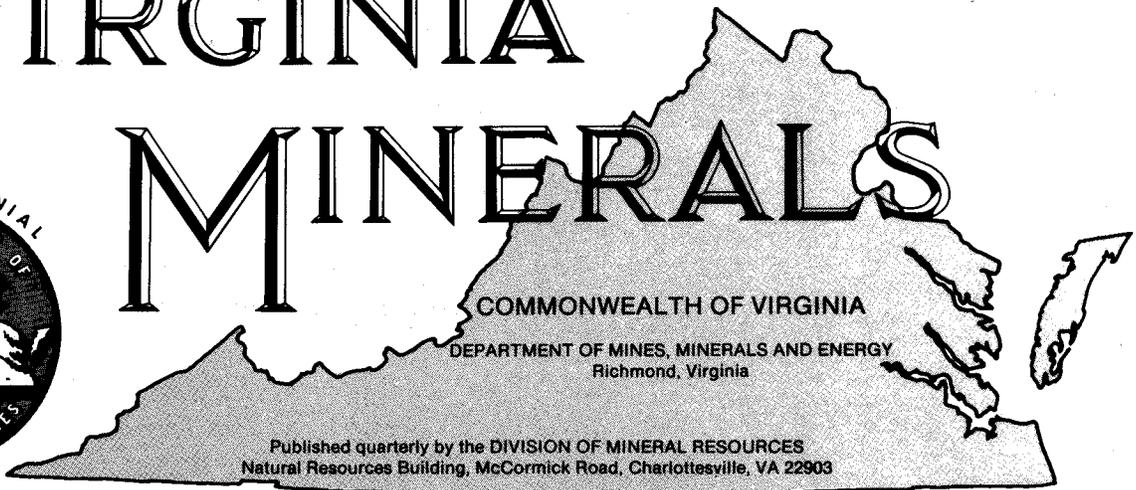


# VIRGINIA

# MINERALS



Published quarterly by the DIVISION OF MINERAL RESOURCES  
Natural Resources Building, McCormick Road, Charlottesville, VA 22903

Commonwealth of Virginia, copyright 1987

Vol. 33

November 1987

No. 4

## GEOLOGY OF THE CAROLINE STONE QUARRY

John D. Marr, Jr.<sup>1</sup> and Lauck W. Ward<sup>2</sup>

The Caroline Stone Quarry is located in southwestern Caroline County, Virginia approximately 1 mile west of U. S. Highway 1 and 1 mile north of the North Anna River (Figure 1). The quarry is owned and operated by the Caroline Stone Company, a subsidiary of the Solite Corporation. *Entrance to the quarry requires permission of the quarry superintendent.* The Caroline Quarry is situated near the western edge of the Hylas fault zone, a northeast trending structure composed of mylonitized and fractured crystalline rocks. In the quarry these crystalline rocks are unconformably overlain by Tertiary age sediments of the Pamunkey and Chesapeake groups. Exposures of both crystalline and sedimentary rocks are uncommon in central Virginia, and the Caroline Quarry offers an exceptional opportunity to observe several geologic features. These include amphibolite facies rocks that have been partially retrograded to the greenschist facies, cataclastic textures preserved in the crystalline rocks on both megascopic and microscopic scales, and the unconformable contact between Piedmont crystalline rocks and the overlying Tertiary-age Coastal Plain sediments.

<sup>1</sup>Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903

<sup>2</sup>United States Geological Survey, National Center, M.S. 970, Reston, VA 22092

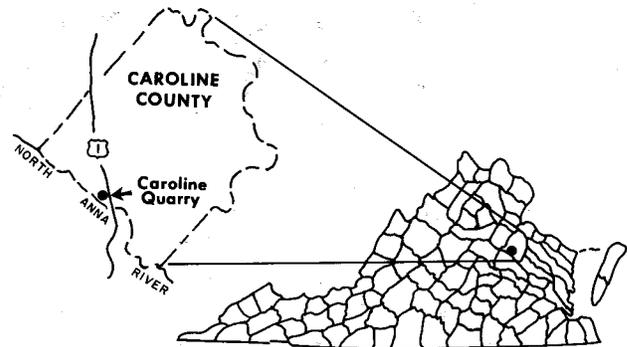


Figure 1. Location of Caroline Quarry.

### GEOLOGIC SETTING

The crystalline rocks within the quarry consist of biotite gneiss and hornblende-rich gneiss believed to correlate with the Maidens gneiss and Sabot amphibolite of Poland (1976) (Marr, 1985). The Maidens gneiss is heterogeneous with respect to lithology and fabric. The dominant rock types of the Maidens are biotite gneiss, augen gneiss, and migmatite gneiss. Thin intermittent mica schist layers, hornblende-biotite rich lenses, and quartzo-feldspathic lenses occur locally. The Maidens lithologies can be interpreted as polymetamorphosed sediments. The Sabot amphibolite consists

of interlayered hornblende gneiss and subordinate biotite gneiss. The Sabot is interpreted as interlayered metamorphosed basaltic lava flows or beds of pyroclastic debris and graywacke-type sediments.

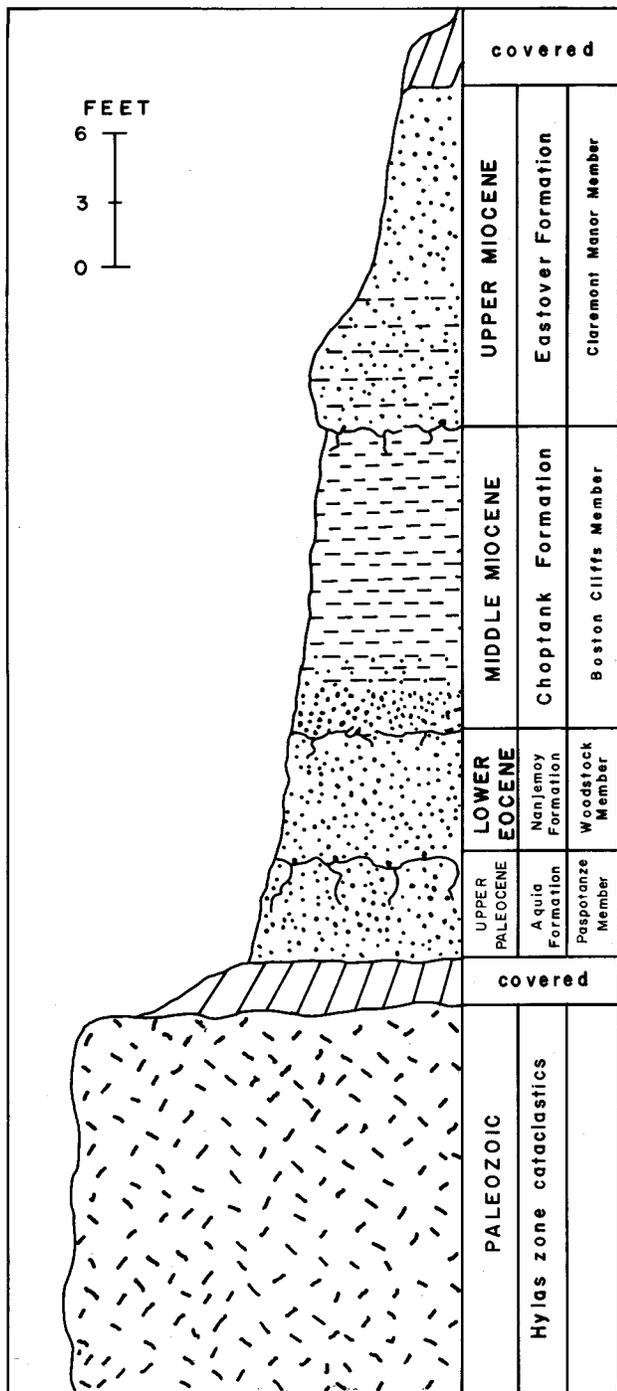


Figure 2. Schematic section of the stratigraphic units exposed at the Caroline Stone Company Quarry (taken from Ward, 1987).

The age of both these units is uncertain. The Sabot amphibolite is underlain by the State Farm Gneiss which has been dated at  $1031 \pm 94$  my Rb/Sr whole rock method (Glover and others, 1978). Both the Maidens gneiss and Sabot amphibolite are correlative with the Po River Metamorphic Suite which has been intruded by the Falls Run Granite Gneiss dated at  $408 \pm 5$  my Rb/Sr by whole rock analyses (Pavrides and others, 1982). These ages provide maximum and minimum age constraints for the Maidens and Sabot.

Unconformably overlying the crystalline rocks are Coastal Plain marginal marine sediments that resulted from high sea-level stands during the Tertiary. Included in the sequence are at least five unconformity-bound units ranging in age from the late Paleocene (54.0 to 57.0 my; see Hazel and others, 1984) to the late Pliocene (approximately 3.0 my) (Figure 2). The beds and their contained fossils indicate very near shore marginal marine settings. During the Tertiary in the area of the Caroline quarry, the paleo-Atlantic lapped against a rocky shoreline much like that along our northeastern U. S. coast today. The Coastal Plain deposits record five distinct marine transgressive events that were the result of global sea level rises, local tectonic movements, or a combination of both factors. The fact that so many of these beds were preserved and not removed by erosion is probably a result of their being deposited in a low area or small basin or a result of their being downfaulted into a protective graben.

The best exposure of the Coastal Plain beds is on the north wall, where the entire sequence is exposed overlying the undulating Piedmont crystalline rocks (Figure 3). On the south wall a much thinner section is exposed and consists of only the upper Miocene and upper Pliocene (?) beds.

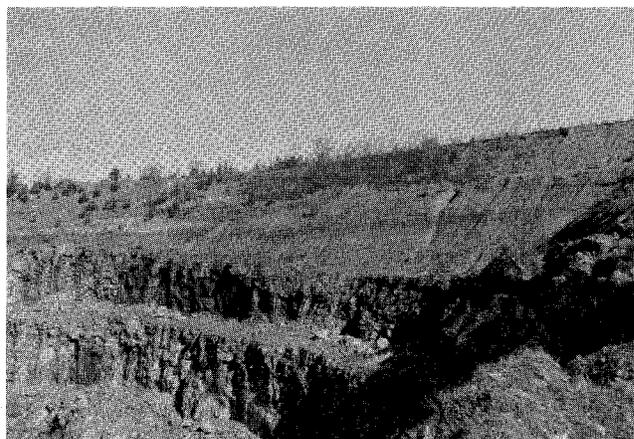


Figure 3. Coastal Plain sediments unconformably overlying crystalline Piedmont rocks.

## GEOLOGIC FEATURES

### Crystalline Rocks

Upon entering the quarry the most apparent feature observed is the crushed and broken fabric of the crystalline rocks. The gneisses are cut by three dominant joint systems, (N67W,V; N37E,V; and N66E,71N). Subsidiary fractures of various orientations are also common. The fault plane of a high-angle reverse fault is exposed in the north wall of the quarry and has an orientation of N12°E, and dips 43°E (Figure 4). This fault shows brittle deformation and is believed to closely reflect the regional orientation of the Hylas fault zone in this area. Fractures within this fault are filled with either calcite or quartz. At another location in the Hylas zone this brittle deformation has been dated from laumontite in vein fillings at 220 my. (Bobyarchick and others, 1976).

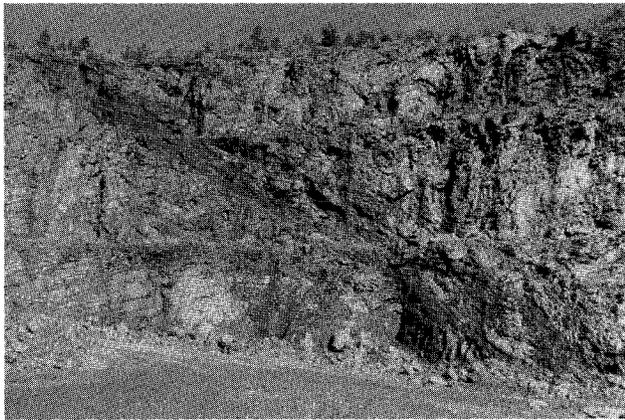


Figure 4. High-angle reverse fault exposed in the north wall of the Caroline Stone Company Quarry.

Table. Modal analyses in percent of seven samples selected from Caroline Stone Company Quarry (500 points counted).

MINERAL	SAMPLE NUMBER						
	C-1	C-2	C-3	C-4	C-5	C-6	C-7
Quartz	31.8	37.8	95.9	30.7	22.8	24.7	28.6
Plagioclase	10.9	47.8	3.5	36.5	45.9	25.4	44.6
Microcline	34.5	12.6	xx	5.5	10.1	4.9	22.7
Biotite	20.0	00.7	xx	14.7	10.5	xx	3.0
Calcite	00.7	00.8	00.4	00.8	xx	3.4	xx
Hornblende	xx	xx	xx	10.8	xx	31.5	xx
Chalcopyrite	00.3	00.1	xx	tr	xx	00.2	00.3
Leucoxene	00.2	tr	xx	00.2	00.3	00.5	xx
Sphene	xx	tr	xx	00.4	00.7	2.2	tr
Sericite	xx	tr	xx	00.2	tr	3.4	00.1
Garnet	00.9	xx	xx	xx	xx	xx	xx
Zircon	00.6	tr	xx	tr	xx	tr	tr
Pyrite	xx	xx	xx	tr	xx	00.1	xx

Within the quarry the dominant mineralogy is biotite-plagioclase-microcline-quartz-calcite  $\pm$  hornblende. Other mineral assemblages include microcline-plagioclase-quartz and quartz-plagioclase (Table). These minerals are contained within light-gray to light-green, medium- to coarse-grained rocks consisting of migmatitic biotite gneiss and biotite-hornblende gneiss. White plagioclase augen are conspicuous. Pink microcline forms large (10 to 20 cm) porphyroblasts. In thin section quartz is the most common mineral ranging from 23 to 95 percent of the total (Table). Quartz occurs as 0.1- to 2.0-mm undulose recrystallized grains, as granulated crush trains, and as inclusions within feldspar and garnet. Plagioclase feldspar is the second most abundant mineral (from 4 to 47 percent) and is found as 0.2- to 2.5-mm grains. It occurs as equant rounded porphyritic crystals that display saussuritization along cleavage planes. Polysynthetic twinning, though rare in the plagioclase, is kinked, twisted, and bent. The plagioclase is cloudy and in some instances displays undulose extinction. Microcline, inverted from orthoclase, occurs as equant grid-twinned perthitic grains intergrown with quartz and plagioclase. Biotite (0.0 to 20 percent, 0.05 to 0.5 mm) occurs as laths that have been altered to chlorite and leucoxene. Calcite is present as microcrystalline vein fillings. Hornblende is rare, but where it is present may locally make up 30 percent of the rock. Garnet when present occurs as 0.5-mm poikiloblastic grains. Accessory minerals include chalcopyrite and pyrite filling small fractures. Sphene and zircon crystals occur in trace amounts. Leucoxene and sericite occur as secondary alteration minerals in trace amounts.

## Sedimentary Rocks

### Aquia Formation

The Aquia Formation directly overlies the Piedmont rocks and consists of very fine-grained sand with trace amounts of glauconite. In most areas the Aquia is very glauconitic, but shoreward (westward) the percentage of glauconite decreases. The Aquia, eastward from this area, contains abundant shells, principally mollusks (Ward, 1984, 1986). At the Caroline quarry, the calcareous component in the Aquia, as in the other units, has been leached leaving only a few molds of mollusks.

The stratigraphic equivalency of the lower bed at the Caroline Stone Company Quarry with the more typically glauconitic sands of the upper Aquia was confirmed on the basis of dinoflagellates and pollen (L. E. Edwards and N. O. Frederiksen, personal communications, 1987, U. S. Geological Survey, Reston, Virginia). The unit, where the molluscan fossils are preserved, contains an assemblage common in upper Paleocene beds from New Jersey to Texas.

### *Nanjemoy Formation*

The Nanjemoy Formation at the Caroline Quarry unconformably overlies the Aquia Formation and consists of very glauconitic fine sand. It is, in turn, overlain by the Choptank Formation. During the Nanjemoy transgression crustaceans burrowed into the underlying Aquia and as a result the bottom parts of these burrows are filled by the sharply contrasting, dark green glauconitic sands. As with the Aquia, the Nanjemoy, eastward of this area, contains abundant molluscan fossils, but the calcareous fraction is leached out at the quarry site as it is in most updip areas. Pollen and dinoflagellate assemblages were identified within the unit to confirm its correlation with the upper Nanjemoy Formation (N. O. Frederiksen, personal communications). The upper Nanjemoy is considered to be early Eocene in age and ranges between 54.0 and 53.5 my old.

### *Choptank Formation*

The Nanjemoy is directly overlain by the basal, gravely coarse-grained sands of the Choptank Formation. This lag deposit of quartz and phosphate pebbles, shark teeth, and bone is about 4 feet thick and grades upward into clay material. Most of the upper portion of the Choptank is a compact, olive-brown, clayey silt which contains abundant marine diatoms. The presence of these diatoms indicate that the unit may be correlated with the Boston Cliffs Member of the Choptank Formation (G. W. Andrews, personal communications, U.S. Geological Survey, Reston, Va.). Basinward, to the east and northeast, the Boston Cliffs consists of shelly sands, but in its inner bay reaches, it grades laterally into a much finer-grained lithofacies. The upper Choptank is considered to be middle Miocene in age and is approximately 12.7 my old.

### *Eastover Formation*

Unconformably overlying the Choptank sediments at the quarry is the Claremont Manor Member of the Eastover Formation. The contact between the Choptank and Eastover is marked by a thin lag deposit of quartz and phosphate pebbles, shark teeth, and bone. The Eastover consists of a silty, fine-grained sand containing scattered molds and casts of mollusks. The mollusks permit certain correlation of this bed with the better-preserved, shelly facies of the Eastover in its type area along the James River in Surry County. The Eastover has been reported to be late Miocene in age and is approximately 7 to 8 my old (Ward and Blackwelder, 1980).

### *Yorktown Formation (?)*

On the north and south walls of the quarry, the Eastover Formation is overlain, apparently unconformably, by a coarse, cross-bedded sand containing clasts of pebble to cobble size. It is unclear whether this conglomerate is associated with the Eastover-Yorktown lowstand of the sea and later Yorktown transgression, or if it is a post-Yorktown depositional event. The unit does contain burrows which are traditionally associated with marine conditions. If the bed's correlation with the Yorktown Formation is correct, the unit can be assigned to the upper Pliocene and is approximately 3.0 my old.

### SUMMARY

The exposure of crystalline rocks and Coastal Plain sediments at the Caroline Stone Company quarry affords an excellent chance to view those units in an area where outcrops are rare to absent. This quarry site affords the geologist a chance to view fracture zones in crystalline rocks in an area where they are generally covered by Coastal Plain deposits. In addition, a series of marginal marine deposits in the inner Coastal Plain have been protected from the processes of erosion. This quarry exposes rocks ranging in age from approximately 1.0 My to approximately 3.0 my, which contain a rich assortment of both mineral and fossil assemblages.

### REFERENCES CITED

- Bobyarchick, A. R., Glover, Lynn III, Weems, R. E., and Goodwin, B. K., 1976, The Hylas "volcanic" rocks northwest of Richmond are cataclastically retrograded gneiss (abs.): Geological Society of America Abstracts with Programs, v. 8, p. 183.
- Glover, Lynn, III, Mose, D. G., Poland, F. B., Bobyarchick, A. R., and Bourland, W. C., 1978, Grenville basement in the eastern Piedmont of Virginia: implications for orogenic models (abs.): Geological Society of America Abstracts with Programs, v. 10, n. 4, p. 169.
- Hazel, J. E., Edwards, L. E., and Bybell, L. M., 1984, Significant unconformities and the hiatuses represented by them in the Paleogene of the Atlantic and Gulf Coastal Province, in Schlee, J. S., Interregional unconformities and hydrocarbon accumulation: American Association of Petroleum Geologists Memoir 36, p. 59-66.

- Marr, J. D., Jr., 1985, Geology of the crystalline portion of the Richmond 1° x 2° quadrangle, *in* Geology of portions of the Richmond 1° x 2° quadrangle: Guidebook for Seventeenth Annual Virginia Geological Field Conference, p. 1-22.
- Pavrides, Louis, Stern, T. W., Arth, J. G., Muth, K. G., and Newell, M. F., 1982, Middle and upper Paleozoic granitic rocks in the Piedmont near Fredericksburg, Virginia, *in* Geochronology: U.S. Geological Survey Professional Paper 1231-B, 9 p.
- Poland, F. B., 1976, Geology of the rocks along the James River between Sabot and Cedar Point, Virginia [M. S. Thesis]: Blacksburg, Virginia Polytechnic Institute and State University, 98 p.
- Ward, L. W., 1984, Stratigraphy of outcropping Tertiary beds along the Pamunkey River—Central Virginia Coastal Plain, *in* Ward, L. W. and Krafft, Kathleen eds., Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, Central Virginia Coastal Plain—Guidebook for Atlantic Coastal Plain Geological Association 1984 field trip: Atlantic Coastal Plain Geological Association, p. 11-77, 240-280, pls. 1-12.
- \_\_\_\_\_ 1986, Stratigraphy and characteristic mollusks of the Pamunkey Group (lower Tertiary) and the Old Church Formation of the Chesapeake Group—Virginia Coastal Plain: U. S. Geological Survey Professional Paper 1346, 78 p., 6 pls.
- \_\_\_\_\_ 1987, Stratigraphy of Tertiary beds along the Pamunkey River, Virginia, *in* Johnson, G. H., Goodwin, B. K., Ward, L. W., and Ramsey, K. W., Tertiary and Quaternary stratigraphy across the Fall Zone and western Coastal Plain, Southern Virginia: Geological Excursions in Virginia and North Carolina, Geological Society of America, Guidebook for Field Trips, Trip no. 3, p. 100-119, pls. 1-13.
- \_\_\_\_\_ and Blackwelder, Blake W., 1980, Stratigraphic revision of upper Miocene and lower Pliocene beds of the Chesapeake Group, middle Atlantic Coastal Plain: U. S. Geological Survey Bulletin 1482-D, 60 p., 5 pls.

## CARBONATE MATERIALS SUITABLE FOR DESULFURIZATION OF FLUE GAS

Palmer C. Sweet,  
Oliver M. Fordham, Jr., and  
William F. Giannini

Industrial plants that utilize coal as a fuel emit sulfur dioxide (SO<sub>2</sub>) gas from the decomposition of sulfide minerals during combustion. The use of coal containing higher sulfur as fuel results in an increased amount of SO<sub>2</sub> emitted into the atmosphere. Regulatory agencies have moved to reduce SO<sub>2</sub> emissions because of environmental and health concerns. In the United States coal fired boilers of greater than 250 million BTU capacity are required by the Environmental Protection Agency not to exceed a stack emission of 1.2 pounds of SO<sub>2</sub> per million BTU capacity. Coal fired boilers of less than 250 million BTU capacity are regulated by the states. Virginia regulations follow the Code of the Federal Register, Part 60, Sections 60.43 and 60.43a (N. S. Saylor, 1988, personal communication). Two systems utilizing carbonate material (limestone, quicklime) to aid in removing SO<sub>2</sub> gas from stack emissions are presented: (1) the fluidized bed combustion system and (2) the scrubber system.

### FLUIDIZED BED COMBUSTION SYSTEM

The fluidized bed combustion or AFBC (atmospheric fluidized bed combustion) process is depicted in Figure 1. This process originated in Germany in the 1920 s. Virginia Power noted in October, 1987, that of the various methods of controlling smoke stack emissions, the most promising was atmospheric fluidized bed combustion. The process involves burning crushed coal in a bed of limestone particles that are held in suspension by the upward flow of air entering a chamber through a perforated air distribution grid below the fluidized bed. The following description of the process is modified from TVA (1985). Crushed limestone is placed in the bed on the air distribution grid (Figure 1a) and the bed is fluidized by injecting air through the grid to form a suspended mass closely resembling a boiling liquid (Figure 1b). Oil is injected into the bed simultaneously with

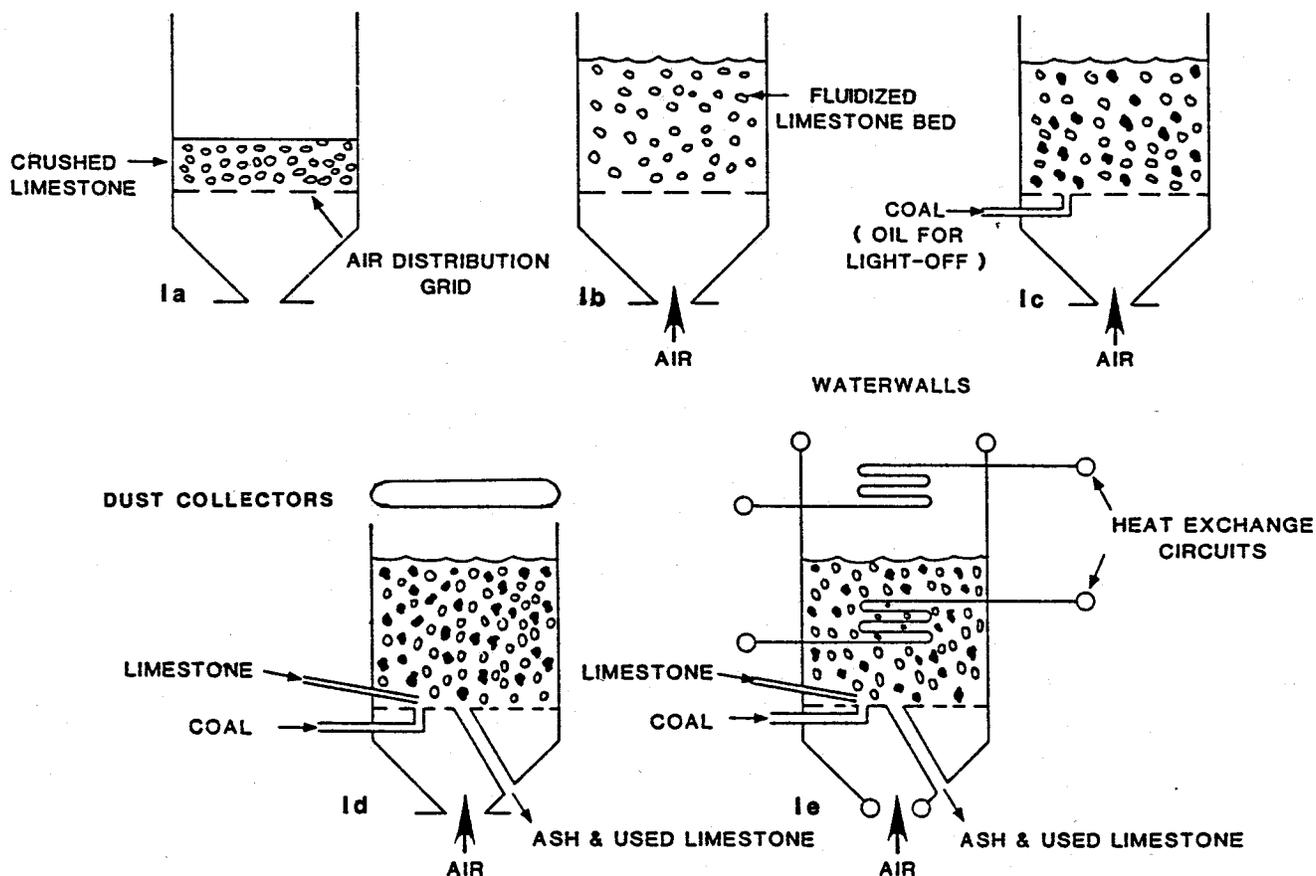


Figure 1. Fluidized bed combustion process. Source: Tennessee Valley Authority.

crushed coal to heat the bed material to ignition temperature (Figure 1c). After light-off, crushed coal and limestone are continuously fed into the combustion chamber (Figure 1d). During combustion, sulfur in the coal combines with available CaO or MgO from the limestone. This reaction removes the majority of the sulfur dioxide gas from the combustion products that are released into the atmosphere. Coarse sulfate materials settle to the bottom and pass through grates while the fines are captured in dust collectors. The dry residue material from the grates is potentially usable as an agricultural supplement, road base filler, or cement additive (TVA, 1985). Steam is produced in tubing located in the fluidized bed and above the bed (Figure 1e). The steam flows to a turbine generator that produces electricity.

#### SCRUBBER SYSTEM

In scrubbers finely ground limestone, wet or dry, is injected above the combustion zone and captures the sulfur in a manner similar to the fluidized bed combustion process but without forced air. This is also referred to as FGD (flue gas desulfurization) system or removal of sulfur after combustion.

#### LABORATORY TEST RESULTS

Two of the most commonly used materials for sulfur removal are limestone (52%) and quicklime (33%) (Bhagwat, 1985). Other carbonate materials account for the remaining 15 percent. Testing performed by EPA at a scrubber test facility at TVA's Shawnee Power Plant, Muscle Shoals, Alabama indicates that for SO<sub>2</sub> scrubbers, a limestone containing greater than 90 percent CaCO<sub>3</sub> with less than 5 percent MgCO<sub>3</sub> and ground to 90 percent passing 325 mesh is suitable for scrubbing. J. L. Harness (1987, personal communication), notes that original specifications used in a coal-fired AFBC electric plant were as follows: a minimum of 88 percent CaCO<sub>3</sub>, a maximum of 3 percent MgCO<sub>3</sub>, and a maximum of 5 percent moisture. Experiments indicate that oolitic limestones react faster. Particle size appears to be as important as chemical composition in removing sulfur dioxide gas. The Westinghouse Research and Development Center, Pittsburgh, Pennsylvania tested 12 limestones and dolomites from Ohio and all were determined to be acceptable as a fluidized bed combustion sulfur sorbent. Other testing for suitability of carbonate materials have been conducted by the Illinois Geological Survey and Georgetown University.

The October 22, 1984 edition of *Coal News* stated that Consolidation Coal Company and its research arm, Conoco Coal Research Division, have tested several limestone injection methods at a DuPont Company facility in Martinsville, Virginia for reducing sulfur dioxide during combustion of high-sulfur coal from northern West Virginia. High-calcium limestone from Virginia was injected into the combustion chamber. Fifty percent reduction of SO<sub>2</sub> gas was achieved during testing and there was no adverse impact on boiler performance (Fink and Hassell, 1984). Costs of SO<sub>2</sub> removal are dependent on factors such as limestone sources, disposal of solid by-products, and existing air-pollution regulations.

VIRGINIA STUDY

Fifteen representative carbonate samples were collected from selected quarries and pits in the Valley and Ridge Province of Virginia (Figure 2). Seven of the samples are from active mineral producers and eight are from inactive operations. An additional sample (Sample A) was evaluated to graphically illustrate a material that did not meet the chemical requirements (Figure 3). Chemical analyses for ten elements (Table 1) were conducted on the samples by X-ray fluorescence. The samples were also evaluated by the SO<sub>2</sub> reactivity method (Table 2) to determine their suitability as a medium for removing SO<sub>2</sub> gases from the combustion products produced at the coal burning facilities (Table 3).

In the SO<sub>2</sub> reactivity test the following procedure utilized by TVA was used (Table 2).

Table 2. SO<sub>2</sub> reactivity test procedure. Source: Tennessee Valley Authority

Step	Action
1.	Dry at least 30 grams of finely ground carbonate at 105°C for 1 hour. Particle size should be 90% passing 200 mesh with 75% of that material passing 325 mesh.
2.	Weigh out 20.0 grams of dried carbonate.
3.	Slurry the weighed carbonate in 2 liters of distilled water for at least 5 minutes. Use a magnetic stirrer with speed adjusted to medium. Control slurry temperature at 52°C.
4.	Connect the pH meter to a strip chart recorder and adjust pen displacement full chart to correspond to 0.0 pH to 14.0 pH units — set chart speed to 1 inch/min.
5.	Immerse the pH electrode in the slurry. When pH reaches a maximum value, add approximately 45 ml/min SO <sub>2</sub> to the slurry.
6.	Record the time (time = 0 when SO <sub>2</sub> is injected) it takes for the pH to reach 7.0 and decrease in 0.2 increments to 4.5.
7.	The run is completed when pH reaches 4.5.

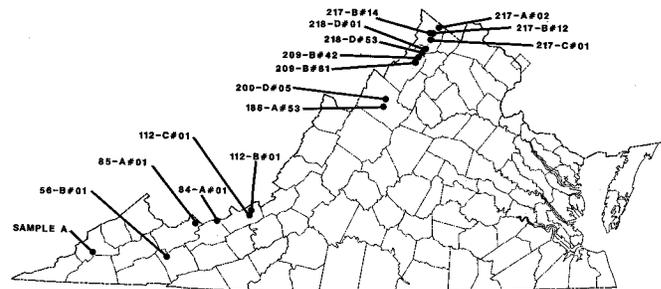


Figure 2. Locations of samples tested for SO<sub>2</sub> reactivity.

Table 1. Chemical analyses of carbonate samples (in percent).

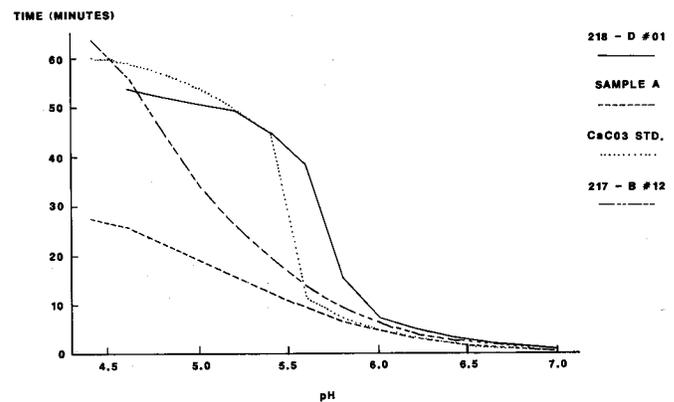
Sample	County	Quadrangle	U.T.M. Location	Formation/ (Deposit)	CaCO <sub>3</sub>	Mg CO <sub>3</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	S
218-D#01	Frederick	Middletown	N4,323,880 E733,160	New Market	99.43	.00	.26	.04	.08	.04	.09	.00	.02	.03
217-A#02	Frederick	Stephenson	N4,347,740 E750,560	New Market	99.33	.00	.36	.07	.12	.04	.00	.01	.07	.01
217-B#12	Frederick	Winchester	N4,344,820 E745,070	(Marl)	96.69	.30	2.01	.20	.44	.15	.00	.03	.12	.05
217-B#14	Frederick	Winchester	N4,344,260 E744,940	(Travertine)	97.08	1.69	.76	.09	.18	.06	.00	.01	.10	.03
217-C#01	Frederick	Stephens City	N4,331,240 E739,880	New Market	98.80	.44	.39	.07	.14	.06	.05	.01	.03	.01
218-D#53	Shenandoah	Middletown	N4,322,400 E731,950	New Market	98.85	.62	.25	.03	.09	.04	.09	.01	.00	.01
209-B#42	Shenandoah	Toms Brook	N4,318,030 E725,980	New Market	98.72	.30	.59	.07	.20	.08	.04	.01	.00	.00
209-B#61	Shenandoah	Toms Brook	N4,313,840 E722,180	New Market	98.34	.56	.63	.10	.21	.09	.06	.01	.00	.00
200-D#05	Rockingham	Broadway	N4,266,050 E688,750	New Market	98.51	.93	.30	.06	.12	.05	.01	.01	.02	.00
188-A#53	Rockingham	Harrisonburg	N4,258,770 E690,190	New Market	98.02	.82	.71	.08	.23	.07	.00	.01	.05	.01
112-B#01	Giles	Lindside	N4,136,900 E530,570	Mosheim	96.34	1.94	1.09	.14	.28	.12	.04	.02	.00	.04
112-C#01	Giles	Pearisburg	N4,135,280 E529,250	Five Oaks	97.18	1.62	.74	.10	.21	.09	.04	.01	.00	.01
84-A#01	Bland	Rocky Gap	N4,120,680 E491,970	Mosheim	90.57	4.93	3.13	.42	.61	.17	.00	.04	.01	.12
85-A#01	Tazewell	Cove Creek	N4,120,350 E469,890	Mid. Ord. Carbonates	93.83	2.68	1.92	.35	.77	.30	.09	.04	.01	.00
56-B#01	Smyth	Broadford	N4,081,660 E440,100	Effna	97.79	1.09	.54	.11	.22	.08	.02	.01	.13	.00

Table 3. SO<sub>2</sub> reactivity test results.

Sample	County	Formation/ (Deposit)	Initial pH	Time in minutes to reach pH values														
				7.0	6.8	6.6	6.4	6.2	6.0	5.8	5.6	5.4	5.2	5.0	4.8	4.6	4.5	
218-D#01	Frederick	New Market	9.15	1.01	1.47	2.17	3.26	4.93	7.28	15.48	38.02	44.80	44.92	50.46	52.08	53.73	54.56	
217-A#02	Frederick	New Market	9.15	1.02	1.42	2.07	3.01	4.59	6.55	12.26	24.02	39.25	44.48	48.17	51.31	53.36	54.36	
217-B#12	Frederick	(Marl)	9.00	0.92	1.32	1.82	2.67	3.87	6.36	9.20	13.49	19.28	26.04	34.10	44.81	56.33	63.59	
217-B#14	Frederick	(Travertine)	9.00	0.87	1.29	1.78	2.55	3.87	5.93	9.11	13.36	19.35	26.74	35.05	43.48	55.41	61.15	
217-C#01	Frederick	New Market	9.15	0.86	1.24	1.82	2.74	4.18	6.17	9.92	19.69	32.46	38.14	42.19	45.42	48.34	49.54	
218-D#53	Shenandoah	New Market	9.15	0.97	1.41	2.15	3.19	4.69	6.89	13.99	28.97	40.40	45.40	49.29	52.40	54.67	55.69	
209-B#42	Shenandoah	New Market	9.15	1.09	1.55	2.25	3.41	5.15	7.28	13.89	26.69	36.70	39.70	44.97	48.04	50.93	52.11	
209-B#61	Shenandoah	New Market	9.15	0.85	1.25	1.81	2.63	3.89	5.60	7.96	12.67	21.45	27.44	31.48	34.91	37.83	39.21	
200-D#05	Rockingham	New Market	9.25	1.02	1.57	2.38	3.64	5.25	7.67	10.97	27.62	38.27	43.32	47.38	50.49	53.13	54.26	
188-A#53	Rockingham	New Market	9.15	0.94	1.40	2.04	2.90	4.49	6.99	13.56	29.03	40.46	44.99	47.70	50.03	52.05	53.12	
112-B#01	Giles	Mosheim	9.15	0.85	1.18	1.73	2.51	3.80	5.42	7.78	11.50	19.27	23.59	27.63	30.85	33.55	34.58	
112-C#01	Giles	Five Oaks	9.05	0.87	1.21	1.74	2.58	3.86	5.68	8.21	12.76	20.03	24.72	28.54	32.27	34.73	36.08	
84-A#01	Bland	Mosheim	9.10	0.87	1.30	1.89	2.72	4.03	6.04	8.65	12.51	20.47	26.13	30.50	33.38	36.80	38.28	
85-A#01	Tazewell	Mid. Ord. Carbonates	9.20	0.87	1.31	1.83	2.70	4.03	5.54	7.93	10.57	18.49	25.06	29.62	33.55	36.57	38.56	
56-B#01	Smyth	Effna	9.05	0.71	1.08	1.50	2.18	3.33	5.18	6.74	9.09	15.69	25.61	32.02	36.24	40.12	41.49	
Standard	J.T. Baker CaCO <sub>3</sub>		9.00	0.56	0.86	1.29	2.01	2.91	4.75	7.09	10.77	44.36	49.56	53.70	56.79	58.85	59.75	

### REACTIVITY TEST RESULTS

Table 3 presents the results of the SO<sub>2</sub> reactivity test and indicates the time it takes for individual samples to reach 4.5 pH as SO<sub>2</sub> is continually added to the carbonate slurry. In general the longer it takes for a sample to reach a lower pH, the better the reactivity of the carbonate material. However the slope of the reaction curve is often modified by the presence of clay and carbonaceous material in the samples. The reactivity of three carbonate samples plus an additional Sample A is graphically illustrated in Figure 3. Sample A, from the Greenbrier Limestone in Wise County, contains less than 90 percent CaCO<sub>3</sub> and more than 5 percent MgCO<sub>3</sub> and is the least reactive of the samples. The smooth reaction curve is due to SO<sub>2</sub> absorption by clay and carbonaceous material in the sample which modifies the normal break in slope between pH 5 and 6 that is found in the plots for the high-calcium limestones. Sample 217-B #12, a marl from Frederick County, containing clay and carbonaceous material is also represented by a smooth upward trending reaction curve. Both sample 218-D #01 and the J. T. Baker CaCO<sub>3</sub> standard produce curves which have a noticeable upward break in slope between pH 5 and 6. At that point the CO<sub>2</sub> is being liberated and the material is very reactive. The majority of the samples from the high-calcium New Market Limestone appear to be very reactive with a time of more than 52 minutes, as noted in Table 3.

Figure 3. SO<sub>2</sub> reactivity curves.

### REFERENCES CITED

- Fink, E. E. and Hassell, T. J., 1984, Demonstration of boiler limestone injection in an industrial boiler: Presentation to EPA/EPRI, San Diego, California, 19 p.
- Bhagwat, S. B., 1985, The lime and limestone market for sulfur removal: potential for 1992: Illinois State Geological Survey Division Mineral Notes 90, 13 p.
- Tennessee Valley Authority, 1985, Atmospheric fluidized bed combustion: Summary Briefing by Tennessee Valley Authority, April 29, 1985, 110 p.

## MINERALS IN HIGH-LEVEL GRAVEL DEPOSITS ALONG THE FALL ZONE OF VIRGINIA

C. R. Berquist

Beginning in 1985, the Virginia Division of Mineral Resources (VDMR) and the Virginia Institute of Marine Science (VIMS) have cooperated in investigations of the heavy minerals in sediments beneath offshore Virginia waters. Partial funding for this work was provided by the Minerals Management Service and the Commonwealth of Virginia (Subaqueous Minerals and Materials Study Commission). Anomalously high concentrations were reported from offshore (Goodwin and Thomas, 1973; Grosz and Escowitz, 1983), and mineral abundances from these reports were verified by analysis of samples collected from recently acquired vibracores and grab samples (Berquist and Hobbs, 1986; Berquist and Hobbs, in preparation).

High concentrations of heavy minerals were observed in the high-level "gravels" along the Fall Zone from Ashland to the Virginia-North Carolina boundary during the regional geologic mapping of the Virginia Coastal Plain (Figure 1; Berquist and others, in preparation). Watson and Hess (1913) reported high zircon concentrations in high-level gravel deposits in the Ashland area. Because of the capability at VIMS to process large volumes of heavy minerals, ten samples were collected from gravel deposits along the fall zone and processed. The 7051-series samples (Tables 1 and 2; Figures 2, 3, 4, and 5) were taken from sediments correlative with "sg" (sand and gravel) on the Bon Air quadrangle (Goodwin, 1980) and "g2" (sand and gravel) on the Glen Allen quadrangle (Goodwin, 1981). The 7071-series samples were taken from sediments



Figure 1. Map showing the location of sampled areas; 1: 7071 series samples; 2: 7051 series samples.

mapped as "g1" on the Hanover Academy quadrangle (Figure 6; Weems, 1981). The depositional environment of the high-level "gravels", based on texture and primary sedimentary structures, is interpreted as fluvial to nearshore marine. The age of the deposits is probably Tertiary based on the stratigraphic position.

### METHODS

Large-volume (6.2 to 28.6 lbs) channel samples were acquired by hand auger in fields or by shovel in roadcuts. Sample grain-size distribution and other characteristics are presented in Table 1. The details on sample processing will be included in a report anticipated to be released in December, 1987 (Berquist and Hobbs, in preparation).

Table 1. RHM, THM, and grain size percentages; dry weight; and sampled interval; mud - material passing through the 230 mesh screen; gravel - material retained on the 10 mesh screen.

Sample	% RHM	% THM	% mud	% sand	% gravel	dry wt (lbs)	Sample Source
7051-1	1.9	2.2	19	81	0	20.0	5' augered hole
7051-2	7.5	9.6	13	87	0	26.2	0- 6' augered hole
7051-3	6.7	7.7	17	83	0	19.4	6-10' augered hole
7051-4	14.0	14.6	9	91	0	28.6	5' channel
7051-5	0.1	0.2	22	78	0	17.4	3' augered hole
7051-6	3.0	4.4	19	80	1	21.3	3' augered hole
7051-7	2.9	3.9	16	84	0	19.4	7' channel
7071-1	0.2	0.4	23	75	2	24.6	5' augered hole
7071-2A	0.2	0.5	27	73	0	6.2	2' augered hole
7071-2B	0.6	1.1	13	87	0	15.6	100' along field surface

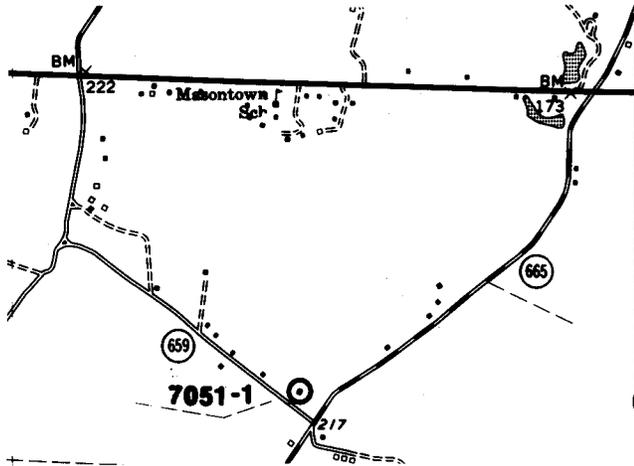


Figure 2. Location map (Cherry Hill 7.5-minute quadrangle) for sample 7051-1.

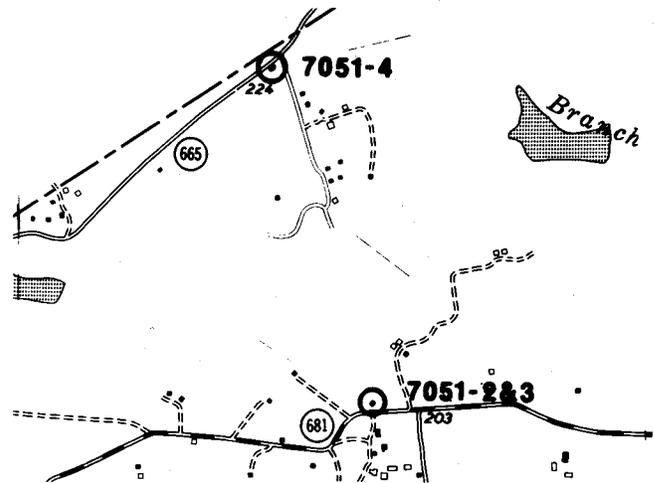


Figure 3. Location map (Cherry Hill 7.5-minute quadrangle) for samples 7051-2, -3, and -4.

Table 2. Mineral composition of the heavy mineral fraction of samples.

SAMPLE	WT% MAG	WT% IL	WT% GAR	WT% EP	WT% STAU	WT% AMPHIB	WT% PYROX	WT% RUTILE	WT% SILL/KY	WT% SPHENE
7051-1	1.17	48.91	0.67	0.00	6.93	0.00	0.00	2.99	3.30	0.11
7051-2	3.77	55.02	0.26	0.00	2.09	0.00	0.20	1.00	1.28	0.02
7051-3	2.07	41.75	0.11	0.00	3.24	0.00	0.27	3.87	3.34	0.11
7051-4	2.38	59.82	1.60	0.16	4.72	0.16	0.10	2.71	0.62	0.13
7051-5	2.07	22.74	0.15	1.02	5.92	0.73	0.10	5.66	8.84	0.00
7051-6	2.90	51.63	0.09	0.00	4.24	0.19	0.23	2.56	2.18	0.00
7051-7	3.48	54.51	0.00	0.00	3.34	0.00	0.00	2.28	2.13	0.05
7071-1	2.56	30.23	0.15	0.22	4.38	0.31	0.22	7.31	5.86	0.86
7071-2A	3.20	50.10	0.29	0.54	6.19	0.18	0.24	4.67	2.48	0.86
7071-2B	1.62	25.56	0.29	0.46	3.89	0.00	0.15	10.29	10.77	0.37
AVERAGE	2.52	44.03	0.36	0.24	4.49	0.16	0.15	4.34	4.08	0.25
STD. DEV.	0.83	13.28	0.47	0.34	1.49	0.23	0.10	2.78	3.36	0.34
MAX VAL.	3.77	59.82	1.60	1.02	6.93	0.73	0.27	10.29	10.77	0.86
MIN VAL.	1.17	22.74	0.00	0.00	2.09	0.00	0.00	1.00	0.62	0.00

Table 2. Continued.

SAMPLE	WT% TOURM	WT% LEUCOX	WT% MONAZITE	WT% ZIRCON	WT% OTHER	WT% ECON	WT% THM	WT% RHM
7051-1	0.00	12.62	0.87	16.97	5.33	0.86	2.23	1.93
7051-2	0.00	9.21	0.86	13.42	12.67	0.81	9.55	7.51
7051-3	0.00	17.88	0.00	21.07	6.18	0.88	7.70	6.67
7051-4	0.02	6.13	0.45	13.55	7.47	0.83	14.56	14.01
7051-5	1.07	17.04	0.10	13.90	20.65	0.68	0.23	0.09
7051-6	0.09	10.67	0.29	10.51	14.32	0.78	4.40	3.04
7051-7	0.00	10.99	0.24	8.39	14.19	0.79	3.93	2.93
7071-1	0.10	11.75	0.51	23.70	11.85	0.79	0.38	0.20
7071-2A	0.60	11.30	0.00	7.55	10.92	0.76	0.50	0.25
7071-2B	0.84	15.83	0.00	25.69	4.23	0.88	1.12	0.65
AVERAGE	0.27	12.34	0.33	15.48	10.78	0.81	4.46	3.73
STD. DEV.	0.41	3.64	0.33	6.27	5.07	0.06	4.77	4.48
MAX VAL.	1.07	17.88	0.87	25.69	20.65	0.88	14.56	14.01
MIN VAL.	0.00	6.13	0.00	7.55	4.23	0.68	0.23	0.09

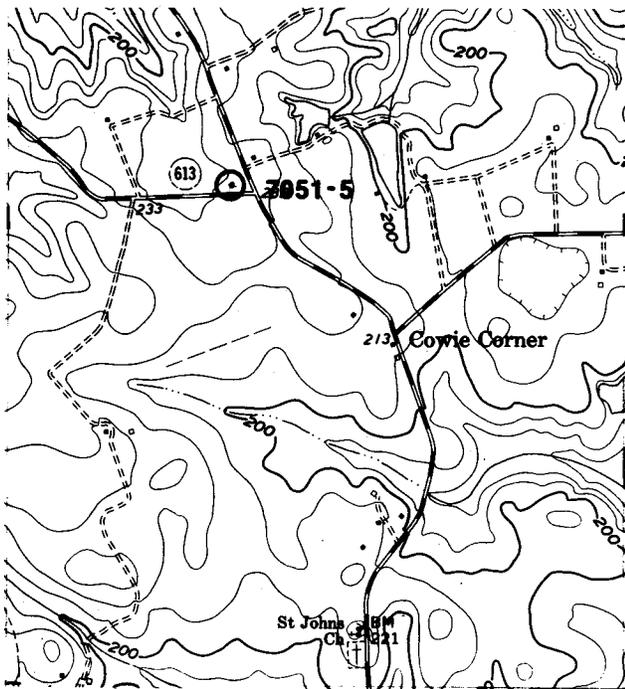


Figure 4. Location map (Purdy 7.5-minute quadrangle) for sample 7051-5.

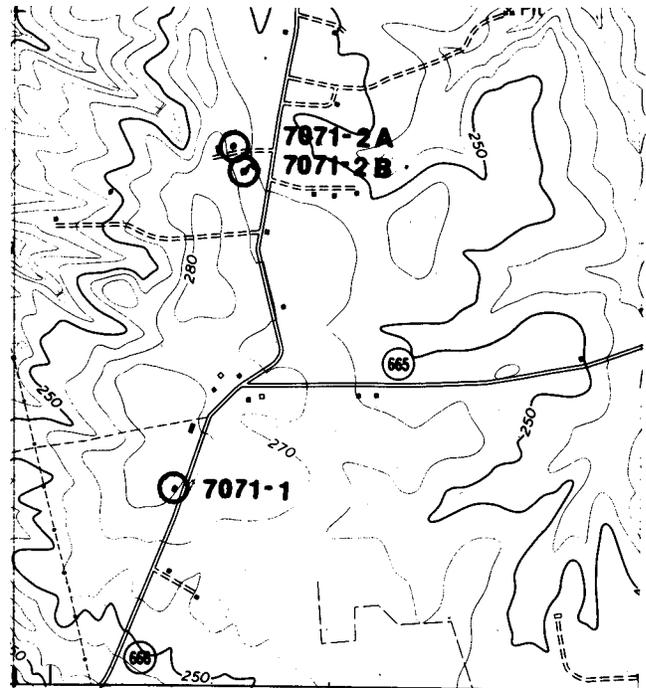


Figure 6. Location map (Hanover Academy 7.5-minute quadrangle) for samples 7071-1, -2A, and -2B.

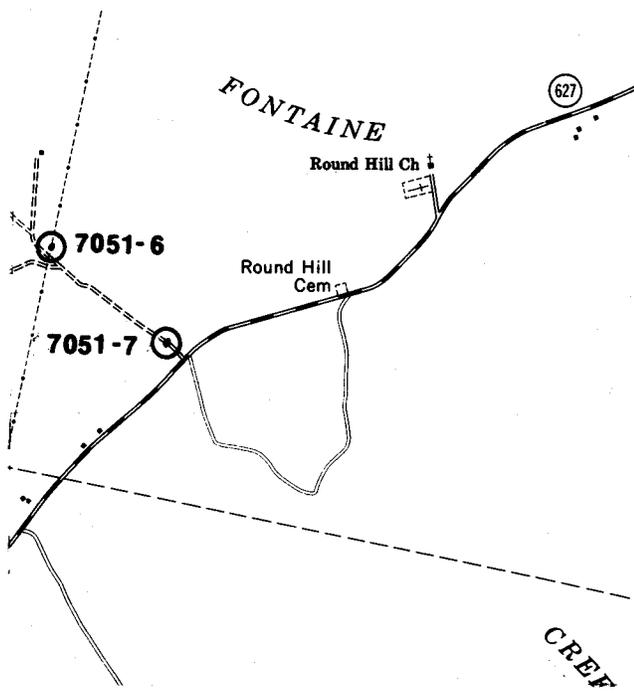


Figure 5. Location map (Emporia 7.5-minute quadrangle) for samples 7051-6 and -7.

### RESULTS

Table 2 presents the mineral composition of the samples. Minerals observed but not listed in Table 2 are collectively included in the category "other". "ECON" is the sum of concentrations of ilmenite, leucoxene, rutile, zircon, monazite, and sillimanite/kyanite. Recovered heavy minerals (RHM) is the amount recovered during processing; total heavy minerals (THM) is determined by adding the calculated amount of light minerals discarded during processing to RHM. "Magnetite" may contain an unspecified fraction of titano-magnetite.

Ilmenite, rutile, leucoxene, zircon, and THM concentrations in several samples are very high. Garner (1976, p. 34) notes that the composition of a potentially economic ore would have the following mineral percentages in the heavy mineral fraction (THM): 45 percent ilmenite, 5 percent leucoxene, 2 percent rutile, and 5 percent zircon. The lateral and vertical persistence of these concentrations within the high-level "gravels" is unknown; however, the thickness of the "sg" unit ranges up to 80 feet in thickness (Goodwin, 1981). The regional geologic map of the Coastal Plain (Berquist and others, in preparation) can be used as a guide for further investigation.

Postmaster:  
Send address corrections to —  
Virginia Division of Mineral Resources  
Box 3667  
Charlottesville, VA 22903

Virginia Minerals  
Second-class postage paid at  
Charlottesville, Virginia  
ISSN 0042-6652

#### ACKNOWLEDGMENTS

The processing and analysis of the samples would not have been possible without the assistance of VIMS personnel and laboratory facilities. The author would like to thank Woody Hobbs, Cindy Fischler, Steve Skrabal, Sarah Dydak, and Lauro Calliari for their assistance. George Burbank of Hampton University made heavy-liquid and magnetic separations as part of the sample preparation procedure.

#### REFERENCES CITED

- Berquist, C.R., Jr., and Hobbs, C.H., III, 1986, Assessment of economic heavy minerals of the Virginia Inner Continental Shelf: Virginia Division of Mineral Resources Open-File Report 86-1, 17p.
- Berquist, C.R., Jr., and Hobbs, C.H., III, in preparation, Assessment of heavy minerals of the Virginia Inner Continental Shelf: Virginia Division of Mineral Resources.
- Berquist, C.R., Mixon, R.B., and Newell, W.L., in preparation, Geologic map of the Coastal Plain of Virginia: Virginia Division of Mineral Resources.
- Garner, T.E., Jr., 1976, Geological classification and evaluation of heavy mineral deposits, in Twelfth forum on the geology of industrial minerals: Georgia Department of Natural Resources Information Circular 49, p. 25-36.
- Goodwin, B.K., 1980, Geology of the Bon Air quadrangle, Virginia: Virginia Division of Mineral Resources Publication 18, text and 1:24,000 scale map.
- Goodwin, B.K., 1981, Geology of the Glen Allen quadrangle, Virginia: Virginia Division of Mineral Resources Publication 31, text and 1:24,000 scale map.
- Watson, T.L., and Hess, F.L., 1913, Zirconiferous sandstone near Ashland, Virginia: U.S. Geological Survey Bulletin 530, p. 165-171.
- Weems, R.E., 1981, Geology of the Hanover Academy quadrangle, Virginia: Virginia Division of Mineral Resources Publication 30, text and 1:24,000 scale map.