing by circulating fresh water to remove drilling fluids.

A five stage, 6 inch turbine line shaft pump was set to 250 feet on November 20, and alternative pumping/recovery cycles were initiated to slowly develop the well while awaiting arrival of a larger pump. On November 26 an electric submersible pump was set to 700 feet and pumped ≈100 gpm for 7-1/2 hours at 160°F. The submersible pump was then lowered to 1000 feet and pumped ≈132 gpm for 7 hours. The well was allowed to recover and then continued pumping for another 24 hour period at variable flow rates.

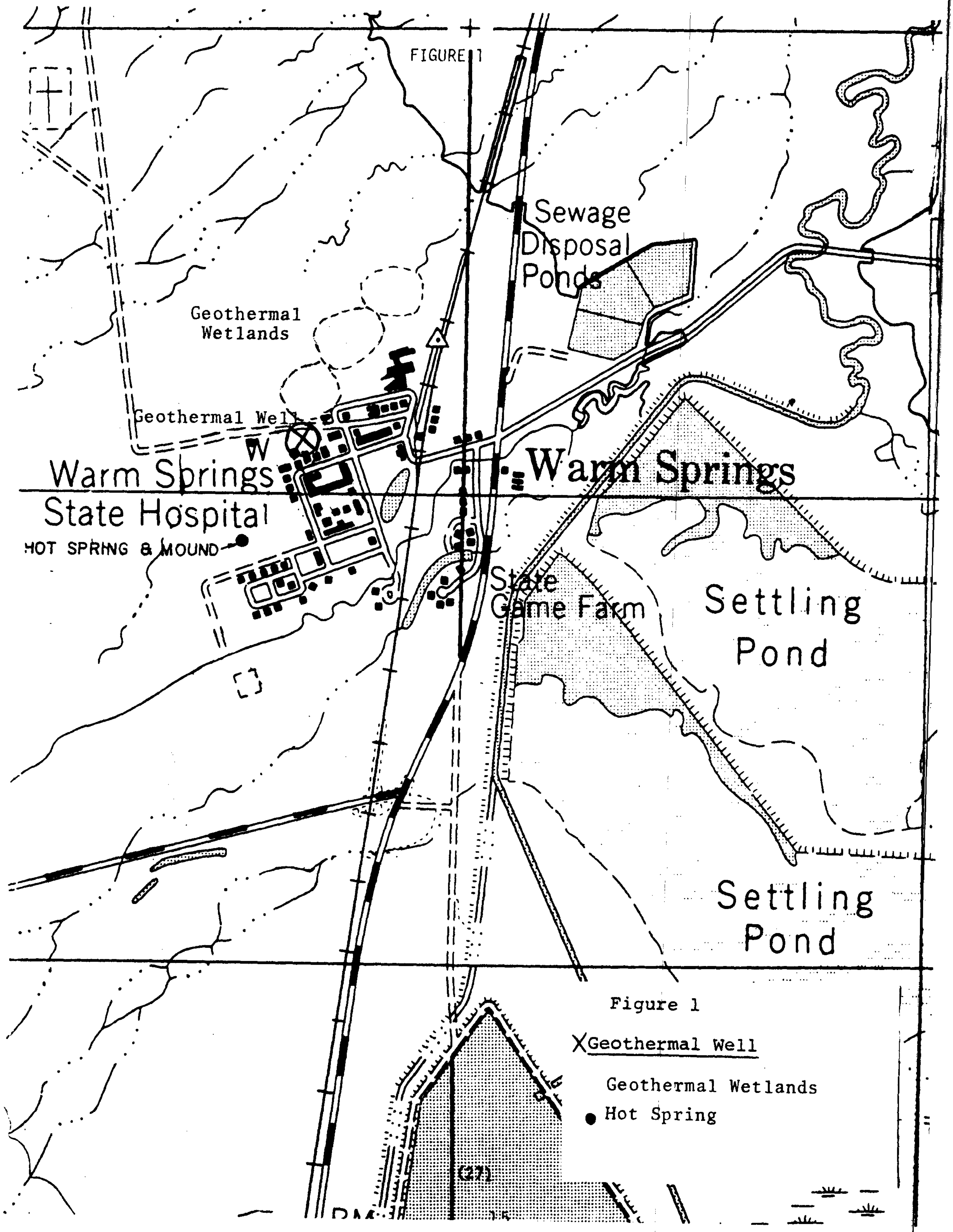


FIGURE 1
Sewage
Disposal
Ponds
Geothermal
Wetlands
Geothermal Well
W
Warm Springs
State Hospital
HOT SPRING & MOUND
Warm Springs
State
Game Farm
Settling
Pond
Settling
Pond
Figure 1
Geothermal Well
Geothermal Wetlands
Hot Spring
(27)

During these pump tests, the decision was made to perform a matrix acid treatment on the well. The acid treatment of the Warm Springs well was conducted on November 30 using Hydrochloric Acid (HCL) based on an analyses of acid reaction to well cuttings.

The actual acidizing job consisted of pumping 4000 gallons of 15% Hydrochloric Acid down the drill pipe and displacing acid by pumping fresh water down the annulus side. The pressure was bled off and then the well was shut in for 24 hours. Jon Carlson, MERDI consultant on the job, indicated that it was likely that the acid went into one or two production zones and that the remaining zones were probably untreated. During a pump test conducted on December 3, 1980, the well flowed 200 gpm for two hours at 160°F, however, the test was stopped due to pump failure.

The decision was made to pursue a more extensive clean-out and well test program due to the limited information obtained from the short tests prior to acidizing and lack of tests after acidizing.

A test plan was developed that would meet the objectives as listed below:

1. Determine local aquifer characteristics.
2. Determine specific capacity.
3. Estimate "long-term" well production.
4. Estimate well losses.
5. Evaluate any influence from shallow ground water aquifer and vice versa.
6. Determine aquifer boundaries in the immediate vicinity of the well.
7. Determine thermal characteristics of the well.

MERDI contracted with Knudsen Irrigation Company of American Falls, Idaho to provide equipment and services to clean-out and test the geothermal production well. The contractor installed a new Worthington line shaft vertical turbine pump on April 29, 1980 and attempted to initiate testing. The test never commenced because upon startup the pump vibrated excessively. The pump was removed and upon examination it was discovered that the rubber bushings spaced every 10 ft on the 830 ft stainless steel shaft had pulled out of the bronze spider bearings.

After examination by Worthington engineers, the 19-stage line shaft pump was again set in the well with bronze bushings and spider bearings rather than rubber bushings. The well was pumped at varying flow rates for ≈120 hours at which time the pump began vibrating excessively again. Investigation into the cause of the vibration is currently underway.

CURRENT ESTIMATED
PROJECT COST:

Total:	$1,166,755		
DOE Share:	$995,108	Participant Share:	$171,647
	85%		15%

PROJECT TITLE: Floral Greenhouse Industry Geothermal Energy Demonstration Project

PRINCIPAL INVESTIGATOR: Ralph M. Wright, Chairman of the Board
Utah Roses, Inc. (801) 295-2023

PROJECT TEAM: Utah Roses, Inc.
Energy Services, Inc.

PROJECT OBJECTIVE: To demonstrate to the public the potential offered by geothermal space heating in a highly populated area, by using geothermal heating in a commercial application.

LOCATION DESCRIPTION: Sandy, Utah
13 miles (21 km) south of Salt Lake City
Population: 51,227. Metropolitan area of 50,000
Area Activities: Agriculture, light industry and commercial development

RESOURCE DATA:

Well Depth: 5009 ft (1527 m)

Date Complete: 12/8/79

Completion Technique: Slotted Liner

Wellhead Temperature: 124°F (51°C)

Flowrate: 230 gpm (14 ℓ/s) with pumping

Summary: Several wells in the area of Utah Roses have shows of warm water, including one within 100 yds. (91 m) of the site, which has 93°F (34°C) water. The present well was drilled into loosely consolidated sandstone formations beneath the Utah Roses property, and encountered the primary production of 132 to 140°F water at 2800 to 3800 ft.

SYSTEM FEATURES:

Application: Greenhouse space heating

Heatload (Design): 4.9×10^6 Btu/hr (1.44 MW) geothermal handles full load to 35°F outside temperature

Yearly Utilization (Maximum): 20×10^9 Btu (0.67 MW-Yr) estimated

Energy Replaced: Fuel oil - 40,000 gal. presently used only for peaking
Natural gas - 14×10^6 cu. ft.

Facility Description: Six acre (24,300 m^2) commercial greenhouse

Disposal Method: Surface discharge to adjacent canal is proposed.

Summary: The Utah Roses facility, in a rapidly growing suburb of Salt Lake City, used $130,000 of fossil fuels during the winter of 1979-80. It is anticipated that the well will provide 25% of the heating for the greenhouse which produces cut roses for the national floral market.

Utah Roses, Inc. (cont'd)

STATUS:

Well was drilled and temperature logged to a depth of 5009 ft, with casing to 2244 ft. Bottom hole temperature 160°F. Liner (5-1/2") was hung to 3885 ft. to prevent bridging. After pump testing, liner was selectively perforated at 3100, 3650, and 3785 ft, with pump testing after each perforation. Production temperatures between 3100 and 3800 ft. are 132 to 140°F, but 1/2 hour transit time to surface results in 8 to 16°F temperature loss. Long term (3 months) drawdown at 230 gpm continuous pumping will be 900 ft. Dissolved solids 2800 ppm (mg/l). Awaiting decision by State Environmental Department to determine if discharge into surface streams will be permitted. Jordan River salinity would be increased 1/2%, but not exceeding the natural high salinity levels reached in June when geothermal heat would not be used.

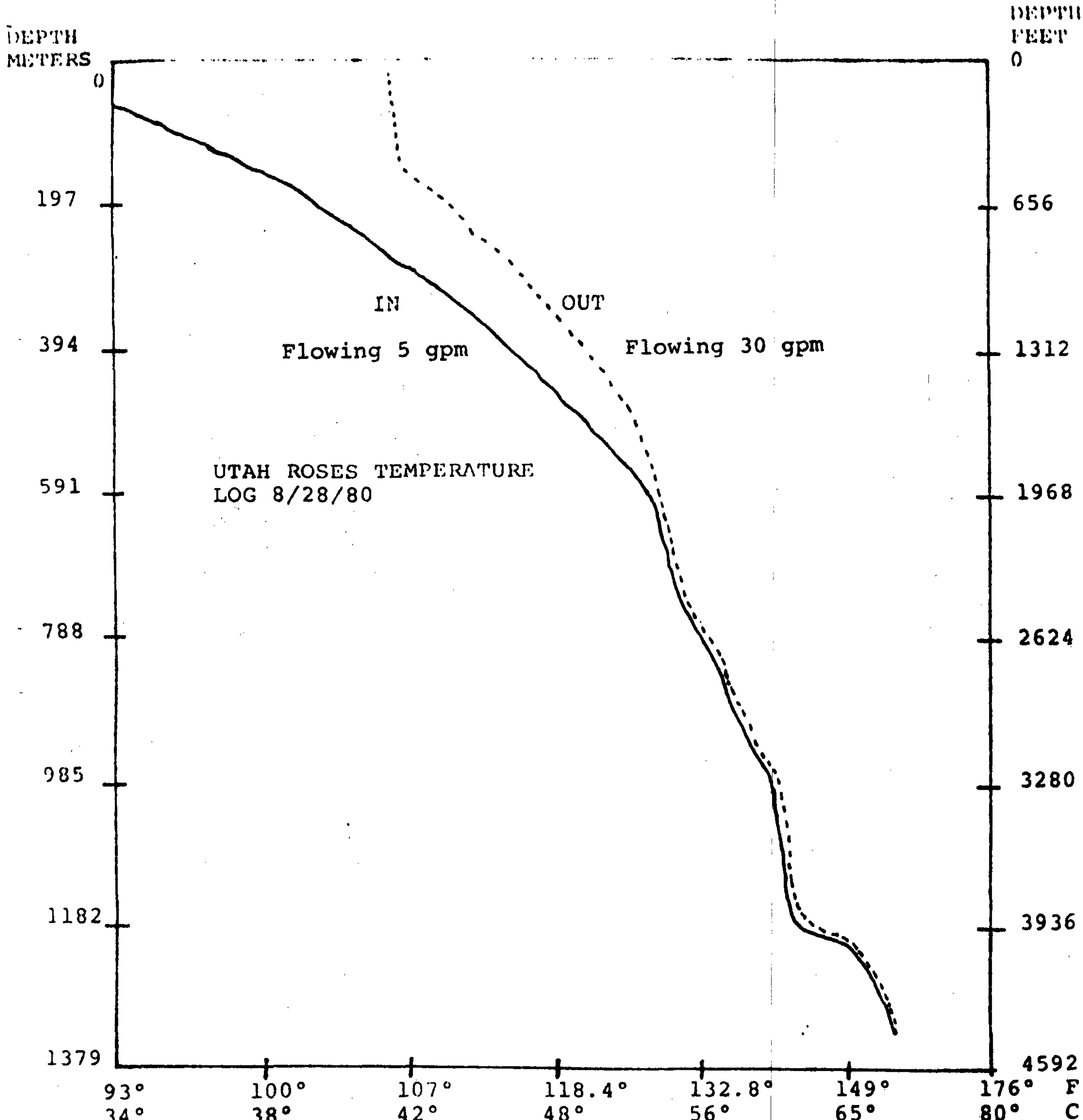
CURRENT ESTIMATED PROJECT COST:

Total:	$856,200		
DOE Share:	$478,312 56%	Participant Share:	$377,888 44%

TOTAL EXPENDITURES TO DATE: $444,000

LESSONS LEARNED:

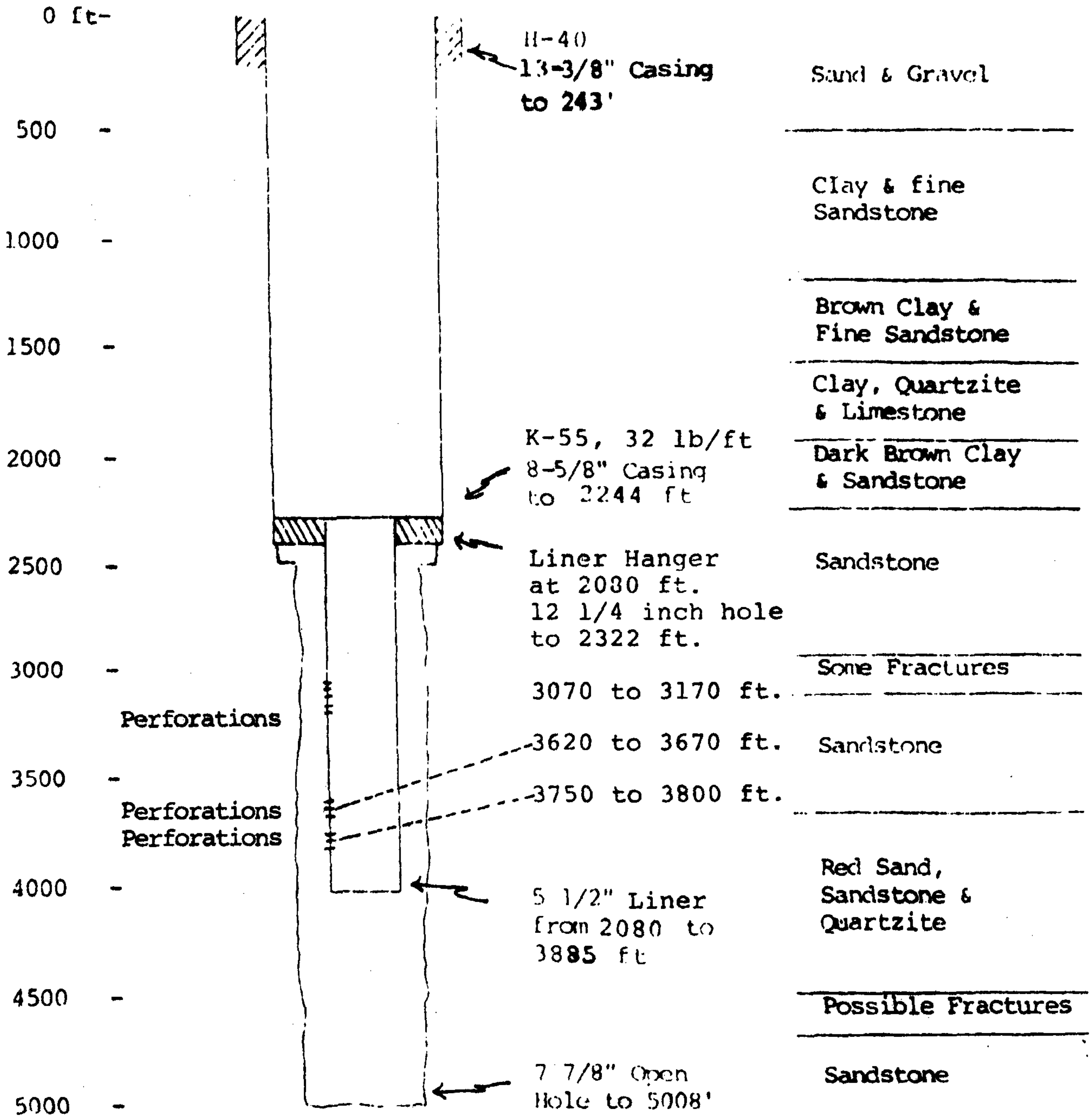
Cost of well and remedial work was only $350,000 for 5000 ft. total depth. Formation is tight, and temperature not as high as anticipated, though about normal gradient for Basin and Range. In the future, wells drilled into this formation should be multiple legged, to increase production; or multiple less expensive wells drilled with 9 5/8" surface casing, 7" production casing. Required depth is 3200 ft. Two wells of this type might be drilled for not much more than single cost of this well. Cable tool or drill-and-drive rotary should probably be used to set surface casing through the very loose gravels. Present economics (competing with 20¢/therm natural gas) cannot justify expenditure of a deep well for reinjection.



Completed Well Temperature Profile

UTAH ROSES

WELL PROFILE AND LITHOLOGY



PROJECT TITLE: Direct Utilization of Geothermal Resources, Field Experiment at the *Utah State Prison*

PRINCIPAL INVESTIGATOR: Jack Lyman, Director, Utah Energy Office
(801) 533-5424

PROJECT TEAM: Utah Energy Office
Utah Department of Social Services
Utah State Building Board
Utah Geological and Mineral Survey
Terra Tek, Inc.

PROJECT OBJECTIVE: To demonstrate the economic and technical viability of using a low temperature geothermal resource in a variety of direct applications at the Utah State Prison.

LOCATION DESCRIPTION: Utah State Prison (near Draper, Utah)
16 miles (25 km) south of Salt Lake City
Population: 5500 (Draper) 560,700 (Salt Lake County)
Area Activities: Mining, light manufacturing and agriculture

RESOURCE DATA:

Well Depth (300 m) proposed
Date Complete: To be drilled in the Spring, 1981
Completion Technique: Not applicable
Wellhead Temperature: 160-190°F (71-87°C) estimated
Flowrate: 600 gpm (37 l/s) desired for peaking
Summary: The Utah State Prison is located adjacent to Crystal Hot Springs. This spring area has a maximum measured discharge temperature of 176°F (80°C) and surface discharge of approximately 640 gpm (35 l/s). A shallow well drilled by Utah Roses in the hot springs area has a reported flowrate of 198 gpm (12.5 l/s) at 192°F (89°C).

SYSTEM FEATURES:

Application: Space and water heating
Heatload (Design): 4.3×10^6 Btu/hr (1.25 MW) estimated
Yearly Utilizaton (Maximum): 18.54×10^9 Btu/yr (.62 MW-Yr) estimated
Energy Replaced: Natural gas - 18×10^6 cu. ft
Facility Description:
The minimum security cellblock of the Utah State Prison.
Disposal Method: Injection well.

Utah State Prison (cont'd)

Summary: The project is designed to provide geothermal space and water heating systems for the minimum security block of the prison. Future expansion of the project may include the extension of these services to other buildings, as well as the use of the thermal water for a variety of other direct applications at the prison dairy and slaughterhouse.

STATUS:

The project is presently approaching the end of Phase I - Resource Assessment. The following tasks have been completed:

1) environmental report (conditinally approved)

2) gravity and aeromagnetic, data collection and initial interpretation

3) test drilling program

The following tasks are presently in progress:

1) spring monitoring program

2) reservoir testing

CURRENT ESTIMATED PROJECT COST:

Total: $637,326

DOE Share: $458,704 72% Participant Share: $178,622 28%

LESSONS LEARNED:

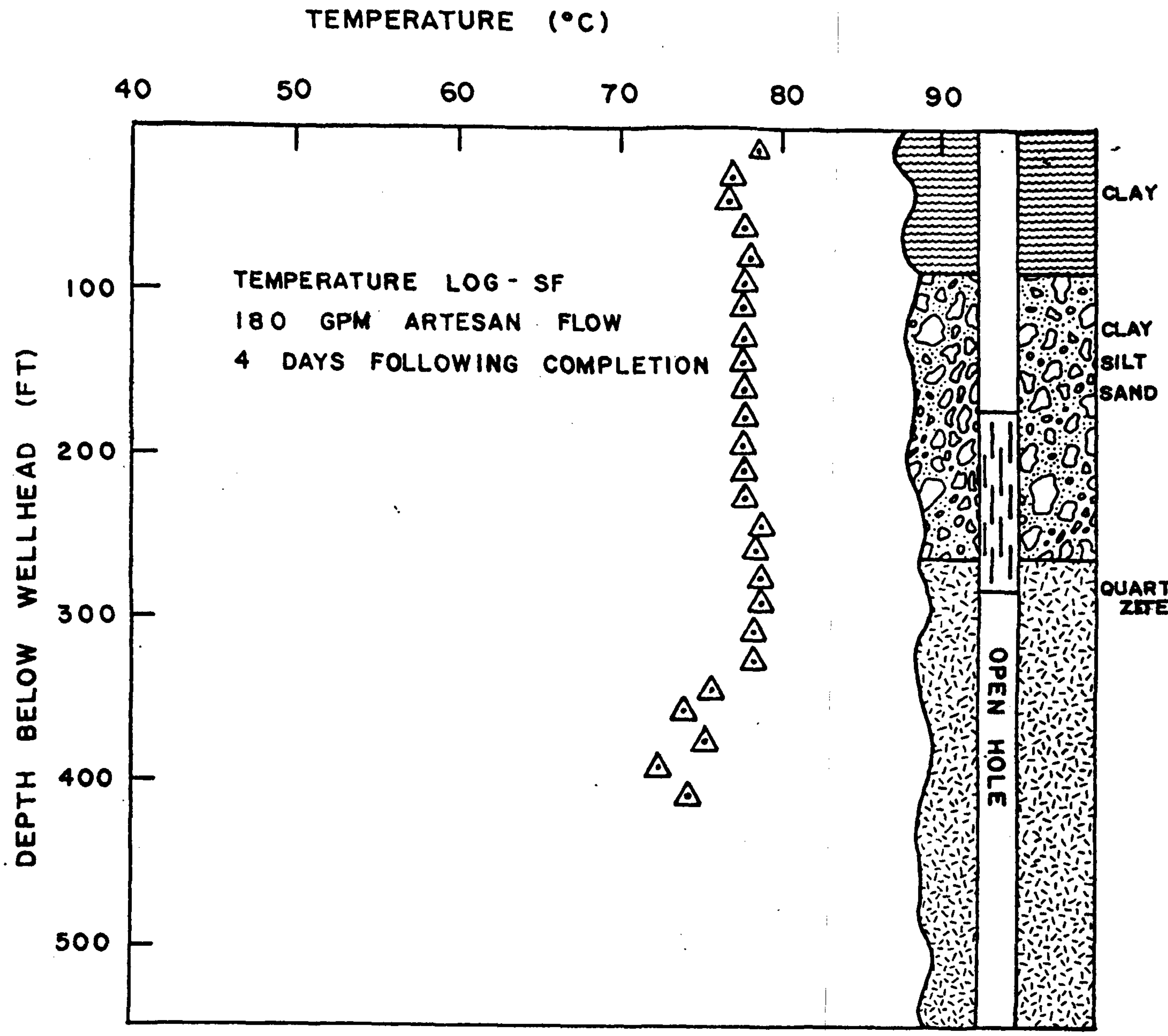
1) Detailed gravity surveys can provide important structural information in the immediate vicinity of thermal systems of the Basin and Range province.

2) The reservoir of the Crystal Hot Spring system:

a) consists of highly fractured quartzite
b) is bound by two normal range-Front Faults
c) is capped by relatively impermeable sediments and further sealed at the top of the reservoir by the deposition of calcium carbonate, and
d) is under pressures of 5 to 10 psi.

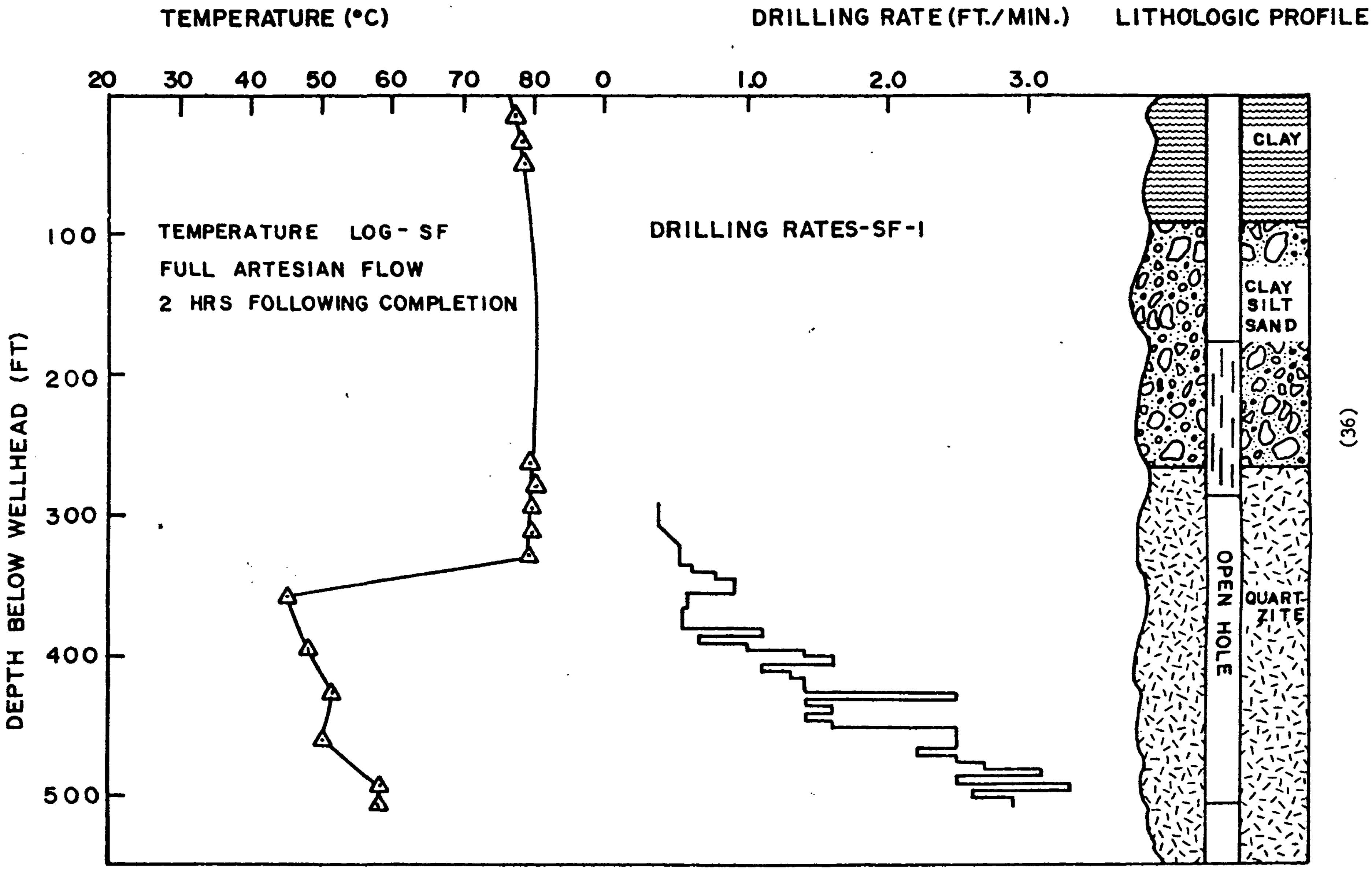
3) Results of the detailed gravity survey suggest the possibility of a reservoir of greater lateral extent than previously known.

FIGURE 1b



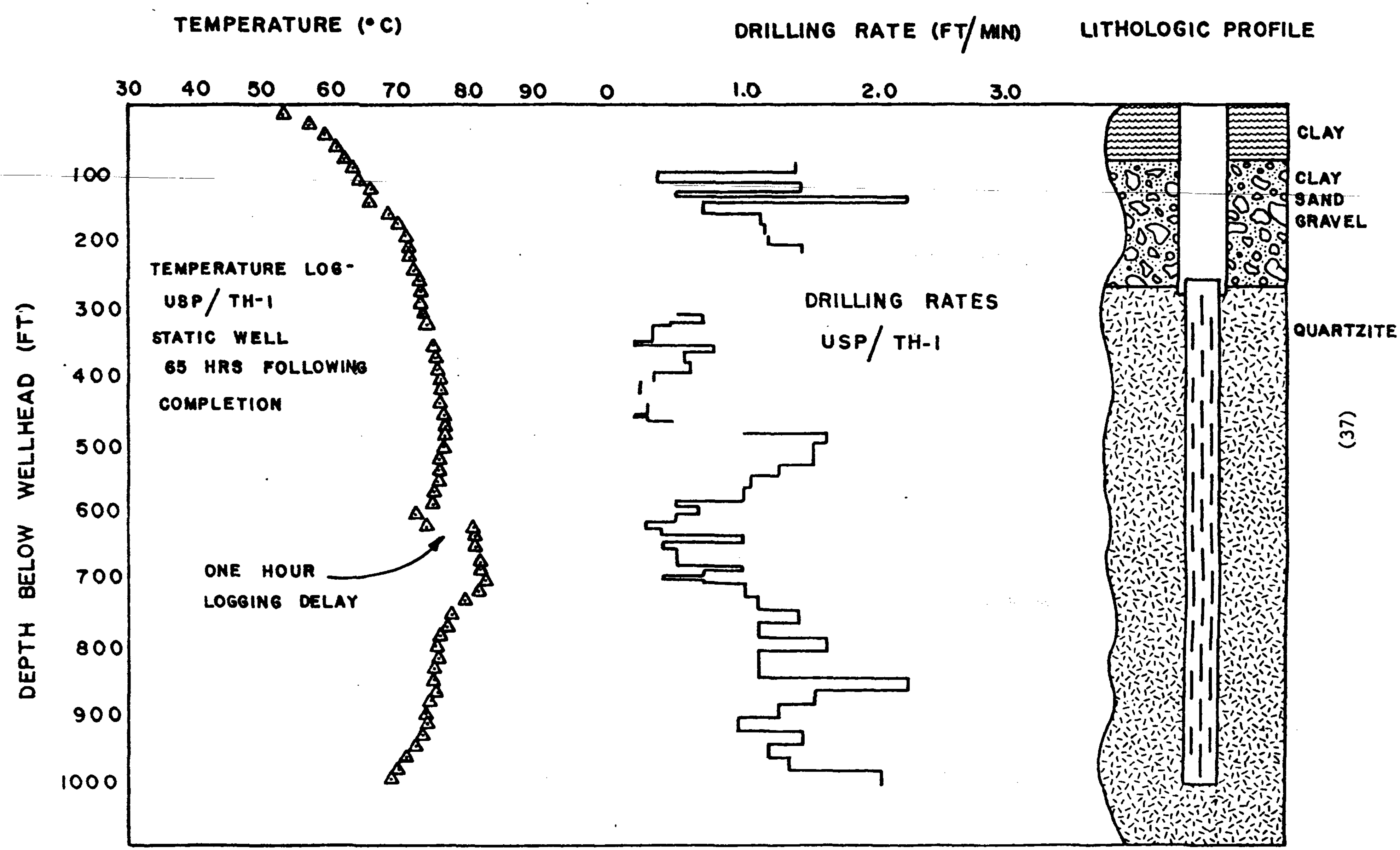
TEMPERATURE (°C)
40
50
60
70
80
90
DEPTH BELOW WELLHEAD (FT)
100
200
300
400
500
TEMPERATURE LOG - SF
180 GPM ARTESAN FLOW
4 DAYS FOLLOWING COMPLETION
CLAY
CLAY
SILT
SAND
QUARTZITE
OPEN HOLE

FIGURE 1a


TEMPERATURE (°C)
DRILLING RATE (FT./MIN.)
LITHOLOGIC PROFILE
20 30 40 50 60 70 80
0 1.0 2.0 3.0
100
200
300
400
500
DEPTH BELOW WELLHEAD (FT)
TEMPERATURE LOG - SF
FULL ARTESIAN FLOW
2 HRS FOLLOWING COMPLETION
DRILLING RATES-SF-1
CLAY
CLAY
SILT
SAND
OPEN HOLE
QUARTZITE

(36)

FIGURE 2


TEMPERATURE (°C)
DRILLING RATE (FT/MIN)
LITHOLOGIC PROFILE
30 40 50 60 70 80 90
0 1.0 2.0 3.0
DEPTH BELOW WELLHEAD (FT)
100
200
300
400
500
600
700
800
900
1000
TEMPERATURE LOG-
USP/ TH-1
STATIC WELL
65 HRS FOLLOWING
COMPLETION
ONE HOUR
LOGGING DELAY
DRILLING RATES
USP/ TH-1
CLAY
CLAY
SAND
GRAVEL
QUARTZITE

PROJECT TITLE: SUSANVILLE GEOTHERMAL ENERGY PROJECT

PRINCIPAL INVESTIGATOR: PHILIP A. EDWARDES

PROJECT TEAM:

AEROJET (Design)
Carl Schwarzer
Ken Unmack

GEOTHERMEX, INC. (Resource Engineers)
Subir Sanyal
Jim McNitt
Carol Peterson

KOEPF & LANGE, INC. (Engineering)
Monte Koepf

LAHONTAN, INC.
(Technical Support and Construction Management)
Fred Longyear
Peter Klaussen

PROJECT DESCRIPTION

A field demonstration utilizing a low temperature (165°F±) geothermal resource for the space heating of 14 public buildings. Cascaded fluids to be utilized in an agri-industry Park of Commerce for economic development purposes.

LOCATION DESCRIPTION

The City of Susanville is located in Northeastern California at the base of the Sierra Nevada Mountains. The City has a population of 6500, is at an elevation of 4300 feet and forms the seat for Lassen County.

RESOURCE DATA

Well Depth - 950 feet
Date Completed - 10 November 1980
Completion Technique - Rotary Air Drill
Wellhead Temperature - 165°F±
Flowrate - expected to be in the 300 - 500 gpm range
Cost - $120,000
Well Name/Description - Susan I
Drilling Contractor - The Water Development Corporation, Woodland, CA
Well Size - Nominal 18" to 540', 12" to 950'
Casing Sizes - 12" cemented solid casing to 350'
12" slotted casing to 540'
8" slotted casing to 950'

DRILLING SUMMARY

Drilling was commenced on October 14 and completed by November 5, 1980.

Considerable problems were encountered in the first 75 feet of drilling which was in the main through old river bed consisting of fine gravel through to rocks the size of a football. Due to the instability of this zone, a "grapel" was used at various stages to extract the larger rocks.

75 - 235 feet - consisted of volcanics and ash and was relatively fast drilling.

235 - 250 feet - mainly ash that caused considerable caving problems. This caving occurred having reached the 500 foot zone. An attempt was made to stabilize the caving by continual circulations in the caving zone. This effort failed, so a cement plug was formed in this zone; and after partial set, was drilled through. The caving ceased until the 900 foot zone was reached when it started again. However, it stabilized after approximately 3 hours.

250 - 800 feet - consisted of volcanics, ash and basalts - medium to fast drilling.
800 - 950 feet - consisted of volcanics, ash and basalts - slow to medium drilling.

LOGGING

Logging was undertaken at 820 feet due to some mild caving from the surface zones. Logs were taken according to the following Logging Plan:

Procedure	Justification
Immediately after drilling, run a combination differential and absolute temperature log.	Need for absolute temperature is obvious. Differential temperature log will show us the anomalous zones due to fracture, lithology or water quality changes.
Run electrical log (SP, 16 in. normal, 64 in. normal, detailed).	For correlation, detection of fractures (if possible), location of sedimentary/volcanic contacts.
Run radioactive log (gamma ray and neutron).	Correlation, qualitative estimates of porosity, possibly sedimentary/volcanic contacts.
Run 4-arm caliper log and run 3-arm caliper log.	Fracture detection, possibly indication of lithology changes.
Wait for 6 hours.	To allow temperature build-up.
Run combination differential and absolute temperature log.	Same as in #1. Will allow use of temperature build-up information.
Inject water in the well to achieve at least 100 gpm rate. If not possible, increase the head by placing a surface casing on the well. If possible, use a pump. Run spinner log.	The spinner will allow detection of fractured zones. At least 100 gpm is required to ensure proper operation of the spinner.

SUMMARY OF WELL DRILLING AND LOGGING

The well drilling program was considerably enhanced by having a temperature gradient hole to a depth of 818 feet 10 feet from the production well site (Suzy 9A) which allowed the driller a preview of the type of drilling to be expected.

Suzy 9A was temperature monitored throughout the drilling program and was extremely useful for the purpose of identifying possible production zones as temperatures changed during the course of drilling and circulation in the Susan I well.

Considerable water losses occurred from approximately 350 feet to 380 feet and water was added at the rate of approximately 50 gpm throughout the drilling program. Some evidence of water gain was evidenced at the 800 foot level for a short period. Due to make-up water at 40°F being added throughout the drilling operation, return fluids from the drilling operation did not reflect down hole temperatures. No additives were utilized to stem the water loss during drilling thus minimizing damage to potential flow zones.

The contractors, The Water Development Corporation of Woodland, California, should be complimented on the high degree of professionalism that prevailed throughout the contract period. Equipment was in excellent condition and no delays were caused through lack of backup support from their head office. Materials required to complete the program were always on site well before they were needed.

STATUS

Construction packages are being advertised and program completion is projected for June-August 1981.

CURRENT ESTIMATED PROJECT COST

TOTAL: $2,039,499.

DOE SHARE: $2,011,187. PARTICIPANT SHARE: $28,312.

LESSONS LEARNED

Well Drilling - Considerable fear of bidding for geothermal production wells by the drilling industry. Greater education is necessary to separate high temperature well drilling problems from low temperature operations.

Large diameter holes limit the number of capable drillers able to respond to bid notices.

Procedure	Justification
If the spinner log has not run well, continue water injection for 4 hours, re-run combination differential and absolute temperature log.	The spinner may not run well if either the flow rate is less than 100 gpm or due to unforeseen mechanical problems. Then temperature log preceded by further cooling due to water injection may allow fracture detection.

Based on an on-site interpretation of the logs, the decision was made to solid case to 355 feet. The logs clearly indicated the major flow to be in the 355 to 380 foot zone at an estimated temperature of 162°F. Other flow zones were identified at:

420' - 480'	estimated	temperature	170°F
530' - 620'	"	"	174°F
630' - 640'	"	"	178°F
760' - 780'	"	"	179°F
915' - 950'	"	"	180°F+

SYSTEM FEATURES

Application — Space heating, cascading effluent fluids of 120°F through an agri-industry Park of Commerce

Heatload (Design) — (14 Buildings) 8,241,000 btu (549 gallons/minute)

Yearly Utilization (Maximum) — 15,930 mbtu

Energy Replaced (Type/Amount) — Approximately 142,000 gallons oil per year

Facility Description — The Public buildings consist of:
County Courthouse and Jail
Washington School
Lassen High School
Veterans Memorial Building
City Fire Hall

Disposal Method — Until water samples have been analyzed, no final decision will be taken on disposal methods. The following methods have been identified by the Water Quality Control Board as being possible:

1) Injection (worst case)
2) Agricultural use
3) Wild fowl habitat
4) Recreational purposes
5) Introduction into the City water system to enhance the ambient temperature of water supplied to residences in winter months

The type of contract to "let" is probably the most difficult decision to make. The City does not regret the decision to place a fixed-price contract under the conditions that were anticipated for Susan I well. Where no hard rock drilling is anticipated, other options could result in a cheaper well.

It is extremely difficult to time-plan a program until well development and well production testing has been completed. The necessity of a well-planned logging program cannot be over emphasized. I would recommend a close interface with contracted loggers prior to contract signing to ensure availability of all logging tools and capability of equipment.

No two geologists will agree on the interpretation of logs obtained. Be prepared to make final decision on the flip of a coin for best results!

PROJECT TITLE: Boise City - A Field Experiment in Space Heating

PRINCIPAL INVESTIGATOR: Phil Hanson, Director, Boise Geothermal
(208) 384-4013

PROJECT TEAM: Boise City
Boise Warm Springs Water District
CH2M Hill Engineers

PROJECT OBJECTIVE: To develop a geothermal space heating system to serve the largest possible market in and around the Boise central business district.

LOCATION DESCRIPTION: Boise, Idaho
Population: 111,100
Area Activities: Commercial, government, and manufacturing center

RESOURCE DATA:

a) Existing Boise Warm Springs Water District (BWSWD) Wells No. 1 and 2:

Well Depth: 400 ft (122 m)

Date Complete: 1890

Completion Technique: Open Hole

Wellhead Temperature: 170°F (76°C)

Flowrate: 1700 gpm (107 ℓ/s) combined flow of wells No. 1 and 2

b) New Wells (Boise City No. 1 and 2, BWSWD No. 3)

Well Depth: Boise City No. 1 and No. 2 - 1000-1500 ft (305-457 m)
BWSWD No. 3 - 500 ft (152 m)

Date Complete: To be drilled Winter 1980-81

Completion Technique: Slotted Liner or Screen

Wellhead Temperature: 170°F (76°C) estimated

Flowrate: BWSWD No. 3 = 1000 gpm (63 ℓ/s) estimated
Boise City No. 1 and No. 2 = 1000 gpm (63 ℓ/s) estimated per well

c) Summary:

The resource area is commonly referred to as the Boise Front. This appears to be fault controlled, with the source of water being the annual runoff in the mountains immediately behind Boise City. Two wells presently serve the existing BWSWD system and provide a peak flow rate of approximately 1,700 gpm (107 ℓ/s). A third well developed under the current project is expected to increase that flow by 1000 gpm (63 ℓ/s). Preliminary planning for the city system has been for two 1000 gpm wells. Ultimate flow rates will depend upon further geology work and testing to be done during the drilling of the first wells.

SYSTEM FEATURES:

Application: District Heating

Heatload (Design): 1 X 10^8 Btu/hour (29.3 MW)

Yearly Utilization (Maximum): 2 X 10^{11} Btu/year (6.7 MW-Yr)

Energy Replaced: Natural gas - 2.92 X 10^8 cu. ft.

Facility Description: 500-1000 residences and 11 office buildings

Disposal Method: Alternatives presently under review. Disposal to Boise River is presently preferred method.

Summary: The proposed Boise City and BWSWD systems will utilize the local geothermal resource, as described above. Production wells for the city system will be located approximately 1.5 miles (2.4 km) from the primary load located in downtown Boise. The pipeline will be sized for 4,000 gpm (250 l/s) to allow for future growth, although initial production capacity is expected to be approximately 2,000 gpm (126 l/s). The BWSWD pipeline will be sized for 3,000 gpm (189 l/s).

STATUS:

Environmental report	completed
Geology data review	completed
Well siting report	completed
Preliminary system design	completed
Market & rate study	completed
Customer confirmation	due: 12/80
BWSWD well specifications	completed
Boise City well specifications	completed
Waste disposal report	completed (draft)
Drilling fund and lease	completed
Drill BWSWD well #3	due: 10/80
Drill Boise City well #1	due: 12/81
Drill Boise City well #2	due: 3/81
Final design of BWSWD system	due: 2/81
Final design of Boise City system	due: 6/81
Construction of BWSWD extended system	due: 11/81
Construction of Boise City system	due: 2/82

PROJECT COST:

Total: $7,608,300

DoE share: $4,226,000 Participant share: $3,382,000

LESSONS LEARNED:

The area assigned to me is "institutional" with direction to discuss problems and resolutions over the past six months. Unfortunately, the institutional issues in Boise with which we have had to deal date to at least 1975. Since these issues have acquired many layers of political, legal, and organizational fact and opinion I will simply define the problem for you, describe the form which our resolution of it took, and try to leave you with some general time boundaries.

1. Problem: The State of Idaho began working with geothermal, as a heat source their buildings, about 1974. In 1978 they connected a 34,000 foot office building to the historic Warm Springs system. Other of their activities resulted in a $190,000 budget to retrofit buildings in the downtown Capital Mall area, and a $105,000 budget to drill an exploratory well. The exploratory well was to be drilled downtown, on state property, to a target depth of 2,200'. The product of the well was to be used to heat major state buildings which were also candidates for the planned Boise Geothermal system. The well was to have been completed in June 1980 but it was completed in November. The problem resulting from these circumstances was our need to know the States mind so that we could design a delivery/disposal system that either did or did not include the state buildings.

   Resolution: Time heals all wounds, almost. Our schedule due to funding committments, product approval, and task delay slipped so that the states decision window will be close to ours. Unfortunately, the decision alternatives they face have very different impacts on our project. The decision options are:

   a. Connect their buildings to our distribution and disposal system.
   b. Connect their buildings only to our disposal system.
   c. Have no interface with their buildings.

   Their five buildings have a heat load of approximately 14.2 X 10^6 Btu/hour which would require about 600 gpm. out of our initial production goal of 2,000 gpm.

2. Problem: Our original project was proposed to be about $9.5 million but DoE offered to provide only $4.9 million. This necessitated that the project be cut back and at the same time some additional funds were raised from EDA and the City. The end result was about $5.5 million available to the project. The problem is when preliminary engineering estimates were completed we needed a total of $8.3 million, or $2.8 million more than we had, and the City did not have that kind of funds nor was the City Council, because of the 1% initiative, willing to try raising that amount through bonds or other conventional financial mechanisms available to cities. THis problem was further complicated by DoE wishing to cut about $700,000 more our of their original committment.

   Resolution: The Boise Warm Springs Water District committed $625,000 toward the $2.7 million of which they have obligated and spent about $265,000 on new piping. The balance was raised through an LID to serve the CBD mall area ($300,000) and a drilling fund of about $2 million to develope production wells. This resolution has raised the spectre of another problem, i.e. the drilling fund being private capital will increase the price per therm of delivered energy even though it enjoys the benefit of assuming total risk of failure in drilling for water of the right temperature and quantity. The proposed cut of $700,000 in DoE funds is not yet resolved.

3. Problem: The Boise Geothermal project is a joint effort of Boise Warm Springs Water District, a special utility district of the State, and Boise City a municipality. These two governments are totally separate and inde-

pendent entities. They are sufficiently chary of each other so that in working on this joint project they have not wanted to relinquish any of their individual authorities to a common venture. The problem has been to determine how to make a two headed organization work.

Resolution: The basic problems created by this dichotomous situation can not be totally resolved. The resolution has involved a number of approaches.

a. Develope an agreement to define ground rules for interaction between the governments. This agreement helped to clarify the relationships but has no legal force and effect.
b. Establish an Executive Committee with members drawn equally (total of four) from BWSWD and the City. This Committee reviews all activity and refers decisions, as appropriate, either to the Boise City Council or BWSWD Board.

4. Problem: The withdrawal of large volumes of water in other parts of the U.S. has resulted in problems of subsidence and interference. The geological engineering solution to this problem is to develope a monitoring progra to track changes of ground or water levels. This solution is straightforward but costly. The institutional problem created is one of finding someone to assume technical and financial responsibility for monitoring. The City believes the State should assume this responsibility, and vice versa.

   Resolution: The only action taken so far is toward a partial resolution of the problem. The state does not want to assume responsibility because they do not have suffcient financial resources for the purpose (up to $500,000 may be required). The absence of some monitoring system poses the future threat of litigation over interference or subsidence, and if that occasion should arise it is critical to have baseline data. The action taken by Boise Geothermal is partial in the sense that we are arranging monitoring equipment to be installed on those wells now in existence and over which we have some control, as well as those we are contemplating drilling in near future. If a complete program would really cost a half million dollars then our level of effort will be a very small fraction of that amount.

5. Problem: We will be producing up to 4,000 gpm in the initial phase of our project which means, after use, we must provide for disposal of this amount. All of the options for disposal are under the regulatory authority of the Department of Water Resources, the federal EPA, State Health & Welfare, the Corps of Engineers, or/and the Bureau of Lands. The preferred disposal option is to return waste water to the river. In this case Health & Welfare and EPA would have principal responsibility. EPA requires preparation of an NPDES but, since the volume of water is small by their standards, they will not be issuing a permit. On the other hand Health & Welfare will only grant permission for disposal of a limited quantity for an indeterminate period of time. The problem is that we will have permission to dispose of some quantity revocable at any time.

   Resolution: This problem is not yet resolved but we are planning some method, perhaps a contract, that will give us discharge permission for, hopefully, a large fraction of the planned useful life of the system. This formalized permission will be required before we invest large amounts of money burying pipes in the ground.

6. Problem: The use of a well drilling fund is a relatively efficient method of raising capital. The fund is predicated on committments by the City to purchase water at wholesale prices. These in turn are based on committments by building owners to purchase the water but building owners will not make committments until they know the delivered price of the water. These prices cannot be finally determined until firm bids, on which the price is based, are received for laying the pipeline and drilling the wells. But we cannot drill wells until the drilling fund raises money.

   Resolution: The needed committments are being acquired in stages.

   a. A preliminary connection agreement has been prepared for signature by building owners. It provides the owners with a maximum price for the water and the drilling fund with a preliminary committment that can be used to raise funds for well drilling. The location and success of these wells will, to a certain extent, determine the pipeline route and cost.
   b. After the wells are proven and bids for the pipeline received a final connection agreement will be signed by building owners that specifies a definite price per therm. This will be backed up by a geothermal service ordinance.

PROJECT TITLE: Multiple Use of Geothermal Energy at Moana KGRA

PRINICPAL INVESTIGATOR: Dr. David J. Atkinson, President
Hydrothermal Energy Corporation
(702) 323-2306; (213) 464-6446

PROJECT TEAM:

- Hydrothermal Energy Corporation, Developer and Heat Supplier
- S.A.I. Engineers, Engineering Design and Construction
- W.L. McDonald & Sons, Drilling
- Global Geothermal Technologies Inc., Drilling Supervision
- Elliot Zais & Associates, Well Testing

PROJECT DESCRIPTION:

For several tens of years, the hot groundwater of the Moana KGRA has been used in southwest Reno for small-scale heating projects in homes and a few apartments and motels.

Our project involves using these thermal waters in a district heating system supplying space and water heating needs in condominium and apartment buildings, an office building, and a school.

After space and water heating needs are handled, we shall add whichever auxiliary uses prove most feasible, to more fully use the available heat, and to aid in disposal of spent geothermal waters.

LOCATION DESCRIPTION:

The site of the project is in a small section of southwest Reno between Plumb Lane and Moana Lane to north and south, and between South Virginia and Plumas to east and west.

RESOURCE DATA:

The first well has not yet been completed.

SYSTEM FEATURES:

Application:

Space and water heating of condominiums and apartments, a school and an office building.

Heatload (Design), estimated: 9,500,000 BTU/HR.

Yearly Utilization (therms):

	Annually	30 Year Project Life
Salem Plaza Condominiums:	156,000	4,680,000
Country Club Villas:	36,000	1,080,000
Anderson Elementary School:	31,000	930,000
Nevada National Bank	21,000	630,000
TOTAL	244,000	7,320,000

Energy Replaced:

The bulk of the fossil fuel energy replaced will be natural gas, amounting to about 732,000,000,000 BTU's over the thirty year life of the project. About 93,000,000,000 BTU's of fuel oil will also be replaced.

Facility Description:

Salem Plaza is a 150-unit condominium complex, with a swimming pool. In both of the large L-shaped buildings that make up the complex, heating of space and water involves a single open-loop system that supplies domestic hot water and provides heat to forced-air systems in each unit. The two roof-mounted boilers are natural gas fired.

Country Club Villas consists of 51 apartments arranged around a central recreational area with a pool. Space heating is handled by a closed-loop system independent of the system that supplies domestic hot water. A third system heats the pool. All three systems are fired by natural gas.

Anderson School is a year-round elementary school, which uses a large oil-fired boiler running on #5 fuel oil.

The office building is a two-story structure with a natural gas fired heating system mounted on the roof.

Disposal Method:

The best method of disposing of spent fluids cannot be determined until drilling gives us the needed data on the chemistry of the geothermal fluid.

Alternatives include surface disposal by various methods, and reinjection.

Summary:

The project involves retrofitting a condominium complex, an apartment complex, a school, and an office building.

The first production well is about to be drilled at the east edge of the Salem Plaza property.

Buried, insulated pipelines will carry the geothermal fluid to and from the existing boiler facilities in the various buildings, which will be retro-fitted with plate-type heat exchangers.

Disposal may be at surface or by reinjection. Additional use of available heat will involve whichever auxiliary applications prove most feasible after the space and water heating systems are operating.

STATUS:

Environmental clearance for the project has been given by DOE, and we have been granted our applications for water rights in the area by the Nevada State Engineer.

The first well site has been selected in the eastern part of the Salem Plaza property, and the site selection has been approved by DOE and its consultants. A revised version of our well testing plan for the first well is required to meet the reviewing group's recommendations.

As a result of this review process relative to the first well, we have changed the well design. We are submitting a proposal asking for approval of these changes and the effect they would have on the budget.

In preparation for the start of drilling we have handled all the other necessary steps, including filing the notice of intent to drill.

Preliminary design work on the heating systems, and the retrofitting and transmission systems is complete. The final design can be completed as soon as the first well gives us the temperature, depth, and chemical composition of the geothermal fluid we shall be using.

CURRENT ESTIMATED PROJECT COST: Total: $982,667

LESSONS LEARNED:

By virtue of our work in changing the project site, we have learned an enormous amount about the practical aspects of marketing geothermal energy to the public, and continue to do so. Some of these lessons were discussed in detail in an earlier report.

Since that time the importance of broad-scale public education about geothermal energy has become even clearer.

In recent surveys we have done, of about one thousand long-time residents of Reno, where geothermal energy has been used directly for fifty years, we still found that 77% consider they know little or nothing about geothermal energy. Fortunately, of those giving their viewpoints, 89% approve or strongly approve of geothermal development. The majority view it as a cheap, clean and available resource that should be used, with only 26% aware of any drawbacks. Of the drawbacks, high development cost is seen as the most significant. The public's perception of barriers to development again puts high initial cost as the most important factor, followed by the utilities, the large oil companies, the government, and public ignorance.

In Reno, (and this reaction is probably typical) the overwhelming wish is for geothermal energy to provide a reduction in fuel bills (79% named this as the most important potential benefit to them of geothermal development).

Recently, the local utility has raised prices for natural gas by 89%, and another large rise is planned for January 1981. This accounts for much of the emphasis on price benefits of geothermal energy.

Our project has been arousing much interest locally, with at least six developments now allowing for geothermal retrofitting in their future plans, if our demonstration is successful. Two private homeowner groups have been looking at the possibility of small district heating schemes.

Most of those who have expressed interest have indicated that they are awaiting the outcome of our project ot decide whether to proceed with geothermal development.

Dr. David J. Atkinson
Hydrothermal Energy Corporation

EL CENTRO

GEOTHERMAL ENERGY UTILITY CORE FIELD EXPERIMENT

Principal Investigator: George S. Parker
City Manager
City of El Centro

Project Team: City of El Centro, WESTEC Services, Inc., Chevron Resources

1.0 PROJECT DESCRIPTION

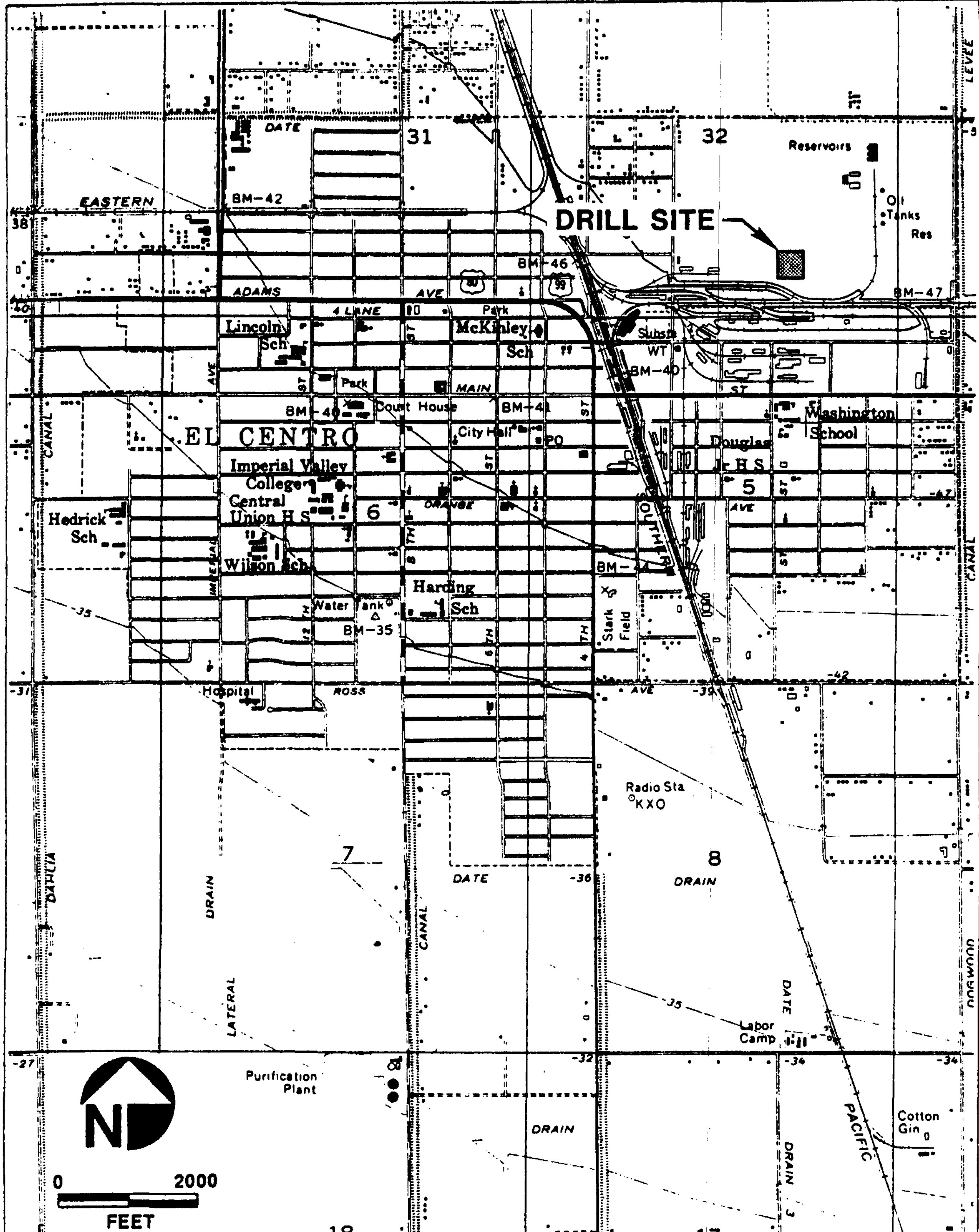
The City of El Centro is proposing the development of a geothermal energy utility core field experiment to demonstrate the engineering and economic feasibility of utilizing moderate temperature geothermal heat for space cooling, space heating, and domestic hot water heating. In this application, geothermal fluid at an anticipated temperature of about 250F (121C) will heat a secondary fluid (water) which will be utilized directly or processed through an absorption chiller, to provide space conditioning and water heating for the El Centro Community Center, a public recreational facility.

2.0 LOCATION DESCRIPTION

The proposed pilot scale facility is located on a 2.75 acre (1.1 hectares) parcel of vacant land owned by the Imperial Irrigation District. It is part of a much larger parcel of IID land within the northeastern corner of the City of El Centro (see Figure 1). The El Centro Community Center is located approximately one-half mile south of the proposed well site.

3.0 RESOURCE DATA

The geothermal resources of the Imperial Valley are incorporated into six Known Geothermal Resource Areas (KGRAs): Salton Sea, Brawley, Heber, East Mesa, Dunes, and Glamis. Four of the KGRAs have been drilled and are considered to be economically viable: Salton Sea, Heber, East Mesa, and Brawley. The geothermal reservoir which is the energy source for the El Centro field experiment is located on the periphery of the 13.5 sq m (35 sq km) Heber KGRA, which is estimated to contain 12.4 percent of the Imperial Valley's total geothermal resources.



DRILL SITE LOCATION

FIGURE 1

The geothermal production well will be drilled to approximately 8500 feet (2590 m), a depth at which it is highly probable that 250F (121C) brine will be found in the absence of geothermal anomalies. This depth was chosen based on gathered data interpreted by Chevron Resources and Eugene V. Ciancanelli of Cascadia Exploration. The actual target depth will be set after analyzing temperature data obtained during the drilling of the 4000 ft (1219 m) injection well, which will be drilled first.

The geothermal production well will be completed with a slotted liner as this is the most economically advantageous completion technique available for this particular well. It is expected that this well will be capable of flowing up to 730 gpm, though the downwell geothermal production pump will be sized for a considerably smaller production output based on system economics.

The contract for drilling the well is currently out for bid with drilling expected to commence in January.

4.0 SYSTEM FEATURES

Heat extracted from the geothermal brine will be used to operate a packaged lithium bromide absorption chiller to provide chilled clean working fluid (water) for space cooling, or to directly heat the working fluid for space heating and domestic hot water needs, depending on seasonal space conditioning requirements.

A total of approximately 6.02×10^8 Btu/yr of energy presently consumed by the El Centro Community Center is potentially replaceable by geothermal energy. For this demonstration, the geothermal hot/chilled water plant will be sized to handle approximately 97 percent of this annual load. This means that approximately 2.0×10^5 cubic feet of natural gas and 8.7×10^4 kilowatt hours of electricity will be replaced each year by geothermal energy.

After the usable heat has been removed from the geothermal brine, it will be disposed of by pumping the fluid down a 4000-foot deep injection well into a shallow, comparatively cool geothermal region.

5.0 STATUS

During the past six months, final permits for well drilling, including the permit issued by the California Division of Oil and Gas, were obtained. Permission was received from Southern Pacific Railroad for utilizing a portion of its right-of-way for an access road to the well site and also to use a storm drain which lies beneath portions of Southern Pacific property for a pipe run.

PROJECT TITLE: KELLEY HOT SPRING GEOTHERMAL PROJECT - Kelley Hot Spring Agricultural Center Preliminary Design

PRINCIPAL INVESTIGATOR: Alfred B. Longyear

PROJECT TEAM: Geothermal Power Corp., Prime Contractor - Frank G. Metcalfe, President and Program Manager; Lahontan, Inc. - A. B. Longyear, P.I., Peter Klaussen, Construction Manager; Ecoview - James A. Neilson, Environmental Assessment; Agricultural Growth Industries, Inc. - Richard H. Matherson, Agriscience; International Engineering Co. - Sam F. Fogleman, Leonard A. Fisher, LAFCO, Systems Engineering; Coopers & Lybrand - William R. Brink, Market and Economics Assessment.

PROJECT DESCRIPTION: A new 1,360 sow, totally confined, environment controlled swine raising complex is being designed to utilize geothermal direct heat for space heating and process energy. The complex will produce over 29,000 live swine per year to be trucked to slaughter in Modesto, California. The complex includes a feed mill, "farrow-to-finish" swine raising facilities and a waste management facility to process animal wastes to produce methane. The space heating will displace 350,000 gallons of fuel oil per year and the generation of methane will displace an additional 300,000 gallons of fuel oil per year.

LOCATION DESCRIPTION: The Project is located near Kelley Hot Spring, Modoc County, California. The site is about one (1) mile north of State Route 299, fourteen (14) miles west of Alturas and four (4) miles east of Canby. The site is on bench land above the Pit River - composed mostly of low yield range land. State Route 299 is an all weather truck route (E-W) between Alturas and Redding. It connects with US395 (N-S) at Alturas and I-5 (N-S) at Redding. The Southern Pacific Railroad crosses State Route 299 near Canby.

RESOURCE DATA:

Well Depth: GRI #1 (near Kelley H.S.) 3,200 ft.
KHS #1 (1-1/2 mi. east of GRI #1) 3,396 ft.

Date Completed: GRI #1 in 1969; KHS #1 in 1974.

Completion Technique: Uncased exploration wells

Wellhead Temperature: Unpumped; Bottom Hole Temperatures:
GRI #1 = 110°C (230°F); KHS #1 = 115°C (239°F).

Flowrate: Unpumped test wells

RESOURCE DATA: (continued)

Summary: The geology, high heat flow, similar lithology in the two test wells, temperature gradients in the test wells, plus the chemistry, large flow and boiling temperature of Kelley Hot Spring, indicate a reservoir on the order of 2,000 ft. thick by four square miles, with a minimum estimate of heat in the fluid on the order of 6.73×10^{16} calories, (not including additional heat by conduction). The system is designed for a flow rate of 325 gallons/min., peak, at 98°C (208°F). Over a thirty (30) year plant life, less than 1% of the reservoir would be utilized for this first application.

SYSTEM FEATURES:

Application: A single well will be drilled to supply 325 gpm at 98°C (208°F) to the complex. Heat will be transferred through heat exchangers for space heating and process energy. The manure slurry is heated through a tube and shell heat exchanger, and processed in an anaerobic digester.

Heatload (Design):

Twelve Swine Buildings:	7,718,000 Btuh (peak)
Methane Fermentation:	1,960,000 Btuh (peak)
Total:	9,678,000 Btuh (peak)

Yearly Utilization (Maximum): 4.8×10^{10} Btu

Energy Replaced:

Space Heating and Process Energy:	350,000 gal/yr. fuel oil
Methane Generation (Equivalent):	300,000 gal/yr. fuel oil
Total	650,000 gal/yr. fuel oil

Note that this is a new facility and not a retrofit.

Facility Description: The swine raising buildings have all concrete floors with sunken gutters that are flushed several times each day. The gutters are covered with slats. The pen shape plus the natural cleanliness of the animals causes waste elimination in the slatted gutter area. The buildings are pre-engineered, metal, one story structures with R-23 insulation in walls and ceilings. Incoming air passes over a double row of finned tubing located in the ceiling air inlet. Summer cooling is accomplished with evaporative pads located in the air plenum in the attics of the buildings. Air is pumped out of each room by exterior wall-mounted fans that are thermostatically controlled. In addition, the farrowing and

SYSTEM FEATURES: (continued)

Facility Description: (continued)

nursery building floors contain radiant heating pipes in the piglet areas only. The piglet areas require up to 90°F and the immediate adjacent sow areas require 65 ± 5°F. To assure minimum maintenance/maximum reliability, the radiant heating utilizes a fresh water loop, receiving geothermal heat through a heat exchanger. A stand-by boiler (water heater) will furnish emergency heat to the piglets. The adult animals need no emergency heat. Humidity moisture must be controlled in all areas by air exchange once every 2 to 8 minutes, depending on cooling or heating mode and animal age and function. Emergency power will be available to run fans and operate pumps.

The feed mill has space conditioning for operator comfort and for sprouted grain production. The mill produces on the order of seven (7) different feed formulas for a total of 35± tons/day.

All animal wastes are flushed separately from each room, as a 75% water slurry, through a closed sewer system to an anaerobic digester. Thermophillic bacteria at 131°F are utilized to convert the 71 tons/day of slurry to 105,000 scf of methane plus other gases. CO_2 and H_2S are scrubbed and the cleaned methane is piped to the facility boundary for use by the utility company to generate electricity. About 400KW continuous power can be generated. The facility buys electricity from the utility at an average demand of 560KW and a peak demand of 750KW. The digester by-products are essentially sterilized fertilizer (1,400 ft^3/day) and agricultural quality water (5+ gpm). This water is recycled for manure flushing in some of the swine facilities. The farrowing and nursery facilities are flushed with fresh water.

Disposal Methods: The surplus agricultural waste water will be disposed of in accordance with local regulations (overland drainage or spray irrigation). Residual geothermal fluids will be utilized for flush makeup and any surplus will be disposed of by overland drainage or spray irrigation. If unacceptable constituents are found in these fluids, a re-injection well will be drilled and utilized.

SYSTEM FEATURES: (continued)

Summary: At the preliminary design state, $8.6 million in facilities and working capital (including inflation), will be utilized in final design, construction and the first year of full production by the end of 1983. The owner's equity should be returned in 3+ years with an internal rate of return of 28+%. The facility requires very professional management, experienced in totally confined swine raising for the production of premium pork. This includes a working knowledge of marketing from such a facility.

The design is based upon Scandanavian and European technology as practiced in the midwest today and adopted to west coast conditions.

STATUS: The Project has completed criteria development, over 50 trade studies, a conceptual design and conceptual economic assessment, a preliminary design, construction plan and economic assessment and an environmental assessment. This comprises Phase I of the Project. The final design and construction phase is dependent upon final agreements for the private share. As a part of this latter effort, the selection of professional staff will be required.

CURRENT ESTIMATED PROJECT COST:

Total: $9,099,729

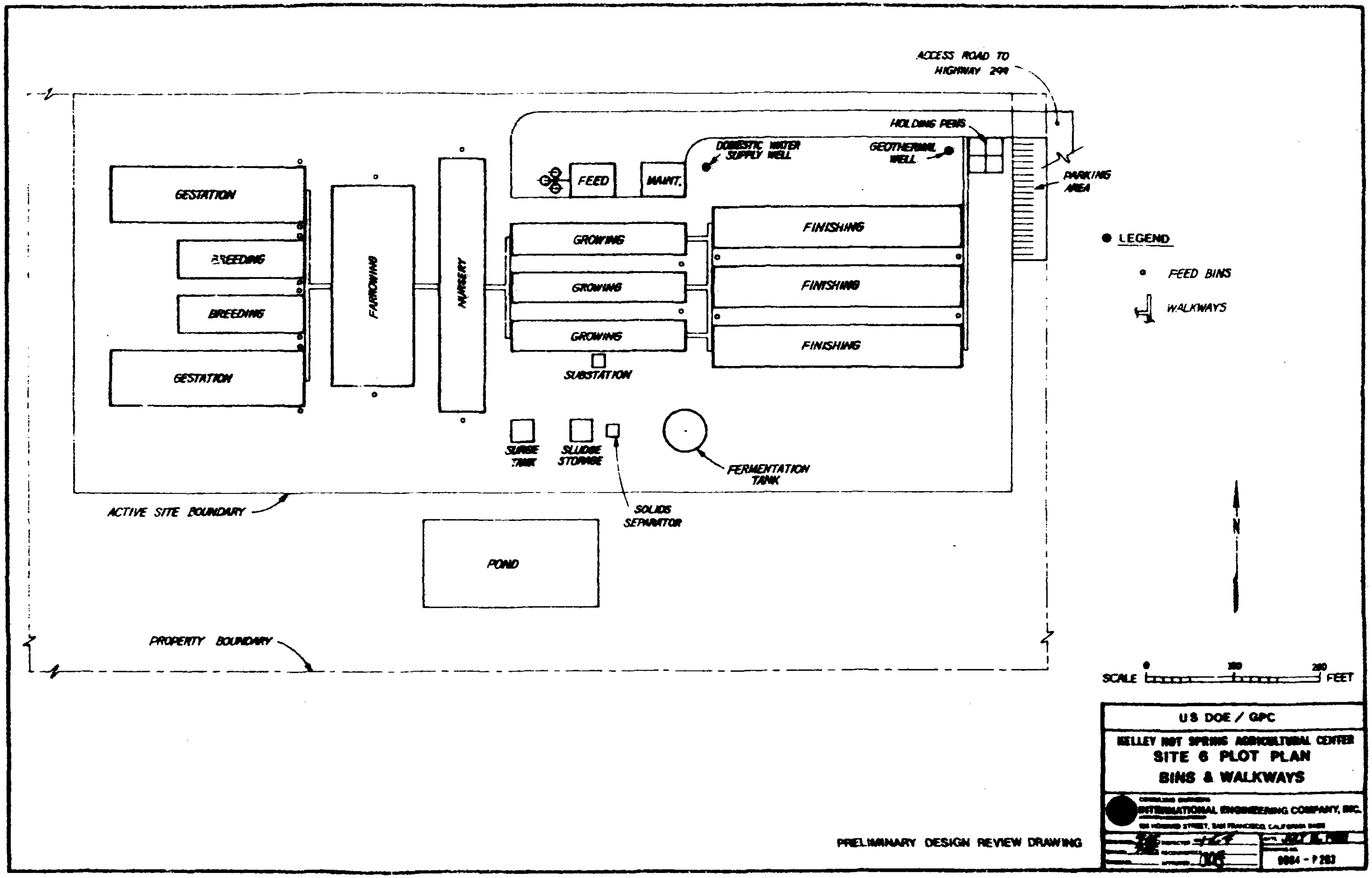
DOE Share:		Participant Share:	
Phase I	$473,303	Phase I	$41,426
Phase II	$1,344,000	Phase II	$7,241,000

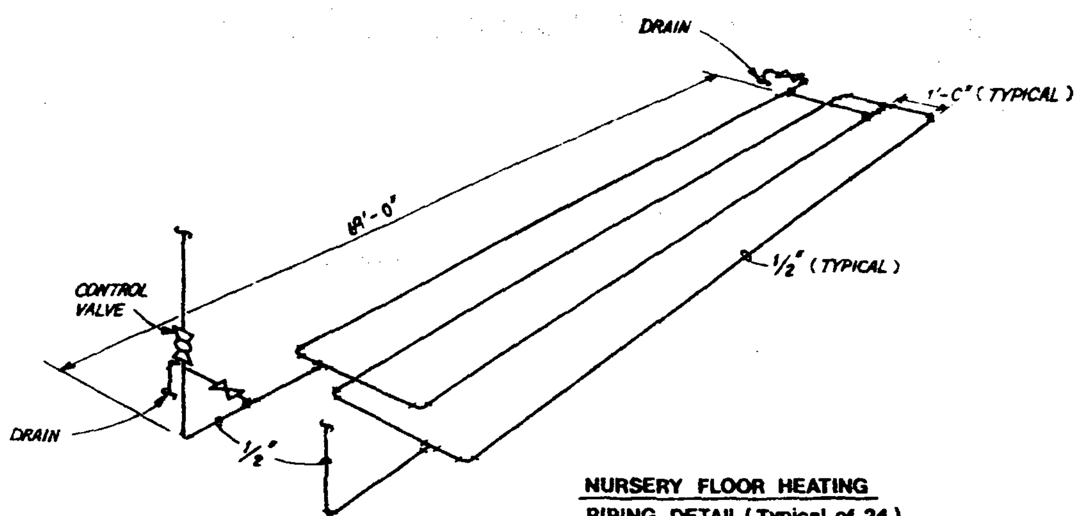
LESSONS LEARNED:

1. Wherever there is a possibility of historical significance related to the Project site, such as a hot spring or other surficial evidence of a geothermal resource, the Project should plan on an archeological field survey as a first activity.
2. The phased program with discrete design activity has precluded consideration of some unique low cost approaches to this livestock complex.

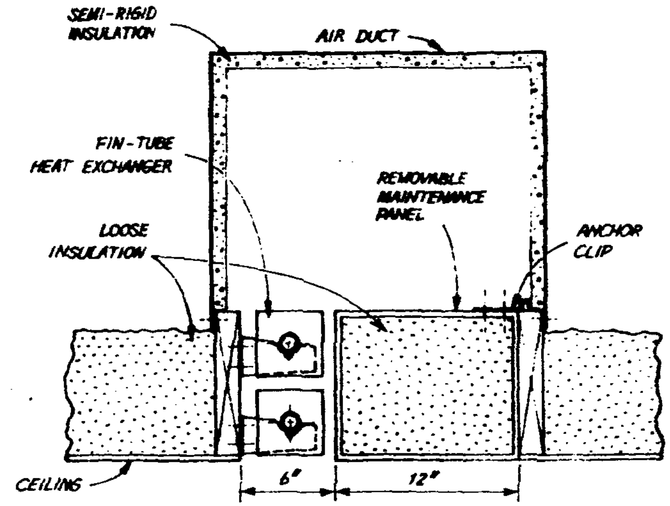
LESSONS LEARNED: (continued)

3. The current economic climate can jeopardize the final financing of the Project. The concept was developed and proposed in 1977-78, contracted in September, 1979, and Phase I studies completed in August, 1980. The investment climate has changed considerably during this period.
4. The Project is in consort with the trends in medium and large size swine raising practices in the United States. However, being located in the West, it is best owned and operated as a medium sized facility with the necessary flexibility in purchasing of feed constituents and marketing of live hogs.
5. The Project is an economic development effort. The geothermal energy utilization is a strong plus, but the easiest part of the problem.

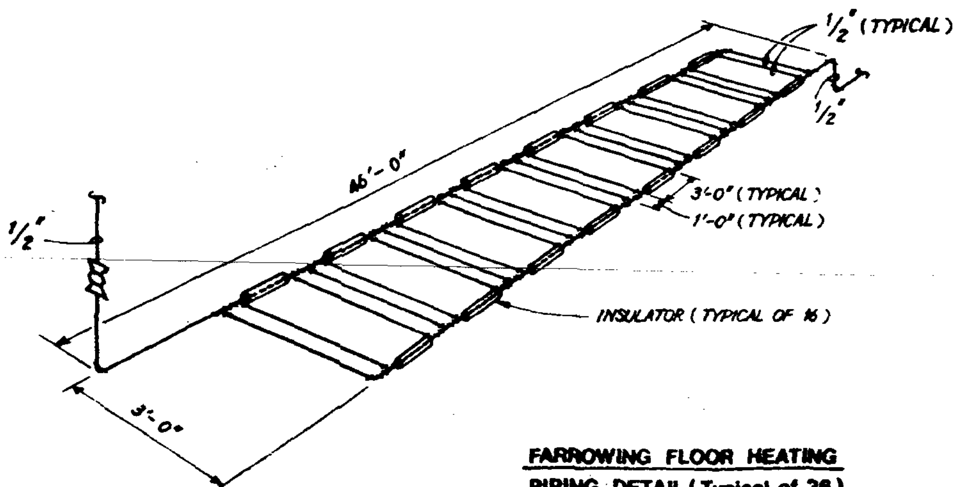

ACCESS ROAD TO HIGHWAY 299
HOLDING PENS
DOMESTIC WATER SUPPLY WELL
GEOTHERMAL WELL
PARKING AREA
FEED
MAINT.
GESTATION
BREEDING
BREEDING
GESTATION
FARROWING
NURSERY
GROWING
GROWING
GROWING
FINISHING
FINISHING
FINISHING
SUBSTATION
SURGE TANK
SLUDGE STORAGE
SOLIDS SEPARATOR
FERMENTATION TANK
POND
ACTIVE SITE BOUNDARY
PROPERTY BOUNDARY
LEGEND
FEED BINS
WALKWAYS
N
SCALE 0 100 200 FEET
US DOE / GPC
KELLEY HOT SPRING AGRICULTURAL CENTER
SITE 6 PLOT PLAN
BINS & WALKWAYS
INTERNATIONAL ENGINEERING COMPANY, INC.
PRELIMINARY DESIGN REVIEW DRAWING



NURSERY FLOOR HEATING PIPING DETAIL (Typical of 24)



BUILDING SPACE HEATING COILS SECTION (Typical)



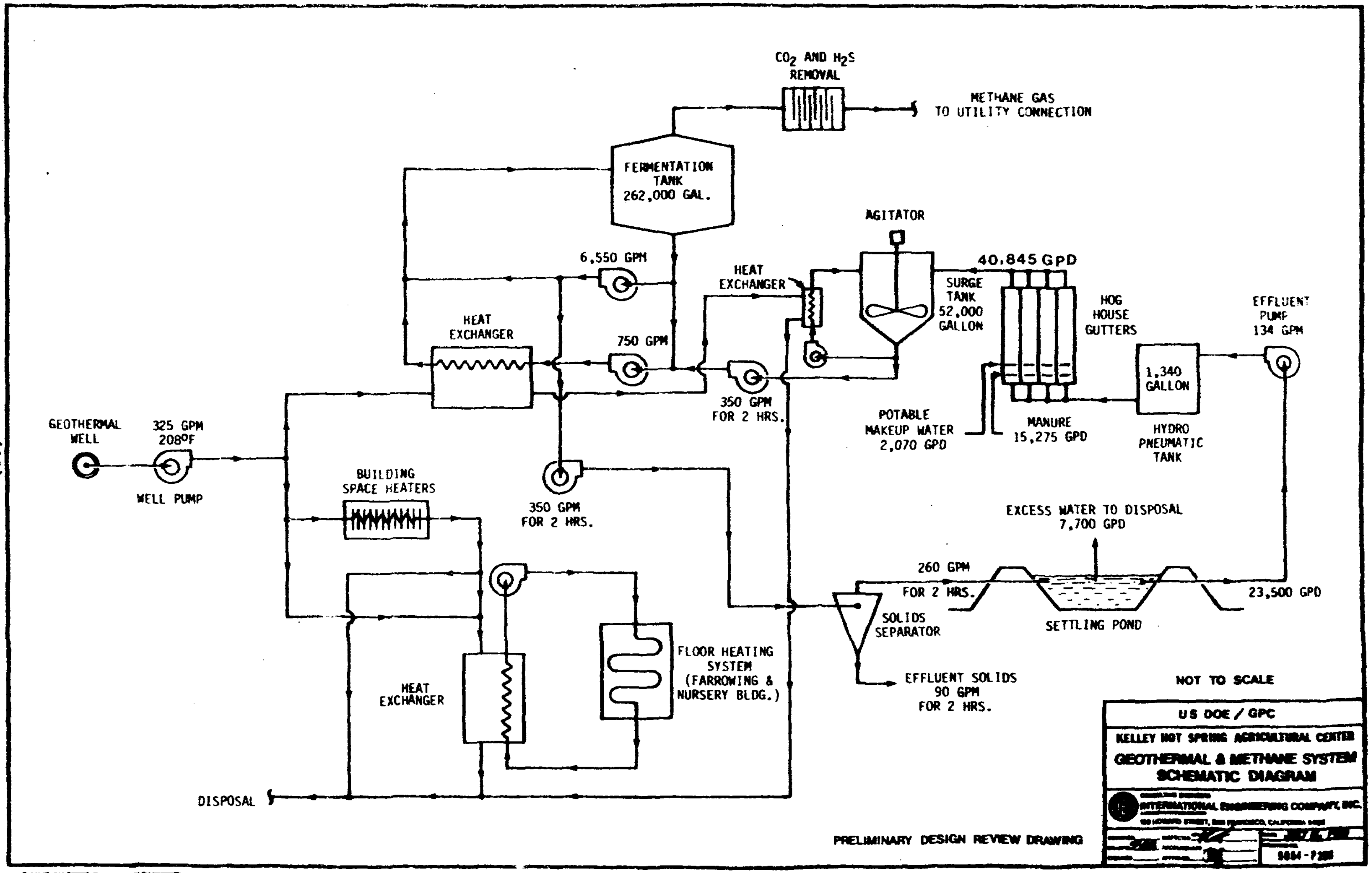
FARROWING FLOOR HEATING PIPING DETAIL (Typical of 36)

PRELIMINARY DESIGN REVIEW DRAWING

NOT TO SCALE

US DOE / GPC
KELLEY HOT SPRING AGRICULTURAL CENTER BUILDING PIPING DETAILS
INTERNATIONAL ENGINEERING COMPANY, INC.
8804 - P 207

(61)



CO_2 AND H_2S REMOVAL
METHANE GAS TO UTILITY CONNECTION
FERMENTATION TANK 262,000 GAL.
AGITATOR
6,550 GPM
HEAT EXCHANGER
40,845 GPD
SURGE TANK 52,000 GALLON
HOG HOUSE GUTTERS
EFFLUENT PUMP 134 GPM
HEAT EXCHANGER
750 GPM
1,340 GALLON
350 GPM FOR 2 HRS.
POTABLE MAKEUP WATER 2,070 GPD
MANURE 15,275 GPD
HYDRO PNEUMATIC TANK
GEOTHERMAL WELL
325 GPM 208°F
WELL PUMP
BUILDING SPACE HEATERS
350 GPM FOR 2 HRS.
EXCESS WATER TO DISPOSAL 7,700 GPD
260 GPM FOR 2 HRS.
23,500 GPD
SOLIDS SEPARATOR
SETTLING POND
HEAT EXCHANGER
FLOOR HEATING SYSTEM (FARROWING & NURSERY BLDG.)
EFFLUENT SOLIDS 90 GPM FOR 2 HRS.
NOT TO SCALE
DISPOSAL
PRELIMINARY DESIGN REVIEW DRAWING
US DOE / GPC
KELLEY HOT SPRING AGRICULTURAL CENTER
GEOTHERMAL & METHANE SYSTEM SCHEMATIC DIAGRAM
INTERNATIONAL ENGINEERING COMPANY, INC.

PRINCIPAL FLOWS THROUGH KHSAC

Item	Rate
Geothermal Fluid (peak)	325 gpm
Geo Heat (peak)	9.68×10^6 Btuh
Effluent Water (ave.)	5.4 gpm
Pork Production-Animals (design)	29,353/year
Pork Production-Animals (max)	33,000/year
Pork Production-Weight (design)	6.69×10^6 lb/year
Methane (design minimum)	105×10^3 scf/day
Manure slurry (75% water) (design)	71 ton/day
Feed (design)	35.5 ton/day
Fresh Water (design)	37,000 gal/day

PROJECT TITLE: Water and Space Heating for A College and Hospital by Utilizing Geothermal Energy at Corsicana, Texas

PRINCIPAL INVESTIGATOR: C. Paul Green, Director of Institutional Development, Navarro College, Corsicana, Texas

PROJECT TEAM:

Prime Contractor:	Navarro College, Corsicana, TX
Principal Utilizer:	Navarro County Memorial Hospital, Corsicana, TX
Geothermal Consulting Engineers:	Radian Corporation, Austin, TX
HVAC Consulting Engineers:	Ham-Mer Consulting Engineers, Austin, Texas
Drilling Consultant:	N. H. Hardgrave, Corsicana, TX
Tubing:	Armco Steel, Houston, TX
Financial:	Wolens & Irwin, Corsicana, TX

PROJECT DESCRIPTION:

The purpose of this geothermal project is to retrofit a college student union building and county hospital space and water heating systems to use geothermal energy, thereby reducing their dependence on fossil fuels. The geothermal heating system will supply heat to the domestic water system, as well as the forced air heating and outside air preheating systems of the college SUB and hospital. At present, heat input to these systems is accomplished via steam provided by low-pressure, natural gas-fired boilers. These boilers will be maintained in place as backup and augmentation. Readily available commercial piping, pumps, valves, controls, flatplate heat exchangers, and insulation will be utilized in the retrofit of the system.

The final phase is a one-year operational demonstration phase, during which potential geothermal users will be encouraged to visit and observe the geothermal heating system.

LOCATION DESCRIPTION:

Navarro College and Navarro County Memorial Hospital are located in Corsicana, Texas (population 22,300), approximately 45 miles south of Dallas.

RESOURCE DATA:

The production well (Well No. 1) is 2664 feet in total depth and was completed in February 1979. The production zone is shot perforated in several intervals from 2400 to 2600 feet. Well pumping tests have produced sustained flow rates of 315 gpm of 125°F fluid, at about 5900 mg/l (ppm) total dissolved solids. The source of the heat is faulting associated with the Ouachita fold belt, which outcrops in Arkansas and underlies much of central Texas. The Woodbine Formation is the groundwater reservoir that makes up the aquifer. Hydraulic interconnection of deeper and shallow formations provided by the Mexia-Talco fault system is the factor responsible for the area's low-temperature geothermal value.

SYSTEM FEATURES:

Geothermal fluid to be used for water and space heating in the College Student Union Building and the adjacent 150-bed County Hospital will be supplied by one 2,664 ft. production well. Flat-plate heat exchangers located in each of the buildings, will be used to achieve maximum geothermal heat utilization and for ease of cleaning. Geothermal fluids will be maintained in a closed system so as to control corrosion and scaling phenomena. At peak winter heating periods, the geothermal heating system will deliver approximately one million Btu/hr to the college's Student Union Building (SUB), and about 3.5 million Btu/hr to the hospital water and space heating systems. This load is represented by a fluid temperature drop of about 35°F at 250 gpm. The utilization of geothermal energy will displace about 7300 million Btu/year (theoretical) now supplied by natural gas. In addition, energy conservation methods will result in further savings of approximately 9,000 million Btu/year for a total savings of 16,300 million Btu/year. The geothermal fluid will be disposed of by injection into the producing formation via a second well which has been completed.

STATUS:

Preliminary design efforts are nearing completion pending results of planned additional production/injection well development and testing.

CURRENT ESTIMATED PROJECT COST:

The total estimated project cost as currently approved is $1,074,860 with DOE contributing $861,650 (80%) and the participant and its benefactors contributing $213,210 (20%).

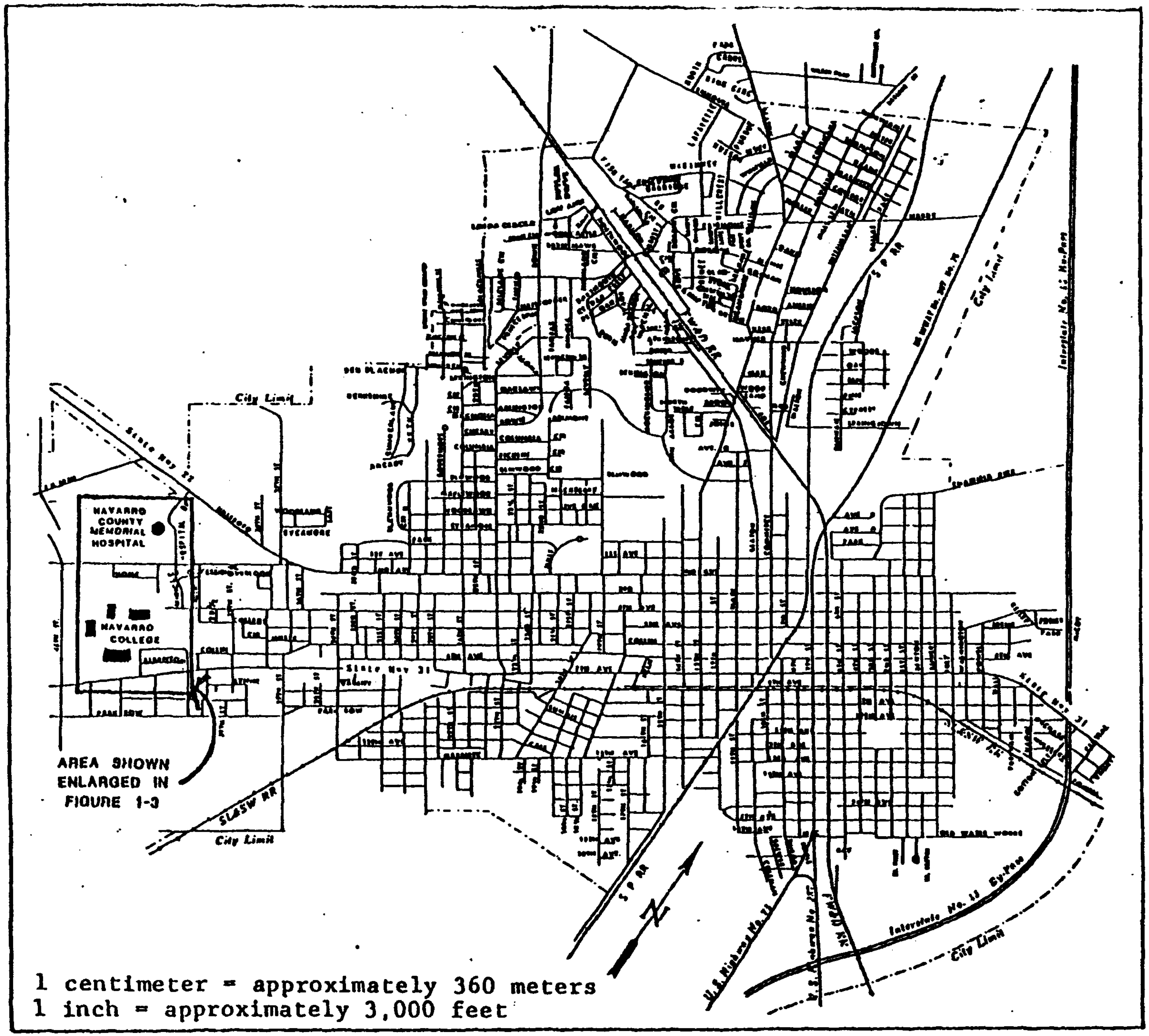


Figure 1. The City of Corsicana, Texas

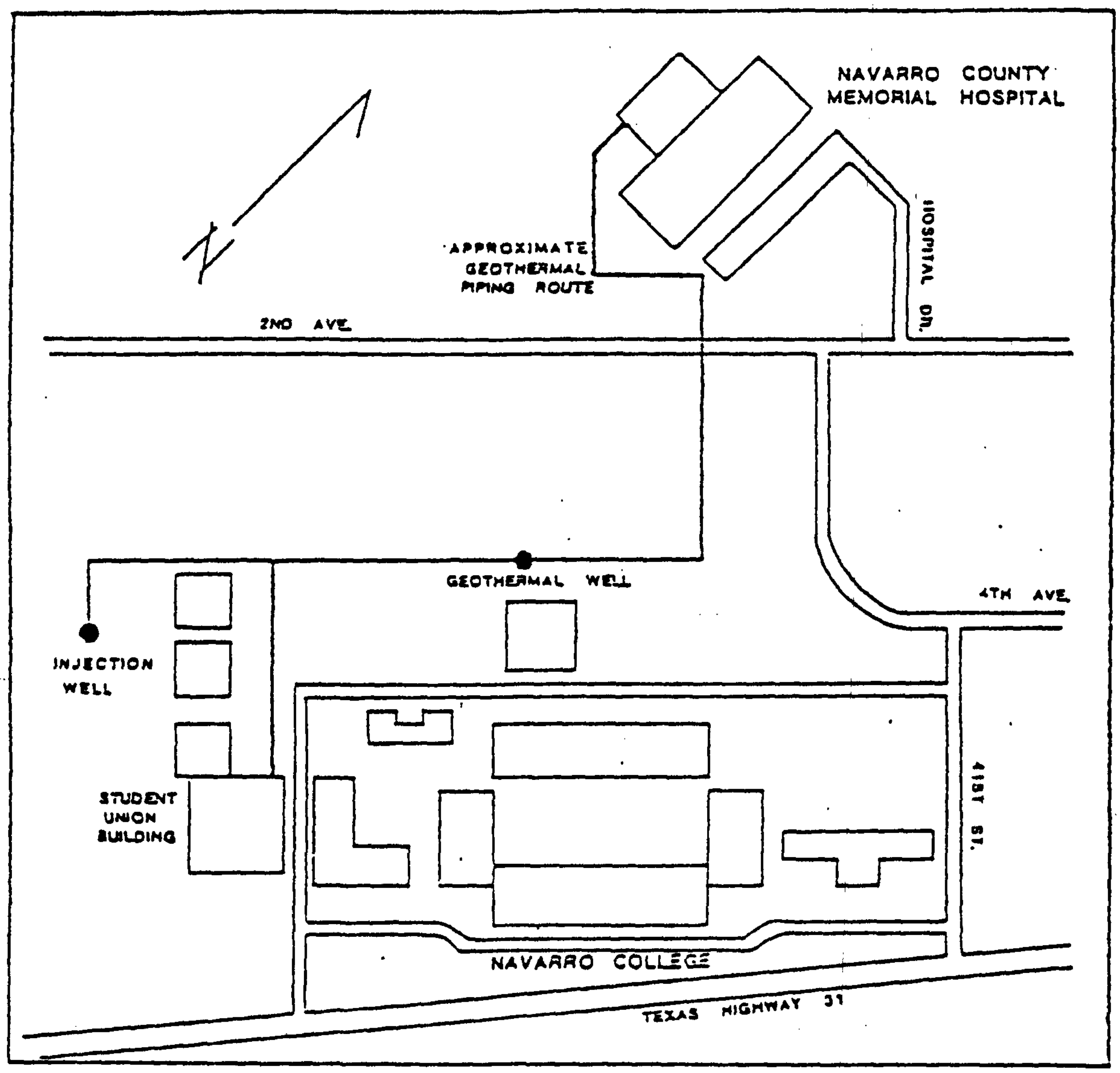


Figure 2. Location of Wells in Relation to Navarro College and Navarro County Memorial Hospital (not to scale)

KLAMATH FALLS, OREGON

PROJECT TITLE: KLAMATH FALLS GEOTHERMAL HEATING DISTRICT

PRINCIPAL INVESTIGATOR: HAROLD DERRAH

PROJECT TEAM: City of Klamath Falls; Balzhiser/Hubbard & Associates, Design Engineers; LLC Geothermal Consultants, Conceptual Design and Master Planning; Geothermex, Inc., Reservoir Engineering; Lawrence Berkeley Laboratory, Reservoir Engineering; Bruun & Sorensen, Engineering and Pipe Line Design; Eliot Allen & Associates, Land Use Planning.

PROJECT DESCRIPTION: The project is the first phase development of the Geothermal Heating District application for use initially within 14 city, county, state and federal buildings. The project is designed in size to service an 11 block commercial area with planning being made for eventual expansion to serve an urban area of 50,000 people. The project is composed of several segments, the first being the wells which will provide resource from two production wells and a primary deep heating line of approximately 4400' in length in concrete conduit to a central heat exchanger building where two plate heat exchangers transfer the heat from the geothermal fluids to a secondary line will be a direct buried F or P line that will take closed loop domestic water to the individual buildings to provide the necessary heat. Geothermal waters will be injected after passing the exchanger into an existing well.

LOCATION DESCRIPTION: Klamath Falls is located in South Central Oregon approximately twenty miles north of the California border. Klamath Falls is located in the second largest KGRA, as designated by the U.S. Geological Survey. The designation carries with it a geothermal equivalent energy resource equal to 8.18×10^{15} BTU's, or approximately 2 billion barrels of oil.

RESOURCE DATA:

Well Depth: Two production wells have been drilled with Well No. 1's depth to 350' and Well No. 2 drilled to a depth of 900'.

Date Completed: Well No. 1 was completed in September, 1979 and Well No. 2 was completed in January of 1980.

Completion Technique: The wells were completed with casing complete to the bottom of the well with perforations in the heat flow and water flow area. The wells were drilled with a rotary rig, using both mud and air as the removal agent of the cuttings.

Wellhead Temperatures: Both wells have temperatures of 225°F.

Flow Rate: Well No. 1 has been pump tested to 680 g.p.m. with minimum drawdown. Well No. 2 has been pumped to 900 g.p.m. with a 60' well drawdown.

Summary: The wells were completed at a cost of approximately $65,000 and provide approximately 1600 g.p.m. with minimum drawdown within the production wells themselves and, more importantly, with a minimum drawdown, as indicated by reservoir sampling techniques, of 3' in the closest surrounding wells. The wells will provide sufficient resource for the project which has an estimated peak requirement of 780 g.p.m. The mean for average flows required for the project are 300 g.p.m.

SYSTEM FEATURES:

Application: The application of the project is for geothermal district heating with initial service to 14 buildings with sizing adequate enough for heat load requirements of an 11 block commercial area.

Heatload: The design heat load for the 14 buildings is based on a cubic foot project size of 4,021,610 cu. ft. The peak heat load will be 15.3 x 10^6 BTU's with a Delta T of 40^o requiring a peak flow of 756 g.p.m. Expansion to the total downtown district will require an estimated heat load of 135 x 10^6 BTU's per hour and will require approximately 6,750 g.p.m. at 200°F with a 40°F temperature drop.

Yearly Utilization: Yearly utilization will be 10 x 6^5 therms of geothermal energy.

Energy Replaced: Energy to be replaced will be 7.06 x 10^6 therms with the development of the 11 block area equaling approximately 250,000 barrels of oil to be replaced during a 20-year period.

Facility Description: The project will involve the use of the two production wells which will be tied into a primary pipe line. The primary pipe line is to be placed within concrete conduit for a distance of approximately 4,420'. The concrete conduit will run along existing right-of-ways and will be sized adequately enough to handle additional pipe. The pipe to be placed within the conduit will be 8" steel pipe with 2" of polyurethane insulation. The purpose of the use of the concrete conduit is to provide easy access for future pipe line, increase the life expectancy of the pipe which was determined based on corrosion testing and provide for easier maintenance for the future of the pipe line. At the end of the primary pipe line, the water will circulate through two plate heat exchangers that will transfer the heat to a secondary closed loop system. After the geothermal fluids have passed through the heat exchanger, the fluids will be injected into the existing well directly adjacent to the central heat exchanger. The closed loop secondary system will then proceed with the distribution of the fluids to the 14 buildings. The sizing of the secondary line will be initially with a 10", then telescoping down to an 8", 6" and 3".

Disposal Method:

Summary:

STATUS: The wells have been completed and final design has been completed both on the secondary and primary pipe line. The primary pipe line which includes the heat exchanger building and associated exchangers was bid on October 21, 1980. the contractor has been notified to proceed with construction. It is anticipated the project will be completed by May 31, 1981.

CURRENT ESTIMATED PROJECT COST:

Total: $2,331,769

DOE Share: $1,547,183 Participant Share: $784,766

LESSONS LEARNED: Perhaps the greatest lesson learned to date on this project is associated with the cost estimating completed in the original proposal. In developing the estimates for the original proposal, they were done under the assumption that the project would proceed within a one to one and one-half year time table. Because of the time involved in the environmental reservoir confirmation and design aspects, the project was delayed for approximately three years and the original cost estimate was not subjected to inflationary review. The inflationary affects on the original proposal amounted to approximately 1% per month. Additionally, the exchanger building and associated equipment was underestimated by approximately 100%. With the primary pipe line and the exchanger building bid out, the associated costs for this project may be used in other projects to determine the accuracy of other district heating projects estimating.

One other lesson learned was the ability of the City of Klamath Falls to drill its own well. The City ran into a bidding process for the production wells twice and in both cases received substantially higher bids than had been allowed for. The City then obtained through a leasing agreement a drill rig and hired well drillers as its employees and drilled the wells under its own internal operation. There is approximately $70,000 to $80,000 saved over the bids received for the initial well development.

One additional lesson learned was that of project management. The City in undertaking the project and because of its limited financial resources was not able to obtain the full-time services of a principal investigator whose sole responsibility would be for the management of the project.

In turn, the City has spread the responsibilities of the project to various department heads who have undertaken their specific requirements of the project along with their other City requirements.
In future projects, it should be recognized that because of the involvement in non-traditional aspects of the district heating geothermal development, that a principal investigator should be assigned to the project with full-time responsibilities directly associated with the project only.

PROJECT TITLE: Direct Utilization of Geothermal Energy for Space and Water Heating at Marlin, Texas

PRINCIPAL INVESTIGATOR: J. D. Norris, Jr., Administrator, Torbett-Hutchings-Smith (THS) Memorial Hospital, Marlin, Texas

PROJECT TEAM:

Prime Contractor:	THS Memorial Hospital, Marlin, TX
Geothermal Consulting Engineers:	Radian Corporation, Austin, TX
Architects:	Spencer Associates, Austin, TX
HVAC Engineers:	Ham-Mer Consulting Engineers, Austin, TX
Drilling and Completion:	Layne Texas Co., Dallas, TX
Surface Disposal:	City of Marlin
Community Coordination:	Marlin Chamber of Commerce
Legal:	J. Welch, Marlin, TX
Accounting:	W. M. Parish & Co., Marlin, TX

PROJECT DESCRIPTION:

The purpose of this geothermal project is to retrofit the 130-bed hospital space and water heating systems to use geothermal energy, thereby reducing its dependence on fossil fuels. The geothermal heating system will supply heat to the hospital domestic water system, as well as to the space heating and outside air preheating systems. At present, heat input to these systems is accomplished via steam provided by a low-pressure, natural gas-fired boiler. This boiler system will remain in place as backup and augmentation. Readily available commercial piping, pumps, valves, controls, flat plate heat exchangers, and insulation will be utilized.

The final phase is a one-year operational demonstration phase, during which potential geothermal users will be encouraged to visit and observe the geothermal heating system.

LOCATION DESCRIPTION:

THS Memorial Hospital is located in Marlin, Texas (population 6,350), approximately 30 miles southeast of Waco, Texas.

RESOURCE DATA:

The production well is 3885 feet in total depth and was completed in July 1979. The production zone is screened (5-1/2" O.D. mill slot screen) from about 3613 to 3883 feet. Pump testing of the well has produced flow rates of 310-315 gpm of 153°F fluid at

4,000 mg/1 (ppm) total dissolved solids. The source of the heat is faulting associated with the Ouachita fold belt, which outcrops in Arkansas and underlies much of central Texas. The coarser-grained sandsones (especially the Hosston member of the Travis Peak formation) are the groundwater reservoirs that define the aquifer. The factor which is responsible for the area's geothermal value is the hydraulic interconnection of deeper and shallow sandstones provided by the Mexia-Talco fault system.

SYSTEM FEATURES:

Geothermal fluid to be used for water and space heating in the 130-bed hospital will be supplied by one 3,885-foot production well. Flat plate heat exchangers, located in a proposed structure adjacent to the hospital, will be used to achieve maximum geothermal utilization and for ease of cleaning. Geothermal fluids will be maintained in a closed system so as to control corrosion and scaling phenomena. At peak winter heating periods, the geothermal heating system will deliver approximately 3.6 million Btu/hr to the hospital heating load. This load is represented by a fluid temperature drop of about 45°F at 160 gpm and will reduce the THS Hospital average annual natural gas consumption by 84 percent. The utilization of geothermal energy will displace about 9,400 million Btu/yr (theoretical) now supplied by natural gas. The geothermal fluid is to be discharged to the Brazos River via the city storm sewer and connecting surface water courses, pending approval by Region VI EPA.

STATUS:

The Final Design Report and Draft Bid Package was submitted to DOE for review in September 1980. The Final Design Review meeting was held on October 15, 1980. Letting of bids for construction is anticipated in the near future pending DOE approval of the final design construction package.

CURRENT ESTIMATED PROJECT COST:

The total estimated project cost as currently approved is $693,550. This total cost includes a donated existing well ($100,000) originally planned for use as an injection well. However, it was found that this well would not accept an appreciable quantity of fluid and surface disposal was considered. Deleting this amount decreases the total approved project cost to $593,550 with DOE contributing $466,820 (79%) and the participant and its benefactors, including the Texas Energy and Natural Resources Advisory Council, contributing $126,730 (21%).

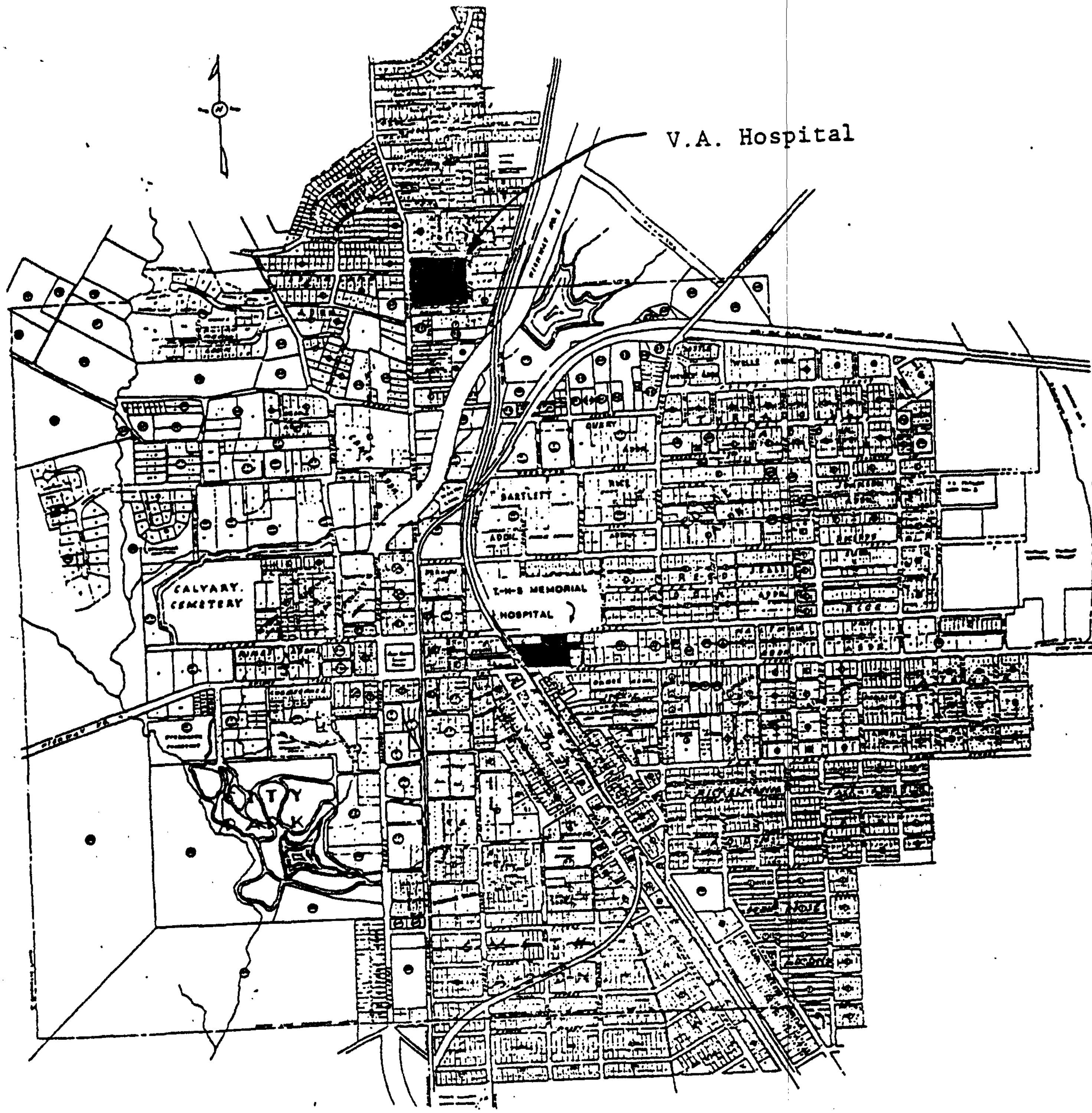


Figure 1. Map of Marlin, Texas, Showing Location of the T-H-S Memorial Hospital (Scale: 1 inch = approximately 850 feet)

PROJECT TITLE: Direct Utilization of Geothermal Energy for Philip Schools

PRINCIPAL INVESTIGATOR: Charles A. Maxon, Superintendent of Schools
(605) 859-2679

PROJECT TEAM: Haakon School District 27-1
Hengel, Berg & Associates

LOCATION DESCRIPTION: Philip, South Dakota
80 miles (128 km) east of Rapid City, SD
Population: 1000
Area Activities: Agriculture, light industry, and trade center

RESOURCE DATA:

Well Depth: 4266 ft (1300 m)
Date Complete: 2/23/79
Completion Technique: Open hole
Wellhead Temperature: 157 degrees F. (69 degrees C)
Flowrate: 300 gpm (18.9 l/s) artesian
Summary: The Madison Formation extends under the western half of South Dakota and into the bordering states of Wyoming, Montana and North Dakota. Most Madison wells in South Dakota are naturally flowing with temperatures ranging from 110 degrees F (43 degrees C) to 170 degrees F (77 degrees C).

SYSTEM FEATURES:

Application: Space, water and district heating
Heatload (Design): 5.5×10^6 BTU/hr (1.61 MW)
Yearly utilization (Maximum): 9.53×10^9 BTU/yr (.32 MW-yr)
Energy Replaced: Electricity - 122,989 kWh
Fuel Oil - 54,729 gals.
Propane - 23,858 gals.

Facility Description: 5 school and 8 business district buildings

Disposal Method: Surface discharge to the Bad River after treatment to remove Radium 226.

Summary: The school heating project has stimulated the development of a business district heating system, Philip Geothermal, Inc. In addition, Little Scotchman Industries, the city water plant and county maintenance building use geothermal fluids from other wells for space heating.

STATUS:

Construction complete. Adjustment of the flow through the system and monitoring to start.

CURRENT ESTIMATED PROJECT COST:

Total:	$1,205,804		
DEO Share:	$ 936,199 78%	Participant Share:	$269,605* 22%

LESSONS LEARNED:

The initial phase of this project was the development of the geothermal resource. A well was drilled into the Madison Formation. The total depth of the well is approximately 4,266 feet. During the drilling operations we had a full time drilling consultant at the well site during drilling operations. He was to be available in the event that drilling problems would shift the drilling operation from a footage basis to a day rate. We would recommend that on a future well that the drilling consultant be placed on a retainer so that he would be available to come to the well site with 24 hours notice. This would reduce the cost of the drilling consultant by eliminating that expense when the drilling operation is procedुring without any problems.

After setting the main casing the open hole completion of the well was drilled. Problems developed during the open hole drilling which included shale lenses and sand pockets in the limestone. This condition could create future problems during operation of the well such as sloughing of the sands and shale into the open hole. A 5" O.D. flush joint casing was suspended inside of the 7 5/8" casing previously installed. On any future wells drilled into the Madison Formation we would recommend that the open hole completion be completed before setting the main casing. If shale lenses or sand pockets that are drilled through they can be cased out with the main casing at a considerable savings in cost.

Samples of the geothermal fluid were tested by the Federal Environmental Protection Agency. Their tests indicate the presents of Radium 226 in the geothermal waters. The level of Radium 226 is approximately 99 pico curies per liter. This exceeds the EPA standards for drinking water 5 pico curies per liter or less. To obtain a discharge permit to discharge the geothermal fluid into the Bad River, the Radium 226 level had to be reduced to less than the 5 pico curies per liter.

Among the various methods investigated for removal of Radium 226, was the method used by the Uranium Mining and Milling Companys. The method they used involved adding a 10% aqueous solution of Barium Chloride to the water. The resulting chemical reaction provides a Barium Sulfate to which the Radium 226 adheres. The result is a floculation that will settle out of the water. This process has a 99% efficiency. The Barium Chloride Treatment facility consists of a building to house the mixing tanks, a short section of discharge line, and an in-line static mixer. The Barium Chloride solution is added by metering pumps to the in-line static mixer. The barium chloride solution is mixed into the geothermal fluid and piped to the holding pond. The holding pond was designed for a three day retention time. The retention pond was divided into two cells so that maintenance could be preformed on one cell while operating would be the one remaining cell.

The heating system in the High School-Armory building and in the Elementary School building were low pressure steam systems. During the planning for the modification of these sytems to a low temperature hot water it was anticipated that the control valves could be reused. However, as the modification contract proceeded it became apparent that the seals in many of the control valves had deteriorated. This showed up when the contractor pressurized the system during standard test procedures.

Another problem that became apparent during the testing of the system was that a few of the baseboard radiation units had developed pin holes at their connections from the years of use. When the pressure test was applied, these areas started to leak water and had to be repaired. On future conversion projects, consideration should be given to pressure testing sections of the system prior to design to determine if that portion of the system could be used or if would have to be replaced. This would add additional cost to the preliminary engineering phase of the project. However, under certain circumstances this may be money well spent.

The contractual arrangement between the Owner and Contractor on this project has been very good. Changes to the construction contract have been kept to a minimum. The negotiated Change Orders with the contractor have been reasonable.

In some of the classrooms the existing steam fin tube radiation and the baseboard radiation units were replaced with hot water fin tube radiation units. The hot water fin tube radiation units were sized based on using water at approximately 140 degrees F. Engineering calculations show that in some instances it was more economical to add a cabinet unit heater along with the baseboard radiation units to provide the required heat for the room. The cabinet unit heaters were installed at the end of the baseboard radiation units were possible, however, in several instances the cabinet unit heater was placed in the middle of a baseboard radiation run. This created a problem because the baseboard radiation covers had to be cut. To make a neat joint between the baseboard radiation cover and the cover on the cabinet unit heater, the contractor provided a PVC window glazing gasket with a profile that covered the raw edge of the baseboard radiation cover.

The piping the boiler room of both the High School and the Elementary School is designed to vary the flow to the space heat exchanger. During periods of maximum heat demand, all of the geothermal fluid is directed to the space heat exchanger. From the space heat exchanger, the geothermal fluid flows to the domestic hot water heat exchanger. During periods of moderate to low space heating demand, the geothermal fluid is diverted around the space heat exchanger to the domestic hot water heat exchanger. The flow is controlled by a pneumatic actuated three way valve. The pneumatic actuated three way valves normally used in commerical installations would not operated against the artesian flow of this project. We were directed by the manufacturer to their industrial division. All of the three way valves on the geothermal side of the system are of the industrial type.

Pipeline

The geothermal fluid is piped to the school buildings, the business district buildings, and to the Barium Chloride Treatment plant using a filiment wound fiberglass expoxy resin pipe. This pipe is designed for applications up to 210 degrees F (99 degrees C).

This pipe is assembled in a bell and spigot method. Whenever the pipe has to be cut in the field the cut end has to be shaved to provide a new spigot. This shaving is done with a specilized pipe shaver provided by the manufacturer.

All of the fittings, sockets, pipe ends and pipe sockets must be clean and dry and must be sanded within 2 hours of assmebly. The sanding was accomplished using a flapper type sander on a drill.

If there is just the least bit of moisture or grease from the hands of the individuals handling the pipe, a perfect bond is not obtained. During the construction of this project we had only two joint failures. The contractor was exceptionally careful butting the pipe together because of the high cost of repairing the pipe failure. The joints if made properly are as strong or stronger than the pipe itself.

To repair a joint failure requires that a section of the pipe be cut out and new bell and spigots be cut on each then sanded and the pieces put back together.

The pipe was bedded in a layer of sand. The sand all passing a 3/8" screen was obtained locally. Approximately 6" of sand was placed under the pipe and another 6" was placed over the pipe. The soil in which the trench was excavated is composed primarily of the pier shale. This soil will expand and contract with changes in moisture. The sand was placed to provide a cushion to the pipe during these periods when the soil around it is moving.

The discharge line from the school is the supply line for the business heating district. The heating district was designed to provide a geothermal fluid at the same relative elevation to all of the eight building to be heated.

The construction of the system was recently completed. We have entered the adjustment and monitoring phase. All of the building in the heating district have not been connected to the system as of this date. As each building is added to the system a readjustment of the valves in the fire-hall and the various businesses will have to be made.

PROJECT TITLE: Diamond Ring Ranch Geothermal Demonstration Heating Project

PRINCIPAL INVESTIGATOR: Dr. S. M. Howard, Professor of Metallurgical Engineering, (605) 394-2341

PROJECT TEAM: South Dakota School of Mines and Technology
Re/Spec, Inc.
Diamond Ring Ranch

PROJECT OBJECTIVE: Utilize existing Madison well to provide grain drying, and space heating for homes.

LOCATION DESCRIPTION: Haakon County, Central South Dakota
50 miles (80 km) west of Pierre, SD
Population: 2900 (Haakon County)
Area Activities: Agriculture

RESOURCE DATA:

Well Depth: 4112 ft (1253 m)

Date Complete: 1959

Completion Technique: Open hole

Wellhead Temperature: 152°F (67°C)

Flowrate: 170 gpm (10.7 ℓ/s) artesian

Summary: The Madison Formation extends under the western half of South Dakota and into the bordering states of Wyoming, Montana, and North Dakota. Most Madison wells in South Dakota are naturally flowing with temperatures varying from 110°F (43°C) to 170°F (77°C).

SYSTEM FEATURES:

Application: Space heating and grain drying

Heatload (Design): 3.35×10^6 Btu/hr (.98 MW)

Yearly Utilization (Maximum): 7.87×10^9 Btu/yr (.26 MW-Yr)

Energy Replaced: Electricity - 185,288 kWh
Propane - 49,415 gal.

Facility Description: Six structures and a 700 bushel/hr grain dryer are served by geothermal water.

Disposal Method: Surface discharge to ranch reservoirs

Summary: Two heating loops circulate water through water-to-air heat exchangers and fan coil units to provide space heating for the hospital barn, mobile homes, shop, employee's home and owner's home. An additional loop provides hot water to the 700 bushel/hr commercial grain dryer.

STATUS:

The system is operating. Monitoring equipment is being installed.

CURRENT ESTIMATED PROJECT COST:

Total:	$403,098		
DOE Share:	$250,725	Participant Share:	$152,373
	62%		38%

LESSONS LEARNED:

1. The 4,000-ft. long pipeline carrying geothermal water to the isolation heat exchangers has three high spots along its length which could have been avoided only at greatly increased pipeline expense. A degasser at the wellhead proved insufficient to prevent gas pockets from forming in the line's high spots. This problem was eventually overcome by installing PVC air vent valves at the first two of the high spots.

2. The space heating system is comprised of a plate-type isolation heat exchanger used to heat recirculating water to six structures: four homes, a hospital barn, and a shop building. These structures are supplied by two loops with the return water mixing as it re-enters the isolation exchanger. The problem of freezing arises in the event of a power failure. Freezing is most likely in the barn and shop since these structures have low thermal mass unlike the homes. To prevent freezing, the recirculating system will be charged with antifreeze. The cost of the antifreeze would have been substantially reduced by use of smaller recirculating lines (2 inch rather than 3 inch) and by dividing the isolation exchange into two units so as to put the structures subject to freezing all on one loop. It should be noted that this would have increased the capital cost but lowered operating cost assuming the antifreeze is lost several times during the system's life.

3. Dividing the exchangers as described above would also have allowed subjugating the heating demands of the barn and shop to the other space heating demands. This would be a distinct advantage since the ambient temperatures of those structures are lower.

PROJECT TITLE: Geothermal Application of the Madison Aquifer for St. Mary's Hospital

PRINCIPAL INVESTIGATOR: James Russell, Hospital Administrator (605) 224-5941

PROJECT TEAM: St. Mary's Hospital
Kirkham, Michael and Associates
Sherwin Artus, Reservoir Consultant
Dr. J. P. Gries, Geologist

PROJECT OBJECTIVE: To demonstrate that 106°F (41°C) water can be used for preheating domestic hot water and space heating.

LOCATION DESCRIPTION: *Pierre, South Dakota*
Population: 14,500
Area Activities: Government (Pierre is the state capitol) and agriculture.

RESOURCE DATA:

Well Depth: 2176 ft (663 m)

Date Complete: 4/21/79

Completion Technique: Perforated casing

Wellhead Temperature: 106°F (41°C)

Flowrate: 375 gpm (23.7 ℓ/s) artesian

Summary: The Madison Formation extends under the western half of South Dakota and into the bordering states of Wyoming, Montana and North Dakota. Pierre is located on the eastern edge of this formation.

SYSTEM FEATURES:

Application: Domestic water preheating and space heating

Heatload (Design): 5.55×10^6 Btu/hr (1.63 MW)

Yearly Utilization (Maximum): 11.44×10^9 Btu/yr (.38 MW-Yr)

Energy Replaced: Fuel oil - 115,000 gals.

Facility Description: The existing 83,000 ft^2 (7710 m^2) hospital and a new 65,000 ft^2 (6038 m^2) addition will be served.

Disposal Method: Surface discharge to the Missouri River.

Summary: Three plate-type heat exchangers provide make-up air heating, space heating via fan coil units and domestic water preheating. The new addition heating system is designed to utilize the geothermally heated water in the hot deck coil of the air handling units and the heat pump.

St. Mary's Hospital (cont'd)

STATUS:

The well was completed in April of 1979. The original flow rate was approximately 250 gpm. After further perforations of the well casing and by pumping 8,000 gallons of 20 percent HCL solution into the well, the flow rate was increased to the present level of 375 gpm.

The construction work for the application of the geothermal resource to the existing hospital and the new addition is completed. The systems were put into operation in mid-October of 1980 and balancing and final adjustments of control systems are now under way. System performance to date have exceeded the anticipated capability as follows:

Completed Well	System Operation
Well Supply Temp. = 106°F	108°F
Closed Loop Supply Temp. = 100°F	104° to 105°F
Domestic Hot Water Supply = 100°F	106°F

CURRENT ESTIMATED PROJECT COST:

Total: $718,000

DOE Share: $538,500 75%   Participant Share: $179,500 25%

LESSONS LEARNED:

1. There is great difficulty in estimating the cost of a producing geothermal well. Our original estimated cost for the well was $125,000. The final well cost was $316,000 which exceeded our original estimate by 150%.

2. Resource and discharge permits can be a problem. We were not familiar with all that was required when we began and, had we been, it could have speeded up the process. Cooperation of the reviewing agency was excellent.

3. Perseverance pays off. In proposing the project, we originally hoped to find 117°F water. When our well came in producing 106°F water there was considerable skepticism even among ourselves that we could accomplish much of what we had set out to do. With the support of DOE, our project continued and is now complete and operational. It appears that our annual fuel savings may be even greater than originally projected. In addition, the temperature of the geothermal fluid increased 2°F in production.

Project Title

Klamath County Direct Use Space and Water Heating Project -
Project No. 1978-YMCA-1

Principal Investigator

Brian C. FitzGerald

Project Team

Engineering - James K. Balzhiser

Drilling Contractor - E. E. Storey & Son

Retrofit Contractor - Patterson Plumbing

Electrical Contrator - East Side Electric

Pump Supplier - Valley Pump

Pump Components - Nelson Drive

Legal - Alan M. Lee

Well Testing - OIT Geothermal Heat; Lawrence Berkeley Laboratories

Environmental Reporting - OIT Department of Natural Sciences

Project Description

The project is a direct use-extraction, exchange-retrofitted to an existing boiler system, reinjection format. Water is extracted from a production well 1410′ in depth, piped 540′ to an exchanger, and then pumped into the reinjection well some 90′ from the heat exchanger. The heat exchanger circulates boiler fluid which in turn maintains necessary heat levels in a swimming pool air coil, swimming pool water heat exchanger, domestic hot water heat exchanger, and multi-zone air heated deck.

Location Description

The project is located on the grounds of the Klamath County YMCA, 1221 South Alameda, Klamath Falls, Oregon 97601. The YMCA is centrally located to the 30,000 population base approximately three miles south of the central business district and two miles north of a suburban population center. The area is well-known as Klamath K.G.R.A. with proven resources ranging from 110°F to 230°F.

Resource Data

Well Depth -- Production well - 1410′
Reinjection well - 2016′

The main production zones within the production well are located at 1150′ with approximately 135° and at 1350′ with approximately 165° water.

Completion Date -- January, 1979

Completion Techniques -- Six hours of 300 psi air surge followed three days later by a 22 hour pump test at a variable rate averaging 310 gpm.

Note: Eight hours into the pump test the geothermal fluid was still clearing up.

Wellhead Temperature -- 147°F - flow rate of 310 gpm capacity with actual use set at 250 gpm, bowls set at 320′. Drawdown from static of 91 to a total of 270′.

Flow Rate -- Available source is 310 gpm. However, the system is designed to fluctuate according to need from a minimum of 60 gpm to a maximum of 250 gpm. Reinjection well capacity for acceptance of water is such that reinjection at 250 gpm requires a head pressure of 31 pounds. Water flowing into the reinjection well at a rate of 110 gpm requires no pressure whatsoever. It is beyond the 110 gpm rate that pressure is increasingly necessary.

Summary -- The system appears to be intact, completed, and functional. The most critical element of work completed in process in our opinion was proper cleaning of the well through air surge and extended, continuous pump testing.

System Features

Application -- Geothermal fluid moves through a 66 plate, stainless steel heat exchanger heating boiler fluid for delivery of heat to various locations within the facility.

Heatload (Design);
Yearly Utilization;
Energy Replaced -- The system was designed to replace a gas-fired, low temperature boiler unit originally engineeered to deliver 77,000 Therms of heat per year. Actual practical heat loads averaged 66,000 Therms per year over a nine year conventional heating history. In order to determine necessary heating requirements, our conventional system was preset to generate 140°F boiler fluid delivered from the boiler, in order to approximate a geothermal supply system. The nine-month program provided through practical experience that a 147°F geothermal supply at 250 gpm would more than adequately serve the needs of the facility.

Facility Description -- Klamath County YMCA is a 30,000 square foot masonry building located on 14 acres of ground in Klamath Falls, Oregon. The structure has approximately 20% of its exterior walls in thermopane glass, the remainder is in brick. Within the facility exists a gymnasium (40x20x24), three classroom facilities (averaging 20x20), two racquetball courts (20x20x20 ea), a martial arts and fitness area (40x40), five offices, mens' and womens' locker room facilities housing 100 lockers and eight showerhead rooms, and a swimming pool (44x74) holding 95,000 gallons of water with an average temperature of 87°, and swimming pool area (60x95x25) with an average temperature of 85°.

Disposal Method -- Reinjection pressure range from 60-110 gpm, zero pounds pressure required. 11-250 gpm, maximum load required is 31 pounds of pressure.

Summary -- The system is intact, functional, and capable of delivering heat at an effective level beyond the conventional system. We have also been able to renegotiate our maintenance contract with Honeywell, Inc. for care of our heating facility from a previous average of $500 per month cost down to $280 per month since we have removed two direct gas fired heating units previously taking care of our gymnasium and swimming pool area as well as being able to shut down our boiler system.

Status

Complete - BTU Meter ordered - expect delivery

Reinjection wellhead cover repaired

Electrical panel moved

Cooling system for Nelson Drive unit recalibrated

Current Estimated Project Cost

Total Cost - $267,254

DOE Share - $209,000

Participant Share - $58,254

Lessons Learned

Our experience is limited to this one project, of course, but, should we be entering this project with what we now feel to be true the following areas seem to be valuable.

1. Problem: Signing the driller's contract without the benefit of the competitive bid process places the owner in a poor position.

   Solution: Take the time to specify what is desired in an Original bid specification package.

2. Problem: Lost circulation

   Solution: Not always lost circulation material, often drilling blind and temporary casing off of the flow can solve the problem. Watch for mud ring of the drilling shaft.

3. Problem: Should we test reinjection.

   Solution: We tested the reinjection capacity of a 2016' hole which produced an excess of 500 gpm 110°F with a drawdown of only 60' to 70' as an afterthought. It turned out that it takes 35 pounds of head pressure to push 250 gpm back into the hole. Without the test, we would have assumed negative head pressure.

4. Problem: How far do you case.

   Solution: Our first hole was cased only to 512', some 400' from the beginning of basalting layers. This uncased area allowed mixing of cooler ground water with the warmer geothermal fluid. Using log data from the first hole, we were able to decide to case the second hole to 968' insuring correction of the mixing problem.

5. Problem: How soon should you test, how long, in what way, and who should do it.

   Solution: We built air and pump testing into the contract signed by the driller. After desired depth was reached, the driller was required to develop the hole with air. The bit was lowered into the hole within 24 hours of depth attainment to 300' - 300 to 400 psi was developed intermittently, thus alternately blowing off the top 210' of fluid and then allowing the fluid to subside. This exerted tremendous surging forces on the well. We think this cleaned the well properly and avoided the problem of sour bentonite caking the production zones. We also had the driller pump test the hole for 24 hours (8 hours of it in reinjection phase). The well cleaned up after 4 hours of surging and 10 hours of pumping. Presently, the fluid has a suspended solid level of less than 350 ppm. With the exception of 8.2 Ph and the sulfate content the fluid passes city code for drinking water. Incidentaly, since the driller could not remove the rig until the test was complete, he borrowed a large tractor and used the power take-off to drive the test pump since local pump people could not meet his time schedule. At $100 per hour cost to the driller for rig time, they can get very creative!

6. Problem: How do you determine the system's ability to provide necessary heat in a retro-fit situation?

Solution: Turn the existing boiler down in cycle temperature and expand the quick recovery capacity of the boiler to approximately the specifications of available geothermal fluid. We had nine months of demonstration data going in which proved that a 135° fluid at 250 gpm - exchanger approach of 7° and draw of 40° would take care of our complete needs.

Presently, the system, functioning at full 250 gpm capacity, is entering 146° geothermal fluid at the exchanger - reinjecting at an average of 142° - boiler fluid in is averaging 133° - boiler fluid out after exchanger is being maintained at a constant 146° - approach of 0.

A sample test can be run by shutting off the swimming pool air boiler fluid loop allowing that to cool fro 133° to 70°. After circulation is created, boiler fluid in drops from 133° to 85°, geothermal fluid out drops from 142° to 125°. Boiler fluid out moves from 146° to 145° for about five seconds.

We also discovered that retrofit of conventional systems allows for renegotiation of maintenance contracts for heating systems and for insurance costs for boiler and pressure vessels since a 147° geothermal system can be guaranteed to never exceed boiling temperature creating pressure stresses.

DEMONSTRATION PROJECT OF RAISING PRAWNS WITH GEOTHERMAL WATER

IN THE COACHELLA VALLEY, CALIFORNIA

PRINCIPAL INVESTIGATOR: Dr. Grajcer, Aquafarms International Inc. (AII)

PROJECT TEAM: Rick Visoria, Project Manager, DOE, Oakland

Dr. Dov Grajcer, President, AII

Rebecca Broughton, Deputy Project Manager, AII

AII's Technical Staff: Vincent Price
Rodney Chamberlain
Mary Price

Dr. Tsvi Meidav, Geothermal Consultant, Meidav Assoc. Oakland

Krieger and Back, Accounting, Palm Desert

PROJECT DESCRIPTION:

Aquafarms International Inc., a small California corporation, is developing a 50 acre prawn farm on its property in the Dos Palmas area, east side of the Coachella Valley. By utilizing geothermally heated water, AII intends a continuous, year round prawn farming operation.

LOCATION DESCRIPTION:

AII's headquarters is located off of California state highway 111 near North Shore (mailing address POB 157, Mecca, CA 92254) DOE project site: Dos Palmas area, Coachella Valley, CA.

RESOURCE DATA:	A-1*	A-2	F1	F2	F3
WELL DEPTH:	910'	100'	325'	180'	800'
DATE COMPLETED:	Jan 80	Feb 80	June 80	July 80	July 80
COMPLETION TECHNIQUE:	1" casing	SCREEN GROUTED AND CEMENTED			
WELLHEAD TEMPERATURE:		82°F	79/92°F	83°F	107°F
FLOWRATE:	testing in progress				
SUMMARY:	Hydrogeothermal peephole	well to control- Not used for time being	2 temp. avaiable being prepared for service while pumping tests are made	Used for tempering water.	Best geothermal well- cave in occurred- awaits hydrofracturing

SYSTEM FEATURES:

Application: The water will be taken from the wells and delivered to the ponds where it will be used directly. That is to say that AII hopes to use the energy with the fluid as opposed to a heat exchange setup.

Yearly Utilization: The geothermal fluid will be used throughout the year as the desert is subject to extreme temperatures as well as extreme temperature fluctuations. This use of the geothermal fluid will enable these temperatures to be mitigated.

Energy Replaced: If fossil fuel were to be used to heat irrigation water, a total of 170 billion BTU/yr would be required per year for a 50 acre farm. As the pond heating is to be 100% geothermal, that amounts to approximately 30,360 barrels of heating fuel/yr (heat value 5.6 X 10^6 BTU/bbl) replaced.

Facility Description: The shrimp grow-out facility is located on approximately 250 acres of land. The northern part of this area is being developed into 50 acres of ponds. 25 of these acres are completed with the plumbing now being installed. Ten new acres are in varying states of completion. The remaining ponds will be developed in the areas indicated by stiples on the attached map.

Disposal Method: When AII's water resources reach a point that a disposal procedure must be adopted, several techniques can be employed. Much water is lost to evaporation and some is percolated through the pond substrate. Surplus water could be impounded and recycled.

Summary: With the direct use of geothermal water it seems to be possible to develop an economically sound 50 acre prawn farm in the Coachella Valley Dos Palmas area. At today's prices there is no payback period if fossil fuel is used as the total production is below the existing value of the conventional fuel saved.

STATUS:

A substantial schedule slippage was caused early in the contract by a very slow reaction to and often ambiguous requirements of various environment-related agencies. Therefore, in order for a cost overrun to not be incurred, AII, with cooperation and advice from the DOE, choose an equivalent expense time extension. Through efficient management and a highly qualified total capability team we have been able to complete some tasks under budget. The reserved funds will be channeled into tasks in which inflation made the largest inroads. In effect, we have completed 75% of all work assigned and thereby, with the extended time, there is no foreseen reason why the contract should not be fulfilled with no added cost to the DOE.

CURRENT ESTIMATED PROJECT COST:

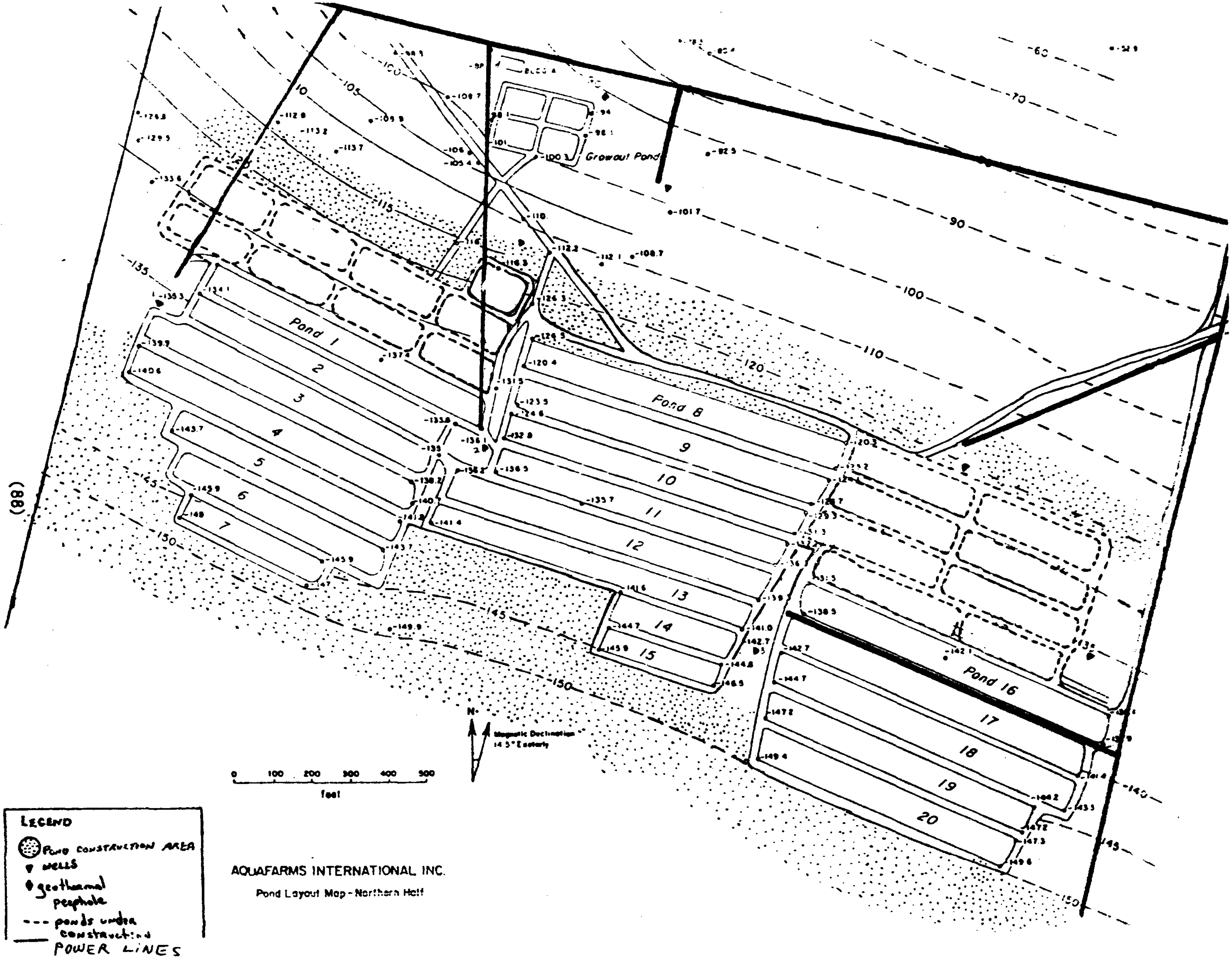
Total: 575,266

DOE Share: 363,000

Participant Share: 212,266

LESSONS LEARNED:

Over the last winter some valuable lessons have been learned and some modifications in pond construction have been made. Incidents during pond construction have underscored the need for various types of equipment needed to excavate ponds. The property being utilized is sand and rock in some areas and boggy clay in others. The same earth move can not be used under both conditions.



AQUAFARMS INTERNATIONAL INC.

Pond Layout Map - Northern Half

DOE/NVO/1558-7

GEOTHERMAL RESOURCES OF THE EASTERN UNITED STATES

J. L. Renner
Tracy L. Vaught

December 1979

Under Contract No. DE-AC08-78ET28373

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U. S. Department of Energy
Division of Geothermal Energy
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Executive Summary

This report on known and potential geothermal resources of the eastern United States was prepared for the Department of Energy's Division of Geothermal Energy as part of a multi-task effort under the Division's program of geothermal resource development. The resources considered are exclusively hydrothermal, and the study was confined to the 35 states east of the Rocky Mountains, excluding the Dakotas. Resource definition in these areas is based entirely on data found in the literature and in the files of a number of state geological offices.

The general geology of the eastern United States is outlined in the first section of the report. Since the presence of geothermal resources in an area is governed by the area's geology, an attempt to define useful geothermal resources is facilitated by an understanding of the geology of the area being studied. Six relatively homogeneous eastern geologic regions are discussed.

The usefulness of geothermal resources is constrained by both technological and economic factors. The accessible geothermal resource base is limited by drilling technology to the upper 10 kilometers (33,000 feet) of the earth's crust. However, only the heat in the upper 4.5 kilometers (15,000 feet) is currently considered to be useful. Geothermal waters at temperatures lower than about 40°C (104°F) are not likely to be economically exploitable except under the most favorable circumstances, and then only if found at depths of 1 kilometer (3,300 feet) or less.

Geothermal Indicators

Useful geothermal resources are normally associated with areas of above-average temperature gradient or above-average flow of heat to the earth's surface. Hence, heat flow studies are carried out in the initial phases of many geothermal exploration programs. Heat flow in the eastern United States is usually about 1×10^{-6} cal/cm^2 sec (1 heat flow unit or HFU) and temperatures change with depth at a rate of about 18.2°C/km (1°F/100 ft). The maximum values of heat flow and temperature gradient expected in this region under the most favorable conditions are about 2.3 HFU and 57°C/km (3.1°F/100 ft).

Geochemical studies are especially useful in exploring for hydrothermal energy. The silica and sodium-potassium-calcium geothermometers are the most widely recognized tools for estimating reservoir temperatures from chemical data. Regional studies of silica concentration in ground water provide important clues for identifying areas having elevated heat flow and subsurface temperature. In the eastern United States a chalcedony, rather than quartz, equilibrium is usually assumed for temperature estimates based on the silica geothermometer.

Since hydrothermal systems are often associated with tectonic activity, available subsurface temperature data in the eastern United States tend to show a good correlation with seismicity.

Indicated Geothermal Resources

The known occurrences of geothermal energy in the eastern United States fall into four categories: warm spring systems, radioactive granite plutons beneath thick sediment covers, abnormally warm aquifers, and deep sedimentary basins with normal temperature gradients.

- Warm springs with the most potential are found in the Appalachian and Ouachita Mountains and in the Trans-Pecos area of Texas. The Appalachian and Ouachita springs are associated with steeply dipping quartzite beds and also may be related to faults. Springs in the Trans-Pecos are related to Basin and Range faulting.

- Radioactive granitic plutons underlying thick, low-conductivity sediments are thought to occur beneath the Atlantic Coastal Plain and are currently the focus of a DOE-sponsored geothermal exploration program. The first deep well drilled as a part of this program encountered an aquifer with a temperature of 56°C (133°F) at 1.2 kilometers (4,000 feet) near Crisfield, Md.

- Abnormally warm aquifers, presumably caused by updip or fracture-zone movement of water, are found at several places in the Gulf Coastal Plain in Texas and Arkansas. Numerous wells at depths of 1 to 3 kilometers (3,000 to 10,000 feet) with gradients in the 30 to 40°C/km (1.6 to 2.2 °F/100 feet) range have been drilled into the Smackover Formation in southern Arkansas. Measured geothermal gradients of 25 to 45°C/km (1.4 to 2.5°F/100 feet) are reported in the Balcones and Luling-Mexia-Talco fault zones in eastern Texas. Warm waters are also thought to be present above the geopressured zones of the Gulf Coast. An extensive area of thermal waters is inferred to lie under the western third of Nebraska.

- Several deep basins exist where temperature gradients are no higher than normal but where sediments are sufficiently thick to provide elevated temperatures near basement. However, these resources cannot be utilized unless drilling costs for deep wells can be greatly reduced.

Undiscovered Resources

Undiscovered geothermal resources are most likely to exist in areas characterized by historical seismic activity or by high heat flow involving radioactive granite plutons, low-conductivity sediments, deep circulation of ground water, or combinations of these factors.

- Radioactive granite plutons are of importance only if covered by thick layers of low-conductivity sediments, and here the Atlantic Coastal Plain holds greatest promise. In general, conductivity in inland regions is too high to permit the generation of sufficiently high temperatures at reasonable depths by this mechanism.

- Deep circulation of ground water is possible under geological conditions similar to those in the folded Appalachians. Conditions in some portions of the Blue Ridge, the Piedmont, the Champlain Valley, and the Ouachita structural trend are favorable for this kind of occurrence.

Introduction

In June 1978, Gruy Federal, Inc. contracted with the Department of Energy's Division of Geothermal Energy to perform various tasks associated with the Division's program of development and utilization of hydrothermal geothermal resources in 35 eastern states. This report, prepared in fulfillment of one of these tasks, provides an overall definition of the known and potential hydrothermal geothermal resources of these states. It does not include discussion of geopressured and hot-dry-rock geothermal resources.

The report includes a brief introduction to those geological features of the eastern United States particularly important to identifying geothermal resources. The reader desiring more information should consult the references cited in the text.

All maps are on the same scale and projection as the U.S. Geological Survey Base Map of the United States (1:16,500,000), to aid in the comparison of data from map to map.

We are grateful to Chester R. Pelto, senior geologist at Gruy Federal's Arlington office, for his helpful discussions and critical review of this manuscript and to Dr. Gerald P. Brophy, DOE technical project officer, for his guidance of the project. The assistance of many state geological surveys and others interested in geothermal energy in the eastern United States is also appreciated.

General Geology of the Eastern United States

Physiographically, the eastern United States is divided into the Laurentian Upland, the Atlantic Plain, the Appalachian Highlands, the Interior Plains, and the Interior Highlands. Each major division is further divided into provinces (Fenneman, 1946), portrayed in a general way in Fig. 1. These provinces are a rough guide to the geological character of the underlying rocks. Since the correspondence is imperfect, and since geothermal resources are controlled by geological features, the following discussion is organized around areas exhibiting geologic similarity.

On the basis of geology and geothermal potential, the eastern United States is divided here into six regions, as shown in Fig. 2. This partitioning is not unique because geologic areas generally do not have sharp boundaries. The largest area considered is the Central Stable region, roughly bounded by mountain systems that lie to the west (Rockies), south (Ouachitas), and east (Appalachians). The Appalachian region includes the Northern, Central and Southern Appalachians. The Ouachita region consists of the Ouachita, Arbuckle, Wichita, and Amarillo Mountains and the deep sedimentary basins associated with them. Although the eastern coastal plain of the United States extends from Texas to Massachusetts, it is divided into the Atlantic and Gulf Coast regions because of differing geologic character and geothermal potential. A portion of West Texas--the Trans-Pecos region--is within the Basin and Range province, the bulk of which lies to the west of the Rocky Mountains. Although small, it is sufficiently different from the other regions to merit special attention.

Figure 3, a geologic map of the eastern United States, and Table 1, showing the major divisions of geologic time, are included for reference in the discussion of the six eastern regions which follows.

Central Stable Region

This region includes the oldest and most stable portion of North America. In the United States it is bordered by the Rocky Mountain system to the west, the Ouachita Mountains and related structures to the south, and the Appalachians to the east. To the north, the stable region extends into Canada.

The region can be divided into two areas: the Laurentian Shield and the Interior Lowlands. In the United States, the Laurentian Shield comprises the exposed Precambrian rocks of northern Minnesota, Wisconsin, Michigan, and the Adirondack Mountains of New York. It has been stable relative to sea level most of the time since the close of the Precambrian, and little or no sedimentary cover has been deposited over it. The Interior Lowlands are the sediment-mantled extension of the Laurentian Shield.

Little is known of Precambrian structures in the Central Stable region except where Precambrian rocks are exposed at the surface or where they act as controls for Paleozoic structures. One exception is the Mid-Continent gravity high extending from central Kansas to the Lake Superior region. Minor earthquakes have been associated with this geophysical anomaly (Steeples and others, 1979).

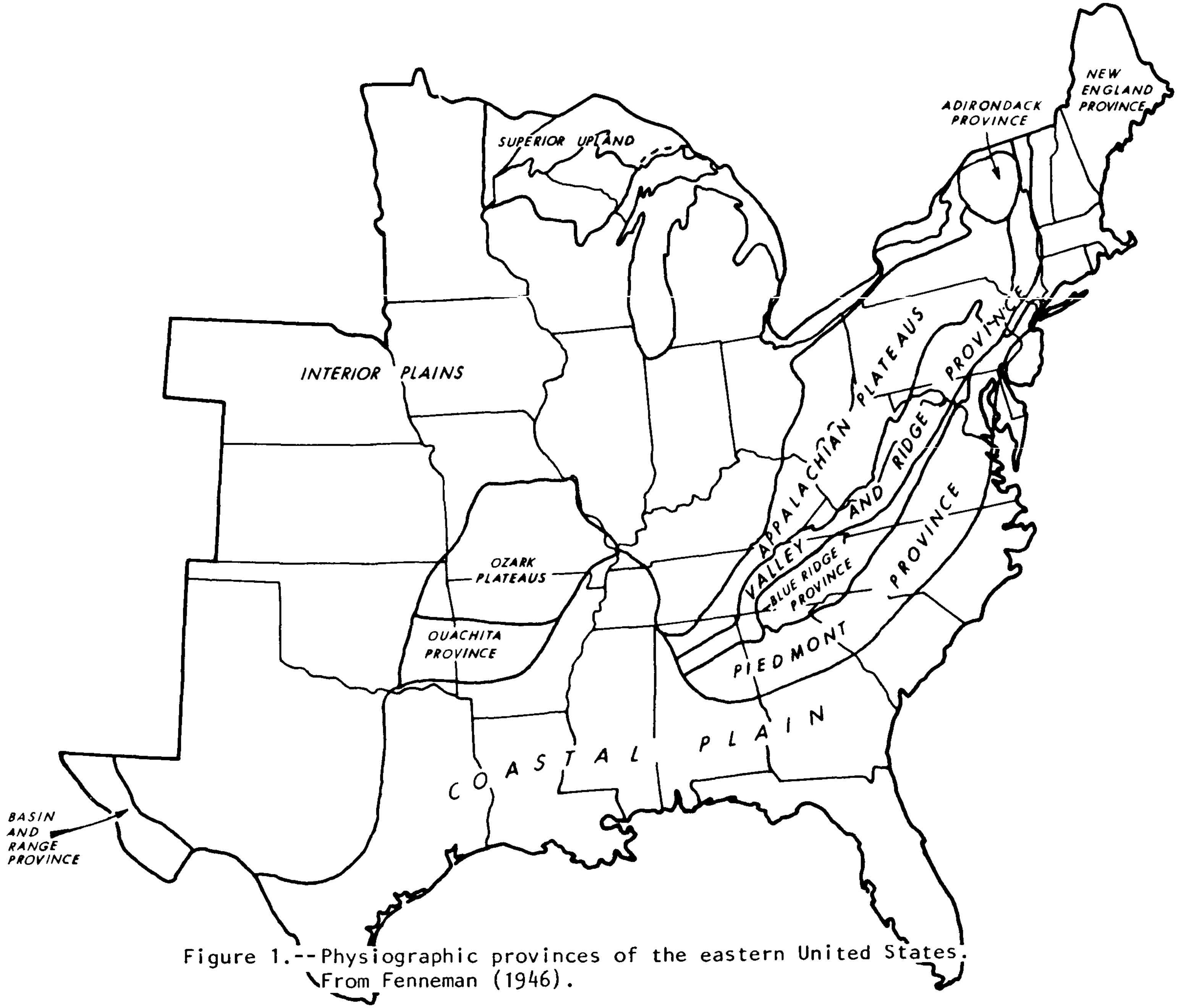

Figure 1.--Physiographic provinces of the eastern United States. From Fenneman (1946).

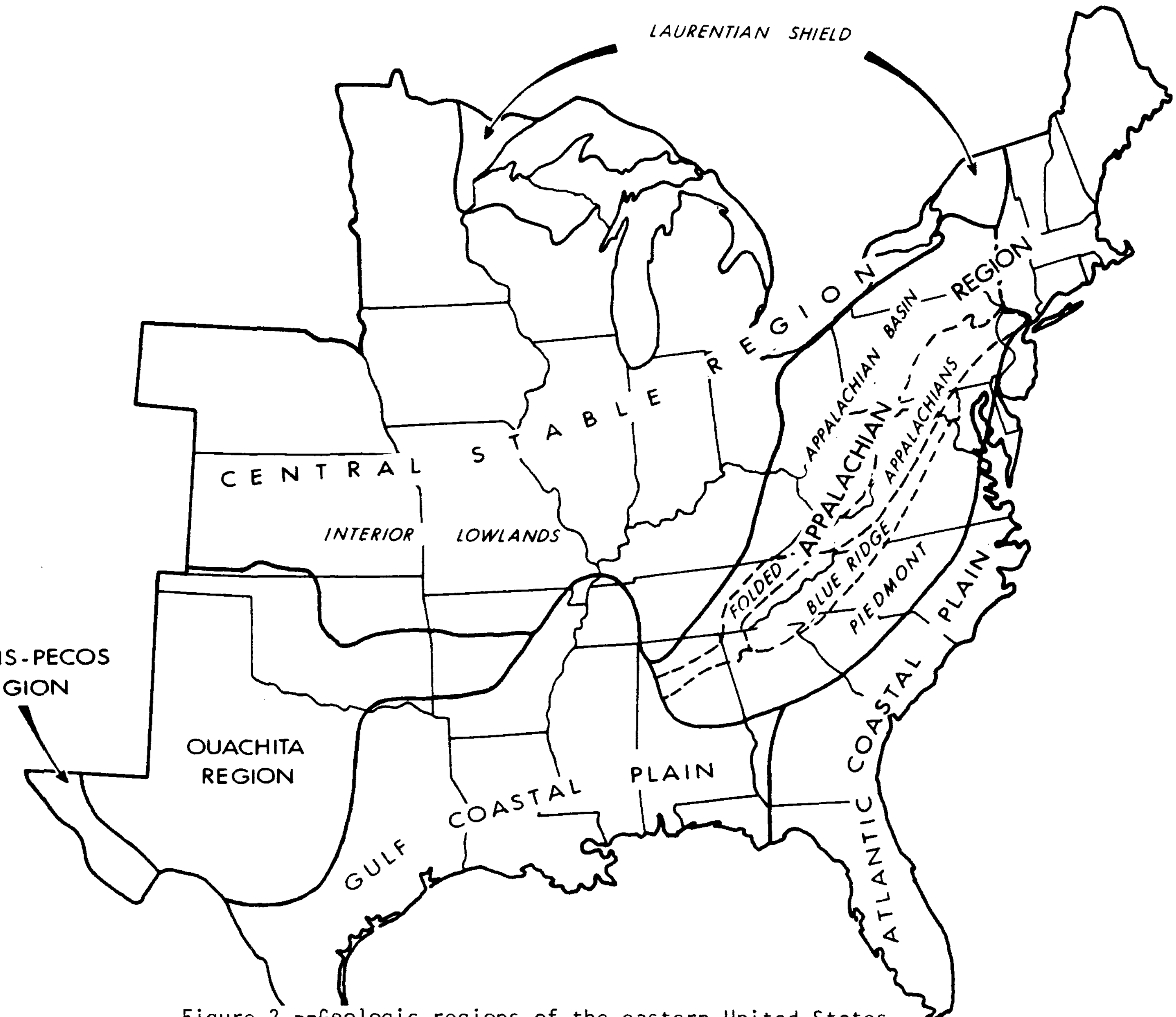

Figure 2.--Geologic regions of the eastern United States.

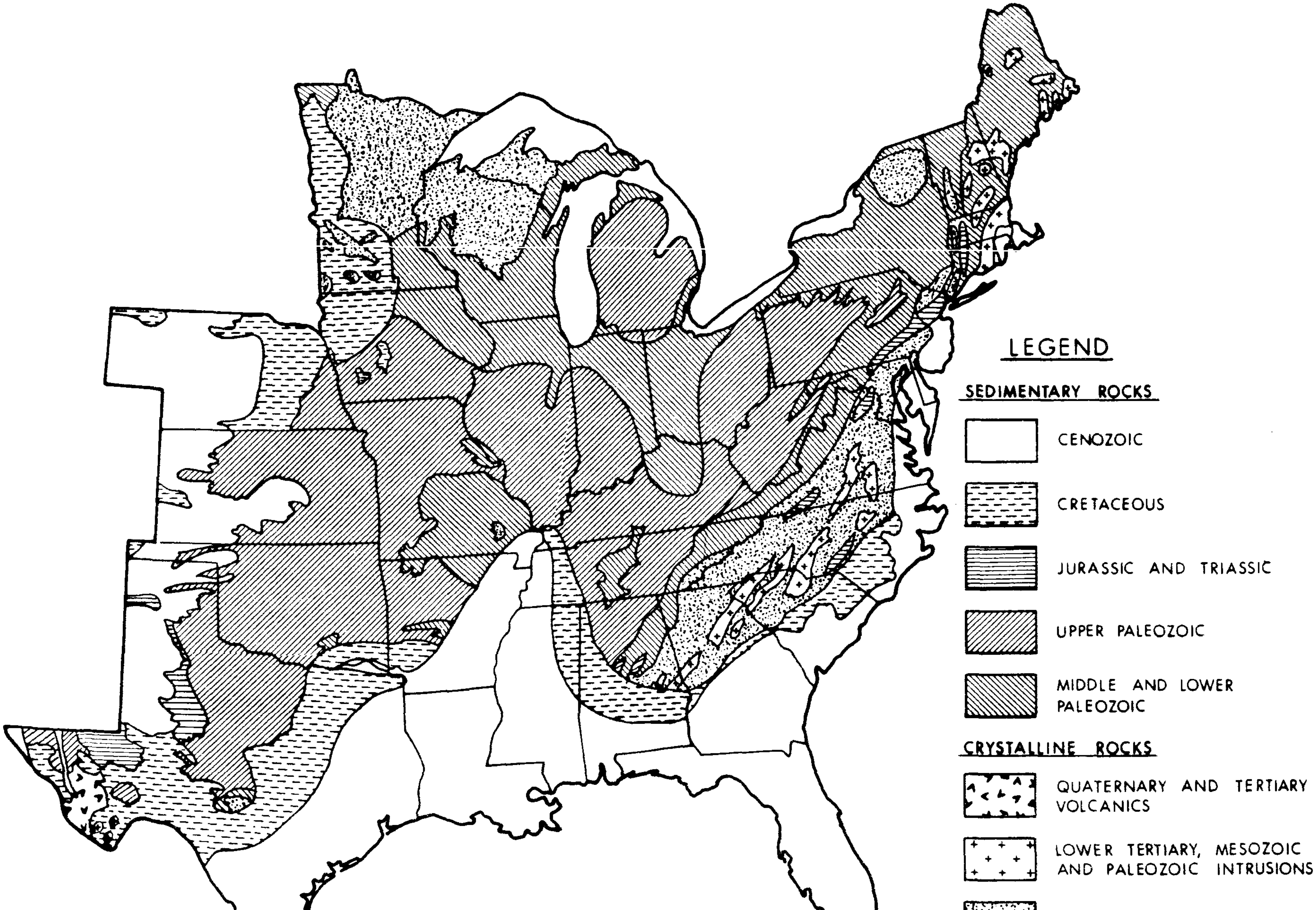

Figure 3.-- Geologic map of the eastern United States. Modified from Kinney (1966).

TABLE 1

MAJOR DIVISIONS OF GEOLOGIC TIME

ERA	PERIOD	Millions of years ago
		0
Cenozoic	Quaternary	3
	Tertiary	65
Mesozoic	Cretaceous	136
	Jurassic	195
	Triassic	225
Paleozoic	Permian	280
	Pennsylvanian	320
	Mississippian	345
	Devonian	395
	Silurian	435
	Ordovician	500
	Cambrian	570
Precambrian		

Times are based on radiogenic dating and are reported in millions of years before the present. Adapted from Newman (1978).

The major post-Precambrian structural features of the area are shown in Fig. 4. For the most part they are gentle domes or arches and shallow basins. Faulting appears not to have been important in the formation of most structures, although minor faults are associated with many of them.

Several areas of the Central Stable region were structural highs during part or all of the Paleozoic Era. Among these, the Nemaha Uplift, Central Kansas Uplift, Cambridge Arch, and Chadron Arch are associated with some recent low-level seismic activity and in some places with elevated temperature gradients. These trends may have some potential for low-temperature thermal waters. The thickness of sediments overlying crystalline rocks, or basement, is controlled by the regional slope of the Precambrian rocks away from the shield area and by the series of arches, domes, and basins developed on the basement, primarily during the Paleozoic Era. Except for the Illinois and Michigan basins and the major depositional basins associated with the Rocky, Ouachita, and Appalachian Mountain belts, sediments are not more than 1,500 meters (5,000 feet) thick within the stable region. Figure 5 is a generalized map of sediment thickness.

The Illinois and Michigan basins are typical of basins developed in stable areas. During the Paleozoic Era they accumulated up to 4,600 meters (15,000 feet) of sediments (Ells and Ives, 1964; Willman and others, 1975). The Michigan basin is the simpler of the two. Roughly symmetrical, it exhibits only minor folding and faulting. Sedimentation was almost continuous in the basin during the Paleozoic so that rocks from each period are represented in the stratigraphic column. In the structurally more complex Illinois basin the major structural element is the LaSalle anticlinal belt extending from north central to east central Illinois.

The most complexly faulted area of the central United States is an east-west trending zone along the 38th parallel from central Missouri to Virginia. The trend of faults, igneous intrusions, and mineral deposits has been termed the 38th parallel lineament by Zartman and others (1966). Heyl (1972) extends the lineament westward to the Rocky Mountains. Associated with it are the Irvine-Paint Creek, West Hickman Creek, Kentucky River, and Rough Creek fault zones in Kentucky; the Rough Creek-Shawneetown and Cottage Grove fault zones in Illinois; and the St. Lawrence and New Madrid fault zones in Illinois and Missouri.

The lineament probably overlies a major fault in the buried Precambrian rocks, and it may be the continental equivalent of such major oceanic fault trends as the Mendocino and Kelvin zones off the U.S. coasts in the Pacific and Atlantic Oceans, respectively (Heyl, 1972). Seismic activity continues along some sections of the lineament.

Appalachian Region

Basic to an appreciation of geothermal potential in the Appalachians is an understanding of their general geologic setting. Several summaries of Appalachian geology have been published in the past 11 years. The works of Rodgers (1970), Zen and others (1968), and Fisher and others (1970) are especially recommended to the reader desiring a more complete background in Appalachian geology.

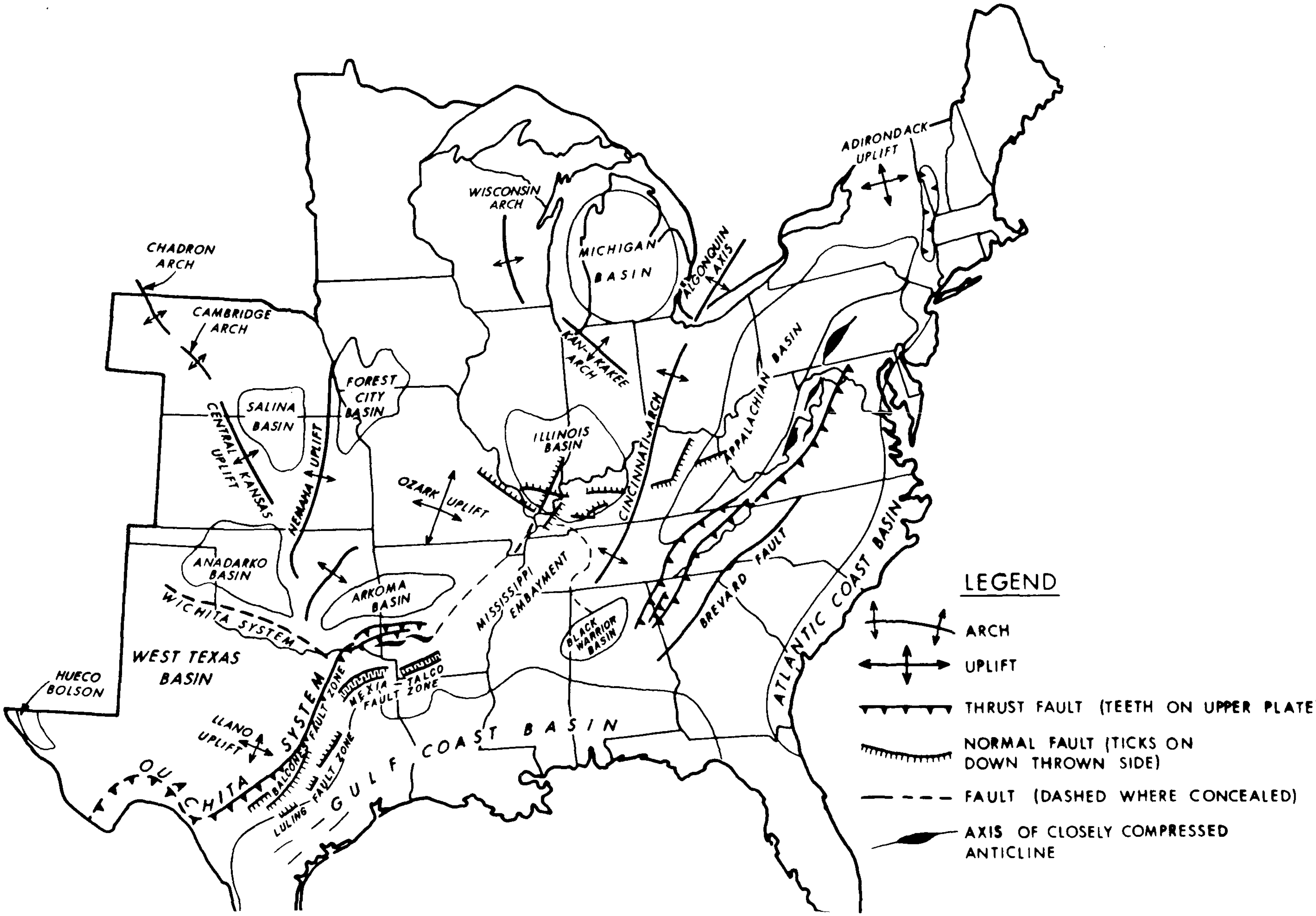

Figure 4.--Major structural features of the eastern United States. Modified from King (1969).

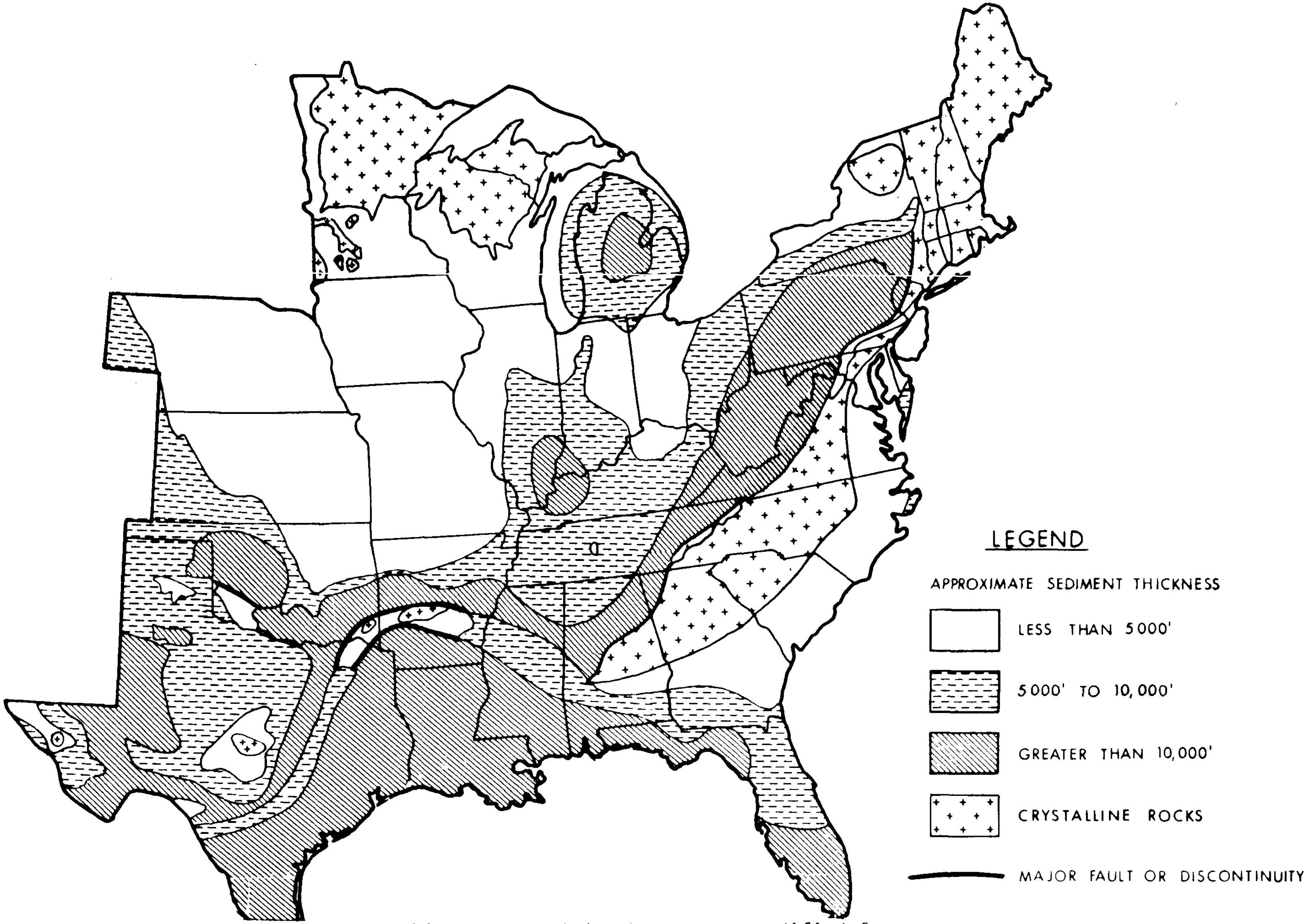

Figure 5.-- Approximate sediment thickness overlying basement. Modified from the American Association of Petroleum Geologists and United States geological Survey (1967).

Precambrian, Paleozoic, and Mesozoic tectonic activity influences the location of geothermal prospects in the Appalachian Region, rather than Cenozoic events that generally dominate geothermal manifestations worldwide. Because of the association with older tectonic features, the geothermal resources of the eastern United States are expected to be more localized and of lower grade.

In the broadest sense, the Appalachian region comprises all that part of the eastern United States where the rocks were significantly deformed during Paleozoic time. The Appalachian structural trend generally parallels the Atlantic coastline. Extending northeastward from Alabama to the Canadian Province of Newfoundland, it separates the flat-lying Paleozoic sediments of the stable Interior Lowland from the gently dipping undeformed Mesozoic and Cenozoic sediments of the Atlantic Coastal Plain. The Appalachians can be divided into three segments from southwest to northwest. The southernmost segment extends from central Alabama to near Roanoke, Va. The Central Appalachians continue from near Roanoke to New York. The third section, the Northern Appalachians, extends from New York through the New England states to the Gulf of St. Lawrence in Canada. Although all sections display many common characteristics, each has its own unique tectonic character.

The Southern and Central Appalachians are structurally divided from northwest to southeast into four provinces: Appalachian Basin, Folded Appalachians or Valley and Ridge, Blue Ridge, and Piedmont.

Appalachian Basin. In the Appalachian Basin, the strata are generally flat and maturely dissected by an arborescent drainage system. In West Virginia, Pennsylvania, and New York, the sediments are slightly deformed into a series of gentle folds, with minor folding and some faulting. The sediments have a low regional slope to the east and may attain thicknesses as great as 9 kilometers (30,000 feet) in the deepest part of the basin along Virginia's western border (King, 1969). The Appalachian Basin represents a broad transition from the flat-lying rocks, gentle arches, and domes of the stable interior to the intensely folded strata of the Folded Appalachians.

Folded Appalachians. The Paleozoic rocks in the Folded Appalachians are highly deformed to yield steep-limbed anticlines and synclines. These folded rocks produce the classic Appalachian landscape of linear ridges and valleys, commonly of great length. The physiography of the region is almost entirely controlled by the geologic structure.

The central section of the Folded Appalachians has been considered to be almost totally dominated by folding, particularly in Pennsylvania. However, some major thrust faults are present, and Gwinn (1964, p. 863) states that "the tectonic style and mode of deformation of the 'folded' Central Appalachians is . . . practically identical with that observed in the 'thrust-faulted' Southern Appalachians. The only important difference between the two regions is that the upward-shearing segments, or 'toes,' of thrust sheets in the Southern Appalachians have been exposed by erosion, whereas the toes of the major Central Appalachian thrust sheets are still covered by a mile or more of stratified rocks."

In the Southern Appalachians, folds and thrust faults dominate. Rich (1934) observed that although the area was broken by faulting, none of the faults brought the oldest rocks of the region to the surface. Sufficient information was not publicly available to document this mode of deformation until Gwinn (1964) published a summary of data from oil and gas exploration programs. That summary, together with regional seismic profiles and deep drilling reported by Jacobeen and Kanes (1974), has confirmed Rich's original concept that deformation is confined to the sedimentary rocks overlying older crystalline rocks.

This style of deformation has been called "thin-skinned" (Rodgers, 1949, p. 1653-1654). It is characterized by sheets of sediments sheared along relatively incompetent shale and thrust to the northwest. In some areas the thrust has been divided among smaller faults near the surface, causing several sheets of sediments to be thrust one upon the other. The Ray Sponaugle well in Pendleton County, W.Va., drilled to 3,963 meters (13,000 feet) in 1960, shows such a repeated section (Perry, 1964). Most of the folding visible at the surface appears to result from thrusting at depth.

Blue Ridge. The third province of the Central and Southern Appalachians, the Blue Ridge, extends from northern Georgia to southern Pennsylvania. Rocks of Blue Ridge type are exposed discontinuously farther to the northeast in the Reading Prong, the New Jersey Highlands, the Berkshire Hills, and the Green Mountains. The width of the Blue Ridge varies inversely with that of the Valley and Ridge Province. In the Central Appalachians it consists of a single mountain ridge to the southeast of the broadest section of the Valley and Ridge Province. In the vicinity of Roanoke the Blue Ridge widens at the expense of the Valley and Ridge into its southern culmination, the Great Smoky Mountains. At Roanoke, the structural style also undergoes an abrupt change comparable to the change in style of the Valley and Ridge Province at this latitude. The Blue Ridge north of Roanoke can be characterized as a fold belt which is itself arched upwards and in places overturned to the west. To the southwest, the structure is similar to that of the southern Valley and Ridge Province. Multiple thrust sheets have been mapped in the Smoky Mountains and several other areas. The warmest springs in the Appalachians issue from steeply inclined rocks of the Blue Ridge at Hot Springs, N.C.

Piedmont. The southeasternmost province of the Appalachians is the Piedmont. It slopes rather gently to the southeast from the Blue Ridge and is eventually overlain by the sediments of the Coastal Plain. The Piedmont is generally covered by a thick mantle of weathered rock that makes detailed geologic investigations difficult. The rocks are mostly Paleozoic in age, although Precambrian rocks can be recognized. Studies of exposed igneous intrusions in the Piedmont are being used in the search for geothermal resources under the Coastal Plain (Costain and others, 1976).

Several major fault zones have been mapped in the Piedmont, and structures similar to those of the southern Valley and Ridge and Blue Ridge provinces have been recognized (Hewett and Crickmay, 1937). Warm Springs, Ga., is located in one of these areas, which Rodgers (1970, p. 194) describes as resembling "the mountains in the Valley and Ridge provinces more than any in the intervening Piedmont (except Talladega Mountain in Alabama)."

The Northern Appalachians are not so easily divided into the classical Appalachian framework as the Central and Southern sections. The Appalachian Plateau setting is essentially absent north of the Catskill Mountains in New York. Valley and Ridge rock types are present in the upper Hudson and Champlain River Valley and somewhat to the east. However, the age and perhaps the style of deformation is different.

The geology of this area has been the subject of heated controversy for more than a century. Zen (1967) has proposed a generally accepted model to explain the complex structural and stratigraphic features. In its simplest form his model has the argillaceous rocks of the Taconic Mountains thrust over other Cambrian and Ordovician sediments in a manner somewhat similar to the thrusted sequences of the Southern Appalachians.

The Berkshire Hills in Connecticut and Massachusetts and the Green Mountains of Vermont are comparable to the Blue Ridge. The remainder of New England tends to correlate with the Piedmont.

Triassic basins, parallel to the trend of the Appalachians, extend from southern Vermont through North Carolina. Basins covered by younger sediments are known as far south as Alabama. They are usually found in the Piedmont Province or its northern equivalent. Two of the more prominent basins are the Newark Basin, extending discontinuously from near New York City to near Charlottesville, Va., and the Connecticut Valley Basin or graben. Sanders (1963) suggests that the Connecticut Valley contains as much as 9 kilometers (30,000 feet) of sediments. The bounding faults of the basins, where exposed in pre-Tertiary rocks, are generally silicified (Rodgers, 1970).

Several explanations for the genesis of the Triassic basins have been presented. The older theories assume rifting caused by relaxation of the forces that gave rise to the Appalachians, or rifting caused by rebound of a thickened crust after the final episodes of Appalachian mountain building. More recently the basins have been studied in the light of continental drift theory and are viewed as a major continental rift system comparable to the modern East African rift system.

Ouachita Region

The region comprises two principal belts of deformation, the Wichita and the Ouachita systems (Fig. 4) and the deep sedimentary basins associated with them. The Wichita system, extending westward from the Ouachita Mountains, is exposed in the Wichita and Arbuckle Mountains of Oklahoma and in the Amarillo Mountains of the Texas Panhandle. Although the rocks of the Wichita trend have been intensely deformed, particularly in the Arbuckle Mountains, they lack the long parallel thrusts and folds of the Appalachian Valley and Ridge. Deformation of the Wichita belt preceded the Ouachita deformation.

The Ouachita structural belt is a Paleozoic feature that rims the Gulf Coastal Plain, extending from Mexico to the Marathon region of west Texas up through Waco and across southern Oklahoma, Arkansas, and Mississippi (Fig. 4). Some geologists believe the belt may stretch into central Alabama and even as far east as northern Florida (Flawn, 1959). Others think it may be an extension of the southern Appalachians, since both the Valley and Ridge and the Ouachita Tectonic Belt were deformed during Pennsylvanian time (Thomas, 1977; King, 1969).

There are only three exposures of the Ouachita system in the United States: in the Solitario and Marathon Uplifts and in the Ouachita Mountains. The major exposure is in the Ouachita Mountains, which are characterized by east-west trending, folded and faulted Paleozic strata quite similar to the structures of the Folded Appalachians. To the south and east, the Ouachita system is covered by the Cretaceous and younger sediments of the Gulf Coastal Plain.

The West Texas Basin lies between the Wichita and Ouachita systems. To the north of the Wichita and Ouachita Mountains lie the Arkoma, Ardmore, and Anadarko basins.

The Arkoma Basin is a northeast-southwest trending basin bounded on the north by the Ozark Uplift and on the south by the Ouachita Mountains. The thickness of the sedimentary section ranges from 1 kilometer (3,300 feet) on the northern edge to 10 kilometers (30,000 feet) near the Ouachita Mountains. Block faulting, folds, and northward overthrust beds are common structural features.

The Ardmore Basin is a small, deep basin bounded on the north by the Arbuckle Mountains uplift, on the southeast by the Ouachita belt, and on the southwest by the Wichita Mountains. Sediment thickness exceeds 6 kilometers (20,000 feet).

The Anadarko Basin in central Oklahoma trends northwest-southeast. Thickness of sediments in the basin ranges from 1.3 kilometers (4,300 feet) on the edge to 12.3 kilometers (37,000 feet) in the deepest part.

Gulf Coastal Plain

Within the United States, the Gulf Coastal Plain stretches from the southern tip of Texas along the Gulf Coast into Florida. It generally extends inland from 240 to 490 kilometers (150 to 300 miles) and up to 960 kilometers (600 miles) in the Mississippi Embayment. Mesozoic and Cenozoic sediments form a thick wedge of gulfward-sloping sediments. The Mesozoic rocks are generally fine-grained marine deposits. Tertiary strata consist primarily of more coarse-grained, land-derived sediments. The lowermost strata are red beds and evaporites, probably of Jurassic age. Thick deposits of rock salt underlie Mississippi, Arkansas, Louisiana, and Texas.

The Balcones Fault Zone (Fig. 4) is a series of en echelon normal faults extending from the Del Rio area in southwest Texas around the southeast side of the Llano Uplift and north to Waco. The faults, which are downthrown on the southeast, are developed in Cretaceous strata and roughly follow the trend of the buried Ouachita system.

The Luling-Mexia-Talco Fault System, to the east and northeast of the Balcones, parallels the Balcones Fault Zone and then curves to the northeast. The Luling-Mexia-Talco faults are downthrown on the northwest. Major movement may have occurred during the Oligocene (Eardley, 1951). The downthrown areas between the Balcones and Luling-Mexia-Talco Fault zones form grabens.

Atlantic Coastal Plain

The Atlantic Coastal Plain extends eastward from the Piedmont province along the Atlantic coastline from Long Island to Georgia and northeastern Florida. (Southwestern Georgia and the Florida Panhandle are included in the Gulf Coastal Plain.) It is generally considered to be a southeastward continuation of the Piedmont. The Florida peninsula is a separate section of the Coastal Plain, included here with the Atlantic Coastal Plain for simplicity.

Only limited information is available concerning the crystalline rocks underlying the Coastal Plain. The sediments of the Coastal Plain are Mesozoic and Cenozoic sandy and clayey rocks. The basement surface and the sediments slope gently toward the ocean, with the sedimentary wedge thickening toward the sea, reaching a maximum thickness of about 3 kilometers (10,000 feet) in the vicinity of Cape Hatteras, N.C. (Brown and others, 1972).

Two models for the coastal plain sediments are currently applied. The older model assumes sedimentary beds gently sloping and thickening seaward with little or no deformation and faulting. A newer model proposed by Brown and others (1972) envisions the Coastal Plain sediments deposited on older rocks consisting of a mosaic of crustal blocks, with the geometry and relative position of each crustal block controlling the depositional environment of the overlying sediments. If the new model is correct, aquifer systems probably would be more variable and localized than in the traditionally accepted "layer-cake" model.

Trans-Pecos Region

The Trans-Pecos region (Fig. 2) of west Texas is part of the Basin and Range physiographic province. It is bounded on the south by the Mexican fold belt, on the northeast by the West Texas Basin, and on the west by the Chihauhua tectonic belt (Henry, 1979). The region is characterized by north- and northwest-trending, block-faulted mountains surrounding flat desert basins or bolsons. Movement of the normal faults in the region is thought to be continuing (Henry, 1979).

The sediments supplied by the erosion of the nearby mountains filled the bolsons during the Miocene. The Hueco Bolson (Fig. 4), east of El Paso, has as much as 2,750 meters (9,000 feet) of sediments. The sediments of the Presidio Bolson and the Labo Valley probably do not exceed 910 to 1,400 meters (3,000 to 4,500 feet) in thickness. The Salt Basin, east of the Diablo Plateau, is relatively shallow; its maximum sediment thickness is 750 meters (2,500 feet). The Rio Grande Trough, extending from south central New Mexico into west Texas near El Paso has about 300 meters (980 feet) of sedimentary fill.

The Río Grande Rift Zone may extend into the Trans-Pecos region. The Hueco and Mesilla Bolsons near El Paso are considered to be a part of this zone (Henry, 1979).

Geothermal Resources

The most obvious manifestations of the earth's thermal energy are in areas of recent volcanism and tectonic activity. It is only natural that the search for and the utilization of geothermal energy has been concentrated in these areas of readily visible high-temperature sources possibly suitable for generation of electricity. Recently, however, attention has shifted to moderate- (90-150°C, 194-302°F) and low-temperature (less than 90°C, 194°F) resources for possible direct-use applications. Consequently, definition of the geothermal potential of the geologically stable and heavily populated eastern half of the United States has begun to receive increasing emphasis.

Resource Terminology

Geothermal energy is a relatively new energy resource for which the scientific terminology is still being developed. Similar terms have often been used with differing intent by different authors. However, any internally consistent set of resource terms developed for geothermal energy should also fit into the framework developed for mineral resources. Muffler and Cataldi (1978) present such a unified terminology for geothermal resource assessment. Their definitions, which will be used in this report, are given below, and Fig. 6 is a diagram showing the relationships among the terms.

> Geothermal resource base in a specified area is all the heat in that portion of the earth's crust existing at temperatures higher than the local mean ambient surface temperature.
>
> Accessible resource base is that part of the resource base accessible by drilling.
>
> Useful resource base represents heat that could reasonably be extracted at costs competitive with other energy sources, now or at some specified future time under improved economics or technology.
>
> > Economic resource is the heat that can be legally and economically extracted under today's conditions.
> >
> > Subeconomic resource is the heat which is not currently cost-competitive or legally extractable, but which would be at a specified future time under improved economics or different legal status.
>
> Residual resource base represents accessible heat that cannot be collected and utilized under even the most optimistic conditions.
>
> Inaccessible resource base is the heat energy in the crust that cannot foreseeably be reached with projected drilling capability.

The above discussion divides the resource base into an economic/technologic hierarchy. To complete the descriptive classification of geothermal ener-

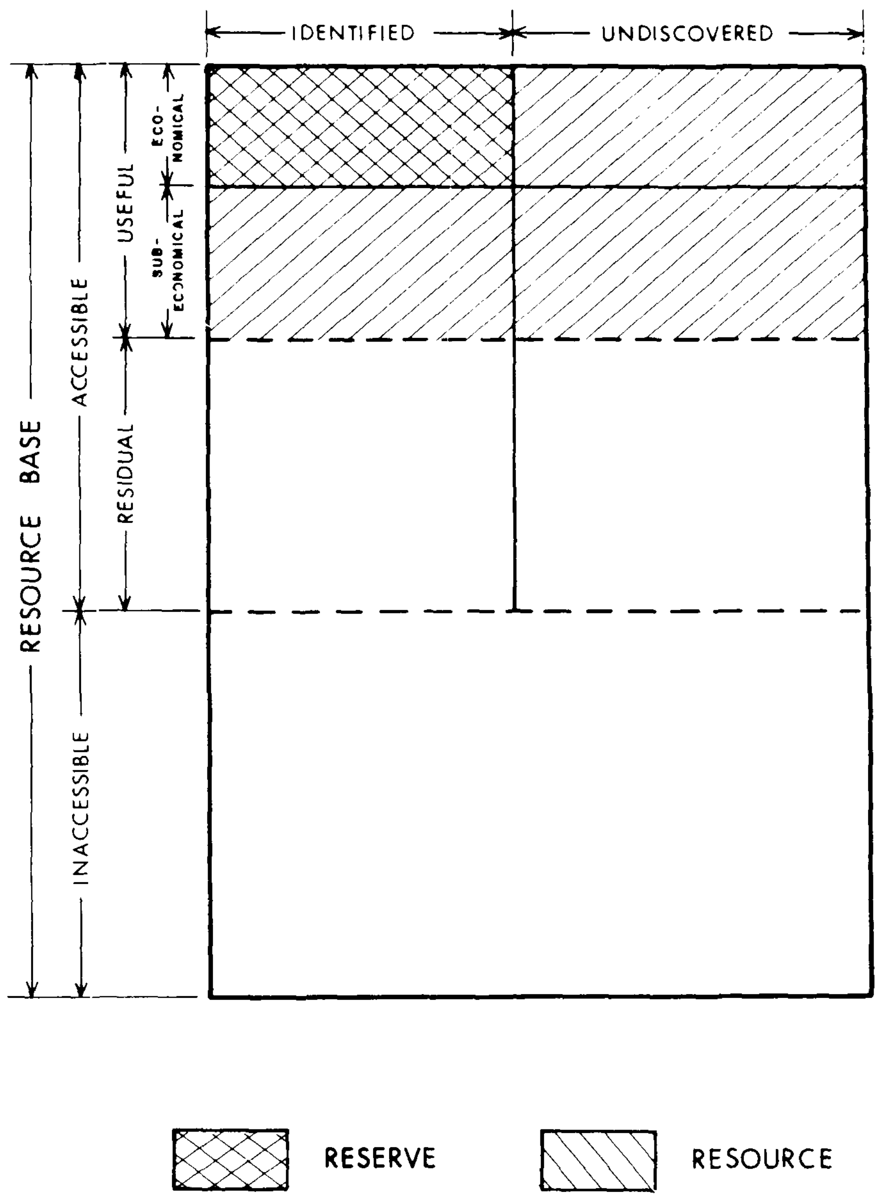

Figure 6.--"McKelvey" diagram showing the derivation of geothermal resource terminology by Muffler and Cataldi (1978).

gy, the degree of geologic assurance should also be specified. The result is the "McKelvey diagram" (McKelvey, 1972) for geothermal resources shown in Fig. 6.

The term "identified" refers to specific concentrations of heat known to exist either from drilling and testing or from geologic, geochemical, or geophysical evidence. The term "undiscovered" refers to unspecified concentrations of heat thought to exist on the basis of broad geologic knowledge.

Our experience with geothermal energy is so meager that the physical limits of the various resource classes are known only in the vaguest way. However, provisional limits for depth and temperature can be set. The accessible resource base can be assumed to lie in the upper 10 kilometers (30,000 feet) of the earth's crust--the approximate maximum depth attainable by drilling technology. It seems probable at this time that the accessible resource base below about 4.5 kilometers (15,000 feet) should not be considered useful resources. (Wells deeper than 3 kilometers (10,000 feet) are uncommon in geothermal exploration, even in areas of high-temperature resources).

Geothermal waters at temperatures below 40°C (104°F) are not likely to be used directly even under the most favorable circumstances. Public acceptance of groundwater heat-pump technology utilizing thermal waters could lower the useful temperature limit to about 13°C (55°F), a value approximating the average groundwater temperature in much of the United States.

Sammel (1979, p. 87) states that "under current or near-future economic conditions, low-temperature waters more than 1 kilometer deep are probably not attractive targets for exploration or development at most places except where usable deep wells have already been drilled for other purposes." Low-temperature waters are those at temperatures less than 90°C (194°F) but greater than 10°C (18°F) above mean annual air temperatures (Sammel, 1979). We are reluctant to estimate a maximum depth below which waters at about 40°C should not be considered as resources, but we provisionally accept 1 kilometer (3,300 feet) as an approximate limit. Our discussion of geothermal potential in the eastern United States places most emphasis on areas where the subsurface increase in temperature is at least 29°C/km (1.6°F/100 ft) and areas with warm springs at temperatures 10°C (18°F) or more above average ambient surface temperature.

Indicators of Geothermal Resources

Geothermal resources are found where nature has provided abnormal concentrations of heat near enough to the surface to be exploited. Until the past few years, geothermal exploration has been guided by surface manifestations of elevated temperature--warm springs, geysers, and recently active volcanoes. As the search for geothermal resources has expanded, more sophisticated methods and combinations have been used, so that the geologic setting of geothermal resources has been delineated to some degree, and regional assessments have been prepared (White and Williams, 1975; Muffler, 1979).

The greatest potential for geothermal energy exists in areas of above-average heat flow; that is, areas of recent volcanic activity or active tectonics. Because the eastern United States is tectonically stable and has experienced no volcanic activity recent enough to provide heat from crystallization, the search for geothermal resources in the east must consider other means of heat generation and accumulation.

Three likely sources of elevated subsurface temperatures in the eastern United States are:

1. Granitic plutons (igneous intrusions) enriched in uranium and thorium that produce elevated heat flow as the result of radioactive decay.

2. Thick sediments of low heat conductivity that cause above-average thermal gradients by allowing the accumulation of heat below them. Costain and others (1977, 1978, 1979) have used this and the preceding concept to model potential geothermal sites in the Atlantic Coastal Plain.

3. Movement of deep waters upward along rock layers or through faults and fractures to produce accumulations of warm water in reservoirs relatively near the surface or warm springs at the surface.

Temperature gradients, heat flow, geochemistry, seismic activity, and regional geology yield the principal clues to such thermal accumulations.

Temperature gradients and heat flow. The temperature gradient (Γ) and heat flow (q) are related to the conductivity (K) of the rocks through which the heat is passing by the relation $q = K\Gamma$. Geophysicists have traditionally recorded q in heat flow units (1 HFU = 1×10^{-6} cal/cm sec), with K in conductivity units (1 CU = 1×10^{-3} cal/cm sec °C) and temperature gradient in °C/km.

Early heat flow studies in the United States showed that the continent could be divided into several provinces typified by characteristic heat flows (Roy and others, 1968a,b), and that the variation of heat flow within a province is caused by differences in the heat generated in upper crustal rocks (Birch and others, 1968). Birch and coworkers found a linear relationship between heat flow and radioactive heat generation (A) in the rocks at each site: $q = q^* + DA$. Here, q^*, reduced heat flow, is the heat flow characteristic of a given province, DA is the component of heat flow due to radioactive heat generation in the upper crust, and D, which changes from one region to another, is related to the thickness of the radioactive crust. Diment and others (1975) suggest values of 0.8 HFU and 7.5 kilometers for q^* and D, respectively, in the eastern United States. Costain and others (1979) use $q^* = 0.65$ HFU and $D = 8.1$ kilometers in the Piedmont province.

As further studies are made, more detailed heat flow and reduced heat flow (q^*) data will be available in addition to those provided by Sass and others (1976). The data used by Sass and others, together with more recent data are listed in Table 2 and shown in Fig. 7. The figure and table show

TABLE 2

HEAT FLOW VALUES IN THE EASTERN UNITED STATES

	State	Location Lat.(N)	Long.(W)	Heat Flow (cal/cm^{2}sec)	Reference
1	Alabama	34°44'	86°30'	0.41	(4)
2		34°44'	86°30'	0.44	(4)
3		33°56'	84°50'	0.24	(4)
4		33°16'	86°01'	0.95	(1)
5		33°18'	87°16'	1.11	(4)
6		31°00'	88°15'	0.95	(4)
1	District of Columbia	39°00'	77°00'	1.12	(1)
1	Florida	30°47'	82°01'	0.5	(5)
2		30°35'	87°07'	1.3	(5)
3		location	uncertain	0.9	(5)
4		29°42'	82°53'	0.1	(5)
5		29°38'	81°38'	0.8	(5)
6		28°28'	81°13'	0.92	(1)
7		28°04'	82°47'	0.7	(5)
8		location	uncertain	0.9	(5)
9		27°22'	82°16'	1.2	(5)
10		27°21'	82°33'	0.8	(5)
11		location	uncertain	0.7	(5)
1	Georgia	34°32'	84°52'	0.34	(3)
2		34°25'	84°21	1.0	(3)
3		34°05'	83°46'	0.64	(3)
4		33°	85°	1.0	(1)
5		33°30'	84°42'	0.94	(2)
6		33°29'	83°12'	1.58	(2)
7		33°27'	83°09'	1.53	(2)
8		33°13'	84°15'	0.97	(1)
9		32°43'	83°15'	0.92	(3)
10		31°36'	81°36°	1.24	(3)
11		31°08'	81°30'	0.51	(3)
1	Illinois	41°01'	88°54'	1.41	(1)
2		40°49'	87°54'	1.42	(1)
3		40°46'	87°48°	1.39	(1)
4		40°45'	87°47'	1.44	(1)
1	Indiana	41°23'	86°14'	1.28	(1)
2		40°59'	84°52'	0.97	(1)
3		40°55'	86°28'	1.41	(1)
4		40°55'	86°27'	1.39	(1)
5		40°53'	86°28'	1.40	(1)

TABLE 2 (cont.)

HEAT FLOW VALUES IN THE EASTERN UNITED STATES

	State	Location Lat.(N)	Long.(W)	Heat Flow (cal/cm^{2}sec)	Reference
1	Kansas	37°57'	101°45'	1.55	(1)
2		38°23'	98°10'	1.50	(1)
1	Maine	44°24'	68°37'	1.44	(1)
2		44°03'	70°37'	1.80	(1)
1	Maryland	38°26'	75°04'	1.45	(2)
2		38°24'	76°11'	1.3	(2)
3		38°24'	75°34'	1.2	(2)
4		38°21'	75°36'	1.5	(2)
5		38°01'	75°50'	1.6	(2)
1	Massachusetts	42°38'	71°25'	1.63	(1)
2		42°37'	72°27'	1.67	(1)
3		42°23'	71°07'	1.20	(1)
4		41°45'	70°05'	1.16	(1)
1	Michigan	47°49'	88°54'	0.75	(1)
2		47°35'	88°13'	0.79	(1)
3		47°24'	88°01'	0.99	(1)
4		47°17'	88°28'	0.93	(1)
5		47°11'	91°15'	0.30	(1)
6		46°45'	89°34'	1.05	(1)
7		44°12'	85°11'	1.10	(1)
8		44°09'	85°00'	1.20	(1)
9		44°04'	85°05'	1.30	(1)
10		44°03'	85°05'	1.10	(1)
11		43°50'	85°35'	1.20	(1)
12		43°32'	85°16'	1.20	(1)
13		43°32'	85°36'	1.00	(1)
14		42°48'	82°44'	0.80	(1)
15		42°44'	86°00'	0.90	(1)
16		42°43'	85°49'	1.07	(1)
17		42°26'	83°34'	1.39	(1)
18		42°26'	83°34'	1.20	(1)
19		42°06'	83°23'	0.8	(1)
1	Minnesota	47°49'	91°43'	0.82	(1)
2		47°09'	95°12'	0.89	(1)
3		46°06'	93°42'	1.03	(1)
4		44°54'	93°12'	1.15	(1)
1	Missouri	39°05'	94°10'	1.17	(1)
2		38°09'	91°15'	1.24	(1)

TABLE 2 (cont.)

HEAT FLOW VALUES IN THE EASTERN UNITED STATES

	State	Location Lat.(N)	Location Long.(W)	Heat Flow (cal/cm^{2}sec)	Reference
3	Missouri	37°39'	91°10'	1.2	(1)
4		37°30'	90°40'	1.24	(1)
1	New Hampshire	44°06'	72°00'	1.34	(1)
2		44°04'	71°10'	1.89	(1)
3		44°02'	71°29'	2.27	(1)
4		43°56'	71°32'	2.15	(1)
5		43°16'	71°59'	1.59	(1)
6		43°12'	71°32'	1.73	(1)
7		43°07'	70°55'	1.08	(1)
8		42°47'	72°08'	1.63	(1)
1	New Jersey	41°06'	74°35'	0.91	(1)
2		39°50'	74°11'	1.05	(2)
1	New York	44°35'	73°54'	1.22	(1)
2		44°20'	74°16'	0.81	(1)
3		44°16'	75°25'	1.22	(1)
4		44°14'	73°28'	0.79	(1)
5		44°13'	73°32'	0.81	(1)
6		43°18'	73°37'	1.05	(1)
7		43°12'	78°28'	1.18	(1)
8		43°05'	79°00'	1.16	(1)
9		42°48'	78°51'	1.20	(1)
10		42°34'	76°57'	1.55	(1)
11		42°27'	78°38'	1.19	(1)
12		42°27'	74°26'	1.00	(1)
13		42°25'	76°54'	1.72	(1)
1	North Carolina	36°26'	78°54'	0.88	(2)
2		36°26'	79°02'	0.97	(2)
3		36°23'	78°58'	0.98	(2)
4		36°20'	78°50'	0.94	(2)
5		36°01'	80°25'	1.44	(2)
6		36°04'	78°08'	0.31	(3)
7		35°55'	82°07'	1.05	(2)
8		35°57'	78°20'	1.02	(2)
9		35°47'	78°25'	1.30	(2)
10		35°45'	75°48'	1.90	(2)
11		35°44'	78°20'	1.13	(2)
12		35°41'	78°56'	0.64	(4)
13		35°40'	75°45'	1.64	(4)
14		35°38'	82°10'	0.84	(4)
15		35°26'	83°27'	1.05	(4)
16		35°17'	80°53'	0.33	(4)

TABLE 2 (cont.)

HEAT FLOW VALUES IN THE EASTERN UNITED STATES

	State	Location Lat.(N)	Long.(W)	Heat Flow ($cal/cm^2 sec$)	Reference
17	North Carolina	34°07'	78°20'	1.64	(4)
1	Oklahoma	36°59'	94°52'	1.4	(1)
1	Pennsylvania	41°56'	77°51'	1.47	(1)
2		41°52'	78°00'	1.31	(1)
3		41°12'	78°39'	1.31	(1)
4		40°59'	80°08'	1.2	(1)
5		40°34'	75°12'	0.89	(1)
6		40°22'	75°50'	0.70	(1)
7		40°06'	77°11'	0.57	(1)
1	South Carolina	34°32'	80°45'	1.05	(2)
2		34°19'	81°09'	1.47	(2)
3		34°10'	81°02'	1.09	(4)
4		33°55'	82°07'	1.62	(2)
5		33°55'	81°10'	1.11	(4)
6		33°17'	81°40'	1.06	(1)
1	Tennessee	36°05'	83°39'	0.83	(4)
2		35°55'	84°19'	0.82	(1)
3		35°34'	84°29'	1.01	(4)
1	Texas	31°55'	106°00'*	11.0	(6)
2		31°55'	106°00'*	7.0-8.0	(6)
3		31°45'	106°30'*	2.0	(6)
4		31°39'	102°15'	1.2	(1)
5		31°27'	104°53'	1.0	(1)
6		31°23'	101°48'	1.1	(1)
7		31°15'	101°28'	1.1	(1)
8		31°12'	101°29'	2.0	(1)
9		31°10'	103°14'	1.1	(1)
10		29°48'	104°24'	1.5	(1)
11		29°07'	99°41'	1.11	(1)
1	Vermont	43°20'	72°33'	1.20	(1)
2		43°17'	72°49'	1.22	(1)
3		43°15'	72°50'	1.23	(1)
1	Virginia	37°46'	78°06'	0.97	(2)
2		37°20'	82°00'	1.7	(1)
3		36°52'	77°54'	1.4	(1)
4		36°50'	77°19'	1.24	(2)

*Location approximate.

TABLE 2 (concluded)

HEAT FLOW VALUES IN THE EASTERN UNITED STATES

	State	Location Lat.(N)	Long.(W)	Heat Flow ($cal/cm^2 sec$)	Reference
5	Virginia	36°49'	81°06'	1.03	(1)
6		37°58'	75°36'	1.8	(2)
7		37°57'	75°27'	1.85	(2)
8		37°53'	76°15'	1.4	(2)
9		37°43'	75°43'	1.3	(2)
10		37°18'	75°56'	1.4	(2)
11		37°04'	76°20'	1.2	(2)
12		36°57'	76°16'	1.3	(2)
13		36°55'	76°42'	1.1	(2)
14		36°51'	76°29'	1.4	(2)
1	West Virginia	39°40'	79°59'	1.2	(1)
2		39°25'	80°05'	1.20	(1)
3		39°18'	80°14'	1.26	(1)
4		39°17'	80°46'	1.22	(1)

References: (1) Sass and others, 1976; (2) Costain and others, 1979; (3) Smith and others 1978; (4) Smith and others, 1979; (5) Smith and Griffin, 1977; (6) Rob Roy, personnel communication, 1979.

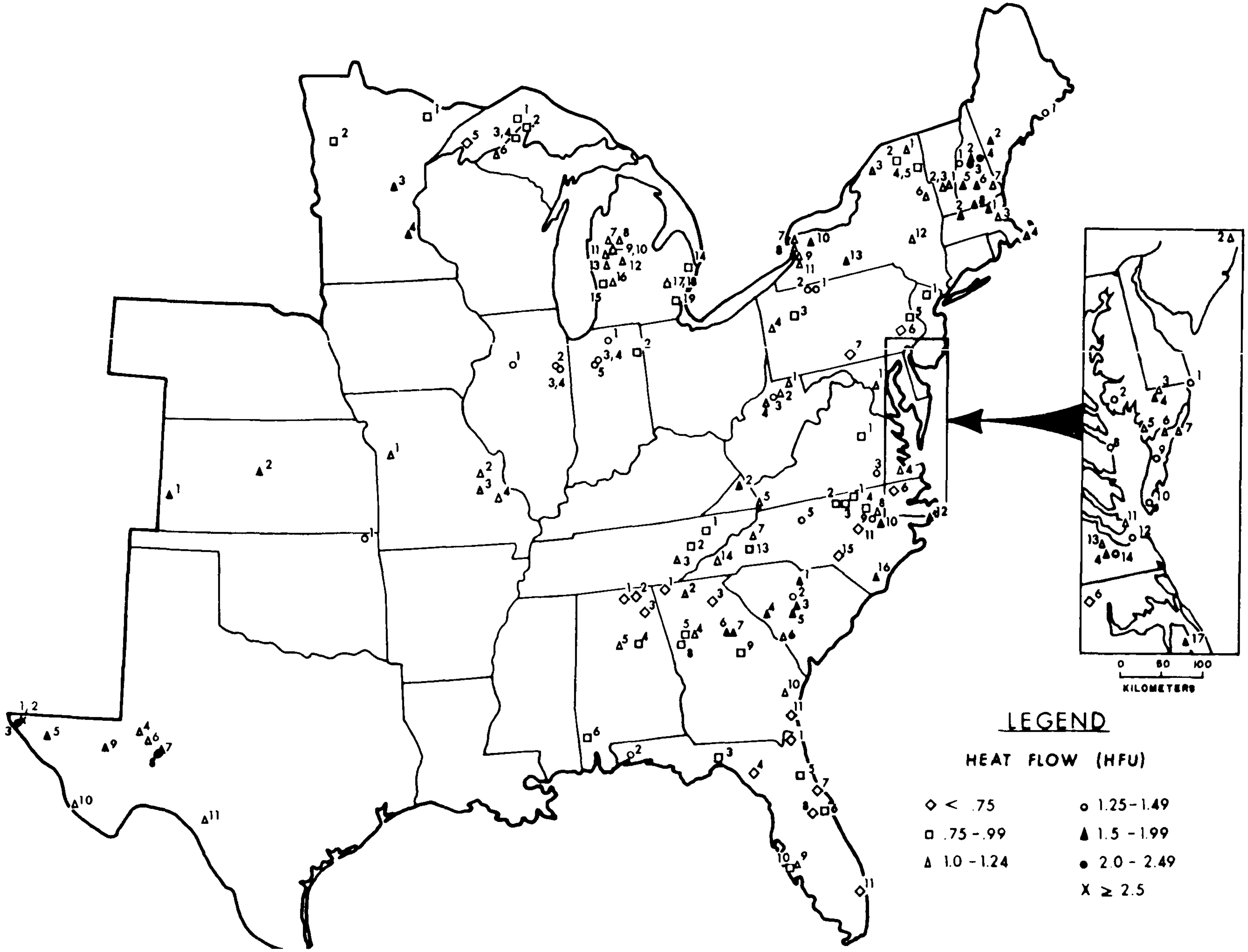

Figure 7.-- Heat flow values in the eastern United States.
The numbers refer to Table 2.

that heat flow values in the eastern United States are usually less than about 1.5 HFU. Exceptions are areas of New England, the Piedmont, and the Atlantic Coastal Plain related to radioactive plutons; certain small areas in south central New York state; and some areas in the Basin and Range portion of Texas. Interpretation of the significance of the high heat flow values in western Texas has not yet been completed, but upward movement of water and the consequent upward transfer of heat probably plays an important role (Rob Roy, personal communication, 1979).

The data currently available provide a good estimate of the regional character of heat flow in the eastern United States. However, some presently unknown regions of high heat flow might be detected by investigation of postulated radioactive plutons in the basement. Such plutons would most likely be of Precambrian or Paleozoic age, but because uranium and thorium decay very slowly, they could provide significant thermal energy, given sufficiently high concentrations of radioactive elements.

Inferences about geothermal resources can be made by examination of the temperature gradient imposed on an area by heat flow and thermal conductivity. Numerous subsurface temperature measurements have been made in the eastern half of the country in the course of petroleum exploration. Recently, the American Association of Petroleum Geologists and the U.S. Geological Survey (1976a,b) have jointly published several maps showing regional variations in subsurface temperatures. The first map, a simplified version of which is shown as Fig. 8, gives average temperature gradients calculated from drill hole information; a second map shows, where data are available, the depth to various isothermal surfaces. These maps, however, have only limited usefulness for geothermal exploration. The bottomhole temperatures used to calculate gradients and the corrections applied to them may introduce errors. Moreover, since the maps were not prepared with geothermal exploration in mind, anomalously high gradients were not taken into account.

Review of data from the Michigan basin shows 20 wells with uncorrected gradients greater than 36.4°C/km (2°F/100 ft). All but three of these wells are less than 900 meters (3,000 feet) deep. Deeper wells in Michigan provided gradients closer to 20°C/km (1.1°F/100 ft). Thus, well depths seem to be negatively correlated with geothermal gradients. At least two mechanisms may be responsible for this observation: shallow wells in Michigan may be drilled through proportionately greater thicknesses of poorly conductive rocks than deeper wells, or shallow wells may be more likely to yield errors in temperature measurement. A careful review of the data will be necessary before definite conclusions can be reached.

Comparison of the temperature gradient map with the map showing approximate thickness of sedimentary rocks (Fig. 5) indicates that the highest gradients are generally associated with the marginal areas of the interior basins rather than with their deeper parts. An exception is the Gulf Coast region; in this case, upward movement of waters from deep geopressured reservoirs is suspected. Updip movement of fluids may also be responsible for the association of higher gradients with basin margins elsewhere.

Despite these problems, the data set from which the gradient map was generated is the best currently available for study of geothermal phenomena in

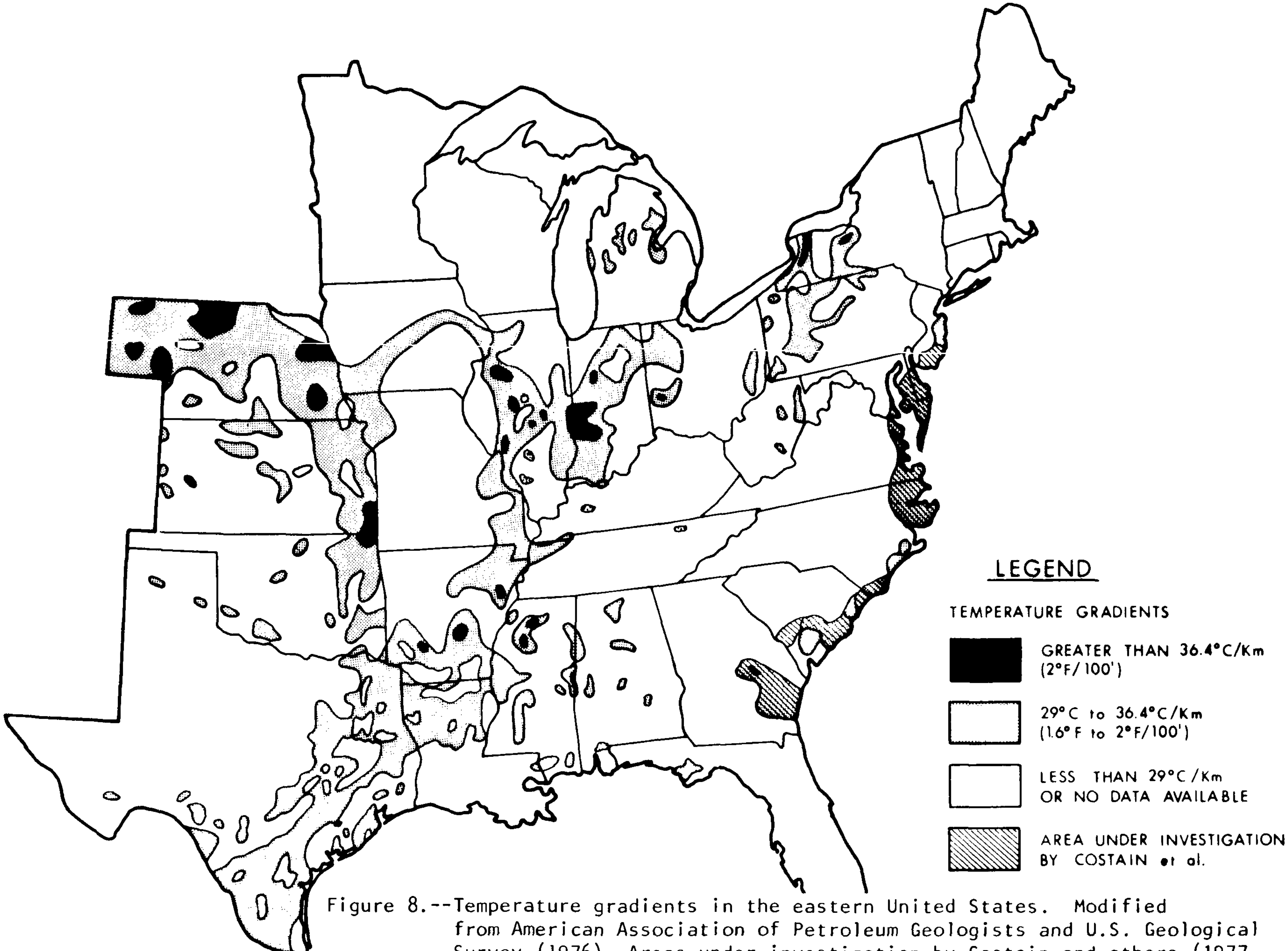

Figure 8.--Temperature gradients in the eastern United States. Modified from American Association of Petroleum Geologists and U.S. Geological Survey (1976). Areas under investigation by Costain and others (1977, 1978, 1979) are also shown.

the eastern United States. The Los Alamos Scientific Laboratory is using the gradient data to target hot dry rock exploration in the east. Preliminary results are encouraging and suggest that some of the anomalies may be more important than the gradient map implies (Maxwell, 1979, and personal communication). Further studies should be made, particularly comparisons of temperature gradients with hole depths and gross lithology types.

If heat flow, conductivity values, and sediment thickness are known, changes of temperature with depth and estimated temperatures at the base of the sedimentary section can be calculated. The results of several such calculations are shown graphically in Fig. 9. Heat flows reported by Sass and others (1976) in the eastern United States generally range from 1 to 2 heat flow units. Diment and others (1975) propose a conductivity (K) of 6×10^{-3} cal/cm sec °C as representative of a thick sequence of crustal rocks. Under these conditions, and with an average surface temperature of 10°C (50°F), temperatures between 35° and 60°C (95° and 140°F) can be reached at a depth of 1,500 meters (4,900 feet).

Caution must be exercised in all cases where gradients are used to project temperatures below the depth of measurement. Temperature gradients vary with rock type, and they may be affected by vertical movement of fluids. In general, conductivities increase with depth, so that gradients decrease with depth. Thus, linear projection of gradients below observation points may predict temperatures much higher than those which actually exist.

<u>Geochemistry</u>. The geochemistry of warm springs is an important key to subsurface water temperatures (White, 1970).

Chemical analysis of waters from springs and geothermal wells yields data from which most predictions of subsurface water temperatures are made. Temperatures can be calculated from chemical analyses because the concentrations of chemical species dissolved in the water vary directly with temperature. The principal methods used are the silica geothermometer (Fournier and Rowe, 1966) and the sodium-potassium-calcium geothermometer (Fournier and Truesdell, 1973).

Several conditions must be met if reservoir temperatures are to be estimated from the chemistry of warm springs. The most important requirements, discussed more completely by Fournier and others (1974), are:

1. Temperature-dependent reaction and equilibration occur at depth.

2. The necessary constituents for the assumed temperature-dependent reaction are available in excess of that necessary for equilibrium.

3. Little or no re-equilibration occurs as the water flows to the surface.

4. The waters are not mixed with shallower ground water while coming to the surface.

Commonly, these restrictions are met in the high- to moderate-temperature geothermal systems of the west. However, because the geochemical temper-

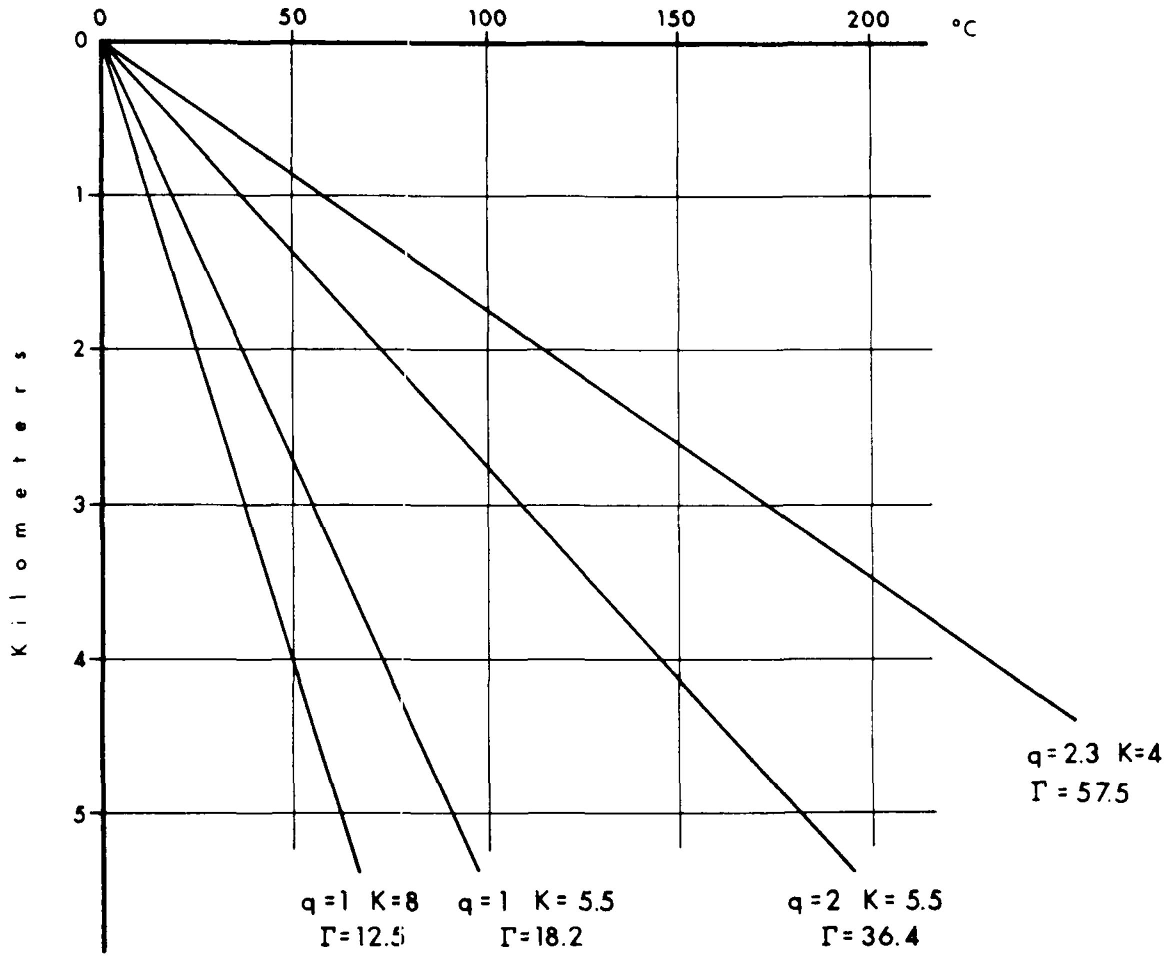

Figure 9.--Temperature increase with depth. Heat flow and average conductivity (K) are as specified. The slope of line (Γ) is calculated from the equation $q=K\Gamma$. The lines show a reasonable minimum conductive gradient ($\Gamma=12.5°C/km$), an average stable continental gradient ($\Gamma=18.2°C/km$), a gradient twice the average ($\Gamma=36.4°C/km$), and a reasonable maximum gradient ($\Gamma=57.5°C/km$) for the eastern United States. Approximate subsurface temperatures can be obtained by adding the appropriate mean surface temperature to values obtained from this chart.

ature scales were chiefly developed from studies of high-temperature thermal systems, the reactions assumed in establishing the geothermometers may not reach equilibrium in the lower temperature systems encountered in the eastern United States.

The silica geothermometer is generally the more reliable at lower temperatures. However, since the principal forms of silica--quartz and chalcedony--have different solubilities, the user must have some idea of which of the two possible equilibria predominates within the reservoir. In low-temperature systems, chalcedony is usually selected (Sammel, 1979) and the geochemical temperatures given in Table 3 for warm springs in the east are generally based on the chalcedony equilibrium.

The other common geothermometer depends on the relative proportions of sodium, potassium, and calcium found in geothermal waters (Fournier and Truesdell, 1973). The method was developed by correlating measured temperatures of geothermal reservoirs with chemical data. The temperature scale is sensitive to calcium concentration, which in turn is quite sensitive to the concentration of dissolved carbon dioxide (CO_2). Reactions in the system $CaCO_3$-CO_2-H_2O are rapid, and re-equilibration occurs with ease. Loss of CO_2 from solution, with consequent deposition of calcite ($CaCO_3$) and readjustment of the relative proportions of sodium, potassium, and calcium, makes utilization of the Na-K-Ca geothermometer difficult in many systems. Interpretation is particularly difficult in areas where CO_2 is lost at spring orifices.

Swanberg and Morgan (1978) have developed a correlation between temperatures based on the silica content of groundwater and regional heat flow. Their approach to the study of silica in groundwater should provide a valuable reconnaissance tool in the search for geothermal resources in the Eastern United States.

Chemical data in the U.S. Geological Survey water quality data bank WATSTORE were used to calculate silica geotemperatures for groundwaters in the United States. The results were presented as a series of histograms showing the distribution of temperature within each of several major physiographic divisions. The mean silica temperature for a province was then plotted against the heat flow (q) for the province, where both parameters were well defined. Temperatures based on the silica geothermometer are indicated here by the symbol $T(SiO_2)$. The plot resulted in the linear correlation $T(SiO_2) = mq + b$. It is thought that the slope m multiplied by thermal conductivity K provides a clue to the mean depth of ground water circulation. Depths of 1.4 and 2.0 kilometers (4,600 and 6,560 feet) are implied for sediments and crystalline rocks, respectively (Swanberg and Morgan, 1978). It is interesting that temperatures for the ground waters sampled correlate well with regional heat flow and do not seem to be appreciably affected by average air temperatures in any given province. Possibly this is the result of the relatively deep source of fluids implied by the model. Such a depth should yield water temperatures about 25° to 36°C (45° to 65°F) above average air temperatures in the conterminous 48 states.

Swanberg and Morgan also averaged the silica geotemperatures over a 1° x 1° grid and contoured the results. The map shows regional trends in temperature variation quite similar to regional heat flow patterns. Presumably a finer grid would provide more detail in areas of particular interest.

Seismic Activity. Major high-temperature convective hydrothermal systems are usually associated with tectonic activity. Most major seismic events also occur in areas of major tectonic activity (spreading ridges, subduction zones, and continental rift zones, in the parlance of continental drift). The eastern United States is generally regarded as tectonically stable; however, some seismicity remains. Because of the close association worldwide between hydrothermal phenomena and seismicity, it is expected that seismically active areas in the eastern United States might have above-average potential for geothermal resources.

Hadley and Devine (1974) have published a seismotectonic map of the eastern United States relating historical seismic activity (1800-1972) and geologic structures. Stover (1977) has prepared a seismicity map for the period 1965-1974. Both maps show generalized tectonic features. However, Stover's map is based on seismic records for such a limited time period that prediction of seismic zones is difficult, and the map prepared by Hadley and Devine covers only the area east of the Mississippi River.

Woollard (1958, 1969) points out several possible zones of seismic activity. The geochemical survey of Swanberg and Morgan (1978) and the temperature gradient map of the American Association of Petroleum Geologists and U.S. Geological Survey (1975) show some correlation with the zones proposed by Woollard. Zones and epicenters from the above sources are shown in Fig. 10.

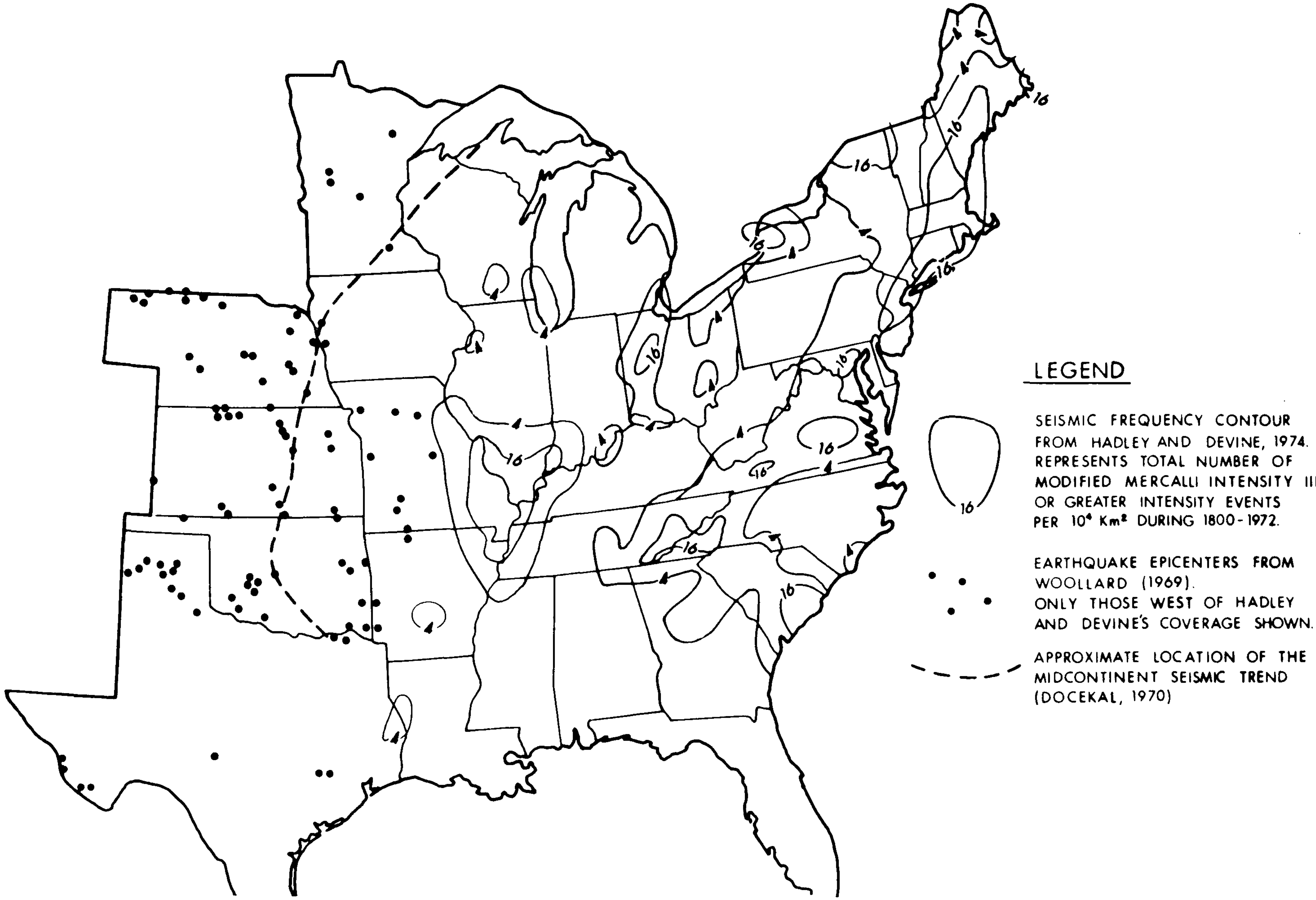

Figure 10.--Historic seismic activity and seismic zones. Modified from Woollard (1969), Hadley and Devine (1974), and Docekal (1970).

Areas of Indicated Geothermal Potential

A refined and updated assessment of U.S. geothermal resources has recently been published (Muffler, 1979). As does an earlier assessment (White and Williams, 1975), this shows that systems related to igneous rocks and hydrothermal convection systems with temperatures of 90°C (194°F) or more are found only in the western United States. The 1979 report, however, includes a comprehensive summary of locations where low-temperature thermal waters are known to be present near the surface in the eastern United States. Also listed are several areas where the existence of subsurface thermal waters has been inferred.

The known occurrences of geothermal energy in the eastern states can be divided into four categories:

1. Warm spring systems,

2. Radioactive, heat-producing granite plutons beneath a thick covering of poorly conducting sediments,

3. Aquifers containing abnormally warm waters, and

4. Deep sedimentary basins with normal geothermal gradients.

These are discussed below.

Warm Springs

Thermal springs have been reported in the eastern United States since colonial times. Nearly all early descriptions dwelt on their therapeutic and recreational values (Crook, 1899; Fitch, 1927; Moorman, 1867). All early data sources contain inaccuracies due to changes in spring character through time, uncertain locations, and, to an unknown extent, inaccurate temperature data.

Peale (1886) provides the most comprehensive early listing of mineral springs in the United States, and his compilation is still a valuable guide to warm spring locations. The most truly encyclopedic listing and today's best source of information on thermal springs of the United States was published by Waring in 1965. The present discussion relies on modern reports or older accounts that have been verified at least in part. The principal sources used are Hobba and others (1976), Sammel (1979), Waring (1965), and Berry (personal communication, 1979).

Thermal springs are defined in various ways. Waring (1965, p. 4) labels as "thermal" those springs with temperatures "at least 15°F [8°C] above the mean annual temperature at their localities," with some adjustment for areas of low and high mean annual temperature. Sammel (1979, p. 87) opts for temperatures greater than 10°C (18°F) above mean ambient temperature as a cutoff, in substantial agreement with Waring.

In general, this report adopts Sammel's definition. The locations and other site-specific information on eastern springs are listed in Table 3.

Locations are also shown in Fig. 11.

No comprehensive reports on the geochemistry and geothermometry of eastern warm springs exist. Chemical analyses, however, are available for most of the important springs. Hobba and others (1976) analyzed the more important springs in the Appalachians. Their data provide the most reliable measurements for geothermometry available in the region. A discussion of the results of their study is currently in press (Hobba and others, 1978).

Bedinger and others (1979) discuss the geology and geochemistry of Hot Springs National Park, Ark.

Table 3 also lists analytical data from published reports and equilibrium temperatures calculated for this report, together with minimum equilibration temperatures proposed by Sammel (1979). In some instances the reservoir temperatures derived from geochemistry are lower than the surface temperatures of the springs. In these cases it is likely that interpretation of the geochemical data is in error due to mixing of thermal water with cool water or equilibration with minerals other than those assumed in the geochemical model. Much of the scatter in the Na-K-Ca derived temperature estimates may be due to deposition of calcite near the spring outlet or to the influence of saline formation waters.

Geochemical considerations suggest that reservoir temperatures are not substantially higher than measured surface temperatures at most eastern thermal springs, a reasonable inference in view of the generally average continental heat flow in the area. These estimated temperatures correspond to maximum circulation depths slightly greater than 3 kilometers (10,000 feet) in areas of average geothermal gradient. Although not all of the warm springs fall into the provisional classification of low-temperature resources--subsurface temperatures of 40°C (104°F) or more within 1 kilometer (3,300 feet) of the surface--they are generally suitable for small-scale, direct-use applications such as swimming pool or space heating.

Appalachian thermal spring model. The warm springs of the eastern states, except for those in Alabama, Florida and western Texas, are found either in the Appalachians or in the geologically similar Ouachita Mountains.

Much has been written about the structural control of warm springs in the Appalachians. Few major changes, however, have been made to the model of deep circulation in folded and faulted rocks originally proposed by Rogers (1884).

Modern work on the origin of "Appalachian" type warm springs is currently under way in Virginia (Costain, 1979) and Arkansas (Maxwell, 1979). The geologic settings of both areas are similar. Review of additional publications on these areas (Bedinger and others, 1979; Purdue and Miser, 1923; Rogers, 1884; Reeves, 1932; Rodgers, 1970; Geiser, 1976; Dennison and Johnson, 1971) and of the geology of other Appalachian warm springs (Massachusetts and New York: Zen, 1967; Pennsylvania: Dyson, 1967; North Carolina: Oriel, 1950, Stose and Stose, 1947; Georgia: Hewett and Crickman, 1937)

TABLE 3

THERMAL SPRINGS OF THE EASTERN UNITED STATES

	Spring	Location lat (N)	Location long (W)	Surface temperature, °C	Chemical analysis ppm SiO_2	Ca	Na	K	Estimated Reservoir Temperature, °C*: Quartz Conductive	Chalcedony	Na-K-$\frac{1}{3}$Ca	Na-K-$\frac{4}{3}$Ca	Minimum Equilibration Temperature	Source**
	ARKANSAS													
1	Warm Springs	36°28.8'	91°03.0'	28	-	-	-	-	-	-	-	-	-	(a)
2	Big Chalybeate Spring	34°32.4'	93°01.2'	26	-	-	-	-	-	-	-	-	-	(a)
3	Hot Springs	34°30.6'	93°03.2'	64	42	45	4	1.5	94	62*	177	4	64	(b)
4	Spring on Little Missouri River	34°24.4'	93°54.5'	23	-	-	-	-	-	-	-	-	-	(a)
5	Caddo Gap Springs	34°23.0'	93°36.4'	35	19	42	3.3	0	62	27*	-	-	-	(b)
6	Spring on Redland Mt.	34°19.3'	93°44.3'	25	-	-	-	-	-	-	-	-	-	(a)
	FLORIDA													
1	Warm Mineral Springs	27°03.6'	82°15.7'	30	16	500	5200	150	56	21*	148	184	30	(i)
2	Little Salt Spring	27°04.4'	82°14.0'	27	19	180	750	23	62	27*	130	101	-	(i)
	GEORGIA													
1	Warm Springs	32°53.6'	84°41.4'	31	20	22	1.2	3.8	64	29*	304	26	34	(d)
2	Parkman Spring	32°51.7'	84°39.0'	25	-	-	-	-	-	-	-	-	-	(a)
3	Tom Brown Spring	32°52.4'	84°32.8'	20	-	-	-	-	-	-	-	-	-	(a)
4	Thundering Spring	32°57.8'	84°29.9'	24	-	-	-	-	-	-	-	-	-	(a)
5	Barker Spring	32°55.2'	84°26.3'	23	-	-	-	-	-	-	-	-	-	(a)
6	Lifsey Spring	33°02.2'	84°22.4'	26	-	-	-	-	-	-	-	-	-	(a)
7	Taylor Spring	33°01.1'	84°19.6'	24	-	-	-	-	-	-	-	-	-	(a)
	MASSACHUSETTS													
1	Sand Spring	42°44.1'	78°12.0'	24	12	25	2.0	0.9	46*	11	180	-3		(e)
	NEW YORK													
1	Lebanon Spring	42°28.8'	73°22.2'	22	12	35	6.9	1.2	46*	11	150	7	51	(d)

*Best geochemical estimate of reservoir temperature shown by asterisk; minimum equilibrium temperatures are taken from Sammel (1979). Discrepancies between surface and reservoir temperatures are probably due to errors in interpretation of geochemical data; see p. 37.

**See end of table.

TABLE 3 (cont.)

THERMAL SPRINGS OF THE EASTERN UNITED STATES

	Spring	Location lat (N)	long (W)	Surface temperature, °C	Chemical Analysis ppm SiO_2	Ca	Na	K	Estimated Reservoir Temperature, °C * Quartz Conductive	Chalcedony	$Na-K-\frac{1}{3}Ca$	$Na-K-\frac{4}{3}Ca$	Minimum Equilibrium Temperature	Source**
		NORTH CAROLINA												
1	Hot Springs	35°53.8'	82°49.6'	42	31	135	10	10	81	48*	245	37	50	(d)
		PENNSYLVANIA												
1	Perry County Warm Springs	40°19.7'	77°14.8'	18	9	38	1.6	0.5	37*	1	154	-20	36	(d)
		TEXAS												
1	Red Bull Spring	30°51.7'	105°20.4'	37	36	15.5	312	11	88	54*	14	125	56	(f)
2	Indian Hot Sprgs.	30°49.4'	105°18.9'	47	40	150	2185	134	92	59*	182	207	60	(f)
3	Capote Warm Sprg.	30°12.6'	104°33.7'	37	37	1.6	120	0.6	89	56*	70	64	57	(f)
4	Nixon Springs	30°08.0'	104°36.1'	32	43	20.5	160	5.5	95	63*	128	84	60	(f)
5	Ruidosa Hot Springs	30°02.3'	104°35.9'	45	35	27.5	148	14.5	86	53*	174	111	55	(f)
		29°48.3'	102°22.6'	32										
6	Las Cienegas	29°47.2'	104°27.7'	30	39	27	228	6	91	58*	120	84	60	(f)
7	Hot Springs	29°10.9'	102°59.5'	41	22	133	108	5.8	68*	33	328	157	41	(f)
8	Rio Grande Village Spring	29°10.7'	102°57.2'	36	21	125	98	5.4	66	31	0.29	43*	36	(f)
		VIRGINIA												
1	Bragg Spring	38°14.3'	79°39.0'	24	-	-	-	-	-	-	-	-	-	(a)
2	Bolar Spring	38°13.1'	79°40.4'	23	11	58	1.6	2.3	43*	8	238	3	30	(d)
3	Warm Springs	38°03.3'	79°46.8'	35	21	112	3.7	7.4	66*	31	274	25	41	(d)
4	Hot Springs	37°59.8'	79°49.8'	41	21	132	7.0	13	66	31	283	42*	41	(d)
5	Healing Springs	37°57.8'	79°51.7'	30	24	118	6.5	2.4	71	37*	176	4	43	(h)
6	Rockbridge Baths	37°53.9'	79°27.7'	22	-	-	-	-	-	-	-	-	-	(a)
7	Layton Springs	37°51.6'	79°59.3'	22	-	-	-	-	-	-	-	-	-	(a)
8	Falling Spring	37°52.2'	79°56.0'	25	18	158	3.8	16	60	25	336	39*	40	(d)
9	Sweet Chalybeate Spring	37°38.7'	80°14.3'	24	-	228	17.9	24.5	-	-	274	53*	-	(c)
10	New River White Sulphur Springs	37°17.4'	80°37.1'	29	-	-	-	-	-	-	-	-	-	
11	Alum Springs	37°09.6'	80°48.4'	22										

*Best geochemical estimate of reservoir temperature shown by asterisk; minimum equilibrium temperatures are taken from Sammel (1979). Discrepancies between surface and reservoir temperatures are probably due to errors in interpretation of geochemical data; see p. 37.

** See end of table.

TABLE 3 (cont.)

THERMAL SPRINGS OF THE EASTERN UNITED STATES

	Spring	Location lat (N)	long (W)	Surface temperature, °C	Chemical Analysis ppm SiO_2	Ca	Na	K	Estimated Reservoir Temperature, °C * Quartz Conductive	Chalcedony	$Na\text{-}K\text{-}\frac{1}{3}Ca$	$Na\text{-}K\text{-}\frac{4}{3}Ca$	Minimum Equilibrium Temperature	Source**
		WEST VIRGINIA												
1	Berkeley Springs	39°37.1'	78°13.8'	22	9.5	45	4.1	1.0	38*	3	156	-4	38	(d)
2	Swan Pond Spring	39°28.3'	77°52.6'	22	-	-	-	-	-	-	-	-	-	(b)
3	Thorn Spring	38°36.3'	79°21.2'	22	-	-	-	-	-	-	-	-	-	(b)
4	Minnehaha Springs	38°09.8'	79°58.5'	21	14	61	4.2	0.4	51*	16	113	-24	34	(d)
5	Old Sweet Spring	37°37.8'	80°14.4'	23	18	-	-	-	-	-	-	-	-	(g)

*Best geochemical estimate of reservoir temperature shown by asterisk; minimum equilibrium temperatures are taken from Sammel (1979). Discrepancies between surface and reservoir temperatures are probably due to errors in interpretation of geochemical data; see p. 37.

**(a) Berry, personal communication, 1979; (b) Bedinger and others, 1979; (c) Helz and Sinex, 1974; (d) Hobba and others, 1976; (e) Hansen and others, 1974; (f) Henry, 1977; (g) Price, 1936; (h) Reeves, 1932; (i) Rosenau and others, 1977.

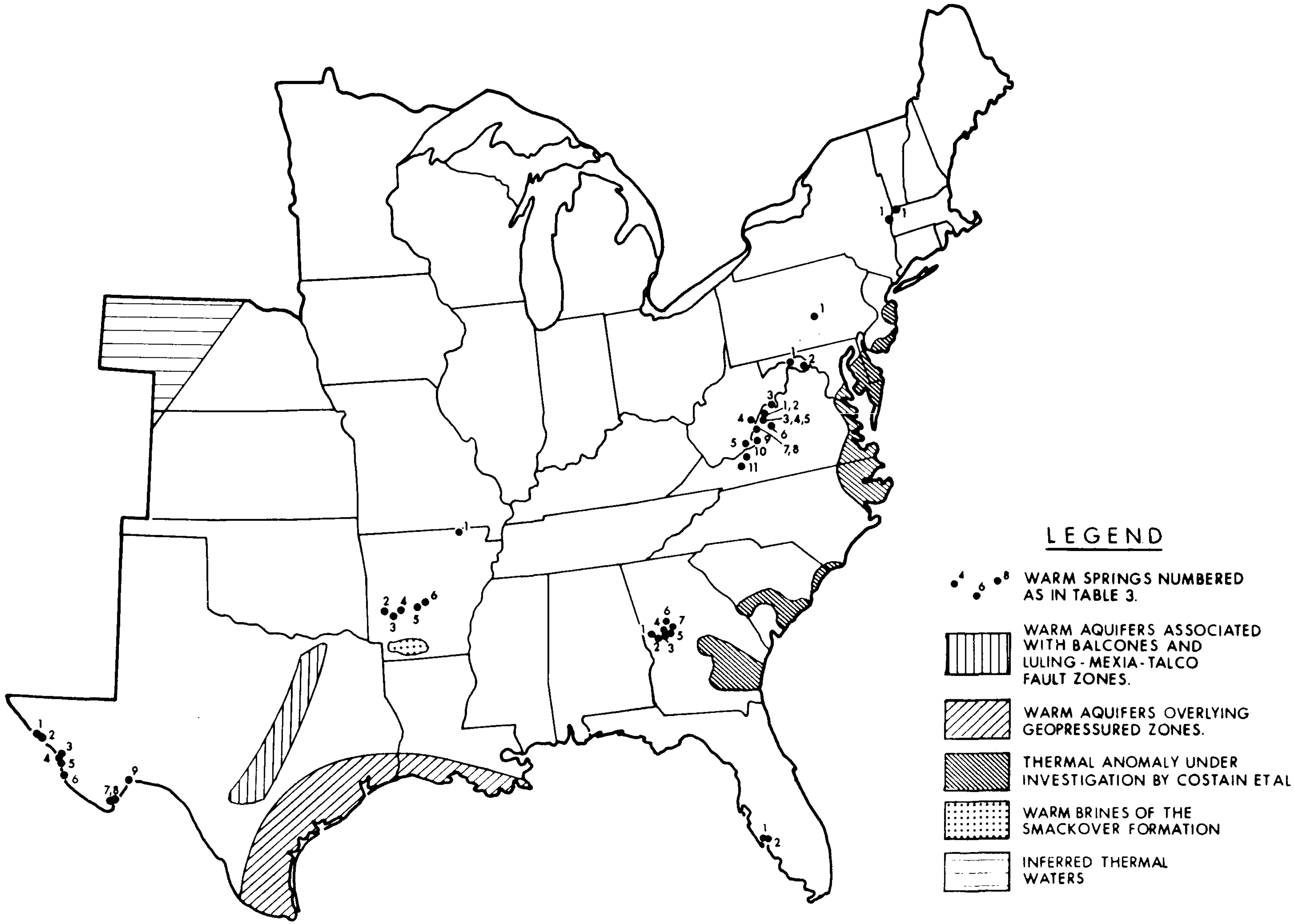

Figure 11.-- Areas of indicated geothermal resources.

suggests that all warm springs in the Appalachian and Ouachita regions have similar origins, despite the substantial distances separating them.

Costain (1979) notes the coincidence of water gaps, warm springs, and steeply dipping quartzite beds in Virginia and postulates that groundwater enters Silurian quartzites or carbonates, descends to depths sufficient to be heated, and then rises rapidly along east-west fracture zones cutting the Warm Springs anticline. Steeply dipping siliceous rocks are also present at Hot Springs, N.C., Warm Springs, Ga., and Hot Springs, Ark. Although transverse fractures are not known to be associated with the springs in these areas, the alignment of the French River near Hot Springs, N.C., suggests the presence of a fault.

No detailed geologic studies of Sand Springs in Massachusetts or Lebanon Springs in New York are available. Their proximity to the Taconic structures described in Zen (1967) suggests that the rocks from which these springs discharge (particularly Lebanon Springs) may be structurally similar to those of the Folded Appalachians, although the relationships are unclear because of the Taconic and succeeding periods of orogeny.

The importance of fault control to Appalachian warm springs is not clear. Faulting is present in all of the hot spring areas of the Appalachian and Ouachita mountains but no springs are known to discharge in fault zones, except those inferred by studies of linears.

Warm springs and faults. Warm springs in the Basin and Range province are commonly found in or near fault zones. Many fault zones, however, are silicified and filled with gouge; the older a fault system, the more likely sealing has occurred. Faults in the Basin and Range province associated with thermal springs are relatively young on a geologic time scale. In fact, there is some evidence that recurrent seismic activity is necessary to maintain thermal springs. Swanberg and Morgan (1978) note that ground waters in the eastern United States are characterized by low silica temperatures, except in tectonically active areas like New Madrid, Mo., southern New York, and South Carolina.

Many currently inactive fault systems in the east, such as the Rough Creek zone in Illinois and Kentucky and the border faults of the Triassic basins, are not associated with obvious thermal anomalies. Rodgers (1970) notes that silification is common in the Triassic border faults, suggesting that movement of silica-rich thermal solutions may have been important in the past.

Faults as old as those of the Appalachians and Ouachitas have had ample time for any original permeability to be closed off. Recent faulting in relatively brittle, clean-fracturing quartzites may allow permeability to be maintained, however. Possibly this is important in the Warm Springs, Va., area through which the 38th parallel lineament is thought to extend and perhaps to be still active (Dennison and Johnson, 1971). Quartzite beds are also present there.

Absence of thermal anomalies where old fault systems occur may be due to other hydrologic conditions. Steeply inclined beds forming recharge zones and topographic lows to localize discharge may be necessary for the development of thermal convection systems.

Other eastern thermal springs. The springs in the Trans-Pecos region of Texas have higher indicated geochemical temperatures than any other thermal springs in the east except those at Hot Springs, Ark. They appear to be associated with Basin and Range style faulting and with the Rio Grande rift (Henry, 1977 and 1979). Henry (1977) lists several wells in the area that have produced abnormally warm waters at shallow depths. The Brisco well in the Presidio Bolson encountered a temperature of about 51°C (124°F) at 27 meters (90 feet). In a Gulf Oil Company well north of Presidio Bolson, 82°C (180°F) water was reported at 874 meters (2,870 feet). Near Terlingua, two occurrences of water at about 45°C (113°F) are recorded at 270 meters (880 feet).

Thermal springs in Florida appear to be caused by the local upwelling of thermal waters originating in the Floridian aquifer. Kohout and others (1977) believe the springs to be the result of convection cells involving heating of sea water as it moves inland along the Floridian Plateau. This model is questioned, but not entirely ruled out, by Sproul (1977). In any event, the waters are not much warmer than the average air temperature in Florida.

Radioactive, Heat-Producing Granitic Plutons

Radioactive, heat-producing granitic plutons buried beneath thick blankets of minimally conductive sediments may provide the best source of geothermal energy along the Atlantic Coast of the United States. Costain and others (1976) are continuing to study this potential resource. Their reports give a detailed account of the theoretical model and the validation procedures used. Only a brief summary of their approach and major results is given here.

Numerous granitic plutons, somewhat richer in uranium and thorium than the surrounding rocks, have been observed in the Piedmont. Similar plutons are thought to exist beneath much of the Atlantic Coastal Plain. Although the concentrations of uranium and thorium are not high--10 ppm of uranium (Glover, 1979) and three to four times as much thorium (Costain, 1979)--enough of these elements is present in many plutons of the Piedmont for elevated heat flows to be observable above buried plutons. Temperature gradients as high as 48°C/km (2.6°F/100 ft) have been recorded in a series of shallow (300-m, 1,000-ft) holes drilled in the Atlantic Coastal Plain above possible plutons inferred from gravity and magnetic data (Costain, 1979).

The thicker the sedimentary cover over a pluton, the higher the temperature expected at the base of the sedimentary sequence. The interrelationships of temperature, depth, thickness of sediments, and heat flow are shown in Fig. 9.

A 1,500-meter (5,000-foot) well drilled near Crisfield, Md., has partially confirmed the Costain model. The 56°C (133°F) water produced from the well at 1.2 kilometers (4,000 feet) depth is subeconomic at present, but has a strong potential to be economic in the not-too-distant future. The locations of temperature and gravity anomalies on the Atlantic Coastal Plain possibly associated with similar or higher-grade geothermal resources are shown in Figs. 8 and 11. The availability in these areas of thermal waters in sufficient quantity for production is not yet confirmed.

Buried granitic plutons may provide heat not only for hydrothermal systems in the overlying sediments but also for hot dry rock systems within the plutons. Los Alamos Scientific Laboratory is currently investigating this possibility.

Abnormally Warm Aquifers

Abnormally warm aquifer water is known or inferred to exist in several areas of the eastern United States. The largest region with this potential lies in Texas and Arkansas in the Ouachita structural belt and in the Balcones and Luling-Mexia-Talco fault zones. Numerous warm-water wells have been drilled here, and measured geothermal gradients range from 25 to 45°C/km (1.4 to 2.5°F/100 ft) within 1 kilometer (3,300 feet) of the surface (Sammel, 1979). Studies are underway to assess more fully the potential of the area and to accelerate development. These and other studies have focused on Cretaceous aquifers within the fault zones or overlying the buried Ouachita structural belt (Woodruff, 1978). The warm waters are probably related to upward migration along fault zones or updip within the Cretaceous sediments.

Complicating the picture in the northern Gulf of Mexico Basin is the presence of geopressured-geothermal reservoirs in almost all Cenozoic formations and some deep Mesozoic rocks (Wallace and others, 1979). Although these reservoirs are not a subject of this report, Sammel (1979) suggests that they may be responsible for elevated temperatures in a broad zone of shallow aquifers possibly extending from South Texas to Alabama. These aquifers, generally Tertiary in age, lie east of the major fault zones and the Ouachita structural belt with which the thermal waters in the Cretaceous rocks of eastern Texas are associated.

The third known occurrence of thermal waters in the eastern United States is an extensive thermal brine field in southern Arkansas. Numerous wells in the Smackover Formation exhibit gradients in the 30 to 40°C/km (1.6 to 2.2°F/100 feet) range at depths of 1 to 3 kilometers (3,300 to 10,000 feet) (Collins, 1974). According to Sammel (1979) the maximum temperatures measured in the deepest wells are about 140°C (284°F).

The existence of an extensive area of thermal waters, an extension of the thermal field of western South Dakota, is inferred under the western third of Nebraska (W. D. Gosnold, personal communication 1979). The Nebraska Conservation and Survey Division is beginning work in this area.

The thermal potential of abnormally warm aquifers is not widely exploited at present. The Department of Energy, however, is currently funding two demonstration projects in these eastern systems. The first will use geothermal water from the Balcones fault zone to provide heating for the Torbett-Hutchings-Smith Memorial Hospital at Marlin, Tex. Warm water of about 60°C (140°F) is expected at 1.2 kilometers (3,900 feet).

A second project will use the hot brines from the thermal brine field in southern Arkansas to generate electricity. Arkansas Power and Light Company will use 99°C (210°F) brine in a binary-cycle generator to provide 100 kilowatts of electrical power.

Deep Sedimentary Basins with Normal Gradients

The geothermal energy of warm springs, shallow thermal aquifers, and radiogenic plutons can be classified as indicated resources and, to a lesser extent, as reserves. The geothermal energy associated with deep sedimentary basins cannot, however, be classified as a resource.

Many deep sedimentary basins have been delineated through petroleum exploration (Fig. 5). Except for the Appalachian, Illinois, and Michigan Basins, sediments thicker than 1.5 kilometers (5,000 feet) occur only in the interior basins associated with the Ouachita, Wichita, and Marathon structural belts of Texas and Oklahoma.

The interior basins are established on continental crust where the basement has been depressed either by gentle downwarping, as in Illinois and Michigan, or by major downwarping associated with mountain building activity, as in the Appalachian, Anadarko, Arkoma, and Ardmore basins. The thick sedimentary sequences in these basins offer targets for fluid production and --because of their great depths--relatively high temperatures. The production capabilities of many of these deep reservoirs and their temperatures are known from petroleum operations. Much of the data remain in company files, but some are available in scattered published reports.

Review of Figs. 5, 7, and 8 shows that most of the deep sedimentary basins in the interior have relatively normal heat flow and temperature gradients. Heat flow in most cases should be about 1 to at most 1.5 HFU. Temperature gradients are generally 18.2 to 29°C/km (1 to 1.6°F/100 feet), although in some cases they reach 36°C/km (2°F/100 feet).

Several of the interior basins are thought to hold fluids at a hydrostatic pressure greater than normal for a given depth. A general description of these geopressured basins is given by Wallace and others (1979). Deep wells drilled for petroleum production in geopressured regions may provide economic geothermal resources if the drilling costs can be written off to oil and gas exploration. Pumping the geothermal fluid from geopressured reservoirs would be less costly.

Undiscovered Resources

On the basis of the foregoing discussion some broad inferences can be drawn about the potential for undiscovered geothermal resources in the eastern United States.

The geothermal resource base is generally considered to be the heat in the earth's crust beneath a specific area where subsurface temperatures are higher than the local mean annual temperature (Muffler and Cataldi, 1978). By this definition, potential geothermal resources underlie all parts of the country. At the present time, however, only waters with temperatures above the average for their source area are being used for their heat content.

Most of the following discussion centers around the possible causes and locations of geothermal occurrences. In the eastern United States these seem to be limited to cases governed by elevated heat flow from radioactive plutons, insulating layers of low-conductivity sediments, deep circulation and rise of ground water, or a combination of these mechanisms. It is not likely that cooling igneous bodies are near enough to the surface to provide locally elevated heat flow.

Diment and others (1975) suggest that maximum heat flow above plutons in the eastern states is about 2.3 HFU. For comparison, Costain and others (1977, 1978, 1979) report maximum observed heat flow values of 1.9 HFU in the Atlantic Coastal Plain and 1.53 HFU above plutons in the Piedmont. The highest heat production in the basement is from large granitic bodies rich in uranium and thorium. Such granites are commonly associated with high-grade metamorphic complexes that have not undergone further metamorphism after the emplacement of the granite. When possible values of heat flow are considered, together with rock conductivities and desired temperatures (Fig. 9), it becomes apparent that thick sequences of poorly conducting sediments must overlie such radioactive granites if elevated temperatures are to develop.

Data available from published basement geologic maps, drill holes, and geophysical studies, coupled with geologic interpretation of regional trends, should yield important clues to the location of large plutons meeting this requirement. Figure 12 shows, among other features, possible locations of felsic batholithic rocks that could exist at relatively high temperatures, given sufficient sedimentary cover.

In the eastern U.S. sediments of lowest conductivity are found in the Coastal Plains. The Gulf Coastal Plain is known to have many areas of geothermal potential. The potential in the Atlantic Coastal Plain, however, is less well known. Heat flows between 1 and 2.3 HFU and conductivities between 3 and 5 CU are apparent limits for the Atlantic Coastal Plain. Sediment thicknesses are less than 1.5 kilometers (5,000 feet) except in the Delmarva Peninsula and extreme eastern North Carolina (Fig. 5). Deep holes will probably have average conductivities near 4 CU. Hence, maximum temperature gradients of about 57.5°C/km (3.2°F/100 ft) are possible.

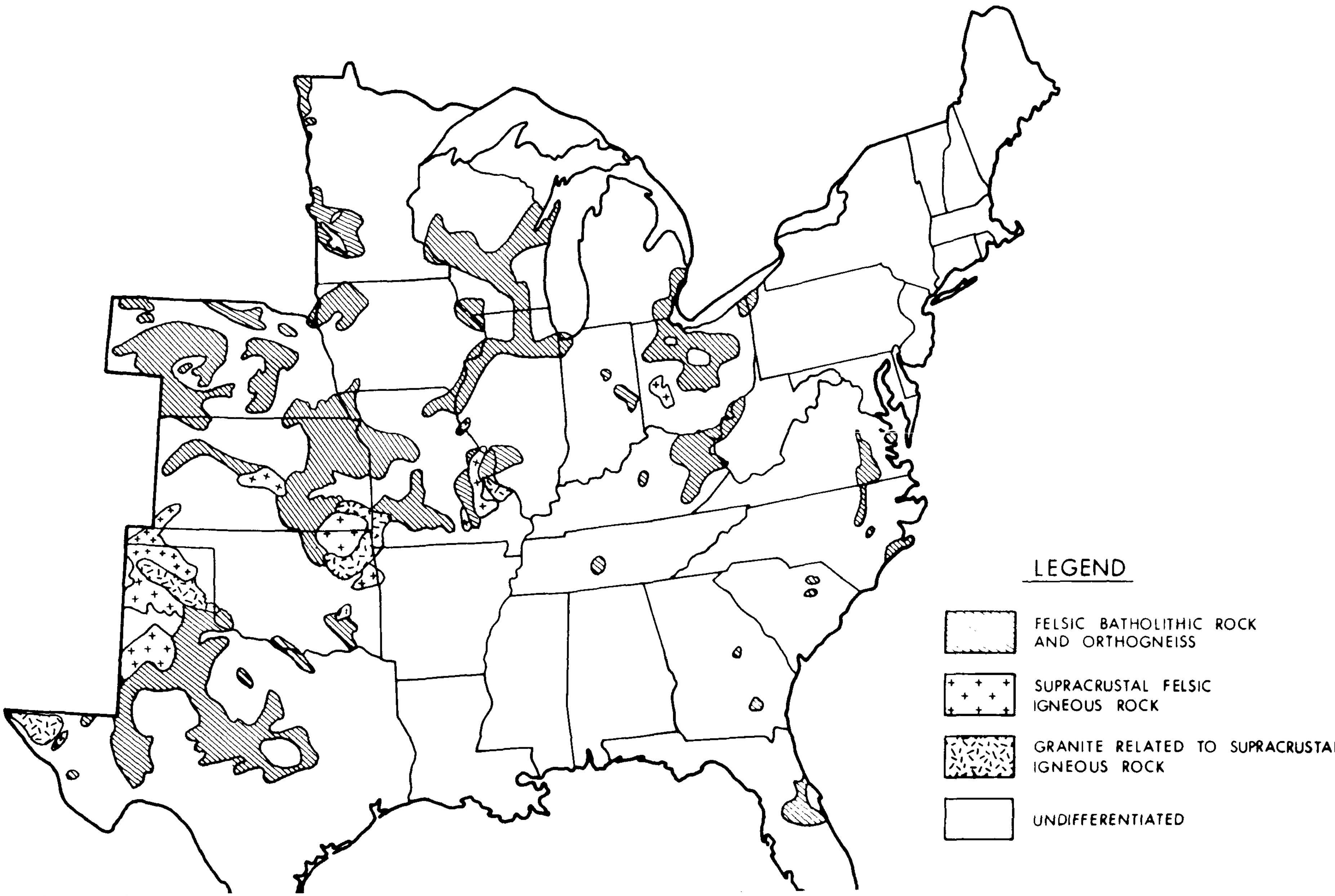

Figure 12.-- Basement geologic map of the eastern United States. Modified from Bayley and Muehlberger (1968)

Although preliminary results from the DOE Atlantic Coastal Plain drilling program suggest that temperature gradients no greater than 37.5°C/km (2.1°F/100 ft) can be expected in deep wells above most radioactive plutons in the region, the prospects are good for finding plutons with heat flows of about 2 HFU overlain by sediments with average conductivity of 4 CU. Hence, temperature gradients of 50°C/km (2.75°F/100 ft) are likely to be found with further exploration. Sediment thicknesses necessary to attain usable temperatures can be estimated from Fig. 8.

Temperature gradients away from the coast are not expected to be quite as high except in areas of very thick shale sequences, such as the Devonian shales in the Appalachian region (Fig. 13). Therefore, evaluation of conduction-dominated geothermal resources should begin where sediments are thicker than about 1.5 kilometers (5,000 feet) and temperature gradients are elevated. Figure 14 points up areas where sediments are thicker than this and where temperature gradients are greater than about 29°C/km (1.6°F/100 ft). The geology of the basement is not well enough known to predict which areas might also be underlain by radioactive plutons.

Movement of water through steeply dipping sediments or fracture zones is the other mode of heat transport in the eastern states. As discussed earlier, the warm springs of the east seem to originate from deep circulation in areas of normal continental heat flow. Since all warm springs in the east are found in similar geologic settings--steeply inclined sedimentary beds with quartzites and possibly also transverse faults present--similar environments elsewhere should be reviewed. The foremost examples are in the Folded Appalachians and in the Ouachita structural trend, where the beds are found exposed as well as extending beneath younger rocks. Several areas of the Blue Ridge and Piedmont, particularly in the southern sections, can be included here.

An extension of the Valley and Ridge style of folding underlies the Champlain River valley; this may provide another target for further investigation. Water temperatures in this geologic setting are unlikely to exceed about 60°C (140°F). Areas where these geologic conditions are possible are shown in Fig. 14. The absence of warm springs in non-mountainous areas of tightly folded rocks may imply that topographically controlled hydraulic gradients are also necessary for development of warm springs.

The major zones of faulting in the eastern United States are shown in Fig. 3, along with other structural features. Except in the Balcones and Gulf Coast sections of Texas, Arkansas, and possibly other states of the Gulf Coastal Plain, abnormally warm waters are not known to exist in fault zones of the east, although warm springs are almost invariably associated with faults in the Basin and Range province.

The Triassic basins have associated fault zones along which major vertical movements must have occurred, yet no thermal anomalies are known to be associated with these basins. Rodgers (1970) mentions that silicification is common in the faults bounding Triassic basins; perhaps faults of this age have been thoroughly sealed through alteration and cementation. Deep, waters with high temperatures and greater chemical activity may have sealed the deeper portions of fault zones over tens of millions of years, even if the upper portions are relatively open to passage of water.

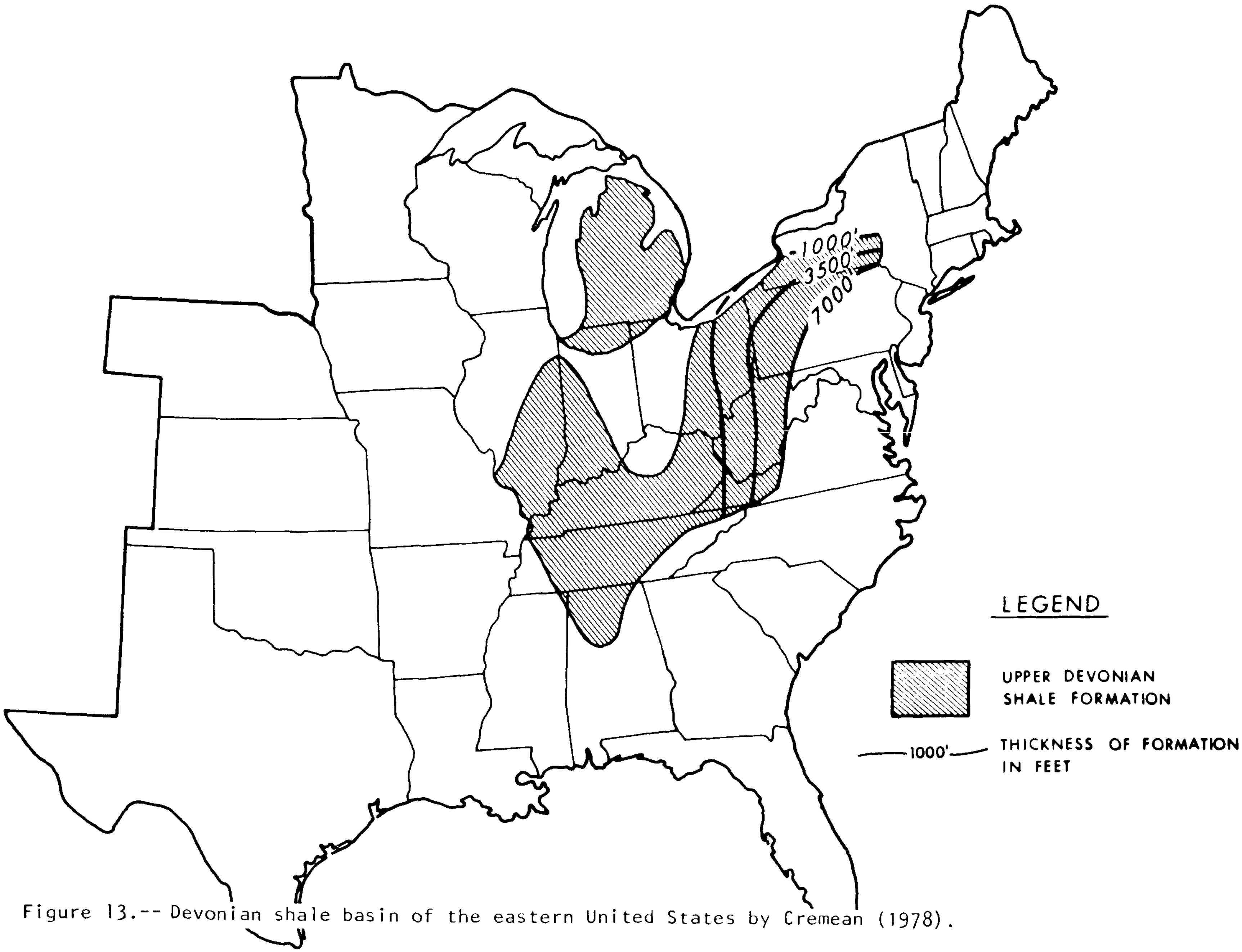

Figure 13.-- Devonian shale basin of the eastern United States by Cremean (1978).

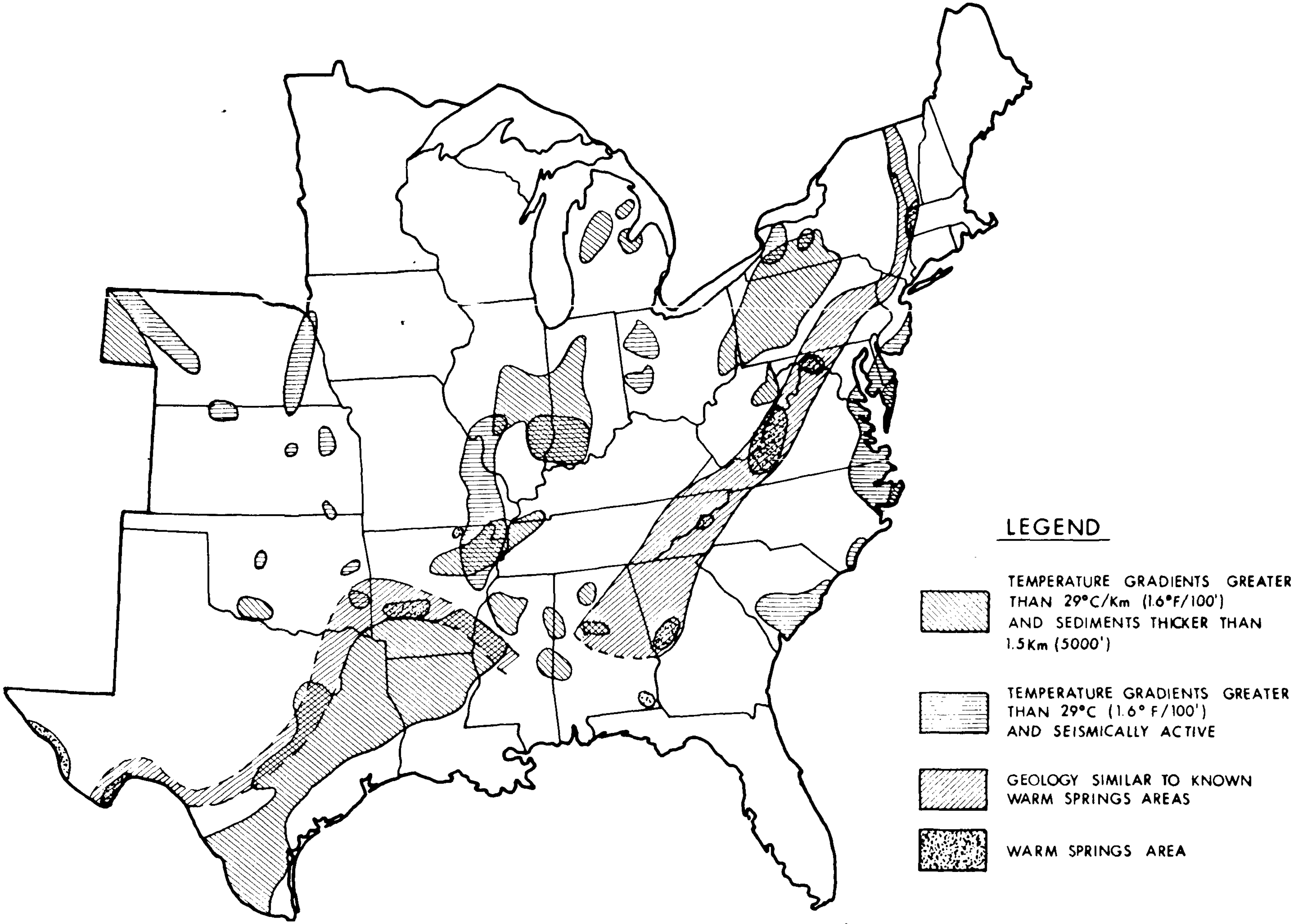

Figure 14.-- Areas of geothermal potential in the eastern United States.

The survey by Swanberg and Morgan (1978) of silica geotemperatures in ground water shows relative highs in several areas of recent seismic activity, such as New Madrid, Mo., northern New York, and South Carolina. This suggests that efforts to seek out deep fluid circulation systems should be concentrated in areas of recent seismic activity. More detailed geochemical modeling in such areas may be the most cost-effective means of geothermal reconnaissance in the east. Maps like those of Stover (1977), Hadley and Devine (1974), and Woollard (1958, 1969), portraying historic seismic activity and tectonic features, may be useful for this purpose.

Study of the temperature gradient map (Fig. 7), the major structural features map (Fig. 3), and seismic data, particularly the seismic zones suggested by Woollard (1958, 1969), points up trends that may be geothermally significant. Among these are the Chadron-Cambridge Arch-Central Kansas Uplift trend; the Nemaha Uplift-Mid-Continent Gravity High trend from Oklahoma to Nebraska and perhaps to Michigan; and the less well defined trend from New Madrid, Mo., northeastward through southern Illinois and Indiana, west central Ohio, western Pennsylvania, and New York into the St. Lawrence River Valley. Areas where temperature gradients greater than 29°C/km (1.6°F/100 feet), structural features, and seismic activity coincide are shown in Fig. 14.

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