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COMMONWEALTH OF VIRGINIA

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

Bulletin 41

Preliminary Report on Ground-Water Resources of Northern Virginia

BY

R. C. CADY

PREPARED IN COOPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

UNIVERSITY, VIRGINIA

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STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA

VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VIRGINIA, January 10, 1933.

To the State Commission on Conservation and Development:

GENTLEMEN:

I have the honor to transmit and to recommend for publication as Bulletin 41 of the Virginia Geological Survey series of reports the manuscript and illustrations of a *Preliminary Report on Ground-water Resources of Northern Virginia,* by Mr. R. C. Cady of the United States Geological Survey.

This report is one of a series being prepared in cooperation with the United States Geological Survey on the ground-water resources of Virginia. It discusses ground water in the northern counties, including Arlington, Fairfax, Prince William, Loudoun, Clarke, and Frederick. In it are summarized the occurrence of ground water in the different types of rocks and the water-bearing properties of the individual formations.

As the amount and distribution of available underground water supplies depend upon geologic conditions, this report should be of particular value to residents in the northern part of the State in aiding them to obtain water supplies from wells.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
State Commission on Conservation and Development,
Richmond, Virginia, January 20, 1933.
R. A. GILLIAM, *Executive Secretary and Treasurer.*

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Preliminary Report on Ground-Water Resources of Northern Virginia

By R. C. Cady

INTRODUCTION

The area covered by this report consists of a tier of six counties which extends across the northern part of Virginia from the West Virginia boundary to the District of Columbia and comprises an aggregate of 1,917 square miles. (See Pl. 1.) From west to east the counties are Frederick, Clarke, Loudoun, Prince William, Fairfax, and Arlington.

This is the first unit area to be covered in a systematic investigation of the underground water resources of Virginia which has been undertaken as a result of a cooperative agreement between the State and Federal Geological Surveys. The investigation was begun by the writer in July, 1931, under the direction of O. E. Meinzer, geologist in charge of the division of ground water, in the United States Geological Survey. The present report is a preliminary one describing the general ground-water conditions. The records of about 1,300 wells that were obtained in the field work and 60 chemical analyses of samples of water collected from representative wells have been released in manuscript form and can be consulted by interested persons, in the office of the United States Geological Survey, Washington, D. C., or in the office of the Virginia Geological Survey, Charlottesville, Virginia. A final report is to be published containing these records and analyses, together with a more detailed discussion of the quantity and quality of the water supplies that can be obtained from wells in the several geologic formations that underlie the area and the best methods of developing these supplies.

The geologic map (Pl. 1) accompanying this report is based mainly upon the geologic map of Virginia published in 1928 by the Virginia Geological Survey and upon the published and unpublished work of Miss A. I. Jonas in the Piedmont region, but the part covering the Shenandoah Valley is based largely on the map resulting from the recent detailed studies of Charles Butts,[1] and the part covering the Triassic area is based largely on the published map of Joseph K. Roberts.[2]

The hydrologic information was obtained in the field by the writer during the summer and early autumn of 1931. Personal observations,

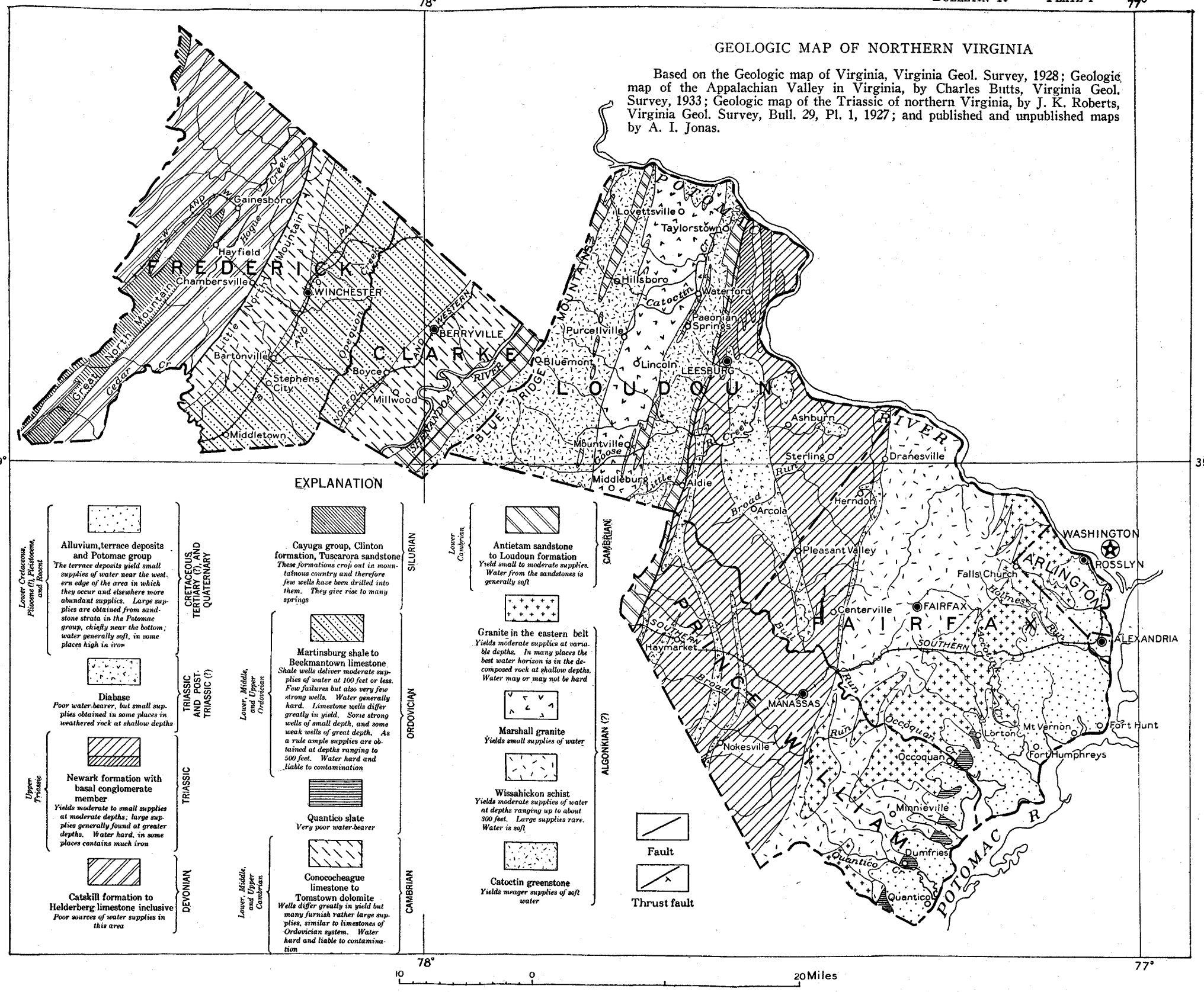
[1] Geologic map of the Appalachian Valley in Virginia, Virginia Geol. Survey, 1933.
[2] Roberts, J. K., Geology of the Virginia Triassic: Virginia Geol. Survey Bull. 29, Pl. 1, 1928.

interviews with the owners of wells and springs, and discussions with well drillers and municipal and corporation officials yielded the data concerning the ground-water conditions of the area upon which this report is based. Much of the information obtained from well owners and drillers was given from memory, and some of it is doubtless inaccurate. Most of the wells in regard to which information was obtained are household wells. When such a well is drilled only a small water supply is desired, and when enough water is obtained the drilling is generally stopped, no effort being made to develop the maximum possible supply. Moreover, strong wells are generally not tested to their maximum capacity. On the other hand, the yield of the wells is not always accurately measured by the drillers and is probably often overestimated. With the above facts in mind, the writer has summarized the information obtained and has interpreted it to the best of his ability on the basis of his studies of the structure, texture, and water-bearing properties of the rock formations.

The water samples were collected by the writer in the course of the field work and were analyzed by S. K. Love in the water-resources laboratory of the United States Geological Survey.

GEOLOGIC MAP OF NORTHERN VIRGINIA

Based on the Geologic map of Virginia, Virginia Geol. Survey, 1928; Geologic map of the Appalachian Valley in Virginia, by Charles Butts, Virginia Geol. Survey, 1933; Geologic map of the Triassic of northern Virginia, by J. K. Roberts, Virginia Geol. Survey, Bull. 29, Pl. 1, 1927; and published and unpublished maps by A. I. Jonas.



GEOMORPHOLOGY

Valley and Ridge province.—Frederick County and most of Clarke County lie in the Valley and Ridge province, which includes all of that part of northern Virginia west of the Blue Ridge. The sandstones, shales, and limestones of Paleozoic age that underlie the province were folded into synclines and anticlines (Figs. 1 and 2), which subsequently were beveled by long-continuous erosion to form a nearly level lowland. This lowland was then elevated in successive steps and was further eroded. The less resistant rocks, such as the shales and limestones, were the most extensively weathered and eroded and hence form the present valley areas. The more resistant rocks, such as the sandstones, were less weathered and eroded and hence form the present ridges.

During the erosion of the rocks of this province, most of the streams courses became so modified by the distribution of hard and soft rocks that they acquired linear patterns. Some streams in the area were not so modified, Cedar Creek being the most noteworthy example, for it cuts through Little North Mountain in a water gap. Gap Run has breached the same ridge near Chambersville, Frederick County. At Cedar Grove and Green Spring there are smaller water gaps. The three examples last mentioned appear to be streams that were once tributary to Opequon Creek but have been captured by headwaters of Back Creek.

Little North Mountain extends northeastward through Frederick County and is the first ridge on the west to rise above the lowland that lies immediately west of the Blue Ridge—the Shenandoah Valley, which is developed upon easily eroded and weathered shales and limestones. West of Little North Mountain the terrane is underlain by some younger, more resistant rocks, such as shale and sandstone, than those east of it, and consequently that area is more mountainous than Shenandoah Valley.

To the most casual observer it is clear that the topography of this province has undergone a complex history. At several times the earth's crust has remained stable long enough for the processes of weathering and erosion to reduce the region to a more or less flat surface or peneplain. The streams, rejuvenated by an uplift of the land, then cut valleys into the old plain, and a new erosion cycle began. The periods of crustal stability and therefore of prolonged erosion have become shorter from the past to the present and each erosion cycle and peneplain has been less complete than the first one, whose remnants are called the summit peneplain.[3] During the oldest erosion cycle, a peneplain was developed by the streams in the whole Appalachian region, includ-

[3] Stose, G. W., Manganese deposits of the west foot of the Blue Ridge, Virginia: Virginia Geol. Survey Bull. 17, pp. 34-40, 1919.

ing the Piedmont province. The interstream divides were cut down largely to the common level, and hard as well as soft rocks were beveled. After a long time the whole region was uplifted with respect to sea level, and the streams became swifter and began to cut valleys into the old plain. When the uplift ceased, the streams cut down nearly to the base-level of erosion and then began, by lateral planation, to remove the interstream divides. The second interval was not long enough for the streams to destroy those portions of the old plain that were underlain by the more resistant rocks, and therefore the ridges of harder rock stood out above the newer plain. Great North Mountain, in Frederick County, presumably retains a remnant of the first or summit peneplain. Still another uplift caused the dissection of the second or upland peneplain, and it was almost completely destroyed except where it was preserved on more resistant rocks in the same manner as the summit peneplain but at a lower altitude. Thus the part of the Blue Ridge which stands 2,500 feet above sea level near Front Royal and portions of Little North Mountain at the same altitude are taken to be remnants of this upland peneplain. A still lower surface known as the intermediate peneplain, was developed and later partly destroyed after crustal uplift, and it is believed to be represented by certain knobs and spurs along the western face of the Blue Ridge and also by the summit of the Blue Ridge near Potomac River. During the next period of crustal quiescence the softer and more soluble rocks of the Shenandoah Valley were weathered and eroded into a broad, flat valley floor, and the valley-floor peneplain may still be seen on the accordant summits of the low hills in the valley at an altitude of about 600 feet. Below these summits is a terrace, developed along the main streams during the last erosion cycle before the present one. The streams have cut below this terrace and are now engaged in widening and deepening their channels, a task which they will continue until there is another disturbance of the base level of stream erosion.

Blue Ridge province.—In northern Virginia the Blue Ridge province is restricted to a single ridge of ancient, hard rock, the Blue Ridge proper. The altitude of the Blue Ridge decreases from south to north. The higher portion at the south represents an ancient erosion surface, the upland peneplain, and knobs, spurs, and coves along the flanks of the Blue Ridge, as well as the lower portion of the crest near Potomac River, are the remnants of the younger intermediate peneplain. Since the time of the summit or perhaps the upland peneplain the Blue Ridge has been a divide for all the streams in the area except Potomac River.

Piedmont province.—The Piedmont province is underlain by rocks differing widely in character, age, and origin. It is a moderately dissected surface extending from the Blue Ridge, on the west, to the

Coastal Plain, on the east, and sloping from an altitude of about 500 feet on its western edge to about 300 feet on its eastern edge. Its drainage is rather complex and in some places shows a remarkable independence of the character and structure of the underlying rocks.

Coastal Plain province.—The Coastal Plain province is underlain by comparatively recent, more or less unconsolidated and undeformed sediments. The landward limit of the province is marked by a belt of country that is commonly called the Fall Line, or Fall Zone, where the ancient rocks that form the land surface of the Piedmont province pass beneath the newer sediments of the Coastal Plain. In the Fall Zone the streams of the Piedmont province descend over rapids into gorges that lead out to the wide and sluggish courses characteristic of the Coastal Plain province. Many of the larger streams, including Potomac River, are estuarine to the Fall Zone. The Coastal Plain province has had a complex erosional and depositional history, during which the coast line has shifted widely in position. At each successive position a sea bench with a wave-cut scarp was formed, and when the sea receded this bench remained as dry land. Thus the surface of the province consists largely of a series of dissected ancient sea benches at successively higher levels in the landward direction. Late in the development of this province the sea level rose and drowned the lower parts of the stream systems, thus converting them into estuaries of very intricate outline.

OUTLINE OF ROCK FORMATIONS

The rocks of northern Virginia may be classified into four broad types, based upon the age and lithology of the formations—(1) the pre-Cambrian and early Paleozoic metamorphosed and deformed sediments and igneous rocks; (2) the less altered, folded Paleozoic sandstones, shales, and limestones of the Shenandoah Valley and the area west of Little North Mountain; (3) the comparatively undeformed Triassic conglomerates, sandstones, and shales with their associated bodies of intrusive and extrusive diabase; and (4) the unconsolidated or slightly consolidated undisturbed Cretaceous and younger sediments of the Coastal Plain. The stratigraphic succession is shown in Table 1.

TABLE 1.—*Geologic formations in northern Virginia*

AGE	GROUP AND FORMATIONS		THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Recent Pleistocene Pliocene (?)	Alluvium and terrace deposits		35±	Clay, loam, sand, gravel, and peat, cross-bedded and heterogeneous, characteristically yellowish. Gravel in a sandy matrix is common.	Recent alluvium, especially in the Potomac estuary, is a good water-bearer, but water may be of doubtful sanitary quality. The terrace deposits are a poor source of water.
Lower Cretaceous	Potomac group	Patapsco formation	0–100	Highly colored, variegated clay, interbedded with and grading into sand, sandy clay, and gravel. Arenaceous material in places indurated; sands usually cross-bedded; some of the clays dark with lignite.	Large supplies may be expected from deep, properly developed wells out from the western boundary of the Coastal Plain; nearer the border they are apt to be weak. Shallow wells usually weak. The water is generally but not everywhere soft. Soft water contains sodium carbonate as chief mineral constituent, and locally iron is present in sufficient quantities to limit the usefulness of the water.
		Patuxent formation	0–200	Prevailingly arenaceous with buff and light-colored sands characteristic, some coarse and some fine, arkosic in many places. Cross-bedding is the rule. Much of the sand is cemented with iron oxide. Red, drab and lignitic clay intercalated.	

TABLE 1.—*Geologic formations in northern Virginia—Continued*

AGE	GROUP AND FORMATIONS	THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Post-Triassic (?) and Upper Triassic	Diabase		Dikes, sills, and stocks of hard gray to greenish-black diabase. Exhibits spheroidal weathering near surface. Composed of plagioclase, pyroxene, olivine, and magnetite, and is wholly crystalline.	Poor water bearer. Best results obtained in weathered zone near surface. Many deep wells are failures. Very hard drilling. Water generally hard.
Upper Triassic	Newark formation	0–1,500	Red shale predominates, but gray, blue, black, and decolorized shales are included. Some parts are fissile, others massive mudstone.	Fair water bearer. The deeper the well, the greater the yield on the average, but care must be taken not to enter the rock floor beneath. Water generally hard.
			Red, gray, and yellow muddy sandstones of varying hardness due to unequal cementation; in places arkosic.	
			Conglomerate borders the northwestern boundary of northern Virginia Triassic basin. Rounded pebbles of limestone having either a white calcareous or a red ferruginous cement.	Fair water bearer down to 200 feet, almost dry below that depth. Water generally hard.

TABLE 1.—*Geologic formations in northern Virginia—Continued*

AGE	GROUP AND FORMATIONS	THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Upper Devonian	Catskill formation	2,000±	Red mudrock and red micaceous sandstone, with some gray, green, and yellow sandstone and shale.	Very poor water bearers. No data on deep wells, but those more than 100 feet deep yield no more, on the average, than those less than 100 feet deep.
	Jennings formation	4,250 (?)	Upper 2,500 feet consists of dark-bluish and green sandstone with some argillaceous and arenaceous shale. Weathers to rusty color. Lower 1,750 feet less sandy, and consists of olive-green, stiff siliceous shale with intercalated beds of green fine- and even-grained flagstone.	
Middle Devonian	Romney shale	1,350	Predominantly fissile black shale with bands of black argillaceous limestone; stiff, hackly olive-green mudrock, and beds of sandstone. Olive-green shale in some places fissile, in others compact, with lenses of black, knotty argillaceous limestone.	

TABLE 1.—*Geologic formations in northern Virginia—Continued*

AGE	GROUP AND FORMATIONS	THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Lower Devonian	Oriskany sandstone	200±	Gray to white and blue siliceous and calcareous sandstone and conglomerate.	Surprisingly poor results. Generally hard water.
	Helderberg limestone	500	Gray to dark-gray, somewhat cherty medium-bedded limestone; fine- to coarse-grained limestone, with beds of knotty, dark siliceous limestone and thin bedded laminated blue limestone.	Surprisingly poor for a limestone. Hard water.
Silurian	Cayuga group	1,050	Thin-bedded black limestone with soft gray calcareous shale which weathers yellow. White and red sandstone, alternating with laminated gray limestone. Red sandstone and much soft fissile yellow shale.	
	Clinton formation	50±	Ferruginous thin-bedded sandstone, buff fine-grained fissile shale, and gray and green shale. Lower half consists of pure-white quartzitic and conglomeratic sandstone grading downward into a dull-red thick-bedded ferruginous sandstone.	
	Tuscarora sandstone	400	Thick-bedded buff, firmly cemented quartzite.	

TABLE 1.—*Geologic formations in northern Virginia—Continued*

AGE	GROUP AND FORMATIONS		THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Upper Ordovician	Juniata formation		150	Red and some gray and green mudrock and red sandstone.	
	Oswego sandstone		200-300	Thick-bedded brownish speckled sandstone.	Martinsburg shale is a reliable, consistent source for shallow drilled wells. Unwise to drill deeper than 200 feet, and chances are poor of obtaining a large supply from a single well. Water likely to be poor and hard.
	Martinsburg shale		2,000-3,000	Yellow, greenish, dark-gray, and black carbonaceous and calcareous shale, with some arkosic sandstone and thin limestone beds. Mostly fissile but in part massive.	
Middle Ordovician	Chambersburg limestone		200–250	Dark compact nodular argillaceous limestone.	Good wells in these formations and in the Frederick limestone.[a] Depth of 400 feet a good place at which to stop drilling an unpromising well. Water generally hard. The Quantico slate[b] is a poor water bearer.
Lower Ordovician	Athens (?) limestone		100±	Shaly limestone with some dark even-bedded limestone.	
	Stones River group	Lenoir limestone	50	Black crystalline limestone containing black chert.	
		Mosheim limestone	50	Light dove-gray compact limestone.	
	Beekmantown limestone		2,500	Bluish fine-grained thick-bedded limestone, sparingly fossiliferous. In part somewhat cherty.	

[a] The Frederick limestone (probably of Chazy age) consists of blue, slaty crystalline limestone, which is brought to the surface by faulting north of Leesburg, Loudoun County.

[b] The Quantico slate (Ordovician) of Prince William County and the southeastern part of Fairfax County consists of blue slate with a conglomerate at the base and some interbedded rhyolite flows.

TABLE 1.—*Geologic formations in northern Virginia—Continued*

AGE	GROUP AND FORMATIONS	THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Upper Cambrian	Conococheague limestone	2,000±	Blue magnesium limestone with thin, contorted argillaceous laminae that weather slowly and stand out on the outcrops in a characteristic fashion. Contains intercalated beds of sandstone and dolomite, with oolitic and conglomeratic limestone.	Very good source of water, but gives erratic results for different localities. Water hard.
Middle Cambrian	Elbrook limestone	1,500±	Blue and gray argillaceous thin-bedded limestone and calcareous shale.	
.....?.....	Waynesboro formation	1,500-1,800	Characterized by red mudrock, mostly green shale, some calcareous flaggy sandstone, and dolomite.	Only one well in this formation; it shows a good yield and is only of moderate depth.
Lower Cambrian	Tomstown dolomite	1,200	Blue-gray to dark-gray coarse-grained thick-bedded dolomite with some beds of limestone.	Fair water bearer; wells less than 100 feet deep give largest yields. Water hard.
	Antietam sandstone	500	White to dull light-brown fossiliferous sandstone composed of well-worn grains of quartz.	Poor source of water; wells 100 to 200 feet deep seem to give best results.
	Harpers shale	800-2,000	Grades vertically into Antietam sandstone. Uniform textured dull bluish-gray sandy shale with a few beds of sandstone. Weathers to light greenish-gray.	

TABLE 1.—*Geologic formations in northern Virginia—Continued*

AGE	GROUP AND FORMATIONS	THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Lower Cambrian	Weverton sandstone	800	White to gray massive-bedded sandstone, composed of fine grains of water-worn quartz. Some fine conglomerate included.	Poor source of water; wells 100 to 200 feet deep seem to give best results.
	Loudoun formation	10-800	Dominantly a dark-gray fine-textured slate, with shale, sandstone, and conglomerate.	

TABLE 1.—*Geologic formations in northern Virginia—Continued*

AGE	GROUP AND FORMATIONS	THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Algonkian (?)	Granite of the eastern belt		Dark bluish-gray when fresh; rather fine and uniform texture; composed of quartz, plagioclase, muscovite, biotite, and subsidiary minerals. Exhibits locally well-marked planes of schistosity. A later, more massive facies shows some mineral parallelism, but not schistosity.	Poor water bearer. Best results seem to be found between 200 and 300 feet, but it is thought that at such depths the water is often of shallower origin. Lower limit of drilling should be 500 feet and preferably 300 feet. Water hard in many places
	Marshall granite		Light-gray, pink, and green granite and quartz monzonite injected by pegmatite with blue quartz. In places spotted with garnets. May be massive, gneissoid, or schistose, with considerable mineral alteration. Relations to granite of the eastern belt unknown.	Poor water bearer; an added yield of 5 gallons a minute for each 100 feet of depth seems to be the rule.
	Peters Creek quartzite		Quartzite and chlorite schist.	
	Wissahickon schist	1,000±	Finely crystalline, sparkling bluish-green schist, composed of chlorite, muscovite, and quartz in variable quantities and albite at certain horizons. Closely crumpled. Contains intercalated lava flows.	Fair water bearer. Scant data seem to indicate a sudden increase in yield below 300 feet, but there is a uniform yield from 100 to 300 feet. Generally good water.

TABLE 1.—*Geologic formations in northern Virginia—Continued*

AGE	GROUP AND FORMATIONS	THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Algonkian (?)	Catoctin greenstone	1,000±	Basalt flows altered to a crystalloblastic green amphibolite, containing remnants of feldspar, hornblende with some original pyroxene, secondary quartz, epidote, and chlorite. Occurs as a massive amygdaloidal as well as hornblende schist.	Poor water bearer; shallow wells seem to be as satisfactory as deep ones. Drilling very difficult. Water generally of excellent quality.
	White marble		White and crystalline.	Not many data. Seems to be only fair water bearer for a calcareous sediment.

GEOLOGIC HISTORY AND STRUCTURE

The geologic history of this area, in so far as it is recorded in the rocks, began in Algonkian (?) time, with the deposition of calcareous materials on the floor of a sea which invaded the western part of the present Piedmont province and perhaps the entire northern Virginia area. Later the sea apparently withdrew and a thick covering of basaltic lava was poured out over the calcareous deposits. Farther to the east, during the same or a subsequent invasion of the sea, a thick deposit of mud was laid down to form what is now the Wissahickon schist, and then it was covered by sand. After an unknown interval granitic magma invaded these sediments in both the eastern and western parts of the Piedmont region, perhaps contemporaneously, to form the Marshall granite and the granite of the eastern belt. A crustal disturbance began to exert tremendous compressive stresses in late pre-Cambrian time and the rocks of the Piedmont area were folded and metamorphosed. As a result of the intrusions and deformations the calcareous deposits were converted into the white marble, the lava flows into the Catoctin greenstone, the mud into the Wissahickon schist, and the sand into the Peters Creek quartzite. The deformation of the Piedmont region was followed by a long period of erosion, as a result of which the deep-seated granites were exposed.

The advent of the Cambrian period ushered in the long Paleozoic era, with almost unbroken marine sedimentation in at least parts of the area. The Lower Cambrian sediments were perhaps the most widespread, as they still occur in outcrops as far east as Bull Run Mountain, in Prince William County.

Most of the other Paleozoic formations were, however, apparently laid down only in the western part of the area. In general, the early Paleozoic deposits above the basal arenaceous deposits are limestones, dolomites, and calcareous shales, whereas the Martinsburg shale and higher formations are with a few exceptions dominantly clastic.

The variations in the sedimentation during the Paleozoic era were produced by only minor geographic changes. It was not until the end of that era that a radical change occurred—the Appalachian revolution. From the southeast came great compressive forces which crumpled the earth's crust, shortening its southeast-northwest dimension in the area affected by many miles, and built up great mountains out of the former sea bottom. The rocks of the Piedmont region were folded into a syncline in the eastern part, and into an arch known as the Catoctin-Blue Ridge anticlinorium farther to the west and further altered. Early in the deformation they were pushed bodily northwestward, along low-angle fault planes, over the younger sediments. One of the main overthrust faults lies at the western foot of the Blue Ridge. (See Pl. 1.)

The dominant structural feature of the Shenandoah Valley east of Little North Mountain is a large syncline, along the axis of which lies an outcrop of Martinsburg shale. The eastern limb of the syncline was partly overridden by the Blue Ridge overthrust mass, and the western limb is terminated by the trace of another overthrust fault along which the syncline itself moved northwestward. (See Pl. 1 and Fig. 3.) West of Little North Mountain is a large anticline with smaller folds near by. The axis of this anticline forms Great North Mountain.

The Appalachian revolution was followed by a long period of erosion during which the mountains were worn down, probably nearly to a plain. Then in the Triassic period an elongated basin began to form in the Piedmont area, and gravel, sand, and mud were deposited by the streams in this basin. During and after this sedimentation igneous material was intruded in the form of sills, dikes, and stocks of diabase and extruded as lava flows. In late Triassic or post-Triassic time the basin was broken into blocks by normal faults, and the western border was down-faulted about 500 feet or less,[4] forming the Catoctin border fault. Thus the Triassic sediments were depressed into the older rocks and were partly preserved from later erosion.

After the Triassic period there was still more erosion, with the development of extensive lowland plains. In early Cretaceous time the nonmarine Patuxent and Patapsco formations were laid down in the eastern part of the area. After their deposition there was probably no more sedimentation in this area until late in the Tertiary period or early in the Pleistocene epoch, when the high-level terrace deposits were laid down. Later in the Pleistocene epoch and in the Recent epoch other gravel deposits were spread over the older formations at lower levels in the eastern part of the area.

[4] Roberts, J. K., The geology of the Virginia Triassic: Virginia Geol. Survey Bull. 29, p. 77, 1928.

OCCURRENCE OF GROUND WATER IN RELATION TO ROCK STRUCTURE

Unconformities mark buried ancient land surfaces and imply the cessation of one period of sedimentation and the beginning of another, generally with an intervening period of erosion. There may or may not be a radical difference in the nature of the deposits in the two series of unconformable sedimentary rocks. Where there is not, the unconformity is of no particular interest in the discussion of ground water, but where there is, especially where there is also a discordance in the dip of the two series of beds, the unconformity must exert some influence upon the movement and disposition of the ground water. For instance, at many places in the Atlantic Coastal Plain the unconformity between the Cretaceous beds and the underlying ancient rocks repre-

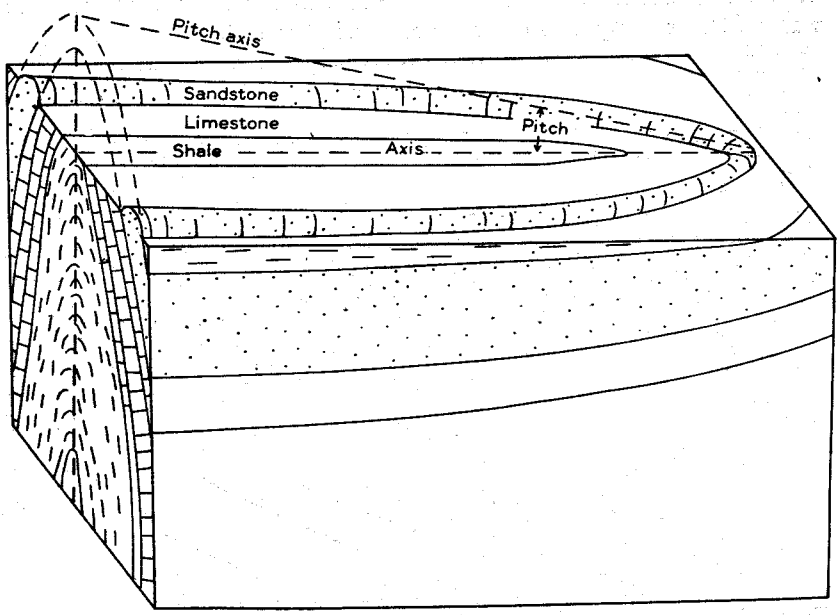


FIGURE 1.—Block diagram of an eroded pitching anticline. The beds of shale, limestone, and sandstone have been closely folded and beveled by streams and other agents. The weak rocks occupy a lowland surrounded by a ridge of resistant sandstone. The anticline pitches to the right, causing the outcrops of formations to disappear successively in that direction.

sents an excellent water horizon, and at the same time it generally marks the lower limit of large water supplies. An unconformity may be marked by a weathered zone, and in such a zone fractures, solution channels, and decomposed rock serve as good water-bearers. Valleys with alluvial fill in the buried ancient land surface may also serve as

excellent water conduits, whereas the ancient divides may be barren of water.

Anticlines, or up-folds, in the beds of rock, affect the ground water in two important respects: First, if the anticlinal axis plunges, artesian head may be developed along the axis (See Fig. 1.) Second, a good water-bearing formation may be brought to or near the surface along the axis of an anticline, whereas on the sides of the anticline this formation may be too deeply buried to be reached in drilling. The Cayuga group of limestones, the Helderberg limestone, and the Oriskany sandstone of the western part of Frederick County are near the surface on the limbs of anticlines, and they are more promising sources of water supplies than the overlying Devonian sediments or the underlying Silurian formations. A well may also tap the water-bearing bed at some point down the dip from the axis, and the water that has percolated from the outcrop down to the well may be less highly mineralized than the water farther away from any outcrop of that bed.

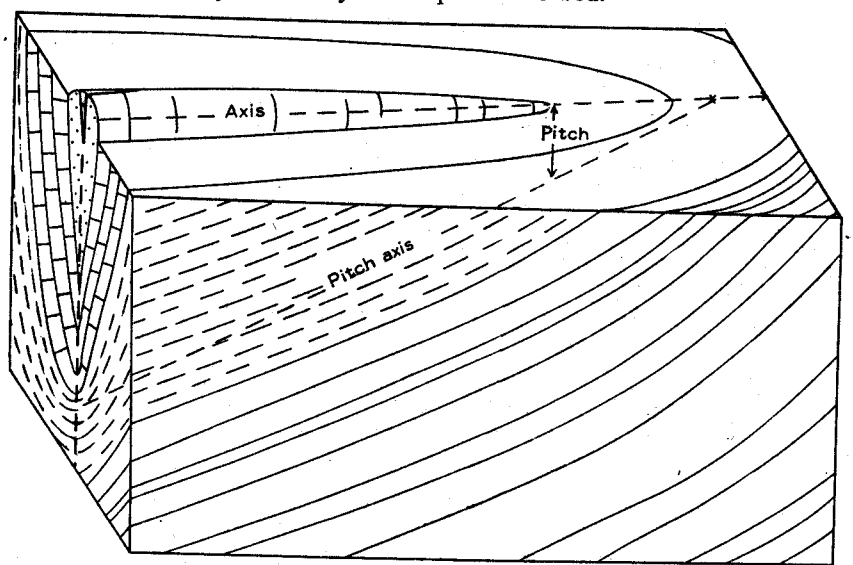


FIGURE 2.—Block diagram of an eroded pitching syncline. (Compare with Fig. 1.) The resistant sandstone forms a ridge in the lowland eroded on the surrounding weaker limestone and shale.

Synclines, or down-folds, are in general favorable to the development of artesian pressure, and if the water-bearing beds crop out in the limbs of the syncline at higher altitudes than the land surface nearer the axis, the conditions are favorable for obtaining flowing wells. (See Fig. 2.) On the other hand, a syncline may carry a water-bearing bed to such great depths as to make it unavailable for wells near the axis of the fold. If water percolates into the outcrop of a water-bearing

bed at a high level on one side of a syncline, it may be carried down the dip of the bed to a great depth, heated as a result of the high temperature prevailing at that depth, and thence carried up by artesian pressure to the opposite side, where it may be discharged as a warm spring at a level lower than the outcrop. The warm springs of central-western Virginia are, according to Reeves,[5] due to this condition.

Faults, or displacements of the rocks along fissures, may act in any of three ways to modify the disposition of ground water. A fault fissure may act as a conduit, especially if the rock which it cuts is brittle. Thus warm water or even hot water may be brought to the surface along faults from great depths. If the fault fissure is filled with gouge it may act as an impenetrable dam to store water on the upstream side, or the water may be dammed if the broken edge of the water-bearing bed is brought next to an impermeable bed by the faulting. A fault may displace a water-bearing bed so that it may be encountered in drilling at either a higher or a lower level than where it is expected, or it may cut out the bed entirely at the well site, or it may cause the bed to be encountered twice in the same well. In the northern Virginia area faults are comparatively rare, and so far as known there are no local examples of the effect of faults upon ground water. (See Fig. 3.)

Joints, fissures, and bedding planes may be efficient conduits for water, especially if they are near enough to the surface to be enlarged by weathering and solution. Joints and fissures are likely to decrease in size and number with depth, but bedding planes may remain channelways even at considerable depths. In beds of soluble rock, such as limestone, the structural features mentioned may be enlarged greatly by the solution of the walls, and a great maze of interconnected tunnels and galleries may carry large quantities of water, forming true underground streams and lakes.

In northern Virginia artesian conditions are best developed in the Coastal Plain, where flowing wells are obtained on the lowlands near sea level. The deposits underlying the Coastal Plain consist of alternating beds of sand, gravel, silt, and clay, which dip at low angles toward the east from their outcrop areas. The water-bearing sand and gravel generally contain water under some artesian pressure, owing to the confining effects of the less permeable clay beds above and below them. Water under artesian head is also encountered in some places in the Triassic rocks, especially in the western part of the Triassic basin, where the westward dip of the rocks is greatest.

[5] Reeves, Frank, Thermal springs of Virginia: Virginia Geol. Survey Bull. 36, pp. 28-35, 1932.

OCCURRENCE OF GROUND WATER IN RELATION TO THE PRINCIPAL TYPES OF ROCKS

Igneous rocks.—Intrusive igneous rocks do not contain interconnected pore spaces through which water may pass, but after earth stresses have acted upon them, they develop joints in two or more intersecting sets and in some places shear zones and faults. The joints are attacked by weathering and solution and consequently are most open near the surface. In addition, the joints become less numerous with depth. In such intrusive rocks ground water in economic quantities is generally found in the joints, and therefore the likelihood of obtaining a water supply from these rocks to depths of more than a few hundred feet is small. Shear zones and faults may yield water freely and go deeper than the joints, but they are found only in certain localities. A zone of weathered rock, most commonly very porous, at the base of the soil is generally promising as a source of water, and it is suspected that in many deep wells drilled in granitic rocks the chief supply of water comes from the weathered material.

Rocks formed of extrusive lava are extensively jointed and contain flow breccia, lava tunnels, and other large openings which are excellent water conduits and make this rock a superior water bearer. In the course of time these openings are generally obliterated by pressure, recrystallization, and other agencies, and hence lava rocks, such as the Catoctin greenstone, that were originally doubtless excellent water-bearing formations have become very unproductive.

Metamorphic rocks.—Contact metamorphism, whereby new material has been introduced into a rock, is usually detrimental to that rock's water capacity, because not only are its pore spaces filled with the new material, but replacement may destroy all the openings that might serve as channelways for water.

Regional metamorphism may increase the capacity of a rock for water, especially where a shale or an igneous rock is compressed into a schist. The incipient fracture planes so developed may become enlarged by weathering, so that large quantities of water may move through or be stored in them. A schist is usually rather soft and easy to drill. A slate behaves very similarly to a schist, in that the slaty cleavage provides excellent space for water when the cleavage planes are once opened up. A gneiss is not usually different from a granite in its water-bearing properties. When a limestone is changed into a marble the joints and solution channels are likely to be closed, but new openings of the same kind may later be developed in the marble. A quartzite is a very poor water-bearer unless it is fractured, and even then it may remain a poor source of water, because its relative insolubility

prevents much enlargement of its fractures by solution. It is also hard to drill.

Sedimentary rocks.—The clastic rocks, such as gravel, conglomerate, sand, sandstone, silt, clay, and shale, and their derivatives of mixed types, differ from one another in their water-bearing properties. Clean gravel, such as some of that encountered locally in the sediments of the Coastal Plain, is one of the best of water-bearing beds. Much gravel, however, has a matrix of silt or sand that diminishes its permeability to a greater or lesser extent. Conglomerate is generally a poorer source of water than gravel, owing to the cementation of the matrix. In cemented conglomerate the water must percolate through fractures, which may be rare, as in the limestone conglomerate of Triassic age in northern Virginia.

A well-sorted sand usually yields large quantities of water. In the Potomac group the chief water supplies are generally found in beds of sand. Sandstone, if the sand was clean and well sorted and has not been cemented too much, is also an excellent water-bearer. Much sandstone is jointed and bedded, and in such rock the joints and bedding planes add considerably to the space available for water. However, the Cambrian, Silurian, Devonian, and Triassic sandstones of northern Virginia are disappointingly poor water-bearers, because of the high degree of cementation and poor sorting. The Triassic sandstones contain much silt, which not only reduces the number of large pore spaces but also makes the rocks less brittle and hence less likely to fracture and produce joints under stress.

Clay is a poor source of water, because it consists of particles that are so small that the pore spaces between them hold the water by molecular attraction. The clays of the Potomac group yield practically no water. If the clay has become hardened into a shale, bedding planes, shaly partings, and joints may be numerous and more or less uniformly distributed, so that most shales are to be considered reliable sources of small water supplies. The Martinsburg shale is an example. Shallow wells in shale tend to survive drought better than similar wells in most other types of rock. The water in the shales of northern Virginia is usually rather highly mineralized. Mudstones like those in the Catskill formation, somewhat similar to shale lithologically but lacking the shaly partings, are usually very poor water-bearers.

Limestone is an erratic source of water. Its joints and bedding planes are enlarged by solution by water charged with carbon dioxide, probably above or immediately below the water table. When the solution channels become sufficiently widened, the water behaves like that in a surface stream. Where a large channel or underground stream is encountered by a well, an almost inexhaustible supply of water may be obtained. If a well misses the channels a dry hole may result. Many

of the channelways become filled with mud, and a well drilled into one of these mud-filled channelways may be a failure unless the mud can be cased off. The behavior of limestone wells during a drought often causes considerable difficulty, because they may go dry with no warning whatever in the nature of a gradual diminution of yield and because the water in most limestone fluctuates widely over periods of excessive and deficient rainfall. The water from limestone wells is usually hard, and it is also liable to pollution owing to the ease and rapidity with which the water moves through it and the lack of natural filtration.

WATER-BEARING PROPERTIES OF THE ROCK FORMATIONS

Pre-Cambrian white marble.—The white marble crops out in small linear areas in which it is exposed by the erosion of the overlying Catoctin greenstone at the crests of small, sharp anticlines, on the eastern limb of the Catoctin-Blue Ridge anticlinorium, in Loudoun County. The outcrops conform to a single axial line trending northeast by north about 1 mile east of the eastern boundary of the Marshall granite outcrop. The outcrops of the marble are too small to be shown on the map that accompanies this report.

Information was obtained from the drillers in regard to six domestic wells drilled into the white marble. These wells range in depth between 25 and 120 feet and average 68 feet. The reported yields range between a quarter of a gallon and 15 gallons a minute and average 8 gallons. The yields appear to be only slightly below normal for ordinary limestone wells. The open spaces in the ancient limestone may have been closed by recrystallization and rock flowage during its metamorphism into marble, and as the formation is buried beneath the Catoctin greenstone, the water may have had little opportunity to circulate and to dissolve large channelways. The analysis of a single sample of water from this formation shows a hardness of 116 parts per million.

Catoctin greenstone.—The Catoctin greenstone lies at the surface in two belts in Loudoun County. (See Pl. 1.) These belts form the western and eastern limbs of the Catoctin-Blue Ridge anticlinorium, bounded on the east by the Catoctin border fault and on the west by the overthrust fault at the western foot of the Blue Ridge. The rock is schistose in the eastern belt and more massive and dense in the western belt. It consists of successive lava flows which have been folded and extensively metamorphosed. The original openings have to a great extent been closed by metamorphism, but some small openings have been produced by the development of cleavage. Altogether the formation is massive and hard and is a poor water-bearer.

TABLE 2.—*Average yield of wells ending in Catoctin greenstone in relation to depth of wells*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	73	¼–30	4
101–200	14	2–30	6
201–300	3	¼– 7¼	4
301–704	3	1–12	6
	93	¼–30	4½

Information was obtained in regard to 93 wells with an average depth of 85 feet, that draw water from the Catoctin greenstone. The yields of these wells, as reported, range from about a quarter of a gallon to about 30 gallons a minute and average about 4½ gallons.

The available information indicates that if a well is unsuccessful in the first 200 to 300 feet, not much is generally gained by drilling deeper. Two of the 93 wells were reported to yield 30 gallons a minute. One of these is 31 feet and the other 188 feet deep. Eight wells were reported to yield between 10 and 20 gallons a minute, of which five are less than 100 feet deep, and the other three are 142, 170, and 350 feet deep. All the other wells in regard to which information was obtained were reported to yield 10 gallons a minute or less.

There are a few wells in the Catoctin greenstone that yield slight flows, but the artesian head does not carry the water far above the ground surface. Wells with a noticeable artesian pressure are rare in this formation, as the fractures are generally more or less vertical, preventing confinement of the water, and also the channelways are comparatively small, thus increasing the effect of friction.

Drilling into the formation is difficult. Bouldery weathering at the base of the soil zone tends to deflect the drill bit, and the formation itself is hard and tough rather than brittle. Where it is tilted a very hard layer tends to throw the bit off the vertical.

Analyses of four samples indicate that the water is generally of excellent quality, being soft and comparatively low in dissolved solids.

Wissahickon schist.—The Wissahickon schist crops out over a large area in Fairfax and Prince William counties. The western boundary of the outcrop passes through Dranesville, near Herndon, and about 3 miles east of Manassas. The eastern boundary is irregular. (See Pl. 1.) The tight folding of this formation is almost obscured by the later schistosity that transects the bedding. Near the surface weathering causes a leaching of the soluble material from the schist, and a skeleton of siliceous and clayey material and mica remains, preserving the structure where undisturbed. The soil under such conditions is rather porous. In the decomposed rock some distance below the surface the same condition of weathering prevails to a less complete degree. The rock itself is somewhat tight, and it is believed that as a rule the ground water is most abundant and is freest to move in this weathered zone. Farther down in the sound rock there are cavities, and they probably are more numerous, though generally smaller, than the joints in granite. At still greater depths the schistosity probably becomes incipient rather than actual. There are many quartz veins in the schist which were injected along the planes of foliation.

TABLE 3.—*Average yield of wells in the Wissahickon schist for each 100 feet of depth.*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	100	¼–35	9
101–200	42	2–70	12
201–300	2	3–60	37 {14, 60}
301–400	1		
	145	¼–70	10

The range in depth of the wells in the Wissahickon schist of which records were obtained is rather small, and only scant data are available concerning conditions below 300 feet. But considering the rather generous average yield of wells shallower than 100 feet and the rather slight increase in the average yield with additional depth—about 2 gallons a minute for each 100 feet down to 300 feet—it is probable that for ordinary household wells 100 feet or thereabouts is generally the most favorable depth to drill. Only about four wells in 130 obtain more than 30 gallons a minute, and three of them are between 120 and 160 feet in depth; therefore the chances of obtaining large yields are poor, and a series of shallow wells perhaps 100 to 200 feet deep should be considered the most feasible source of a large supply of water. This generalization should be emphasized, especially in view of the fact that the wells have rather consistently uniform yield.

Drilling in this formation is easy, for the rock is soft. It tends to be rough rather than brittle and does not fracture as easily as some types of rock, but this is a minor objection. The quartz veins are apt to deflect the bit when encountered at an angle.

Analyses of three samples from the Wissahickon schist indicate that the water is soft and low in dissolved mineral matter. It is therefore highly desirable for most uses.

Marshall granite.—The outcrop of the Marshall granite occupies the axis of the Catoctin-Blue Ridge anticlinorium, in a belt 6 miles wide at the north end of the district and 4 miles wide at the south end. Middleburg, Mountville, Lincoln, and Lovettsville are about on the median line of the outcrop. (See Pl. 1.) This granite intrudes the Catoctin greenstone and the white marble; outside of the area shown on the map it invades sediments held to be equivalent in age to the Wissahickon schist, thereby showing its age to be younger than the pre-Cambrian[6] sediments of the eastern part of the Piedmont province.

[6] Jonas, A. I., Oral communication.

The granite where massive is practically impermeable except for joints and other secondary fractures, but in places, chiefly toward the east side of the outcrop area, it is somewhat schistose, and in such rock, water is abundant, especially near the surface, where the planes of foliation are widened by weathering. The granite, taken as a whole, is a hard rock and a poor water-bearer, and the openings in which the water occurs decrease in number within the first few hundred feet of depth.

The available data are summarized below.

TABLE 4.—*Average yield of wells ending in the Marshall granite for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	64	½–20	4
101–200	23	0–30	9
201–300	4	4–41	16
301–400	4	8–35	21
401–500	1	12–40	26 {12, 40}
501–600	1		
	97	0–41	7

The deeper wells, those from 300 to 400 feet deep, deliver the largest yields. Below 400 feet the results are not uniform and hence probably too uncertain to warrant exceeding that depth. Down to 400 feet the wells show an increase of about 5 gallons a minute for each additional 100 feet of depth, and therefore the depth of drilling is to be determined by the importance of the extra 5 gallons a minute yield as weighed against the cost of drilling another 100 feet. The range in yield increases with the depth of wells down to 200 to 300 feet and then it begins to decrease. The maximum yield occurs between 200 and 300 feet. Anyone desiring more than 20 gallons a minute should plan on drilling more than one well, keeping in mind the fact that there is a definite possibility of a totally dry hole.

Drilling in the hard granite is difficult, and therefore expensive. The wear on the bits is rapid, and dressing the tool is a frequent interlude in the course of drilling. A likely source of water is probably to be found in the zone of decomposed rock below the soil, and the well casing should be driven into the rock in such a manner as to take full advantage of this possibility.

The water in the granite is of good quality for drinking and household use. The hardness in two samples analyzed averaged 121 parts per million, which is higher than the hardness of most waters from granite.

Granite of the eastern belt.—The granite of the eastern belt crops out along the eastern border of the Piedmont province in Arlington, Fairfax, and Prince William counties. On the west its contact with the Wissahickon schist is very irregular, with salients, outliers, and inliers, and on the east it is overlapped by the sediments of the Coastal Plain. (See Pl. 1.) The age relation of this granite to the Marshall granite is unknown; it may be older, contemporaneous with, or younger than the Marshall.

The granite is sheared and in some localities gneissoid and even schistose. Where it is more massive, it contains systems of joints, which intersect at rather uniform intervals. As the granite is in general massive, the formation as a whole is a poor water-bearer, although there are some wells of moderately high yield. Data on these wells are summarized below.

TABLE 5.—*Average yield of wells ending in the granite of the eastern belt for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	43	½–18	6
101–200	19	1–27	8
201–300	4	0–40	16
301–400	2	5–50	26
401–500	2		28
501–600	..		22 ..
601–700	..		..
701–800	2		7
	72	0–50	9

According to the above table there is a sudden increase in the average yield of wells between 200 and 300 feet and another between 300 and 500 feet. Below 500 feet the yields seem to decrease. Thus the most favorable depth, so far as the yield is concerned, seems to be in the zone 200 to 500 feet below the surface. However, as the number of wells listed in the table having a depth of more than 200 feet is small, it is probable that for ordinary uses wells not more than 300 feet deep are the safest; the maximum yield to be expected increases with depth, but the minima remain nearly constant at all depths. Where the need for water warrants the expenditure of more money, the limit of drilling might be set at 500 feet. There is an unknown factor in the above generalizations, and that is the possibility that much of the water yielded by the deeper wells was encountered in shallower zones. Such

FIGURE 3.—Structure section across Frederick and Clarke counties, Virginia. From the Geologic map of the Appalachian Valley in Virginia, by Charles Butts, 1933. Dck, Catskill formation; Db and Dch, Brallier shale and Chemung formation (together called Jennings formation in this report); Dr, Romney shale; Doh, Helderberg limestone and Oriskany sandstone; Scy, Cayuga group; Stc, Tuscarora sandstone and Clinton formation; Omb, Martinsburg shale; Oc, Chambersburg limestone; Oa, Athens shale (called Athens (?) limestone in this report); Olm, Stones River group; Ꝑb and Ꝑs, Beekmantown limestone; Ꝑc, Conococheague limestone; Ꞓe, Elbrook limestone; Ꞓr, Rome formation (called Waynesboro formation in this report); Ꞓs, Shady dolomite (called Tomstown dolomite in this report); Ꞓbq, Basal Cambrian quartzites; pꞒ, pre-Cambrian.

was the case, according to reliable reports, in the municipal wells at Falls Church, Fairfax County. The water was encountered in the zone of weathered rock below the soil, and although drilling was continued to a depth of about 300 feet, the yield was not increased to any appreciable degree. Until further and more detailed knowledge is available concerning the exact depth at which most wells in granite encounter their supplies, it may be wise to place the lower limit of drilling at the somewhat arbitrary depth of 300 feet.

Only 1 in 3 of the wells in the granite for which data are available delivers more than 10 gallons a minute, and only 1 in 11 delivers more than 20 gallons a minute, so that if a supply of 20 or even 10 gallons a minute is required, plans probably should be made for drilling more than one well. It should be kept in mind also that there is a chance of about 1 in 35 that a well will be a failure.

The granite is fairly difficult to drill, because of its hardness. Casing should be carried below the soil, of course, but an effort should be made to utilize the water that is so likely to occur in the zone of decomposed rock just below the soil.

The water in the granite may be very soft but is not soft everywhere. One deep well, owned by a laundry, delivered such hard water (hardness about 184 parts per million) that it was never used.

Loudoun formation, Weverton sandstone, Harpers shale and Antietam sandstone.—The Loudoun, Weverton, Harpers, and Antietam formations—all of early Cambrian age—are considered together for convenience. They crop out in Clarke, Loudoun, and Prince William counties. In Clarke County they are exposed along the western flank of the Blue Ridge and at its foot east of Shenandoah River. The overthrust fault along

which the Blue Ridge-Piedmont mass was pushed westward over the younger Paleozoic formations of the Valley and Ridge Province (see p. 16) cuts the outcrop of these formations. (See Pl. 1.) Hence the rocks west of the fault are in place, whereas the rocks east of the fault were carried westward on the overthrust mass into juxtaposition with them. (See Fig. 3.) In Loudoun County, the formations as a complete or incomplete group occur as narrow, infolded masses, aligned in a northeast by north direction. One of the larger masses lies about a mile west of Hillsboro and extends north to Potomac River, and three smaller areas are strung along the same axis, southwest by south, for a distance of 6 miles, passing about 2 miles east of Round Hill. Still another synclinal outcrop is on the same axis near the boundary of Fauquier and Loudoun counties, and it is almost continuous with the tip of another outcrop that lies almost wholly in Fauquier County. Three miles east of Middleburg a small spur of a large body in Fauquier County crosses northward into Loudoun County. Another outcrop extends from a point about 2 miles north of Mountville, southward for 5 miles toward Middleburg. Two miles east of this mass is another one, about twice as large, that covers the contact between the Catoctin greenstone and the Marshall granite. On the strike with this mass, near Paeonian Springs, is another one, 7 or 8 miles long and less than a mile wide. The largest outcrop is contiguous on the west with the Catoctin border fault between Leesburg and Potomac River, widening northward. There is a small break near Leesburg, and the mass continues southward to the Fauquier County line.

In Prince William County the Lower Cambrian formations crop out on the west side of the Catoctin border fault, at the boundary of Prince William and Fauquier counties.

These formations have been metamorphosed, probably to a great extent during the Appalachian revolution. The shale has in part been compressed into slate, and the sandstone changed into quartzite. The shale and slate, as in other similar formations, are not sources of copious ground water, but probably the quartzites are especially poor, except where they are brecciated. The formations as a whole show the greatest alteration toward the east; slate and schist have been derived from the fresher shales as seen near the Blue Ridge, and the sandstones have developed a cleavage near the eastern limits of the outcrop area.

The data for 21 wells, given in Table 6, show an average depth of 164 feet, with a range from 30 to 530 feet.

TABLE 6.—*Average yield of wells ending in the Lower Cambrian rocks for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	11	1–15	6
101–200	5	¼–15	6
201–300	1	3–16	5
301–400	3		10
401–500	..		..
501–600	1		5½
	21	¼—16	4

The average yield of wells 100 feet or more deep shows no increase over that of the wells less than 100 feet deep. Apparently the average yield scarcely increases below 200 feet. The chances that only 1 gallon a minute or even less will be obtained seem to be greater in the wells 100 feet or less in depth, and therefore it seems advisable to drill to 200 feet before considering an unpromising well a failure; but if an average quantity of water is obtained in the first 200 feet, the chances are uncertain that the yield will be augmented materially at greater depth. Considered as a whole, these Lower Cambrian rocks are poor sources of water. They contain shale and slate, which are generally poor sources, and beds of hard sandstone and quartzite which, unless highly shattered, probably would yield very little water. Quantities of more than 15 gallons a minute should not be expected in a single well.

The shale and slate are easy to drill, being soft but not brittle. The folded beds might tend to deflect the drill, but this has not been reported as a serious obstacle.

As slaty cleavage, fracture cleavage, and joints that cut through the bedding more or less vertically are prevalent in this group of rocks, artesian pressure is uncommon, in spite of the synclinal structure shown by the outcropping masses. Water levels 10 to 60 feet below the surface are reported (most of them the water levels at the time of drilling).

A single water sample from these sediments shows a hardness of 46 parts per million, and it is otherwise low in dissolved solids. It is possible that samples collected from some of the deeper wells in the slate or shale members would be mineralized more highly than the sample already tested.

Tomstown dolomite.—The Tomstown dolomite is exposed only in Clarke County in a belt about 1 mile wide along the foot of the Blue Ridge, and the outcrop is so disposed that Shenandoah River flows along its axis through much of the area under discussion.

The formation occupies the far edge of the syncline centered in eastern Frederick County, but of more immediate concern are the abundant small, sharply plunging folds superimposed upon the major structure. Joints are rather prominent on weathered outcrops, where solution has widened them.

There are seven wells that tap this formation concerning which data have been obtained. The average depth is 111 feet, with a range of 30 to 220 feet, and the reported yield averages 10 gallons a minute, ranging between 2 and 15 gallons a minute. The yield of wells less than 100 feet deep averages 13 gallons a minute and ranges between 8 and 15 gallons, whereas the yield of wells more than 100 feet deep averages 8 gallons a minute and ranges between 5 and 15 gallons.

These scanty data indicate a definite wakening of supply at depths greater than 100 feet, and it is therefore regarded as unwise to drill below 200 feet. The reason is, perhaps, that dolomite is not very soluble except at depths where water charged with carbon dioxide circulates rather vigorously. This generalization is by no means dogmatic, however, because wells of much greater depths conceivably might tend to exhibit, on the average, a reverse in the trend of the shallower wells and the yields at lower levels might become greater. The largest yield to be expected is problematic, but probably 15 gallons a minute would be an optimistic estimate.

The analysis of a single sample of water from the Tomstown dolomite shows a hardness of 268 parts per million and total dissolved solids of 292 parts per million. It is a typical calcium-magnesium bicarbonate water from dolomite, with somewhat less hardness than many waters from pure limestone.

Waynesboro formation.—The Waynesboro formation, like the Tomstown dolomite, is exposed only in Clarke County, and its outcrop is immediately west of the dolomite. The outcrop is about 2 miles wide at the south end, gradually narrows to 1½ miles midway to the West Virginia boundary, and widens to 2½ miles near Castleman's Ferry, as a result of secondary folding.

The formation is soft and shaly near the surface, but where less weathered it is a rather compact mudrock, apparently with few openings other than bedding planes, shaly partings, and a few joints.

The only well drilled into this formation concerning which data were obtained is 190 feet deep and is reported to yield 15 gallons a minute.

Elbrook and Conococheague limestones.—The Elbrook limestone crops out in Clarke County in a strip 1 mile or less wide, contiguous with the western boundary of the Waynesboro formation. In Frederick County it occupies a narrow belt along the eastern foot of Little North

Mountain. Its eastern boundary is a normal sedimentary contact with the Conococheague limestone; on the west it is separated from late Ordovician or Silurian sediments by an overthrust fault.

The exposure of the Conococheague limestone lies midway between Opequon Creek and Shenandoah River in Clarke County, striking northeast by north, and is approximately 2½ miles wide. Berryville and Millwood are on the outcrop, and Boyce is near the contact with the Beekmantown limestone. In Frederick County the outcrop lies immediately east of the Elbrook limestone. In the southern part of Frederick County it is about 1½ miles wide, but near Bartonsville it increases to 4 miles, owing to strong secondary folding, and it narrows gradually northeastward to 1½ miles at the West Virginia State line.

These limestone formations are synclinal in structure, but there are secondary folds which make the local recognition of the dominating structure difficult and, in fact, of rather less importance to the prospective seeker of a water supply. Near the surface joints have been greatly enlarged by solution, and to considerable distances below the surface large caverns and solution passages are likely to be found. According to Hall,[7] wells drilled into the Lower Ordovician limestone formations do not encounter large cavities in considerable numbers much below the level of Shenandoah River, except to the extent that the water table may have dropped below that level in periods of drought. The solution cavities are the outstanding features that affect the water-bearing properties of limestone, for the quantity of water delivered by channelways of other origins must, because of their small size, be far less. The presence or absence of large solution channels is often reflected in the incongruous results of near-by wells of similar depth drilled into the limestone. The position of the larger solution channels, although originally determined by joint systems, appears to be erratic.

The combined data of 95 wells in these formations are summarized in Table 7.

TABLE 7.—*Average yield of wells ending in the Elbrook and Conococheague limestones for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	26	1–50	17
101–200	45	½–30	11
201–300	17	½–90	19
301–400	7	1–30	11
	95	½–90	10

[7] Hall, G. M., Ground water in the Ordovician rocks near Woodstock, Virginia: U. S. Geol. Survey Water-Supply Paper 596, pp. 58-59, 1927.

One well between 700 and 800 feet deep yielded 1½ gallons a minute. The above summary is rather disappointingly uniform in that it shows no depth at which wells obtain outstandingly copious yields. The average yield of the wells does not vary by more than 8 gallons a minute. The reason for this may be a mechanical one. It is generally considered that the formation of solution channels in limestone goes on most actively above and immediately below the water table, where the water in the rocks is most highly charged with carbon dioxide and circulates most vigorously. The water table fluctuates vertically in response to rainfall, and the magnitude of the fluctuations increases away from the main streams, being greatest in the divides between streams and least at the stream channels. Therefore, the vertical dimension of the zone in which wells may encounter large solution channels and possibly obtain large yields, when the position of the water table is adjusted to "normal" rainfall conditions, increases out from the stream channels toward the divides. The application of this discussion to the wells in the Elbrook and Conococheague limestones is apparent when it is recalled that these formations crop out near the Shenandoah River, on the eastern limit of the major syncline, whereas the western limit of the syncline brings the formations to the surface 18 miles west of the river. In addition to the position with respect to the drainage, the western outcrop is in an area of higher altitude (500 feet above Shenandoah River) and of greater surface relief, which makes for still less uniformity in the depth at which the wells may encounter solution channels below the "normal" water table. The average yield of wells in these limestones in the western outcrop area is uniform to a depth of 400 feet (and there are no data of wells deeper than 400 feet in that area), but in the eastern outcrop area, the average yields decrease below 300 feet. Therefore, a well in the eastern area should stand the best chance of success at a depth less than 300 feet, whereas in the western area it is not known to what depth the favorable zone extends.

Only 1 out of 8 wells recorded here obtains more than 20 gallons a minute, and only 1 out of 24 obtains more than 30 gallons a minute. It is therefore proper to consider these probabilities in drilling for a definite quantity of water. A well on the eastern outcrop area, if it derives its water at a depth of 200 feet or more, probably will survive any drought that does not completely dry up Shenandoah River. In the western outcrop area the absolutely safe depth is probably somewhat greater.

Drilling in limestone is not difficult, although the high content of argillaceous material characterizing the Elbrook and Conococheague limestones makes for less brittleness under impact. The dip of the formations causes some difficulty, which, however, is not as serious as it would be in a less uniform and harder rock.

The water from these limestones is very hard, eight samples averaging about 380 parts per million. The taste characteristic of hard water is noticeable, and boilers, cooking utensils, and pipes tend to accumulate lime very rapidly. The water should be softened for industrial and public supplies.

Beekmantown limestone, Stones River group, Athens (?) limestone, and Chambersburg limestone.—The Beekmantown,, Stones River, Athens (?) and Chambersburg formations crop out on both limbs of the major syncline in Frederick and Clarke counties and lie immediately against the Martinsburg shale, both on the east and on the west. (See Pl. 1.) In addition to these limestones the Frederick limestone[8] is brought to the surface by faulting in the northwest corner of the Triassic basin, north of Leesburg, Loudoun County.

In the Shenandoah Valley these formations are folded into small, narrow, plunging anticlines and synclines in addition to the major structure. They are jointed and contain bedding planes, but the largest openings through which water may percolate in the zone of saturation are the solution channels.

The data of 93 wells in these limestones are tabulated below.

TABLE 8.—*Average yield of wells ending in the Beekmantown, Stones River, Frederick, Athens (?), and Chambersburg limestones for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	43	¼–33	10
101–200	35	1–75	14
201–300	10	1–16	6
301–400	2	12–32	24
401–500	..	.....	..
501–600	2	2–16	9
1,401–1,500	1	.....	150
	93	0–150	13

The permanent weakening with depth of the wells in these limestone formations does not seem to take place until a depth of 400 feet is reached, although there appears to be a slight decrease between 200 and 300 feet. One well between 300 and 400 feet in the Beekmantown limestone near Winchester encountered an opening 1½ feet in diameter at the bottom. Just how common these openings are below 300 feet is unknown, but it is likely that household wells should make use of the favorable zone less than 200 feet in depth. If a suitable supply is not

[8] The Frederick limestone, probably of Chazy age, is blue, slaty, crystalline limestone.

encountered in that zone, drilling another 200 feet should bring in water, but if not, the hole probably should be abandoned. It is still more difficult to lay down any rules about obtaining a given large quantity (say 100 gallons a minute or more), because the well at the Winchester Woolen Mills, which was put down to a depth of 1,432 feet, encountered large water-bearing channels between 1,100 and 1,200 feet, according to W. J. Gochenour, the driller, but none below that. It is possible that the openings in the rock were originally faults. The data above given seem to indicate a weakening of wells below 400 feet, and it is probable that unless there is unusual necessity for water, drilling should not be carried below that depth. At the same time, the decreased yields between 200 and 300 feet should be kept in mind.

Only 1 well in 2 of those tabulated above obtains a yield exceeding 20 gallons a minute, and many of them deliver less than 10 gallons a minute. Therefore the cheapest source of a large quantity of water probably would be a series of 200-foot wells.

The water in these formations, as in the Upper Cambrian limestones, is very hard, averaging 370 parts per million for five samples.

Quantico slate, Martinsburg shale, and Oswego sandstone.—The western boundary of the Martinsburg shale south of Winchester, Frederick County, coincides roughly with the Baltimore and Ohio Railroad, and north of Winchester it follows the Pennsylvania Railroad to the West Virginia line. The eastern boundary of the outcrop is marked approximately by Opequon Creek.

The Martinsburg shale is rather tightly folded, especially at the north end of the outcrop area, near the West Virginia boundary, into a major syncline upon which a large number of small folds are superimposed. In addition to the folds, cleavage cuts across the bedding and in places almost obscures it. The cleavage is very well marked on weathered outcrops, but where the shale is harder and more massive, the bedding is the more noticeable.

The Quantico slate, of Ordovician age, occupies the axis of a syncline, crossing the southern boundary of Prince William County just east of the Fall Zone, and extending along it in a strip about 2 miles wide as far as Lorton, Fairfax County, where it goes under the sediments of the Coastal Plain. This slate is a "soft, caving rock," and fissile, having a well-defined cleavage which crosscuts the bedding.

The Oswego sandstone is not important as a source of water because of its small outcrop area, and no information as to wells in it was obtained.

The data of wells in the shale and slate are summarized below.

TABLE 9.—*Average yield of wells ending in the Martinsburg shale for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	31	½–30	10
101–200	8	1–50	11
201–300	2	8–30	19
	41	½–50	11

TABLE 10.—*Average yield of wells ending in the Quantico slate for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	4	1½–5	3
101–200	2	¼–7	4
301–400	1	.....	1
	7	¼–7	2½

The Martinsburg shale is capable of delivering fairly small but rather reliable supplies of water from wells of small to moderate depth. Wells less than 100 feet deep are as satisfactory on the average as those 100 to 200 feet deep. The yield of two wells deeper than 200 feet is greater than that of the wells less than 200 feet, and this, perhaps, should be expected, as the slaty cleavage of this formation is not confined to the zone near the surface and therefore water should be encountered for considerable depths. It is doubtless true, however, that the yields are greater on the whole in the shallower zone of weathering than at extremely great depths, and that supplies of more than 20 gallons a minute should be sought by drilling more than one shallow well rather than a single deep one. In the Martinsburg shale an average yield of wells is a rather significant figure compared to that in a limestone, for instance, because in the long run the results of drilling in the shale are very consistent.

The wells in the Quantico slate for which data are available are very weak. Slightly better results seem to be obtained in wells less than 200 feet deep than in those more than 200 feet.

Both formations are soft and easy to drill, although they tend to compact rather than fracture like more brittle rocks. As they are fairly uniform in hardness and texture, there is less trouble in the drilling of tilted beds through deflection of the bit than in many other types of rock.

Three samples from the Quantico slate show an average hardness of 130 parts per million, and two samples from the Martinsburg shale had a hardness of 438 and 669 parts per million, with comparatively large quantities of sulphate and chloride.

Juniata formation, Tuscarora sandstone, Clinton formation and Cayuga group.—The Juniata, Tuscarora, Clinton, and Cayuga formations crop out in the mountainous area of western Frederick County. Because of its superior resistance the Tuscarora sandstone crops out in anticlines that stand out as ridges. Thus the Tuscarora sandstone and the overlying Clinton formation and Cayuga group of limestones are exposed where there are but few if any wells, and nothing is known of their water-bearing properties. The Juniata formation has so small an outcrop area that no data of wells in it are available. Because these formations are similar to others whose water-bearing properties are known, however, a few guesses may be made as to their possibilities as sources of water. As they occur on mountains, the water table in them would probably be subject to rather great fluctuations in response to rainfall. Probably the water in the Juniata formation would be rather scanty, owing to the silty but massive nature of the rock; the Tuscarora sandstone, really a quartzite in this area, would probably be dry except where highly shattered; the Clinton formation would probably be a lean water bearer in the shaly portion near the top, and the lower quartzite members would be very hard and very poor as sources of water. The Cayuga limestones probably do not differ materially from the other limestones of the region and should yield good quantities of water.

Helderberg limestone.—The Helderberg limestone crops out in three localities, all in Frederick County. Along the faulted area at Little North Mountain it occupies a narrow, irregular and interrupted belt. A better-developed exposure occupies the eastern slope of Great North Mountain, swings around the north end, and continues along the western flank. A small area cuts northeastward across the extreme northwest corner of the county.

As data for only five wells are at hand, the usual summary will be omitted, and the data merely set forth.

TABLE 11.—*Yield of wells ending in the Helderberg limestone*

WELL NUMBER	DEPTH (FEET)	YIELD (GALLONS A MINUTE)
31	100	10
43	195	3
53	160	3
60	80	1
92	104	10
Average	128	5

These wells do not show such good results as those in many other limestones farther east. It may be that the isolated limestone outcrop is not acted upon by such vigorously circulating water as the broad limestone terranes. It is also possible that the wells have merely failed to encounter large cavities that nevertheless may exist in this limestone.

No water samples from this formation were analyzed chemically, but it is probable that the water is hard.

Oriskany sandstone.—The Oriskany formation crops out immediately west of the Helderberg limestone at Little North Mountain, down the slope from it at Great North Mountain, and east of it in the northwest corner of Frederick County. It is only about 200 feet or less thick and therefore where tilted steeply its outcrop is very narrow. The three wells in the Oriskany sandstone concerning which data are available are tabulated below.

TABLE 12.—*Yield of wells ending in the Oriskany sandstone*

WELL NUMBER	DEPTH (FEET)	YIELD (GALLONS A MINUTE)
36	118	1
38	130	6
47	142	8

Here again it is difficult to understand why a formation which in many places is an excellent water bearer should yield such small supplies. More abundant data perhaps would show better results.

A water sample taken from a well which ended in the Oriskany sandstone but which had passed through the overlying Romney shale was analyzed. It showed a hardness of 253 parts per million—a result, partly at least, of the calcareous cementing material in the sandstone.

Romney shale, Jennings formation, and Catskill formation.—The Romney, Jennings, and Catskill formations constitute the bedrock under the lowlands west of Little North Mountain and east, north, and northwest of Great North Mountain.

The formations are made up chiefly of arenaceous shale and mudstone, with limy material in the Romney shale and predominatingly mudrock and sandstone at the top in the Catskill. They are folded into synclines and anticlines, and are jointed but not otherwise altered to any great extent by the Appalachian deformation. The Jennings formation, composed mainly of siliceous shale and sandstone, with minor amounts of sandy mudrock in the upper 2,000 feet is jointed finely, so that the beds appear to be made up of brick-shaped fragments.

The data of 100 wells in these formations are summarized as follows:

TABLE 13.—*Average yield of wells ending in the Romney shale, Jennings formation, and Catskill formation for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	82	0–16	5
101–200	18	½–16	5
	100	0–16	5

The wells in these formations are very weak, and the depth to which they are drilled seems to make very little difference in the yield, although the wells delivering from 10 to 16 gallons a minute average slightly deeper than those delivering less than 10 gallons a minute. It is probable, in the light of this fact, that the water circulates mainly through bedding planes and joints, which are small. The reason why most of the wells are shallow is not definitely known, but probably it is because of the expense of drilling deeper for larger supplies that are not absolutely necessary. It is unfortunate that no records of deep wells in the outcrop area of these formations are available, for in other regions the Catskill formation, especially, is a fairly good source of water. Some flowing wells are reported in the outcrop areas of these formations, but the artesian head does not extend much above the surface of the ground.

Five water samples from these formations show an average hardness of 189 parts per million, the Romney shale having the hardest water. In the Romney shale and Jennings formation much of the water has the odor of hydrogen sulphide.

Newark formation and associated diabase.—The eastern boundary of the Upper Triassic (Newark) sediments is a sedimentary contact which extends almost north and south from the northwest corner of Fairfax County through Dranesville, a mile east of Herndon and Center-

ville, crosses into Prince William County at a point northeast of Manassas, passes 2 miles east of Manassas, and swings southwest by south to the boundary of Stafford County. The western boundary is the Catoctin border fault, which trends northeast by north through Loudoun County, 2 miles west of Leesburg, and the western extremity of Prince William County.

Three separate and parallel belts of the border conglomerate of the Newark formation lie in the territory between Leesburg and Potomac River, in Loudoun County. The outcrops are faulted and dip steeply westward toward the border fault. Widely spaced joints cut the formation.

TABLE 14.—*Average yield of wells ending in the border conglomerate of the Newark formation for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	20	½–20	9
101–200	10	0–50	9
201–300	1	.....	½
301–400	1	.....	(?)
	32	0–50	9

Although the yields of wells between 100 and 200 feet in depth average the same as those of wells less than 100 feet, the yields of 10 to 20 gallons a minute are obtained from wells that are shallower on the average than those which yield less than 10 gallons a minute. It seems likely that below some depth (indefinite through lack of data) the joints and solution channels diminish in size and number.

Potomac River is the permanent control of the water table, and it is doubtful if the ground water should sink below the river bed even in long periods of diminished rainfall, for it is known that the course of the river is a very ancient one. If it is agreed that solution of limestone does not proceed noticeably below the water table under ordinary conditions, then it would be expected that the solution of joints in the limestone conglomerate would be practically negligible below the Potomac River level, and therefore wells in the conglomerate below a depth of say 200 feet would suffer a diminishing chance of obtaining good supplies.

A single sample from the border conglomerate was a typical calcium carbonate water with a hardness of 186 parts per million. The water is, however, softer than most limestone waters in the Shenandoah Valley.

The Newark sediments dip westward with a monoclinal structure toward the downfaulted edge of the Triassic basin, and as their surface outcrop has been beveled by erosion their thickness increases westward. Faulting within the basin has cut the sediments into tilted blocks, whose boundaries, owing to the lack of horizon-marking beds, are very obscure. Joints break the rocks chiefly in one direction, parallel to the strike of the beds, and two other systems are less well developed.

The summarized data of 318 wells in the sandstone and shale follow:

TABLE 15.—*Average yield of wells ending in the Newark sediments above the border conglomerate for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	198	0–55	4
101–200	108	½–50	7
201–300	9	½–55	27 {15
301–400	..	.....	..
401–500	1	.....	50
501–600	2	27–120	73
	318	0–120	7

There is a marked increase in yield with greater depth, probably because the bedding planes and porous beds of only moderately consolidated sandstone are original and do not decrease in number and efficiency as water bearers, like the joints in granite, which are secondary features, or the solution channels in limestone, which are probably controlled by the position of the water table. Therefore the yield of a deep well in the Triassic basin represents usually the combined contribution of beds and bedding planes and joints from the top of the well to the bottom. Drilling should not pass into the rock basement below the sediments, for it is probably dry. The chances of obtaining more than 10 gallons a minute from a single well less than 200 feet deep in the sandstone and shale are poor and those of getting more than 20 gallons a minute are negligible.

There is some indication that the water is likely to lie above trap sheets, with an unsaturated zone immediately below—or if the zone is saturated, the water is under diminished head. Where such water is encountered care should be taken not to puncture the trap sheet, lest the water pass down and be lost.

There is some artesian head locally in the sandstone and shale, especially in the western part of the basin, where the dips are steepest. The wells that flow must be pumped, however, if the water is to be lifted

above the surface of the ground, or if the quantity of water desired is at all large, for the weak head causes only a mere trickle to issue from the well.

Drilling through the sandstone and shale is usually easy. The shales are soft, and the sandstone, in many places poorly consolidated, crumbles easily under impact.

The hardness of the water of six samples from sandstone and shale ranges from 125 to 250 parts per million, some of the water being harder than many limestone waters. Silica and iron are noticeable in some samples, especially the iron, which makes the water unfit for boiler or laundry work and even gives trouble when the water is used for cooking and in household water systems. The water is decidedly poor for most industrial uses other than cooling.

Diabase or trap.—The diabase or trap associated with the Newark sediments crops out in several bodies of varying size and form. (See Pl. 1.) The trap bodies have been injected as sills between the bedding planes of the sandstone and shale, as dikes into fractures that crosscut the bedding, and in the form of irregular masses known as stocks. In addition some were extruded as lava flows. Below the zone of surface weathering this massive, dense rock has but few open spaces through which water may percolate except faults and joints, which are not numerous. Near the surface, however, the rock weathers into rectangular fragments grading toward the surface into spheroidal masses and then into soil containing isolated masses. In this zone most of the ground water is to be found.

TABLE 16.—*Average yield of wells ending in the Newark trap for each 100 feet of depth*

Depth (Feet)	Number of Wells	Yield (Gallons a Minute)	
		Range	Average
0–100	91	0–60	7
101–200	12	0–20	4
301–400	1	.....	2½
801–900	1	.....	3
	105	0–60	6

The table shows the weakening in yield of wells with depth. Some of the very shallow wells yield large quantities of water. For instance, two wells that deliver 60 gallons a minute average only 48 feet in depth. Many of the deeper wells that obtain considerable quantities of water encounter most of it in shallower zones. It is true, however, that the deeper zones in the trap are not absolutely devoid of usable quantities

of water, but the supplies are usually very small. Wells drilled into the trap should not be located in stream valleys where the weathered rock has been eroded away, as was the 803-foot well, which delivered only 3 gallons a minute. Drilling deeply in trap, therefore, is likely to be wasteful, for if a good supply is not found in the first 100 feet it is almost certain that the well will be poor. Only 1 well in 9 obtains more than 10 gallons a minute, and 1 well in 16 obtains more than 20 gallons a minute. Where larger quantities are desired, several shallow wells, 100 feet or less in depth, should be put down rather than a single deep one.

Drilling in the trap is very difficult, because the hardness and toughness of the sound rock necessitate frequent dressing of the drilling bit and because the round masses produced by spheroidal weathering are very difficult to drill through, the tool being deflected and often jammed by loose "boulders."

The water in the trap is very hard, one sample showing a hardness as high as 350 parts per million. Such a hardness is high even for limestone wells. Other samples show between 100 and 200 parts per million of hardness. Water in the weathered zone may be very soft—40 parts per million in one sample—showing that most of the soluble mineral matter has been leached.

Potomac group.—The Potomac group of formations crops out on the Coastal Plain; the western boundary begins at the north, across the Potomac from Washington, and trends parallel to that river in a southwest by south direction; at the east it passes under Potomac River.

These deposits are of an entirely different type from those discussed above, being practically or wholly unconsolidated lenses of sand, overlain by and grading into silt and clay. The water follows the sandy portions, in places segregated from the water in other beds. Down the dip from the western edge of the outcrop artesian pressure is commonly exhibited, but owing to the slight difference in altitude of intake and outlet the head is small. There are very few evidences of any structural disturbance in the Potomac group. The seaward dip of the formations is only slightly greater than the dip of the original rock floor upon which they were deposited, and no important folds, faults, or joint systems have been developed. There seems to be an east-west ridge in the rock floor beneath the Potomac sediments in the vicinity of Fort Humphreys, Fairfax County, which apparently has decreased the gradient of the rock floor at that point. Near the base of the Potomac group, just above the rock floor, is a zone of coarse sediment, more noteworthy as a zone of water-bearing beds than the higher portions of the group. Near Washington this zone dips seaward from the western boundary of the Coastal Plain at about 100 feet to the mile, but farther south the slope appears to be nearer 70 feet to the mile, and at Fort

Humphreys it is 45 feet to the mile. In projecting the rock floor it must always be remembered that the old surface is somewhat irregular, owing to an ancient drainage system that existed before the deposition of the Potomac sediments and also, possibly, to some post-Cretaceous folding.

Deeper wells intersecting more and better water-bearing beds in these formations have larger yields than the shallow ones. Another factor, however, which enters strongly into the contrasting yields of deep and shallow holes is the development of the wells after they are drilled. A "hard rock" driller, knowing but little of the highly specialized technique involved in developing wells in unconsolidated materials, is more than likely to obtain yields characteristic of "hard rock" formations, whereas a more skilled operator could develop a very successful well at the same point. Of course this explanation does not account for the comparatively poor results of all the shallow drilled wells, but it is certainly a factor in many of them. Near the western boundary of the Potomac group, where it is not very thick, the results seem to be especially poor.

On the basis of the data available there is about 1 chance in 4 of obtaining 50 gallons a minute or more from wells in these formations, but actually the chances are better if the site for drilling is not too near the western boundary of the Coastal Plain. A well 8, 10, or 12 inches in diameter, properly developed, should yield at least 50 gallons a minute more often than not.

The water is in some places hard but more usually soft, and in northern Virginia the quality does not seem to be related to either depth or to the nearness to the border of the outcrop. In the soft water sodium carbonate is the chief constituent. Iron is locally present in such quantities as to stain utensils and clothing, clog pipes, and render the water undrinkable.

Pliocene (?), *Pleistocene, and Recent deposits.*—The deposits of terrace gravel, which are of Pliocene (?) and Pleistocene age, are thin beds laid down on wave-cut platforms or on old land surfaces. They overlie the Potomac group and the older rocks of the Piedmont province in Virginia. The older (higher) terrace gravel has been almost entirely removed by erosion, and only more or less isolated outliers are left. The Recent sediments are represented by valley-floor alluvium, chiefly in the Potomac estuary.

Near the Fall Zone the terrace gravel deposits, because of their shallow depth and small intake area, are not a good source of water supplies, but farther east they are reported to yield copious amounts. A well 30 feet deep and one 60 feet deep drilled into the formation derive from it only 3 gallons a minute each.

The Recent valley fill is near the stream levels and is in many places saturated almost to the ground surface. Two wells near the west end of the Highway Bridge, in Arlington County, 27 and 5 feet deep, deliver 320 and 350 gallons a minute.

No analyses were made of samples from these formations.

SUMMARY

TABLE 17.—*Summary of data on wells in northern Virginia*

Rock Formation	Number of Wells	Depth (Feet)		Yield (Gallons a Minute)	
		Range	Average	Range	Average
Recent, Pleistocene, and Pliocene (?) formations	4	5–60	31	3–350	169
Potomac group	75	24–530	145	0–320	32
Diabase or trap	105	14–803	71	0– 60	6
Newark formation	318	22–531	105	0–120	7
Conglomerate of Newark formation	32	28–360	101	0– 50	9
Romney shale, Jennings formation and Catskill formation	100	22–171	71	0– 16	5
Oriskany sandstone	3	118–142	127	1– 8	5
Helderberg limestone	5	80–195	128	1– 10	5
Silurian formations	0	.....	.....	.....	.....
Martinsburg shale	41	40–289	102	½– 50	11
Quantico slate	7	40–310	126	¼– 7	2½
Lower and Middle Ordovician limestones	93	23–1,432	145	0–150	13
Elbrook and Conococheague limestones	95	32–725	162	½– 90	10
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Tomstown dolomite	7	30–220	111	2– 15	10
Lower Cambrian sediments	21	30–530	164	¼– 16	4
Granite of eastern belt	72	38–740	136	0– 50	9
Marshall granite	97	25–550	109	0– 41	7
Wissahickon schist	145	39–305	95	¼– 70	10
Catoctin greenstone	93	23–704	85	¼– 30	4½
Pre-Cambrian white marble	6	25–120	68	¼– 15	8

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