Geothermal Resources of Arizona
1982

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Map prepared by the
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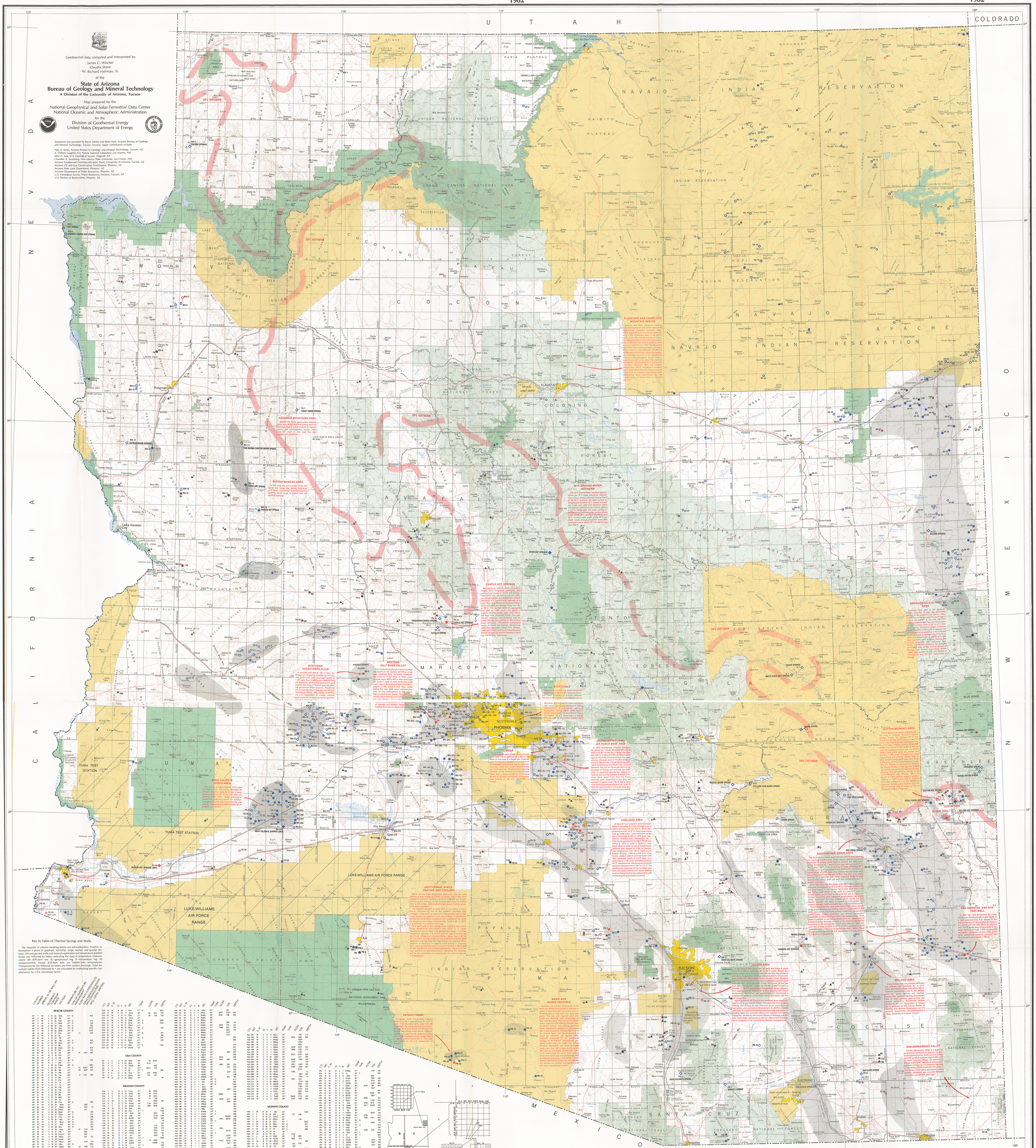
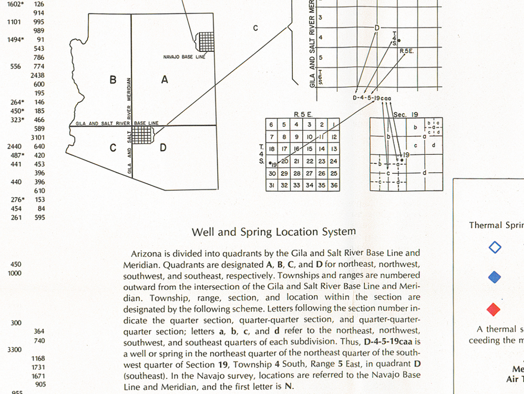


Key to Table of Thermal Springs and Wells

The majority of column headings below are self-explanatory. Position information is given in quadrant, township, range, section, and quarter section. Oil and gas test wells and mineral exploration and temperature gradient holes are followed by letters indicating the type of temperature measurement: D—drill-stem test, G—geophysical log, T—temperature log. All measurements except drill-stem tests are bottom-hole temperatures. Temperatures not followed by letters are from surface discharge. Total dissolved solids (TDS) followed by * are calculated by multiplying specific conductance by a 0.6 conversion factor.

Well and Spring Location System



Arizona is divided into quadrants by the Gila and Salt River Base Line and Meridian. Quadrants are designated **A**, **B**, **C**, and **D** for northeast, northwest, southwest, and southeast, respectively. Townships and ranges are numbered outward from the intersection of the Gila and Salt River Base Line and Meridian. Township, range, section, and location within the section are designated by the following scheme. Letters following the section number indicate the quarter section, quarter-quarter section, and quarter-quarter-quarter section; letters **a**, **b**, **c**, and **d** refer to the northeast, northwest, southwest, and southeast subdivision. Thus, **D-4-5-19caa** is a well or spring in the northeast quarter of the northeast quarter of the southwest quarter of Section **19**, Township **4** South, Range **5** East, in quadrant **D** (southeast). In the Navajo survey, locations are referred to the Navajo Base Line and Meridian, and the first letter is **N**.

Purpose

This map is a product of a statewide inventory and evaluation of Arizona's geothermal resources by the Arizona Bureau of Geology and Mineral Technology, under the sponsorship of the U.S. Department of Energy. Emphasis has been on identification of low-temperature (lower than 100°C) and intermediate-temperature (100° to 150°C) geothermal resources. The primary purpose of this map is to aid potential users in developing this important energy resource in Arizona.

In recent years, much interest has been shown in geothermal energy for electric power generation. While this is an important use of high-temperature (higher than 150°C) geothermal resources, it is now recognized that the most widespread potential use is for direct-heat (non-electric) applications, including space heating and cooling of buildings, agricultural operations, and industrial processes. Low- and intermediate-temperature geothermal resources with good chemical quality are suitable for such direct-heat applications. Numerous successful direct-heat geothermal operations have been developed by individuals, industry, and government in the United States and other countries.

Availability of Additional Information

Detailed chemical data for most thermal springs and wells shown on this map are available from the computer file GEOTHERM (GEOTHERM Project, U.S. Geological Survey, 345 Middlefield Road, MS84, Menlo Park, California 94024).

Information concerning drilling requirements; leasing and permitting agencies; potential agricultural, commercial, and industrial uses of geothermal resources; resource assessments of specific areas; and other supplementary geologic data is available in open-file reports at the Arizona Bureau of Geology and Mineral Technology, 845 N. Park Avenue, Tucson, Arizona, 85719.

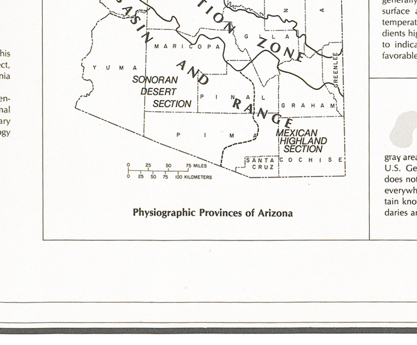
Thermal Springs and Wells

Thermal Springs

- Warm spring—50°C or lower and 15°C or less above mean annual air temperature
- Hot spring—50°C or lower and more than 15°C above mean annual air temperature
- Hot spring—Higher than 50°C

A thermal spring in Arizona is defined as one having a temperature exceeding the mean annual air temperature by 10°C or more.

Average Mean Annual Air Temperature	Physiographic Province
11°C	Colorado Plateau
15°C	Transition Zone
18°C	Mohave Section and Mexican Highland Section of the Basin and Range province
21°C	Sonoran Desert Section of the Basin and Range province



Physiographic Provinces of Arizona

Thermal Wells

- Temperature 50°C or lower and gradient 50°C/km or lower
- Temperature 50°C or lower and gradient higher than 50°C/km
- Temperature higher than 50°C and gradient 50°C/km or lower
- Temperature higher than 50°C and gradient higher than 50°C/km

Wells for which depth information is lacking are included in the open symbol category (gradient 50°C/km or lower).

A thermal well in Arizona is defined as one in which the surface discharge temperature is both 20°C or greater and at least 10°C higher than the mean annual air temperature. Average discharge temperature is 26°C for 1,983 wells south of the 20°C ground-water isotherm. Thus, wells in this area with discharge temperatures of 20°C to 34°C are arbitrarily not shown in the table or on the map. However, such wells may have significant geothermal potential for heat-pump applications. Wells with bottom-hole temperature information are included where they meet the above temperature criteria. However, all bottom-hole temperatures should be used with caution. Temperature gives no indication of potential water production and may even have been measured in a "dry" hole.

In calculating a gradient (temperature change with increasing depth), the mean annual air temperature is subtracted from the bottom-hole temperature. The difference in degrees Celsius (°C) is divided by well depth in meters (m), and the quotient is multiplied by 1,000. The gradient is in degrees Celsius per kilometer (°C/km). For some wells bottom-hole temperatures are direct measurements. For others it is assumed that surface discharge temperatures represent bottom-hole temperatures.

Wells with temperature gradients of 50°C/km or lower may not reflect unusual thermal conditions because normal gradients in southern Arizona valleys are 30° to 50°C/km. Holes with gradients higher than 50°C/km are generally in areas where thermal waters may flow toward or upward into near-surface aquifers. Temperature gradients should not be used to predict temperatures at depths below the well. However, wells where wells have gradients higher than 50°C/km (solid symbol category), the gradients are useful to indicate areas where geothermal resource potential is probably most favorable.

The 20°C ground-water isotherm approximates the 14°C mean annual air temperature contour where it crosses Arizona. South of the 20°C isotherm, the mean annual air temperature exceeds 14°C, except in mountain areas over 1,500 m in elevation. Since the average temperature of Arizona springs is 6.5°C higher than the mean annual air temperature, ground-water temperatures south of the 20°C isotherm should exceed 20°C. In fact, wells south of the 20°C isotherm nearly always encounter water temperatures near or above 20°C at depths less than 300 m.

Low-Temperature Geothermal Waters

Gray areas are favorable for discovery and development of low-temperature (lower than 100°C) geothermal resources. They are defined on the basis of thermal springs, thermal wells, and ground-water, geologic, and geophysical surveys. These gray areas are modified, in the light of later information, from those shown in U.S. Geological Survey Circular 790 (Muffler, 1979). Existing knowledge does not in general permit the inference that thermal waters may be found everywhere within the depicted areas, nor do the boundaries represent certain knowledge of the areal extent of the geothermal resources. The boundaries are subject to change as new information is obtained.

Heat Flow

Convection and conduction are physical processes that transfer heat from the earth's interior to the surface. In convection, moving fluids transport the heat; examples of convective systems include volcanoes (magma) and thermal springs (water). Heat is also transferred by conduction through rocks. Heat transfer is measured as heat flow: the amount of heat transmitted across a unit area of rock in a unit of time. Heat flow is measured in milliwatts of heat energy flowing across a square meter (mW/m²). Worldwide average heat flow is 60 mW/m².

The two determinates of conductive heat flow (Q) are rock thermal conductivity (K) (ability of rock to conduct heat) and the temperature gradient (G). The relationship is Q=KG. Anomalous heat sources can include molten rock in the crust, unusually radioactive crystalline rock, and geothermal convection systems (circulating hot water at depth). Background heat sources are the mainly the mantle and radioactive minerals in crystalline rock of the crust.

- 69 ▲ Heat-flow measurement, mW/m². See references for data sources.
- C ▲ U.S. Geological Survey heat-flow value (in preparation—John H. Sass, 1981, personal communication.)

Code	mW/m²
A	<35
B	36— 48
C	49— 60
D	61— 73
E	74— 85
F	86—102
G	>103

- Known Geothermal Resources Area (KGRA) as designated by the U.S. Department of the Interior. Name of KGRA in red lettering.
- Indian reservation
- Military reservation
- National forest
- National park, monument, wilderness area, primitive area, natural area, wildlife refuge, recreation area, state park, county park, regional park.

Private land may exist within federal boundaries.

Metric Conversion

1 meter = 3.281 feet
1 kilometer = 0.621 mile
1 liter = 0.264 gallon
1 milligram/liter = 1 part per million
1 milliwatt/meter² = 0.024 Heat Flow Unit (HFU)
°Celsius = 5/9 (°Fahrenheit − 32)
°Fahrenheit = 9/5 °Celsius + 32

Population Key

PHOENIX	more than 100,000
MESA	25,000 to 100,000
Prescott	5,000 to 25,000
Benson	1,000 to 5,000
Bowie	less than 1,000

Population indicated by size of letters.

- State capital
- County seat
- City, town, or village
- Scheduled service airport
- Built-up area shown for towns over 5,000 population
- County boundary
- Interstate highway
- U.S. highway
- State highway
- Other principal roads

Scale 1:500,000
1 centimeter equals 5 kilometers
1 inch equals approximately 8 miles

Contour interval 500 feet
Datum is mean sea level
1927 North American datum
Lambert conformal conic projection based on standard parallels 33° and 45°
Base map supplied by the U.S. Geological Survey

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Map available free of charge from:
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