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ESTIMATES OF THE OCCURRENCE AND RESULTING EFFECTS OF DAMAGING EARTHQUAKES IN VIRGINIA

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INTRODUCTION

The occurrence of a devasting earthquake in the San Francisco Bay area of California this past October 17, 1989, has caused many Virginians to inquire about the earthquake potential in their home state. Their questions deal with the likelihood of future damaging earthquakes, along with their probable severity, location, and effects. After first discussing the two principal measures of earthquake size, the following sections will address each of those topics in turn.

MEASURE OF EARTHQUAKE SIZE

To consider earthquake history and seismic hazard, it is necessary to understand the two principal measures of earthquake size - **magnitude** and **intensity**.

The magnitude measure is well-known and is often called the "Richter magnitude," after Charles F. Richter, California Institute of Technology professor who 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, within experimental error, be the same for a given earthquake. There is ***only one magnitude value (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 amplitude. As a general rule-of-thumb, 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 **effects** on people, structures, and the landscape at that point. It will be largest near the epicenter and usually will decrease with distance away from that location. Thus, there are ***many intensity values (numbers) associated with each shock***. 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 those values. The resulting map, that depicts the areas which experienced the same levels of shaking, is termed an isoseismal map or an intensity map. In general, earthquakes with larger magnitudes will have higher intensities.

The intensity scale used in the United States is called the Modified Mercalli Intensity Scale (MMI) and has 12 degrees or levels, ranging from I (felt by only a few people under especially favorable circumstances) to XII (total damage). There is such a wide range of effects included in each intensity level that, depending on the depth and distance of the earthquake as well as other factors, a range of magnitudes can result in the same intensity. Damage begins at about the intensity VI level. The following Table contains a listing of the intensity VI-X effects and has the estimated magnitude range expected for each of those levels. By convention, Roman numerals are used to denote intensity and

Arabic numbers for magnitude.

Table. Modified Mercalli Scale for intensities VI through X.

Intensity	Description of Effects	Magnitude
VI	Felt by all; many frightened and run outdoors. Some heavy heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	4.0 (3.2-4.6)
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 (4.3-5.9)
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.	5.8 (5.2-6.4)
IX	General panic. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; danage 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.	

HOW LIKELY IS VIRGINIA TO HAVE A DAMAGING EARTHQUAKE(S)?

The first recorded occurrence of an earthquake in Virginia was on February 21, 1774, when many houses in Petersburg and Blandford were reported to have moved considerably off their foundations and the inhabitants were so alarmed that they ran out of doors. We have record of 286 earthquakes having occurred in Virginia since the 1774 event, for an average of 1.3 earthquakes per year. The earliest portion of the record is incomplete and includes only those shocks large enough be noted in the newspapers or entries in personal journals.

During the past eight years, Virginia has experienced 104 earthquakes for an average of 13 earthquakes per year. The majority of those shocks (96) were very small and were not felt by people, but were detected by the 20-station seismographic network of the Virginia Tech Seismological Observatory. Virginia residents, however, did feel the vibrations from at least eight earthquakes; the largest was a Richter magnitude 4 shock in Fluvanna County, southeast of Charlottesville, in 1984. Other locales where earthquakes were felt were Richmond, Scottsville, Pulaski, Narrows, Galax, Farmville, Blacksburg, Bristol, and Pennington Gap. This recent level of seismicity is a continuation of the seismic activity that has persisted since at least 1774. The modern activity indicates that, even though the larger shocks occurred prior to the turn of the century, the seismic processes are still active in the Commonwealth and the potential for future damaging activity is therefore real.

Virginia has experienced earthquake damage in the past from earthquakes centered within as well as outside of its borders. In particular, during the 19th century, portions of the State experienced moderate earthquake damage on at least four occasions. The largest Virginia earthquake (magnitude = 5.8, MMI = VIII) occurred at Pearisburg in Giles County on May 31, 1897. That shock was felt by people over 280,000 square miles in 13 southeastern states. Effects in Giles County included: extensive damage to chimneys, several brick houses were damaged severly, tons of rock fell from overhanging cliffs onto railroad tracks derailing a freight train, springs and streams were muddied, ground fissures were formed, and small landslides occurred. Fortunately, no one was killed and no injuries were reported. The next largest earthquake in Virginia was in Goochland County on December 22, 1875 (magnitude = 5.0, MMI = VII). Effects similar to those in Giles County, but less intense, were felt over an area of 50,000 square miles. There was great alarm, near panic, in Richmond where people "rushed into the street in all sorts of clothing" (time of occurrence was 11:45 PM local).

As previously mentioned, large earthquakes occurring outside of Virginia can cause in-state damage. Extensive areas of architectural damage (MMI = VI) in Virginia was observed as the result of large earthquakes centered in Missouri (New Madrid,1811-12) and in South Carolina (Charleston, 1886).

Estimating the probability of any future damaging earthquake occurrences in Virginia is an especially difficult task. Geologic processes are intrinsically very long term, up to millions of years in duration. Thus, the 2-plus centuries of earthquake data available for the Commonwealth, while very long term by human measure, is very short indeed by geologic measure. Six earthquakes of magnitude 6 or greater have occurred in the eastern United States during the period 1800-1985. Using simple rate estimates and the Poisson model yields a 28 percent probability for the recurrence of a similar size earthquake in the next 10 years and a 56 percent probability in the next 25 years. That is, there is roughly a one in four chance of a damaging shock in the next 10 years, and a one in two chance in the next 25 years. Exactly where in the region such an earthquake would occur is unknown, but clearly Virginia is a candidate site. Moreover, as previously mentioned, large earthquakes centered in other states have caused damage in Virginia.

On the other hand, if we consider only earthquakes in Virginia, then the historic record indicates that there have been three magnitude 5 or greater shocks (MMI ≥ VII) during the past 215 years. The same approach as the preceding paragraph gives a 13 percent probability for another magnitude 5 shock in the next 10 years, and a 29 percent probability in the next 25 years. Thus, there is about a one in three chance that a damaging earthquake will occur in the Commonwealth by the year 2015 (well within the lifetime of most structures built today).

It is important to emphasize that these are only rough estimates. The full estimation of seismic hazard is a considerably more complex endeavor and should be undertaken for Virginia at some stage.

HOW SERIOUS ARE DAMAGING EARTHQUAKES IN VIRGINIA LIKELY TO BE?

The response to this question can make effective use of the Modified Mercalli Intensity (MMI) scale presented earlier. That scale provides a graduated description of the types of damage and other effects caused by earthquakes and it will be employed herein.

As previously discussed, the two largest Virginia earthquakes were a MMI VIII (Giles County, 1897) and a MMI VII (Goochland County, 1875). The question that logically follows is: "Are those the largest possible earthquakes that could occur in the Commonwealth?", that is, are they "maximum earthquakes." A variety of geological and geophysical evidence from studies of Virginia earthquakes as well as from seismic hazard studies for critical facilities (nuclear power plants and large reservoirs) suggests that the answer to the question posed is "no."

There are a variety of procedures for estimating maximum magnitude earthquakes, but a simple and direct method that is sometimes used is simply to increase the maximum historical earthquake size by one unit. Many, if not most, seismologists would consider such earthquakes to be very possible physically. (If anything, some would probably argue that such a procedure is not conservative enough.) The one unit increment for Virginia earthquakes would imply a magnitude 6.8 (MMI IX) in the western part of Virginia and a magnitude 6.0 (MMI VIII) in the central portion of the state. Damaging earthquakes in Virginia are likely to be very serious.

It is important to note that the lower frequency of eastern United States earthquakes with respect to western United States earthquakes is offset by the fact that the attenuation of earthquake vibrations is much lower in the east than in the west. For a given magnitude earthquake, the areas of damage in the east can be up to 10 times as large as for a comparable sized shock in the west. Thus, much larger damage areas are expected for eastern earthquakes. This fact also accounts for the occurrence of damage in Virginia from earthquakes that are centered in nearby states.

WHERE ARE DAMAGING EARTHQUAKES IN VIRGINIA MOST LIKELY TO OCCUR?

This question has already been addressed in the preceding text. Figure 1 shows the spatial distribution of the seismicity in the region and in the Commonwealth. The active areas are judged to be the most likely for the occurrence of future activity. Accordingly, we have prepared hypothetical MMI maps (Figures 2, and 3) for the estimated maximum earthquakes in each of the two Virginia seismic zones. Those maps show that:

1. From one-half to virtually all of the state would be subjected to minor damage levels (MMI VI), and

2. Major damage areas (MMI VIII and X) would be appreciable, ranging from approximately 400 square miles to 7,000 square miles.

Note that several urban areas (Richmond, Petersburg, Charlottesville, and Lynchburg) are situated within or near the periphery of the central Virginia seismic zone (Figure 1). At this stage, we consider that the maximum earthquake (MMI VIII) for the zone could occur anywhere within the zone with equal likelihood; hence, the cities noted above could incur substantial damage from earthquake vibrations.

WHAT ARE THE ESTIMATES OF THE LIKELY RANGE OF LOSSES OF LIFE AND DOLLARS?

We are unable to respond to this question. First of all, some type of inventory (presumably accurate and complete) of the elements at risk (populations, facilities, lifelines, and structures) in the MMI VI - IX areas of Figures 2 and 3 would be required. Then, the procedures outlined in the

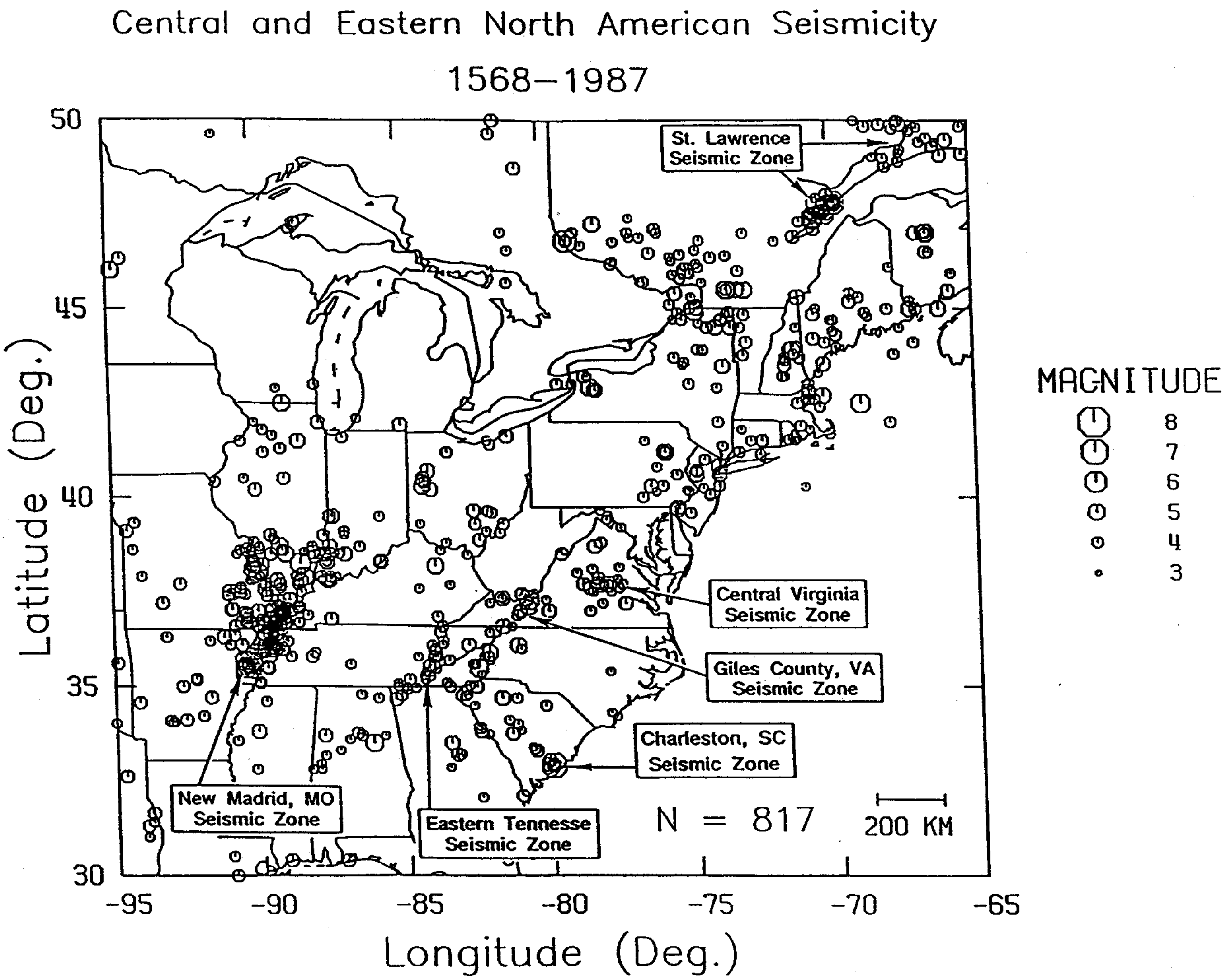

Figure 1. Seismicity map for central and eastern North America for the time period 1568 through 1987 showing earthquake epicenters (octagonal symbols scaled to magnitude) and seismic zones. Total number of epicenters shown, N=817.

publication *Estimating Losses from Future Earthquakes* could be implemented to develop the required estimates.

DOES THE PUBLICATION *ESTIMATING LOSSES FROM FUTURE EARTHQUAKES - PANEL REPORT* CONTAIN ANY IMPORTANT APPLICATIONS TO WHICH VIRGINIA SHOULD PAY SPECIAL ATTENTION?

The subject publication discusses the procedures and problems associated with the estimation of losses to be expected in a given area by a given earthquake. The Panel authors also develop a general set of guide lines to be followed in conducting such loss studies.

The relevaance of this publication to the Commonwealth concerns the allocation of funds for emergency response. The recommendation of the Panel is that a probabilistic risk analysis should be employed, "When the objective is to select the best allocation of resources for hazard reduction, ..." (page 1). While the earthquake hazard in Virginia is certainly much less than that in California, the preceding discussions have documented that a hazard is present, and it is probably much higher than is generally preceived by most State residents. It is also worth repeating the fact that the lower attenuation of earthquake vibrations in the eastern United States tends to offset the region's lower frequency of earthquake occurrence. Thus, if a larger magnitude shock does occur, it will be accompanied by large damage areas. That factor needs to be explicity accounted for in any rick/loss studies for Virginia. It would seem that an evaluatory risk/loss study for the Commonwealth would be in

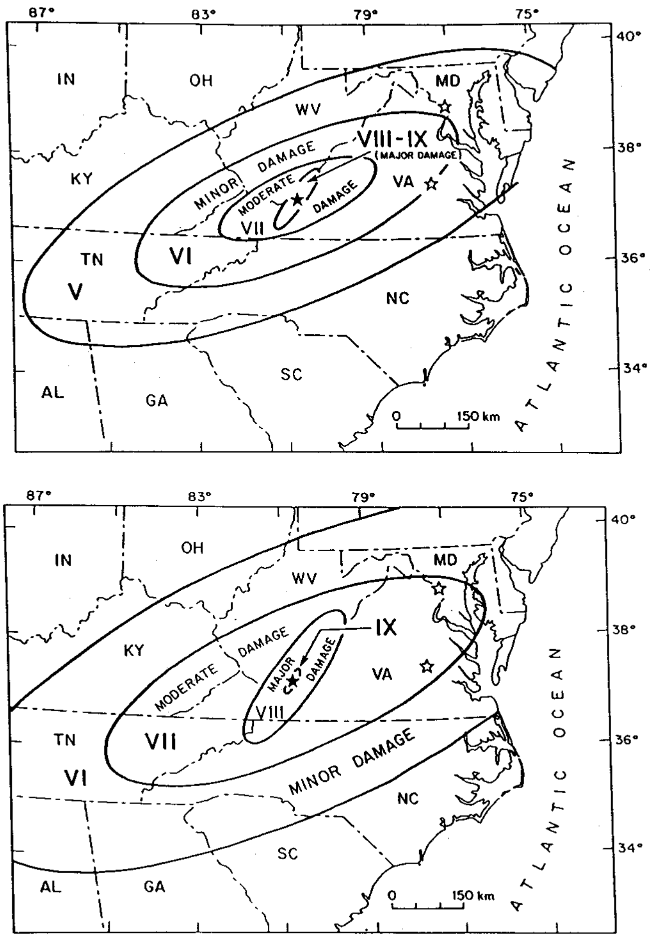

Figure 2. Hypothetical intensity maps (MMI scale) for a postulated magnitude 7/MMI IX Giles County, Virginia earthquake. Upper: For an intensity attenuation curve derived from a 1944 New York earthquake. Lower: For an intensity attenuation curve derived from the 1897 Giles County earthquake. Solid star represents the epicenter and open stars locate Richmond and Washington, D.C. The trend of the innermost isoseismal contours are controlled by the trend of the Giles County seismic zone, while the trend of the outermost isoseismal contours follow the trend of the Appalachian highlands (Bollinger, 1981).

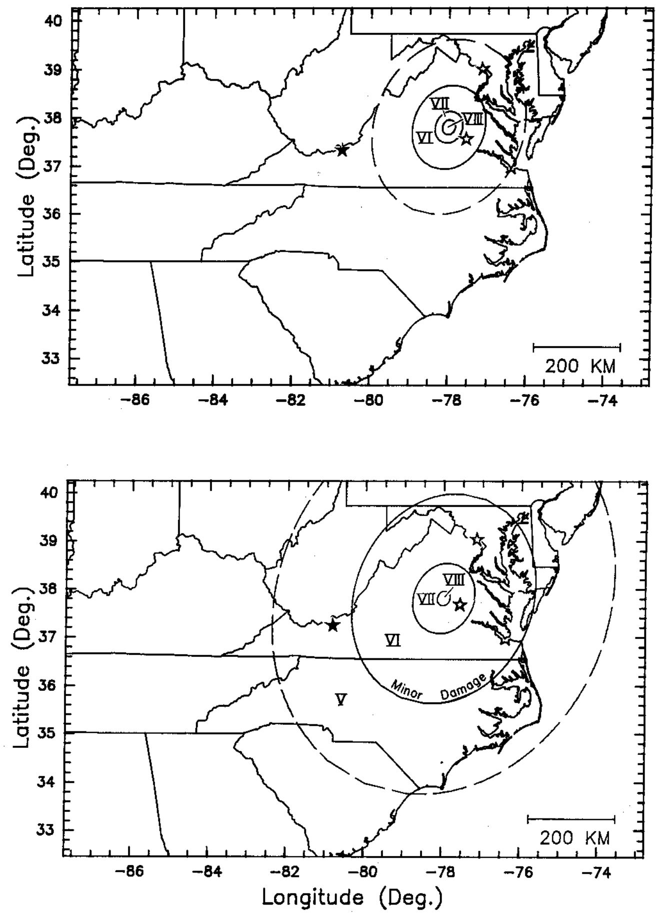

Figure 3. Hypothetical intensity maps (MMI scale) for a postulated magnitude 6/MMI VIII Goochland County, Virginia earthquake. Upper: For an intensity attenuation curve derived from a 1944 New York earthquake. Lower: For an intensity attenuation curve derived from the 1897 Giles County earthquake. Solid star represents the Giles County epicenter and open stars locate Richmond and Washington, D.C. Size and configuration of isoseismals derived from: (1) 1875 Goochland County earthquake and the 1984 Fluvanna County earthquake, and (2) Bollinger (1981).

order to: (1) provide initial loss estimates, and (2) ascertain if and where more elaborate studies are warranted.

SOME FINAL COMMENTS

The preceding discussions are directed primarily to the general public for their information, but Disaster Planners may also find the results useful. The writers wish to emphasize that those results are, however, not suitable for engineering purposes or for the development of building codes. The latter requirements may be very site specific and will generally require formal seismic hazards analyses such as those described by the National Research Council's Panel on Seismic Hazard Analysis (1988) or as exemplified by the national study by Algermissen and others (1982) of the U.S. Geological Survey. Finally, the results and interpretations herein are those of the writers and do not represent an official position of the Commonwealth of Virginia or any of its agencies.

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STAFF NOTES

AIPG National Meeting

The 26th Annual Meeting of the American Institute of Professional Geologists was held in Arlington during the first week of October. Several members of the Division staff played important roles in this meeting. Robert Milici, State Geologist, gave the Invited Keynote Address. Stan Johnson, Chief Geologist, was the General Chairman for the Annual Meeting. It was also a significant occasion for Stan. At the annual banquet he was awarded one the Institute's highest National awards, the Martin Van Couvering Memorial Award.

Donald C. Le Van, who retired from the Division in November 1988, wrote the Citation for Stan's award. The citation follows:

Citation for Stanley S. Johnson, CPG 3472

Our institute celebrated its Silver Anniversary in 1988 and is now one year into its second quater century of existence. It is somewhat sobering to consider that the second 25 years will take this organization well into the 21st century. We can be sure that the application of our science and the requirements for geologists will be different from what they are today. The membership owes a large measure of gratitude to those dedicated individuals whose vision and tireless efforts have resulted in the many accomplishments of this Institute, and who are striving to guide it successfully into this uncertain future. Each year, the Martin Van Couvering Memorial Award is bestowed upon one exceptional member in recognition of his or her outstanding service to the Institute. The 1989 recipient of this award, Stanley Stevens Johnson, is truly deserving of this recognition.

Thomas Jefferson observed about his Presidency that "no duty the Executive had to perform was so trying as to put the right man in the right place." Stan Johnson has proven himself to be the right man in the right place in many significant endeavors of the Institute, as well as in other facets

of his life.

Stan's professional career began in 1963 when he was graduated from the University of Virginia and was employed as a geologist with his present organization, the Virginia Division of Mineral Resources. His early work with the Division was in economic geology, chiefly in the nonmetallic minerals. He subsequently became interested, also , in geophysics, and was chosen in 1970 to head a newly-created Geophysical Investigation Section. Among his major accomplishments in this aspect of Survey research were establishment of a Virginia gravity-base network, development of state gravity and aeromagnetic maps, and geophysical studies of Mesozoic-age basins. In directing and pursuing these studies Stan never lost his touch as a field man, and he took quiet satisfaction in being able to occupy more gravity stations in a day than any of his colleagues, in spite of suspicious landowners, hostile dogs, and ever-present poison ivy. Stan was promoted in 1983 to Geology Program Supervisor for grants and contracts, and in March 1989 was named Manager of the Geologic Research Branch of the Division. He has authored or co-authored more than 40 publications, articles, and abstracts on Virginia geology, mineral resources, geophysics, and geochemistry.

Stan's contribution of time and effort to the Institute has indeed been exceptional since he became a member in 1976. He has served as President, Vice President, and Secretary-Treasurer of the Virginia Section, and as Chairman for many of that Section's annual and special meetings. At the

National level, Stan has been involved in many activities of the Institute. He is the General Chairman for this, our 26th Annual Meeting. He was Secretary of the Institute in 1986-87 and was a candidate for President-Elect in 1987. Stan served as Chairman of the State Affairs and Registration Committtee in 1988 and is currently a member of that Committee. In 1988, he was also a member of the Committee for Future AIPG Direction and was our representative to the American Association for the Advancement of Science. During that year he was asked by our President to review and submit a report on the membership of our Institute. Stan was awarded the President's Certificate of Merit in 1984 and again in 1987.

The AIPG has not been the only beneficiary of Stan's hard work, wise counsel, and capable handling of complex issues. He is active in the Society of Exploration Geophysistics, and was General Vice-Chairman of the 55th Annual International Meeting in Washington, D.C., and Second Vice-President in 1986-87. He has been Chairman and Vice-Chairman of the Membership Committee of SEG and was also a member of the Professional Affairs Committee. Stan served as Secretary of the affiliated Potomac Geophysical Society in 1979-80 and as its President in 1980-81.

With these many professional demands upon him, Stan has always made time during his busy career to be a leader in the administration and other activities of his church. He is a devoted family man, and a good friend to many of us.

The many occasions on which Stan's counsel and help are sought testify to the high regard in which he is held by his friends and colleagues across the county. Those acquainted with him know that he can be counted upon for energetic and unselfish effort, whether in a leadership or a supportive role. We all take pleasure in the honor that is being accorded to Stan through this award.

Donald C. Le Van
CPG 1184

Eurokarst

Staff geologist David Hubbard travelled, at his own expense, through the karst regions of eastern Europe for six weeks this summer. Mr. Hubbard presented a paper comparing the nitrate constituents of caves in Virginia, France, West Germany, and Spain at the 10th International Congress of Speleology in Budapest, Hungry. On a 10 day congress field trip of the hydrology of Hungry, he toured the Transdanubian Central Mountains karst region, which extends from Balaton Lake to Budapest, and the Northeast Range karst region including the Bükk Mountains and the Aggtelek karst areas. During another week-long congress field trip he toured the Bohemian and Moravian karst regions of Czechoslovakia. On private excursions Mr. Hubbard travelled through the Carpathian karst region in Slovakia (Czechoslovakia) and the Silesia-Cracow and Tatra Mountains karst regions of Poland. The Dinaric karst region of Yugoslavia and Italy also was visited. The spectacular travertine deposits of Plitvice Lakes, located in the Dinaric Mountains of Yugoslavia, were of special interest because of Mr. Hubbard's involvement with the recently completed volume on the Virginia travertine-marl deposits.

Mr. Hubbard, the division's karst specialist, was impressed with the high level of interest and protection afforded to the karst areas in Czechoslovakia and Hungry. The governments of these countries are cognizant of the importance of their groundwater resources. The determination of the hydrologic and geologic intricacies of the karst features, such as caves, is the first level of understanding the nature of and how to protect the groundwater resources in karst areas.

POTENTIAL GEOLOGIC HAZARDS

David A. Hubbard, Jr.

The **International Decade for Natural Disaster Reduction** begins in January, 1990. The primary way in which the severity of natural disasters can be reduced is through the enlightment of the public and policy makers to the potential natural hazards that threaten to cause disasters throughout the world, the United States, or Virginia. We can better understand natural hazards by studying the disasters wrought by them. This integration of cause and effect allows us to gain insight into method for reducing the magnitude of future disasters through physical and social adjustments (National Research Council, 1989).

As a geologist with the State, I am concerned with the geologic hazards which potentially threaten Virginia. Earthquakes, expansive soils, radon, shoreline erosion, slope instability, and subsidence hazards occur in the Commonwealth.

Earthquake activity within Virginia largely has occurred in two areas: the central Virginia and the Giles County seismic zones (Bollinger, this issue). The immediate damage and mortality resulting from an earthquake may be increased by secondary losses because of the disruption of life lines which normally provide services, such as water for fire abatement and transportation access for evacuation of the injured. Attention to the design and placement of lifelines in Virginia's seismic zones is a disaster-reduction strategy.

Expansive soils are soils which shrink or swell with changing water content. Cracking and "heaving" of road surfaces, walls in contact with soils, and floor slabs are the most commonly observed damages associated with this hazard. Design considerations and soil treatment can minimize the effects of expansive soils where they are identified.

Radon (Rn) is a naturally occurring decay product of uranium. The half life of $Rn^{22}$is only 3.8 days. The gas radon poses a potential health hazard proportional to both the period

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of exposure and the concentration. The testing for radon concentrations in living and work areas is the only definitive means of locating potentially hazardous accumulations.

Shoreline erosion can occur along rivers and coastlines. Erosion is accentuated by high water levels resulting from precipitation and the increased wave activity associated with severe storms, such as tropical storms and hurricanes. Future sea level rise, related to global warming, will be a long term cause of shoreline erosion.

Slope stability is dependent on the strength of the materials comprising the slope. Increases in the water content or water pressures in soils or the water pressure in rock fractures are the primary cause of instability or failure of steep slopes. Vibrations associated with man's activities or earthquakes also may initiate slope failure.

Subsidence may result from many different causes including collapse into subsurface voids or adjacent excavations, and consolidation of soils because of loading, dewatering, or reordering of soil structures. Subsidence may be a slow or catastrophic process. Observed damages may be as slight as minor cracking of walls or as significant as the loss of structures or life lines.

Look for information about specific potential geologic hazards in future issues of "Virginia Minerals."

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