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HYDROGEOLOGY OF SELECTED SITES IN THE GREATER NEWARK AREA, DELAWARE

BY

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NEWARK, DELAWARE

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ABSTRACT

Additional sources of ground water have been located in the Piedmont Province as a result of a ground-water exploration program conducted by the Delaware Geological Survey at the University of Delaware in cooperation with the City of Newark. Drilling sites for relatively high-yielding wells were located through the use of geophysical investigations, air-photo interpretation, field mapping, and review of existing data.

Eleven deep test wells were drilled in the Piedmont north and northeast of Newark. The capacities of five of the test wells warrant their development as production wells. In order to sustain high yields for long periods of time, optimum pumping rates are recommended.

A detailed review of both published and unpublished data on the ground-water resources of the Greater Newark Area shows that no additional major sources of ground water are likely to be found nearby in the Coastal Plain sediments.

INTRODUCTION

Purpose and Scope

The primary objective of this study is to locate additional ground-water to supplement the City of Newark's present supply. Newark's existing well fields, situated in the Coastal Plain, were also evaluated to determine the potential for future development in the area south of the City.

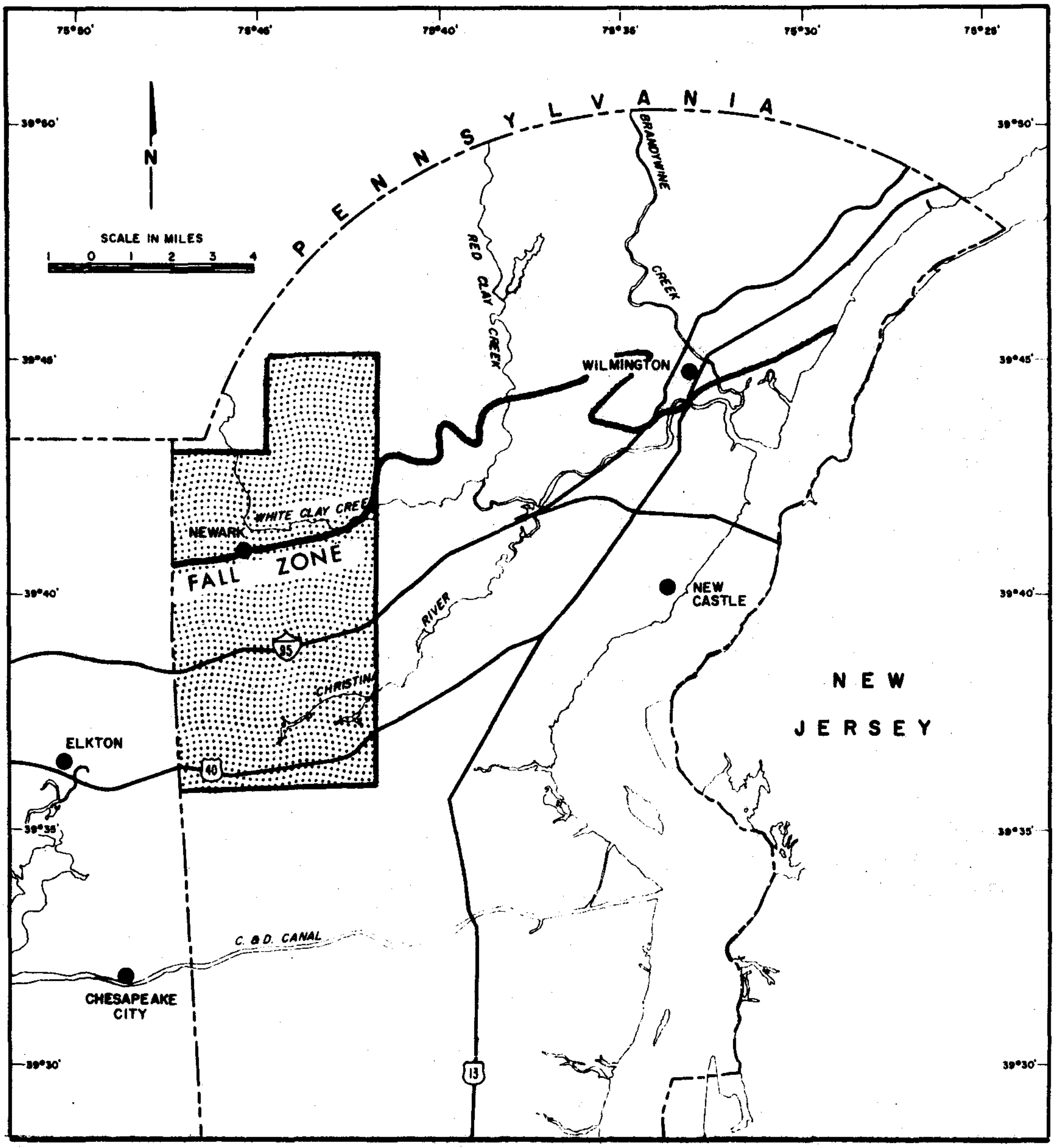

Figure 1. Area of investigation

The investigation was prompted by the current growth of Newark, coupled with a decline in the production capabilities of Newark's existing Coastal Plain well fields. Water consumption during 1973 averaged 3.0 mgd (million gallons per day); the projected use for 1980 is estimated to be 4.1 mgd. Eighty-five percent of the water used was withdrawn from the City's well fields and the remainder was purchased from a private water company.

The work described here was carried out under a cooperative agreement between the City of Newark and the University of Delaware. The field investigations, laboratory work, and report preparation were performed by the Delaware Geological Survey (DGS) at the direction of the University of Delaware. The study included drilling, aquifer evaluation, and final well design. Specific information, including geophysical well logs, geologic samples, and pump test information are retained in the files of the DGS. Records of production wells and detailed geologic logs are compiled and held in DGS and City of Newark files.

Methods

In order to assess the ground-water resources of an area, it is essential to establish its geologic and hydrologic framework. Because the Newark area lies within two geologic provinces, the Appalachian Piedmont and the Atlantic Coastal Plain, the geology and hydrology are quite complex. The Coastal Plain portion has been explored in other studies (Groot and Rasmussen, 1954; Rasmussen et al., 1956; Geraghty and Miller, 1967a, 1967b, 1969; Woodruff et al., 1972). Accordingly, study of the Coastal Plain during this program was limited to a review and compilation of existing data generated by previous investigators.

This program was concentrated on the Piedmont Province where 1,000 feet of seismic profiling and 10,000 feet of magnetometric surveying were completed. Eleven deep test wells (335-448 feet) totaling 4,397 feet were drilled under contract with the Walton Corporation and eight test holes totaling 602 feet were drilled by the DGS with the University drill rig assigned to the Water Resources Center. The deep test wells were drilled by the air rotary method in which compressed air moving at high velocity was used to carry cuttings and water to the surface. This method is highly practical in that it allows a preliminary evaluation of at least minimum well yields while drilling is in progress.

A total of 5,881 feet of temperature, gamma-ray, caliper, and flowmeter logs were run in the test wells. Pumping tests ranging in duration from 15 to 48 hours were performed on five of the test wells. The locations of the test wells and test holes are shown in Figures 3 and 4.

Well Numbering System

The State is divided into 5-minute quadrangles of latitude and longitude for the purpose of numbering wells in Delaware. The quadrangles are lettered north to south with capital letters, and from west to east with lower case letters. Each 5-minute quadrangle is further subdivided into 25 1-minute blocks which are numbered from north to south in series of 10 from 10 to 50 and are numbered from west to east in units from 1 to 5 (Figure 2). Wells within these 1-minute blocks are assigned numbers as they are scheduled. The identity of a well is established by prefixing the serial number with an upper and lower case letter followed by two numbers to designate the 5-minute and 1-minute blocks, respectively, in which the well is located. For example, well number Cb41-3 is the third well to be scheduled in the 1-minute block that has coordinates "Cb41."

Previous Investigations

The first detailed investigation of the geology and ground-water resources of the Newark, Delaware area was conducted by J. J. Groot and W. C. Rasmussen in 1954. The purpose of their study was to determine the thickness, extent, and hydrologic characteristics of the water-bearing units and to estimate the quantity of ground water that could be safely withdrawn over a long period of time. Their investigation was confined to the areas underlain by permeable sediments on the Coastal Plain. Marine and Rasmussen (1955), Rasmussen et al. (1956), and Baker et al. (1966), have also written reports that have dealt in part with the ground-water resources of the Newark area.

Between 1965 and 1970 a private consulting firm was retained by the City of Newark to make a preliminary analysis of ground-water conditions in the vicinity of the South Well Field and to look into alternate sources of water supply. Their investigation, like all others, was concentrated in the Coastal Plain.

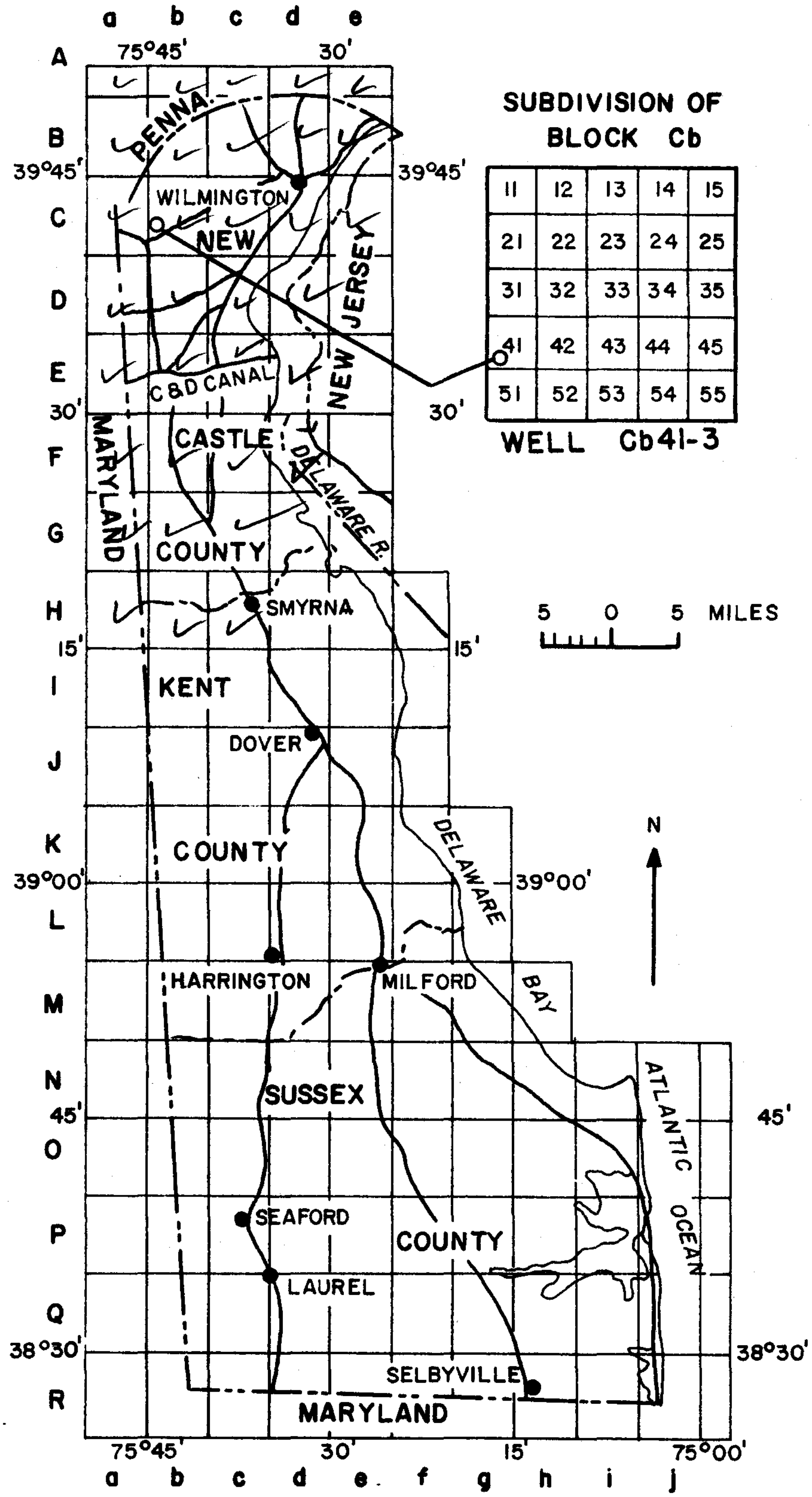

Figure 2. Map showing the coordinates for the well-numbering system.

In 1971-72, an intensive ground-water study was conducted on University of Delaware property in both the Piedmont and Coastal Plain Provinces. The investigation, a cooperative effort between the University of Delaware and the City of Newark, was conducted by the DGS. The results are reported in DGS Report of Investigations No. 18 (Woodruff *et al*., 1972). This program was a pioneer one in that it was the first ground-water exploration program conducted in crystalline rocks in this area.

ACKNOWLEDGMENTS

This study, in its original form, was a ground-water exploration program conducted by the DGS at the University of Delaware in cooperation with the City of Newark.

Newark City Manager Peter Marshall and Rex Gilmore, Director, Water and Waste Water Department, cooperated throughout the study and made available existing records and reports. Assistance of the drilling contractor, the Walton Corporation, and especially Messrs. Roy T. Walton, Max R. Walton, and Joseph M. Holtzman was excellent. Special thanks are given to the many private citizens who permitted access to their properties.

Arrangements for this study were made by Donald F. Crossan, Vice President for University Relations and Business Management, University of Delaware, who provided essential coordination throughout the investigation.

Discussions of various topics related to this study were held with the staff of the DGS. The contributions of Robert R. Jordan, State Geologist, Kenneth D. Woodruff, Senior Hydrologist, John C. Miller, Hydrogeologist, and Nenad Spoljaric, Geologist, are gratefully acknowledged. Alan Crossan, Boris J. Bilas, John Barone, and Bruce Lanzl provided support in drilling operations and in conducting pumping tests.

REGIONAL GEOLOGY

The Greater Newark Area lies within two geologic provinces: the Appalachian Piedmont and the Atlantic Coastal Plain. The Piedmont, which extends from central New Jersey to Alabama, is underlain by ancient igneous and metamorphic rocks of complex origin. The erosional surface of the Piedmont rocks slopes southeastward and disappears beneath the Atlantic Coastal Plain. The Atlantic Coastal Plain is the emerged portion of the continental shelf and extends from New England to central Georgia. The rocks on the Coastal Plain consist of unconsolidated to partially consolidated gravels, sands, silts, and clays of Juriassic (?), Cretaceous, Tertiary, Pleistocene, and Holocene age. The Coastal Plain sediments form a wedge-shaped mass which thickens from a featheredge at the Fall Zone, to several thousand feet in southeastern Delaware. Such standard references as Rodgers (1970) and Murray (1961) provide information and additional sources on the Piedmont and Atlantic Coastal Plain, respectively.

The Fall Zone marks "...the boundary between the ancient and resistant crystalline rocks of the Piedmont Plateau and the younger and softer sediments of the Atlantic Coastal Plain..." (Gray *et al.*, 1972, p. 251). The reader is referred to a report by Spoljaric (1972) for a detailed description of the geology of the Fall Zone in Delaware.

COASTAL PLAIN AREA

Geology

The Coastal Plain sediments in the area of investigation directly overlie the crystalline basement complex and attain thicknesses greater than 300 feet in the southern portion of the study area. The Coastal Plain units present are: the Potomac Formation of Early Cretaceous age, the overlying Columbia Formation of Pleistocene age, and younger unnamed deposits.

Crystalline Basement Complex

The crystalline rocks of the Piedmont extend southward beneath the younger Coastal Plain sediments, thereby forming the "basement complex."

Not much is known about the rocks lying beneath the sedimentary cover for several reasons: (1) they cannot be observed in outcrop, (2) they have not been drilled to any degree because they were thought to be of little importance as a source of ground water, and (3) drilling costs are relatively high.

The surface of the crystalline basement contains much relief and is broken by faults with displacements up to 130 feet (Spoljaric, 1972).

Overlying the crystalline basement rocks are their weathering products, which consist of compact, varicolored clays and very clayey, poorly sorted sands and silts. The variability in thickness of the weathered rocks is probably a result of original rock composition, geochemical environment, structural deformation, and slumping and sliding of material on steep slopes.

These materials are not considered to be a useful source of ground water because they are usually very clayey and thus relatively impermeable. In fact, they may act as a confining layer thereby preventing or retarding ground-water recharge from the overlying sedimentary rocks to the crystalline rock.

Potomac Formation

The Potomac Formation consists of variegated red, yellow, white, gray, and purple clays and silts, buff to light yellow sands, and small amounts of pebble-sized gravel. The sands are generally fine- to medium-grained, often poorly sorted, and contain about 5 per cent clayey and silty matrix (Groot, 1955; Spoljaric, 1972). The sandy zones are concentrated in the central and southern portions of the study area where they form "shoestring" sand bodies that are difficult to trace laterally. The form and distribution of the Potomac sediments suggest that the material was transported and deposited by a complex stream system that entered the area from the east and northeast. Detailed studies of the Potomac Formation by Spoljaric (1967b, 1972) suggest that at least the initial deposition of these sediments was controlled largely by the configuration of the surface of the crystalline basement complex.

Saturated sands within the formation sustain the yields in several production wells in the Coastal Plain well fields.

Columbia Formation

The Columbia Formation in this area consists of gravels, sands, silts, and clays of fluvial origin. The areal distribution and geometry of the sand bodies suggests that the materials were deposited in relatively straight valleys by streams entering the area from the north and northeast (Jordan, 1964; Spoljaric, 1972). The coarsest material is confined predominately to two sandy areas. One is located beneath Newark's existing North Well Field while the other is located south of the City and extends from the South Well Field to as far south as Glasgow. In places, the sandy zones of the Pleistocene Columbia Formation directly overlie and are cut deeply into the sandy units of the Potomac Formation thereby forming a thick saturated section which functions hydrologically as one water-bearing unit.

Younger Quaternary Sediments

The youngest sediments in the area of investigation appear to be restricted to an area along the Fall Zone. Evidence indicates that these brown to yellow-brown, poorly sorted, cross-bedded sands were deposited as alluvial fans. The maximum known thickness is only 30 feet; therefore, they are not of hydrologic importance as sources of ground-water (Spoljaric, 1972).

Ground Water in the Coastal Plain, Newark Area

The City of Newark obtains a large percentage of its potable water from two well fields (North Well Field and South Well Field) and several individual wells located in the Coastal Plain. Production wells are completed in the water-bearing zones of the Potomac and Columbia Formations. Evaluation of 198 auger holes, test wells, and production wells in the Coastal Plain reveals that all of the material capable of yielding substantial quantities of ground water has probably been developed. In addition, many of the Potomac sands, although saturated and relatively thick, are very fine-grained, which makes well development in them difficult.

PIEDMONT AREA

Geology

The Piedmont portion of the area of investigation consists of a complex series of igneous and metamorphic rocks belonging to the Wilmington Complex and the Glenarm Series (Figures 3 and 4, pp. 19, 20). Ward (1959) divided the Wilmington Complex into amphibolites, gabbros, banded gneisses, and some granite. The Complex in the Newark area is represented by a narrow band of felsic and mafic gneiss with minor schist which is situated along the Fall Zone between the Wissahickon Formation to the north and the Coastal Plain sediments to the south. This unit contains substantial amounts of amphibolite (mafic gneiss). Woodruff _et_ _al_. (1972) reported the amphibolite to be intruded by pegmatites along the planes of foliation.

The Glenarm Series (Knopf and Jonas, 1922) comprises the most extensive rock unit in the Newark area of the Piedmont and has been divided into the Wissahickon Formation and the Cockeysville Marble. Woodruff and Thompson (1974, in press) have divided the Wissahickon into metagraywacke and pelitic facies. The metagraywacke facies consists of interbedded quartz-biotite-ologoclase feldspar gneiss and schist. The pelitic facies, which lies to the north of the metagraywacke facies, consists predominately of foliated mica schist. Locally both facies contain pegmatites.

The area underlain by the Wissahickon Formation is marked by distinct valleys and ridges the development of which was controlled predominately by lithology and structure. The thickness of the regolith is highly variable and difficult to predict in most areas; however, it is generally thicker on hilltops than in stream valleys.

The Cockeysville Marble, which underlies the Wissahickon Formation stratigraphically, occupies a relatively small valley along Pike Creek near Pleasant Hill in the northeastern portion of the area. The formation is composed of dense to vuggy, white and gray calcitic and dolomitic marble with interbeds of "dirty" or micaceous (phlogopite) marble. The marble weathers to a gritty and friable dolomitic sand. The topography is marked by gently rolling hillocks and valleys underlain by a highly variable thickness of regolith.

Although dating of the Glenarm Series is imprecise, an Early Paleozoic age has been assigned.

Other crystalline rocks occur southwest of Newark where they form Iron and Chestnut hills. The rocks consist of gabbro, norite, and pyroxenite and are entirely surrounded by Coastal Plain sediments. Because the contacts are buried, it is not known how the rocks are related to the adjacent Piedmont.

The trend of foliation of the crystalline rocks is predominately northeast-southwest. The dip of foliation is commonly between 45° to the southeast and vertical. Many second order folds within the Wissahickon Formation dip at shallow angles to the northwest and southeast. The rocks are marked by four readily identifiable sets of joints. The orientation and origin of joints are discussed elsewhere in this report.

Occurrence of Ground Water in the Piedmont

The crystalline rocks of the Delaware Piedmont are generally considered to be poor aquifers which yield relatively small and unpredictable quantities of water. Rasmussen et al. (1956) reported the average yield of 141 rock wells to be 23gpm (gallons per minute). Sundstrom and Pickett (1971), in a more comprehensive study, reported an average yield of 16 gpm in 103 wells finished in rock classified as granodiorite, gabbro, Wissahickon Formation, and Cockeysville Marble. The average specific capacity was 0.8 gpm/ft (gallons per minute per foot of drawdown). The majority of wells documented were domestic wells constructed to produce small quantities of water (up to 10 gpm) at relatively shallow depths. The tests performed on the wells were of short duration with relatively little drawdown used. The wells were drilled in convenient locations generally without attempting to obtain maximum yields.

Recent ground-water explorations conducted by the DGS and other organizations have produced results that indicate that substantial quantities of water are available from hard rock aquifers. However, drilling sites must be located in carefully selected geologically and hydrologically favorable areas and the wells drilled often to depths up to 400 feet.

In a recent study on the evaluations of yields of wells in consolidated rocks along the Eastern Seaboard from Maine to Virginia, D. J. Cederstrom (1972, p. 10) stated that "...a reasonable evaluation of a rock formation is believed to be possible only where industrial wells (preferably many) are present..." Domestic well records are not reliable for overall ground-water appraisal.

Ground-Water Availability

The natural recharge to the ground-water system in the Newark Piedmont comes directly from precipitation. Of the 44 inches (average) of annual precipitation, about 16 inches is lost to runoff and 28 inches is lost to evapotranspiration. The runoff is equal to direct overland runoff plus base flow. Water being discharged from the aquifers to the streams is represented by base flow which averages approximately 11 inches per year. As base flow must equal ground-water recharge over a long period of time, the ground-water recharge is equal to approximately 0.5 mgd per square mile. The base flow figure of 11 inches was derived by Olmsted and Hely (1962) in a study of the Brandywine Creek basin in southeastern Pennsylvania. Their base flow figure is probably applicable to this area as the geology, topography, and climatology are similar.

Geologic Control of Ground Water in Crystalline Rocks

Because of the massiveness and hardness of crystalline rocks they yield little or no interstitial water to wells. The storage and flow of ground water in these rocks is controlled by such factors as the hydrologic cycle, rock structure (jointing, faulting, schistosity), lithology, topography, and thickness and texture of regolith.

Joints

Joints, the most common secondary structures in crystalline rocks, are plane surfaces between rocks in which little or no movement has taken place. Joints usually occur in sets consisting of parallel or nearly parallel arrays of joints with two or more sets constituting a joint system. The secondary porosity of the rock may be entirely dependent upon a joint set which provides channels for ground-water flow.

Four joint sets have been identified in the study area. One set, which is classified as strike joints, is oriented parallel to the regional strike of the rocks and dips predominately to the southeast at shallow angles. This joint set is most often seen in pegmatites (W. L. Leis, personal communication). The other three joint sets are oriented N70°-80°W, N20°-30°W, and N-S, respectively. The dips of these sets are nearly vertical and they have been interpreted as tensional cross joints developed during regional uplift and deformation of the area (Woodruff *et al.*, 1972).

Examination of aerial photographs reveals moderately long lineations (several hundred feet to one mile) which are oriented parallel or subparallel to joint sets observed in the field. These lineations have been interpreted as the surface traces of inclined fracture zones (Woodruff *et al.*, 1972). Preliminary analysis of a major water-bearing fracture zone encountered in three wells along White Clay Creek indicates that the zone strikes nearly N-S and is inclined to the west at a relatively small angle.

The orientation of these joint sets is often reflected in the topography and drainage pattern. Most of the streams in the area, both large and small, consist of parallel and/or straight segments which are coincident with the joint sets and regional strike.

Faults

Faults are defined as surfaces or zones of rock fracture along which there has been displacement, from a few inches to several thousand feet. The fault planes and associated joints function as avenues for ground-water flow through the rocks. Thus, faulting may result in an increase in both porosity and permeability. However, many fault zones also contain gouge which may weather to an impermeable clay thereby resulting in an increase in porosity and a decrease in permeability.

Recent studies of the structure of the crystalline rocks of the Delaware Piedmont (Woodruff *et al.*, 1972; Spoljaric, 1972; Woodruff and Thompson, 1974) suggest that faults are much more common than previously assumed.

Lithology

Lithology, when coupled with structural features and topography, can play an important role in locating water-rich zones. Micaceous schists are usually fairly soft and "tight" because the openings resulting from deformation are small and essentially closed by readjustment of the mineral grains. In many instances the minerals in the rock absorb the stress and do not fracture at all. Rock units consisting of quartzose gneisses are fairly competent, densely jointed, and maintain their openings to depths of several hundred feet. Lithology appears to be especially important in areas where the competent rocks are densely fractured. The dip of joints and the strike of the rocks may be oriented in such a way that both intersect the surface in stream beds, thus allowing for surface recharge.

Topography

Topographic position can have an important effect on the occurrence of ground water and on obtaining maximum well yields. In a recent study in the Maryland Piedmont, Nutter and Otton (1969) concluded that wells constructed in valleys and draws statistically yield greater quantities of water than do wells on hilltops and uplands. The reasons for this are: (1) ground water is generally discharged in topographically low areas along ravines and stream valleys, (2) the water table in such areas is near the surface, thus providing greater available drawdown, (3) seasonal water table fluctuations are generally smaller in low areas. Many of the stream valleys consist of relatively straight stream segments which are aligned parallel to major structural features such as joints and schistosity. Wells drilled in such areas will generally intersect more fractures than wells located in other locations. Densely jointed rock in stream beds may also provide avenues of potential recharge to the ground-water system.

Nature and Thickness of Regolith

The nature and thickness of regolith can affect well yields. Regolith is the mantle of unconsolidated rock material of transported or residual origin that overlies the crystalline rock. Large quantities of ground water are generally stored in thick sections of regolith. However, due to the relative low permeability exhibited by most of these soils, water is "leaked" to the hard rock aquifers very slowly by gravity drainage. The amount of water released depends upon the permeability of the material, the water levels (heads), and the orientation and density of interconnections of openings in the weathered rock with the fractures in the fresh rock. In many instances the weathered rock zone is fairly thin, as in valleys, and does not contribute greatly to the well yields.

Hydraulic Properties of Crystalline Rocks

Porosity

Porosity is defined as the percentage of total volume which consists of voids (openings or pores). Crystalline rocks exhibit two types of porosity: primary and secondary. Primary porosity is usually very small in crystalline rocks as the original pore spaces have been removed by metamorphic processes. Secondary porosity results from openings in the rocks caused by forces acting after the rocks were formed or emplaced. Most of the water in hard rocks is stored in joints, faults, and solution cavities. Accordingly, high yielding wells are located in areas where the secondary porosity is well developed. The porosity in the regolith is generally considerably greater than in the fresh rock.

Coefficient of Storage

The coefficient of storage of an aquifer is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head. The coefficient of storage is a dimensionless term. Because of the complexity of hard rock aquifers, the coefficient of storage is difficult to derive and may have only local significance. The values of storage obtained in this study indicate that several of the aquifers are artesian while others can be classified as "leaky-artesian."

Coefficient of Permeability

Permeability is the capacity of a porous medium to transmit water. The coefficient of permeability is defined as the quantity of water in gallons per day that will flow through a cross-sectional area of one square foot under a hydraulic gradient of one foot per foot at a temperature of 60°F. In crystalline rock aquifers the permeability depends to a very large extent on the size, density, and interconnection of fracture openings and solution cavities.

Coefficient of Transmissibility

The coefficient of transmissibility, which is usually calculated from aquifer test data, is the rate in gallons per day at which water will flow through a vertical strip of aquifer one foot wide and extending the full saturated thickness of the aquifer under a hydraulic gradient of 100 per cent. It is equal to the coefficient of permeability multiplied by the saturated thickness of the aquifer.

Transmissibility values calculated from residual drawdown curves of both pumping and observation wells ranged from 560 gpd/ft to 7,000 gpd/ft (gallons per day per foot). The variability in transmissibility values calculated from pumping well and observation well data obtained during an individual test indicate the heterogeneity and complexity of Piedmont aquifers. Nevertheless, the values can probably be used to compare the potential yields of the different water bearing units.

Specific Capacity

The specific capacity of a well is the yield per unit of drawdown expressed in gallons per minute per foot of drawdown (gpm/ft). When used in conjunction with the total available drawdown in a well, the specific capacity provides valuable data on the amount of water that can be pumped from a well. It has been suggested that during aquifer tests (pumping tests) wells should be pumped at a rate which will result in near maximum available drawdown (at least 100 feet) and that the specific capacity be computed at the end of the test.

Specific capacities in the five test wells pumped ranged from 0.5 gpm/ft to 4.9gpm/ft with the available drawdown exceeding 120 feet in all wells.

Aquifer Tests

Aquifer tests are used to determine well performance in a given aquifer, to determine optimum pump settings, and to aid in the design of pump equipment. An aquifer test involves pumping water from a well at a constant rate with the drawdown (decline in water level) measured in the pumped well and in one or more observation wells at accurately measured times after pumping began and measuring the rise in water levels (recovery) after the pump is turned off. In this study the non-equilibrium well formula (Theis, 1935) and the modified non-equilibrium well formula (Cooper and Jacob, 1946) were used to analyze pumping test data. (The values of transmissibility and storativity derived from the Cooper and Jacob "straight-line method" were more consistent). The values of transmissibility reported in Table 1 were derived from recovery data from the pumped wells. In many instances the transmissibilities derived from the observation wells were several orders of magnitude larger than those derived from the pumped wells. The variability in transmissibilities is probably due to the anisotropy of the aquifers.

Many of the assumptions on which the well formulas are based are violated in crystalline rock aquifers. Consequently, the values of transmissibility are not necessarily true values and should only be used for comparative purposes among the individual wells in the study area. Specific capacities, shapes of the time-drawdown curves, and to a lesser degree, transmissibilities, were relied upon to evaluate the potential magnitude of yield and the long term effects of pumping.

The well casings above ground surface in wells Cb32-8 and Cb32-9 were removed prior to performing aquifer tests on these wells. The static water levels were recorded prior to casing removal and were used in determining the specific capacity and available drawdown.

Geophysical Well Logging

Several geophysical well logging techniques were used in conjunction with lithologic logs in locating the depth to water bearing fracture zones in rock wells. The gamma-ray log was used to locate lithologic changes within the well and to determine the exact depth of casing. Locally the gamma-ray log has also proven useful in identifying quartzose and clayey zones. The flowmeter tool was most useful in locating zones of water flow into the well under artesian conditions. The caliper tool measures borehole diameter and was used to locate fracture zones. One well log in itself is generally not always definitive. However, when two or more logs are run in the same well and compared with the driller's log, very useful data can be extrapolated.

RESULTS OF DRILLING AND TESTING

Eleven test wells were drilled to determine the nature of the lineations observed on aerial photographs and to evaluate the ground-water availability in the fracture zones penetrated. The locations of, and data on, the test wells are presented in Figures 3 and 4, and Table 1, respectively.

Test Well Ca45-39

Test well Ca45-39 was drilled to a depth of 360 feet near the intersection of three lineations identified on aerial photographs and directly north of a magnetic low located by a magnetometric survey. The drill site is situated in a topographically low area on the flood plain of White Clay Creek. The water table is about 10 feet below ground surface and occurs at the top of a thick saturated zone of alluvium and saprolite (in situ decomposed rock). A water-bearing fracture zone was intercepted between 172 feet and 212 feet and yielded 200 gpm while drilling with compressed air. The rock in this interval consists of gray and green quartz-biotite gneiss and schist with thin stringers of pegmatite. Rock cuttings exhibit parallel joints many of which have mineralized surfaces (chlorite with some pyrite). Additional water-bearing fracture zones were encountered below 212 feet. An accurate well yield could not be determined at the time of drilling because of the limited air capacity of the drill. Accordingly, a minimum well yield of 200 gpm was recorded.

A 24-hour pumping test verified the yield obtained during drilling. The shape of the time-drawdown curve indicates that a recharge boundary is nearby, probably White Clay Creek (Figure 5). The effects of such a boundary were felt 250 minutes into the test. The pumping of test well Ca45-39 affected an observation well (Ca45-19) located 850 feet west of the pumping well along a N70°-80°W lineation. It appears that well Ca45-39 is located in the more permeable part of the same fracture zone as its yield, specific capacity (4.9 gpm/ft), and transmissibility (3,700 gpd/ft) are much greater than in observation well Ca45-19.

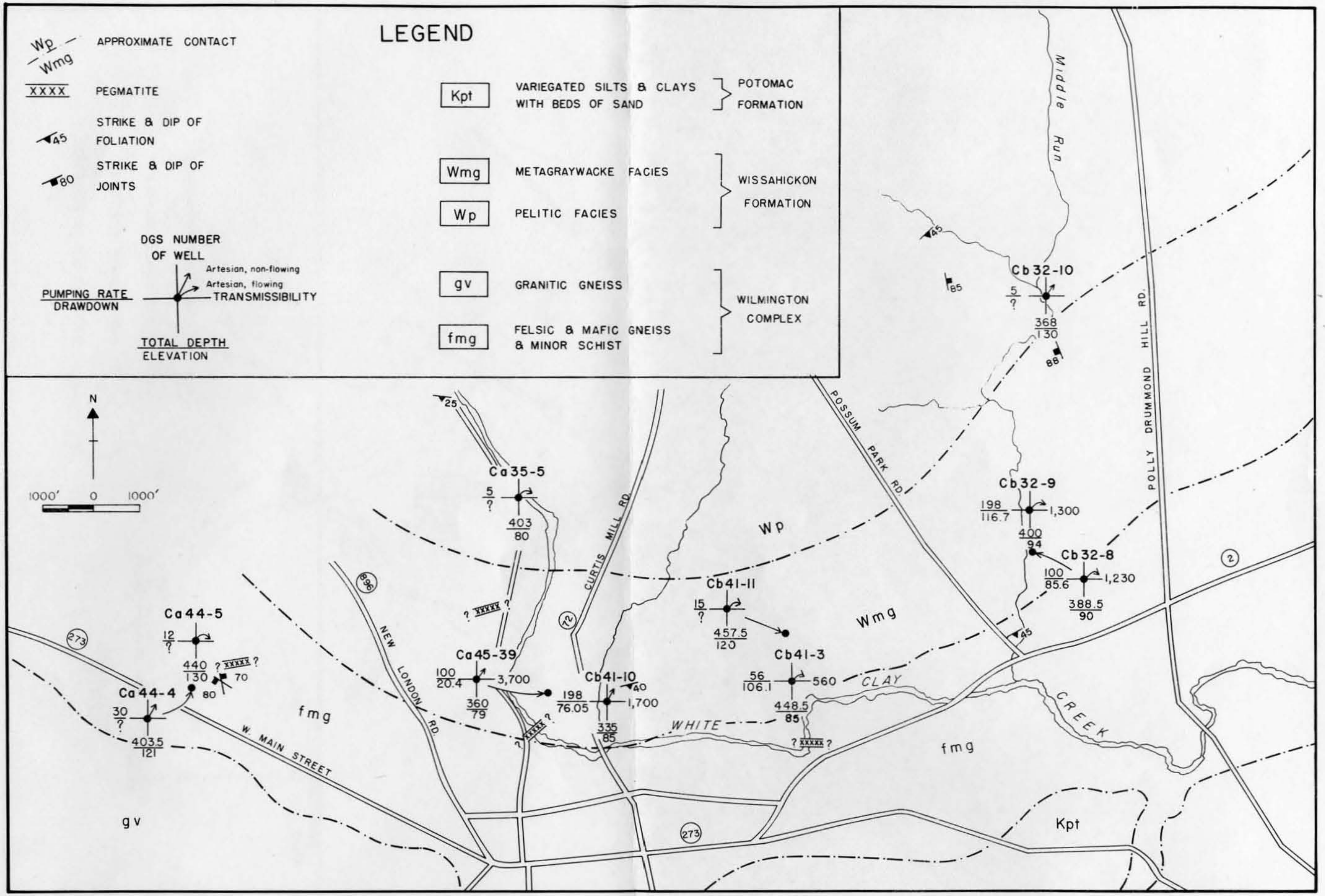

FIGURE 3. GROUND WATER GEOLOGY OF NORTHERN NEWARK

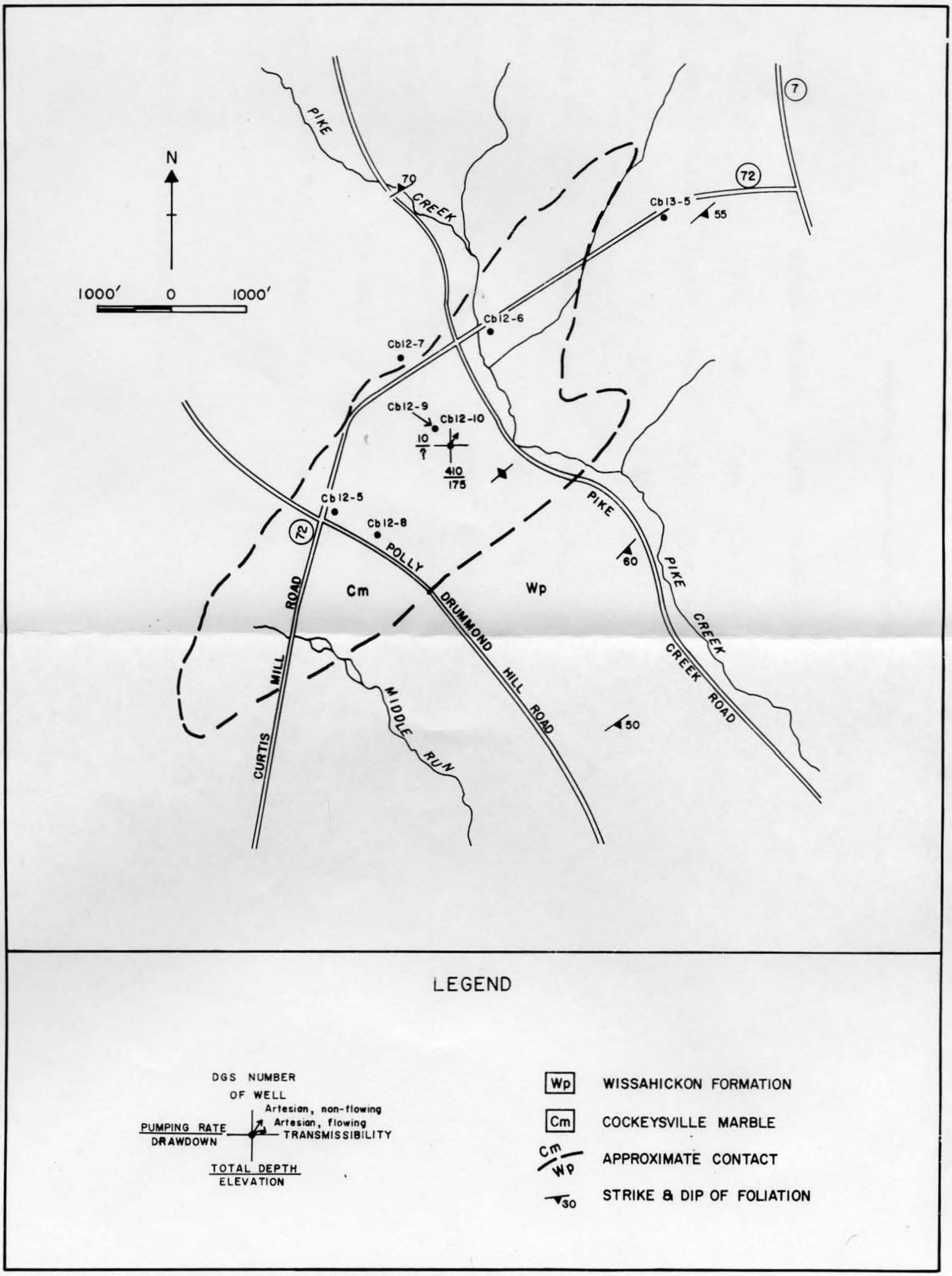

FIGURE 4. GROUND WATER GEOLOGY OF NORTHEASTERN NEWARK

Table 1. Data for Piedmont test wells near Newark, Delaware.

Test Well No.	Ca45-39	Ca35-5	Ca44-4	Ca44-5	Cb12-10	Cb32-8	Cb32-9	Cb32-10	Cb41-3	Cb41-10	Cb41-11
Depth (ft.)	360	403	403	440	410	388	400	368	448	335	460
Elevation (ft.)	78.9	80	121	130	175	90±	94±	130±	85±	85.3	120±
Static Water Level (ft., relative to grd. elevation)	-7.3	+0.9	-3.9	+1.5	-10	+16.3	+12.5	-4.6	+3.2	-11.1	+6.4
Pumping Rate (gpm)	100**	5*	30**	12*	10*	100**	198**	5*	56**	198**	15*
Duration (hrs.)	23	-	1	-	-	17	48	-	15	43	-
Drawdown (ft.)	20.4	-	134+	-	-	85.6	116.7	-	106.1	76.1	-
Specific Capacity (gpm/ft drawdown)	4.9	-	<0.3	-	-	1.2	1.7	-	0.53	2.6	-
Available Drawdown (ft.)	162	-	-	-	-	230	160	-	220	120	-
Transmissibility (gpd/ft)	3,700	-	-	-	-	1,320	1,300	-	560	1,700	-

* Pumped with compressed air through drilling rod

**Pumped with electric submersible pump

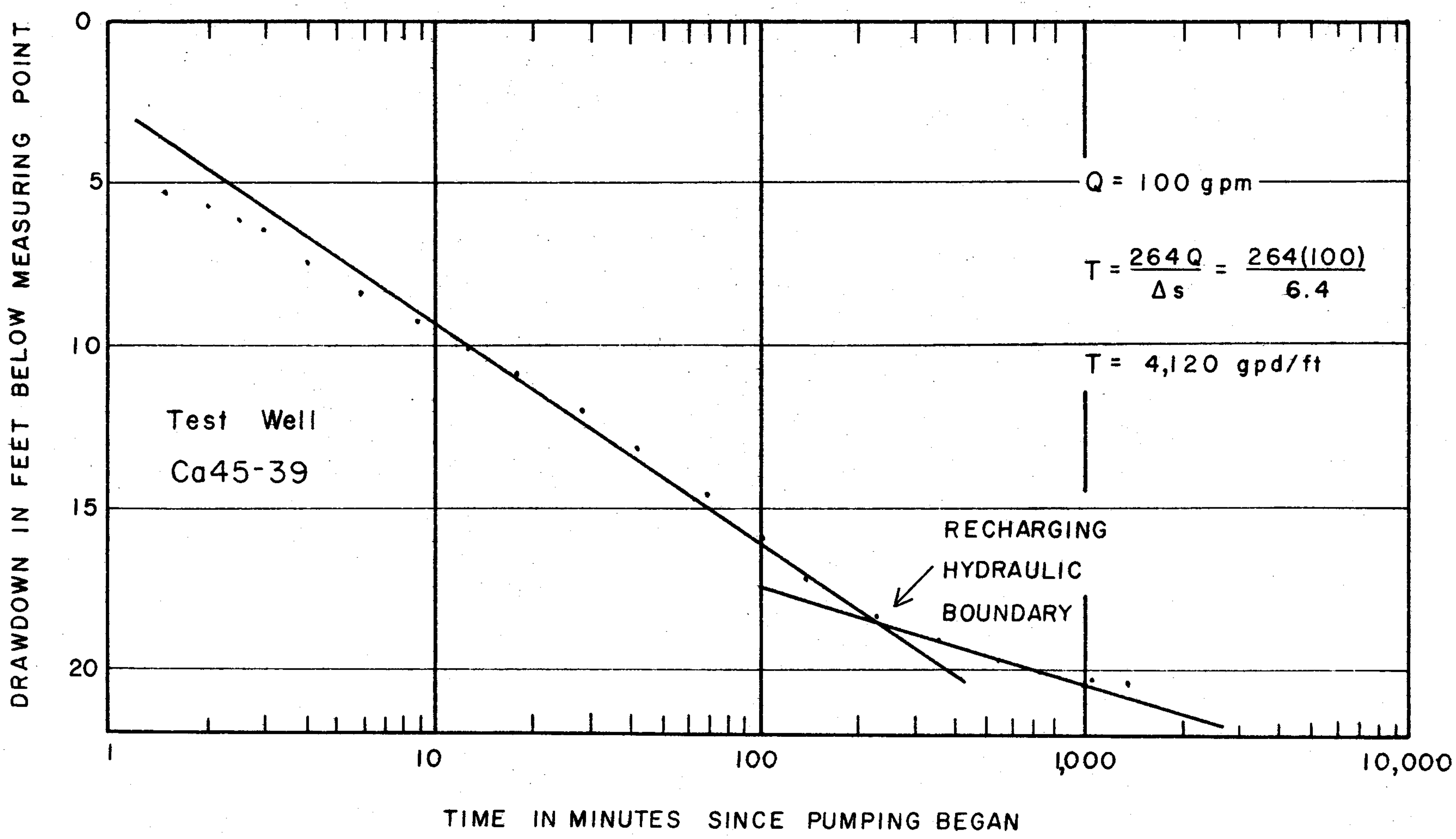

Figure 5. Time versus drawdown graph of test well Ca45-39

Figure 6 is a composite lithologic, caliper, and gamma-ray log of test well Ca45-39. The caliper log verifies the presence of a fracture zone between 172 feet and 212 feet. The variability of the gamma-ray log indicates the inhomogeneity of the structure and mineralogy in this interval. The low radioactive zones are probably indicative of quartzose rocks and voids, whereas the more radioactive zones reflect the presence of micaceous minerals.

Coefficient of storage and the presence of the effects of earth tides on hydrograph records indicate artesian conditions. However, the rapid response of the water level in the well to precipitation and stream flow suggests a water table condition. The response to rainfall may be due to rapid infiltration into the thick permeable zone above the fresh rock or it may be attributable to a loading effect upon the aquifer in areas where the fracture zones intersect the surface in streams.

Test Well Cb41-10

Test well Cb41-10 is located 1350 feet southeast of well Ca45-39 in a relatively straight and moderately incised stream valley. This well was drilled to test the nature of three lineations that intersect near the drill site. The well lies along a N70°-80°W lineation which also passes through well Ca45-39.

The regolith is approximately 38 feet thick and consists of soft greenish-gray micaceous schist. Surface casing was set in medium hard quartz-biotite gneiss and schist that contain stringers of white quartz. A very thick intermittently fractured zone, which yielded greater than 150 gpm while pumping with compressed air, was penetrated between 130 feet and 180 feet. The rock in this zone is a hard and competent quartz-biotite gneiss with thin stringers of quartz and pegmatite. Many rock fragments in the water-bearing zone exhibit closely spaced parallel joint surfaces and traces of pyrite. A caliper log verified the presence of this fracture zone. Numerous thin fractured rock zones which probably yielded additional quantities of water were encountered from 180 feet to a depth of 270 feet. Below 270 feet the rock is softer and more schistose than above.

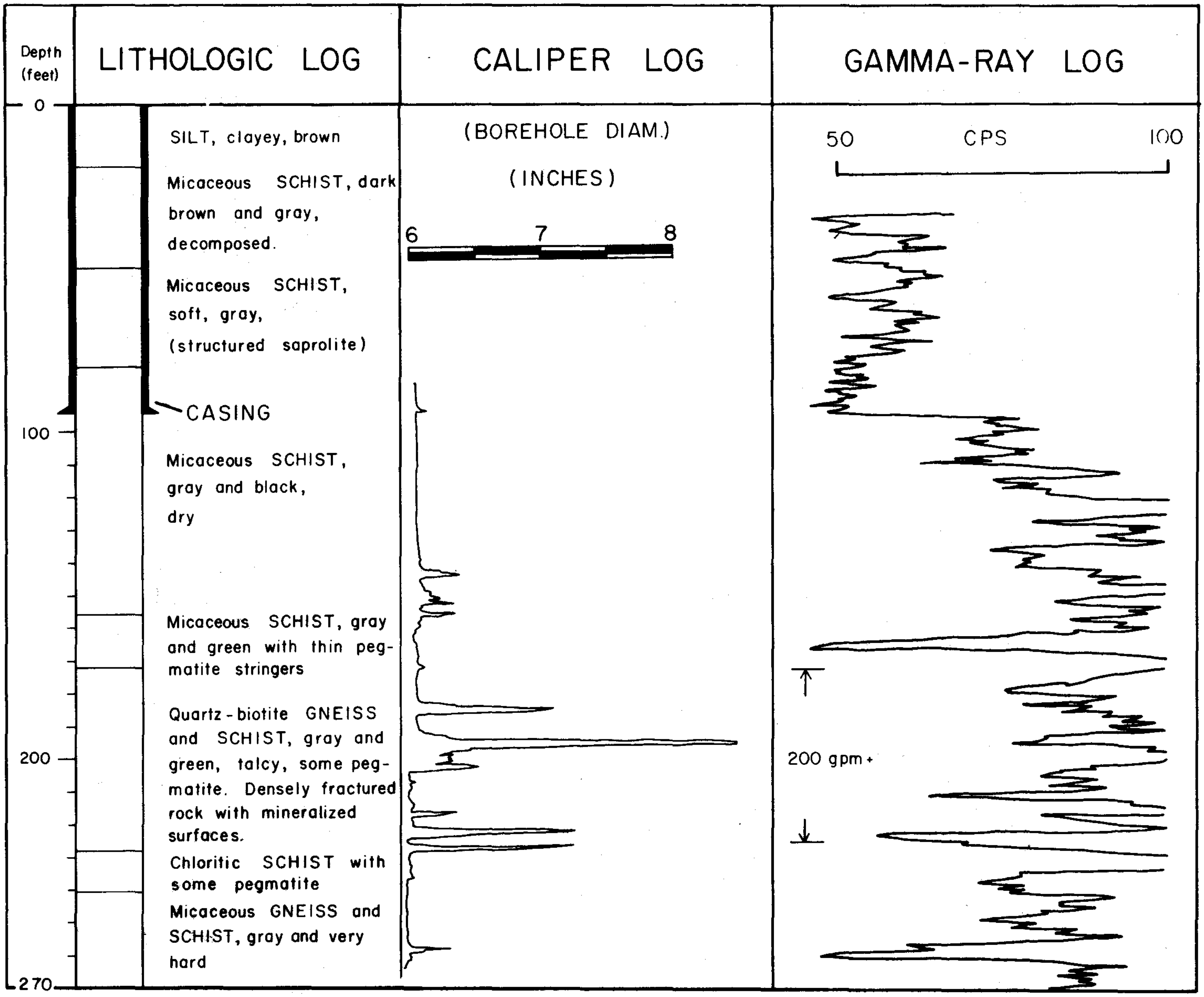

FIGURE 6. LITHOLOGIC, CALIPER, AND GAMMA-RAY LOGS OF TEST WELL Ca45-39

A 48-hour pumping test showed the specific capacity to be 2.6 gpm/ft. The transmissibility was calculated to be about 1,700 gpd/ft. The effects of a recharge boundary were evident after 200 minutes of pumping and the time-drawdown curve flattened out entirely after 500 minutes of pumping (Figure 7). The location of the recharge boundary could not be accurately determined because of a lack of observation wells in the immediate vicinity of the pumping well. The total drawdown in observation well Ca45-39 was 0.3 feet. The drawdown and recovery data from observation well Ca45-39 could not be used to determine aquifer characteristics because of the interference effects caused by earth tides. Additional anticipated drawdown in the observation well was not achieved due to the effect of the recharge boundary encountered. The drawdown in Ca45-39 coupled with the similarity of water chemistry in each well verifies that the wells are connected hydraulically to some degree. The effects on Cb41-10 of pumping Ca45-39 were not determined as Ca45-39 was tested prior to completion of test well Cb41-10.

Test Well Cb32-8

The location for test well Cb32-8 was chosen because: (1) outcrops adjacent to the site consist of relatively densely jointed quartz-biotite gneiss and schist, (2) the orientation of the joint sets are favorable in that one set strikes N-S coincident with the orientation of a long straight segment of Middle Run, and the other two sets strike N20°-30°W and N65°-80°W respectively, and (3) the potential for induced recharge under such conditions from Middle Run is favorable.

Test well Cb32-8 was drilled to a depth of 388 feet. Two major and several minor water-bearing fracture zones were penetrated. Thirty-three gpm were obtained in the interval 72 feet to 90 feet. The presence of this fracture zone was verified by a caliper log (Figure 8). Cuttings from this interval exhibit parallel joint faces, pyrite, and mineralized surfaces. The second, and most prolific, water-bearing zone, which yielded in excess of 100 gpm, occurs in the interval 230 feet to 260 feet. The caliper log indicates that this zone is highly fractured.

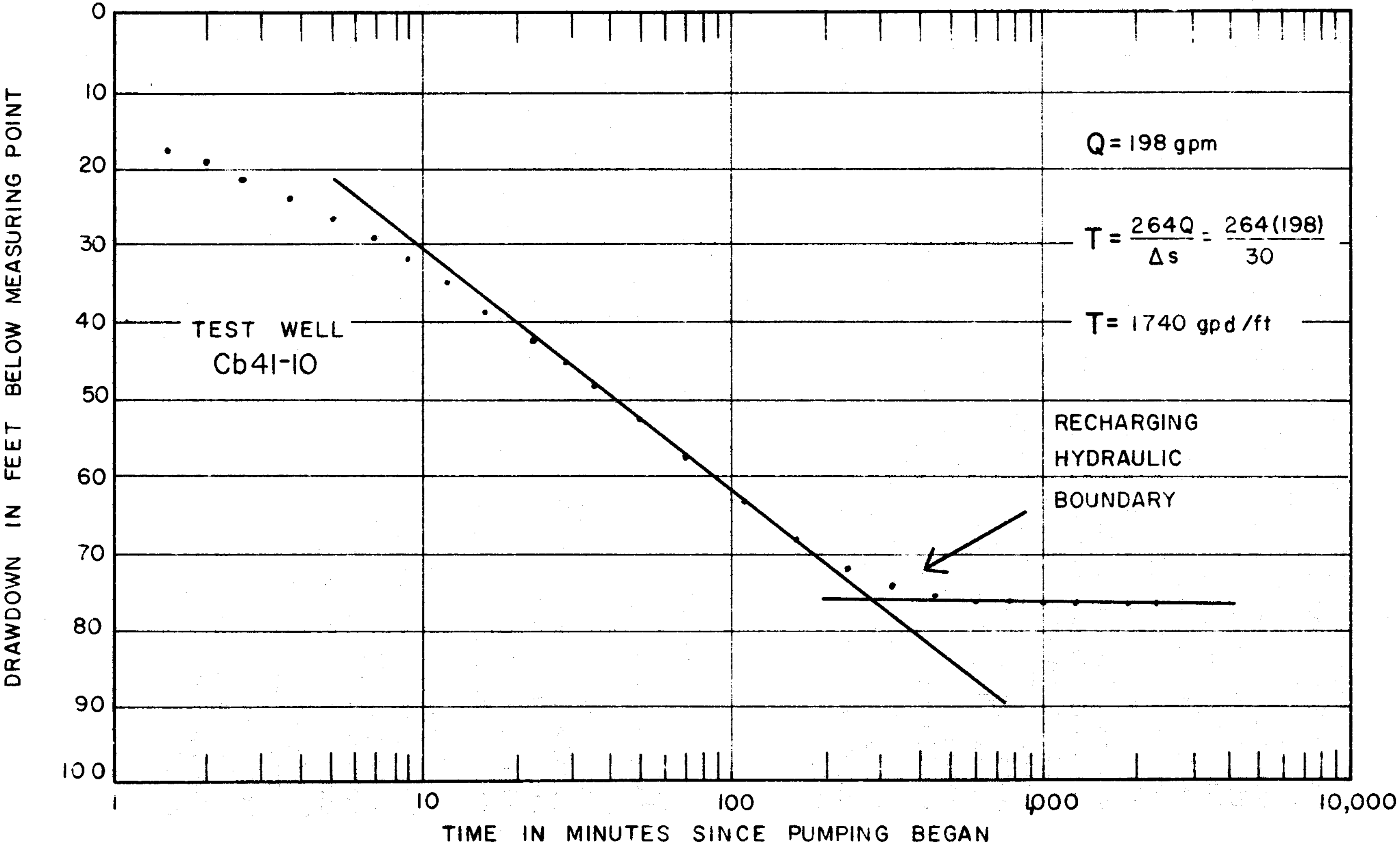

Figure 7. Time versus drawdown graph of test well Cb41-10

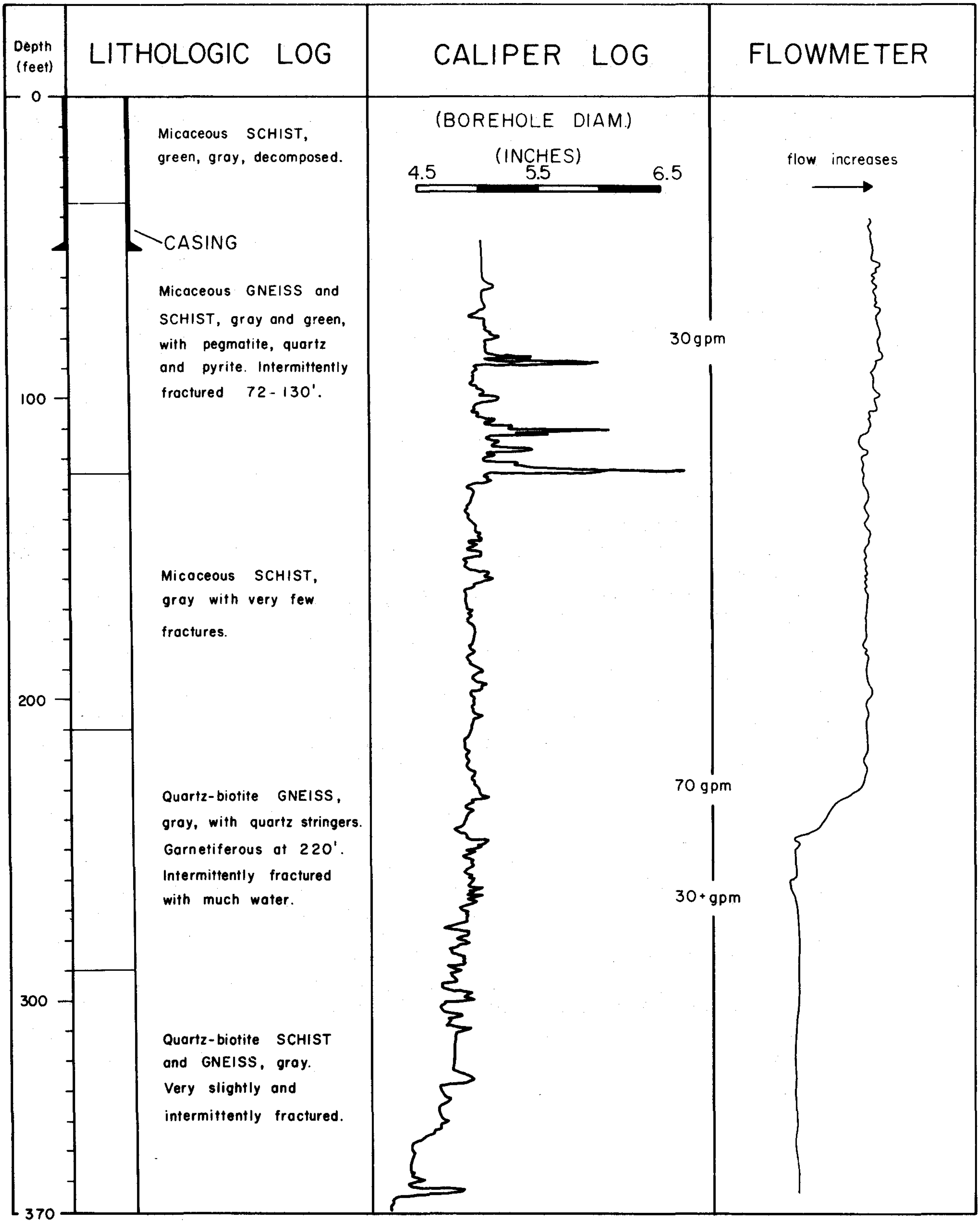

FIGURE 8 LITHOLOGIC, CALIPER, AND FLOWMETER LOGS OF TEST WELL Cb32-8

A flowmeter log (Figure 8) shows that a substantial amount of water is entering the well at a depth of 245 feet. Additional fracture zones were encountered below 260 feet and probably contribute small quantities of water to the well. Water flows from the well under artesian conditions at a rate of 25-30 gpm and the static water level is 17 feet above ground surface.

Well Cb32-8 was pumped at 100 gpm for 17 hours. The specific capacity is 1.2 gpm/ft and the transmissibility is 1,320 gpd/ft (Figure 9). The mutual response of wells Cb32-8 and Cb32-9 when one or the other is pumped, suggests that at least one major common fracture zone exists beneath this portion of Middle Run.

Test Well Cb32-9

Test well Cb32-9 was drilled to test the nature of the intersection of two linear features. One of the lineations is controlled by a joint set and the other is oriented parallel to the regional strike of the country rock. Fractured water-bearing rock was penetrated from 151 feet to 166 feet, and yields up to 175 gpm were obtained from this zone. The presence of the fracture zone is detected by the caliper and flowmeter logs (Figure 10). Additional thin fracture zones were intercepted below a depth of 166 feet as evidenced by descriptive and caliper logs. However, the amount of water that they contributed to the entire system could not be accurately determined, as the individual zones could not be isolated.

This well was pumped at the rate of 198 gpm for 48 hours to determine the aquifer characteristics. The well has a specific capacity of 1.7 gpm/ft and a transmissibility of 1,300 gpd/ft. The effects of a recharging hydraulic boundary were felt approximately 300 minutes into the test (Figure 11). The slope of the time-drawdown curve in observation well Cb32-8 started to flatten out 2,400 minutes into the test. Although pumping tests indicate that the wells are hydraulically connected, the chemistry of the waters are strikingly different. Test well Cb32-9 is artesian and flows approximately 20 gpm at ground surface. The static water level is 12 feet above ground surface.

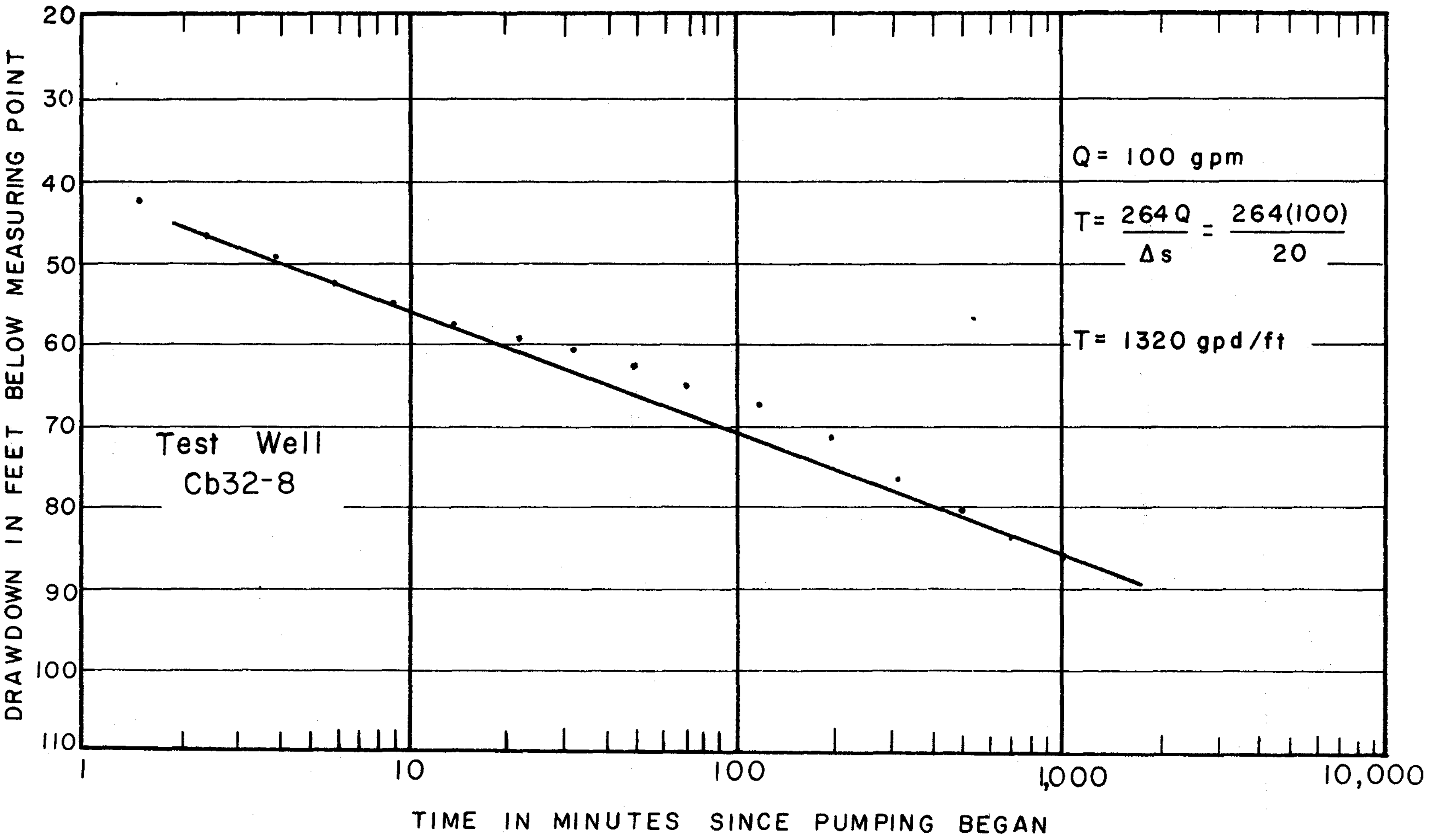

Figure 9. Time versus drawdown graph of test well Cb32-8

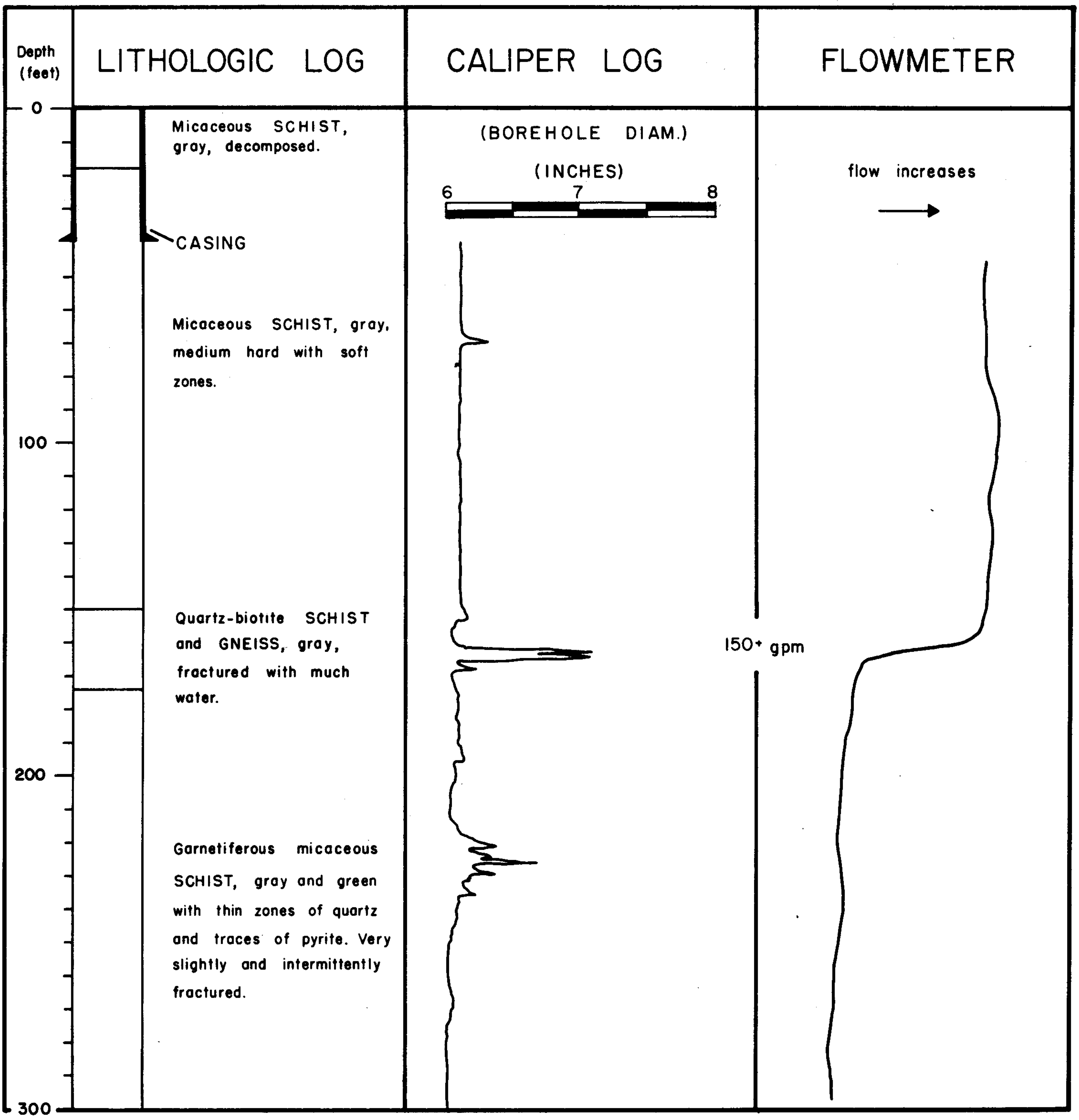

FIGURE 10. LITHOLOGIC, CALIPER, AND FLOWMETER LOGS OF TEST WELL Cb32-9

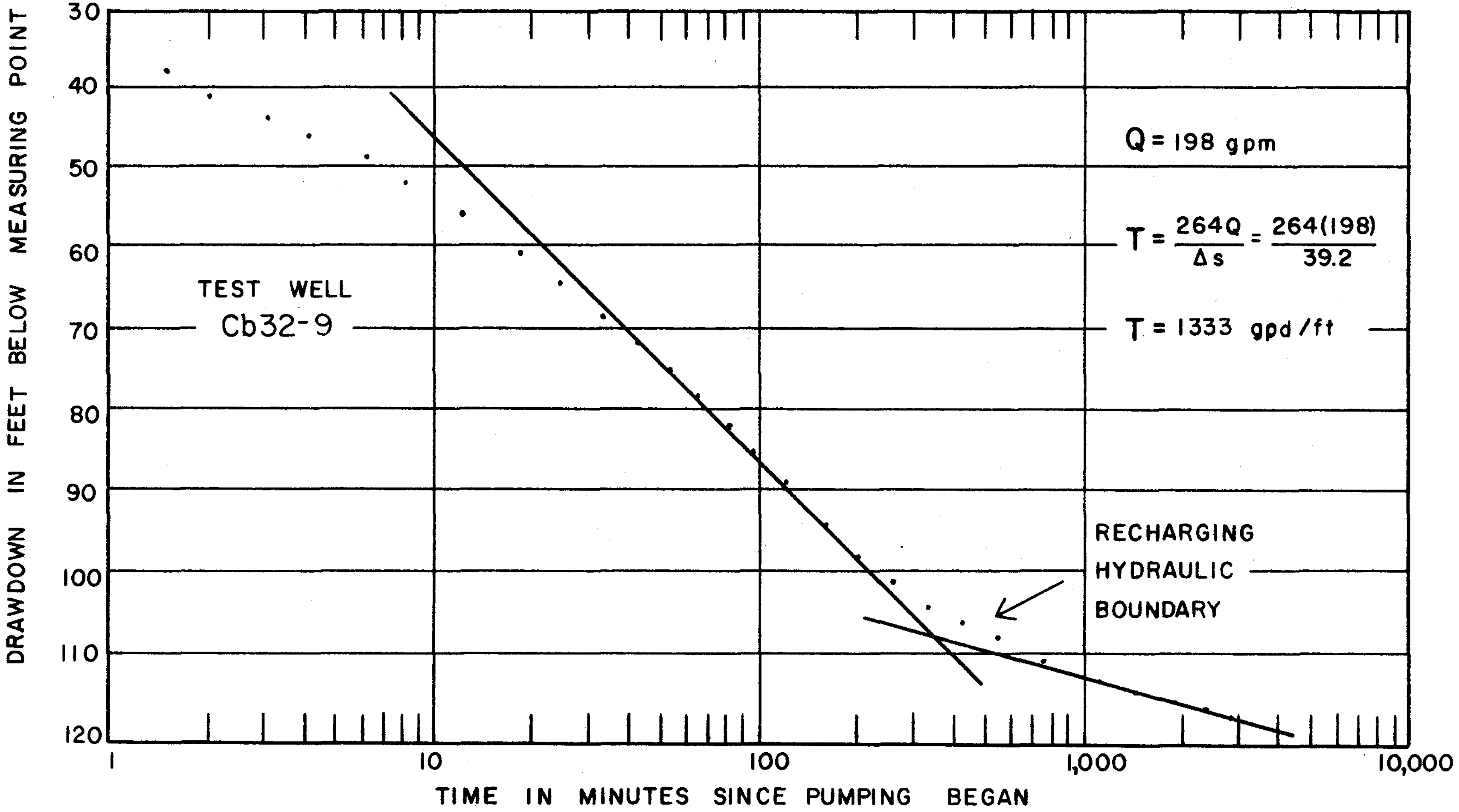

Figure 11. Time versus drawdown graph of test well Cb32-9

Test Well Cb41-3

Test well Cb41-3 was drilled for the following reasons: (1) the site is located adjacent to White Clay Creek and is coincident with a major joint set, (2) a relatively long lineation, which is parallel to the N10°-20°W joint set, is adjacent to the site, (3) the site is near the contact of the Wissahickon Formation and the Wilmington Complex, and (4) rocks which outcrop near the site are densely jointed and lie within the bed of White Clay Creek.

The rock penetrated in this well consists of medium hard, gray and black, very micaceous schist with thin stringers of pegmatite. The major water-bearing fracture zones occur at depths ranging from 212 feet to 375 feet. Nearly equal amounts of water were obtained from four small fracture zones. Many thin zones were intercepted above 200 feet, but they did not yield appreciable quantities of water.

A 15-hour pumping test was performed on this well at a pumping rate of 56 gpm. The specific capacity is relatively low (0.53 gpm/ft); however, the available drawdown is 220 feet. The large available drawdown together with the fact that a recharge boundary exists nearby suggests that the well will yield 80 gpm to periodic pumping and perhaps 60 gpm on a continuous basis (Figure12).

Test Well Cb41-11

Test well Cb41-11 is located approximately 800 feet north of Cb41-3. The well was drilled parallel and directly adjacent to a N10°W lineation in a small stream valley marked by numerous springs. Pegmatite, gneiss, schist, and gabbroic rocks were mapped near the site. The rock penetrated in the well is competent and fractured, but yielded negligible quantities of water. Twenty gpm was encountered at the base of the weathered rock zone at a depth of 29 feet; however, it was cased off. The final yield was 15 gpm and the well flows at the surface at a rate of 1-2 gpm.

Test Well Cb32-10

Test well Cb32-10 was drilled to test the nature of one of the most prominent linear features observed in the

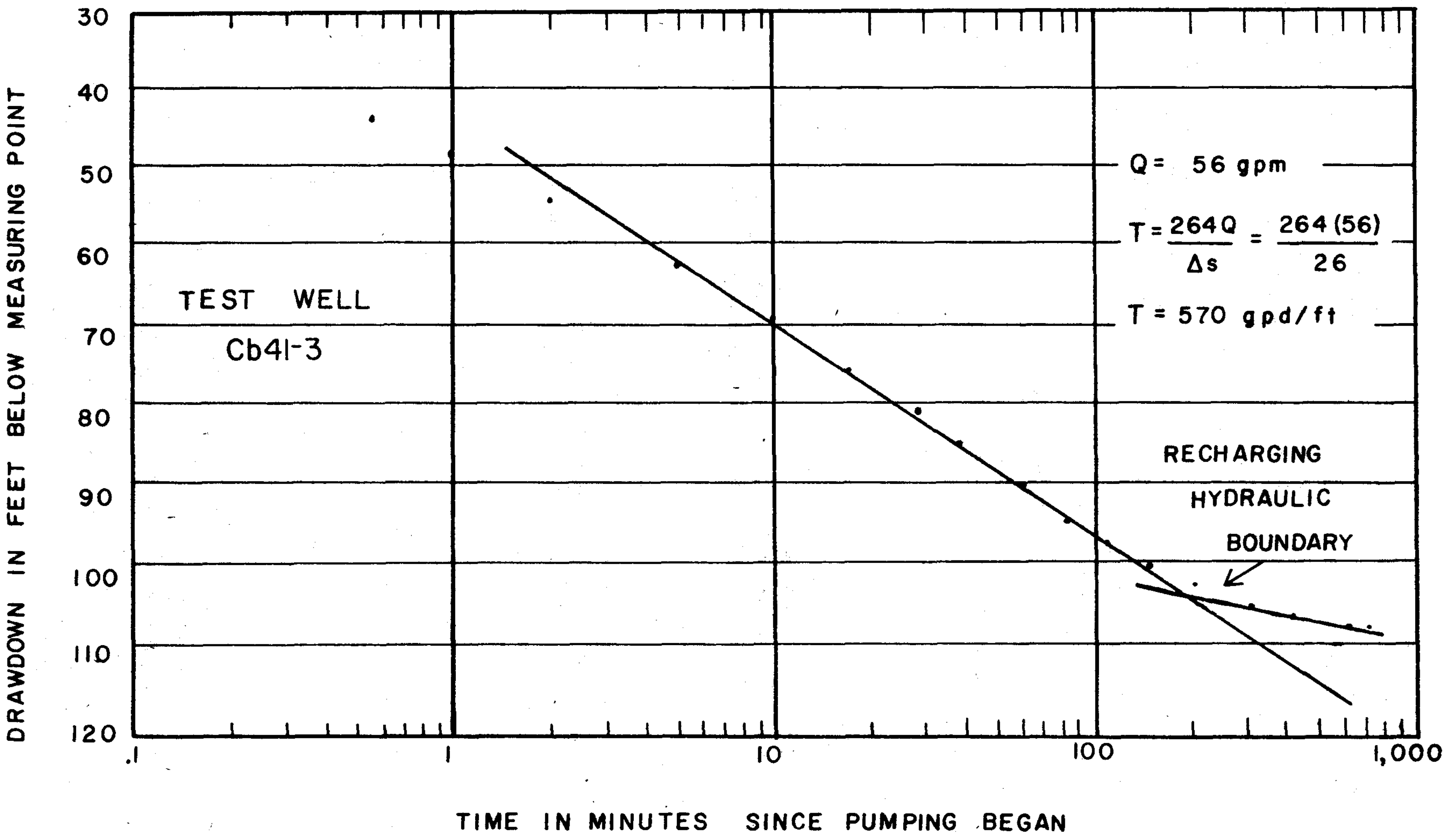

Figure 12. Time versus drawdown graph of test well Cb41-3

Delaware Piedmont. The strike of the lineation is N65°W and can be traced on aerial photographs for nearly four miles. The well is located adjacent to and south of the lineation along a relatively straight portion of Middle Run. Rock of variable hardness consisting of black, gray, and green, quartz-biotite gneiss and schist, garnetiferous mica schist, and chlorite schist was penetrated. The presence of weathered rock and clay beneath fresh rock suggests that some movement has taken place in the area. Hard, competent quartzose gneiss, which usually forms the water-bearing zones in the Piedmont, is lacking at this site. The yield at 368 feet was 5 gpm.

Test Well Ca35-5

Test well Ca35-5 was drilled north of the intersection of two lineations (N70°-80°W and N20°-30°W) on the flood plain of White Clay Creek. A small tributary to White Clay Creek which is oriented parallel to regional schistosity (N60°-70°E) traverses the site. The rock beneath the site is mapped as the pelitic facies of the Wissahickon Formation. Very few fractures were encountered as the rock was consistently soft and micaceous. The adjacent fracture zones apparently dip to the southeast and were therefore not intercepted by the well. The well is 403 feet deep and yields 5 gpm.

Test Well Cb12-10

Test well Cb12-10 was drilled on top of a northwest-southeast trending lineation which is aligned with a straight segment of Pike Creek. A disappearing stream and very permeable soils in this marble valley indicated favorable conditions for a test well. The weathered rock is 100 feet thick. Below 100 feet the rock consists of hard to medium hard, slightly fractured, grayish-white and white calcitic and dolomitic marble. The well yield was 10 gpm at 410 feet.

Test Wells Ca44-4 and Ca44-5

Test well Ca44-4 was drilled in a wide and flat valley on the flood plain of the east branch of the Christina River. A northwest-southeast lineation traverses the site. The area is mapped as felsic and mafic gneiss, but a large body of pegmatite is located immediately north of the well. The well yielded 30 gpm at 403 feet. The water was obtained from several thin fracture zones at 102 feet, 136 feet, 250 feet, and 380 feet.

Test well Ca44-5 is located in the same valley approximately 1,000 feet north of Ca44-4. The two wells are separated by a pegmatite unit. The rock penetrated in this well is similar to that encountered in Ca44-4. It consists of hard, gray and black, micaceous gneiss and schist with stringers of pegmatite. Several zones of green-colored schist and white quartz were penetrated throughout the well. The relatively few fractured rock zones yielded small quantities of water. The final well yield was 12 gpm at a depth of 440 feet.

Chemical Quality of Ground Water

Table 2 lists the major chemical constituents in ground water from five test wells. The water is generally low in total solids, slightly acidic to slightly basic, and is classified as soft (0-60 mg/1 of $CaCO_3$) to medium hard (61-120) (Durfor and Becker, 1964). Iron content is highly variable, ranging from less than 0.05 to 2.35 mg/1. The variability of iron in aquifers which are hydraulically connected (Cb32-8; Cb32-9) reflects the complexity of the geology and local ground-water flow systems. Waters high in iron corrode pipes, taste bad, and cause staining of fixtures and clothing. Iron can be removed by treatment with polyphosphates. The relatively high turbidity (15) and color (15) in test well Cb32-9 are probably a result of high iron content and incomplete well development.

The naturally occurring concentrations of fluoride are fairly constant and should be considered prior to designing treatment facilities.

RESULTS

The results of this exploration demonstrate that useful quantities of ground water are available from crystalline rocks in at least part of the Delaware Piedmont. However, because of the complexity and variability of ground-water systems in crystalline rocks, it is essential that drill sites be carefully selected to obtain optimum yields. Geologic criteria found useful for identifying areas for test drilling in the area of study included: (1) locations adjacent to, or on top of, lineations (fracture traces) and preferably at the intersection of several lineations, (2) topographically low areas in valleys and draws, (3) areas underlain by competent, but densely jointed rocks, and (4) areas along stream courses.

Table 2. Chemical analyses of water samples from selected Piedmont test wells. (Chemical constituents are in milligrams per liter).

Well Number	Ca45-39	Cb41-3	Cb32-9	Cb41-10	Cb32-8
Sample Collected	5-23-73	7-16-73	8-15-73	11-7-73	1-22-74
Total solids	146	133	98	144	116
Total hardness	58	76	41	50	59
Free Carbonic Acid	15.0	8.0	4.5	6.0	3.2
Alkalinity (m.o.)as $CaCO_3$	77.7	91.3	53.8	61.5	79.4
LAS	0.08	0.12	0.076	1.65	0.76
Chloride	4.3	2.3	3.5	5.1	5.0
Iron (Fe)	0.21	0.1	2.35	<0.1	<0.05
Manganese (Mn)	0.37	0.23	0.20	0.25	0.04
Magnesium (Mg)	1.3	1.6	1.4	-	0.40
Fluoride (F)	0.12	0.17	0.19	0.20	0.15
Sodium (Na)	11.4	10.0	11.8	7.8	18.4
Calcium (Ca)	21.0	27.8	13.9	-	22.9
Sulfate (SO_4)	6.4	4.3	10.7	7.67	6.67
pH	6.5	7.9	5.8	6.6	8.1
NO_3 as N	0.18	0.10	0.41	0.003	0.16
Nitrate as NO_3	0.81	0.44	1.80	-	0.68
Turbidity (JTU)	0.37	0.72	15	0.64	0.91
Color	2	2	15	<1	<1

The criteria described above, and to a lesser degree, magnetometric and seismic profiling, were used to select drill sites for eleven test wells. Five of the test wells are capable of supplying appreciable quantities of water. Table 3 presents the predicted performances of selected test wells in their present state. Conversion to production wells will entail reaming several of the wells to accommodate pumps and assure good hydraulic efficiency of the wells. Reaming may improve the performances of individual wells beyond our predictions. The pumping rates and drawdowns presented in Table 3 have been calculated in a conservative manner from data obtained from pumping tests.

Table 3. Predicted performances of selected Piedmont test wells.

Test Well No.	Ca45-39	Cb32-8	Cb32-9	Cb41-3	Cb41-10
Pumping rate (gpm)	300	100	200	60	200
Drawdown (ft.)	80	153	153	154	114
Time since start of pumping (days)	70	70	70	70	70

Analysis of descriptive and geophysical logs shows that appreciable quantities of ground water were encountered below a depth of 275 feet in only one of the test wells (Cb41-3). It is suggested, therefore, that test wells drilled in this area be limited to a depth of 300 feet except where geologic conditions warrant deeper exploration.

The value of recording accurate geologic descriptive logs and determining preliminary estimates of at least minimum wells yields while drilling have been established. The use of gamma-ray, caliper, and flowmeter geophysical logs proved invaluable in analyzing borehole conditions, in locating water-bearing fracture zones, and in determining available drawdown.

The pumping tests were analyzed using the non-equilibrium well formula (Theis, 1935) and the modified non-equilibrium well formula (Cooper and Jacob, 1946). The values of transmissibility derived from these equations should be used with care because many of the assumptions on which the formulas are based are violated in crystalline rock aquifers. Nevertheless, our experience in this part

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Based on review of pumping data from production wells which have been in operation for more than a year in the Newark Piedmont, it is recommended that pumping rates, pumping water levels in production wells, and water levels in pertinent observation wells be carefully recorded to allow for periodic assessment of the well fields. These data will also provide background information for detailed studies of sustained yields in crystalline rock aquifers.

The shape of the time-drawdown curves for test wells Ca45-39, Cb32-9, Cb41-3, and Cb41-10 indicate that recharge boundaries were encountered. As all of these test wells are located within relatively small distances of streams, the induced recharge can probably be attributed to surface sources. Accordingly, the quality of the streams must be maintained.

The chemical quality of ground water is generally quite good as shown in Table 2. The water is soft to medium hard. The water quality should be monitored on a periodic basis so that any changes in chemisry that would affect treatment programs could be accommodated.

Magnetometric and seismic profiles were made across several drill sites; however, the results were not entirely conclusive. A more detailed and elaborate testing program will be required to evaluate the effectiveness of geophysical methods in locating and defining trends of fracture traces in the Delaware Piedmont.

A review of published and unpublished data on 198 production wells, test wells, and auger holes drilled in the Coastal Plain in the Greater Newark Area indicates that no additional major sources of ground water are likely to be found nearby in the Coastal Plain sediments.

The success of this ground-water exploration program supports the conclusions reached by many investigators that above average to substantial quantities of ground water can be developed in crystalline rocks through the application of sound geologic principles.

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APPENDIX A

Table for the conversion of English Units to the International System of Units (SI)

APPENDIX A

The following factors may be used to convert data from the English Units published herein to the International System of Units (SI).

Multiply English units	By	To obtain SI units
inches (in)	25.4	millimeters (mm)
inches (in)	.0254	meters (m)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
gallons per minute (gpm)	.003785	cubic meters per minute (m^3 $min.^{-1}$)
million gallons per day (mgd)	3,785	cubic meters per day (m^3 day^{-1})
gallons per day per foot (gpd/ft)	.012387	square meters per day (m^2 day^{-1})
square feet (ft^2)	.0929	square meters (m^2)

APPENDIX B

Logs of test wells drilled for the City of Newark, Delaware between April, 1973 and March, 1974

DESCRIPTIVE LOG

DGS No. Ca35-5
Drilling Method Air Hammer
Date Drilled 4/16/73
Local No.
Project Newark
Logged by J. Talley

Depth	Lithology and Hydrology
0-21	Sand, silty, and gravel (schist rock fragments), brown. Wet at 5'.
21-52	Schist and gneiss, micaceous, black and gray, with quartz fragments, medium hard. Total of 5 gpm at 34'.
52-143	Gneiss and schist, micaceous, medium hard, with thin pegmatite stringers throughout. Very, very slightly fractured. Fairly easy drilling with powdery cuttings. Rapid penetration. Installed 64.5' of 6" dia. steel casing.
143-240	Schist and gneiss, micaceous, moderately hard to easy. Several soft zones throughout interval. Green and chloritic rock about 200'.
240-270	Schist, micaceous, hard to moderately hard.
270-403	Schist, micaceous, medium hard to hard, sporadic zones of pegmatite and quartz. Very consistent drilling throughout interval with little or no fracture zones.

Total yield of well at 403' is about 5 gpm.

DESCRIPTIVE LOG

DGS No. Ca44-4	Drilling Method Air Hammer	Date Drilled 5/4-11/73
Local No.	Project Newark	Logged by J. Barone & J. Talley

Depth	Lithology and Hydrology
0-30	Sand, gravel, micaceous, brown.
30-66	Schist, micaceous, gray and green, with some thin stringers of pegmatite (foliated and fractured). 4 gpm at 63'. Installed 51.5' of 5" dia. steel casing.
66-67	Pegmatite, picked up 2 gpm.
67-98	Gneiss, micaceous, white and gray, medium grained, mostly quartz with some mica. Large cuttings up to 1".
98-136	Gneiss, schist, quartz-biotite, grayish-white, with stringers of pegmatite, hard drilling. Slightly fractured with a total of 10 gpm at 136'. Some green rock.
136-147	Gneiss, quartz-biotite, dark gray to black, very hard, some magnetic minerals.
147-149	Pegmatite.
149-169	Gneiss and amphibolite?, dark gray and black, very hard, some white quartz stringers.
169-188	Pegmatite, very hard, white water. Total of 15 gpm at 188'.
188-200	Granodiorite, black and white, slightly fractured.
200-208	Pegmatite. Total of 16 gpm at 200'.
208-243	Gneiss, quartz-biotite, with some pegmatite and green rock. Slightly fractured.

Ca44-4 (continued)

Depth	Lithology and Hydrology
243-303	Gneiss, quartz-biotite, gray, very hard for the most part. Fractured rock: 250'; 268'; 273'; 280'. Total of 19 gpm at 263'.
303-403.5	Gneiss, quartz-biotite,gray, very hard, with thin pegmatite stringers at 306', 310', and 380'. Fractured zone: 380-382'. Total of 30 gpm at 383'.
	Total of 30 gpm at 403.5'. Very rapid recovery.

DESCRIPTIVE LOG

DGS No. Ca44-5 Drilling Method Air Hammer Date Drilled 6/19-20/73

Local No. Project Newark Logged by J. Talley

Depth	Lithology and Hydrology
0-16	Topsoil and schist, micaceous, decomposed, brown, and wet.
16-44	Schist, gray, medium hard.
44-120	Schist, micaceous, gray with some black and green, moderately hard. Slightly fractured at: 65-70', 1-2 gpm; 76-77'; 80-83'; 91'; 105'; 114'. Installed 45.5' of 6" dia. steel casing.
120-156	Schist and amphibolite?, black with very little quartz, hard. Interval contains thin zones of green fractured rock with pyrite at 133' and 137-139'.
156-180	Schist, micaceous, gray, with some zones of pegmatite, black rock, and green rock. Fractured rock: 156'; 167' -5 gpm.
180-195	Gneiss and schist, micaceous, gray and green with thin pegmatite stringers. Green rock is slightly fractured but yielded no water.
195-280	Gneiss and schist, gray, black, hard, with stringers of black rock (much mica-little quartz) and pegmatite. Fractured rock: 234-236'; 245-250' -picked up 4 gpm, green water; 261-263'; 267-275'. Black rock dominates from 250-270'.
280-330	Schist, micaceous, gray and green, medium hard with many soft zones and stringers of black rock. Fractured rock: 297'; 301'.

Ca44-5 (continued)

Depth	Lithology and Hydrology
330-440	Schist, micaceous, gray and white, moderately hard, with zones of quartzose rock, pegmatite, and black rock throughout interval. Some zones contain green rock. Fractured rock: 346-350' -total of 12 gpm. Quartzose rock: 350'; 363'; 369' (large mica); 372'; 439'.
	Total of 12 gpm at 440'.

DESCRIPTIVE LOG

DGS No. Ca45-39 Drilling Method Air Hammer Date Drilled 4/11-13/73

Local No. ______ Project Newark Logged by J.Talley

Depth	Lithology and Hydrology
0-15	Silt, clayey, brown, very moist.
15-50	Schist, micaceous, dark brown and gray, decomposed. Grades to a more competent rock with depth. Wet at 15'.
50-80	Schist, micaceous, gray, (structured saprolite). Picked up about 10 gpm according to driller.
80-157	Schist, micaceous, gray and black, dry. Installed 92' of casing. Cased off 10 gpm.
157-172	Schist, micaceous, gray and green with thin pegmatite stringers. Picked up 1-2 gpm at 157'.
172-212	Gneiss and schist, quartz-biotite, talcy, with stringers of pegmatite. Rock is densely fractured with smooth and mineralized surfaces. 172' 3-5 gpm 185' 30 gpm 189' 100 gpm 197' 150 gpm Water becomes light green in color at 207'. Hard drilling 210-212'.
212-215	Pegmatite, fractured, perhaps somewhat sandy. Lost water for a very brief period.
215-240	Schist, micaceous, talcy, gray and green, with stringers of pegmatite. Rock is moderately hard and does not appear to be fractured past 220'. Water yield increasing up to 217' -perhaps 200 gpm. Increase in yield probably due to well development. Gray water at 230'; green water at 235'. Fractured at 235' with small increase in yield.

Ca45-39 (continued)

Depth	Lithology and Hydrology
240-320	Schist and gneiss, hard, gray, with some green, some feldspar fragments. This section consists of rather hard rock with a few small fracture zones. Yield at 257 is about 250 gpm. Fractured zones 255-260' and 297-300'.
320-360	Schist, micaceous, gray, hard, some small pegmatite stringers. Cuttings are small and fine. Thin soft zone occurs about 337'.
	Major water bearing fracture zone occurs between 172' and 200'. Total yield at 360' is about 250 gpm.

DESCRIPTIVE LOG

DGS No. Cb12-10
Drilling Method Air Hammer
Date Drilled 9/25/73
Local No.
Project Newark
Logged by J. Talley

Depth	Lithology and Hydrology
0-4	Silt, clayey, brown.
4-19	Clayey silt and silty clay, tan brown, with boulders.
19-80	Sand, carbonate, with carbonate rock fragments, soft. Contains much micaceous material and perhaps lenses of decomposed schist. Many soft zones. Some water 20-30'.
80-105	Same as above, except that the material becomes harder and more competent with depth. Decrease in soft zones. 20 gpm at 105'. Installed 105' of 6" steel casing. 20 gpm cased off.
105-155	Carbonate rock, grayish-white, with traces of mica, medium hard to slightly soft. Returns have consistency of cement.
155-259	Carbonate rock, grayish-white to white, medium hard. Thin soft zones occur at: 161'; 170'; 174'; 182'; 184'; 188-190'; 205-210'; 214'; 219'; 223'; 226'; 241'; 250'. Rock generally becomes harder past 170'. Mica is very evident from 180-190'.
259-260	Carbonate rock, white and brown,with much mica (schist stringer?) and some pyrite.
260-344	Carbonate rock, grayish-white to white, hard, Soft zones: 265'; 267'; 270-275'; 278'-279'. 10 gpm at 285'.
344-346	Carbonate rock with many black specks.
346-410	Carbonate rock, white and grayish-white, medium hard, with intermittent soft zones.

Total yield at 410' is 10 gpm. Very slow recovery.

DESCRIPTIVE LOG

DGS No. Cb32-8 Drilling Method Air Hammer Date Drilled 6/14/73

Local No. ______ Project Newark Logged by J.Talley

Depth	Lithology and Hydrology
0-3	Topsoil and clayey silt.
3-35	Schist, micaceous, green and gray, soft and decomposed. Moist at 30', dry at 40'.
35-125	Schist, micaceous, gray, moderately hard with a few thin pegmatite stringers and some green rock fragments. Installed 51' of 5" dia. steel casing. Fractured rock zones: 75-80' -12 gpm; 83' -total of 18 gpm; 88-90' -total of 30 gpm; 91-97'; 106-110'; 120-124'. Total yield of 30 gpm at 125'.
125-210	Schist, micaceous, gray, moderately hard with soft zones, slightly fractured.
210-288	Gneiss, quartz-biotite, gray, hard, with thin zones of quartz, intermittently fractured. Fracture zones: 230-232'-100 gpm; 235-240'; 243-245'; 259-261'; 265-276.5'. Recovery very fast, well flows greater than 15 gpm.
288-388.5	Schist and gneiss, hard, gray, intermittently fractured. Note: Some additional water may have been picked up as air pressure gauge rose.

Total yield is 130 gpm+ at 388.5'.

Major water bearing fracture zones:
83-90'- 30 gpm
230-276- 100 gpm

DESCRIPTIVE LOG

DGS No. Cb32-9
Drilling Method Air Hammer
Date Drilled 6/21/73
Local No.
Project Newark
Logged by J. Talley

Depth	Lithology and Hydrology
0-5	Topsoil and silt, clayey.
5-18	Schist, micaceous, gray, soft, slightly decomposed.
18-150	Schist with minor gneiss, micaceous, gray, medium hard with many soft zones. Fractured rock: 104'-2-3 gpm; 107-110'; 118-123'. Soft zones: 131-133'; 137-139'. Installed 41.0' of 6" dia. steel casing.
150-178	Schist and gneiss, quartz-biotite, gray, densely fractured with much water. Fractured rock zones: 151'- 42 gpm total; 161-166'; 174'- 150-175 gpm total.
178-400	Schist, micaceous and garnetiferous, gray and green with thin zones of quartz and traces of pyrite. Intermittently fractured. Fractured rock: 213-215'; 314'; 320-325' picked up some water according to driller; 345-347'. Additional water probably was picked up below 200'; however, the amount was difficult to determine because of the limited air capacity on the drill machine.

Major water bearing fracture zone: 151-175'. Total final yield at 400' is 175-200 gpm.

DESCRIPTIVE LOG

DGS No. Cb32-10 Drilling Method Air Hammer Date Drilled 10/9-10/73
Local No. Project Newark Logged by J. Talley

Depth	Lithology and Hydrology
0-8	Silt and clay, brown.
8-13	Sand, silt, and gravel, brown, moist.
13-28	Schist, micaceous, gray and brown, weathered.
28-60	Schist, micaceous, gray, medium hard. Picked up 5 gpm at 28'. Installed 60' of 6" dia. steel casing.
60-93	Schist, very micaceous, black and gray with some green, very hard.
93-180	Schist, micaceous, gray, moderately hard, sometimes garnetiferous, with thin zones of green chloritic schist. Rock becomes more quartzose below 140'. 1-2 gpm at 168'.
180-187	Gneiss and schist, micaceous, mostly green, somewhat fractured. No water.
187-188	Pegmatite.
188-236	Schist, micaceous, black and gray, moderately hard, with stringers of pegmatite.
236-285	Schist, micaceous, soft (perhaps a faulted and/or weathered zone. Picked up 5 gpm at 258'.
285-368	Schist, micaceous, gray, moderately soft (very easy drilling), with thin zones of green rock. Drills like it is fractured but the cuttings are all chewed up and very micaceous. Some zones appear to contain weathered rock and clay.

Total yield at 368' is 5 gpm.

DESCRIPTIVE LOG

DGS No. Cb41-3
Drilling Method Air Rotary
Date Drilled 6/4-5/73
Local No.
Project Newark
Logged by J. Talley

Depth	Lithology and Hydrology
0-5	Top soil and clayey silt, brown and moist.
5-40	Schist, micaceous, brown and gray, decomposed. Rock becomes harder with depth. Installed 40.5' of 5" dia. casing.
40-70	Schist, micaceous, dark gray to black. Picked up about 2 gpm at 45'.
70-148	Schist, micaceous, gray to black, medium hard, with more quartz than above. Fractured rock at 70-74'; 106-108'; and 119' with no water.
148-160	Pegmatite and quartz, hard.
160-230	Schist, micaceous, dark gray to black, hard, with several fractured zones. Fractured rock at: 161-163'; 210'; 224' - 12 gpm; 235-237' -some additional water.
230-239	Schist, micaceous (muscovite), greenish. Yield increases to 15 gpm in this interval.
239-308	Schist, very micaceous, dark gray, medium to coarse grained. Fractured rock zones: 241'; 245'; 296'; 304'.
308-408	Schist, micaceous, dark gray, very hard to moderately hard. Fractured rock zones: 316' picked up 23 gpm; 325'; 327'; 330'; 334'; 340-345'; 348' -total of 43 gpm. 375'-picked up an additional 20 gpm.

Cb41-3 (continued)

Depth	Lithology and Hydrology
408-448.5	Schist, micaceous, dark gray, hard.

Major water bearing rock zones:

Depth	Amount	Total
224'	12 gpm	12 gpm
245'	6-8 gpm	20 gpm
316'	23 gpm	43 gpm
375'	20 gpm	60 gpm

DESCRIPTIVE LOG

DGS No. Cb41-10
Drilling Method Air Hammer
Date Drilled 10/1-3/73
Local No.
Project Newark
Logged by J. Talley

Depth	Lithology and Hydrology
0-7	Fill, paper, brickbats, wire, concrete, etc., probably from apartment construction.
7-12	Fill and soil, disturbed.
12-38	Schist, micaceous, soft and decomposed, becomes harder at 34'. Wet at 32'.
38-52	Schist and gneiss, quartz-biotite, medium hard to hard with thin stringers of quartz. 3 gpm at 45'; 4 gpm at 45.5'. Set 52' of 6" dia. steel casing. Water cased off.
52-103	Gneiss and schist, quartz-biotite, black and white, with thin stringers of pegmatite. Soft zone at 68'. Slightly fractured zones at 76' and 82'. No water.
103-178	Gneiss, quartz-biotite, medium hard to hard, with thin lenses of quartz and pegmatite. Some pyrite. Densely fractured with substantial quantities of water. Fractured zones:130' much water; 135'; 138'; 143' -more water and rusty; 144' -some blue-green rock; 148'; 153'-total of about 120 gpm; 155-156'; 162'; 165' -total of 150 gpm; 167-169'; 170-172'; 175'; 178'.
178-228	Gneiss, quartz-biotite, hard, black and white, some green rock and potash feldspar. Soft seams at 179-181'; 185'; 194'; 196-198'.
228-285	Gneiss, quartz-biotite, hard, black and white, some green rock and potash feldspar. Fractured rock or soft zones at: 248'; 250'; 253'; 258'; 266'; 269'; 273'; 279'. Yield at 260' is about 175-200 gpm.

Cb41-10 (continued)

Depth	Lithology and Hydrology
285-335	Schist and gneiss, quartz-biotite, soft to medium hard with few pegmatite or fractured rock zones.
	Major water bearing fracture zone: 130-178'.
	Total yield at 335' is 200gpm.

DESCRIPTIVE LOG

DGS No. Cb41-11 Drilling Method Air Hammer Date Drilled 3/8-11/74

Local No. ____ Project Newark Logged by J.Talley

Depth	Lithology and Hydrology
0-14	Gravel, sand, silt, clayey, brown and gray.
14-20	Schist, micaceous, gray and green, soft, with some pink feldspar fragments.
20-43	Schist, micaceous, gray, medium-hard, with thin pegmatite stringers. Alternating hard and soft zones. Picked up 15 gpm in schist and pegmatite 29-36'.
43-132	Schist, very micaceous, black and gray, medium-hard, with thin pegmatite stringers. Installed 45.5' of 6" dia. steel casing. 15 gpm cased off.
132-208	Schist and gneiss, micaceous, quartzose, black and white, medium-hard, pegmatite.
208-219	Pegmatite, abundant feldspar, hard.
219-226	Gneiss, micaceous, gray and green, slightly altered and fractured. Competent. No water.
226-238	Pegmatite, hard.
238-245	Gneiss, micaceous, green, slightly fractured and altered. Picked up 2 gpm.
245-280	Schist and gneiss, micaceous, black and gray, medium-hard, some white quartz.
280-300	Gneiss, micaceous, black and green, altered and slightly fractured, with pegmatite stringers.

Cb41-11 (continued)

Depth	Lithology and Hydrology
300-400	Schist, micaceous, black and gray, hard, some pegmatite stringers.
400-460	Schist and gneiss, micaceous, black and gray with zones of green, hard. Picked up 13 gpm in this interval.
	Total final yield at 460' is about 15 gpm.