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ARIZONA GEOLOGICAL SURVEY

THE STATE AGENCY FOR GEOLOGIC INFORMATION

MISSION

To inform the public about geologic processes, materials, and resources in Arizona and assist citizens, businesses, governmental agencies, and elected officials in making informed decisions about managing Arizona's land, water, mineral, and energy resources.

GOALS

- Inform the public about geologic processes, materials, and resources in a timely manner.
- Map and describe the bedrock and surficial geology of Arizona.
- Investigate and document geologic processes and materials that might be hazardous to the public or have adverse impact on land use and resource management.
- Administer the rules, regulations, and policies established by the Arizona Oil and Gas Conservation Commission.

Oil Prices and Geothermal Resources

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Just 13 months ago, in February 1999, the average U.S. monthly crude oil price was \$9.29 per barrel and the average monthly price of self-service unleaded gasoline was 95.9 cents per gallon. In March 2000 the same crude was \$26.21 per barrel and gasoline was \$1.49 per gallon.

Now may be the time to reevaluate the need for a national energy policy. Dependence on foreign oil has serious implications. The purpose of this article is to indicate that when the economics and politics are favorable, Arizona has potential geothermal water that may be used as an alternative energy source.

Oil price fluctuations, 1973-2000. On October 5, 1973, Egypt and Syria, equipped by the Soviet Union, attacked Israel during the evening of Yom Kippur, the Jewish Day of Atonement. The United States and other countries in the western world supported Israel. Saudi Arabia, Iran, Iraq, Abu Dhabi, Kuwait, and Qatar, members of the Organization of Petroleum Exporting Countries (OPEC), retaliated by using oil as a weapon against those "unfriendly" nations who supported Israel. The OPEC unilaterally raised crude oil prices and cut production. These actions caused the price of OPEC crude oil to increase from about \$3 per barrel in

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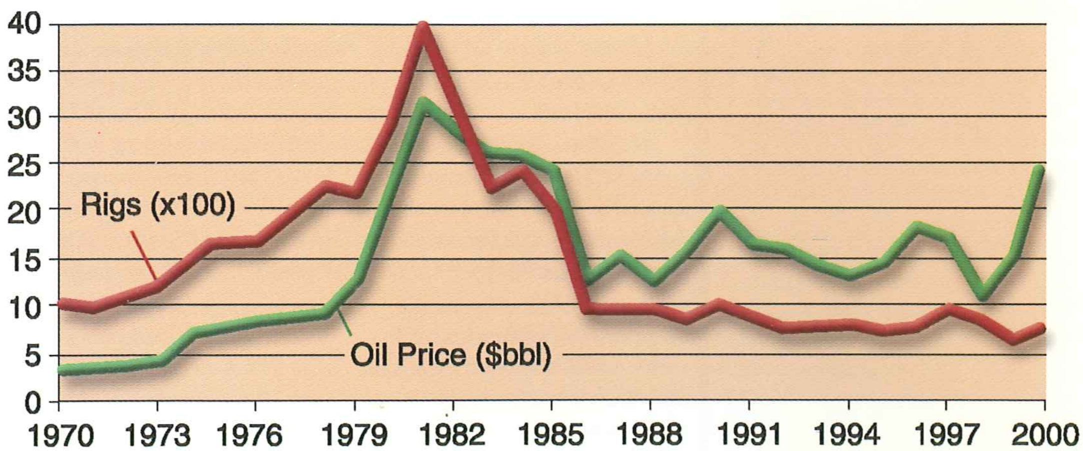

***Figure 1**. Fluctuations in the average annual price of crude oil, 1970-2000 (green line) have a profound impact on the U.S. drilling industry. Notice how closely the number of drilling rigs active in the U.S. (red line) parallels the price of crude oil.*

Oil Prices *(continued from page 1)*

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1972 to more than $11 by the end of 1973. These increases are reflected in Figure 1, which shows the average annual price of crude oil (OPEC plus non-OPEC). This was the first oil-supply disruption to cause major price increases and a world energy crisis. In the United States it was necessary to wait in line at the filling station for gasoline – if gasoline was available. The average U.S. annual crude oil prices stabilized for several years but rose sharply from 1979-1981, when the price of OPEC crude increased because of the Iranian revolution and the Iran-Iraq war.

In response to the 1973 price increases, the United States increased domestic oil production and took other measures to reduce consumption (Figure 2). Among other actions, Congress in 1975 authorized the U.S. Department of Energy (DOE) to set and enforce automobile-gas-consumption standards. As a result the miles-per-gallon rating for new cars increased from 15.6 in 1975 to 28.3 in 1988. Fifty-five-mile-per-hour speed limits were set to conserve gasoline (and save lives). As a result of these actions oil imports declined from 1980-1985.

In 1986 Saudi Arabia increased oil production substantially. It's production had decreased from 9.9 million barrels per day in 1980 to 3.4 million in 1985. As a result, oil prices fell almost immediately to less than half of what they were in 1981. Because oil prices were low again, energy efficiency seemed to be much less important in the United States. At the same time, domestic production began a steady decline and imports of foreign oil began to increase.

Figure 1 shows that the rate of drilling for oil is closely related to the price of oil. The domestic oil industry was devastated by the sharp drop in world oil prices in 1986. The average annual number of active drilling rigs in the United States declined from nearly 4000 in 1981 to fewer than 1000 in 1986 and reached an historic low of about 625 in 1999. The lowest weekly U.S. drilling rig count recorded since 1940 was 488 in April 1999.

Except for the Gulf War "spike" in September-November 1990, crude oil prices are higher now than they've been since 1985 and this country is importing more foreign oil than ever (Figure 2). In 1972, the year before the embargo, the United States imported 30 percent of its oil; today we import 53 percent. Once again discussions are being held, as they were in the mid-1970s, on fuel economy of vehicles and alternative energy sources.

Geothermal energy. High oil prices and dependence on imported oil give incentives to increase domestic production and to find other types of energy. The 1973 OPEC oil embargo gave a large boost to geothermal exploration and development. In the mid-1970s the DOE initiated a national program to assess potential geothermal resources. As a result, many areas in 10 western states, including Arizona, were shown to have potentially useable geothermal resources. The Geological Survey Branch of the Arizona Bureau of Geology and Mineral Technology, predecessor of the Arizona Geological Survey, actively participated in the program from 1977-1982.

In January 2000, in response to the increase in demand for energy resources, the DOE unveiled ***GeoPowering the West***, an initiative to help increase the use of geothermal energy for electricity production, industrial process applications, and heating for commercial establishments and residences. Goals are to (1) provide 10 percent of the electricity needs in the western states by 2020, (2) supply the electrical power or heat energy needs of at least 7 million homes by 2010, and (3) double the number of states with geothermal electric power facilities to eight by 2006. California, Hawaii, Nevada, and Utah currently produce electricity from geothermal sources.

Geothermal energy is natural heat from the interior of the Earth. An inexhaustible quantity of heat is available deep within the Earth. This heat flows outward toward the Earth's surface, but in the process becomes so diffuse that the heat is not considered to be an energy resource.

In many parts of the Earth geologic conditions have created large areas of heat that is accessible at or near the Earth's surface. These areas are called *geothermal anomalies.* Geothermal water is defined as low temperature if it's cooler than 100°C, moderate temperature if it's between 100 and 150°C (212-302°F), and high temperature if it's greater than 150°C.

The Geothermal Steam

Act of 1970 established geothermal energy as a leasable commodity on public lands, subject to the same laws that apply to coal, oil, gas, and other resources. In this act a *Known Geothermal Resource Area* (KGRA) is defined as one in which the geology, nearby discoveries, competitive interests, or other factors are sufficiently high to justify resource development.

One of the most important single uses of geothermal energy is to generate electricity. High-temperature systems that boil and produce steam when penetrated by wells are the best for this purpose.

Potential geothermal resources in Arizona. From 1977-1982 the Geothermal Assessment Team within the Arizona Bureau of Geology and Mineral Technology completed and released many reports in which they evaluated the potential for geothermal resources in the State. This work, funded by the DOE, showed that Arizona has many areas where low- to-moderate-temperature geothermal fluids (to about 140°C) are known or interpreted to occur at depths shallow enough to make them useful as alternative sources of energy (Figure 3).

Low-to-moderate-temperature geothermal anomalies were identified in nine Arizona counties, including in the metropolitan Phoenix and Tucson areas, 16 communities with populations greater than 1000, and 17 smaller communities (Figure 3). Reports on geothermal potential were done for the Clifton, Castle Hot Springs, Harquahala-Tonopah, Hyder, Papago farms, Safford, Scottsdale-Paradise Valley, Springerville, Tucson, Willcox, Yuma, and other areas.

The geothermal anomalies, confined largely to the Basin and Range province, were defined on the basis of thermal springs and wells, as well as ground-water, geological, and geophysical surveys.

Possible uses of geothermal energy in Arizona. Although some exploration for high-temperature geothermal water has been done in Arizona, including in the KGRAs, resources suitable for generating electricity have not been located. Based on knowledge of the geology of the State, high-temperature resources are not likely to be present.

Low-to-moderate temperature geothermal fluids have many possible uses. Geothermal space conditioning, especially heating, which requires lower fluid temperatures than cooling, could probably be used in a number of Arizona towns. Other possible applications include preheating boiler water for conventional power plants, controlled-environment agriculture (greenhouses and nurseries), fish farming, grain and vegetable drying, and soil warming for mushroom growing and earthworm farms. Geothermal water is also effective in improving metal recoveries and recovery rates in ore processing.

The Geothermal Commercialization Team within the University of Arizona's Department of Chemical Engineering, with funding from the DOE, studied possible uses of geothermal resources. They completed geothermal development plans for Cochise, Graham, Greenlee, Maricopa, Pima, Pinal, Santa Cruz, and Yuma counties. These reports were released by and are available from the Arizona Geological Survey.

If low-grade heat is needed, the possibility of using geothermal energy could be an option in many parts of Arizona. Opportunities for geothermal development await the entrepreneur!

(See publications, page 6.)

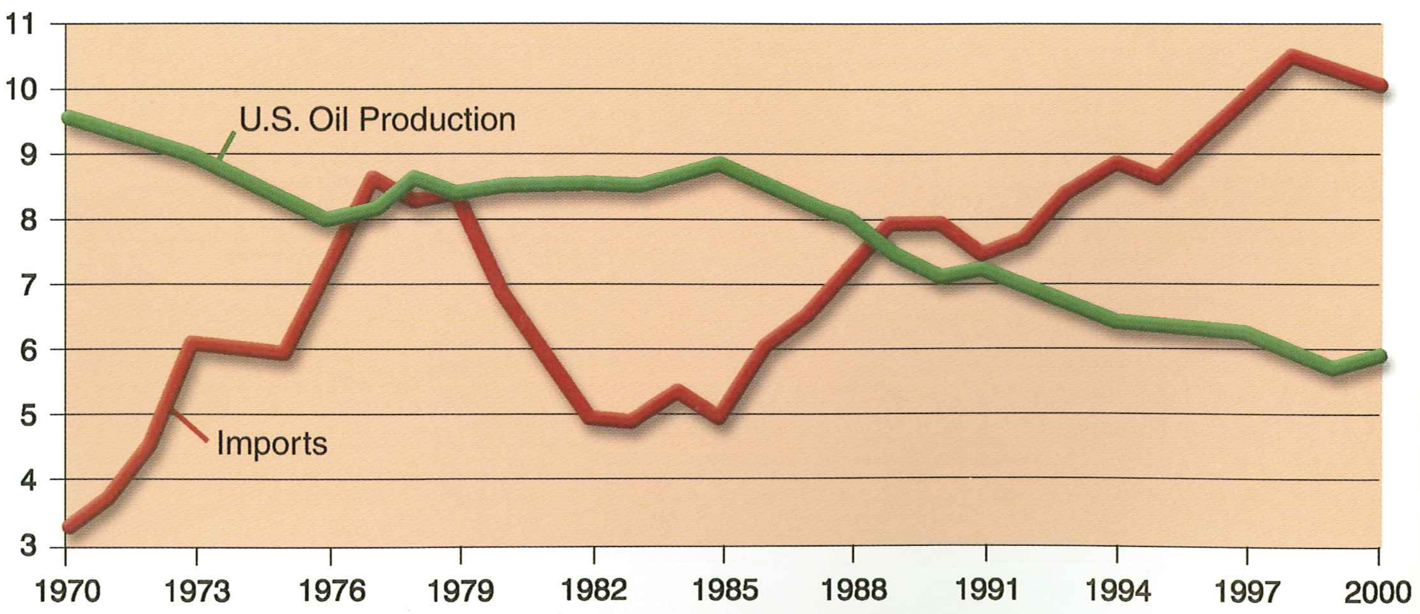


Figure 2. *As U.S. oil production (green line) declined from 1970-2000, the amount of oil imported (red line) increased.*

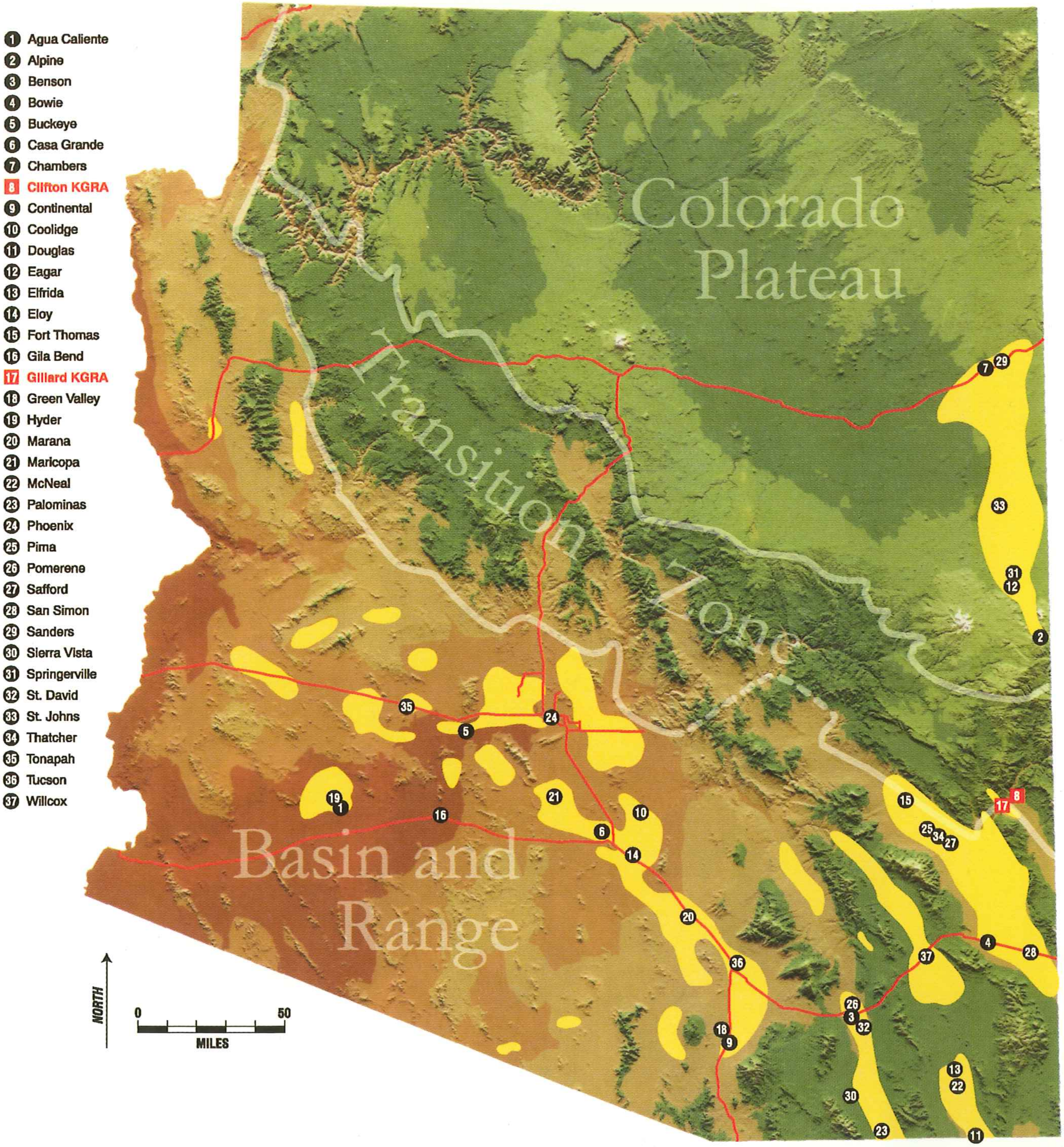


Figure 3. *Yellow areas are interpreted to have potential for low-to-moderate temperature geothermal resources. Thermal water may not be present everywhere within these areas. The boundaries shown are estimates of the areal extent of the potential resource and will change as new drilling and other information is obtained.*

Communities within the potential geothermal areas are shown as numbered black circles. Names of the communities that match the numbers are listed below the map. Known Geothermal Resource Areas (KGRA) are shown as red squares.

This map is modified from Geothermal resources of Arizona, *by J.C. Witcher, Claudia Stone, and W.R. Hahman, Jr., 1982, Arizona Bureau of Geology and Mineral Technology Map 15-2, scale, 1:500,000.*

Just Released

Annual report of the Arizona Geological Survey, 1999: L.D. Fellows, 1999, Arizona Geological Survey Open-File Report 99-27 (Pub. number OFR 99-27), 19 p. $3.75

Contents include the agency mission, goals, summaries of projects and activities that were completed, lists of reports and maps that were released, and information about staff, organization, and expenditures during the fiscal year.

Hydrology and geomorphology of the Santa Maria and Big Sandy Rivers and Burro Creek, western Arizona: J.E. Klawon, 2000, Arizona Geological Survey Open-File Report 00-02, 46 p. $8.00

This report provides hydrologic and geomorphologic information to aid in the evaluation of navigability of the three streams. These streams flow through rugged mountainous terrain into Alamo Lake, which is formed by a dam across the Bill Williams River. Each stream has reaches with perennial flow. Substantial channel changes have occurred in response to large historic floods, especially around the end of the 19th century, when farmlands and the old mining town of Greenwood along the Big Sandy River were washed away. The most dramatic channel changes documented by aerial photo interpretation were from 1978-1995.

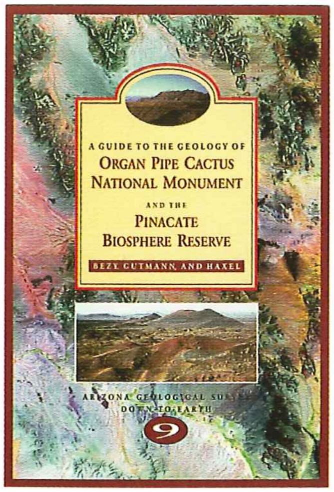
A guide to the geology of Organ Pipe Cactus National Monument and Pinacate Biosphere Reserve: J.V. Bezy, J.T. Gutmann, and G.M. Haxel, 2000, Arizona Geological Survey Down-to-Earth 9, 64 p. $7.95

This book includes descriptions of the geologic history and geologic features that can be observed from or close to roads within the Organ Pipe Cactus National Monument (OPCNM) and the Pinacate Biosphere Reserve (PBR).

The OPCNM is a 500-plus-square-mile portion of the Sonoran Desert in southernmost Arizona about 30 miles south of the town of Ajo. Rocks within the Monument record a discontinuous series of intrusive, volcanic, structural, and erosional events that began during Precambrian time.

Eleven geologic features are highlighted within the OPCNM: seven are along the 21-mile Ajo Mountain Drive northeast of the Visitor Center and four are along the 53-mile Puerto Blanco Drive west of the Visitor Center. The features described include four rock types (rhyolite, latite, mylonite, and granite) and seven erosional features (rock varnish, a beheaded stream, talus cones, desert pavement, bajada and pediment, alluvial terraces, and fault-controlled springs).

The PBR, almost 600 square miles, is in northernmost Sonora, Mexico, about 35 miles west-southwest of the southern margin of the OPCNM. The Reserve has



A guide to the geology of Organ Pipe Cactus National Monument and Pinacate Biosphere Reserve

hundreds of small volcanic cinder cones and nine large craters (maars) that formed during explosive eruptions. Rising magma heated ground water and caused the steam explosions that formed these craters. The volcanic activity began a few million years ago and continued until recent times. Some volcanic features have been modified so little by erosion that they appear to have formed only yesterday. The PBR is a remarkable showcase of basaltic volcanism.

This book includes 10 stops to view volcanic rocks and landforms: aa and pahoehoe basalt (chilled lava flows), tuff breccia, dike, cinders, cinder cone, tuff cone, maar crater, Sierra Pinacate, eroded Pinacate volcanics, and playa.

Rocks in the PBR are younger, predominantly of volcanic origin, and contain more iron and magnesium than those in the OPCNM.

Ordering Information

You may purchase publications at the AZGS office or by mail. Address mail orders to AZGS Publications, 416 W. Congress St., Suite 100, Tucson, AZ 85701. Orders are shipped by UPS, which requires a street address for delivery. All mail orders must be prepaid by a check or money order payable in U.S. dollars to the Arizona Geological Survey or by Master Card or VISA. Do not send cash. Add 7% sales tax to the publication cost for orders purchased or mailed in Arizona. Order by publication number and add these shipping and handling charges to your total order:

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Geothermal Publications* *(continued from page 3)*

Geothermal energy in Arizona: Final report, Claudia Stone and J.C. Witcher, 1982, Arizona Bureau of Geology and Mineral Technology Open-File Report 83-12, 398 p. This is the final report that was submitted to the U.S. Department of Energy when work on the geothermal assessment that began in 1977 was completed. The report brings together in a single volume current knowledge and basic data on potential geothermal resources in Arizona.

Geothermal Resources of Arizona, J.C. Witcher, Claudia Stone, and W.R. Hahman, Jr., 1982, Arizona Bureau of Geology and Mineral Technology Map 15-2, scale 1:500,000. This map shows the areas that are interpreted to have potential for low-to-moderate geothermal resources and gives brief descriptions of the major areas. The map also locates thermal springs and wells and gives temperature data for them.

A summary appraisal of the principal geothermal resource areas in Arizona, by Claudia Stone, *in* Geologic evolution of Arizona: J.P. Jenney and S.J. Reynolds, 1989, Tucson, Arizona Geological Society Digest 17, p. 817-825. The purpose of this summary is to present 11 case studies that represent some of the more promising, interesting, and (or) typical geothermal systems in Arizona and to summarize the conclusions that can be drawn from those investigations.

Potential geothermal resources in Arizona, by Claudia Stone, 1983, Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 13, no. 4, p. 1-4. This 4-page summary of the potential for geothermal resources in Arizona was prepared soon after the final report of the geothermal assessment project was submitted to the DOE.

Geothermal energy, *in* Energy resources of Arizona, by J. T. Duncan and F. P. Mancini, 1991, Arizona Geological Survey Down-to-Earth 1, p 11-13, map, scale 1:1,000,000. This book includes brief summaries of geothermal and other energy sources in Arizona, including coal, hydroelectric power, nuclear, oil and gas, solar, wind, and biomass. It also includes a map that shows the areas in which different types of energy resources are known or have potential to be present.

Geothermal resources in Arizona: a bibliography, by S.S. Calvo, 1982, Arizona Bureau of Geology and Mineral Technology Circular 23, 23 p. This report lists citations to more than 200 reports and maps that address various aspects of geothermal resources. The citations are indexed by subject and geographic area.

Thermal springs of Arizona, by J.C. Witcher, 1981, Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 11, no. 2, p. 1-4. This article locates and gives temperature information about 45 thermal springs in Arizona. Identification of thermal springs helps one assess a region's geothermal character.

**These publications are available at the Arizona Geological Survey Sales Office. Please see ordering information on page 5.*

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