UNDERGROUND STORAGE OF LIQUID HYDROCARBONS IN INDIANA

by

JOHN B. PATTON

Indiana Department of Conservation
GEOLOGICAL SURVEY
Report of Progress No. 9

1955

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George N. Craig, Governor

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Harley G. Hook, Director

GEOLOGICAL SURVEY
Charles F. Deiss, State Geologist
Bloomington

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UNDERGROUND STORAGE OF LIQUID HYDROCARBONS IN INDIANA

By John B. Patton

ABSTRACT

Artificial reservoirs excavated from bedrock at depths of 200 to 500 feet offer the best prospects for underground storage of petroleum and its liquid products in Indiana. All the Paleozoic bedrock systems from Ordovician to Pennsylvanian contain potential reservoir sites in shale, siltstone, or limestone at places within the state. Suitable Ordovician rocks lie at proper depths beneath a greater area than the rocks of any other system. Competent beds for natural roof are more common in central and southern Indiana than in the northern part of the state. Thick glacial drift increases the difficulty of locating good storage sites in much of northern Indiana.

INTRODUCTION

Purpose of this report

Underground storage of petroleum, and particularly of liquid petroleum products, is relatively new and is growing rapidly in favor. The increased use of this method is caused, in part, by economic factors such as cheaper cost per barrel of storage space and the need for ever-increasing stocks of stored products required by the rising consumption of petroleum fuels. Underground storage also affords protection from fire, explosion, and other destructive forces that may result from war or accident.

The purpose of this report is to furnish general information on the distribution of favorable areas for underground storage in Indiana. A company that is seeking a favorable site should make a general survey of the entire area that is acceptable geographically. This survey should cover regional stratigraphy and lithology of the bedrock to the maximum depth at which storage is considered feasible, glacial geology, ground-water conditions, and local structural conditions. After a generally favorable area has been selected, a detailed exploration program will be necessary in order to select the exact site for the underground reservoir, Such exploration must include core drilling and should also include such studies as clay mineralogy and detailed petrology. Further information on glacial geology, ground water, and structural conditions can also be obtained at this stage by test drilling.

General requirements for underground storage

Most of the underground storage projects now in use or under construction are either (1) cavities that are dissolved artificially from salt beds, or (2) caverns that are excavated in bedrock by conventional mining methods expressly for the purpose of underground storage. A few underground reservoirs have been developed from abandoned mine workings, and a few liquid storage projects utilize the pore space of permeable bedrock. Of these types, excavated reservoirs are potentially the most promising in Indiana and are the only type that can be developed in large parts of the state.

The general requirements for bedrock that is to be excavated for the storage of liquids are that the rock be relatively impervious (lacking both the type of permeability that results from connected pore space and the type that results from fracture) and that it neither react with the liquid to be stored nor contribute impurities. The strength of the material excavated will determine, to some extent, the width of the openings and the number, size, and spacing of pillars. The ease with which the rock can be excavated is an important economic factor. Competent rock is desirable for the roof of the caverns, but need not be the same type of rock that is excavated. Incompetent beds can be supported by roof bolting or timbering, but either of these artificial methods of roof support costs more than natural roof composed of competent rock. The rock, glacial drift, or other material that the shaft must penetrate before reaching the reservoir should ideally carry little water, as excavation problems are greatly increased if a large volume of water is encountered. Petroleum and its products that are liquid at atmospheric pressure can be stored at shallow depths. Liquid products that vaporize at atmospheric pressure must be stored in reservoirs that are sufficiently deep to contain the storage pressures plus a safety factor. The depths favored by the companies that use underground storage for propane, butane, and other volatile hydrocarbons range from 200 to 500 feet. Areas in which glacial drift is more than 200 feet thick are considered undesirable. Glacial till is difficult to excavate because till is tough and does not yield to blasting. In addition, layers of water-bearing sand and gravel are common in drift.

Generalizations about the most suitable rock types are difficult to make because this method of storage is so new. Each company tends to prefer that rock type in which it has installed a successful reservoir. Conversely, a company that has difficulties in the installation of a reservoir tends to blacklist the type of rock that was encountered. By tempering the extremes of success and failure and applying a few geologic principles, we can say that shale and siltstone have apparently been the most satisfactory types of sedimentary rocks because they are impervious, fairly strong, and relatively easy to excavate. Shale is not suitable for cavern roofs, and siltstones range from poor to good for this purpose. Successful reservoirs also have been installed in limestone and dolomite, although many dolomites and some limestones are permeable as a result of connected pore spaces, and both limestone and dolomite are more likely to be jointed and fractured and to contain open bedding planes than are siltstones or shales. Sandstones may possess all or none of the characteristics of a good mined reservoir, as their permeability, strength, and contaminating impurities may range widely.

The companies that install storage reservoirs generally have geographic preferences or requirements in addition to the geologic and engineering considerations. The geographic considerations include nearness to population centers, pipelines, railroads) and highways.

ACKNOWLEDGMENTS

This report is a compilation that has resulted from the discussions of the Indiana Committee on Underground Storage of Petroleum and Its Products, a subcommittee of the Research and Coordinating Committee, Interstate Oil Compact Commission. The committee members are C. V. Kroeger, Engineer with the Central Indiana Gas Company at Muncie; and T. A. Dawson, Charles E. Wier, Haydn H. Murray, and John B. Patton, of the Indiana Geological Survey. Arthur P. Pinsak and Allan M. Gutstadt, Indiana Geological Survey, have contributed to the study. A. H. Bell and P. A. Witherspoon, both of the Illinois Geological Survey, have assistedby making available information compiled by the parallel committee in Illinois.

REGIONAL GEOLOGIC CONDITIONS

Stratigraphy

The sedimentary bedrock of Indiana ranges in age from late Cambrian to late Pennsylvanian. Strata that lie within 500 feet of the surface are confined to Middle Ordovician and younger rocks (fig. 1 and table 1).

Structure

Indiana lies in the stable east -central part of the North American continent, and the sedimentary strata are relatively flat-lying. The

Table 1. --Summary of conditions for underground storage in Indiana

System	Series	Lithology	Storage possibilities	Area No. on pl. 1
Quaternary	Pleistocene	Till, outwash, loess, and lacustrine clay and silt.	None.	
Pennsylvanian	Conemaugh	Shale, sandstone, limestone, and local coal.	Good. Shelburn formation contains shales between Coal VII and West Franklin limestone in Posey, Gibson, and Vanderburgh Counties and above Coal VII in Knox, Sullivan, and Vigo Counties that are especially favorable.	12
	Allegheny	Shale, sandstone, coal, and limestone.	Generally poor because of coal beds. Shales above and below Coal III have possibilities.	11
	Pottsville	Sandstone and shale; local coals.	Poor.	
Mississippian	Chester	Alternating sandstone, shale, and limestone.	Good prospects in shale units underlying limestone. Limestones in middle and lower parts are sufficiently thick but possibly water bearing.	10
	Meramec	Limestone: Thin-bedded to massive.	Excavation feasible; water bearing in most localities; solution channels common in subsurface.	
	Osage	Siltstone, shale, sendstone, and limestone.	Good prospects in ..other. Idiana, especially in upper two-thirds of section in massive siltstones and shales.	9
	Kinderhook	Limestone overlying shale.	Limestone too thin for roof or chamber in southern Indiana.	
			Fair prospects in northern Indiana in Ellsworth shale.	8

Devonian	Upper	Shale: Mostly highly carbonaceous.	Excavation feasible; contamination and fractures may be excessive.	
	Middle	Limestone in southern Indiana: Pure to extremely impure, thin-bedded to massive.	Storage possible in Silver Creek limestone in Clark and Floyd Counties.	7
		Mostly limestone in northern Indiana: Lower part contains bedded gypsum and anhydrite in part of Michigan Basin.	Fair storage possibilities in northern Indiana.	6
Silurian	Niagaran	Limestone, shale, and dolomite in northern Indiana.	Mississinewa shale, particularly upper part, good prospect.	5
		Limestone and shale in southern Indiana.	Limestones thin-bedded and water bearing in southern Indiana.	
			Waldron shale offers possibilities in Floyd and Clark Counties.	4
	Albion	Limestone: Cherty and dolomitic in places,	Too thin in southern Indiana; possible in northern Indiana.	
Ordovician	Cincinnatian	Limestone and shale: Mostly thin-bedded~ fossiliferous.	Entire series has possibilities. Middle and upper parts (Maysville-Richmond) have better prospects for natural roof. Saluda limestone probably satisfactory in Jefferson and Clark Counties because of massive nature.	3
			Lower part (Eden) easy to excavate but in part carbonaceous.	2
	Mohawkian (not exposed)	Limestone and dolomite.	Good, but lies at desirable depth only in and near Ohio Valley in southeast corner of state.	1
	Chazyan and older	Dolomite and sandstone.	Too deep throughout Indiana.	

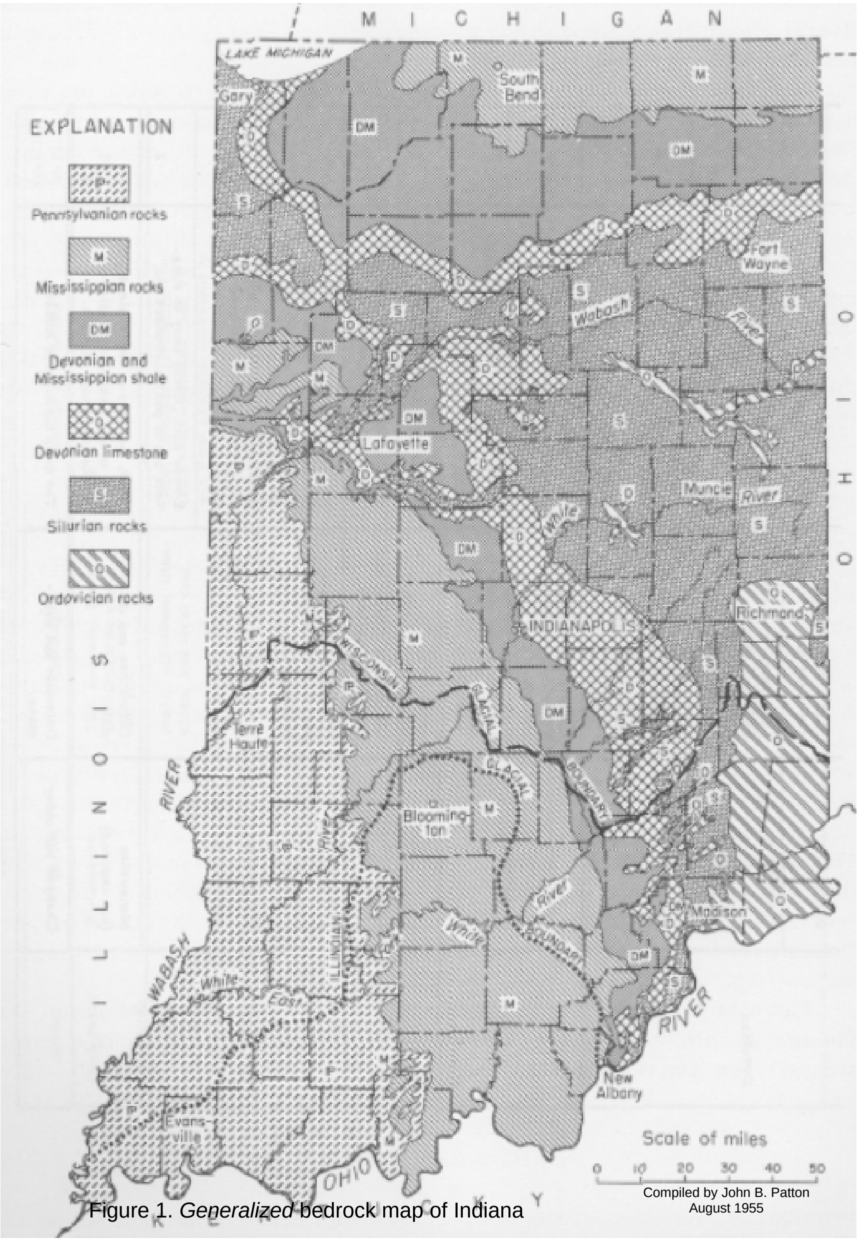


Figure 1. *Generalized* bedrock map of Indiana

southeastern part of the state lies near the crest of a large positive element called the Cincinnati Arch, which extends northward and northwestward from southeastern Indiana to southern Wabash and Miami Counties. Throughout this broadly arched area, dips are low and their direction is unpredictable.

Westward and southwestward from the Cincinnati Arch the rocks dip toward the center of the Illinois Basin, in south-central Illinois. The dip increases from less than 10 feet per mile near the crest of the arch to about 30 feet per mile in south-central Indiana and locally to as much as 50 feet per mile in southwestern Indiana. Northward from the Cincinnati Arch the beds dip into the Michigan Basin at an average rate of 20 feet per mile. In north-central and northwestern Indiana a positive belt, much narrower than the Cincinnati Arch, separates the Illinois and Michigan Basins.

Faults are so rare in the surface and shallow subsurface beds in Indiana that they are not likely to be encountered in underground storage projects.

Present distribution of bedrock systems

The distribution of the bedrock systems at the surface (fig. 1) is the result of long-continued erosion that has beveled the gently dipping strata to a nearly level surface. Thus, the oldest exposed rocks appear in the region that is structurally highest, the Cincinnati Arch, where Ordovician rocks lie at the surf ace in eight counties of southeastern Indiana. Westward, down the flank of the Arch and into the Illinois Basin, strata ranging in age from Silurian to Pennsylvanian appear progressively, the younger to the west of the older. The same pattern is repeated northward from the Cincinnati Arch into the Michigan Basin, except that only the Silurian, Devonian, and Mississippian systems are represented within the state. The ridgelike separation between the Illinois and Michigan Basins in northwe stern Indiana expose s Silurian rocks, and younger systems appear progressively southwestward and northeastward into the respective basins (fig. 1).

Locally preglacial and interglacial valleys occur as troughs that bite deeply into the bedrock, cutting out the youngest strata that might normally be expected in the area.

Glacial geology

Only the last two of the four stages of Pleistocene glaciation left prominent effects on the surface of Indiana. The Illinoian ice sheet covered the southeastern part of the state and the westernmost part of southern Indiana (fig. 1). Illinoian glacial drift in Indiana is generally thin and will not affect the development of underground reservoirs. The Wisconsin ice sheet, however, covered the northern two thirds of Indiana(fig. 1) and left glacial drift that is thin in a few places but that is generally 100 to 300 feet thick and reaches a thickness of more than 500 feet. The drift is particularly thick where the depth of preglacial or interglacial valleys, now filled with drift, is added to the normal thickness of the drift sheet.

STORAGE POSSIBILITIES IN INDIANA

Ordovician system

Middle Ordovician in this report refers to the Chazyan and Mohawkian series. The rocks of the Chazyan series are too deep throughout Indiana for excavation of reservoirs; for this reason rocks of the Chazyan series and older rocks are not considered in this report. The Mohawkian series consists of limestone and dolomite in Indiana. It lies at or immediately beneath the surface only in the Ohio Valley in eastern Switzerland County. The area in which some part of the series lies within 200 to 500 feet of the surface includes most of Switzerland, Ohio, and Dearborn Counties and parts of Jefferson, Clark, Ripley, and Franklin Counties (area 1, pl. 1). In this area the series consists principally of limestone. An excavated reservoir would have to be far enough below the, top of the limestone to provide an adequate roof, as the overlying shales are not competent. The Mohawkian rocks include the famed Trenton limestone reservoirs that have produced oil and gas for more than 50 years in east-central Indiana and northwestern Ohio, but the permeable reservoir beds are lacking in the southeast corner of the state. The contact between the Trenton and the Eden is not sharply defined in southeastern Indiana but is represented by a transition zone in which shale and limestone are interbedded. Shale beds in this transition zone might offer good reservoir possibilities because of their limestone floors and roofs, but the extent and nature of the interfingering are not well known.

The upper Ordovician Cincinnatian series consists, in ascending order, of the Eden, Maysville, and Richmond groups. The Eden group averages about 235 feet in thickness in southeastern Indiana and consists largely of shale in which thin interbedded limestones are increasingly abundant toward the top of the group. The Eden shale could be excavated readily and would be impervious. Parts of the shale, however, are carbonaceous and might contaminate stored liquid hydrocarbons, and the shale might not be strong enough for the walls to support the weight of thick overburden after an excavation is made. Eden shale, because it slides on hillsides and in road cuts, has presented grave problems to highway engineers. The sliding occurs when the shale is wet, but if water is kept away, the shale may be structurally sound. Perhaps the greatest difficulty in using these shales for storage reservoirs is that a limestone section thick enough and massive enough to serve as a roof may be difficult to locate. For this reason, the chances of finding a suitable natural roof are progressively better upward through the Eden group and are best directly beneath the overlying Maysville group, which contains more limestone. The Eden shale lies at a suitable depth for storage in large parts of Ripley, Franklin, Fayette, Union, and Wayne Counties and in small parts of Switzerland, Jefferson, and Clark Counties (area 2, pl. 1). In parts of Wayne County glacial drift exceeds 200 feet in thickness.

The Maysville and Richmond groups of the Cincinnatian series are not readily distinguished in the subsurface. Their combined thickness ranges from 150 to 530 feet. The unit consists of thinly interbedded fossiliferous limestone and shale, the ratio of limestone to shale generally increasing upward through the section. In Jefferson and Clark Counties (pl. 1) the Saluda limestone reaches its greatest thickness and lies at or near the top of the Richmond group because younger Ordovician strata are thin or absent. The Saluda consists of drab-gray granular massive dolomitic limestone which probably could be excavated for a satisfactory reservoir. North of Jefferson and Clark Counties the Saluda is not massive and is overlain by thinly interbedded shale and limestone of the Whitewater formation. The most promising stratigraphic position for mined caverns maybe directly beneath the overlying Silurian lime stones, which could serve as roof. At places the beds at the base of the Silurian are cherty and may be sufficiently fractured to cause permeability. Because of the low dips on the northwestward extension of the Cincinnati Arch, the Maysville and Richmond groups have greater areal extent within the 200- to 500-foot depth range than any other favorable stratigraphic unit (area 3, pl. 1). Preglacial or interglacial valleys, now filled with glacial drift, cause drift thickness to exceed 200 feet at many places in the area.

Silurian system

The lower Silurian Albion series is too thin in southern Indiana to offer potential reservoir sites. An extremely cherty zone, thought to be Albion in age, lies at the base of the Silurian system except near the outcrop. Information available on these rocks is sparse but suggests that they are too fractured to offer satisfactory reservoir conditions.

The rocks of the middle Silurian Niagaran series offer widespread storage possibilities. In southern Indiana the Waldron shale reaches a thickness of 20 feet in Floyd and Clark Counties (area 41 pl. 1). It consists of fairly soft calcareous shale that could be excavated readily and that is probably strong enough to support the required amount of overburden. The overlying Louisville limestone is generally thick-bedded and would furnish an adequate roof.

The Mississinewa shale, also Niagaran in age, consists largely of silty argillaceous dolomitic limestone that should make an excellent reservoir (area 5, pl. 1). If the Mississinewa were not satisfactory for roof rock, the overlying Niagaran limestone should serve this purpose in central and northern Indiana. From Marion County southward, the Mississinewa is directly overlain by Devonian dolomite and dolomitic limestone. The Mississinewa lies at proper depth for storage reservoirs in a long belt that extends from New Albany, on the Ohio River, northward and northwestward to the Illinois line and in an extensive east-west belt just north of the Cincinnati Arch and the structurally positive area that separates the Illinois and Michigan Basins. Typical Mississinewa lithology disappears at both ends of this east-west belt, in northwestern Indiana and near the Ohio line. In the northern two-thirds of the state much of the area outlined to show storage possibilities inthe Mississinewa is dissected by drift-filled bedrock valleys that cause total drift thickness in excess of 200 feet. In addition, the Mississinewa contains Niagaran reefs of vuggy dolomite that locally rule out the possibility of storage reservoirs.

Devonian system

Middle Devonian limestones and dolomites are water bearing at so many places in southern and central Indiana that the possibilities for underground storage in them are generally poor. However, the Silver Creek limestone offers some possibilities in parts of Floyd, Clark, and Scott Counties (area 7, pl. 1). The Silver Creek is drab gray argillaceous silty limestone that is used for manufacturing natural cement. A thin cap of hard, crystalline, thick-bedded limestone is present at most places where the top of the Silver Greek is exposed, but locally the black New Albany shale, which would not constitute a satisfactory roof, lies directly on the Silver Creek. In LaPorte, St. Joseph, Elkhart, Kosciusko, Marshall, and Starke Counties, rocks of Ulsterian age (Middle Devonian) contain dense limestones, locally interbedded with gypsum and anhydrite, that offer storage prospects (area 6, pl. 1).

Upper Devonian rocks in Indiana include the lower 80 feet of the New Albany shale. The upper 20 feet of the New Albany is Mississippian in age. The formation consists mainly of black fissile bituminous shale that has low but recoverable oil content. The New Albany could be excavated readily but is so brittle that it is characteristically fractured and for this reason it may not be sufficiently impermeable. In addition, the shale would not make a satisfactory natural roof. These factors, together with the likelihood of contamination by the organic material in the shale, are discouraging to the storage possibilities of this formation, although zones of noncarbonaceous and nonbrittle shale are known in some areas.

Mississippian system

The oldest Mississippian rocks (Kinderhookian series) are thin in southern Indiana. They include the upper part of the New Albany shale and the Rockford limestone, which probably is not thick enough to act as roof for mined caverns in the shale. In the northernmost part of Indiana the Ellsworth shale, here considered to be Kinderhookian in age, ranges from 40 to slightly more than 100 feet in thickness. Lithology ranges from clay shale to indurated siltstone. Competent beds for roof rock are not present within the shale or as caprock, but if artificial roof support is feasible, the formation offers storage possibilities (area 8, pl. 1).

The Osage series of lower Mississippian rocks offers good storage possibilities in a belt that extends from Harrison and Floyd Counties on the Ohio River northwestward to the Illinois line in Warren County (area 9, pl. 1). In Indiana nearly all the rock of Osagian age is part of the Borden group, which consists largely of shale, siltstone, and impure sandstone. The lowest formation of this group is a thick clay shale (New Providence), which is soft and probably would not support much weight per square foot of pillar. Cavern roofs would be likely to require artificial support. Like Eden shale, the New Providence is greatly affected by water and causes structural failure of roads and buildings. Storage may be possible in the New Providence, but the area in which it lies at favorable depth has not been indicated on plate 1. Above this formation, the Borden group contains a higher proportion of siltstone and argillaceous sandstone. The siltstones and shales should afford good storage sites, particularly at the top of the group, where the overlying Harrodsburg limestone might serve as roof.

Middle Mississippian rocks (Meramec series) are regarded as poor prospects for underground storage because they are water bearing and contain solution and collapse features. Careful exploration may reveal satisfactory storage conditions in some localities, but the area in which depth is favorable has not been indicated on plate 1.

Upper Mississippian rocks (Chester series) consist of alternating sandstone, shale, and limestone units. The shale units that underlie limestones should afford good prospects for storage reservoirs throughout a belt that extends from the Ohio River in Perry County northward to eastern Clay County (area 10, pl. 1). The Chester rocks have been largely removed by erosion north of Clay County. The Chester series, because of post-Mississippian erosion, thins progressively northward through this belt. Both the limestone and the sandstone units locally carry water, and this feature should be checked carefully before a Chester reservoir is planned.

Pennsylvanian system

The lower Pennsylvanian Pottsville series consists largely of sandstone and shale and contains local coal beds in the lower part and regional coal beds in the upper part. Abrupt facies change is common, and extremely detailed prospecting would be required. The storage prospects are considered poor, although shales of a satisfactory nature could be found locally. Competent beds for roof rock might be difficult to locate.

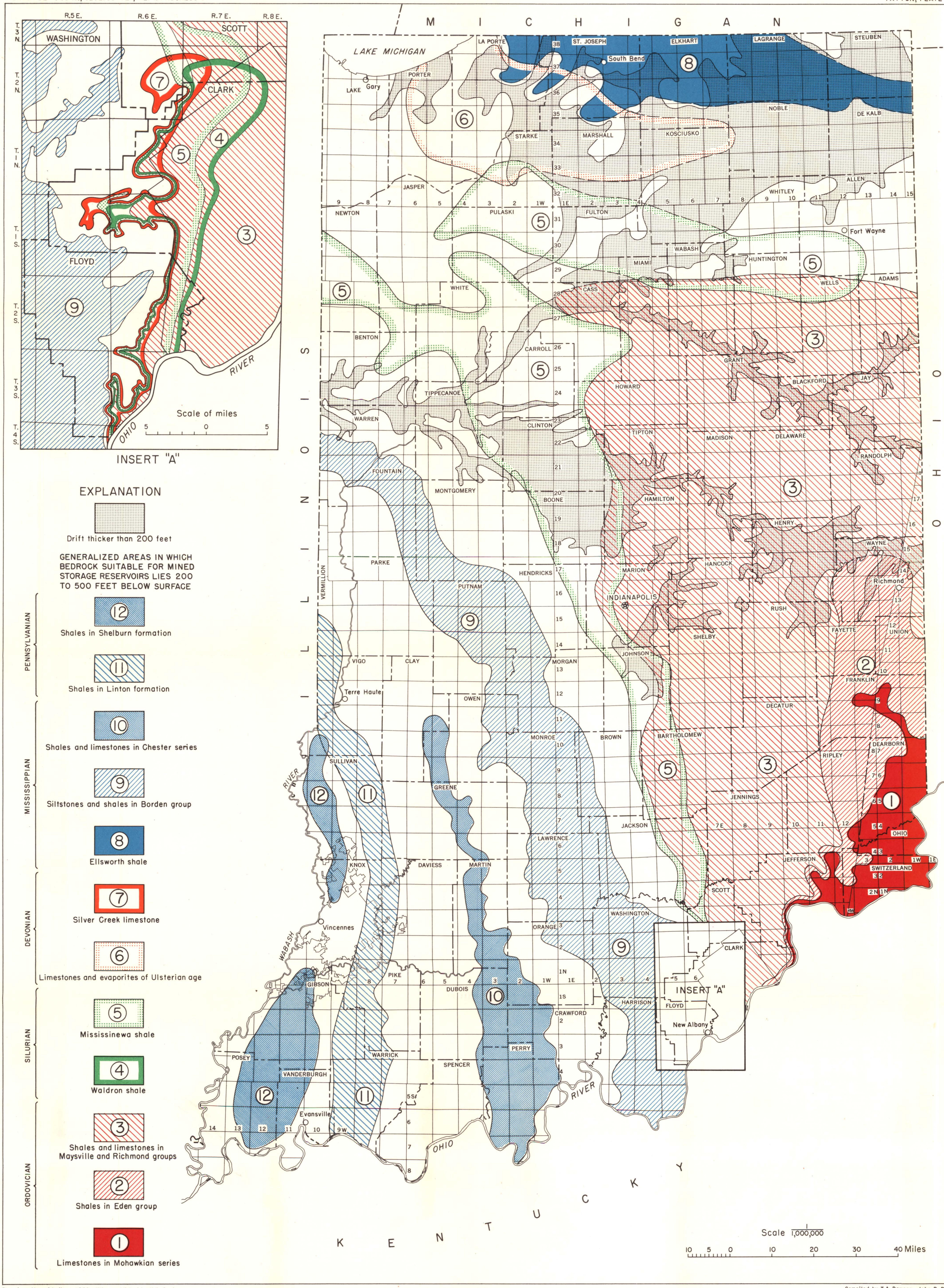
The middle Pennsylvanian Allegheny series consists of shale, sandstone, coal, and limestone. Because of permeability and the possibility of contamination, the numerous coal beds rule out much of this series. However, shales that are commonly present above and below Coal III offer possibilities wherever satisfactory roof conditions can be obtained in a belt that extends from the Ohio River in Warrick County northward to the Illinois line in Vigo and Vermillion Counties (area 11, pl. 1; distribution of shales below Coal III not shown because of scanty data). These shales are locally cut out by sandstones.

The Conemaugh series, which lies at the top of the Pennsylvanian sequence in Indiana, consists mainly of shale, sandstone, and limestone and locally contains coal. Storage possibilities are considered to be good in shales above Coal VII in Knox, Sullivan, and Vigo Counties and above Coals VII and IX in Vanderburgh, Posey, and Gibson Counties (area 12, pl. 1). In most of these areas suitable roof rock maybe difficult to locate. A Pennsylvanian limestone named the West Franklin offers roof possibilities in Posey County, western Gibson County, and the westernmost part of Vanderburgh County. Faults that trend about S. 20° W. have been revealed by oil and gas drilling in this area and should be considered carefully in their relation to storage reservoirs.

CONCLUSIONS

Suitable conditions for excavating underground reservoirs for storing liquid hydrocarbons are present in many parts of Indiana. All the Paleozoic bedrock systems from Ordovician to Pennsylvanian contain potential reservoir sites somewhere within the state (table 1). Storage areas are more difficult to locate in the northern two-thirds of the state than in the southern one-third because of thick glacial drift. The northernmost part of the state contains rock units that are impermeable and that could be excavated readily, but, in general, suitable roof rock is lacking.

The information presented here is entirely regional. Detailed geologic and engineering studies, based on extensive test drilling, will be necessary to select precise locations for reservoirs. Additional and more detailed information on the geology of all the potential storage areas may be obtained from the Geological Survey, Indiana Department of Conservation, Bloomington, Ind. Because published information that pertains directly to sites for excavated reservoirs is scarce, interested persons should visit the Geological Survey in order to use unpublished reports and open-file data.



Base from Map of Indiana, 1950 edition, published by U.S. Geological Survey. Minor revisions and additions made from Indiana Department of Conservation, Geological Survey, county base maps.

MAP OF INDIANA SHOWING FAVORABLE AREAS FOR UNDERGROUND STORAGE OF LIQUID HYDROCARBONS

Compiled by T. A. Dowson, John B. Patton, Arthur P. Pinsak, and Charles E. Wier. Drift thickness by William J. Wayne. June 1955