ABSTRACT

Wells and springs capable of yielding high quantities of water are known to exist in carbonate and shale aquifers of Berkeley County, West Virginia. Adequate representation of this aquifer system requires understanding of factors influencing aquifer properties and groundwater flow patterns. Fracture trace mapping of the area using aerial photography was completed providing additional detail to existing geologic maps. Approximately 200 single-well aquifer tests were conducted to investigate the relationship between geologic features and aquifer transmissivity. Highly transmissive zones can be found at all depths. Shallow water bearing fractures, when encountered, in wells less than 150 ft deep are often the most highly productive. Areas near cross-strike features or complex fold structures generally had higher transmissivities. Wells located in the Beekmantown Group had the highest median transmissivity than any other units. However, high yielding wells are found in almost any geologic setting within the aquifer.

INTRODUCTION

In Berkeley County, West Virginia, rural residents and public water suppliers alike depend on wells and numerous springs found in limestone and dolomite aquifers of the eastern portion of the county for drinking water. Following economic and population growth of the past three decades, increased demands, contamination fears, and recent drought conditions have created concern for county water managers. Highly transmissive areas of the aquifer able to produce large quantities of water to meet the needs of future growth are also the areas highly susceptible to contamination.

Bedrock fractures expressed on land surface, termed fracture traces, are identified as natural linear features observed on aerial photographs and satellite imagery. Soil tonal changes, vegetative and ridge gap alignments, topographic swales, and straight stream valleys often reflect fracture zones of increased permeability, weathering, and solution. Water wells drilled along, adjacent to, and at intersections of fracture zones in carbonate rock terrain are known to produce between 10 times and 100 times more water than wells drilled away from these features (Lattman and Parizek, 1964).

Description of Study Area

Berkeley County occupies 325 square miles in West Virginia's eastern panhandle region, approximately 70 miles northwest of Washington, DC. The county is bounded by the Potomac River to the north; the state of Virginia to the south; Opequon Creek and Jefferson County, West Virginia to the east; and Morgan County, West Virginia to the west. Roughly separating the county in half, the NE-SW trending North Mountain forms a boundary between eastern and western valleys 300 to 400 feet above mean sea-level. The western half of the county is underlain by sandstones and shales and drains to Back Creek and Meadow Branch, both of which eventually discharge to the Potomac River. The eastern half is underlain by easily erodible limestones and dolomites of the Shenandoah Valley. Of interest to this study are the low lying carbonate and shale areas in eastern Berkeley County encompassing an area 18 miles long and 5 to 6 miles wide. Elevations in this area range from 310 to 800 ft of altitude. Locally, the Bunker Hill anticline and syncline underlies the valley and is bounded in the west by North Mountain and to the east by the resistant metamorphic rocks of the Blue Ridge of Jefferson County. The anticlinal axis underlies Opequon Creek and the Martinsburg Shale. Gently rolling topography developed on the carbonates dominate the eastern portion of the county and gives way to steeper slopes and incised valleys within 2 miles of Opequon Creek. Most of this area is drained by Opequon Creek.

Purpose and Scope

Efforts have been initiated by management agencies of Berkeley County to further the understanding of the spatial distribution of fractures in the carbonate regions and their correlation with aquifer properties. This report presents transmissivity values from about 200 single-well aquifer tests and a map of fracture-traces determined from aerial photos and field investigations. Transmissivity values were compared to geologic factors possibly affecting its magnitude.

Previous Investigations

The relationship between geology and groundwater supply and quality in the Martinsburg, WV area was first discussed by Jeffords (1945). Cardwell (1945) investigated geologic controls on groundwater quantity of the Inwood area. Beiber (1961) discussed groundwater levels, lithologic controls, use, and quality in a study of Berkeley and Jefferson Counties. He also reported the aquifer properties of various stratigraphic units in the area. Data collected by Hobba and others (1972) in a study of water resources of the Potomac River Basin in West Virginia were presented in a later report by Friel and others (1975). Taylor (1974) examined linear structures in the Hedgesville and Williamsport 7.5 minute topographic quadrangles to assess the influence of topography, lithology, and structure on groundwater recharge. Hydrologic characteristics of rocks in the Upper Potomac River Basin were described by Trainer and Watkins (1975) and included a discussion on Berkeley County. Hobba (1976) investigated the groundwater hydrology including water levels, underground discharge, and water quality of Berkeley County. Zewe (1991) related surficial lineaments and stratigraphic units of Berkeley and Jefferson County to driller reported well yields. Shultz and others (1995) studied groundwater levels, recharge rates, structural controls, lithologic effects, well yields, springs occurrence, and water quality of the aquifers of Berkeley County.

LINEAMENT ANALYSIS

Linear Features at different scales

Linear features that are mappable on aerial photography and topographic maps have been noted for well over a half century (Lattman, 1958). Termed "fracture traces", these features are postulated to relate to zones of increased fracturing of the underlying bedrock, thereby increasing porosity and permeability, and as such, have been used rather extensively for about the same period of time for groundwater exploration (Lattman and Parizek, 1964). These authors, as well as others, have shown that increased groundwater yields can be produced by drilling wells on individual fracture traces, or better yet, on intersections of fracture traces.

Mapping Fractures in Study Area

False-color aerial photographs (9 x 9 inch format, scale: 1:40,000) were acquired from the USGS EROS Data Center, Souix Falls, South Dakota. Two different data-collection periods were required to cover the eastern end of Berkeley County, dated March 27, 1980 and April 14, 1982. These aerial photographs were viewed as stereo pairs with a mirror stereoscope, using both the standard ocular, as well as the 10x magnifying oculars to view a fine detail preserved in these images. Fracture traces were plotted on special permanent marking pens on a clear mylar material attached to each photo. Fracture traces were examined on each stereo photo pair, taking care to map the fracture traces on each photo in a pair set, in order to make the fracture trace mapping as comprehensive as possible. Some repetition of mapped fracture traces occurred, amounting to less than five percent of the total number of fracture traces. Repeated fracture traces were eliminated upon transfer of the fracture to the base topographic and geologic maps. The mapping of the fracture traces was done without any prior consultation with a geologic map or with knowledgeable field personnel in order to minimize mapping biases.

Fracture traces were mapped in the Lower Paleozoic carbonate rocks and the shaley Martinsburg Formation in the eastern part of the county. No fracture trace mapping was done west of the northeast trending outcrop of the Tuscarora Quartzite.

Cross-Strike Fracture Traces

Cross-strike fracture traces are quite prominent and readily mappable in the Martinsburg Formation, forming straight lines, along first through third order stream valleys. These fracture traces are oriented nearly perpendicular to the strike of the bedding. These features virtually disappear from view when they are projected into the neighboring carbonate rocks where they become subdued, discontinuous, and have very short individual extents. Furthermore, these fracture traces do not appear to follow the straight-line paths perpendicular to strike, but tend to curve away obliquely from the trends established in the Martinsburg Formation. Some of the cross-strike fracture traces in the carbonates appear to occur along zones where small amplitude folds plunge out.

Part of the reason for this change in regimen between the clastic and carbonate rocks may be related to the competency and porosity/permeability differences between the two rock types. The incompetent shale lacks high porosity and permeability, thereby causing water to flow along the ground surface, taking advantage of fractures imparted in the shale by tectonic activity. This surface flow weathers and erodes the shaley rocks creating steep-sided stream valleys. The more competent carbonates, on the other hand, tend to fracture more readily by brittle deformation, increasing porosity and permeability that is further enhanced by solution. Therefore, subterranean water flow is more likely as water is lost from surface pathways into the subsurface conduit system that commonly forms in humid-environment carbonate terrains. The result is relatively less physical weathering and erosion at the ground surface.

Strike-Parallel Fracture Traces

Strike-parallel fracture traces form some prominent trends in the westernmost carbonate valley abutting the Tuscarora Quartzite and other clastic rocks on the west side of the study area. Based on the geologic map, which was consulted after the fracture trace mapping was completed, the long linear features of this area most likely are related to a major thrust fault.

SINGLE-WELL AQUIFER TEST ANALYSIS

Approximately 200 wells (municipal and domestic) were inventoried and tested to estimate aquifer properties during this investigation. Well information and locations can be found in the Table 1. All data were collected over a one-year period beginning Spring 2003. Consequently, an accurate depiction of the potentiometric surface can not be created from this data given temporal variations of head within the aquifer.

Short-term aquifer tests (30 minutes) at relatively low flow (2 to 15 gpm) were conducted at each domestic site to determine transmissivity. At most sites, recovery data were recorded for 100 minutes following the pumping period. Parameter estimates from drawdown and recovery data generally agreed to within ± 30%; reported values reflect the average of the two values. For wells where pump cycling was a problem, transmissivity was computed from recovery data.

Drawdown and recovery tests were analyzed using the Cooper-Jacob (1946) method. The Cooper-Jacob straight-line method is a graphical simplification of the Theis (1935) method and is subject to the same aquifer assumptions (i.e. homogenous, isotropic aquifer, uniform in thickness, and infinite in extent). Further, the well is assumed to be infinitesimally small in diameter and to fully penetrate a confined aquifer. The method is valid if the Theis parameter (u) is less than 0.01, a condition met by most pumping wells. Well losses and partial-penetration of the aquifer have minimal effect on transmissivity values calculated using the Cooper-Jacob method. However, parameter estimates in poorly transmissive regions of the aquifer are subject to error due to unaccounted for wellbore storage effects.

Single-well tests in this study are subject to limitations based on the highly heterogeneous nature of the area's carbonate aquifer. As in most aquifer tests Theis assumptions are routinely violated; thus, use of the Theis method or methods based on the Theis method may be problematic for analysis of single well data in this terrain. Although previous data has been published with use of the method, caution should be used when applying these values to real world problems. Tiedeman and Hsieh (2001) expressed particular concern over use of this type of analysis in open-wells found in fractured crystalline rocks. They thought it questionable if the value obtained from this method is actually representative of true rock properties. Likely, the open hole connects several highly permeable zones separated by relatively impermeable crystalline rock. Hsieh and Shapiro (1996) state single-well tests show the effects of only the few highly transmissive fractures. These zones may or may not be in connection outside of the borehole and error can be introduced. Schad and Teutsch (1994) suggested that the use of the Theis solution does not satisfy properties of the aquifer, so parameters from the Theis method should only be used for comparison of values within a single dataset and not represent real rock.

RESULTS

Results in figures A through D show transmissivity values calculated for each single-well aquifer test compared with well depth, depth to water, type of nearest fold, and geologic unit, respectively. Figure E compares transmissivity from cross fault wells (wells located <250 meters from a cross fault) to non-cross fault wells (wells located >250 meters from a cross fault). Major results are summarized below.

1) Wells completed to <150 ft depth have higher median transmissivity than those completed to greater depths. Many deeper wells are likely located where productive-shallow fractures are absent or have been cased-off, although the spatial distribution of these fractures is unclear.
2) Median transmissivity values are higher near NW-SE-trending cross strike fractures (local strike is NE-SW).
3) With the exception of overturned synclines, areas underlain by overturned and/or plunging folds are more transmissive than those underlain by more open, upright folds.
4) Wells completed in rocks of the Beekmantown Group have higher median transmissivity than other geologic units.
5) Wells located within 250 meters of a cross fault have greater probability of being completed in a higher transmissivity zone than those a further distance from a cross fault.
6) High and low transmissivity zones are found in all geologic settings and all well depth classes. Although in many cases, several wells within a few hundred square foot area bisected by a cross fault will show drastically different aquifer test results.

Boundary Effects During Pumping Periods

In some cases, boundary effects were evident during drawdown periods. When a well is pumped the water level surrounding the well is lowered and a cone of depression is formed. At some point the cone of depression may intersect a recharge boundary (creek, pond, or water-bearing fracture) or an impermeable boundary (impermeable valley wall). At that point, the plot of drawdown versus time in the pumping well will deviate from the assumed theoretical drawdown in a homogenous isotropic aquifer of infinite extent and uniform thickness. In wells near recharge boundaries, the observed drawdown would at some point be less than the expected drawdown in a theoretical aquifer. Likewise, in wells near impermeable boundaries, the observed drawdown would at some point be greater than the expected drawdown in a theoretical aquifer. In Figure F water drawdown is similar to theoretical drawdown during the pumping period in well 49.

Figures G shows well 87 where the drawdown curve abruptly deviates from the slope of the theoretical curve at point (1), thus indicating the existence of a recharge boundary. A recharge boundary in carbonate rocks is often indicative of larger or more abundant water filled solution openings. Figure H shows well 7 and the effect of an impermeable boundary at point (2). In carbonate regions impermeable boundaries are likely encountered as the cone of depression reaches an area of smaller or less abundant water-filled fractures.

Drawdown data from 45 wells were evaluated for boundary effects. The remaining wells in the dataset were unable to be used due to pump cycling during pumping periods. Of the 45 wells, 16 followed the theoretical curve and no boundary conditions were evident, 18 showed the effects of a recharge boundary, and 11 showed the effects of an impermeable boundary. The median drawdown during 30 minutes of pumping in wells near recharge boundaries and impermeable boundaries was 1.95 and 52 ft, respectively.

CONCLUSIONS

The eastern portion of Berkeley County West Virginia, underlain by a synclinal aquifer comprised of Cambrian and Ordovician limestones and shales, maintains a major source of groundwater supplies for both public and domestic users. Cross faults found throughout the limestones are thought to serve as conduits of flow and represent high transmissive zones. These conduits can be solutionally enlarged, and are capable of yielding 100 gpm at fracture intersections. Values of transmissivity can range widely in any given geologic setting, and wells located adjacent to targeted geologic features are likely to produce a wide range of yields. In fractured rock aquifers, the specific location of individual fractures should be investigated by field verification. Transmissivity values presented in this study should not be used for direct comparison with data from other areas, although they may be considered to provide a range of values to begin evaluation with more complex methods of aquifer testing.

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REFERENCES

Beiber, P.P., 1961, Ground-water features of Berkeley and Jefferson Counties, West Virginia: West Virginia Geologic and Economic Survey, Bulletin 21, 81p.

Cardwell, D.H., Erwin, R.B., and Woodward, H.P., 1968, Geologic Map of West Virginia: West Virginia Geological and Economic Survey, 2 sheets, scale 1:250,000.

Cooper, H.H. and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well field history, American Geophysical Union Transactions, v. 27, 526-534.

Dean, S.L., Kulander, B.R., and Lessing, P., 1987, Geology of the Hedgesville, Keedysville, Martinsburg, Shepherdstown, and Williamsport quadrangles, Berkeley and Jefferson Counties, West Virginia: West Virginia Geological and Economic Survey, Map WV-31, scale 1:24,000.

Friel, E.A., Hobba, W.A., Jr, and Chisholm, J.L., 1975, Records of wells, springs, and streams in the Potomac River basin, West Virginia. West Virginia Geological and Economic Survey, Basic Data Report No. 3, 96p.

Graeff, G.D., Jr., 1953, Ground water conditions in a typical limestone area near Inwood, West Virginia: United States Geological Survey, Open-File Report 53-78, 7p.

Hobba, W.A., Jr., Friel, E.A., and Chisholm, J.L., 1972, Water resources of the Potomac River basin, West Virginia. West Virginia Geological and Economic Survey, River Basin Bulletin 3. 110p.

Hobba, W. A., Jr., 1976, Ground-Water Hydrology of Berkeley County, West Virginia: West Virginia Geological and Economic Survey Environmental Geology Bulletin 13. 21 p.

Hsieh, P.A., and Shapiro, A.M., 1996, Hydraulic characteristics of fractured bedrock underlying the FSE well field at the Mirror lake site, Grafton County, New Hampshire, in Morganwalp, D.W., and Aronson, D.A., eds., U.S. Geological Survey Toxic Substances Hydrology Program-Proceedings of the technical meeting, Colorado Springs, Colo., September 20-24, 1993: U.S. Geological Survey Water-Resources Investigations Report 94-4015.

Jeffords, R.M., 1945, Water supply at Martinsburg, West Virginia. United States Geological Survey Open-File Report, 10p.

Lattman, L.H., 1958, Technique of mapping geologic fracture traces and lineaments on aerial photographs: Photogrammetric Engineering and Remote Sensing, vol. 24, no.4, p.568-576.

Lattman, L.H., and Parizek, R.R., 1964, Relationship between fracture traces and the occurrence of groundwater in carbonate rocks. Journal of Hydrology, vol. 2, no. 2, p. 73-91.

Orndorff, R.C., and Goggin, K.E., 1994, Sinkholes and karst-related features of the Shenandoah Valley in the Winchester 30' x 60' quadrangle, Virginia and West Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF-2262, scale 1:100,000.

Schad, H., and Teutsch, G., 1994, Effects of the investigation scale on pumping test results in heterogeneous porous aquifers, Journal of Hydrology, v. 159, no. 1-4, 61-77.

Shultz, R.A., Hobba, W.A., Jr, and Kozar, M.D., 1995, Geohydrology, water availability, and water quality of Berkeley County, West Virginia, with emphasis on the carbonate-rock area. United States Geological Survey Water-Resources Investigations Report 93-4073, 88p.

Southworth, S., Brezinski, D. K., Drake, A.A., Jr., Burton, W.C., Orndorff, R.C., and Froelich, A.J., 2002, Digital geologic map of the Frederick 30x60 minute quadrangle, Maryland, Virginia, and West Virginia: U.S. Geological Survey Open-file Report 02-437, scale 1:100,000, http://pubs.usgs.gov/of/2002/ofr02-437/.

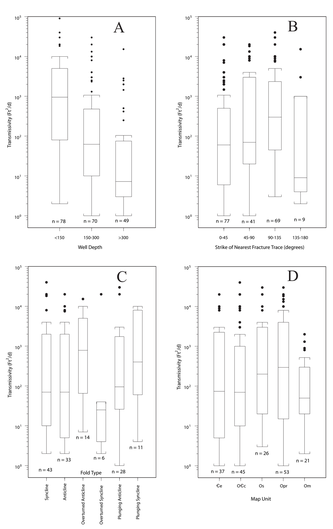
Taylor, L.E., 1974, Bedrock geology and its influence on ground-water resources in the Hedgesville and Williamsport 7 ½ minute quadrangles, Berkeley County, West Virginia: Toledo, Ohio, The University of Toledo, unpublished Master's thesis, 82p.

Thiis, C.V., 1935, The lowering of the piezometer surface and the rate and discharge of a well using ground-water storage. American Geophysical Union Transactions, v. 16, 519-524.

Tiedeman, C.R., and Hsieh, P.A., 2001, Assessing open-well aquifer test in fractured crystalline rock, Groundwater, v. 39, no. 1, 68-78.

Trainer, F.W., and Watkins, F.A., Jr., 1975, Geohydrologic reconnaissance of the upper Potomac River Basin: U. S. Geological Survey Water-Supply Paper 2035, 68p.

Zewe, B.T., 1991, The influence of lineaments and hydrogeologic setting on well yield in Berkeley and Jefferson Counties, West Virginia. Morgantown, WV, West Virginia University, Department of Geology and Geography, Master's thesis, 232p.



Box Plot Key
Outlier
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
n = number of samples

DESCRIPTION OF MAP UNITS

Smc **McKenzie Formation (Upper and Middle Silurian)** -- Shale and siltstone. Shale, olive-gray and light-olive-gray, fissile, and fossiliferous. Siltstone, calcareous. Only exposed in the North Mountain fault zone in the extreme southwestern part of the map

No wells reported

St **Tuscarora Quartzite (Lower Silurian)** -- Quartzite, light- to medium-gray, medium- to coarse-grained, thick-bedded, some beds conglomeratic. Base placed at base of quartzite ledges. Thickness about 400 ft. Only exposed in the North Mountain fault zone in the extreme southwestern part of the map

No wells reported

Om **Martinsburg Formation (Upper and Middle Ordovician)** -- Interbedded shale and lesser graywacke-siltstone and graywacke-sandstone. Shale, medium-gray to dark-gray and light-olive-gray, grayish-orange- and dark-yellowish-orange-weathering, commonly silty, generally noncalcareous, although calcareous intervals occur in lower part of formation. Sandstone and siltstone , medium-gray, grayish-orange-weathering, very fine to fine-grained, commonly graded (fining upwards), lenticular, slightly calcareous to noncalcareous. Many small crossbeds. Graywacke is more abundant and more thickly bedded higher in section where it forms conspicuous ribs in creek beds and may comprise as much as 30 percent of some intervals that are several hundred feet thick. Thicker beds are generally graded and display characteristics of complete Bouma cycles, although Bouma cycles c-e appear to be most abundant. Regional thickness may be more than 5,000 feet.

Well yields range from 2-50 gallons per minute (gpm) (Hobba and others, 1972)

Omu **Middle Ordovician limestones**, undivided -- Limestone and interbedded limestone and calcareous shale. Includes rocks assigned by various mappers to the Middle Ordovician Row Park Formation, Middle Ordovician New Market, and Chambersburg Limestones; Middle Ordovician Edinburg Formation; Middle Ordovician Trenton, Black River, and St. Paul Groups. Total thickness about 700 ft

Well yields range from 1-630 gpm (Hobba and others, 1972)

Opr **Pinesburg Station Dolomite and Rockdale Run Formation of the Beekmantown Group, undivided (Middle and Lower Ordovician)** -- Dolomite, dololamimite, and limestone

Pinesburg Station Dolomite (Middle Ordovician) -- Dolostone and dololamimite, medium- to light-gray, buff- to light-weathering, fine-grained, medium- to thick-bedded, some beds cross-laminated, thin and light-gray chert nodules. Weathered surfaces exhibit "butcher-block" (cross-hatched joints) structure. Also contains a few thin, medium-gray, fine-grained limestone beds in lower part. Paleokarst features of irregular bedding and collapse breccia common near top of formation. Lower contact placed at base of first light-gray, thick-bedded dolostone overlying dominantly limestone cycles of the Rockdale Run Formation (Or). Thickness ranges from 650 to 875 ft

Rockdale Run Formation (Middle and Lower Ordovician) -- Interbedded limestone and dolostone. Limestone, bluish-gray, medium-gray, and dark-gray, fine- to medium-grained, thin- to medium-bedded, fossiliferous. Dolostone, medium-gray, fine- to medium-grained, medium-bedded, crystalline. Limestone beds also contain intraformational conglomerates, algal bioherms, bioclastic zones, and burrow mottling. Lithologies occur as carbonate cycles. Gray chert common, occurring as nodules as much as 6 in. in diameter and as large masses as much as several feet in diameter; large masses of Cryptozoan chert lime soil in lower part of formation and form topographic knolls with little bedrock exposure. Gastropod Lecanospira is common in lower and middle parts of formation. Lower contact placed at base of first crystalline dolostone or dololamimite bed overlying dark-gray, thick-bedded limestone of the Stonehenge Limestone (Ok). Thickness approximately 1,500 ft

Well yields for entire Beekmantown Group range from 1-330 gpm (Shultz and others, 1995)

Ok **Stonehenge Limestone of the Beekmantown Group (Lower Ordovician)** -- Limestone, dark-gray, fine- to medium-grained, thick-bedded, fossiliferous, with crinkly laminations and minor black chert. Also contains algal bioherms, intraformational conglomerates, bioclastic beds, and minor dolostone beds. Contact with underlying Conococheague Limestone (OCc) is gradational. Base placed at first dark-gray limestone with crinkly siliceous laminations and above dolostone that caps Conococheague carbonate cycles. Thickness ranges from 600 to 650 ft

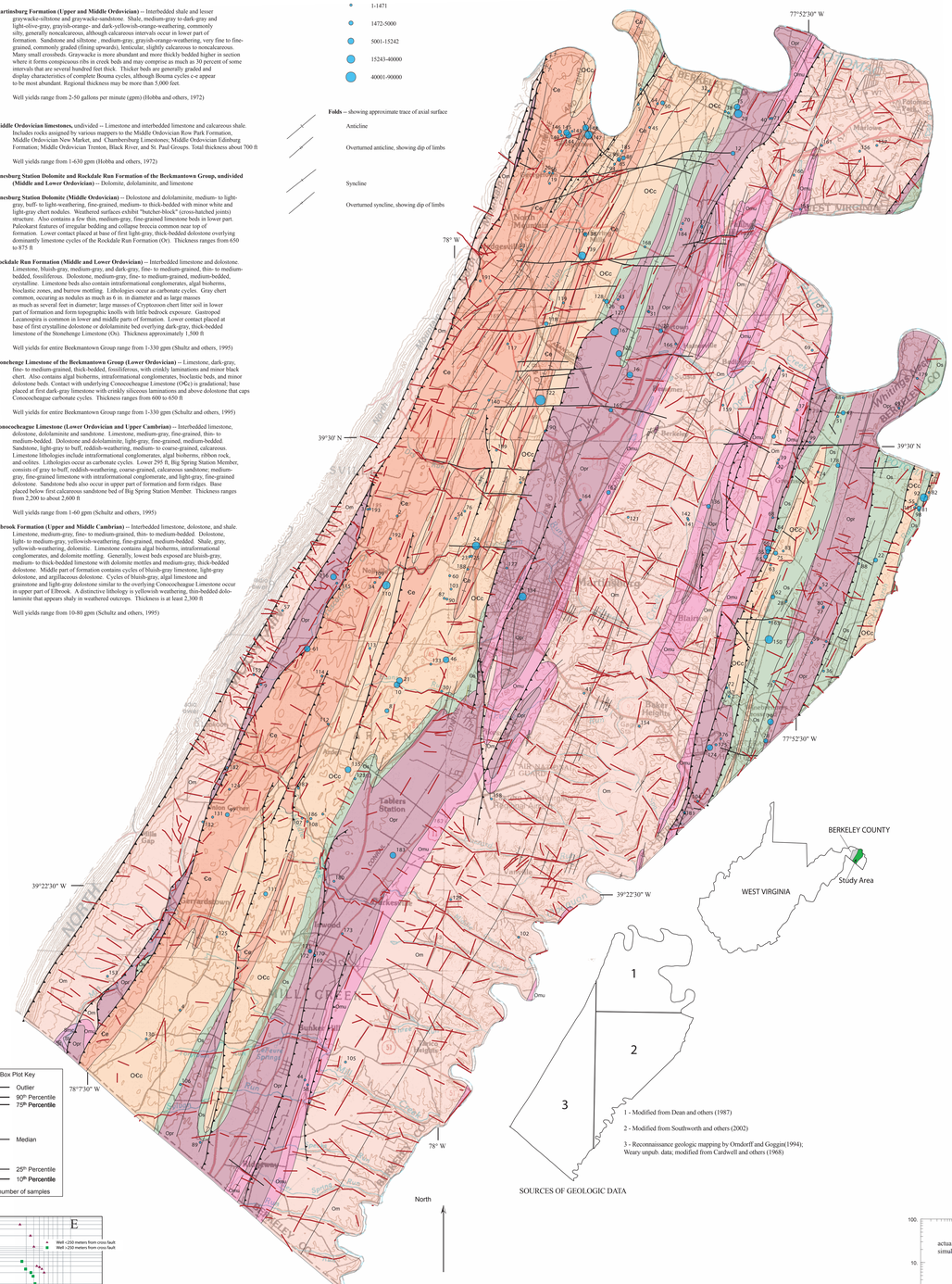
Well yields for entire Beekmantown Group range from 1-330 gpm (Schultz and others, 1995)

OCc **Conococheague Limestone (Lower Ordovician and Upper Cambrian)** -- Interbedded limestone, dolostone, dololamimite and sandstone. Limestone, medium-gray, fine-grained, thin- to medium-bedded. Dolostone, light- to medium-gray, yellowish-weathering, fine-grained, medium-bedded. Sandstone, light-gray to buff, reddish-weathering, medium- to coarse-grained, calcareous. Limestone lithologies include intraformational conglomerates, algal bioherms, ribbon rock, and oolites. Lithologies occur as carbonate cycles. Lower 295 ft, Big Spring Station Member, consists of gray to buff, reddish-weathering, coarse-grained, calcareous sandstone; medium-gray, fine-grained limestone with intraformational conglomerate, and light-gray, fine-grained dolostone. Sandstone beds also occur in upper part of formation and form ridges. Base placed below first calcareous sandstone bed of Big Spring Station Member. Thickness ranges from 2,200 to about 2,600 ft

Well yields range from 1-60 gpm (Schultz and others, 1995)

Ce **Elbrook Formation (Upper and Middle Cambrian)** -- Interbedded limestone, dolostone, and shale. Limestone, medium-gray, fine- to medium-grained, thin- to medium-bedded. Dolostone, light- to medium-gray, yellowish-weathering, fine-grained, medium-bedded. Shale, gray, yellowish-weathering, dolomitic. Limestone contains algal biohermes, intraformational conglomerates, and dolomite mottling. Generally, lower beds exposed are bluish-gray, medium- to thick-bedded limestone with dolomite mottles and medium-gray, thick-bedded dolostone. Middle part of formation contains cycles of bluish-gray limestone, light-gray dolostone, and argillaceous dolostone. Cycles of bluish-gray, algal limestone and grainstone and light-gray dolostone similar to the overlying Conococheague Limestone occur in upper part of Elbrook. A distinctive lithologic is yellowish weathering, thin-bedded dolo-laminite that appears shaly in weathered outcrops. Thickness is at least 2,300 ft

Well yields range from 10-80 gpm (Schultz and others, 1995)



Base topographic maps enlarged from U.S. Geological Survey 1:100,000 scale maps. Projection UTM Zone 17N, Datum NAD 1983

Scale 1:48,000

1 - Modified from Dean and others (1987)

2 - Modified from Southworth and others (2002)

3 - Reconnaissance geologic mapping by Orndorff and Goggin(1994); Weary unpub. data; modified from Cardwell and others (1968)

SOURCES OF GEOLOGIC DATA

EXPLANATION OF MAP SYMBOLS

Fracture trace

Faults

Thrust fault -- saw teeth on upper plate

Cross fault-- includes dip-slip and strike-slip faults that cut across the strike of bedding at a high angle

Well location - dot size in classes proportional to transmissivity (ft^2/day) value ranges. Number corresponds to well number in table 1.

- 1-1471
- 1472-5000
- 5001-15242
- 15243-40000
- 40001-90000

147

Folds -- showing approximate trace of axial surface

Anticline

Overturned anticline, showing dip of limbs

Syncline

Overturned syncline, showing dip of limbs

WELL NUMBER	WELL DEPTH (ft below surface)	CASING DEPTH (ft)	WELL DIAMETER (in)	TRANSMISSIVITY* (ft^2/day)	SPECIFIC CAPACITY (gpm/ft)	STATIC WATER LEVEL (ft below surface)	AQUIFER UNIT	DRILLER REPORTED WELL YIELD (gpm)	PUMPING DISCHARGE (gpm)	DRAWDOWN (ft)	PUMP TEST DURATION (min)
1	455	125	6	3*	0.12	50.95	Conococheague Limestone	3	9.0	72.00	25
2	155	125	6	450	1.70	74.24	Elbrook Formation	30	10.0	6.30	59
3	197	19	6	2*	0.62	9.43	Elbrook Formation	5	16.0	26.00	22
4	366	61	6	2*	0.18	49.31	Conococheague Limestone	4	3.5	20.00	10
5	200	60	6	4*	0.25	35.41	Conococheague Limestone	12	6.9	28.00	21
6	240	110	6	10*	0.13	20.36	Stonehenge Limestone	20	6.7	52.00	20
7	245	65	6	10*	0.33	33.03	Pinesburg Station Dolomite and Rockdale Run Formation undivided	20	12.0	36.00	30
8	300	18	6	3000	20.00	15.00	Conococheague Limestone	50	7.5	5.00	30
9	285	18	6	8*	0.35	11.23	Conococheague Limestone	30	10.0	30.00	12
10	160	59	6	10000	14.00	15.49	Conococheague Limestone	30	14.0	1.00	18
11	150	58	6	2000	4.40	5.13	Elbrook Formation	15	13.6	3.10	31
12	300	79	6	7500	9.80	28.56	Pinesburg Station Dolomite and Rockdale Run Formation undivided	10	5.5	0.56	60
13	200	38	6	25*	0.74	33.06	Pinesburg Station Dolomite and Rockdale Run Formation undivided	10	10.3	14.00	37
14	325	24	6	4*	0.21	21.54	Stonehenge Limestone	6	5.5	26.00	11
15	60	57	6	5000	73.00	13.25	Stonehenge Limestone	7.5	7.5	0.10	17
16	80	60	6	7500	62.00	28.85	Pinesburg Station Dolomite and Rockdale Run Formation undivided	8.0	8.0	0.13	59
17	180	19	6	10*	0.43	36.59	Pinesburg Station Dolomite and Rockdale Run Formation undivided	8	5.4	13.00	12
18	460	39	6	4*	0.17	46.08	Elbrook Formation	10	8.9	52.00	15
19	300	100	6	6*	0.21	44.10	Elbrook Formation	3	4.3	20.38	28
20	120	39	6	400	6.30	46.51	Elbrook Formation	25	3.2	0.51	33
21	220	99	6	8000	7.70	27.85	Conococheague Limestone		10.0	1.00	23
22	140	3	6	1600	14.00	31.93	Stonehenge Limestone		11.0	0.81	34
23	115	34	6	10*	0.46	60.85	Conococheague Limestone		8.0	17.00	30
24	125	35	6	20000	158.00	39.83	Conococheague Limestone		11.0	0.07	31
25	118	24	6	10*	0.42	52.05	Conococheague Limestone		5.6	13.00	20
26	250	31	6	2*	0.11	35.68	Conococheague Limestone		4.4	38.00	21
27	82	11	6	4000	18.00	40.55	Pinesburg Station Dolomite and Rockdale Run Formation undivided		6.7	0.42	30
28	320	27	6	2	0.42	47.55	Stonehenge Limestone		12.0	28.00	5
29	80	40	6	20000	20.00	8.98	Pinesburg Station Dolomite and Rockdale Run Formation undivided		8.2	0.50	34
30	300	16	6	60*	1.20	8.28	Conococheague Limestone	60	60.0	52.00	24
31	220	19	6	6*	0.27	50.00	Conococheague Limestone		7.5	28.00	30
32	122	124	6	90	1.60	60.62	Conococheague Limestone		4.4	4.30	25
33	416	103	6	5*	0.18	59.57	Pinesburg Station Dolomite and Rockdale Run Formation undivided	3	4.7	26.00	29
34	300	20	6	4*	0.17	50.11	Elbrook Formation		5.3	32.00	30
35	125	61	6	5000	13.00	30.74	Pinesburg Station Dolomite		5.4	0.41	27
36			6	200	0.95	32.63	Stonehenge Limestone		10.0	11.00	30
37	60		6	40*	0.76	11.33	Middle Ordovician limestones undivided		3.8	5.00	21
38	270	29	6	20*	0.62	45.84	Stonehenge Limestone		9.3	8.50	30
39	28	0	6	300	3.20	8.21	Martinsburg Formation		3.6	1.10	27
40	300	20	6	80*	1.20	21.13	Pinesburg Station Dolomite and Rockdale Run Formation undivided		5.0	4.30	20
41	170	20	6	60*	1.10	69.45	Martinsburg Formation	30	4.7	4.10	27
42	207	1	6	30*	0.79	7.20	Middle Ordovician limestones undivided		3.5	4.20	30
43	420	59	6	6*	0.20	48.72	Pinesburg Station Dolomite and Rockdale Run Formation undivided	20	9.7	49.00	16
44	300		6	4*	0.15	22.63	Pinesburg Station Dolomite and Rockdale Run Formation undivided		6.0	39.00	30
45	336	39	6	140	3.40	33.09	Elbrook Formation		4.3	3.10	30
46	72	28	6	8000	110.00	32.17	Conococheague Limestone		6.4	0.16	28
47	68	20	6	2000	0.81	13.59	Stonehenge Limestone		1.9	2.40	28
48	500	21	6	3*	0.09	102.11	Stonehenge Limestone		5.7	63.00	23
49	352	125	6	2*	0.26	95.46	Pinesburg Station Dolomite and Rockdale Run Formation undivided		7.0	27.00	20
50	425	64	6	2000	8.50	15.59	Elbrook Formation		4.5	0.81	30
51	115	52	6	90	1.30	33.21	Stonehenge Limestone	18	5.0	3.90	30
52	194	39	6	70*	1.20	0.00	Elbrook Formation		6.0	3.10	30
53	280	59	6	2*	0.10	52.37	Elbrook Formation		4.5	47.00	22
54	125	18	6	6*	0.16	60.25	Elbrook Formation		5.3	38.00	30
55	105	118	6	40*	0.95	8.21	Stonehenge Limestone	12	7.9	8.00	3
56	360	39	6	2*	0.17	35.35	Elbrook Formation	4	6.0	35.00	11
57	120	42	6	20*	0.07	0.16	Martinsburg Formation		5.2	21.00	30
58	400	33	6	10*	0.18	38.46	Middle Ordovician limestones undivided		4.6	26.00	30
59	137	78	6	100	2.30	25.36	Pinesburg Station Dolomite and Rockdale Run Formation undivided		7.7	3.40	31
60	215	118	6	4*	0.22	33.21	Conococheague Limestone		6.6	30.00	15
61	110	52	6	7000	34.00	4.41	Pinesburg Station Dolomite and Rockdale Run Formation undivided	50	8.4	8.00	30
62	100	20	6	3000	26.00	37.00	Stonehenge Limestone		11.4	0.30	30
63	119	27	6	400	7.50	32.68	Conococheague Limestone		5.2	1.60	29
64	160	62	6	10*	0.26	71.34	Elbrook Formation		7.9	30.00	30
65	105	78	6	5000	18.00	25.01	Pinesburg Station Dolomite and Rockdale Run Formation undivided	50	7.7	0.