LA-9222-HDR

UC-66b

Issued: April 1982

LA--9222-HDR

DE82 015898

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HEAT-FLOW RECONNAISSANCE OF THE GULF COASTAL PLAIN

by

Douglas L. Smith and Spencer S. Shannon, Jr.

ABSTRACT

Most of the 46 new values of heat flow determined for the Gulf Coastal Plain are in the low to normal range, but heat-flow values averaging 1.8 heat-flow unit (HFU) were obtained in Claiborne, Ouachita, and Union parishes, Louisiana. Moreover, a zone of relatively high heat-flow values and steep thermal gradients ($35\text{--}46^{\circ}\text{C/km}$) extends from northern Louisiana into southwestern Mississippi. Also near Pensacola, Florida, temperatures of 50°C at 1-km depth have been extrapolated from thermal gradients. Future development of low-grade geothermal resources may be warranted in these areas.

INTRODUCTION

This report presents the results and interpretations derived from a project to acquire additional temperature-gradient and heat-flow data for a reconnaissance of geothermal conditions in the southeastern United States. Temperatures were measured in available boreholes, selected through cooperation with state geological surveys and the United States Geological Survey Water Resources Division.

In the summer of 1979, 21 new heat-flow values were obtained from wells in Florida, Alabama, Mississippi, and Louisiana. The range of values suggested a westerly extension of the low-to-normal heat flux, which characterizes the southern Atlantic Coastal Plain and the southern Appalachian Mountains (Smith, Gregory, and Emhof, 1981). No exceptionally high anomalies were found, but the areas having higher values in northern Louisiana and southwestern Mississippi should be investigated. Anomalous high values

reported in Arkansas (Fig. 1) by von Frese et al. (1980) support the credibility of the Louisiana values. Similarly, the initial work seems to extend a zone of anomalously low heat flux into central Alabama from the Appalachian Plateau and Valley and Ridge provinces of northeastern Alabama and northwestern Georgia (Fig. 2).

Thermal gradients exceeding $30^{\circ}\text{C}/\text{km}$ were recorded in several wells, and conditions at other sites suggest that the subsurface-water temperatures approach those of low-grade resources.

Some bias was introduced into the selection of borehole sites for continuation of the project in 1980 because results of the first phase included areas having higher heat-flow values than expected, and these required further investigation. Examination of other areas was necessary to achieve a relatively uniform spatial distribution of data points throughout the Gulf Coastal Plain. Twenty-five new heat-flow values were determined in 1980. Measurements were not made in certain areas, such as southern Louisiana, because no nonflowing boreholes were available.

All 46 values determined in 1979-80, and the procedures for the acquisition of these data, are presented herein. The resource potential of favorable areas, and their relations to basement structure are interpreted from the data acquired.

PROCEDURES

Borehole temperatures were measured at discrete depths with a thermistor-probe assembly coupled to a four-conductor cable. A Mueller-type Wheatstone bridge having an Electroscientific Industries six-decade variable resistor and a Leeds and Northrup 2437 null detector was used to match thermistor resistances. The system was calibrated from 10°C to 40°C using a platinum resistance thermometer. The estimated accuracy of individual temperature measurements is $\pm 0.1^{\circ}\text{C}$. The accuracy of successive-temperature differentials obtained from computer-derived, least-squares gradient values is considered to be $\pm 0.01^{\circ}\text{C}/\text{km}$. The terrain at all drill hole sites is sufficiently gentle that no topographic corrections to the computed-temperature gradients are necessary (Smith and Dees, 1982).

Thermal-conductivity values were determined with two divided-bar assemblies similar to those described by Sass et al. (1971). Both bars were calibrated with fused-quartz and natural-quartz standards supplied by the

Valtec Corporation having the values of Beck (1957). No boreholes logged had been cored, so only cuttings were available for conductivity measurements. For many sites where rock samples were unavailable, cuttings from nearby drill holes were used.

Thermal-conductivity values on drill cuttings were determined following the procedures and using equipment described by Sass, Lachenbruch, and Munroe (1971). The Coastal Plains sedimentary rocks were assigned a uniform porosity of 30%, but the observed variations in porosity would not affect the calculated conductivity values significantly. Heat-flow values were determined as the product of least-squares temperature gradients and harmonic means of thermal-conductivity values.

DATA

The temperature-gradient, thermal-conductivity, and location data for the 46 drill holes are summarized in Table I. Figure 3 depicts the location of new-value measurements except for two sites in north-central Florida beyond the eastern limit of the map.

Temperature gradients commonly vary within a single borehole. Such changes result from lateral flow in aquifers, or rarely from contrasts in strata that have distinctively different thermal-conductivity values. Figures 4 through 49 show the depth/temperature profiles. Measurements at Winnfield, Louisiana, and Columbus, Mississippi, have large changes in gradients. For each borehole, a separate heat flow was computed for each depth zone, and an average value, weighted by depth intervals, was determined and plotted on the figures. The observed variations in some boreholes are examples as to why caution must be used in extrapolating temperatures to greater depths.

A low-to-average heat flow predominates throughout the eastern Gulf Coastal Plain. Except for a limited area in the western part of the Florida panhandle (Fig. 3), all new heat-flow values from southwestern Georgia, Alabama, and Florida are less than 1 heat-flow unit (HFU).

Measurements at Natchez and Utica in southwestern Mississippi yielded thermal gradients as high as 46°C/km (over the 180- to 340-m-depth interval at Utica) and heat-flow values of 1.4 HFU and 1.5 HFU (Fig. 3). Utica overlies the Jackson Dome, a major subsurface feature associated with elevated temperatures discovered from petroleum-exploration efforts. Values from ten sites in

TABLE I
GEOHERMAL-GRADIENT AND HEAT-FLOW DATA
FOR HOLES LOGGED IN THE GULF COASTAL PLAIN

Location	Latitude	Longitude	Depth (m)	Gradient (°C/km)	Interval (m)	No. Sample Analyzed	Conductivity Units (mcal/cmsec°C)	Heat Flow Units (μcal/cm²sec)
FLORIDA								
Gainesville Deerhaven	29°45'32"	82°23'18"	500	12.04	100-500	14	3.11	0.37
Wellborn	30°09'36"	82°48'45"	300	19.71	40-300	3	3.15	0.62
Gretna	30°37'13"	84°38'24"	280	26.26	60-160	6	3.22	0.84
				24.82	200-280	2	3.40	0.84
St. George Is.	29°40'30"	84°50'05"	273	21.18	120-273	10	2.77	0.58
Chattahoochie USGS Well W12493	30°42'30"	84°53'02"	140	23.77	20-140	7	3.49	0.83
Prime Beef USGS Well W14102	30°30'21"	86°35'14"	300	27.73	40-300	13	5.56	1.54
Ft. Walton Beach	30°23'55"	86°35'52"	500	31.54	100-340	13	3.29	1.03
				23.52	340-500	5	2.88	0.67
Navarre	30°24'09"	86°52'35"	280	22.45	60-140	18	3.29	0.74
				34.13	140-280			1.12
Camp Henderson	30°59'42"	86°58'00"	148	12.49	60-148	6	3.34	0.4
Whiting Field	30°42'52"	87°00'22"	360	28.70	120-260	6	3.66	1.05
				27.81	300-360	3	3.52	0.97
GEORGIA								
Kolomoki State Park	31°25'43"	84°57'51"	168	19.66	60-168	7	3.28	0.64
ALABAMA								
Ozark USGS Well Dle 1	31°22'39"	85°34'49"	140	10.36	40-140	8	4.75	0.49
Union Springs	32°08'09"	85°40'54"	267	23.84	80-267	8	3.10	0.74
Eclectic USGS Well Elm 1	32°37'57"	86°01'39"	110	7.08	20-110	5	4.17	0.29
Thomaston	32°13'06"	87°37'30"	340	22.20	40-120	3	2.27	0.50
				37.07	140-280	5	2.38	0.88
				19.92	300-340			0.74 ^a
Eutaw USGS Well Gr 3	32°50'05"	87°53'20"	108	10.70	20-108	6	4.71	0.50
Guin	33°57'42"	87°55'00"	149	0.76	20-120			
				11.28	120-149	6	3.50	0.39
MISSISSIPPI								
Columbus Hooker Chem 122	33°25'28"	88°23'53"	306	17.31	20-100	14	3.55	0.62
				15.70	100-306			0.56
Brooklyn	31°01'35"	89°09'31"	218	20.08	60-220	14	5.06	1.06
Forest Industrial Prk	32°21'45"	89°30'05"	380	21.09	120-240	20	3.77	0.79
				27.73	240-380			1.04
Durant USGS Well T14	33°04'58"	89°51'09"	119	8.94	20-100	7	5.15	0.46
Senatobia	34°37'24"	89°58'12"	334	19.94	100-340	18	5.10	1.01
Utica	32°06'30"	90°37'30"	380	25.75	80-160	5	6.50	1.67
				45.98	180-340	16	3.09	1.42
Shelby USGS Well D31	33°56'30"	90°46'15"	500	49.97	20-80			2.43
				23.97	100-500	7	4.86	1.16

Table I (cont)

Location	Latitude	Longitude	Depth (m)	Gradient (°C/km)	Interval (m)	No. Sample Analyzed	Conductivity Units (mcal/cmsec°C)	Heat Flow Units (μcal/cm ² sec)	
MISSISSIPPI (continued)									
Pace USGS Well MW643	33°47'37"	90°51'18"	280	16.23	40-280	6	5.55	0.90	
Cary USGS Well 644	32°48'21"	90°55'31"	190	17.11	120-190	10	4.68	0.80	
Natchez	31°27'52"	91°20'22"	260	27.96	120-260	13	5.07	1.42	
LOUISIANA									
Bogalusa	30°49'00"	89°54'26"	440	17.71	60-440	13	5.90	1.04	
Baton Rouge (south)	30°25'09"	91°08'27"	500	22.42 23.64	100-260 260-500	6 5	5.29 4.42	1.19 1.04	1.10 ^a
Baton Rouge (north)	30°26'14"	91°08'30"	500	25.64 22.06	120-300 300-500	4	5.07	1.30 1.12	1.21 ^a
Scotlandville	30°32'51"	92°11'50"	500	23.55 19.57	80-280 300-500	5 5	5.56 6.10	1.30 1.19	1.24 ^a
Bastrop	32°43'52"	91°53'10"	258	26.54 37.45	60-120 120-260	3 3	5.45 4.92	1.44 1.84	1.72 ^a
Bosco USGS Well Ou 402	32°17'14"	92°04'14"	236	20.79 29.00	40-100 120-236	13	4.07	0.85 1.18	1.07 ^a
Haile USGS Well Un 79	32°49'55"	92°08'40"	236	22.58 34.98	60-100 100-236	8	6.46	1.46 2.26	2.08 ^a
Deville USGS Well R 893	31°23'39"	92°09'45"	250	24.94	40-250	8	4.51	1.12	
Kelly USGS Well Ca 86b	32°01'54"	92°16'46"	172	26.56 44.23	60-120 120-172	7	5.72	1.52 2.53	1.99 ^a
Calhoun USGS Well Ou 443	32°31'00"	92°16'58"	260	31.08	60-260	10	5.12	1.59	
Truxno USGS Well Un 80	32°49'17"	92°24'20"	215	33.13	60-215	9	6.49	2.13	
Sikes USGS Well W 172	32°05'41"	92°29'16"	200	30.30	60-200	9	5.93	1.80	
Vernon	32°23'57"	92°34'17"	217	18.76 29.11	40-120 120-220	3 3	5.45 4.92	1.04 1.43	1.26 ^a
North Hodge USGS Well Ja 156	32°17'30"	92°37'37"	200	23.74	40-200	7	5.40	1.28	
Winnfield USGS Well W 177	31°53'38"	92°40'00"	215	13.20 27.65	20-80 100-215	5	5.73	0.76 1.58	1.30 ^a
Bernice USGS Well C1 151	32°00'08"	92°44'35"	220	22.73 32.17	60-120 120-220	8	6.17	1.40 1.98	1.76 ^a
Junction City USGS Well C1 149	33°00'02"	92°44'59"	230	24.94	120-230	9	6.02	1.50	
Marsalis USGS Well C1 136	36°39'43"	92°57'36"	258	27.48	80-258	6	6.50	1.79	
Simpson	31°15'44"	93°00'25"	378	26.82	60-380	7	4.78	1.28	

^aWeighted average.

TEMPERATURE, °C

DEPTH, m

GAINESVILLE, FLORIDA

Depth (m)	Temperature (°C)
10	24.5
20	24.2
30	24.8
40	24.5
50	24.2
60	24.0
70	23.8
80	23.5
90	23.2
100	23.0
120	22.8
140	22.6
160	22.5
180	22.4
200	22.3
220	22.2
240	22.1
260	22.0
280	21.9
300	21.8
320	21.7
340	21.6
360	21.5
380	21.4
400	21.3
420	21.2
440	21.1
460	21.0
480	20.9
500	20.8

Fig. 4.

Depth/temperature profile in Gainesville, Florida well.

Fig. 5.
Depth/temperature profile in
Wellborn, Florida well.

Fig. 6.
Depth/temperature profile in
Gretna, Florida well.

Fig. 7.

Depth/temperature profile in St. George Island, Florida well.

Fig. 8.

Depth/temperature profile in Chattahoochee, Florida well.

Fig. 9.

Depth/temperature profile in
Prime Beef, Florida well.

Fig. 10.

Depth/temperature profile in
Ft. Walton Beach, Florida well.

Fig. 11.

Depth/temperature profile in Navarre, Florida well.

Fig. 12.

Depth/temperature profile in Camp Henderson, Florida well.

Fig. 13.

Depth/temperature profile in
Whiting Field NAS, Florida well.

Fig. 14.

Depth/temperature profile in
Kolomoki State Park, Georgia well.

Fig. 15.

Depth/temperature profile in Ozark, Alabama well.

Fig. 16.

Depth/temperature profile in Union Springs, Alabama well.

Fig. 17.

Depth/temperature profile in Eclectic, Alabama well.

Fig. 18.

Depth/temperature profile in Thomaston, Alabama well.

Fig. 19.

Depth/temperature profile in Eutaw, Alabama well.

Fig. 20.

Depth/temperature profile in Guin, Alabama well.

Fig. 21.

Depth/temperature profile in
Columbus, Mississippi well.

Fig. 22.

Depth/temperature profile in
Brooklyn, Mississippi well.

Fig. 23.

Depth/temperature profile in Forest, Mississippi well.

Fig. 24.

Depth/temperature profile in Durant, Mississippi well.

Fig. 25.

Depth/temperature profile in Senatobia, Mississippi well.

Fig. 26.

Depth/temperature profile in Utica, Mississippi well.

Fig. 27.

Depth/temperature profile in Shelby, Mississippi well.

Fig. 28.

Depth/temperature profile in Pace, Mississippi well.

Fig. 29.

Depth/temperature profile in
Cary, Mississippi well.

Fig. 30.

Depth/temperature profile in
Natchez, Mississippi well.

Fig. 31.

Depth/temperature profile in Bogalusa, Louisiana well.

Fig. 32.

Depth/temperature profile in Baton Rouge (South), Louisiana well.

Fig. 33.

Depth/temperature profile in Baton Rouge (North), Louisiana well.

Fig. 34.

Depth/temperature profile in Scotlandville, Louisiana well.

Fig. 35.

Depth/temperature profile in Bastrop, Louisiana well.

Fig. 36.

Depth/temperature profile in Bosco, Louisiana well.

Fig. 37.

Depth/temperature profile in Haile, Louisiana well.

Fig. 38.

Depth/temperature profile in Deville, Louisiana well.

Fig. 39.

Depth/temperature profile in Kelly, Louisiana well.

Fig. 40.

Depth/temperature profile in Calhoun, Louisiana well.

Fig. 41.

Depth/temperature profile in Truxno, Louisiana well.

Fig. 42.

Depth/temperature profile in Sikes, Louisiana well.

Fig. 43.

Depth/temperature profile in
Vernon, Louisiana well.

Fig. 44.

Depth/temperature profile in
North Hodge, Louisiana well.

Fig. 45.

Depth/temperature profile in Winnfield, Louisiana well.

Fig. 46.

Depth/temperature profile in Bernice, Louisiana well.

Fig. 47.

Depth/temperature profile in
Junction City, Louisiana well.

Fig. 48.

Depth/temperature profile in
Marsalis, Louisiana well.

Fig. 49.

Depth/temperature profile in Simpson, Louisiana well.

Mississippi average 1.1 HFU, and thus approximate typical Gulf Coastal Plain values.

Quachita, Union, and Claiborne parishes in northern Louisiana where three sites exceed 2.0 HFU and another six sites exceed 1.5 HFU (Fig. 3). Geothermal gradients in northern Louisiana range from 25°C/km to more than 40°C/km in the 120- to 170-m depth interval at Kelly. Several sites have gradients that exceed 30°C/km (Table I). The relatively higher heat flow in northern Louisiana results from both higher gradients and slightly higher thermal-conductivity values (Table I).

The positive thermal anomalies in northern Louisiana are linked with higher gradients in west-central Mississippi and the western part of the Florida panhandle to form a wedge-shaped zone (Fig. 50) of near-surface thermal conditions in the gulf coastal area.

Positive and negative heat-flow anomalies are evident in Fig. 3. A broad region, including most of central and southern Alabama, east-central Mississippi, southwestern Georgia, and north-central Florida, has heat-flow values less than 0.7 HFU. In Alabama and Florida, these measurements are

Fig. 50.

Depth/temperature profile in
Compass Lake, Florida well
(after Dees, 1981).

consistent with earlier measurements in sedimentary rocks reported by Smith, Gregory, and Emhof (1981). The abnormally low heat-flow values can be attributed to exceptionally low geothermal gradients (typically 10-15°C/km). Only at Thomaston, Alabama, is a high geothermal gradient (37°C/km over 140- to 280-m depth interval) associated with a low heat flux (0.9 HFU in the same range; 0.7 HFU weighted average).

The influence of hydrologic conditions is unclear although there may be some causal effects. Temperature measurements at Compass Lake, in the middle of the Florida panhandle, show a near-zero thermal gradient over a 160-m depth interval. As the top of the Florida aquifer is only 50 m deep there, a relation between the aquifer and the subsurface-temperature distribution is probable.

DISCUSSION

As Costain et al. (1980) postulated 150°C temperatures at 2-km depth, comparable extrapolations of certain temperature gradients in similar geologic

environments in the Gulf Coastal Plain are proposed. Subsurface temperature extrapolations to depth, particularly in sedimentary terrains having extensive hydrologic activity, are conjectural. For the Gulf Coastal Plain, near-surface (0- to 500-m depth) temperature data can be considered with bottom-hole temperatures from deeper oil and gas tests to be of some use in predicting temperatures at greater depths.

Using general gradients of $25^{\circ}\text{C}/\text{km}$ and temperatures of 24°C at a depth of 200 m in northern Louisiana, a temperature range of 44°C might be expected at 1-km depth, and temperatures as high as 78°C can be postulated at 2 km. If some perhaps anomalous gradients ($35\text{--}44^{\circ}\text{C}/\text{km}$) are used, the extrapolated temperature values at depth would be considerably higher.

In the Pensacola area of the Florida panhandle, gradients of $30\text{--}34^{\circ}\text{C}/\text{km}$ and temperatures of 35°C at 500-m depth can be extrapolated to 50°C temperatures at 1 km.

Although definitions vary, low-grade geothermal resources that have potential use in space-heating and auxiliary-power for the eastern United States require temperatures of at least 40°C at less than 1-km depth. Practical utilization of low-temperature ($<90^{\circ}\text{C}$) resources for direct-heat or heat-pump applications is also dependent on nearby consumer markets.

The near-surface temperature gradients observed in this study indicate that specific regions in northern Louisiana, western Mississippi, and the western part of the Florida panhandle may have the minimum geothermal conditions for eventual exploitation. The entire wedge-shaped zone described in Fig. 51 may contain marginal thermal resources.

In northern Louisiana a possible association between higher thermal conditions and salt intrusions can be inferred from Fig. 51. However, the area of known salt intrusions (Fig. 52) excludes several sites having higher heat-flow values in northern Louisiana, so it can be argued that the higher thermal conditions in northern Louisiana are spatially related to the distribution of subsurface alkalic plutons peripheral to the Monroe uplift. The relation of salt intrusions to high thermal gradients is of interest because the thermal conductivity of salt is three to four times greater than that of the country rock. Therefore, a salt diapir essentially would act as a preferential thermal conduit (Jacoby and Paul, 1974).

Smith, Dees, and Harrelson (1981) describe the northwesterly trending zone of anomalously low heat flow in southern Alabama and north-central

Fig. 51.

Distribution of new heat-flow values in the Gulf Coastal Plain. Shaded areas are those having salt-dome intrusions. The two dashed lines depict the zone of relatively high geothermal gradients (after Smith and Dees, in press).

Mississippi as being underlain by oceanic basement and a thick sequence of sedimentary rocks. The Pickens-Gilbertown fault system (Fig. 53) divides this zone on the south from oceanic crust distinguished by mobilized, thermally conductive salt diapirs. Smith, Dees, and Harrelson (1981) describe the Wiggins Arch intruded by Paleozoic granitic rocks in southernmost Mississippi and the Angelina-Caldwell flexure in southern Louisiana as representative of continental crust having average heat-flow values of 1.0-1.1 HFU.

Most drill holes in the Gulf Coastal Plain used in this reconnaissance penetrated one or more aquifers. The thermal influence of an aquifer commonly is perceptible on a depth/temperature profile. Most variations appear as discrete temperature offsets, whereas the temperature gradient may remain undisturbed or only slightly perturbed. Ideally, an aquifer having the capacity for convective overturn would act as a heat sink at its base and a heat source at its top, resulting in the predominance of convective rather than conductive heat transport. Such aquifers commonly have a relatively uniform internal

Fig. 52.

Distribution of known subsurface igneous rocks and salt intrusions in the Gulf Coastal Plain (after Smith, Dees, and Harrelson, 1981).

temperature and a temperature gradient near zero. Such conditions may explain the exceptionally low temperature gradients and low heat-flow values determined in Alabama and north-central Florida. Throughout most of Mississippi and Louisiana, however, evidence of hydrologic influence on the thermal regime is less apparent.

CONCLUSIONS

A total of 46 new heat-flow values were determined for drill holes in the Gulf Coastal Plain of southwestern Georgia, Florida, Alabama, Mississippi, and Louisiana during the 20-month project. In general, the Gulf Coastal Plain is characterized by low-to-normal heat-flow values as well as exceptionally low temperature gradients in Alabama and peninsular Florida.

In extreme western Florida, thermal gradients to 500-m depth are approximately 30-34°C/km, and temperatures of 50°C can be extrapolated to 1 km.

Fig. 53.

Subsurface structural features in the Gulf Coastal Plain (after Smith, Dees, and Harrison, 1981).

Continued evaluation of conditions in this area seems warranted in view of the substantial population and the industrial complex in the Pensacola-Mobile area.

In northern Louisiana (and a small but undetermined portion of southwestern Mississippi), thermal gradients of $35\text{--}46^\circ\text{C/km}$ and heat-flow values as large as 2.1 HFU are observed. A broad area of relatively high heat flow has been identified, and a three-parish area of particular interest has been recognized.

The near-surface thermal conditions observed to date in the Gulf Coastal Plain do not warrant immediate development, but conditions in specific regions eventually may be considered for exploitation.

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