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Heat-Flow Measurements in the State of Arkansas

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HEAT-FLOW MEASUREMENTS IN THE STATE OF ARKANSAS
Final Report

by

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and James C. Maxwell

ABSTRACT

Six new heat-flow values are reported for Arkansas, ranging from 1.06×10^{-6} cal/cm^2/s to 3.13×10^{-6} cal/cm^2/s. The pertinent holes are located in the four major geological divisions of the state. The most reliable results are those from Glenwood (1.09 h.f.u.) and Little Rock (1.06 h.f.u.); ground-water problems make the higher remaining values somewhat questionable. Despite the presence of hot springs in the Ouachita region, these figures are not especially encouraging as indicators of a possible geothermal resource, and the low heat-flow in the syenite intrusion at Little Rock is certainly disappointing in terms of hot dry rock exploitation.

The most promising area geothermally is in the southern counties (in the Gulf coastal plain), where a compilation of geothermal gradient estimates, made from published well-temperature data, shows a trend towards higher than average gradients.

I. INTRODUCTION

Regional heat-flow studies are important in defining the thermal characteristics of geologic provinces, and, more specifically, in showing areas which may be of interest for geothermal resources. Major geothermal exploration has been under way for some years in the western U.S., where heat-flow is generally of the order of 2 h.f.u. or higher (Roy, et al., 1973). In the central and eastern U.S., heat-flow values are lower, ranging from about 1.5 to less than 1 h.f.u. No published values exist for the state of Arkansas; the nearest are from northeastern Oklahoma (1.4 h.f.u.), and northern and eastern Missouri (1.2-1.3 h.f.u.) (Roy et al., 1968). Although these numbers are not particularly encouraging for geothermal energy, they may be significant in the light of current interest in the recovery of the earth's heat by Hot Dry Rock extraction methods. This report describes six new heat-flow measurements in Arkansas and discusses their possible significance to geothermal development in the area.

II. GEOLOGICAL BACKGROUND

Physiographically, the state of Arkansas can be divided into four regions (Fig. 1):

1. The Ozark Mountains, in the northwestern part of the state, consisting of gently folded and faulted sediments ranging in age from Lower ordovician to Upper Pennsylvanian.

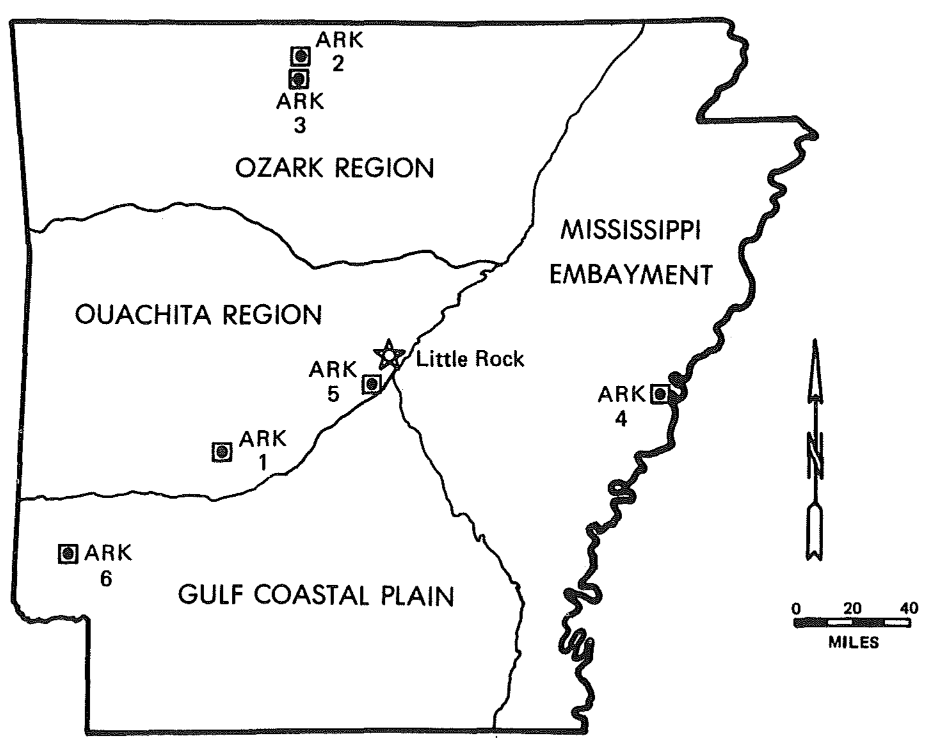

Fig. 1
Physiographic provinces of Arkansas, and location of heat-flow holes.

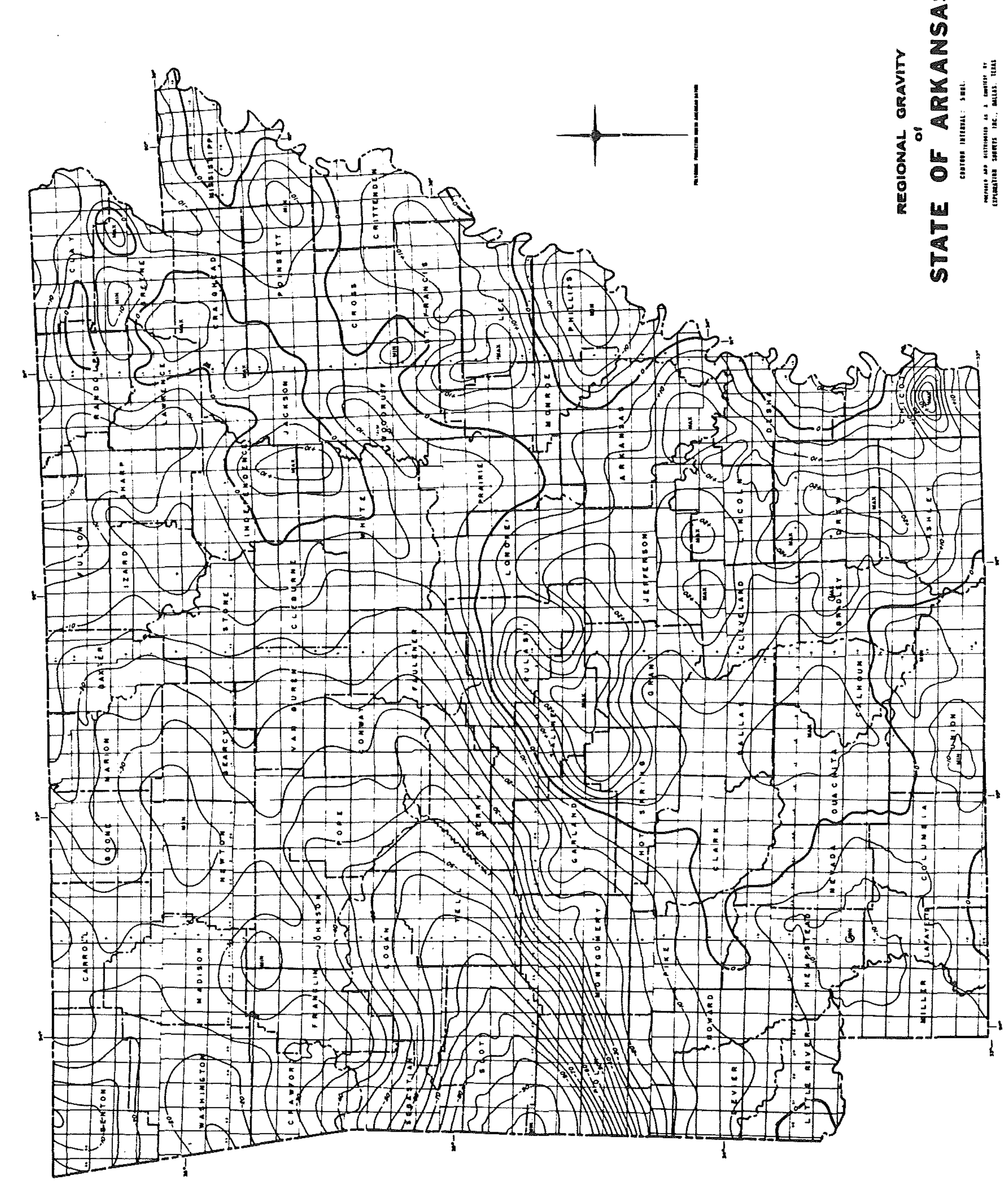

Fig. 2
Regional Gravity Map of State of Arkansas.

2. The Ouachita Mountains, separated from the Ozarks by the coal-producing Arkansas Valley. These are comprised of contorted Lower Paleozoic rocks, representing the eastern end of the Ouachita thrust belt.
3. The Gulf Coastal Plain; Cretaceous through Recent sediments extending northwards to overlap the Ouachita Front.
4. The Mississippi Embayment, occupying the eastern part of the state and consisting mainly of unconsolidated Quaternary sands and gravels. The Embayment is the furthest inland extension of the Gulf geosyncline.

The division between fold-mountains and plain is quite clearly distinguishable on the regional gravity map of Arkansas (produced by Exploration Surveys, Inc., and reproduced in Fig. 2), by a broad gravity gradient forming a northeast-southwest feature across the state. Several small gravity "highs" in the Embayment region are also of interest. The largest (areally) of these occurs in the central part of Arkansas, just south of Little Rock, and appears to coincide with the nepheline syenite intrusions, parts of which surface in the area. If this correlation is valid, then the other positive anomalies in the Embayment may also be due to intrusions (concealed beneath lower density sediments), and these could be possible targets for hot dry rock tests.

The thermal waters at Hot Springs, Arkansas, in the Ouachitas, have been known for many years, and are used for their supposed curative powers. Forty-seven springs emanate from a sandstone member of the Upper Mississippian Stanley Shale, near the axis of a large overturned anticline; flow temperatures are around 60°C. Silica concentrations indicate the source temperature to be not much higher than this (Bedinger et al., 1979), and the general chemical similarities between hot and cold springs in the area suggest that the hot waters are merely deeply circulating ground water, with the jointing and faulting of the area providing channels for the uprising of the waters to the surface. The existence of a high-temperature resource in this vicinity therefore seems unlikely.

Sharp et al. (1979), in a geochemical reconnaissance of the Ouachita region, have delineated two trends in which there is a 30°C, or greater, difference between equilibrium temperatures, calculated with the silica geothermometer, and surface temperatures. They use an assumed regional geothermal gradient of 36°C/km to derive a circulation depth of about 1000 m for the

waters. However, the present study indicates that, in the area of Glenwood (some 35 miles west of Hot Springs) at least, the gradient is between 18 and 21°C/km; this would necessitate a greater depth for any water circulation model.

Hot waters have also been encountered in the Smackover Formation (Upper Jurassic) of southern Arkansas. Bromine-rich brines and petroleum are recovered from this formation, from depths over 2000 m. The brines reach the surface at around 100°C, and are normally reinjected into the ground, after the bromine has been extracted, the heat content being lost in the process. Recently, however, an experimental geothermal energy recovery plant has been set up at Marysville (near El Dorado) to investigate the usage of these hot brines for electrical power production. The system uses a binary fluid cycle (isopentane is the second fluid) to extract the heat from the brine, and generate electricity.

The geothermal gradient for the above is between 30 and 40°C/km; this is achieved by compiling a mean annual surface temperature from weather stations in the Coastal Plain area (about 17.3°C), and assuming no heat loss of the brines on their rise to the surface. Data on well temperature and depth in the Coastal Plain of Arkansas from Plebuch (1962) were treated in this manner to produce "pseudo-gradients," which are shown, contoured, in Fig. 3. This shows a general increase in geothermal gradient from the Ouachita-Coastal Plain overlap to the southernmost part of the state.

III. HEAT-FLOW MEASUREMENTS

Nine boreholes were initially located for heat-flow determinations in this study. Of these, six were finally used, and are described below; their locations were shown in Fig. 1.

Geothermal gradients were measured with a thermistor probe and resistance-bridge apparatus, temperatures being measured usually every 10 m downhole. Thermal conductivities were determined using a divided-bar assembly, both for solid core and cuttings, the latter using the method of Sass et al. (1971), in which the cuttings are packed into cells (made of copper and plastic) and saturated with water. Solid cores were first water-saturated under 2500 lb/in^2 pressure. Heat flows were evaluated on straight sections of temperature gradients (themselves derived by a least-squares routine) by

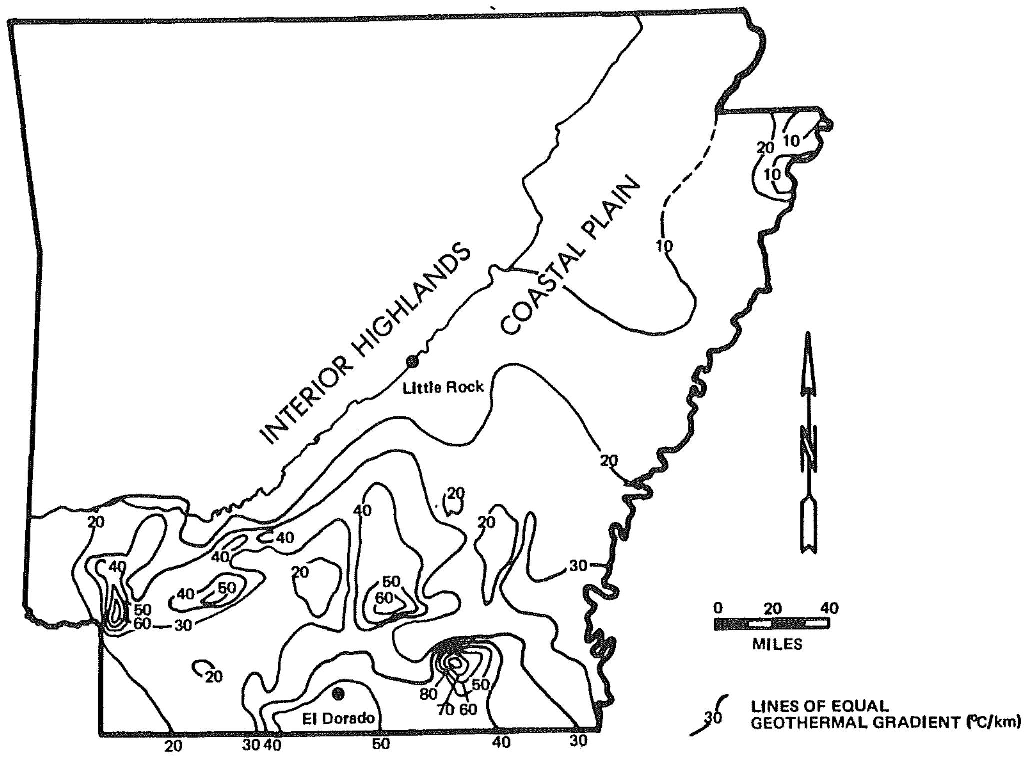

Fig. 3
Pseudo-geothermal gradients in the coastal plain of Arkansas.

multiplying the gradient by the mean thermal conductivity over that section. Where boreholes were situated in hilly terrain, corrections were made to the gradients for the changes in topography, out to at least 5 km from the hole. Summary results for all six holes are given in Table I. Individual descriptions of the sites follow; graphical representations of the data for each hole form the Appendix.

- ARK 1, near Glenwood: A mineral exploration hole for barite in the Upper Mississippian Stanley Shale (interbedded sandstone and carbonaceous shale). Temperature measurements were made inside a 1-1/4-in. water-filled steel pipe, lowered into the hole, and conductivities were determined from solid core (1-7/8-in. diam). The gradient falls in two sections, with corresponding conductivities; both sections yield the same heat flow, namely 1.09 h.f.u. A terrain correction of less than 2% was applied to the result.
- ARK 2, Zinc: A cased mineral exploration hole in the lead-zinc producing area of the Ozarks, penetrating Lower Ordovician and Upper

TABLE I

SUMMARY OF RESULTS FOR HEAT-FLOW SURVEY OF ARKANSAS

Hole No.	Location	Long./Lat.	Elevation (meters)	Depth Used (meters)	Gradient (°C/km)	Mean Conductivity (mcal/cm/s/°C)	Heat Flow ($\times 10^{-6}$ cal/cm^2/s)	Acknowledgments
ARK 1	Near Glenwood Montgomery Co.	93°50' 34°23'	317	40-310	21.1	5.17 (8)	1.09[a] ± 0.01	F.C. Gale, Milchem, Inc.
				320-530	18.46	5.92 (20)	1.09[a] ± 0.02	" "
ARK 2	Zinc, Boone Co. T19N R18W S20	92°55' 36°17'	274	480-610	20.3	13.91 (5)	2.82 ± 0.11	J.R. Reeves, Placer Amex, Inc.
ARK 3	Pindall, Searcy Co. T16N R18W S2	92°52' 36°03'	360	450-590	13.0	12.42 (5)	1.61[a] ± 0.02	W. Moore Placer Amex, Inc.
ARK 4	Marianna, Lee Co. T1N R4E S9	90°42' 34°42'	61	30-320	23.8	13.17 (8)	3.13 ± 0.06	J. Edds, U.S.G.S.
ARK 5	Little Rock, Pulaski Co. T1N R12W S25	92°15' 34°42'	87	65-175	25.5	4.16 (14)	1.06[a] ± 0.01	Granite Mountain Quarries
ARK 6	Horatio, Sevier Co. T10S R31W S1	94°15' 33°55'	117	40-90	19.6	10.20 (1)	2.0 ± 0.01	R. Gage, J. Gray

[a]Terrain correction applied; numbers in brackets refer to the number of samples used.

Cambrian rocks. Water movements in the upper part of the hole, especially through the Roubidoux Sandstone, limited a meaningful gradient determination to the bottom 200 m, which is comprised of siliceous and chalky dolomites of the Eminence Formation; with corresponding conductivities, this resulted in a heat flow of 2.82 h.f.u. This is an unexpectedly high value, and probably should be accepted with caution. The gradient may be raised by a ground-water disturbance through the mineralized belt in the vicinity of the hole.

- ARK 3, Pindall: Another lead-zinc test hole, only 15 miles south of ARK 2, and a little higher in the Ordovician sequence. Again, water disturbances in the upper section of the hole restricted useful measurements to the lower half. In both ARK 2 and ARK 3, conductivities were measured using crushed split-core, since solid core was not available in ARK 3. The representative samples were siliceous dolomites of the Jefferson City and Gasconade Formations. The resulting heat flow, 1.61 h.f.u., which was terrain corrected (the correction amounting to only 0.2%), is more in keeping with the regional pattern, and thus is probably the more reliable value of the two in the Ozark region.

- ARK 4, Marianna: The only measurement made in the eastern part of the state, this U.S. Geological Survey (USGS) water-test hole was situated in the alluvial plain of the Mississippi, and did not penetrate consolidated rock. The geothermal gradient used is that section down to 320 m; the corresponding conductivities were measured on cuttings from the well, and are widely scattered in value, reflecting the variation of lithology (from clays to sands) in this Middle and Upper Eocene section. The heat-flow of 3.13 h.f.u. is the highest measured in the present study.
- ARK 5, Little Rock: This hole is located in a nepheline-syenite intrusion which occurs at the overlap of the Coastal Plain/Mississippi Embayment and the Ouachita Front. The rock is quarried for bauxite, where weathered, and elsewhere for roadstone; ARK 5 was situated in a roadstone quarry. Temperature measurements were made inside a 1-1/4-in. water-filled steel pipe, and conductivities were determined on 1-7/16-in. core recovered from the hole. The geothermal gradient is undisturbed to the bottom of the hole, although the conductivities show some slight variation (see Appendix). A resistivity log shows almost no change, except at the top of the hole, where a pegmatite dike was penetrated. Some syenites are quite radioactive, and so samples from ARK 5 were analyzed for K, U, and Th (using a gamma-ray spectrometer), in order to investigate the radioactive heat production. Values are constant down the hole, at about 11 heat generation units (1 HGU = 10^{-13} cal/cm^3/s), but are seen to double on encountering the dike. Table II gives the results of the K, U, Th analysis. A reduced heat flow, q*, of 0.24 h.f.u., derived from the formula below, is found for the nepheline syenite.

$$Q^* = Q \text{ surface} - dA \qquad (1)$$

where Q* = reduced heat-flow (i.e., the contribution from the lower crust and mantle).

Q surface = measured surface heat flow

TABLE II
GAMMA RAY SPECTROMETRY AND RADIOACTIVE HEAT GENERATION MEASUREMENTS OF ARK 5, NEPHELINE SYENITE, GRANITE MOUNTAIN QUARRY

Depth (meters)	Th (ppm)	U (ppm)	K (%)	HGU (total)
2.4 - 3.0	33.4	8.7	5.0	23.34
5.2 - 5.7	30.6	7.7	5.2	21.53
9.1 - 9.5	14.8	4.5	5.0	11.10
18.3 - 18.8	15.7	4.5	5.0	11.65
24.4 - 25.0	15.2	4.5	5.0	11.34
36.6 - 37.0	14.3	4.0	4.8	10.65
45.7 - 46.2	15.0	3.9	5.0	10.51
54.9 - 55.3	16.2	4.4	5.1	11.96
63.7 - 64.3	14.5	3.9	4.8	10.75
73.5 - 73.8	14.8	4.4	5.1	10.94
82.3 - 82.7	15.9	4.7	4.8	11.76
91.1 - 91.6	16.3	4.4	5.1	12.01
100.6 -101.0	15.2	4.3	5.1	11.30
112.5 -113.0	14.3	4.3	5.1	10.75
118.3 -118.8	14.6	4.3	5.1	10.93
128.0 -128.5	13.2	3.6	4.6	9.85
136.6 -137.0	15.0	4.2	5.1	11.18
144.5 -145.0	14.8	4.8	5.1	11.17
155.4 -155.7	14.3	4.2	5.0	10.73
164.6 -165.0	13.8	4.2	4.9	10.47
173.7 -173.9	14.0	4.1	4.9	10.51
182.9 -183.2	14.1	4.1	5.0	10.59
Mean value over section 65-175 m =				10.97

d = depth of radioactive layer (taken as 7.5 km in this case)

A = radioactive heat production (taken as 11.01 HGU, the mean of 20 measurements)

The value of 7.5 km for d was assumed from that of the eastern United States province (Roy et al., 1973). However, the reduced heat-flow is less than half the 0.8 h.f.u. found for this same province. Figure 4 shows surface heat flow, Q, versus radioactive heat production, A (after Roy et al., 1973); the three lines represent the Basin and Range, eastern United States and Sierra Nevada heat-flow provinces. ARK 5 is marked by a star.

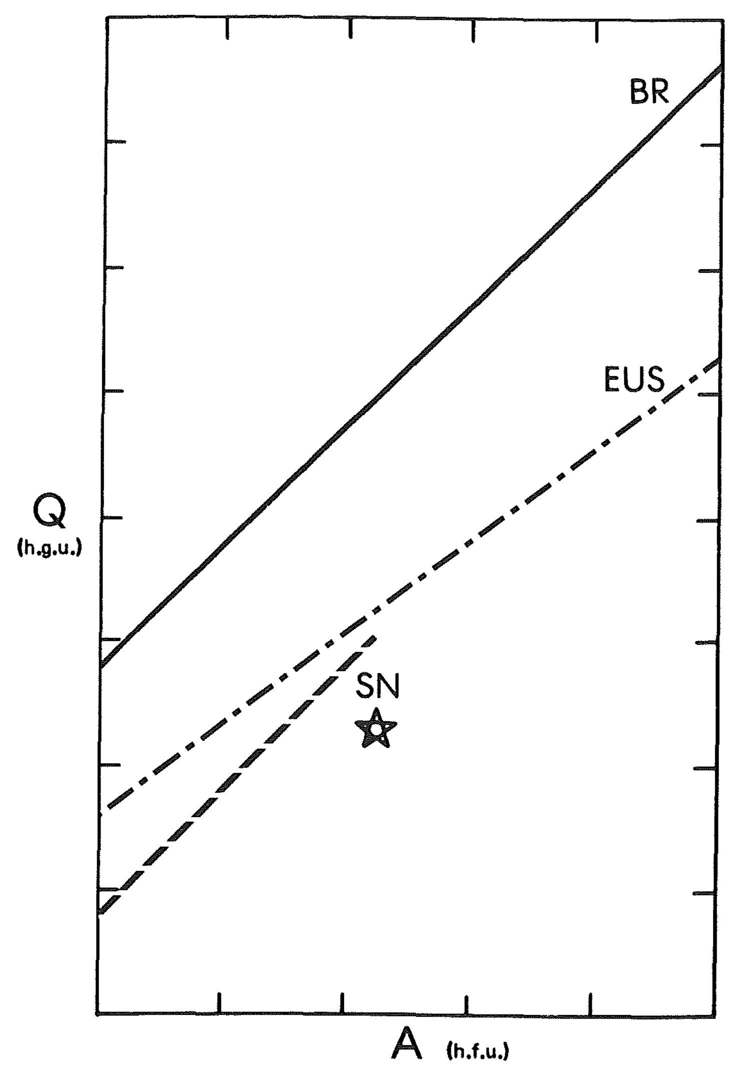

Fig. 4
Surface heat-flow versus heat generation for the Basin & Range (BR), Eastern United States (EUS), and Sierra Nevada (SN) Provinces (after Roy et al., 1973). ARK 5 is marked by a star.

- ARK 6, Boratio: An abandoned oil-test hole in the Wildcat Field of southwestern Arkansas. Temperature measurements were taken down to 90 m, where the hole was blocked. Only one sample was available for conductivity measurements, and this resulted in a heat-flow of 2.0 h.f.u.

IV. INTERPRETATION AND CONCLUSIONS

Six new heat-flow values have so far been determined for the state of Arkansas. The somewhat scattered nature of these is not too significant, considering the differing geological environments in which they were determined.

Three of these, namely ARK 1, 3, and 5, display heat-flows fairly typical of the central United States; available data in surrounding states agree closely with these results. The 1.09 h.f.u. value for ARK 1, in the Ouachita, is perhaps a little disappointing in terms of a potential geothermal resource, although the geochemistry from the Hot Springs area does not indicate a high-temperature water reservoir. The two holes in the Ozarks (ARK 2, ARK 3) give widely differing results. The 1.61 h.f.u. value measured at Pindall is the more reliable; the exaggerated gradient (and hence heat-flow) at Zinc is probably the manifestation of a water disturbance in the hole. Because no measurements are available in the Mississippi Embayment for comparison, the 3.13 h.f.u. at Marianna (ARK 4) stands. Deep circulating waters in the river plain may be responsible for the higher gradient here. The 2.0 h.f.u. result from Horatio (ARK 6) is probably too high, since only one conductivity measurement was available for the hole.

It was hoped to obtain a higher heat-flow in the nepheline syenite at Little Rock (ARK 5) than was actually determined. The 1.06 h.f.u. result is not encouraging for a hot dry rock geothermal test; the reduced value of 0.24 h.f.u. suggests that the syenite (with its relatively high heat-production figures) does not extend to any great depth and that the associated gravity anomaly is due to some other feature, such as a gabbroic intrusion. However, this result should not necessarily preclude further investigations in the intrusions of the area. Possible drilling targets could be the "highs" further out in the Coastal Plain, shown by the regional gravity map.

ACKNOWLEDGMENTS

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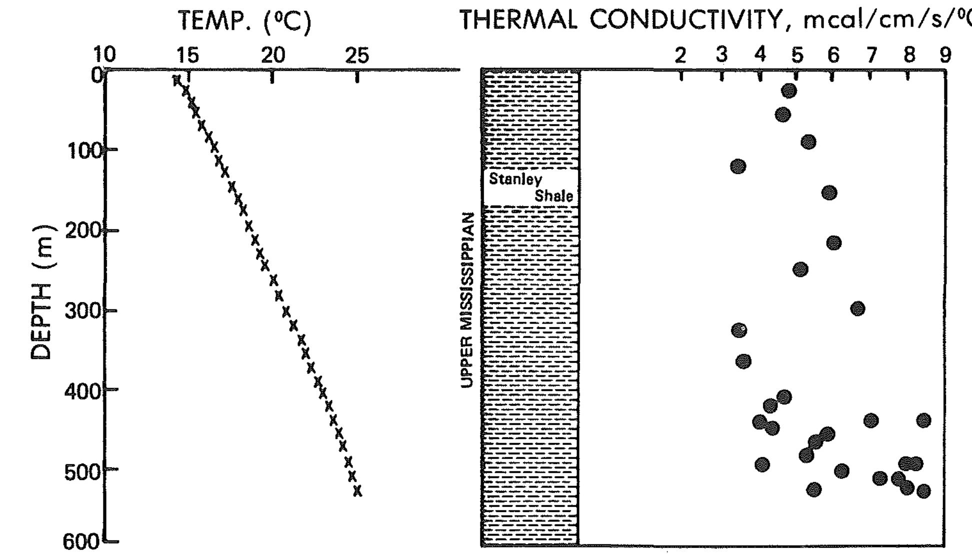
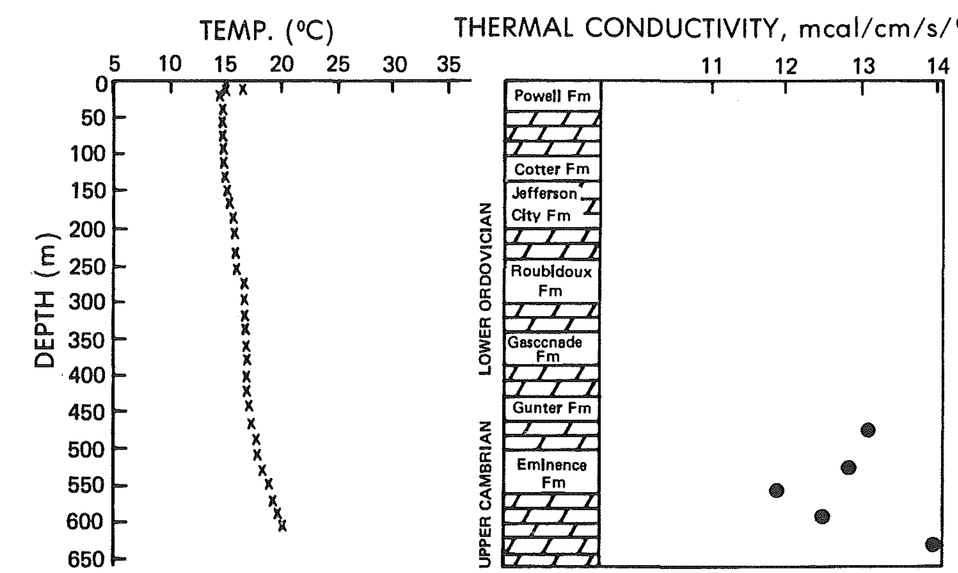
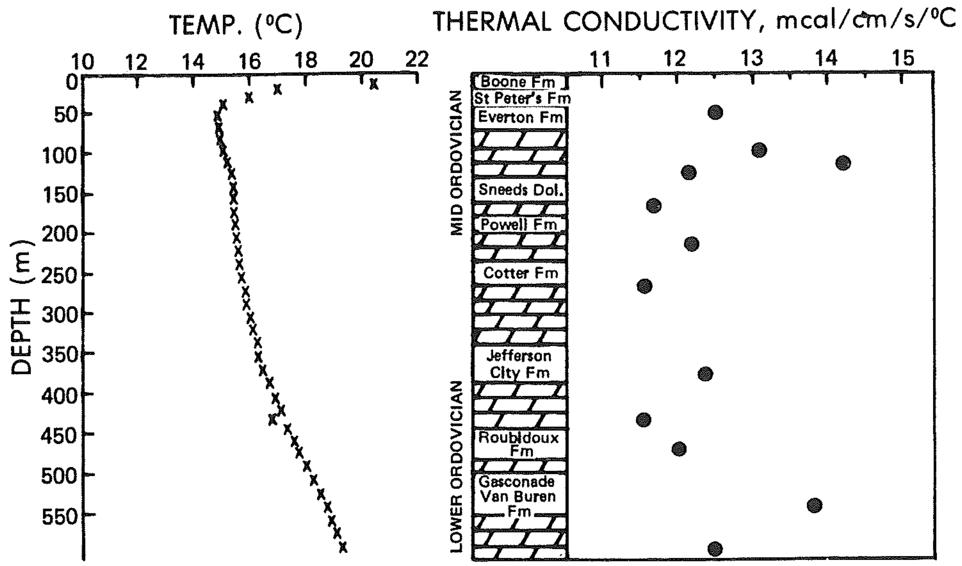
APPENDIX



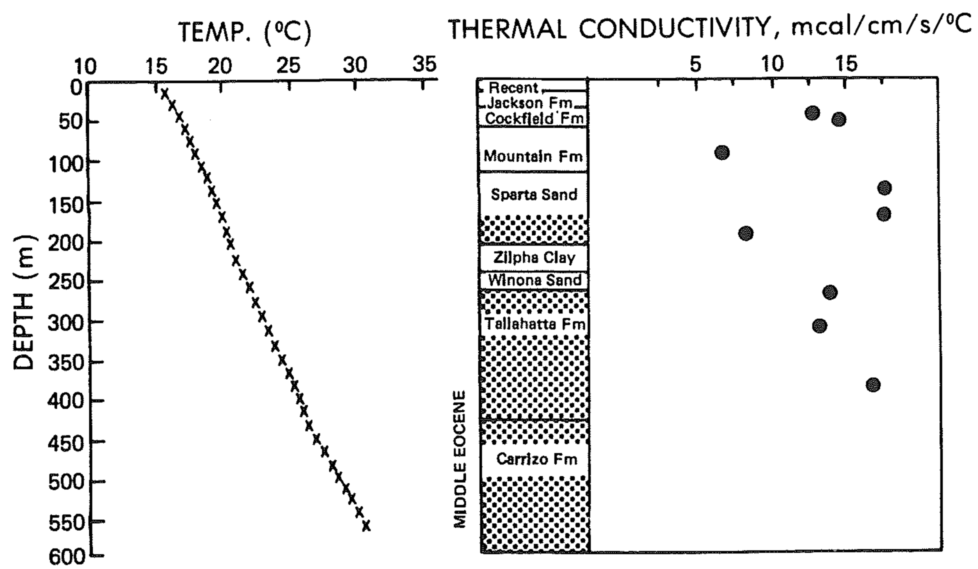
ARK 1 - NEAR GLEENWOOD, MONTGOMERY COUNTY, ARKANSAS



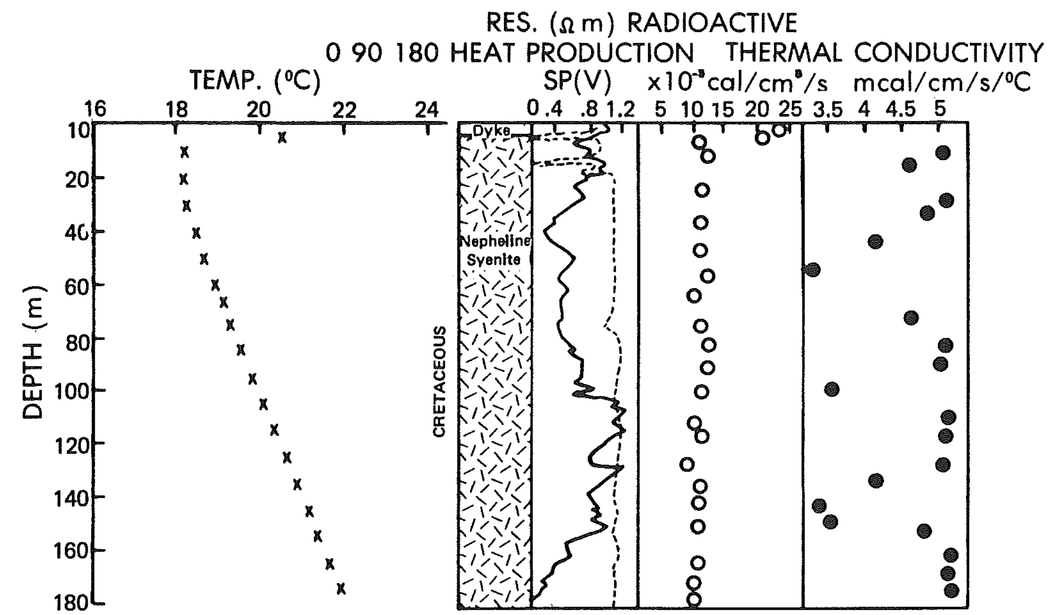
ARK 2 - ZINC, BOONE COUNTY, ARKANSAS



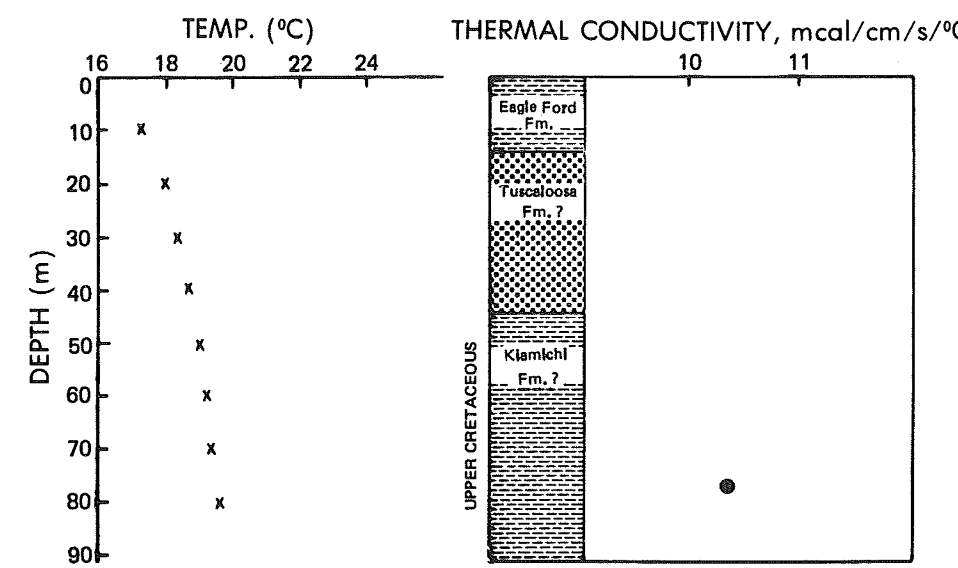
ARK 3 - PINDALL, SEARCY COUNTY, ARKANSAS



ARK 4 - MARIANNA, LEE COUNTY, ARKANSAS



ARK 5 - LITTLE ROCK, PULASKI COUNTY, ARKANSAS



ARK 6 - HORATIO, SEVIER COUNTY, ARKANSAS

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