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LOW-TEMPERATURE GEOTHERMAL RESERVOIR SITE EVALUATION IN ARIZONA

QUARTERLY PROGRESS REPORT FOR PERIOD
NOVEMBER 1, 1977 - JANUARY 31, 1978

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ABSTRACT

The Department of Energy, Division of Geothermal Energy, has charged the Bureau of Geology and Mineral Technology, Geological Survey Branch with the development of a cost-effective exploration program for low- to moderate-temperature geothermal resources. As part of this program two or three demonstration projects in Arizona will be brought on stream.

The site-specific exploration, evaluation and development program as well as the state wide reconnaissance exploration program is continuing. The compilation of data for the 1:500,000 geothermal energy resource map is continuing. Drafting and data collection for the 1:1,000,000 preliminary map, Geothermal Energy Resources of Arizona, Geothermal Map No. 1, requested the first week in January by DOE/DGE is nearing completion. This preliminary map should be published in March, 1978.

All outside projects are either complete or on schedule.

RESEARCH OBJECTIVES

The principal research objective of this program is the development of a successful exploration technique for the location, evaluation and development of low- to moderate-temperature geothermal resources for use by the general public and private industry. The development of an efficient exploration program, which is also cost-effective will require the close coordination of the three geoscience disciplines: geology, geophysics and geochemistry.

For immediate utilization, low- to moderate-hydrothermal energy resources, to be economic, must be located near the user whether it be for space heating or cooling, or, industrial processing. Current plans call for three demonstration projects, utilizing low- to moderate-temperature hydrothermal geothermal energy, to be brought on stream. The first two projects will be the training and testing ground for the third demonstration project which must be brought on stream through utilization of an economic, cost-effective exploration and development program.

While the detailed or site-specific exploration, evaluation and development programs are in progress, the reconnaissance exploration program will continue to attempt to locate additional areas of interest. Current thinking is that the reconnaissance program will cover the entire State of Arizona. At present, however, most of the available data is in the Basin and Range physiographic province.

Another object of this program is the compilation of a special library on geothermal energy. This comprehensive geothermal library will be for public use at the Geological Survey Branch of the Bureau of Geology and Mineral Technology in Tucson, Arizona.

The program has been expanded to include the compilation and publication of a geothermal energy resource map of the State of Arizona. This map will be produced through a joint effort by the U.S.G.S. Geotherm project, the National Oceanic and Atmospheric Administration and the Arizona Bureau of Geology and Mineral Technology, Geological Survey Branch. It is anticipated that the map will be available to the public in 1979.

INTRODUCTION AND REVIEW

The Arizona geothermal energy program was initiated in response to prior geothermal research and reconnaissance programs conducted primarily under the aegis of the federal government. The inital program, extremely limited in scope, rapidly expanded to an exploration and development program for geothermal energy covering the State of Arizona. The primary emphasis of the program is the location and development of low- to moderate-temperature geothermal resources. However, moderate- to high-temperature geothermal resources, including hot dry rock, suitable for electrical generation will not be bypassed.

A major mission of the Arizona program is the development of a cost-effective exploration program for low- to moderate-temperature geothermal resources. A second short term project is the compilation and publication of a geothermal energy resource map for the State of Arizona. A third ongoing project is the establishment of a comprehensive library on geothermal energy to be available to the public.

The period November 1, 1977 through January 31, 1978, of the Arizona exploration and development program for low- to moderate-temperature geothermal energy (to 140^{o} - $150^{o}C$) was one of considerable progress. All outside projects are on schedule or have been completed. The drafting of the ten plates for the preliminary map of the geothermal energy resources of Arizona was completed.

PROGRAM PERSONNEL

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COMPLIANCE WITH CONTRACTUAL REQUIREMENTS

The principal investigator, W. Richard Hahman, Sr., in accordance with Article I and Article A-I of Appendix A of DOE Contract EG-77-S-02-4362 has devoted his full time, from November 1, 1977 through January 31, 1978, to the contract work. He plans to devote his full time to the contract work during the next quarter, February 1, 1978 through April 30, 1978. The principal investigator and the program are in compliance with the requirements of the contract.

W. Richard Hahman, Sr.

OPERATIONS

Geology

On January 9, 1978, the U.S. Department of Energy, Division of Geothermal Energy requested the Arizona exploration team to construct a preliminary geothermal energy resource map for the state. Work on the project commenced January 9th and the completed maps were returned from the printer March 3rd. The map is printed in color on scale-stable Kimdura synthetic paper. This map shows locations of thermal springs, lineaments, extrusive igneous rocks 3,000,000 years and younger, regions of high geothermal gradients, high heat flow, high chemical geothermometers, warm and hot wells and areas with potential for hot dry rock.

During the prior nine months of exploration and evaluation, five areas have been designated for more detailed investigation. These areas are: (1) Springerville-St. Johns, (2) Clifton-Morenci-Safford, (3) San Bernardino valley, (4) Phoenix, and (5) Tucson. In addition, an area near the prison complex in Florence will probably be investigated for the purpose of determining the possibility of supplying geothermal energy to the facility.

The geological program, as well as determining new regions of investigation, includes detailed and reconnaissance mapping using as base maps the available U.S.G.S. topographic maps. Attention will be given to determining the structure, stratigraphy, alteration and lithologic relationships of important rock units. The subsurface structure and stratigraphy, as determined from drill logs and cuttings on file with the Bureau of Geology and Mineral Technology, Geological Survey Branch in Tucson, will be studied, where available, in order to construct a three dimensional geologic picture which is most necessary in order to define and model the geothermal energy resource under investigation.

The geochemical program consists primarily of collecting for chemical analyses 500 water samples from wells and springs. This sampling program is designed to supplement previous work done by the U.S. Geological Survey and Dr. Chandler Swanberg of New Mexico State University. Sampling will be conducted in the main areas of interest and also on a regional reconnaissance basis. Each sample will be analyzed for Na, Ca, K, SiO_2 and total dissolved solids. Eh and pH measurements will be conducted in the field at the time of sample collection. The elements and compounds being analyzed are used as geochemical geothermometers to determine possible/probable subsurface reservoir temperatures.

Additional money has been budgeted in the geochemical program for soil and rock analyses, rock age dating, and the manufacture of thin-sections for petrographic analysis.

The geophysical program is currently in a state of flux. Dr. Marc Sbar, Seismologist, University of Arizona, has planned a passive seismic study in three areas, Springerville-St. Johns, Clifton-Morenci-Safford and San Bernardino valley.

The purpose of this passive seismic study is as follows:

1. map active faults which may serve as conduits for hot water or steam
2. determine principal stress orientations in the area of the seismicity
3. determine orientation and sense of strike and/or dip slip on the faults
4. define the extent and depth of a magma chamber, should one exist within the limits of detection of the survey
5. detect regions of fluid saturation
6. detect active fluid movement within the seismic study area

As well as contributing valuable exploration information to the program, the passive seismic survey will also contribute to the environmental assessment of the areas under exploration. The monetary value of the passive seismic program and the information obtained from it will greatly exceed the actual cost of the program.

At the present time negotiations to combine geophysical programs are underway among Los Alamos Scientific Laboratory, outside advisors to the Arizona program, New Mexico State University, and the Geological Survey Branch, University of Arizona, all of whom have planned to undertake geophysical work in Arizona this year. The combined programs would cover more and larger areas, thereby maximizing effort and minimizing cost.

Additional geophysical programs, including well temperature logging and heat flow measurements are being planned and will be conducted by the combined groups. Monies have been budgeted to assist these programs.

Geophysics

The following report, Recent Research on the Gravity of Arizona, by Dr. John S. Sumner, Department of Geosciences, University of Arizona follows.

"The Arizona gravity data base is currently being expanded to include gravity observations made and reported by groups outside of the University of Arizona. In particular, data sources that have been located are the Arizona State University Master of Science theses by Deslanriers (1977), Jennings (1977) and Lausten (1974). With the inclusion of the gravity data from these theses the Arizona gravity data base will be expanded by an additional 700 data points in the areas of Maricopa and Pinal counties.

"The possibility of acquiring gravity data obtained by Northern Arizona University students is being investigated. Also, inquiry is being made into other possible data sources such as mining companies."

The following report, Thermal Gradients in Arizona, by Claudia Stone, Bureau of Geology and Mineral Technology, Geological Survey Branch, University of Arizona discusses several anomalous areas.

"Temperature gradient is a measure of the change in temperature with increasing depth in the earth. It has been found that, apart from the top few tens of meters of the earth's crust which are subject to seasonal change, the temperature steadily rises with increasing depth at a rate of about 30°C/km. At the surface, however, temperature gradients vary considerably, ranging from less than 10 to more than 50°C/km. This variation is due mainly to differences in the thermal conductivity of the soil and rock through which heat slowly travels by conduction; it is also due in part to the mean annual temperature of the area, and in part to local radioactivity. Truly anomalous, high temperature gradients are caused by conditions other than those cited above, and this distinction must be made in determining whether a high temperature gradient is anomalous. Anomalous thermal gradients may exist near the surface due to (1) magmatic intrusion into the upper crust, or (2) upward convection of hydrothermal water along fractures zones. Such ground water could be heated by descending to deeper levels of the fracture zone where gradients are high but normal for that depth, or by above-normal gradients associated with magmatic intrusion into the lower crust.

"The preferred method of measuring the temperature gradient is to probe the total depth of a well or bore hole at five-meter intervals after equilibrium, initially disturbed by drilling, has been re-established. A less accurate method is to compute the gradient by extrapolating a measured temperature (either bottom hole or pumped-water temperature) over the total depth of the well.

"Heat flow is the product of the temperature gradient and the thermal conductivity and, unlike a simple gradient, it is reasonably constant over many parts of the earth, the average value being 1.5×10^{-6} cal/cm^2 sec. Areas of anomalous heat flow for this reason are more accurately detected than are areas of anomalous thermal gradients. One problem encountered in computing heat flow values, however, is that of obtaining adequate core or cutting chips from the bore hole on which to measure the thermal conductivity. This problem is not encountered in computing or measuring temperature gradients, thus making an assessment of gradient data an easier, more rapid, and less expensive geothermal reconnaissance tool. While accuracy is sacrificed for ease with this latter method, temperature gradients are nevertheless a useful way in which to take a "first look" at the thermal character of an area.

"A reliable evaluation of thermal gradients in Arizona is presently constrained by two problems. The first problem is that most of the currently available thermal gradient data were computed rather than measured. In addition, possible errors may exist in the data due to (1) non-equilibrium conditions existing in the well at the time the temperature measurement was made, and (2) possible mixing of waters in the producing zone. The second problem is more qualitative and occurs because the paucity of information in many areas of the state necessarily precludes a definitive assessment of the entire state by this method at the present time. Nevertheless it is felt that the computed thermal gradients for Arizona warrant more than a casual examination at this time. During the next year additional gradients will be computed from the literature and from unpublished sources for counties presently lacking gradient data. More importantly, many temperature gradients will be measured throughout the state, in situ, at five-meter intervals, in an effort to increase the resolution and confirm the validity of suspected anomalies and to fill the numerous gaps which currently exist in the thermal gradient map of Arizona. Where cores or cuttings are available from a well or bore hole, a heat flow value will be computed as well.

"Preliminary contouring of the existing temperature gradient data reveals the occurrence of areas of high thermal gradients in all quadrants of the state. Most high gradients occur in the Basin and Range physiographic province as might be expected, but the lack of adequate information for many parts of the state, as mentioned above, undoubtedly biases the present picture. Three areas of anomalously high gradients are discussed in the present report; the completed map will be published in the next report.

"The first anomaly (Fig. 2) occurs in Maricopa county, east of the cities of Mesa and Chandler. Williams Air Force Base and the town of Buckhorn lie within the immediate area (Fig. 1). That portion of the anomaly where gradients exceed 150°C/km covers a surface area of approximately 4 km^2 (2.5 $mi.^2$). Gravity data (CAP Report, 1976, Fig. 80) indicate that the anomaly lies within a structural basin with gravity lows to the south and southeast. Depth to crystalline rock is estimated at greater than 1500 m. The existence of a possible anomaly in this area is supported by the following independent evidence. (1) The area shown in Fig. 2) is part of a larger region designated a Known Geothermal Resource Area by the State Land Department. (2) A report by Swanberg and others (1977) shows moderate thermal gradients (36 to 150°C/km) extending across and to the west of the region. (3) A map prepared by Druitt and Conley (1977) indicated the presence of moderate (50 to 165°C/km) and high (greater than 165°C/km) thermal gradients within the area. The anomalous gradients are most likely caused by hydrothermal convection of ground water heated at depth and rising along the fault planes of numerous faults cross cutting the basin.

"The second anomaly (Fig. 3) is west of Phoenix, between Phoenix and the White Tank Mountains (Fig. 1). Gravity data (CAP Report, 1976, Fig. 50) indicate that the area lies within a structural basin with estimated maximum depth of about 300 - 3600 m. The area is cut by a northwest trending basement fault. The gravity low in this basin occurs in the northeast corner of Fig. 3 and somewhat to the north thereof. Additional evidence for this anomaly follows. (1) Swanberg and others (1977) show high heat flow (greater than 2.5 H.F.U.) and high chemical geothermometers in this region. (2) Druitt and Conley (1977) indicate the presence of moderate (50 to 165°C/km) and high (greater than 165°C/km) thermal gradients. A highly faulted and structurally complex prophyry copper deposit, with associated Tertiary volcanics thought to be rhyolite, is known to occur at the north end of the White Tank Mountains (W. Richard Hahman, Sr., personal communication, 1978). Igneous intrusives associated with the volcanics most probably give rise to the hydrothermal fluids responsible for the observed anomaly. Additional heat may also be supplied by the upward migration along a fault plane of ground water heated at depth where the near-normal gradient is high.

"The third anomaly (Fig. 4) is located in east-central Apache county, east of the Petrified Forest National Park (Fig. 1). Two small areas with anomalously high thermal gradients, 75-150°C/km, are surrounded by a region of lower gradients, 37-75°C/km (Fig. 4). The Geologic Map of Navajo and Apache Counties (Wilson and others, 1960) depicts within the area a northwest-trending anticline truncated to the southeast by a northeast-trending fault. Small outcrops of Quaternary basalt are found to the west and south of the region. The White Mountains, approximately 35 miles to the south, were the site of middle to late Cenozoic volcanism (Merrill and Pewé, 1978) Gravity is relatively constant across the area, decreasing eastward on a regional scale from -220 to -225 milligals (West and Sumner, 1973). Additional evidence for a thermal anomaly follows. (1) Druitt and Conley (1977) identified 22 shallow wells with temperature gradients between 15-50°C/km, trending parallel to the Puerco River where it flows southwest through the area. (2) Swanberg and others (1977) identified a large region of moderate thermal gradients east of the area shown in Fig. 4. The presence of young volcanics in the White Mountains implies the presence of associated magmatic intrusives in the upper crest which are probably responsible for the heating and upward convection of ground water along fracture zones. Such hydrothermal convection and the presence of fractures in the area are the probable explanation for the anomaly.

Summary and Conclusion:

"An assessment of temperature gradient data in Arizona, supplemented additional evidence of gradient anomalies independently generated by other works, strongly suggests the presence of large areas of potentially useable low- to moderate temperature geothermal energy in Arizona. Temperature gradient data, especially data that is computed rather than measured must be used with care and must be supported by additional geological, geophysical and geochemical investigations.

"It is probable that geothermal gradient anomalies are created by factors unique to each geographic and tectonic setting. Understanding an anomaly, therefore, must be base upon a thorough site-specific geological, geochemical and geophysical assessment of the area."

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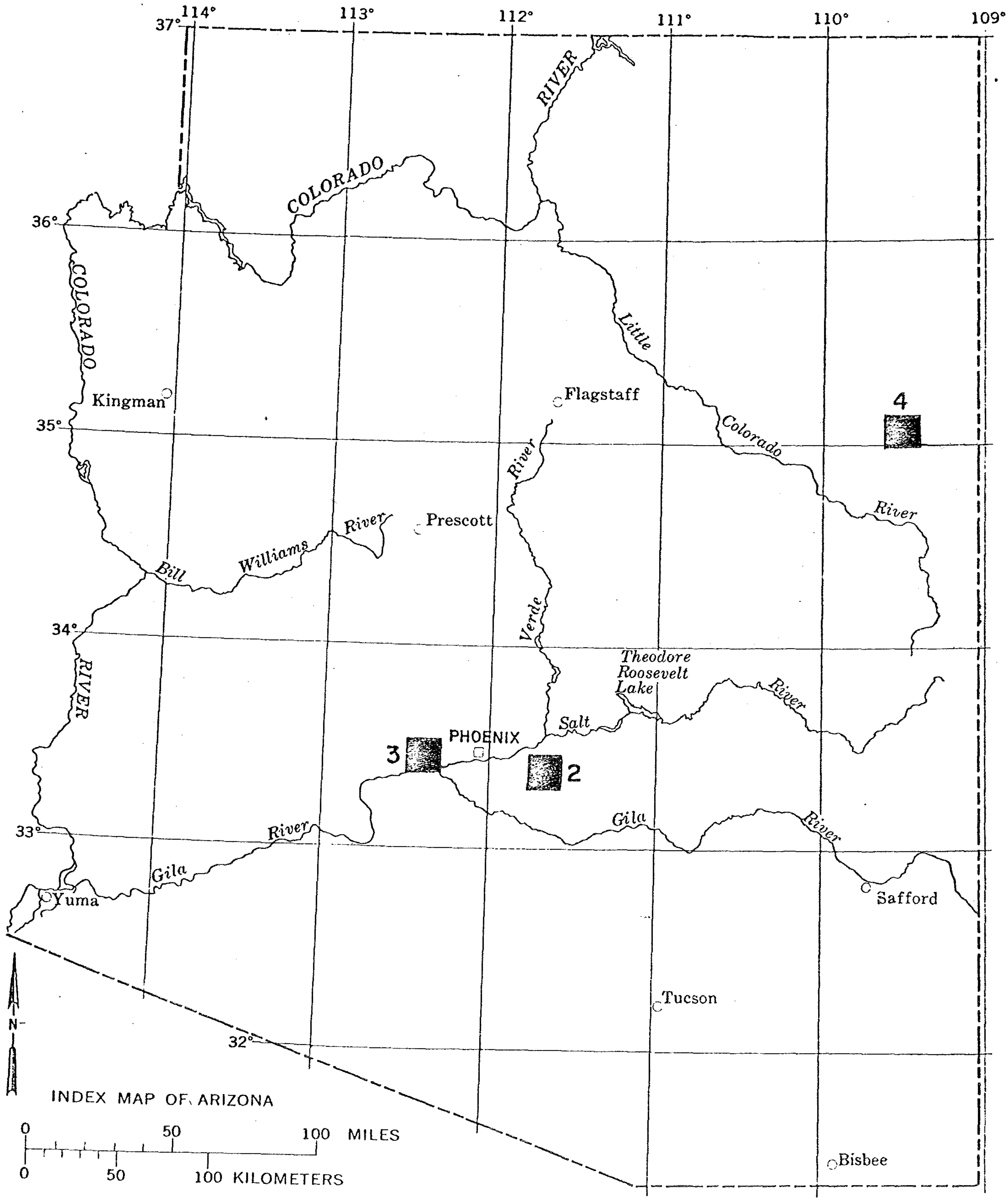


FIGURE 1: Map showing location of figures 2,3 and 4: selected areas with anomalously high temperature gradients.

MARICOPA COUNTY, AZ (BUCKHORN AREA)

T1N, R6E T1N, R7E

T1S, R6E T1S, R7E

FIGURE 2

THERMAL GRADIENTS

- > 150° C/km
- 75° - 150° C/km
- 37° - 75° C/km

SCALE

0 1 2 MILES

GILA AND SALT RIVER MERIDIAN

MARICOPA COUNTY, AZ (LITCHFIELD PARK AREA)

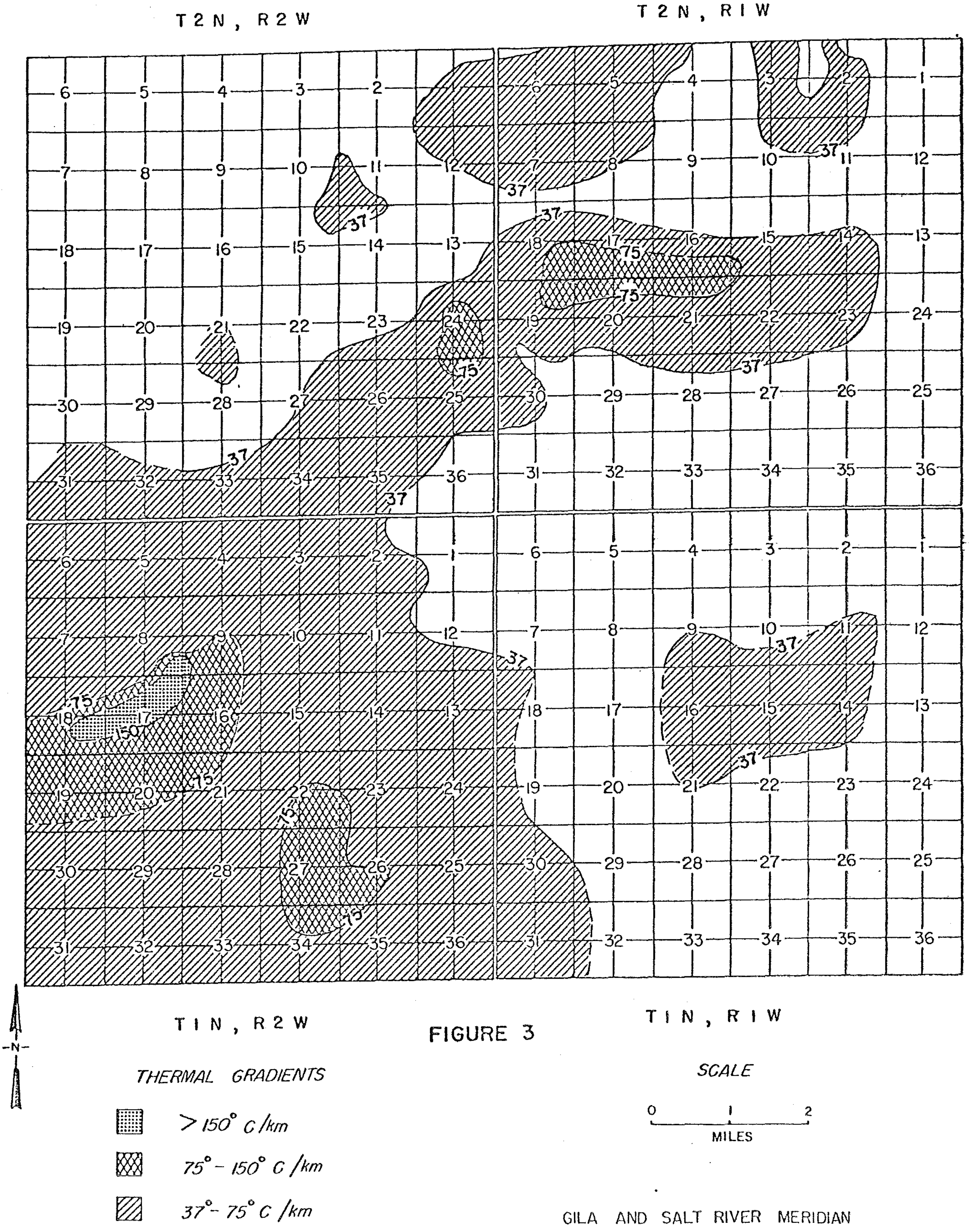
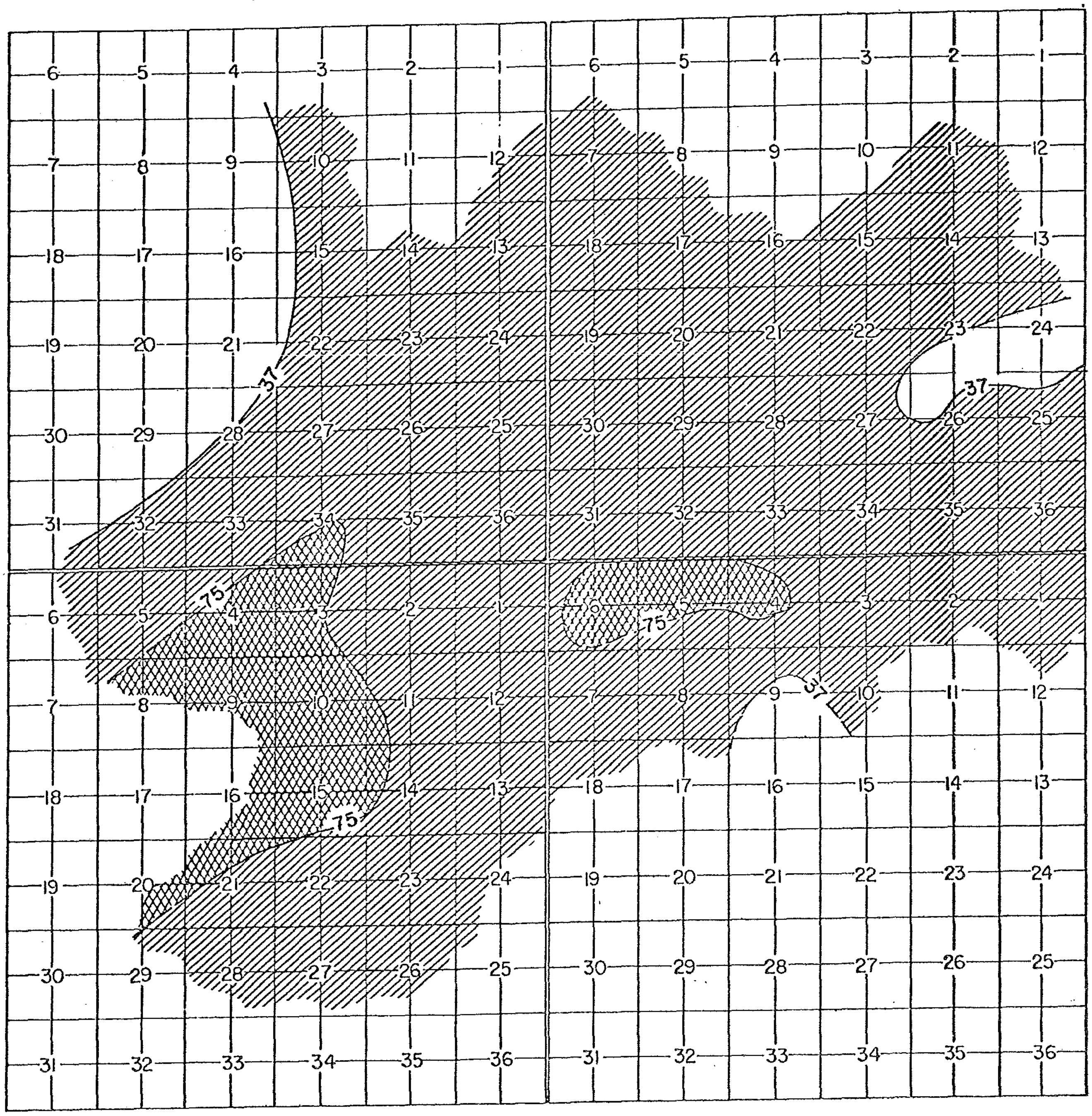


FIGURE 3

APACHE COUNTY, AZ. (EAST OF PETRIFIED FOREST NATIONAL PARK)

T 20 N, R 26 E

T 20 N, R 27 E



T 19 N, R 26 E

T 19 N, R 27 E

N

FIGURE 4

THERMAL GRADIENTS

- > 150° C/Km
- 75° - 150° C/Km
- 37° - 75° C/Km

SCALE

0 1 2

MILES

GILA AND SALT RIVER MERIDIAN