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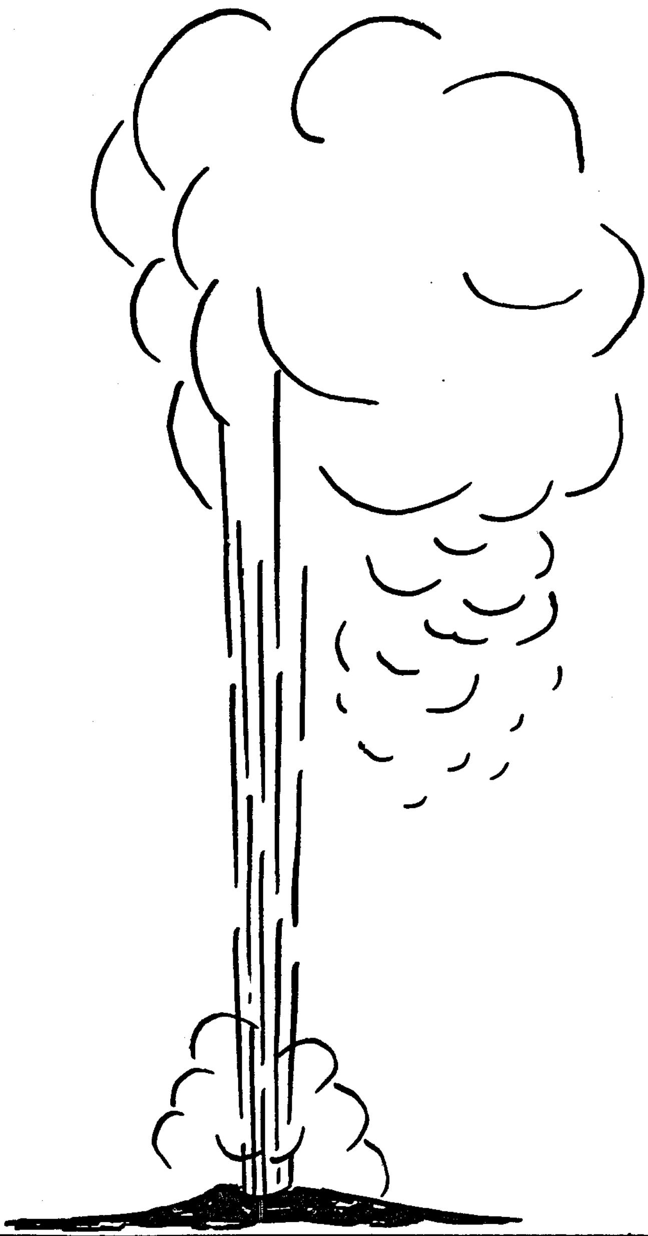

AN ASSESSMENT OF THE GEOTHERMAL RESOURCES OF ILLINOIS BASED ON EXISTING GEOLOGIC DATA

By
Tracy L. Vaught

December 1980
Date Published

Work Performed Under Contract No. AC08-80NV10072

Gruy Federal, Inc.
Arlington, Virginia

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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Price: Printed Copy A03
Microfiche A01

DOE/NV/10072-2
Distribution Category UC-66a

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Preface

This assessment of geothermal resources in the State of Illinois is part of a series of investigations concerning geothermal energy in the eastern half of the United States. These studies are being conducted by Gruy Federal, Inc. for the U.S. Department of Energy's Division of Geothermal Energy.

An initial study, completed in 1979, assessed the overall geothermal potential of the 35 states east of the Rocky Mountains. Subsequent investigations are focusing on individual midwestern states. In addition to this Illinois study, reports on Michigan and Indiana are scheduled for completion during DOE's 1980 fiscal year.

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Introduction

In the eastern United States, obvious manifestations of subsurface heat--such as geysers, recently active volcanoes, and hot springs--are far less common than they are in the west. The search for geothermal resources in the east, therefore, must be based on careful interpretation of regional and local geology, since it is the geology of a particular area that determines whether such resources are present.

General Geology of Illinois

Physiography

Physiographically, Illinois is a part of the Central Stable region, which is bounded on the west by the Rocky Mountains, on the south by the Ouachita Mountains and related features, and on the east by the Appalachian Mountains. This region includes the oldest and most tectonically stable portion of North America.

The Central Stable region, which includes portions of the United States and Canada, can be divided into two areas, the Laurentian Shield and the Interior Lowlands. The Laurentian Shield has been stable relative to sea level most of the time since the close of the Precambrian, and little or no sedimentary cover has been deposited over it. Illinois is a part of the Interior Lowlands, which is the sediment-mantled extension of the Laurentian Shield (fig. 1). In the Interior Lowlands, the thickness of the sediments that overlie crystalline basement is controlled by the regional slope of the Precambrian rocks away from the shield area and by a series of arches, domes, and basins developed on the basement.

Structural Features

Illinois is characterized by gentle tilting, mild folding, and numerous faults. Mild crustal deformation produced arches and basins of regional proportions during Paleozoic time (figs. 2, 3). The sediments are relatively thin on the arches where younger sediments have been eroded. In the Illinois basin, sediments are thick--up to 15,000 ft--and the strata dip continuously from the arches into the basin (Carpenter and others, 1975). The major structural features of Illinois are the Illinois basin, the Hicks dome, the Kankakee arch, the La Salle anticlinal belt, the Des Plaines and Gladford Disturbances, the Cap au Grès faulted flexure, the Rough Creek lineament (which includes the Shawneetown and Cottage Grove fault zones in Illinois), the Ste. Genevieve fault zone, and the Fluorspar area fault complex.

Illinois basin. This structure has been compared to a nest of spoons (Swann, 1968) oriented NNW-SSE. It underlies parts of Illinois, Indiana, and Kentucky and is bordered by the Wisconsin arch on the north, the Mississippi River arch on the northwest, the Ozark uplift on the southwest, the Pascola arch on the south, the Cincinnati arch on the east, and the

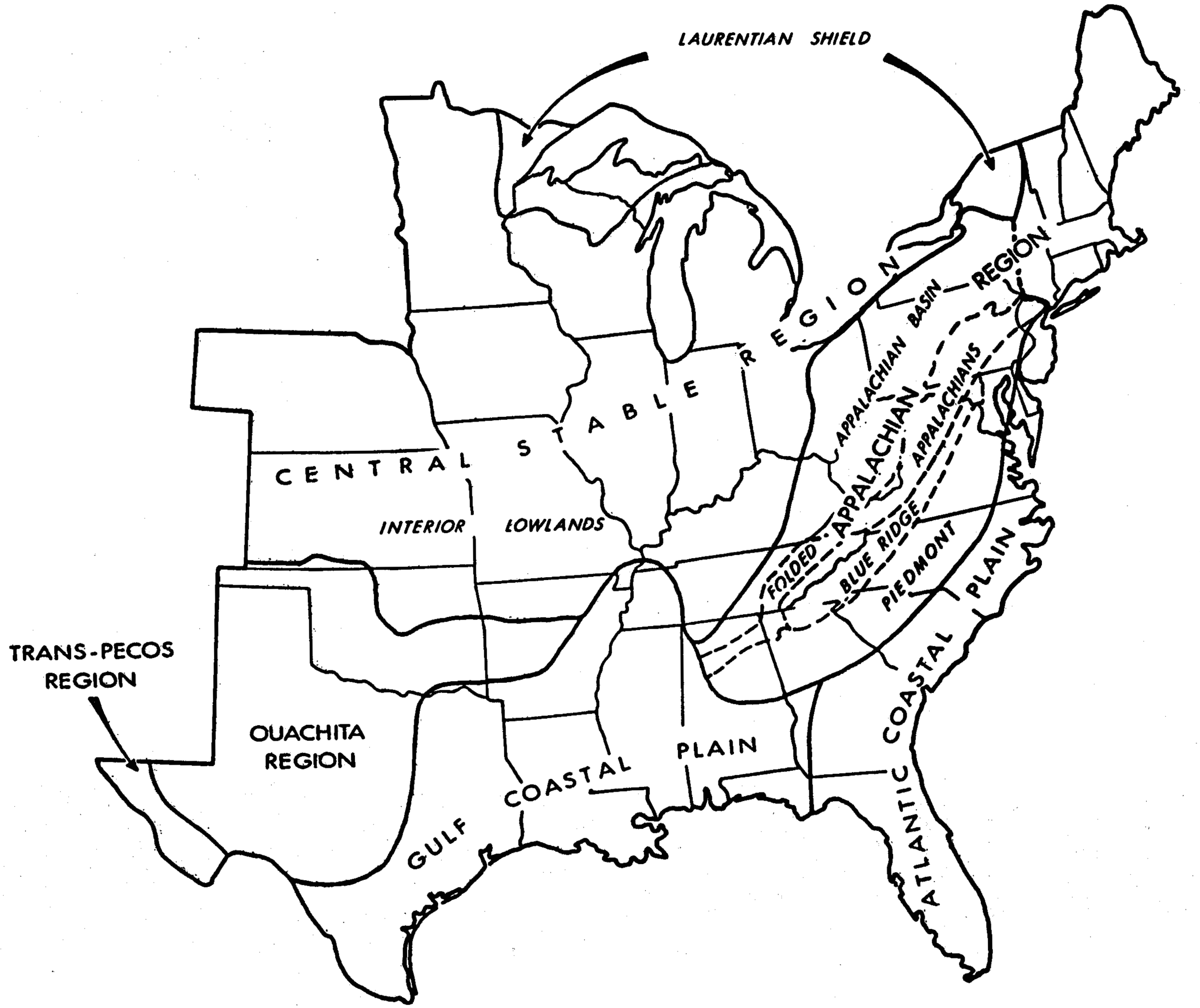

Figure 1.--Geologic regions of the eastern United States.

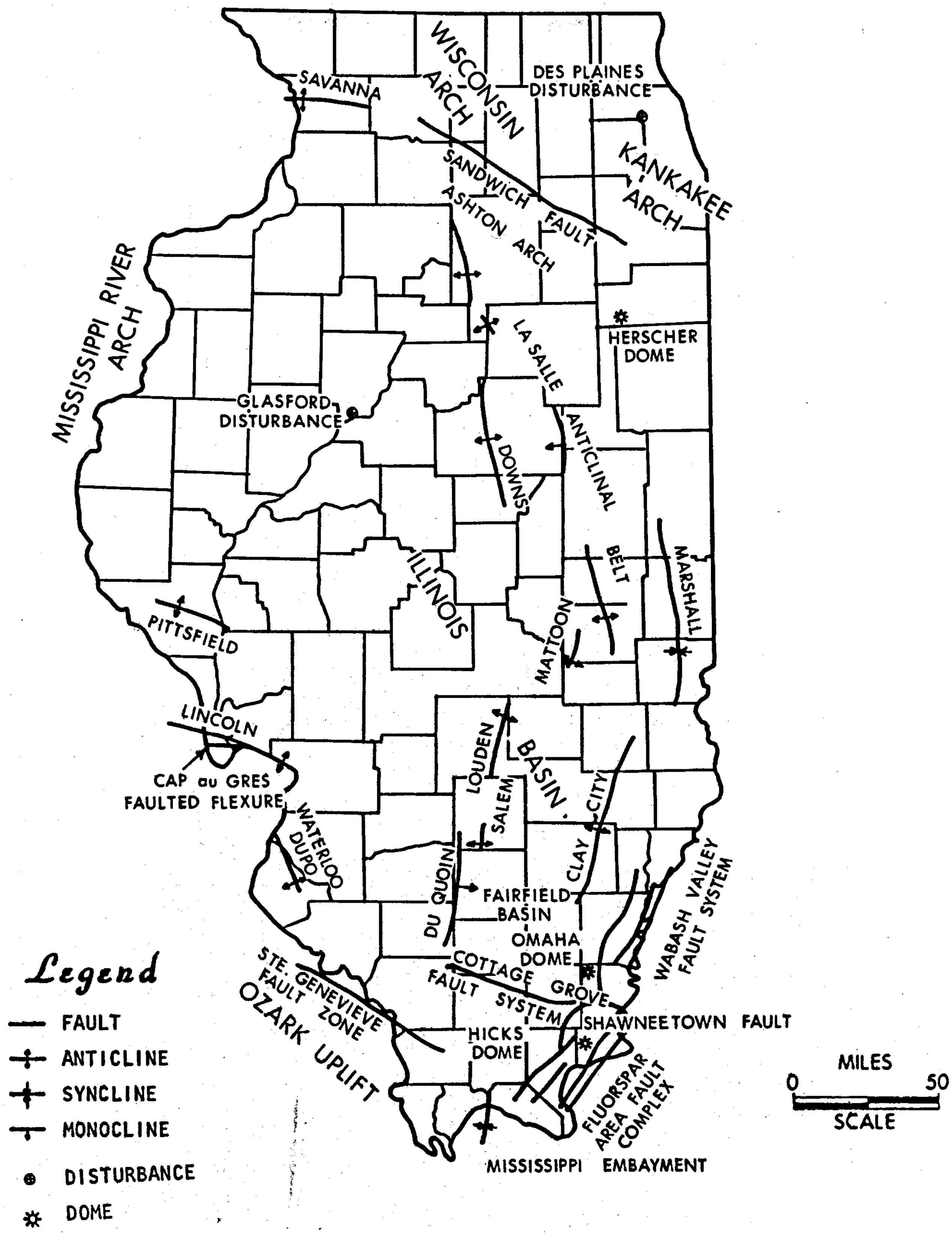

Figure 2.--Principal geologic structures of Illinois (from Willman and others, 1975).

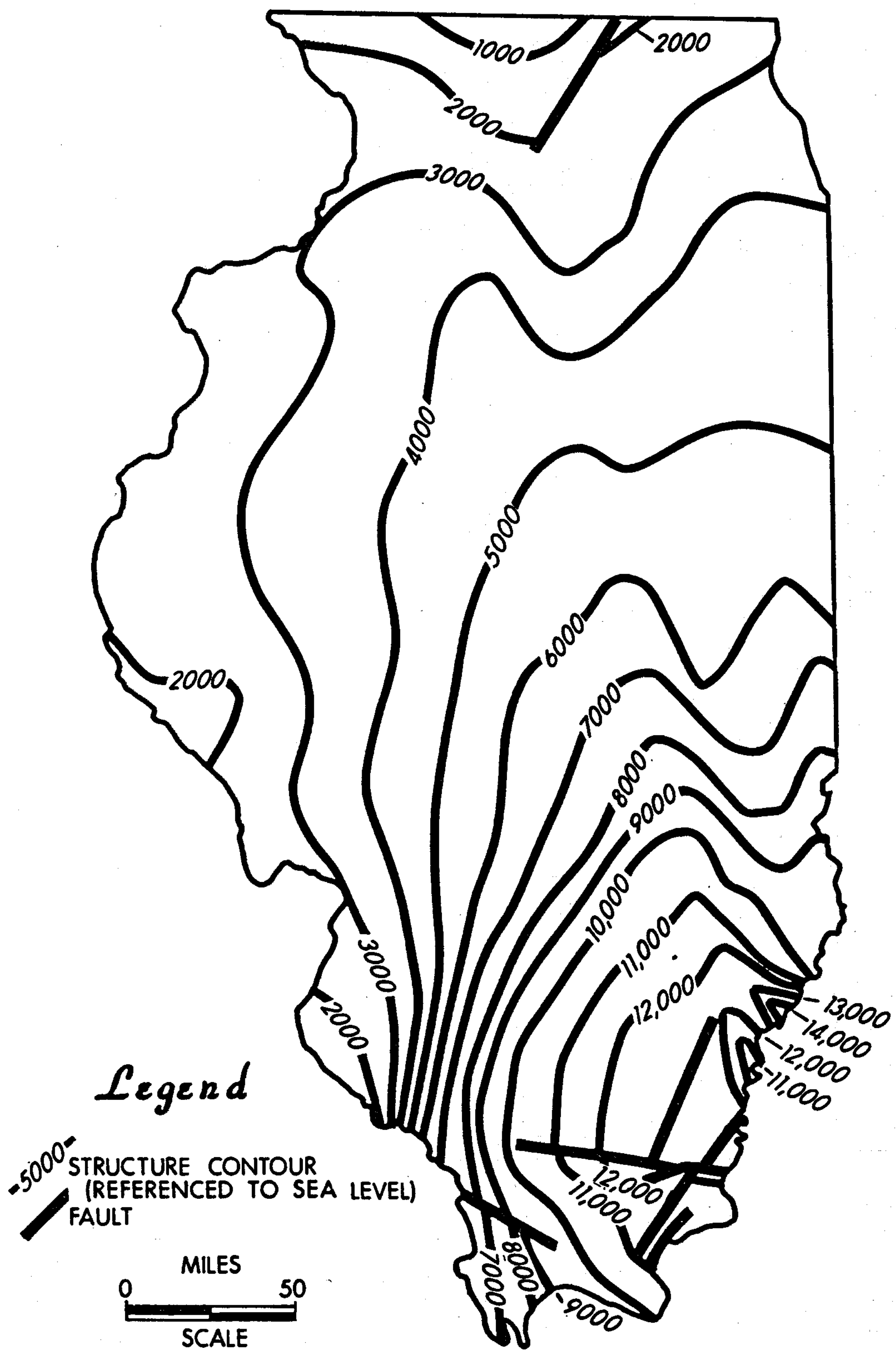

Figure 3.--Structure contours on Precambrian basement (from Bayley and Muehlberger, 1968).

Kankakee arch on the northeast. It is characterized as a broad, gentle structural depression where the strata generally dip from the top of the arches to the bottom of the basin in an unbroken slope (Swann, 1968).

Structurally, the basin extends to the tops of the bordering positive areas, but the edge of the basin is generally considered to be the -500 or -1000 ft contour on top of the Trenton Limestone of Ordovician age.

The deepest part of the basin is in Wayne, White, and Hamilton Counties in southeastern Illinois, where sediment thickness reaches 15,000 ft. Pennsylvanian rocks are gently downwarped into the basin, but below these rocks is an unconformity beneath which the structure is more complex.

Faults are common in the southern part of the Illinois basin. Most of the faults are normal with relatively small displacements, but some have displacements greater than 1,000 ft. A few thrust faults are present, such as the Shawneetown fault. Most of the faults in southern Illinois are the structural extension of the Fluorspar district. This area has been characterized as a large collapsed oval dome having a large number of associated faults. The major ones strike northeast-southwest and are aligned to form a series of subparallel grabens in which the beds dip irregularly northward (Ross, 1963). Folds and faults actually occur throughout the basin, but most have gentle slopes and less than 200 ft of relief (Willman and others, 1975).

The sinking of the basin relative to the surrounding positive areas occurred at a rate of 0.75 in. per 1,000 years (Swann, 1968) through the Paleozoic Era, at least until after the end of the Pennsylvanian. The absence of sediments of Permian, Triassic, Jurassic, and Early Cretaceous age has prevented a determination of the time when uplift and subsidence ended in the basin and when the uplift of the east-west Pascola arch occurred (Willman and others, 1975). This arch closed off the basin to the southwest and gave it its present spoon-shaped configuration.

The last of several major movements which deformed Pennsylvanian rocks probably occurred at the end of the Paleozoic Era at the time of the last major tectonic disturbances associated with the Appalachians.

Hicks Dome. This is a large oval feature with 4,000 ft of structural relief and a diameter of about 9 miles (Heyl, 1972). It is located in extreme southeastern Illinois near the Fluorspar fault complex. The dome formed as the result of a deep igneous intrusion but it is not intensely deformed. Igneous rocks, such as intrusion breccias and basic dikes and sills, are present in and surrounding the dome (Willman and others, 1975).

Kankakee Arch. In Illinois, this arch extends from the town of Oregon at least as far as the Des Plaines River, a distance of 75 miles. The trend coincides with that of the northwest branch of the Cincinnati arch in Indiana. It passes northwesterly across Indiana and Illinois and connects with the Wisconsin arch. The earliest uplift of the arch relative to the nearby basins occurred before the deposition of the St. Peter Sandstone, according to Eardley (1951). Ekblaw (1938) states that movement took place between the depositions of the Shakopee Dolomite and the St. Peter Sandstone. Actually, since the beds of Cambrian and Early Ordovician age are believed to be about 400 ft thick both on the Kankakee arch and in the Illinois basin, the arch must have been subsiding at the same rate as the basin, at least until Early Ordovician time (Eardley, 1951). The arch acquired its relief by greater subsidence of the surrounding basins rather than by actual uplift.

In Late Mississippian time, the maximum differential movement of the arch caused a monocline in which all of northeastern Illinois was uniformly raised 500 to 600 ft relative to the region to the southwest. Later movements probably did not exceed 200 ft (Ekblaw, 1938). After uplift, northeastern Illinois was peneplaned and cut by stream valleys.

La Salle Anticlinal Belt. This trend extends from La Salle County in north central Illinois to the southeast part of Lawrence County, near Vincennes, Indiana, on the Wabash River (fig. 2). It is characterized by a group of individual anticlines rising 500 to 2,500 ft above the basin floor. The western edge of the belt is a relatively steep monoclinal slope that faces west. The asymmetrical anticlines dip locally up to 1,000 ft/mi on the west. To the east they dip gently at about 100 ft/mi (McGinnis and others, 1976). Faulting accounts for only a small amount of relief in the belt, although deep-seated faulting in Precambrian rocks may account for the deformation of the overlying sedimentary rocks.

Du Quoin Anticlinal Belt. This feature is a generally north-south trending group of individual anticlines and eastward-facing monoclines that form the southwestern border of the Illinois basin. (The northeastern border is formed by the La Salle anticlinal belt.) The Du Quoin anticlinal belt is similar to the La Salle anticlinal belt, but it is much smaller-featured and has fewer anticlines. The Fairfield basin (the deep portion of the Illinois basin), the La Salle anticlinal belt, and the Du Quoin anticlinal belt appear as anomalies in the region's gravity field.

Sandwich Fault Zone. This fault zone is located southwest of the Kankakee arch, extending 150 miles from south of Joliet to near the town of Oregon. It trends northwest-southeast and is downthrown to the northeast with a maximum displacement of more than 900 ft near its center (McGinnis and others, 1976). Movement along the fault zone occurred some time after the Silurian.

Des Plaines and Gladford Disturbances. These are roughly circular, cryptoexplosion structures probably caused by meteoric impact (Willman and others, 1975). They are the most intensely deformed areas in Illinois. The Des Plaines disturbance, located in northeastern Illinois on the border between Cook and Du Page Counties, is buried by glacial drift. The Gladford disturbance is in southern Peoria County and is buried by Late Ordovician and younger Paleozoic rocks.

Cap au Grès Faulted Flexure. This domed structure is located in western Illinois and eastern Missouri (fig. 2), north of St. Louis. It is on the southern boundary of the asymmetrical Lincoln Fold, whose vertical displacement may be as much as 1,000 ft. Cole (1961) thinks a component of strike-slip may be associated with the structure.

Rough Creek Lineament. This lineament consists of three components: the Rough Creek fault zone in Kentucky, the east-west portion of the Shawneetown fault zone in Illinois, and the Cottage Grove fault system in Illinois. It is a segment of the 38th parallel lineament, which extends from northeastern Virginia to south central Missouri (Heyl, 1972). Displacement is generally vertical (McGinnis and others, 1976), but portions of the Shawneetown fault exhibit high-angle thrusting. The throw reaches as much as 3,000 ft down to the north. Heyl (1972) suggests that the zone is characterized by right lateral movement, evidenced by the presence of strike-slip slickensides and mullions on many faults. The lineament is also associated with major mining operations. The Fluorspar district in southeastern Illinois and western Kentucky is a part of this trend.

Ste. Genevieve Fault Zone. This zone extends northwestward across Union and southwestern Jackson Counties and across the Mississippi River into Missouri. The vertical displacement on the fault is greater than 1,000 ft and is downthrown to the north (McGinnis and others, 1976). Movement probably began as early as Devonian time (McGinnis and others, 1976).

Fluorspar Area Fault Complex. This is a large collapsed oval dome with numerous associated faults. It trends northwestward from western Kentucky to southeastern Illinois. The faults are known to trend southwest from their intersection with the Shawneetown fault in Pope, Hardin, Gallatin, and Massac Counties to the Cretaceous cover in extreme southern Illinois. The faulting seems to extend below the Cretaceous rocks, roughly paralleling the axis of the Mississippi Embayment. The faults are normal with displacements ranging from a few feet to more than a thousand feet.

Stratigraphy

The sedimentary rocks of Illinois are predominantly marine sediments deposited during the Paleozoic Era. In southern and western Illinois, Cretaceous rocks are characterized by unconsolidated marine deltaic or nearshore sediments. Cenozoic glacial drift covers most of the state. The sediments are unconsolidated surficial clastics whose thickness is generally less than 30 ft but reaches 100 ft in some areas. A bedrock geologic map is shown as fig. 4.

The Precambrian basement rocks in Illinois are characterized by granites and rhyolites more than 1.2 billion years old (McGinnis and others, 1976). The basement is overlain by 2,000 to 15,000 ft of Paleozoic rocks. In general, the coarse-grained sandstones and dolomites of early Paleozoic time gave way to fine-grained clastics, carbonates, and sediments rich in organic matter later in the Paleozoic Era. The younger sediments form the bedrock surface in central and southern Illinois, while the older Paleozoic strata underlie the glacial drift in the northern parts of the state. Thin wedges of Cretaceous and Tertiary sediments overlie Paleozoic rocks in southern Illinois, and Cretaceous sediments are locally preserved in western Illinois. Table 1 is a stratigraphic column for the state.

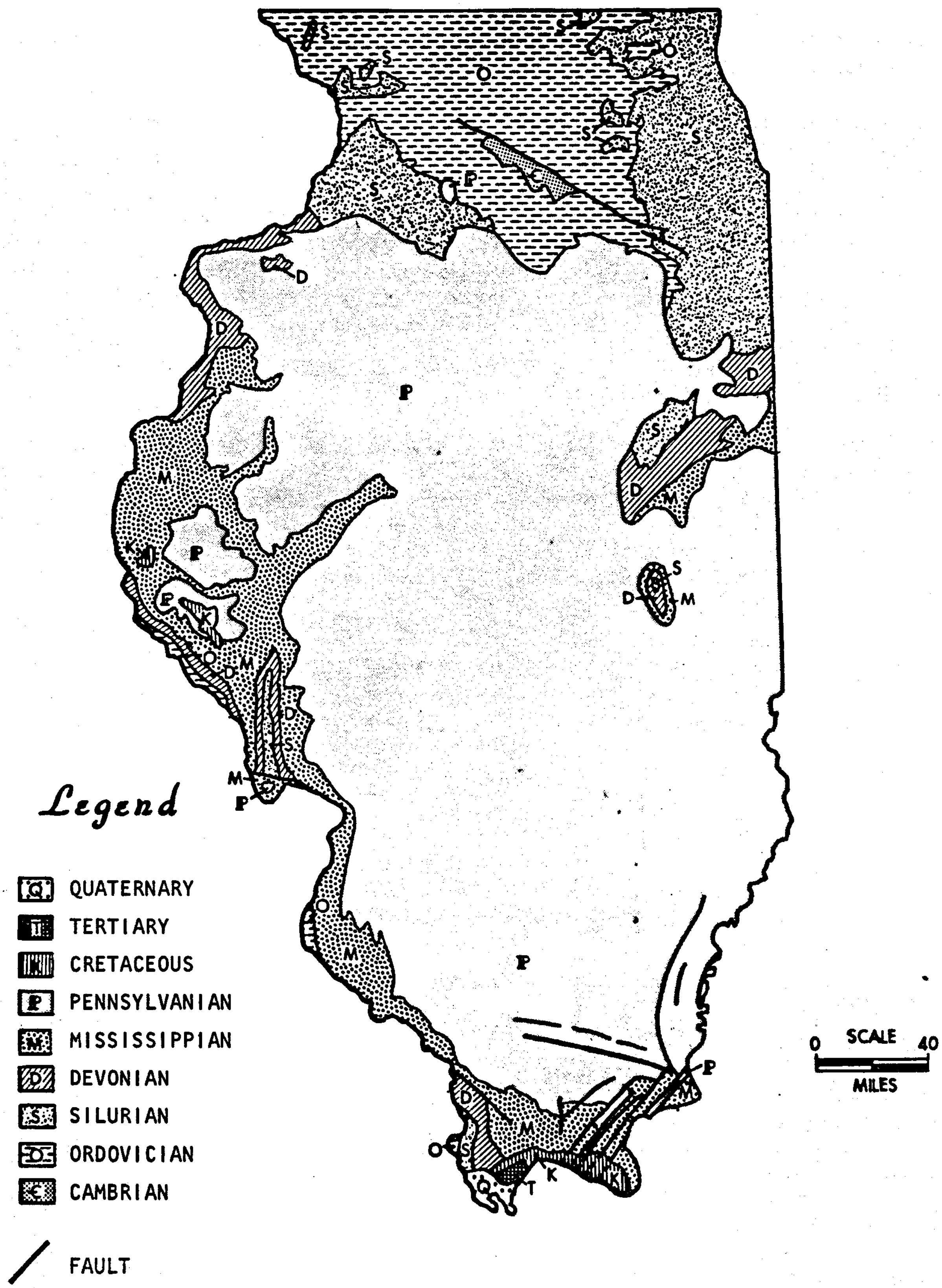

Figure 4.--Geologic map of Illinois (adapted from King and Biekman, 1974).

TABLE 1

GENERALIZED STRATIGRAPHIC COLUMN FOR ILLINOIS
(from Willman and others, 1975)

Era	System	Series	Group	Formation
Cenozoic	Quaternary	Pleistocene		Loess and alluvium
	Tertiary	Pliocene		Grover Gravel
				Mounds Gravel
		Eocene		Wilcox
		Paleocene		Porters Creek Fm
				Clayton Fm
Mesozoic	Cretaceous	Gulfian		Baylis Fm (W)
				Owl Creek Fm (S)
				McNairy Fm (S)
				Tuscaloosa Fm (S)
				Little Bear Soil (S)
Paleozoic	Pennsylvanian	Virgilian	McLeansboro	Mattoon Fm
		Missourian		Bond Fm
		Desmoinesian		Modesto Fm
			Kewanee	Carbondale Fm
				Spoon Fm
		Atokan	McCormick	Abbott Fm
		Morrowan		Caseyville Fm
	Mississippian	Chesterian		Grove Church Sh
				Kinkaid Ls
				Degonia Ss
				Clore Fm
				Palestine Ss
				Menard Ls
				Waltersburg Fm
				Vienna Ls
				Tar Springs Ss
				Glen Dean Ls
				Hardinsburg Ss
			Okaw (W)	
				Haney Ls
			Golconda (E)	Fraileys Sh
				Beech Creek Ls
				Cypress Ss
			West Baden (E)	Ridenhower Fm
				Bethel Ss
			Paint Creek (W)	
				Downeys Bluff Ls
			Cedar Bluff (E)	Yankeetown Ss
				Renault Ls
		Valmeyeran		Aux Vases Ss
				Ste. Genevieve Ls
				St. Louis Ls
				Salem Ls
				Ullin Ls
				Fort Payne Fm (SE)
				Sonora Fm (NW)
				Warsaw Sh (SW, W)
				Springvine Sh (E)
				Borden Sts (S)
				Keokuk Ls (NW)
				Burlington Ls (NW)
				Fern Glen Fm (N, W)
				Meppen Ls (N)
			North Hill	Chouteau Ls (S)
		Kinderhookian		Starrs Cave Ls (N)
				Prospect Hill Sts (W)
				McCraney Ls (W)
			New Albany	Hannibal Sh
				"Glen Park" Fm

TABLE 1 (continued)

Era	System	Series	Group	Formation
Paleozoic	Devonian	Upper	New Albany	Louisiana Ls (N,W)
				Saverton Sh (N, W)
				Grassy Creek Sh
				Sweetland Creek Sh
				Sylamore Ss
		Middle		Blocker Sh (S, E)
				Alto Fm (S, W)
				Lingle Fm (S, E)
				Cedar Valley Ls (N, W)
				Grand Tower Ls (S, E)
				Wapsipinicon Ls (N, W)
		Lower		Clear Creek Chert (S, E)
				Backbone Ls (S, E)
				Grassy Knob Chert (S, E)
				Bailey Ls (S, E)
	Silurian	Niagaran		Moccasin Springs Fm
				St. Clair Ls
				Racine Fm
				Marcus Fm (NW)
				Sugar Run Fm (NE)
				Joliet Fm (NE)
		Alexandrian		Sweeny Fm (NW)
				Blanding (NW)
				Kankakee Fm (NE, W)
				Tete des Morts (NW)
				Elwood Fm (NW)
				Mosalem (NW)
				Wilhelmi Fm (NE)
				Sexton Creek Ls (S)
				Edgewood Fm (S, W)
	Ordovician	Cincinnatian		Girardeau (SW)
			Maquoketa	Neda Fm
				Brainard Sh
				Fort Atkinson Ls
				Scales Sh
				Cape Ls
			Galena	Dubuque Fm (N)
				Wise Lake Fm
				Dunleith Fm
				Guttenberg Fm
				King's Lake Fm (SW)
				Specht's Ferry Fm
			Platteville	Quimby's Mill Fm
				Nachusa Fm
				Grand Detour Fm
				Mifflin Fm
				Pecatonica Fm
			Ancell	Joachim Dol (S)
				Dutchtown Ls (S)
				Glenwood Fm (N)
				St. Peter Ss
				Everton Dol
		Canadian	Prairie du Chien	Shakopee Dol
				New Richmond Ss
				Oneota Dol
				Gunter Ss
	Cambrian	Croixian		Jordon Ss (NW)
				Eminence Fm
				Potosi Dol
				Franconia Fm
				Ironton Ss (N)
				Galesville Ss (N)
				Eau Claire Fm
				Mt. Simon Ss

P R E C A M B R I A N

Indicators of Geothermal Energy

In the past, the search for and utilization of geothermal energy has been concentrated in areas where there are surface manifestations of elevated temperature, such as warm springs, geysers, and recently active volcanoes. Since the eastern United States is tectonically stable and has not experienced recent volcanic activity, which is typically associated with geothermal resources in the west, evidence of eastern geothermal resources is more subtle.

There are three likely sources of elevated subsurface temperatures in the eastern United States: (1) granitic plutons (igneous intrusions) enriched in uranium and thorium that produce elevated heat flow as the result of radioactive decay, (2) thick sediments of low conductivity that cause above-average thermal gradients by allowing the accumulation of heat below them, and (3) movement of deep waters upward along rock layers or through faults and fractures to produce accumulations of warm water in reservoirs relatively near the surface or warm springs at the surface. Temperature gradients, heat flow, geochemistry, seismic activity, and regional geology are important indicators of these resources.

Heat Flow and Thermal Gradient

The temperature gradient (Γ), heat flow (q), and conductivity (K) of the rocks through which the heat is passing are related by the equation

$$q = K\Gamma.^{\dagger}$$

Early heat flow studies showed that North America could be divided into several provinces, each with its characteristic heat flow (Roy and others, 1968a,b). Heat flow varies within a province because of differences in the heat generated in upper crustal rocks (Birch and others, 1968). There is a linear relationship between heat flow and radioactive heat generation (A) in the rocks at each site:

$$q = q^* + DA.\S$$

---

†When q is expressed in heat flow units (1 HFU = 1 x 10^{-6} cal/cm^2 sec) and K in conductivity units (1 CU = 1 x 10^{-3} cal/cm sec °C), Γ is in °C/km if the factor 10^{-2} is introduced to make the units consistent.

§q* (reduced heat flow) is the heat flow characteristic of a given province; DA is the component of heat flow due to radioactive heat generation in the upper crust; and D is related to the thickness of the radioactive crust (changes from one region to another). Diment and others (1975) suggest values of 0.8 HFU and 7.5 km for q* and D, respectively, in the eastern U.S.

As further studies are made, more detailed heat flow and reduced heat flow (q*) data will be available in addition to those provided by Sass and others (1976). The Illinois heat flow data compiled by Sass and coworkers are shown in fig. 5.

Only four heat flow holes have been drilled in Illinois, three in Iroquois County in the east central part of the state and one in Macon County in central Illinois (fig. 5). The heat flow values range from 1.39 to 1.44 HFU, slightly above the average for the eastern United States but not high enough to be considered abnormal. These values represent only the heat flow of the areas in which they are located, and many more heat flow holes must be drilled before a generalized picture of the state's heat flow can be developed.

Temperature gradient measurements are useful in the exploration for geothermal resources because they allow ready detection of thermal anomalies and estimation of their areal extent. Caution must be exercised, however, in using gradients to project temperatures below the depth of measurement, for three reasons:

1. Temperature gradients vary with rock type. Shales and unconsolidated sediments have considerably lower conductivity than dolomites, limestones, and well cemented sandstones. Since conductivity affects temperature gradients, projection of temperatures to depth must rely on a knowledge of geology.

2. Conductivities generally increase with depth because of increased compaction and cementation, so that gradients decrease with depth. Thus, linear projection of gradients below observation points may predict temperatures much higher than those which actually exist.

3. Gradient measurements made in shallow holes are strongly influenced by near-surface effects such as precipitation and movement of groundwater. Geothermal workers have long recognized that anomalously high bottomhole temperatures (and thus, elevated gradients) often occur in shallow wells. Even in relatively deep gradient holes (up to thousands of feet) movement of groundwater can alter the geothermal gradient.

The American Association of Petroleum Geologists and the U.S. Geological Survey (1976a,b) jointly published maps showing regional variations in temperature gradients and subsurface temperatures. (A simplified version of the Illinois portion of the gradient map is shown as fig. 6.) A second AAPG map shows, where data are available, depth to various isothermal surfaces. These maps have only limited utility for geothermal exploration. They were not prepared with geothermal exploration in mind, so anomalously high gradients were disregarded. Moreover, there is evidence for substantial errors in bottomhole temperatures used to calculate gradients for the maps (Vaught, 1980). Despite these problems, the data set (American Association of Petroleum Geologists, 1976) from which the gradient maps were generated is the best currently available for study of geothermal phenomena in the eastern United States.

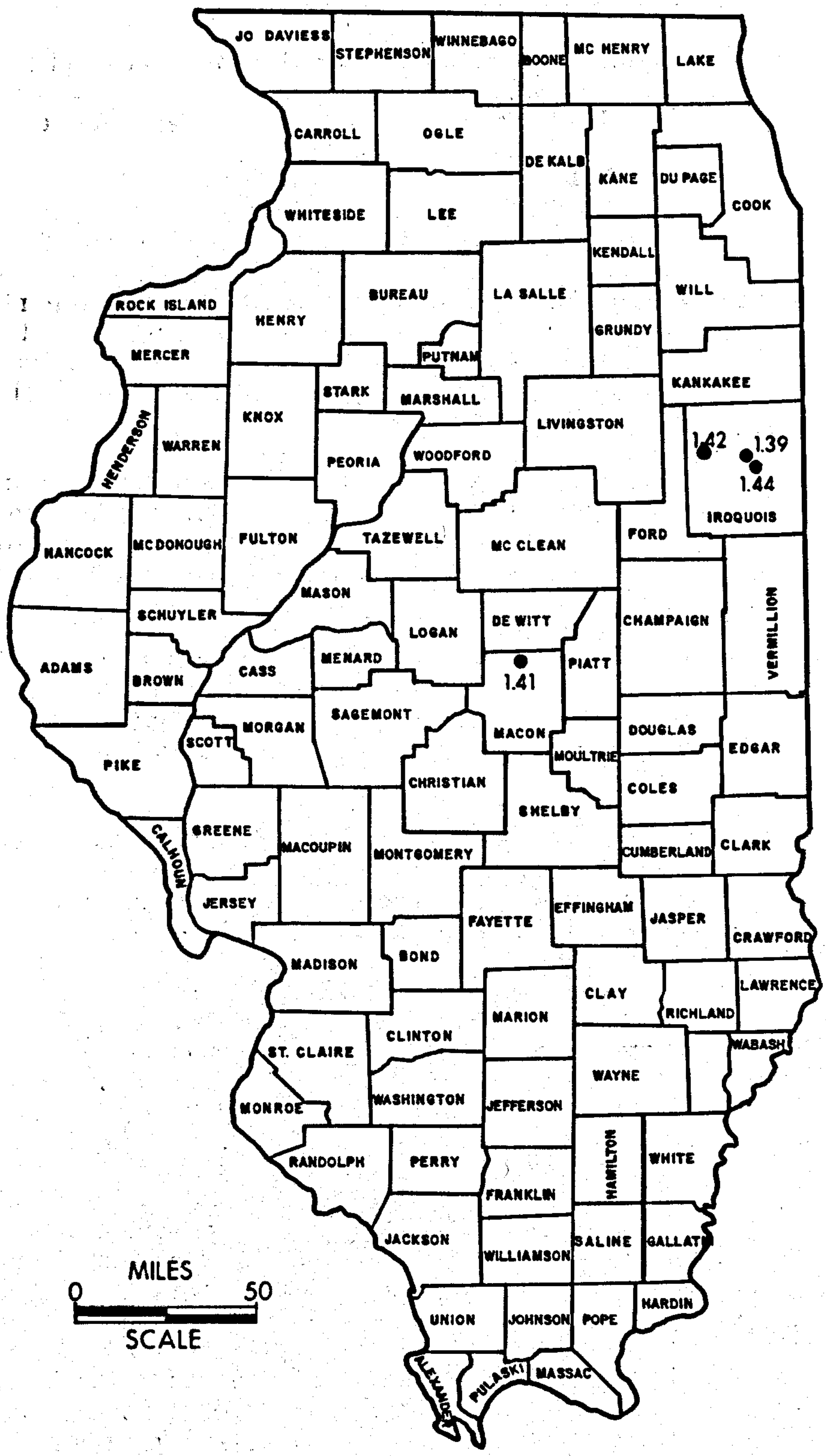

Figure 5.--Heat flow values in Illinois (from Sass and others, 1976).

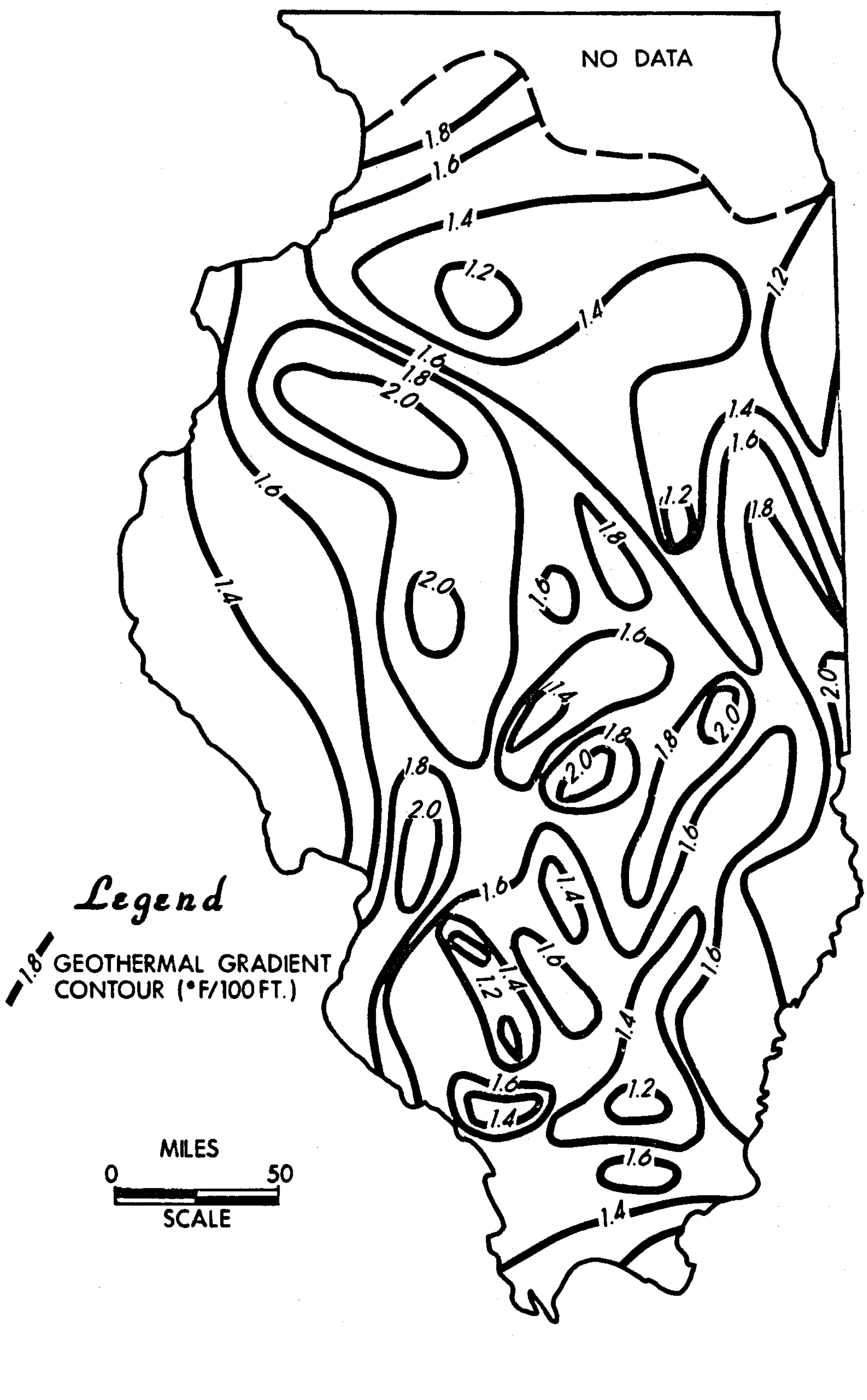

Figure 6.--Geothermal gradient map of Illinois (from AAPG and USGS, 1976b). Contour interval 0.2°F/100 ft.

Figure 7 is a plot of geothermal gradient against depth for Illinois wells deeper than 3,000 ft. Pertinent information for these wells--such as bottomhole temperature, location, age of deepest sediments penetrated by each well, and ambient surface temperature--is given in Table 2. No corrections have been made to the data used in the table or the graph; corrected gradients would be at most only a few tenths of a degree per 100 ft higher.

Even though deep-well data are sparse, a trend is apparent. Generally, the shallow wells seem to have higher gradient values than the deep wells. A similar trend has been noted in Michigan (Vaught, 1980), where there is a pronounced difference in the gradients calculated for shallow and deep wells. Hodge and others (1979, p. xxiii-2), in their study of New York, noted that "The data from wells shallower than 500 meters generally give locally variable gradients which probably reflect the temperatures of relatively shallow groundwater circulation systems rather than the temperature of the underlying strata."

The anomalously high geothermal gradient values in shallow wells may be caused by movement of groundwater, errors in bottomhole temperature measurement, or variation in the heat flow and thermal conductivity of the rocks penetrated by the wells. These data suggest that bottomhole temperatures taken from shallow oil and gas wells may not be reliable indicators of geothermal gradient at depth.

Cartwright (pers. comm.) is skeptical about the validity of these elevated temperature gradients in shallow holes and suggests that the true average gradients are much less than those shown on the AAPG-USGS gradient map. Most of the wells in Illinois are shallow and consequently were drilled into clastics that have a lower conductivity than the more consolidated, primarily carbonate sequences in the deeper part of the Illinois basin. Cartwright thinks that the high gradients of the shallow wells are probably related to this lower conductivity and therefore cannot be projected to depth or used as an average for the basin. He estimates the average gradient for the state to be 1.0 to 1.2°F/100 ft and submits that this range is remarkably consistent throughout the state.

Temperature data from deep wells in Illinois, which should be more reliable, give lower temperature gradients, in the range characteristic of the eastern United States. Figure 8 shows the locations of Illinois wells deeper than 3,000 ft. Gradient and depth are given for each well.

If the consolidated Paleozoic rocks of Illinois are assumed to have an average conductivity of approximately 7 CU (Diment and others, 1975) and the heat flow averages about 1.42 HFU (as indicated by available data), the average geothermal gradient would be expected to be about 1.10°F/100 ft. This value agrees with Cartwright's estimate.

Heigold and others (1971) have observed positive temperature anomalies around the perimeter of oil fields in Illinois. However, the magnitude of these anomalies is commonly only a few tenths of a degree per 100 ft (Cartwright, pers. comm.). The presence of these abnormally warm waters may be associated with the mechanism of aquifer recharge. The deeper aquifers of the Illinois basin are recharged on the perimeter of the basin where they

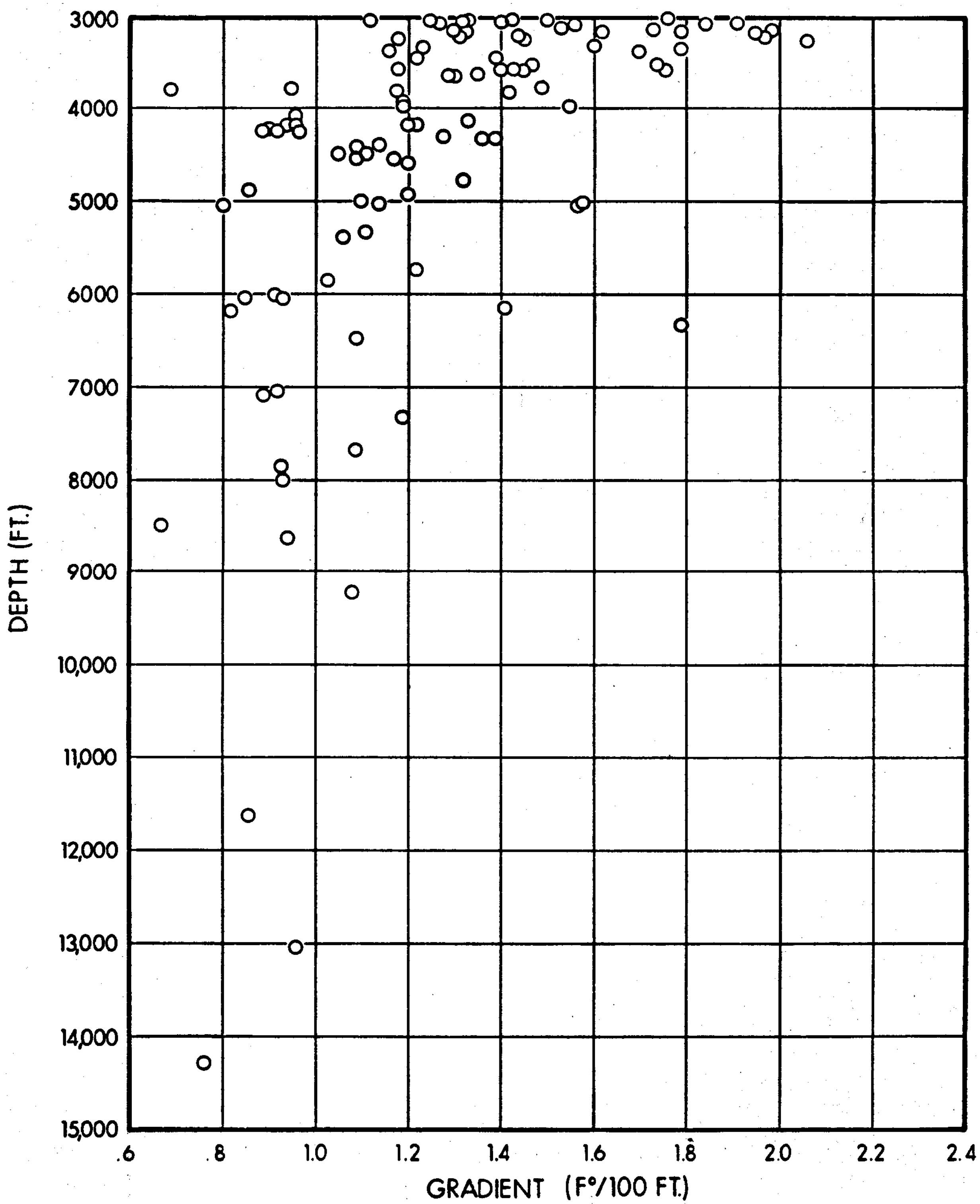

Figure 7.--Temperature gradient plotted against well depth (data from AAPG, 1976). Locations of holes are given in figure 8.

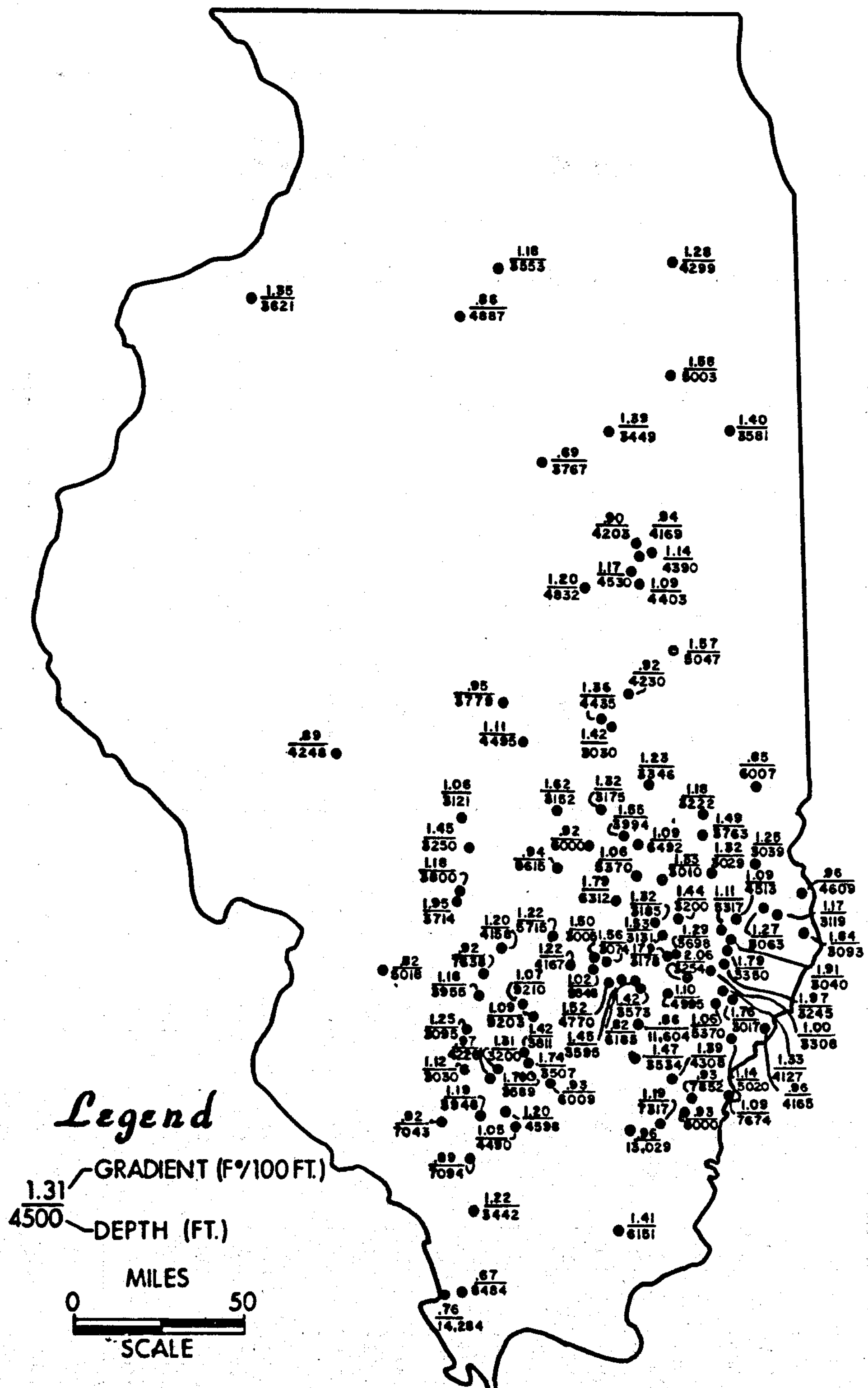

Figure 8.--Temperature gradient and depth of wells deeper than 3,000 feet (data from AAPG, 1976). Some closely spaced data points with similar values have been omitted in southern Illinois.

TABLE 2

DATA FOR ILLINOIS WELLS DEEPER THAN 3,000 FEET (from AAPG, 1976)

Location, lat (°N)	Location, long (°W)	Depth, ft	Bottom-hole temp., °F	Ambient surface temp., °F	Gradient, °F/100 ft	Age of deepest unit penetrated
37.3500	89.4000	14,284	164	55	0.76	
38.0250	88.4750	13,029	180	57	0.96	p€
38.4620	88.4200	11,609	155	57	0.86	p€
38.5550	89.0300	9,203	155	56	1.08	p€
39.1100	88.8750	8,615	136	55	0.94	p€
37.3750	89.3350	8,484	115	58	0.67	€
38.0900	88.2100	8,000	129	55	0.93	
38.1450	88.1500	7,852	128	55	0.93	
37.7100	88.2500	7,674	139	58	1.09	O
38.0700	88.3200	7,313	142	55	1.19	
37.9200	89.3000	7,094	118	55	0.89	
38.0700	89.4300	7,043	120	55	0.92	
38.6700	89.2100	7,038	120	55	0.92	
39.2000	88.4300	6,492	126	55	1.09	
38.9650	88.5250	6,312	168	55	1.79	O
38.6500	88.4500	6,185	106	55	0.82	
37.6100	88.5300	6,151	142	55	1.41	
38.2400	88.8800	6,009	111	55	0.93	
39.4200	87.8100	6,007	106	55	0.85	
39.1950	88.6700	6,000	110	55	0.92	
38.7000	88.6500	5,848	115	55	1.03	
38.8300	88.8600	5,715	125	55	1.22	
39.0800	88.4300	5,370	112	55	1.06	
38.8400	87.9800	5,317	114	55	1.11	
39.8800	88.3000	5,047	134	55	1.57	
38.3950	87.9350	5,020	112	55	1.14	
38.6750	89.7500	5,018	96	56	0.80	€
41.0300	88.1200	5,003	130	51	1.58	
38.5800	88.2800	4,995	112	57	1.10	D
40.2240	88.7250	4,932	112	53	1.20	€
41.2750	89.3250	4,877	93	51	0.86	p€
38.6400	88.5700	4,770	118	55	1.32	
38.1100	89.0900	4,598	110	55	1.20	
40.2650	88.3890	4,530	105	52	1.17	€
38.8700	87.9100	4,513	104	55	1.09	€
39.6380	89.0200	4,495	103	53	1.11	€
38.1050	89.0500	4,490	102	55	1.05	
40.1100	88.4100	4,403	103	55	1.09	
40.3400	88.3300	4,390	105	55	1.14	
39.7300	88.6500	4,335	112	53	1.36	O
38.2300	88.2400	4,308	115	55	1.39	
41.5000	88.2250	4,299	106	51	1.28	p€
39.5700	90.0000	4,248	93	55	0.89	
39.7900	88.4600	4,230	91	52	0.92	O
38.2400	89.1850	4,226	96	55	0.97	
40.3600	88.4300	4,203	90	52	0.90	€
40.3200	88.4000	4,169	91	52	0.94	€
38.6900	88.7700	4,167	107	56	1.22	O
38.4500	87.7700	4,165	95	55	0.96	
38.7700	89.1200	4,158	106	56	1.20	O
38.5900	87.9800	4,127	110	55	1.33	
38.9100	87.7200	4,069	94	55	0.96	
39.2100	88.4600	3,994	116	54	1.55	O
38.5950	89.2400	3,955	102	55	1.19	
38.0900	89.2300	3,948	102	55	1.19	
38.3400	89.0500	3,811	110	56	1.42	O
39.0500	89.3400	3,800	100	55	1.18	€
39.7700	89.1250	3,779	89	53	0.95	O
40.7000	88.9200	3,767	81	55	0.69	
39.2200	88.0700	3,763	110	54	1.49	O

TABLE 2 (continued)

Location, lat (°N)	Location, long (°W)	Depth, ft	Bottom-hole temp., °F	Ambient surface temp., °F	Gradient, °F/100 ft	Age of deepest unit penetrated
38.7300	88.2100	3,648	102	55	1.29	M
38.1200	88.4000	3,618	104	57	1.30	M
38.6500	88.4900	3,595	108	56	1.45	M
38.2400	88.5600	3,589	120	57	1.76	M
40.8000	87.8900	3,581	102	52	1.40	€
41.3900	89.1400	3,621	100	51	1.35	€
38.6000	88.4000	3,573	106	55	1.43	
41.3900	89.1400	3,553	93	51	1.18	p€
38.3100	88.4200	3,534	109	57	1.47	M
38.2900	88.5500	3,507	118	57	1.74	M
40.8100	88.5800	3,449	100	52	1.39	€
37.7000	89.2400	3,442	99	57	1.22	
39.1000	88.3300	3,365	93	54	1.16	D
38.7000	88.0400	3,362	112	55	1.70	M
38.6400	88.1400	3,350	115	55	1.79	M
39.4300	88.3800	3,346	94	53	1.23	D
38.7000	88.0300	3,308	108	55	1.60	M
38.6400	88.1800	3,254	122	55	2.06	M
39.1900	89.2800	3,250	102	55	1.45	O
38.6800	87.9400	3.245	119	55	1.97	M
39.3000	88.0900	3,222	94	56	1.18	O
38.9000	88.2100	3,200	100	54	1.44	M
38.2800	89.2000	3,200	98	56	1.31	D
38.8500	88.3500	3,185	96	54	1.32	M
38.7300	88.2600	3,178	112	55	1.79	M
39.3100	88.6100	3,175	95	53	1.32	O
38.9600	89.3300	3,174	117	55	1.95	O
39.3400	88.8300	3,152	104	53	1.62	
38.8300	88.2500	3,152	96	55	1.30	M
38.8200	88.3000	3,131	104	56	1.53	M
39.3000	89.3200	3,121	88	55	1.06	O
38.6500	87.9700	3,119	109	55	1.73	M
38.8300	87.5700	3,093	112	55	1.84	M
38.8000	87.9600	3,090	114	55	1.91	M
38.7200	88.5400	3,074	104	56	1.56	M
38.3700	89.3000	3,063	99	56	1.40	D
38.9000	87.7300	3,063	94	55	1.27	O
38.4300	89.2900	3,045	94	56	1.25	O
39.0900	87.8200	3,039	93	55	1.25	O
39.7000	88.6000	3,030	95	52	1.42	M
38.2800	89.2700	3,030	90	56	1.12	D
38.9900	88.0700	3,029	94	54	1.32	M
38.5500	87.9300	3,017	110	57	1.76	M
39.0700	88.2800	3,010	94	54	1.33	M
38.7200	88.5900	3,005	101	56	1.50	M

outcrop. The recharge waters travel downdip toward the center of the basin in the direction of the lowest hydrostatic head. The difference in the hydrostatic head of the recharge waters (100 to 500 feet) forces the deeper waters to move up through the overlying formations. These waters are deflected around oil-bearing rocks, causing warmer water to be present around oil fields.

Another area of potential elevated subsurface temperatures is the region surrounding Hicks dome, an intrusive volcanic plug in southeastern Illinois. Some wells near this dome show slightly elevated bottomhole temperatures (Cartwright, pers. comm.).

Seismic Activity

Major high-temperature, convective hydrothermal systems are usually associated with tectonic activity. Most major seismic events also occur in areas of tectonic activity, such as spreading ridges, subduction zones, and continental rift zones. Although the eastern United States is generally regarded as tectonically stable, some seismicity remains. Because of the close association worldwide between hydrothermal phenomena and seismicity, seismically active areas in the eastern United States might be expected to have greater potential for geothermal resources than other areas. Seismic activity may keep faults open, thereby allowing upward movement of thermal fluids, which may provide accumulations of warm water at depths shallow enough for exploitation.

Hadley and Devine (1974) have published a seismotectonic map of the eastern United States showing historical seismic activity from 1800 to 1972. The Illinois portion of this map (fig. 9) shows several areas of high seismic intensity. One such area, centered in the Mississippi embayment, is associated with two major earthquakes--the 1811-1812 New Madrid shocks and the 1968 southern Illinois earthquake. Maximum seismic activity in this area coincides with the crest of the Pascola arch and with a possible extension beneath the embayment of a group of northwest-trending faults west of the seismic zone. North of the crest of the Pascola arch, northwest-directed compressional fault movements dominate, but south of the crest, normal fault movements on north-trending faults are more common (Hadley and Devine, 1974).

Woollard (1958) notes two seismic trends that include Illinois: a north-south alignment from the Arkansas-Tennessee border through St. Louis and along the southwestern Illinois border, and a northeast-striking alignment from the Missouri-Kentucky area across southeastern Illinois and Indiana into the St. Lawrence River Valley. Neither of these trends is known to correspond to any geologic controls.

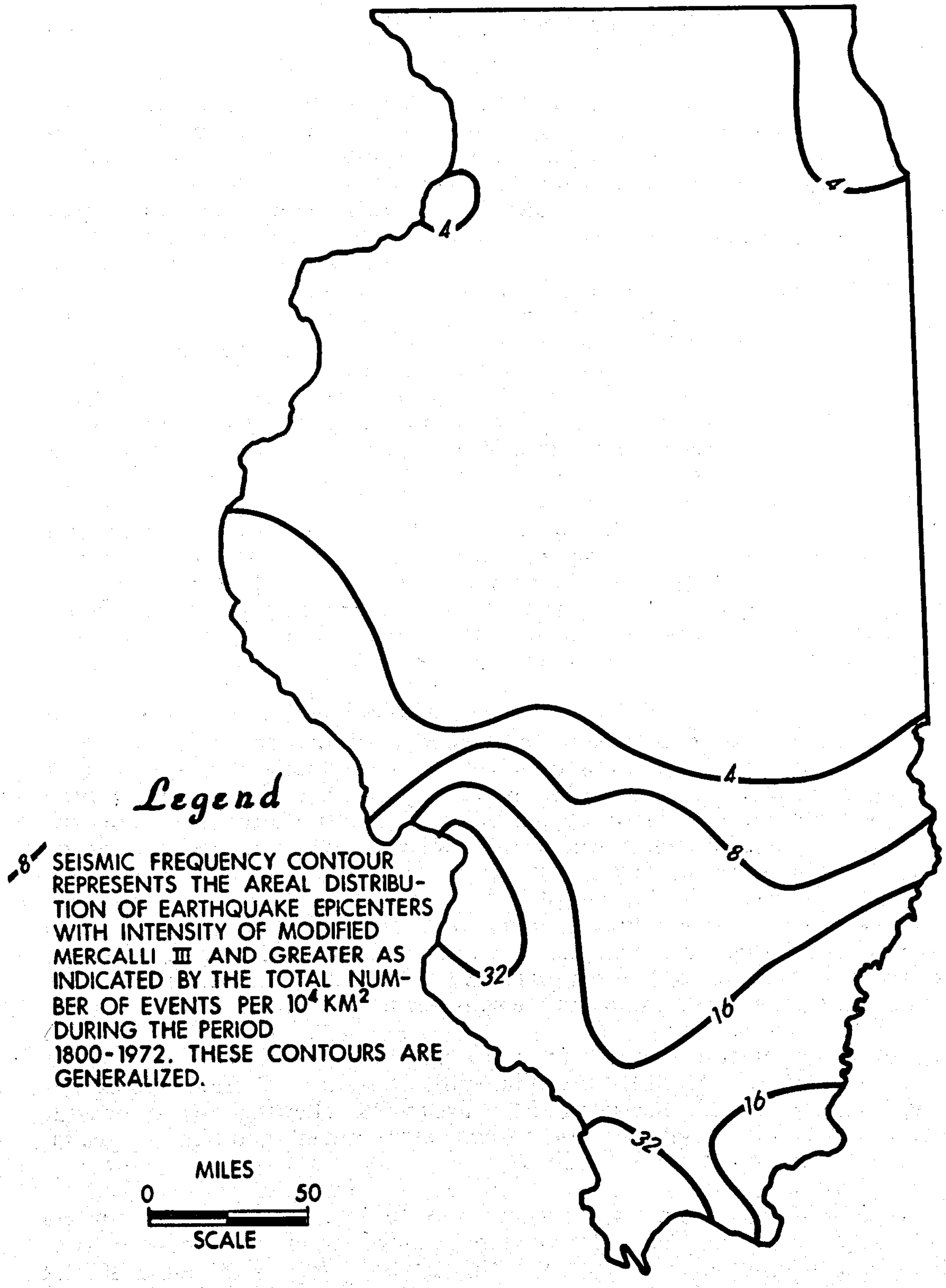

Figure 9.--Seismic activity in Illinois (from Hadley and Devine, 1974).

Geothermal Energy in Illinois

The geothermal resource base is generally considered to be the heat in the earth's crust beneath a specific area where subsurface temperatures are higher than the local mean annual temperature (Muffler and Cataldi, 1978). By this definition, potential geothermal resources underlie all parts of the country. At present, however, only waters with temperatures above the average for their source area are being used for their heat content.

The physical limits to geothermal development are not fully established, but provisional limits for depth and temperature can be suggested. The accessible resource base can be assumed to lie in the upper 30,000 ft of the earth's crust--the approximate maximum depth attainable by drilling technology. It seems probable that the accessible resource base below about 15,000 ft cannot now be considered economically useful. Wells deeper than 10,000 ft are uncommon in geothermal exploration, even in areas with high-temperature resources.

Recently, attention has shifted to moderate- (90-150°C) and low-temperature (less than 90°C) resources for possible direct-use applications. Groundwater heat pump technology could lower the useful temperature limit of geothermal waters to 13°C, a value close to the average groundwater temperature in the United States. However, the direct use of water at temperatures below 40°C is not likely.

Sammel (1979) conservatively estimates that low-temperature waters found below 3,000 ft are neither economic nor near-economic targets for exploration, except where usable wells have already been drilled for other purposes. (Low-temperature waters are defined by Sammel as being less than 90°C but greater than 10°C above mean annual air temperature.) The provisionally accepted depth below which waters at about 40°C should not be considered a resource is 3,000 ft.

Geothermal resources are not known to exist in Illinois. But from the data presented in this report on heat flow, thermal gradients, depth to basement, seismic activity, and low-conductivity sediments, inferences may be drawn about the possible presence of resources in the state.

Three types of geothermal occurrences are possible in Illinois: (1) radioactive, heat-producing granitic plutons lying beneath a thick insulating sedimentary sequence, (2) heavily faulted areas that allow upward movement of fluids, and (3) deep sedimentary basins with normal geothermal gradients.

Granitic heat-producing plutons may underlie Illinois, but this cannot be confirmed at present because relatively few holes have been drilled that reach basement in the deeper parts of the basin. However, even if the presence of such plutons were confirmed, the conductivity of the overlying sedimentary rocks is not sufficiently low to confine the heat. The Cambrian and Ordovician sediments contain a high percentage of dolomite, which has a very high conductivity (12 CU). Some of the shallower rocks include shale, which has a low conductivity (2.5 to 4 CU), but usually it is not pure. Most of the shales are interbedded with other lithologies or contain other rock types mixed in. Therefore, there is not a sufficiently thick, pure shale sequence to trap the heat that would be produced from a radioactive granite.

Heavily faulted areas that allow upward movement of fluids along fault planes may be present in Illinois. Southern Illinois contains numerous fault zones, some of which may be open to allow water movement. Warmer waters from below may travel up along the fault planes to a shallower level, thereby raising the temperature of the original formation waters in the upper zone. Figure 4 shows elevated gradients in southeastern, southwestern, and central Illinois where fault zones are known to exist.

Although some deep Illinois wells have relatively high temperature gradients, most do not. Most of the higher gradients seem to be associated with shallow wells. Cartwright suggests that the high gradients in Illinois shown on the AAPG-USGS Geothermal Gradient Map of North America may be as much as twice the representative gradient for the area, primarily because of convection and the presence of low-conductivity sediments. In the area of Hicks dome in southeastern Illinois, several wells have bottomhole temperatures slightly higher than average. Further data need to be gathered in this area to confirm these temperatures and to identify the source of the heat.

Although deep sedimentary basins with normal geothermal gradients are not considered a resource, they are discussed here because of their enormous, albeit future, potential. The thick sedimentary sequences in the Illinois basin offer targets for production of fluids which, because of their great depths, would have relatively high temperatures. The reservoirs are known from petroleum operations, although some areas of the basin remain relatively unexplored.

The highest temperatures would most likely be reached in the deepest portion of the basin, but compaction due to the weight of the overlying sediments may have substantially reduced the permeability of the sediments there. Figures 10 through 25 are isopach maps of several of the Cambrian and Ordovician units, some of which may contain warm and producible geothermal fluids. However, production of such fluids is not economic at present.

Review of the structural features map (fig. 2), the Precambrian basement structure map (fig. 3), the temperature gradient map (fig. 6), and the seismic data map (fig. 9) indicates some trends of possible geothermal significance. Areas of southern Illinois look interesting because portions of the area have: (1) a sufficiently thick sedimentary sequence to reach warm temperatures, (2) numerous faults that may allow upward migration of warm waters, (3) seismic activity that may keep faults open, and (4) temperature gradients that may be elevated.

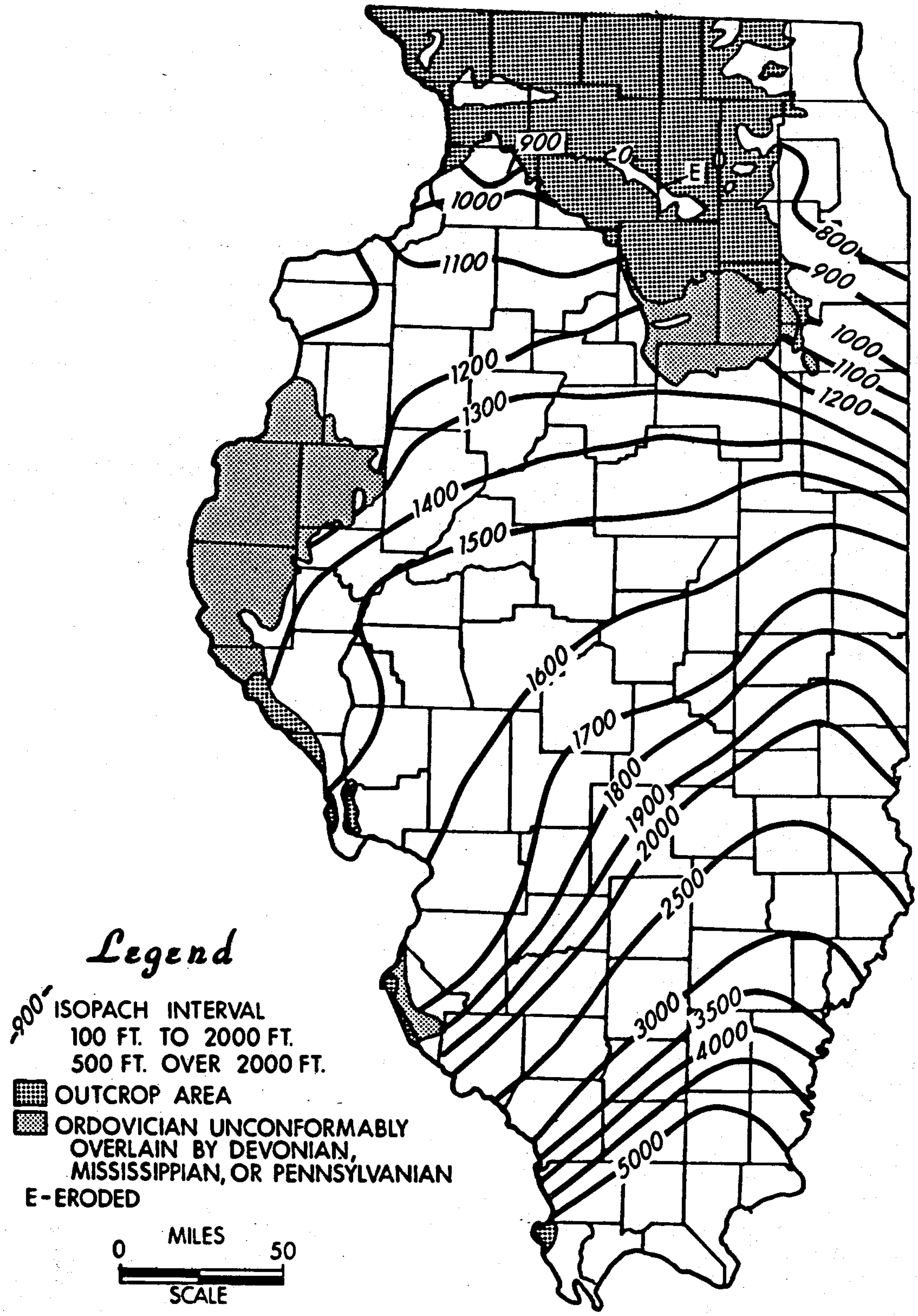

Figure 10.--Thickness of the Ordovician System (from Willman and others, 1975).

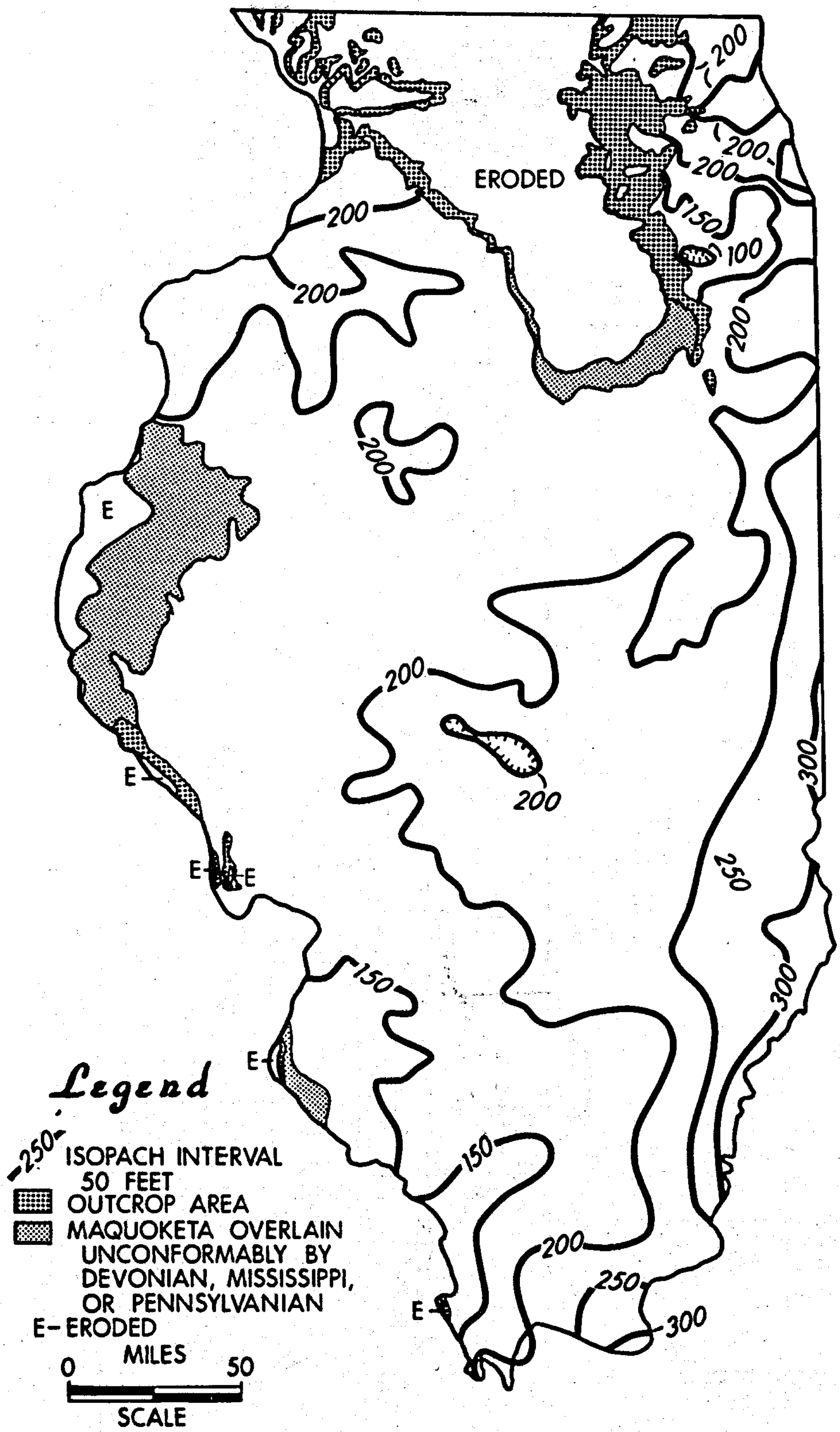

Figure 11.--Thickness of the Maquoketa Group (from Willman and others, 1975).

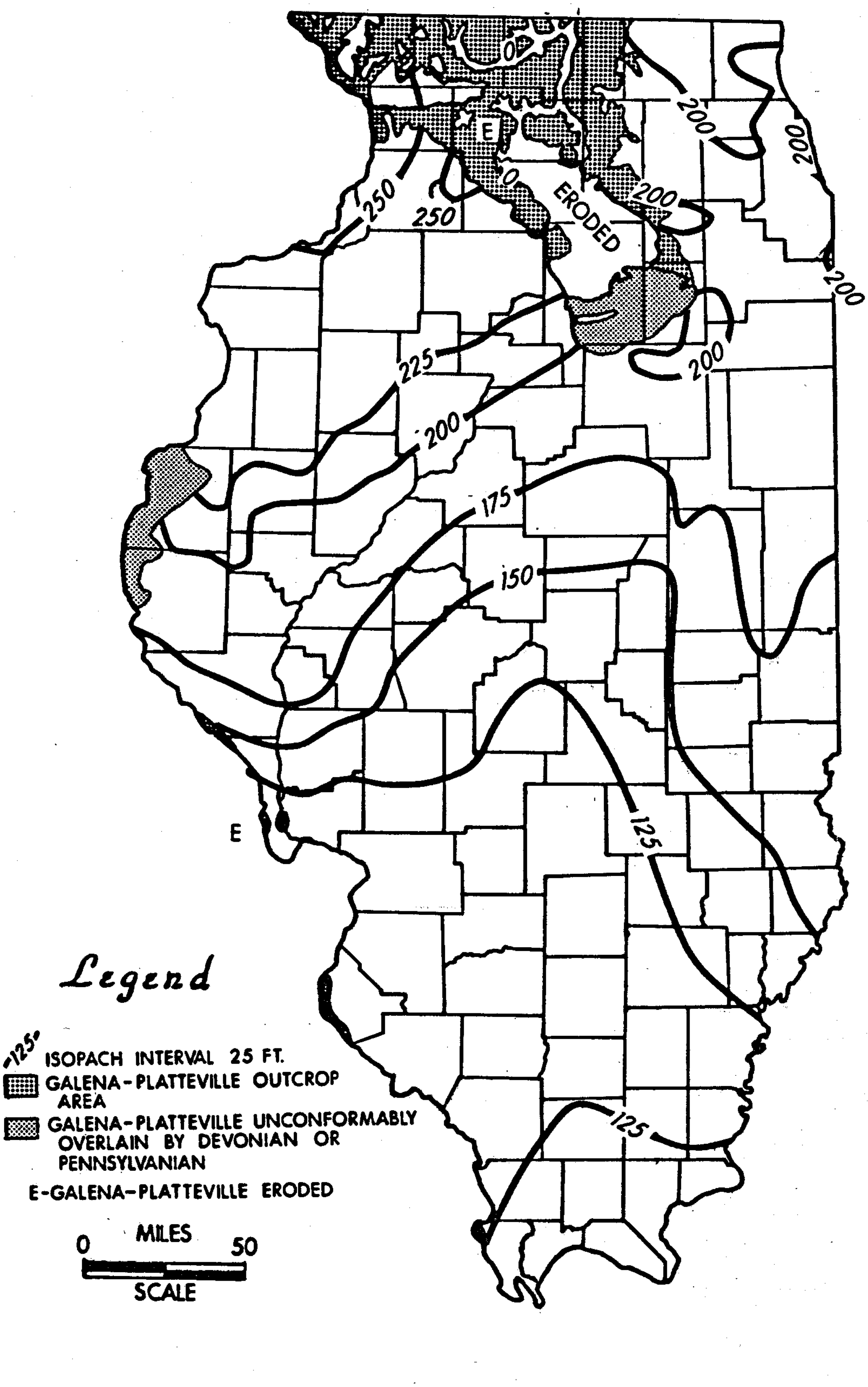

Figure 12.--Thickness of the Galena Group (from Willman and others, 1975).

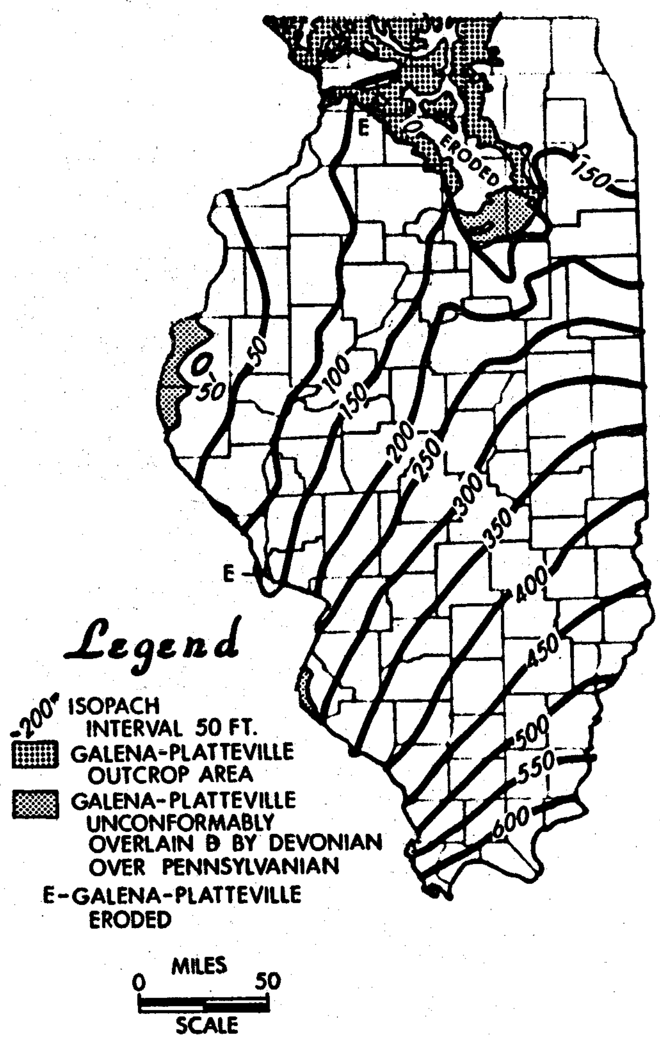

Figure 13.--Thickness of the Platteville Group (from Willman and others, 1975).

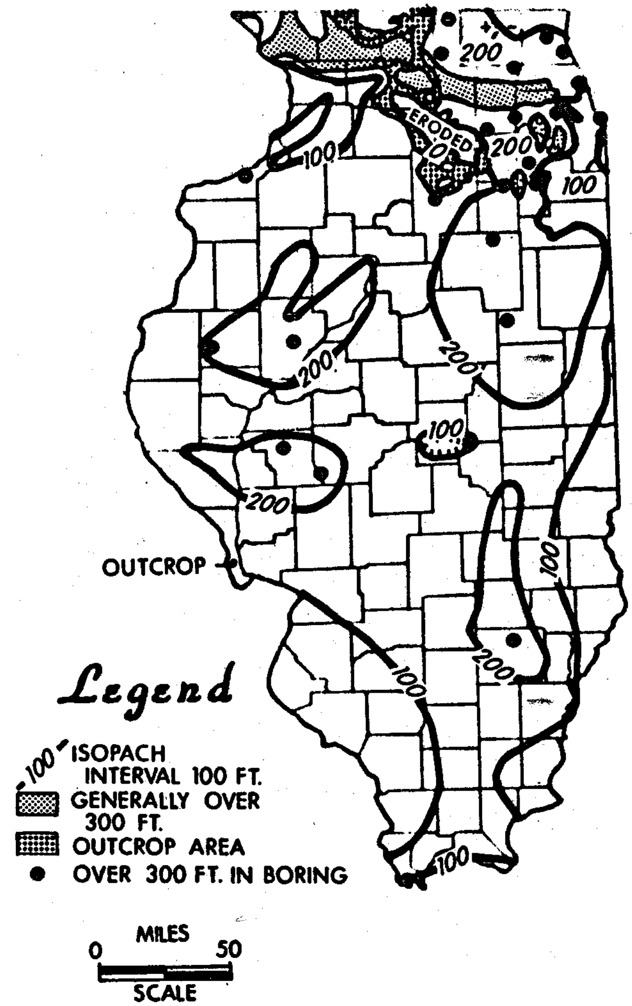

Figure 14.--Thickness of the St. Peter Sandstone (from Willman and others, 1975).

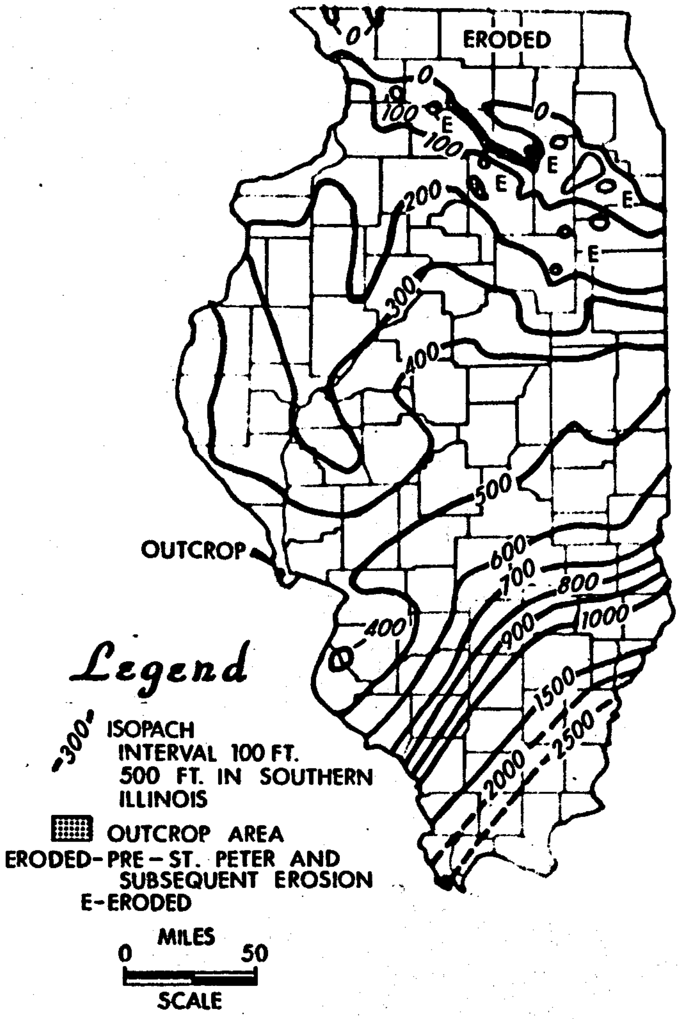

Figure 15.--Thickness of the Shakopee Dolomite (from Willman and others, 1975).

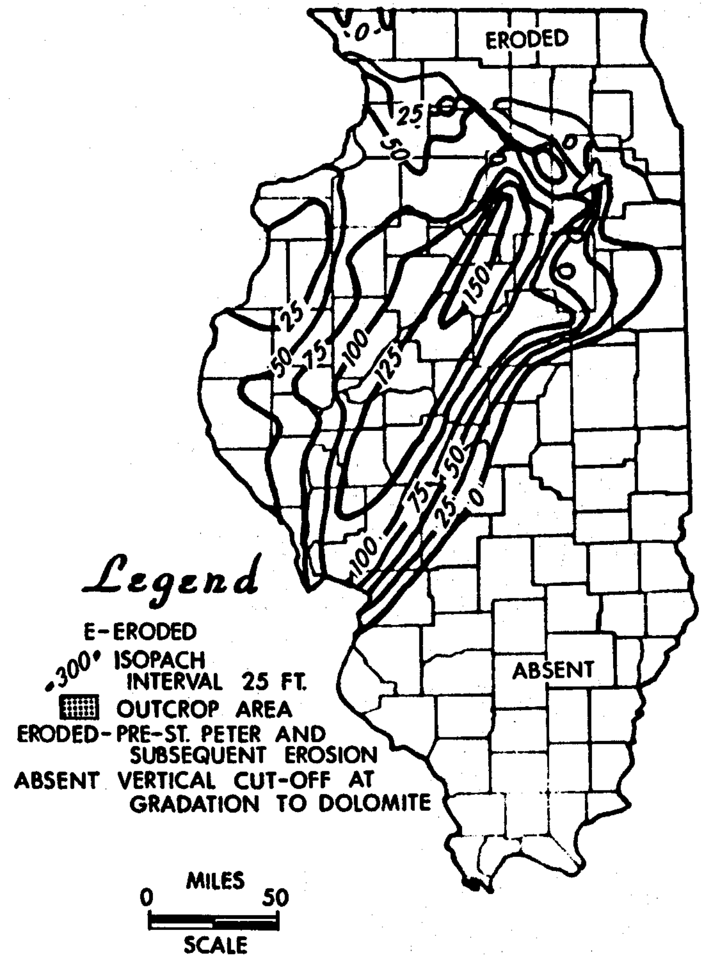

Figure 16.--Thickness of the New Richmond Sandstone (from Willman and others, 1975).

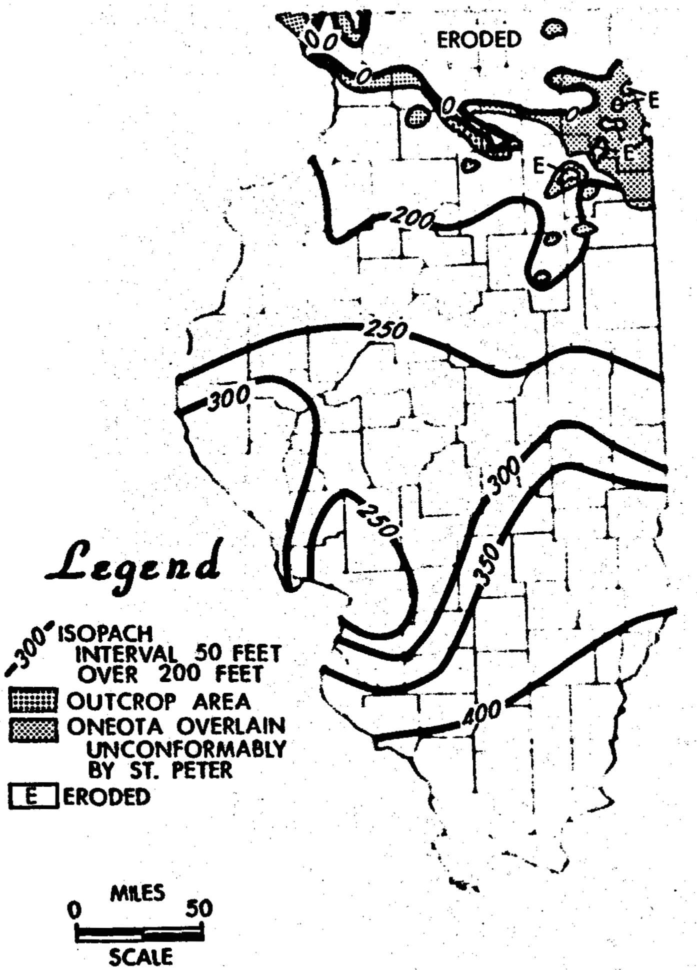

Figure 17.--Thickness of the Oneota Dolomite and the Gunter Sandstone (from Willman and others, 1975).

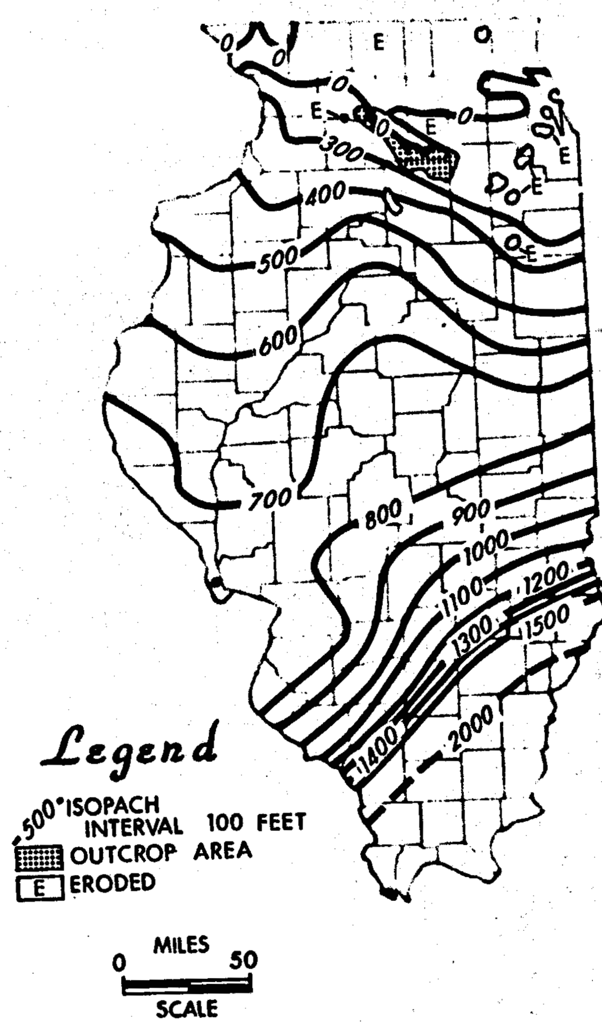

Figure 18.--Thickness of the Prairie du Chien Group (from Willman and others, 1975).

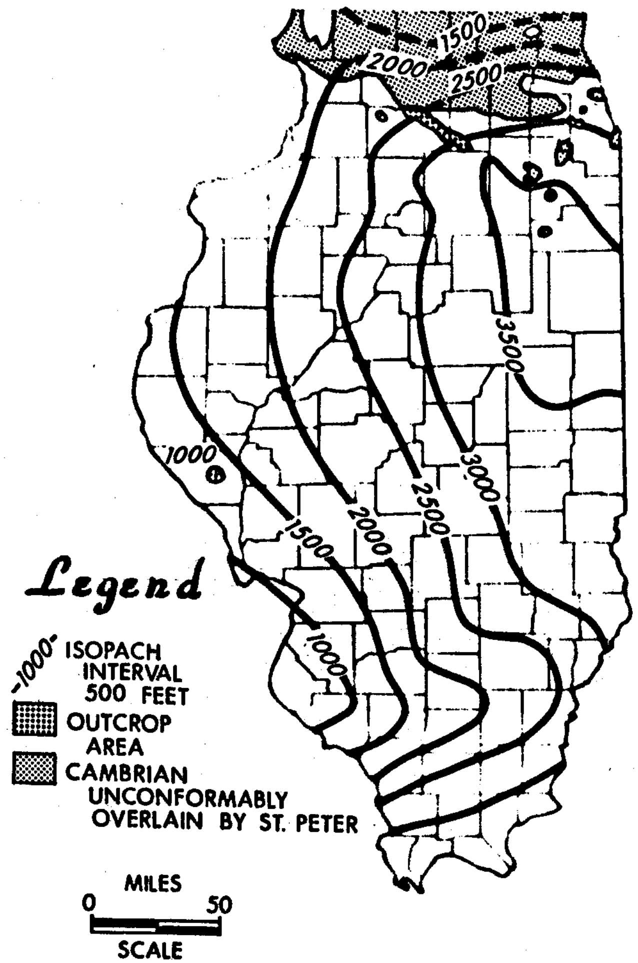

Figure 19.--Thickness of the Cambrian System. The dashed lines show reconstructed thicknesses (from Willman and others, 1975).

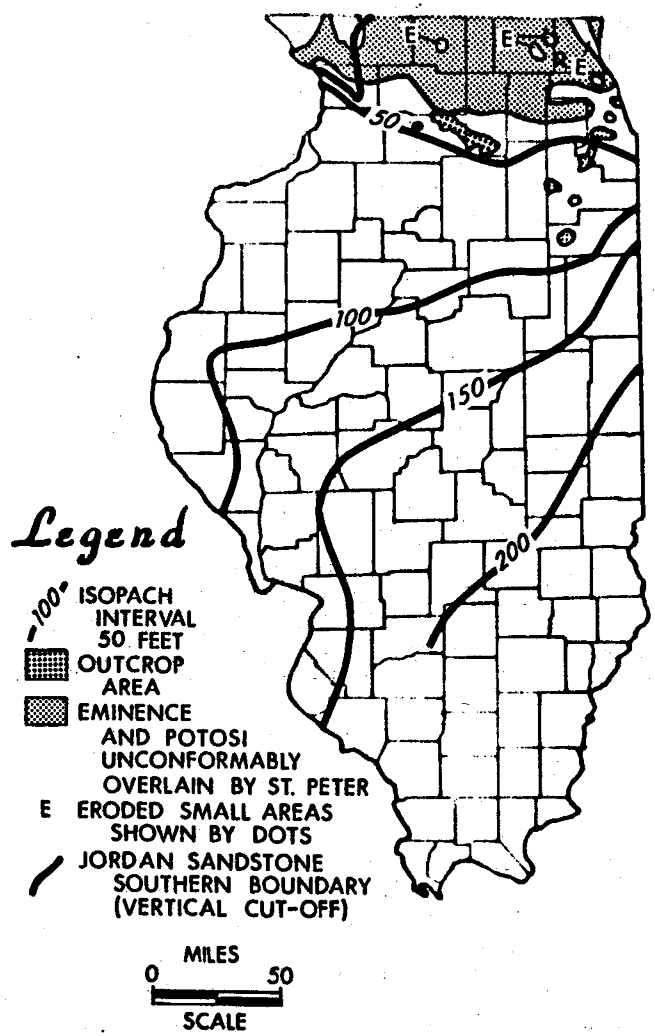

Figure 20.--Thickness of the Eminence Formation (from Willman and others, 1975).

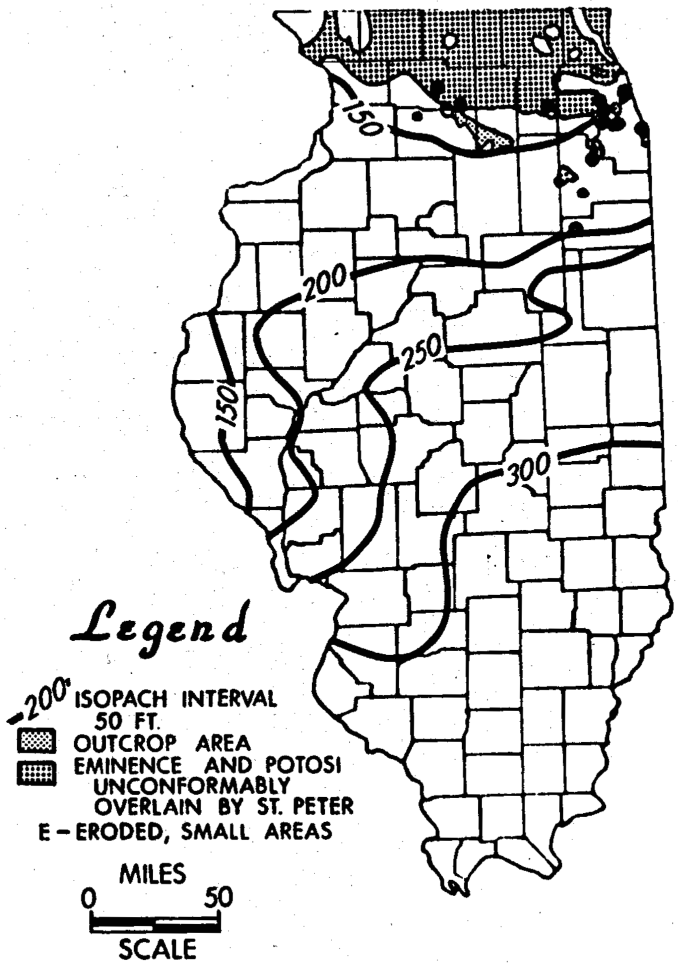

Figure 21.--Thickness of the Potosi Dolomite (from Willman and others, 1975).

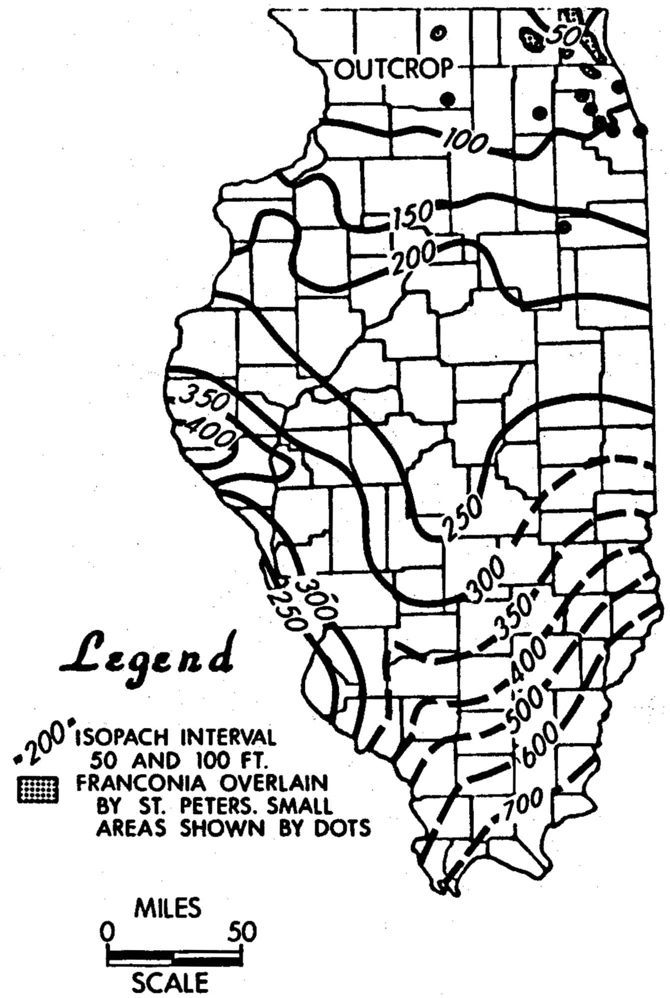

Figure 22.--Thickness of the Franconia Formation (from Willman and others, 1975).

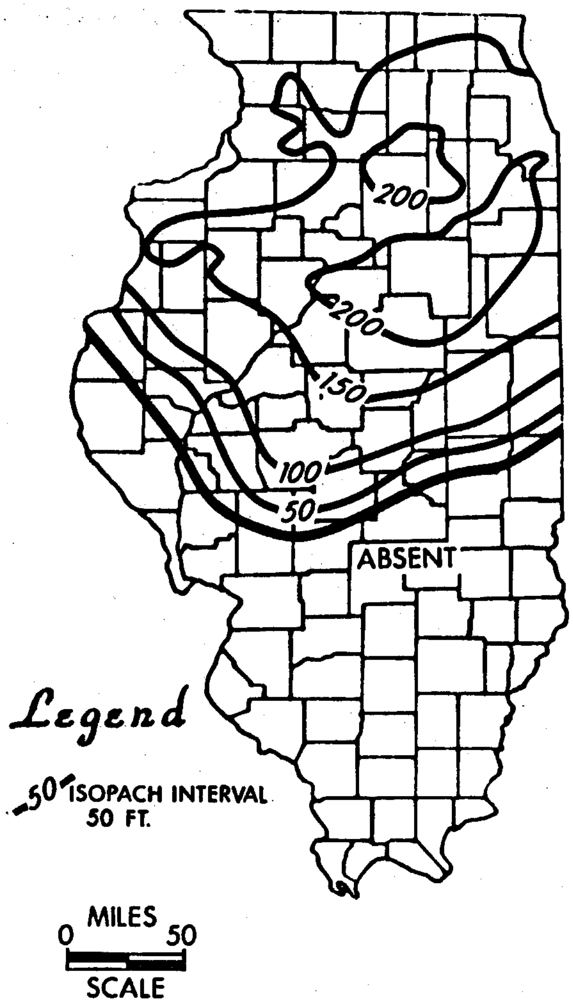

Figure 23.--Thickness of the Ironton and Galesville Sandstones (from Willman and others, 1975).

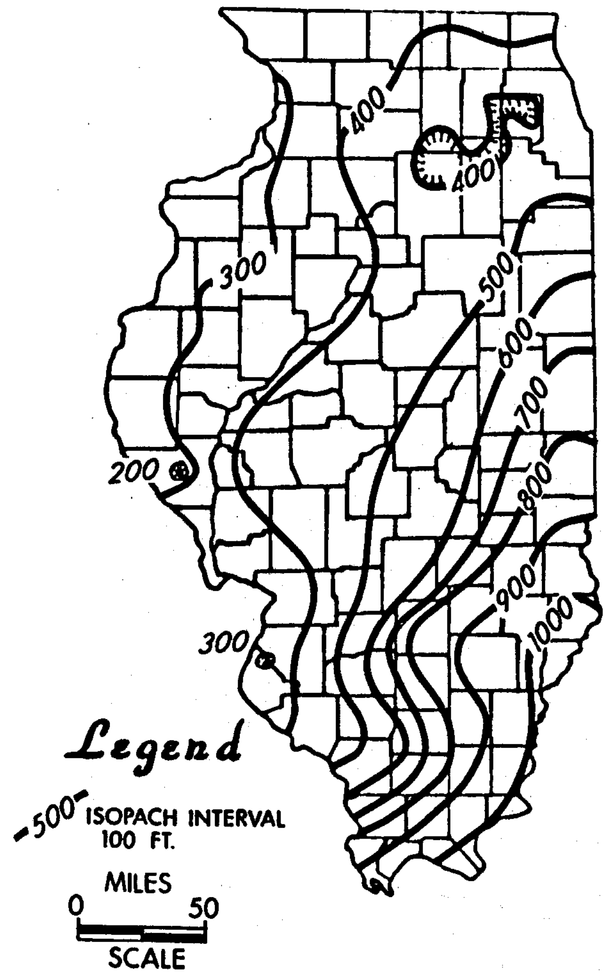

Figure 24.--Thickness of the Eau Claire Forma- from
tion (from Willman and others, 1975).

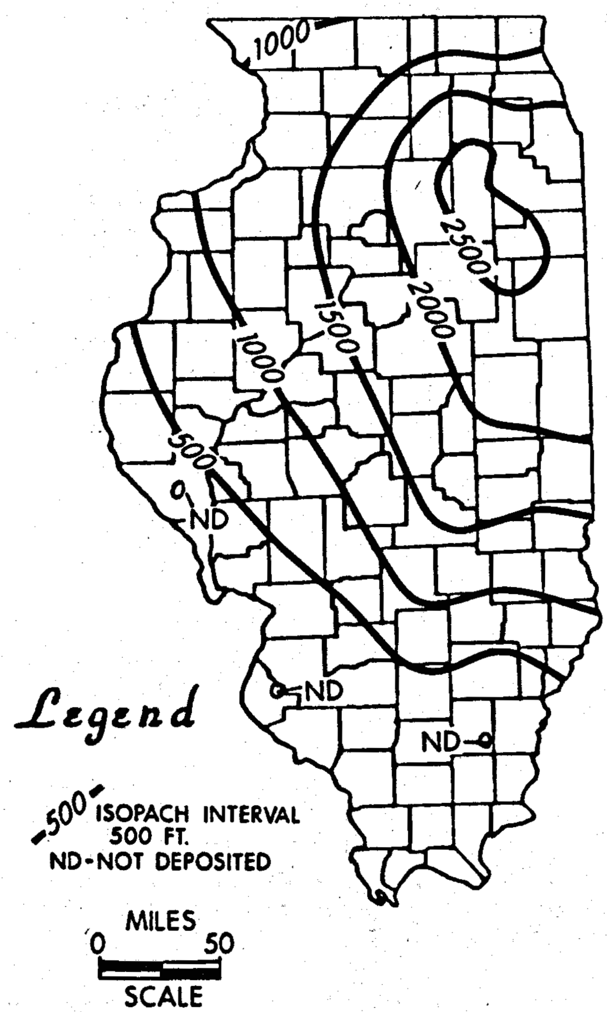

Figure 25.--Thickness of the Mt. Simon Sandstone (from Willman and others, 1975).

References Cited

American Association of Petroleum Geologists, 1976, Basic data file--data from American Association of Petroleum Geologists geothermal survey of North America: Norman, Oklahoma, University of Oklahoma.

American Association of Petroleum Geologists and U.S. Geological Survey, 1976a, Subsurface temperature map of North America: U.S. Geological Survey, scale 1:5,000,000, 2 sheets.

------- 1976b, Geothermal gradient map of North America: U.S. Geological Survey, scale 1:5,000,000, 2 sheets.

Bayley, R. W., and Muehlberger, W. R., compilers, 1968, Basement rock map of the United States exclusive of Alaska and Hawaii: U.S. Geologic Survey, scale 1:2,500,000, 2 sheets.

Birch, F., Roy, R. F., and Decker, E. R., 1968, Heat flows and thermal history in New England and New York, in Zen, E-an, White, W. S., Hadley, J. B., and Thompson, J. B., Jr., eds., Studies of Appalachian geology: Northern and maritime: New York, Interscience, p. 437-451.

Carpenter, G. L., Dawson, T. A., and Keller, S. J., 1975, Petroleum industry in Indiana: Department of Natural Resources, Geological Survey Bulletin 42-N, 57 p.

Cole, V. B., 1961, The Cap au Grès fault in northeastern Missouri and west-central Illinois, in Malone, D. J., ed., Guidebook, 26th annual field conference: Wichita, Kansas, Kansas Geological Society, in cooperation with the Missouri Geological Survey and the Illinois Geological Survey, p. 86-88.

Diment, W. H. R., Urban, T. C., Sass, J. H., Marshall, B. U., Monroe, R. J., and Lachenbruch, A. H., 1975, Temperatures and heat contents based on conductive transport of heat, in White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States--1975: U.S. Geological Survey Circular 726, p. 84-103.

Eardley, A. J., 1951, Structural geology of North America: New York, Harper Brothers Publishers, 624 p.

Ekblaw, G. E., 1938, Kankakee arch in Illinois: Illinois State Geological Survey Circular 40, 6 p.

Hadley, J. B. and Devine, J. F., 1974, Seismotectonic map of the eastern United States: U.S. Geological Survey Miscellaneous Field Study Map MF-620, scale 1:5,000,000, 3 sheets, 8 p. text.

Heigold, P. C., Mast, R. F., and Cartwright, Keros, 1971, Temperature distributions and groundwater movements associated with oil fields in the Fairfield basin, in Proceedings of symposium on future petroleum potential of NPC Region 9 (Illinois basin, Cincinnati arch, northern part of Mississippi embayment): Illinois State Geological Survey, Illinois Petroleum 95, p. 127-140.

Heyl, A. W., 1972, The 38th parallel lineament and its relationship to ore deposits: Economic Geology, v. 67, p. 879-894.

Hodge, S., Hilfiker, Kenneth, Morgan, Paul, and Swanberg, C. A., 1979, Preliminary geothermal investigations in New York State, in Geothermal energy and the eastern U.S., technical information interchange meeting, minutes: Johns Hopkins University, Applied Physics Laboratory, APL/JHU, QM-79-261.

King, P. B., and Beikman, H. M., compilers, 1974, Geologic map of the United States (exclusive of Hawaii and Alaska): U.S. Geologic Survey, scale 1:2,500,000, 2 sheets.

McGinnis, L. D., Heigold, P. C., Ervin, C. P., and Heidari, M., 1976, The gravity field and tectonics of Illinois: Illinois State Geological Survey Circular 494, 28 p.

Muffler, L. J. P., and Cataldi, R., 1978, Methods for regional assessment of geothermal resources: Geothermics, v. 7, no. 2-4, p. 53-89. Also 1977, U.S. Geological Survey Open-File Report 77-870, 76 p.

Ross, C. A., 1963, Structural framework of southernmost Illinois: Illinois State Geological Survey Circular 351, 27 p.

Roy, R. F., Decker, E. R., Blackwell, D. D., and Birch, F., 1968a, Heat flow in the United States: Journal of Geophysical Research, v. 72, p. 5207-5221.

Roy, R. F., Decker, E. R., and Blackwell, D. D., 1968b, Heat generation of plutonic rocks and continental heat flow provinces: Earth and Planetary Science Letters, v. 5, p. 1-12.

Sammel, E. A., 1979, Occurrence of low temperature geothermal waters in the United States, in Muffler, L. J. P., ed., Assessment of geothermal resources of the United States--1978: U.S. Geological Survey Circular 790, p. 83-131.

Sass, J. H., Diment, W. H., Lachenbruch, A. H., Marshall, B. V., Monroe, R. J., Moses, T. H., Jr., and Urban, T. C., 1976, A new heat-flow contour map of the conterminous United States: U.S. Geological Survey Open File Report 76-256, 24 p.

Swann, D. H., 1968, A summary of the geological history of the Illinois basin, in Geology and petroleum production of the Illinois basin, a symposium: Illinois and Kentucky-Indiana Geological Societies, p. 3-22.

Vaught, T. L., 1980, Temperature gradients in a portion of Michigan: a review of the usefulness of data from the AAPG geothermal survey of North America: U.S. Department of Energy Report No. DOE/NV/10072-2.

Willman, H. B., Atherton, Elwood, Buschbach, T. C., Collinson, Charles, Frye, J. C., Hopkins, M. E., Lineback, J. A., and Simon, J. A., 1975, Handbook of Illinois stratigraphy: Illinois State Geological Survey Bulletin 95, 261 p.

Woollard, G. P., 1958, Areas of tectonic activity in the United States as indicated by earthquake epicenters: American Geophysical Union Transactions, v. 39, no. 6, p. 1135-1150.

APPENDIX

LITHOLOGIC DESCRIPTION OF ORDOVICIAN AND CAMBRIAN UNITS (from Willman and others, 1975)

Ordovician

Maquoketa Group

Neda Formation Red shale interbedded with red-brown or black oolite consisting of geothite or hematite. Contains some gray or green shale. It is generally less than 10 feet thick.

Brainard Shale In outcrop it is a greenish-gray to green shale which is partly dolomitic and locally silty. Siltstone, limestone, and dolomite beds are present in the subsurface. Two thin bentonite beds occur near the top in southeastern Illinois. It is commonly fossiliferous and its thickness generally ranges from 75 to 100 feet. It is present over most of the state except in north central Illinois, where it has been eroded.

Fort Atkinson Limestone Varies from white to pink, coarse-grained, crinoidal limestone to brown, fine-grained dolomite or gray, argillaceous limestone. In northwestern Illinois, it becomes very shaly and in other areas it includes limestone that is laterally equivalent to the shale. It is usually 15 to 40 feet thick and is widely distributed in Illinois.

Scales Shale The lower part is dark gray to dark brown shale; the upper part is a gray shale containing beds of argillaceous limestone. In southwestern Illinois, brown sandstone and siltstone beds are present. It is generally 75 to 100 feet thick and is present over most of the state.

Cape Limestone Light gray to reddish-gray, coarse-grained, fossiliferous calcarenite. It occurs in medium to thick beds with shale partings. It is less than 10 feet thick and is present in southwestern Illinois. Figure 11 is an isopach map of the Maquoketa Group.

Galena Group

Dubuque Formation The lower part grades from pure thick-bedded dolomite to shaly dolomite. In the upper part, thin argillaceous dolomite beds are interlayered with beds of thin dolomitic shale. A thin bed of red-brown shale occurs 20 feet below the top, and calcite-filled vugs are common in the top 2 feet. It is present in northwestern Illinois and is about 40 to 45 feet thick.

Wise Lake Formation Non-cherty, medium- to thick-bedded, vuggy, pure dolomite in the northern outcrop area. The southern outcrop facies is a thick-bedded, fine-grained to lithographic pure limestone. It is 67 to 75 feet thick and occurs in the northern and central part of the state.

Dunleith Formation In northwestern Illinois it consists of alternating pure limestone or dolomite argillaceous units. The pure units are medium- to thick-bedded and vuggy; the argillaceous units are thin- to medium-bedded and dense with chert nodules. It is subdivided into 10 members. At East Dubuque the lower 27 feet is dolomite-mottled limestone and the upper 85 feet is dolomite. To the south and east, the limestone is progressively replaced by dolomite from the top down. It is 100 to 135 feet thick.

Guttenberg Formation In western Illinois, it is a thin-bedded, tan with white-weathering, very fine grained limestone interbedded with brown-red shale. Toward the east, it grades into a brown, medium-grained, vuggy dolomite containing thin beds of brown shale. In western Illinois it is 10 to 15 feet thick; it thins to the east.

Kings Lake Formation Argillaceous, very silty, dolomitic limestone with thin beds of shale, calcarenite, and bentonite. It reaches 15 feet in thickness but thins out northward. It is exposed only in Calhoun County.

Spechts Ferry Formation Interbedded shale and sandstone. Shale is dominant in the north, limestone in the south. The shale is bright green but locally it is greenish-gray and the basal few inches is brown. It is characterized by two thin bentonite beds and by persistent thin beds of dense, fine-grained limestone, coquinite, and dark purplish-gray, coarse-grained calcarenite. It is 5 to 10 feet thick in western Illinois but absent in central and eastern Illinois. Figure 12 is an isopach map of the Galena Group.

Platteville Group

Quimbys Mill Formation In the type area in northwestern Illinois, it is characterized by a brown lithographic limestone with brown shale partings. It shows conchoidal fracture. In the outcrop area in north central Illinois, it is a light brown, dense, very fine grained, slightly argillaceous dolomite that weathers yellow. In the southern outcrop area, it is a fine-grained to lithographic limestone with green-gray shale partings and some thin layers of conglomerate, fossil debris, and bentonite. It is 30 to 35 feet thick in the south and thins northward.

Nachusa Formation Fine- to medium-grained vuggy dolomite in northern Illinois and dolomite-mottled lithographic limestone in the southern area. It is pure to slightly argillaceous, cherty, fucoidal, and thick-bedded to massive. In the southern outcrop area it contains layers of bentonite, calcarenite, and conglomeratic limestone. It reaches a thickness of 75 feet but thins to the north.

Grand Detour Formation Dolomite-mottled, lithographic, slightly argillaceous to pure limestone that contains thin beds of calcarenite; locally it is fine- to medium-grained dolomite. It is usually medium-bedded, with thin, brown-red, dark gray, or black shale partings but contains persistent units that are thick-bedded to massive, fucoidal, and pure. It is about 50 feet thick in the northern outcrop area but thickens southward to about 210 feet in southern Illinois.

Mifflin Formation Gray lithographic limestone, thin-bedded and shaly. In the northern outcrop area it grades into shaly, fine-grained dolomite; locally and in western Illinois it grades into sandy shale and sandstone. In the northern outcrop area, it is characterized by a persistent, massive, middle unit and in Calhoun County and southward it has an oolite bed in the lower part. In southern Illinois it reaches 125 feet but thins northward to 15 to 25 feet.

Pecatonica Formation In northern Illinois, it is a brown, vuggy dolomite in medium to thick beds and contains large chert nodules. Southward, it is a brownish-gray lithographic limestone mottled with dolomite. It is 150 feet thick in southern Illinois and thins northward to 20 feet. Figure 13 is an isopach map of the Platteville Group.

Ancell Group

Joachim Dolomite Largely light gray, argillaceous, silty or sandy dolomite which contains beds of brownish-gray pure dolomite, sandstone, and limestone, thin shales, and algal domes of pure dolomite. Cherty, anhydrite, and brecciated layers are present. It is not fossiliferous. In southern Illinois it reaches 385 feet but thins northward.

Dutchtown Limestone Dark gray, argillaceous, lithographic limestone and dolomite. It contains beds of gray and brown shaly limestone and dolomite, calcareous siltstone, and dolomitic sandstone. In southeastern Illinois it is about 200 feet thick and it thins to the north.

Glenwood Formation Poorly sorted bimodal sandstone, impure dolomite, and green shale. Present in northern Illinois; thickness ranges from 25 to 75 feet.

St. Peter Sandstone Fine- to medium-grained, well sorted, well rounded, pure, frosted grains of quartz sand, friable and weakly cemented. It is commonly 100 to 200 feet thick but reaches 700 feet locally. Figure 14 is an isopach map of the St. Peter sandstone.

Everton Dolomite It has only been penetrated by a few wells and is characterized by a sandstone overlain by a dolomite. It may reach 500 feet in thickness in southern Illinois but it thins northeastward.

Prairie due Chien Group

Shakopee Dolomite Argillaceous to pure, very fine grained dolomite with some thin beds of medium-grained, cross-bedded sandstone, medium-grained dolomite, green to light gray shale, and buff siltstone. The dolomite is light gray to light brown, the brown increasing toward the deep part of the Illinois basin. It contains oolitic, partly sandy chert in bands and nodules. It may be as thick as 2,500 feet in southeastern Illinois but it thins and disappears in northern Illinois. Figure 15 is an isopach map of the Shakopee Dolomite.

New Richmond Sandstone White to light gray, fine- to medium-grained, subrounded to rounded, friable, moderately sorted, cross-bedded, ripple-marked sandstone interbedded with sandy dolomite. The dolomite is sandy, light colored, and fine-grained, and contains oolitic chert. It is present in northwestern Illinois and reaches a thickness of 150 feet in north central Illinois. Figure 16 is an isopach map of the New Richmond Sandstone.

Oneota Dolomite Fine- to coarse-grained, light gray to brownish-gray cherty dolomite containing minor amounts of sand and thin shaly beds at its base. It is present in most of the state and thins northward from a maximum of about 400 feet in southern Illinois. Figure 17 is an isopach map of the Oneota dolomite.

Gunter Sandstone Medium- to fine-grained, moderately sorted, subrounded quartz grains. It contains thin beds of light gray, fine-grained dolomite and small amounts of green shale. It has a patchy distribution; thickness ranges up to 25 feet. Figure 18 is an isopach map of the Prairie du Chien Group.

Cambrian

Jordon Sandstone Present only in extreme northwestern Illinois. It ranges from several feet to 75 feet in thickness. The Jordon is characterized by a white to yellowish-gray sandstone, fine- to medium-grained at the base but coarse to very coarse grained at the top. The bedding is variable. It grades laterally into the Eminence Formation toward the south and the east.

Eminence Formation Present in all but the extreme northern part of Illinois. Its thickness generally ranges from 50 to 250 feet. The lithology of the Eminence is characterized by a light gray, brown, or pink arenaceous, fine- to medium-grained dolomite. Oolitic chert and thin sandstone beds are present. Figure 20 is an isopach map of the Eminence Formation.

Potosi Dolomite Present in most of Illinois. Its thickness ranges from about 100 feet to more than 300 feet. Its distribution and thickness are shown in the isopach map presented in fig. 21. The Potosi is a brown to pinkish-gray dolomite, finely crystalline and slightly argillaceous. Glauconite is present at the top and at the base.

Franconia Formation Underlies all of Illinois and ranges in thickness from 50 to more than 500 feet. Lithologically, it is characterized by a gray to pink, glauconitic, silty, argillaceous, fine-grained dolomitic sandstone. Various amounts of red and green shale are present, increasing in abundance in the lower part toward the south. Figure 22 is an isopach map of the unit.

Ironton Sandstone Present in the northern half of Illinois, usually 50 to 100 feet thick and thinning toward the northwest. In extreme northern Illinois, the unit is characterized by a white, medium-grained, poorly sorted sandstone with coarse-grained beds near the top. It is commonly dolomite-cemented. Toward the south, the Ironton grades into a sandy dolomite. Figure 23 is an isopach of the Ironton and the Galesville Sandstones.

Galesville Sandstone Present in the northern half of Illinois and is about 40 to 100 feet thick. This unit is characterized by a white to buff fine-grained, locally silty, moderately well sorted, friable sandstone with local dolomitic cement. The Galesville and Ironton Sandstones are important aquifers in Illinois.

Eau Claire Formation Present throughout Illinois, ranging in thickness from less than 300 to more than 1000 feet. In the north and west it is a dolomitic, fine- to medium-grained gray sandstone with shaly siltstone, glauconite, and brownish-gray dolomite. In central and eastern Illinois, it grades into a dolomitic siltstone containing glauconitic and oolitic limestone and dolomite. In southern Illinois, the Eau Claire is a fine-grained gray dolomite or limestone. Figure 24 is an isopach map of the unit.

Mount Simon Sandstone Underlies all of Illinois except in small local areas where Precambrian rocks are exposed. Its thickness ranges from less than 500 feet to 2600 feet. The unit is characterized by a fine- to coarse-grained, poorly sorted, pebbly, friable sandstone. The arkosic basal section is as thick as 350 feet. The Mount Simon is an important aquifer and has been used for gas storage. Figure 25 is an isopach of this unit.

*U.S. GOVERNMENT PRINTING OFFICE: 1980-740-145/1064