GLO1276

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September 5, 1986

go light on what Geoth is -- these people know
- what are applic and prospects to State cut)
history in Utah, etc

Dr. Michael Wright
University of Utah Research Institute
Earth Science Laboratory
420 Chipeta Way, Suite 120
Salt Lake City, UT 84108

Dear Mike,

I was recently informed of your willingness to be the speaker for the geothermal committee of the Interstate Oil Compact Commission, (IOCC), at its Annual Meeting in Salt Lake City on December 7th-10th, 1986. I thought I should make it "official" by sending this letter of invitation to you and tell you a little about what to expect.

The IOCC was originally created by six states in 1935 to play a leading role in conservation of oil and gas through prevention of physical waste. Today there are 36 member states who support the IOCC as a source of objective and accurate information on matters relating to energy, be it enhanced recovery, environmental, legal and engineering concerns or, in our particular case, geothermal energy potential.

Your audience will be composed of those government and oil company representatives at the meeting who are interested in geothermal energy. Generally there are 25 to 30 people in attendance. The usual topic is a review of the geothermal activities and potential of the host state, but if you have a more timely topic in mind, please let me know. As a matter of fact, I just received a letter from IOCC last week asking for ~~an abstract, biography and audio-visual requirements~~ text no later than November 25, in order that copies be available at the meeting in December.

or at time we [illegible]

As you might expect, we always try to make the next meeting the best yet, and part of that is to have all information as early as possible to set up the program. Your cooperation will be appreciated.

Oct. 8. Abstract, biog + audio visual Requirements

length of talk 30 - 45 mins

most like 35 mm slides

TELEPHONE: 301-338-7066

I thank you ahead of time for agreeing to be our speaker. You may contact me at the above address or at (301) 554-5525. By copy of this letter, I am notifying IOCC, whose address is P.O. Box 53127, Oklahoma City, OK, 73152. Mr. W. Timothy Dowd is their Executive Director, and can be reached at (405) 525-3556. I suggest you mail the speakers' requirements directly to Tim with a copy to me. I look forward to hearing from you.

Yours very truly,

Kenneth A. Schwarz

Kenneth A. Schwarz
Chairman
Geothermal Committee, IOCC

301-554-5525

cc: W. Timothy Dowd-IOCC
Will Gosnold- Univ. of N. Dak.

Agenda: w/ Pat, Dowd's secretary - reg table

Sched: Geoth Resources Committee
Tue 9th 11:30 AM 30 min.
Marriott - Millcreek Rm.

- Stnd Pod
- 35 mm w/ remote
- screen
- pointer

copies = 50-75 make ± 100?

Show up - Will Gosnold →

w/ Diane

- good meeting
- lots regulatory ~~issues~~ people
- they want to here other issues
  let them know about reg probs, though
- develop in whole, or
- issues in development, etc.
- people will have expertise, but not
  so much expl / develop

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November 24, 1986

Dr. Phillip M. Wright,
University of Utah Research Institute
Earth Science Laboratory
420 Chipeta Way, Suite 120
Salt Lake City, UT 84108

Dear Mike,

This is to let you know that the state funding for 1986 is such that it will prevent my attendance at the IOCC meeting next month. But take heart! Dr. Will Gosnold of the University of North Dakota, the vice chairman of the Geothermal Resources Committee, will be there at the meeting to assist you in whatever way you need. Also, Mr. Bob Cooper and the rest of the IOCC staff are always there when you need them. I suggest you contact them for any last minute changes, if there are any. I enclose a copy of the flyer for the Annual Meeting for your perusal.

Thank you again for accepting this speaking engagement and I'm sorry I won't be able to hear your talk.

Yours very truly,

Ken Schwarz

Kenneth A. Schwarz
Program Chief
Environmental Geology & Mineral
Resources Program
Chairman, IOCC
Geothermal Resources Committee

KAS/rda

Enclosure

cc: Will Gosnold, UND
Bob Cooper, IOCC

PRESENTATION TO THE INTERSTATE OIL COMPACT COMMISSION

by

Phillip Michael Wright
Vice President
University of Utah Research Institute

ABSTRACT

Geothermal energy has the potential to contribute significantly to the energy requirements of the United States and the world. The U.S. Geological Survey has estimated that the portion of the hydrothermal resource base which could be developed for generation of electricity in the U.S. is about 127,000 MWe for 30 years and that the portion which could be developed for direct use is about 151,000 MWt for 30 years. These rough estimates exclude development within the national parks but include an undiscovered portion that is about five times the size of the discovered portion. The estimates do not include energy that may ultimately be derived from hot dry rock, magma or geopressured resources.

Important research and technology development are needed to make the majority of our geothermal resources commercially viable. Yet, federal research programs dealing with energy development have been severly cut in recent years. I believe that there is an urgent need for the formulation of a national energy policy. Our high-technology society in the U.S. is critically dependant upon an inexpensive, reliable supply of energy. The Carter administration attempted to formulate such a policy, but the Reagan administration has ignored this important problem. Priorities for energy research are currently being determined by politics rather through the scientific peer review process applied to a rational energy development plan.

In Utah, hydrothermal resources are being used both in the generation of electricity and in direct application. One 20 MWe plant is being operated at Roosevelt Hot Springs by Utah Power and Light, which supplies the power to their grid. The resource is owned and is being developed by Chevron Geothermal Company. In addition, one 3.2 MWe plant is being operated at Cove Fort/Sulphurdale by Mother Earth Industries, who also controls and develops the resource. Mother Earth sells the power to the City of Provo. At both of these areas, the indicated potential for ultimate resource development is in the range of several hundred megawatts. These two operations illustrate options for geothermal development--large developer coupled with large utility and small developer operating his own plant and selling the power to specific buyers.

Direct uses of hydrothermal energy in Utah include greenhouse heating in the Salt Lake valley, space conditioning at

the state prison facility and balneology. One project at Monroe was stopped after the drilling phase for economic reasons, but with higher energy costs the project will be viable. In several areas of the state, such as in the northern and western parts of Salt Lake City, thermally anomalous ground water underlies large areas. Although these groundwaters are not hot enough to be used for space heating by themselves, there is the potential for using them with heat pumps.

I conclude that the uses of hydrothermal energy will grow during the next several decades, that the more futuristic types of geothermal resources, such as hot dry rock and magma energy, will ultimately be commercially developed and that geothermal energy may contribute as much as 0.5 to 1.0 per cent to the total energy consumption in the U.S. by the year 2000. I note that a number of underdeveloped countries have hydrothermal potential that is only now beginning to be tapped. These countries include Kenya, Ethiopia, Mexico and other countries on the west coast of Central and South America, the Philippines, Indonesia, and China. Geothermal exploitation in these lands would significantly change the amount of energy available to them and, thus, enhance their ability to lift themselves from poverty while, at the same time, displace the burning of petroleum and preserve this resource for other uses. The ultimate contribution of geothermal energy in the U.S. and in the world remains to be determined. However, as energy costs continue their predicted long-term increase, there will no doubt be increased use of geothermal energy.

Use Calculations

1 MW year = $10^6 \frac{\text{Joul}}{\text{Sec}} \times 365 \times 24 \times 60 \times 60$

10^{18} J = 1Q

1 MWy = $365 \times 24 \times 36 \times 10^8$

$$\begin{array}{r} 36 \\ 24 \\ \hline 144 \\ 72 \\ \hline 864 \\ 365 \\ \hline \end{array}$$

$$\begin{array}{r} 900 \\ 300 \\ \hline 270000 \end{array}$$

$27 \times 10^4 \times 10^8 = 27 \times 10^{12}$

3×10^{13}

27×10^{12} per MW used

3×10^{13} per MW

electrical 4800 direct heat 4000

$9000 \times 3 \times 10^{13} = 27 \times 10^{16}$

$= 0.27 \times 10^{18} = 0.27$ Q

$\frac{0.27}{80} = \frac{0.3}{100}$

0.27 quads

GEOTHERMAL DEVELOPMENT IN UTAH

AND

STATUS OF THE U.S. GEOTHERMAL INDUSTRY

Presentation to the

INTERSTATE OIL COMPACT COMMISSION

9 December 1986

by

Phillip Michael Wright

Earth Science Laboratory

University of Utah Research Institute
391 Chipeta Way, Suite C
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28 NOVEMBER 1986

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ABSTRACT

Geothermal resources are being actively developed on a worldwide basis. Current geothermal electrical generating capacity is about 4,800 megawatts, with the United States accounting for 2,115 megawatts of the total. Current direct uses of geothermal energy amount to about 10,000 megawatts, with the U.S. contributing about 400 megawatts. Geothermal resources worldwide produce enough energy to displace the use of about 80 million bbl of petroleum annually. Utah has two areas, Roosevelt Hot Springs and Cove Fort/Surphurdale, generating a total of 25.7 MWe of electricity, and this capacity represents the first electrical generation from geothermal resources in the U.S. outside of the State of California. In addition, there are about a dozen individual direct uses of lower-temperature geothermal resources in Utah, which consume about 9 X 10^{10} BTU per year. Most of Utah's known geothermal resources and its potential for future development lie in the Basin and Range geologic province, in the western half of the State.

Geothermal development in Utah is presently rather depressed due to the comparatively low energy costs of today and the excess electrical generating capacity that exists in the West. Growth in geothermal generating capacity in the U.S. is forecast at a rate between 6 and 9 percent per year from the present to the year 2005, with essentially all of this development being in the hydrothermal convective type of resources. Contrary to its

stated policy, the Federal government is not adequately supporting the research and technology development needed to bring the bulk of the known hydrothermal resource base on line. We all have a duty to help educate the public and our elected federal officials and others in the Administration to the facts of our energy-based economy in this country and to the importance in using this grace period in energy costs to prepare ourselves as a nation for times of sharply higher energy costs.

INTRODUCTION

Development of geothermal resources is being aggressively pursued on a worldwide basis. Approximately 4,800 MW of electricity (MWe) are currently being generated from geothermal energy, and about 10,000 thermal megawatts (MWt) are being used for direct heat applications. While this may seem small compared to the estimated 8.4 million megawatts of total human use of fossil energy (Williams and Von Herzen, 1974), it nevertheless represents a savings in the consumption of about 80 million barrels of oil per year worldwide.

It is very difficult to estimate the ultimate potential contribution of geothermal energy to mankind's needs for at least three reasons: 1) long-range future energy costs, although generally predicted to be higher than today's levels, are uncertain, and a large number of lower-grade geothermal resources would become economic at higher energy prices; 2) only preliminary estimates of the worldwide resource base have been made; and, 3) technology for making economic use of energy in geopressured, magma, hot dry rock and normal thermal-gradient resources, whose potential contributions are very large, is not yet available.

The State of Utah has an abundance of thermal occurrences and is a promising area for geothermal exploration and development. Goode(1978) reports records of about 1,500 thermal springs and wells, many of which yield water that is appreciably above mean ambient air temperature. Two areas, Roosevelt Hot Springs and Cove Fort/Sulphurdale, produce electrical energy from hydrothermal systems, and direct uses are being made of natural thermal water in more than a dozen separate areas. The Utah Geological and Mineral Survey (UGMS), the Utah Energy Office, the State Division of Facilities and Construction Management, and the State Division of Water Rights are all active in promoting geothermal development. In addition, the University of Utah Research Institute (UURI) is one of the primary geothermal research facilities supported by the U.S. Department of Energy, and the Earth Science Laboratory at UURI has provided geologic expertise and analytical services in the evaluation and development of several of Utah's resources.

The purpose of this presentation is to present the current status of development in Utah and to review the outlook for geothermal development in the United States.

NATURE OF GEOTHERMAL RESOURCES

Geothermal energy is heat that originates within the earth. The earth is an active thermal engine. Many of the large-scale geological processes that have helped to form the earth's surface features are powered by redistribution of internal heat as it flows from inner regions of higher temperature to outer regions of lower temperature. The mean value of the surface heat flow for the earth is 42 million megawatts (Williams and Von Herzen,1974), which represents heat that comes to the surface and is lost by radiation into space. Generation of new oceanic crust at spreading centers such as the mid-Atlantic ridge, motion of the great lithospheric plates, uplifting of mountain ranges, release of stored strain energy by earthquakes and eruption of volcanos all owe their origin to the outward transport of internal heat. Plastic, partially molten rock at estimated temperatures between 600 deg C and 1200 deg C is postulated to exist everywhere beneath the earth's surface at depths of 100 km or less. By comparison, using present technology applied under favorable circumstances, holes can be drilled to depths of about 10 km, where temperatures range upward from about 150 deg C in average areas to perhaps 600 deg C in exceptional areas.

Models of Geothermal Resources

Exploitable geothermal resources owe their origin to the transport of heat near to the surface through one or more of a number of geological and hydrological processes. Geothermal resources commonly have three components: 1) a heat source, 2) permeability in the rock, and 3) water to transfer the heat. The heat source for most of the high-temperature resources (>150 deg C) appears to be a molten or recently solidified intrusion, whereas many of the lower-temperature resources seem to result from deep circulation of meteoric water with heating due to the normal increase in temperature with depth. Most geothermal systems appear to have a preponderance of fracture permeability, but intergranular permeability is important also in some systems. Water is, of course, the ideal heat transfer fluid because it has a high heat capacity and high heat of vaporization, and can therefore transport more heat per unit volume than any other common fluid.

Geothermal resources are commonly classified as shown in Table 1. Only the hydrothermal resources have been commercially developed. The more futuristic types such as geopressured, hot dry rock and magma resources will require new technology and higher energy prices in order to be economically viable. Convective hydrothermal resources are geothermal resources in which the earth's heat is carried upward by the circulation of naturally occurring hot water or steam.

Models for high-temperature convective hydrothermal systems have been discussed by White et al. (1971), Mahon et al. (1980), and Henley and Ellis (1983), among others. Underlying higher-temperature hydrothermal resources is presumably a body of still-molten or recently solidified rock that is hot (300 deg C to 1200 deg C). Interaction of this hot rock with groundwater causes heating of the groundwater, which then rises by buoyancy. The bulk of the fluid in hydrothermal systems is derived from meteoric water, with the exception of those few systems where the fluids are derived from seawater or connate brines (Craig, 1963). A circulating system is set up with the heated water ascending in the center of the system along zones of permeability, spreading outward in the shallow subsurface or discharging to the surface, and with cool water descending along the margins and recharging the system. Rapid convection produces uniform temperatures over large volumes of the reservoir. The temperatures and pressures generally lie near the curve of boiling point versus depth for saline water, and sporadic boiling may occur. Whether or not steam actually exists in a hydrothermal resource depends, among other less important variables, on temperature and pressure conditions at depth. Escape of hot fluids at the surface is often minimized by a near-surface sealed zone or cap-rock formed by precipitation from the geothermal fluids of minerals in fractures and pore spaces.

Virtually all of industry's geothermal exploration effort in the United States is presently directed at locating vapor- or water-dominated hydrothermal convection systems having temperatures above 200 deg C. It is these resources that have the greatest likelihood of being economically viable for generation of electricity. Temperatures down to 140 deg C may become more interesting for generation in the near future with further development of binary conversion technology.

Occurrence of Geothermal Resources in the U.S.

Figure 1 displays the distribution of various geothermal resource types in the United States. Information for this figure was taken mainly from Brooke et al. (1978) and Reed (1982). Not shown are locations of hot dry rock or magma resources because very little is known. It should be emphasized that the present state of knowledge of geothermal resources of all types is poor. We can expect new additions to the growing list of known resources as exploration and assessment continue.

Figure 1 shows that most of the known hydrothermal resources and all of the presently known sites that are capable of electric power generation are in the western half of the U.S. The preponderance of thermal springs and other surface manifestations of underlying resources is also in the west. Large areas underlain by warm waters in sedimentary rocks exist in Montana, North and South Dakota and Wyoming (the Madison group of aquifers), but the extent and potential of these resources is poorly understood. Another important large area, much of which is underlain by low-temperature resources, is the north northeast-trending Balcones Zone is Texas. The geopressured resource areas of the Gulf Coast and surrounding states are also shown. Resource areas indicated in the eastern states are highly speculative at this date because little drilling has taken place to confirm their existence.

Regarding the temperature distribution of geothermal resources, low- and intermediate-temperature resources are much more plentiful than are high-temperature resources. There are many thermal springs and wells that have water at temperatures only slightly above the mean annual air temperature, the temperature of most non-geothermal shallow ground water.

GEOTHERMAL RESOURCES IN UTAH

The State of Utah has a number of known geothermal occurrences, some of which are under development for power generation and/or direct use. A present surplus of generating capacity within the region and low energy costs compared to those of the recent past are suppressing development in Utah to some degree.

Regional Geologic Setting

Utah is comprised of parts of three physiographic provinces which were defined by Fenneman(1931) as the Middle Rocky Mountains, the Colorado Plateaus and the Basin and Range. The Middle Rocky Mountains includes the Wasatch Range and the Uinta Mountains in the northeastern portion of the State, both of which are composed predominantly of pre-Cenozoic sedimentary and silicic plutonic rocks. The Colorado Plateaus province is an area of broad uplift in the south-eastern and south-central portions of Utah having essentially horizontal strata of Mesozoic and older sedimentary rocks. In addition, Tertiary and Quaternary volcanic rocks occur in south-central Utah and there are a few scattered Tertiary intrusive bodies in the southeastern part of the state.

The Basin and Range Province, which comprises essentially the western half of Utah, is separated from the Middle Rocky Mountains by the Wasatch Fault zone in the north and from the Colorado Plateaus by a transition zone in the south. The Basin and Range contains rocks of widely ranging composition and age.

Older rocks consist of a variety of Mesozoic and Paleozoic sedimentary rocks and their metamorphosed equivalents. Overlying the sedimentary and metamorphic rocks are Cenozoic volcanic rocks and valley fill. Valley fill, mostly alluvium, may be as thick as 10,000 ft in some basins. The valleys in the Basin and Range are considered to be grabens and the ranges are horsts. A sizeable east-west extension is believed to have taken place in the last 17 million years to form these north-south trending structures. In western Utah, igneous rocks and hydrothermal mineral zones occur in well-defined east-west belts, with successively younger ages to the south (Stewart et al., 1977). However, the youngest igneous rocks, less than 6 million years old with some less than 10,000 years old, appear to be controlled by the north-south Basin and Range structure. The very young volcanic rocks, potentially related to geothermal resources, are found in a belt from west-central Utah to the southwestern corner, where they continue into Arizona. These rocks are largely basaltic, but scattered rhyolitic cones and domes are known. Silicic intrusive rocks were emplaced at the same time as the eruption of the silicic volcanic rocks (Whelan, 1970). The largest exposure of such an intrusive body in Utah is in the Mineral Mountains, adjacent to which the Roosevelt Hot Springs hydrothermal system is located.

Regional Heat Flow

The worldwide average conductive heat flow to the earth's surface is about 61 milliwatts per square meter for the continents (Williams and Von Herzen, 1974). Considerable variation in heat flow exists in Utah. The area of highest heat flow in Utah is the Basin and Range province, which has typical values in the range 80 to 120 mw/m^2. The Colorado Plateaus and the Middle Rocks Mountains provinces in Utah have heat-flow values near the average for the earth's surface (Sass and others, 1974; Sass and Munroe, 1974).

Geothermal Occurrences in Utah

The earliest known reference to geothermal systems in Utah is by Gilbert(1890), who described Fumarole Butte and the nearby Crater Hot Springs. Stearns and others (1937) and Waring(1965) summarized the knowledge to the time for about 60 thermal occurrences. A comprehensive data report on the thermal springs of Utah was made by Mundorf(1970), and estimates of subsurface temperatures were made by Swanberg(1974) using chemical geothermometers. Goode(1978) and Rush(1983) both produced summaries of geothermal occurrences in Utah. Goode's data compilation is particularly complete, whereas Rush's geologic descriptions are especially useful. In addition to these references, various authors from the Utah Geological and Mineral Survey, the Utah Energy Office and the University of Utah Research Institute have published details on geothermal systems and geothermal applications in Utah. References to all of this literature were compiled by Budding and Bugden(1986).

With few exceptions, all of the known areas of geothermal occurrences are in the western half of Utah, in the Basin and

Range province or in the transition zone between the Basin and Range and the Colorado Plateaus. Of the 327 thermal wells and springs with temperatures greater than 20 deg C identified on the Geothermal Resources of Utah map (Utah Geological and Mineral Survey, 1980), only 13 are located in the eastern part of the state. The largest known hot water occurrence in eastern Utah comes from the oil wells of the Ashley Valley oil field, which produce about 200 bbl of nearly fresh water at temperatures between 43 deg C and 55 deg C for every bbl of oil (Goode, 1985). In 1981, this area yielded 3,360 acre-feet (26.1 million bbl) of water.

Most thermal springs and wells in central and western Utah are in the valleys near their margins with the mountain blocks. Many spring locations are controlled by the most recently active Basin and Range faults. Some springs, however, are in the valley bottoms, and others are on upland slopes. Only a few thermal springs are in a mountainous setting.

Swanberg(1974), Rush(1983) and Cole(1983) considered the application of chemical geothermometers to Utah springs in an attempt to help define areas of highest subsurface temperature. Table 2 shows a summary of results from these and other sources. I have included on this table the known springs with flowing temperatures above 40 deg C along with drill holes that have clearly anomalous temperatures for their depths. Rush(1983) believes that six areas have reservoir temperatures above 150 deg C, and therefore have potential for generation of electrical energy. These areas are Roosevelt Hot Springs, Cove Fort/Sulphurdale (both of which are now producing electrical power), Thermo Hot Springs, Joseph Hot Springs, the Newcastle area and the Monroe-Red Hill area. In addition, an area in the Drum Mountains has been explored for electrical potential. Six other hot spring areas may have reservoir temperatures in the range 90 deg C to 150 deg C. Figure 2 shows the locations of the geothermal occurrences indicated in Table 2. Also shown on this figure by shading are the areas that are considered to have the largest potential for occurrence of undiscovered low- and moderate-temperature resources.

At the present time, electrical power is being generated at Roosevelt Hot Springs and Cove Fort/Suphurdale. The total rated output from these two areas is 23.2 MWe. In addition, direct use is being made of geothermal waters for greenhouses in Newcastle (southwestern Utah), and at Bluffdale (in the Salt Lake valley), and for space heating at Bluffdale. Ten other areas, mostly resorts, use geothermal water for space heating and balneology. Total energy consumption for these direct uses is estimated by Lienau(1986) to be 9 X 10^{10} BTU/yr.

In order to convey a better understanding of the uses of geothermal energy in Utah, we will briefly discuss three of the most important of them. We will first discuss the generation of electrical power in the Roosevelt and Cove Fort areas and then consider the direct uses in the Jordan Valley, where Salt Lake City is located.

Roosevelt Hot Springs

The hydrothermal systems at Roosevelt and Cove Fort both lie along approximately north-south Basin and Range faults, on the western flanks of two adjacent mountain ranges (Figure 3). In addition, their locations also appear to be controlled by the Wah Wah-Tushar mineral belt, a zone of intrusive activity, mineral deposits and geophysical anomalies that trends roughly east-west. A substantial portion of the area between Roosevelt and Cove Fort is rumored to be thermally anomalous, although much of the data needed to substantiate this rumor is privately held in company files. The large thermal anomaly in the area can probably be compared through analogy to the concept of a mining district, which generally covers a substantial area and in which there are one or (usually) more individual mineral deposits. The Roosevelt-Cove Fort geothermal district comprises one of the larger thermal anomalies in the United States, and may cover more than 500 sq mi.

The Roosevelt Hot Springs hydrothermal system has been undergoing intensive exploration since 1974, when Phillips Petroleum Company successfully bid for acreage in the KGRA. After considerable exploration by Phillips and other land holders, the area was unitized with Phillips as the operator and Thermal Power Company, AMAX Exploration, Inc. (now Steam Reserve Corp.), O'Brien Resources Company and VTN Consolidated, Inc. as participants. In 1985, Phillips sold its interest in Roosevelt along with most of its other geothermal holdings to Chevron Geothermal Company of California, who operates the field today.

The bedrock geology of the area is dominated by metamorphic rocks of Precambrian age and felsic plutonic phases of the Tertiary Mineral Mountains intrusive complex (Nielson et al., 1978; Ross et al., 1982). Rhyolite flows, domes and pyroclastic rocks reflect igneous activity between 0.8 and 0.5 million years ago. The structural setting includes older, low-angle normal faulting and east-west faulting produced by deep-seated regional zones of weakness. North-trending faults are the youngest structures in the area, and they control present fumarolic activity. The geothermal reservoir is controlled by intersections of the principal fault zones.

Production has been encountered at depths between about 1,200 ft and 8,000 ft, and downhole temperatures as high as 254 deg C have been reported. The hydrothermal fluids are relatively dilute sodium-chloride brines which contain approximately 7,000 ppm total dissolved solids. Most production data from flow tests and power generation are proprietary. However, data from Utah State 14-2 and Utah State 72-16 are in the public domain as a result of the U.S. Department of Energy's Industry Coupled Program, a data and drilling cost-share program with industry that is no longer being funded by DOE. After considerable testing by Thermal Power Company, 72-16 was rated at 12.5 MWt and 14-2 was rated at 4.5 MWt. Phillips has more recently drilled two wells specifically to feed the 20 MWe Blundell plant, and these wells have been reported to have a combined flow capacity of greater than 2.25 million pounds per hour, making them among the most prolific hot water producers yet completed in North America.

The field is being developed jointly by the operator, Chevron, and Utah Power and Light Company. The first power to be generated was the result of an experimental run of a 1.6 MWe Delaval biphase rotary separator turbine which went on line in late 1981. This unit ran for more than one year with no significant problems, producing 1250 MW-hr of power for the UP&L grid during 1982. In 1984, a single-flash plant rated at 20 MWe, the Blundell Unit I, came on line. This plant represents the first significant commercial generation of electricity from geothermal resources in the U.S. outside of California. Because of the high temperature of the resource (260 deg C), the hydrothermal fluids contain a significant amount of silica (510 ppm), and silica scaling has been a concern. In the early months of its operation, the plant had to be taken off line approximately every six weeks to remove scale from the high-pressure seals and the turbine blades. Addition of cleaning pots to the lines in the gathering system has largely solved the scaling problem now. The plant was taken off line most recently in September, 1986 after one year of continuous operation, and the scale buildup was found to be minimal (David Godfrey, UP&L, personal communication). Godfrey also reports that the plant has been running at greater than its rated capacity since the beginning of 1986 with no problems. It currently produces 25.2 MWe gross power and 23 MWe net power.

Although Utah Power and Light is justifiably happy and proud of their geothermal development, they have no current plans for further geothermal development until after 1990. The excess generating capacity that most of the utilities in the U.S. presently have will delay development of new capacity. UP&L initially had plans to install and operate a 14 MWe wellhead modular biphase unit, and had gone through the design phase based on their experience with the 1.6 MW biphase experiment. These plans are shelved for the moment.

Cove Fort/Sulphurdale. The Cove Fort/Sulphurdale thermal system in located near the junction of the Pavant Range and the Tushar Mountains on the eastern margin of the Basin and Range province. These highlands, composed largely of Paleozoic to Mesozoic sedimentary rocks and Tertiary volcanic rocks form part of the High Plateaus subprovince that marks the transition between the Colorado Plateaus and the Basin and Range provinces. The Tertiary volcanic rocks were erupted between about 30 and 19 m.y. ago from widely scattered centers in two distinct volcanic terranes - the Marysvale volcanic field to the south and the Basin and Range. Volcanic activity was renewed between 1 and 0.3 m.y. ago (Best et al., 1980), and Steven et al. (1979) have suggested that the heat source for the present geothermal system may be related to this basaltic volcanism.

Geologic and geophysical data indicate that permeability within the geothermal system is controlled by faults and fractures (Ross and Moore, 1985). Basin and Range tectonism has produced both high- and low-angle faults that trend northerly and easterly. Low-angle faults form the lower bound of gravitational glide blocks in much of the area. The gravitational glide blocks form a nearly impermeable cover over the geothermal system that has profoundly influenced the distribution of surficial manifestations of the system and the temperature gradients in shallow holes.

From 1975 to 1979, Union Oil Company of California (now UNOCAL) explored the area. Much of this exploration was jointly sponsored by the DOE's Industry Coupled Program and the data are therefore public domain. Union drilled four deep exploration wells, one of which, CFSU 42-7, recorded temperatures of 178 deg C. The high cost and great difficulty of drilling in this area, high corrosion rates, low indicated reservoir pressure, and the apparent limited extent of the high-temperature reservoir led Union to a premature conclusion in 1980 that the field was not economic for large-scale electric power production.

Since 1980, Mother Earth Industries (MEI) has been exploring the area. In October, 1983, MEI drilled its first well and encountered a pressurized steam reservoir at about 1200 ft. This well blew out on October 24 and shot a spectacular steam jet into the air during the ensuing weeks before it was brought under control and then plugged and abandoned on November 18. Since then, two other wells have been drilled which have a combined rated capacity of 8.4 MW. The production temperature is believed to be about 200 deg C.

In September, 1985, Mother Earth officially dedicated a power plant which consists of four ORMAT modular binary units with a capacity of 0.8 MW each or 3.2 MW total net power. They are housed in a single building. The City of Provo has a power purchase contract with MEI which includes the right to take the first 200 MWe developed by MEI at Cove Fort. Power is being wheeled to Prove via the Utah Power and Light grid. At present, the plant has been in operation since its dedication with a net power output of 2.7 MWe. MEI has plans for further drilling and additional power production over the next several years.

Jordan Valley

Two areas of hot springs have been known for many years in the Jordan Valley, where Salt Lake City and its suburbs are located - the Beck-Wasatch area, known as the Warm Springs area, at the north end of the valley, and the Crystal (Bluffdale) area at the south end of the valley. The Utah Geological and Mineral Survey was funded by the U.S. Department of Energy under its State-Coupled Resource Assessment program to study the valley and define other areas that may contain thermal water. The State Coupled program is a DOE program that has been active for the last nine years in which DOE funds an appropriate agency in a state to evaluate low- and moderate-temperature resources (less than 150 deg C). The UGMS and others believed that other geothermal resources in the valley could be important in view of the urban development and the high likelihood of an end user being collocated with a resource.

Klauk (1984) published the results of the study, and they are summarized in Figure 4. Groundwater temperatures were measured at 214 locations in the valley and available data for 24 additional locations were compiled. An attempt was made to measure temperatures in wells that intercepted the principal aquifer, which is a deep, confined aquifer with a thickness up to about 1,000 ft that provides recharge to a shallow artesian aquifer. Where no wells intercepting the principal aquifer were available, shallow wells were used. The criterion used to distinguish thermal water followed that of Nathenson et al.(1982). Thermally anomalous water was defined as groundwater having a temperature of 10 C deg or more above the mean annual air temperature, increasing with depth at a rate of 25 C deg per km to a maximum of 90 deg C. The mean annual air temperature in the Jordan valley was taken to be 10 deg C. Based on this criterion, six general areas and three isolated wells were defined. Two of the areas comprise the previously known hot spring areas at Beck-Wasatch and Crystal (Bluffdale). Maximum temperatures in the four newly defined areas range up to only 30 deg C. It, therefore, appears that there is no large amount of geothermal water underlying the populated areas around Salt Lake City at shallow depth that is high enough in temperature for district heating. Some of the thermal fluids, however, could probably be developed for use in local space heating or other applications in conjunction with groundwater heat pumps. Waters of higher temperature could probably be found by drilling deeper, but the minimum depths needed for most direct uses would probably exceed 4,000 or 5,000 ft, and the economics of this kind of development at the present time would be in question.

As Table 2 shows, the discharge temperatures of the hot springs at Bluffdale measure 58 deg C, and the chemical geothermometers give some hope of encountering water of higher temperature at depth. The area has been actively explored and developed since 1979, and there are now two separate installations using the geothermal water. The largest user is Utah Roses, which uses geothermal water from a pumped well to heat greenhouses. The other major user is the State of Utah, which has been heating a portion of the state prison complex with geothermal energy. Several smaller private operations use either the discharge water from Utah Roses or the natural spring discharge, which collects in a pond before flowing into the Jordan River.

The exploration program leading to the development at Bluffdale was carried out for the most part by the Utah Geological and Mineral Survey in conjunction with other State agencies. The program was based on sound exploration principles and was a success. Geophysical studies were used to project bedrock geology under the alluvial cover that surrounds the area and to site shallow temperature gradient holes of small diameter. The gradient drilling program generated the data necessary to locate deeper test wells of production diameter. At the present time, Utah Roses and the State of Utah each have one principal operating well. It has been found in the process of development that production from each of these wells interferes with production from the other, and there is little likelihood of further major development of the resource at depths less than 1,000 ft.

The state prison project was summarized by Lunis (1986) and is discussed in other literature cited by him. The project resulted from a response by the Utah State Energy Office to a DOE funded program opportunity notice (PON). DOE's so-called "PON Program" funded about 30 such projects throughout the U.S. at sites having high geothermal potential and a defined user. Two test wells were drilled, and one had adequate temperature and flow to be used for production. The existing hot water heating system in the Minimum Security facility on the prison grounds was modified to accommodate a closed-loop system in which the fresh circulating water was heated by the geothermal fluids in a plate-type heat exchanger. The majority of the energy supplied to the system was used to heat culinary water with the rest used for space heating. Initial problems with corrosion and scaling were solved by maintaining a CO_2 blanket in the surge tank to keep this gas in solution and to prevent aeration. The system still had problems, however, and was operational only part of the time. The Minimum Security facility has recently been demolished and a new, larger facility is being erected at the site. A geothermal heating system is being incorporated into the design of the new building, and it is expected that this new system will avoid the problems encountered and only partially solved with the retrofit system in the old building. The new system is designed to use 250 gpm of 175 deg F water in a plate-type heat exchanger which will produce a 35 F deg drop in the geothermal water as it extracts heat. There are plans for cascaded used of the water, including growing shrimp and flowers on the prison grounds (Lee Hathon, personal communication).

Utah Roses, Inc. is one of the premier rose growers in the country. In their greenhouses at Bluffdale, they maintain 66,000 rose plants and cut about 8,000 roses per day, more than 60 percent of which are long-stem roses (stems 24 inches or more). These roses are chilled immediately after cutting and are shipped the same day to destinations throughout the United States. Roses are shipped to florists in bundles of 25, and Utah Roses guarantees that each rose will be usable. If not, they will replace the entire bundle at no charge.

Geothermal water from one of two pumped wells is used to heat 160,000 sq ft of greenhouses at Bluffdale. On a typical autumn day, the flow rate is 450 gpm of water at about 190 deg F (88 deg C). The geothermal water is run through a plate-type heat exchanger, in which the heat is transferred to city water. The geothermal water is then discharged to an open ditch, while the heated city water is circulated in a closed system to the greenhouses. Downstream from Utah Roses, five other private concerns make use of the geothermal water for growing pigs, cattle and tropical fish before the water finally flows into the Jordan river as it meanders toward the Great Salt Lake. In the greenhouses, the geothermally heated city water is circulated in fin-type pipes for heating and is also used for irrigation after dilution with cold water to a suitable temperature (85 deg F).

Low heating costs have brought certain competitive advantages to Utah Roses besides the net savings on utility bills. The roof ventilators can be opened for at least part of the day on all but the coldest winter days, and the greenhouses can be ventilated with fresh air. This helps substantially in keeping down disease, which, in turn, helps maintain high product quality and provides savings in chemical treatment.

The heating system was not without its problems in the beginning. The geothermal fluids are corrosive and tend to produce scale if they are reduced in pressure to the point where the carbon dioxide comes out of solution or if they are exposed to the air, from which they can acquire oxygen. Experience has shown that maintenance costs are too high if the geothermal water is used directly in the heating system. The answer has been the incorporation of the very efficient plate-type heat exchangers to allow the geothermal fluids to be kept under pressure and isolated from the atmosphere until discharged. Utah Roses reports (Murray Harmon, personal communication) that they are very happy with the geothermal heating system and have gained confidence in it since they have successfully solved problems in how to use the resource. They have plans to build another greenhouse at the site and to study the feasibility of using the resource for their cooling needs.

CURRENT STATUS OF U.S. GEOTHERMAL INDUSTRY

The current status of the U.S. geothermal industry has recently been reviewed by Lacy (1986), who confined his remarks to the generation of electricity from hydrothermal resources. It is worthwhile to abstract from his paper to form a clearer understanding of today's situation.

In the early- to mid-1970's, many utilities in the western U.S. were heavily dependent on petroleum for the production of electrical energy. The only diversification from petroleum being seriously considered was rather large nuclear or coal plants. Technology for the generation of electricity from geothermal resources had been demonstrated at only one location, The Geysers in California, a dry-steam resource. There was considerable doubt that this limited experience could be extrapolated to the much more plentiful hot water resource base.

The oil crisis caused energy prices to soar and inflation rates to increase dramatically. Within a matter of months, the utility industry fell into complete disarray. The utilities' response was to explore alternatives to nuclear, coal and oil, a response supported by the regulatory commissions. Among the western states, geothermal energy was an option that many of the utilities found interesting, and this provided impetus for increased exploration and research. The geothermal industry, however, was not able to offer a truly viable generation option using hot water resources. Technology to explore for and assess these resources was not adequate and costs were therefore high.

In addition, the long-term performance of the reservoir could not be predicted with confidence and there were no adequate ways to deal with the produced brines from the environmental, scaling or corrosion perspectives. Most of these problems remain to be solved today, although progress has been made in some areas.

During the past five years, important energy conservation measures have been implemented and the economy has seen only sluggish growth. These factors have brought about reduced electrical demand at a time when energy costs are lower. The geothermal industry has, as a result, been going through a period of depression and upheaval. Utilities are dropping, scaling down or deferring plans for new generating capacity while geothermal generation costs have difficulty competing with other generation costs. The industry has been in a mode of retrenchment, and some of the marginal members have dropped out.

Lacy (1986) expects further shakeout of participants in the geothermal industry during the next five years. He believes that the result will be a leaner and stronger industry. We will see some geothermal development in this time span, especially at The Geysers. A few larger plants and several wellhead plants can be expected to come on line in other areas. Lacy(1986) also believes that the geothermal industry "has an unprecedented opportunity during the rest of this decade to position itself for a market place that will be wide open in the 1990s". In order to be able to compete effectively in the long term, he believes that the industry will have to: develop more hard cost data so that the utilities can adequately evaluate economics and risk; perform research and technology development to increase materially our ability to define the resource, predict reservoir performance and to decrease the drilling, operating and capital costs; solve some permitting and environmental issues; take steps to ensure adequate water for cooling, and; solve the problem of access to transmission lines. The challenge to the geothermal industry and to the federal and state agencies that support it are clear.

WORLDWIDE GEOTHERMAL USE AND FORECASTS

Because plate tectonic geologic processes control the regions of the earth that are active geologically, and are therefore the regions of highest geothermal potential, the locations of most of the world's geothermal occurrences are along such plate tectonic features as spreading centers, transform faults and volcanic arcs. Figure 5 depicts the locations of the world's known geothermal occurrences. The regions bordering the Pacific ocean, the Mediterranean area and the young oceanic volcanic islands comprise most of the favorable prospecting area.

Current Electrical Power Generation

DiPippo (1985) compiled data on the worldwide use of geothermal energy for generation of electric power. His results are summarized in Table 3. All of the producing geothermal systems are of the hydrothermal convection type. Electricity is being generated from geothermal energy in the United States, the Philippines, Mexico, Italy, Japan, New Zealand, El Salvador, Kenya, Iceland, Nicaragua, Indonesia, Turkey, China, the Soviet Union, and on the islands of Guadeloupe, Azores, and Milos, in decreasing order of production capacity. Although the U.S. is out in front at the present time, the Philippines and Indonesia have tremendous power potential which they are working hard to develop. In these and other third-world countries, geothermal exploitation frees petroleum for sale and enables them to obtain much needed foreign exchange. These two countries have rapidly become experts in installing geothermal systems by allowing U.S.

companies to participate in development on their soil. The Soviets have also begun to pay attention to their geothermal resources, believed by some to be the largest in the world, especially since the disaster at Chernobyl has produced disenchantment with their large system of nuclear plants. Africa and South and Central America have large, high-temperature resources, but development is very slow due to depressed economies and sometimes hostile governments with many problems. The traditional producers of geothermal energy, Italy, Iceland and New Zealand, are proceeding relatively slowly with new development also. This is mostly a function of planning for their energy needs. Mexico badly needs the power that their geothermal resources could yield, especially in the Mexican volcanic belt close to Mexico City, but they lack the capital for development and have suffered setbacks in their plant at Cerro Prieto in the Mexicali valley. Canada has some potential for geothermal development, but will probably not exercise those options to any great extent until their hydropower resources are more fully exploited.

Current Direct Uses

Direct uses have been made of geothermal energy for many years, mostly for balneology. Gudmundsson (1985) gives the most recent report on worldwide use. At the end of 1984, the installed thermal power of all direct use projects in the world was about 7072 megawatts thermal (MWt) if only useful thermal power above 35 deg C is considered. The data are summarized in

Table 4. Direct-use projects differ greatly from electric power plants when it comes to assigning a capacity value to the installation. Electric power plants have their capacity stamped on the generator. The installed capacity of direct use projects, however, depends on how much the geothermal fluids are cooled. For example, a district heating installation using 500 kg/s of 80 deg C water will have an installed capacity of 84 MWt or 105 MWt, depending on whether the discharge temperature is 40 deg C or 30 deg C. Also, the flow rates and inlet and outlet temperatures in most direct use applications are poorly documented. This means that considerable guesswork is involved in estimating the power and energy values associated with direct-use applications. By neglecting the direct uses for discharge temperatures below 35 deg C, Gudmundsson's (1985) data underestimate the total direct use by some amount that is difficult to establish. As an example of the magnitude of energy used in these very low-temperature applications, the fish farm at Buhl, Idaho, not included in Table 4, uses an estimated 35 MWt at temperatures below 35 deg C. I conclude that, on a worldwide basis the total energy used in direct heat applications is of the order of 10,000 MWt.

The use of geothermal waters for bathing in Japan dominates the statistics on direct uses worldwide. Gudmundsson (1985) found that it was not possible from the survey data returned to him by the responding countries to separate direct uses precisely into catagories. He states, however, that district heating and cooling represent the major portion of direct uses, followed by bathing, greenhouses and other growing and, lastly, industrial processes. Gudmundsson (1985) also estimates that direct uses replace the consumption of about 2.8 million metric tons or about 29 million bbl oil annually. He concludes that many countries have large, untapped resources suitable for direct use, that district heating and cooling will see the largest growth in future years, and that cities that are collocated with resources will have advantages over those that are not if energy supplies again become scarce or expensive.

Forecasts for Electrical Power Generation

Roberts and Kruger(1986) give results from the tenth annual survey of the utility industry made by the Electric Power Research Institute (EPRI) for the purpose of obtaining estimates of future geothermal capacity. They also show data on projected electric supply and demand compiled by the North American Electric Reliability Council (NERC) and by the Western System Coordinating Council (WSCC). NERC predicts that the net energy load for the whole U.S. will grow at an annual rate of 2.26 percent per year between now and 1994, and WSCC predicts a growth rate in load of 2.33 percent per year over the same interval for 13 western states. For comparison, Table 5 shows the projected electrical generating capacity by fuel type for the whole U.S. and Table 6 shows the same data for the 13 western states. For the U.S. as a whole, geothermal energy presently contributes 0.2 percent of our generating capacity, and by the year 1994, this contribution is expected to grow to 0.5 percent. In the west, geothermal energy provides 1.6 percent of our electrical capacity, and this amount is expected to grow to 2.4 percent by the year 1994. These tables also indicate that the contribution by oil and gas will decrease for the U.S. between now and 1994, and that the growth rate for geothermal energy will be larger than that of any other fuel.

Results from the tenth annual EPRI survey of utilities are shown by region in Table 7. The 1986 data are actual while the rest are utility estimates. The figures are given at three levels of confidence: (1) Announced (An) - either publicly or through PUC-type reports; (2) Probable (Pr) - based on successful demonstration of technology for cost-effective use of liquid-dominated resources; and (3) Possible (Ps) - based additionally on anticipated growth of electricity demand and favorable regulatory treatment. The Gulf states comprise the states with potential resources of geopressured thermal and natural gas deposits. The northwest states include the contribution from British Columbia and Alberta. It is noted in Roberts and Kruger (1986) that several of the newest plants are designed to operate with rotary separator turbines or binary cycles, which should accelerate the development of the more numerous moderate-temperature geothermal resources.

We see that, whereas the current geothermal electrical capacity is 2115 megawatts in the U.S., there is the probability of having 6800 megawatts and the possibility of having 10,000 megawatts by the year 2005. These amounts would correspond to annual growth rates of 6.3 percent and 8.5 percent, respectively, in reasonable agreement with the NERC (1985) and WSCC (1986) estimates for geothermal energy. All of these figures tend to confirm Lacy's (1986) conclusions, discussed previously, that geothermal energy has the opportunity to penetrate the market to a much more significant extent in the next decade than it has so far. It is worthwhile noting that none of these surveys anticipate significant development of hot dry rock or magma energy resources in the time frames of the forecasts.

CONCLUDING REMARKS

There are critical conditions that must be met if geothermal energy is to make the future contributions predicted. There is a need for research and technology development to reduce costs and risks of developing, installing and operating geothermal plants. The fledgling geothermal industry has been looking to the federal government to provide most of this research, and the federal government is turning an increasingly deaf ear. Whereas the National Energy Policy Plan published in the fall of 1983 calls for development of a mix of energy resources, with some emphasis on renewable types, the geothermal research budget has been steadily shrinking. The geothermal budget has been repeatedly cut by the Office of Management and Budget (OMB) and there are only a few members of Congress that appear to have enough interest in furthering geothermal development to restore moneys. Yet, geothermal energy is the only one of the so-called "renewable" energies that is contributing significantly to U.S. energy needs. The main components of the geothermal budget are now politically determined in Congress and are earmarked for the more futuristic types of geothermal resources, namely the hot dry rock and geopressured resources. No one in industry or the government predicts that these resource types will make significant contribution to the energy mix in the United States until well into the next century. The share of the budget allocated for the type of research which Lacy (1986) and many other industry people recommend is deemed to be wholly inadequate for the job. These research needs are mainly in topics designed to assist industry in the development of hydrothermal resources, and include:

1. Research to bring down the cost of drilling a well field. Research should take place on two broad fronts; in learning how to drill more cheaply, and in learning how to site wells more efficiently, so that there are fewer unsuccessful wells. The cost of putting in the well field is about half of the total development cost for generating electric power.

2. Research to increase our ability to predict the long-term behavior of a reservoir and to design better production and injection strategies. Utilities and financial institutions are understandably reluctant to commit money and resources to a geothermal project if long-term production from the resource can not be guaranteed.

3. Research to increase the efficiency of conversion, so that the more plentiful lower-temperature resources can be used.

In addition to these research needs, both the federal and the state governments need to streamline the permitting process and other aspects of regulation to the maximum extent possible. This will help the developers to hold down costs and enable them to proceed in these highly competitive times.

I have concluded that our elected officials in Congress and many people in the present Administration have little interest in the energy industry in the U.S. They are not likely to develop an interest until the next energy crises, which some people believe is not far off. We have a brief period now of plentiful energy during which we can either prepare to ensure an adequate supply of acceptable forms of energy for our future or we can neglect to act and be overtaken again as world markets undergo another high-amplitude swing. I believe that groups such as the Interstate Oil Compact Commission, which has an understanding of the energy industry in the U.S. and the world market that it operates in, have a duty to help educate the public at large, and our elected officials in particular, to the facts of our energy-based society. I encourage you to take this duty seriously. Our future depends on us.

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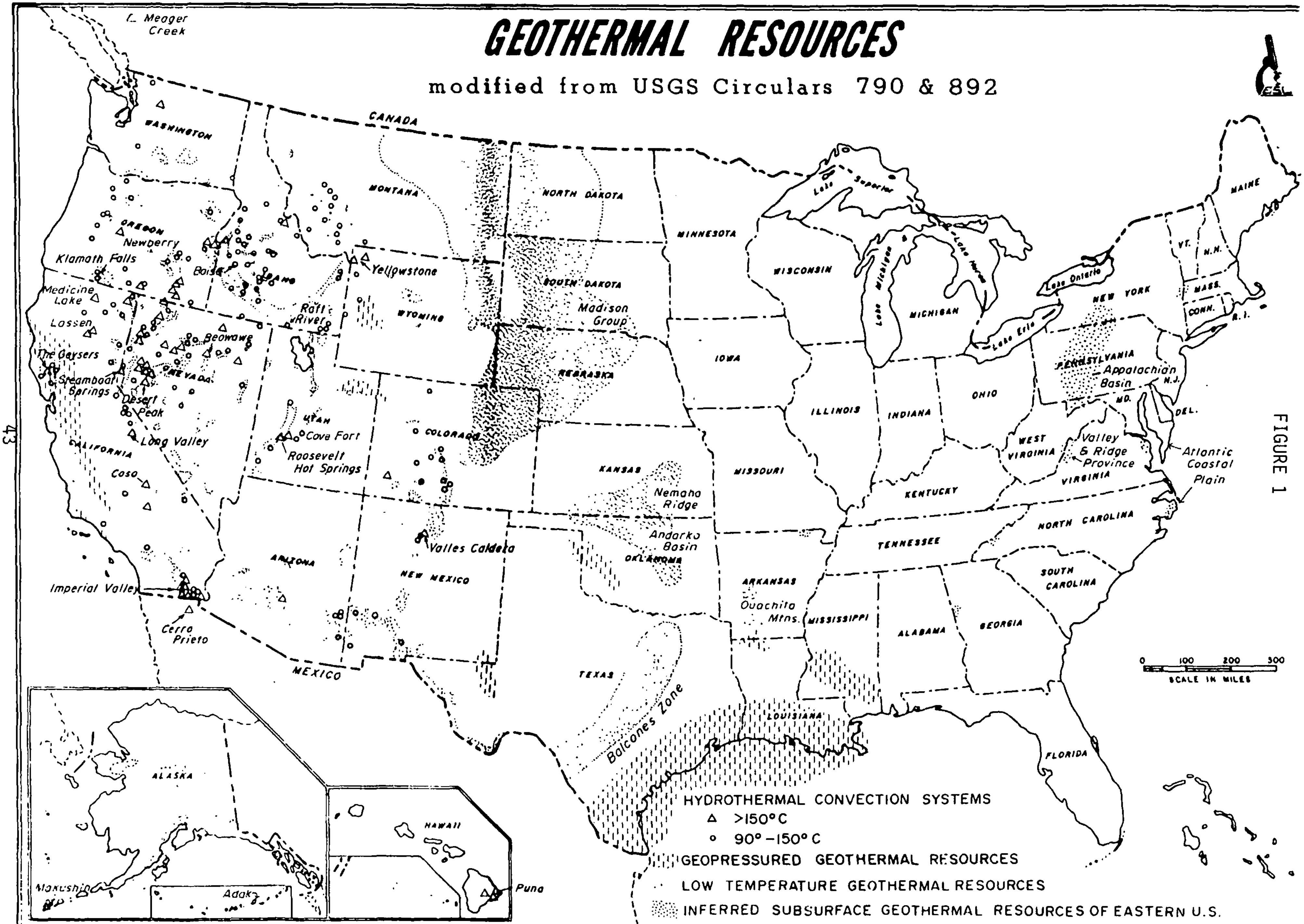
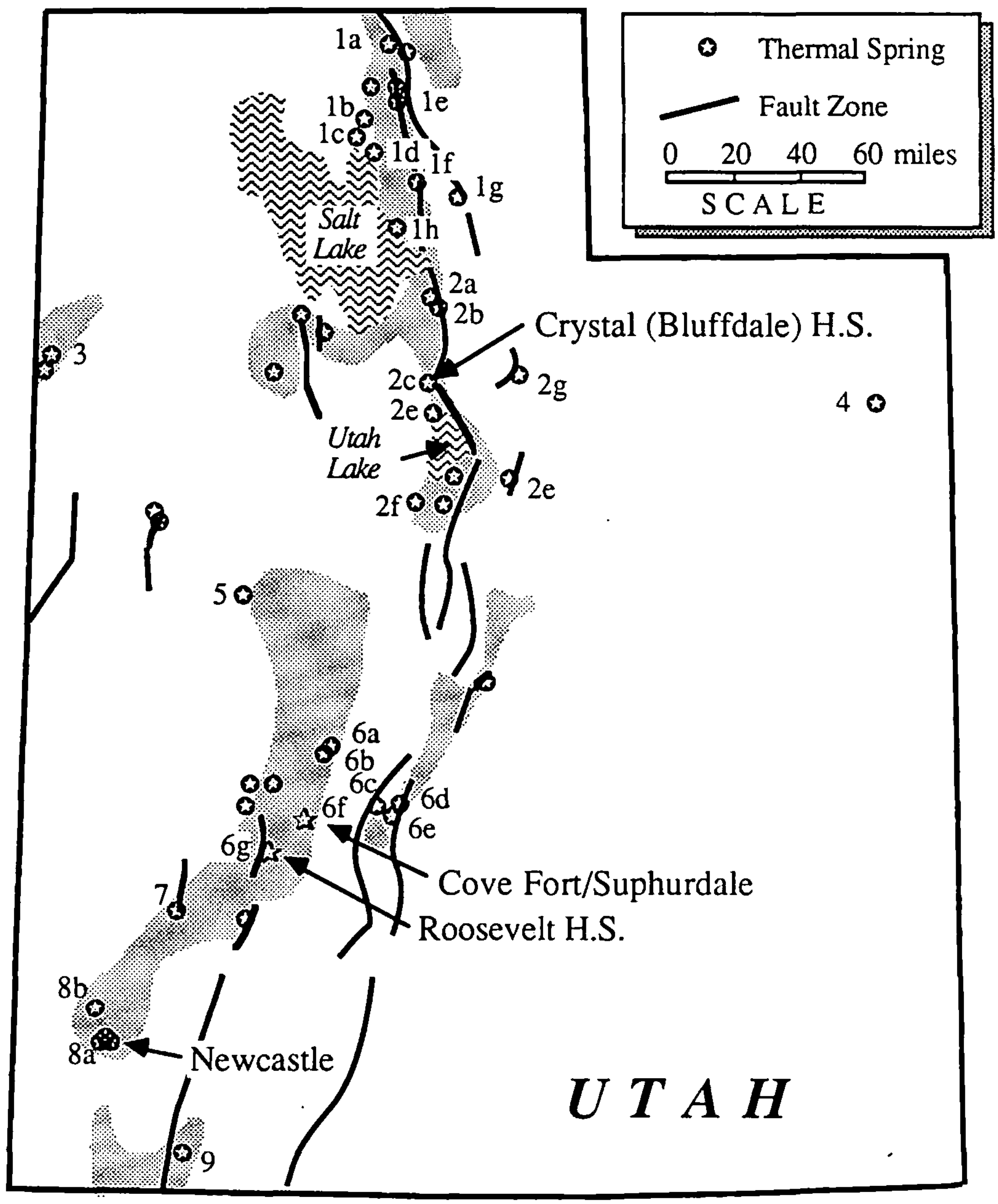


GEOTHERMAL RESOURCES
modified from USGS Circulars 790 & 892
Meager Creek
CANADA
WASHINGTON
OREGON
Newberry
Klamath Falls
Medicine Lake
Lassen
The Geysers
Steamboat Springs
Desert Peak
Long Valley
CALIFORNIA
Coso
Imperial Valley
Cerro Prieto
Boise
IDAHO
Raft River
Beowawe
NEVADA
MONTANA
Yellowstone
WYOMING
UTAH
Cove Fort
Roosevelt Hot Springs
COLORADO
ARIZONA
NEW MEXICO
Valles Caldera
MEXICO
NORTH DAKOTA
SOUTH DAKOTA
Madison Group
NEBRASKA
KANSAS
Nemaha Ridge
Andarko Basin
OKLAHOMA
TEXAS
Balcones Zone
MINNESOTA
IOWA
MISSOURI
ARKANSAS
Ouachita Mtns.
LOUISIANA
MISSISSIPPI
WISCONSIN
ILLINOIS
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
MICHIGAN
INDIANA
OHIO
KENTUCKY
TENNESSEE
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
Valley & Ridge Province
PENNSYLVANIA
Appalachian Basin
MD.
DEL.
N.J.
Atlantic Coastal Plain
NEW YORK
VT.
N.H.
MAINE
MASS.
CONN.
R.I.
ALASKA
Makushin
Adak
HAWAII
Puna
0 100 200 300
SCALE IN MILES
HYDROTHERMAL CONVECTION SYSTEMS
△ >150°C
∘ 90° – 150° C
GEOPRESSURED GEOTHERMAL RESOURCES
LOW TEMPERATURE GEOTHERMAL RESOURCES
INFERRED SUBSURFACE GEOTHERMAL RESOURCES OF EASTERN U.S.

FIGURE 1

FIGURE 2



GEOTHERMAL OCCURRENCES IN UTAH

FIGURE 3

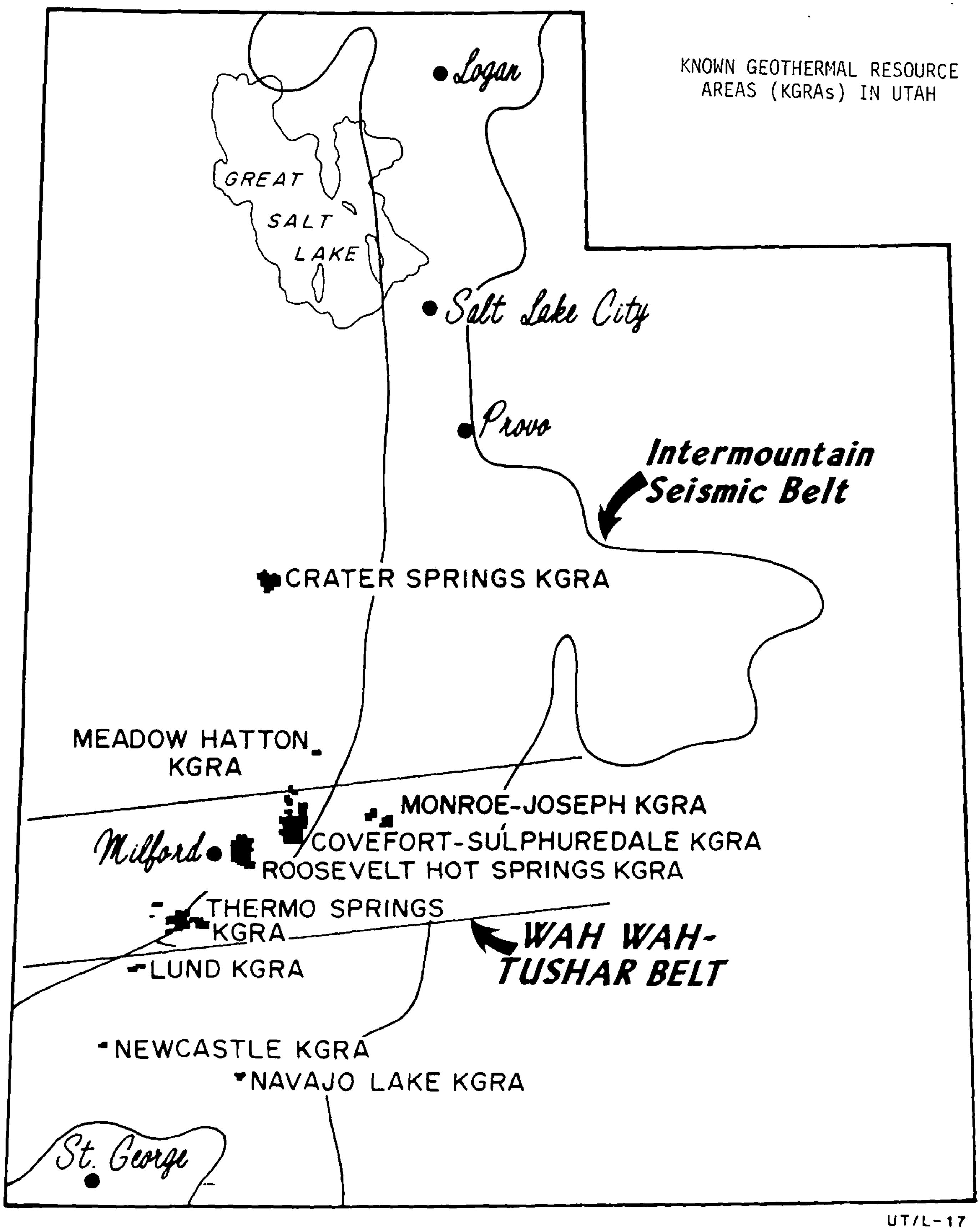
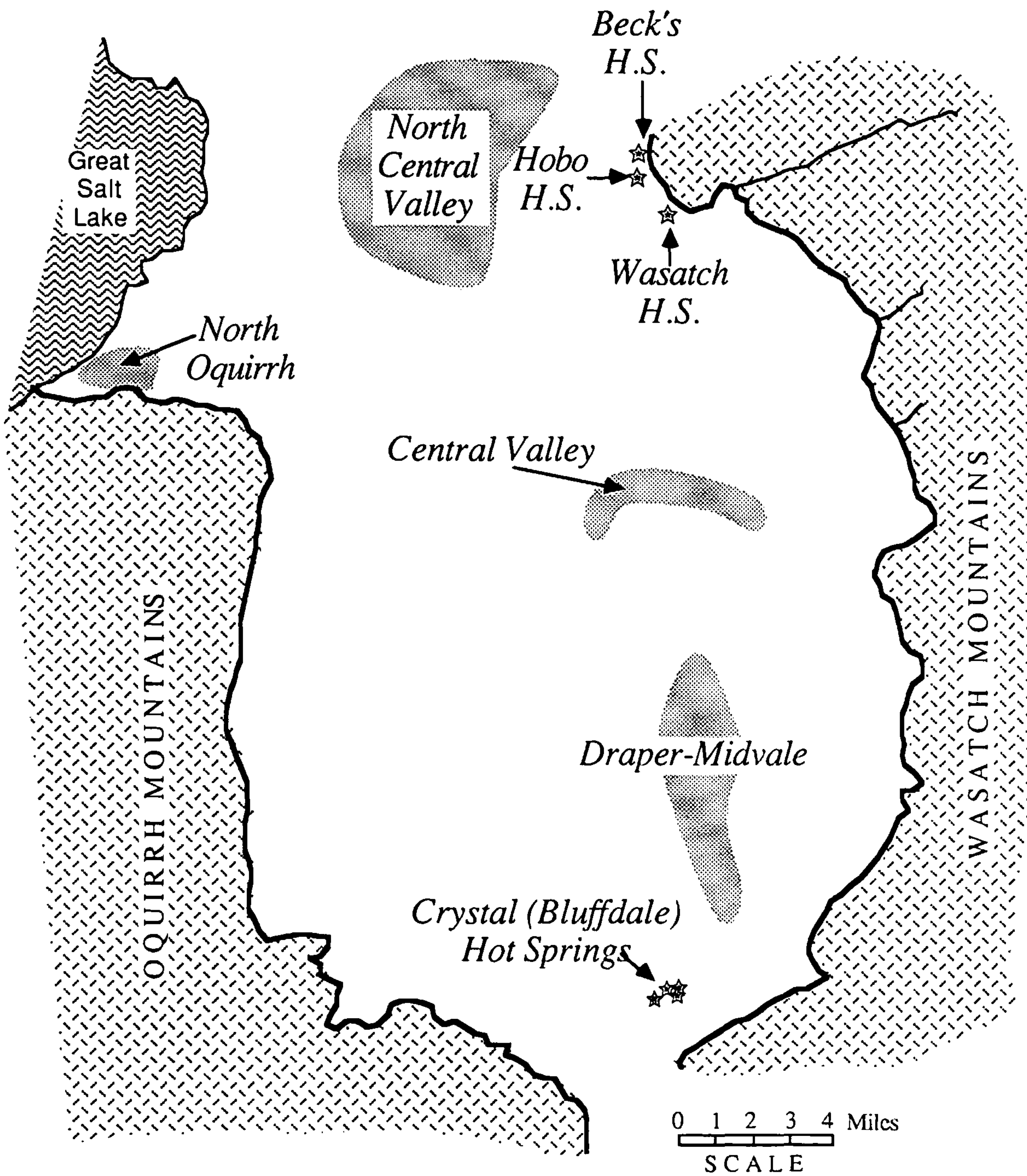
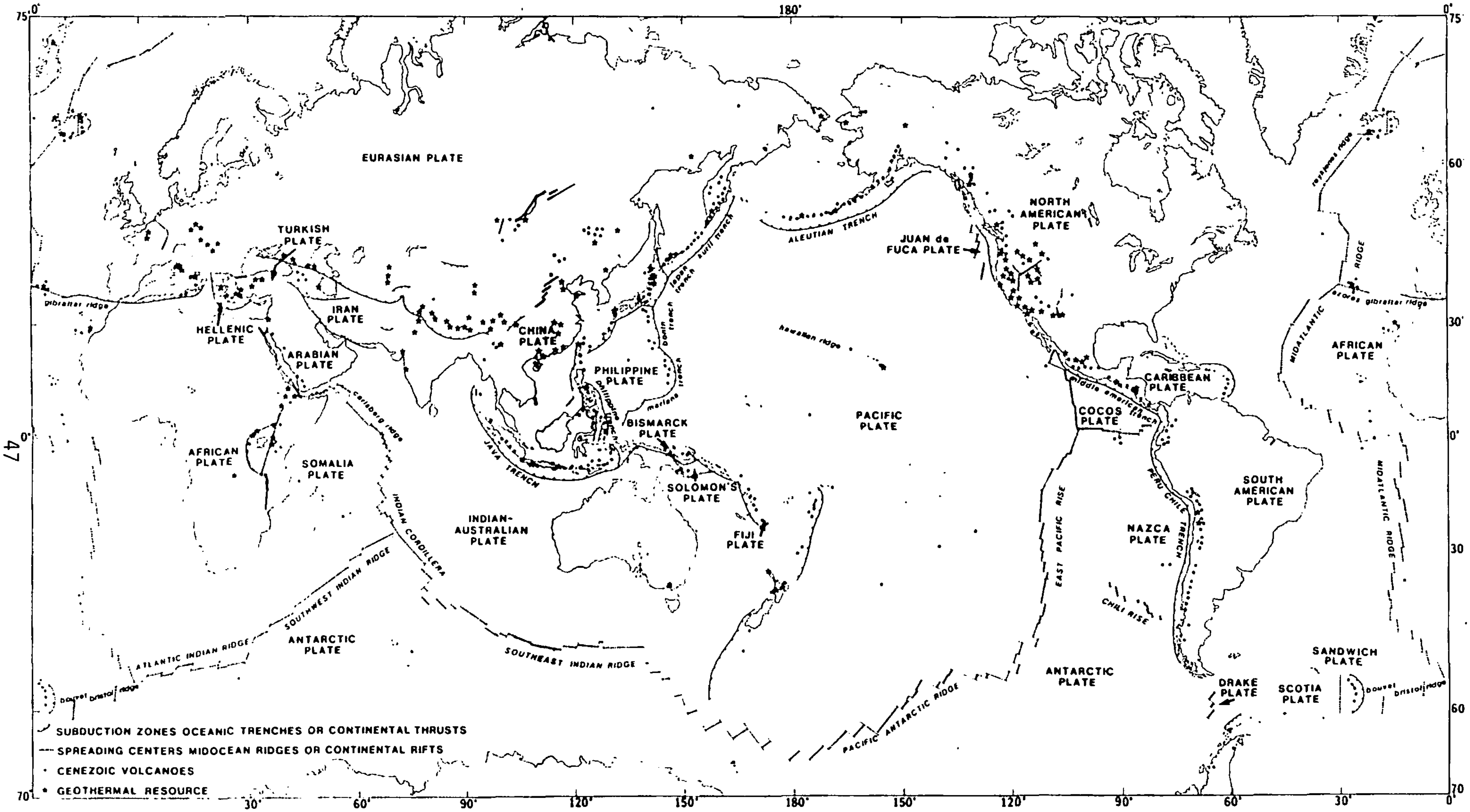

KNOWN GEOTHERMAL RESOURCE
AREAS (KGRAs) IN UTAH
Logan
GREAT
SALT
LAKE
Salt Lake City
Provo
Intermountain
Seismic Belt
CRATER SPRINGS KGRA
MEADOW HATTON
KGRA
MONROE-JOSEPH KGRA
COVEFORT-SULPHUREDALE KGRA
Milford
ROOSEVELT HOT SPRINGS KGRA
THERMO SPRINGS
KGRA
LUND KGRA
WAH WAH-
TUSHAR BELT
NEWCASTLE KGRA
NAVAJO LAKE KGRA
St. George
UT/L-17

FIGURE 4



Geothermal Occurrences
in the Jordan Valley

(after Klauk, 1984)



GEOTHERMAL RESOURCES AND PLATE TECTONIC FEATURES

FIGURE 5

TABLE 1

Geothermal Resource Classification

(Modified from White and Williams, 1975)

Resource Type	Temperature Characteristics
Convective Hydrothermal Resources	
Vapor dominated	~ 240°C
Hot-water dominated	~ 30°C to 350°C +
Other Hydrothermal Resources	
Sedimentary basins/Regional aquifers (hot fluid in sedimentary rocks)	~ 30°C to 150°C
Geopressured (hot fluid under pressure that is greater than hydrostatic)	~ 90°C to 200°C
Radiogenic (heat generated by radioactive decay)	~ 30°C to 150°C
Hot Rock Resources	
Part still molten	higher than 600°C
Solidified (hot, dry rock)	90° to 650°C

TABLE 2

SELECTED SPRINGS AND WELLS IN UTAH

NAME		DISCHARGE TEMP,C	DISCHARGE FLOW,GPM	ESTIMATED RESV. TEMP,C	DEPTH, FT
4 Ashley Valley field		55	-	-	4200
2a Beck's	hs	55	-	60-100	
3 Bonneville DBW3	dh	88	-	-	1636
2f Burgin Mine		55	2700	-	
2g Castilla	hs	40	20	50-90	
1d Chesapeake Duck Club	dh	74	20	-	-
8a Christensen Bros	dh	96	1700	-	500
6f Cove Fort/Sulp. area		175	-	180-225	av 1200
5 Crater (Abraham)	hs	87	250	100-150	
1e Crystal (Madsen)	hs	55	1600	30-90	
2c Crystal (Bluffdale)	hs	58	-	90-120	
8b DeArmand #1	dh	149	1000	-	7000
6b Hatton	hs	36	25	70-110	
1h Hooper	hs	60	-	80-120	
6c Joseph	hs	65	100	90-150	
9 Laverkin	hs	42	4500	50-90	
1c Little Mountain	hs	42	450	-	
6a Meadow	hs	41	-	70-120	
2d Midway area		40	200	-	
6e Monroe	hs	76	40	90-120	
1g Ogden	hs	58	75	70-100	
8a Newcastle area		95	-	140-170	
6d Red Hill	hs	76	40	100-160	
1a River Pools	hs	46	5500	-	
6g Roosevelt	hs	85	10	260-290	
6g Roosevelt area		-	-	240-260	av 8500
2e Saratoga	hs	46	125	60-100	
1b Stinking	hs	51	50	70-90	
7 Thermo	hs	83	30	140-200	
1a Udy (Belmont)	hs	43	900	50-90	
1f Utah	hs	58	-	70-100	
2b Wasatch	hs	42	-	50-90	

Note. The number-letter designation left of the name is keyed to locations on Figure 2.

TABLE 3

Worldwide Geothermal Electricity Generation

OCTOBER 1985
(After D. Pippo)

Country	Generating Capacity, MW: Operational	Generating Capacity, MW: Under Const. or Planned
KENYA	45.0	60
EL SALVADOR	45.0	30
NICARAGUA	35.0	35
MEXICO	425.0	865
UNITED STATES	2022.0	1309
CHINA	14.0	–
TURKEY	20.6	–
AZORES	3.0	–
USSR	11.0	230
ICELAND	39.0	–
GUADELOUPE	4.2	–
ITALY	459.0	60
INDONESIA	32.3	965
JAPAN	215.0	108
NEW ZEALAND	167.0	116
PHILIPPINES	894.0	1303
	4431.1 MW	5081 MW

Table 4

Worldwide Geothermal Direct Use

Country	Power (MW)	Energy (GWh)	Load (%)
China	393	1945	56
France	300	788	30
Hungary	1001	2615	30
Iceland	889	5517	71
Italy	288	1365	54
Japan	2686	6805	29
New Zealand	215	1484	79
Romania	251	987	45
Soviet Union	402	1056	30
Turkey	166	423	29
United States	339	390	13
Other	142	582	47
total	7072	23957	39*

* Based on total thermal power and energy

TABLE 5

U.S. Electrical Capacity by Fuel

(NERC, 1985)

Fuel	Existing 1984 (GW)	Existing 1984 (%)	Forecast 1994 (GW)	Forecast 1994 (%)	Growth (%/a)
coal	262.3	43.4	311.6	43.8	1.74
oil and gas	103.4	17.1	99.0	13.9	-0.43
dual + other	91.3	15.1	98.0	13.8	0.71
water	83.7	13.9	88.1	12.3	0.51
uranium	62.1	10.3	111.7	15.7	6.05
geothermal	1.42	0.2	3.23	0.5	8.56
totals	604.2		711.6		1.65

TABLE 6

WSCC Electrical Capacity by Fuel

(WSCC, 1986)

Fuel	Existing 1986 (GW)	(%)	Forecast 1996 (GW)	(%)	Growth (%/a)
water	60.0	43.9	63.5	39.6	0.57
oil and gas	35.9	26.3	41.8	26.1	1.53
coal	30.8	22.5	39.1	24.4	2.41
uranium	7.8	5.7	12.0	7.5	4.40
geothermal	2.2	1.6	3.9	2.4	5.89
totals	136.7		160.3		1.61

TABLE 7

1986 EPRI Utility Geothermal Survey
(Roberts and Kruger, 1986)

	Capacity (MWe) by Year		
	actual	estimated	
	1986	1995	2005
Southwest			
An	67	159	159
Pr		247	730
Ps		597	1845
Northwest			
An	0	0	0
Pr		20	60
Ps		35	145
CA/HI			
An	2048	3509	3509
Pr		4439	6003
Ps		5434	8058
Gulf States			
An	0	0	0
Pr		0	0
Ps		5	20
Total Forecast			
An	2115	3668	3668
Pr		4706	6793
Ps		6071	10068

WRIGHT

GEOTHERMAL DEVELOPMENT IN UTAH

AND

STATUS OF THE U.S. GEOTHERMAL INDUSTRY

Presentation to the

INTERSTATE OIL COMPACT COMMISSION

9 December 1986

by

Phillip Michael Wright

Earth Science Laboratory

University of Utah Research Institute
391 Chipeta Way, Suite C
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(801) 524-3422

28 NOVEMBER 1986

ESL

ESL/86027-TR

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ABSTRACT

Geothermal resources are being actively developed on a worldwide basis. Current geothermal electrical generating capacity is about 4,800 megawatts, with the United States accounting for 2,115 megawatts of the total. Current direct uses of geothermal energy amount to about 10,000 megawatts, with the U.S. contributing about 400 megawatts. Geothermal resources worldwide produce enough energy to displace the use of about 80 million bbl of petroleum annually. Utah has two areas, Roosevelt Hot Springs and Cove Fort/Surphurdale, generating a total of 25.7 MWe of electricity, and this capacity represents the first electrical generation from geothermal resources in the U.S. outside of the State of California. In addition, there are about a dozen individual direct uses of lower-temperature geothermal resources in Utah, which consume about 9 X 10^{10} BTU per year. Most of Utah's known geothermal resources and its potential for future development lie in the Basin and Range geologic province, in the western half of the State.

Geothermal development in Utah is presently rather depressed due to the comparatively low energy costs of today and the excess electrical generating capacity that exists in the West. Growth in geothermal generating capacity in the U.S. is forecast at a rate between 6 and 9 percent per year from the present to the year 2005, with essentially all of this development being in the hydrothermal convective type of resources. Contrary to its

stated policy, the Federal government is not adequately supporting the research and technology development needed to bring the bulk of the known hydrothermal resource base on line. We all have a duty to help educate the public and our elected federal officials and others in the Administration to the facts of our energy-based economy in this country and to the importance in using this grace period in energy costs to prepare ourselves as a nation for times of sharply higher energy costs.

INTRODUCTION

Development of geothermal resources is being aggressively pursued on a worldwide basis. Approximately 4,800 MW of electricity (MWe) are currently being generated from geothermal energy, and about 10,000 thermal megawatts (MWt) are being used for direct heat applications. While this may seem small compared to the estimated 8.4 million megawatts of total human use of fossil energy (Williams and Von Herzen, 1974), it nevertheless represents a savings in the consumption of about 80 million barrels of oil per year worldwide.

It is very difficult to estimate the ultimate potential contribution of geothermal energy to mankind's needs for at least three reasons: 1) long-range future energy costs, although generally predicted to be higher than today's levels, are uncertain, and a large number of lower-grade geothermal resources would become economic at higher energy prices; 2) only preliminary estimates of the worldwide resource base have been made; and, 3) technology for making economic use of energy in geopressured, magma, hot dry rock and normal thermal-gradient resources, whose potential contributions are very large, is not yet available.

The State of Utah has an abundance of thermal occurrences and is a promising area for geothermal exploration and development. Goode(1978) reports records of about 1,500 thermal springs and wells, many of which yield water that is appreciably above mean ambient air temperature. Two areas, Roosevelt Hot Springs and Cove Fort/Sulphurdale, produce electrical energy from hydrothermal systems, and direct uses are being made of natural thermal water in more than a dozen separate areas. The Utah Geological and Mineral Survey (UGMS), the Utah Energy Office, the State Division of Facilities and Construction Management, and the State Division of Water Rights are all active in promoting geothermal development. In addition, the University of Utah Research Institute (UURI) is one of the primary geothermal research facilities supported by the U.S. Department of Energy, and the Earth Science Laboratory at UURI has provided geologic expertise and analytical services in the evaluation and development of several of Utah's resources.

The purpose of this presentation is to present the current status of development in Utah and to review the outlook for geothermal development in the United States.

NATURE OF GEOTHERMAL RESOURCES

Geothermal energy is heat that originates within the earth. The earth is an active thermal engine. Many of the large-scale geological processes that have helped to form the earth's surface features are powered by redistribution of internal heat as it flows from inner regions of higher temperature to outer regions of lower temperature. The mean value of the surface heat flow for the earth is 42 million megawatts (Williams and Von Herzen,1974), which represents heat that comes to the surface and is lost by radiation into space. Generation of new oceanic crust at spreading centers such as the mid-Atlantic ridge, motion of the great lithospheric plates, uplifting of mountain ranges, release of stored strain energy by earthquakes and eruption of volcanos all owe their origin to the outward transport of internal heat. Plastic, partially molten rock at estimated temperatures between 600 deg C and 1200 deg C is postulated to exist everywhere beneath the earth's surface at depths of 100 km or less. By comparison, using present technology applied under favorable circumstances, holes can be drilled to depths of about 10 km, where temperatures range upward from about 150 deg C in average areas to perhaps 600 deg C in exceptional areas.

Models of Geothermal Resources

Exploitable geothermal resources owe their origin to the transport of heat near to the surface through one or more of a number of geological and hydrological processes. Geothermal resources commonly have three components: 1) a heat source, 2) permeability in the rock, and 3) water to transfer the heat. The heat source for most of the high-temperature resources (>150 deg C) appears to be a molten or recently solidified intrusion, whereas many of the lower-temperature resources seem to result from deep circulation of meteoric water with heating due to the normal increase in temperature with depth. Most geothermal systems appear to have a preponderance of fracture permeability, but intergranular permeability is important also in some systems. Water is, of course, the ideal heat transfer fluid because it has a high heat capacity and high heat of vaporization, and can therefore transport more heat per unit volume than any other common fluid.

Geothermal resources are commonly classified as shown in Table 1. Only the hydrothermal resources have been commercially developed. The more futuristic types such as geopressured, hot dry rock and magma resources will require new technology and higher energy prices in order to be economically viable. Convective hydrothermal resources are geothermal resources in which the earth's heat is carried upward by the circulation of naturally occurring hot water or steam.

Models for high-temperature convective hydrothermal systems have been discussed by White et al. (1971), Mahon et al. (1980), and Henley and Ellis (1983), among others. Underlying higher-temperature hydrothermal resources is presumably a body of still-molten or recently solidified rock that is hot (300 deg C to 1200 deg C). Interaction of this hot rock with groundwater causes heating of the groundwater, which then rises by buoyancy. The bulk of the fluid in hydrothermal systems is derived from meteoric water, with the exception of those few systems where the fluids are derived from seawater or connate brines (Craig, 1963). A circulating system is set up with the heated water ascending in the center of the system along zones of permeability, spreading outward in the shallow subsurface or discharging to the surface, and with cool water descending along the margins and recharging the system. Rapid convection produces uniform temperatures over large volumes of the reservoir. The temperatures and pressures generally lie near the curve of boiling point versus depth for saline water, and sporadic boiling may occur. Whether or not steam actually exists in a hydrothermal resource depends, among other less important variables, on temperature and pressure conditions at depth. Escape of hot fluids at the surface is often minimized by a near-surface sealed zone or cap-rock formed by precipitation from the geothermal fluids of minerals in fractures and pore spaces.

Virtually all of industry's geothermal exploration effort in the United States is presently directed at locating vapor- or water-dominated hydrothermal convection systems having temperatures above 200 deg C. It is these resources that have the greatest likelihood of being economically viable for generation of electricity. Temperatures down to 140 deg C may become more interesting for generation in the near future with further development of binary conversion technology.

Occurrence of Geothermal Resources in the U.S.

Figure 1 displays the distribution of various geothermal resource types in the United States. Information for this figure was taken mainly from Brooke et al. (1978) and Reed (1982). Not shown are locations of hot dry rock or magma resources because very little is known. It should be emphasized that the present state of knowledge of geothermal resources of all types is poor. We can expect new additions to the growing list of known resources as exploration and assessment continue.

Figure 1 shows that most of the known hydrothermal resources and all of the presently known sites that are capable of electric power generation are in the western half of the U.S. The preponderance of thermal springs and other surface manifestations of underlying resources is also in the west. Large areas underlain by warm waters in sedimentary rocks exist in Montana, North and South Dakota and Wyoming (the Madison group of aquifers), but the extent and potential of these resources is poorly understood. Another important large area, much of which is underlain by low-temperature resources, is the north northeast-trending Balcones Zone is Texas. The geopressured resource areas of the Gulf Coast and surrounding states are also shown. Resource areas indicated in the eastern states are highly speculative at this date because little drilling has taken place to confirm their existence.

Regarding the temperature distribution of geothermal resources, low- and intermediate-temperature resources are much more plentiful than are high-temperature resources. There are many thermal springs and wells that have water at temperatures only slightly above the mean annual air temperature, the temperature of most non-geothermal shallow ground water.

GEOTHERMAL RESOURCES IN UTAH

The State of Utah has a number of known geothermal occurrences, some of which are under development for power generation and/or direct use. A present surplus of generating capacity within the region and low energy costs compared to those of the recent past are suppressing development in Utah to some degree.

Regional Geologic Setting

Utah is comprised of parts of three physiographic provinces which were defined by Fenneman(1931) as the Middle Rocky Mountains, the Colorado Plateaus and the Basin and Range. The Middle Rocky Mountains includes the Wasatch Range and the Uinta Mountains in the northeastern portion of the State, both of which are composed predominantly of pre-Cenozoic sedimentary and silicic plutonic rocks. The Colorado Plateaus province is an area of broad uplift in the south-eastern and south-central portions of Utah having essentially horizontal strata of Mesozoic and older sedimentary rocks. In addition, Tertiary and Quaternary volcanic rocks occur in south-central Utah and there are a few scattered Tertiary intrusive bodies in the southeastern part of the state.

The Basin and Range Province, which comprises essentially the western half of Utah, is separated from the Middle Rocky Mountains by the Wasatch Fault zone in the north and from the Colorado Plateaus by a transition zone in the south. The Basin and Range contains rocks of widely ranging composition and age.

Older rocks consist of a variety of Mesozoic and Paleozoic sedimentary rocks and their metamorphosed equivalents. Overlying the sedimentary and metamorphic rocks are Cenozoic volcanic rocks and valley fill. Valley fill, mostly alluvium, may be as thick as 10,000 ft in some basins. The valleys in the Basin and Range are considered to be grabens and the ranges are horsts. A sizeable east-west extension is believed to have taken place in the last 17 million years to form these north-south trending structures. In western Utah, igneous rocks and hydrothermal mineral zones occur in well-defined east-west belts, with successively younger ages to the south (Stewart et al., 1977). However, the youngest igneous rocks, less than 6 million years old with some less than 10,000 years old, appear to be controlled by the north-south Basin and Range structure. The very young volcanic rocks, potentially related to geothermal resources, are found in a belt from west-central Utah to the southwestern corner, where they continue into Arizona. These rocks are largely basaltic, but scattered rhyolitic cones and domes are known. Silicic intrusive rocks were emplaced at the same time as the eruption of the silicic volcanic rocks (Whelan, 1970). The largest exposure of such an intrusive body in Utah is in the Mineral Mountains, adjacent to which the Roosevelt Hot Springs hydrothermal system is located.

Regional Heat Flow

The worldwide average conductive heat flow to the earth's surface is about 61 milliwatts per square meter for the continents (Williams and Von Herzen, 1974). Considerable variation in heat flow exists in Utah. The area of highest heat flow in Utah is the Basin and Range province, which has typical values in the range 80 to 120 mw/m^2. The Colorado Plateaus and the Middle Rocks Mountains provinces in Utah have heat-flow values near the average for the earth's surface (Sass and others, 1974; Sass and Munroe, 1974).

<u>Geothermal Occurrences in Utah</u>

The earliest known reference to geothermal systems in Utah is by Gilbert(1890), who described Fumarole Butte and the nearby Crater Hot Springs. Stearns and others (1937) and Waring(1965) summarized the knowledge to the time for about 60 thermal occurrences. A comprehensive data report on the thermal springs of Utah was made by Mundorf(1970), and estimates of subsurface temperatures were made by Swanberg(1974) using chemical geothermometers. Goode(1978) and Rush(1983) both produced summaries of geothermal occurrences in Utah. Goode's data compilation is particularly complete, whereas Rush's geologic descriptions are especially useful. In addition to these references, various authors from the Utah Geological and Mineral Survey, the Utah Energy Office and the University of Utah Research Institute have published details on geothermal systems and geothermal applications in Utah. References to all of this literature were compiled by Budding and Bugden(1986).

With few exceptions, all of the known areas of geothermal occurrences are in the western half of Utah, in the Basin and

Range province or in the transition zone between the Basin and Range and the Colorado Plateaus. Of the 327 thermal wells and springs with temperatures greater than 20 deg C identified on the Geothermal Resources of Utah map (Utah Geological and Mineral Survey, 1980), only 13 are located in the eastern part of the state. The largest known hot water occurrence in eastern Utah comes from the oil wells of the Ashley Valley oil field, which produce about 200 bbl of nearly fresh water at temperatures between 43 deg C and 55 deg C for every bbl of oil (Goode, 1985). In 1981, this area yielded 3,360 acre-feet (26.1 million bbl) of water.

Most thermal springs and wells in central and western Utah are in the valleys near their margins with the mountain blocks. Many spring locations are controlled by the most recently active Basin and Range faults. Some springs, however, are in the valley bottoms, and others are on upland slopes. Only a few thermal springs are in a mountainous setting.

Swanberg(1974), Rush(1983) and Cole(1983) considered the application of chemical geothermometers to Utah springs in an attempt to help define areas of highest subsurface temperature. Table 2 shows a summary of results from these and other sources. I have included on this table the known springs with flowing temperatures above 40 deg C along with drill holes that have clearly anomalous temperatures for their depths. Rush(1983) believes that six areas have reservoir temperatures above 150 deg C, and therefore have potential for generation of electrical energy. These areas are Roosevelt Hot Springs, Cove Fort/Sulphurdale (both of which are now producing electrical power), Thermo Hot Springs, Joseph Hot Springs, the Newcastle area and the Monroe-Red Hill area. In addition, an area in the Drum Mountains has been explored for electrical potential. Six other hot spring areas may have reservoir temperatures in the range 90 deg C to 150 deg C. Figure 2 shows the locations of the geothermal occurrences indicated in Table 2. Also shown on this figure by shading are the areas that are considered to have the largest potential for occurrence of undiscovered low- and moderate-temperature resources.

At the present time, electrical power is being generated at Roosevelt Hot Springs and Cove Fort/Suphurdale. The total rated output from these two areas is 23.2 MWe. In addition, direct use is being made of geothermal waters for greenhouses in Newcastle (southwestern Utah), and at Bluffdale (in the Salt Lake valley), and for space heating at Bluffdale. Ten other areas, mostly resorts, use geothermal water for space heating and balneology. Total energy consumption for these direct uses is estimated by Lienau(1986) to be 9 X 10^{10} BTU/yr.

In order to convey a better understanding of the uses of geothermal energy in Utah, we will briefly discuss three of the most important of them. We will first discuss the generation of electrical power in the Roosevelt and Cove Fort areas and then consider the direct uses in the Jordan Valley, where Salt Lake City is located.

Roosevelt Hot Springs

The hydrothermal systems at Roosevelt and Cove Fort both lie along approximately north-south Basin and Range faults, on the western flanks of two adjacent mountain ranges (Figure 3). In addition, their locations also appear to be controlled by the Wah Wah-Tushar mineral belt, a zone of intrusive activity, mineral deposits and geophysical anomalies that trends roughly east-west. A substantial portion of the area between Roosevelt and Cove Fort is rumored to be thermally anomalous, although much of the data needed to substantiate this rumor is privately held in company files. The large thermal anomaly in the area can probably be compared through analogy to the concept of a mining district, which generally covers a substantial area and in which there are one or (usually) more individual mineral deposits. The Roosevelt-Cove Fort geothermal district comprises one of the larger thermal anomalies in the United States, and may cover more than 500 sq mi.

The Roosevelt Hot Springs hydrothermal system has been undergoing intensive exploration since 1974, when Phillips Petroleum Company successfully bid for acreage in the KGRA. After considerable exploration by Phillips and other land holders, the area was unitized with Phillips as the operator and Thermal Power Company, AMAX Exploration, Inc. (now Steam Reserve Corp.), O'Brien Resources Company and VTN Consolidated, Inc. as participants. In 1985, Phillips sold its interest in Roosevelt along with most of its other geothermal holdings to Chevron Geothermal Company of California, who operates the field today.

The bedrock geology of the area is dominated by metamorphic rocks of Precambrian age and felsic plutonic phases of the Tertiary Mineral Mountains intrusive complex (Nielson et al., 1978; Ross et al., 1982). Rhyolite flows, domes and pyroclastic rocks reflect igneous activity between 0.8 and 0.5 million years ago. The structural setting includes older, low-angle normal faulting and east-west faulting produced by deep-seated regional zones of weakness. North-trending faults are the youngest structures in the area, and they control present fumarolic activity. The geothermal reservoir is controlled by intersections of the principal fault zones.

Production has been encountered at depths between about 1,200 ft and 8,000 ft, and downhole temperatures as high as 254 deg C have been reported. The hydrothermal fluids are relatively dilute sodium-chloride brines which contain approximately 7,000 ppm total dissolved solids. Most production data from flow tests and power generation are proprietary. However, data from Utah State 14-2 and Utah State 72-16 are in the public domain as a result of the U.S. Department of Energy's Industry Coupled Program, a data and drilling cost-share program with industry that is no longer being funded by DOE. After considerable testing by Thermal Power Company, 72-16 was rated at 12.5 MWt and 14-2 was rated at 4.5 MWt. Phillips has more recently drilled two wells specifically to feed the 20 MWe Blundell plant, and these wells have been reported to have a combined flow capacity of greater than 2.25 million pounds per hour, making them among the most prolific hot water producers yet completed in North America.

The field is being developed jointly by the operator, Chevron, and Utah Power and Light Company. The first power to be generated was the result of an experimental run of a 1.6 MWe Delaval biphase rotary separator turbine which went on line in late 1981. This unit ran for more than one year with no significant problems, producing 1250 MW-hr of power for the UP&L grid during 1982. In 1984, a single-flash plant rated at 20 MWe, the Blundell Unit I, came on line. This plant represents the first significant commercial generation of electricity from geothermal resources in the U.S. outside of California. Because of the high temperature of the resource (260 deg C), the hydrothermal fluids contain a significant amount of silica (510 ppm), and silica scaling has been a concern. In the early months of its operation, the plant had to be taken off line approximately every six weeks to remove scale from the high-pressure seals and the turbine blades. Addition of cleaning pots to the lines in the gathering system has largely solved the scaling problem now. The plant was taken off line most recently in September, 1986 after one year of continuous operation, and the scale buildup was found to be minimal (David Godfrey, UP&L, personal communication). Godfrey also reports that the plant has been running at greater than its rated capacity since the beginning of 1986 with no problems. It currently produces 25.2 MWe gross power and 23 MWe net power.

Although Utah Power and Light is justifiably happy and proud of their geothermal development, they have no current plans for further geothermal development until after 1990. The excess generating capacity that most of the utilities in the U.S. presently have will delay development of new capacity. UP&L initially had plans to install and operate a 14 MWe wellhead modular biphase unit, and had gone through the design phase based on their experience with the 1.6 MW biphase experiment. These plans are shelved for the moment.

Cove Fort/Sulphurdale. The Cove Fort/Sulphurdale thermal system in located near the junction of the Pavant Range and the Tushar Mountains on the eastern margin of the Basin and Range province. These highlands, composed largely of Paleozoic to Mesozoic sedimentary rocks and Tertiary volcanic rocks form part of the High Plateaus subprovince that marks the transition between the Colorado Plateaus and the Basin and Range provinces. The Tertiary volcanic rocks were erupted between about 30 and 19 m.y. ago from widely scattered centers in two distinct volcanic terranes - the Marysvale volcanic field to the south and the Basin and Range. Volcanic activity was renewed between 1 and 0.3 m.y. ago (Best et al., 1980), and Steven et al. (1979) have suggested that the heat source for the present geothermal system may be related to this basaltic volcanism.

Geologic and geophysical data indicate that permeability within the geothermal system is controlled by faults and fractures (Ross and Moore, 1985). Basin and Range tectonism has produced both high- and low-angle faults that trend northerly and easterly. Low-angle faults form the lower bound of gravitational glide blocks in much of the area. The gravitational glide blocks form a nearly impermeable cover over the geothermal system that has profoundly influenced the distribution of surficial manifestations of the system and the temperature gradients in shallow holes.

From 1975 to 1979, Union Oil Company of California (now UNOCAL) explored the area. Much of this exploration was jointly sponsored by the DOE's Industry Coupled Program and the data are therefore public domain. Union drilled four deep exploration wells, one of which, CFSU 42-7, recorded temperatures of 178 deg C. The high cost and great difficulty of drilling in this area, high corrosion rates, low indicated reservoir pressure, and the apparent limited extent of the high-temperature reservoir led Union to a premature conclusion in 1980 that the field was not economic for large-scale electric power production.

Since 1980, Mother Earth Industries (MEI) has been exploring the area. In October, 1983, MEI drilled its first well and encountered a pressurized steam reservoir at about 1200 ft. This well blew out on October 24 and shot a spectacular steam jet into the air during the ensuing weeks before it was brought under control and then plugged and abandoned on November 18. Since then, two other wells have been drilled which have a combined rated capacity of 8.4 MW. The production temperature is believed to be about 200 deg C.

In September, 1985, Mother Earth officially dedicated a power plant which consists of four ORMAT modular binary units with a capacity of 0.8 MW each or 3.2 MW total net power. They are housed in a single building. The City of Provo has a power purchase contract with MEI which includes the right to take the first 200 MWe developed by MEI at Cove Fort. Power is being wheeled to Prove via the Utah Power and Light grid. At present, the plant has been in operation since its dedication with a net power output of 2.7 MWe. MEI has plans for further drilling and additional power production over the next several years.

Jordan Valley

Two areas of hot springs have been known for many years in the Jordan Valley, where Salt Lake City and its suburbs are located - the Beck-Wasatch area, known as the Warm Springs area, at the north end of the valley, and the Crystal (Bluffdale) area at the south end of the valley. The Utah Geological and Mineral Survey was funded by the U.S. Department of Energy under its State-Coupled Resource Assessment program to study the valley and define other areas that may contain thermal water. The State Coupled program is a DOE program that has been active for the last nine years in which DOE funds an appropriate agency in a state to evaluate low- and moderate-temperature resources (less than 150 deg C). The UGMS and others believed that other geothermal resources in the valley could be important in view of the urban development and the high likelihood of an end user being collocated with a resource.

Klauk (1984) published the results of the study, and they are summarized in Figure 4. Groundwater temperatures were measured at 214 locations in the valley and available data for 24 additional locations were compiled. An attempt was made to measure temperatures in wells that intercepted the principal aquifer, which is a deep, confined aquifer with a thickness up to about 1,000 ft that provides recharge to a shallow artesian aquifer. Where no wells intercepting the principal aquifer were available, shallow wells were used. The criterion used to distinguish thermal water followed that of Nathenson et al.(1982). Thermally anomalous water was defined as groundwater having a temperature of 10 C deg or more above the mean annual air temperature, increasing with depth at a rate of 25 C deg per km to a maximum of 90 deg C. The mean annual air temperature in the Jordan valley was taken to be 10 deg C. Based on this criterion, six general areas and three isolated wells were defined. Two of the areas comprise the previously known hot spring areas at Beck-Wasatch and Crystal (Bluffdale). Maximum temperatures in the four newly defined areas range up to only 30 deg C. It, therefore, appears that there is no large amount of geothermal water underlying the populated areas around Salt Lake City at shallow depth that is high enough in temperature for district heating. Some of the thermal fluids, however, could probably be developed for use in local space heating or other applications in conjunction with groundwater heat pumps. Waters of higher temperature could probably be found by drilling deeper, but the minimum depths needed for most direct uses would probably exceed 4,000 or 5,000 ft, and the economics of this kind of development at the present time would be in question.

As Table 2 shows, the discharge temperatures of the hot springs at Bluffdale measure 58 deg C, and the chemical geothermometers give some hope of encountering water of higher temperature at depth. The area has been actively explored and developed since 1979, and there are now two separate installations using the geothermal water. The largest user is Utah Roses, which uses geothermal water from a pumped well to heat greenhouses. The other major user is the State of Utah, which has been heating a portion of the state prison complex with geothermal energy. Several smaller private operations use either the discharge water from Utah Roses or the natural spring discharge, which collects in a pond before flowing into the Jordan River.

The exploration program leading to the development at Bluffdale was carried out for the most part by the Utah Geological and Mineral Survey in conjunction with other State agencies. The program was based on sound exploration principles and was a success. Geophysical studies were used to project bedrock geology under the alluvial cover that surrounds the area and to site shallow temperature gradient holes of small diameter. The gradient drilling program generated the data necessary to locate deeper test wells of production diameter. At the present time, Utah Roses and the State of Utah each have one principal operating well. It has been found in the process of development that production from each of these wells interferes with production from the other, and there is little likelihood of further major development of the resource at depths less than 1,000 ft.

The state prison project was summarized by Lunis (1986) and is discussed in other literature cited by him. The project resulted from a response by the Utah State Energy Office to a DOE funded program opportunity notice (PON). DOE's so-called "PON Program" funded about 30 such projects throughout the U.S. at sites having high geothermal potential and a defined user. Two test wells were drilled, and one had adequate temperature and flow to be used for production. The existing hot water heating system in the Minimum Security facility on the prison grounds was modified to accommodate a closed-loop system in which the fresh circulating water was heated by the geothermal fluids in a plate-type heat exchanger. The majority of the energy supplied to the system was used to heat culinary water with the rest used for space heating. Initial problems with corrosion and scaling were solved by maintaining a CO_2 blanket in the surge tank to keep this gas in solution and to prevent aeration. The system still had problems, however, and was operational only part of the time. The Minimum Security facility has recently been demolished and a new, larger facility is being erected at the site. A geothermal heating system is being incorporated into the design of the new building, and it is expected that this new system will avoid the problems encountered and only partially solved with the retrofit system in the old building. The new system is designed to use 250 gpm of 175 deg F water in a plate-type heat exchanger which will produce a 35 F deg drop in the geothermal water as it extracts heat. There are plans for cascaded used of the water, including growing shrimp and flowers on the prison grounds (Lee Hathon, personal communication).

Utah Roses, Inc. is one of the premier rose growers in the country. In their greenhouses at Bluffdale, they maintain 66,000 rose plants and cut about 8,000 roses per day, more than 60 percent of which are long-stem roses (stems 24 inches or more). These roses are chilled immediately after cutting and are shipped the same day to destinations throughout the United States. Roses are shipped to florists in bundles of 25, and Utah Roses guarantees that each rose will be usable. If not, they will replace the entire bundle at no charge.

Geothermal water from one of two pumped wells is used to heat 160,000 sq ft of greenhouses at Bluffdale. On a typical autumn day, the flow rate is 450 gpm of water at about 190 deg F (88 deg C). The geothermal water is run through a plate-type heat exchanger, in which the heat is transferred to city water. The geothermal water is then discharged to an open ditch, while the heated city water is circulated in a closed system to the greenhouses. Downstream from Utah Roses, five other private concerns make use of the geothermal water for growing pigs, cattle and tropical fish before the water finally flows into the Jordan river as it meanders toward the Great Salt Lake. In the greenhouses, the geothermally heated city water is circulated in fin-type pipes for heating and is also used for irrigation after dilution with cold water to a suitable temperature (85 deg F).

Low heating costs have brought certain competitive advantages to Utah Roses besides the net savings on utility bills. The roof ventilators can be opened for at least part of the day on all but the coldest winter days, and the greenhouses can be ventilated with fresh air. This helps substantially in keeping down disease, which, in turn, helps maintain high product quality and provides savings in chemical treatment.

The heating system was not without its problems in the beginning. The geothermal fluids are corrosive and tend to produce scale if they are reduced in pressure to the point where the carbon dioxide comes out of solution or if they are exposed to the air, from which they can acquire oxygen. Experience has shown that maintenance costs are too high if the geothermal water is used directly in the heating system. The answer has been the incorporation of the very efficient plate-type heat exchangers to allow the geothermal fluids to be kept under pressure and isolated from the atmosphere until discharged. Utah Roses reports (Murray Harmon, personal communication) that they are very happy with the geothermal heating system and have gained confidence in it since they have successfully solved problems in how to use the resource. They have plans to build another greenhouse at the site and to study the feasibility of using the resource for their cooling needs.

CURRENT STATUS OF U.S. GEOTHERMAL INDUSTRY

The current status of the U.S. geothermal industry has recently been reviewed by Lacy (1986), who confined his remarks to the generation of electricity from hydrothermal resources. It is worthwhile to abstract from his paper to form a clearer understanding of today's situation.

In the early- to mid-1970's, many utilities in the western U.S. were heavily dependent on petroleum for the production of electrical energy. The only diversification from petroleum being seriously considered was rather large nuclear or coal plants. Technology for the generation of electricity from geothermal resources had been demonstrated at only one location, The Geysers in California, a dry-steam resource. There was considerable doubt that this limited experience could be extrapolated to the much more plentiful hot water resource base.

The oil crisis caused energy prices to soar and inflation rates to increase dramatically. Within a matter of months, the utility industry fell into complete disarray. The utilities' response was to explore alternatives to nuclear, coal and oil, a response supported by the regulatory commissions. Among the western states, geothermal energy was an option that many of the utilities found interesting, and this provided impetus for increased exploration and research. The geothermal industry, however, was not able to offer a truly viable generation option using hot water resources. Technology to explore for and assess these resources was not adequate and costs were therefore high.

In addition, the long-term performance of the reservoir could not be predicted with confidence and there were no adequate ways to deal with the produced brines from the environmental, scaling or corrosion perspectives. Most of these problems remain to be solved today, although progress has been made in some areas.

During the past five years, important energy conservation measures have been implemented and the economy has seen only sluggish growth. These factors have brought about reduced electrical demand at a time when energy costs are lower. The geothermal industry has, as a result, been going through a period of depression and upheaval. Utilities are dropping, scaling down or deferring plans for new generating capacity while geothermal generation costs have difficulty competing with other generation costs. The industry has been in a mode of retrenchment, and some of the marginal members have dropped out.

Lacy (1986) expects further shakeout of participants in the geothermal industry during the next five years. He believes that the result will be a leaner and stronger industry. We will see some geothermal development in this time span, especially at The Geysers. A few larger plants and several wellhead plants can be expected to come on line in other areas. Lacy(1986) also believes that the geothermal industry "has an unprecedented opportunity during the rest of this decade to position itself for a market place that will be wide open in the 1990s". In order to be able to compete effectively in the long term, he believes that the industry will have to: develop more hard cost data so that the utilities can adequately evaluate economics and risk; perform research and technology development to increase materially our ability to define the resource, predict reservoir performance and to decrease the drilling, operating and capital costs; solve some permitting and environmental issues; take steps to ensure adequate water for cooling, and; solve the problem of access to transmission lines. The challenge to the geothermal industry and to the federal and state agencies that support it are clear.

WORLDWIDE GEOTHERMAL USE AND FORECASTS

Because plate tectonic geologic processes control the regions of the earth that are active geologically, and are therefore the regions of highest geothermal potential, the locations of most of the world's geothermal occurrences are along such plate tectonic features as spreading centers, transform faults and volcanic arcs. Figure 5 depicts the locations of the world's known geothermal occurrences. The regions bordering the Pacific ocean, the Mediterranean area and the young oceanic volcanic islands comprise most of the favorable prospecting area.

Current Electrical Power Generation

DiPippo (1985) compiled data on the worldwide use of geothermal energy for generation of electric power. His results are summarized in Table 3. All of the producing geothermal systems are of the hydrothermal convection type. Electricity is being generated from geothermal energy in the United States, the Philippines, Mexico, Italy, Japan, New Zealand, El Salvador, Kenya, Iceland, Nicaragua, Indonesia, Turkey, China, the Soviet Union, and on the islands of Guadeloupe, Azores, and Milos, in decreasing order of production capacity. Although the U.S. is out in front at the present time, the Philippines and Indonesia have tremendous power potential which they are working hard to develop. In these and other third-world countries, geothermal exploitation frees petroleum for sale and enables them to obtain much needed foreign exchange. These two countries have rapidly become experts in installing geothermal systems by allowing U.S.

companies to participate in development on their soil. The Soviets have also begun to pay attention to their geothermal resources, believed by some to be the largest in the world, especially since the disaster at Chernobyl has produced disenchantment with their large system of nuclear plants. Africa and South and Central America have large, high-temperature resources, but development is very slow due to depressed economies and sometimes hostile governments with many problems. The traditional producers of geothermal energy, Italy, Iceland and New Zealand, are proceeding relatively slowly with new development also. This is mostly a function of planning for their energy needs. Mexico badly needs the power that their geothermal resources could yield, especially in the Mexican volcanic belt close to Mexico City, but they lack the capital for development and have suffered setbacks in their plant at Cerro Prieto in the Mexicali valley. Canada has some potential for geothermal development, but will probably not exercise those options to any great extent until their hydropower resources are more fully exploited.

Current Direct Uses

Direct uses have been made of geothermal energy for many years, mostly for balneology. Gudmundsson (1985) gives the most recent report on worldwide use. At the end of 1984, the installed thermal power of all direct use projects in the world was about 7072 megawatts thermal (MWt) if only useful thermal power above 35 deg C is considered. The data are summarized in

Table 4. Direct-use projects differ greatly from electric power plants when it comes to assigning a capacity value to the installation. Electric power plants have their capacity stamped on the generator. The installed capacity of direct use projects, however, depends on how much the geothermal fluids are cooled. For example, a district heating installation using 500 kg/s of 80 deg C water will have an installed capacity of 84 MWt or 105 MWt, depending on whether the discharge temperature is 40 deg C or 30 deg C. Also, the flow rates and inlet and outlet temperatures in most direct use applications are poorly documented. This means that considerable guesswork is involved in estimating the power and energy values associated with direct-use applications. By neglecting the direct uses for discharge temperatures below 35 deg C, Gudmundsson's (1985) data underestimate the total direct use by some amount that is difficult to establish. As an example of the magnitude of energy used in these very low-temperature applications, the fish farm at Buhl, Idaho, not included in Table 4, uses an estimated 35 MWt at temperatures below 35 deg C. I conclude that, on a worldwide basis the total energy used in direct heat applications is of the order of 10,000 MWt.

The use of geothermal waters for bathing in Japan dominates the statistics on direct uses worldwide. Gudmundsson (1985) found that it was not possible from the survey data returned to him by the responding countries to separate direct uses precisely into catagories. He states, however, that district heating and cooling represent the major portion of direct uses, followed by bathing, greenhouses and other growing and, lastly, industrial processes. Gudmundsson (1985) also estimates that direct uses replace the consumption of about 2.8 million metric tons or about 29 million bbl oil annually. He concludes that many countries have large, untapped resources suitable for direct use, that district heating and cooling will see the largest growth in future years, and that cities that are collocated with resources will have advantages over those that are not if energy supplies again become scarce or expensive.

Forecasts for Electrical Power Generation

Roberts and Kruger(1986) give results from the tenth annual survey of the utility industry made by the Electric Power Research Institute (EPRI) for the purpose of obtaining estimates of future geothermal capacity. They also show data on projected electric supply and demand compiled by the North American Electric Reliability Council (NERC) and by the Western System Coordinating Council (WSCC). NERC predicts that the net energy load for the whole U.S. will grow at an annual rate of 2.26 percent per year between now and 1994, and WSCC predicts a growth rate in load of 2.33 percent per year over the same interval for 13 western states. For comparison, Table 5 shows the projected electrical generating capacity by fuel type for the whole U.S. and Table 6 shows the same data for the 13 western states. For the U.S. as a whole, geothermal energy presently contributes 0.2 percent of our generating capacity, and by the year 1994, this contribution is expected to grow to 0.5 percent. In the west, geothermal energy provides 1.6 percent of our electrical capacity, and this amount is expected to grow to 2.4 percent by the year 1994. These tables also indicate that the contribution by oil and gas will decrease for the U.S. between now and 1994, and that the growth rate for geothermal energy will be larger than that of any other fuel.

Results from the tenth annual EPRI survey of utilities are shown by region in Table 7. The 1986 data are actual while the rest are utility estimates. The figures are given at three levels of confidence: (1) Announced (An) - either publicly or through PUC-type reports; (2) Probable (Pr) - based on successful demonstration of technology for cost-effective use of liquid-dominated resources; and (3) Possible (Ps) - based additionally on anticipated growth of electricity demand and favorable regulatory treatment. The Gulf states comprise the states with potential resources of geopressured thermal and natural gas deposits. The northwest states include the contribution from British Columbia and Alberta. It is noted in Roberts and Kruger (1986) that several of the newest plants are designed to operate with rotary separator turbines or binary cycles, which should accelerate the development of the more numerous moderate-temperature geothermal resources.

We see that, whereas the current geothermal electrical capacity is 2115 megawatts in the U.S., there is the probability of having 6800 megawatts and the possibility of having 10,000 megawatts by the year 2005. These amounts would correspond to annual growth rates of 6.3 percent and 8.5 percent, respectively, in reasonable agreement with the NERC (1985) and WSCC (1986) estimates for geothermal energy. All of these figures tend to confirm Lacy's (1986) conclusions, discussed previously, that geothermal energy has the opportunity to penetrate the market to a much more significant extent in the next decade than it has so far. It is worthwhile noting that none of these surveys anticipate significant development of hot dry rock or magma energy resources in the time frames of the forecasts.

CONCLUDING REMARKS

There are critical conditions that must be met if geothermal energy is to make the future contributions predicted. There is a need for research and technology development to reduce costs and risks of developing, installing and operating geothermal plants. The fledgling geothermal industry has been looking to the federal government to provide most of this research, and the federal government is turning an increasingly deaf ear. Whereas the National Energy Policy Plan published in the fall of 1983 calls for development of a mix of energy resources, with some emphasis on renewable types, the geothermal research budget has been steadily shrinking. At $20 million for FY87, it is a factor of about 9 The geothermal budget has been repeatedly cut by the Office of Management and Budget (OMB) and there are only a few members of Congress that appear to have enough interest in furthering geothermal development to restore moneys. Yet, geothermal energy is the only one of the so-called "renewable" energies that is contributing significantly to U.S. energy needs. The main components of the geothermal budget are now politically determined in Congress and are earmarked for the more futuristic types of geothermal resources, namely the hot dry rock and geopressured resources. No one in industry or the government predicts that these resource types will make significant contribution to the energy mix in the United States until well into the next century. The share of the budget allocated for the type of research which Lacy (1986) and many other industry people recommend is deemed to be wholly inadequate for the job. These research needs are mainly in topics designed to assist industry in the development of hydrothermal resources, and include:

1. Research to bring down the cost of drilling a well field. Research should take place on two broad fronts; in learning how to drill more cheaply, and in learning how to site wells more efficiently, so that there are fewer unsuccessful wells. The cost of putting in the well field is about half of the total development cost for generating electric power.

2. Research to increase our ability to predict the long-term behavior of a reservoir and to design better production and injection strategies. Utilities and financial institutions are understandably reluctant to commit money and resources to a geothermal project if long-term production from the resource can not be guaranteed.

3. Research to increase the efficiency of conversion, so that the more plentiful lower-temperature resources can be used.

In addition to these research needs, both the federal and the state governments need to streamline the permitting process and other aspects of regulation to the maximum extent possible. This will help the developers to hold down costs and enable them to proceed in these highly competitive times.

I have concluded that our elected officials in Congress and many people in the present Administration have little interest in the energy industry in the U.S. They are not likely to develop an interest until the next energy crises, which some people believe is not far off. We have a brief period now of plentiful energy during which we can either prepare to ensure an adequate supply of acceptable forms of energy for our future or we can neglect to act and be overtaken again as world markets undergo another high-amplitude swing. I believe that groups such as the Interstate Oil Compact Commission, which has an understanding of the energy industry in the U.S. and the world market that it operates in, have a duty to help educate the public at large, and our elected officials in particular, to the facts of our energy-based society. I encourage you to take this duty seriously. Our future depends on us.

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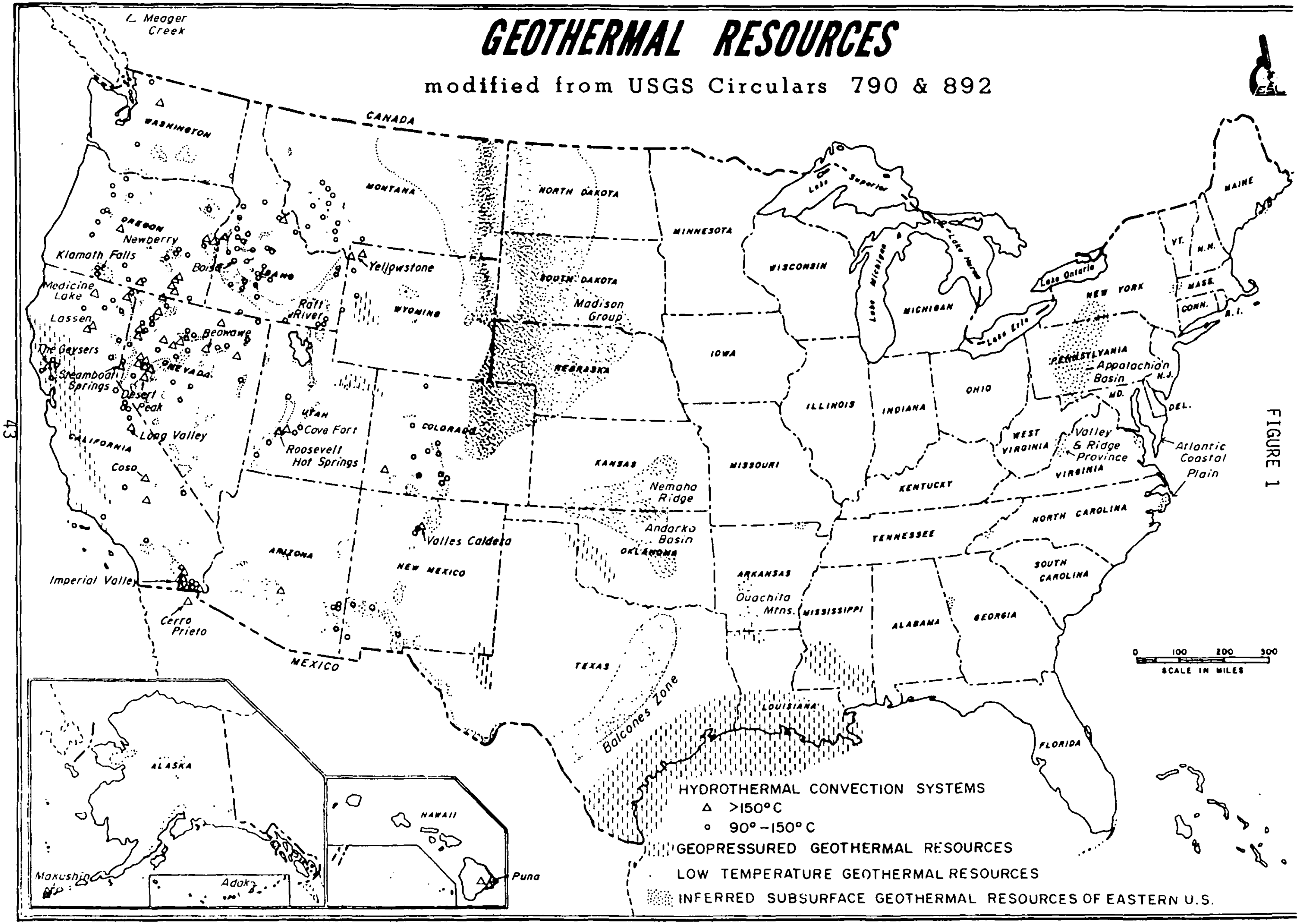
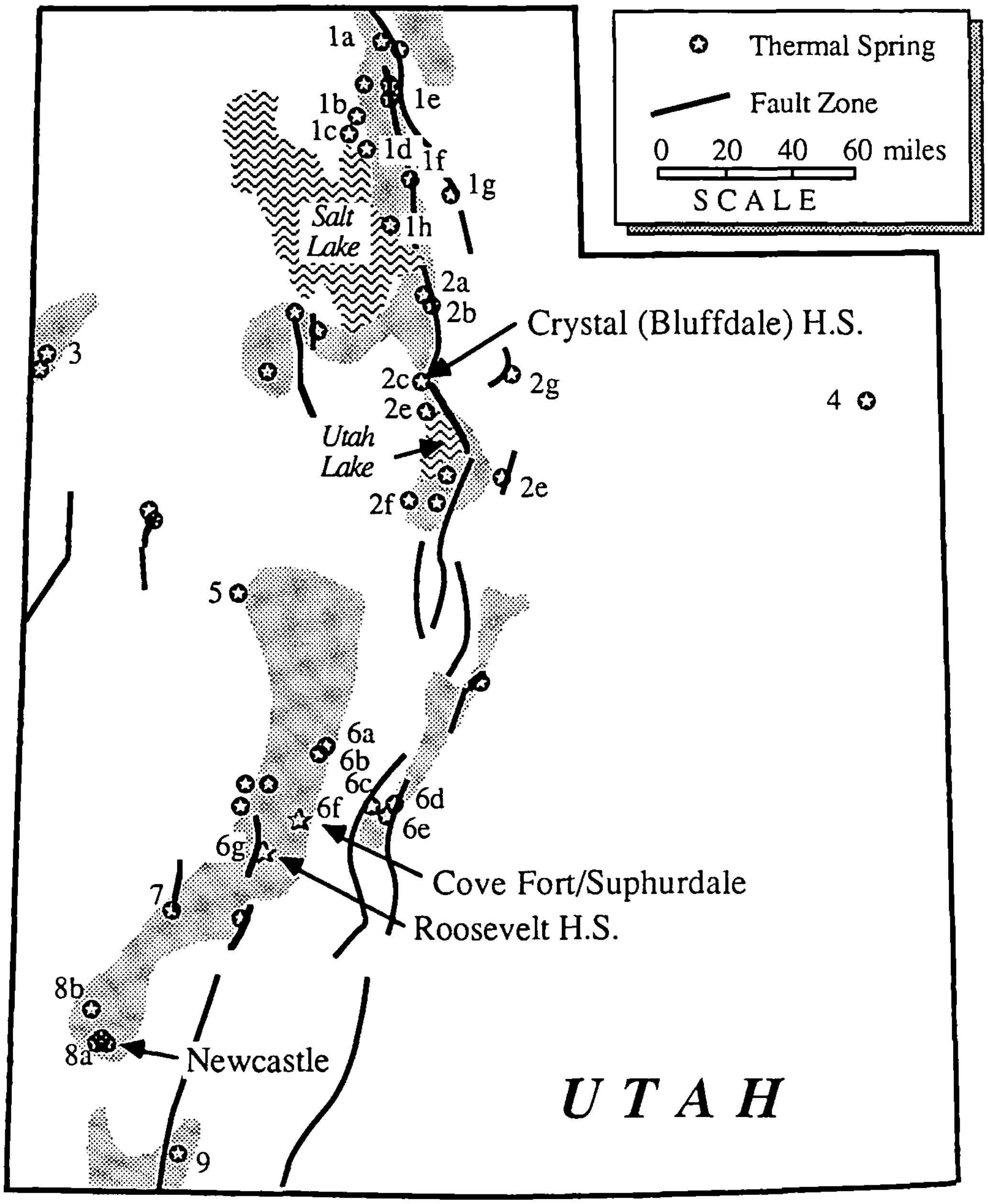


FIGURE 1

Geo/RM-003

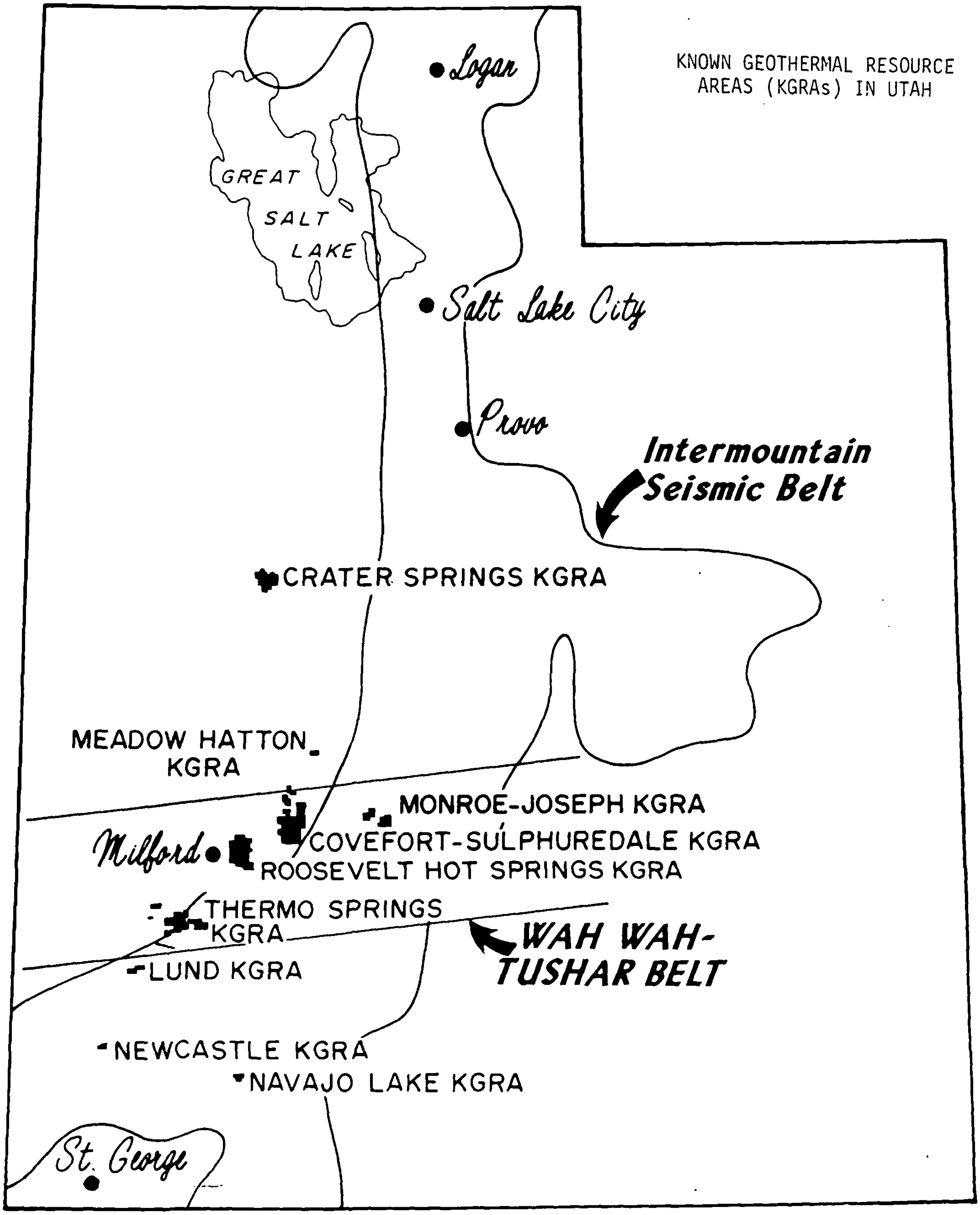
FIGURE 2



GEOTHERMAL OCCURRENCES IN UTAH

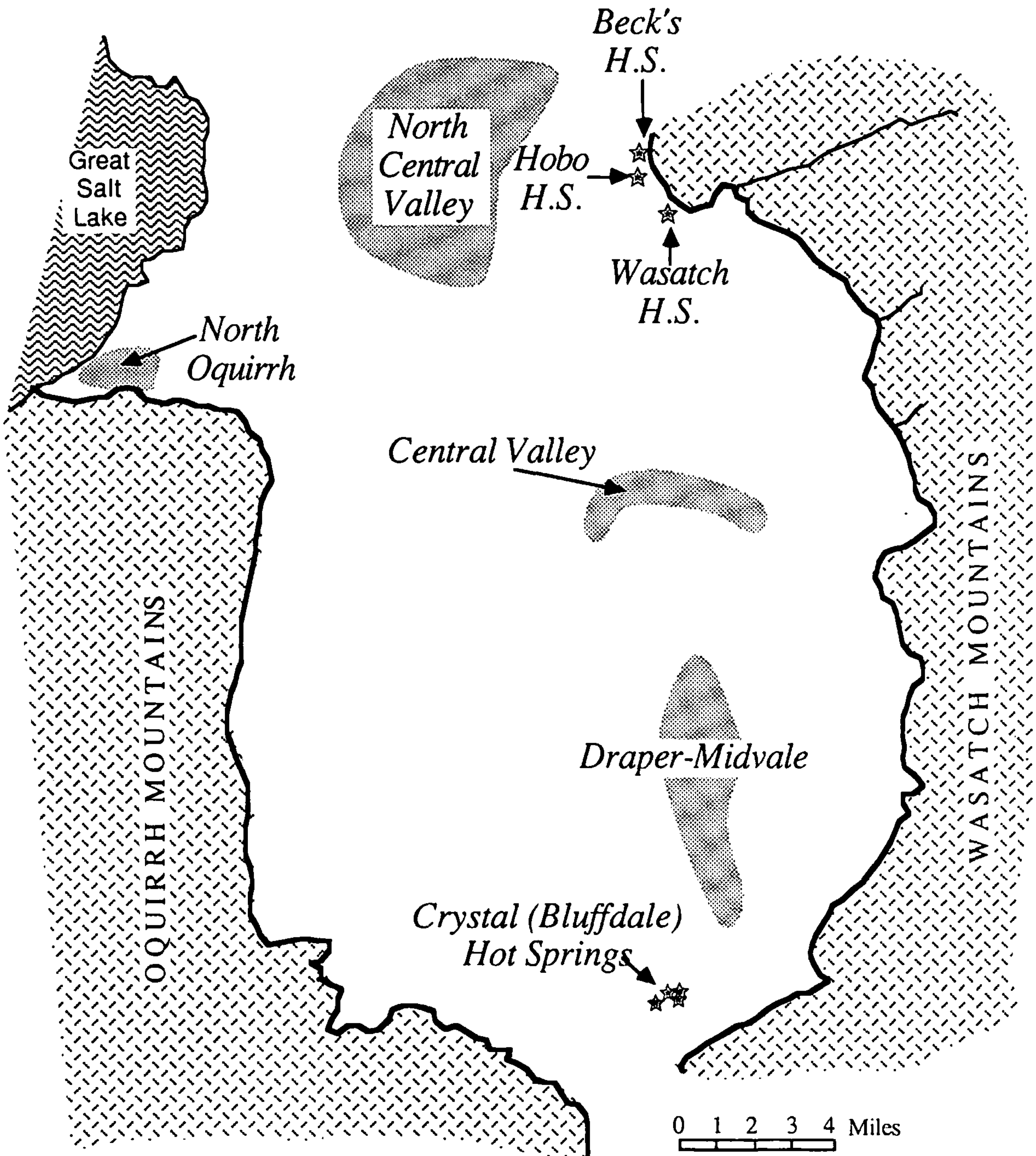
FIGURE 3

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs) IN UTAH



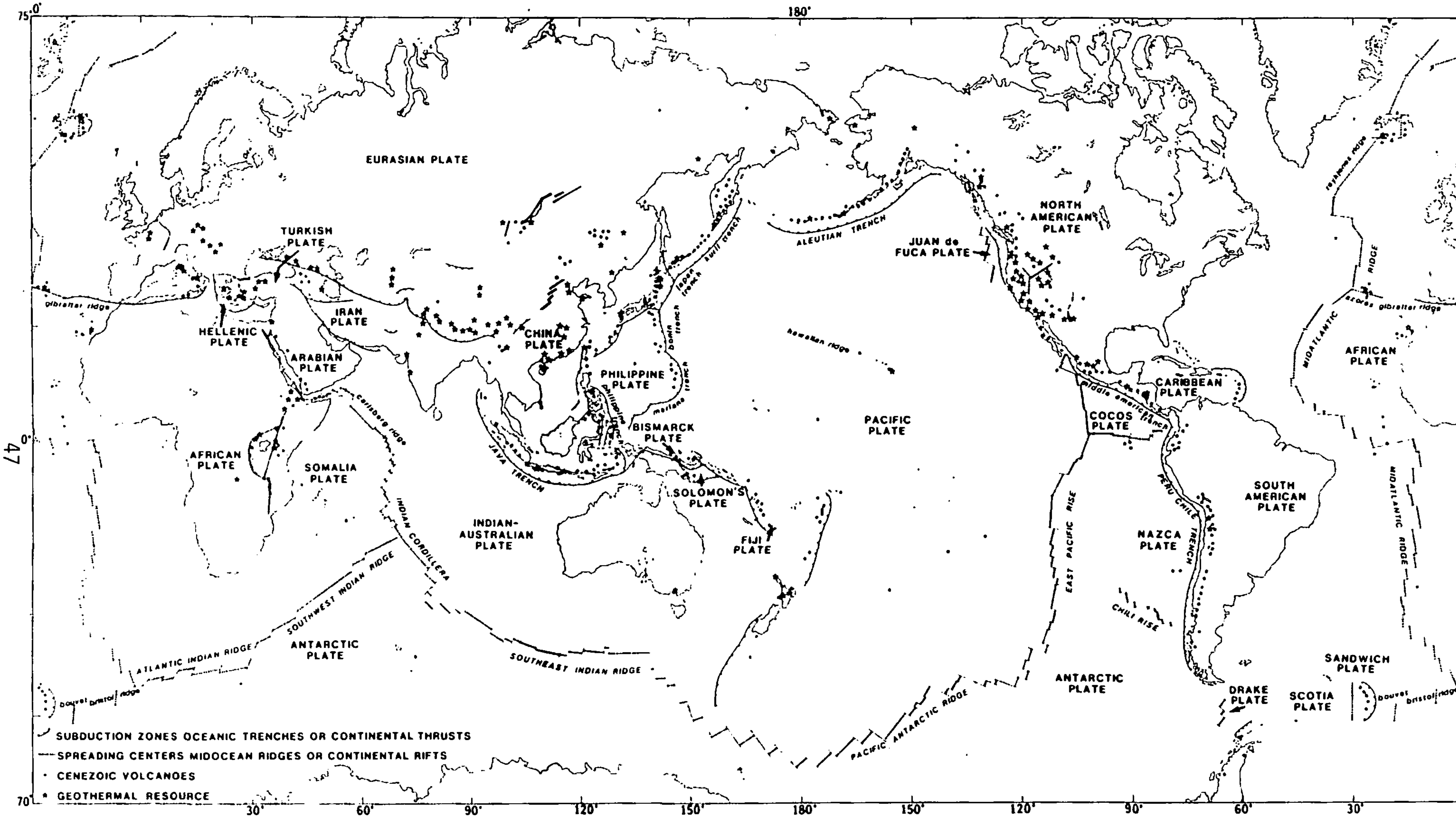
UT/L-17

FIGURE 4



Geothermal Occurrences in the Jordan Valley

(after Klauk, 1984)



GEOTHERMAL RESOURCES AND PLATE TECTONIC FEATURES

FIGURE 5

TABLE 1

Geothermal Resource Classification

(Modified from White and Williams, 1975)

Resource Type	Temperature Characteristics
Convective Hydrothermal Resources	
Vapor dominated	~ 240°C
Hot-water dominated	~ 30°C to 350°C +
Other Hydrothermal Resources	
Sedimentary basins/Regional aquifers (hot fluid in sedimentary rocks)	~ 30°C to 150°C
Geopressured (hot fluid under pressure that is greater than hydrostatic)	~ 90°C to 200°C
Radiogenic (heat generated by radioactive decay)	~ 30°C to 150°C
Hot Rock Resources	
Part still molten	higher than 600°C
Solidified (hot, dry rock)	90° to 650°C

TABLE 2

SELECTED SPRINGS AND WELLS IN UTAH

	NAME		DISCHARGE TEMP,C	DISCHARGE FLOW,GPM	ESTIMATED RESV. TEMP,C	DEPTH, FT
4	Ashley Valley field		55	-	-	4200
2a	Beck's	hs	55	-	60-100	
3	Bonneville DBW3	dh	88	-	-	1636
2f	Burgin Mine		55	2700	-	
2g	Castilla	hs	40	20	50-90	
1d	Chesapeake Duck Club	dh	74	20	-	-
8a	Christensen Bros	dh	96	1700	-	500
6f	Cove Fort/Sulp. area		175	-	180-225	av 1200
5	Crater (Abraham)	hs	87	250	100-150	
1e	Crystal (Madsen)	hs	55	1600	30-90	
2c	Crystal (Bluffdale)	hs	58	-	90-120	
8b	DeArmand #1	dh	149	1000	-	7000
6b	Hatton	hs	36	25	70-110	
1h	Hooper	hs	60	-	80-120	
6c	Joseph	hs	65	100	90-150	
9	Laverkin	hs	42	4500	50-90	
1c	Little Mountain	hs	42	450	-	
6a	Meadow	hs	41	-	70-120	
2d	Midway area		40	200	-	
6e	Monroe	hs	76	40	90-120	
1g	Ogden	hs	58	75	70-100	
8a	Newcastle area		95	-	140-170	
6d	Red Hill	hs	76	40	100-160	
1a	River Pools	hs	46	5500	-	
6g	Roosevelt	hs	85	10	260-290	
6g	Roosevelt area		-	-	240-260	av 8500
2e	Saratoga	hs	46	125	60-100	
1b	Stinking	hs	51	50	70-90	
7	Thermo	hs	83	30	140-200	
1a	Udy (Belmont)	hs	43	900	50-90	
1f	Utah	hs	58	-	70-100	
2b	Wasatch	hs	42	-	50-90	

Note. The number-letter designation left of the name is keyed to locations on Figure 2.

TABLE 3

Worldwide Geothermal Electricity Generation

OCTOBER 1985
(After D. Pippo) (After Di Pippo, 1985)

Country	Operational	Under Const. or Planned
	Generating Capacity, MW	
KENYA	45.0	60
EL SALVADOR	45.0	30
NICARAGUA	35.0	35
MEXICO	425.0	865
UNITED STATES	2022.0	1309
CHINA	14.0	–
TURKEY	20.6	–
AZORES	3.0	–
USSR	11.0	230
ICELAND	39.0	–
GUADELOUPE	4.2	–
ITALY	459.0	60
INDONESIA	32.3	965
JAPAN	215.0	108
NEW ZEALAND	167.0	116
PHILIPPINES	894.0	1303
	4431.1 MW	5081 MW

Table 4

Worldwide Geothermal Direct Use

(After Gudmundsson, 1985)

Country	Power (MW)	Energy (GWh)	Load (%)
China	393	1945	56
France	300	788	30
Hungary	1001	2615	30
Iceland	889	5517	71
Italy	288	1365	54
Japan	2686	6805	29
New Zealand	215	1484	79
Romania	251	987	45
Soviet Union	402	1056	30
Turkey	166	423	29
United States	339	390	13
Other	142	582	47
total	7072	23957	39*

* Based on total thermal power and energy

TABLE 5

U.S. Electrical Capacity by Fuel

(NERC, 1985)

Fuel	Existing 1984 (GW)	(%)	Forecast 1994 (GW)	(%)	Growth (%/a)
coal	262.3	43.4	311.6	43.8	1.74
oil and gas	103.4	17.1	99.0	13.9	-0.43
dual + other	91.3	15.1	98.0	13.8	0.71
water	83.7	13.9	88.1	12.3	0.51
uranium	62.1	10.3	111.7	15.7	6.05
geothermal	1.42	0.2	3.23	0.5	8.56
totals	604.2		711.6		1.65

TABLE 6

WSCC Electrical Capacity by Fuel

(WSCC, 1986)

Fuel	Existing 1986 (GW)	Existing 1986 (%)	Forecast 1996 (GW)	Forecast 1996 (%)	Growth (%/a)
water	60.0	43.9	63.5	39.6	0.57
oil and gas	35.9	26.3	41.8	26.1	1.53
coal	30.8	22.5	39.1	24.4	2.41
uranium	7.8	5.7	12.0	7.5	4.40
geothermal	2.2	1.6	3.9	2.4	5.89
totals	136.7		160.3		1.61

TABLE 7

1986 EPRI Utility Geothermal Survey

(Roberts and Kruger, 1986)

	Capacity (MWe) by Year		
	actual	estimated	
	1986	1995	2005
Southwest			
An	67	159	159
Pr		247	730
Ps		597	1845
Northwest			
An	0	0	0
Pr		20	60
Ps		35	145
CA/HI			
An	2048	3509	3509
Pr		4439	6003
Ps		5434	8058
Gulf States			
An	0	0	0
Pr		0	0
Ps		5	20
Total Forecast			
An	2115	3668	3668
Pr		4706	6793
Ps		6071	10068