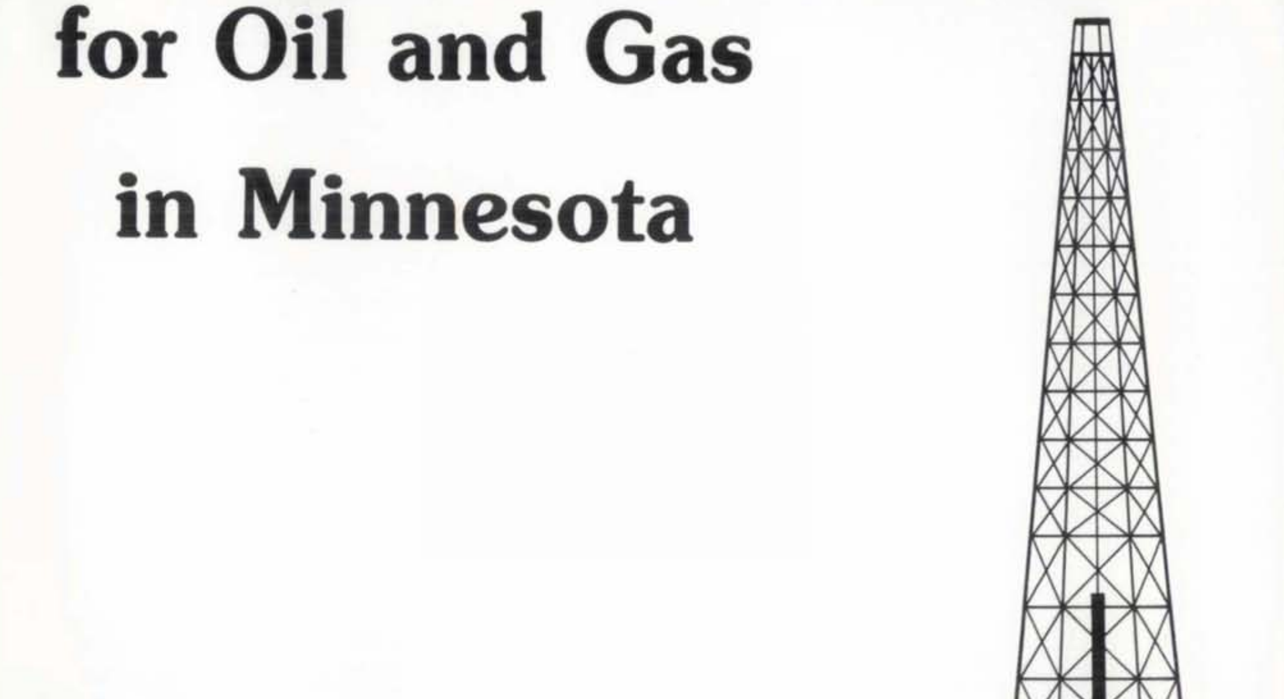
Educational Series-6
ISSN 0544-3083

THE SEARCH

for Oil and Gas in Minnesota



MINNESOTA GEOLOGICAL SURVEY

[illegible] L. Southwick

THE SEARCH
for Oil and Gas
in
Minnesota

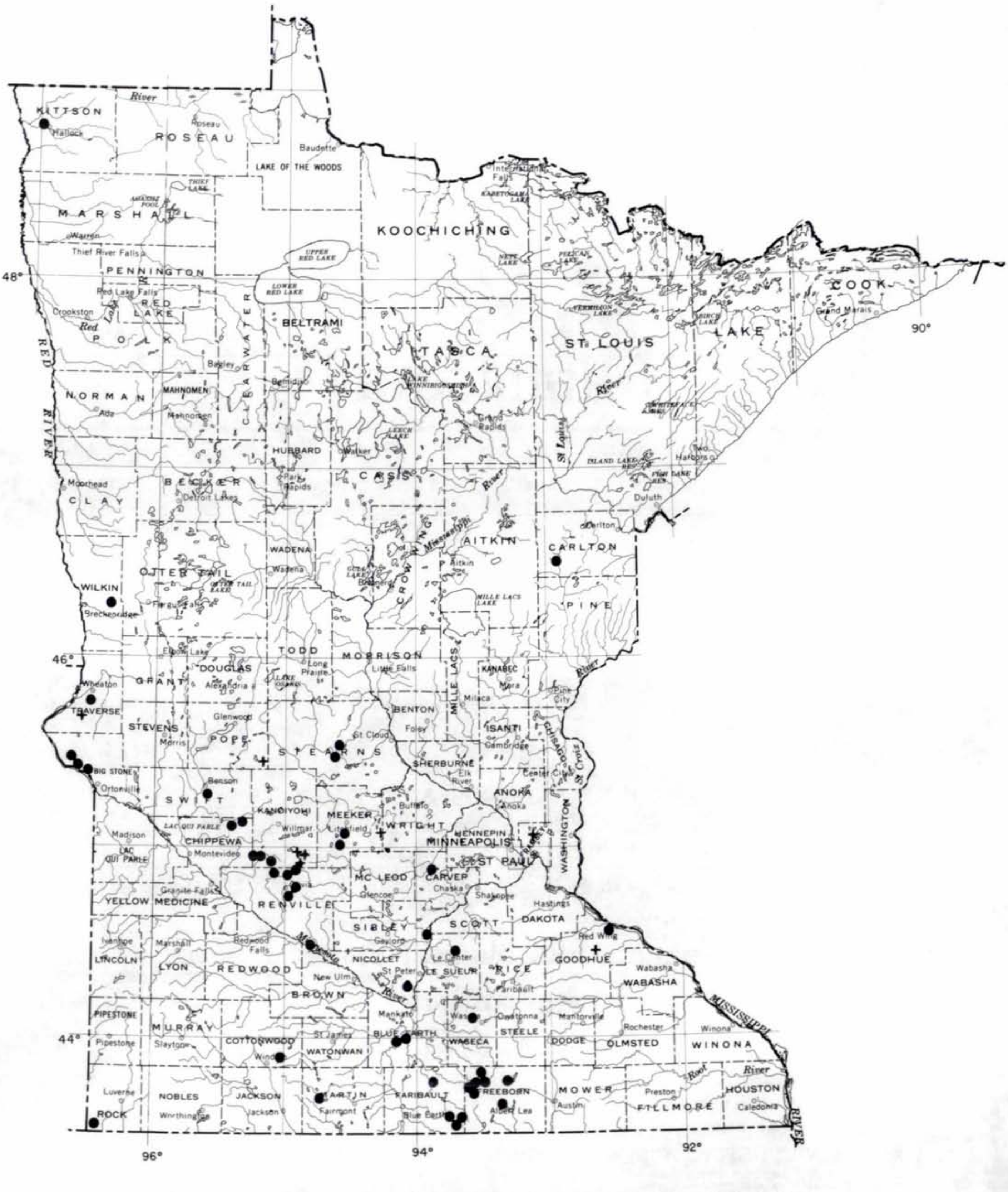
by

G.B. Morey

Minnesota Geological Survey
Educational Series 6

ISSN 0544-3083

UNIVERSITY OF MINNESOTA
Saint Paul—1984



Frontispiece. Locations of the reported natural gas (o) and "oil" (+) occurrences in Minnesota described in the text.

INTRODUCTION

The fossil fuels—coal, oil, and natural gas—are essential in Minnesota. We use much fuel just to keep warm in winter. Automobiles need gasoline. Trucks and tractors run on diesel fuel. Of the energy consumed in the state, almost 45 percent derives from oil, about 23 percent is natural gas, and roughly 22 percent is coal, about five-sixths of which is used to produce electricity. Nuclear energy, used to produce electricity, makes up the remaining 10 percent of the state's energy consumption. Aside from the unknown potential of the vast peatlands of northern Minnesota, the state has no fossil fuels of its own, and all must be imported from outside the state.

The need was acute even during the early days of statehood, when the problem was compounded by the lack of a year-round, reliable transportation network. Aggressive exploration by private individuals for fuel deposits that could be used locally did lead to the discovery of several small coal and natural gas deposits before the turn of the century. None of them, unfortunately, proved to be of commercial importance.

Most of the natural gas discoveries in Minnesota were accidental. Many were spectacular. A few were tragic. Not one was profitable as a commercial venture. But the incentives are strong, and the search continues. Today, after millions of dollars have been invested in hundreds of wells, and after 100 years of frustration, what have Minnesotans learned? Not nearly enough is the answer that this history would suggest.

BRIEFING ON PETROLEUM

The idea that large petroleum deposits "are waiting to be found" in Minnesota is an idea that is still widely held. Unfortunately, it is based almost entirely on misunderstandings as to (1) how oil and gas form in nature, (2) how they are concentrated into deposits large enough to be worth drilling, and (3) how such deposits can be found. This report was prepared to help Minnesota's citizens understand why the Minnesota Geological Survey (MGS) still believes, as it did in 1889, that commercially exploitable petroleum deposits are not to be found in the state.

Petroleum is an organic substance made up of molecules composed primarily of hydrogen and carbon atoms (hydrocarbons) combined in various ways. When hydrocarbons occur in rocks, they are known as petroleum, from the Latin for rock (petra) and oil (oleum). Most petroleum is either a vapor (natural gas) or a liquid (crude oil). Tar sands and oil shale are solid phases.

How Petroleum Originates

Petroleum forms from the remains of organisms that lived in large bodies of water or were washed down into them with mud and silt from rivers and streams. The organic matter accumulated in the sediments as they built up on the seafloor (Fig. 1). Over time, and beneath additional layers, the sediments were compacted and solidified to sandstone, shale, and limestone or dolomite.

Decay of organic matter at or near the surface generally involves oxygen in the atmosphere and produces carbon dioxide (CO_2) and water (H_2O). However, if decay occurs where oxygen is excluded, as in a deeply buried pile of sediments, hydrocarbons will be produced. The simplest of these is methane (CH_4). This compound is a gas, and natural gas is chiefly methane, but may include other simple hydrocarbon compounds that contain four or fewer carbon atoms per molecule. Hydrocarbon compounds that contain a large number of carbon atoms per molecule form liquids, and naturally occurring crude oil consists of complex mixtures of various types of hydrocarbons.

Not all natural gas has anything to do with the crude oil. In its definition of the petroleum series, the American Geological Institute's *Glossary of Geology* states, "The gases usually exclude methane when it occurs as marsh gas." Marsh gas is methane produced from rotting vegetation in swamps and peat bogs.

Organic-rich layers in sedimentary rocks that did not achieve the heat needed to produce crude oil may nonetheless contain natural gas. Methane also can be produced from plant-derived organic matter, largely peat, that has been buried within clayey glacial deposits. The explosive coal mine gas called firedamp is methane.

Where stagnant swamp water is poor in oxygen, bacterial destruction of the plants is incomplete, and the remains accumulate as peat. Deposits of coal are the result of burial of peat by younger sediments following a rise of sea level or subsidence of the swamp area. Deeper burial of the low-grade coal (lignite) found in Minnesota—and consequent pressure and heat—would have produced bituminous coal or anthracite, or if too deep, a graphite-like end product. But not crude oil.

For crude oil to result, not only must oxygen have been excluded, but the organic material must have been buried deeply enough to have been heated to between 120 and 300°F for a million years or more. This so-called "petroleum window" is but a small part of the temperature variation of the earth's crust. If subjected to too much heat, any oil that has formed is destroyed. Natural gas that formed in conjunction with crude oil could have formed both below and above the petroleum window.

If you have read John McPhee's delightful book, *In Suspect Terrain,* you know that geologists currently use the color variations of microfossils known as conodonts as a "geothermometer." Minnesota's sandstones, shales, and limestones contain these fossils, but their pale color and pristine condition indicate that the rocks never reached the heat of the petroleum window. "Oil" occurrences in the state are thus rather a puzzle.

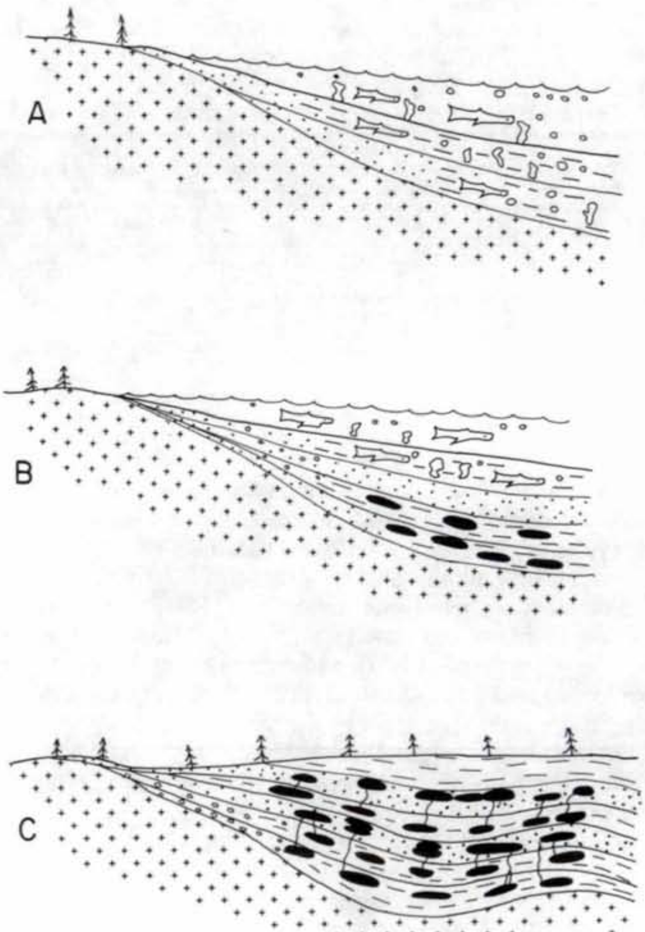
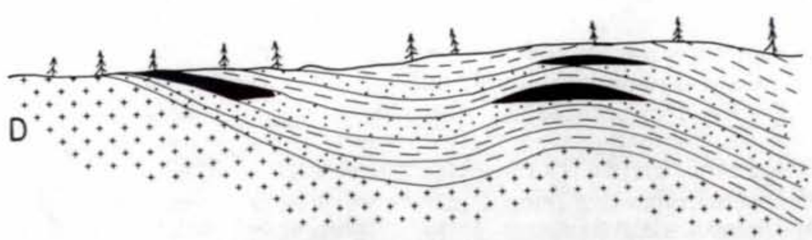


Figure 1. Origin of petroleum.

A, animals and plants in an ancient shallow sea die; their remains—especially the remains of single-celled plants called algae—accumulate in mud and silt on the seafloor. B, perhaps millions of years later, plant and animal life still exists in the sea, and their remains continue to accumulate. However, the sedimentary sequence has increased in thickness; the more deeply buried mud is altered to shale and its organic material to petroleum. C, at a still later time, the sea no longer exists. The rocks have been somewhat flexed. The petroleum formed in the shaly source beds is squeezed into suitable reservoir rocks. D, still later, the sedimentary rocks have been folded, and petroleum in the reservoir rocks migrates upward along the limbs of the anticlines and accumulates beneath younger layers of impervious shale. Much of the petroleum, however, escapes from the reservoir rocks in places where traps do not exist. Some of this petroleum, as at the left side of the diagram, may reach the surface in seeps.

The drawings are schematic and not to any particular scale. Note that the sandstone reservoirs (dotted) accumulated near the shore, and the layers of shale (dashed pattern) were deposited in deeper water. The plus-mark pattern is commonly used for granite. Calcium carbonate and calcium-magnesium carbonate would have been precipitated in still deeper water to form layers of limestone and dolomite, which are not shown in these sketches.



Where Petroleum Occurs

For oil and natural gas to occur in quantities that are commercially valuable, four geologic features are required. These are a source rock, a reservoir rock, a trap, and a seal.

As the name implies, a source rock is the rock in which gas and oil originated. One common kind of source is organic-rich shale, which is produced from mud containing abundant remains of algae. Burial beneath younger layers of sediment (Fig. 2) compacts the mud to shale, and the heat that is associated with deep burial breaks down the organic compounds to petroleum hydrocarbons. With the passage of time, the petroleum may be squeezed out of the shale and accumulate in a reservoir rock.

Good reservoir rocks have ample void spaces (porosity) and channelways that interconnect these spaces (permeability) to allow the petroleum to seep from void to void and saturate the rock (Fig. 3), and subsequently to allow it to escape through a well. By contrast, shale is composed of particles whose small size and tabular shape allow them to be packed tightly together, somewhat like a deck of cards, and shale is thus relatively impermeable.

Layers of sandstone make good reservoir rocks because they are commonly both porous and permeable. These attributes existed in the sand as it was deposited. Thus sandstone is said to have "primary porosity." Limestone and dolomite also make good reservoir rocks, but their porosity and permeability typically result from ground water seeping into them, dissolving away some of the carbonate material, and leaving void spaces (Fig. 3D). Porosity formed in this way is referred to as "secondary porosity," meaning that it developed sometime after the rock formed.

Although sandstones and carbonates are the most common reservoir rocks, any kind of rock that contains open spaces so that the oil or gas can move through it may form a reservoir. Ridgelike or moundlike reefs, composed exclusively of the remains of marine organisms, especially corals, have well-developed porosity and perme-

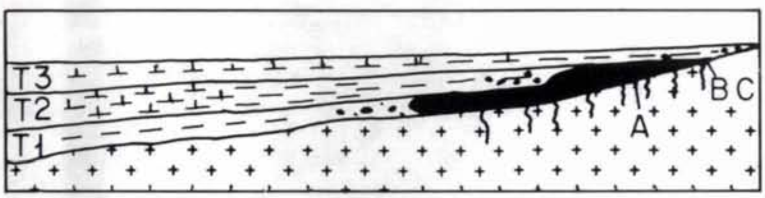


Figure 2. Diagrammatic section showing stratigraphic traps near the shoreline of a sea that transgressed onto older rocks, in this case granite. At Time 1 (T1), the shoreline was at point A where sand was being deposited at the beach; finer sediments that would become shale were accumulating in deeper water. At T2, the sea has transgressed the land to point B; shale is being deposited above the sandstone of T1, and limestone above the shale of T1. At T3, the sea has transgressed to point C, and some of the T2 sands are being covered by T3 shales. Petroleum migrating updip would accumulate in the sandstones of T1 and T2, which are capped by shales of T2 and T3. Any petroleum in the sandstone of T3, which lacks an impervious seal, would be lost. Some petroleum may accumulate in open cracks and fractures in the granite beneath the reservoirs of T1 and T2.

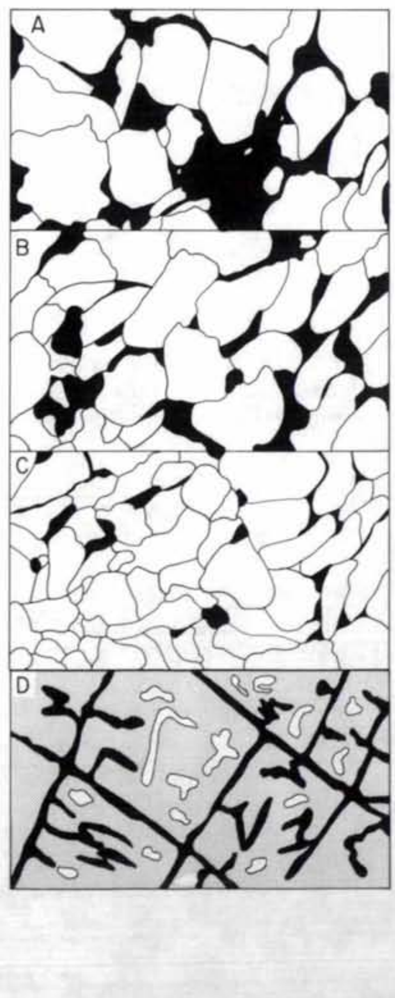


Figure 3. Porosity and permeability. Examples A, B, and C are three kinds of sandstone as seen in thin section at magnifications of 10 times their original size. A is an excellent reservoir rock with good porosity and permeability because it has many large void spaces between grains that are interconnected. B is a good reservoir rock. C is a poor reservoir rock that has very few interconnected void spaces. D is an illustration of secondary porosity (shown in black) in a limestone whose original, or primary porosity was limited. Ground water passing along fractures has dissolved the carbonate walls, widening the fractures and connecting otherwise isolated cavities. Solution channels developed in this way range in width from microfractures to tens of feet.

ability. They are typically enclosed in carbonate rocks which also have these attributes (Fig. 4A). Igneous and metamorphic rocks, such as basalt, granite, and gneiss, lack porosity and permeability because of their interlocking crystal structure. They can form local reservoirs if they contain cracks and fractures that are connected with source beds, but these rocks are rarely closely associated with good source beds for petroleum.

Once in a reservoir rock, oil and gas will continue to move through it until the movement is halted by some kind of trap. There are two general types of traps: structural traps (Figs. 4B and C) and stratigraphic traps (Figs. 4A and D-F). Because oil and gas tend to move upward in the rock, both types of traps require an impermeable bed or seal that prevents the petroleum from escaping from the reservoir rock.

In conclusion, petroleum deposits are not large subterranean caverns that contain pools or lakes of oil. They are beds of rock, commonly only a few feet thick but possibly extending laterally for miles, whose cracks and pores are saturated with oil or gas. It normally takes 10 to 30 years to drain the recoverable petroleum from a producing field—a tiny fraction of the time it originally took to form and accumulate the petroleum.

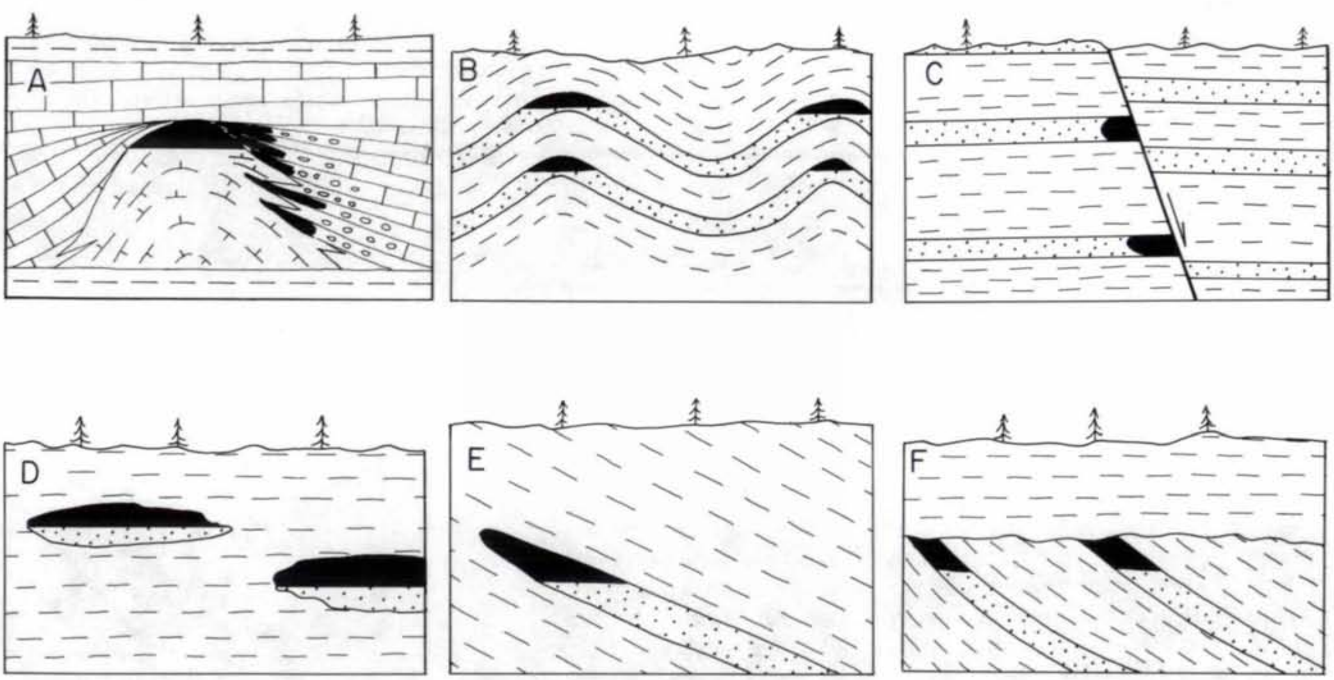


Figure 4. Diagrammatic sections showing various types of oil traps with oil shown in black.

A, section through a reef complex that began to grow on a soft muddy seafloor and was later buried by chemically precipitated limestone. The asymmetrical shape and the location of fragments of reef imply that the reef grew in a current that flowed from left to right. Note that petroleum accumulates in the reef itself, as well as in the flanking beds of reef material and limestone.

B, anticlinal traps where a sandstone (dotted) and shale (ruled) sequence has been arched upward. The petroleum migrated upward along the limbs of the anticlines to the point where its movement was halted by an impervious cap rock or seal. Traps of this type may be detected by mapping geologic features on the land surface.

C, fault traps at two levels in a sandstone-shale sequence. In this diagram the rock layers on the right side of the break have moved downward. The petroleum has migrated from the left to the fault where it has been halted by the seal of impervious rock across the fault. This trap could be detected by mapping geologic features on the land surface.

D, two stratigraphic traps formed in sandstone lenses (dotted) completely surrounded by impermeable shale (ruled). There is no indication on the land surface that these traps exist, and therefore they can be detected only by geophysical methods.

E, a stratigraphic trap on the updip edge of a gently dipping sandstone tongue within an impervious shale sequence. The presence of gently dipping strata can be detected by mapping on the land surface, but the trap itself can be detected only by geophysical methods.

F, two stratigraphic traps associated with an unconformity surface, here the result of erosion. Note that the petroleum accumulated in the traps after the post-unconformity shale was deposited. These traps have no surface expression and can be detected only by geophysical methods.

How Petroleum Is Found

Virtually all of the world's petroleum comes from sedimentary basins. A sedimentary basin is a large segment of the earth's crust that has slowly subsided over millions of years and become a persistent "low spot" in which thick accumulations of sedimentary rocks have been deposited. The Gulf of Mexico is a sedimentary basin that began to form about 130 million years ago and is continuing to subside, and to receive sediments, today. Many of these basins have come into existence, received great thicknesses of sedimentary fill, and then ceased to subside during the long history of the earth. Such "fossil" basins include the Williston basin, the Michigan basin, and many others in North America.

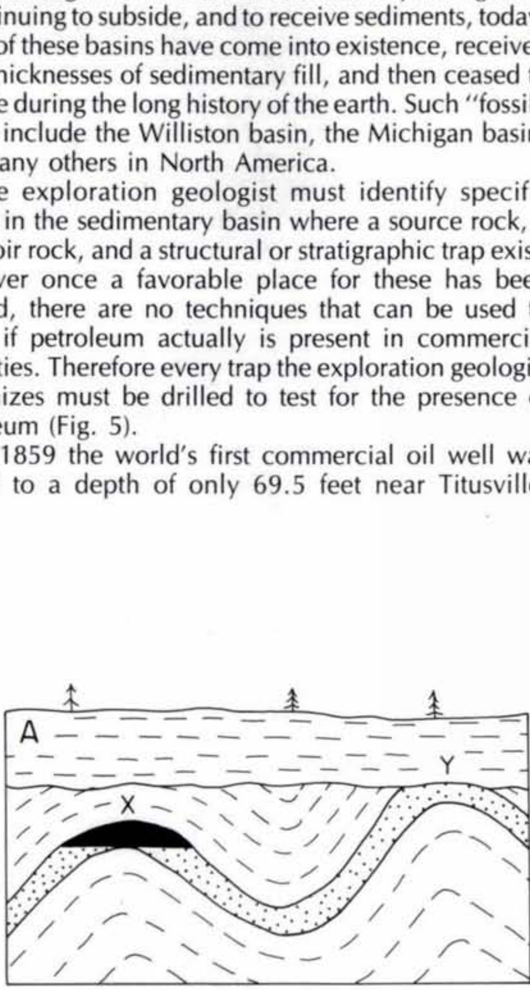
The exploration geologist must identify specific places in the sedimentary basin where a source rock, a reservoir rock, and a structural or stratigraphic trap exist. However once a favorable place for these has been defined, there are no techniques that can be used to "see" if petroleum actually is present in commercial quantities. Therefore every trap the exploration geologist recognizes must be drilled to test for the presence of petroleum (Fig. 5).

In 1859 the world's first commercial oil well was drilled to a depth of only 69.5 feet near Titusville, Pennsylvania, where there were natural seeps, and in the early days of exploration, holes of several hundred feet were considered to be very deep.

Geologic mapping based on surface exposures of layered sedimentary rocks commonly indicates the presence of geologic structures, such as anticlines and faults, at shallow depths. Many major petroleum fields were located in this way in the late 19th and early 20th centuries. The study of aerial photographs and satellite imagery of some parts of the world also may indicate patterns that are possibly related to shallow subsurface traps.

Most modern exploration is for structural and stratigraphic traps that are buried beneath very thick deposits of younger strata, because the near-surface resources have largely been exploited. In fact, exploration wells drilled 5 miles or more into the earth's crust are not unheard-of. Today's exploration geologists must therefore resort to indirect methods to infer the presence of traps at such depths. These methods are referred to generally as geophysical surveys. They include magnetic, gravity, and seismic techniques.

Magnetic surveys measure small variations in the earth's magnetic field that are caused by small variations in the magnetic properties of the different kinds of rocks that make up the earth's crust. Geophysicists know how



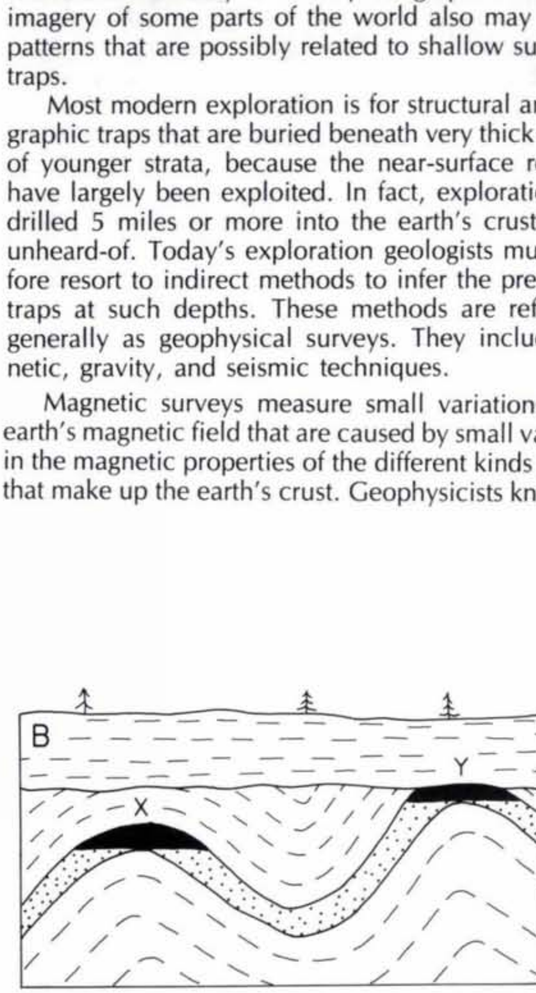


Figure 5. Diagrammatic sections showing how a surface of unconformity may not only conceal an oil 'pool,' as at X, but also explain a barren trap as at Y in diagram A. Originally there could have been two pools, one at X and the other at Y, but the pool at Y was breached and exposed to erosion.

Contrast with diagram B, which shows the same geology as A except for an oil deposit in the breached anticline at Y. The presence of oil at Y indicates that the petroleum accumulated there after the post-unconformity rocks were deposited. Because the traps are concealed, they must be located by geophysical methods. In situation B, drilling at Y will produce petroleum, but in situation A, the hole will be dry. The geologist, however, has no way of knowing which situation actually exists, because there is no way to detect the petroleum itself or to determine when petroleum migrated into a particular trap. Therefore both traps must be drilled.

particular kinds of rock affect the earth's magnetic field. Therefore when a particular magnetic signature is encountered, the presence of a particular kind of rock can be inferred even though it is not exposed at the surface.

Gravity surveys measure small differences in the earth's gravity field that are caused by small differences in the density of various types of rocks. Like the magnetic signatures, particular gravity signatures may indicate the presence of a particular class of rocks. The information obtained from both techniques is organized as maps that can be used by an experienced geologist to predict the geometric arrangement of the various kinds of rocks in a particular area. Much of our knowledge of Minnesota's geology, which is largely concealed beneath a thick blanket of unconsolidated glacial deposits (Fig. 6), is inferred from gravity and magnetic data.

Magnetic and gravity techniques commonly give ambiguous results in sedimentary basins because the rocks in the basins lack well-defined magnetic and density contrasts. The most informative method for subsurface exploration in sedimentary basins is seismic surveying. Seismic surveys are conducted by creating shock waves at or near the earth's surface and recording the time it takes the waves to travel through rock layers and back to the surface. Part of the energy of the shock returns to the surface in the form of waves that are reflected from rock surfaces at depth, and the time taken for a shock wave to reach and bounce back from a buried reflector is related to the depth of the reflector beneath the surface, the inclination of the reflector, and the physical properties of the rocks being penetrated.

A seismic shock wave may be generated either by the detonation of explosives in shallow drill holes or by the use of "thumpers" or "vibrators." The thumper method uses a heavy (ca 3 tons) weight, which is lifted and dropped to the ground by special truck-mounted equipment. The vibrator uses several large trucks with vibrator pads that are lowered to the ground and vibrated at some known rate. Like explosive charges, both these methods generate shock waves that penetrate the earth at a velocity that changes whenever a different kind of rock is encountered. However, unlike explosive charges, the thumper and vibrator methods are not destructive and therefore are more useful in populated areas.

The reflected shock waves produced by any of these methods are detected and measured at the earth's surface by devices called seismometers, which have been placed on the ground at specific distances from the source of the shock wave. The seismometers are connected to banks of electronic equipment which record the amount of time it takes for a shock wave to travel from the source to a particular seismometer. Seismic methods require the mathematical manipulation of large quantities of data before a geological interpretation can be made. Therefore computers are used to produce various kinds of graphic displays which can be used by geologists to infer the structural configuration of the rocks beneath the surface.

All of the geophysical techniques described above involve expenditures of hundreds of thousands of dollars. As often as not, the surveys do not show encouraging indications of petroleum traps. However if the results are encouraging, a decision may be made to drill an exploratory well. Drilling will require the additional commitment of hundreds of thousands or even millions of dollars.

It should be emphasized that the decision to drill is based on the inferred presence of a geologic structure where a large deposit of petroleum could have accumulated. It is not based on the presence of the petroleum itself, because no scientific method can detect the actual presence beneath the surface of either oil or natural gas.

Drilling is a high-risk venture. In 1980, 16 of every 17 holes drilled in suitable geologic settings were either dry holes or holes that encountered deposits of noncommercial size. Given the expensive and chancy nature of petroleum exploration, it should be obvious that no reliable exploration company will decide to drill an exploration hole without first evaluating the geology of the particular target in any way that it can.

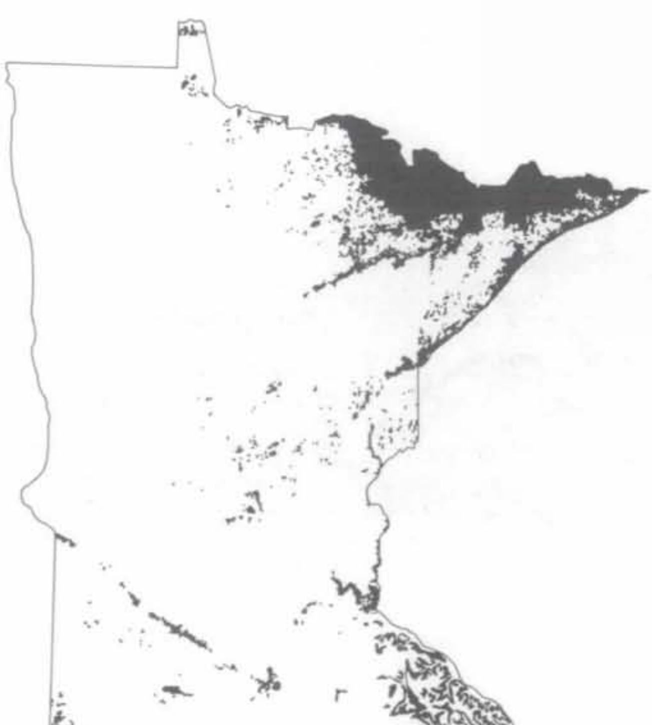


Figure 6. Distribution of bedrock exposures in Minnesota. The bedrock geology of large areas of the state cannot be mapped at all without subsurface data from drilling and geophysics because of the cover of glacial deposits.

GEOLOGY OF

MINNESOTA AND THE UPPER MIDWEST

Geologically, Minnesota straddles the boundary between Precambrian rocks of the Canadian Shield and younger sedimentary rocks that were deposited for the most part in sedimentary basins on the Precambrian basement, which is the southward extension of the Canadian Shield (Fig. 7). Petroleum has been found in commercial quantity in our neighbor states, but their geology is considerably different from ours, because their sedimentary rock formations are much thicker and the Precambrian basement lies much deeper than in Minnesota.

The Long Precambrian

About seven-eighths of geologic time is made up of the Archean and Proterozoic Eons (Fig. 8), which will be referred to here simply as Precambrian. Minnesota is unique in that within its boundaries many of the Precambrian rocks were formed under conditions not duplicated elsewhere in the U.S. These rocks have been studied extensively for more than 100 years, and probably more has been written about them than about any other rocks in any area of comparable size in the world.

Figure 7. The Canadian Shield (igneous rock pattern) and sedimentary basins of the Upper Midwest. The arches and Wisconsin dome were areas of higher elevation between the basins.

For this discussion the Precambrian succession is divided into five terranes (Fig. 9). Of these, Terranes I and II are fundamental crustal segments older than 2,500 million years (m.y.). Formed in part about 3,600 m.y. ago, Terrane I was intruded and metamorphosed by igneous rocks several times prior to 2,500 m.y. ago. Metamorphism is the process whereby heat and pressure change the form of a rock and at the same time eliminate most or all of its porosity and permeability. Examples are the changes of limestone to marble, shale to slate, and granite to gneiss. Terrane I consists of a variety of gneisses that were once deeply buried and heated to temperatures of more than 1,100°F. Terrane II consists of layered and plutonic rocks formed about 2,650 m.y. ago. The layered components include several kinds of volcanic and sedimentary rocks that were extensively folded, faulted, and metamorphosed when the plutonic rocks were emplaced. This greenstone-granite terrane is separated from the older gneiss terrane by the Great Lakes tectonic zone, a major geologic structure about 30 miles wide that trends northeastward across the central part of Minnesota. The zone, which was the locus of several small earthquakes in historic time, consists mainly of faulted and folded rocks of Terrane II.

In east-central Minnesota the tectonic zone was the locus of a large sedimentary basin that filled with layered volcanic and sedimentary rocks around 2,000 m.y. ago. These layered rocks, assigned here to Terrane III, were folded and metamorphosed about 1,870 m.y. ago when several large granite batholiths were emplaced.

Terrane IV, which consists chiefly of red quartzite and shale, was deposited between 1,725 and 1,600 m.y. ago in several small basins on the gneissic rocks of Terrane I in southwestern Minnesota.

Terrane V consists of mafic plutonic and volcanic rocks and derivative red-colored, nonmarine sedimentary rocks that accumulated in a major rift that broke the older terranes in northeastern, east-central, and southeastern Minnesota about 1,200 m.y. to 950 m.y. ago.

Petroleum chances. Because of their complex igneous and metamorphic history, it is highly improbable that the rocks of Terranes I, II, or III were ever the source for, or now contain any petroleum. Although little metamorphosed and deformed, the rocks of Terranes IV and V are nonmarine in origin and formed for the most part in an oxygen-rich environment, and therefore were not important source beds for petroleum.

Any of the Precambrian rocks could contain small amounts of oil or natural gas in cracks or fractured zones,

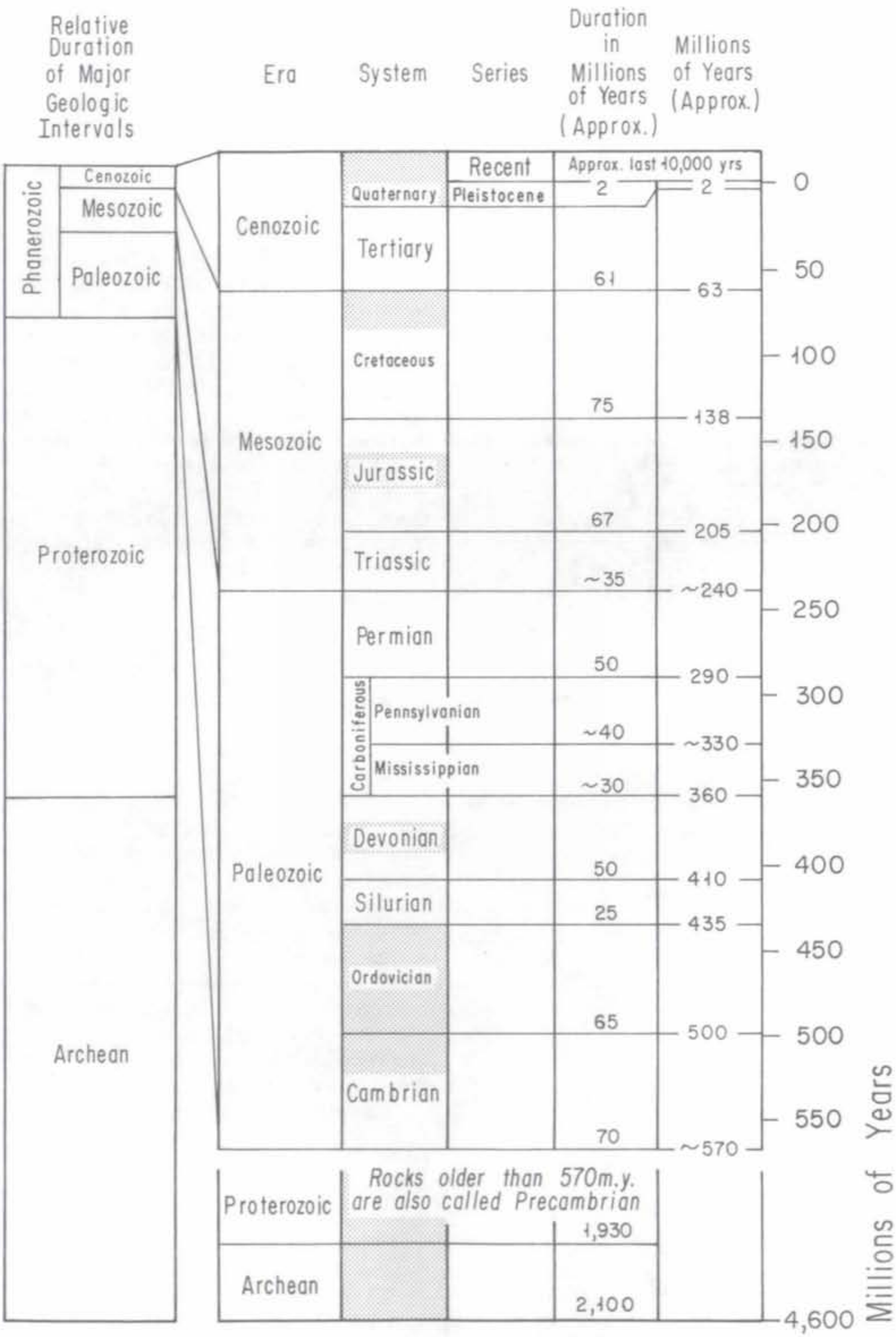


Figure 8. Geologic time scale showing major subdivisions of geologic time. Shading indicates rock systems found in Minnesota.

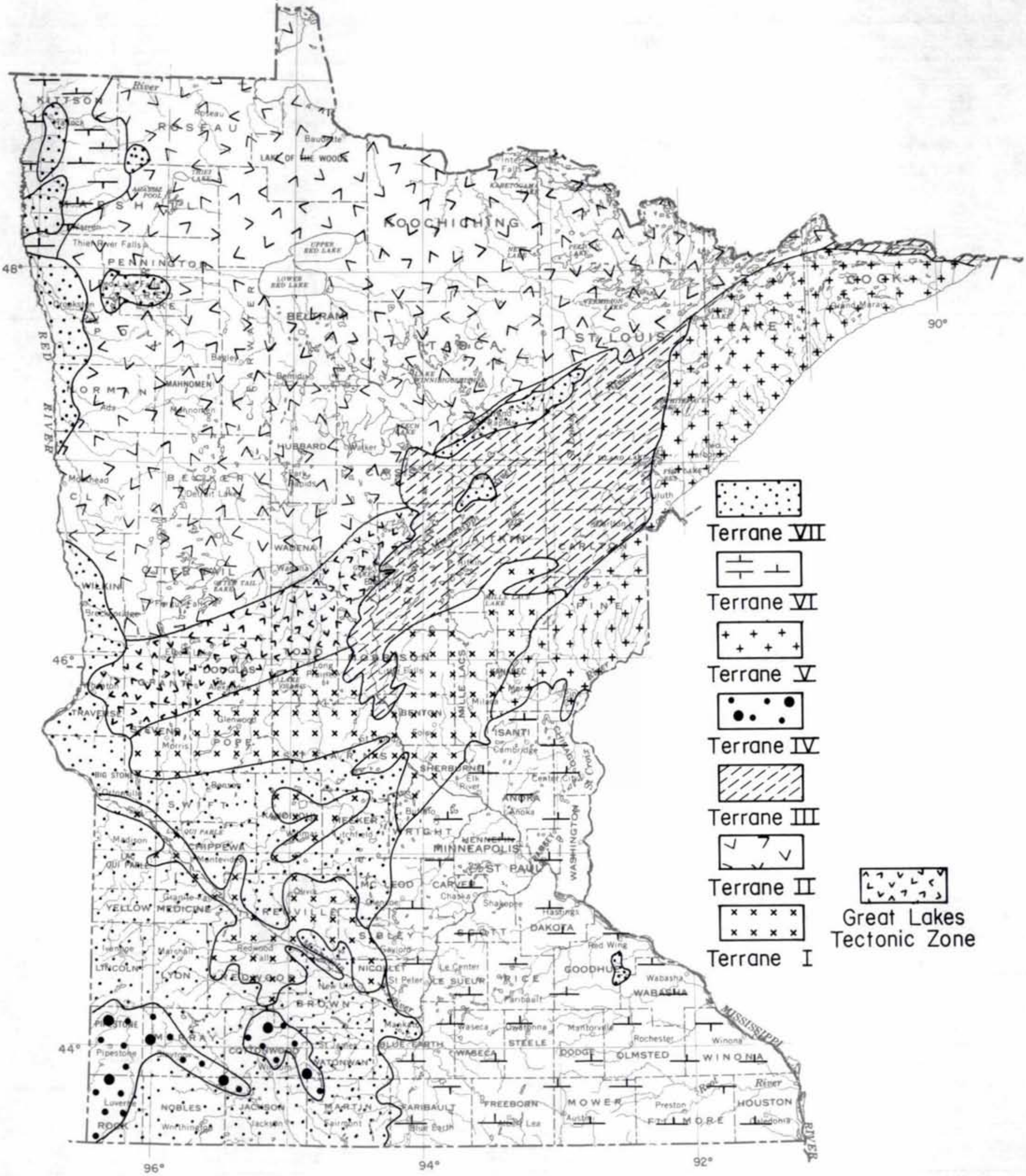


Figure 9. Inferred distribution of bedrock terranes in Minnesota (see text for discussion). Terrane I, gneiss terrane; Terrane II, greenstone-granite; Terrane III, intracratonic stratified rocks; Terrane IV, platform-type supracrustal rocks; Terrane V, rocks of the Midcontinent rift system; Terrane VI, Paleozoic rocks; Terrane VII, Mesozoic rocks.

if the void spaces adjoined source beds in younger sedimentary strata. However, such occurrences are rare, and the upper surface of the Precambrian basement generally defines the lower limit of exploratory drilling. The areas where these terranes are shown on the geologic map (Fig. 9) are areas where they are exposed at the surface or occur directly under a shallow cover of glacial debris—areas where there are virtually no prospects for commercial petroleum discoveries. In the Midcontinent once Precambrian rocks are encountered, there are no petroleum-bearing sedimentary rocks underneath. Further drilling, with the idea of getting "beneath" the granite or gneiss, is futile.

Paleozoic Rocks

The Upper Midwest is part of the so-called Central Stable Region which extends from the Appalachian Mountains to the Rocky Mountains. Only small structural modifications have occurred in this geologic province during the last 570 million years, but gentle flexing and warping of the basement Precambrian rocks during this time created several large sedimentary basins separated by equally large arches and domes (Fig. 7).

Sedimentary rocks of Paleozoic and younger ages were deposited for the most part in seas that repeatedly transgressed the sedimentary basins of the Upper Midwest. The deposits can be generalized according to age, primarily on the basis of fossils in them, into sequences called systems. Many of the boundaries between the systems are surfaces of erosion or nondeposition called unconformities, but other boundaries are gradational over tens or hundreds of feet of rock. Individual systems commonly extend over large parts of the region, but not all of the recognized systems extend to all parts of the region, nor were rocks of one system in one place necessarily connected with those of the same system elsewhere.

The causes of the vertical movements of large fault-bounded blocks in the Precambrian basement are unknown, but they produced arches and basins in various ways. Greater subsidence of basins and less subsidence of arches and domes led to the deposition of thicker sedimentary sequences in the basins relative to those on the arches. Where actual uplift of the arches occurred during relatively brief periods of time, sedimentary units were eroded from the flanks of the arches and redeposited within the basins. The central parts of some basins now contain more than 20,000 feet of strata, but the sedimentary cover on the uplifted areas is typically about 1,000 feet thick and in places is entirely missing. Figure 10, if the several hundred feet of glacial deposits are subtracted, shows the present thickness of these sedimentary rocks in the Upper Midwest.

In southeastern Minnesota the Paleozoic sedimentary rocks (Terrane VI on Fig. 9) accumulated in the Hollandale embayment, a broad southward-plunging extension of the Forest City basin in Iowa. In northwestern Minnesota this terrane, represented only by rocks of the Ordovician System, defines the eastern edge of the Williston basin in North Dakota.

Rocks of the Cambrian System were deposited in southeastern Minnesota after a prolonged period of crustal stability, erosion, weathering, and leaching had led to the development of thick soils on the Precambrian bedrock surface. The Cambrian rocks are mostly thick, porous and permeable sequences of sandstone interlayered with thin beds of shale and chemically precipitated limestone and dolomite. Compare the distribution of Cambrian rocks in Minnesota and elsewhere in the Upper Midwest on Figure 11A.

The succeeding Ordovician System (Fig. 11B) is very similar to the underlying Cambrian System, but it contains more limestone and dolomite and less sandstone and shale. No Cambrian rocks were deposited in northwestern Minnesota, but the Ordovician rocks there are similar to those in southeastern Minnesota and the two areas may once have been interconnected. The later emergence of the Transcontinental arch, which trends diagonally across the state from southwest to northeast, would have led to the erosion of any connecting strata.

Although the Silurian sea (Fig. 11C) may once have covered Minnesota, any Silurian rocks that may have formed in Minnesota were removed by erosion before the deposition of limestone and dolomite in the Hollandale embayment in Middle Devonian time.

Once the Devonian sea withdrew from the Hollandale embayment, Minnesota must have stood above sea level for the next 225 million years, although Paleozoic sedimentation continued elsewhere in the Upper Midwest. Coal deposits in the Illinois and Forest City basins record the existence of extensive forests and swamps of tree ferns, giant mosses, scouring rushes, and primitive conifers. Deposits of gypsum and nonmarine sedimentary rocks were forming in contemporary basins farther west, and the youngest Paleozoic rocks in the Dakotas are shallow marine limestones of the Permian System.

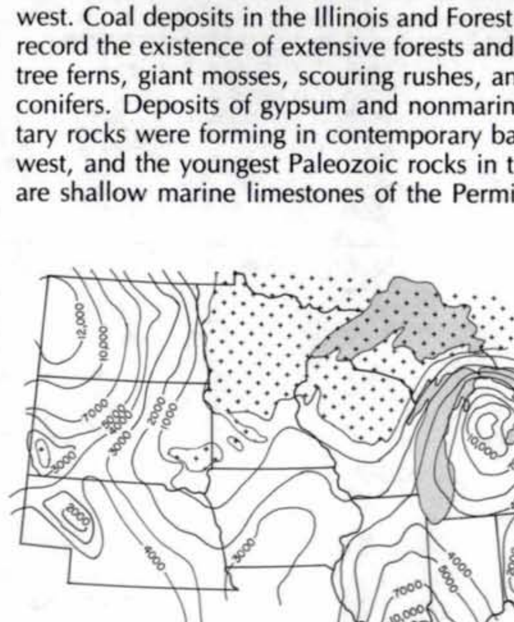


Figure 10. Depth from the land surface to Precambrian basement rocks (in feet). Igneous rock pattern shows where Precambrian rocks are at the bedrock surface.

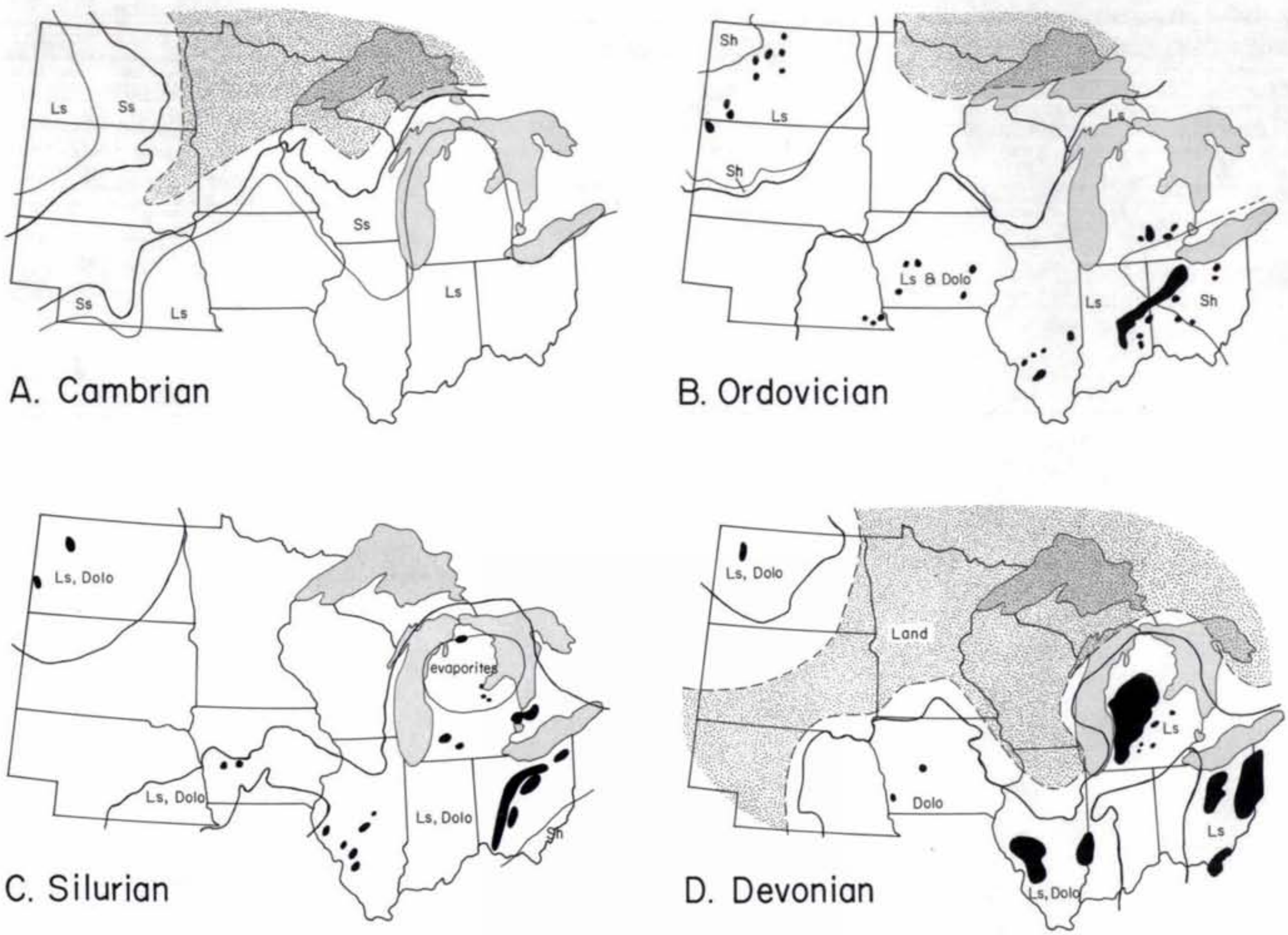


Figure 11. Paleogeographic evolution of the Upper Midwest and its relation to petroleum-bearing rock formations (modified from the Shell Oil Company's (1975) *Stratigraphic Atlas of North and Central America*). Sand pattern denotes land areas. Heavy solid lines show the approximate present edge of rock strata; note that some rocks were deposited on land and are nonmarine in origin. Thinner lines indicate transitions between shale (Sh), sandstone (Ss), and limestone (Ls) or dolomite (Dolo). Areas of oil or gas production or of substantive petroleum shows in rocks of the respective systems are shown in black.

A. In Late Cambrian time (500 m.y. ago) a shallow sea advanced over the continent from what is now southeast and south. The large, low-lying landmass of the Canadian Shield supplied sand, silt, and clay to the sea where they were deposited near the shoreline. At the same time, carbonates (limestone and dolomite) were being deposited in somewhat deeper water some distance from the shoreline.

B. By Middle to Late Ordovician time (450 m.y. ago) the landmass had been eroded to an even lower level, and the transgressing sea may have covered all but the northeastern part of Minnesota. Ordovician rocks in some parts of the Upper Midwest have produced petroleum (black).

C. Late Silurian time (420 m.y. ago). By near the end of Silurian time, all of the Upper Midwest probably was covered by a vast shallow sea. The absence of sandstone, siltstone, and shale in Silurian rocks implies that rivers carrying mud and silt emptied into the sea far away in what is now Canada.

D. Middle Devonian time (380 m.y. ago). During the early part of Devonian time the sea had retreated from much of the Upper Midwest, exposing many of the older rocks to erosion. Regional geologic evidence implies that there were two Middle Devonian seas that advanced toward each other. The two seas probably were separated by the Transcontinental arch, but the arch may have been breached during Late Devonian time.

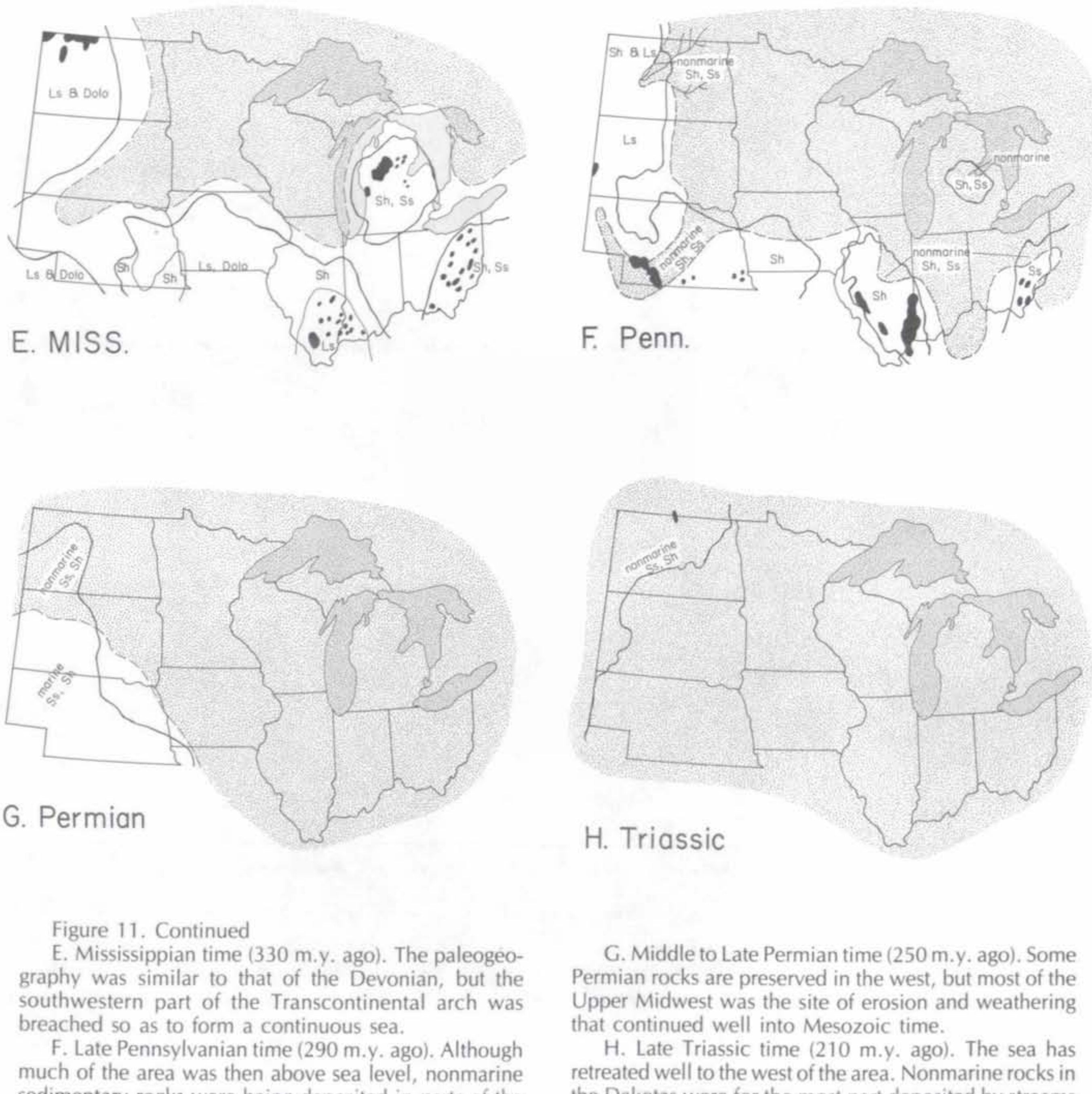


Figure 11. Continued

E. Mississippian time (330 m.y. ago). The paleogeography was similar to that of the Devonian, but the southwestern part of the Transcontinental arch was breached so as to form a continuous sea.

F. Late Pennsylvanian time (290 m.y. ago). Although much of the area was then above sea level, nonmarine sedimentary rocks were being deposited in parts of the Michigan basin, northwestern Iowa, Nebraska, and western North Dakota.

G. Middle to Late Permian time (250 m.y. ago). Some Permian rocks are preserved in the west, but most of the Upper Midwest was the site of erosion and weathering that continued well into Mesozoic time.

H. Late Triassic time (210 m.y. ago). The sea has retreated well to the west of the area. Nonmarine rocks in the Dakotas were for the most part deposited by streams flowing off the Canadian Shield to the west toward the sea.

Petroleum chances. Most producing fields within the basins (Fig. 11B-F) exploit anticlinal and fault traps, but some production also has come from stratigraphic traps, particularly in Pennsylvanian strata and where tilted Paleozoic rocks underlie the Cretaceous System. Reef structures and associated deposits in the Silurian and Devonian Systems are major petroleum producers in the Michigan basin.

The trouble with Minnesota's Paleozoic rocks—as a source of petroleum—is their lack of source beds. Many of the sandstone and limestone or dolomite units have a well-developed primary or secondary porosity and are interlayered with impervious shale units. Evidence of structural or stratigraphic traps in northwestern Minnesota is lacking, but excellent structural traps exist in Dakota, Faribault, Waseca, and Washington Counties in southeastern Minnesota. One of these is being used by Minnegasco as a readymade place to store natural gas.

As is common around the edges of sedimentary basins, Minnesota's Paleozoic rocks are filled with fresh water. They lie near the present land surface, and the pristine condition of the microfossil conodonts which they contain indicates that they were never heated by deep burial. (Their counterparts in deeper parts of the basins elsewhere in the Upper Midwest, have produced petroleum because sedimentation continued longer, and they were buried and heated.) Furthermore, the units in Minnesota that contain some carbonaceous material and small amounts of hydrocarbons, like the "Vadnais Heights crude" (see the section on occurrences, 1982), are merely shale partings no more than inches thick scattered within some of the rock formations.

Mesozoic Rocks

Lower Mesozoic rocks of Triassic and Jurassic age are confined to the western part of the Upper Midwest and to a small area in southern Michigan, but Upper Mesozoic rocks belonging to the Cretaceous System were deposited in a shallow sea that encroached from the Gulf of Mexico to the Arctic Ocean and spread eastward into Minnesota (Fig. 11J).

Much of Minnesota was dissected by west-flowing streams in Cretaceous time, and the resulting channels were filled with a heterogeneous assemblage of organic-rich clay, thin beds of low-grade coal called lignite, quartz-kaolin shale derived locally from the weathered tropical soil, and sandstone. As the Cretaceous sea transgressed from west to east, these nonmarine rocks were successively overlain by marine sandstone, siltstone, and shale. Although rocks of the Cretaceous System once covered much of Minnesota, most of them were eroded prior to the onset of glacial activity in Pleistocene time. They now occur along the Red River of the North and in southwestern Minnesota as an erosionally dissected blanket and in other parts of the state as small outliers. They are shown as Terrane VII on Figure 9.

Petroleum chances. Small quantities of natural gas have been encountered in sandstone beds toward the bottom of the Cretaceous sequence in Minnesota, where these beds are juxtaposed with thin lignite-rich units. It seems likely that the natural gas formed at shallow depths by bacterial processes akin to those which produce methane gas in modern swamps. The lignite was never buried deeply enough to attain the temperature necessary to form a better grade of coal. What the Cretaceous rocks in Minnesota do contain in quantity is water. In all probability they do not contain gas, let alone oil, in exploitable quantity.

Cenozoic Rocks

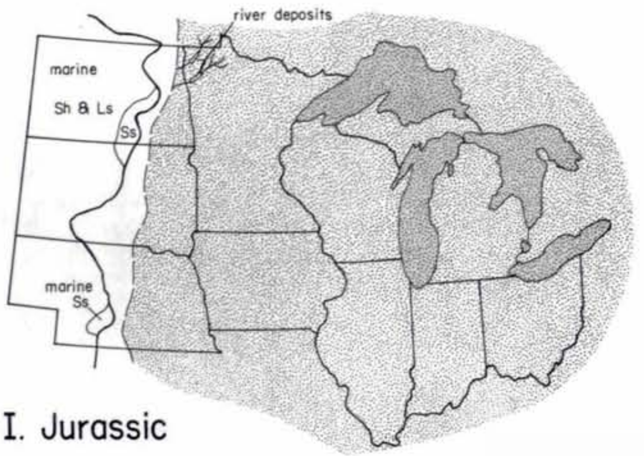
Continental lake and swamp deposits (lignite) of the lower part of the Tertiary System occur in the western part of the Upper Midwest. They are overlain by a thin blanket of upper Tertiary sand and gravel, which were eroded from the Rocky Mountains to the west, and now form the surface of the Great Plains.

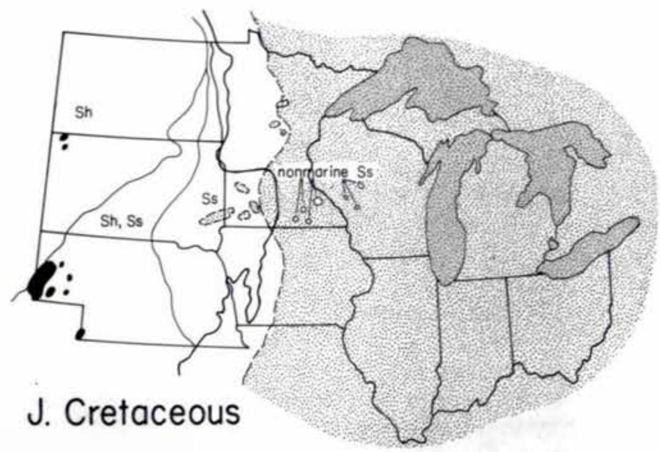
In Minnesota the stream erosion that removed much of the Cretaceous System also removed pre-Cretaceous rocks down to and including some of the Precambrian basement. Major preglacial highlands and lowlands formed, which influenced the flow of the ice lobes that advanced over the state in Pleistocene time.

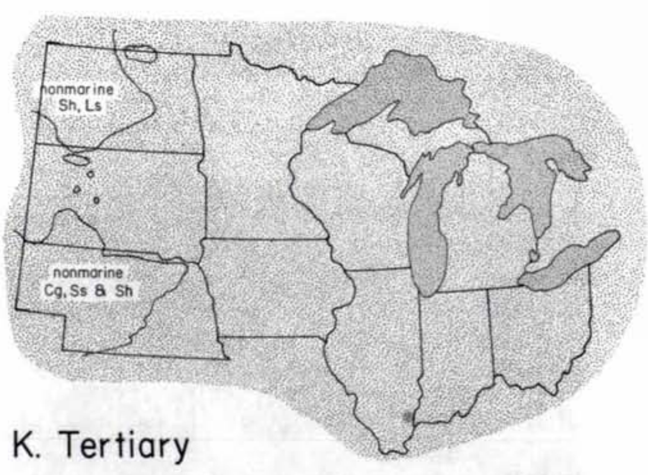
About 90 percent of the bedrock in Minnesota is now covered by unconsolidated glacial and postglacial debris (Fig. 6). Most of the glacial deposits at the present land surface were laid down by several discrete ice lobes during late Wisconsinan time between 20,000 and 9,500 years ago (Fig. 11L). Older sheets of glacial till, which are buried beneath these deposits, record many more advances and retreats of glacial ice over the Upper Midwest including Minnesota.

Petroleum chances. The till sheets themselves are an unpromising source, even for natural gas. However, ancient peat bogs and forest beds, which formed during warmer interglacial intervals, are incorporated in the till in places. Methane that formed in this organic material by bacterial processes was prevented by the surrounding till from escape. These pockets of organic matter have been chiefly responsible for the natural gas encountered during the drilling of water wells.

Despite the high pressure of the gas encountered in some of the pockets in the glacial drift, the gas is soon entirely depleted. The gas is not the result of the formation of petroleum—by deep burial and heat—in the much older bedrock at depth, and consequently further drilling does not increase the flow.







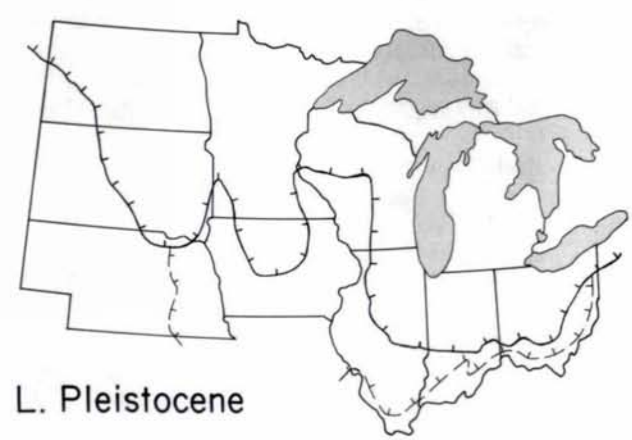


Figure 11. Continued

I. Middle Jurassic time (150 m.y.). A shallow sea again has advanced on the continental crust into the western Dakotas and Nebraska. As in Triassic time, rivers apparently flowed from the Canadian Shield into the Jurassic sea.

J. Late Cretaceous time (90 m.y. ago). The sea has advanced over much of Minnesota. Nonmarine rocks were being deposited for the most part by westward-flowing rivers.

K. Tertiary time (63 m.y. to 2 m.y. ago). Early Tertiary nonmarine sandstone, shale, and lignite are abundant in the Dakotas. Late Tertiary nonmarine conglomerate (Cg) and sandstone are abundant in Nebraska, and also occur as scattered remnants in the Dakotas.

L. Boundaries of the late Wisconsinan (solid line) and older Pleistocene ice sheets (dashed line). The bedrock north of these lines is largely covered by a mantle of glacial debris.

HYDROCARBON OCCURRENCES IN MINNESOTA

Many small pockets of natural gas have been discovered in Minnesota, and some traces of oily substances, as well (see frontispiece). A list of occurrences, arranged in more or less chronological order of discovery, has been compiled from published or file reports of the Minnesota Geological and Natural History Survey and its successor, the Minnesota Geological Survey (MGS), and from contemporary newspaper accounts in MGS files and in the library of the University of Minnesota. Except as otherwise noted, all of the information on early events in this section and in the section on wildcatting was taken from *Natural Gas in Minnesota* by N.H. Winchell, which was published in 1889 as *Bulletin 5* of the Minnesota Geological and Natural History Survey. Although far from complete, the compilation represents the kinds of hydrocarbon deposits that have been found and that may be found in the future.

Before 1875—Freeborn County, near Freeborn (T. 104 N., R. 23 W.). Water in several wells, including the well at the hotel in Freeborn, was "spoiled" by carburetted hydrogen (methane), and pieces of Cretaceous lignite taken out while digging wells had incited ardent expectations of coal, according to N.H. Winchell in the Annual Report for 1874. Methane was encountered in a drill hole bored prior to sinking a shaft for a coal-mining venture. When ignited, the gas flamed up 8 or 10 feet above the wellhead with a roaring sound. When the shaft itself was dug, it drained off the gas gradually from the test hole allowing dilution with air and thus prevented rapid burning. This may have been the event described by F.D. Drake in a letter to the *Freeborn County Standard* dated February 2, 1885:

> *The question was asked in the STANDARD last week if any one would give a history of the gas found at Freeborn some years ago. The writer was prospecting for coal and unexpectedly struck a vein of gas about fifty feet from the surface of the ground. It came out with a rushing and roaring sound from the drill hole. It caused quite an excitement and the people gathered round to hear the noise, speculating what it could be, as it was not visible. Some time after, perhaps an hour or two, Mr. E.D. Rodgers upon whose land it was, wishing to smoke, lit a match and in the act of lighting his pipe it came in contact with the escaping gas. It took fire a little sooner than was expected. Mr. Cram, now at Alden, had his whiskers trimmed without the aid of a barber. All moved out of the way, as we had a column of fire twelve feet high in an instant, and a hot one at that. The derrick had to come down out of the way of so destructive an agent. It was a grand sight to see a column of fire, as it was not connected with anything, not even the ground apparently, as the gas came with such force that it did not burn within two feet of the ground. The column swayed back and forth as the wind blew upon it. It was a grand sight, and very conclusive evidence of coal that we were looking for; but the coal has never been found as yet. This was the largest vein of gas yet struck.*

Before 1884—Martin County, Manyaska Township (T. 102 N., R. 32 W.), railroad well SW¼ sec. 7, near Sherburne. As reported in volume 1 of the Final Report, p. 488, the well was dug 7 feet square to a depth of 76 feet and bored below that. At 113 feet gas rose with a loud roaring sound and filled the well. The source apparently was a gravel layer underlain and overlain by "blue clay." The gas was either carbon dioxide or carbon monoxide inasmuch as it would extinguish a flame. The gas also caused the death of one worker, after "some implement having been accidentally dropped into the well, the foreman commanded one of his men to go down for it, and being angry at his refusal, himself rashly descended and was immediately killed . . ."

Before 1884—Big Stone County, Prior Township near Prior (T. 123 N., R. 47 W.). On the farm of J.R. Edwards, NW¼ sec. 24, a water well in glacial drift at 78 feet produced methane from a gravel layer overlain by "red till." On the farm of Samuel Varco, sec. 18, a water well in glacial drift at 102 feet produced dark-colored water and methane from a sand layer overlain by "blue till."

Before 1884—Rock County, Martin Township (T. 101 N., R. 47 W.), farm of Thomas Kennedy, NW¼ sec. 35. A water well in glacial drift at 42 feet produced "dangerous gas" from a layer of dark-colored sand beneath an organic-rich layer containing tree logs and rubbish of bark and leaves.

Before 1884—Big Stone County. In the making of a well near Big Stone Lake the workmen of the Chicago, Milwaukee and St. Paul Railroad met with "curious manifestations." There were slight explosions, accompanied by strong odors of gas. Finally a more severe and nearly disastrous explosion, which threw the workmen back and against the side of the excavation, alarmed them so that the work ceased. C.H. Pryor of the railroad submitted a sample from the bottom of the well to N.H. Winchell of the Minnesota Geological and Natural History Survey who concluded that the gas (methane) originated in beds of lignite and dark shale of Cretaceous age.

Before 1884—Traverse County. In Arthur (probably T. 125 N., R. 48 W.), on the farm of James H. Flood, a large flow of gas was encountered at 180 feet, said to be below the till sheet of the drift. It rushed out with such force as "to throw out a heavy iron bolt inserted in the pipe." The flow continued but a short time.

Before 1884—Waseca County, Woodville Township (T. 107 N., R. 22 W.), farm of Francis Bossard near Waseca. Two water wells in glacial drift at depths of approximately 65 feet produced gas that burned at the wellheads with a blue flame extending 8 or 10 feet in the air. When burning there was a noise which could be heard, as alleged, a mile and a half, and the earth trembled "as if by heavy thunder." Water from the wells, when left to stand, showed an oily scum on its surface.

Before 1884—Goodhue County. The following story was related by Winchell in *Bulletin 5* (1889).

> *Mr. August Peterson reported signs of gas at the mouth of the Cannon river in Goodhue County. This was in the sinking of a drill for the purpose of artesian water. "At the depth of 85 feet there was an upheaval of sand and gravel, marked and forcible; filling the pipe to the height of twenty feet with sand, packing it so tightly that we had to drill it out. After cleaning it out there was another upheaval, sending the gravel and sand thirty feet, and so it kept on. We worked a month on twenty-five feet. Whenever we got within 8 or 10 feet of the bottom of the pipe, up the gravel would come. At 115 feet we got the pipe clean, I think. The last cleaning out, however, showed a considerable yellow sand which looked as though coated with mustard; the very last, however, being a brown or blackish and oily substance which on being poured out separated from the water, a smoke or steam rising from it. Then we sent the drill down again, fully believing we were to the rock. The drill, weighing 1,500 pounds, was sent up about 15 feet in the pipe, and the sand the whole length of the drill, which is 28 feet, and shut the drill in solid, requiring several hours of work to loosen it. The parties working becoming both discouraged and angry, the thermometer ranging in the thirties (minus—N.H.W.), in extremity they procured a pile-driver and bent the pipe, so we left the place."*
>
> *Making another trial at 100 feet from this place, toward the main river bluff, Mr. Peterson obtained a fine flowing well of pure water without any trouble, at the depth of 350 feet.*

Before 1887—Blue Earth County, Vernon Center (T. 106 N., R. 28 W.), C.B. Frazer property, sec. 26. A water well at 115 feet produced a voluminous discharge of carbon dioxide (CO_2) gas from a sandy layer overlain by clay or shale of Cretaceous character.

Before June 1888—Freeborn County. Some residents of Albert Lea formed a syndicate for commercial development of the natural gas and drilled several new holes. As exuberantly reported in the *Freeborn County Standard* (date unknown):

> *The scene of operations was the farm of L.T. Scott. The prospecting well was being bored within a foot or so of his main well, used for his extensive water supply, and when the party arrived there, it had reached a depth of about 60 feet. The boring continued to a depth of 75 feet when signs of disappointment were visible and expressed by Mr. Scott and other anxious spectators, for that was the depth at which Mr. Scott's well had met with the great vein of gas that burst forth when lit and illumined his premises for a distance around of 20 rods* [330 feet]. *The well borers were directed to proceed with the work, to go still deeper, until when a depth of 95 feet had been reached, the drill was taken out and an examination made. The representative of the STANDARD tore a leaf from his note book, lit it and applied it to the sunken pipe. No blaze followed. But wait: He heard a bubbling, gurgling, boiling sound in the pipe. All standing by soon heard it; it increased in violence and intensity. The lighted paper was again applied by the STANDARD man, and again for the third time, without results. A few moments of anxious suspense and the STANDARD man perseveres with another trial, when behold! hurrah! the flames burst forth and fiercely leap into the air. The entire party soon gather around, and cheers and congratulations convert the scene into a jubilee. The flames steadily burst forth, and the test is complete, the well is a success. The ladies then announced supper, spread on Mr. Scott's handsome lawn, when Mr. Sergeant brings the big coffee pot to the well, filled to supply the wants of the entire party; he holds it over the flames of gas, it warms, it heats, it boils, and is poured forth in brimming cups to the hungry prospectors.*
>
> *After supper, all bear a hand and string inch pipes from the three inch pipe in the gas well a distance of 250 feet; connections are quickly made at the joints; a length is bent; a hole is made in the wire netting of the parlor window of Mr. Scott's commodious residence; the pipe is thrust through; the STANDARD man again ap-*

plies the lighted paper; the golden flames burst forth as large as a palm leaf fan and THE FIRST HOUSE WEST OF THE FATHER OF WATERS IS LIGHTED WITH NATURAL GAS. And it was a splendid light. It burned intensely and was intensely hot. Arrangements were made with Mr. Scott to superintend the boring of another large and deeper well immediately, when the horses were hastily hitched to carriages, for the rumbling thunders threatened rain, a hasty "good night" was said to our hospitable hosts, and the party were soon speeding to the city, which was safely reached after a short and inspiring ride.

Thus was demonstrated the genuineness of the great and wonderful NATURAL GAS RESOURCES OF FREEBORN COUNTY.

We use these terms advisedly, for it has been demonstrated that the gas is of the best quality, that it is inexhaustible, and that the deeper into the bowels of the earth the investigation is made the greater is THE VOLUME AND PRESSURE.

June 1888—Freeborn County, Freeborn Township (T. 104 N., R. 23 W.), farm of Mr. Scott, NW¼ sec. 13 and Carlston Township (T. 103 N., R. 23 W.), farm of Mr. Jackson, western part of sec. 9. Winchell reported in *Bulletin 5* that

there was a party of fifteen or more and they all witnessed the exhibition of gas-burning from the tops of two inch pipes sunk into the earth about seventy-five feet. That there could be no deception as to the genuineness of this, and the origin of the gas as claimed, the sand pump was sunk into each one and gravel and clay were brought from the bottom. The pumping was also intended to relieve the gas from obstructions caused by water and gravel which get into the pipe and choke the flow of gas. Four such wells are in existence in the immediate vicinity of Freeborn, and afford gas intermittently, the stoppage being caused probably, as represented, by obstructions that now interfere with the current of gas, and choke up the bottom of the pipe. I am credibly informed also that indications of gas have been met with in numerous other instances in the sinking of wells in the neighborhood of Freeborn, and I know, of my own observation, that now nearly fifteen years ago, when I first surveyed Freeborn county, such exhibition of gas was witnessed in the sinking of a shaft for explorations for "coal," and that it permeated the water of some wells and rendered the water unfit for general use.

The current of gas coming from one of these wells burned with considerable roaring, when allowed to escape in full force, issuing from a series of gas-jets arranged about a central disk, and, when regulated by the stop-cock, it becomes luminous, and burned with the regularity of any gas-supply.

[For a further discussion of the Freeborn County sites see the section on wildcat exploration.]

Before 1888—Carver County, Waconia Township (T. 116 N., R. 25 W.), farm of N.L. Swenson, sec. 8. A water well in white sand at 38 feet produced gas with a roaring sound and a disagreeable smell for about 20 minutes. The sand is overlain by 33 feet of "yellow and blue till" with lignite fragments.

Before 1888—Nicollet County, Belgrade Township (T. 109 N., R. 27 W.), farm of L.P. Parsons. A water well in glacial drift at 121 feet produced carbon dioxide from 31 feet of sand and gravel overlain by "yellow and blue till." Two men were killed by the gas.

Before 1888—Sibley County, Henderson Township (T. 112 N., R. 26 W.), property of John Mahr in town of Henderson. A water well in glacial drift at 28 feet produced gas of an uncertain composition from a layer of hard iron-rich gravel.

Before 1888—Meeker County, Greenleaf Township (T. 118 N., R. 31 W.), farm of Ross and Becker in sec. 23. A water well in glacial drift at 48 feet produced a large amount of gas with a roaring sound from a dark sand layer with a disagreeable odor. The gas probably was carbon dioxide or carbon monoxide inasmuch as it immediately killed a worker at the site. It flowed abundantly for approximately 6 weeks. In the same area, 75 feet away, a second well at 57 feet intersected a small quantity of gas from 1.5 feet of sand and gravel having a strong kerosene odor.

Before 1888—Stearns County, Zion Township (T. 123 N., R. 32 W.). On the farm of Michael Traun, SE¼ sec. 13, a water well in glacial drift at 51 feet produced gas from a gravel layer 13 feet thick. The gas, which was not flammable, suffocated a man. On the farm of Ferdinand Grutzmacher, SW¼ sec. 13, a water well in glacial drift at 59 feet produced a small quantity of gas of unknown composition from a gravel layer 15 feet thick.

1889—Freeborn County, Albert Lea Township (T. 102 N., R. 21 W.) near business district in the city of Albert Lea. A water well at the depth of 38-40 feet produced gas that would not burn (carbon dioxide or carbon monoxide) from a layer of "sandy muck . . . with leaves and sticks."

June 6, 1889—Freeborn County, Riceland Township (T. 103 N., R. 20 W.) 6 miles northeast of Albert Lea. A water well in glacial drift at 63 feet produced methane which burned "with considerable violence, and in a quantity sufficient to operate a ten-horse power engine."

About 1900—Faribault County, Foster Township (T. 102 N., R. 24 W.), farms of William Klunder and Herman Lawrenz, most likely in sec. 33. Water wells in glacial drift at approximately 130 feet produced methane that allegedly was used to heat the residences of the owners for 6 months. Flow all but ceased in 1900, although small amounts issued as recently as 1917.

December 5, 1916—Le Sueur County, Lexington Township (T. 111 N., R. 24 W.), farm of M.L. Kehoe about 1 mile north and half a mile west of Le Center. A water well produced gas from a sand layer at 255 feet. The gas erupted violently, together with mud and water that spattered the derrick to a height of 40 feet. Pressure on the wellhead after capping was 6-8 lbs. Apparently at first the gas was nonflammable (carbon dioxide or carbon monoxide). Later when Mr. Kehoe was standing about 10 feet away from the wellhead, he struck a match to light his pipe, and the gas exploded, burning the hair and faces of bystanders.

A sample of the flammable gas was collected by W.H. Emmons, director of the Minnesota Geological Survey, and found to contain 2.84% carbon dioxide, 0.50% carbon monoxide, 3.85% oxygen, 65.90% methane, and 26.91% nitrogen. The presence of so much nitrogen suggests that common air had been mixed with the methane in the drill hole. Although the gas was most likely produced from glacial drift, Emmons noted that it could have leaked from underlying Paleozoic strata located near the crest of a shallow anticline that was first defined in 1911 in U.S. Geological Survey Water-Supply Paper 256. It is interesting to note that this structure now "produces" natural gas put there by the Minneapolis Gas Company for storage.

April 1917—Faribault County, Kiester Hills Township (T. 101 N., R. 24 W.), farm of J.W. Yost about 1.5 miles north of Kiester in an area known as the Kiester Hills. A water well in glacial drift at 90 feet produced methane from 7 feet of soft mud and sand lying between 84 feet of "blue clay" above and 64 feet of "blue clay" below. As the gas flowed, water and mud spouted several feet above wellhead. Subsequently the drilling rig was moved a few feet to the west and a second hole was drilled in glacial drift to 90 feet where a strong flow of flammable gas was encountered. A sample of this gas, also collected by W.H. Emmons, contained 0.20% carbon dioxide, 0.90% carbon monoxide, 1.40% heavy hydrocarbons, 0.06% oxygen, 83.9% methane, and 13.0% nitrogen. [For more on Kiester Hills see the section on exploration, 1938 and 1950.]

December 1919—Kittson County, Kvark farm 3 miles from Hallock. A water well in glacial drift at 25 feet produced methane that gushed up with force and was ignited by a heater being used by the well driller, according to the *Minneapolis Journal*, December 17.

Summer of 1920—Meeker County, Collinwood Township (T. 118 N., R. 29 W.), farm of Barney Arnett S½NW¼ sec. 8, near Dassel. A water well 90-100 feet deep reportedly pumped a mixture of water and oil. Mr. Arnett completed another well nearby which also reportedly produced oil. In a letter dated August 5, 1929, G.A. Thiel of MGS advised an oil company that the oil at Dassel came from thin Cretaceous sediments overlying granite—too thin to be of commercial value. MGS acquired a sample of this oil sometime between 1920 and 1928, but given the amount of time that the sample was stored, the significance of recent analytical results is equivocal. [For a further discussion of this site see the section on wildcat exploration.]

July 1923—Faribault County, Lura Township (T. 104 N., R. 26 W.), farm of John Remp near Easton. A water well at a depth of 142 feet produced gas of unknown composition. Pressure forced water and gas high into the air for part of a day and all of one night. (*Mpls. Journal*, July 15.)

February 1925—Cottonwood County, Lakeside Township (T. 105 N., R. 35 W.), Thomson farm about 5 miles east of Windom. A "deep well" encountered natural gas of unknown composition in such quantities as to lift the drilling machinery. The gas continued to flow for 3 days. (*Mpls. Journal*, February 20.)

1926—Kandiyohi County. The *Minneapolis Journal* of February 26 reported natural gas struck by well drillers at Raymond. Reports of "gasoline" at Lake Lillian (T. 117 N., Rs. 33 or 34 W.) are not credible, but some oily substance may have been found. [See the section on wildcat exploration.]

March 1928—Renville County, Camp Township (T. 112 N., R. 33 W.) at bridge over Minnesota River, 6 miles from Fairfax. Drilling for engineering tests on the bridge abutments encountered methane at a shallow but unknown depth. The gas ignited, and the flame rose 30 feet. Apparently no additional tests were made. (*Mpls. Journal*, March 3.)

June 10, 1937—Traverse County, Walls Township (T. 126 N., R. 47 W.), SE¼ sec. 2, near Wheaton. Wildcat oil exploration hole produced 3 barrels a day of crude oil with an A.P.I. value of 37°, according to the August 19 issue of *Oil and Gas Journal*. [For a further discussion of this site see the section on wildcat exploration.]

Before September 1950—Faribault County, Kiester-Bricelyn area. An analysis of a gas sample by the Twin City Testing Laboratory was shown to geologist Malcolm P. Weiss. After cleaning of dilutants, the sample consisted of 80.9% methane and 19.1% ethane. The laboratory concluded that the sample was not swamp gas because of the high ethane content, but did not suggest that it indicated the presence of oil. [For a further discussion of this site see the section on wildcat exploration.]

August 1954—Goodhue County, Vasa Township (T. 112 N., R. 16 W.), farm of A.F. Safe. A water well 62 feet deep brought to the surface several gallons of an oily substance that was thick, dark, and had the odor of oil or gasoline. Although the owners did not believe so, the source probably was a leaking gasoline tank located about 100 feet from the drilling site. (*Red Wing Daily Republican-Eagle*, August 23.)

Before September 1954—Renville County, either Troy (T. 115 N., R. 35 W.) or Bird Island (T. 115 N., R. 34 W.) Township, farm of Francis Tisdale south of Olivia. A water well at this farm and at other farms in the general vicinity were allegedly affected by gaseous explosions on several occasions and produced a fluid substance that was highly flammable. (*Willmar Daily Tribune*, September 21, 1954.)

1975—Pope County, Lake Johanna Township (SE¼ sec. 35, T. 123 N., R. 36 W.), the Visser farm near Brooten. A water well drilled through 500 feet of glacial deposits, 73 feet of Cretaceous strata, and—when drilling ceased in 1982—1,274 feet of Precambrian granitic gneiss reportedly encountered a small quantity of an oil-like substance at a depth of 777 feet. Apparently the "oil show" persisted for only a few minutes. [For a further discussion of this site see the section on wildcat exploration.]

1976—Carlton County, Split Rock Township (SE¼ sec. 2, T. 46 N., R. 21 W.), farm of Lee Hattenberger near Kettle River. A water well at 785 feet in the Thomson Formation of Precambrian age produced salty-tasting, fizzy water. In 1976 the toilet in the bathroom exploded—a candle had ignited the accumulating gas—and it was found that gas in the water flowing from the faucets would burn. Samples were collected on November 3, 1976 by E.C. Alexander, Jr., of the Department of Geology and Geophysics at the University of Minnesota and Matt Walton and G.B. Morey from MGS. Water analyses by the University of Minnesota and Union Carbide Corp. indicated that the water is a sodium, calcium, magnesium brine. It was impossible to eliminate atmospheric contamination from the gas samples, so it was necessary to normalize the analysis by deducting atmospheric ratios of nitrogen, oxygen, and carbon dioxide. The residual gas consisted of approximately 98% methane, 2% helium, and less than 0.01% ethane.

The isotopic composition of the methane is intermediate between petrogenic CH_4 and bacteriogenic CH_4, and thus it is not "swamp gas" somehow entrained in deep-circulating ground water. The black slates, which are the host for this gas, are rich in graphite that probably was derived from organic materials in the original clayey mud. The methane most likely formed by the cooking of ground water and the carbonaceous graphite under conditions of moderate heat via the reaction: $C + 2H_2O \rightarrow CH_4 + O_2$. We did not entertain the hypothesis that the gas was primordial. MGS advised the farmer that he had a most interesting geologic curiosity that had little or no chance as a significant energy resource. For understandable reasons he was disinclined to accept this view; see the following section on wildcat exploration.

April 13, 1982—Ramsey County. In a humorous article headlined OIL DISCOVERY—VADNAIS HEIGHTS CRUDE ENOUGH TO QUELL SQUEAK, Jim Nagel reported in the *St. Paul Dispatch* that oil (perhaps enough to silence a squeaky hinge) was encountered in a water well at the headquarters of the H.B. Fuller Co. The well log in MGS files records the presence of a black substance in the Platteville-Glenwood interval (Middle Ordovician) between 86 and 100 feet. Such occurrences of "oil" in these rocks are fairly common throughout southeastern Minnesota. They contain abundant fossils and thin layers that locally have large concentrations of organic material.

WILDCAT EXPLORATION FOR PETROLEUM IN MINNESOTA

"Wildcat" is the term used for exploration ventures in territory not known to be productive. According to the records of the Minnesota Geological Survey (MGS) the first wildcat well for oil or natural gas was drilled in Minnesota prior to 1887. Wildcatting since then has been more or less continuous, and holes have been drilled at one time or another in all parts of the state (Fig. 12). Unfortunately, the state had no mechanism until the mid-1970s for recording these ventures accurately, and thus, although we know that these wells could number in the thousands, we know almost nothing about them. The following discussion is a selected review of the data in publications and file reports of the MGS and its predecessor, the Minnesota Geological and Natural History Survey, and some contemporary newspaper accounts. For convenience, the review is divided into five arbitrary time periods: 1880-1900, 1900-1930, 1930-1950, and 1960-1983.

1880-1900

Major discoveries of oil and gas deposits in the 1880s in Pennsylvania and states of the Upper Midwest led many people to believe that valuable oil and natural gas fields existed in Minnesota. Indeed for a time, this was a reasonable assumption. First, the geologic principles governing the occurrence of oil and natural gas deposits were poorly understood, even in places where such deposits had been found in commercial quantities. Second, the work of the Minnesota Geological and Natural History Survey had only recently begun, and the geology of the state was still poorly understood.

On March 8, 1887, by act of the State Legislature, state geologist N.H. Winchell was directed to make practical and actual tests by drilling or digging for any hidden mineral resources that he might deem likely to exist in any of the rock strata of the state; $5,000 was appropriated for 1887 and $5,000 for 1888. In *Bulletin 5*, published in 1889, Winchell described the known occurrences of natural gas and reported what had been done by the survey to investigate the possible gas-reservoirs in Minnesota.

The Minnesota Geological and Natural History Survey purchased a derrick, steam engine, and all hardware necessary for a well 2,000 feet deep and 6 inches in diameter, and chose a site near **Freeborn**. On June 16, 1888, Winchell wrote to the Minnesota Gas, Oil and Fuel Company of Albert Lea, Minnesota, which was to perform the actual drilling, "I am satisfied . . . that the gas that issues at Freeborn is natural rock gas. In the absence of reliable data for determining the character and age of the underlying rock at Freeborn, I can only give you hypothetical explanations of the source of this gas. . . . The general geology of that part of the state will permit the existence of either one or two of those formations that supply gas, at Freeborn, viz.: the Cretaceous, or the Trenton [Ordovician]. . . . The "coal" that was sought by shafting at Freeborn in 1873 and 1874 was Cretaceous lignite. . . . [The Trenton] is well known in Indiana, in Illinois and Ohio as the source of great quantities of natural gas, and it may be the source of that at Freeborn. Even if gas issues now from the Cretaceous, it may come primarily from the Trenton. At Findlay, Ohio, it rose from the Trenton through several hundred feet of strata, and at the surface escaped for thirty years from the Niagara [Silurian] limestone. It was only a deep well that penetrated the Trenton that revealed its real origin. So here, in case of drilling at Freeborn, the drill ought not to cease till the Trenton be reached, even if gas in considerable amount should issue before reaching it."

Winchell's letter concludes, "In view of the importance of this investigation to the State at large, I shall take pleasure in allowing the use of the deep well machinery belonging to the State, in such a test; and under the law of the appropriation made by the last Legislature, will allow such further aid as I consistently can to have the exploration made thorough and complete."

The rig arrived at Freeborn in July of 1888 and a well was begun which by December reached a depth of 950 feet. No natural gas or oil were encountered in commercial quantities. However H.C. Day of the company reported finding a small quantity of oil in the Ordovician limestone, but it was only temporary and no trace of it could be found on a subsequent visit by Winchell. Natural gas shows also were reported at 534 and 565 feet in the St. Peter Sandstone, but these shows also could not be confirmed by Winchell. When the hole had penetrated 50 feet of the St. Lawrence limestone of Cambrian

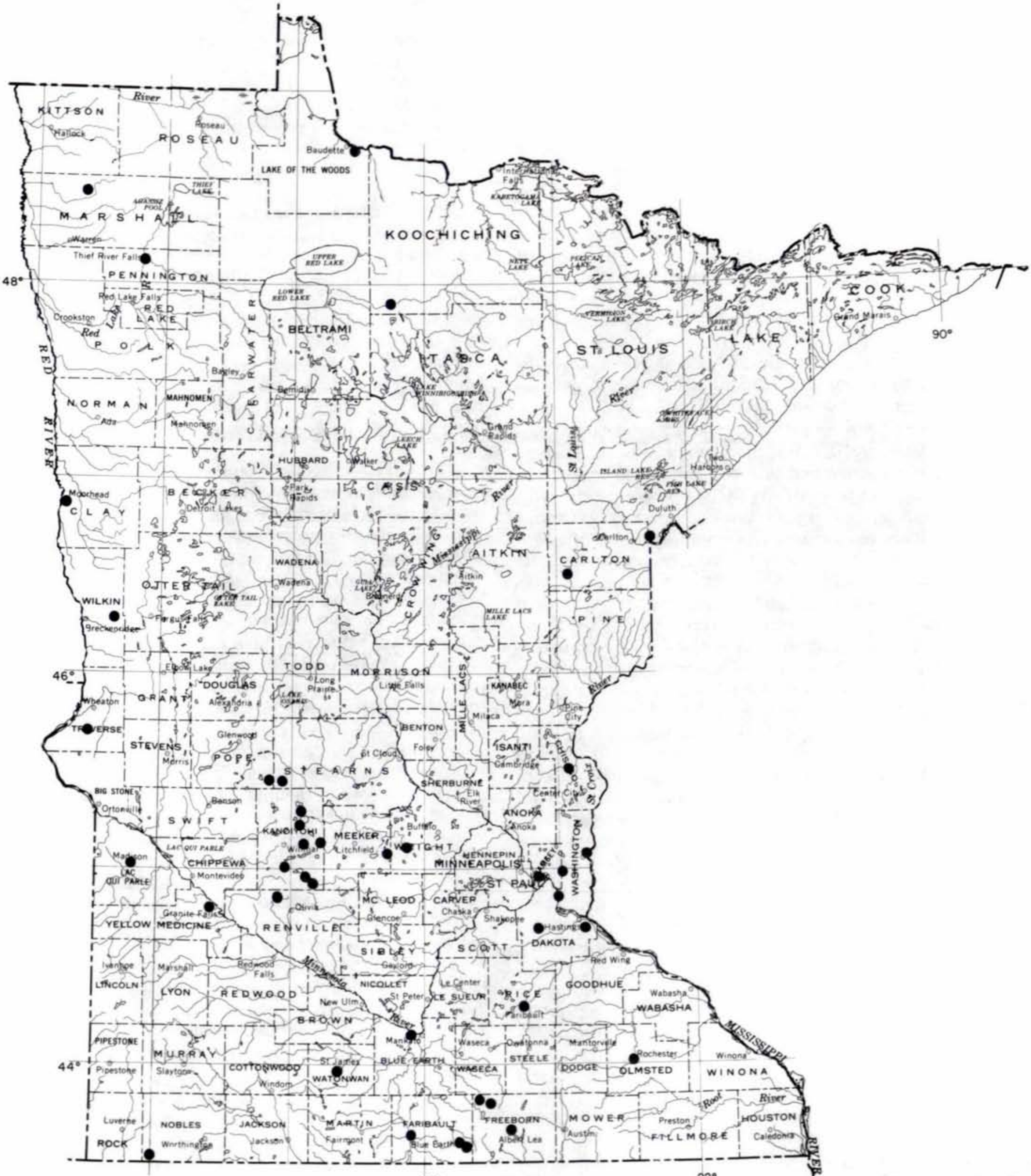


Figure 12. Locations of wildcat exploration activities described in the text. A comparison with the frontispiece shows that many were conducted in areas where natural gas had been encountered at shallow depths.

age at 950 feet, Winchell terminated the survey's participation in the project because rocks of this age were not believed to be a petroleum source.

Day and his backers, however, were determined to go deeper despite difficulties caused by the water which occurred together with the gas indications. As of the writing of *Bulletin 5* the machinery was still engaged in the undertaking, but at the expense of the gas company.

No Cretaceous strata were encountered in the test hole, but Winchell did not rule out the possibility that some of the gas in Freeborn County was generated in organic-rich Cretaceous units. He concluded that none of the natural gas in the county derived from Ordovician limestones, but rather that it came mostly from a sandy layer overlain by clay in the glacial drift, and thus there was little likelihood that any discoveries would be commercial in size. Already in 1889 it was evident to Winchell that most of the rock formations that furnish gas in the United States are lacking in Minnesota.

Bulletin 5 relates how Winchell's geologic conclusions were for the most part ignored by wildcatters. "Experts" asserted that large deposits would be found in the state simply by drilling to the "proper depth," and investors listened eagerly. Over and over again various "experts" cited the experience at Findlay, Ohio, where the state geologist had delivered a lecture stating that natural gas would never be found there, and gas was discovered before he had time after his lecture to leave town. This embarrassing event was a major blow to the prestige of the young profession of geology in Minnesota, for it confirmed the general suspicion that geologists knew nothing about where oil or gas could be found because they "had never been there."

Because an "expert from Pennsylvania" in the early 1880s insisted that deposits of natural gas could be found in the **Minneapolis-St. Paul** area at several hundred feet of depth, a group of local businessmen formed the St. Paul Heat and Power Company to explore for these deposits. Drilling began at several places including the State Fair Grounds in what is now Falcon Heights, and in North St. Paul, South St. Paul, and Faribault. Winchell was consulted about these sites, but his advice was ignored. That he was later unable to obtain the well records must have been the last straw, for *Bulletin 5* remarks that these wells "will go to posterity with no record except as a monument to the infatuation which can be inspired by the positive assertions of a wanton adventurer in the minds of men ignorant of geology but eager for wealth."

At about the same time, a deep well was drilled for gas at **Minneopa Falls** near **Mankato** by a company of local investors who sought the services of a well-known diviner from Ohio, for which they payed him a fee of $250. According to Winchell, the diviner "passed over the ground and was taken with jerks and shakings so violently in certain places that he could not endure the current. He was obliged to stand on one foot, placing the other against his knee to break the electric flow." He ultimately selected the place where the investors themselves had thought that gas might occur, and a 1,000-foot hole was drilled, finally intersecting Precambrian basement rocks. No natural gas was found, confirming Winchell's earlier conclusion that the geologic structure in this part of the state was unsuitable.

Other deep wells were drilled at **Duluth** (1,507 feet) and at **Stillwater** (3,500 feet) into Precambrian rocks without encountering natural gas. We do not know why these holes were drilled, but the geologic setting of both places was obviously unsuitable for either natural gas or oil.

A deep well at **Moorhead** appears to have been drilled for gas. This well, which was drilled with public money, was started without consulting the state geologist. When Winchell finally saw the cuttings from the well, which already was at a depth of 1,205 feet, he immediately recognized that the drill had entered Precambrian granitic gneiss. He urged that the drilling be stopped, stating in a letter of May 8, 1889, "You ought to have stopped when the drill struck the rock at the depth of 390 feet, the rock being granitic and of that sort which forbids any hope of obtaining artesian water or other product of value."

The drilling continued, however, on the grounds that "having gone so far, it was heart-rending to give it up now." Cuttings from the deepened well also were sent to Winchell who did not see any reason to change his original opinion. The drilling continued, and the local newspaper, the *Fargo Argus,* commented "Mayor Hansen of Moorhead says they intend to continue sinking the Artesian well in spite of professor Winchell's prognostications. And in this the whole Red River Valley says—'good for Hansen.' There is no geological or other prescience that can guess dead sure on Red River Valley matters. Success is what is wanted and Hansen shows true-grit."

A third set of cuttings down to 1,425 feet was subsequently sent to Winchell. These cuttings contained granitic fragments as before, but also included samples from a "bed of quicksand near the bottom of the well from which water quickly rose to near the top of the ground." On examining the sample from this interval, Winchell found "water-worn sand, . . . films of iron rust, scales of slag from some furnace, or fire box where coal was burned, angular bright pieces of soft coal, . . . and some seeds which look fresh enough to sprout." To Winchell this array of materials reflected the probable "intentional tampering with the record, by which it was hoped the enterprise would be pushed further." As of May 26, 1889, the mayor of Moorhead was still drilling in granite. Obviously natural gas was never encountered.

1900-1930

Wildcatting during the first third of the 20th century suggests that Minnesotans are just as gullible as they want to be, for their state geologist's conclusions back in 1889 seem to have brainwashed hardly anybody. After all, the pockets of gas really did exist, and where there was gas in commercial deposits elsewhere, there commonly also was oil. There were periodic reports of striking it rich using divining rods. Logically, if one worked in an actual oil field, one should develop expertise: Minnesotans listened when "experts" from out of state spoke.

As one example, at **Foxhome** in **Wilkin County** near Fergus Falls, a farmer who needed water got unwanted surprises instead. In one well at a depth of 200 feet there was a rush of gas that forced earth 75 feet up the pipe; in another there was a vein of what looked like crude oil at a depth of 100 feet. By 1922 he was convinced of the existence of a lake of oil beneath the Otter Tail-Wilkin County border, and he wrote to then Governor J.A.O. Preus asking for state aid in drilling for oil to a depth of 1,000 to 2,000 feet. He was unable to interest the state in this venture, but he was able to involve several neighbors. The project touched off a small land boom and 126 lots were reported sold. Actual drilling started in November of 1925, but difficulties were immediately encountered—not enough water could be obtained to carry on the drilling operations. The Minnesota Geological Survey has no record of the results of this drilling venture, but obviously no oil or natural gas deposits were discovered. (*Minneapolis Journal,* July 3, 1922 and November 22, 1925.)

The **Rochester** area of Olmsted County in southeastern Minnesota also was the site of an "oil boom" in the early 1920s. Unlike the other exploration projects of this period, the venture at Rochester was not based on any previous evidence of oil or natural gas in the area.

The boom was initiated by a mining engineer from Missouri who was "an old hand in the oil game." He apparently had come to Rochester in 1923 for surgery and while recovering, spent considerable time driving around the countryside. Although at first reluctant, the engineer finally confided to his doctor that the "lay of the land" was similar to several oil fields he had seen out west.

Ultimately the doctor and a local realtor, together with the mining engineer, formed a syndicate called the Rochester Oil and Development Co. The members of the syndicate originally invited 25 local men to participate who could afford not only to invest substantial sums, but also to lose money should the hole be dry. However word spread quickly that "prospects looked good for an oil strike" near Rochester and people flocked to the realtor's office demanding that they be allowed to invest. Although warned by the principals of the syndicate that they could lose their money, 200 people were finally "allowed" to invest in the project. By September 8, 1923, $125,000 of capital stock had been sold and from 10,000 to 20,000 acres of land had been leased from local farmers.

After it was decided that oil occurred somewhere in the Rochester area a "geologist" from "out west" who was "versed in the art of reading the stone formations" was hired to establish the precise location of the oil well. After several months, a site was selected to the east of Rochester on a high piece of ground that was claimed to be the site of a dome in the bedrock.

State geologist W.H. Emmons spent an entire day with backers of the project before drilling started, explaining why the Rochester area had little potential for oil or natural gas, and that Precambrian granitic rocks would be intersected at a depth of several hundred feet. Emmons and geologists from the University emphasized that there was little chance of finding oil or natural gas in Precambrian rocks, but the syndicate "expert" rationalized that "inasmuch as oil has never been discovered in these ancient rocks, there is no data based on practical experience that may serve as a guideline and that a discussion of the possibilities necessarily rests entirely on theoretical considerations."

By March of 1925 the drill had penetrated 9 feet of glacial material, 417 feet of Ordovician strata, 766 feet of Cambrian strata, and 2,033 feet of Precambrian sandstone and shale before encountering Precambrian granite and schist at 3,225 feet. The fact that Precambrian granitic rocks were not encountered at several hundred feet tended to discredit the opinions of the MGS and was used to lend credence to the idea that an oil deposit would be found. The promoters issued bulletins from time to time during the drilling, reporting the presence of veins of natural gas that could be burned and the presence of trace amounts of oil. Various out-of-state "experts" appeared on the scene and predicted that oil would be encountered with only a few hundred more feet of drilling. When they gave up, the hole was at 3,265 feet, the deepest hole in the state at that time. Oil in commercial quantities was never encountered, the "experts" disappeared, and the boom evaporated.

This story, from contemporary *Minneapolis Journal* articles, the *Rochester Post-Bulletin* of January 14, 1983, and the well log in MGS files, reads like a classic "con" operation perpetrated on gullible investors. Correspondence in University archives from several shocked geologists from other states to state geologist W.H. Emmons indicates that fees being charged to the project were much higher than the going rates for such work elsewhere, and they were convinced that investors were being "taken." However at least some of the principals may have been sincere, because at that time many people still believed that oil or natural gas exists almost everywhere in the Earth's crust in a manner not explainable by geology.

The following key ideas and excerpts from *Minneapolis Journal* articles on the goings-on at **Lake Lillian** in **Kandiyohi County** provide an idea of the spirit of the time.

March 19, 1926. MINNESOTA WELL DUG FOR WATER YIELDS 'PURE GASOLINE' WHERE EVEN PETROLEUM DOESN'T EXIST

- 13 gallons of mysterious "gasoline" taken out of Axel Lundquist's water well in the basement of his restaurant in Lake Lillian. The well is 19 feet.
- The "gasoline" is said to be so pure as to run A. Lundquist's automobile.
- Geologists at the University of Minnesota said there simply can't be any gasoline.
- Lundquist lowered a bucket in well to get water, got gasoline instead.
- Erick Nordeen, a farmer 2 miles out of Lake Lillian,

claims he skims his stock water tank every morning and runs his tractor with it--too oily for stock to drink unless he does this.

- Lundquist says he has been offered a $20,000 option on his three lots with an 8% royalty from oil taken from land.
- A year earlier a townswoman claimed she smelled oil when excavators were digging in her basement.
- F.F. Grout of the Minnesota Geological Survey says that the formations in that part of Minnesota couldn't possibly yield petroleum, that nature doesn't yield gasoline pure enough to be used in a gas engine. "I feel confident in saying that if there is anything in that well that will run a gasoline motor, it was put there by a human being, or came there from a human agency."

July 10, 1926. FIRST OIL DRILLERS REACH LAKE LILLIAN

- Erection of drilling outfit brought hundreds of curious persons.
- Just a year ago Axel Lundquist dug a hole that yielded 13 gallons of gasoline pure enough to run an automobile every day, in spite of protests of University geologists that it "couldn't be done."
- Will drill in the rear of Mr. Lundquist's famous basement.

July 26, 1926. LAKE LILLIAN OIL DRILLING TO BEGIN

- The drill has been moved to the William Troggan farm, 1 mile south of here.

April 1, 1927. BILL ASKS TEST OF LAKE LILLIAN OIL WELL THEORY

> *The state of Minnesota may have geologists attempt to solve the mystery of Lake Lillian's gasoline and kerosene wells and test the theory of a 75-year-old retired Methodist minister who surveyed Lake Lillian's "oil fields" himself with a new type of divining rod and declared that the mysterious flow of gasoline and kerosene comes to Lake Lillian through a sand wick, hundreds of miles long, which runs up from the oil fields of the south.*
>
> *Senator V.E. Lawson and Representative H.S. Nelson today brought before the legislature a resolution calling for a state investigation to determine whether there are any oil deposits under lands in Kandiyohi County for which the state holds mineral rights. . . .*
>
> *The proposed state geological survey would test the theory of Rev. Jacob Berger, 1626 Fremont Avenue No., who, with a divining rod with which he has experimented 47 years, made a survey of Lake Lillian. . . .*
>
> *Since oil has a tendency to rise above water, Mr. Berger theorized, it was logical that the vast amount of water which flows from Minnesota to the Gulf of Mexico should force oil in southern fields upward through a strata to Minnesota and the long trip of oil through sand and limestone would refine the oil so that it would come to the surface in Minnesota as pure oil and gasoline, he said.*
>
> *Just a year ago, Axel Lundquist, restaurant man at Lake Lillian, started to dig a well for water in the basement of his restaurant. . . . For months afterward, Mr. Lundquist bailed 18 gallons of gasoline from his basement "filling station" every day. And geologists at the University of Minnesota still contend that "any gasoline found there has been placed there by a human agency."*

The Lawson-Nelson resolution failed to receive legislative approval, but Nelson never gave up his belief that there was oil under Kandiyohi County. We do not know when the Lake Lillian drillers gave up, but the lure of Kandiyohi oil persisted.

Wildcat drilling for oil in 1928 included a venture at **Baudette** in **Lake of the Woods County** and one at **Granite Falls** in **Yellow Medicine County,** according to *Minneapolis Journal* articles on September 28, November 11, and December 3. An attempt was made, beginning in the summer of 1928, to evaluate the source of an oil seepage at the Arnett farm near **Dassel** in **Meeker County,** according to articles in the *Minneapolis Journal.* On June 1 of that year, an application was made to the Minnesota Department of Commerce by the Northwestern Development Company of Minneapolis to sell stock in Meeker, Wright, and McLeod Counties, preliminary to sinking a test well. The company was formed by several Dassel and Minneapolis businessmen expressly for the purpose of exploring for oil in the Dassel region. After it was organized, the company retained a "petroleum engineer from Shelby, Montana," who asserted that there is "plenty of evidence to indicate strong possibilities of oil being found [in the Dassel vicinity] in commercial quantities." In this matter, F.W. Sardeson, formerly of the Department of Geology at the University of Minnesota and geologic consultant to the Minnesota Department of Commerce held, "there is no oil to be found in Minnesota outside of tank cars and filling stations." Predictably the petroleum engineer rejoined with the old adage, "there is only one way to find out definitely [if oil is present] and that is to dig." Ultimately permission was given to sell a limited amount of stock, with the proviso that no money could be used to pay salaries to officers of the company and that all funds collected be placed in a bank until $10,000 were available to insure completion of the test well. On September 20th, it was announced that a "driller of oil wells from Cody, Wyoming" was contracted to sink the first test well.

The *Meeker County News* reported on May 9, 1929 the arrival of the first shipment of drilling equipment and preparations to erect a 70-foot tower on the Arnett farm; on February 20, 1930, it reported that the well was at 960 feet and that enough money had been raised to continue drilling to a planned depth of 1,200 feet. This appears to have been the last mention of the Dassel well, at least during the rest of 1930.

On November 28, 1929 the *Meeker County News* reported the formation of a corporation to drill a test well at **Cosmos** in **Meeker County** on the Nelson farm between Cosmos and Thompson Lake. A railroad spur was being extended to transport the drilling equipment being shipped from Texas. On April 17, 1930 the *News* reported that the well was at 1,300 feet in hard gray granite, and the drilling had stopped for repairs. On June 17, 1930 the *News* reported that the drilling, then at 2,100 feet and still in granite, was continuing. According to that article, "One large pocket with heavy black petroleum was struck some time ago." This apparently is the final mention of the Cosmos well during 1930.

1930-1950

Records of wildcat drilling in Minnesota between 1930 and 1950 are scanty. However despite the warnings of geologists at the University and MGS, several wells were drilled in **southeastern Minnesota** during the 1930s. One well named the Lund-Gunberg No. 1 was drilled sometime in 1935 near Rosemount (sec. 13, T. 115 N., R. 20 W.) in Dakota County. According to MGS records, this well intersected 110 feet of glacial deposits, 822 feet of Paleozoic strata, and 1,468 feet of Precambrian sedimentary rocks, without producing any oil or natural gas. Another well drilled near Blue Earth in Faribault County during the period 1930-1937 also was finished in Precambrian sedimentary rocks without producing oil or natural gas in commercial quantities.

Exploration wells were drilled for one reason or another at other places in Minnesota, including Madison in Lac Qui Parle County, Northome in Koochiching County, Thief River Falls in Pennington County, Florian in Marshall County, and Cokato in Wright County. The idea of a "lake of oil" beneath **Kandiyohi County** had not been forgotten, and wildcat wells were drilled at one time or another near Svea, Spicer, Kandiyohi, Atwater, and New London. None of these wells produced oil or gas in commercial quantities, although several may have yielded small quantities of natural gas from glacial deposits at shallow depths.

In 1937 the *Oil and Gas Journal,* a trade magazine of the petroleum industry, reported that an oil well called No. 1 Fee, which was rated at about 3 barrels per day of 37° A.P.I. crude oil, was completed about June 10 in Walls Township, **Traverse County,** near the town of Wheaton. Production was reported to be from the Dakota Sandstone of Cretaceous age at a depth of 864 feet. The discovery had started an active leasing campaign in the area.

In an article on the same page, G.A. Thiel, geologist for the Minnesota Geological Survey, described the geologic setting of Traverse and Big Stone Counties and noted that the sandstone beds in the base of the Cretaceous rocks are only a few inches to a few feet thick. Moreover he reported that they had been penetrated by artesian wells which showed that they were filled with fresh water under sufficient hydrostatic head to bring the water to or nearly to the surface. Furthermore, the artesian wells in Walls Township had intersected Precambrian granite at depths of less than 450 feet. He also noted that there were no secondary structures that might have trapped oil in commercial quantities. The "structure" at No. 1 Fee was a beach ridge of Glacial Lake Agassiz, and the acreage being leased was on similar structures (beaches and moraines). Although it seems likely that Thiel suspected a hoax, his conclusion is scholarly in tone. "All subsurface relations in western Minnesota indicate that the possibilities for commercial oil or gas are exceedingly remote."

An attempt was made to drill for petroleum in the **Kiester Hills** area in **Faribault County** from 1931 to 1933, but was hampered by financial difficulties. A second well near the same site began with the erection of a 96-foot derrick on the Henry Katzung farm 2 miles north and half a mile east of Kiester in August 1935. Drilling was delayed by the failure of the state Securities Commission to grant a permit, and apparently terminated when, as reported in the *Kiester Courier* on September 3, 1936, "strong winds brought down the derrick and smashed it."

Continued interest in the possibility of commercial oil and gas in the Kiester Hills prompted Thiel to write an article for the *Oil and Gas Journal* of July 28, 1938. The interest was apparently based, not only on the occurrence of shallow gas deposits, but also on a report that the Kiester Hills were underlain by a northwest-trending structural trap with several hundred feet of closure. Stating that such reports were based on "wishful thinking" and not on available geologic facts, Thiel observed that deep wells drilled for water in and near the hills indicate that the bedrock structure beneath Faribault and Freeborn Counties is monoclinal with a gentle dip toward the southeast at approximately 8 feet per mile.

Thiel's view of the bedrock structure was based on data then available. Recent tests for a place to store natural gas have located a small anticline arched about 100 feet above surrounding bedrock not far west of the Kiester Hills. However, even had the wildcatters drilled in the right place for their structural trap, they still would have found neither oil nor gas. Thiel's article concludes

> *The glacial drift has furnished most of the "indications" of gas in the Bricelyn-Kiester region. Numerous shallow water wells have encountered pockets of gas that "bounce the tools" or occasionally throw out quantities of mud and other rock debris. These "puffs" are of short duration, and further drilling does not increase the flow of gas. The highest gas pressure definitely recorded is 22 pounds. Such pressure subsides in a few hours, but small quantities of gas may issue from the wells for several years. No gas has been encountered in holes drilled into bedrock. Some has been reported in the channels of the upper part of the Devonian limestone. It undoubtedly was derived from the drift also.*
>
> *Since the only "indications" of oil or gas are in the glacial drift, the probabilities of commercial productions are so remote that it is not*

practical to give the region serious consideration.

1950-1960

The advent of the second World War had an inhibiting effect on wildcat exploration in the state. However once the war was over, wildcat activities soon resumed their prewar role in the peacetime economy.

A man named Johnson who had lost money on the 1935 venture at **Kiester Hills** in **Faribault County** persisted in his belief that oil was there for the drilling. Drilling equipment for the proposed 3,000-foot well arrived by railroad in Bricelyn in March 1950, and newspaper articles brought the project to the attention of George Schwartz, then director of the Minnesota Geological Survey. Schwartz immediately wrote to Johnson, asking to examine the drill cuttings after the company no longer had use for them. In mid-September geologist Malcolm P. Weiss, then a graduate student, called on Johnson at Schwartz's request. Among other things, Weiss's letter provided the following information:

> *The first hole caved in at about 600 feet in depth. A second was drilled 50 feet away, and that hole is now at 1,000 feet. The bottom of the hole is in "clean, white sand, just as fine and white as sugar." This sand is friable and causes some difficulty in drilling because the casing cannot be allowed to lag far behind the drill.*
>
> *For two years Mr. Johnson has been an ardent doodlebug fan, having learned the secret in Illinois. His bug is a one-ounce bottle filled with Illinois crude (only crude works) and suspended by a string pierced through the cap. When over oil it swings in a circle. When beside oil it swings like a pendulum in the direction of the oil. I was favored with a demonstration, using a puddle of crude on a newspaper for the doodlebug "bait." Mr. Johnson's manual dexterity is at a low ebb. His hand movements are almost embarrassingly obvious!*

The Minnesota Geological Survey has no record as to when and at what depth the drilling ended, but the venture never produced commercial quantities of either oil or natural gas.

Despite the number of dry holes that had been drilled in southeastern Minnesota, yet another attempt was made in 1955 by a group of investors from St. Paul and Hastings, Minnesota. No information is available as to why they selected the particular site 3 miles south of **Hastings,** but this group apparently invested around $18,000 in the venture. However 2 weeks after drilling had begun, the hole caved in and buried the drill stem, valued at about $6,000, and the venture was abandoned.

The discovery of petroleum in the Williston basin of North Dakota in 1951 led to renewed and intense interest in the possibility of commercial oil and gas deposits in western Minnesota. This interest was especially strong in Kandiyohi, Renville, and Swift Counties. In December of 1952, a syndicate obtained drilling rights on some 21,000 acres in the southwestern part of **Kandiyohi County** and the adjoining part of **Renville County.** One member of the syndicate claimed to have a "sixth sense" for finding oil and used that sense to select the site of the first well. He believed very strongly in his ability to find oil, stating that "a year from now, it is reasonable to expect there will be 150 wells in operation." When G.M. Schwartz, director of the Minnesota Geological Survey, was asked if there was any possibility of this, he replied "none, absolutely none." Nevertheless a wildcat well was drilled in the spring of 1954 in Crooks Township (T. 116 N., R. 36 W.) in northwestern Renville County 4 miles south of Prinsburg. According to the *Willmar Daily Tribune* of September 21, 1954, the hole was drilled by an "experienced oil well driller who had been previously engaged in drilling operations in the oil fields in Texas and Oklahoma." Apparently the hole intersected 640 feet of Pleistocene glacial deposits and 5 feet of granite. The newspaper reported that a sandy layer containing oil and gas was encountered between 290 and 390 feet. It also reported that at a depth of 414 feet the drill cut a fisher [*sic*, fissure or crack] from which a bucket of pure crude oil was obtained. The operation was halted by the Minnesota Securities Commission which had questions about the financing, but nonetheless the promoter "emphatically stated that 'the hole will be dug deeper' and will prove his oftmade assertion that there is oil in the area." As yet, no oil has been reported from Renville County in commercial quantities.

In an attempt to quash rumors of extensive oil deposits in the state, G.A. Thiel, then chairman of the Department of Geology at the University of Minnesota, wrote a series of popular articles in the 1950s on the geology of many of the counties in Minnesota. The articles for Kandiyohi and Swift Counties were printed in late 1954 by the *Willmar Tribune* and the *Benson Monitor,* respectively, and several readers took exception in succeeding issues of the newspapers.

Former State Representative Nelson, who had called for state investigation of the Lake Lillian oil in 1927, was the first to denounce Thiel's conclusions regarding Kandiyohi County. Citing the many shallow natural gas occurrences, he asserted, "We have got more oil in Minnesota than 4 or 5 states south of us—including Kansas which is known as an old oil state." Regarding Precambrian granitic rocks as places to find oil, he wrote that Minnesota geologists did not know anything about oil "except what they had learned in books, as they hadn't had any practical experience in the oil fields." As far as Kandiyohi County was concerned, Nelson wrote, "The state owns mineral rights on 10 sections of land . . . that I know of, and ½ of the land that I have checked has oil. . . ." Noting that the state geologists had consistently opposed this position since 1926, Nelson opined that the Geology Department at the University of Minnesota had "better come down off their high horse and do something for the benefit of the people and the State of Minnesota." As far as the "big oil companies" were concerned, "they don't want any oil discovered in the state because they have leases on land which will take 100 years before they get the leases drilled out that they now have." Nelson was not one to let geologic observations sway his personal beliefs.

At about the same time, James R. Burnip of Benson disputed Thiel's conclusions regarding the lack of commercial oil deposits in Swift County. It was obvious to Burnip, as it was to Nelson, that the shallow gas deposits indicated the presence of oil at depth. Although he accepted the statement that granitic rocks were present at depths of about 500 feet in Swift County, Burnip suggested that oil could occur possibly in "openings here and there" or in "other formations coming with the granite, or before the granite, or subsequent thereto, excepting the overlying glacial drift, sand and shale." Therefore he concluded that the possibility of oil under Swift County, ". . . cannot be answered definitely until a drilling has been made to an adequate depth, which in this locality would be approximately 2,000 feet." Burnip was sure oil would be found at that depth because he had a "special gift" whereby he could identify oil deposits by measuring vibrations emanating from the oil, although "no one realizes more fully than I, the fantastic nature of the method I employ. . . . I get the same results in going over the land in Swift County that I have obtained in going over fields in oil-producing localities." As scientists, both Thiel and Schwartz held divining to be useless for locating oil or any other kind of geological material and also believed that it was a common ploy in illegitimate ventures. Burnip recognized this possibility, and was "in full accord with the good officials of the state to protect the citizens . . . against the purchase of bogus stocks or any form of illegitimate investments." However Burnip protested that Thiel and Schwartz "should not stress their opinion on this subject so strenuously as it would tend to stifle the development along this line in our state." Burnip reasoned that because ". . . the big oil companies depend upon geologists for their oil information, therefore, so long as the geologists definitely and persistently declare there is no oil here they are going to believe it."

The letters express the popular suspicion that some sort of conspiracy between geologists and the major oil companies was keeping Minnesota's oil from being exploited. They also show that even after 70 years of repeated attempts and subsequent failures, many people still believed that oil and natural gas could exist almost anywhere in the earth's crust and could easily be found by using divining techniques of one kind or another.

1960-1983

Divining was still in vogue from the 1960s to the 1980s. For example, during 1963 or 1964 a diviner claimed to have "had a vision" that oil could be found near **North Branch** in **Chisago County.** A local company was formed and a hole was drilled to a depth of 675 feet through mostly Precambrian sedimentary rocks without encountering oil or gas. On December 14, 1981, the *Minneapolis Tribune* reported that an "oil deposit" near **Ellsworth** in **Nobles County** in southwestern Minnesota was identified by dowsing using copper wires. The dowser disagreed with geologists who said the area was unsuitable for oil or gas because dowsing told him otherwise. The site was being drilled by the Southwest Oil Exploration Company, a group of local investors, who reportedly had $175,000 obligated the day the drilling started. The hole was drilled through 270 feet of glacial drift, 265 feet of Cretaceous strata, and 610 feet of Precambrian rocks without finding oil or natural gas. The same paper on the same day also reported that a group of farmers in nearby **Murray County** had engaged a "Texas oilman and evangelist" to lead a prayerful search for oil that the farmers were sure was there. As of this writing the Minnesota Geological Survey is unaware of leasing or wildcat drilling in Murray County; possibly the reported need to come up with a million dollars killed enthusiasm.

The doodlebug discoveries of Henry J. Steinmetz received tongue-in-cheek treatment in the January 23, 1981 edition of the *St. Paul Pioneer Press.* Working at his home in Indiana with a **pendulum-bob** and **maps** of various parts of the country (for field work he uses television rabbit ears), Steinmetz detected the presence of oil in Beltrami, Big Stone, Blue Earth, Koochiching, Olmsted, Red Lake, Roseau, and Watonwan Counties. Wells in all fields would produce more than 500 barrels a day except in Big Stone which would produce 50 to 500 barrels a day. The fields, which range in size from a little more than 1,000 acres to 7,600 acres, lie between 2,500 feet and 13,500 feet below the surface!

A wildcat hole more than 13,000 feet deep in Minnesota is awesome to contemplate. Compare the depths to Precambrian crystalline strata (Fig. 10) and the depths drilled at Rochester in 1925 and at Kettle River and Brooten as described below. Producing wells in Pennsylvanian and Ordovician strata in the Fryburg Oil Field, according to the North Dakota Geological Survey's Educational Series No. 1, are as deep as 13,750 feet, but these wells are in deep basins of Paleozoic and younger sedimentary rocks, in which conditions needed for the formation of oil and gas on a significant scale exist. The Precambrian basement rocks which underlie the basins in North Dakota rise steadily toward the east and appear at the surface in Minnesota as the margin of the Canadian Shield. Nowhere in Minnesota are the Precambrian rocks of the shield overlain by as much as 2,000 feet of sedimentary rocks, and repeated tests have shown that this is not enough for significant oil and gas deposits to form.

During the 1970s and 1980s several wildcat exploration holes were drilled in places where small quantities of natural gas or oil had been found previously. For example, a group of investors near **Kettle River** in **Carlton County** organized Turmoil Inc. in January of 1979 to drill a deep hole on the Hattenberger farm where natural gas in the well water was literally explosive (see the section on occurrences, 1976). According to newspaper accounts, $100,000 to $300,000 were spent on the project, despite the advice of Matt Walton, director of the Minnesota Geological Survey, "take the money to Las Vegas —your chances of coming home a winner are a lot better." The hole, already in Precambrian rock from 30 feet to 785 feet, was deepened to approximately 7,400 feet, and is now by all odds the deepest hole drilled in Minnesota. The results were disappointing to the investors, but according to the last reports we have, the investors still believe that oil is present and, "as soon as we get this hole drilled and oil is coming out, they're going to have to rewrite their textbooks." Walton would agree that it would indeed be revolutionary, but he is waiting to see the oil before revising more than a century of work by the Minnesota Geological Survey.

Space-age technology in the form of remote-sensing imagery from NASA and conventional aerial photographs reportedly led the Atlantic Petroleum Corp. of Arlington, Virginia, to believe that there are millions of dollars worth of natural gas in **southeastern Minnesota.** The company, which opened an office in Austin, Minnesota, in April 1982, leased the mineral rights, including water, on approximately 100,000 acres. However on June 10, 1982, the *Minneapolis Tribune* reported that, because of an industry-wide slowdown, the company was leaving the state and postponing drilling operations for at least 2 years. Payment of one dollar per acre for the leases reportedly was not to be made until the following year. This operation is included here because, although air photos and satellite imagery are useful exploration tools in some parts of the world, they are not directly applicable in southeastern Minnesota. Where much of the bedrock is covered by glacial debris, the features that can be seen on the photographs reflect processes that occurred in the glacial deposits rather than in the underlying rocks.

Oil near **Brooten** in west-central Minnesota was the subject of a press conference on January 12, 1983. On the following day Minnesotans could read

- It spewed out of control for nearly 5 minutes before the well was capped [the stock broker] said. Witnesses said the gusher reached heights of 5 to 6 feet and flowed at a rate of more than a barrel a minute (*St. Paul Pioneer Press*).
- Oil shot 5 to 6 feet into the air through a 3-inch pipe for seven minutes (*Minneapolis Star and Tribune* quoting brokerage).
- Oil gushed 5 or 6 feet into the air (*Minnesota Daily,* quoting Wilmoth).
- It gushed almost 3 feet into the air and was totally uncontrollable for about 7 minutes. Reports of a higher gusher were "slightly exaggerated" (*St. Paul Dispatch,* also quoting Wilmoth, but from an interview following the press conference).

Geologists of the Minnesota Survey suddenly became, by our standards, wildly popular. They were interviewed in person, on the telephone, on television, and from as far away as Texas. What could we say—if the oil was there, it was there. However, there were geologic reasons for skepticism as to the production estimates (originally of 250 barrels a day, later downgraded to 100). These reasons have been outlined in this publication.

From the newspaper reports over the following weeks, it appears that the venture began with an "oil show" at the 777-foot depth in the water well drilled on the Visser farm in 1975 (see the section on occurrences). A firm named Orlyn Exploration Co. then performed additional drilling in the hole to 1,847 feet, apparently as money and equipment were available, and by June of 1981 they had secured leases for drilling on 70,000 acres. The company is a group of local investors.

In September of 1982 another firm, Earth Science Explorations, Inc. of Le Sueur, was brought in as operating partner. Doug Wilmoth of Kansas City, Mo., and Petroleum Specialists, Inc. of Williston, North Dakota, were eventually hired to do the actual work at the site. Limited partnerships were sold to 34 investors by a Minneapolis stock brokerage, whose prospectus warned investors of the high risk involved. They were quoted as saying that nobody having less than a million dollars or less than $200,000 annual income should invest.

The *Minneapolis Star and Tribune* reported on January 14, 1983 that Wilmoth had put a drinking cup down the old well and found it full of crude oil when he pulled it up; thus his work on "Visser No. 1" seems to have involved only the pump. The premium quality of the oil, described ecstatically at the initial press conference, allegedly was determined from Wilmoth's first cupful.

By January 19 the *Star and Tribune* had interviewed Steve Hoffman, a field supervisor for Halliburton Services, whose crew was pouring cement to set the well's casing when the great event occurred. It reported that Hoffman claimed the well had yielded mostly water, although "we did see there was an oil skim on top" of water samples he collected in jugs.

The project was in the news repeatedly over the next 3 weeks, mainly because of various difficulties with the pump. On February 4, an estimated 2 barrels of oil were reported, and on February 20 ("We've put production in the tank"), 70 barrels of an oil-bearing fluid. On February 4 the well was primed with about 10 barrels of water; we do not know how much of the initial "gusher" and later "production" was priming fluid. Drilling had begun for a second well 2½ miles away, but was temporarily abandoned in late February when a blockage in the hole hindered drilling.

On February 9 in a copyrighted article the *Star and Tribune* broke the news of its 3-week investigation: '[Wilmoth] has left in recent years in several states a trail of investors who say they were defrauded, lawsuits seeking thousands in damages, bouncing checks, unpaid judgments, ignored subpoenas, and contempt-of-court citations." The paper had interviewed a lot of angry people. It also had interviewed Wilmoth who denied the allegations.

With its own reputation now threatened, the stock brokerage called another press conference to make it clear that Wilmoth was only an employee who had been hired because of his skills in bringing in oil wells.

In the first week in April, after another attempt at developing the Visser well, a spokesman announced that the well produced only a "minute amount, a slight trace, not even 1 percent of oil" and concluded that it "won't produce any commercial quantities of oil and should be plugged and abandoned." As to the second well, it would cost $25,000 to $30,000 to redrill it, and because of the financial condition of the project, redrilling could not be recommended. The entire project was reported to be at least $400,000 in debt and anticipating a potential tangle of legal problems.

Some concluding comment on the Brooten business would seem in order. It has not been established how much, if any, oil originated in the rock at the site. Analytical information in our files suggests that there was no appreciable quantity of natural hydrocarbons in the hole. Furthermore there is no scientifically valid reason for thinking that there could be.

Epilogue: The *Star and Tribune* of August 25, 1983 reported that drilling will be resumed on the site, and quoted the president of Orlyn Exploration as saying, "They don't want oil in this dang state. That's the whole problem. I think we have more oil in this state than they got in a lot of them. There's been a lot of time spent on this. All we would like is a chance to prove our point." The conspiracy theory of Nelson and Burnip in 1927 and the sentiment of the folks at Moorhead in 1889 about its being "heart-rending, having gone so far, to give it up now" are still with us.

CONCLUSIONS

In conclusion, what can be said about the possibility of finding petroleum deposits in Minnesota? All of Minnesota is underlain by Precambrian rocks of one kind or another. In general petroleum is rarely found in such rocks. Some commercial occurrences have been described, but not in Minnesota. The general metamorphism and the lack of porosity and permeability of most Precambrian rocks make them unsuitable as reservoirs, even for water. In Minnesota there are virtually no prospects of future commercial petroleum discoveries in Precambrian rocks, because where they have any porosity and permeability, there are no source beds.

Similarly the glacial deposits themselves everywhere lack the attributes necessary for large petroleum deposits. Nonetheless many water wells dug or drilled to shallow depths have encountered small pockets of gas under pressure high enough to "bounce the tools" and throw out sand and rock debris. These gases were formed by the bacterial decay of buried swamp or forest deposits and are not "indications" of larger occurrences at greater depths.

Unlike the Precambrian and Pleistocene formations, the intervening rocks of Paleozoic and Mesozoic age have some of the attributes necessary for a major petroleum deposit to occur. These rocks, however, lack the deposits which could have been source beds for petroleum, and they were never buried to depths sufficient to produce crude oil.

It is important to remember that thousands of water wells have been drilled in Minnesota, but only a few of them have yielded any trace of oil or natural gas. Furthermore, not one of the drill holes specifically sited by whatever means for oil or natural gas in Minnesota has intersected petroleum deposits of any commercial significance. Given these facts, there is no reason to doubt the correctness of Winchell's conclusion in 1889 that there is little possibility of finding commercial petroleum deposits in Minnesota. All the additional experience and data that have accumulated since 1889 have only supported his conclusion. The geologic conditions for significant deposits of oil and gas do not exist in Minnesota.

SELECTED BIBLIOGRAPHY

A list of publications is available on request from the Minnesota Geological Survey, 2642 University Avenue, St. Paul, MN 55114-1057. Nontechnical publications on oil or on Minnesota geology, most of which can be purchased from MGS, include the following books and maps.

McPhee, John, 1983, *In Suspect Terrain:* New York, Farrar, Strauss, Giroux, 210 p. (not available from MGS).

Ojakangas, R.W., and Matsch, C.L., 1982, *Minnesota's Geology:* Minneapolis, University of Minnesota Press, 255 p. (paperback, $16.95).

Sansome, C.J., 1983, *Minnesota Underfoot, a Field Guide to the State's Outstanding Geologic Features:* Bloomington, Minnesota, Voyageur Press, 224 p. (paperback, $9.95).

Small-scale (1 inch = 50 miles) maps of Minnesota in color with explanatory texts that have been prepared by the Minnesota Geological Survey ($1.00 each) are:

Bedrock geology (M-24)
Quaternary (surficial) geology (S-4)
Bedrock hydrogeology (S-5)
Quaternary hydrogeology (S-6)
Bedrock outcrops (S-10)
Aeromagnetic anomaly map (S-11)
Bouguer gravity anomaly map (S-12)

Petroleum

Occurrences

Wildcatting

Petroleum chances