STATE OF DELAWARE
DELAWARE GEOLOGICAL SURVEY
REPORT OF INVESTIGATIONS NO.4

POSSIBILITIES FOR THE STORAGE OF NATURAL GAS IN DELAWARE

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Newark, Delaware
May, 1961

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INTRODUCTION

Considerable quantities ofnatural gas are used in Delaware; however, there are no facilities for the storage of large quantities of gas within the state. All the gas is "piped in" and distributed by the local public utility companies. These companies are interested in the possibilities for the underground storage of natural gas, but there are no obvious underground reservoirs such as depleted oil or gas fields.

About 95% of Delaware is situated in the Atlantic Coastal Plain Physiographic Province. The unconsolidated sediments of Mesozoic and Cenozoic age, which make up this province, dip gently toward the southeast and thicken "down-dip". Possibilities for the storage of natural gas do exist within the Delaware Coastal Plain, however, the stratigraphy and structure are not understood in enough detail to make any specific recommendations.

GENERAL GEOLOGY OF DELAWARE

General Statement

The state of Delaware extends into two physiographic provinces - the Piedmont and the Atlantic Coastal Plain. A small portion of the State, north of a line drawn between Wilmington and Newark, lies inthe Appalachian Piedmont Province; the rest of the state is in the Atlantic Coastal Plain.

The Piedmont is characterized by rolling hiils which are developed on the Pre-Cambrian or Paleozoic crystalline rocks. The regional structures in this area trend northeast. A weathered zone averaging 35 1eet in thickness mantels the area. The rocks of the Piedmont extend to the southeast and form the basement complex which underlies the Coastal Plain formations.

The Coastal Pla,in portion of the state has flatter topography. The rocks in the Coas'tal Plain 'are predominantly unconsolidated sediments of Mesozoic and Cenozoic age. They strike .northeast and form a wedge-shaped mass which feathers out at the fall line and thickens to approximately 8,000 feet in the southeastern part of the state. Nearly all of the Coastal Plain is covered by a relatively thin mantle of Pleistocene sediments.

The boundary between the Coastal Plain and the Piedmont is termed the Fall Line. Alongthis line the topography changes from hilly to flat and the rocks change from crystallines to sediments. The streams which cross this zone often develop rapids or small waterfalls due to the difference in the ease of erosion of the two types of rocks.

Piedmont Province

Glenarm Series

The oldest rock units known in Delaware are the Cockeysville marble and the Wissahickon schist. Both of these formations belong to the Glenarm series of metasediments.

The Cockeysville marble underlies two small areas in the Delaware Piedmont (see geologic map, fig. 1). In outcrop the rock is a dense, white to light gray, coarsely crystalline limestone; it is sometimes dolomitic. Areas in which the Cockeysviile is exposed are interpreted as unroofed anticlines. At an abandoned quarry site near Pleasant Hill the Cockeysville is tightly folded. The Cockeysville has been quarried for lime in the past.

In Delaware, the Wissahickon schist directly overlies the Cockeysville marble. The Wissahickor i. highly variable mica schist which contains several small bodies of amphibolites as well as several generations of pegmatites. At the Wooddale Quarry a small mass of granite occurs in the Wissahickon and there is a small body of serpentine near Mount Cuba.

The age of the .Cockeysville marble and the WissahicLon schist is open to question. Although they were first considered to be pre-Cambian (Bascom & Miller, 1920) it has been suggested more recently (Watson, 1957) that they may be equivalent to'the less highly metamorphosed lower Paleozoic' rocks of nearby Pennsylvania. They have probably been subjected to several regional deformations culminating with the Appalachian Revolution,

Wilmington Complex

The eastern and southeastern portion of the Delaware Piedmont is underlain by rocks of igneous origin. The various rocks of this area are known collectively as the Wilmington complex. The Wilmington complex comprises roughly one-half of the Delaware Piedmont. Ward (1959) has divided the complex into several rock units and describes each in detail.

The largest part of the complex consists of a banded gneiss which occupies most of the eastern part of the area. Near the center of the banded gneiss, north of Wilmington, an area of about 4 square mile" is underlain by the Arden granite. According to Ward (1959, p. 1438) the Arden granite "... in some places has the composition of a true granite". It'appears to be intrusive into the banded gneiss. Towards the southwest the banded gneiss grades into amphibolites of varying compositions. A small stock of gabbro intrudes the banded gneiss at Bringhurst, north of Wilmington. Similar stocks form Iron and Chestnut Hill near Newark, Delaware, and Grays Hill near Elkton, Maryland. The relationship of the last three masses mentioned is unknown because they are inliers and each is surrounded by Cretaceous and Pleistocene sediments.

A small area west of Newark is underlain by the Port Deposit granodiorite. The Port Deposit is an extensive unit in nearby Maryland. Near Newark it is intrusive into the amphibolites of the Wilmington complex.

The main structural features of the complex parallel those of the Cockeysville marble and Wissahickon schist. This may indicate simultaneous deformation•. The Arden granite and the gabbro stocks probably intruded the older rocks (banded gneiss and amphibolites) at a time very late in the regional metamorphism for they are not deformed; Ward (1959, p. 1456) suggests that the Port Deposit granodiorite "... may be in part older and in part younger than..." the gabbro.

Coastal Plain

Rocks similar to those of the Piedmont province are known to extend far beyond the Fall Line and to make up the basement complex upon which the homoclinal Coastal Plain sediments are deposited. The homocline dips gently to the southeast, toward the Atlantic Ocean. Each unit dips slightly less than the underlying unit. The individual units thicken down dip. The maximum total thickness reaches about 8,000 feet in the southeastern corner of the state. Except for the marine Cretaceous outcrops in banks of the Chesapeake and Delaware Canal and the various sand and gravel pits in the Pleistocene, the Coastal Plain sediments are very poorly exposed in Delaware. ,Facies changes are common between butcrop and down-dip wells.

Triassic System

Rocks of Triassic age are not definitely known in Delaware; however, they are reported from deep oil test wells in Maryland not far south of the Delaware state line. Anderson (1948) states that in both th Ohio Oil Company's Hammond No.1 well, near Salisbury, Maryland and the Socony-Vacuum Oil Company's Bethards No. 1 Well, near Berlin, Maryland strata occur which are referable to the Newark series of Triassic age on the basis of their lithology. In the Bethards well the Triassic consists of indurated conglomerate, red and green sandstone and reddish-brown and greenish-gray shales and sandy shales. Anderson places the top of the Triassic system in the Bethards well at approximately 6, 566 feet (30'el.). He recognizes 585 feet of Triassic sediment from the well. In the Hammond well, the Triassic is 135 feet thick and the top of the unit is at a depth of 5, 363 feet (70' el.). The relationship of the Triassic sediments to the underlying basement or to the overlying Cretaceous sediments is unknown.

The proximity of such a thickness of Triassic sediments to Delaware suggests that rocks of Triassic age may occur at similar depths in southeastern Delaware.

Cretaceous System

The sediments of the Cretaceous System of Delaware may be referred to an older, non-marine section and a younger, marine section. The non-marine Cretaceous consists of the Lower Cretaceous Patuxent and Patapsco formations (Potomac group) and the Upper Cretaceous Raritan formation according to Miller (Bascom and Miller, 1920). Groot (1955, pp. 25-26) found that the Patuxent, Patapscp and Raritan formatiolls connot be reliably differentiated in the field in Delaware. Various

autho'rs have assigned different ages within the Cretaceous to the non-marine deposits. Recent palynological studies by Groot and Penny (1960) have led to the conclusion that the non-marine sediments range from Lower Cretaceous to lower Upper Cretaceous age. The fact that the greater thickness of the non-marine section belongs to the Lower Cretaceous is shown by samples from wells near Delaware City, Delaware and Salisbury, Maryland.,

The sedim,ents are variegated clays and sandy clays with lenses of fine to coarse sand. Some of the sands may be channel deposits. The outcrop area, which is manteled by a thin layer of Pleistocene sand, occupies a band about 10 miles wide adjacent to the Fall Line. The non-marine Cretaceous sediments are reported by Anderson (1948, pp. 92-94) to reach a thickness of about 5,230 feet in a well 100 miles down dip near Ocean City, Maryland. The non-marine Cretaceous sediments dip southeast about 30 feet per mile.

The overlying Magothy formation is thought to represent the transitional phase between the deposition of the non-marine and marine Cretaceous sediments. Where it is exposed in the banks of the Chesapeake and Delaware Canal, the Magothy consists of black, lignitic clays, brown silty sands and fine to very coarse, cross-bedded, clean white sands. It reaches a thickness of about 30 feet in the Canal outcrops. The Magothy is recognized by Rasmussen, Groot and Depman (1958) as occupying the interval from 1,283 feet to I, 385 feet in a cored well at Dover Air Force Base near Dover, Delaware.

The Merchantville is the oldest of the truly marine Cretaceous formations in Delaware. The Merchantville together with the overlying Wenor-ah formation constitute the Matawan group. In the exposures in the Chesapeake and Delaware Canal the Merchantville is a dark blue to black, poorly sorted glauconitic and micaceous, silty, quartz sand. The contact between the Merchantville and the Wenonah is gradational. TbeWenonah is a brown to gray, fine, well sorted quart;z sand with small amounts of mica and glauconite. A characteristic of the Wenonah formation is the presence of numerous tubes of uncertain origin which have been called Halymenites major Lesquereux. In outcrop the Merchantville is about 30 feet thick and the Wenonah is about 10 feet thick. Both formations appear to become somewhat calcareous and more glauconitic down dip.

Above the Matawan group are the sediments of the Monmouth group. Groot, Organist and Richards (1954) bave described two formations of the Monmouth group from the banks of the Chesapeake and Delaware Canal. The Mount Laurel and Navesink formations, named from exposures in New Jersey, could not be differentiated in Delaware and are treated as one unit, the Mount Laurel-Navesink formation. The Mount Laurel-Navesink, in outcrop, is a dark-green, fine, poorly sorted, highly .lauconitic, silty, quartz sand. It is often highly fossiliferous.' It grades upward into the Red Bank and appears to grade downward into the Wenonah. The Mount Laurel-Navesink is about 10 feet thick at the canal. The Red Bank formation, which overlies the Mount Laurel-Navesink, is a reddish-brown, fine to medium, fairly well sorted, quartz sand.

In the Dover Air Force Base well, 35 miles down dip from the outcrop, the interval assigned to the Monmouth group consists of gray, glauconitic silts and clays. In this well the top of the Monmouth group, which is also the top of the Cretaceous System, occurs at 980 feet.

Tertiary System

, Paleocene Series. Rocks of Paleocene age are not definitely known to crop out in Delaware. Paleocene sediments are, however, present in the subsurface. The well at Dover Air Force Base penetrated more than 100 feet of gray, glauconitic silts and clays belonging to the Paleocene. This section is believed to be equivalent in age to the Hornerstown formation of New Jersey and to the 3rightseat formation and a part of the Aquia formation of Maryland.

Eocene Series. Greensands of probably Eocene age crop out in southern New, Castle County. These sediments are' referred to the Rancocas formation on the 1906 geologic map (Miller 1906). Paleontological evidence, .however, 'is limited to the subsurface; work currently in progress at the Delaware Geological'Survey suggests that a rather complete Eocene section is present. The lower part of the Eocene section in the Dover Air Force Base well consists of gray, glauconitic silts and clays. Above the silts and clays the greensands reach a thickness of 250 feet. At Dover the top of the greensand occurs at -310 feet (sea level datum).

Miocene Series. The Miocene series is known mainly from water wells in central Kent County.

It is described by Marine and Rasmussen (1954, p. 45) as consisting of three units of clay separated by two units of sand. The Miocene is almost entirely unknown farther down dip where stratigraphically higher units, chiefly silts and fine sands, are added to the section. The Miocene deposits constitute the Chesapeake group (Clark, Mathews and Berry, 1918, p. 218).

Pliocene (?) Series. Gravely sand which occurs in thin patches on the uplands north of Wilmington and 1n nearby Pennsylvania has been called the Bryn Mawr gravel. No direct evidence for the age of the Bryn Mawr gravel exists. It is referred to as Pliocene (?) by Bascom and Stose (1932).

Quaternary System

Pleistocene Series. The Pleistocene deposits of Delaware consist of tan sands and gravels with some dark, clayey silts and silty clays. These deposits mantel the entire Delaware!Coastal Plain. In the northern portion of the state they are coarser than in the south and often take the form of stream channel deposits. In southern Delaware the Pleistocene sediments reach a thickness of 100 to 150 feet.

POSSIBILITIES FOR NATURAL GAS STORAGE IN DELAWARE

General Statement

Delaware does not produce nor has it produced any natural gas or natural petroleum products of commercial value. At the present'time, the state does not store any natural gas underground although most of the gas marketed in the state is natural gas. Deiaware is experiencing a period of economic expansion and population growth. If this expansion and growth continue, heavier demands will be placed upon the public utilities which supply natural gas. The suppliers of natural gas must concern themselves with "peak days", that is very cold days when the heaviest demands are made by the consumer. If the situation should ever arise that much heavier demands are made by the domestic consumer, the suppliers might find that they had to divert the gas being used by the industrial customer to the domestic consumer resulting in a financial loss to the industrial customer. This situation is, of course, highly undesirable and the only solution is that the gas supplier must increase the gas supply on peak days. In order to do this the suppliers must be able to store large quantities of gas, or produce their own gas.

One of the desirable characteristics for gas storage is a location close to the market area so that the gas may be delivered quickly. This is an advantage which the gas suppliers in Delaware do not enjoy. All of the natural gas is piped into the state by the Transcontinental Gas Pipe Line Corporation of Houston, Texas. It therefore would be highly desirable to develop, within the state, areas which would serve as storage reservoirs for natural gas. At present, there is no known structure suitable for the storage of natural gas, however, more detailed study of the stratigraphy of the state and more research on rock units which may be suitable for gas storage could lead to the development of reservoir sites.

The desirable and/or necessary characteristics for a gas storage field include: location close to the market area, well defined limits of closure so that the gas does not migrate, high total capacity and suitable confining pressure or strength of the enclosing rock unit, and a suitable method for injecting and withdrawing the gas quickly. Some of the formations in the Delaware Coastal Plain have, or could develop, all of the features except the well defined limits of closure. This is not to say that there are no suitable structures in the Delaware Coastal Plain, only that structures with this potential have not been discovered or developed.

Pre-Cambrian and Paleozoic Rocks

The Pre-Cambrian and Paleozoic crystallines of Delaware are not very suitable for the storage of natural gas. Although some of the foliate rocks may have suitable porosity and volume to hold considerable quantities, it is doubtful that there are any traps which would retain the natural gas. An important roll which the crystallines may play in providing suitable areas for the storage of natural gas is the effect they may have in controlling structures in overlying sediments in the Coastal Plain Province.

Mesozoic Rocks

Rocks of Mesozoic age in Delaware are chiefly Cretaceous, although Triassic sediment may form a wedge in the southern part of the state, Layers of conglomerate, sandstone, and shale of Triassic age

are reported from some deep wells in Maryland a few miles south of the Delaware State line. Such a mixtu're of porus and non-porus beds may make excellent conditions for the storage of natural gas, however, at the present time one can only speculate as to the continuity of these beds, and the possibility of their having sufficient closure.

Unconformably overlying the Triassic sediments and the crystalline basement complex, are the sediments of Cretaceous age. The lower part of the Cretaceous section is composed of non-marine sands and clays. It is believed that some of these sands are channel deposits. This fact combined with the southeasterly dip of the formations may provide excellent conditions for the storage of natural gas but again the subsurface stratigraphy is not understood in enough detail to make any specific recommendations.'

The Magothy formation overlies the non-marine Cretaceous section. It is composed of lignitic shales, mixed with cross-bedded, quartzose sands. These sands are also channel or near-shore marine deposits and conceivably could provide reservoirs for the storage of natural gas. The Magothy formation is over 100 feet thick at Dover, Delaware.

The Magothy is overlain by typical marine formations of the Matawan and Monmouth groups. The Matawan group grades from silts and clays near the base to fine sands at the top. The sandy members of this group have sufficient porosity and permeability, in the area in which they outcrop, to act as storage reservoirs. However, down dip they tend'to become more clayey and impervious. The Monmouth group which overlies the Matawan is composed of fine to medium sands which also have sufficien porosity and permeability for storage. Once again, however, the problem is finding a structure with suitable closure.

Cenozoic Rocks

The Cenozoic rocks of Delaware are chiefly of Paleocene, Eocene, Miocene, and Pleistocene age The Paleocene and Eocene parts of the section are similar to the Upper Cretaceous marine deposits previously described. They consist of marine shelf deposits of silt and sand with sufficient porosity to store natural gas but no proven structures which would serve as traps. The greensands of this series act as aquifers in the central part of the state. Structures may be developed locally in the upper margins of these sands due to the unconformable relationship of the overlying beds. If suitable structures are present, the lower Tertiary greensands could probably be used for the storage of natural gas.

The Miocene series is composed of alternating layers of sand and clay which wedge out towards the northwest. The top of the series dips approximately 9 feet per ,mile while the bottom of the series dips approximately 18 feet per mile. Within the series, there are alternating layers of sand and clay which presumably could supply storage reservoirs. In addition, there may be sand lenses in the Miocene sediments which might provide small storage areas.

The Miocene is unconformably overlain by Pleistocene gravels, sands and clays. The unconformable relationship which the Pleistocene has to the underlying strata no doubt provides suitable structures as far as closure is concerned, but the Pleistocene sediments make up only a thin mantle which covers the state and are not of sufficient thickness or strength to provide the necessary pressure required to contain large quantities of natural gas.

Summary

There are no areas which have been proven suitable for the storage of natural gas in Delaware; however, there are several possible areas which may deserve investigation. These possible storage beds are here listed, figure 2 shows these potential areas diagrammatically. (1) The erosional surface on the top of the pre-Cretaceous crystallines may have been responsible for forming structural or stratigraphic traps in the Cretaceous sediments which unconformably overlies the crystallines. (2) The Triassic wedge in the southern part of the state may form a stratigraphic trap. (3) In the non-marine Cretaceous formations, high porosity channel deposits and sandy lenses may provide storage beds. (4) High porosity channel deposits in the Magothy formation may be surrounded by impervious clays and form a trap. (5) Limited greensand layers in the marine Cretaceous and lower Tertiary may also be suitable for gas storage. (6) Stringer sand bodies and sandy wedges which are unconformably overlain by impervious clays in the Miocene section may provide excellent traps.

THE USE OF NATURAL GAS IN DELAWARE

All of the gas sold in Delaware at the present tinJe is natural gas with the exception of propane-air which is sold and distributed by the Georgetown Service and Gas Company and liquified petroleum gasses sold in bottles and tanks in other communities having no distribution system. All of the natural gas is piped in by the Transcontinental Gas Pipe Line Corporation of Houston, Texas. This gas is chiefly methane of 0.59 specific gravity and heat content of approximately 1040 B. T. U. per cubic foot.

The two major distributors in the state are the Delaware Power and Light Company and the Eastern Shore Natural Gas Company. Delaware Power and Light supplies gas *to* the northern part of New Castle County and Eastern Shore Natural Gas Company services the remainder of the state. Table 1 shows the actual or estimated sale of natural gas in Delaware for 1959, 1960, and 1961.

Table 1

Sales of Natural Gas in Delaware for Three Years

Year	Estimated or Actual	Annual Sales in MCF (thousand cu. ft.)
1959	Actual	9,698,968
1960	Estimated	11,368,400
1961	Estimated	13,816,600

With the expected rise in population and increasing industrial demands, the sales of natural gas in Delaware will probably continue to increase. The only storage facilities in the state are those owned by the city gas distribution companies. Several of these companies have 30, 000 gallon propane storage tanks and propane air plants. These plants are generally used for peak shaving and emergency standby supplies.

REGULATIONS AFFECTING NATURAL GAS STORAGE

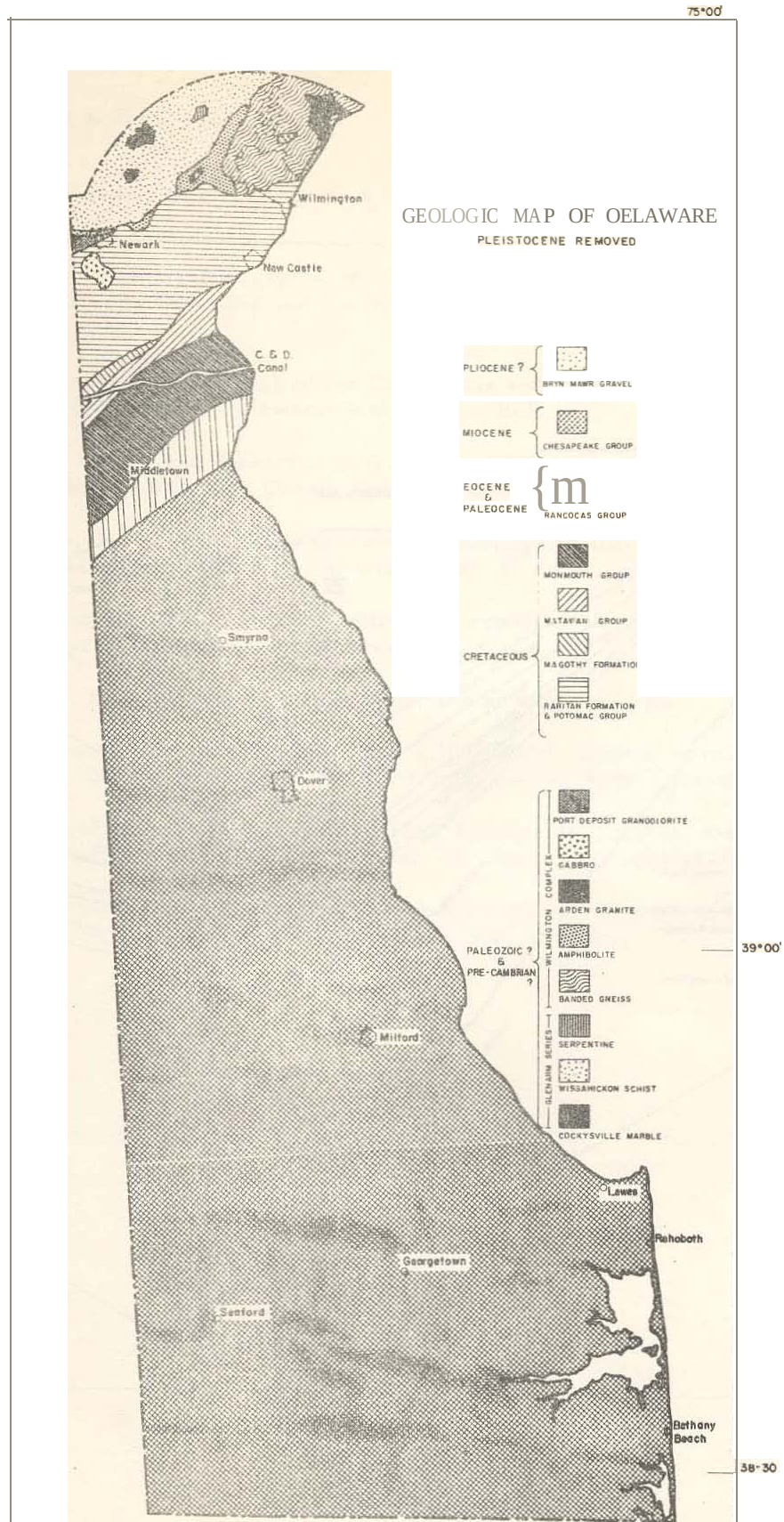
There are very few Delaware State legal regulations which would affect the storage of natural gas in Delaware. Storage would be, of course, subject to federal regulations which are more precise and detailed than any Delaware statutes. State legislation would depend on the circumstances of any particular case involving the storage of natural gas but might very well be subject to public utility regulations. By statute, .a public utility includes everyone who operates any "manufactured gas, (or) natural gas ... service, system, plant or equipment, for public use." (Z6 Del. Code, #101). The Public Service Commission has general regulatory supervision over all public' utilities and their property (Z6 Del. Code, #121). The Public Service Commission also controls public utilities entering upon a public utility activity (#16Z).

Another chapter of the law relating to gas companies gives corporations organized for "production, distribution and sale of gas" certain powers with respect to the installation of equipment, laying out pipelines, etc. Some language in this law, as well as the general common law, is to the effect that gas companies have a duty to conduct their activities so as not to endanger life or interfere with the use of other property. Any contamination or pollution of property such as soil, surface water, and ground water due to the storage of natural gas would be prohibited by common law (personal communication with the Office of the Attorney General). In Delaware, as in most of the eastern states, the natural resources beneath the land are the property of the land owner.

RECOMMENDATIONS AND SUMMARY

The poss.ibility of the storage of natural gas in Delaware is questionable. At the present time, no suitable structures are definitely known; however, potential areas may be inferred from the limited information of the general stratigraphy of the state. The writers do not believe that any area in the extreme northern part of the state would lend itself to the storage of natural gas because of the dense, crystalline nature of the rocks in that area. However, possibilities do exist in the Coastal Plain.

The expected increase in the demand for natural gas, both by domestic and industrial consumers, makes Delaware an excellent location to consider for the development of natural gas storage sites. It is not expected that state legislation would be a serious problem when considering the storage of natural gas in Delaware although the storage company would probably corne under the control of the Publicj Service Commission.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GEOLOGIC MAP OF OELAWARE
PLEISTOCENE REMOVED
PLIOCENE ?
BRYN MAWR GRAVEL
MIOCENE
CHESAPEAKE GROUP
EOCENE & PALEOCENE
RANCOCAS GROUP
CRETACEOUS
MONMOUTH GROUP
MATAWAN GROUP
MAGOTHY FORMATION
RARITAN FORMATION & POTOMAC GROUP
PALEOZOIC ? & PRE-CAMBRIAN ?
WILMINGTON COMPLEX
PORT DEPOSIT GRANODIORITE
GABBRO
ARDEN GRANITE
AMPHIBOLITE
BANDED GNEISS
GLENARM SERIES
SERPENTINE
WISSAHICKON SCHIST
COCKYSVILLE MARBLE
Wilmington
Newark
New Castle
C. & D. Canal
Middletown
Smyrna
Dover
Milford
Lewes
Rehoboth
Georgetown
Seaford
Bethany Beach

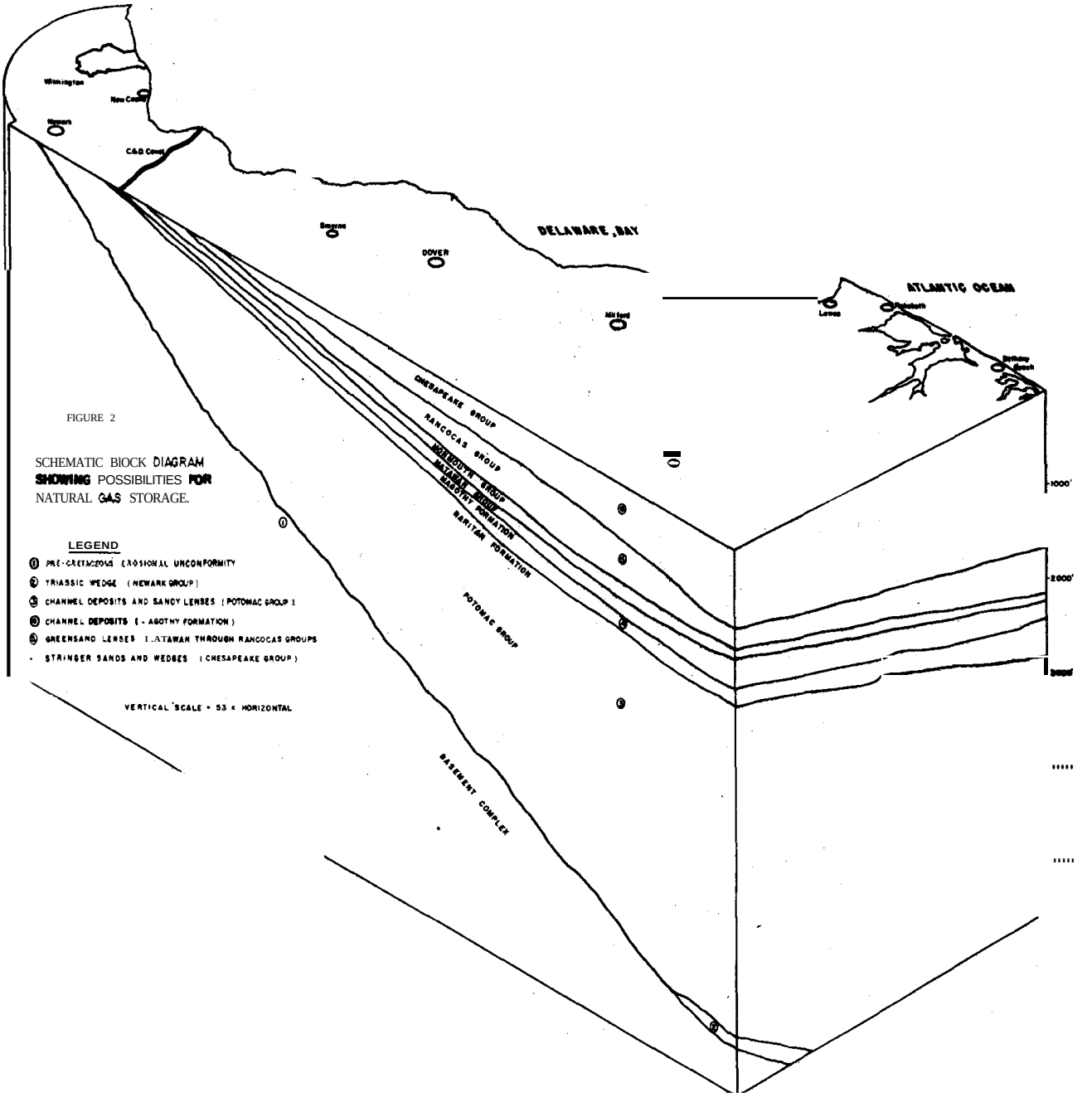

FIGURE 2

SCHEMATIC BIOCK DIAGRAM **SHOWING** POSSIBILITIES **FOR** NATURAL GAS STORAGE.

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