COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINERAL RESOURCES

PUBLICATION 102, PLATE 1
GEOLOGIC MAP OF CLARKE COUNTY VIRGINIA

# GEOLOGIC MAP OF CLARKE COUNTY, VIRGINIA

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## EXPLANATION

- a — Alluvium, travertine-marl (stippled pattern)
- t — Terrace deposit
- Omb — Martinsburg Formation
- Ooe — Oranda Formation and Edinburg Formation
- Oln — Lincolnshire Limestone and New Market Limestone
- Opr — Pinesburg Station Dolomite and Rockdale Run Formation
- Ost — Stonehenge Limestone
- O€co — Conococheague Formation
- €e — Elbrook Formation
- €wb — Waynesboro Formation
- €t — Tomstown Dolomite
- €a — Antietam Formation
- q €h — Harpers Formation
- €w — Weaverton Formation
- €p€c — Catoctin Formation

## KEY

Attitude of Rocks
- 23 Strike and dip of beds
- 26 Strike and dip of overturned beds
- Strike of vertical beds
- Horizontal beds

Contacts
- Exposed or approximate

Faults
- T U D Exposed or approximate (black line); arrows indicate relative movement; T, upper sheet; U, upthrown side; D, downthrown side.

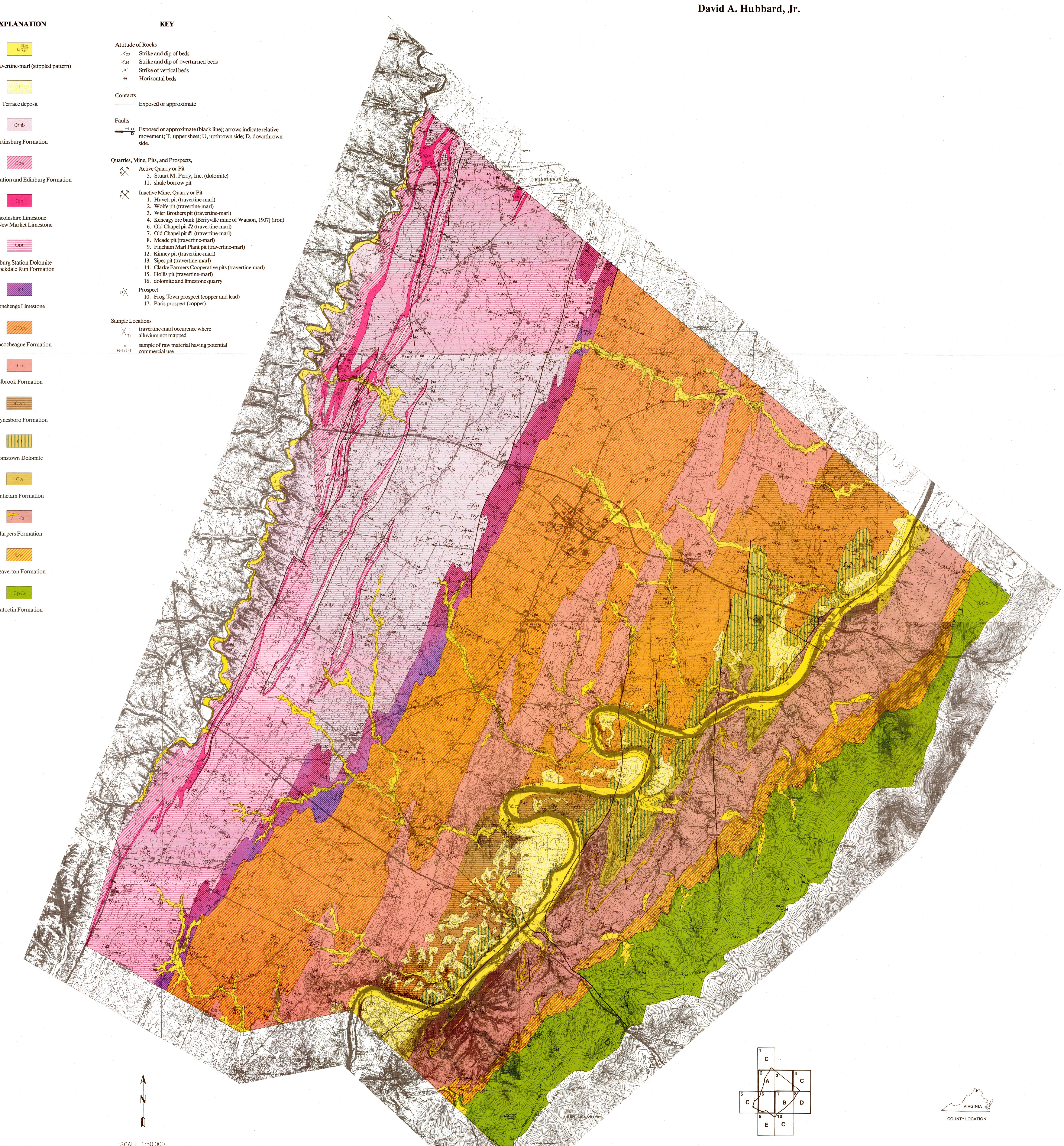
Quarries, Mine, Pits, and Prospects,

Active Quarry or Pit
5. Stuart M. Perry, Inc. (dolomite)
11. shale borrow pit

Inactive Mine, Quarry or Pit
1. Huyett pit (travertine-marl)
2. Wolfe pit (travertine-marl)
3. Wier Brothers pit (travertine-marl)
4. Keneagy ore bank [Berryville mine of Watson, 1907] (iron)
6. Old Chapel pit #2 (travertine-marl)
7. Old Chapel pit #1 (travertine-marl)
8. Meade pit (travertine-marl)
9. Fincham Marl Plant pit (travertine-marl)
12. Kinney pit (travertine-marl)
13. Sipes pit (travertine-marl)
14. Clarke Farmers Cooperative pits (travertine-marl)
15. Hollis pit (travertine-marl)
16. dolomite and limestone quarry

Prospect
10. Frog Town prospect (copper and lead)
17. Paris prospect (copper)

Sample Locations
- m — travertine-marl occurence where alluvium not mapped
- R-1704 — sample of raw material having potential commercial use




| MAPPERS | QUADRANGLE NAME |
|---|---|
| A. R.S. Edmundson and W.E. Nunan | 1. Inwood |
| B. T.M. Gathright, II and P.G. Nystrom, Jr. | 2. Stephenson |
| C. D.A. Hubbard, Jr. | 3. Berryville |
| D. P.E. Parker, modified by T.M. Gathright, II and D.A. Hubbard, Jr. | 4. Round Hill |
| E. M.T. Lukert and E.B. Nuckols, III | 5. Stephens City |
| | 6. Boyce |
| | 7. Ashby Gap |
| | 8. Bluemont |
| | 9. Linden |
| | 10. Upperville |



| SYSTEM AND SERIES | | FORMATION AND MEMBER | DESCRIPTION |
|---|---|---|---|
| QUATERNARY | | Alluvium and terrace deposits | Alluvium: Sand, silt, and clay with beds of pebbles to boulders of quartzite, limestone, dolomite, and metabasalt. Thickness: up to 20 feet. Terrace deposits: Cobble and boulder deposits in sand, silt, and clay matrix, intricately dissected remains of ancient alluvial deposits. Thickness: up to 20 feet. |
| ORDOVICIAN | Upper | Martinsburg Formation | Shale, dark-gray to black, fissile to subfissile, several thin K-bentonite beds near the base of the formation. Thickness: greater than 400 feet. |
| ORDOVICIAN | Upper | Oranda-Edinburg Formation | Oranda Formation: Shale, limestone, siltstone, and minor K-bentonite, interbedded. Shale and siltstone, calcareous, gray, weathers brown. Limestone, grayish-black, fine-grained, impure. K-bentonite clays, micaceous, pinkish-gray, thin. Thickness: 28 feet. Edinburg Formation: Limestone, shale, siltstone, and minor K-bentonite, interbedded. Two major facies: limestone, gray to black, very-fine-grained, cobbly to nodular with interbedded black shale up to 2 inches thick (Lantz Mills facies); limestone, black, in 2 to 4 inch thick beds separated by black shale partings (Liberty Hall facies). Siltstone, dark-gray, weathers brown, thin beds near the top of the formation. K-bentonite, pinkish-gray, several thin beds. Thickness: 200 to 550 feet. |
| ORDOVICIAN | Middle | Lincolnshire-New Market Limestone | Lincolnshire Limestone: Limestone, dark-gray to black, fine- to medium-grained, locally bioclastic, commonly with black, nodular, or bedded chert. Thickness: 10 to 85 feet. New Market Limestone: Limestone, light-gray to medium-bluish-gray, aphanitic, commonly with a chalk-like weathering rind, limestone pebble conglomerate at base. Thickness: 15 to 68 feet. |
| ORDOVICIAN | Middle / Lower | Pinesburg Station Dolomite; Rockdale Run Formation | Pinesburg Station Dolomite: Dolomite, light- to dark-gray, fine- to medium-grained, weathers very-light-gray, "butcher-block weathering," some white chert nodules, occurs only in northern portion of the county. Thickness: up to 385 feet. Rockdale Run Formation: Limestone and dolomite, interbedded. Limestone, light- to medium-gray, fine-grained. Limestone, light-gray, medium-grained with anastomosing burrow structures filled with light-gray, medium-grained dolomite. Limestone with anastomosing burrow structures grades into ribbon banded limestone, gray, fine- to medium-grained interlaminated with light-gray, fine- to medium-grained dolomite. Dolomite, light-gray, medium-grained. Black chert nodules and chertified stromatolites occur locally within the formation. The base of the formation is marked by a zone of gray, sandy chert nodules. Thickness: 2400 feet. |
| ORDOVICIAN | Lower | Stonehenge Limestone | Limestone and limestone interbedded with limestone pebble conglomerates. Limestone, light- to dark-gray, fine- to medium-grained, beds 3 to 4 feet thick, tubular structures in light-gray, fine-grained beds, 0.1 inch in diameter and 1 inch long. Limestone, dark-gray, fine-grained with siliceous laminations, interbedded with limestone conglomerate having pebbles of siliceous limestone up to 4 inches in diameter, algal structures common. Stoufferstown member (at base): limestone, fine- to medium-grained, distinctive crinkly siliceous partings to laminae. Limestone, coarse-grained, lense shaped, bioclastic beds, contains cephalopod, brachiopod, gastropod, and pelmatozoan fragments. Thickness: 750 feet. |
| ORDOVICIAN / CAMBRIAN | Lower / Upper | Conococheague Formation | Limestone, dolomite, and sandstone. Limestone, medium- to dark-gray, fine- to medium-grained, ribbon-banded with siliceous laminae, weathers light-gray to yellowish-gray. Limestones, gray to dark-gray, fine-grained, interbedded with dolomite. Limestone with intraformational conglomerate, beds up to 18 inches thick. Dolomite and dolomitic limestone, light- to dark-gray, fine-grained. Sandstone, seen as float, porous, coarse-grained and friable suggesting carbonate cement except at top of formation where cement is siliceous and sandstone is abundant. Big Springs Station member (at base): limestone, dolomitic limestone, dolomite, and sandstone interbedded. Limestone, light-gray, fine- to medium-grained, weathers light-bluish-gray. Dolomitic limestone, medium-light-gray, medium-grained, weathers medium-gray. Dolomite, light- to dark-gray, fine- to medium-grained, weathers gray to light-yellowish-gray. Sandstone, light-gray to pale-yellow, medium- to coarse-grained, weathers brown and friable, thin-bedded. A few chert nodules occur throughout the member. Thickness: 2300 feet. |
| CAMBRIAN | Middle | Elbrook Formation | Limestone, dolomite, shale, and siltstone. Limestone, medium- to light-gray, fine-grained with argillaceous limestone or dolomite laminae which weather yellowish-gray. Limestone, medium-gray, fine- to medium-grained. Dolomite, argillaceous, light- to dark-gray, fine- to medium-grained, weathers dark-rusty-brown (grayish-red). Limestone and dolomite, argillaceous and sandy, interbedded, dolomite weathers yellowish-tan (yellowish-orange). Dolomite, light- to dark-gray, fine- to medium-grained, weathers yellowish- to dark-brownish-gray. Dolomite, argillaceous, light-gray, fine- to medium-grained. Dolomite, light-gray, saccharoidal, interbedded with limestone, shale, and siltstone. Shale, mudstone, and siltstone, green to dusky-red, mostly in lower part. Thickness: 2900 feet. |
| CAMBRIAN | Lower | Waynesboro Formation | Shale, argillaceous limestone, dolomite, siltstone, and sandstone. Shale, grayish-olive, brown, and dusky-red, interbedded with siltstone and medium- to fine-grained sandstone. Limestone, argillaceous, locally dolomitic, dark-gray, very-fine-grained, weathers yellow, blebs and stringers of dolomite, medium-gray, medium-grained, nodular black chert. Dolomite, light-gray, coarse-grained. Dolomite, argillaceous, light-yellowish-gray, laminated. Thickness: 1300 feet. |
| CAMBRIAN | Lower | Tomstown Dolomite | Dolomite, dolomitic limestone, and limestone. Dolomite, light- to dark-gray, fine- to coarse-grained, medium- to thick-bedded, locally laminated, white chert rosettes and nodules near top. Dolomite, light-gray to yellowish-gray, medium-grained, thick to massive bedding. Dolomite, light- to medium-gray, mottled. Dolomitic limestone, dark-gray to very-dark-gray, very-fine-grained, thin-bedded with argillaceous laminations, limestone or dolomite blebs and stringers, interbedded with limestone. Limestone, dark-gray to black, very-fine-grained, thin-bedded. Thickness: 1100 to 1200 feet. |
| CAMBRIAN | Lower | Antietam Formation | Quartz sandstone, quartzite, and phyllite. Sandstone, tan (yellowish-gray) to light-brown, fine- to very-fine-grained, well-sorted, quartz-sericite-feldspar composition, interbedded with quartzite, beds may be separated by phyllite laminations. Quartzite, light-tan (light-yellowish-gray), fine- to medium-grained, arkosic, very resistant. Phyllite, light-gray to pale-olive, fine-grained, sericitic. Primary structures in sandstone and quartzite include cross laminations, quartz-pebble lenses, and scour and fill. *Scolithus* tubes are common in sandstones and quartzites. Thickness: 200 to 800 feet. |
| CAMBRIAN | Lower | Harpers Formation | Phyllite, feldspathic sandstone, quartz sandstone, and quartzite. Phyllite, dark-grayish-green, very-fine-grained, thick-bedded. Phyllite, dark-gray, faint purplish cast. Sandstone, feldspathic, dark-grayish-green. Quartz sandstones, ferruginous, dark-purplish-gray, magnetite- and hematite-cemented, sericitic and argillaceous locally. Quartzite, light-olive-gray, fine-grained. *Scolithus* tubes and *Arenicolites* burrows occur in sandstone and quartzite beds. Thickness: 2200 to 2500 feet. |
| CAMBRIAN | Lower | Weverton Formation | Upper member: pebbly quartzite and quartz-pebble conglomerate. Middle member: phyllite and quartz sandstone. Phyllite, dark-gray, sandy to pebbly, interbedded with quartz sandstone. Quartz sandstone, phyllitic. Lower member: quartzite, phyllite, and quartz-pebble conglomerate. Quartzite, light-gray, grayish-yellow, and purplish-gray, medium- to coarse-grained, interbedded with phyllite and quartz-pebble conglomerate. Phyllite, dark-gray, sandy. Thickness: 440 to 600 feet. |
| CAMBRIAN | Lower | Catoctin Formation | Upper member: grayish-red amygduloidal slates or phyllites (upper 100 feet). Metabasalts and epidosite. Metabasalt, dark-green, fine-grained, very-thick-bedded, well developed cleavage, plagioclase-actinolite-epidote-chlorite-magnetite, quartz-feldspar-epidote-chlorite amygdules near top and bottom of some metabasalt beds. Epidosite, pale-yellow-green, fine-grained, chemical alteration of metabasalt occurring as lenses and beds. Thickness: greater than 1200 feet. |

## INTRODUCTION

Clarke County is located in northern Virginia. It has an area of about 178 square miles and is bounded by Frederick County to the west, Warren County to the south, Fauquier and Loudoun counties to the east, and Jefferson County, West Virginia to the north. The county is in the Valley and Ridge and Blue Ridge physiographic provinces and includes portions of the Shenandoah Valley and the Blue Ridge Mountains. It lies within the drainage basins of the Shenandoah River and Opequon Creek, tributaries of the Potomac River, and has a variety of springs.

The published geologic maps used in the compilation of this map are the Ashby Gap quadrangle by Gathright and Nystrom (1974), Berryville, Stephenson, and Boyce quadrangles by Edmundson and Nunan (1973), the Bluemont quadrangle by Parker (1968), and the Linden quadrangle by Lukert and Nuckols (1976). Field mapping of the Clarke County portions of the Inwood, Round Hill, Stephens City, and Upperville quadrangles was begun in April, 1985 and completed in June, 1986. The Elbrook-Waynesboro (Rome of some previous authors) contact was repositioned stratigraphically downward in the Berryville and Boyce quadrangles to correspond with the mapped position in the adjacent Ashby Gap quadrangle and in Warren County. The geologic report is adapted from Edmundson and Nunan (1973) and Gathright and Nystrom (1974). The historical account of travertine production was compiled from interviews with Paul Chapman, John and Dudley Digges, Winston Sipes, Cecil Wolfe, and data from the U.S. Bureau of Mines (production data and "Minerals Yearbook") and the Virginia Division of Mineral Resources.

## STRATIGRAPHY

A part of the Catoctin Formation, comprised of Cambrian- or Precambrian-age rocks of volcanic origin, is exposed near the crest of the Blue Ridge Mountains along the eastern edge of the county. Paleozoic-age sedimentary rocks are present along the northwestern slope of the Blue Ridge Mountains and the adjoining lowlands of the Shenandoah Valley. The Cambrian-age clastic rocks comprising the northwest slope of the Blue Ridge Mountains and the Cambrian- to Ordovician-age rocks underlying the Shenandoah Valley are assigned to 15 formations and are represented as 12 map units. Measured sections from the previously published quadrangles and estimated thicknesses interpreted from mapped formation widths indicate that the combined thickness of the Paleozoic-age rocks in Clarke County, from the base of the Cambrian-age Weaverton Formation to the Middle Ordovician-age Martinsburg Formation, is about 16,500 feet. Sand, clay, travertine-marl, gravel, and colluvium of Cenozoic age are present in floodplain and terrace deposits on many of the upland areas bordering the Shenandoah River.

## ECONOMIC GEOLOGY

Crushed stone is produced from dolomite at the Stuart M. Perry, Inc. quarry in the Berryville quadrangle. In the past, limestone and dolomite, marl, shale, and iron ore deposits have been worked in Clarke County. Barite, fluorite, copper, lead, and high-silica resources also are present and may have economic potential.

### Industrial Limestone and Dolomite

Limestone and dolomite are potentially suitable for use for soil enrichment and stability, general chemical purposes, glass manufacture (calcium and magnesium), lime (calcium and magnesium), paints and fillers, Portland cement, and refractory and steel flux (open hearth and blast furnace). Carbonate rocks having potential industrial use are arbitrarily catagorized as high-calcium limestone, if they contain greater than 95 percent calcium carbonate, or high-magnesium dolomite, if they contain greater than 40 percent magnesium carbonate; both generally contain less than 4 percent noncarbonate materials. Because the noncarbonate constituents, chiefly silica, alumina, and iron oxide, are important for certain uses, the term impure limestone is used to describe those formations which are commonly low in magnesium carbonate or contain more than 5 percent noncarbonates. Chemical analyses of carbonate rocks from selected localities in Clarke County are listed in Edmundson (1945). Additional analyses have been performed by the Virginia Division of Mineral Resources (Giannini, in preparation). Physical test data for rocks from selected Clarke County localities are listed in Parrott (1954).

The New Market Limestone, the chert free portions of the Lincolnshire Limestone, and layers interbedded with magnesian limestone and dolomite of the Rockdale Run Formation are the major sources of high-calcium limestone in Clarke County. An outcrop of the New Market Limestone with an observed thickness of 67 feet is located 0.3 mile east of Opequon Creek and 200 feet north of State Road 761. Only the upper 39 feet of this exposure appears to meet specifications for high-calcium limestone. The New Market Limestone is 65 feet thick in the east limb of the Wadesville anticline, where it is exposed along State Road 661 approximately 3100 feet southeast of Wadesville. There, the upper 30 feet of the formation appears to be a good quality high-calcium limestone. A 45-foot-thick section of the New Market Limestone has a calcium carbonate content of 98.15 percent where it is exposed on the west limb of the Stones Chapel syncline on State Road 657, approximately 8000 feet east of Opequon Creek. A 10 foot thick, exposed section of the New Market Limestone has a calcium carbonate content of 99.39 percent at a location 1200 feet west of State Road 635 and 450 feet south of Dry Marsh Run (Giannini, in preparation).

The Lincolnshire Limestone, generally, contains too much chert and shale to meet the specifications of high-calcium limestone. One high-calcium limestone occurrence in the Lincolnshire is located about 800 feet northeast of the crossing of State Road 661 and the tracks of the Baltimore and Ohio Railroad at Wadesville. The Rockdale Run Formation contains units of high-calcium limestone interbedded with magnesian limestone and dolomite in exposures on State Road 646 about 1.5 miles northwest of White Post.

At some locations the Pinesburg Station Dolomite may meet the specification for high-magnesian dolomite in the Inwood and Stephenson quadrangles of Clarke County, but chemical analyses of two samples indicate 39.76 and 34.63 percent magnesium carbonate (Giannini, in preparation). The upper two-thirds of the Tomstown Dolomite is mostly high-magnesian dolomite. Analyses of the upper parts of the Tomstown Dolomite average more than 40 percent magnesium carbonate with less than 4 percent noncarbonate impurities (Edmundson, 1945). A 30-foot section of the Tomstown Dolomite at the Stuart M. Perry, Inc. quarry contains 45.10 percent magnesium carbonate and 1.36 percent noncarbonate impurities (Giannini, in preparation).

Impure limestone units, including the Stonehenge, the Lincolnshire at most localities, the Edinburg, and other units interbedded with dolomite may be crushed and used as aggregate. Stone used as an aggregate in highway construction and maintenance is classified into grades A, B, and C on the basis of three physical properties: abrasion loss, absorption, and specific gravity. According to Gooch and others (1960), "Grade A and B aggregate are utilized for aggregate base course, soil aggregate surface course, bituminous concrete, Portland cement, surface treatment, stabilization aggregate, or crusher run. Grade C is used for soil aggregate surface course and stabilization aggregate."

In Clarke County portions of all of the carbonate rock formations, the Chilhowee Group quartzites, and the Catoctin Formation have a grade A classification (Parrott, 1954). Large amounts of aggregate are currently produced from the Tomstown Dolomite near the southern boundary of the Berryville quadrangle, about 0.5 mile southwest of the junction of State Highway 7 and State Road 612, by the Stuart M. Perry Company, Inc. Aggregate was also produced at a quarry in the Rockdale Run Formation south of Double Tollgate from 1948 through the 1960s.

### Travertine-marl

Travertine-marl deposits were extensively worked in Clarke County. Production records from seven of 11 producers indicate that a total of 295,698 short tons of material were sold from 1940 through 1956 (Hubbard and others, 1985).

The earliest commercial production of travertine-marl in Clarke County was by Snowden Strother in the mid-1930s. This operation was situated on old Chapel Run just south of Briggs. Strother sold his operation to W. R. Thompson in the mid-1940s, but retained the rights to haul with one truck from the Old Chapel site. In 1947, J. C. Digges and Sons purchased W. R. Thompson's operations at Old Chapel Run and worked these deposits until about 1970. In 1970 the Meade pit was opened by J. C. Digges and Sons and was worked until about 1979. The southernmost of the Old Chapel marl pits was known as the Fincham Marl Plant pit and was operated by Simon Newland in the late 1940s. A. Golightly and Burkner assumed the operation of the Fincham site in 1950. Aimee Strother, son of Snowden, operated the Fincham site from 1952 until 1958.

The second oldest travetine-marl operation was situated on Spout Run just above its confluence with the Shenandoah River at Calmes Neck. The Clarke Farmers Cooperative opened the site about 1940 and operated it until 1950. A. Golightly was the manager of this operation until he assumed the operation of the Fincham site at Old Chapel. Other operators on Spout Run included Winston and Nelson Sipes on the west side of the run across from the Farmers Cooperative. The Sipes brothers produced marl from 1947 until 1950. Upstream from the Sipes and cooperative workings, J. C. Digges and Sons opened the Hollis pit in 1953 and operated it until September of 1960. Approximately two miles to the west, Elmer G. Kinney opened a site on Spout Run at Millwood in 1958. Kinney's operation continued until 1962.

The Weir Brothers site on Dry Marsh Run is situated about a mile-and-a-quarter east of Burnt Factory. It was operated from about 1948 until the 1950s, with the Sipes brothers doing most of the hauling. A West Virginia firm (name unknown) hauled some of this material in the 1960s and 1970s.

The Huyett pit at Gaylord on Long Marsh Run was worked by Paul Chapman in the late 1940s and early 1950s. About a mile east, on Long Marsh Run, Elmer Kinney worked the Wolfe pit in 1958 and 1959. Much of the marl at this site was borderline for commercial production, because of the minimum requirement of 85 percent $CaCO_3$.

Clarke County travertine-marl materials vary in texture from fine grained and friable marls to indurated ridges of travertine containing leaf impressions, such as sycamore, and tree trunk and root casts. Snail and small fresh-water clam shells are abundant.

Travertine-marl deposits were identified in 14 streams drainages in Clarke County. Deposits typically have Weaver soils developed on them. These soils form from calcareous alluvial sediments and contain C horizons with 5 to 50 percent calcareous material (Edmonds and Stiegler, 1982). Characteristically, Clarke County deposits occupy broad, flat stream segments, commonly with waterfalls at their downstream margins. Available chemical analyses indicate that travertine, where free from contamination, contains more than 97 percent calcium carbonate (William F. Giannini, 1986, personal communication). Generally, the marl found on the flood plains of streams is intermixed with variable amounts of fine sand and clay and the calcium carbonate content ranges from about 65 to 94 percent, with the magnesium carbonate content less than one percent. Most of the impurities are silica and organic matter.

Commercial marls contain 85 to 98 percent calcium carbonate. Winston Sipes reported one of the best marls he had observed was the Clarke Farmers Cooperative's "fine grained red marl." This material reportedly contained 98 percent $CaCO_3$ and ranged up to 20 feet thick. The Digges operations on Old Chapel Run also worked a 20-foot-thickness of marl. The Sipes operation on the west side of Spout Run worked up to 10 feet of marl. The Weir deposit is believed to have been only about 5 feet thick.

### Clay, Shale, and Related Material

Tests and determinations of properties required to evaluate the potential ceramic and nonceramic uses of raw materials in the northern counties of Virginia have been published by Calver and others (1961). In Clarke County, one sample of shale with interbedded thin layers of siltstone from the Martinsburg Formation (R-1704) indicates a potential use as a lightweight aggregate. Tests on a sample from the Waynesboro Formation (R-6949) indicate a potential use as "structural clay products (e.g., building and floor brick at 1100°-1150°C)" (Sweet, 1982). A shale pit in the Martinsburg Formation located in the northeastern corner of the Stephens City quadrangle intermittently has provided material for road construction.

### High-Silica Sand

The Antietam Formation is comprised primarily of silica-cemented, fine- to coarse-grained quartzite and metasubarkose with minor phyllite partings. Good exposures of parts of the formation, including vitreous quartzite, can be seen on Gibson Ridge and The Blue Ball. In Clarke County, Harris (1972a) refers to an exposure of the Erwin Quartzite (Antietam Formation of this report) on the south end of Gibson Ridge 0.1 mile east of State Road 638. In an open-file report Harris (1972b) concludes that the "rock material would be extremely difficult to crush for use as high-silica sand."

### Barite

Small masses of very coarsely crystalline barite ($BaSO_4$) occur in fractured dolomite and in the overlying saprolite of the upper member of the Tomstown Dolomite in a fault zone exposed in the east wall of the Stuart M. Perry, Inc. quarry. A second occurrence in the Tomstown Dolomite is associated with limonite in float at the Berryville mine site. Barite also occurs in fractures in quartzite of the Antietam Formation near an apparently small-displacement reverse fault exposed 7500 feet east of Lockes Landing, on the north side of State Road 621.

### Fluorite

Fluorite ($CaF_2$), commercially known as fluorspar, was observed in minor amounts in highly deformed, overturned limestone beds of the lower Tomstown Dolomite approximately 8000 feet east of Lockes Landing on the north bank of the Shenandoah River. The occurrence of fluorite in Cambrian and Ordovician limestone in Clarke County was noted by Watson (1907).

### Iron

"Brown Hematite Ore" was mined for several years in the early 1900s from the Berryville mine also referred to as the "Keneagy Ore Bank" (VDMR economic geology files). Analyses of this ore in the 1890s indicate that it contained from 54 to 59 percent iron. Ore from this mine was hauled to Berryville and shipped to northern furnaces, including Dunbar Furnace, at Dunbar on Dunbar Creek in Fayette County, Pennsylvania. Holden (1907) reported that iron ore in the form of "limestone limonite" occurs in a number of places a short distance west of the Shenandoah River. Some of this ore was hauled to the Shannondale Furnace near the Shannondale Ferry on the Shenandoah River in Jefferson County, West Virginia. Several old exploration pits expose siliceous limonite near the Tomstown-Antietam contact, mostly southwest of Willow Lake in the Ashby Gap quadrangle. These pits may represent unsuccessful searches for manganese ore during the last century. Additional occurrences of siliceous limonite are found associated with terrace deposits on limestones of the Waynesboro and Elbrook formations.

### Copper and Lead

Copper has been reported at two localities in Clarke County. At the Paris prospect, native copper reportedly was associated with malachite in small seams of epidotized greenstone in the Catoctin Formation (Keith, 1894; Luttrell, 1966; Sweet and Bell, 1980). The second locality, the Frog Town prospect, contained traces of copper and lead in the Tomstown Dolomite (Luttrell, 1966; Sweet and Bell, 1980).

## STRUCTURE

Clarke County is on the southeast limb of the Massanutten synclinorium and the northwest limb of the Blue Ridge anticlinorium. Compressional tectonic forces acting on the stratified rocks have produced a complex series of folds and faults that dominate the geologic structure of the county. Tectonic transport of the Paleozoic-age strata from the east has overstepped and locally overturned the west limbs of anticlines. Folding of the rocks has produced well developed, southeast dipping, axial-plane cleavage in the more argillaceous beds throughout the county. Longitudinal, transverse and diagonal joints are well developed in the competent rock units. Faults appear to postdate much of the folding. Detailed descriptions of the large folds and major faults can be found in Edmundson and Nunan (1973), Gathright and Nystrom (1974), and Lukert and Nuckols (1976).

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COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINERAL RESOURCES

PUBLICATION 102, PLATE 2
MAP OF SELECTED HYDROGEOLOGIC COMPONENTS
FOR CLARKE COUNTY, VIRGINIA

# MAP OF SELECTED HYDROGEOLOGIC COMPONENTS FOR CLARKE COUNTY, VIRGINIA

David A. Hubbard, Jr.

**EXPLANATION**

- a — Alluvium, travertine-marl
- t — Terrace deposit
- Omb — Martinsburg Formation
- Ooe — Oranda Formation and Edinburg Formation
- Oln — Lincolnshire Limestone and New Market Limestone
- Opr — Pinesburg Station Dolomite and Rockdale Run Formation
- Osl — Stonehenge Limestone
- OCco — Conococheague Formation
- Ce — Elbrook Formation
- Cwb — Waynesboro Formation
- Ct — Tomstown Dolomite
- Ca — Antietam Formation
- Ch — Harpers Formation
- Cw — Weaverton Formation
- Cpc — Catoctin Formation

**KEY**

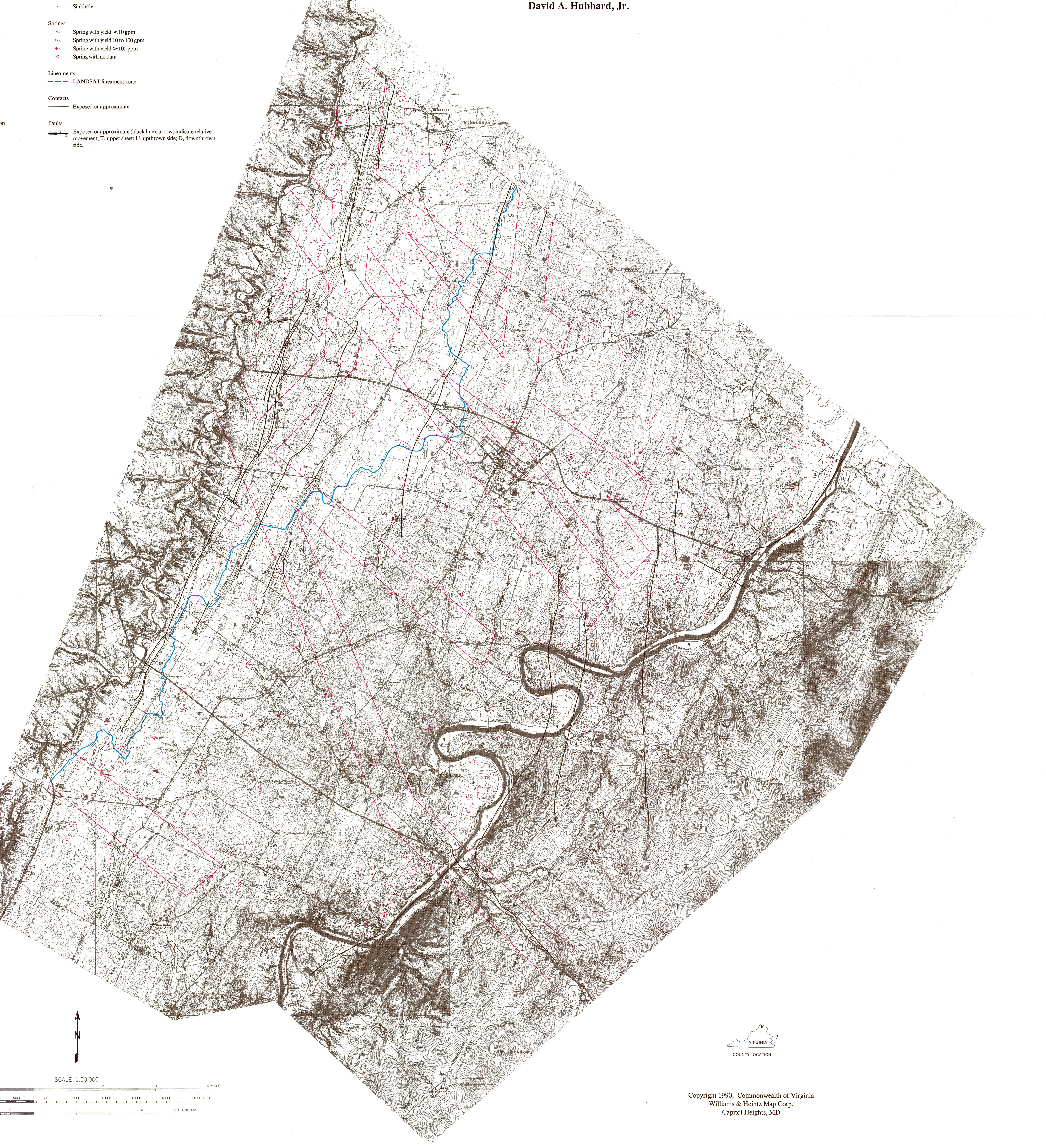
Karst Features
- Cave
- Sinkhole

Springs
- Spring with yield < 10 gpm
- Spring with yield 10 to 100 gpm
- Spring with yield > 100 gpm
- Spring with no data

Lineaments
- LANDSAT lineament zone

Contacts
- Exposed or approximate

Faults
- Exposed or approximate (black line); arrows indicate relative movement; T, upper sheet; U, upthrown side; D, downthrown side.





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## INTRODUCTION

In response to changes in land use activity during the next few decades administrators of Clarke County and the Lord Fairfax Planning District Commission have designed a groundwater protection plan in an attempt to insure adequate future groundwater resources for Clarke County. Current groundwater sources in the county include both springs and wells. This study was initiated during the formulation of Clarke County's groundwater protection plan in order to provide planners with the geologic data and interpretations essential to their study.

Approximately 74 percent of the county is located on folded and fractured carbonate rocks that exhibit karst development. The term "karst" refers to terrain characterized by the differential solution of bedrock, development of underground drainage, and distinctive features such as pinnacled bedrock, sinkholes, and caves (Hubbard, 1983). Soil cover in Clarke County is relatively thin, but significant variations in thickness occur over horizontal distances of a few feet. Dolomitic beds generally have little or no soil cover while adjacent limestone beds are generally overlain by many feet of soil. Surficial basin-like, funnel-shaped, or vertical-sided depressions in soils or sediments are termed sinkholes. Sinkholes usually form by the subsidence or collapse of unconsolidated materials into voids resulting from the dissolution of carbonate bedrock but the location and rate at which sinkholes form can be affected by man's activities. These subsidence features may be significant input points for surface waters entering the subsurface drainage system. Pollutants entering sinkholes can access the groundwater system without undergoing filtration, through the soil profile, and cause contamination of the groundwater.

The subsurface "plumbing" system in the carbonate bedrock is due to solutional enlargement along bedding and joint and cleavage fractures. Solution openings provide flow paths in an aquifier dominated by a diffuse sponge-like network containing a number of large solution conduits, indicated by large springs and a small number of caves.

The extreme variability and unpredictability of groundwater flow paths, combined with the potential for rapid influx of pollutants into the subsurface drainage network, should cause concern for the susceptibility of groundwater to pollution hazards in karst terrains. The generally thin soils and enhanced permeability, because of carbonate rock dissolution, in karst areas provide little filtering of bacteria or viruses from agricultural or domestic sewage effluents. Once in the subsurface, bacteria and viruses are protected from the ultraviolet radiation of the sun, which effectively reduces their numbers in shallow surface waters (Aley and Thomson, 1981). The poor filtering characteristics of thin soils and sinkholes allow sewage nutrients and toxic and carcinogenic chemical pollutants to readily degrade groundwater quality.

Pollutants in the groundwater system may move miles in a few hours through solution conduits (Crawford, 1984). Seemingly confined concentrations of pollutants floating on the surface of groundwater may migrate during groundwater level fluctuations. Floating pollutants trapped in solution pockets may be forced into upper-level subsurface overflow conduits or back upstream in conduits during periods of high-water level. Accumulations of hydrocarbon or other toxic fumes may be forced out of solution pockets and rise into homes and wells by high groundwater conditions (Crawford, 1984 and 1986). Potentially explosive or toxic pollutants may remain absorbed in extensive fine-grained sediment accumulations in conduits after high groundwater levels have receded (Crawford, 1984) and may result in fumes in houses or fumes and liquid impurities in wells. Droughts reverse the process and may lower groundwater levels sufficiently to allow floating pollutants to escape ceiling pockets in solution openings.

A number of hydrologic and hydrogeologic studies have been conducted in and around Clarke County. An early hydrologic study of the groundwater resources of the Shenandoah Valley (Cady, 1936) did not include Clarke County specifically, but made note of the lack of perennial surface drainage in the county and implied a dependence of residents on groundwater resources. A report on the groundwater hydrology of adjacent Jefferson County, West Virginia (Hobba, 1981) noted that much of that county is underlain by fractured and cavernous limestone aquifers that are susceptable to contamination. High nitrate concentrations were "almost always associated with limestone aquifers." Attempts to trace the movement of groundwater by the injection of dye into two sinkholes were not successful even after eight weeks of monitoring discharge points; indicating the unpredictability of groundwater velocity and direction in this karst terrain. A hydrogeologic study was conducted of the National Fisheries Center in Leetown, Jefferson County, West Virginia, approximately 9 miles north of Clarke County (Jones and Deike, 1981). The geology of this area of Jefferson County is very similar to that of western Clarke County. Findings of the study indicated that all springs and wells in the vicinity of the Fisheries Center originate from a common aquifer which has a diffuse flow pattern through a complex system of solution-enlarged joints and fractures. Recharge for the area is itself diffuse and dye tracing indicates multiple resurgences and relatively long groundwater residence times (60 to 80 days), atypical of karst regions (Jones and Deike, 1981). Dye tracing in the Leetown area did not reveal any specific integrated solution networks but the report did acknowledge the presence of solution pockets and cavernous zones.

A study by Schnabel Engineering Associates (1983) addressed the hydrogeology of the Prospect Hill Spring within Clarke County. Parameters such as rock type, fracture trends, solutional modification of the carbonate rocks, soil characteristics, and the southwestward regional groundwater flow trend were examined. Only the soil characteristics parameter and surface drainage divides were indicated on the land-use map illustrating the report's recommended precautions. Recommendations on how to protect the spring included the designation of land-use restriction zones and the installation of a network of observation wells. The delineation of the restricted zones and the location of the observation well sites apparently was based upon isotropic (and probably unrealistic) groundwater flow and "approximate drainage divide(s)" (Schnabel Engineering Associates, 1983).

Two hydrogeologic studies were conducted in Clarke County in 1986. Sandberg (1986) discussed septic drainage field contamination, leaking underground storage tanks, and the gypsy moth aerial spraying program in the Blue Ridge Mountains of the county. Smith (1986) generated a water-table contour map and discussed some pollution problems in the valley region of Clarke County.

An overview of the groundwater resources of Clarke County (Jones, 1987) included information on the hydrogeologic setting, geologic influences, karst landforms, development of secondary fractures in carbonate rocks, groundwater theory, karst drainage basins, pollution risk assessment, and tracer tests. Jones utilized findings of an earlier study (Jones and Deike, 1981) in Jefferson County, West Virginia, with research conducted within Clarke County to classify the carbonate aquifer as having anisotropic permeability and diffuse circulation developed in a slightly enlarged fracture network. Dye tests in Jefferson and Clarke counties indicated a half-radial groundwater flow pattern subparallel to the local strike and down the hydraulic gradient. The Clarke County dye traces indicated groundwater flow to the east and southeast with about a one-and-two-thirds longer travel time than for similar distances for the earlier Jefferson County traces. The longer travel times are explained in terms of the "exceptionally light rainfall" experienced during the test period. Jones (1987) reported that elevated bacteria and nitrogen levels and a few localized oil spills are associated with Clarke County groundwater. Measures to protect the carbonate rock aquifer include the exclusion of landfills or other dumping from carbonate rock areas and the prohibition of waste disposal in sinkholes or caves. Additional concerns about storage tanks, septic drain fields, runoff from areas containing agricultural wastes, and the use of fertilizers and pesticides are described (Jones, 1987).

The U.S. Geological Survey Water Resources Division in Richmond, Virginia has completed in a hydrological study of the county, which includes a description of the groundwater flow system and the distribution of the parameters describing the water quality in wells and springs (Winfield Wright, 1990, personal communication).

The dye tracer test results of Jones (1987) and Jones and Deike (1981) indicate that the diffuse groundwater movement in the Clarke County aquifer is slower than the flow expected from a well developed conduit karst system. The small number of known caves in Clarke County can be interpreted as an indication that large solution conduits are not as prevalent as in other karst areas. The fact that some caves and large carbonate-rich springs exist in the county is evidence of solution conduit development and the potential for rapid transport of pollutants along unknown routes. In addition, the diffuse movement of groundwater that is characteristic of groundwater flow within the county indicates that there is a potential for widespread dispersal of pollutants over a period of months before a problem would be detected.

### Clarke County Pollution Problem

A number of groundwater pollution problems have been reported in Clarke County. Problems include the presence of fecal bacteria and high nutrient (nitrate) concentrations, toxic and carcinogenic chemicals, and hydrocarbon fumes and residues.

A review of the Environmental Protection Agency's STORET System of well data for Clarke County by the Lord Fairfax Planning District Commission found 47 wells with fecal-coliform bacteria (Most Probable Number Method) and 9 wells with nitrate levels greater than 10 mg/L (Lord Fairfax Planning District Commission, 1985, written communication). Both the fecal-bacteria and nitrate levels could be the result of either sewage tank absorption fields or agricultural sources.

In October of 1980, E. O. Gooch and Associates conducted a study of the Berryville sewage lagoon, that was reportedly leaking at an approximate rate of 55,000 gallons per day. The study reported, "In those portions of the lagoon bottom that were not covered with a thick layer of sludge we found areas in which the liner was either missing (rock exposed) or the liner was not the required two feet thick." Additionally, a number of "undisturbed Shelby tube samples" were "too soft to test" or had unacceptably high permeabilities (E. O. Gooch and Associates, 1980). The Berryville sewage lagoons were constructed in 1968 on carbonate rocks of the Cambrian-age Elbrook Formation (Edmundson and Nunan, 1973).

Complaints of a strange odor and taste prompted testing of the Town of Berryville's water wells (The Clarke Courier, October 9, 1980). Testing revealed that the wells were contaminated with phenols, xylene, nitrates (State Water Control Board, December 30, 1980, written communication), creosol, and trimethylbenzene (The Clarke Courier, March 26, 1981). At that time, the well sites were "within several hundred feet of" "a fertilizer company, two-cold storage facilities, a box factory, a basket factory, and an oil distributor." Additionally, a storage tank was located approximately 500 feet away from the northern-most well and was found to contain the fertilizer "liquid N" during the initial on-site investigation (State Water Control Board, October 9, 1980 and December 30, 1980, written communications). An "open drainage way flows to the west of the well sites. During our visit of December 9, 1980 there was a significant flow through the channel. However, at a point approximately 100 feet west of the North Well, flow terminated and apparently was infiltrating through the bottom of the channel.. . It is highly possible that runoff waters entering the drainage channel are the source of the contaminants" (State Water Control Board, December 30, 1980, written communication). The Berryville town wells were constructed in 1953 to depths of 365 feet (north well) and 230 feet (south well), and grouted to depths of 100 feet and 53 feet, respectively. Both wells have static water levels 93 feet below the surface (State Water Control Board, 1986, written communication). During the years that these wells were in operation, about six sinkholes formed to the east of the well sites (Jim O'Brien and Jim Sipes, 1985, personal communication). Approximately 500 feet to the southwest, Dog Run (known locally as Town Run) has been observed to sink in its channel during periods of low flow (Jim O'Brien, 1985, personal communication).

Complaints of hydrocarbon contamination have been investigated at three sites in Clarke County. Occasional complaints of odors and the taste of hydrocarbons from well water have been investigated at Waterloo and White Post. Water samples taken at these locations have yet to confirm problems. Both sites were near operating or abandoned service stations (Clarke County Health Department, November 25, 1985, written communications; State Water Control Board, February 5, 1986 and March 31, 1986, written communications). The third site of hydrocarbon pollution is the Pine Grove area of the county (Ken Hinkle, 1986, personal communication) which overlies clastic rocks of the Cambrian-age Harpers Formation.

### Description of Map Components

The karst component map contains the locations of sinkholes, caves, springs, and LANDSAT lineament zones. The sinkholes indicated on this map were transferred from maps by Edmonds and Stiegler (1982) and Hubbard (1983). A total of 806 sinkholes are indicated on this map. The locations of the five caves plotted on this map are from Douglas (1964), Holsinger (1975), and Winfield Wright of the U.S. Geological Survey (1986, personal communication). The spring locations were provided by the U.S. Geological Survey (1986, written communication) and are depicted on this map as having estimated yields of less than 10, 10 to 100, greater than 100 gpm, or no data available. LANDSAT lineament zones represent linear areas observed to contain two or more parallel to subparallel lineaments. These zones were identified by T. M. Gathright, II (1986, personal communication) using orthoscopic and oblique viewing of band 7, unenhanced, black and white, LANDSAT imagery. The geologic significance of LANDSAT lineaments is not well understood, however, the lineament zones depicted may contain areas of denser fracturing of the bedrock and may serve as recharge areas into the groundwater system. The systematic recognition of lineaments from conventional aerial photography was inhibited by the extensive agricultural use of the county.

### Discussion of Map Components

Approximately 50 percent of the sinkholes displayed are within the drainage basin of Opequon Creek, a tributary of the Potomac River. The drainage basin of Opequon Creek within Clarke County represents only 20 percent of the county area. Most of these sinkholes are associated with the main belt of soil types classified as having less than severe restrictions for septic tank absorption fields (Edmonds and Stiegler, 1982). These soils overlie the Stonehenge and Rockdale Run Formations.

Other concentrations of sinkholes are found north and south of U.S. Highway 50 adjacent to the Shenandoah River, and are developed on the Tomstown and Waynesboro Formations. The southern of these two groups may be related to steep drainage gradients. The northern group is developed on terrace deposits in a meander bend of the river. Sinkhole development may be attributed to flow along solutionally enlarged fractures through rocks of the meander neck.

A small cluster of sinkholes located about a mile northeast of Double Tollgate is separated from a similar cluster to the north by the Opequon Creek divide. This southern cluster may have been part of the Opequon Creek basin until its drainage was pirated by Borden Run, a tributary of the Shenandoah River. Geomorphic evidence of this drainage shift is the continuation of a low ridge that comprises the Opequon Creek divide to the north, located to the east of this southern cluster.

A concentration of sinkholes north and southwest of Cool Spring in the northeastern corner of the county appears to be lithologically controlled. These sinkholes are located in a narrow belt around the noses of the anticline at Cool Spring and the adjacent syncline to the southwest. Structural control of sinkhole development includes increased fracture permeability related to axial-plane cleavage and to the longitudinal, transverse, and diagonal fractures developed during folding. Axial aligning and fold nose clustering of sinkholes reflects this structural influence. Examples include sinkholes on the syncline east of Calmes Neck located between the Shenandoah River and Willow Lake and on the southern end of the anticline through Wadesville.

As previously noted, sinkholes should be regarded as potential sites for the influx of pollutants into the groundwater supply. The 806 sinkholes indicated on this map are only a fraction of the total number of sinkholes in the county. Areas that contain high densities, or linear trends, of sinkholes probably will contain more sinkholes than were detected in this study. Potential sources of pollution in these areas should be monitored closely.

Another problem associated with sinkholes is subsidence or collapse. The development of new sinkholes is more likely to occur in the vicinity of other sinkholes. The occurrence or reactivation of sinkhole subsidence or collapse may result from a number of conditions, including changes in the water-table elevation. Rapid and extreme groundwater fluctuations associated with the pumping of wells, either during well development or subsequent heavy use, has been established as a cause of sinkhole subsidence or collapse. Sinkhole development associated with the previously mentioned Berryville wells is one example of this hazard. Other documentation includes: Foose (1968), Newton and Hyde (1971), and Newton and others (1973). Other causes of sinkhole subsidence or collapse include increases in loading, vibration, and increases in storm water runoff. The use of sinkholes as drainage outfalls, for disposal of channelled effluents, is discouraged. Increased hydrologic input into sinkholes can result in induced subsidence or collapse (Kemmerly, 1980) as well as in the propagation of new sinkholes. The larger the volume of the hydrologic input the greater the risk.

The elevation of springs and the static water level in wells serve to define the potentiometric groundwater surface (water-pressure surface) which may have extreme variability in relief. Water-bearing zones perched on impermeable or low permeability rocks may further complicate the mapping of this surface. Maps of the potentiometric surface can be used to predict the direction of groundwater flow and indicate general areas of recharge. Conduit flow paths may vary significantly from the general flow direction indicated by these maps. Large springs and high-yield wells are indicators of the presence of conduit flow.

Wells depicted as having had fecal coliform contamination (Most Probable Number Method) are widely distributed over the county. These and nitrate-contaminated wells do not show a close relationship to sinkhole occurrences. The distribution of wells with high bacteria and nitrate levels indicates places where these pollutants were detected, but not necessarily where they entered the groundwater system. Where polluted wells have high yields and conduit flow of groundwater is suspected, pollution sources may be located miles away. Where polluted well yields are low, diffuse groundwater flow may be more prevalent and pollution sources are more likely to be local. Fractured carbonate bedrocks overlain by shallow soils provide little if any filtering of domestic or agricultural sewage effluents and thus may allow pollution direct access to the groundwater.

The LANDSAT lineament zones may represent corridors of higher permeability as a result of fractures or the solutional enlargement of fractures in the bedrock. At present, however, there is little or no data that would demonstrate a relationship between groundwater production and LANDSAT lineament zones in Clarke County. Fewer sinkholes occur within lineament zones than in surrounding areas as demonstrated by the two sinkhole concentrations adjacent to the Shenandoah River. These concentrations are separated by a lineament zone, that projects to a traverse fault. A number of springs occur along these lineament zones, however, and water-table elevations and yields of wells located in these zones should be compared with surrounding well data to determine the importance of these zones to groundwater flow patterns and recharge.

The integration of information about the distribution of sinkholes, caves, springs, and lineament zones with a potentiometric groundwater surface map and dye tracing studies will further the understanding of groundwater resources and problems.

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