GEOTHERMAL ENERGY

INTERNATIONAL MONTHLY
JOURNAL DEVOTED TO
TERRESTRIAL HEAT UTILIZATION

VOLUME 7•NUMBER 11•NOVEMBER 1979

GEOTHERMAL ENERGY IN ARIZONA

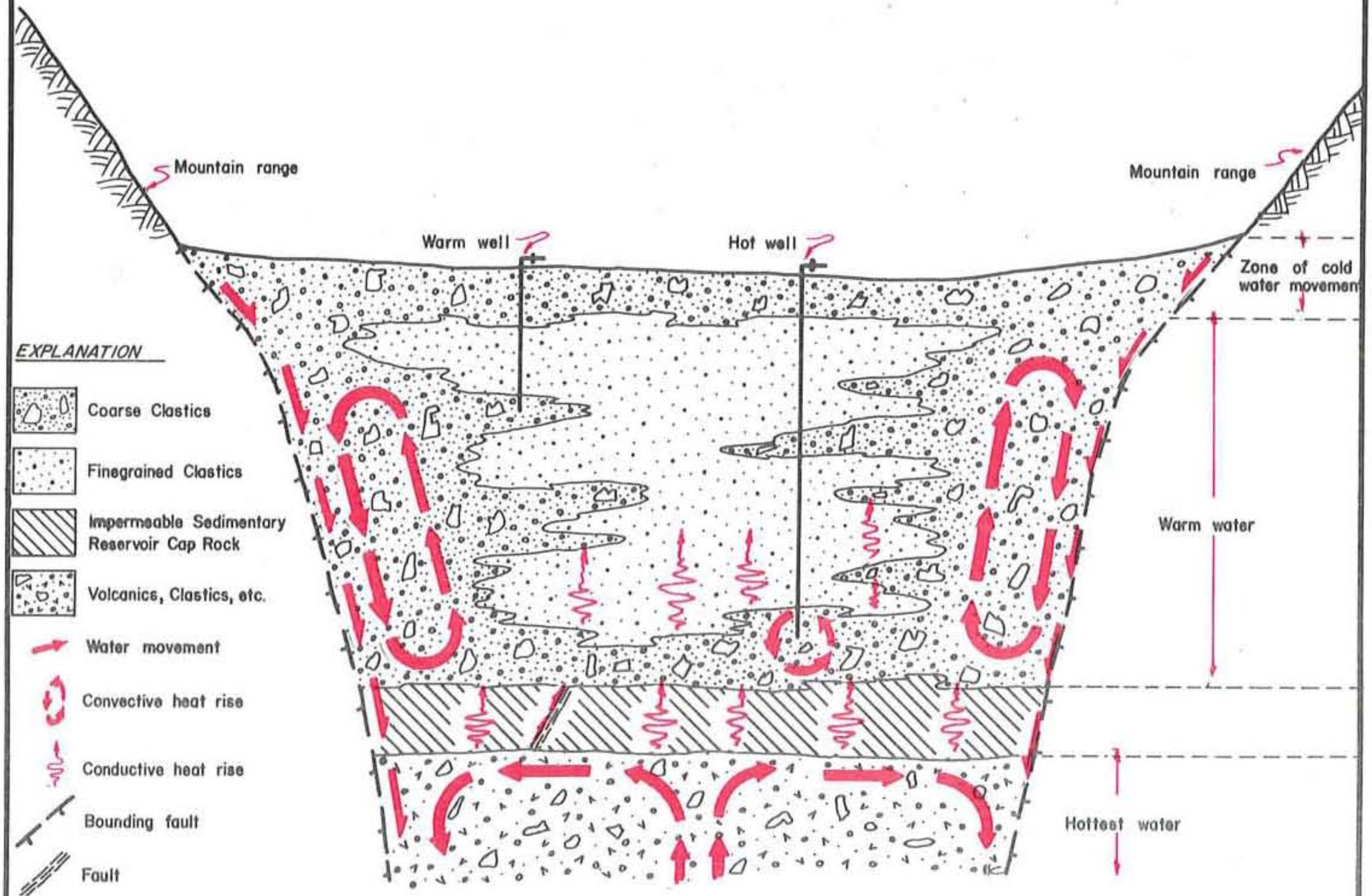


FIGURE 7. Schematic composite cross section showing probable reservoir formation and heat transfer mechanisms existing in basins of the Basin and Range province of Arizona.

REPUBLIC GEOTHERMAL, INC.

Republic is a rapidly growing and fully integrated geothermal resource company in its sixth year of operations.

Over the past several years the company has developed considerable expertise and is now actively engaged with its partners in exploring for and developing geothermal resources. Republic received the first Federal Loan Guaranty from the Department of Energy under Public Law 93-410 for commercialization of the geothermal resource at East Mesa, Imperial County, California.

The East Mesa development has demonstrated the existence of substantial commercial wet steam reserves, which will soon be developed for electrical power generation. Scale inhibitors that are available commercially are adequate to prevent scale formation in the production wells, gathering lines, and injection wells. High volume well pumping using shaft driven centrifugal pumps has been proved technologically and commercially practical.

Republic is continuing field development drilling and a team has been established to build the power plant. The General Electric Medium Turbine Division will be providing the turbines and the systems engineering and The Ralph M. Parsons company will be the architect and engineering firm. The GE/Parsons/Republic team expects to have the first power on line at East Mesa by early 1980.

Republic has been the third most active operator in the geothermal industry in footage drilled over the past three years and has ongoing projects in California, Nevada, Utah, Oregon, and recently overseas.

Republic Drilling Company, a wholly owned subsidiary, runs four rigs, three of them with depth capabilities greater than 12,000 feet. These rigs are drilling oil, gas and geothermal wells for a number of operators in California and other western states. The steady growth of the drilling company has been an integral part of the development of Republic Geothermal, Inc. as a full-fledged geothermal energy company.

The Republic team would like to thank its customers, suppliers, partners, and friends for their support and assistance in working toward achieving its corporate goal of developing commercial quantities of geothermal resources to help meet our country's growing demand for energy.

Main Office: 11823 E. Slauson Ave., Suite One, Santa Fe Springs, CA. 90670 (213) 945-3661
Land Office: 1101 College Ave., Santa Rosa, CA. 95405 (707) 527-7755

GEOTHERMAL ENERGY IN ARIZONA

By W. Richard Hahman, Sr.

ABSTRACT

The Bureau of Geology and Mineral Technology, Geological Survey Branch, using federal funds, has been exploring for geothermal energy since May, 1977. The known major geothermal systems in Arizona are apparently caused by deep circulation of meteoric water through the complex fracture systems of the Basin and Range region and transition zone. This type of system is thought to be capable of generating geothermal reservoirs with temperatures on the order of 150°C - 200°C at 2-3 km depth in the intermontane basin.

INTRODUCTION

Geothermal energy in Arizona was probably first used by the Indians who recognized the therapeutic value of the warm and hot springs. With the arrival of the white man the spa industry developed and still flourishes today in Maricopa and Graham counties.

In the early 1970's Geothermal Kinetics, Inc., and AMAX Exploration, Inc., conducted exploration programs for geothermal energy in the state. The drilling that resulted from these programs, while providing significant geological data, was not productive from an energy standpoint.

In May, 1977, the Arizona Bureau of Geology and Mineral Technology, Geological Survey Branch, with funding for low-to-moderate-temperature resource assessment from the U.S. Department of Energy, Division of Geothermal Energy, commenced its current exploration program for geothermal energy. The program was initiated in response to prior geothermal research and reconnaissance programs conducted primarily under the aegis of the federal government. The initial program was extremely limited in areal extent but expanded rapidly to include the entire state of Arizona. In 1978, the U.S. Department of the Interior, Bureau of Reclamation, became a participant in the program. The Bureau of Reclamation wishes to utilize geothermal energy as the power source for desalination of brines to augment Arizona's municipal and industrial water supply.

This paper presents some of the results of the exploration and evaluation program for geothermal energy in Arizona.

DISCUSSION

Regional Geology of Arizona

The state of Arizona may be divided into two physiographic provinces: the Colorado Plateau in the northeast part of the state, and the Basin and Range Province in the southwest part of the state (Figure 1). There is a transition zone between the two provinces. The complex lithologies and overall structure of the Basin and Range province are the result of a long history of tectonic activity that commenced during Precambrian times, over 1.5 billion years ago. The physical features visible today, such as north and northwest trending mountain ranges and sediment-filled intermontane basins, are largely the result of complex tectonic activity, predominantly regional extension, that commenced approximately 14 million years ago and may continue in some places.

The Colorado Plateau, compared to the Basin and Range province, has been tectonically stable. The land forms that characterize this province are deep canyons, broad plains, plateaus, buttes and mesas. These features have been formed by differential erosion of resistant and nonresistant sedimentary rocks.

Regional Geothermal Characteristics

Lachenbruch and Sass (1977, Figures 2 and 3, pages 629 and 630) give a regional heat flow for the Arizona Basin and Range region of 1.5 to 2.5 heat flow units. A heat flow unit (HFU) is defined as 10^{-6} calories/cm^2/second, or 41.8 mW/m^2. It is the measure used to describe the outward flow of heat from the earth over a given area during an elapsed time. The same autors give a regional heat flow for the Colorado Plateau of Arizona of 0.75 to 1.5 HFU. Since the Basin and Range Plateau, it follows that groundwater in the Basin and Range province has a greater temperature than groundwater of the Colorado Plateau.

Swanberg, Morgan, Stoyer and Witcher (1977, Figure 9, page 30) used well and spring temperature data from the U.S. Geological Survey water quality file to calculate mean water temperature values for the Colorado Plateau, 16.1°C (Gerlach, Norton, DeCook and Sumner, 1975) mean annual air temperature of that region. There is no similar correlation found in the Basin and Range province where the mean annual air temperature is 21°C (Gerlach and others, 1975). This lack of correlation confirms the occurrence of higher heat flow in the Basin and Range region.

The paucity of known thermal springs and wells, especially wells, in the Arizona section of the Colorado Plateau could be the result of lack of observation; however, it most likely is the result of the Plateau's relatively low heat flow.

The background thermal gradient for the Basin and Range province in Arizona is 30°C to 35°C/km. Current work indicates that a gradient greater than 48°C/km may be indicative of geothermal water in Arizona (Swanberg, personal communication, April, 1979).

Table 1. MEASURED THERMAL GRADIENTS - ARIZONA

Colorado Plateau		
	Nutrioso	51°C/km
		53°C/km
Basin and Range Province		
	Papago Indian Reservation	136°C/km
	Hassayampa Plain	160°C/km
		112°C/km
		86°C/km

Widely used in geothermal exploration is the theoretical relationship between water chemistry and the temperature in the originating reservoir. The silica geothermometer (Fournier and Rowe, 1966) is probably the most accurate of the water chemistry geothermometers. This geothermometer is based on the temperature dependence of quartz solubility in water. Swanberg and others (1977) estimated that the minimum temperatures for the silica geothermometer are 30° to 40°C higher for waters from the Basin and Range province than for waters from the Colorado Plateau. The higher temperatures for the Basin and Range province probably result from the higher heat flow and the deep circulation of groundwater in the alluvium-filled basins.

With the possible exceptions of the San Francisco Peaks, Springerville, San Bernardino and Pinnacate areas, Arizona does not have any obvious igneous point source system by a near-surface, igneous intrusive body generally of silicic composition, less than one million years old and often still partially molten (Figure 2). Preliminary investigations by the Geothermal Project of the Bureau of Geology and Mineral Technology indicate geothermal energy potential in the proximity of several of the younger basalt fields (Hahman, Sr., Stone and Witcher, 1978) 3 m.y.B.P. and younger in Arizona. Whether exploitable geothermal energy will be located in proximity to any or all of the Quarternary basalt fields is not known at present. Whether there is a direct cause and effect relationship between the young basalts and the geothermal energy also remains to be proved.

In Arizona, natural thermal springs and drilled wells serve as indicators of hydrothermal geothermal systems. Thermal springs and wells are widely distributed throughout the state, but are most abundant in the Basin and Range province and transition zone. Possible explanations for this relative concentration of geothermal phenomenon are itemized and then discussed in detail.

1. Deep circulation of meteoric water through intense, complex fracture systems.

2. Igneous point source intruded along fractures or zones of weakness, not exposed at the surface.
3. A combination of the prior two possiblities.
4. Heat generated by decay of radioactive elements in igneous rocks.
5. Exothermic reaction resulting from the hydration of bedded anhydrite in the evaporite sequence of sediments that occur in some of the intermontane basins.

Investigations to date by the Geothermal Project indicate that the likely explanation is deep circulation of meteoric water through the complex network of fracture systems in the Basin and Range province and the transition zone as suggested by Chapman, Kilty and Mase (1978). This type of system is apparently capable of generating geothermal reservoirs with temperatures of 150°C to 200°C in the intermontane basins, and will be discussed in detail in a later section.

Current investigations indicate that the best chances for igneous point source geothermal energy are associated with the young, Quaternary volcanic fields scattered across the state in both the Basin and Range and Plateau provinces.

Heat generated by radioactive decay of uranium and thorium mineralization in buried Precambrian granites will probably make a significant contribution to geothermal energy in Arizona. A conservative guesstimate is that there are many cubic miles of buried Precambrian granite in Arizona, and a situation similar to the Conway granite of North and South Carolina with its anomalously higher concentrations of radioactive elements should be expected. Reiter and Shearer (1979, in press) have determined an area of high heat flow 2.6 and 3.8 HFU, just south of Sanders, Arizona. Hahman, Sr., and others (1978) show several anomalous areas in northeastern Arizona. Quite possibly these geothermally anomalous areas are the result of heat generated by radioactive decay of radioactive elements in basement granite. The relatively abundant, naturally occurring radioactive elements U^{238}, U^{235} and Th^{232} give end products of lead and helium. Quite possibly helium found in the Holbrook basin is the result of radioactive decay, the helium having migrated upward into structural or stratigraphic traps in the overlying sediments.

Alternate hypotheses to explain the limited areas of high heat flow in the Colorado Plateau have been posed by other investigators. Reiter, Mansure and Shearer (1978) state "that the sources of these high heat flows are associated with the volcanics of the area and their sources." Laughlin (personal communication, 1979) states that the preliminary analysis of Los Alamos Scientific Laboratory magnetotelluric data indicates the possibility of an upwelling in the mantle in the Sanders area which could explain the high heat flow.

For the Basin and Range province, it has been proposed by Gerlach and others (1975) that the exothermic reaction of anhydrite altering to gypsum in the evaporite sequences occurring in many of the intermontane basins is supplying heat for some of the geothermal resources. Exploration to date by the Geothermal Project indicates that warm water moving along faults in the basin fill is a more plausible explanation.

Exploration and Evaluation Program

Hydrothermal resources suitable for electrical generation are expected to be encountered in several areas in the state. These favorable areas have been identified (1) by geochemical thermometers indicating projected reservoir temperatures as calculated from chemical analyses of water from wells and springs and (2) by temperature logging of water wells and drill holes. The favorable areas are the San Bernardino valley, Clifton-Morenci-Safford, Springerville-St. Johns-Alpine, Flagstaff, Phoenix and Hyder valley areas. Additional exploration is expected to locate other areas favorable for electrical generation from hydrothermal resources.

Hahman, Sr., and others (1978) show both high-temperature and low-to-moderate temperature areas on their map of Geothermal Energy Resources of Arizona. Again, it can be seen that most of the favorable areas are situated in the Basin and Range physiographic province. Preliminary investigations indicate that low-to-moderate temperature geothermal energy will be available for use at most of the populated areas in the Arizona Basin and Range province.

The current major uses of low-to-moderate temperature geothermal resources in Arizona are in space heating and cooling, industrial processing and agribusiness.

Arizona also has potential for hot dry rock geothermal energy for use in electrical generation and direct applications.

Byerly and Stolt (1977) defined a broad zone through central Arizona where the Curie point rises to less than 10 km and often less than 5 km below sea level (Figure 3). The Curie point, that temperature at which materials lose their magnetic property, is 575°C for magnetite. Therefore, if the Curie point is at 5+km, one might reasonably expect to have a temperature of approximately 575°C at that depth. The zone where the Curie point is within 5+km of the surface would be a much more favorable zone in which to look for hot dry rock and/or hydrothermal resources associated with young, concealed, silic, igneous intrusive rocks than a section where the Curie point is at a depth of 20 or 30 km.

Regional exploration and reconnaissance in Arizona is continuing, with the main thrust directed toward devising an efficient, cost effective exploration, evaluation and development procedure for low to moderate temperature (<150°C) geothermal energy resources. Simultaneously, exploration and evaluation for moderate to high temperature (greater than 150°C) geothermal resources suitable for electrical generation, including hot dry rock, is being conducted. During the course of these investigations, anomalies have been located, and site specific investigations are being conducted.

The following are summaries of the site specific investigations:

Because of favorable geochemical geothermometer data, the proximity of young volcanic rocks and favorable regional lineaments intersections determined from Landsat photography, the initial target chosen for site specific work was the Springerville-St. Johns area. As work progresses, the target area shifted from between Springerville and St. Johns to between Springerville and Alpine. The anomalous area (Figure 4), with the anomaly still open to the southwest and extending onto the Fort Apache Indian Reservation, has been further defined by a large gravity low (-245 milligals), geochemical geothermometers, a large anomalous resistivity low, and thermal gradient logs of water wells. Heat flow drilling to depths of 1,250 feet began in May, 1979.

Another target area picked early in the program is Clifton and the lower San Francisco river area. Preliminary evaluations of the water geochemistry from warm and hot springs indicate minimum reservoir temperatures of 150-188°C. The resource then is moderate to high temerature and should be considered for electrical generation as well as non-electrical uses. Preliminary geologic investigations indicate that the reservoir could be structural in nature. That is, the reservoir may consist of very hot water contained along a series of interconnecting faults. Detailed geologic mapping of the Clifton 15' topographic quadrangle started in May, 1979, and four heat flow holes are scheduled to be drilled during the fall of 1979.

Reconnaissance exploration indicated some anomalous areas in the vicinity of Safford (Figure 5). A request from the town of Safford, City Engineer's office, for geothermal energy for electrical generation and water supply augmentation through the desalination of geothermal water initiated the site-specific work. Results to date have defined several anomalous areas (Figure 5). Resistivity surveys, over 100 line miles, are currently being used to refine these target areas. Upon completion of this work, thermal gradient drilling is scheduled. Geochemical geothermometery, oil-well test bottom-hole temperatures and water-well temperature gradients indicate temperatures of 50-120°C are to be expected at depths to 1 km; however, assuming a normal Basin and Range temperature gradient gives reason to believe that temperatures in excess of 150°C may be expected at depths approaching 2 km.

At the request of the Bureau of Geology and Mineral Technology, Geological Survey Branch, a preliminary study of the Tucson basin was undertaken as part of a study for the Office of Arid Land Studies, University of Arizona. The initial results have been favorable, and the site specific evaluation is continuing (Figure 6). The results of the Exxon drilling in the Tucson basin indicate hot water around 150°C may be expected at depths of 3 km.

Addtional site-specific work is taking place in the following areas: Phoenix, Chandler-Higley, Buckeye-Tonopah-Hassayampa, Verde valley, Wickenburg, Kingman, Willcox, Papago Reservation, Fort Apache Reservation, Hyder, Yuma and the San Pedro river valley.

Geothermal Model for the Basin and Range Province of Arizona

During the two years of the program's existence, the staff has attempted to develop a model or working hypothesis to explain what is being observed in the field. Ideas change as additional data are generated. It is hoped that this model or a future modification is corrrect; however, the only requirement is that this model work as an exploration tool. It is not important that the geothermal energy is found for the "right" or "wrong" reasons; it is very important that the geothermal energy is found.

Eberly and Stanley, Jr. (1978) in a study of the Cenozoic stratigraphy and geologic history of southwestern Arizona divided the basin lithologies into an older Unit I and a younger Unit II. The sediments of early Cenozoic Unit I time were continental deposits laid down in broad depressions. The sediments of late Cenozoic Unit II time, again primarily continental deposits, were laid down in troughs or grabens created by the Basin and Range disturbance that commenced approximately 20 m.y.B.P. (Loring, 1976). Eberly and Stanley found a major unconformity separing Unit I from Unit II.

In the initial assessment of the geothermal potential for the Basin and Range province, (Hahman, Sr., and others, 1978) the large difference between normal gradient, 35°C/km, and gradients in anomalous areas was readily apparent, as was the association of anomalies with Landsat lineaments and lineament intersections. Also, some deeper oil and water wells encountered very high gradients at the bottom, not reflected in the upper part of the hole. These temperatures, 150-200°C within depths of 2-3 km, are of considerable practical interest. But the questions remained, "What, or where is the source of the heat and how do these systems work?" There is no real geophysical evidence for mantle plumes or upwellings in Arizona, nor is there significant geological nor gephysical evidence for silicic igneous point sources. It is conceivable, however, that an igneous point source could exist in the basement of a basin, such as the San Bernardino and western Gila River valleys, but that is apparently not the norm. The only remaining choice is thermal gradient; if one cannot take the heat to the water, one must take the water to the heat. The Basin and Range disturbance, iniated during late Oligocene to early Miocene (20 m.y.B.P.) (Loring, 1976), with its associated deep faulting, basin formation and sedimentation offers a general solution to the heat source problem. Keller, Grose, and Crewdson (1978), using a geophysical approach, came to the same conclusion. Water is apparently circulated downward through permeable faults in the mountain block and bounding and transverse fault zones in the bottom of the basin. Waters, heated by thermal gradient, rise by convection into the basin where some of it may be trapped in the lower part of the basin, Unit I (?) of Eberly and Stanley, by overlying, impermeable basin-fill material such as shales and silts. These same materials provide insulation from cooler, descending waters. Direct evidence for the existence of these hot water reservoirs at depth, such as high temperature gradients, low resistivities, hot springs and wells, usually is sparse. These deeper reservoir sites are easily masked by the movement of cool groundwater through the upper part of the basin fill, Unit II (?) of Eberly and Stanley. Heat transfer, however, can occur via conduction through a reservoir cap rock, sometimes leading to convection in overlying water-saturated sediments. Heat transfer also occurs through leakage of warm or hot water upward along basin margin faults or fractures and through fractures in the basin-fill material. Figure 7 is a schematic drawing of a Basin and Range province geothermal system as it is presently envisioned for many basins in Arizona. However, exploration of the south Santa Cruz basin near Coolidge (Dellechaie, 1975) shows that this diagram does not hold true for all basins in the Basin and Range province of Arizona. The more obvious possibilities for compromise are impeded plumbing systems and/or the absence of an effective "cap" rock needed to retain the heat and trap the hot water. This model, which emphasizes the natural geologic setting, is believed to offer realistic opportunities to explore for and develop viable goethermal energy resources in the Basin and Range province of Arizona. It is in this province, where over 90% of the state's population resides, that energy demands are and will be increasingly concentrated.

CONCLUSIONS

Arizona has a realistic potential for the development of viable goethermal energy resources. These resources are buried, and their geological manifestations often are very subtle. However, we are encouraged that they can be located and developed through prudent, integrated programs utilizing geology, geophysics, and geochemistry, the principal exploration tools.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge the staff of the Geothermal Project. This article could not have been written without their input of time and discussion. The writer also wishes to thank his reviewers, H. W. Peirce, A. W. Laughlin, A. K. Loring, C. Stone and J.P. Jenney for their constructive comments. Any errors of fact or interpretation are the sole responsibility of the writer.

BIBLIOGRAPHY

Amstead, H.C.H., 1978 Geothermal Energy - Its Past, Present and Future Contributions to the Energy Needs of Man, John Wiley & Sons, Inc., New York, 375 p.

Bierman, S.L., Stover, D.F., and Lamont, W.J., 1978, Geothermal Energy in the Western United States, Praeger Publishers, New York, 466 p.

Byerly, D.E., and Stolt, R.H., 1977, An attempt to define the Curie point isotherm in northern and central Arizona: Geophysics, Vol. 42, No. 7.

Chapman, D.S., Kilty, K.Y., and Mase, C.W., 1978, Temperatures and their dependence on groundwater flow in shallow geothermal systems, Geothermal Resources Council, TRANSACTIONS, Vol. 2, p. 79-82.

Dellechaie, Frank, 1975, A Hydrochemical Study of the South Santa Cruz Basin near Coolidge, Arizona, Proceedings, Second United Nations Symposium on the Development and Use of Geothermal Resources, Vol. 1, p. 339-348.

Eberly, L.D. and Stanley, Jr., T.B., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona, G.S.A. Bulletin, Vol. 89, p. 921-940.

Fournier, R.O., and Rowe, J.J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: American Journal of Science, Vol. 264, p. 685-697.

Gerlach, T., Norton, D., DeCook, K.J., and Sumner, J.S., 1975, Geothermal water resources in Arizona: Feasbility Study, University of Arizona, Tucson, 36 p.

Giardina, Jr., S., 1978, Geothermal anomalies, Basin and Range province of Arizona, Interstate Oil Compact Commission Committee Bulletin, Vol. 20, No. 20.

Hahman, Sr., W.R., 1977-1979, Geothermal reservoir site evaluation in Arizona, Quarterly and semiannual progress reports, May 1, 1977-July 31, 1977, 7 p.; August 1, 1977-October 31, 1977, 12 p.; November 1, 1977-January 31, 1978, 23 p.; February 1, 1978-April 30, 1978, 120 p.; July 15, 1978-January 15, 1979, 157 p.; Bureau of Geology and Mineral Technology, Geological Survey Branch, Tucson.

Hahman, Sr., W.R., Stone, C., and Witcher, J.C., 1978, Preliminary Map, Geothermal Energy Resources of Arizona, Geothermal Map No. 1, Bureau of Geology and Mineral Technology, Geological Survey Branch, Tucson.

Keller, G.V., Grose, L.T., and Crewdson, R.A., 1978, Speculations on nature of geothermal energy in Basin and Range province of western United States: Colorado School of Mines Quarterly, Vol. 73, No. 4, Part 2.

Kruger, P., and Otte, C., 1973, Geothermal Energy, Stanford University Press, Stanford, 360 p.

Lachenbruch, A.H., And Sass, J.H., 1977, Heat flow in the United States and the thermal regime of the crust, in the Earth's Crust, Geophysical Monograph 20, John G. Heacock, ed., American Geophysical Union, Washington, D.C., pp. 626-675.

Laughlin, A.W., 1979, Personal communication, Los Alamos Scientific Laboratory.

Loring, A.K., 1976, The age of Basin and Range faulting in Arizona, Arizona Geological Society Digest, Vol. 10, p. 229-257.

Mason, B., 1958, Principles of Geochemistry, 2nd Edition, John Wiley & Sons, Inc., New York, 310 p.

Reiter, M., Mansure, A.J., and Shearer, C., 1978, Geothermal Characteristics of the Colorado Plateau in Plateau Uplift, Mode and Mechanism: Compiled by the Lunar and Planetary Institute, Contribution 329, Houston, p. 43.

Reiter, M. and Shearer, C., 1979, Terrestrial Heat Flow in Eastern Arizona, A First Report: Journal of Geophysical Research, in press.

Scarborough, R.B. and Peirce, H.W., 1978, Late Cenozoic Basins of Arizona, New Mexico Geol. Soc. Guidebook, Land of Cochise, pp. 253-259.

Stone, C., 1979, An overview of the geothermal potential of the Springerville area, Arizona; in Hahman, Sr., W.R., Geothermal reservoir site evaluation in Arizona, Semi-annual progress report, July 15, 1978-January 15, 1979, Bureau of Geology and Mineral Technology, Geological Survey Branch, p. 1-25.

Swanberg, C.A., Morgan, P., Stoger, C.H., and Witcher, J.C., 1977, An Appraisal Study of the Geothermal Resources of Arizona and Adjacent Areas in New Mexico and Utah and Their Value for Desalination and Other Uses, Report No. 5, New Mexico Energy Institute, Las Cruces, 76 p.

Swanberg, C.A., 1979, Personal communication, New Mexico State University.

Wahl, E.F., 1977, Geothermal Energy Utilization, John Wiley & Sones, New York, 302 p.

Witcher, J.C., 1979, A preliminary report on the geothermal energy potential of the Safford Basin, southeastern Arizona, in Hahman, Sr., W.R., Geothermal reservoir site evaluation in Arizona, Semi-annual progress report, July 15, 1978-January 15, 1979, Bureau of Geology and Mineral Technology, Geological Survey Branch p. 42-72.

Witcher, J.C., 1979, A preliminary study of the geothermal potential of the Tucson metropolitan area, in Hahman, Sr., W.R., Geothermal reservoir site evaluation in Arizona, Semi-annual progress report, July 15, 1978-January 15, 1979, Bureau of Geology and Mineral Technology, Geolotical Survey Branch, p. 73-91.

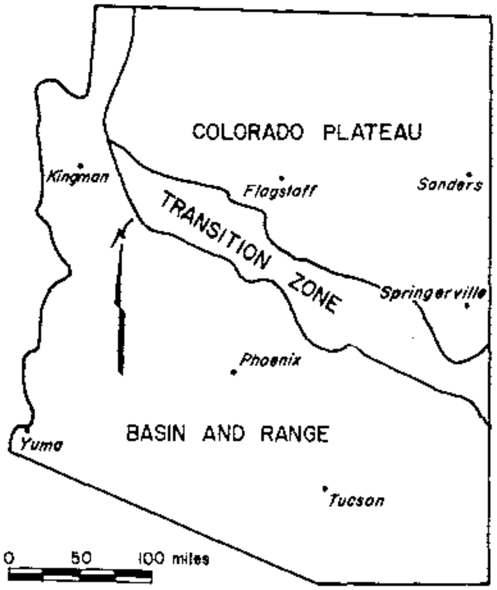


FIGURE 1. Physiographic provinces of Arizona.

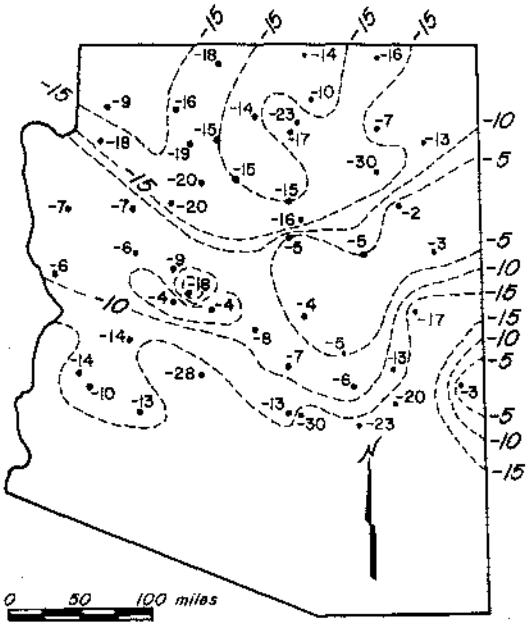


FIGURE 3. Depths (km. b.s.l.) to the base of the magnetic crust in northern and central Arizona (after Byerly and Stolt, 1977).

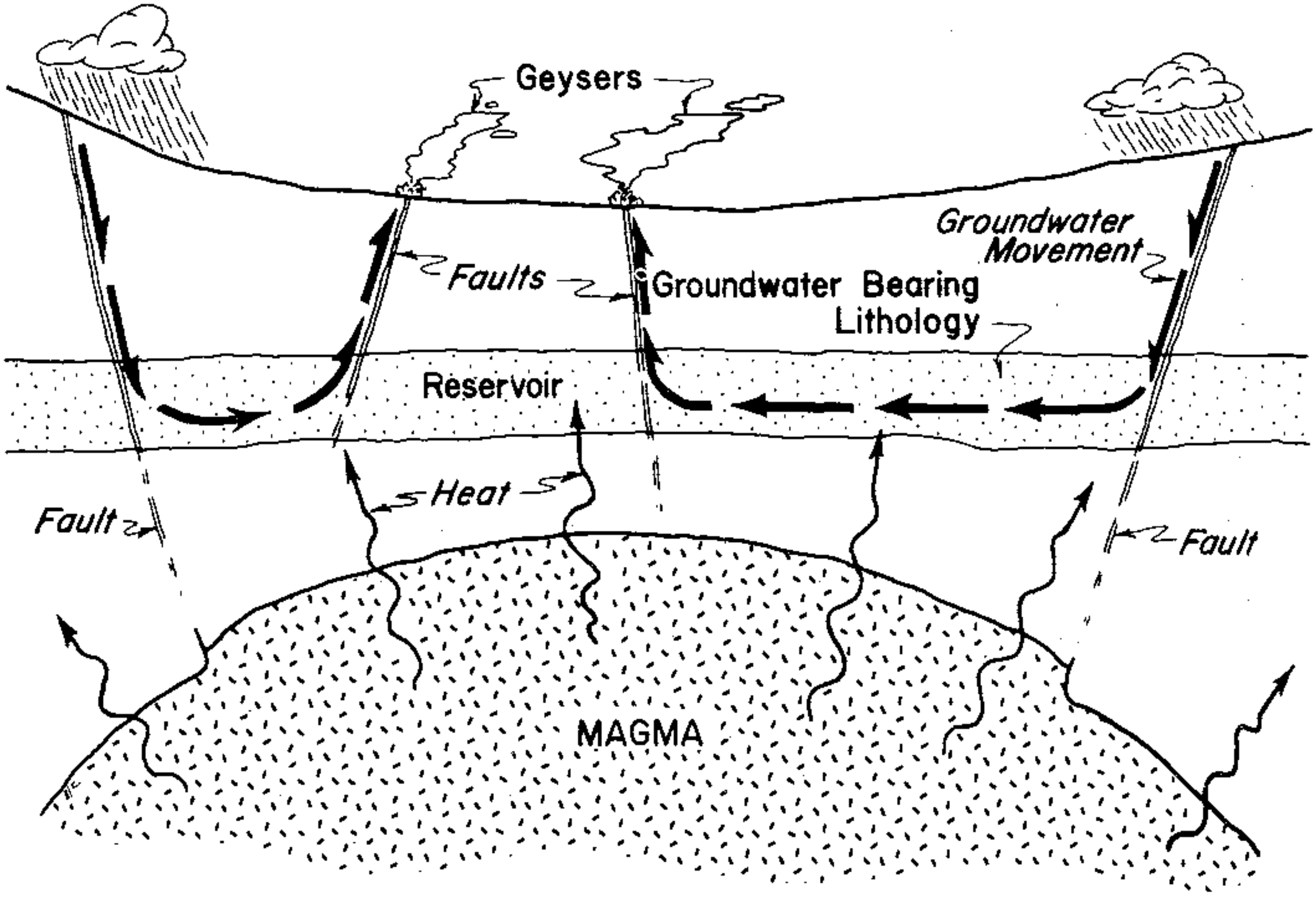


FIGURE 2. Stylized drawing of an igneous point source geothermal system.

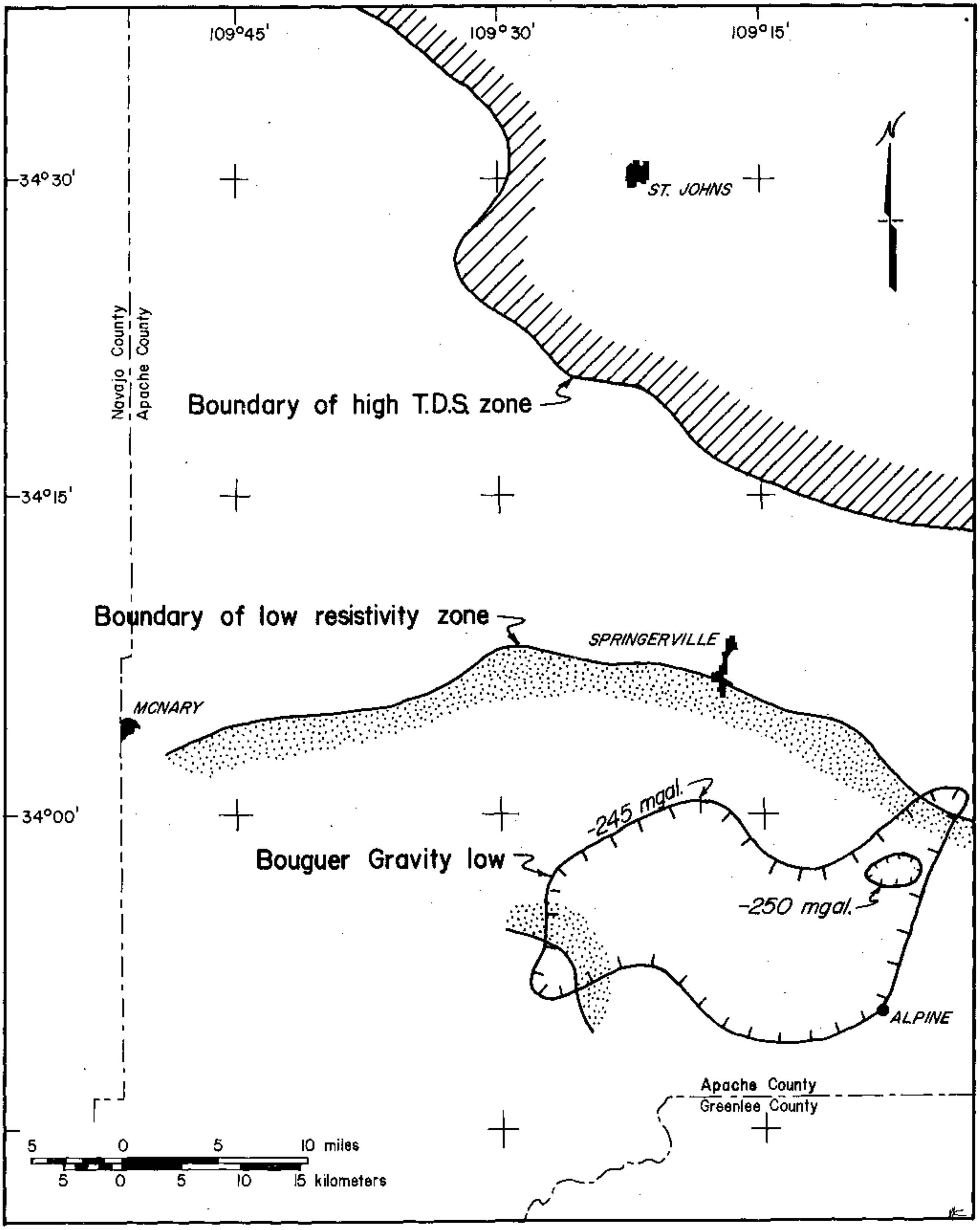


FIGURE 4. Gravity, resistivity, and high T.D.S. in the Springerville area (from Stone, 1979).

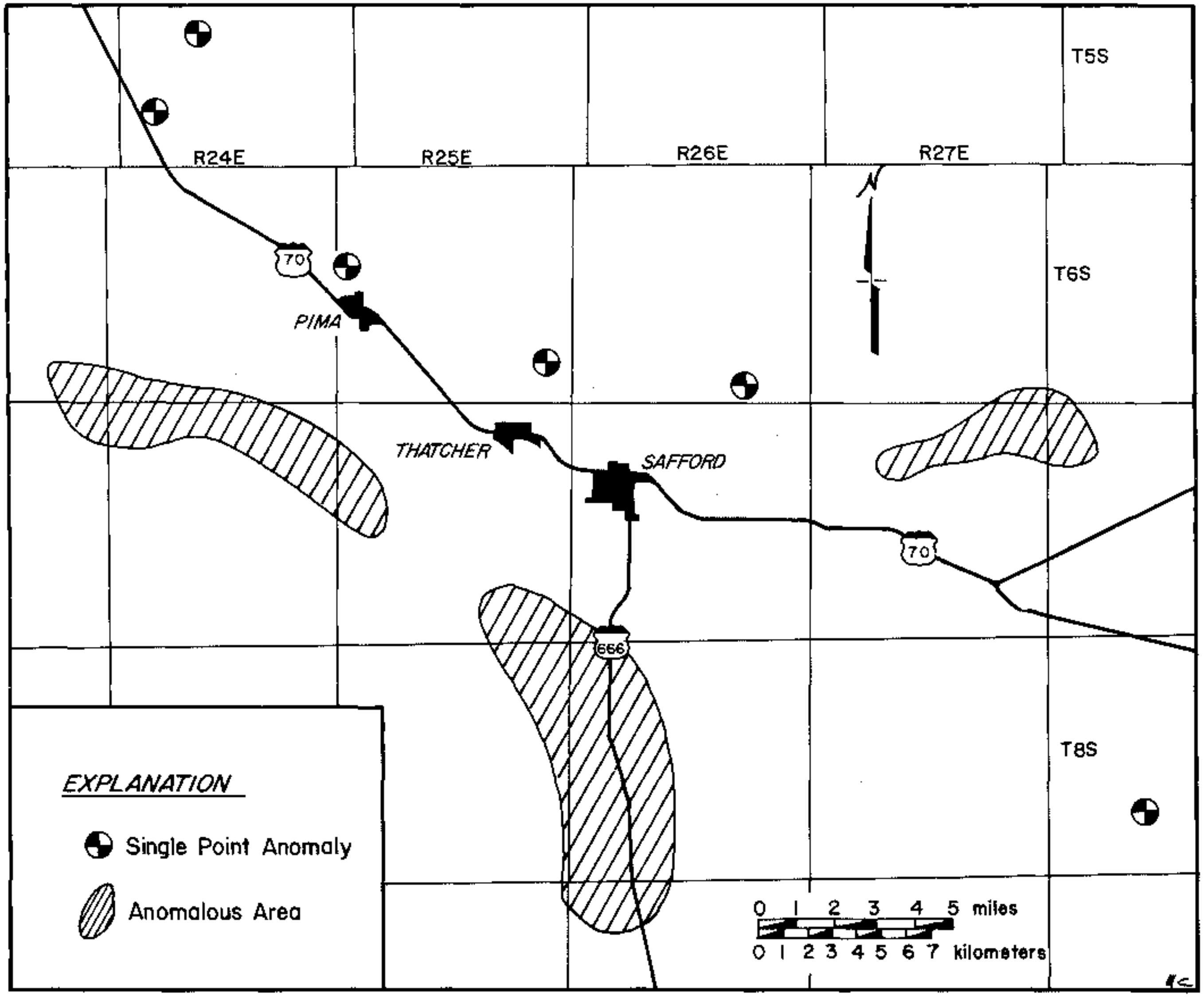


FIGURE 5. Geothermal anomalies in the Safford area (from J. Witcher, 1979).

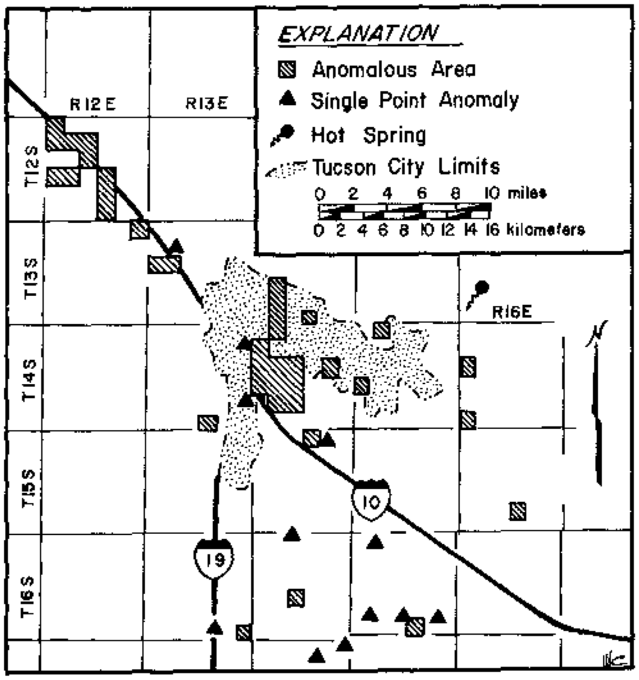


FIGURE 6. Geothermal anomalies in the Tucson area (from Witcher, 1979).

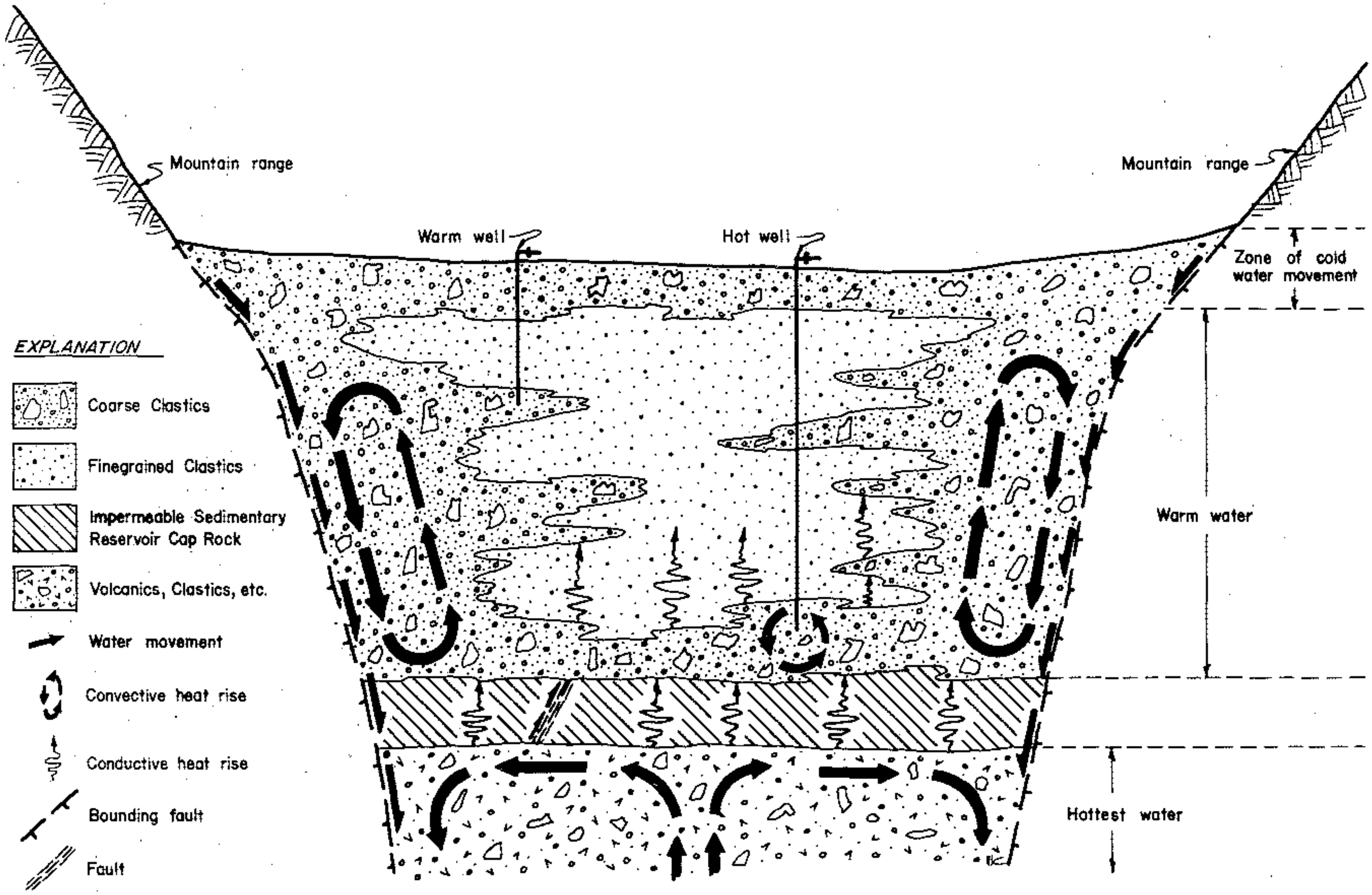
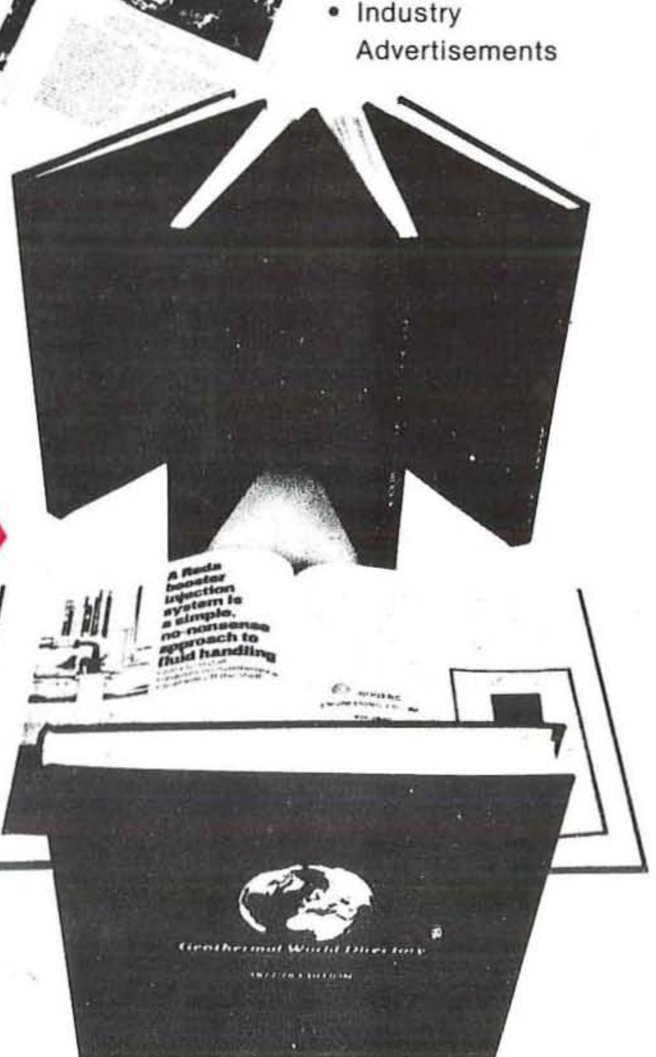


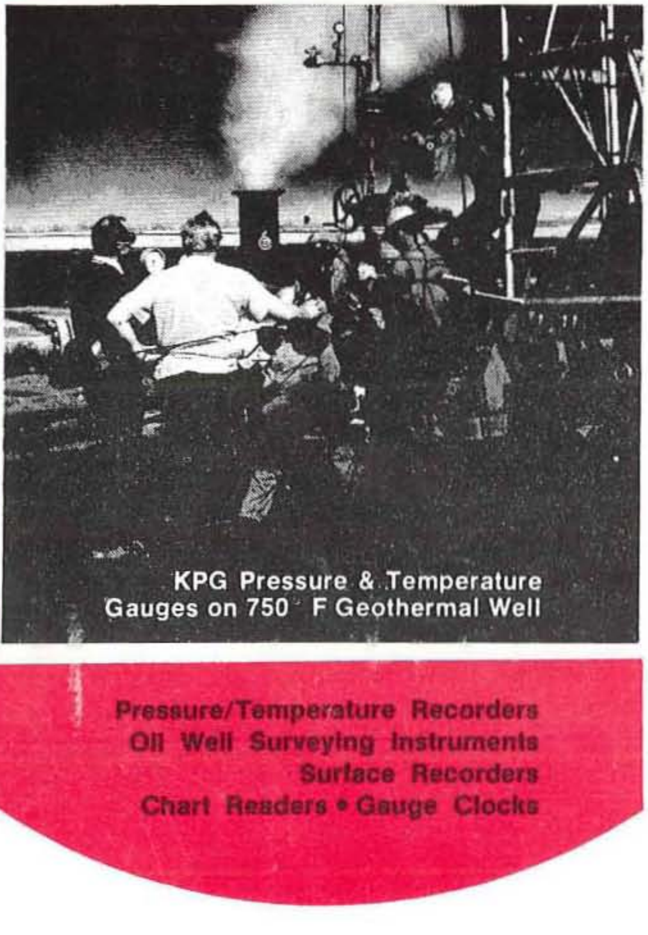
FIGURE 7. Schematic composite cross section showing probable reservoir formation and heat transfer mechanisms existing in basins of the Basin and Range province of Arizona.


GEOTHERMAL ENERGY
"THE FUTURE IS NOW..."
Geothermal Power Pl
WHAT IF THE WATER ISN'T HOT ENOUGH?
GEOTHERMAL EXPLORATION
STRATEGY AND BUDGETING


A Reda booster injection system is a simple, no-nonsense approach to fluid handling
Geothermal World Directory

Kuster Outstanding Subsurface Instruments

Over
Forty Years Experience
Sales • Service • Rentals



KPG Pressure & Temperature
Gauges on 750° F Geothermal Well

Pressure/Temperature Recorders
Oil Well Surveying Instruments
Surface Recorders
Chart Readers • Gauge Clocks

KUSTER COMPANY

2900 East 29th Street ▪ P.O. Box 7038
Long Beach, California 90807
Ventura ▪ Houston ▪ Lafayette ▪ New Orleans