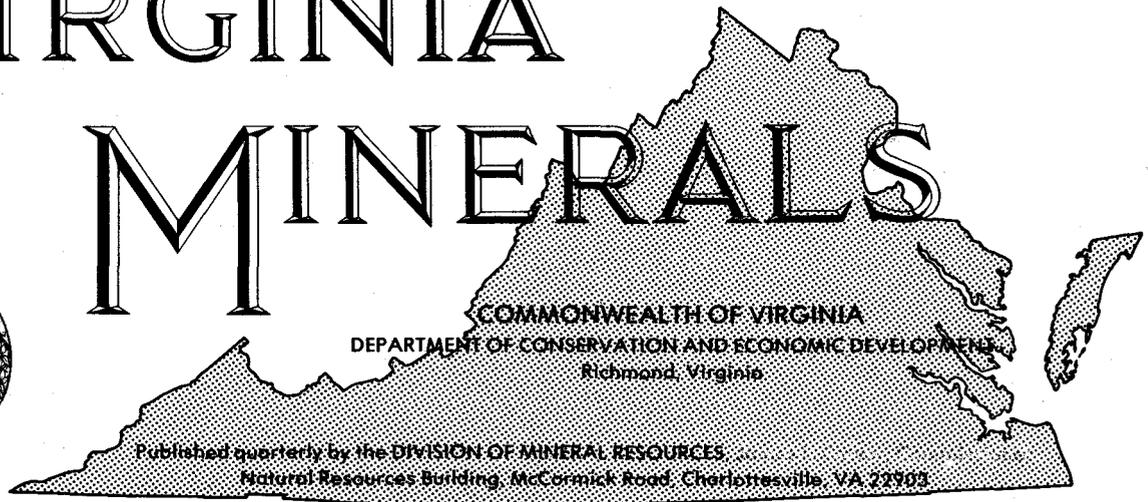


VIRGINIA

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SEISMIC HAZARD IN VIRGINIA

G. A. Bollinger¹

With respect to its sister states, Virginia has an intermediate level of earthquake risk. It is not as aseismic as South Dakota or as seismically active as California. Virginia has experienced moderate (magnitude ≤ 5.8) earthquakes within her borders in the historic past as well as being affected by larger earthquakes centered in South Carolina (magnitude = 6.6-6.9) and in Missouri (magnitude ≤ 7.3). The State's earthquake activity during the past several decades has been low but persistent. During the current decade (1968-78), Virginia residents have felt the vibrations from 15 small (magnitude ≤ 3.5) shocks. This continuing seismic activity, plus the record from the past, indicates the need for both preparedness and surveillance.

MEASURES OF EARTHQUAKE SIZE

To consider earthquake history and seismic risk, it is necessary to understand the two measures of earthquake size—magnitude and intensity. The former is well-known and often called the "Richter magnitude" after the California Institute of Technology professor that developed the scale. It is a quantitative measure of the energy released as seismic waves by an earthquake. Because it contains a distance-correction term, determinations at different observatories should, with-

in experimental error, be the same for a given earthquake. There is *only one magnitude number associated with each shock*. The magnitude scale is logarithmic and thus each increase of one unit corresponds to a tenfold increase in ground vibration amplitudes. In a very approximate manner, damage is slight at the 4.5 magnitude level, becomes moderate at the 5.5 level, and from 6.5 up can be considerable to great.

The intensity measure of earthquake size is qualitative and intended to specify the severity of the earthquake motion at a given point by its effect on people, structures and the landscape at that point. It will be largest near the epicenter and decrease with distance away from that location. Thus, there are *several intensity numbers associated with each shock*. As a general rule only the maximum of these is listed in earthquake catalogs. A typical application of intensity data is to plot the values for a given earthquake at their appropriate locations on a map and then to contour these values. The resulting map, that depicts the areas which experienced the same levels of shaking, is termed an isoseismal map or an intensity map.

The intensity scale used in the United States is called the Modified Mercalli Scale and has 12 degrees, ranging from I (felt by only a few people under especially favorable circumstances) to XII (total damage). By convention, Roman numerals are used to denote intensity and Arabic numbers for magnitude. Damage begins at about the intensity VI level. Table 1 contains a listing of the intensity VI-X effects and has the estimated magnitude range expected for each of those levels.

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Table 1. Modified Mercalli Scale, intensities VI through X.

Intensity	Description of Effects	Magnitude
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	4.5-5.0
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving automobiles.	5.0-5.7
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, some partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving automobiles disturbed.	5.7-6.3
IX	General panic. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, some partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	6.5+
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water thrown over banks on canals, rivers, etc. Serious damage to dams, dikes, and embankments.	

Currently magnitude and intensity are determined for each earthquake. However, prior to the 1950's there were too few seismographs in the eastern United States to make magnitude calculations. Thus, most of the historical data base consists of only intensity data. Modern data has been used, however, to infer magnitudes for the older shocks.

EARTHQUAKE HISTORY OF VIRGINIA

During the period 1774-1970, some 128 Virginia earthquakes have been cataloged (Bollinger, 1975). A thorough search of archival data sources (journals, diaries, newspapers, etc.) resulted in a detailed listing of the effects at specific Virginia localities for 100 of those shocks (Hopper and Bollinger, 1971; Bollinger and Hopper, 1972). The largest earthquake known to have occurred in Virginia was in Giles County on

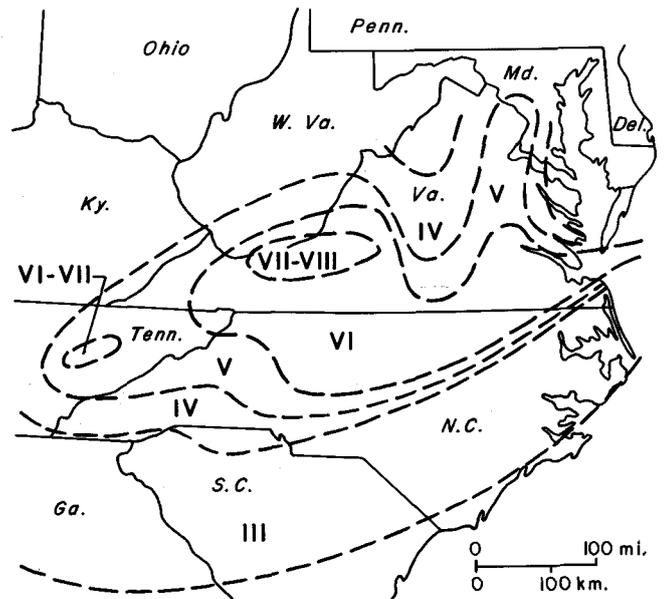


Figure 1. Isoseismal map for the Giles County, Virginia earthquake of May 31, 1897.

May 31, 1897. That shock was felt in portions of 12 states over an area of at least 280,000 square miles (Hopper and Bollinger, 1971, 1972; Figure 1). Its maximum intensity was VIII and the magnitude has recently been estimated to have been 5.8 (Nuttli, Bollinger and Griffiths). Effects in the epicentral area (Pearisburg) were structural damage to some brick buildings, rock slides and landslides (in one instance derailing a freight train) and muddying of springs and creeks. There was considerable fright among the people of the region but no reported injuries or deaths. Hundreds of people in Richmond and Norfolk left their homes in alarm.

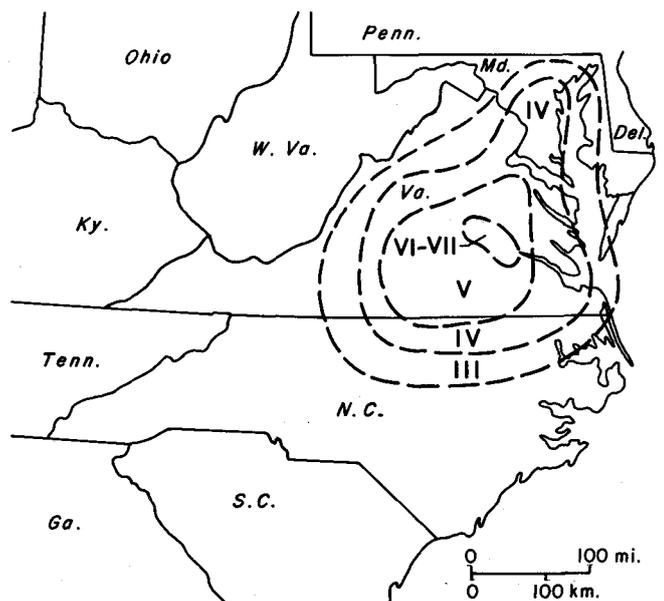


Figure 2. Isoseismal map for the Chesterfield County, Virginia earthquake of December 22, 1875.

The second largest earthquake in Virginia was on December 22, 1875 in Chesterfield County (Hopper and Bollinger, 1971, 1972; Figure 2). It was felt over 50,000 square miles and had an intensity of VII and an estimated magnitude of 5.0 (Nuttli, Bollinger and Griffiths). Effects noted were trembling of large buildings, awakening and frightening many people, broken windows, chimney and plaster damage and waves at the James River Dock that caused several craft to part their cables and drift down stream from the wharf.

The most recent earthquake to cause damage in Virginia was on November 19, 1969, and centered just across the State line at Glen Lyn near Elgood, a small West Virginia community (Bollinger and Hopper, 1970; von Hake and Cloud, 1969). Its magnitude was 4.6 and the felt area was 125,000 square miles (Figure 3). The effects in Glen Lyn were: many windows,

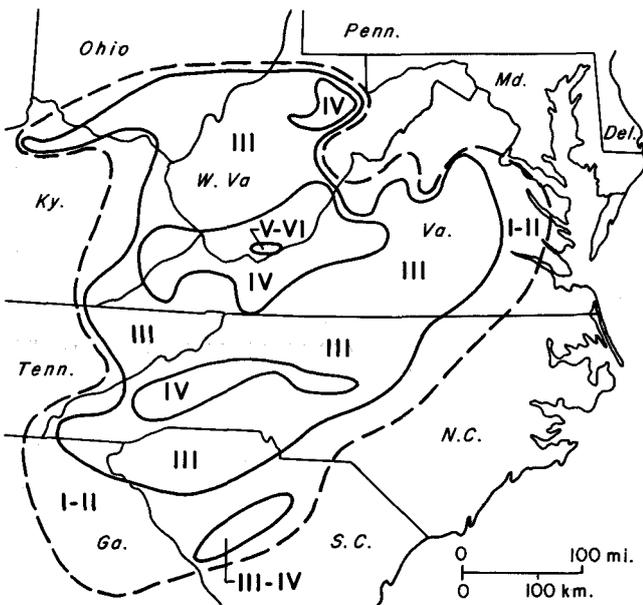


Figure 3. Isoseismal map for the Elgood, West Virginia earthquake of November 20, 1969.

including display windows, were broken, cracked and fallen plaster and a large boulder rolled onto the railroad tracks. The foreman on duty at the Glen Lyn Power Plant reported that, had the vibrations continued for another several seconds, he would have shut the generators off.

SEISMIC ZONES IN VIRGINIA

Study of the historical data base plus seismographic investigations of recent shocks has led the writer to the delineation of three seismic zones in which the majority of the earthquakes have occurred in Virginia (Bollinger, 1973; Figure 4). Faults associated with the earthquakes are thought to occur at depths of three to ten miles and their association, if any, with the faults mapped by geologists on the surface, is unknown in

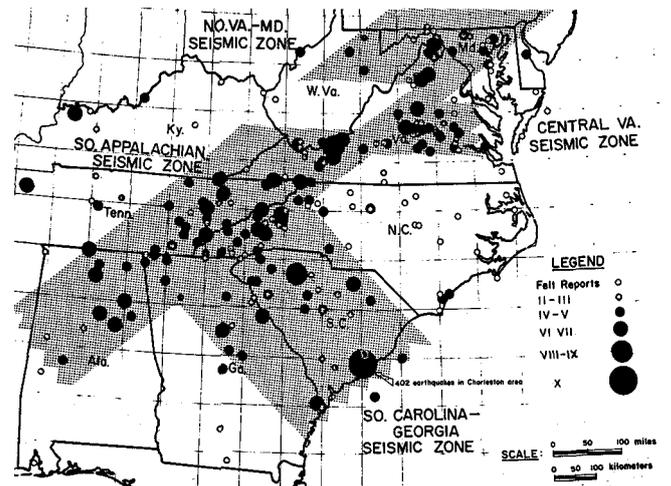


Figure 4. Southern Appalachian seismicity, 1754-1970. Delineation of seismic zones in the southeastern United States.

Virginia or, for that matter, in the eastern United States. These zones have been named: the central Virginia seismic zone, the northern Virginia-Maryland seismic zone and the southern Appalachian seismic zone and are located where earthquake occurrence is most expected. However, the effects from out-of-state earthquakes must also be considered in any

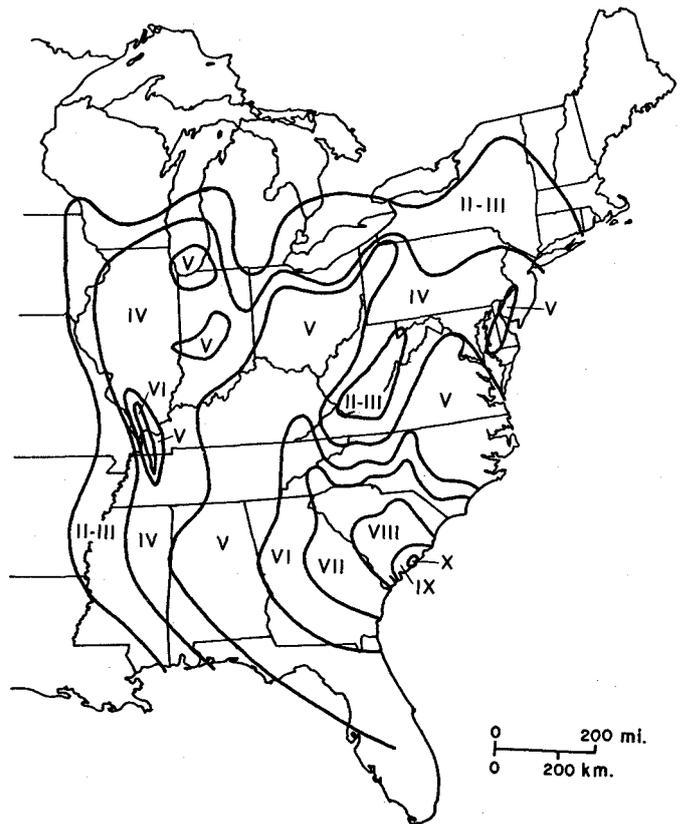


Figure 5. Isoseismal map of the eastern United States contoured to show the broad regional patterns of the reported intensities for the 1886 Charleston earthquake.

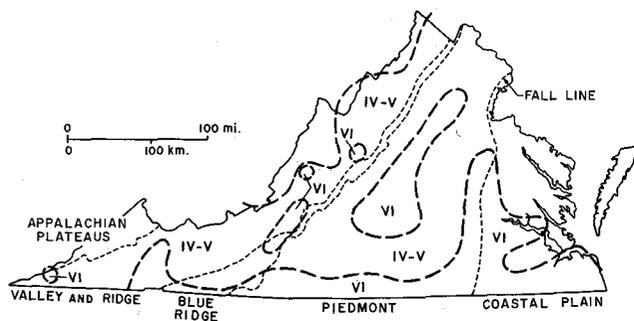


Figure 6. Iseismal map for the effects in Virginia from the 1886 Charleston earthquake.

risk evaluation. The two major examples of this type of situation are the 1886 Charleston, South Carolina earthquake and the 1811-12 New Madrid, Missouri earthquakes.

The 1886 Charleston, South Carolina earthquake is the largest event known to have occurred in the southeastern United States. It was felt over two million square miles, caused five million dollars damage (1886 dollars) and approximately 60 deaths (1886 population density) (Bollinger, 1972; Figure 5). The maximum intensity was X and the magnitude has been estimated between 6.6 and 6.9 (Nuttli, Bollinger, Griffiths). The areas reportedly affected in Virginia are shown in Figure 6 (Ayers and Bollinger, 1975). The more severe of these are listed (Table 2). These accounts indicate that widespread alarm and minor damage resulted in Virginia from an earthquake centered some 300 miles to the south. Figure 6 also shows that there are two regions in the State—the Coastal Plain-Piedmont boundary (Fall Line) and the Pied-

Table 2.—Effects of the Charleston earthquake of 1886 in Virginia.

Locality	Effects
Culpeper	Chimneys thrown down
South Boston	Chimneys thrown down
Henrico County	Difficult to remain standing
Richmond	Population in the streets; chimneys knocked down; prisoners rioted in cells at penitentiary, militia and police called out to restore order; pictures and plaster fell from walls; many residents felt nausea caused by the vibrations; people thrown from their feet
Abingdon	Plaster shaken down
Chesterfield County	Chimney and plaster damage
Danville	Chimney damage; walls cracked
Farmville	Plaster and chimney damage
Lee County	Plaster and chimney damage; broken windowpanes
Lynchburg	Chimney damage
Norfolk	Chimneys broken; light framework thrown down; large warehouses damaged; panic at Opera House; many people nauseated
Petersburg	Windowpanes broken
Patrick County	Bricks thrown from courthouse
Surry County	Plaster damage
Williamsburg	Plaster damage

mont-Blue Ridge boundary—where exaggerated or amplified vibrational effects can occur. This particular aspect, special ground conditions, will be discussed in a later section.

The Mississippi Valley earthquakes (vicinity of New Madrid, Missouri) of 1811 and 1812 rank as the largest to have occurred in North America since its settlement. There were three principal shocks, each with intensities up to XI and magnitudes greater than 7, that were felt over two million square miles (Nuttli, 1973a). Because of the sparseness of the population at that time, the effects of these great earthquakes are not as

Table 3.—Earthquake cyclicity.

Maximum Intensity	Number Expected Per 100 Years	Recurrence Rate (Yrs)	Years Since Last Occurrence
V	115	0.9	0
VI	30	3.4	2
VII	8	13	62
VIII	2	51	65
(IX, X)	(0.5, 0.1)	(200, 780)	92

well documented as those for the 1886 South Carolina shock. However, reports from Richmond newspapers indicated that the events were distinctly felt throughout the city, "most sensibly felt on the hill." Many people ran from their houses in alarm and bells were set ringing. These reports, plus Nuttli's study, again emphasize the large distances to which earthquake effects can extend.

EARTHQUAKE FREQUENCY IN VIRGINIA

It is well-known that large earthquakes occur less frequently in Virginia than in California. A question that logically follows is: what is the frequency of occurrence of a certain magnitude earthquake at a certain place? Studies of the recurrence rates of earthquakes assume that the geological process leading to their occurrence are stable enough to give a cyclical pattern. This assumption appears to be valid in regions of high seismicity, but in regions such as Virginia it is an unverifiable assumption. There have been too few large events to establish their recurrence rate (if there is one). Fortunately in this regard such bad experiences have not occurred but without them it would be difficult to specify when the next one will happen. An analogy here is: given the precipitation amount for one month, predict the annual rainfall.

On the assumption that cyclicity can be applied to the two centuries of data compiled for the southeastern United States (the data for Virginia alone are too sparse to permit this type of analysis), frequencies and recurrence rates may be calculated as shown in Table 3 (Bollinger, 1973). The values in parentheses are extrapolated values. These data indicate that either the region (southeastern United States) is overdue for

the occurrence of a damaging shock (intensity = VII or VIII) or that there is a change toward a lower level of activity. The problem of possible secular change (increasing or decreasing) in the seismicity of the southeastern United States remains unresolved.

EFFECTS OF NEAR SURFACE CONDITIONS

It is well-known to seismologists and earthquake engineers that earthquake intensities are greater on alluvium (deposits from rivers, streams, etc. such as are found on flood plains) than on hard rock sites for the same earthquake at the same distance. A soft surficial layer (soil, sand, alluvium, etc.) can, as a rule of thumb, increase ground displacements by a factor of 4 to 5 and accelerations by about 1 to 1.5 (Nuttli, 1973b). This response to vibration causes a variety of instability effects: 1. liquefaction of saturated sands and of thin sand layers with the resultant loss of bearing strength; 2. landslides; 3. fissuring and slumping on slopes and along river and stream banks; 4. settlement of cohesionless soils; and 5. sand craters and mud spouts.

While it is possible for these effects to occur at the lower intensity levels (VI-VII), they usually begin at the VIII level (Table 1). For example, they were present to only a small extent in the intensity VIII, 1897 Giles County earthquake, but this could be because of the absence there of large areas of soft surface layers.

A pronounced example of this class of effects, where the surficial layers are loosely-consolidated sands with a high water table, was the Charleston, South Carolina area after the 1886 shock. That locale experienced more than 50 miles of damaged railroad track (in one case derailing a train) and 500 square miles of extensive development of craters (with depressions up to 20 feet in diameter) and fissures. Additionally, in the city of Charleston, much of which is on made-land, most of the buildings were destroyed or seriously damaged.

Because of the similarity between the Coastal Plain in South Carolina and Virginia, the 1886 earthquake effects in the former can serve as a model for the latter. In addition, South Carolina does not have the pronounced estuary system as does the Virginia coastline. These narrow waterways can respond to earth motion with large wave action. As noted earlier, the intensity VII, 1875 earthquake did cause waves such that several craft parted their cables. Consideration of the foregoing factors plus the historical data base suggests that the region in Virginia most susceptible to this class of physical surface condition effects is the entire Coastal Plain.

The vertical configuration of the Coastal Plain sedimentary rocks is that of a wedge which has a feather-edge at the Fall Line and thickens to thousands of feet at the coastline. These soft sediments overlie a hard rock basement that is exposed in the Piedmont to the

west. Thus, there is a soft, wedge-shaped layer overlying a much more rigid sublayer. Such a situation can cause channeling of the vibrations within the wedge with resultant amplification at the thin wedge-edge. This effect in the Coastal Plain of Virginia is seen in the intensity patterns of the 1875 earthquake (Figure 2).

Earthquake vibrations can have a pronounced effect on the earth's surface or near surface layers. The most obvious of these are rock slides and landslides. The resulting damage to structures on a valley floor and/or damming of streams (sometimes with subsequent failure and flooding) is well-known. In Virginia, the Valley and Ridge and Blue Ridge provinces contain many areas susceptible to this type of effect (Sorensen and others, 1975). A minor amount of sliding did occur in the Giles County earthquake as a result of the 1897 event.

Another geometric effect is topographic amplification. Both theory and observation show that mountains and ridges can enhance ground vibrations by a factor of two to three times. What occurs is a "tuning" or "resonance" effect when the wavelength of the incoming seismic waves approximates the distance or "wavelength" between ridges. Although there are few structures built on ridge crests in Virginia, it is possible that existing high-voltage line towers might be affected.

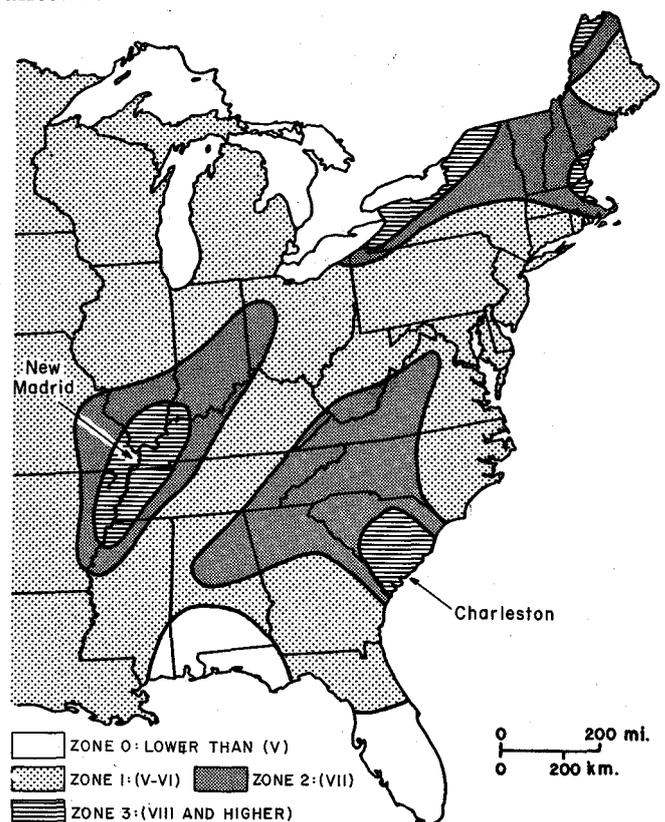


Figure 7. Deterministic seismic risk map for the eastern United States (after Algermissen, 1969).

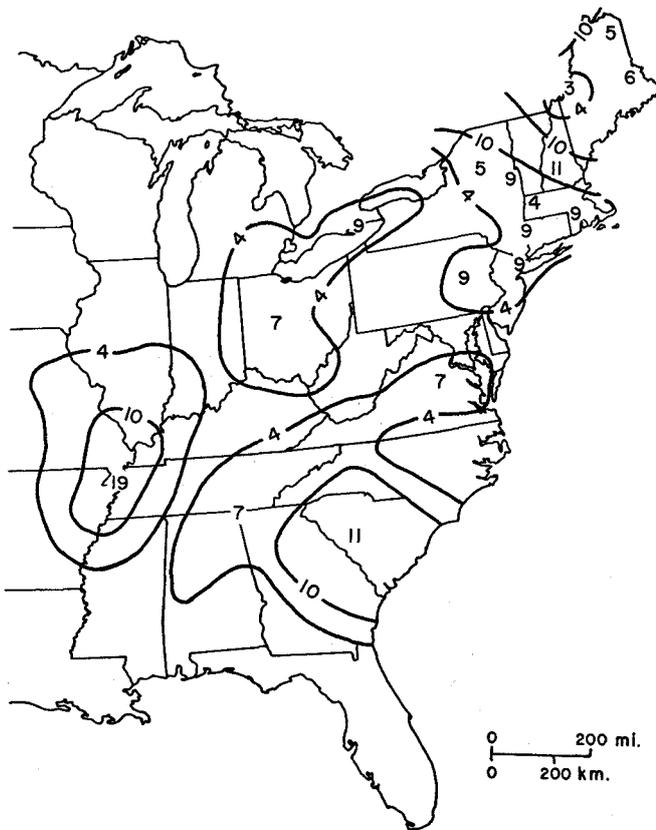


Figure 8. Probabilistic seismic risk map for the eastern United States (after Algermissen and Perkins, 1976). Numbers represent the horizontal acceleration level expressed in percent of gravity which has a 90 percent probability of not being exceeded in 50 years.

PREDICTED LEVELS OF GROUND SHAKING

The U. S. Coast and Geodetic Survey (Algermissen, 1969) issued a seismic risk map of the United States (Figure 7). This map was deterministic in that it was based primarily on the known distribution of historic, damaging earthquakes and their probable frequency of occurrence was not considered. In 1970 it was incorporated into the Uniform Building Code, the authoritative construction guide of the building industry. Two thirds of Virginia was classified at a zone 2 level that corresponds with intensity VII—moderate damage.

In 1976 the U. S. Geological Survey published a probabilistic risk map of the United States (Algermissen and Perkins, 1976; Figure 8). Extreme values of ground acceleration in the country range from 60% of gravity in California to less than 4% of gravity for most of the Great Plains. For Virginia, a maximum horizontal acceleration in hard rock of 7% of gravity was predicted to have a 90% probability of not being exceeded in 50 years. That level of acceleration would correspond to an intensity of VI (Murphy and O'Brien,

1977). Allowing one intensity unit higher for soft surficial sediments would bring the level to VII, the same as the 1969 Risk Map.

Thus, the two most comprehensive seismic risk studies for the country as a whole, plus the earthquake frequency analysis (Table 3), indicate that an intensity VII level of shaking—damage slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; chimneys broken; everyone runs outdoors—is possible in Virginia. Very poor ground conditions could easily increase these effects locally. Time of day would also be an important factor—children in school, people at work, etc.

Recently, McGuire (1977) has shown that intensities VIII to IX have an annual probability of 1 in 10,000 of being equaled or exceeded along the East Coast. His study included two sites in Virginia, but he did not consider the probability of occurrence of events at lower intensity levels

SEISMIC SURVEILLANCE IN VIRGINIA

The current seismic monitoring programs at Virginia Polytechnic Institute and State University (VPI & SU) and at the Division of Mineral Resources, Virginia Department of Conservation and Economic Development, will actually constitute seismic surveillance of the State. This surveillance is especially important to disaster mitigation in that the possibility for an "early warning" thereby exists.

In addition to the Worldwide Standard Seismograph Observatory already at Blacksburg, a recent Nuclear Regulatory Commission contract to VPI and SU is making possible the installation of a 10-station seismic network—five in Giles County and five in central Virginia. This network should be completely operational by the end of the year. Also, Virginia Electric and Power Company has donated four of its North Anna Power Plant (Louisa County) seismic stations and four of its Bath County Pumped Storage project seismic stations to VPI & SU. The data from all 18 of these seismographs will be carried to the Blacksburg campus for recording and analysis by telephone circuits.

The Division of Mineral Resources operates a short-period three-component seismograph system on a daily basis and as such contributes into the State's seismic network. An article describing this operation and data generated therefrom was published in the February issue of *Virginia Minerals* (Lasch, 1977). Both Virginia Polytechnic Institute and State University and the Division of Mineral Resources have worked cooperatively on seismic monitoring—this collective State network should allow excellent surveillance of the Commonwealth.

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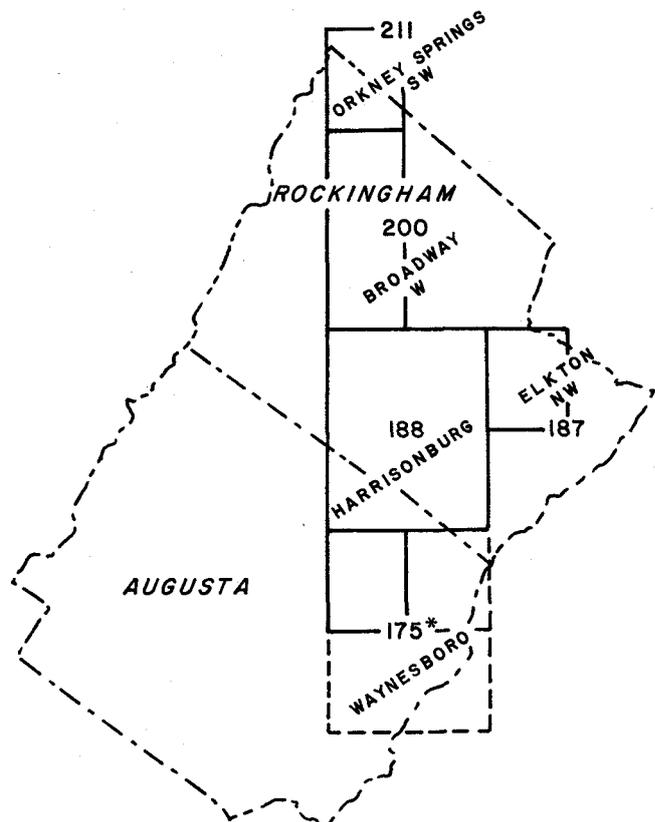


RADIOMETRIC MAPS—NORTHWESTERN VIRGINIA

An aeroradioactivity survey that covers 510 square miles in parts of Rockingham and Augusta counties has been released by the Virginia Division of Mineral Resources. This extends from Bergton southward through Harrisonburg to Ft. Defiance. Information is illustrated on five separate maps at a scale of 1:62,500.

This geophysical survey adjoins similar surveys obtained in 1975 and 1976 of the area approximately bounded by Appomattox, Rappahannock and Powhatan counties. It was flown at 500 feet above terrain in an east-west direction with flight lines one-half mile apart. A gamma-ray spectrometer was utilized to record the total counts per second as well as the individual responses of potassium, thorium and uranium. Radiometric maps are useful in the mapping of rock types, especially where they are covered by soil, and in the location of possible uranium occurrences.

Order maps by 15-minute area name (see illustration; *map includes Waynesboro City area from 1976 radiometric survey). These are available as ozalid copies for \$5.20 (includes \$0.20 State sales tax) each from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA. 22903. An ozalid composite copy of the total survey at the scale of 1:250,000 is available for \$10.40 (includes \$0.40 States sales tax); an unfolded mylar copy is available for \$15.60 (includes \$0.60 State sales tax).



POTHOLES

Bruce K. Goodwin¹

Massive exposures of the Petersburg granite occur in the bed of the James River at Richmond. Some of the dominant surficial features are the many circular depressions which have been scoured into the solid rock by the turbulent action of the river. These depressions, called potholes, are ground out from the bedrock of stream beds by the abrasive action of coarse sand, pebbles, cobbles, or boulders which are swirled around and kept in motion by eddies or the force of the stream's current in a given spot. Once a small pothole develops, the depression tends to accumulate coarse sediments and to be subjected to intensified whirling action of currents. Through this continued localized abrasion they tend to increase in depth and diameter with time.

Numerous potholes have developed in the bed of the James River between Belle Isle and the river's south bank west of the Robert E. Lee Bridge, Figure 1.

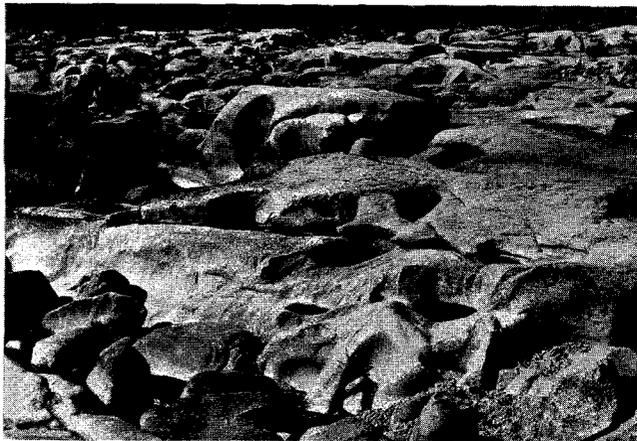


Figure 1. Numerous rounded potholes developed in the Petersburg granite.

The river flows around the island in two channels. A dam between the north end of Belle Isle and the south bank of the river has diverted the main flow of the stream into the north channel. As a consequence, during low flow stages little water enters the stream bed south of Belle Isle and a broad expanse of granite bedrock is exposed. At times of normal flow many of these exposures are covered by turbulent water and during flood stages the James River has risen to over twenty-six feet above its normal surface at Richmond. A railroad bridge formerly connecting the east end of Belle Isle to the south bank of the river was partially

demolished by the severe floods of 1972 and bears testimony to the violent force of the James River during times of flood.

The large exposures in the bed of the river are accessible from the eastern parking lot of the James River Park, which is a short distance upstream from the south end of the Robert E. Lee Bridge at the junction of Riverside Drive and 22nd Street. From the granite steps at the northeastern corner of the parking lot cross over the railroad tracks on the Park footbridge. From the overlook at the north end of the bridge is a beautiful panoramic view of the James River Valley and the Fall Zone of the James. This zone has rapids and small waterfalls that mark the head of navigation in the river. Granitic rocks of the Piedmont occur upriver to the west and sediments of the Coastal Plain, downriver to the east. These sediments have easily been eroded by the river while the granite has resisted erosion thus creating the falls of the James. Descend the steps and follow the rocky path east along the river to a concrete walkway which will lead to a broad, flat exposure of granite.

A few potholes occur on this broad exposure and hundreds more are "carved" into the surface of the granite between the river's south bank, Belle Isle, and the dam. Arcuate remnants of potholes which have been partially eroded away are prominent on many of the near vertical granite faces where the stream has cut along joint planes. They vary in diameter from a few inches to over five feet and some are five feet deep. The bottoms of the potholes are usually covered with well-rounded sand, pebbles, and cobbles. These gravels are composed dominantly of resistant materials such as quartzite and vein quartz; rock types from as far away as the Blue Ridge are present. Some potholes are circular and many are elliptical; in a few, the granite was abraded so that the potholes are wider at the bottom than at the top. At least two potholes, both adjacent to Belle Isle, have been cut completely through overhanging ledges producing steeply inclined tunnels in the granite.

Pothole development may be a major process by which some streams deepen their channels. It appears that the inception and growth of potholes has been a dominant factor in aiding the James River in cutting and deepening its channel through the granitic bedrock. Their locations have been determined by inherent characteristics of the rock on which they have formed. The Petersburg granite in some of these exposures is highly foliated and contains broad bands of differing composition and texture. It is cut by aplite, mafic, and pegmatite dikes and locally contains an abundance of xenoliths. These xenoliths are fragments of host rocks which were broken off during magma intrusion and are now preserved as inclusions within

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Figure 2. Debris filled pothole at intersection of two joints.

the granite. Numerous joints and some small faults with slight displacement cut the granite as straight, steeply inclined fractures. Two dominant joint sets intersect at an angle of about sixty degrees.

Joints and minor faults have been the chief factor in causing the localization of potholes. Many elliptical potholes are located on and parallel to joints. On this broad flat exposure is an excellent example of a small elliptical pothole developed along a minor fault. Along joints at the rock surface, mechanical weathering and stream erosion rapidly create slight surficial irregularities which cause the water's currents to eddy and swirl. Fragments are localized in these eddies and their abrasive action in a small area initiates a pothole. Joint intersections have also been favorable sites for pothole development, Figure 2. Here complete transition may be observed from small potholes just developing along joints to large, elliptical potholes aligned in a series along prominent joints. Also there are deep joint-controlled channels with large crescent shaped pothole remnants on their sides, where much of the original enclosing rock has been eroded away.

Changes in lithology have also served to localize pothole development. Where two types or textures of rock are in contact, differential weathering and erosion have also produced irregularities in the surface of the exposure. If a small xenolith or thin mafic dike occurs it has usually been more deeply eroded than the surrounding granite and potholes have frequently developed directly on the softer rock. Major compositional and textural contrasts occur along the margins of felsic and mafic dikes, xenoliths, and foliation planes within the granite.

The potholes in the bed of the James River are dynamic illustrations of the erosive power of a turbulent stream where its transported sediments have scoured into solid granite. This surficial process is often strongly controlled by structural and lithologic characteristics of the bedrock. The development of potholes has been a dominant process by which the James River has incised its path through granite.

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NEW AERIAL MAPPING PHOTOGRAPHY

High-altitude, quad-centered black and white aerial photography, taken 1978 is now available for revision inspection sector 2. The series of overlapping 9-inch by 9-inch prints can be used for stereo studies and for comparison with the corresponding 1:24,000 scale topographic map areas they portray. This sector includes that part of Virginia east of 77° west longitude and that area south of 37° north latitude between 77° and 78° west longitude (see reference map on page 12). The cities of Chesapeake, Emporia, Franklin, Hampton, Newport News, Norfolk, Poquoson, Portsmouth, Virginia Beach and Williamsburg are shown. By comparing this coverage with similar photography taken 1973 changes in physical and cultural features can be interpreted. Photographic reproductions of prints and enlargements can be obtained *only* from the National Cartographic Information Center-East, Mail Stop 536, U. S. Geological Survey, Reston, VA. 22092.

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ADDITION TO STAFF

Mr. Gilpin R. Robinson joined the Division staff on July 16, 1978 and is engaged in geologic mapping activities in the Piedmont. He received his B.S. in geology from Tufts University, Medford, Massachusetts and M.A. in geology from Harvard University. Mr. Robinson was previously employed with the U. S. Geological Survey in Reston, Virginia.

NEW PUBLICATIONS

(Available from the Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; State sales tax is applicable only to Virginia addresses)

Publication 1. BIBLIOGRAPHY OF VIRGINIA GEOLOGY AND MINERAL RESOURCES 1960-1969, by F. B. Hoffer, 68 p., 1977. Price \$2.34 (\$2.25 plus \$0.09 State sales tax.)

Some 1300 references to published research, unpublished theses from U. S. colleges and universities, and Federal and State open-file reports on the Commonwealth's geology and mineral resources, are available as Publication 1. This 68-page bibliography has two listings, one by subject, county and city and the other by author. The publication was compiled by the Division librarian for the period 1960-1969.

Similar bibliographic listings are available for the years 1941-1949 (Information Circular 14—\$0.52) and 1950-1959 (Information Circular 19—\$1.30). Note that the Division's new Publication series replaces the former bulletins, reports, and information circulars.

Publications 8-13 are geologic studies of quadrangle areas. Rock type, structure and distribution are shown in color on topographic map bases. Origin and geomorphic expression of the units are described. Geologic and economic factors affecting man's modification of the land are discussed.

Publication 8. GEOLOGY OF THE NORFOLK NORTH QUADRANGLE, VIRGINIA, by W. J. Barker and E. D. Bjorken; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State sales tax).

This quadrangle depicts the western portion of Norfolk City and the adjoining part of the City of Portsmouth in southeastern Virginia. Unconsolidated and semiconsolidated sediments exposed at the surface comprise the Sand Bridge and Tabb formations of Pleistocene age. Older Pleistocene age sediments (Norfolk Formation) and Pliocene age sediments (Yorktown Formation) occur in the subsurface. Structural configuration of the top of the Yorktown Formation is indicative that the present river systems reflect Pleistocene drainages. Four prominent geomorphic features are present, Willoughby spit; Diamond Springs scarp; Hampton flat; and Deep Creek swale.

Geologic units shown on the map are discussed in terms of potential use, permeability, slope stability, aquifer recharge, erosion resistance, and plasticity/sensitivity. Flood-prone areas are designated as those below 10 feet (3 m) elevation and which may be initially affected during extreme high water before run off or subsidence takes place. General load bearing capacities are depicted on the map. Extensive areas of fill are indicated along the Elizabeth and Lafayette rivers which outline the shoreline change between 1887 and 1973. Sources of sand are discussed.

Publication 9. GEOLOGY OF THE NORFOLK SOUTH QUADRANGLE, VIRGINIA, by W. J. Barker and E. D. Bjorken; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State sales tax).

The Norfolk South quadrangle depicts the eastern part of Portsmouth City and adjacent areas of the cities of Chesapeake and Norfolk in southeastern Virginia. Unconsolidated and semiconsolidated sediments exposed at the surface are mapped as the Sand Bridge and Norfolk formations of Pleistocene age. Pliocene age sediments (Yorktown Formation) occur in the subsurface. Structural configuration of the top of the Yorktown Formation indicates that the present river systems reflect Pleistocene drainages. Three prominent geomorphic features are present: the Churchland flat; the Deep Creek swale; and the Fentress rise.

Each geologic unit shown on the map is evaluated in terms of potential use, permeability, slope stability, aquifer recharge, erosion resistance, and plasticity/sensitivity. Flood-prone areas are designated as those below 10 feet (3 m) elevation and which may be initially affected during extreme high water before run off or subsidence takes place. General load bearing capacities are depicted on the map. Extensive areas of fill indicated along the Elizabeth River show the shore line change between 1887 and 1973. The uses of four abandoned quarries are good examples of sequential land use. Sources of sand and silt are discussed.

Publication 10. GEOLOGY OF THE GROTTOS QUADRANGLE, VIRGINIA, by T. M. Gathright II, W. S. Henika, and J. L. Sullivan III; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State sales tax).

This quadrangle is located in southern Rockingham and the adjoining portion of Augusta counties in west-central Virginia. The dominant geologic structure is the deep trough of the Massanutten synclinorium, the axis of which nearly bisects the quadrangle from southwest to northeast. The synclinorium is bounded on the west by the Pulaski-Staunton fault and on the east by the west limb of the Blue Ridge anticlinorium. Bedrock consists of Cambrian and Ordovician carbonate and clastic rocks that are intruded in places by diabase dikes of Triassic age. Most of the southeastern third of the quadrangle is covered by relatively thick alluvial and colluvial deposits. The rocks, which are well-jointed and exhibit a well-developed slaty cleavage, have been metamorphosed to lower greenschist facies; metamorphism seems to be more prominent in the asymmetric-to overturned folds on the east limb of the synclinorium.

Limestone, dolomite and quartzite have been quarried for building stone and road metal, and limestone for the production of lime. Aggregate for concrete, masonry sand, and sized gravel are produced from alluvial deposits along South River.

Geologic units shown on the map are discussed with respect to slope stability, erodability, and response to ground-water withdrawals, and excavations. Reference localities described in the text are identified on the map as areas where representative exposures of 13 bedrock units may be examined. Areas of known or potential sinkhole and cave development have been identified on the map.

Publication 11. GEOLOGY OF THE MOUNT SIDNEY QUADRANGLE, VIRGINIA, by T. M. Gathright II, W. S. Henika, and J. L. Sullivan III; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State sales tax).

The Mt. Sidney quadrangle is located in west-central Virginia in Augusta and Rockingham counties with the towns of Mt. Crawford, Mt. Sidney, and Weyers Cave depicted. The salient geologic structures are the Massanutten synclinorium, the Pulaski-Staunton fault, and the Burketown structure that is bounded by the Middlebrook anticline and the Long Glade syncline. Bedrock consists of upper Cambrian and Ordovician carbonate and clastic rocks that were intruded in the west-central portion by alkalic dikes of Jurassic age. The Burketown structure is the most complex area in the quadrangle where Beekmantown and Conococheague carbonates were thrust over deformed clastic rocks of the Edinburg and Martinsburg formations. The rocks, some of which exhibit well-developed slaty cleavage, have been metamorphosed to the lowermost greenschist facies.

Crushed stone has been produced from rocks of the Beekmantown Group and could be quarried from several of the other carbonate units. High-calcium limestone of the New Market Formation has potential for development; other carbonate formations are possible sources for agricultural or hydraulic lime. Slate beds in the upper member of the Martinsburg Formation may be potential sources for brick and lightweight aggregate.

Geologic units shown on the map are discussed with respect to slope stability, erodability, and response to ground-water withdrawals, and excavation. Areas of known or potential sinkhole and cave development have been identified on the map, as are reference localities for representative exposures of several formations.

Publication 12. GEOLOGY OF THE FORT DEFIANCE QUADRANGLE, VIRGINIA, by T. M. Gathright II, W. S. Henika and J. L. Sullivan III; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State sales tax).

The Fort Defiance quadrangle is located in west-central Virginia in the northeastern part of Augusta county. Almost one-half the quadrangle is underlain by the clastic Martinsburg Formation that occurs in the trough of the Massanutten synclinorium. Carbonate rocks of Ordovician and upper Cambrian age on the west limb have only minor small-scale folds. Some

are intruded by alkalic dikes of Jurassic age. The same carbonate formations on the east limb are asymmetrically folded, overturned in places, faulted in others, and have been intruded by Triassic diabase dikes. Cleavage and schistosity is well developed, and metamorphic mineral growth parallels the cleavage.

Limestone has been quarried for crushed stone and lime, and several carbonate units free from sandstone and chert have some potential for crushed stone. The New Market Limestone is a source for high-calcium limestone but its extent, thickness and steep inclination limits the quantity available for quarrying. In the upper (sandstone-bearing) member of the Martinsburg Formation slate and argillite strata have a potential for brick or lightweight aggregate where they are non-calcareous and free from sandstone.

Geologic units shown on the map are considered for slope stability, erodability, and response to ground-water withdrawals, and excavation. Areas of known or potential sinkhole and cave development have been identified on the map, as are reference localities for representative exposures of several formations.

Publication 13. GEOLOGY OF THE CRIMORA QUADRANGLE, VIRGINIA, by T. M. Gathright II, W. S. Henika, and J. L. Sullivan III; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State Sales tax).

The Crimora quadrangle is located in west-central Virginia in the northeastern part of Augusta and the adjoining portions of Albemarle and Rockingham counties. Steeply dipping to overturned upper Cambrian and Ordovician carbonates underlie most of the western third of the area; slate and argillite beds are present in Martinsburg Formation. Relatively thick alluvial and colluvial deposits cover the middle Cambrian carbonate formations in the central third of the area. The eastern third is underlain by clastic rocks of the lower Cambrian Chilhowee Group, and the basalts and metasediments of the Precambrian Catoctin Formation. In Blue Ridge asymmetric to overturned, closed to isoclinal, non-cylindrical folding of these rocks form the dominant physiographic and structural features.

Sand and gravel are processed from the alluvial deposits along South River, and impure carbonate from the Beekmantown Group and Conococheague Formation may be a source for crushed stone, agricultural limestone and hydraulic lime. Manganese deposits occur along the west foot of the Blue Ridge; at one time the Crimora mine was the largest producer of manganese in the United States.

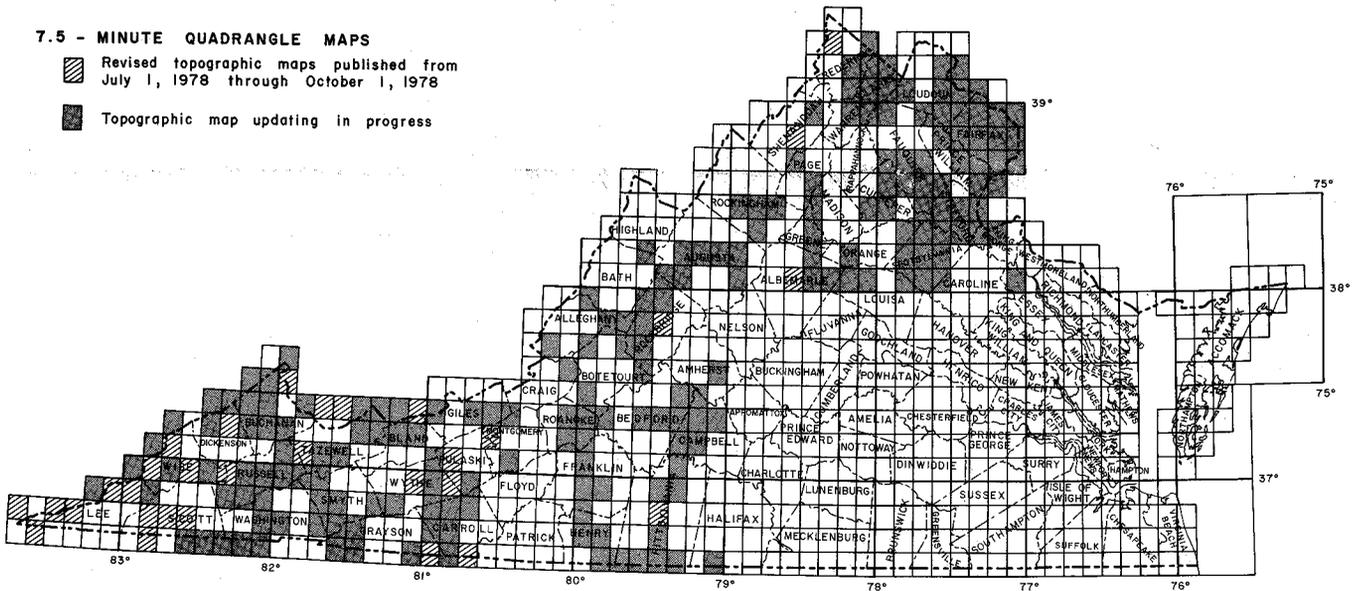
Geologic units shown on the map have been evaluated for slope stability, erodability, and response to ground-water withdrawals, and excavation. Areas of known or potential sinkhole and cave development have been identified on the map, as are reference localities for representative exposures of several formations.

Return Postage Guaranteed

TOPOGRAPHIC MAPS

7.5 - MINUTE QUADRANGLE MAPS

-  Revised topographic maps published from July 1, 1978 through October 1, 1978
-  Topographic map updating in progress



Revised 7.5-minute quadrangle maps published from July 1 through October 1, 1978:

Appalachia	Cumberland Knob	Fosters Falls	Keokee	Princeton	St. Paul
Cana	Duffield	Gary	Lexington	Pulaski	War
Charlottesville West	Edinburg	Gate City	Panther	Radford North	Wheeler
Chatham	Ewing	Gore	Pennington Gap	Richlands	Wise
Clinchport	Flat Gap	Haysi	Plum Grove	Rose Hill	Wytheville

ADVANCE PRINTS

Advance prints are available at \$1.25 each from the Eastern Mapping Center, Topographic Division, U.S. Geological Survey, Reston, Virginia 22902.

PUBLISHED TOPOGRAPHIC MAPS

Total State coverage completed; index is available free. Updated photorevised maps, on which recent cultural changes are indicated, are now available for certain areas of industrial, residential, or commercial growth. Published maps for all of Virginia are available at \$1.25 each (plus 4 percent State sales tax for Virginia residents) from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, Virginia 22903.