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STATE OF MICHIGAN

DEPARTMENT OF ENVIRONMENTAL QUALITY
GEOLOGICAL SURVEY DIVISION

Report of investigation #3

GEOLOGY FOR LAND AND GROUNDWATER DEVELOPMENT IN WAYNE COUNTY, MICHIGAN

BY

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PREFACE

This report is a summary of geologic information for Wayne County. It has been prepared primarily for engineers and planners who frequently need geologic data for proposed construction projects, site development, and land use planning. It should also serve as a useful reference for teachers, students, and others.

The main objectives of this project have been two-fold: to depict the surface and subsurface geology of the county on a series of maps, compiled at the same scale, and to include some discussion of geologic and hydrologic principles making the maps and illustrations more meaningful to the reader.

The task of gathering, locating and evaluating the well and test boring data used in the compilation of the bedrock topography and drift thickness maps began several years ago. This facet of the project, to a significant degree, was supported by funds provided by the United States Department of the Interior as authorized under the Water Research Act of 1964, Public Law 88-379.

Firms, agencies, and individuals contributing data for this project were simply too numerous to acknowledge individually. Nonetheless, all were important and are appreciated. Major contributors include: 0. 0. Corsaut and Company, Raymond Concrete Pile Company, Michigan Drilling Company, Michigan Department of State Highways, and Wayne County Road Commission.

In a project of this kind, a great deal of data plotting, checking, and correcting of basic data is always necessary prior to the final drafting of maps and illustrations. These tasks were diligently performed by Eugene I. Smith, Jon E. Salsburg, Dan W. Walchak, and John Alwin, students in the Department of Geology. The author is indebted to Mrs. Patricia L. Mozola for many hours of her time devoted to data acquisition and subsequent assistance in the field. Finally, Mr. Robert W. Kelley of the Michigan Geological Survey accepted the task of editing the text. His many comments and suggestions for improvement of this report are not only duly acknowledged but sincerely appreciated.

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GLOSSARY

Acidizing	Injecting acid, usually under pressure, into calcareous rocks to increase porosity and permeability by partial removal of mineral constituents.
Aggregate	Sand and/or gravel mixture suitable for mortar or concrete when mixed with cement or other bonding agents.
Alluvium	Clastic sediments deposited by recent streams.
Basement complex	Rock series of complex composition and structures beneath a sedimentary rock sequence. Usually Precambrian age but occasionally younger.
Calcareous	Containing calcium carbonate ($CaCO^3$)
Carbonate	A salt or ester of carbonic acid; compound containing the radical CO^3.
Overburden	Glacial or recent deposits resting on bedrock.
Potable	Suitable for human consumption.
Stratigraphy	The study, description, and correlation of stratified rocks. Beneath land surface.
Subsurface Tectonic	Pertaining to rock structures resulting from the deformation of the earth's crust.

Abstract

Knowledge of subsurface conditions can be an important consideration for future construction, site development, and land use projects. This report deals essentially with the subsurface geology of Wayne County, Michigan, and is intended primarily as a reference for those engaged in planning activities. The principal feature of this report is the series of county maps (in pocket), half inch-to-the-mile scale, that depict bedrock geology, bedrock topography, glacial drift thickness, and glacial geology.

Because water becomes involved directly or indirectly with many projects, this report briefly describes the bedrock and glacial deposits that are present beneath the county and the occurrence of ground-water in such materials. A small scale bedrock map of the state and a Michigan Stratigraphic Nomenclature Chart are also included in this report to show the relationship of the geology of Wayne County to the rest of the state.

INTRODUCTION

Each of us, in his daily movements, observes the changes that have taken place since the end of World War II. These changes reflect the increasing demands of an expanding population that is expected to reach a total of 350 million people by the year 2000. An overwhelming majority of these people will reside within the ever-expanding urban complexes that are becoming a way of life in this country. As a direct consequence, problems concerning pollution, conservation, and the regulation of our water and mineral resources are developing faster than our ability to find answers. Obviously, the problems of urban planning will multiply and, therefore, it is clearly evident that land must be put to the best of all possible uses. The many problems arising from diverse interests, economics, emotions, and politics, at any given moment in time, will make absolute solutions difficult, if not impossible, to attain. Compromises will be necessary but they should be based on factual data and translated into measures assuring the optimum development of our land, water, and mineral resources. The decisions that are ultimately made will involve people from many disciplines, both social and scientific, working together.

Among the disciplines concerned with the governmental, sociological, and the physical problems of these urban complexes, geology is most concerned with the physical aspects. Master planning involves the evaluation of the advantages and disadvantages of one use of land as against another. In this evaluation, consideration must also be given to subsurface geologic details, not only to the surface features of the landscape. Only in rare instances has geology been seriously applied, in advance, to zoning or project planning in this county. As a result, man through neglect or unavailability of geologic information has placed structures on unsound materials; has failed to consider depth to bedrock in terms of foundation structures and costs; has placed structures or subdivisions over land acreages underlain by nonmetallic resources having economic potential; or has otherwise overlooked geologic advantages which could have contributed to the economic or aesthetic betterment of the community. Our resources are not unlimited, as we are prone to believe at times. As long as man insists on living in close quarters he creates problems relating to land use, raw materials, construction, waste disposal, and pollution of his environment. Resolving land use problems in urbanized areas does require the skills of many disciplines including that of the geologist.

PART I -- BEDROCK GEOLOGY

Relation to Michigan Basin

Michigan, geologically speaking, is a structural basin in which layers of sedimentary rock dip inward from all directions toward the central area of the Southern Peninsula. This arrangement of strata is comparable to a set of shallow mixing bowls of different diameters that have been nested together. Because of this gentle dip, or inclination, a rock formation outcropping along the margin of the state becomes more deeply buried by progressively younger formations toward the center of the basin. If the overlying unconsolidated glacial deposits could be completely stripped away, thus exposing the bedrock surface, the gently inclined strata would appear as concentric, but irregular, bands of varying widths as shown in the small geologic map of Michigan (in pocket). On any traverse outward from the center of the basin, the age of the formations encountered beneath the glacial deposits is always from youngest to oldest. The basin structure originated in the geologic past by slow tectonic movements within the crust and so extends beyond our state boundaries into adjacent areas of Ohio, Indiana, Illinois, Wisconsin, and the Province of Ontario, Canada.

Figure 1 -- Pre-glacial physiographic features influenced the deployment of ice lobes.

The bedrock surface of Michigan is a highly irregular surface. The major physical features of this hidden surface consist of dissected uplands and lowlands. The uplands stand at elevations between 600 to more than 1000 feet in some areas, the lowlands between 400 and 600 feet. Wayne County, except for its western-most extremity, is situated on the Erie-Huron lowland along the southeast margin of the Michigan basin.

Stratigraphy

The sedimentary rock strata beneath Wayne County are composed of materials deposited in ancient salty seas during the Paleozoic Era. The sequence of the resulting rock formations, ranging from the Coldwater Shale of early Mississippian age (youngest) to the Lake Superior Sandstones of late Cambrian age (oldest), is depicted in Chart I (in pocket). These Paleozoic strata, in turn, rest on the Precambrian basement complex consisting of crystalline rocks of igneous and metamorphic origin.

Sedimentary rocks are usually subdivided into two broad categories, namely clastic and nonclastic. Clastic rocks are composed of fragments or grains that have been consolidated e.g., shales, siltstones, sandstones, breccias, and conglomerates. The nonclastics are chemical or biochemical precipitates from sea water and are usually crystalline, e.g., gypsum, anhydrite, rock salt, limestone and dolomite; the latter two are often termed "carbonate rocks". Most clastic rocks contain varying amounts of chemically, or biochemically, precipitated salts usually as a cementing material, and most nonclastics contain some clastic material in varying proportions. Sedimentary rocks of high chemical purity (high-calcium limestone, high-quartz sandstone) or of highly uniform physical characteristics are often important non-metallic resources. Unfortunately their occurrence is limited; they are exceptions rather than the rule.

Chart 1 provides both outcrop and subsurface nomenclatures. Where rock exposures are readily accessible for study, the outcrop nomenclature that has developed is more widely used and generally more detailed with respect to the names of formations and smaller rock units. On the other hand, subsurface nomenclature is often less refined since the recognition of rock units is largely dependent on samples, as well as cuttings and cores, recovered during drilling. Highly refined subsurface nomenclatures exist for those rock units having a proven economic value. However, most of our knowledge of the Michigan basin has been obtained from subsurface investigations.

Furthermore, the correlation of a particular stratigraphic unit in the subsurface in one area with that of another some distance away may be complicated by a transitional change of lithology. The unit may be a true limestone in one area, elsewhere a dolomitic limestone, dolomite, or even a calcareous shale. Similarly, the upper and lower boundaries of a given unit may vary physically resulting in added difficulties in recognizing its upper and lower contacts. In Chart 1, the contacts of stratigraphic units are shown by either straight or jagged lines, the former indicates sediments in the ancient seas were deposited more or less continuously from one unit to the next; whereas, a jagged line implies the withdrawal of the seas from the region and that some of the previously deposited sediments were removed by .erosion. For example, an erosional interval is indicated along the bottom contact of the Sylvania Sandstone. In some parts of the state, the formation rests directly on the Bois Blanc Formation; elsewhere it rests on other formations considerably older than the Bois Blanc. This relationship is termed an unconformity and represents an interruption in the stratigraphic sequence. Where a project requires the recognition of rock units and their correlation from one area to another, a geologist familiar with stratigraphic details should be consulted.

If additional information and examination of samples are required with respect to a proposed or an active project, the State Geological Survey in Lansing maintains a file of oil and gas well logs, a library of rock cuttings, and a file of electric logs. In addition, the Survey maintains a file of water well logs most of which provide data pertaining to the nature of the materials encountered in the glacial overburden. Subsurface sample libraries (cores and rock cuttings) are also maintained by the principal state universities. A useful reference entitled "Sources of Geological Information" is published by the Michigan Geological Survey.

Descriptions of the bedrock formations in outcrop beneath the drift in Wayne County are given in the appendix of this report.

Economic Potential

Sedimentary rocks are noted for their nonmetallic resources. Some of them such as limestones and dolomites, along with sand and gravel associated with glacial deposits, are basic to many industries. Their combined dollar value often exceeds the metallic resources both in Michigan and the nation. Unlike the metals, most nonmetals have a high "place" but a low "unit" value; a fact not usually appreciated because of the widespread occurrence of these deposits. Their seeming abundance, however, becomes greatly curtailed since a nearby consuming market is required for raw materials characterized by low unit values. Further curtailments are imposed by such factors as overburden thickness and chemical and physical quality which directly affect accessibility and the potential use, or uses, to which these "seemingly" abundant materials are put. Ironically, the expanding population which creates the demand for these resources has already eliminated thousands of acres of land with mineral potential. Finally, the physical and chemical characteristics of rock formations can, and usually do, vary drastically within short distances, thus further limiting the supply of the total resource available.

The physical and chemical uses of carbonate rocks are so numerous that they cannot be listed here. As a rule they must be carefully sampled and tested for their specific use, or uses, before a program for their extraction is started. If nothing more, many limestones and dolomites can be quarried and processed as crushed stone for uses ranging from rip-rap to aggregate material for concrete.

The high-calcium horizons in the Dundee Limestone, Anderdon Formation and Traverse Group are important to the cement, chemical, and agricultural industries. High-purity dolomites in the Detroit River Group have potential for refractory bricks, linings, and as a future source of magnesium. High-calcium limestone and high-purity dolomite are used as fluxing agents in the iron and steel industry. Among the clastic rock units, the Sylvania Sandstone, because of its high content of quartz, is a major raw material for the glass, chemical, and refractory industries. Other clastic rocks such as shales are used in brick, tile, and pottery making. Those with good bloating characteristics are in demand by the light-weight aggregate industry. Depending upon alumina content, shales are basic to cement production. The Traverse rock unit contains both high-calcium limestone and shale for making of Portland cement. The availability of these raw materials for economic development is limited to a great extent by the thickness of the overburden and existing land use zoning ordinances. Predicting mineral resource changes and demands is another matter. As an example, in some areas of the United States the shortage of available high-calcium limestone reserves at the surface is so acute that the stone is now extracted by underground mining methods.

The economic potential of rock formations below the Sylvania Sandstone includes oil and gas (Northville area), salt, gypsum, anhydrite and natural brines.

The Bedrock Geology Map (Plate 1)

This map depicts the approximate areas of outcrop of the sedimentary rock units beneath the glacial overburden of Wayne County. Due to the county's position along the southeast margin of the structural basin, the outcrop areas occur as irregular bands trending northeast-southwest. These units have a regional inclination, or dip, to the northwest with each unit becoming more deeply buried by progressively younger beds in the direction of dip (Figure 2—centerspread— "Geologic Structure Sections"). The inclination is very slight, often less than 50 feet per mile. The angle of inclination is not always constant since rock flexures within the larger basin structure are also present. Variations in the width of an outcrop of a particular rock unit can be affected by its angle of dip, its thickness, and the topography of the bedrock surface.

Mapping subsurface rock units is not without its difficulties. Of hundreds of test borings and well records obtained for Wayne County only a small percentage, principally oil and gas logs, were useful for geologic map compilation. These logs are prepared by geologists experienced in the recognition of subsurface rock units largely from well cuttings, and occasionally cores, in the course of drilling operations. Logs of water wells and test borings contribute very little towards the compilation of geologic maps unless the bedrock present beneath the overburden is penetrated and the driller is capable of recognizing the rock unit. This is rarely the case with such records. Therefore, the detail that can be presented on the Wayne County geologic map greatly depends on the number of points per given area for which the underlying rock units have been identified in the subsurface. In many instances, the similarity in litho-logic characteristics of two or more successive rock units makes differentiation between them difficult. Thus, some rock units appearing on the county geologic map consist of two or more formations which, elsewhere in the state may be mapped separately because of better quality and more abundant records or, perhaps, they are exposed and so accessible for detailed study.

It should be clearly understood that the rock unit boundaries that appear on the map have been established from subsurface records and hence are largely inferred; their accuracy with respect to position depends on the density and distribution of known pieces of information. If a new boring encounters the Dundee Limestone, rather than the Traverse Group as perhaps shown on the map, the inexperienced user is apt to question the validity of the entire map. The geologist, on the other hand, considers the new boring an added control point and modifies the formation boundary on the map accordingly. On the county geologic map, some formation contacts have strong northwest extensions conspicuously interrupting their regional northeast-southwest trends. This pattern results from the variation in the dip angle of the rock units and topographic irregularities in the bedrock surface.

In summary, a bedrock geologic map should be considered a progress report, never a final product. Each new bit of information increases its accuracy. Generally speaking, formation contacts appearing as relatively straight lines or smooth curves indicate minimal control. Conversely, crooked or jagged contacts suggest an abundance of control points.

The Bedrock Topography Map (Plate 2)

The irregularities in the bedrock surface beneath the glacial overburden were developed initially by erosion long before the glacial episode, and subsequently modified by repeated glacial invasions during Pleistocene time. Except in the extreme west, the county occupies the Erie-Huron lowland underlain by sedimentary formations older than the Berea Sandstone. The extreme western portion is within the southeastern and lowermost slope of the Thumb upland surface underlain by the Berea Sandstone and younger formations. Thus, the highest bedrock elevations are in the western and northwestern parts of the county. The maximum relief of the bedrock surface is approximately 252 feet.

The altitude of the rock surface of the Erie-Huron lowland is between 475 and 575 feet above sea level except where incised by former stream valleys. These valleys appear fairly broad, between 50 to 100 feet in depth, and become narrow and more sharply defined as they approach the Thumb upland surface. The valley network indicates a regional drainage to the northeast. Whether these valleys are glacial or pre-glacial in origin has not been determined. Of particular interest is the bedrock valley coinciding approximately with the course of the Detroit River. Today the river flows south, while the bedrock gradient slopes northeast. From present boring data, the head of this rock valley appears to terminate in the vicinity of Grosse lie which forms part of an east-west bedrock divide in the southeast part of the county. This divide extends eastward into the Province of Ontario and westward into Monroe County. At Grosse lie, another bedrock valley slopes southward and, on the basis of mapping completed for Monroe County, must be tributary to a bedrock valley in the vicinity of Maumee Bay, Ohio.

Joining the Detroit River valley, in the vicinity of Belle Isle, is another bedrock valley that trends northwest for a distance of 25 miles to the City of Pontiac, and presumably terminates at the bedrock divide of the Thumb upland surface in Oakland County. The axis of this valley coincides with Woodward Avenue (U.S. 10) passing through, or near, the cities of Hamtramck, Highland Park, Huntington Woods, Royal Oak, Birmingham, and Bloomfield Hills (Mozola, 1954). This valley has a depth of 75 to 100 feet, a width of nearly two miles at its junction near Belle Isle, but decreases in width to one mile at the Wayne-Oakland County line.

Other defined rock valleys, 50 to 75 feet deep, passing through or near the cities or villages of Redford, Northville, Plymouth, Belleville, and New Boston extend from the southeast margin of the Thumb upland with either southeasterly, easterly, or northeasterly trends but eventually converge in the Detroit area. Cutting across this fan-shaped arrangement of bedrock valleys is a northeast-southwest cross-cutting channel that appears to lie approximately along the boundary between the Thumb upland and the Erie-Huron lowland surfaces. The cross-channel extends from the northeast corner of Redford Twp. (T1S - R10E), trends southwest for several miles and, thence, to a more southerly course through the towns of Wayne and New Boston. From there, the cross-channel takes a southwest course again through Sumpter Twp. (T 4S - R8E) where it leaves the county. Additional investigations suggest continuation of this cross-channel into both Oakland County to the north and Monroe County to the south. Other minor cross-channels are also indicated; one immediately east of Romulus and another to the west of Plymouth.

Channels do not usually cut across inter-stream divides in the normal development of valleys. Therefore, an explanation of these cross-cutting channels is warranted. Preexisting uplands and lowlands influenced the movement of the vast Pleistocene ice sheets. The ice invaded Wayne County from the southeast (Figure 1). Thus, if the eastern portion of the county was occupied by ice to a position just east of the principal cross-channel and, if the ice front were more or less static, then the normal drainage from the deglaciated portion of the Thumb upland slope would be impeded, resulting in a series of lakes in the valleys in front of the ice. As the level of the impoundments rose, water would spill across the lowest points along the interstream divides and erode connecting channels between them. Drainage at this moment would be to the south or southwest because the areas to the north, northeast, and southeast would still be occupied by ice lobes within the Saginaw and Erie-Huron lowland areas. If this interpretation is valid, then additional cross-channels, both large and small, will be revealed as the bedrock topography is mapped in greater detail in the future.

In contouring any irregular surface, the results depend on scale and the number of elevation points. For surfaces visible to the eye or camera, an accurate detailed contour map can be compiled by conventional surveying methods or by sophisticated photogrammetric techniques. Obviously, for hidden surfaces, this cannot be true inasmuch as both the density and distribution of control points, as shown by the small circles or the bedrock topography map, are controlled by the availability of existing well and test boring data. Rarely are control data sufficient to accurately portray the topography of a buried bedrock surface. The philosophy used in compiling formation boundaries on geologic maps, is also used in compiling a bedrock topography map. Each new verified bit of information adds to the detail. Where bedrock elevations are numerous, the contour lines are usually very irregular in form; where lacking, they tend to appear as fairly straight, or gently curving, lines. The major bedrock valleys are not of simple form as depicted on this map but most probably are irregular and interrupted by numerous tributary valleys. The rock surface for the northern part of Sumpter Twp. (T 4S -R 8E) and the adjacent area of Van Buren Twp. (T 3S - R 8E) is not a flat plane, or bench, as suggested by the contours, but a dissected surface comparable to the divide separating the conspicuous bedrock valleys near Plymouth and Northville (T IS - R 8E). In using this type of map, interpretation of details is not simply desirable, but necessary. Like geologic maps, the subsurface bedrock contour map must be revised periodically as new records become available.

PART II -- GLACIAL GEOLOGY

Nature of Glacial Deposits

Resting directly on the bedrock surface is an unconsolidated overburden of glacial origin, termed drift, that varies greatly in thickness and composition. Its character and distribution and the features it forms on the landscape are related to the Pleistocene ice masses which advanced over the irregular pre-glacial surface of the Great Lakes region. More detail on the glacial geology of southeastern Michigan is available in the works of Leverett and Taylor (1915), Sherzer (1917), Stanley (1936), Bay (1938), Bergquist and MacLachlan (1951), Hough (1958), and Wayne and Zumberge (1965).

Drift is composed of loose fragmented rock particles varying greatly in size and composition. It is deposited directly by the glacial ice, or by the action of melt-waters issuing from the ice. The former produces unsorted deposits often rich in clay, or clay mixed with varying amounts of coarser particles. Deposits of this description are called till, and they constitute the moraines and till plains. Materials deposited by glacial meltwaters are sorted, stratified, often cross-bedded, and usually low in the clay- and silt-size fractions. Landforms composed of these sediments include outwash plains, marginal outwash, glacial spillways, eskers, kames, and kame terraces—classified as glaciofluvial deposits. In contrast to till, they are more favorable to the transmission of ground water.

The following concepts should be kept in mind in viewing the glacial overburden: (1) glaciers can deposit debris both as till and glaciofluvial materials during both advance and retreat of the ice front, (2) the position of the ice front fluctuates, (3) the volume of meltwater varies during a given year as well as from year to year, (4) the ratio, or volume, of outwash to till is smaller during an advancing ice front (cooling climate) but becomes progressively greater as the ice front retreats (warming climate), and (5) Michigan experienced several major episodes of glaciation. Hence, the variety and complexity of sediments in the drift ranges all the way from ice-deposited clay-rich till to meltwater (glaciofluvial) sediments with many possible gradations between the two extremes. Sharp demarcations between till and glacio-fluvial sediments are exceptions rather than the rule. Changes in the lithology of the sediments are usually subtle.

Movement of an ice mass over an established land surface disrupts the pre-existing drainage by impounding formerly existing streams and converting them to lakes. This is evidenced by such features (glaciolacus-trine) as beaches, bars, deltas, sand plains as well as silty and clayey lake beds. Inland from the old lake beaches, wind-deposited sand dunes may be present.

Drift Thickness Map (Plate 3)

In Wayne County, the thickness of glacial drift varies from a minimum of 20-30 feet in the southeast corner to a maximum of 390 feet in the northwest. The thick cover of 210 to 390 feet in the Plymouth-Northville area is the morainic landscape which contrasts sharply with the gently sloping glacial lake plain characterizing most of the county. Though the lake plain is essentially flat, the glacial overburden is not of uniform distribution. Its irregularities strongly reflect the topography of the underlying bedrock surface.

In preparing the drift thickness map, the well and test boring records used were the same as for the bedrock topography map. Inasmuch as the density and distribution of these primary control points was far from ideal, supplementary points representing estimated thickness were plotted for each 160-acre tract. The estimated value for each of these points represents the difference between the elevations of the bedrock surface and ground surface. This method assures that contour trends exhibited on the drift thickness map conform to features in the bedrock surface.

Glacial History of Wayne County

The present surface features of Wayne County were formed during the Wisconsin stage (youngest) of Pleistocene glaciation, as modified by subsequent erosion and deposition. Materials forming the present surface features do not necessarily extend downward to bedrock. It is probable that some of the buried material was deposited during glacial episodes prior to the Wisconsin stage. For example, the hardpan encountered just above bedrock in the downtown Detroit area may date from the Illinoian ice age which preceded the Wisconsin.

The position and succession of glacial features found in Wayne County are related to the advance and withdrawal of the Erie-Huron ice lobe. In the northwest corner of the county, are two northeast-southwest moraines, the Outer Defiance and Inner Defiance, separated by a narrow band of outwash. Moraines are ridge-like hilly deposits, essentially till, formed along the margin of a nearly static ice front, in this case the Erie-Huron lobe. Some sand and gravel deposits, as kames and kame terraces, occur on the surface in association with the morainic hills, and also as bodies of various magnitude interspersed at different depths within the moraines. Till deposited as a flat or gently rolling terrain, rather than hilly accumulations in well defined belts, forms a feature known as a till plain or ground moraine. Thus, small areas of till plain are also associated with moraines. The marginal outwash consists of sand and gravel deposited by meltwaters confined by the Outer Defiance Moraine to the northwest and by the stationary ice front to the southeast which, at the time, was forming the Inner Defiance Moraine. Marginal outwash deposits can contain subordinate amounts of till and also may be underlain by till. The highest point in the county, 972 feet, occurs within this morainic area.

From the southeast limit of the Inner Defiance Moraine, marked by the highest glacial lake shore line shown on Plate A, the remainder of the county, nearly four-fifths, is a southeast-sloping plain of low relief incised by present streams. From an elevation of 800 feet in the northwest, the plain declines gradually to 574 feet at the Detroit River, a difference of 226 feet in 22 miles, or, a gradient of about 10 feet per mile. This feature is part of the glacial lake plain of southeastern Michigan—a terrain veneered with sediments deposited in lakes ancestral to our present Great Lakes. The geologic history of lake stages, represented by shore lines on the map, is described in detail by Hough (1958) and summarized by Kelley and

Farrand (1967). The waters forming the lake were impounded by the higher morainic topography to the northwest and by the shrinking Erie-Huron ice lobe to the southeast. The level of any particular lake stage depends upon the elevation of its outlet. When an outlet persists for a considerable time, waves and currents develop shore lines and associated beach features. As the several ice lobes in the Great Lakes region advanced and retreated, different outlets were covered and uncovered, determining the levels of each particular lake. Remnants of several beaches at different elevations are found in Wayne County today. Behind the shore lines, winds formed small sand dunes subsequently modified by rising water levels and wind erosion.

As the Thumb upland was deglaciated, streams built deltas in the ancestral lakes. Declining lake levels resulting from lower outlets uncovered by the retreating ice-front caused existing streams to extend their courses downstream. Thus, the lower segments of streams such as the River Rouge and the Huron River are younger than their upper parts. Alluvial materials were deposited along their flood plains. Downcutting by these streams occurred whenever their base levels were lowered during the retreat of the shore lines of the former lakes. As a result, some of the flood plain deposits are now alluvial terraces standing well above the present flood plains of the larger streams, particularly along their uppermost segments. Whatever materials were deposited by the ice mass directly or indirectly in the area of the lake plain, the resulting surface was undoubtedly reworked by the waters of the ancestral lakes and subsequently veneered with lacustrine sands, silts, and clays. Beneath this veneer may be expected till deposits as ground moraine and as water-laid moraines. Inasmuch as the retreat of the ice was marked by occasional minor readvances, even lacustrine sands, silts, and clays can be found buried beneath the present surface.

Summary of Glacial Features (Plate 4)

The landscape of Wayne County consists of till features as moraines, till plains, and their water-laid counterparts in the lake plain area; glaciofluvial deposits as marginal outwash, kames, and kame terraces; glacio-lacustrine materials as beaches, deltas, offshore bars, and lake bottom sands, silts, and clays; glacio-eolian deposits, as sand dunes and plains, deposited behind the various beaches but which have since been modified. Along the flood plains of the principal water courses are alluvial deposits of late Pleistocene and Recent age. Those of the Pleistocene age now stand as terraces above the floor of the present flood plains. For a more complete interpretation of the origin and composition of glacial features with respect to the glacier ice regimen, the reader is referred to Flint (1957).

The surficial geology map was compiled essentially from the works of Sherzer (1916) and Russell and Leverett (1915) with some modifications. Since the original mapping, some of glacial features just described have been modified by man. The boundaries delineating most of the glacial features are gradational. Very few are sharply defined.

Economic Potential

The Pleistocene and Recent deposits are significant sources for nonmetallic minerals: sand or gravel for the construction industry; clay for cement, lightweight aggregate, brick, tile, and pottery industries; peat and marl for agricultural and horticultural purposes. Above all, the glacial overburden constitutes an important reservoir of ground water.

PART III -- GROUND WATER

Introduction

Though the development of ground-water resources for public water supplies in Wayne County may not be immediately important, in view of present development of additional supplies from Lake Huron, nevertheless, ground water is directly or indirectly involved with problems resulting from man's occupancy of the land. Furthermore, in geologically favorable areas, ground water should be developed for special uses. At some depth, the glacial drift and the underlying bedrock formations are saturated with water, but the occurrence, movement, quantity, or quality of ground water can be reasonably determined only by geological investigations and hydrologic tests. Wells drilled into the saturated portion of permeable surface deposits result in water-table wells that are usually successful in terms of the required yield; those attempted in saturated surface clays, or clay mixtures, produce such small quantities of water they are often designated as dry holes. In terrains underlain by tills or clays, water supplies are obtained from wells penetrating permeable sand and gravel bodies that are partially or completely enclosed by materials of lower permeability. These wells, whether flowing or non-flowing, are termed artesian. Thus, ground water in subsurface materials can be under both unconfined (water-table) and confined (artesian) conditions.

Hydrologic Principles

The water table represents a surface below which the soil and rocks are saturated with water provided interconnected voids are present in the materials. This surface thus delineates the upper vadose zone (unsaturated) from the saturated ground water zone. The water table rises or falls in response to precipitation. When it declines, the vadose zone increases, a seemingly unfavorable condition. On the other hand, this decline provides for more ground-water storage during the next wet period, thus reducing flood potential. A temporarily saturated vadose zone increases runoff and stream flooding. As a surface, the water table is not a smooth plane but one which, if it can be seen, approximates the topography of the land surface. It should be appreciated that surface topographic and hydrologic features influence the configuration of the water table.

Figure 3 -- The water table reflects surface topography but is modified by man's activities.

Porosity is the percentage of void space in any given material. The interstices between grains in unconsolidated sediments are primary porosity. Rock formations, in addition to primary porosity, also have secondary porosity, e.g. joint systems, irregular fractures, bedding planes, solution channels, and other openings. When interconnected, they form an effective porosity. Porosity allows for ground-water storage which, when determined quantitatively, is designated "storage capacity".

Permeability is the ease with which a liquid or gas moves through a porous medium, and is expressed quantitatively as the "coefficient of transmissibility". It represents frictional resistance that the materials offer to the passage of water. Though porosity must exist for material to possess permeability, high porosity does not necessarily imply high permeability. Clays commonly have high porosity but sand and gravel with lower porosity can have appreciably more permeability. In bedrock formations, shales are less permeable than sandstones, limestones, or dolomites. Porosity-permeability relationships govern the infiltration of water into the subsurface and its movement underground. Though infiltration may constitute only a fraction of a particular rainfall, the total amount stored over a large area can be significant. Because reservoir materials may possess considerable variations in their lithology, both laterally and vertically, the direction of ground water movement is complex and difficult to determine.

Water-table, or unaonfined, aonditions: Water seeks its own level. In Figure 4, the subsurface materials are assumed to possess uniform bulk characteristics (isotropic) . Since the stream valley serves as a discharge outlet, the slope of the water table that has developed indicates not only the head available for ground water movement, but also the direction in which it is moving. The path taken by an individual water particle is a compromised one between gravity and the water table gradient. Since materials in this case are isotropic, smooth but curving flow lines result. This has been demonstrated in laboratory ground water models (Harshbarger et al, 1963).

Wells in Figure 4 are water-table wells because the water level in each stands at or near the level of saturation of the sediments surrounding the well. When the well is operated, water is withdrawn from the aquifer at a rate exceeding the natural rate of movement through the material. Hence, the saturated sediments immediately around the well are de-watered first, developing a "cone of depression" in the water table. This dewatering steepens the water-table gradient so that movement of water toward the pumped well nearly balances the amount being withdrawn.

Figure 4 -- Movement of ground water under unconfined conditions.

Though the cone, after some period of pumping, appears to be in equilibrium, it does not actually attain that state unless the volume of water withdrawn from storage is replaced simultaneously by recharge into the aquifer. With continued pumping, the cone, after initial development, increases its dimensions very slowly, provided the pumping rate does not exceed the material's coefficient of trans-missibility. Inasmuch as a well in operation is a discharge outlet, the natural flow pattern is modified in the vicinity of the well. In Figure 4, the cone developed by the.pumped well extends beyond the observation well and, in turn, has lowered its water level. Substituting a lake for the observation well shows how a lake level can be affected by heavy withdrawal of ground water. The discharge of well water into the lake for the purpose of raising its level, for example, results merely in the circulation between the surface and subsurface water entities. Cessation of pumping leads to the disappearance of the cone and a nearly complete recovery of the water table to its original level and gradient.

Artesian', or confined, aonditions: The term artesian is often misunderstood. To some, it implies that such wells are always flowing; to others, that the artesian or confined condition represents a system completely independent of ground water under water-table conditions. Except for the inclusion of two clay horizons Figure 5 is similar to Figure 4. Flow lines are now distorted and some water passes through the permeable sediments between the clay layers. Hence, some degree of confinement now exists. As the number of confining beds becomes greater, at the expense of the more permeable materials, a progressively greater degree of confined ground water movement results. Furthermore, when the confining materials are irregular or distorted, the movement of water toward some discharge outlet obviously must travel an irregular path. Devious as that path may be, due to changing lithologies, it is still the path of least resistance, or, the most efficient one in terms of water-head expended.

Figure 5 -- Development of artesian conditions.

Figure 6 -- Relation between artesian and water table conditions.

Figure 6 depicts the relationship between artesian and water-table conditions of ground water occurrence. The artesian condition is represented by a structure consisting of an inclined sandstone aquifer confined between less permeable shales. In the unconsolidated, but isotropic, overburden, a water-table condition prevails. The artesian structure in this example is but one of many possibilities. If the following principles are appreciated then they apply to all other artesian structures whether present in bedrock or overburden.

Piezometrio Levels: Water placed in an upright U-shaped tube will stand at the same level in both ends. An analogous situation (Figure 6) may be traced through well #1, thence into the confined sandstone aquifer, and finally into well #10 and up the dotted lines representing the well casing extended above ground level. In a hypothetical closed, water-tight system with no frictional resistance in the sandstone, the water level in well #10 would correspond to the level in well #1. Line A-B is the theoretical piezometric (water-pressure) surface. The total head, or water-pressure, available for water movement through the structure is indicated by B-D, determined by the highest and lowest water elevations within the sandstone aquifer. Under most natural conditions, a static, water-tight and closed system does not exist because water in a confined formation moves and eventually discharges at some outlet. Also, water may penetrate confining beds, even though slight, producing a loss of head through leakage. In addition, water moving through the interstices of the sandstone must overcome frictional resistance resulting in a further loss of head. These combined losses equal B-C. The line A-C, therefore, is the actual piezometric surface. The actual piezometric surface is a pressure surface—not a water-table surface. It indicates the height to which water from the sandstone aquifer, if given the opportunity, would rise in a well at a particular site. Noting the relation of the piezometric level to the ground surface and the water table, the following points can be logically summarized from Figure 6:

Figure 7 -- Wells and lakes depend upon location in a drainage basin.

1 — Ground water occurs under both water table and artesian conditions, constituting a single system—not separate and independent entities. For the water table wells (#1, 4, 7, 8, 9) the depth to the water table is largely a matter of local topography. However, the seasonal variation in the water level of each well depends upon position within the drainage basin (Figure 7). The seasonal fluctuation of the water table is greatest at the divide and the least in the area adjacent to a stream. Wells (#2, 3, 5, 6, 10) penetrating the sandstone aquifer are artesian and in each case the water rises to the piezometric surface. An aquifer is classed as artesian whenever its water pressure is greater than atmospheric pressure.

2 — Flowing artesian wells (#5 and 6) occur where the piezometric level is above the ground surfaces; non-flowing artesian wells (#2, 3 and 10) result where the piezometric level is below ground surface. Intermittent flowing wells (3) occur where the piezometric and ground surfaces intersect inasmuch as both water table and piezometric levels rise or fall in response to precipitation. Since permeability varies within the confined aquifer due to changes in lithologic characteristics, the piezometric surface is not a smooth inclined plane, as shown, but highly irregular.

3 — A flowing well is an effective discharge point. Pressure loss is greatest at the well and diminishes radially, producing a cone of pressure relief. Other flowing wells situated within the dimensions of this cone would be affected in terms of discharge. The situation is analogous to the lessened discharge at a household faucet whenever another one is opened. Each flowing well produces a cone of pressure relief and, when wells are closely spaced, a composite cone results. When the combined discharge from closely spaced wells exceeds the natural recharge into the confined aquifer, the piezometric surface declines. This results in the failure of flowing wells, one by one, within the area as the piezometric surface is gradually lowered down to, and eventually below, the ground surface. The cone of pressure relief is not to be confused with a cone of depression developed under water table conditions; the latter represents an actual dewatering of sediments, whereas, the confined aquifer remains completely saturated but the pressure of water has been reduced. Non-flowing artesian wells must be equipped with pumps, and when in operation also produce cones of pressure relief but which are developed below the ground surface. When pumping is discontinued the cone of pressure relief recovers. The effect on nearby wells is again analogous to the recovery in pressure and discharge from a faucet whenever others have been closed.

Figure 8 -- Schematic geologic cross-section showing nine different aquifers and their corresponding piezometric levels.

4 — Exchanges of water between confined and unconfined aquifers is a common occurrence. Assuming water table well #9 represents a municipal field consisting of several wells, heavy withdrawal will produce a large, composite, cone of depression whose apex may extend below the piezometric level of the confined aquifer at that point. Induced infiltration of water from the aquifer into the overburden takes place through cross-bed leakage, bedrock fractures, or by way of buried rock valleys that extend to the confined sandstone. Thus, mineralized water is introduced into the overburden containing fresh water of higher quality. Conversely, heavy withdrawal from an artesian field, represented by well //2, reduces the water pressure in the sandstone aquifer so that its piezometric level drops below the water table, resulting in movement of fresher water from the overlying shale and overburden into the confined aquifer.

Occurrence in Glacial Drift

Figure 8 schematically illustrates ground water occurrence in the diverse lithology of glacial drift and the underlying bedrock. It approximates a northwest-southeast section of the glacial lake plain in the Wayne County area. To the left of this section the terrain rises northwest towards the several distinct morainic belts beyond which lies the interlobate moraine. This latter feature developed in the re-entrant between the Saginaw and Erie-Huron ice lobes (see Figure 1), and hence situated along the Thumb upland divide. The interlobate area consists of extensive glaciofluvial deposits with interspersed tracts of till. The importance of the glaciofluvial materials lies in their high permeability that is favorable for recharge by precipitation. Because the water table is a subdued replica of the ground surface, it also rises to the northwest. To the right of the section, the ground surface and the water table decline southeast to the level of Lake Erie.

The dissected bedrock surface is overlain by till and lacustrine deposits within which are sand and gravel bodies of various sizes. In Figure 8, note the dominance of till and lacustrine deposits to the permeable materials present under conditions of confinement. For ground water development in clay-rich terrains, the problem is largely one of locating an aquifer in the subsurface that is adequate for the need. The confined aquifers in Figure 8 have diverse origins. Some may be buried beaches, bars, and deltas associated with former glacial lakes. Some may be eskers, kames, kame terraces, or even sand plains and dunes. While others could be glaciofluvial deposits associated with meltwater drainage at the glacier front. The illustration may give an impression that the confined sand and gravel bodies are isolated and hence ineffective as aquifers. However, the aquifer boundaries are usually gradational with the matrix—not sharply defined except on rare occasions. Furthermore, considering their many possible shapes and magnitudes, it is not unlikely that in many instances they are interconnected and hence related to each other. Perhaps this is more clearly illustrated by considering present surface deposits of the region.

Figure 9 shows the surface distribution of sand and gravel deposits of the last glacial episode in southeastern Michigan, with emphasis upon permeable deposits of glaciofluvial, alluvial, lacustrine, and eolian origin. Elsewhere the area is underlain by till or lacustrine sediments of lesser permeability. In plan view, most of these features are interconnected. Their elevation decreases northwest and southeast from the Thumb Upland Surface.

When permeable deposits such as these are buried by glacial till, confinement results which in some instances may be partial. Hence this system of interconnected aquifers of glacial origin is analogous to a municipal water supply system consisting of primary distribution mains and their secondary laterals. Unlike a municipal system, however, the artesian system consists of "conduits" of highly irregular shape and size without booster stations and gate valves to control pressure, volume, velocity, and direction of flow. Calculating these characteristics for any point is difficult. Nor can the data be used to interpolate between points with a high degree of confidence at all times. In addition, where the municipal distribution system is generally watertight, artesian structures are subject to cross-bed leakage because confining sediments are not completely impervious.

How is an artesian system replenished with water? The usual explanation is that some part of the artesian aquifer must outcrop at, or near, the surface to intercept precipitation. This recharge is analogous to the elevated storage tanks of a municipal system. Spot elevations in Figure 9 show a decline in elevation of sandy aquifers (assumed to be confined) from the crest of the system marked by the axis of the interlobate moraine. The difference in water elevation between the highest and lowest points of the system provides the pressure head for water movement.

Figure 9 -- Distribution of permeable surface deposits in southeast Michigan.

Confined aquifers are also recharged by cross-bed leakage. Textbook illustrations of artesian systems unintentionally convey the impression that such aquifers are water-tight. This is rarely true in nature. Permeability in glacial drift is relative—not simply pervious or impervious. For example, a large cross-section of clay till could pass as much water as a small cross-section of sand. A large sand and gravel body, even if enclosed by till of low permeability, can still function as a good aquifer because of the extensive contact with the surrounding till. Furthermore, the more irregular the shape of the confined aquifer, the greater the area of contact. The following example demonstrate the significance of this principle. A till transmitting one cubic centimeter of water per square inch per day at the contact, equals 0.038 gallons of water per square foot, equals 1655 gallons per acre, equals 1.06 million gallons per square mile. Though the aquifers in Figure 8 vary in magnitude and depth, many of them are connected as shown in Figure 9. Very few in all probability occur as completely isolated bodies. All the aquifers and surrounding matrix are saturated with water if they occur below the water table. The withdrawal of water from a deeply confined aquifer results in a greater water pressure differential between aquifer and matrix than might occur if the aquifer were at a shallower depth below the water table. As the water table rises or falls, the pressure differential created between aquifer and till matrix will correspondingly increase or decrease. In summary, the essential points to be noted in Figure 8 are:

1 — In Wayne County ground water is under both confined and unconfined conditions. Surface aquifers can include false water tables and can also be partly confined. Heavy water withdrawal from surface, or shallow, aquifers as at site X, can produce almost immediate effects on surface water. These effects often appear in pump tests of short duration. Response of surface water bodies, as well as the water table, to heavy withdrawal from deeply confined aquifers can be slow, and hence, not immediately noticed. Long observation periods are required to detect these responses.

2 — Drift aquifers have varied litho-logies, hence a varying resistance to the passage of water. For the confined aquifers shown, the piezometric level may be either above the ground surface, or within the un-saturated vadose zone, or below the water table. Because permeability varies within each aquifer, piezometric levels are not smooth inclined planes, but irregular surfaces. The preceding comments also apply to bedrock aquifers.

3 — A well at site Y would yield little water and hence classed as a dry hole by drillers. At site Z, the well shown would have several different water-levels reported as drilling progressed into the different aquifers. This should demonstrate the difficulty in compiling plezometric surface and water table maps. For most areas, the number, distribution and details of existing well records allow only for generalized maps.

Availability of Supplies from Glacial Drift

Alluvium: Flood plains and terraces along the larger streams in Wayne County are composed of water-sorted alluvial deposits of sand, gravel, silt, and clay ranging up to 75 feet, or more, in thickness. Ground water in these deposits occurs under water table conditions readily adaptable to shallow wells. Alluvial deposits are not homogeneous, hence they are not entirely without some structure. Thus, the probability of encountering semi-artesian, or artesian, conditions become more probable with increasing depth. Well yields are highly variable ranging from a few gallons per minute to more than 1500—depending upon clastic material, well design, and development procedures. Exceptional yields from alluvial deposits along the Huron and River Rouge valleys were documented by McGuiness (1949). Alluvial aquifers are favorably situated for recharge by infiltration from streams. Distance of the well from river channel determines whether treatment of the water is required. Quality of water is generally good but the total hardness may exceed 200 ppm.

Marginal Outwash deposits consist mostly of sand and gravel with some silt and clay. Outwash is the most favorable glacial deposit for developing high-yield wells. Ground water is generally unconfined, but, again, semi-artesian, or artesian, conditions are likely to be encountered with increasing depth. Out-wash may overly till. In view of the 200 to 300 feet of overburden present in this area, confined sand and gravel aquifers are distinctly possible. Quality of water is usually good but the characteristically abundant carbonate pebbles impart hardness.

Moraines and Till Plains, composed mostly of till, border the marginal outwash deposits. With a total drift thickness varying from 180 to 400 feet, sand and gravel bodies of various size and configuration may occur beneath the surface. Where these permeable aquifers are present in the till matrix, ground water occurs under artesian conditions. Penetration by wells usually results in nonflowing, rather than flowing, artesian wells. Water table conditions occur only in sands and gravels at the surface within the moraines and till plains. Morainic belts are favorable for wells of small to moderate yields. Development of large yields normally requires extensive test drilling and well development. Water is usually fresh but hard. In deep aquifers within the till, quality may be impaired by increased mineral content and hydrogen sulfide originating from the underlying bedrock.

Glacial Lake Plain: This area is least favorable for the development of wells of moderate to large yields. Though the lake plain has the highest frequency of reported "dry holes", small domestic supplies are normally possible. For surface aquifers, ground water is under water table conditions. Storage capacity is considered limited and well failures may be expected during prolonged droughts. Contamination is highly probable by the downward percolation of polluted surface water and effluent discharge from septic tanks. In aquifers buried within the lake plain deposits, ground water occurs under artesian conditions, and both flowing and non-flowing wells can be expected.

Southeast from the junction of the lake plain with the moraines, the frequency of occurrence, the thickness, and extent of buried aquifers decreases toward the Detroit River. The overburden thickness likewise decreases, from approximately 180 to 20 feet. For surface aquifers, the water is usually soft and potable unless contaminated by man. In buried aquifers, mineralization increases with depth. Quality of water from deep artesian aquifers is often impaired by chlorides, hydrogen sulfide and methane gas. One or both gases commonly occur, constituting a severe hazard in excavations and well drilling projects. Hydrogen sulfide is poisonous, while methane is highly explosive. Their presence in ground water cannot be accurately predicted.

Buried Bedrock Valleys: These features are favorable for ground-water development. Besides the increased drift thickness over them, their floors are often veneered with permeable alluvium. Water in them is often high in dissolved minerals, sometimes brackish, occasionally saline—and sometimes contains methane and sulfide gases. This is especially true for valleys eroded into the Antrim Shale.

Occurrence and Availability in Bedrock

Ground water in the sedimentary rock formations in Wayne County occurs under artesian conditions. Water in bedrock moves through pore spaces (primary porosity) and along its fractures, joints, bedding planes, and other openings (secondary porosity). Because of the many possible variations in lithology, both horizontally and vertically, permeability can be controlled by both primary and secondary porosity. Hence, yields from wells in bedrock are also variable. In the absence of sufficient data, meaningful figures on water potential from specific rock units are generally lacking. Initial yields, however, can usually be raised by increasing diameter, deepening, acidizing, or fracturing the rock aquifer.

Limestone and dolomite can be good producers even when finely crystalline, if secondary openings form an effective permeability. Inasmuch as carbonate rocks are relatively soluble, their secondary openings become increasingly enlarged with time making even more effective conduits. If little or no solution has occurred along the secondary openings, the desired yield often can be obtained by deepening the well to intersect a larger number of joints and fractures, or by acidizing.

Sandstones, when loosely cemented, are usually favorable aquifers because they have an effective primary porosity. Shales and siltstones, like clays and silts, normally have low permeability. Recovery of water from shales and siltstones depends largely on movement along secondary openings. These are often tightly closed, or filled with fine sediment, resulting in small yields. The remaining rock types, anhydrite, gypsum, salt beds, and their interbedded sequences with carbonate and clastic material, consistently have low permeability. Furthermore, they are often highly mineralized and therefore not prime sources of fresh water.

Water from bedrock aquifers is usually more mineralized than that recovered from the glacial drift. As a general rule, mineralization increases with depth. Quality also can be impaired by hydrocarbons, hydrogen sulfide or methane gas. The latter two are hazardous to well construction. Potable supplies are possible from most formations within the limits of their outcrop area immediately beneath the drift provided the wells are of shallow penetration into rock. Fresh water from the drift serves to dilute the mineralized water in the bedrock. Both yield and quality become more favorable if the formation, in addition to its joints and fractures, is also highly weathered. Some unusually favorable yields for domestic purposes have been reported from the weathered Antrim Shale in the Belleville area.

Copious, and at times unexpected, quantities of ground water are encountered in excavations into, or approaching, the bedrock surface. In part, the water may be derived from artesian aquifers in the drift. As the bedrock surface is approached, additional artesian flow from rock aquifers into the permeable drift zone sometimes necessitates grouting. This problem is most probable in areas where the glacial drift is underlain by carbonate rocks or sandstones rather than shales. Test boring logs usually note the presence of water. Evaluating the aquifer, however, should also depend upon the character of the underlying rock. Borings are generally small-diameter, hence, provided limited data for estimating water infiltration. Too, each boring is normally grouted before the next is started. A large excavation, on the other hand, is analogous to a large-diameter well in that a much larger cross-section of the aquifer is exposed for water seepage to occur; a more serious situation results when solution enlarged joints in carbonate rocks are uncovered. Water problems in engineering projects are difficult to predict in advance without recourse to adequate boring data. If a water problem is indicated for a proposed project, an aquifer performance test is recommended to determine the storage and transmissibility characteristics of the materials involved.

CONCLUSIONS

This report presents basic geologic information that should be considered prior to site development, particularly in an urbanized area as Wayne County. The maps inclosed in the pocket should be consulted in the first stages of land-use planning, particularly in selecting geologic factors favorable to several types of uses. For example, shallow overburden is favorable to both heavy industry anticipating new plants and to the mineral industries seeking sources of raw materials from bedrock. For both the depth to bedrock is an important economic consideration.

Compiling detailed geologic maps of the surface and subsurface requires gathering a great deal of information over an extended period. Without adequate basic data, sound geologic interpretations are impossible. Nor can geologists see any further beneath the surface than permitted by the data available. Good well and test boring data are not available for every square mile. For this reason planning agencies and municipalities should maintain base maps showing locations of wells and test borings for the area of their jurisdiction or interest. Availability of this information provides future economies since fewer test holes will be required to evaluate future projects.

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APPENDIX

DESCRIPTIONS OF ROCK UNITS PRESENT IN OUTCROP BENEATH DRIFT IN WAYNE COUNTY

Sources: Oil and gas logs, geological reports, and field notes

COLDWATER-SUNBURY FORMATIONS

(Early Mississippian)

These two formations are shown as a single unit because of difficulty separating them in the subsurface. In fact, either one or both may not extend into the county.

Coldwater Lithology: Dominantly shale, micaceous, blue, blue-gray to greenish gray in color becoming reddish and more sandy in upper part. Some reddish and purplish shale, though not widespread, near base of section. Occasional lenses or thin beds of dolomite, sandstone, or siltstone. In some areas inter-bedded shale and sandstone horizons appear but not widespread. Clay-ironstones appear to be distinctive (Wooten, 1951). Upper contact of Coldwater difficult to place because it grades upward in lithology and color into the basal beds of the Marshall Sandstone. According to Newcombe (1933) the change from Coldwater to Marshall may be indicated by presence of several varieties of micaceous minerals. Lower contact is recognized by the first definite dark brown to black shales of the underlying Sunbury Shale. Outcrop: Outcrop beneath glacial drift in county is extremely doubtful. No surface exposures.

Sunbury Lithology: Shale, hard, dark brown, dark gray to black, with traces of dolomite. Lithologically similar to the Antrim Shale but lacking the abundance of fossil plant spore cases. The Sunbury probably thickens to the north and northwest. Lower contact usually placed at first consistent appearance of the light-gray to blue shales, or the light gray, fine-grained sandstones of the underlying Berea formation. Thickness: If present, not more than 20 feet. Outcrop: Narrow band of doubtful extent beneath drift in westernmost Northville, Plymouth, and Canton townships. No surface exposures.

BEREA-BEDFORD FORMATIONS

(Mississippian and/or Devonian unassigned)

Berea Lithology: Sandstone and shale. Fine-grained, micaceous, white, gray, light drab to brown sandstone in beds of varying from 25-40 feet thick. Nearly everywhere separated by equal thicknesses of gray to blue-gray shales having sporadic zones of calcareous or dolomitic material. The sandstone is well-cemented but friable. Waterbearing horizons are occasionally encountered. Lower contact with underlying Bedford is not easily recognized due to similarity of shale beds. Thickness: 0 to 60 feet. Outcrop: see below.

Bedford Lithology: Dominantly shale. Generally light gray, limey or sandy shale with sporadic dark gray horizons. Occasional micaceous sandstone and/or shaly dolomite or limestone. Lower contact of Bedford is usually placed at the first persistent appearance of the dark brown to black Antrim Shale. Thickness: 0 to 100 feet. Outerop: Because the Berea-Bedford contact is difficult to recognize in the subsurface, the two formations are shown as a single unit. Outcrops beneath the drift in northwest and north-central parts of county. No exposures.

ANTRIM SHALE

(Late Devonian)

Lithology: Mostly a dark brown to black bituminous shale. Finely laminated and fissile. Frequently described by water-well drillers as "black slate". Some gray shale may appear near base. Pyrite and/or marcasite nodules present throughout. Hard, black to brown, crystalline, and nearly spherical concretions are usually present in lower part. These concretions, composed of the mineral "anthraconite" (a petroliferous variety of calcium carbonate), often exceed 3 or 4 feet in diameter and may be mistakenly logged as limestone beds during drilling. An excellent outcrop revealing these concretions occurs at Kettle Point, Ontario. Also characterized by an abundance of very small, but visible, disc-like resinous and reddish-brown structures, identified as fossil spore cases of floating fossil plants. Lower contact of the Antrim is uncertain because basal gray beds resemble the blue-gray shales of the underlying Traverse Group. Thickness: 0 to 145 feet. Outcrop: Band of irregular width trending ENE-WSW in the northern one-third of the county. No exposures.

TRAVERSE GROUP

(Middle Devonian)

Lithology: Shales, limestones, and dolomites not subdivided into separate formations in the subsurface. Shales are usually blue-gray to gray, occasionally brown, containing some thin calcareous or dolomitic beds. The limestone and dolomite beds have varying thicknesses and are occasionally cherty. Limestone beds are light-gray, gray, or gray-brown, fine to coarse grained, high in calcium and at times so fossiliferous as to be called "shell limestone" by drillers. The dolomite beds are normally gray or buff. Ratio of carbonate rock to shale varies considerably, but gradually, from one area to another. Some logs show a dominance of shale over carbonate materials; others the opposite. Pyrite is common. The Traverse-Dundee contact in the subsurface can be difficult to recognize where limestones or dolomites of the Traverse rest upon similar beds of the underlying Dundee. In the Northville area, this contact is reasonably sharp. Thickness: 0 to 273 feet. Outcrop: Occurs as band of varying width trending northeast-southwest through middle of county. The nearest outcrop is in a quarry near Milan in Washtenaw County. No exposures in Wayne County.

DUNDEE LIMESTONE

(Middle Devonian)

Lithology: Gray, buff to light-brown, cherty limestones and dolomites. Finely to coarsely crystalline. The 70-foot section in the quarry at Trenton consists of thin to massive, gray, buff, and bluish limestones containing cherty and siliceous beds, secondary calcite, and fossiliferous zones. Carbonaceous partings between beds. Cavities containing hydrocarbons are common. Frosted quartz sand abundant in basal beds. The lower contact, when resting on limestones of the underlying Detroit River Group, can be difficult to recognize. Thickness: 0 to 152 feet. Outayop: A very broad band trending northeast-southwest within the southeast half of the county. Exposed at Sibley Quarry in Trenton.

DETROIT RIVER GROUP

(Middle Devonian)

Where exposed at surface in the southeast Michigan and northern Ohio, this group has been subdivided (top to bottom) into the Anderdon, Lucas, Amherstburg, and Sylvania formations (Ehlers, Stumm, and Kesling, 1951). With the exception of the Sylvania Sandstone, the other formations are difficult to subdivide in the subsurface, hence shown as a single unit, Detroit River dolomites, on Plate 1.

Lithology: Mostly dolomite, occasionally argillaceous and/or cherty. Gray, buff, light-brown, or white. Finely crystalline to granular. The Anderdon, mostly a high calcium limestone, 20 to 30 feet thick, cannot always be differentiated from the overlying Dundee Limestone. Cavities of irregular shape and size are common. Many contain calcite crystals up to four inches long in a form known as "dogtooth spar". Anhydrite, particularly in the Lucas Formation, occurs in localized lenses or thin beds. The basal beds contain an increased amount of frosted quartz sand grains similar to those in the Sylvania Sandstone. The lower contact is placed at the first persistent appearance of sandstone or dolomitic sandstone of the underlying Sylvania. Thickness: 0 to 300 feet. Outcrop: Prominent east-west band in southern part of county. Uppermost beds are exposed along floor at Sibley Quarry. Formerly exposed at south end of Grosse lie.

SYLVANIA SANDSTONE

(Middle Devonian) Basal formation of Detroit River Group

Lithology: A white to light gray, cross-bedded, fine- to medium-grained, high purity, quartz sandstone. Grains are frosted, sub-angular to rounded and usually poorly cemented. The formation is extremely friable upon exposure to weathering and, when washed and screened, resembles granular sugar. Cavities lined or filled with calcite and/or celestite crystals are common. Down dip toward the center of the Michigan basin, changes to a sequence of sandy dolomites, dolomitic sandstones, and sandstones. Where the upper beds consist of sandy dolomite, differentiation from the basal beds of the overlying Detroit River Group becomes difficult. Basal beds of the Sylvania rest unconformably on the Bois Blanc Formation, and on the Raisin River Dolomite of the Bass Islands Group. In Ohio, the basal beds of the Sylvania Sandstone contain pebbles derived from the underlying Raisin River Dolomite of Silurian age. The Sylvania is oldest formation outcropping immediately beneath the glacial overburden in Wayne County. Thickness: 0 to 250 feet. Outorop: Flat Rock, Michigan.

BOIS BLANC FORMATION

(Middle Devonian)

Lithology: Chert-rich dolomite. Dense to finely crystalline. Gray, white, or buff to brown. Upper contact is an erosional unconformity with an unusual amount of weathered chert. The lower contact with the underlying Bass Islands Group is also marked by an erosional unconformity. Thickness: 28 to 44 feet. Outcrop: Not known.

BASS ISLANDS GROUP

(Late Silurian)

Lithology: Consists of the Raisin River and Put-in-Bay (older) dolomites, usually undivided in the subsurface. Dense to finely crystalline. Light-gray to brown, but some zones are dark gray and/or dark brown. Occasional thin distinct beds, lenses or stringers of chert and anhydrite. Some shales, dolomitic shales, and shaly dolomites with anhydrite generally appear near base. Contact with the underlying Salina Group is very difficult to identify. Thickness: 220-350 feet. Outorop: Not known.

SALINA GROUP

(Late Silurian)

Lithology: A thick section of alternating sequence of carbonates, shaly carbonates, shales and evaporites. The carbonate rocks are essentially dolomite, or shaly dolomite, with occasional limestone. Generally gray and buff-brown to brown. Dense to coarsely crystalline. Some beds characterized by high porosities. Occasional dolomite breccia. The evaporite rocks are primarily salt but appreciable amounts of anhydrite and some gypsum also present. Salt beds vary in thickness from a few feet up to 330 feet. The salt is usually white, though some beds are clear and transparent; others are brown or reddish. The anhydrite is mostly white or tan, occasionally pink, and frequently containing dark streaks or bands. Aggregate thickness of salt beds in Wayne County ranges from 430 to 730 feet. The fine-grained elastics are largely shales, dolomitic shales, with minor amounts of sand. Shales are generally gray to dark gray, but some are brown. In general, the upper half of the Salina sequence is a shale, carbonate, evaporite lithology changing to a dominant carbonate lithology in the bottom third. However, this may not persist areally. Contact with the underlying Niagaran is not easily recognized in the subsurface but could be placed below the last known occurrence of salt and anhydrite. Thickness: 1132 to 1490 (?) feet. Outcrop: Not known.

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