STATE OF DELAWARE

DELAWARE GEOLOGICAL SURVEY

BULLETIN NO. 7

ENGINEERING MATERIALS OF NORTHERN NEW CASTLE COUNTY

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RICHARD F. WARD
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Newark, Delaware
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Prepared in cooperation with
the United States Geological Survey
and the
State Highway Department of Delaware

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ABSTRACT

This investigation was undertaken to locate deposits of rock, sand, gravel, fill and borrow in northern New Castle County which may be potential sources of material for highway construction, and to prepare maps and descriptions of the surficial earth materials relative to their geologic and engineering properties.

Northern Delaware has been undergoing a marked increase in population and industrial activity for over a decade. To construct and maintain a highway system adequate to serve an expanding area requires large quantities of building materials and to do this at reasonable costs local materials must be utilized in the utmost. Stone production in the area has decreased during this decade and although sand and gravel production have increased sharply, deposits have probably been exploited much faster than new ones have been located. The rapid spread of suburban development throughout the area has been attended by increased land values and stringent zoning laws which make it difficult to operate a pit or quarry in most areas and impossible to do so in others.

That portion of New Castle County lying north of a line drawn from Newark to Wilmington is part of the Piedmont physiographic Province and is underlain by igneous and metamorphic crystalline rocks. The metamorphic rocks are a crystalline limestone called the Cockeysville marble and a dense gneissic schist called the Wissahickon formation. Before being metamorphosed these were a limestone and a shale. The Wissahickon formation which underlies most of the northeastern half of the Piedmont has been divided into three zones or facies which show increasing firmness and decreasing schistosity from southwest to northeast. The Cockeysville marble underlies two small areas which are surrounded by schist. The igneous and metaigneous rocks which underly the eastern half of the Piedmont comprise massive gabbro, banded gabbro, amphibolite, granodiorite and granite. Minor intrusive igneous bodies are widespread. The crystalline rocks were subjected to field and laboratory study and their value as potential sources of crushed stone has been investigated. Steep-sided valleys along the White Clay Creek, Mill Creek and the Red Clay Creek often have little overburden, good drainage and stone of the Wissahickon formation of moderate quality. The population density is low in these areas and quarrying may be feasible. The area north of Wilmington is underlain by igneous rock which would make excellent road stone, but the even topography and the spreading suburbs have made most of the rock inaccessible. If the land can be obtained a few places along the banks of the Brandywine Creek are still rural and have good relief. Iron Hill, south of Newark, appears to be a likely place for a quarry. The Cockeysville marble, granodiorite, pegmatite, and serpentine are, for various reasons, unlikely prospects.

South of the Piedmont is the Coastal Plain which is underlain by wedge-shaped bodies of unconsolidated sedimentary formations which increase in thickness to the southeast. The oldest of these are the nonmarine Cretaceous formations which comprise sands, clays, and gravels in small,

irregular bodies. Above these are the younger, marine Cretaceous formations which comprise about one hundred feet of silty and clayey sands. Above the Cretaceous formations and forming the surficial material for more than 95 per cent of the Coastal Plain area is the Pleistocene series, made up of silty and gravelly sands with minor clays. The Pleistocene materials appear to consist entirely of stream and estuary deposits which in this area form one or more alluvial fans. An important feature of the Pleistocene deposits is the presence of ancient channels, now filled with sand. These channels, which are shown on plate 3, were discovered, delimited and described on the basis of the following techniques: outcrop descriptions, power augering, cored drill holes, electrical earth resistivity, well canvass, mechanical analysis and mineral analysis.

Mineral and mechanical analysis of the pre-Pleistocene formations indicate that they usually contain too large a proportion of fines to be suitable for highway work. In addition their position below the Pleistocene series renders them inaccessible in most cases. Analyses of Pleistocene samples show that the materials lying within the mapped channels are consistently of useful character, while Pleistocene deposits of poorer quality tend to lie outside the channels. Future prospecting should be guided by these relationships.

INTRODUCTION

PURPOSE AND SCOPE

This investigation was initiated in July, 1954 to determine the nature and distribution of the geologic formations of New Castle County north of the Chesapeake and Delaware Canal, with particular attention to their engineering properties and their potential as sources of crushed stone, sand and gravel. This account of the investigation is directed mainly to engineers engaged in preparing plans for the great expansion of Delaware's highways which will take place during the next decade.

High grade deposits of sand, gravel and stone are no longer easily located and exploited in Delaware. If high grade materials must be imported from outside the State or if local materials must receive costly processing in order to make them suitable for highway purposes, these facts must be taken into account during the planning. The present study, then, is an attempt to evaluate Delaware's supply of these resources so that the best possible use can be made of local materials particularly where local deposits are undeveloped while similar materials are being imported at great expense.

This report may also be of value to private contractors who are interested in exploiting deposits of sand, gravel or stone for the large local market and who have found old geologic maps and reports out-of-date or otherwise inadequate. The geologic maps and accompanying formation descriptions are intended to supply engineers and planners with complete and accurate geological data, so that foundation, subbase and drainage conditions may be anticipated when highways, structures, dams and other projects are being planned.

PERSONNEL AND COOPERATION

The investigations upon which this report is based were conducted by the Delaware Geological Survey and the U. S. Geological Survey in cooperation with the State Highway Department. W. C. Rasmussen, District Geologist of the U. S. Geological Survey contributed to the planning of field and laboratory work, reviewed the manuscript and prepared the map of the base of the Pleistocene series. The portion of the manuscript dealing with the Coastal Plain was written by the State Geologist, J. J. Groot, and the remainder was written by R. F. Ward. The geologic map accompanying this report was prepared cooperatively by Rasmussen and Groot for the Coastal Plain and Ward for the Piedmont portion. The writers are indebted to many persons for field and laboratory assistance during the preparation of the report. Mr. Stanley Scarborough of the State Highway Department Testing Laboratory generously supplied information concerning properties of and requirements for engineering materials and showed interest in the program throughout its duration. The electrical resistivity study was made under the supervision of H. Cecil Spicer, Geophysicist, Fredrick K. Mack, Geologist, and Richard A. McCullough, Mathematician, all of the U. S. Geological Survey. Dr. Herbert Glass, Illinois State Geological Survey, did the clay analyses which are cited herein. Donna M. Organist and

Marilyn D. Maisano, Geologists, Delaware Geological Survey, prepared maps, mineral analyses and graphs which were used directly or indirectly for the report, and Catharina R. Groot, Geologist, U.S. Geological Survey, prepared some of the mechanical analyses and maps presented here.

Grateful acknowledgment is made to the well drilling companies operating in Delaware who have provided well logs and samples, thereby contributing materially to our knowledge of the subsurface geology of the entire area.

NUMBERING SYSTEM

The system used for numbering outcrops in this work is the same as the one which has been used to designate wells in the ground-water investigations of Delaware. The State has been divided into 5-minute quadrangles of latitude and longitude. These are numbered from north to south with upper case letters and from west to east with lower case letters. Within each quadrangle the outcrops were given consecutive numbers in the order in which they were visited. A given outcrop, then, is indicated by an upper case letter, a lower case letter and a number, such as Bb16. Those outcrops mentioned in the test are shown by appropriate numbers on the base map, plate 1.

GEOGRAPHY

AREA

The area covered by this study includes that portion of Delaware which lies north of the Chesapeake and Delaware Canal. In the text the area is referred to as northern New Castle County. The total area is 278 square miles of which 241 square miles are land. This comprises 55 per cent of the area of New Castle County and 12 per cent of the area of the entire State of Delaware. Pennsylvania forms the northern boundary of the area under consideration, New Jersey (and the Delaware River), the eastern boundary, Maryland the western and the Canal the southern boundary.

TOPOGRAPHY AND DRAINAGE

A line drawn between Newark and Wilmington divides New Castle County into two areas having markedly different topography, (see section on Geologic Provinces). The northern portion is irregularly hilly and ranges in elevation from about 100 feet to over 400 feet near Centerville. The drainage of this part of the state is accomplished by three larger streams, the White Clay Creek, the Red Clay Creek and Brandywine Creek, and a number of smaller ones including Pike Creek, Mill Creek, Shellpot Creek and Naaman's Run. All of these flow in a southeasterly direction and discharge into Coastal Plain streams or directly into the Delaware River.

The southern, or Coastal Plain, portion of the area under consideration is a low-lying plain with elevations ranging from about 100 feet above sea level in the north to sea level along the Delaware River and its tributaries. The major drainage ways of this area are the White Clay Creek, the Christiana River, Red Lion Creek and Dragon Run which flow in an easterly to northeasterly direction into the Delaware River. All of these creeks are tidal in their lower portions. Much of the land along these tidal streams is marshy in contrast with the well drained land upstream and to the north.

POPULATION AND CULTURE

The official 1950 census showed a population of 218,879 for New Castle County. This represents 69 per cent of the population of the entire State. Since the 1950 census, northern New Castle County has experienced a tremendous population increase and in 1956 it was estimated that there were 250,000 persons living north of the Chesapeake and Delaware Canal. It has further been estimated that by the year 2000 the population will be 500,000 (Rasmussen, and others 1957). This great increase in population, which has already brought the population density to over 1000 persons per square mile, has been accompanied, of course, by nearly explosive residential expansion and marked increase in medium and heaw industry.

From an engineering viewpoint such population and cultural changes impose marked restrictions upon the availability of materials. The competition for land has greatly increased its cost -- up to tenfold. The materials which may underlie such land become too expensive for highway use unless the deposits are extremely high grade. The presence of residences and housing projects in the suburbs and rural areas introduces another problem, that of zoning. Pits and quarries are less than desirable neighbors, so areas which undergo residential expansion sooner or later become zoned against them.

These few facts make clear, then, the dilemma which develops: as the population and industrial activity increase the need for better roads likewise increases, but the material with which they must be built becomes increasingly expensive and difficult to procure.

REVIEW OF THE GEOLOGY OF NORTHERN NEW CASTLE COUNTY

GEOLOGIC PROVINCES

Northern New Castle County lies in two of the major geologic, or physiographic, provinces of the Eastern United States, the Coastal Plain and the Piedmont. These zones are narrow belts lying parallel to the Atlantic Coast. The Coastal Plain is a region of gently dipping sands, clays and gravels which extends inland from the ocean beaches for distances ranging from a few miles to more than 100 miles. Inland from the Coastal Plain is the Piedmont, a broad zone of low hills, which in Delaware is underlain by a complex of igneous and metamorphic rocks. Where the seaward-flowing streams run off the hard Piedmont rocks onto the easily eroded sediments, falls and rapids occur. The narrow zone separating the Piedmont and the Coastal Plain is therefore called the Fall Zone. Being the landward limit of navigation and a source of abundant water power, the Fall Zone is the site of many of America's oldest cities, including Newark and Wilmington, Delaware.

The generalized cross section through northern New Castle County, figure 1, shows the relative positions of the Piedmont, the Fall Zone and the Coastal Plain. The geologic map, plate 2, shows the distribution of formations or strata in the area.

GEOLOGIC HISTORY

Glenarm Series

The area now occupied by the Piedmont was, in Precambrian and early Paleozoic time, some 500 million years ago*, a shallow sea in which marine sediments were being deposited. That sea extended southeast of the present Piedmont and included much of the area now occupied by the Coastal Plain. The sediments which were deposited in the basin are known as the Glenarm series. The two uppermost formations of the Glenarm series, in Delaware, were a limestone about 200 feet thick, and above it a formation comprising about 5000 feet of shale. These are the Cockeysville marble and the Wissahickon formation. No local record exists of formations in this series which were deposited above the Wissahickon formation. The relative positions of the formations are shown in table I.

Regional Metamorphism

In the geologic periods that followed their deposition, the formations of the Glenarm series were deeply buried in the Earth's crust and subjected to high temperatures and extreme pressures during one or more of the great mountain building revolutions which elevated a great Appalachian Mountain system. This took place in the middle and late Paleozoic Era, some 260 million years ago. The limestone was recrystallized to form the Cockeysville marble, and the shales of the Wissahickon

*estimates of time from Gilluly and others, 1951, p. 163

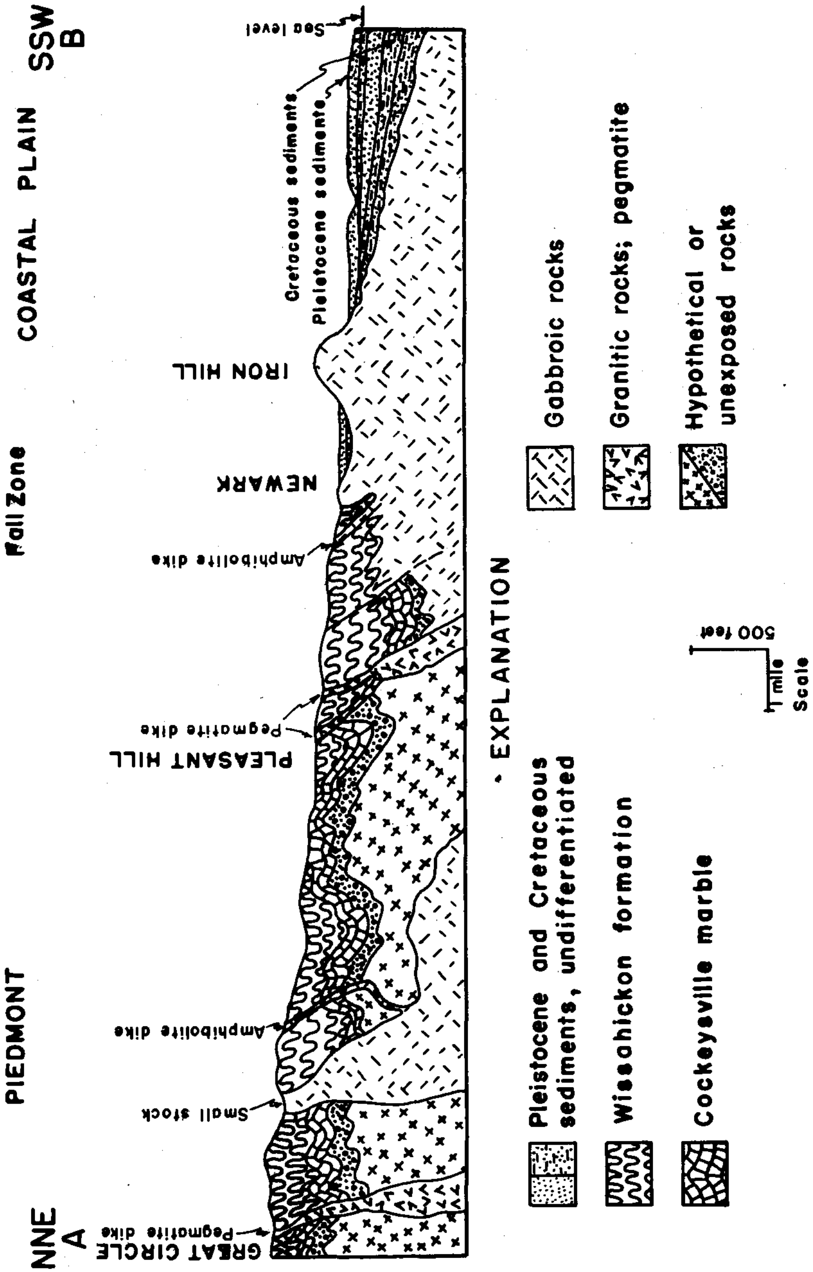

Figure 1. Generalized cross section through northern New Castle County.

formation recrystallized to form a schist. Reconstitution of such great masses of rock is known as regional metamorphism.

Igneous Activity

Gabbro

During metamorphism molten rock, or magma, or many varieties was intruded into the marble and the schist, and replaced portions of them. Much of the eastern and southern parts of the Delaware Piedmont is underlain by gabbro, a dark rock of igneous origin. As with the sedimentary rocks, the gabbro has been profoundly changed by regional metamorphism. From a practical viewpoint, however, the metamorphism of igneous rocks is of small importance because those physical properties which have engineering importance usually suffer little change.

Granodiorite

In the southwestern part of the Piedmont there is a large body of igneous rock related to granite. This formation has been named the Port Deposit Granodiorite after a locality where it is quarried for building and road stone. Studies in Maryland have shown it to be younger, in part at least, than the gabbro. The granodiorite, too, bears a strong mark of the deformation which followed its emplacement.

Minor Intrusives

Amphibolite

Within the Wissahickon formation and elsewhere in the Piedmont there are irregular masses and tabular bodies of dark amphibole-plagioclase rock called amphibolite. These probably represent small apophyses of the gabbro pluton which have been completely recrystallized during metamorphism. In many places outside of Delaware such rocks are quarried for building and highway material.

Serpentine

A mile north of Mount Cuba are four or more small bodies of serpentine which have been intruded into the Wissahickon formation. Serpentine is a soft, fibrous, greenish rock which has been used for such purposes as stone, asbestos and chromium ore. Locally, however, the rock has no economic value or potential.

Pegmatite

Pegmatite veins are more or less tabular bodies of coarsely crystalline quartz-feldspar rock which are common in terrains of regional metamorphism. Chemically and geologically related to granite, they are usually found in and around large intrusions of granitic rock. In northern Delaware pegmatites are largest and most abundant north and west of Newark, near the big granodiorite body. In the eastern Piedmont they are small and uncommon.

Cretaceous Sediments

The geologic events occurring in the huge interval of time between the formation of the present Piedmont rocks, in Paleozoic time, and the deposition of the Cretaceous series, 120 million years ago, can be inferred only in broad outline. During times of metamorphism and intrusion a great Appalachian Mountain system was raised. In the roots of these mountains lay rock bodies which are now exposed in the Piedmont. By the beginning of the Cretaceous period these mountains had been eroded down to a hilly plain. A warping of this plain took place, with the present Fall Zone marking the approximate position of the axis. Southeast of the axis the land was gradually depressed to sea level or below while the land to the northwest was elevated and supplied material to the streams which flowed southeastward into the Atlantic Ocean. Throughout most of Cretaceous time these streams deposited gravel, sand, and clay on floodplains and in shallow seas. Eventually these materials formed a huge wedge of sediments which thickens from a few feet at the Fall Zone to several thousand feet on the continental shelf beneath the Atlantic Ocean.

The lower sediments, which crop out farthest inland are, locally, entirely nonmarine in origin; that is to say, they were deposited in floodplains, river and stream channels and estuaries. As a result of the difficulty involved in separating these discontinuous bodies into distinct formations they are generally referred to as the nonmarine Cretaceous sediments.

Later, as the Cretaceous seas advanced inland, the Magothy formation was deposited. It comprises irregularly alternating sands and clays, partly marine and partly nonmarine in origin, and forms the transition between the nonmarine below and the marine formations above.

The Cretaceous formations deposited after Magothy time are all of distinctly marine character. This marine Cretaceous sequence consists of up to 100 feet of formations comprising sand, clay, and mixtures of the two. In many places fossils are abundant, permitting accurate identification and correlation. The names and stratigraphic positions of the marine Cretaceous formations, along with brief descriptions are given in table I.

Tertiary Sediments

In the Coastal Plain the marine deposition which started in Late Cretaceous time continued, intermittently, throughout much of the Tertiary period. The Tertiary formations, though quite thick in southern Delaware, are absent north of the Chesapeake and Delaware Canal, except for a small patch of material reported to be Tertiary in age which occurs north of Wilmington as a thin gravelly deposit lying on the gabbro. This material is probably of latest Tertiary age -- Pliocene. It is a poorly sorted, cross-bedded material which must have had a nonmarine origin in floodplains,

Table I--The engineering qualities, thickness and stratigraphic relations of the geologic formations of northern New Castle County.

Geologic unit	Approximate thickness (ft.) in outcrop	Lithology and engineering properties
Pleistocene series	0-90	Brown and buff, usually poorly sorted sands with some gravel. Generally suitable for ordinary fill, and partly for select borrow.
Bryn Mawr formation	0-70*	Sandy and gravelly clays and silts; thickness very variable; may have some use as common fill.
Red Bank formation	12	Reddish-yellow to reddish-brown, fine to medium, well sorted quartz sand with some glauconite. Too fine grained to be suitable for select borrow or aggregate.
Mount Laurel-Navesink	15	Dark green and greenish-brown, very fine, glauconitic, clayey sand and dark green to black silt with abundant glauconite. Not a potential construction material.
Wenonah formation	15	Rust brown and gray, fine, well sorted, micaceous quartz sand. Too fine grained to be suitable for select borrow or aggregate.
Merchantville formation	40	Dark blue to dark greenish-brown very fine micaceous, clayey quartz sand and micaceous, glauconitic silt. Not a potential construction material.
Magothy formation	15	White, lignitic sands and black, carbonaceous clays. Not a potential construction material.

Table I--Continued.

Geologic unit	Approximate thickness (ft.) in outcrop	Lithology and engineering properties
Patapsco-Raritan zone	200 ?	Red, white and gray sandy clays and white, brown and red sands with thin gravel layers. May be useful as common fill in some places.
Patuxent zone	175	White and gray sands with some feldspar, and red, white, and yellow silts and clays. Some sands are suitable for fine aggregate or select borrow.
*Pegmatite	**	Very coarse grained rock in dike-like bodies; usually shows little weathering; stone potential slight.
*Granodiorite	**	Light colored, medium grained rock; Delaware outcrop area small; locally inaccessible.
*Amphibolite	**	Dense, dark rock ("trap"); overburden moderate; good stone potential.
*Serpentine	**	Soft rock in small bodies; no commercial potential; overburden very thin.
*Gabbro	**	Coarse grained, heavy igneous rock; weathering moderate; probably good potential road metal.
*Granodiorite gneiss	**	Medium grained crystalline rock; weathering moderate; good road metal if accessible.

Table I--Continued.

Geologic unit	Approximate thickness (ft.) in out crop	Lithology and engineering properties
Granite	**	Firm igneous rock; weathering usually slight to moderate; good road metal if accessible.
Banded Gabbro	**	Firm igneous rock; weathering usually slight; excellent for road metal where accessible.
Wissahickon formation	5000	Mica schist and mica gneiss; in part firm enough for road metal; overburden moderate to thick.
Cockeysville marble	200	Coarse grained marble and talc schist; very firm when fresh, usually deeply weathered.

(*) Relative ages obscure
(**) Vertical extent unknown

small deltas and perhaps inland lakes. In Delaware it is present in detectable amounts only on the divide between the Brandywine Creek and the Delaware River, and although its original distribution may have been much wider it has since been eroded away from the rest of the Delaware Piedmont.

Pleistocene Sediments

The Pleistocene epoch, or Ice Age, covers a span of geologic time from about one million years ago to perhaps 15,000 years ago. During this interval the great continental ice sheets advanced four times to within 200 miles of Delaware. As warmer climates forced the retreat of the glaciers, streams swollen with melt-water carried huge quantities of sand, gravel and finer sediments to the floodplains and estuaries of the Coastal Plain. In each successive stage the previous deposits were in part eroded or destroyed and in part buried by new material as new stream channels were cut and filled. By the end of the Pleistocene epoch nearly all of Delaware below an altitude of about 200 feet was covered with Pleistocene sediments. Most of the Piedmont is free of Pleistocene sediments and in many small patches in the northern Coastal Plain the Cretaceous shows through, but more than 90 per cent of Delaware has a few feet to more than 150 feet of Pleistocene material.

Recent Sediments

The erosion, deposition and reworking of sediments that have taken place since the end of the Pleistocene epoch are minor, and are restricted to the beds and immediate floodplains of present day streams. Where Cretaceous material crops out along Coastal Plain streams it may be inferred that the Pleistocene cover has been removed during recent erosion. Where recent deposition has occurred, however, the material is virtually indistinguishable from Pleistocene sediments. Recent alluvium in the Piedmont floodplains shares the highly variable character of the Pleistocene sediments.

Weathering

Except on steeper slopes the crystalline rocks in the Piedmont are covered with soil and unconsolidated products of rock disintegration. These materials, collectively called overburden, are products of atmospheric attack upon the minerals which form the rock. As weathering proceeds in the uplands some of the decomposition products are carried to the streams, and thence seaward, in solution, suspension and by traction. The remaining residue mantles the rock with thicknesses up to 100 feet, depending upon the nature of the underlying material and the topographic position. In a deep roadcut or excavation a gradual transition from fresh hard rock to loose overburden can be observed.

In the Coastal Plain, weathering is a much less important process. The quartz and clay minerals of the sediments are stable under atmospheric conditions and undergo little change when exposed to the atmosphere. Boulders and cobbles derived from crystalline rocks, however, often become

profoundly weathered after deposition and disintegrate when moved. For this reason the engineering evaluation of potential coarse aggregate deposits must consider both the mechanical composition and the mineralogy.

ECONOMIC DEPOSITS OF THE PIEDMONT

During the last century several mineral products of the Delaware Piedmont have been commercially worked. These have usually been small operations supplying local markets. In the last few decades, however, mechanization of the mining and quarrying industries and the development of cheap, nationwide transportation have made it impossible for small operators to continue profitable operations. Iron ore was mined on Iron Hill and Chestnut Hill, pegmatite veins in the western half of the Piedmont were worked sporadically for potash feldspar; crystalline limestone from pits at Pleasant Hill and Hockessin was burned for mortar and may have been used for fertilizer. Many abandoned kaolin pits can be seen in the western portion of the Piedmont. This material was used for ceramics and as filler in local paper manufacturing. Residual clay produced by the weathering of the gabbro north of Wilmington has been used for the manufacture of building brick. A plant using this material is still in operation on Silverside Road near Faulk Road.

By far the most important mineral resource of the Piedmont is stone. Quarries of a wide range of sizes have, over the past century, produced stone for a variety of uses. Huge abandoned gabbro quarries near the city of Wilmington, and other old quarries of every size can be found in nearly every formation in the Piedmont region. The smallest of these were private operations, producing stone for local buildings, roads or fences. The larger quarries were operated for many years producing rough dimension stone and crushed stone for roads, structures, railroad beds and similar purposes.

ECONOMIC IMPORTANCE OF ENGINEERING STONE

Uses

The use of crushed stone is intimately involved with the development of an industrial society and the network of paved highways which serves its dense population. Concrete and other paving materials consume the largest amount of crushed engineering stone. Railroad ballast and riprap are important uses for smaller quantities.

Production and Value

The increase in quantity and value of crushed stone sold in the United States during this century is a good measure of its ever-increasing importance in our economy. In 1908 approximately 33 million tons were produced with a value of about 20 million dollars; in 1952 the production was about 299 million tons, having a value of over 408 million dollars. This represents a tenfold increase in production and a twentyfold increase in value. Although exact figures are not available for the period from 1952 to the present it is certain that the increase has continued. An even greater increase can be expected in the coming decade as a result of projected highway expansion on county, state and national levels. This investigation of Delaware's raw material potential is a part of the State's preparation for

greatly increased engineering activity in future years.

Methods of Production

During the great increase in production of stone all but the most efficient producers have been eliminated. Small quarries depending largely upon human labor have been replaced by larger, highly mechanized operations. In general, two main methods of quarrying exist. The more important is the open surface pit method. The less common method is that of underground quarries, which in some areas are used for the production of limestone. At present underground quarries are virtually unknown in this part of the country but they may become more common as land values and population pressure increase.

Quarrying machinery may be large and stationary as it is for permanent installations, or smaller and portable for short term operations.

Regardless of the size of the operation, however, the process is essentially as follows: rock is blasted from the quarry face, oversized pieces are reduced to workable size by additional blasting or with air hammers and then put into the crushers. After crushing, the rock is sieved, graded, washed to remove dust, and hauled to the job by truck, rail or barge.

REQUIREMENTS FOR COMMERCIAL STONE DEPOSITS

Location

Considering that crushed stone is a bulk commodity which is marketed in cubic yards or tons, it is imperative that the quarry be located as close as possible to the area or areas of greatest construction activity, because the cost of stone hauled by truck twenty miles or more is such that closer sources of stone, or substitute materials must be sought. This matter of proximity to markets is so important that it must be weighted carefully against all of the following factors in choosing a quarry site.

The problem of locating a quarry close to the areas of most active highway construction is complicated by the rapidly increasing population of the eastern United States which has produced high land values and zoning restrictions. If a projected quarry is known to have a ready market it may not be unwise to pay a thousand dollars or more per acre for a desirable location. Zoning restrictions, however, commonly make it very difficult to find desirable locations near urban centers.

The location of a quarry with respect to the local road and highway system is a consideration which may have a major influence upon the delivered price of the stone. Those locations are most desirable which do not require the building of great lengths of road from the quarry to the surfaced public roads and especially do not require that bridges be built or maintained. Other considerations are: must all material hauled from the quarry to work areas pass through cities or congested areas; and will it be necessary to reroute heavy loads in order to avoid weak highway bridges?

In locating a crushed stone quarry near the Fall Zone one other matter should be considered. If a site is chosen which is near a railroad or has easy access to rail or barge it may be possible to ship rock to the Coastal Plain areas at competitive prices. The Coastal Plain will become an increasingly important market for crushed stone as good coarse gravel deposits are worked out.

Size and Overburden

When a small temporary quarry is to be established using portable machinery to supply material for a local project the site chosen will probably be one where rock crops out in a small cliff or old quarry. In such places the overburden and extent of the rock body are minor considerations. Where, however, a permanent installation is being planned, considerable prospecting must be done to establish that there is sufficient high grade rock to supply a long term operation and that the overburden can be removed economically.

Prospecting, even where steep cliffs expose some rock, is done with core drills. The depth of the holes is governed by the depth to which quarrying can be profitably done; fortunately, once fresh hard material has been encountered for five or ten feet the likelihood that undesirable material lies below it is small. The spacing of holes is a matter which must be adjusted to the material encountered. If the overburden thickness and rock character are found to be uniform in widely spaced holes, say 200 feet apart, then very closely spaced ones may be unnecessary. Bowles (1939, p. 13) suggests that no major commercial operation should be started with a site which does not promise a 20 year reserve of good material. Certainly many quarries with good rock and a good market have closed, or will soon close, because they have quarried to the limits of their own land and can no longer purchase adjacent land which could once have been bought very cheaply.

The overburden revealed by exploratory drilling may be composed of residual clay, sand and boulders in any proportion. In some places there are likely to be minor amounts of sedimentary sands and clays. The range in thickness of the overburden may be great, from a few inches to one hundred feet and more. Where the thickness approaches the latter figure it is probably impossible to strip the area economically by any method. Where the unconsolidated debris covering the fresh rock is of reasonable thickness, say ten or fifteen feet, its removal can be accomplished by one or more of several methods. Power shovels or dragline scrapers are most commonly used for overburden removal. Bulldozers may be useful alone or in combination with other methods. In disposing of the overburden consideration must first be given to the possibility that it may be sold, in part at least, for topsoil or for fill in road or building construction. When removing the overburden, care should be taken not to pile it in an area which

may later be used for roads, storage or actual quarrying. Rehandling of waste material can prove to be very expensive.

Texture and Composition

In grain size the igneous rocks range from very coarse-grained, with crystals many inches across, to dense, glassy materials. Consolidated sediments range from shales, with clay-sized particles to very coarse conglomerates. The metamorphic rocks usually have a much smaller range of grain size and are rarely considered unsuitable on the basis of grain size alone. Texturally, most igneous and metamorphic rocks are made up of interlocking crystal grains and are therefore very dense and tough. In some metamorphic rocks, such as schists, the constituent grains are flattened or elongated, resulting in a tendency for the rock to break into platy or spindle-shaped pieces. This renders the rock unsuitable for many engineering uses.

Chemically and mineralogically most rocks are nearly inert under atmospheric conditions and also under the conditions which exist in concrete. There are, however, some constituents which, in large quantities, render a rock unsuitable for use as an engineering material.

These are:

1. Glass. This may cause a reaction with cement. No glasses are present in Delaware rocks.

2. Clay. Large amounts of clay render a rock mechanically unsound and chemically unstable in some cements. Locally, clays are present in very small quantities in fresh rock.

3. Micaceous minerals. Micas are soft and in some metamorphic rocks tend to impart a distinct schistosity to the rock. They are present in varying amounts in the Wissahickon formation. For this reason the Wissahickon is in part unsuitable for some engineering uses.

4. Olivine. In otherwise fresh, sound rocks olivine is commonly altered to a mixture of clay and small particles of micaceous minerals. In Delaware olivine is present only locally in the gabbro and then only in very small quantities.

5. Calcium-rich plagioclase. Plagioclase feldspar becomes unstable when it is very rich in calcium. This mineral may be present in very small quantities around Iron Hill but is otherwise absent.

There are a few other minerals or textures which have been known to produce undesirable qualities in road metal or concrete aggregate but they do not occur in Delaware or adjacent areas, and so have only academic interest.

Resistance to Abrasion

It is desirable to determine, before use, how a particular crushed stone will perform under the rigorous conditions to which highway pavements, subbases and similar materials are subjected. Over the years, many tests evaluating such properties as hardness, resistance to wear, resistance to impact, and porosity have been made a part of the testing procedure and materials specifications of many engineering laboratories.

From these tests the Delaware State Highway Department has chosen for its specifications for coarse aggregate an abrasion test proposed by the American Association of State Highway Officials. This is AASHO specification T96-49 -- "Abrasion of coarse aggregate by use of the Los Angeles Machine" (Standard Specifications for Highway Construction, 1954, p. 325). In this test a graded charge of the aggregate is rotated in a ball mill with a charge of steel or cast iron balls for a specified number of revolutions. The results are expressed in a percentage of weight lost. The State Highway Department will accept no coarse aggregate in which the loss of weight exceeds 40 per cent.

Such a test is of value in comparing rocks and predicting their performance. It is important to realize, however, that a particular aggregate may give good results in the Los Angeles test and yet fail to perform satisfactorily. In such cases a thorough knowledge of the mineralogy and texture of the rock may aid in discovering the factors leading to failure. Detailed descriptions of representative specimens of the geologic formations are therefore discussed in this report.

NATURE AND HISTORY OF OPERATIONS IN DELAWARE

The earliest quarrying in Delaware certainly took place when the first settlers arrived more than two centuries ago. The stone which they used can still be seen in the few remaining colonial buildings. Stone probably was taken from outcroppings as close as possible to the building site. Commercial operations came into being before the end of the 18th century, for by 1827 a large commercial quarry was in operation at Quarryville by Jaquet, Carr and Co.; this quarry was operated for many years, finally abandoned, and is now used as a reservoir. There were many additional quarries opened in the vicinity of Wilmington which supplied huge quantities of stone and were subsequently abandoned. The most prominent of these can be seen along the east bank of Brandywine Creek near Alapocas Woods and on the Red Clay Creek north of Wooddale. The only stone quarry still operating in Delaware is located near the Shellpot Creek, south of Market Street, in Bellefonte. This quarry was opened in 1885 by Phillip R. Tyre and is now operated by Petrillo Bros., Inc.

Character of the Material

Those quarries which operated in and very near the City of Wilmington were in the gabbroic rock, or Brandywine Blue Granite as it is known locally. This rock was produced at all the large operations in Delaware ex-

cept the quarry at Wooddale which is located in the Wissahickon formation. The many small abandoned quarries scattered throughout the northern part of the State produced stone of many varieties -- usually Wissahickon schists and gneisses but also marble and amphibolite. The physical properties of these materials will be discussed in the descriptions of the individual formations.

Methods of Quarrying

The operations of the 18th and 19th centuries were, apparently, always started on steep slopes, or where outcrops were large. In such locations little prospecting was required and quarry faces were easily established. During that period human and animal power were employed, probably exclusively, for drilling, removing stone from the quarry face, crushing and hauling. In later operations the quarry sites remained the same but modern, efficient methods came into use. In the one remaining quarry, drilling is done with compressed air, stone is blasted from the quarry face with explosives and all crushing, grading and hauling is done by machine. It is only by such elimination of human beings as a source of power that large quantities of stone can be produced at low prices.

Production and Value

Figures on the quantity and value of stone produced in Delaware are given in the U. S. Bureau of Mines Minerals Yearbooks which have been published annually since 1933. Values for Delaware production are missing for several years; nevertheless certain conclusions can be drawn. (See figure 2).

The stone industry recovered well from the business depression of the nineteen thirties, for the highest production in recent years occurred in 1940 and 1941 when it reached one hundred ten thousand short tons. In the middle nineteen forties, during the war, production was sharply curtailed, and apparently stopped altogether in 1945. The post-war boom with its high prices stimulated a large increase in stone production. In each year since 1950 more than seventy-five thousand tons have been produced. However, the figures show annual decreases since 1951. This does not reflect the demand for stone for the demand has increased steadily since the war. The decline in production in the face of an increased market reflects a lack of supply and points up the need for new quarries in Delaware.

PRESENT INVESTIGATION

In the past there have been several geological investigations which covered, in part, the Piedmont area of Delaware. However, no previous investigation of northern Delaware has been made from the viewpoint of rock resources. In this study the geologic techniques of field study and laboratory examination have been the main sources of data.

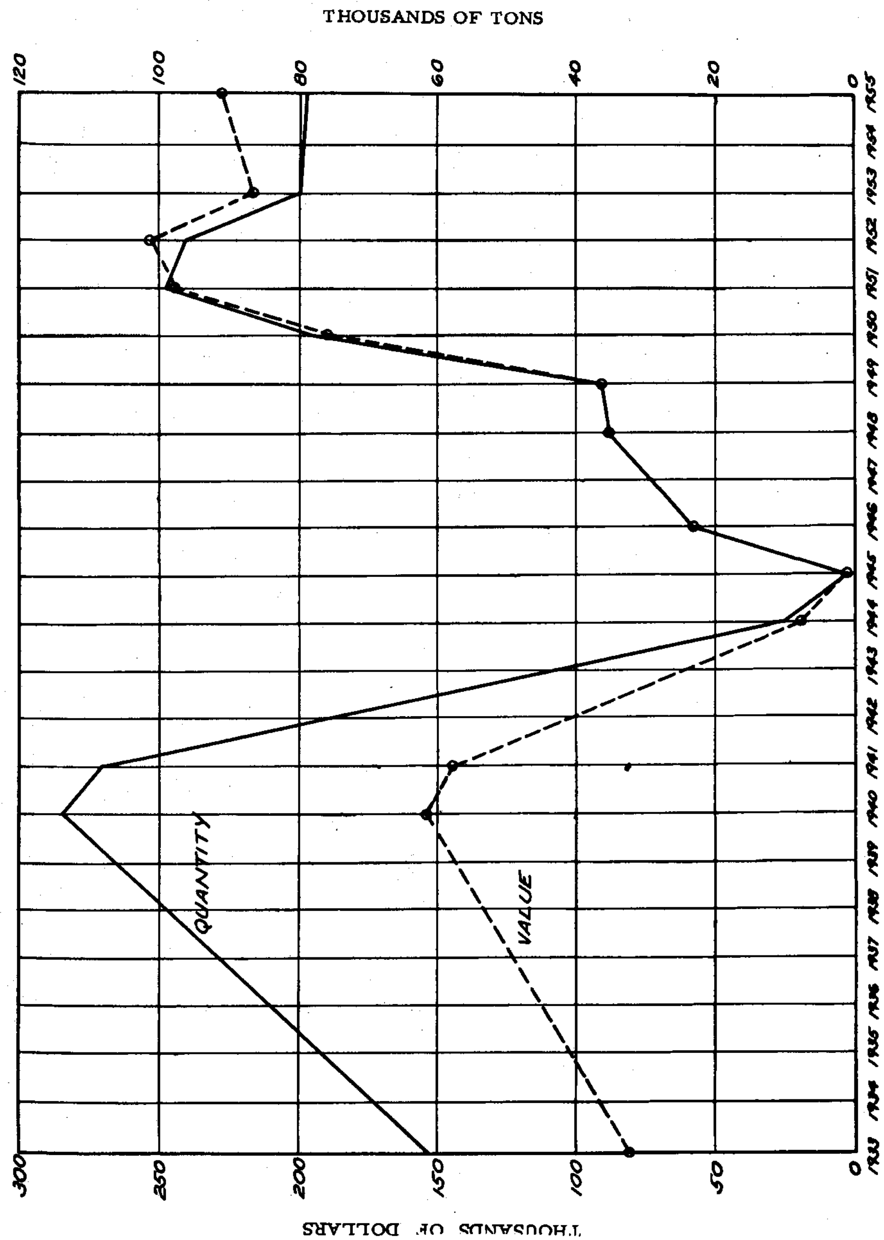

Figure 2. Quantity and value of stone produced in Delaware, 1933 to 1955.

Areal Geologic Studies

During parts of the summers of 1954, 1955 and 1956 the author spent many weeks in the field in northern Delaware. Several hundred outcrops, road cuts and quarries were examined. Descriptions were made of the lithology, measurements were made of such structural elements as the joints and the schistosity, and in most instances specimens of the rock were taken for further examination. Traverses were made at more or less regularly spaced intervals along streams and across fields and wooded areas so that by the time the reconnaissance was completed the area had been thoroughly covered. In assembling the lithologic data into a geologic map aerial photographs were used. This permitted a comparison of the topographic features in areas underlain by various rock types and aided in the drawing of rock boundaries. A map of the structural features was prepared from measurements taken of schistosity, lineation and jointing. These maps will be discussed at greater length along with the description of the geologic formations. The thickness and character of the overburden were noted at various exposures, and logs of wells were examined for further data on overburden thickness.

Investigations of Mineralogy and Texture

During the course of this study about 500 specimens of the various rock types were collected. After preliminary examinations about one hundred of these were chosen to have thin sections made for microscopic examination. Under the microscope, determinations were made of the minerals present, the textures and mutual relationships of the grains were noted, and the nature of alteration products, if any, was recorded. In addition, the percentage composition of the constituents was either estimated or measured by various methods. In representative or characteristic specimens the composition of the soda-lime feldspar (plagioclase) was determined by refractive index methods in oils.

The samples of rock were collected and submitted to the State Highway Testing Engineer for Los Angeles abrasion tests. Unfortunately the results emphasize that material collected with a sledge hammer cannot easily be compared with rock which has been crushed and screened mechanically at a quarry. This is borne out by the fact that duplicate samples prepared in this manner gave significantly different values when subjected to identical tests. In addition, the feldspar in rocks taken from outcrops is always somewhat altered by weathering; such rock tends to disaggregate rather easily. For these reasons it was decided to discontinue the program of Los Angeles tests for this report. When, in the future, sites are being considered as possible locations for quarries, large samples of the rock should be taken and crushed and screened with standard quarry machines in preparation for abrasion tests.

GEOLOGIC FORMATIONS

Wissahickon Formation

The Wissahickon formation, which is also known as the Wissahickon gneiss and the Wissahickon schist, underlies the northwestern half of Delaware's Piedmont. In the past this formation has only once been the site of major quarrying operations -- the Wooddale quarry. This is largely a result of the fact that the Wissahickon underlies the more rural portion of the Piedmont where in previous times markets were small and transportation inadequate. The marked increases in population and industrialization which have taken place in the post-war years have made it necessary and desirable to consider the Wissahickon carefully as a possible source of engineering stone.

As seen in highway and railroad cuts a typical Wissahickon exposure reveals a few inches to a foot or so of sandy soil underlain by several inches to many feet of disintegrated rock. The transition to unweathered rock is usually gradual. The fresh rock is characterized by a conspicuous planar element or foliation which results from the fact that platy and tabular crystals are oriented with their broad surfaces in a common plane. In addition, a weakly developed alternation of light and dark minerals produces a gneissic appearance which emphasizes the foliation.

At most outcrops the foliation makes a high angle with the horizontal, usually 45 to 90 degrees. Tight folds in the plane of foliation mark those layers least able to resist the deforming forces to which the rock was subjected. Adjustment to these forces produced another conspicuous physical feature -- joints. These are smooth, parallel fractures, or incipient fractures with a spacing of less than an inch to several feet. Usually two, and often more intersecting sets of joints are present in an exposure. Depth of weathering, ease of excavation and water-bearing qualities of the rock are largely determined by the character of the joints. The foliation and joints are plotted in plate 5.

On the geologic map, plate 2, it can be seen that the Wissahickon formation lies north and west of an irregular line drawn from the Delaware-Maryland boundary near Newark to the Delaware-Pennsylvania boundary near Brandywine Raceway. In the northeast it is bounded by gabbro and in the southwest it is delimited in part by the gabbro and in part by the overlap of Coastal Plain sediments. Within the Wissahickon there are several small gabbro or amphibolite bodies, and in two places it has been completely eroded away, exposing the underlying Cockeysville marble.

Mineralogically the Wissahickon formation is characterized by a composition indicating extreme metamorphism. The essential minerals present are quartz, orthoclase feldspar, oligoclase feldspar, biotite, sillimanite and garnet. In some places muscovite is among the more prominent constituents. The following accessory minerals occur in small amounts throughout the formation: zircon, tourmaline, apatite, rutile, magnetite and ilmenite.

The relative proportions of the essential minerals vary somewhat from place to place as a result of differences in the composition of the original sedimentary material and the nature of the metamorphism to which the rock was subjected. These differences have permitted a rough subdivision of

the Wissahickon formation in Delaware into the three zones or facies which are shown on the geologic map. These were delimited on the bases of the texture, mineralogy and appearance of the material in outcrops. Generally the rock appears to be most schistose in the southwest and to increase in toughness and density to the northeast, with a corresponding decrease in platy micas and oriented sillimanite crystals. This progression is at best, irregular and within any of the three zones occasional exposures can be found in which the rock appears atypical. Three specimens, judged to be typical of the three main zones of the formation in Delaware, are described below:

Southwestern Facies

In the southwest the Wissahickon formation is often quite schistose, having a larger percentage of micas and sillimanite than it does to the northeast.

An outcrop of this micaceous schist (Cb 17) occurs in a creek bed 1 mile northeast of Milford Crossroads. In the hand specimen this coarse grained schist shows large spangles of mica in thin layers alternating with thin layers containing gray quartz and pink to white feldspar. There are about 20 laminations to the inch. Needles of sillimanite are visible, some reaching a length of more than 1/8 of an inch. Light brown iron hydroxide staining is common.

Under the microscope dynamic effects are conspicuous. Many component crystals are bent and broken. The estimated composition in per cent is:

Sillimanite	40
Quartz	20
Biotite	15
Feldspar	10
Muscovite	10
Garnet	5
Zircon, apatite, opaques	traces

A common feature of the Wissahickon and of similar rocks throughout the world is migmatite or mixed rock. This name is given to schists and gneisses containing small lenses and sheets of granite. In Delaware migmatite rich areas occur throughout the Wissahickon formation but are most common in the southwestern facies, particularly in the vicinity of pegmatite veins.

Central Facies

Toward the central portion of the outcrop area the formation becomes a less micaceous and the schistosity correspondingly decreases. Field and laboratory work suggest that the country rock, where the effects of gabbroic intrusion are absent, is a quartz-feldspar rock such as is found at Bc109.

At the outcrop this rock is a skein of minor folds up to a foot or so in amplitude. These folds are made visible by rather wide bands having slight differences in feldspar or biotite content.

In the hand specimen the rock is fine-grained, composed very largely of gray to white quartz and feldspar. Small, irregularly oriented plates of biotite and minute crystals of red garnet are present. Muscovite, which in small quantities seems to be characteristic of the more southerly variety, is present here only as a few remnant shreds.

The estimated composition in per cent is:

Quartz	50
Plagioclase	25
Orthoclase	10
Biotite	10
Garnet	3
Sillimanite	2
Muscovite, zircon, opaques	traces

Northern Facies

The northern third of the Wissahickon area in Delaware is underlain by rocks which are massive, weakly schistose, and often garnet-rich. The physical and mineralogical character reflects the intense heat and extreme pressure to which they were subjected when the nearby gabbro was emplaced. A hand specimen of the rock (Bd38) shows irregular lenses composed largely of pink garnet and flakes of biotite alternating with lenses which comprise clear quartz and white feldspar.

Much of the northern material is best characterized by the textural term gneiss, because the platy, schistose character of the southwestern facies is much less pronounced here.

Under the microscope this rock shows the same mineral species as those present in the south, except that muscovite is apparently absent and some of the feldspar occurs as perthite -- a mixture of albite plagioclase and orthoclase. The estimated percentage composition is:

Quartz	35
Orthoclase	25
Garnet	20
Perthite	10
Sillimanite	6
Biotite	2
Opaques	2

The three specimens described represent typical varieties of the Wissahickon formation in Delaware. Many exposures, particularly those near the borders of a given facies, show transitional characteristics.

None of the constituents present is known to be unstable or harmful in

any way in concrete. Texturally, however, the mica-rich, schistose portions of the Wissahickon are likely to prove to be too soft to meet minimum hardness and abrasion requirements. This is particularly true where the micas are rather well aligned in parallel planes, for then the tendency for the stone to split along mica-rich planes is pronounced. It must be emphasized, however, that it is misleading to judge the textural character of the rock from its appearance in partially weathered outcrops because weathering is selective and a rock which appears fissile and powdery in the outcrop is often very firm and dense below the zone of weathering.

Structural Features

The larger physical aspects of a geologic formation are grouped together as structural features. Inasmuch as these structures effect the distribution of a formation and its characters in outcrop or subsurface, they may have considerable engineering significance.

Folds

Undulations of bedding or foliation are called folds. Upwarps are known as anticlines, downwarps as synclines. The compass direction of a bed or fold, measured in a horizontal plane is its strike; the angle which it makes with the horizontal is its dip, that is to say a horizontal bed has zero degree dip and a vertical one has 90 degrees dip.

Folds, along with most other mineral and structural features of the Wissahickon formation reflect the pressure and deformation to which it was subjected. In size, the folds range from plications of less than an inch in amplitude to broad warps many miles across. The tiny folds have little practical significance except to identify the material which contains them as highly micaceous and consequently softer and more easily excavable than most of the local material. In Delaware this structure is restricted to the highly schistose portions of the southwestern facies. The predominant folds, of which an individual outcrop forms only a part, are about two to three hundred feet in amplitude.

Folds are important for an engineering study because they determine the attitude of the bedding or foliation, which, in turn, determines the attitude of a desirable or undesirable body of stone in an excavation. In the Wissahickon not only are its own beds approximately parallel to the foliation but the smaller gabbro or amphibolite bodies within it are also usually concordant.

Only one fold of truly regional magnitude has been recognized in Delaware. This is a broad anticline which has a northeasterly trend, running from Pleasant Hill through Hockessin, then curving somewhat to the east and apparently dying out in the vicinity of Centerville. Erosion of the Wissahickon from the crest of this anticline has exposed the underlying Cockeysville marble in two large areas and perhaps also in smaller undetected places. The upwarp has also brought to the surface a variety of the Wissahickon which contains an abundance of small gabbro and amphibolite bodies.

Joints

Metamorphic rocks are among the most abundantly and conspicuously jointed rocks known. In areas of abundant vertical joints the rock is usually thoroughly and deeply weathered. Even in fresh rock the attitude and spacing of the joints can be of primary importance in excavating and quarrying. Joints are actually fractures along which movement may or may not have taken place, and by making the best use of these naturally occurring fractures rock can be excavated more easily than otherwise.

Within any small area the character and attitude of the joints are relatively constant. Consequently, information gained by careful study of their nature before and during quarrying operations can be of lasting value.

This distinct tendency for joints to exhibit regular arrangement with respect to folds has given rise to the geometrical classification illustrated in figure 3. In figures 3A and 3B each of the planes represents a series of parallel joints called sets. A pair of sets making a high angle with each other is called a system.

In the Wissahickon formation in Delaware the best formed joint set is a cross joint which can be seen at nearly every outcrop; even loose boulders often show fine lines perpendicular to the foliation and mineral lineation indicating incipient cross joints. These joints usually have a more or less vertical dip, but depart from the ideal situation in that the strike direction is usually rotated several degrees west of a direction perpendicular to the strike of the formation.

A diagonal system is also discernable, but careful examination of the map (plate 5) shows that this system tends to grade into cross joints as the angle between the sets becomes smaller while the angle between them and the foliation increases. There is no discernable strike system present.

An additional jointing phenomenon, sheeting, is displayed in portions of the Wissahickon formation. Sheeting is the tendency for rocks to develop a joint system parallel to the present topography and is ordinarily present only in igneous rocks, where it greatly facilitates quarrying. The nature of the exposures in Delaware is such that the sheeting planes are nearly horizontal. Their topographic control is emphasized by their spacing; 3 or 4 inches at the surface, gradually increasing with depth to a foot or two. A few yards below the surface sheeting is no longer discernable. Those portions of the Wissahickon which have been made most massive by baking when nearby gabbro bodies were intruded show sheeting best. This feature is clearly displayed at Wooddale Quarry near the main gabbroic mass and in the railroad cut near Ashland (Bc 16), an area with abundant small intrusions.

Fault Shear Zones

Failure of the rock by rupture, or faulting, must have been a common

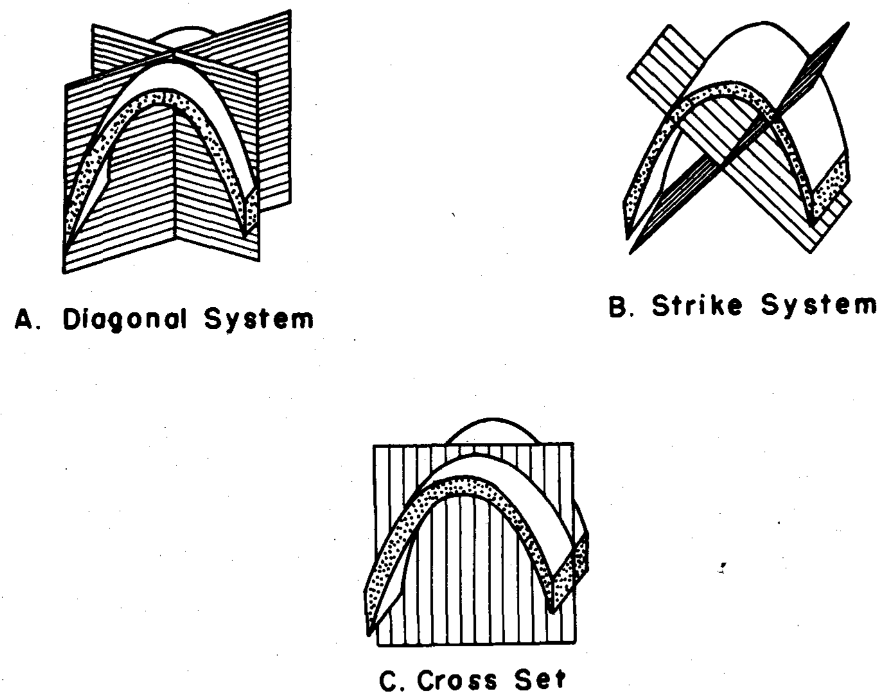

Figure 3. Joint sets and systems.

occurrence during the periods of deformation of the Wissahickon. During faulting the rock along the fault plane becomes crushed and granulated in zones up to a dozen or more feet wide. The nearly loose debris in these shear zones has physical properties very unlike those in the nearby fresh rock.

The fact that no large faults have been recognized in this area is probably due to the fact that large crushed zones are easily weathered and, therefore, underlie valleys and topographically low areas. Road and railroad cuts have, however, exposed several smaller fault shear zones. In the walls of the large railroad cut at Winterthur Station (Bc 67) there are several zones 5 to 6 feet thick in which the schist is badly crushed and deeply weathered. It may be of value to note that these zones, like the similar one in the railroad cut at Bb 61 is parallel to the foliation plane. It is probable, therefore, that during quarrying for highway excavations, shear zones encountered will have the same relationship to the foliation. In planning it is important to take note of the faults present because fault zone material has no value as stone, can usually be excavated without blasting, and has such different water bearing qualities from the adjacent fresh rock that the presence of shear zones may create drainage problems in both quarries and highway road cuts.

Whatever large faults of a regional nature may exist are of little immediate practical concern for quarrying or road alignment because in Delaware, at least, no surface expression of such faults has been detected. They are, however, of gravest concern for such projects as aquaducts, dams and tunnels where their presence and nature must be determined by exploratory borings.

Cockeysville Marble

For the United States as a whole, limestone and crystalline limestone, or marble, are probably the most commonly used road and building materials. In Delaware, however, the marble offers very little promise as a source of stone.

The two areas mapped as being underlain by the Cockeysville are in the western part of the Piedmont (see geologic map, plate 2). Their total area is about 3 square miles. In the more southerly outcrop area, around Pleasant Hill, the marble is exposed in the old Eastburn quarry where it was used for manufacture of mortar. The more northerly outcrop area also has a single exposure -- an abandoned quarry in Hockessin. This quarry is quite unsatisfactory for determining the nature of the rock because it is flooded and has been used as a dump. Information concerning its composition has been deduced from fragments found in the vicinity of the quarry.

Mineralogy and Texture

In the Eastburn quarry the rock is made up of dense, white, coarse grained, dolomitic marble containing lenses of friable calc-mica schist. These lenses range up to 1 foot thick and are 4 or 5 feet long. In this exposure the schistose layers make up about 20 per cent of the total exposure but this relationship can be expected to vary considerably from place to place.

In the massive portions, the rock is made up nearly entirely of interlocking grains of calcite and dolomite. Tiny flakes of phlogopite, a magnesian mica, comprise less than 1 per cent of the rock in the microscope slides examined. The calc-mica schist lenses are made up of grains of calcite and dolomite with a much larger proportion of phlogopite. A thin section made from a typical specimen showed 95 per cent calcite-dolomite and 5 per cent phlogopite mica. The material taken from the Hockessin quarry has a composition and texture nearly identical with the pure marble from Pleasant Hill.

Weathering and Overburden

Calcite and dolomite are soluble in slightly acid ground water. For this reason most crystalline limestone taken from the upper part of outcrops is friable and easily disintegrates into granular material.

In most of the outcrop area of the Cockeysville in Delaware, chemical weathering has proceeded to considerable depth and it appears that the only places in which fresh rock can be found very near the surface is in the two quarries mentioned. In the logs of wells dug and drilled in the Cockeysville areas the overburden is commonly 60 or more feet and wells are known in which 200 feet of unconsolidated material overlies fresh rock. These areas are low-lying and have very little relief. The water table appears never to be more than about 15 feet below the surface.

Although it is possible that careful prospecting in the vicinity of the Hockessin quarry might reveal a deposit of potentially exploitable crystalline limestone, the very thick overburden, the high water table and the fissile nature of some of the material are discouraging factors. The area underlain by the Cockeysville presently holds little promise as a source of stone.

Gabbro Complex

The southern and eastern portions of the Piedmont are underlain by dense, dark, crystalline rocks of igneous origin. In the general portions of this report, as in previously published studies of this region, this body is undifferentiated. The descriptions of individual specimens given below show, however, that the mineralogy and texture range so widely that the term "gabbro", while convenient, is not geologically accurate.

Considering that the outcrop area of the gabbro coincides with the region of greatest population density and industrial activity in Delaware, it is not surprising that it has been the major source of stone for the State. The great increase in population in the post-war years and the rapid spread of the suburbs north and west from Wilmington has rendered much potentially good stone inaccessible. While the physical characteristics of this rock are important for making engineering evaluations, they are a smaller factor in its potential as a quarry stone than the factors of land value and zoning.

A typical exposure of the gabbro in a railroad or highway cut shows several inches to a few feet of heavy, dark red, clayey soil. This soil usually contains rounded cobbles and boulders of the bedrock. Below this zone, which comprises largely unconsolidated material, is another zone ranging from 3 or 4 to a dozen feet thick which comprises equant boulders of the bedrock in a clayey soil matrix (see figure 4). This is the zone in which weathering processes are most active. The boulders are blocks of bedrock bounded by joints. Ground-water solutions working along these openings have attacked the adjacent rock producing unconsolidated soil material. The weathering solutions continue to attack the rock, producing the more or less spherical boulders which are ultimately reduced to loose soil. The transition to solid bedrock is usually rather abrupt although very minor amounts of unconsolidated material may be present in open joints to depths of 100 feet. Thick zones of "rotten rock" in the gabbro area, though occasionally present, are rare. The boulders in the soil have a rind of friable weathered material about one-half inch thick. This is a sharp contrast with the Wissahickon formation where the transition from fresh rock to loose soil often extends over many feet. The color of the weathered rind on the boulders varies from the red or brown of iron oxides to white, the color of the clay minerals formed by the decomposition of the plagioclase feldspar. The dark specks in the light matrix are partially decomposed crystals of ferromagnesian minerals.

In most places the fresh rock appears fine-grained, bluish and relatively homogeneous. The color results from the rather bluish cast of the quartz which in some places makes up nearly one-third of the rock. Whatever foliation may be present is usually not detectable at fresh outcrops. Quartz veins which occur sparingly may be up to a foot in width but are usually only 2 or 3 inches wide.

Steeply-dipping joint planes are widely spaced, from 3 to 20 feet apart, and it is only with difficulty that joint sets and systems can be discerned even in large exposures. Sheeting, the sub-horizontal joint set, is usually better developed than other joints and appears to be the main avenue for atmospheric attack on the bedrock.

The geologic map, plate 2, shows that the gabbro underlies most of the area north of Wilmington and east of the Brandywine, the southerly half of the Red Clay Creek Valley, a narrow belt near Newark, and the Iron - Chestnut Hill area. West of Newark the gabbro is cut out by an intrusion of granite. In the northern portion the gabbro extends beyond the Great Circle and occupies an area in Pennsylvania nearly equal to that in Delaware.

Geologically it is bounded on the north and west by the Wissahickon formation and on the south and east by Coastal Plain sediments of Cretaceous and Pleistocene age. Along the divide between the Delaware River

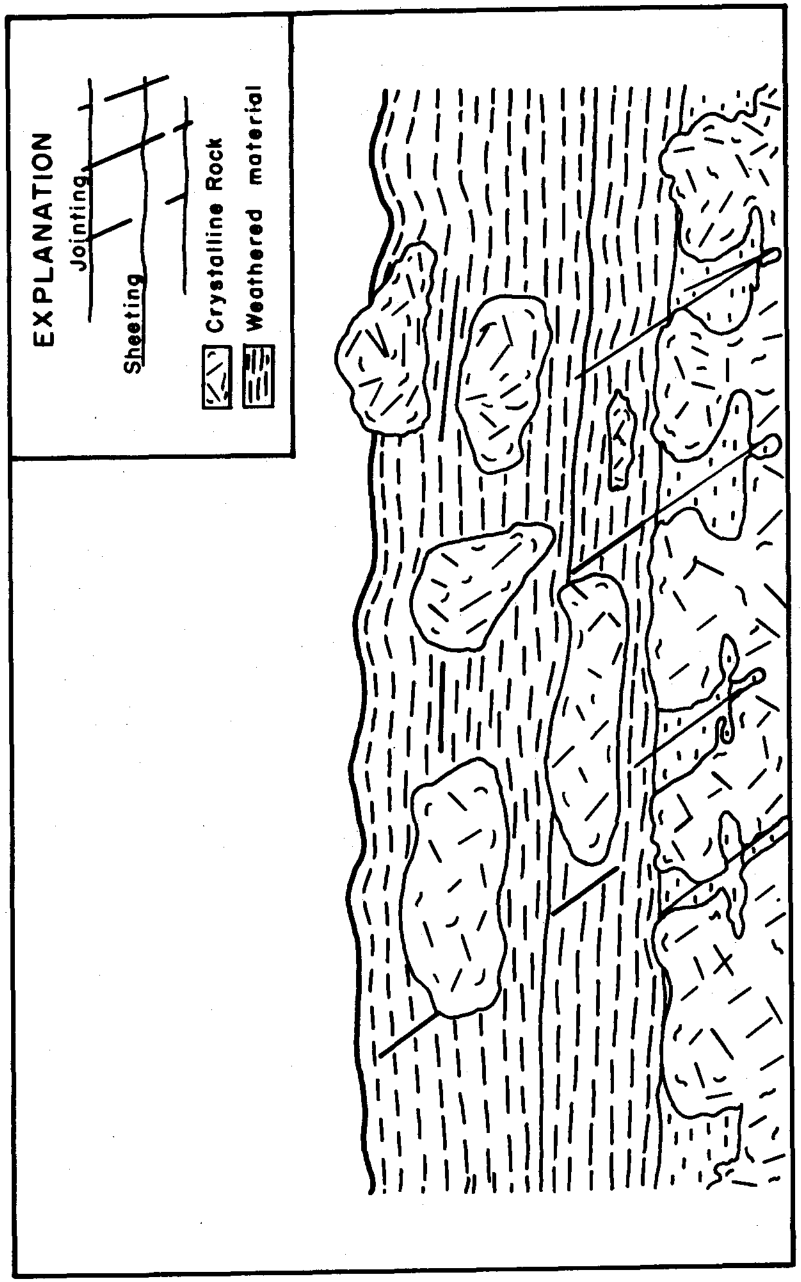

Figure 4. Schematic cross section through gabbro overburden.

and the Brandywine Creek there is an area about one by five miles in which the gabbro is covered by thin discontinuous sediments.

The mineralogical variations within the gabbro complex are so great that it is not possible to give an average or generalized composition. Consequently, six major varieties and a representative specimen of each are described below.

Banded Gabbro

The variety which is most widespread and therefore considered first is the "Brandywine Blue Granite" of commerce. On the geologic map, plate 2, this rock and the amphibolite bodies with which it is usually gradational, are indicated by a common symbol. In most exposures this banded gabbro is an extremely tough, bluish rock made up predominantly of quartz and plagioclase feldspar. Such ferromagnesian minerals as augite, hypersthene, hornblende and biotite range in quantity from less than 10 per cent to more than one-third of the total. Within this light rock there are tabular bodies of a darker rock at most exposures. These dark bands are usually 6 inches to a foot wide and may extend the entire length and height of an exposure. In some places the dark bands are folded and pinched out. In such places they are commonly represented by pod or lens shaped bodies a few feet long. Where the dark bands are most abundant and conspicuous they make up about 15 per cent of the mass. In most places, however, they make up less than that, and may not be discernable at all. The areal distribution of the dark bands probably has geologic significance, but to date the patterns have been neither plotted nor studied.

Mineralogically, the dark bands comprise sub-equal amounts of plagioclase feldspar and one or more ferromagnesian minerals. The dominant ferromagnesian mineral is usually hypersthene and is accompanied by lesser amounts of augite. These minerals, however, may be replaced by a brownish hornblende with or without minor biotite. The grain size is smaller than that of the associated light material, but the texture is similarly granoblastic.

Specimen No: Bd 52 (1) Location: NW of Silverside

Hand Specimen: A very light gray, fine-grained rock comprising largely quartz and feldspar. Tiny patches of black minerals are so arranged as to give a faint gneissoid structure which in no way alters the massive fracture. The irregular joint surfaces have thin films of iron oxide and those surfaces which have been long exposed to the atmosphere are covered with a yellowish weathered rind about one-quarter inch thick.

Thin Sections: Under the microscope the rock is seen to be made up almost completely of quartz and plagioclase with small rounded masses of hypersthene. The texture is distinctly granoblastic (metamorphic). The plagioclase has the composition An_{40}. The hypersthene, pleochroic red (X) to yellow (Y) to bluish green (Z), has (-) $2V = c.\ 70^{o}$. Magnetite, biotite, zircon, apatite, monazite, ilmenite, pyrite and allanite are present in minute amounts.

Composition (in per cent)

Plagioclase (An_{40})	50
Quartz	44
Hypersthene	3
Opaques	1
Biotite	0.7

Specimen No: Bd 52 (2) Location: NW of Silverside

Hand Specimen: A dark, fine-grained rock containing apparently subequal quantities of plagioclase and pyroxene. The hand specimen appears perfectly massive but close examination reveals a faint banded character. Fracture irregular. In weathered specimens the friable weathered rind is about one-eighth inch thick. This weathered material consists largely of the clayey decomposition products of the feldspar stained brown by iron oxide.

Thin Section: This is a fresh, granoblastic, banded granulite comprising plagioclase, hypersthene, diopsidic augite, and hornblende. Quartz and magnetite are present in small quantities while ilmenite, pyrite, chalcopyrite, rutile, apatite, allanite and kyanite occur in minute amounts.

The plagioclase has the composition An_{40}. Hypersthene, (-) $2V = c.\ 70^{o}$, is pleochroic red (X) to yellow (Y) to bluish green (Z). The clinopyroxene is greenish-yellow, nonpleochroic, (+) $2V = c.\ 70^{o}$; $Z \wedge C = c.\ 48^{o}$. The hornblende is pleochroic brownish yellow (X) to greenish yellow (Y) to dark olive (Z). (-) $2V = c.\ 75^{o}$ and $Z \wedge C = c.\ 30^{o}$.

Composition (in per cent)

Plagioclase	65
Hypersthene	15
Clinopyroxene	10
Hornblende	6
Quartz	2
Opaque	1.5

In every way this banded gabbro is suitable for such an engineering use as road metal. It is tough and dense, and there is never any marked tendency to break into elongated or flattened pieces. The major minerals present are hard and are not known to have undesirable chemical reactions upon exposure to the atmosphere, to concrete or to asphalt. Only the biotite is soft and it is not present in sufficiently large proportions to affect performance. The fact that this rock is rarely well or closely jointed lowers its value as a potential building stone and makes the quarrying process more difficult.

Such variations as occur within this material are unlikely to cause detectable changes in those physical properties which have engineering significance. The selection of a quarry site in this material is far more dependent upon the characteristics of the overburden and accessibility of the land than upon the character of the rock in a given locality.

Amphibolite

Along the borders of the gabbroic body and occasionally within it, irregular bodies of amphibolite are developed. In addition, those bodies of basic rock within the Wissahickon formation are amphibolites. This material was probably formed as a result of strong shearing of the gabbro during recrystallization. It is often composed entirely of plagioclase and green hornblende, but rocks gradational with the banded gabbro occur commonly. This gradational character makes it impractical to give the amphibolites a separate map unit.

Thin sections of this rock show it to be fresh and dense, with its major constituents in sub-equal proportions. The fact that the hornblende crystals are elongated and have a tendency toward parallel orientation imparts a minor schistosity to the rock which does not appear to materially affect its engineering characteristics.

The thin section described below is a good representative of this group.

Specimen No: Bd 5 (2) Location: Rockland

Hand Specimen: A medium-grained, dark amphibole-plagioclase rock with moderate linear schistosity. The main constituents occur in sub-equal amounts. Surfaces which have been exposed to the atmosphere are not deeply weathered; the amphibole is dull, and the feldspar chalky.

Thin Section: A weakly lineated hornblende-plagioclase rock with minor magnetite. The hornblende is poikiloblastic, often containing smaller hornblende or plagioclase. Bluish green; (-) $2V = c. 80^{\circ}$; $Z\wedge C = c. 25^{\circ}$. Intergrowths with magnetite and peripheral magnetite are common. The plagioclase, composition An_{70}, contains occasional dust-like or acicular inclusions of what is probably an epidote mineral.

Estimated Composition (in per cent)

Hornblende	44
Plagioclase (An_{70})	54
Magnetite	2

As a potential engineering material the amphibolite has no disqualifying physical or mineralogical properties. Any quarries which may be opened in the Wissahickon formation will encounter at least small amounts of amphibolite. And within the banded gabbro part of the material quarried anywhere will approach amphibolite in composition and texture. However, this lack of petrographic uniformity should affect neither the preparation nor the performance of the rock products.

Granite

In the extreme northeastern part of the Piedmont of Delaware the banded gabbro has been intruded by a gray, coarsely crystalline, rock of truly granitic composition. This body underlies an area of about 2 square miles in the vicinity of Arden and Carpenter Station. It is on the regional strike with, and probably related to the Ridley Park granite (Postel, 1940). The major constituents of the granite are orthoclase, feldspar, soda-rich plagioclase feldspar and quartz. Biotite and magnetite occur in smaller amounts and hypersthene is present at some locations. Portions of the body have undergone deformation and crushing which have reduced the grain size. This crushing, however, is not widespread. Most exposures of the granite are found in cuts of the B & O Railroad. The following description is from a cut near Carpenter Station.

Specimen No: Be 4 Location: Carpenter Station

Hand Specimen: A fresh, medium grained rock with a light gray to greenish color. This specimen comprises largely quartz and feldspar with minor biotite. The specimen is completely massive with neither gneissoid nor schistose appearance. Where it has been exposed to the atmosphere the rock has a shell of typical granite saprolite ranging in thickness from a small fraction of an inch to more than a foot. The saprolite is white, sandy and poorly consolidated.

Thin Section: The rock is composed of quartz, orthoclase, sodic plagioclase feldspar and minute amounts of biotite. Many crystals have granulated borders indicating strong shearing. The plagioclase has a composition about An_{20} -- oligoclase.

Estimated Composition (in per cent)

Orthoclase	59
Quartz	25
Plagioclase (An_{20})	15
Biotite	1
Magnetite	+

On the bases of its mineralogy and texture this rock is well suited to engineering uses. This is especially true because it appears to have little overburden. Unfortunately, it is located in a highly populated area where it is difficult of access.

Granodiorite Gneiss

An area of about 1 square mile near the border of the schist near Wooddale is underlain by a complex which is sufficiently distinct to warrant a separate map symbol and description. Composition-wise the rock ranges from a granodiorite to a diorite. The lighter, felsic rock is distinctly gneissic, having lineation and conspicuous segregation of light and dark components into narrow bands. The darker, more femic, phase is more massive and coarser grained, but faint planar and linear fabric is discernable. Although included with the igneous rocks this complex may well be of hybrid origin.

The specimen described below is from the granodioritic phase of this complex.

Specimen No: Bc 22 — Location: S. of Wooddale

Hand Specimen: A medium-grained gneiss, not at all fissile or schistose. Banding is a result of imperfect segregation of quartz-feldspar layers and layers richer in dark minerals. Where weathered, a granular saprolite is formed ranging in thickness from less than an inch to several feet.

Thin Section: The rock comprises quartz, orthoclase, plagioclase, biotite and hornblende. The segregation of minerals into bands is apparent here as in the hand specimen. Granulation and bending of crystals took place during deformation. The plagioclase is somewhat perthitic and has a composition An_{30}. The small biotite shreds are well-oriented. Their pleochroism is light yellow to very dark brown. The hornblende, (-) 2V = c. 70°; Z∧C = c. 30°; is pleochroic light green to dark green to bluish green. It has been replaced in part by biotite. The irregular opaque grains rimmed by rutile are ilmenite. Zircon and apatite occur in minor amounts.

Estimated Composition (in per cent)

Plagioclase (An_{30})	42
Quartz	27
Orthoclase	15
Biotite	11
Hornblende	3
Ilmenite	2
Rutile	+
Apatite	+
Zircon	+

As with most of the other igneous and meta-igneous rocks present in Delaware, this material is massive, inert and dense and has no physical characteristics which would be detrimental in a road metal. The neighborhood which it underlies is undergoing suburban expansion and the likelihood that a quarry could be opened there is becoming progressively smaller.

Gabbro (sensu stricto)

The hills of crystalline rock which jut up through the Coastal Plain sediments forming Iron Hill and Chestnut Hill south of Newark are true gabbro. Another body of this material crops out northeast of Wilmington where it can be seen in the Shellpot Creek at Bringhurst Woods Park and

in nearby portions of Turkey Run and Matson Run. These bodies of gabbro are perhaps the only igneous rocks in the State which do not show clear marks of dynamic metamorphism. The Iron Hill material ranges in grain size from very coarse to medium, while at Bringhurst the range is from very coarse to coarse. In both places the coarsest rock contains crystals up to 2 inches long. Mineralogically the rock is made up largely of calcic plagioclase and pyroxene. At Bringhurst the pyroxene appears to be largely hypersthene; at Iron Hill both hypersthene and augite occur along with secondary amphibole which replaces the primary ferromagnesian constituents. In some instances, including the slide described below, this replacement by hornblende is complete. Minor amounts of zoisite, rutile, apatite and zircon are also to be found.

Specimen No: Da 6 — Location: Iron Hill

Hand Specimen: A heavy, dark, coarsely crystalline rock. Massive. No schistosity or foliation. Quartz and micas absent. A slightly fibrous green amphibole is the predominent constituent. The remainder is gray plagioclase. Weathered surfaces are covered with thin flakey rind of iron oxide resembling metallic rust.

Thin Section: This is a uralite gabbro composed of saussuritized calcic plagioclase feldspar and a pale green to colorless uralitized amphibole.

The plagioclase, composition An_{87}, is charged with acicular crystals of an epidote mineral, probably zoisite. The amphibole is irregularly developed, and somewhat fibrous. Small oriented opaque inclusions are common. Pleochroic colorless to pale green to pale blue, (-) 2V = c. 80°; Z∧C = c. 21°; birefringence = c. .025 -- actinolitic hornblende. Zoisite is present as abundant small, well-formed crystals with anomalous first order colors. Many small rutile and a few small zircon crystals occur.

Estimated Composition (in per cent)

Hornblende	64
Plagioclase (An_{87})	35
Zoisite	1
Rutile	+
Zircon	+
Opaque	+

As an engineering material this gabbro is worthy of consideration. The Bringhurst rock is inaccessible because of its occurrence in a highly populated area. In addition, its very coarse texture probably precludes its extensive use as a crushed stone.

At Iron Hill, on the other hand, most of the rock is of much finer grain and the rural aspect of the area is such that quarrying operations may be feasible. The distribution and nature of the overburden are matters which require careful investigation because of the development of residual iron ores on the upper portions of the mass. It seems likely that the ores have been eroded away on the flanks of the hills and fresh rock immediately underlies the soil. This soil is clayey and rather deep in places and no large exposures of bedrock can be found. Those masses of gabbro which are found at the surface appear in most cases to be large boulders lying in the soil above the bedrock.

Structural Features

In contrast with the Wissahickon formation in which the structural features are important and distinct, the gabbro complex is nearly featureless structurally. The very weak foliation which can be discerned in places has no practical significance, in that it affects neither the distribution nor the excavation qualities of the rock. In general, joints are widely spaced and poorly developed. The exceptions to this rule, however, are worth noting. Subhorizontal sheeting is well developed throughout the complex. This feature can probably be used to advantage during excavation.

In the amphibolite areas within the Wissahickon and along the margins of the gabbro complex a cross joint is usually well developed. This joint is developed perpendicular, or nearly so, to the hornblende lineation, which is generally parallel to the regional fold trend -- northeast-southwest. The cross joints, then, strike more or less northwest-southeast and dip vertically.

No faults or associated shear zones have been discovered within the gabbro during the present study and none has been reported from previous investigations.

The contrast between the structurally complex Wissahickon formation and the structurally featureless gabbro complex is displayed most strikingly in the differences between the topography developed on the two. The Wissahickon area is characterized by extremely irregular topography. There are subparallel ridges and valleys reflecting the folded and faulted nature of the bedrock and there are also cross-cutting streams which follow joints. The surface of the gabbro area, by contrast, is nearly flat and pronounced ridges are absent. The streams usually run in gentle valleys and the drainage pattern lacks geometric regularity. All of these factors suggest that there are no structural or lithologic variations of sufficient magnitude or regularity to be reflected in the topography.

Serpentine

In the central portion of the Piedmont, near the northerly end of Hoopes Reservoir, several small outcrops of serpentine occur. On the basis of careful field work three small bodies have been delimited and additional road cuts or excavations might reveal additional small bodies. This is a marked change from the earlier map (Bascom & Stose, 1932) which shows one continuous body occupying about 1 square mile. Peridotite and pyroxenite which accompany serpentine in many places are apparently absent here. This observation, too, is at variance with other published reports (Bascom & Stose, 1932, p. 11).

Outcrops of serpentine reveal an inch or so of soil underlain by a soft, occasionally fibrous, green rock. The material is traversed by a number of closely spaced, irregularly developed joint sets. The rock is too fine-grained to permit identification of its component minerals in the hand specimen, but the microscope reveals that it is made up largely of the serpentine minerals serpophite and antigorite, in sub-equal proportion. Minor amounts of talc, chromite and a carbonate, probably dolomite, also are present.

Even if the rock were suitable for road metal, the bodies are too small, and local real estate values far too high, to permit quarrying. If, in the future, highways should be built in the area certain qualities of the rock should be noted. So far as can be observed in Delaware and elsewhere, the unconsolidated overburden on serpentine bodies is always thin, never exceeding a few inches to a foot. This results from the fact that the minerals present are quite stable under atmospheric conditions and have a paucity of soda and potash. This lack of compounds necessary for plant life makes the vegetation on serpentine "barrens" particularly sparse.

Although serpentine is much softer than other crystalline rocks in this area, it is massive and dense and will require blasting in cuts. At the same time, cuts in serpentine may be made quite steep, for there will be little tendency for the rock to disintegrate and fall or slide.

Pegmatite

Inspection of the geologic map, plate 2, shows that pegmatite bodies are abundant only in the western portion of the Piedmont between Newark and Yorklyn. Such distribution is normal in that these bodies are largely restricted to granites and associated schists and gneisses.

In size, pegmatites range from veinlets a few inches wide to tabular bodies 200 feet thick. Because of the size range, and because small veins are occasionally abundant, only the larger, more conspicuous, pegmatite dikes are shown on the map. It can be seen that in map view they conform with the regional strike of the Wissahickon formation. In the field it can be seen that they likewise follow the dip of the formations in which they occur.

The minerals present in the pegmatite dikes are quartz, the potash feldspar microcline, muscovite, biotite and iron-bearing tourmaline. Of these, quartz and microcline are most abundant, making up over 75 per cent of the local bodies. Muscovite is the third most abundant mineral in the pegmatites; other constituents are present in relatively small quantities.

The outstanding characteristic of pegmatites is the large size of the individual crystals: in no other rocks is the grain so coarse. Individual quartz and feldspar crystals are commonly the size of a person's fist and crystals more than a foot long are not unusual.

From an engineering viewpoint two aspects of the pegmatite bodies are noteworthy. The first is their large grain size which renders them somewhat more resistant to weathering and erosion than the surrounding rocks, and makes boulders of pegmatite rather common in the soil. This coarseness of grain also makes these bodies unlikely prospects for crushing for road metal. The second important characteristic is one found in only a few local pegmatites: several small pegmatites near Hockessin, a larger one extending from Hockessin to Yorklyn, and two bodies of moderate size at Pleasant Hill have been chemically attacked by solutions of unknown origin. This attack has converted the microcline feldspar to kaolin, resulting in an unconsolidated mixture of clay and quartz which is known to extend, in places, to a depth of 90 feet and may extend to even greater depths. It is interesting, therefore, that highway alignments which cross pegmatitic dikes will encounter a wider range of conditions than is usually found on a single rock type: where roads cross fresh pegmatite, excavations will often be necessary while roads crossing the altered pegmatites may require a certain amount of fill as a result of the swampy terrain which sometimes accompanies them.

AREAL EVALUATION BY 5-MINUTE QUADRANGLE

The 5-minute quadrangles described in the section on the outcrop numbering system serve to divide the region into smaller areas of convenient size for individual descriptions. In the following pages each 5-minute quadrangle in the Piedmont will be given a brief description as to its area, culture, topography, drainage, and nature of the bedrock, and an evaluation of potential quarry sites.

There are 13 such quadrangles in the crystalline rock area of the State. Of these there are three wholly within the area in question and 10 which will be considered only in part because they contain portions of the Coastal Plain or portions of adjacent states. Some of the partial quadrangles have areas too small to warrant separate treatment, so will be included in the descriptions of adjacent partial or full quadrangles.

A 5-minute quadrangle at the latitude of northern New Castle County measures approximately 5 3/4 miles north-south by 4 1/2 miles east-west giving an area of about 26 square miles.

Quadrangles Ac and Ad

Quadrangles Ac and Ad, having a total area of less than 2 square miles, include the most northerly portion of the Great Circle region. West of route 202 the area is rural, while the portion east of that route is occupied largely by Brandywine Raceway and a few residential buildings. The more rural portion is deeply dissected, having a total relief of about 310 feet. Most of the area is drained by Brandywine Creek and its immediate tributaries; the extreme eastern section is drained by Naaman's Creek.

The contact between the Wissahickon formation and the gabbro complex is nearly coincident with route 202. The contact area is obscured by upland sediments which, in places, have a thickness of more than 10 feet.

In the area between Brandywine Raceway and the State Line these sediments are an especially likely source of moderate quantities of granular material. The minor amount of gabbro east of the contact holds no promise as a source of stone.

West of the contact the Wissahickon formation is often dense and gneissic. If the land is obtainable, and the overburden not too thick, the steep slopes on the east side of Brandywine Creek would make a likely location for a quarry. The stone, while of poorer quality than the igneous rocks in Delaware, would probably be acceptable for many purposes.

Quadrangles Ba and Bb

Quadrangles Ba and Bb occupy the northwestern corner of the Piedmont part of the State and have an area of about 14 1/2 square miles -- 1/4 in Ba and 14 1/4 in Bb. The area is largely rural in character; farming and mushroom growing are the most common activities of the area. Many residences have been built in recent years but these are individual dwellings or groups of a few houses; the only large development is at North Star. The fiber mill and the boat factory on Red Clay Creek at Yorklyn are the large industries in these quadrangles.

Topographically, the area is varied; in the north the hills and valleys are steep and show a distinct strike orientation. The central area which is underlain by the Cockeysville marble is nearly flat and has a relatively high water table making it rather swampy in contrast with the surrounding region in which the drainage is usually good. In the southern part of the quadrangle, near the head of Pike Creek the land is high and moderately dissected. Many places in the quadrangle have elevations above 400 feet while the lowest portions of the stream valleys are only slightly above 150 feet, giving a total relief of about 250 feet. The Red Clay Creek is the largest stream in the area, but it drains only the extreme northern portion. Pike Creek and Mill Creek both rise in this quadrangle and constitute its major drainageways, while some of the rills in the extreme southern portion run into the White Clay Creek.

The geologic map, plate 2, shows that the bedrock underlying this area is probably more varied than elsewhere in the Piedmont. In evaluating these materials as possible sources of engineering stone, the topography and its influence upon overburden are major considerations. As stated above, the Cockeysville marble is a poor stone prospect from an overburden viewpoint, and the high, rather level divide area south of the marble outcrop is likewise a poor prospect considering that throughout the Piedmont the undissected divides tend to have thicker overburden than land with steeper slope. The remaining areas are those in which the best stone prospects lie:

1. North and west of Yorklyn, between route 82 and the State Line. The rock here is dense hard amphibolite with some schist or gneiss. The land is rural in character and the topography is irregular, permitting good drainage and facilitating establishment of quarry faces.

2. The Mill Creek valley in the southern portion of this quadrangle has rather steep walls in which the exposed Wissahickon formation is usually fresh and gneissic. At present the area is still sufficiently rural that it may be possible to acquire enough land to open a quarry.

Quadrangle Bc

This quadrangle occupies the north-central portion of the Piedmont. Twenty-two square miles of its area are underlain by crystalline rocks in Delaware. The northern and western part of this quadrangle are still rather rural; the southeastern portion is urban and suburban, while the western side is occupied mostly by large estates.

The topography reflects the character of the underlying rock. In the northeastern two-thirds, underlain mostly by the Wissahickon formation, the surface is irregular with ridges rising sharply from the stream valleys. The southeastern portion, which is underlain by gabbro, is relatively flat or gently rolling; reflecting the marked differences in physical properties of the two rock types. The more homogeneous igneous material gives rise to a smooth topography while the Wissahickon formation with its gneisses and schists -- sometimes firm, sometimes micaceous -- has an irregular surface topography. Most of this quadrangle is drained by the Red Clay Creek and its tributaries. Along the eastern edge a small portion drains into the Brandywine and a little of the southeastern corner drains into Little Mill Creek.

As with most of the State the important problem facing a prospective quarry here is not so much the character of the rock as it is the accessibility of the land. There are only two areas in the quadrangle where the quarry possibilities seem to be favorable. They are:

1. In the south-central portion along the Red Clay Creek immediately north of Lancaster Pike (route 48) -- the underlying rock here is a granodiorite gneiss which is potentially an excellent road metal. The slopes here are steep and the overburden, as a consequence, is probably not excessive.

2. The walls of the Red Clay Creek valley in the northwestern part of the quadrangle are underlain by dense quartzo-feldspathic Wissahickon gneiss. The rock is easily accessible because of the steep valley walls, and the area is sufficiently rural that a quarry may be tolerated. On the basis of outcrops studied during this survey, it seems likely that the stone here would pass the tests for highway use.

Quadrangle Bd

Except for scattered patches of thin sediments quadrangle Bd is underlain wholly by crystalline rocks of the Piedmont. The extreme northeastern portion still retains a rural character, but the remainder of the area has undergone great development in the last few years and is now almost completely suburban and urban. Along the southern part of the Brandywine

Creek there is a concentration of industry on its immediate course; in the northern part of the quadrangle the creek valley is completely undeveloped.

Topographically, this quadrangle is marked by relative flatness compared with the quadrangles to the west. The Brandywine has incised a steep valley into the western edge of the plateau, and along the eastern border of this quadrangle the land surface begins a terrace-like descent to the level of the Delaware River. The drainage divide between the Delaware River and Brandywine Creek runs down the center of the quadrangle approximately coincident with Concord Pike (route 202).

The geologic map, plate 2, shows that this quadrangle is underlain mostly by rocks of the gabbro complex with some thin sediments along the drainage divide and in the south and east. A dense phase of the Wissahickon formation forms the bedrock of the extreme northwestern corner.

Considering only the nature of the bedrock this area should supply unlimited quantities of stone. However, the extreme flatness of much of the area, coupled with its urban and suburban character makes most of the stone inaccessible. Nevertheless, there are some localities with excellent stone potential which merit further investigation. The first of these is on the east bank of the Brandywine one-quarter mile south of Garden of Eden Road. The gabbro is almost continuously exposed in a very steep slope about 200 feet high and 1/2 mile long. The rock is among the densest materials in the State. Advantages of the site are the apparent ease for establishment of a quarry face, the relative absence of drainage problems and the good location with respect to highways and markets.

The second potentially useful area lies approximately 1 mile north of the one just discussed on the east bank of Brandywine Creek, between Smith's Bridge and Thompson's Bridge. The underlying rock here is part of the Wissahickon formation and, therefore, less dense than the gabbro. It would, however, make a stone acceptable for many uses. With respect to drainage, topographic expression and location, this locality is closely comparable to the previous one.

Quadrangle Be

Quadrangle Be, occupying the corner of the State bordered by the Delaware River and Chester County, Pennsylvania, has an area of about 10 square miles. It is underlain by igneous rock which, near the banks of the river, is partly covered by sediments. The area is almost completely urban and industrial in character, and those areas which still retain a somewhat rural character, such as the strip between Naaman's Road and the State Line, are rapidly being developed.

The drainage of this quadrangle is accomplished by a number of minor streams which run directly into the Delaware River; the more important ones being Naaman's Creek, Holly Oak Creek and Stoney Creek. The surface of the area drops down in a series of rather distinct steps from an elevation of 350 feet in the northwest to sea level at the river's edge.

The bedrock is banded gabbro and granite. The number of large abandoned quarries in this area attest to the fact that the rock is of good quality and often covered with little overburden. Little is known about the thickness of the sediments that obscure the bedrock along the river. It seems likely, however, that their thickness rarely exceeds about 20 feet.

With respect to potential quarry sites, it is difficult to find locations sufficiently far from residences that a quarry would be tolerated. One likely location is a farm on the northwest side of the B & O Railroad just north of Carpenter Station. The rock here is a very fresh gray granite which is overlain by clays and sands of probably Pleistocene age. This overburden ranges from 0 to about 7 feet thick. The locality is conveniently located with regard to transportation and proposed highway alignments.

Quadrangle Ca

Eight square miles of western Delaware bordering Maryland and Pennsylvania are included in quadrangle Ca. Newark, and its immediate vicinity, which occupies the southern portion of the quadrangle, is urban and suburban, but the remainder of the area is rural in character. Near the Fall Line a rather flat topography with an altitude of about 100 feet is dominant. The land surface rises gradually to the north to an elevation of almost 300 feet. The two conspicuous features of the region are a broad drainage divide and the steep sided White Clay Creek valley. The divide, which separates the tributaries of the White Clay Creek from those of the Christiana River, is approximately coincident with route 896.

Several kinds of rock underlie this quadrangle (see plate 2). In the south, granodiorite occupies an area of about 2 square miles. The topography here is flat and the rock exposed is usually deeply weathered. A careful search is required to find an outcrop of fresh granodiorite. North of the granodiorite outcrop is a narrow strip of gabbro. Although there are only a few exposures, it shows a range in composition from banded gabbro to amphibolite. Near the northern boundary of the quadrangle, another gabbroic body crops out. This one is apparently entirely amphibolite. More or less tabular pegmatite bodies traverse the area in a northeast-southwest fashion. These are well exposed only in the walls of the White Clay Creek valley. The Wissahickon formation, which underlies most of this area is commonly quite micaceous and schistose although in some places it is dense and gneissic.

Several companies surveyed this area and prospected for stone here during the winter of 1956-57. Actual core drilling was restricted to the Wissahickon formation on the southwest bank of the White Clay in Pennsylvania, a few hundred yards west of the Delaware State Line. Whether or not a quarry will be opened here depends upon many factors which are still under consideration.

Presently, (April 1957), one company is considering a pegmatite body about 2 miles north of Newark as a potential quarry site. The commer-

cial potential of this coarse-grained rock is doubtful in view of the fact that the bodies appear to be highly irregular in shape, and variable in texture and composition. One potential site which is not known to have been investigated is the amphibolite body in the northern part of the quadrangle. Little is known concerning the thickness of overburden developed on it, but the body is well located and merits consideration.

Quadrangle Cb

This quadrangle, in the southwestern part of the Piedmont, contains about 14 square miles which are immediately underlain by crystalline rocks. Most of the area is rural except for the portion along the Fall Line, which generally coincides with Capitol Trail (route 2). This part of the quadrangle is rapidly being developed.

As with other areas underlain predominantly by the Wissahickon formation, the area north of the Fall Line is irregularly hilly with streams running in sharply defined valleys. In the vicinity of Pleasant Hill, where crystalline limestone crops out, the topography becomes quite level.

Drainage of the area is effected by the White Clay Creek, Middle Run, Pike Creek and Mill Creek, all of which run down the dip and join White Clay Creek where it runs as a subsequent stream along the Fall Line.

The Wissahickon formation which forms the bedrock for most of the area, ranges in texture from dense and gneissic to micaceous and fissile. The crystalline limestone in the north crops out only at Eastburn's Quarry. Elsewhere it is covered by a thick residual overburden. The gabbro which is mapped along the course of the White Clay Creek at the southerly boundary of the Piedmont here can usually be seen only in the bed of the creek, and so has little potential as a source of stone.

All things considered, there are few places in this quadrangle where the desirable combination of factors such as location, good rock and thin overburden occurs, and although a likely spot may be found by diligent search none has been located thus far.

Quadrangle Cc

Only about 2 square miles in this quadrangle are underlain by crystalline rocks. The topography is relatively even and the area highly populated. For these reasons the rock is not often seen in outcrop, and is probably nowhere available as a quarry stone.

Quadrangle Cd

Approximately 1 square mile in the northwestern part of this quadrangle is underlain by banded gabbro and amphibolite. A part of this area is in the city of Wilmington where it may be encountered in building excavations and highway alignments, but is not available for quarrying.

One locality on the outskirts of Wilmington is presently being considered for a quarry, and so merits a brief description. This locality is bounded on the north by Maryland Avenue and on the west by Little Mill Creek. The land surface ascends from about 10 feet above sea level near the creek to 100 feet at Maryland Avenue. It has been tentatively proposed to start quarrying in the southwestern corner and work north and west. The geologic map, plate 2, shows a ridge of gabbro here, with a patch of sedimentary material capping it. The base of the sediments is at about 60 feet elevation. It must be noted, however, that sediments may extend below that elevation wherever there are irregularities in the surface of the crystalline material and that it is also most likely that sedimentary material has crept down the slope and covered the crystalline material in places. On the strength of these observations, it should be reiterated that any large investment in a potential quarry, here or elsewhere, should be preceded by a well planned program of test drilling.

Quadrangles Da and Db

About 2 miles south of Newark two large hills of bedrock extend up through the Coastal Plain sediments forming Iron Hill and Chestnut Hill (see figure 1). These hills, which can be considered as a unit geologically, occupy approximately 4 square miles.

Most of the area is still rural and wooded. There are, however, several small residential areas. These are developed along Chestnut Hill Road which runs over the crest of the more northerly hill, Glasgow Road (route 896) near the intersection with Cooch's Bridge Road, and along Cooch's Bridge Road on the south flank of Iron Hill. Along the other roads there are a few isolated houses and small farms.

The hills rise gradually out of the sediments, which lie at about 100 feet elevation, to altitudes of about 300 feet. This gives an average slope of approximately 6 1/2° (11.5 per cent). The small streams which drain the area have a radial pattern. Those running down north and east slopes run directly into the Christiana River while those draining the south and west slopes drain into Persimmon Run or Muddy Run which are tributaries of the Christiana.

The bedrock of the hills is a medium to coarse-grained, dark colored gabbro. Residual iron ore produced by weathering of this rock in the geologic past has been mined on the top of both hills and also certain places on the flanks. Such ore bodies have little value as stone and are to be avoided when developing quarry sites.

As a consequence of the low slope of the hills, there are no gullies or cliffs where large areas of bedrock are exposed. The bedrock is usually covered with a mantle of residual clay and boulders. It appears from well logs and building excavations that this overburden ranges in thickness from about 3 to about 25 feet.

There are three places on Iron Hill that appear to have potential as

quarry sites. These are:

1. the east flank west of route 896
2. the west flank about one-half mile north of Cooch's Bridge Road and,
3. south of Welsh Tract Church Road about one-quarter mile west of route 896.

In view of the excellent location of Iron Hill with respect to highways and areas of probable future development, no locality in Delaware is more worthy of investigation. It should be noted, however, that the area around Newark is being developed so rapidly that within a very few years the area may be so completely urbanized that it will no longer be possible to start a quarry.

ECONOMIC DEPOSITS OF THE COASTAL PLAIN

ECONOMIC IMPORTANCE OF SAND AND GRAVEL

Sand and gravel are of great economic importance because these materials are suitable for a great variety of uses and are common in many parts of the United States. They are easily and inexpensively mined or excavated and as a result are one of the cheapest of our non-metallic mineral resources.

Uses

Among the numerous uses of sand and gravel deposits, the following are outstanding in the United States (in order of decreasing production): as building and paving material, for molding, glass manufacture, as traction material for railroad engines, as railroad ballast, and as a filter material. In Delaware, sand and gravel are used nearly exclusively for road construction, concrete aggregate, and other building purposes; in addition some engine sand is produced in Sussex County from dune deposits near Lewes.

Methods of Production

Unconsolidated sands and gravels are excavated in open pits. All excavation is done with power tools; bulldozers for the removal of the undesirable overburden, power shovels to scoop the material from the banks of the pit into trucks. In many places desirable deposits extend below the water table, and where this occurs, sand and gravel are usually excavated by suction dredge, electrically or diesel driven. If the mechanical composition of the material is not to be changed, however, excavation by power shovels above the water table is necessary.

In addition to the actual excavation, sand and gravel may need certain preparation, depending on the characteristics of the deposit and the use to which it will be put. Inasmuch as grain size distribution, clay and silt content, and mineral composition are important factors affecting the use of sand and gravel deposits, they may be modified by screening, mixing of sands, washing, crushing or grinding of large particles and removal of undesirable constituents. The more rigid the specifications are for a certain use, the more preparation is usually needed, increasing the cost of the material. Building and paving sands and gravels, and material used for railroad ballast, often need little or no preparation.

Production and Value

The sand and gravel industry produces vast quantities of materials, particularly paving and building sand. Because of continually expanding highway construction programs in the United States, production has been steadily increasing, except during the years of the depression, and during World War II (see figure 5).

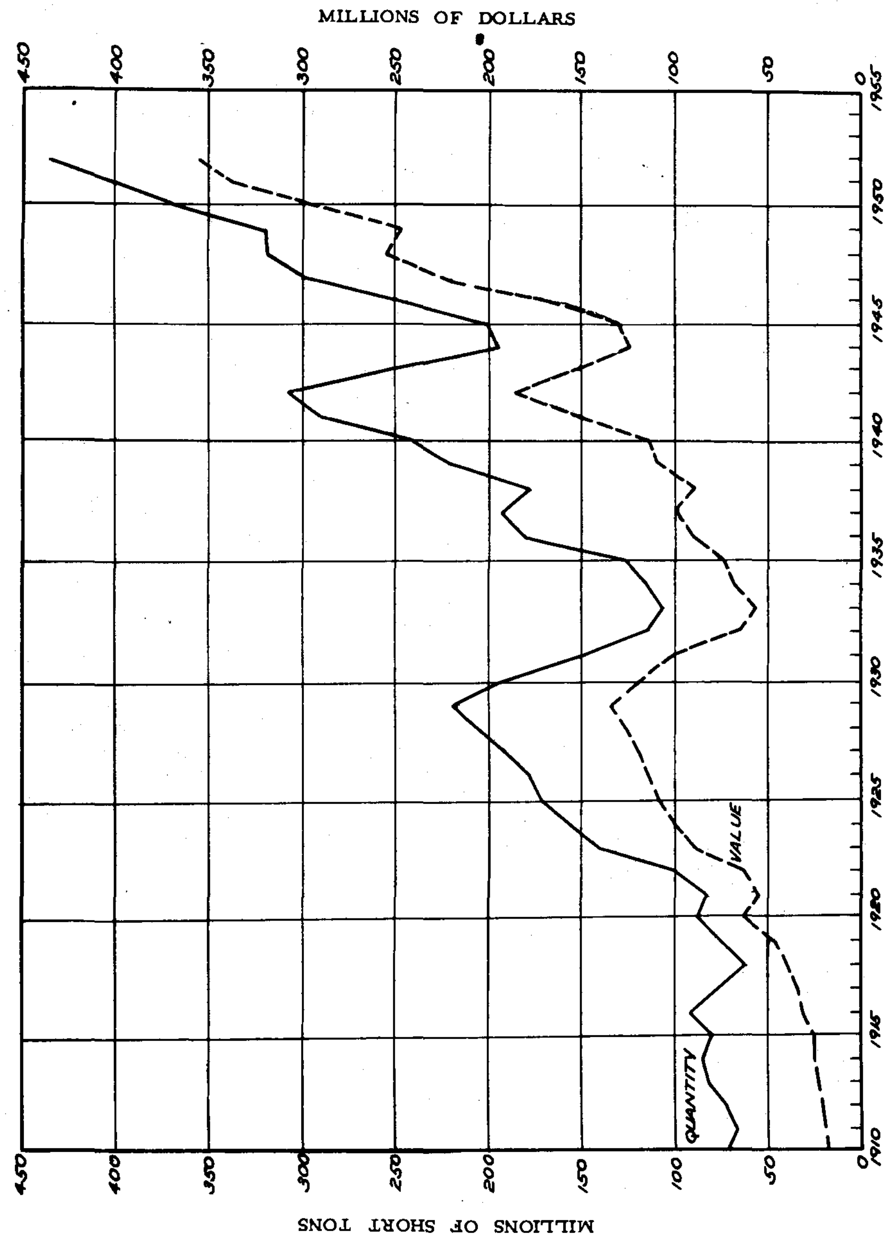

Figure 5. Quantity and value of sand and gravel produced in the United States, 1910 to 1952.

In 1952, total production of sand in the United States (including Alaska, Hawaii and Puerto Rico) in commercial and government-and-contractor operations was 156,092,506 short tons with a total value of $148, 712, 186; about 86% of this production, accounting for approximately 73% of the total value, was used as building and paving sand. During the same year, total production of gravel was 279, 418,727 short tons with a value of $204,672,029; about 94% of the gravel production, representing 94% of the value, was used as paving and building material.

The value of all sand and gravel production in 1952, $353,384,215, indicates that this industry is one of major economic importance. It is exceeded in value only by petroleum, coal, iron ore, and copper production, and exceeds that of many other minerals, as shown in table II.

Table II--Value of mineral production in the continental United States, 1952. (figures from Minerals Yearbook, U.S. Bureau of Mines, 1952)

Mineral	Value in dollars
Petroleum (crude)	5, 785, 230, 000
Coal (bituminous, lignite, anthracite)	2, 663, 115, 054
Iron ore	590, 346, 970
Copper	447, 882, 468
Sand and gravel (including ground sandstone)	351, 509, 117
Zinc	222, 981, 864
Lead	125, 631, 842
Clays (including Fuller's earth)	122, 385, 736
Salt (common)	70, 870, 767
Ilmenite	8, 022, 752

Sand and gravel output in Delaware, nearly all used in paving and building, has risen sharply, particularly during the last few years, and in view of the need for building more and better highways, will probably remain at a high level for some time to come.

Table III shows the tonnage and dollar value of sand and gravel sold or used by producers in the State.

REQUIREMENTS FOR COMMERCIAL SAND AND GRAVEL DEPOSITS

Characteristics of Sand and Gravel

Properties of clastic sedimentary rocks such as sands and gravels include texture, mineralogical composition, color, bedding and other structural features, and the presence or absence of organic matter. Texture refers to the grain size distribution of a sedimentary deposit, the shape and degree of roundness of the constituent grains, and the manner in which the grains are "packed". Finally, the nature of any cementing material holding the individual grains together must be considered.

Table III--Sand and gravel sold or used by producers in Delaware 1920-1955.

Year	Short tons	Value
1920	31, 320 (all sand)	$ 20, 337
1921	43, 958	25, 347
1922	32, 492 (all sand)	30, 561
1923	53, 022 (all sand)	34, 113
1924	41, 499 (all sand)	33, 271
1925	81, 052 (all sand)	48, 506
1926	83, 325 (all sand)	61, 186
1927	61, 177	42, 338
1928	68, 615	50, 209
1929	78, 055	59, 266
1930	74, 897	55, 193
1931	110, 678	64, 473
1932	73, 931	38, 116
1933	58, 297	33, 223
1934	84, 820	52, 625
1935	50, 860	28, 671
1936	83, 667	51, 794
1937	83, 994	47, 468
1938	108, 875	63, 366
1939	102, 850	61, 556
1940	167, 138	91, 913
1941	168, 359	102, 854
1942	169, 267	95, 298
1943	186, 923	99, 409
1944	88, 445	47, 269
1945	82,674	43, 678
1946	187, 229	123, 532
1947	235, 464	195, 002
1948	not available	
1949	233, 977	196, 451
1950	367, 524	291, 715
1951	654, 563	363, 643
1952	515, 399	382, 484
1953	520, 817	399, 685
1954	971, 647	752, 528
1955	2, 297, 074	1, 407, 196

In order to make valid interpretations with regard to the origin of sediments, knowledge of the properties mentioned above is essential. It is equally important, however, to consider these properties in relation to various industrial uses of sand and gravel deposits. So far as sand for industrial use is concerned, size frequency distribution and mineralogical composition are the most important characteristics.

Mechanical Composition

Various grade scales expressing mechanical composition have been developed by geologists, engineers and soil scientists. The scale used by American geologists is the one adopted by the National Research Council (1947). The limits of the various grades, expressed in millimeters, are all powers of 2. Thus, grade limits are 2^2, 2^1, 2^0, 2^{-1}, 2^{-2} mm, etc., or 4, 2, 1, 1/2, 1/4 mm, etc. If more detail is desirable class intervals may be reduced, and grade limits may be, for instance, 2^1, $2^{1/2}$, 2^0, $2^{-1/2}$, 2^{-1}, $2^{-1\ 1/2}$ mm, etc. For ease in plotting the results of size analyses, the phi (ϕ) scale, or negative logarithm to the base 2 of the National Research Council scale, can be used to prepare cumulative curves and to compute statistical values.

The American Society for Testing Materials (A. S. T. M.) uses a grade scale on the mesh system. The relationship between the geological and engineering grade scales is shown in table IV.

Mineralogical Composition

Most sediments are composed largely of detrital grains, that is, material derived from pre-existing rocks through the processes of weathering, erosion, transportation and deposition. These processes have a selective influence on the mineral composition of the sediments, because only those minerals and rock particles which can successfully resist the chemical and physical attacks made on them, will be found in sedimentary deposits.

The composition of the detrital material depends on many factors, amongst which are the nature of the source rocks, the climatic conditions under which they were formed, the physiography and the diastrophic history of the source area, and the mechanical composition of the sediments. If the source rocks contain large amounts of feldspar and other minerals which are subject to chemical weathering, clay minerals and micas may be formed, while quartz and other very stable minerals remain unaltered. If climatic conditions are warm and humid, chemical weathering may be severe, resulting in decomposition of all, or most, unstable minerals; if, however, climatic conditions in the source area are cold or dry, even unstable minerals may survive, and consequently be found in the sedimentary deposits. Physiography, or the landforms which existed at the time the detrital materials were formed also has an influence on the composition of the sediments: in a low-lying source area with little vertical erosion the weathering processes tend to be prolonged, resulting in the destruction of many unstable minerals, while in an area of considerable relief,

Table IV--Classification of grain size of clastic sediments.

Geologic classification				A. S. T. M. classification		
Designation	Size (mm)	Size (powers of 2)	Phi (ϕ) grades	Mesh	Opening (mm)	Designation
				5	4.00	Sand
				6	3.36	
Gravel	greater than 2	greater than 2^1	less than -1	7	2.83	
				8	2.38	
				10	2.00	
				12	1.68	
Very coarse sand	2 to 1.41	2^1 to $2^{1/2}$	-1 to -1/2	14	1.41	
				16	1.19	
	1.41 to 1	$2^{1/2}$ to 2^0	-1/2 to 0	18	1.00	
				20	0.84	
Coarse sand	1 to 0.71	2^0 to $2^{-1/2}$	0 to 1/2	25	0.71	
				30	0.59	
	0.71 to 0.5	$2^{-1/2}$ to 2^{-1}	1/2 to 1	35	0.50	
				40	0.42	
Medium sand	0.5 to 0.35	2^{-1} to $2^{-3/2}$	1 to 1 1/2	45	0.35	
				50	0.297	
	0.35 to 0.25	$2^{-3/2}$ to 2^{-2}	1 1/2 to 2	60	0.250	
				70	0.210	
Fine sand	0.25 to 0.177	2^{-2} to $2^{-5/2}$	2 to 2 1/2	80	0.177	
				100	0.149	
	0.177 to 0.125	$2^{-5/2}$ to 2^{-3}	2 1/2 to 3	120	0.125	Silt, Clay
				140	0.105	
Very fine sand	0.125 to 0.088	2^{-3} to $2^{-7/2}$	3 to 3 1/2	170	0.088	
				200	0.074	
	0.088 to 0.0625	$2^{-7/2}$ to 2^{-4}	3 1/2 to 4	230	0.062	

Table IV--Continued.

Geologic classification				A. S. T. M. classification		
Designation	Size (mm)	Size (powers of 2)	Phi (ϕ) grades	Mesh	Opening (mm)	Designation
Very coarse silt	0.0625 to 0.03125	2^{-4} to 2^{-5}	4 to 5	270	0.053	Silt, Clay
				325	0.044	
Coarse silt	0.03125 to 0.016	2^{-5} to 2^{-6}	5 to 6			
Medium silt	0.016 to 0.008	2^{-6} to 2^{-7}	6 to 7			
Fine silt	0.008 to 0.004	2^{-7} to 2^{-8}	7 to 8			
Clay	Smaller than 0.004	Smaller than 2^{-8}	Greater than 8			

vertical erosion is relatively rapid, exposing fresh rock, and providing detrital material composed of a great variety of minerals.

The factors briefly described above operate simultaneously. Thus, the composition of the detrital sediment is determined by the interaction of all these factors.

Because a sediment is the product of its environment, the question arises as to what type environment can be expected to produce a sand and gravel deposit suitable for a particular industrial use. Because a coarse grained deposit is required for aggregate and select borrow material, and in the case of the latter, some admixture of silt or clay, the environment should include a transporting agent capable of carrying a wide size range of detrital grains. Air and ocean currents are generally not capable of doing this, and, therefore, it is unlikely that suitable building and paving sands will be found in eolian or marine deposits. Streams, however, particularly those whose great competency is due to steep gradients or large discharge, provide the most likely medium for transporting and depositing the coarse-grained sediments suitable for road building materials. These may be expected, therefore, in continental sediments laid down during gelogic periods characterized by active diastrophism, heavy precipitation, or the melting of continental glaciers. In Delaware, Early Cretaceous time was a period of moderate subsidence, and during the Pleistocene Epoch large amounts of water flowed down the Delaware River as a result of the melting of the great ice sheet which covered eastern North America, as far south as northern New Jersey. Thus, the river-borne sediments of the Patuxent zone and also the Pleistocene series (see section on geologic formations) may be expected to offer the best chances for locating materials with a mechanical composition suitable for road building.

If a sediment is composed of a great variety of minerals as a result of its having been formed during a period of cold or dry climate, its industrial uses may be limited by deleterious components, particularly if some of the unstable materials suffer post-depositional decomposition. Under conditions of great chemical weathering in the source area of the sediments, only very stable minerals, primarily quartz, remain, and such deposits have a mineral composition suitable for most industrial uses. This is the case with the nonmarine Cretaceous sediments. The Pleistocene sediments which were deposited in part during glacial stages, and in part during interglacial stages, have a more varied mineral composition than those of the nonmarine Cretaceous. This tends to limit their industrial uses. However, the requirements for building and paving sand are not very strict, and few Pleistocene sands are expected to be mineralogically unfit for this use.

The mechanical composition of the detrital material also has an important bearing on its mineral composition. Gravel consists of large quartz particles and rock fragments which are mineral aggregates; sands are generally composed of individual mineral grains, and the fine-grained clays consist of clay minerals.

Common detrital material of gravel size consists of quartz, chert, various types of sandstone, shale, limestone and many types of igneous and metamorphic rocks. Some of these rock fragments may be weathered and soft, and, therefore, unsuitable for aggregate. Soft shales and sandstones are particularly undesirable. Chert, although not soft, causes chemical reactions in aggregate which make it a deleterious material.

Common detrital minerals in the sands of the Coastal Plain are quartz, chert, feldspar and muscovite. Other detrital material occurring in small quantities (generally 3 per cent or less by weight) is formed by a group of so-called heavy minerals (s.g. 2.87 or more), such as the opaque minerals magnetite, ilmenite, and pyrite, and a great variety of nonopaque grains, such as zircon, tourmaline, garnet, rutile and other titaniferous minerals, staurolite, kyanite, sillimanite, andalusite, chloritoid, epidote, hornblendes, augite and diopside. Some minerals, particularly muscovite and biotite, have a specific gravity close to 2.87 and may be found both in the light and heavy fractions of a sediment. The accessory heavy minerals are of no great importance insofar as most uses of sand are concerned, except where very low iron content is desired.

The fine grained clays are generally composed of a group of clay minerals, which consist largely of hydrous aluminum silicates. Kaolinite, illite, chlorite and montmorillonite are found in the Coastal Plain deposits.

Minerals which have been added to a sedimentary deposit during or after deposition are glauconite, a soft green mineral formed in relatively shallow marine waters; pyrite and marcasite, iron sulfides often associated with organic sediments; limonite, a hydrous oxide of iron and some clay minerals. These minerals can also occur as detrital materials due to redeposition.

Requirements for Structural Sand

Structural sand includes building and paving sand. Desirable properties are: reasonable freedom from clay-coated grains, lumps of clay, flat or elongated grains, organic matter, and pyrite, and a minimum of clay and silt (material passing the 100 mesh sieve). The upper limit of grain size is placed at 1/4 inch to 3/8 inch (Weigel, 1927, p. 73).

Requirements for Building Sand

The specifications for building sand, and particularly sand for concrete aggregate, are more detailed than those described above. Of particular importance are proper size frequency distribution and absence of deleterious minerals. For fine aggregate, the American Society of Testing Materials recommends the following:

Sieve	Sieve opening	ϕ Scale equivalents	Percentage passing (by weight)
3/8 inch	3/8 inch	-3 1/4 (abt)	100
No. 4	4.75 mm	-2 1/4	95-100
No. 16	1.19 mm	-1/4	45- 80
No. 50	0.297 mm	+1 3/4	10- 30
No. 100	0.149 mm	+2 3/4	2- 10

Standard specifications for light aggregate adopted by the State Highway Department are as follows:

Sieve	Percentage passing (by weight)
No. 4	95-100
No. 50	28% max.
No. 100	2-7% max.

For coarse aggregate, grain size should lie between a lower limit of 1/4 inch and a higher limit of 3 inches (approximate phi equivalents: -2.6 and -6.2).

Mineralogically weak or soft particles should not make up more than 3 per cent of the deposit. Such undesirable materials are: clay or shale particles; organic matter, such as lignite; glauconite; poorly consolidated sandstone granules or pebbles; in addition, pyrite and chert are undesirable if present in significant quantities. Partly decomposed feldspar grains are soft and may also be deleterious.

Requirements for Paving Sand

The requirements for paving sand and gravel are not as rigid as those for aggregate, and specifications vary with the type of road to be constructed and materials available. Many kinds of sands can be successfully used.

For highway subbase material, the sand should provide good stability, good drainage even when compacted, and should be such as to minimize damage from frost action. The requirement of good drainage points to a relatively coarse sand in which silt and clay passing the 200 mesh sieve (phi equivalent 3 3/4) should not exceed 7 to 12 per cent. Other requirements for paving sand found in the section on State Highway Department specifications regarding the texture of borrow material are as follows: not more than 50 per cent retained on No. 10 sieve, 35 to 60 per cent passing No. 10 sieve and retained on No. 40 sieve, and 10 to 25 per cent passing No. 200 sieve.

Specifications for light aggregate and select borrow are graphically presented in figure 6.

Location

The price of sand and gravel per short ton ranged in 1952 from $.49 for railroad ballast to $2.66 for glass sand. Truck transportation per mile per cubic yard costs about five cents. From these figures it is obvious that the cost of the material to the consumer is greatly influenced by the distance from the place of excavation to the place of use; as is the case with stone, long distance hauling is uneconomical, and road transportation over 10 miles or more is generally not practical. If transportation is by barge, longer distances may be covered economically.

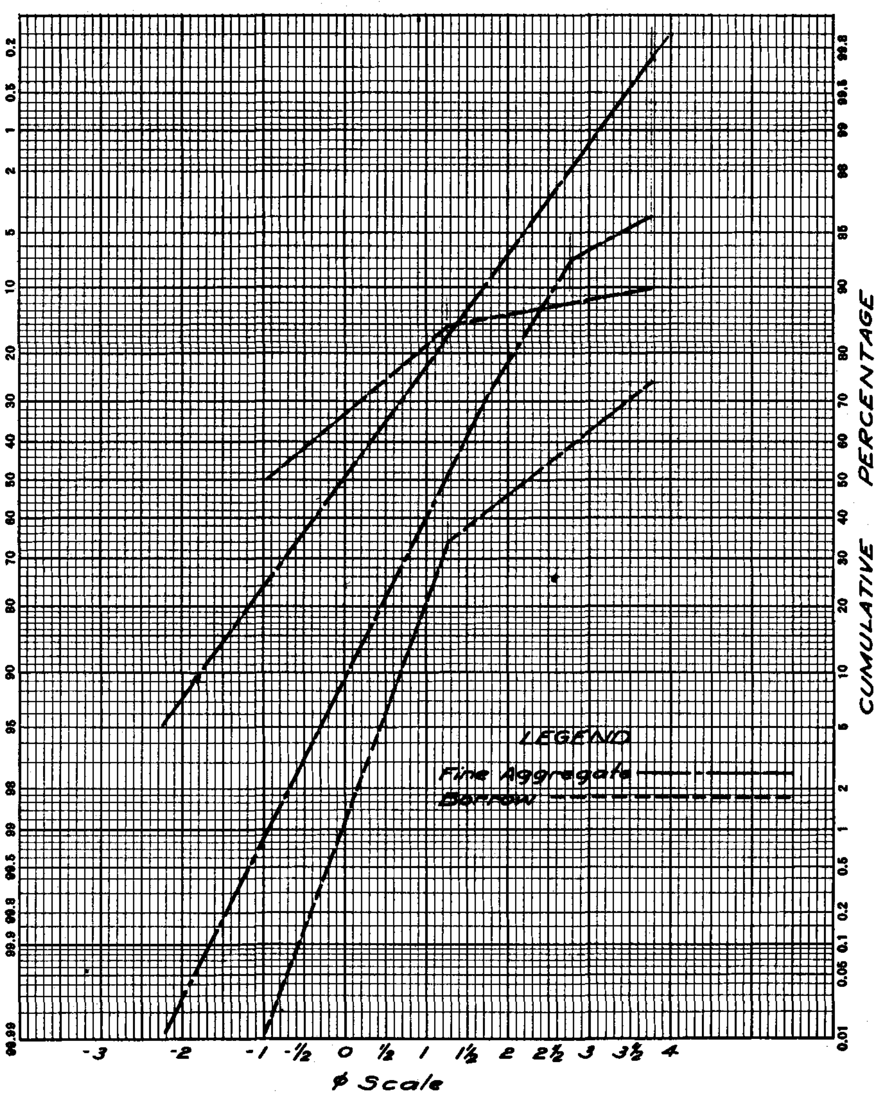

Figure 6. Specifications for fine aggregate and borrow.

The price at which sand and gravel can be produced also depends on land values. In many areas where considerable road building is in progress, the price of the land per acre may be so high as to make mining impossible, unless pits were already in operation before land values greatly increased.

The thickness of the overburden, the undesirable material which has to be removed with bulldozers, also plays a role. However, in the Coastal Plain the overburden is generally not more than a few feet thick, and is not a serious detriment to mining operations.

PRESENT INVESTIGATION

It was the purpose of the investigation to determine:

1. the distribution of the surficial sand and gravel deposits in northern Delaware in relation to the geologic formations present in the area, and

2. the physical and mineralogical characteristics of these deposits with regard to their use as paving material and as coarse and fine aggregate.

Areal and subsurface geologic investigations were made to determine the occurrence and characteristics of the geologic formations in the area. The subsurface exploration included a well canvass and the collection of well logs made available by water well contractors, test augering by the Delaware Geological Survey, and an electrical resistivity survey carried out by the Geophysics Branch of the U. S. Geological Survey. The mineral composition of the sands and gravels was studied, and size frequency determinations were made of a number of outcrop and well samples throughout the Coastal Plain of northern Delaware.

Areal Geologic Studies

Areal geologic studies have been carried out in Delaware during the last six years, and the results have been published by the Delaware Geological Survey in a number of reports (Groot and Rasmussen, 1954; Groot, Organist and Richards, 1954; Marine and Rasmussen, 1955). A study of the water resources of northern Delaware (Rasmussen, Groot, Martin, McCarren, in press), and the present investigation for the State Highway Department have added considerable data to that collected in previous years. Of particular interest for the purposes of this study are the geologic map (plate 2) and the map showing the base of the Pleistocene deposits (plate 4).

An investigation was made of all suitable outcrops in sand and gravel pits, and along the banks of the Chesapeake and Delaware Canal; samples were collected for mineralogical and size determinations. The evaluation of the geologic formations in terms of suitable building and paving materials is largely based on this study.

Subsurface Studies

Well Canvass

The well canvass, including the collection of well logs, is a relatively inexpensive method of obtaining subsurface geologic information, although its value is limited by several factors for the purposes of the present investigation. First, samples of the subsurface materials are not usually available for mineralogical and size determinations, and evaluation has to be based exclusively on the drillers' descriptions. Second, such descriptions are always subjective to an undetermined degree, and what is called a medium sand by one person may be called coarse sand by another. In spite of these drawbacks, the well canvass proved to be of considerable value, particularly with regard to determining the thickness of the surficial sands and gravels.

The total number of wells canvassed in the Coastal Plain of northern Delaware is 1,460, of which 685 have well logs.

Test Augering

Where subsurface information was unavailable or unreliable, test holes were augered in the Pleistocene sands and gravels. Samples were taken at intervals of 5 feet, and at every change in lithology. In total 40 holes were augered and more than 325 samples were studied.

The results of the well canvass and the logs of wells and test holes are available at the offices of the Delaware and U. S. Geological Surveys, Newark, Delaware.

Electrical Resistivity

The purpose of the electrical resistivity survey was to obtain data on the presence and thickness of highly resistant beds of sediments, such beds usually being composed of sands or gravels suitable for highway construction. It was expected that this geophysical technique would be a faster, and less expensive way of locating sand and gravel deposits than test augering, although it obviously has the disadvantage of not providing samples of the materials it may discover. After testing this technique during the summer of 1954, it was concluded that although satisfactory results could be obtained in many places, the presence of metal fences, electric wires, pipelines, etc. made the operation a difficult one. Also, the well drained near-surface soil often prevented good contact for the electrodes. These difficulties delayed the resistivity investigation, and further prospecting was done by power auger.

The results of the resistivity investigation were presented in an open file report, available for inspection at the offices of the Delaware Geological Survey, the U. S. Geological Survey, both at Newark, Delaware, and at the State Highway Department, Dover, Delaware.

The resistivity survey proved particularly helpful in determining the base and the thickness of the Pleistocene sand and gravel deposits.

Mineral and Size Determinations

Disaggregation and dispersion of the samples were the first steps taken in order to obtain reliable data on the mechanical composition of the sediments. Although all samples were taken from unconsolidated materials, some particles were lightly cemented by iron hydroxide or clay, and some silt and clay particles adhered to the larger sand grains. Disaggregation was accomplished by gently crushing the sample with a mortar and a rubber pestle; the sample was then treated with hydrogen peroxide and dilute hydrochloric acid, washed by decantation, and the fine particles brought into suspension by boiling with a solution containing sodium pyrophosphate and sodium carbonate.

Sieving was used for the mechanical analysis of the coarse portion of the sediments (particles 62 microns and larger). A Ro-Tap automatic shaking machine was used with U. S. Standard sieves, separating the various sand fractions. The fine portion of the sediments was analyzed by the pipette method.

The samples were split in fractions according to the National Council Research scale, described previously. The phi scale was used for plotting the cumulative curves on arithmetic probability paper. This method has an advantage in that symmetrical size frequency distributions are plotted as straight lines, and that the character of the mechanical composition can be easily comprehended.

The mineral content of the samples taken from outcrops and drill holes was studied by splitting each sample in two portions; the light fraction (sp.gr. less than 2.87) and the heavy fraction. The light fraction was studied under the binocular microscope, and the percentages of the main mineral constituents were estimated. The heavy fraction, separated in bromoform after appropriate chemical treatment with acids to remove iron or manganese stains from the grains, was mounted on glass slides in Canada balsam, and one hundred non-opaque grains were determined on each slide. The opaque minerals were counted, but not determined.

The composition of the gravels was determined from specimens collected in sand and gravel pits; attention was focused on the occurrence of deleterious materials, such as shales, chert, soft sandstones and deeply weathered fragments.

Geologic Formations in Relation to Sand and Gravel Deposits

Nonmarine Cretaceous Sediments

The nonmarine Cretaceous sediments have been subdivided into two zones on the basis of their heavy mineral content (Groot, 1955): a lower zone characterized by abundant staurolite, and an upper zone with abundant zircon, tourmaline and rutile. The lower zone is called the Patuxent zone and the upper one is called the Patapsco-Raritan zone. The lower zone is found at the surface or beneath the Pleistocene sediments near the Fall Line, and forms a belt roughly parallel to it (see plate 2). The upper zone occurs in a belt located to the southeast of the Patuxent zone. As a boundary between these two belts can only be established on the basis of time-consuming heavy mineral determinations, its exact position is not known.

Patuxent Zone

The sediments of the Patuxent zone consist of predominantly white, gray, buff and light brown, fine to coarse, usually angular, well sorted to poorly sorted sands, often displaying small scale cross bedding. The sands contain thin intraformational gravels, and in nearby Maryland basal gravels have been reported (Clark, et al., 1911, p. 59). The sands contain varying amounts of feldspar, although, in Delaware, never enough to warrant the term "arkose". At some places a little lignite is present.

The silts and clays are often sandy, gritty or pebbly, plastic or hard, and display a variety of colors, with red, gray and white predominant. Some clays are dark gray or black due to finely disseminated carbonaceous matter.

The sands of the Patuxent zone grade laterally and vertically into silts and clays within short distances. Most sands are channel type deposits rather than extensive sheets.

Quartz is by far the main mineral constituent of the sands of the Patuxent zone; usually the quartz content is as high as 95 per cent; in addition, small amounts of weathered feldspar grains are present (1 to 4 per cent), some heavy minerals (1 to 3 per cent), and a little muscovite. The chief heavy minerals are black opaques such as magnetite and ilmenite, and staurolite, zircon, tourmaline, and kyanite. Detailed information on the heavy mineral content of Cretaceous sands may be found in Bulletin 5 of the Delaware Geological Survey (Groot, 1955).

The clays of this zone are composed of a mixture of kaolinite, vermiculite and illite (Glass, 1955, personal communication), with kaolinite the chief constituent. The gravel is composed nearly completely of quartz pebbles.

As far as the mineral content is concerned, the Patuxent sands should be suitable as borrow material and for aggregate, except where they contain more than a few per cent weathered feldspar or lignite.

Twenty-nine samples were subjected to mechanical analysis; the results are shown in table V. Only one sample (no. 2008) had a high percentage of gravel, consisting of quartz pebbles of one to two inches in diameter. Consequently, it must be expected that the Patuxent sands do

Table V--Texture of Patuxent zone sands in relation to borrow material and fine aggregate.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1016	--	7	82	24	5	--	Cc	El. not det.	Most samples obtained from drill cores
1017	tr	5	82	16	2	--	Cc	El. not det.	
2001	tr	4	88	45	22	--	Dc	34-35	
2002	11	71	11	2	tr	fine aggr.	Dc	54-55	
2003	tr	5	86	32	5	--	Dc	74-75	
2004	18	65	12	6	3	fine aggr.	Dc	94-95	
2005	tr	40	25	5	tr	fine aggr.	Dc	99-100	
2008	46	60	30	15	10	borrow	Dc	73-74	
2009	tr	4	87	59	28	--	Dc	88-89	
2010	15	41	36	25	18	borrow	Dc	121-122	
2011	1	21	71	54	46	--	Dc	141-142	
2016	1	12	70	22	13	--	Dc	100-101	
2017	1	7	82	40	10	--	Dc	129-130	

Table V--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft.lsd)	Remarks
2019	2	38	46	21	10	borrow	Dc	58-59	Most samples obtained from drill cores
2020	13	43	37	25	16	borrow	Dc	107-108 112-113	
2021	14	21	39	27	18	borrow	Dc	117-118 122-123	
2026	tr	5	83	44	11	--	Dd	134-135	
2029	1	38	51	33	23	borrow	Cc	59-60	
2030	33	45	16	7	4	fine aggr.	Cc	64-65	
2031	1	7	81	40	22	--	Cc	74-75	
2035	tr	tr	97	64	30	--	Cc	20-21	
2036	5	37	38	16	10	borrow	Cc	147-148	
2037	2	2	85	22	12	--	Dc	54-55 59-60	
2038	1	9	68	16	5	--	Dc	79-80	
2039	6	73	14	6	3	fine aggr.	Dc	114-115	
2040	tr	7	66	11	5	--	Dc	139-140	

Table V--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft.lsd)	Remarks
2085	tr	14	54	36	32	--	Dd	59-60	Most samples obtained from drill cores
2086	tr	3	70	10	7	--	Dd	64-65	
2087	--	2	82	16	5	--	Dd	69-70	

not constitute a likely source of coarse aggregate. Of the twenty-nine samples investigated, five had a mechanical composition in accordance with the specifications for fine aggregate of the State Highway Department; these sands had such a small silt and clay content that they could probably be used without washing.

Seven samples had mechanical compositions indicating suitability as select borrow material. Unfortunately, most samples consisted of sands too fine-grained to be of use in highway construction.

Although some of the Patuxent deposits may be suitable as select borrow material and for fine aggregate, the main difficulty is that they crop out in very few places, and are nearly everywhere overlain by Pleistocene sands. Therefore, it must be concluded that they are of small economic importance in Delaware. Only where the overlying Pleistocene is thin, and rests immediately upon Patuxent sands, could excavating these materials be considered worthwhile.

Patuxent zone sands may be seen in an abandoned sand pit in the eastern part of Newport where they are overlain by about 10 feet of Pleistocene material.

Patapsco-Raritan Zone

This zone immediately overlies the Patuxent zone and is found at or near the surface in a belt approximately parallel to the Fall Line southeast of the Patuxent zone (see plate 2). It consists largely of variegated sandy silts and clays predominantly red in color, but white, yellow and drab clays have also been observed. Intraformational gravels have been found, although they are of very limited extent. Some kaolinized feldspar is present, but less than in the Patuxent zone.

Within the Patapsco-Raritan zone, and particularly in the upper portion, sand lenses occur. The sands are usually white or gray, although brown and red ones are also found. A little lignite or other carbonaceous matter is present in some places.

As in the Patuxent zone, there are rapid changes in lithology both in a horizontal and a vertical direction; the sands are channel sands of limited lateral extent.

The sands are composed nearly completely of quartz; very small quantities of heavy minerals are present, mainly black opaques, zircon and tourmaline. Feldspar is nearly absent. The little gravel present is nearly exclusively quartzose. The clays consist mainly of kaolinite, and smaller quantities of vermiculite and ilmenite (Glass, 1955, personal communication).

So far as their mineral composition is concerned, the sands of this zone should be suitable for construction purposes, as they do not contain deleterious materials in any appreciable quantity.

The texture of the sands of the Patapsco-Raritan zone is reviewed in table VI. None of the samples investigated is coarse enough to fall within the specifications for select borrow material and fine aggregate, whereas the near absence of gravel indicates that there is no material available for coarse aggregate. Even if some suitable material were to be found, its use would be sharply limited by the fact that the Patapsco-Raritan zone is restricted in outcrop area to a few narrow strips along streams, particularly the Christiana Creek.

A small abandoned pit in these sediments is located along the east bank of the Christiana Creek, south of Christiana.

Magothy Formation

The Magothy formation consists mainly of white, "sugary", subangular, well sorted sands with some lignitized branches and tree trunks, and lenses of black, carbonaceous clays. In some localities marcasite and pyritized or marcasitized lignite are found.

The sands of the Magothy occur as sheet sands rather than as channel sands which are common in the nonmarine Cretaceous sediments. They are well stratified, with cross bedding not uncommon. The thickness of the Magothy sands does not exceed 15 feet in outcrop.

The Magothy formation crops out in the banks of the Chesapeake and Delaware Canal, but it is not found at the surface anywhere in Delaware. It is found beneath the Pleistocene deposits in a relatively narrow belt to the southeast of the sediments of the Patapsco-Raritan zone, but, due to the presence of an unconformity between the nonmarine Cretaceous and the Magothy, this belt is a discontinuous one, the Magothy sediments having been eroded in many places before deposition of the marine Cretaceous formations.

The mineral content of the Magothy sands is characterized by high quartz percentages: usually 95 to 98 per cent. A moderate to large amount of heavy minerals, mostly black opaques, staurolite and tourmaline, is present. The average heavy mineral content is approximately 2 per cent, but a few samples with a percentage as high as 13 have been found. Feldspar is practically absent and muscovite occurs in small quantities. Some small quartz pebbles occur in places. It must be concluded that the mineral composition of the Magothy formation does not preclude its use as a construction material, except that lignite should be removed.

The texture of the Magothy sands is summarized in table VII. These sands are usually too fine grained to be suitable for borrow material or fine aggregate. Although many samples do not contain appreciable amounts of silt and clay, they lack the large amount of coarse material which is desired for construction material. Of the twenty-one samples analyzed, only two were found suitable for select borrow material, and one for fine aggregate. Lack of gravel indicates that the Magothy formation cannot be considered a source of coarse aggregate.

Table VI--Texture of Patapsco-Raritan zone sands in relation to borrow material and fine aggregate.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft.lsd)	Remarks
1288	--	3	89	52	29	--	Db		Elevation not determined
1289	--	tr	98	66	35	--	Db		Elevation not determined
2015	16	3	77	62	39	--	Dc	63-64	
2063	2	7	81	44	20	--	Db	9-9'9"	
2088	--	tr	97	75	51	--	Cc	34-35	

Table VII--Texture of sands of the Magothy formation in relation to borrow material and fine aggregate.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft.sld)	Remarks
1099	tr	tr	97	26	4	--	Ea	2	
1103	3	tr	97	92	36	--	Ea	4	
1106	3	30	44	5	1	--	Ea	2	
1107	--	tr	97	22	1	--	Ea	2	
1250	--	14	60	7	tr	--	Ea	4	
1251	--	--	100	48	2	--	Ea	3	
1269	--	tr	98	66	23	--	Eb	2	

The generally unsuitable mechanical composition of the Magothy sands, the need to remove lignite and their presence below Pleistocene sands and gravels, combine to make these sediments of little, if any, economic importance for highway construction purposes.

Marine Upper Cretaceous Formations

The marine Upper Cretaceous formations have been described by Groot, Organist and Richards (1954). They are, in order of decreasing age: the Merchantville, the Wenonah, the Mount Laurel-Navesink and the Red Bank formations. They are well exposed in the banks of the Chesapeake and Delaware Canal, but do not occur in outcrop except in very few places along creeks in the southeastern part of northern Delaware. Nearly everywhere they are covered by a blanket of Pleistocene or Recent sediments.

Merchantville Formation

This formation grades from a dark blue to black, very coarse to coarse, poorly sorted, micaceous, glauconitic silt to a dark greenish brown, very fine, subangular, poorly to well sorted, micaceous, glauconitic quartz sand with considerable silt and clay. The uniformity of its lithology throughout northern Delaware is striking compared with the heterogeneous nonmarine Cretaceous sediments.

In addition to abundant glauconite and finely divided mica, the Merchantville formation contains about 1 per cent heavy, accessory minerals, including black opaques, epidote, chloritoid, staurolite, kyanite, sillimanite, tourmaline, zircon and garnet. On the basis of its mineralogy, particularly the presence of the very soft mineral glauconite in relatively large quantities (from 4 to 60 per cent), it is expected that the Merchantville is generally unsuitable as a construction material.

Table VIII indicates that the mechanical composition of the Merchantville is that of a very fine, very silty and clayey sand, with a nearly complete lack of coarse material. (Silt and clay samples from this formation are not included in this table). It must be concluded, therefore, that the Merchantville does not contain any materials suitable for road construction.

Wenonah Formation

The Wenonah differs from the underlying Merchantville formation both in mineral composition and texture. It is composed of rust-brown and gray, well stratified, fine, subangular, well sorted, micaceous quartz sand, with some glauconite. The accessory heavy minerals are the same as those found in the Merchantville formation, except for the near-absence of garnet.

The Wenonah does not contain any deleterious material, although the relatively high percentage of muscovite may be considered a drawback.

The texture of the Wenonah sands, shown in table IX, is completely unsuitable for construction purposes, in that they contain very little coarse

Table VIII--Texture of sands of the Merchantville formation in relation to borrow material and fine aggregate.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft.sld)	Remarks
1108	tr	tr	99	70	21	--	Eb		Elevation not determined
1120	tr	tr	99	85	34	--	Eb	2	
1124	tr	tr	99	92	50	--	Eb		Elevation not determined
1125	tr	tr	99	86	36	--	Eb		Elevation not determined
1132	tr	tr	98	60	10	--	Eb	4	
1133	tr	tr	98	64	18	--	Eb	8	
1134	--	tr	99	64	14	--	Eb	7	
1135	tr	tr	98	64	19	--	Eb	5	

Table IX--Texture of sands of the Wenonah formation in relation to borrow material and fine aggregate.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. sld)	Remarks
1110	tr	tr	99	70	22	--	Eb	4	
1112	tr	tr	99	74	22	--	Eb	4	
1119	--	tr	99	66	13	--	Eb		Elevation not determined
1146	tr	1	96	64	23	--	Eb		Elevation not determined
1154	tr	tr	97	60	25	--	Eb	5	
1155	tr	tr	97	60	19	--	Eb	4	
1158	tr	1	96	61	28	--	Eb		Elevation not determined
1168	--	tr	98	66	15	--	Eb	2	
1206	--	tr	98	62	16	--	Eb	8	
1256	tr	tr	98	60	16	--	Eb	22	
1257	tr	1	98	60	21	--	Eb	19	
1305	--	tr	99	65	17	--	Eb	10	

material. Even in the coarsest samples 97 per cent of the sediment passes the No. 50 sieve. Its texture, as well as its position below Pleistocene sands, prevents the Wenonah formation from being of value as a source of construction material.

Mount Laurel-Navesink Formation

Dark green to black highly glauconitic coarse silt predominates in the Mount Laurel-Navesink formation. Some parts, however, consist of dark green and greenish-brown, very fine to fine, poorly sorted, subangular glauconitic quartzose sand with some silt and a little mica. Accessory heavy minerals present are essentially the same as those in other marine Cretaceous formations.

The abundance of glauconite in most of this formation is expected to render it generally unsuitable for construction purposes. Moreover, it contains abundant organic matter in the form of calcareous shells. As a result, the more clayey and calcareous portion of the Mount Laurel-Navesink was, in the past, excavated for use as a fertilizer.

Table X indicates that the Mount Laurel-Navesink contains fine to very fine sand, with a near-absence of coarse sand, and only a few traces of gravel. It must be concluded that the Mount Laurel-Navesink sediments are not suited as borrow material and fine aggregate, both from the viewpoint of mechanical and mineralogical composition.

Red Bank Formation

The youngest of the marine Upper Cretaceous formations consists of reddish-yellow to reddish-brown, fine to medium, well sorted, subrounded, slightly silty quartz sand with some glauconite, and a little mica and feldspar. Most of the quartz grains are stained with iron hydroxide. The accessory heavy mineral content is similar to that of the other marine Cretaceous formations, although staurolite is more abundant in the Red Bank than in the older marine formations.

The percentage of soft minerals, such as glauconite, mica, and partially weathered feldspar, is small, and mineralogically the Red Bank is probably a suitable source of material for construction purposes.

Table XI indicates the mechanical composition of the Red Bank formation. The sands are too fine grained to be useful as select borrow or fine aggregate. Moreover, its occurrence below Pleistocene sands will probably preclude economical excavation.

Tertiary System

The patchy upland sediments which lie along the drainage divide between the Brandywine Creek and the Delaware River must have been deposited upon a very irregular surface for their thickness changes rapidly from place to place. A hole drilled on the west side of Shipley Road

Table X--Texture of sands of the Mount Laurel-Navesink formation in relation to borrow material and fine aggregate.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft.sld)	Remarks
1118	2	tr	94	62	37	--	Eb		Elevation not determined
1149	tr	2	93	50	24	--	Eb		Elevation not determined
1150	tr	1	98	68	12	--	Eb		Elevation not determined
1151	1	2	96	88	53	--	Eb		Elevation not determined
1152	tr	tr	98	66	22	--	Eb		Elevation not determined
1153	--	tr	99	92	50	--	Eb	25	
1161	--	6	80	28	19	--	Eb	11	
1162	1	1	92	51	29	--	Eb	9	
1170	--	tr	97	64	18	--	Eb	8	
1183	tr	tr	98	72	49	--	Ec	4	
1191	tr	2	93	60	49	--	Ec	2	
1204	--	8	68	15	12	--	Ec	1	
1209	2	5	88	50	23	--	Eb		Elevation not determined
1304	--	6	87	50	30	--	Eb	18	

Table XI--Texture of sands of the Red Bank formation in relation to borrow material and fine aggregate.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft.s ld)	Remarks
1116	tr	6	81	30	21	--	Eb		Elevation not determined
1117	--	1	95	31	17	--	Eb		Elevation not determined
1188	--	7	72	18	14	--	Ec	13	
1189	--	tr	68	18	15	--	Ec	10	
1190	--	tr	75	22	17	--	Ec	8	
1203	--	1	57	17	15	--	Ec	3	
1292	--	tr	80	34	26	--	Eb		Elevation not determined
1293	--	1	94	52	39	--	Eb		Elevation not determined

one mile north of Silverside Road encountered over 60 feet of light colored sands, silts and clays while holes drilled a few hundred yards away encountered rock only a few feet below the surface.

In general, the upland sediments appear to average less than 5 feet thick and are made up largely of silt and clay with scattered pebbles. On the basis of these facts, along with the highly populated character of the area in which the upland sediments occur, no extended prospecting was undertaken.

Pleistocene Series

Sediments of Pleistocene age occur throughout the Coastal Plain of northern Delaware. They rest unconformably upon the older Cretaceous sediments previously described, and in a few places, upon the crystalline rocks of the Piedmont. The Pleistocene sediments form a blanket of uneven thickness covering these older formations, which, for this reason, are usually not readily available for excavation.

The Pleistocene sands, gravels, and silts were deposited partially by streams, and partially in estuarine waters. The stream deposits which seem to form a large alluvial fan in northern Delaware, or perhaps a number of coalescing fans are characterized by the presence of rather deep and pronounced sand-filled channels, the bottoms of which go down to 40 feet below present sea level within the land area of northern Delaware, and to even lower elevations below the present channel of the Delaware River. The location of the Pleistocene channels is shown in plate 3.

The thickness of the Pleistocene deposits generally increases from the Fall Line in a southeasterly direction, but it is also greatly influenced by pre-Pleistocene or early Pleistocene topography, particularly the channels already referred to, and the present topographic features which are a result of post-Pleistocene erosion. The Pleistocene sediments reach their greatest thickness where Pleistocene channels are deepest, and where little or no recent dissection by streams has occurred.

The sand-filled channels are of considerable economic importance because they form aquifers of great potential ground-water yield, or are the source of large amounts of material for construction purposes. A map showing the approximate thickness of the Pleistocene sediments is presented in plate 4.

The accuracy of this isopach map varies with the quality of the many well logs on which it is based, and on the distribution of such data over the area. Control is rather good in the southeastern part of the area, but in the region between the Fall Line and the Christiana Creek it is relatively light, except in the area southeast of Newark.

The Pleistocene sediments of the presumed alluvial fan consist mainly of brown, buff and gray, fine to coarse, usually poorly sorted, angular to

subrounded, although generally subangular, gritty or pebbly quartz sands with some gravel beds which seldom exceed three feet in thickness. The sand grains are often coated with iron oxide or manganese oxide, and fine silt or clay particles nearly always adhere to the quartz grains, giving the appearance of a very "dirty" sand.

The quartz content of these sands is high (80-90 per cent); some feldspar and muscovite are invariably present. Accessory heavy minerals occur in the Pleistocene in larger amounts and greater variety than in any of the older geologic formations, but seldom over three per cent (by weight). Characteristic heavy minerals are: black opaques, green and brown hornblende, epidote and sillimanite, and small percentages of tourmaline, zircon, garnet, titaniferous minerals such as rutile and titanite, staurolite, kyanite, chloritoid, actinolite and tremolite, augite and diopside, and hypersthene.

Variety in composition is also characteristic of the Pleistocene gravel. Whereas the Cretaceous gravel was limited in composition to quartz, that in the Pleistocene contain some chert and pebbles, cobbles and boulders of various sandstones, shales, and crystalline rocks, although by far the greatest portion consists of quartz.

The silt and clay fraction of the deposits has not been investigated as to its mineral content.

Pleistocene sediments of estuarine origin occur in a narrow belt along the shore of the Delaware River. As only one outcrop was available for investigation (on the property of the Tidewater Oil Company near Delaware City) during excavation work in early 1956, little can be stated concerning their composition and texture. In the one outcrop referred to, gray sandy silt was exposed.

In some test holes drilled for foundation studies of the Delaware Memorial Bridge, sand and gravel deposits were encountered in a low lying area adjacent to the western shore of the River overlain by five to ten feet of the sandy clay. The presence of these sands and clays suggests that it may be possible to excavate them by dredging as is done farther north.

The mechanical composition of the Pleistocene sediments was investigated in some detail, because these surficial deposits provide the best opportunities for obtaining road building material. The results of the mechanical analyses of the Pleistocene sands are presented in table XII.

Practically no sands are suitable for light aggregate without some preparation, either washing or sieving, because in nearly all samples the amount of material passing the No. 100 sieve exceeds 7 per cent, and also because in most sands clay particles adhere to the coarser grains. However, many sands need only small modifications of their mechanical composition to make them suitable for light aggregate.

The Pleistocene sediments can only be a relatively minor source of coarse aggregate due to the paucity of the gravel contained in them. Al-

Table XII--Texture of Pleistocene sands.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1003	12	65	11	4	2	fine aggr.	Db	5	In Pleistocene channel; slightly deficient in silt
1004	tr	51	30	11	7	--	Db	6 1/2	for borrow material.
	6	58	21	8	5	--			Average composition.
1008	--	26	62	44	35	--	Db	3	
1010	62	19	13	6	4	--	Db	6 1/2	
1011	29	42	21	13	11	borrow	Db	7 1/2	
	30	29	32	21	17				Average composition.
1012	7	35	47	36	32	--	Cc	2	
1013	9	17	65	60	58	--	Cc	1	
1014	51	18	25	19	16	--	Cc	3	
1015	10	60	20	14	12	borrow	Cc	4 1/2	
	19	33	39	32	30				Average composition.
1020	3	37	38	17	14	borrow	Cc	3	
1021	41	41	12	8	7	--	Cc	6	
	22	39	25	13	11	borrow			Average composition.
1023	18	37	30	17	14	borrow	Dc	3	
1024	7	48	24	15	13	borrow	Dc	6	In Pleistocene channel.
1022	50	36	9	7	6	--	Dc	8	
	25	40	21	13	11	borrow			Average composition.

Table XII--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1025	--	2	97	96	94	--	Cd	2	No. 1025 considered over-
1026	10	43	38	28	25	borrow	Cd	4 1/2	burden. Not used in de-
1027	42	41	12	10	9	--	Cd	16	termining average com-
1028	11	66	14	9	8	--	Cd	21	position. In Pleistocene channel. Average com-
	21	50	21	16	14	borrow			position.
1029	9	13	74	68	66	--	Dc	1	No. 1029 overburden. See
1030	20	36	35	24	22	borrow	Dc	3	note above. In Pleistocene
1031	--	40	36	26	23	borrow	Dc	6	channel.
1032	tr	33	40	22	18	borrow	Dc	11	
	10	36	37	24	21	borrow			Average composition.
1033	46	14	34	23	19	--	Dc	2 1/2	
1034	tr	36	30	16	14	borrow	Dc	6	In Pleistocene channel.
1035	--	56	30	16	11	borrow	Dc	10	
1036	tr	68	15	10	8	--	Dc	13	
1037	2	13	50	18	14	--	Dc	35	
	10	37	32	17	13	borrow			Average composition.
1038	15	27	49	39	34	--	Dc	4	In Pleistocene channel. Probably overburden.
1039	7	56	30	18	12	borrow	Dc	10	Close to Pleistocene
1040	tr	28	52	16	12	--	Dc	22	channel.
	4	42	41	17	12	borrow			Average composition.

Table XII--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1042	11	22	50	28	22	--	Dc	3	
1043	tr	8	62	17	13	--	Dc	8	
	6	15	56	23	18	--			Average composition.
1044	39	33	16	3	2	--	Dd	4 1/2	
1045	12	40	24	11	9	borrow	Cd	15	Close to, or in Pleistocene channel.
1047	38	19	39	30	24	--	Db	4 1/2	Close to Pleistocene channel.
1048	--	53	33	23	18	borrow	Db	8	
1049	3	67	20	13	10	--	Db	13	
	14	46	31	22	17	borrow			Average composition.
1051	6	15	68	47	41	--	Cb	2 1/2	
1052	6	49	29	17	15	borrow	Cb	2 1/2	
1053	2	75	13	9	7	--	Dc	2	
1054	2	9	80	25	17	--	Dc	7	In Pleistocene channel.
1055	tr	2	95	33	19	--	Dc	9	
1056	--	80	11	8	7	--	Dc	10	
	1	42	50	19	13	borrow			Average composition.

Table XII--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1057	tr	44	20	7	6	--	Ec	4	In Pleistocene channel.
1058	47	43	7	5	4	--	Ec	2	
1059	2	34	44	15	12	--	Ec	5	
	25	39	26	10	8	--			Average composition.
1097	19	67	9	7	6	--	Ea	4	
1098	tr	53	21	9	8	--	Ea	7	
	10	60	15	8	7	--			Average composition.
1100	8	66	15	8	7	--	Ea	25	
1101	2	70	13	8	6	--	Ea	24	
	5	68	14	8	7	--			Average composition.
1102	--	32	40	13	9	--	Ea	34	Base of Pleistocene.
1114	2	62	15	9	8	--	Eb	5	
1115	tr	58	29	11	8	--	Eb	11	
	1	60	22	10	8	--			Average composition.
1127	2	3	90	65	42	--	Eb		
1128	17	3	77	65	33	--	Eb		Elevation not determined.
1129	tr	4	91	58	30	--	Eb		
	10	3	86	63	35	--			

Table XII--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1136	tr	3	95	89	87	--	Db	2 1/2	Overburden, not
1137	tr	30	46	15	9	--	Db	3	included in average
1138	tr	3	86	50	21	--	Db	4 1/2	percentage.
1139	22	48	21	12	9	--	Db	5	
	7	27	51	29	13	--			Average composition.
1140	tr	74	12	9	7	--	Dc	7	In channel.
1141	4	46	18	9	7	--	Dc	11	
	2	60	15	9	7	--			Average composition.
1142	tr	3	86	40	13	--	Eb		
1143	--	tr	98	64	19	--	Eb		Elevation not
1144	2	13	75	55	46	--	Eb		determined.
1145	9	11	73	53	42	--	Eb		
	3	7	83	53	30	--			Average composition.
1147	tr	10	70	27	11	--	Eb	1	
1148	4	17	50	10	6	--	Eb	2	
	2	14	60	18	9	--			Average composition.
1156	tr	30	38	6	5	--	Eb		Elevation not
1157	tr	tr	97	56	18	--	Eb		determined.
	tr	15	68	31	12	--			Average composition.

Table XII-Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1159	tr	11	74	51	46	--	Eb		Elevation not
1160	tr	1	96	60	24	--	Eb		determined.
	tr	6	85	55	35	--			Average composition.
1167	tr	13	60	12	7	--	Eb	18	
1171	--	tr	99	91	30	--	Eb		Elevation not determined.
1172	--	tr	95	50	14	--	Eb		In Pleistocene channel.
	--	tr	97	70	22	--			Average composition.
1173	--	1	95	52	10	--	Eb		Elevation not
1174	1	12	66	17	5	--	Eb		determined.
1175	1	13	66	20	6	--	Eb		In Pleistocene channel.
	tr	8	75	30	7	--			Average composition.
1176	--	tr	97	58	18	--	Eb		Elevation not determined.
1177	tr	10	79	55	39	--	Eb		Elevation not determined.
1179	2	52	17	3	2	--	Ec		Elevation not determined.
1180	tr	10	68	16	5	--	Ec	3 1/2-5(sld)	
1181	tr	21	54	12	5	--	Ec	5-7 (sld)	
	tr	16	61	14	5	--			Average composition.

Table XII--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1182	5	42	28	4	2	fine aggr.	Ec	1 (sld)	In Pleistocene channel.
1186	2	52	24	5	2	fine aggr.	Ec	6 (sld)	In Pleistocene channel.
1192	2	34	38	11	7	--	Ec	7 (sld)	
1193	4	16	64	22	11	--	Ec	4 (sld)	
1194	4	14	68	23	11	--	Ec	3 (sld)	
	3	21	57	19	10	--			Average composition.
1195	4	34	47	28	26	--	Ec	5 (sld)	
1196	tr	40	30	10	7	--	Ec	6 (sld)	
1197	2	12	71	31	22	--	Ec	3 (sld)	
1198	tr	2	93	66	24	--	Ec	8 (sld)	
1199	tr	tr	99	92	50	--	Ec	7 (sld)	
	tr	1	96	79	37	--			Average composition.
1200	2	41	35	11	8	--	Ec	30 (sld)	
1201	3	72	17	11	10	--	Ec	18 (sld)	
1202	tr	68	17	10	9	--	Ec	5 (sld)	
	2	60	23	11	9	borrow			Average composition.
1210	19	39	27	7	5	--	Eb	7 (sld)	
1211	4	16	67	43	25	--	Eb	5 (sld)	
	12	28	47	25	15	--			Average composition.

Table XII--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
1214	tr	6	87	76	71	--	Db		Elevations not determined.
1215	3	35	40	19	13	borrow	Db		
	2	22	64	48	42	--			Average composition.
2000	tr	4	95	94	93	--	Dc	4-5	Fill; close to Pleistocene channel.
2006	tr	1	98	97	96	--	Dc	4-5	Fill; not in Pleistocene channel.
2007	79	11	8	5	4	--	Dc	19-20	
	40	6	53	51	50	--			Average composition.
2012	1	4	91	86	83	--	Dc	5-6	Not in Pleistocene channel.
2018	1	4	93	89	83	--	Dc	4-5	Not in Pleistocene channel.
2024	36	43	17	10	7	--	Dd	9-10	Not in Pleistocene channel.
2027	6	18	71	65	63	--	Cc	9-10	In Pleistocene channel.
2028	23	29	32	7	3	--	Cc	19-20	
	15	24	52	36	33	--			Average composition.
2032	tr	2	96	92	90	--	Cc	5-6	
2033	1	2	96	93	91	--	Cc	10-11	Not in Pleistocene channel.
2034	tr	3	96	93	91	--	Cc	15-16	
	tr	2	96	93	91	--			Average composition.

Table XII--Continued.

Sample No.	Retained on No. 10 sieve %	Passing No.10 sieve, retained on No.40 sieve %	Passing No.50 sieve %	Passing No.100 sieve %	Passing No.200 sieve %	Suitable for	Location (quadrangle)	Depth (ft. lsd)	Remarks
2060	tr	7	87	76	71	--	Ec	9-10	Not in Pleistocene channel.
2062	21	26	36	13	7	--	Db	4 1/2	Close to Pleistocene channel.
2064	tr	22	52	25	16	--	Db	4-5	Not in Pleistocene channel.
2065	20	28	33	16	12	--	Db	9-10	
	10	25	43	21	14	--			Average composition.
2066	3	18	52	21	17	--	Ea	4-5	Close to Pleistocene channel.
2067	2	44	32	18	15	borrow	Ea	9-10	
	3	31	42	20	16	--			Average composition.
2069	tr	4	82	32	24	--	Eb	9-10	Close to Pleistocene channel.
2070	tr	13	79	71	67	--	Db	4-5	Not in Pleistocene channel.
2071	tr	3	96	94	92	--	Db	4-5	In or close to Pleistocene channel.
2072	7	42	35	22	19	borrow	Db	9-10	In or close to Pleistocene channel. Average composition.

though gravel percentages in some samples are high (50 per cent or over), consistent gravel beds more than two or three feet thick are rare. Moreover, gravel is defined as granular material over 2 mm in diameter, and much of the gravel is in the size interval of 2 mm to 1/2 inch and, therefore, too small for coarse aggregate.

Of all Pleistocene samples analyzed (121), only 18, or less than 15 per cent, are suitable as select borrow material within the specifications of the State Highway Department without washing, sieving or other modifications. If the material is judged on the basis of suitable pits, outcrops, and series of samples from cored drill holes rather than on analysis of individual samples, and eliminating those samples which were taken from soil or overburden at a depth of 5 feet or less, it is found that of the 52 sites investigated 13, or 25 per cent should yield suitable select borrow material. This percentage must be considered as only a rough approximation of the amount of suitable material because sampling could not be done on a grid system, which would avoid any statistical prejudice on the part of the investigator. Moreover, no "channel" samples representing a complete outcrop or the total thickness of the Pleistocene, were obtained. However, the degree of accuracy of the percentage of suitable material becomes of relatively small importance when the geographic distribution of suitable and unsuitable select borrow material is studied.

Such study reveals that borrow material according to State Highway specifications is generally located in Pleistocene channels (see map, plate 3). Nearly all sands located within the boundaries of these channels are suitable as select borrow, and nearly all sands outside the channels are unsuitable, unless washing and/or sieving of the material were to be done. Thus, prospecting for additional borrow material of good quality should be guided by a knowledge of the location of the Pleistocene channels, not only because the most suitable materials appear to be found there, but also because they occur there in greatest thickness (see map, plate 4). It is a significant fact that the location of the major sand and gravel pits in operation at the present (January, 1957) coincides with that of the Pleistocene channels.

Plate 4 should be used with some caution in prospecting for borrow material, because the channels were located on the basis of a study of well logs and resistivity data (see section on Areal Geologic Studies) which are, in some cases, open to several interpretations; moreover, the density of control points varies considerably from one area to another. Consequently, there may be channel deposits which have not been recognized as yet, and additional prospecting outside the known channels may be warranted in some places. In addition, many sands throughout the area have textures close to that of select borrow, and may be used as fill.

The Pleistocene channel deposits serve not only as sources of construction materials, but also as important ground-water reservoirs. The City of Newark, Llangollen Estates, the State Hospital at Farnhurst, and many other water users are wholly supplied with water from these sediments. The Tidewater Oil Company, although deriving most of its water supply from the nonmarine Cretaceous sands, pumps 1000 to 1500 gallons per minute from a Pleistocene channel sand. Ground-water supply and excavation of sand and gravel are not necessarily incompatible, provided excavation below the water table and drainage of a pit are not attempted in the vicinity of pumping wells. If such deep excavation were to be done in the area affected by the cone of influence of any pumping well, depletion of the ground-water resources stored in the Pleistocene sands would certainly take place.

Recent Series

Recent sediments occur mainly as floodplains and tidal flat deposits along the major streams in northern Delaware. Because the floodplains in this area are narrow, little material for construction purposes can be expected, even if they were to prove suitable from the viewpoint of mineral and mechanical composition. The tidal flat deposits are usually composed of fine silts and clays with abundant organic matter, and it is very unlikely that they are of economic value as construction material. In view of the knowledge of these few facts, no further investigation of the Recent sediments was carried out.

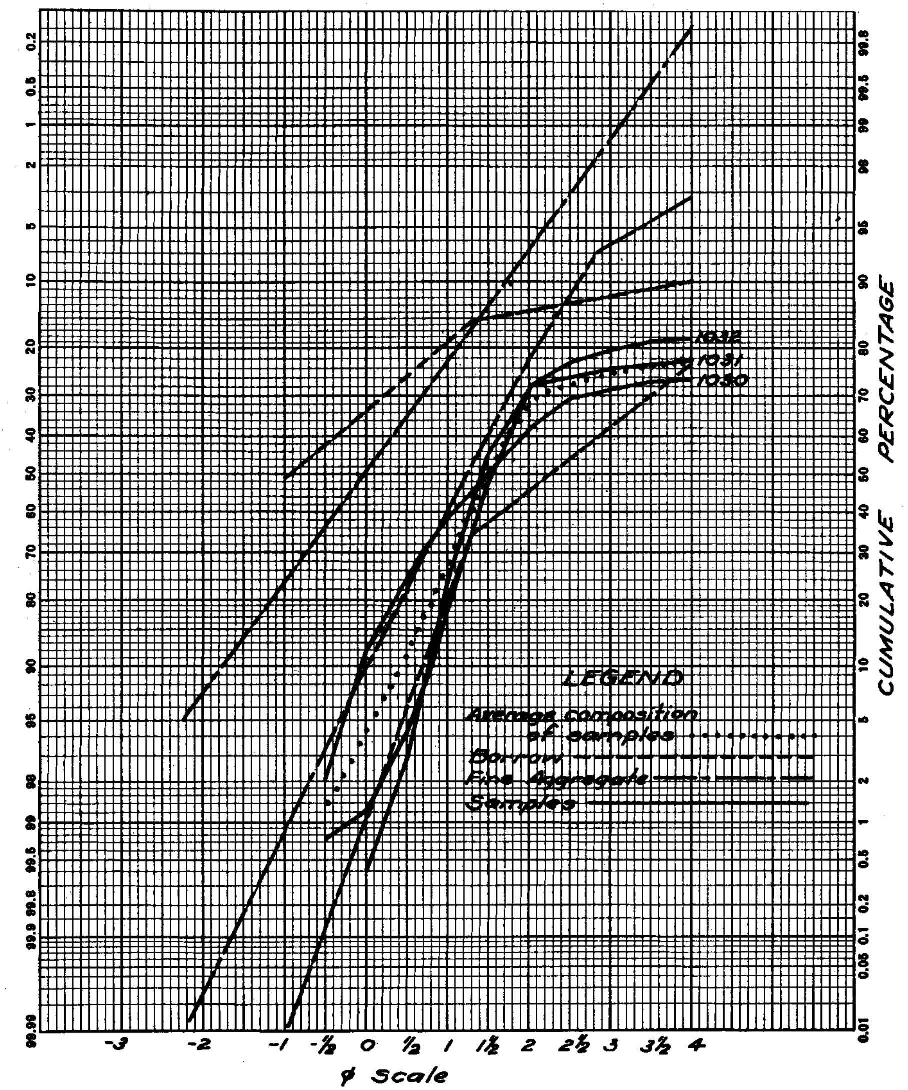

Figure 7. Pleistocene channel sands suitable for select borrow.

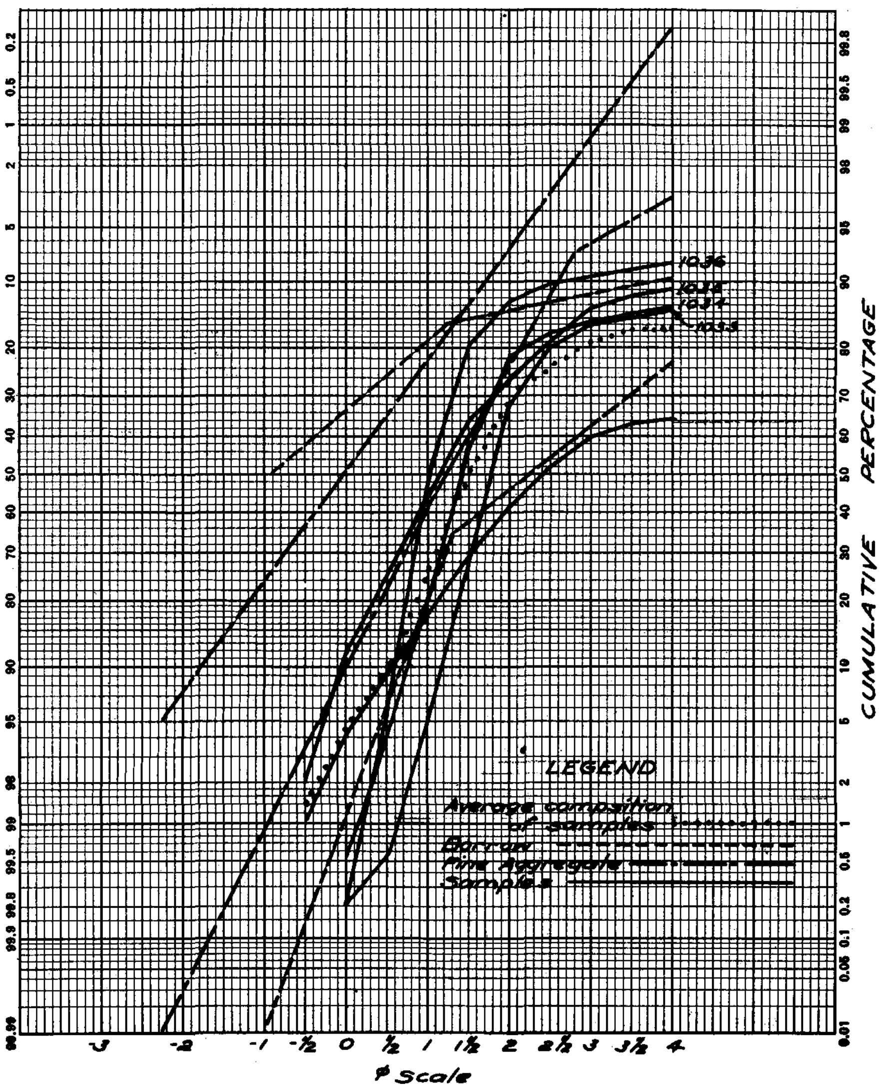

Figure 7--Continued.

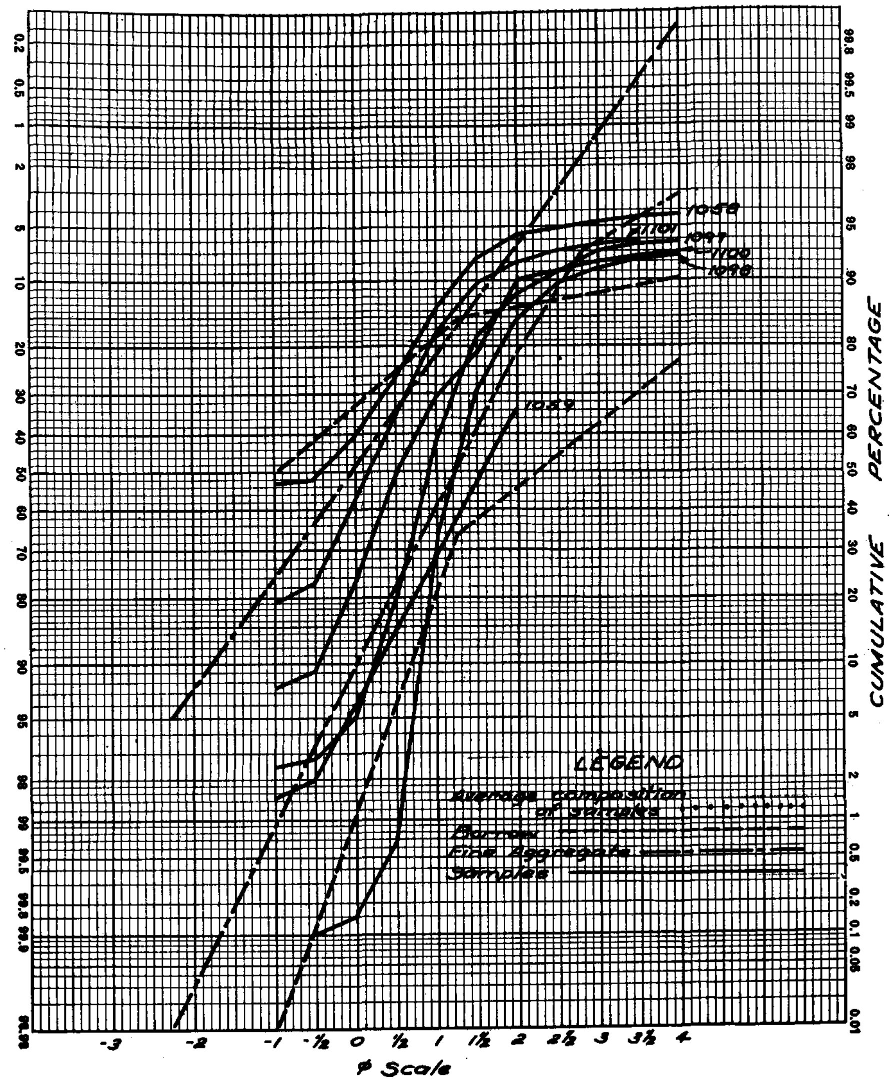

Figure 8. Pleistocene sands unsuitable for select borrow.

CONCLUSIONS

Delaware is well endowed with stone. The best materials are rocks of the igneous complex which underlies the southeastern portion of the Piedmont. Unfortunately, rapid urban and suburban expansion in that area have rendered those materials largely inaccessible.

The Wissahickon schist and gneiss which underlie the western part of the Piedmont are more accessible because of the rural nature of the area. Although part of this rock will probably make an adequate road stone, a portion of it is of schistose character and may fail to meet State Highway Department specifications. Such a possibility suggests that a more economical use of local materials might be made if material specifications were changed to admit the use of lower grade materials for less critical uses.

From the viewpoints of availability and character of the material the following areas appear to have the best stone potential:

1. The east bank of Brandywine Creek between Rockland and Thompson's Bridge.
2. The Red Clay valley near Yorklyn.
3. The White Clay Creek valley near the Pennsylvania State Line.
4. Iron Hill.
5. The valleys of Mill Creek and Pike Creek.

In any of these areas it should be possible to develop sites which would ultimately yield 5 million tons or more.

In the Coastal Plain the Pleistocene series is the only major source of granular materials suitable for select borrow or fine aggregate. Material for coarse aggregate is not available in the Coastal Plain in large quantities and should be obtained in the Piedmont.

The maps of the base and the thickness of the Pleistocene sediments, plates 3 and 4, indicate that these deposits are thickest in old stream channels which are now filled with sand. Laboratory study of the texture of Pleistocene sand samples indicates that the channel sands generally have a mechanical composition which conforms with the specifications for select borrow, and that, with some washing, are also suitable for fine aggregate. Samples obtained from inter-channel areas are usually unsuitable either for select borrow or fine aggregate. Consequently, future prospecting for engineering materials is expected to be most rewarding if confined to the channels indicated on plate 3, although some commercial deposits may be found elsewhere.

On the basis of the present study it seems likely that fine aggregate and select borrow pits could be developed in northern New Castle County which would supply several million tons of material.

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