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DELAWARE GEOLOGICAL SURVEY

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PRELIMINARY REPORT ON THE EARTHQUAKE OF FEBRUARY 28, 1973

BY

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FOREWORD

Many, if not most, of the residents of northern Delaware and adjacent Pennsylvania and New Jersey were abruptly awakened early on the morning of February 28, 1973 by the most severe earthquake felt in this area in one hundred years. The Delaware Geological Survey, knowing of the many needs for information about this event and believing that persons are reassured by the immediate availability of factual data, has made every effort to collect and disseminate knowledge about the event as rapidly as possible. In this effort we have enjoyed exceptional cooperation and assistance from experts in seismology, local agencies, industries, news media, and individual citizens.

We are particularly grateful to the almost 4,000 citizens of Delaware, Maryland, Pennsylvania, and New Jersey who reported their observations to us. It is noteworthy that all of these reports were serious and thoughtful, and that many persons troubled to volunteer additional information in letter form. Many reports contained notes of thanks and good wishes that are truly appreciated.

We cannot thank each person who assisted in this investigation individually, but hope that this report, and others that will follow, will help all of us to understand the recent earthquakes in this area and will assure you that we are putting your information and your assistance to beneficial use.

Robert R. Jordan
State Geologist

PRELIMINARY REPORT ON THE EARTHQUAKE OF FEBRUARY 28, 1973

INTRODUCTION

This report has been prepared to fill an immediate need for information on the earthquake that affected northern Delaware on February 28, 1973. Public interest in seismic events has grown in the past two years because of a series of small, local events (Jordan et al., 1972) and has been heightened considerably by the event described in this report.

Various stresses on and within the earth lead to periodic adjustments or changes by the rocks making up the earth's crust. Many changes are too slow or small to be measured within a human lifetime, but earthquakes can be a very perceptible phenomenon, expressing more rapid adjustment. Indeed, earthquakes in many areas of the world are a serious geologic hazard and a threat to life and property. Thus, it must be recognized that the earth is a dynamic body and its processes are not bound to the convenience of man.

ACKNOWLEDGMENTS

Cooperation of other agencies and individuals in this investigation has been excellent. The response of the general public in submitting felt reports has been overwhelming and is greatly appreciated. Particular acknowledgment is due to the following:

Mr. James F. Lander, Director, National Earthquake Information Center, National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado

Dr. Marc Sbar, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York

Mr. Chris Stephens, Department of Geological Sciences, Cornell University, Ithaca, New York

Dr. and Mrs. Peter B. Leavens, Department of Geology, University of Delaware, Newark, Delaware.

GEOLOGY

Epicenter locations of the February 28 event as calculated by various workers fall within an area bounded by Chester, Pennsylvania, Wilmington, Delaware, and Penns Grove, New Jersey. Wilmington and Chester are located approximately on the Fall Line, the division between the Piedmont physiographic province to the north and the Coastal Plain province to the south. Piedmont rocks in the immediate area are schists and gneisses of the Wissahickon Formation (Cambro-Ordovician age) and mafic gneisses of the Wilmington Complex (Figure 1, modified after Ward, 1959). The nature of the contact and the relationship between these two units is not entirely clear at this time. There are several known faults in the area and other faults have been postulated from the results of drilling, geophysical investigations, and interpretation of aerial photographs (Spoljaric, 1972; J. C. Miller, personal communication). It is not known now which, if any, of the known faults are active.

South of the Fall Line and within the area of the postulated epicenter, the unconsolidated Coastal Plain sediments range in thickness from a few feet near the Fall Line to several hundred feet farther to the south and east. Sediments beneath the Delaware River are mainly Quaternary in age, but those immediately adjacent are predominantly Early Cretaceous.

INSTALLATION OF PERMANENT SEISMIC MONITORING STATION

One of the conclusions of the 1972 (Jordan, et al.) study was that a permanent earthquake monitoring station be established in the immediate area. The 1971 and 1972 earthquakes in and near Wilmington were too small to be recorded at any distance and thus it was extremely difficult to obtain accurate instrumental data for calculation of epicenter and travel time. Through the efforts of a private donor to the University of Delaware, and the Delaware Division of Emergency Planning and Operations, a short period, vertical motion station was installed by the Delaware Geological Survey at the University of Delaware in the fall of 1972 (Figure 1). The station has been in operation at the offices of the Delaware Geological Survey since that time but severe background vibrations from vehicles limited its full potential. The sensor has now been located some distance away at a quieter location and the signal is telemetered to the recorder. Before the permanent station was acquired, a semi-portable station was in operation at the

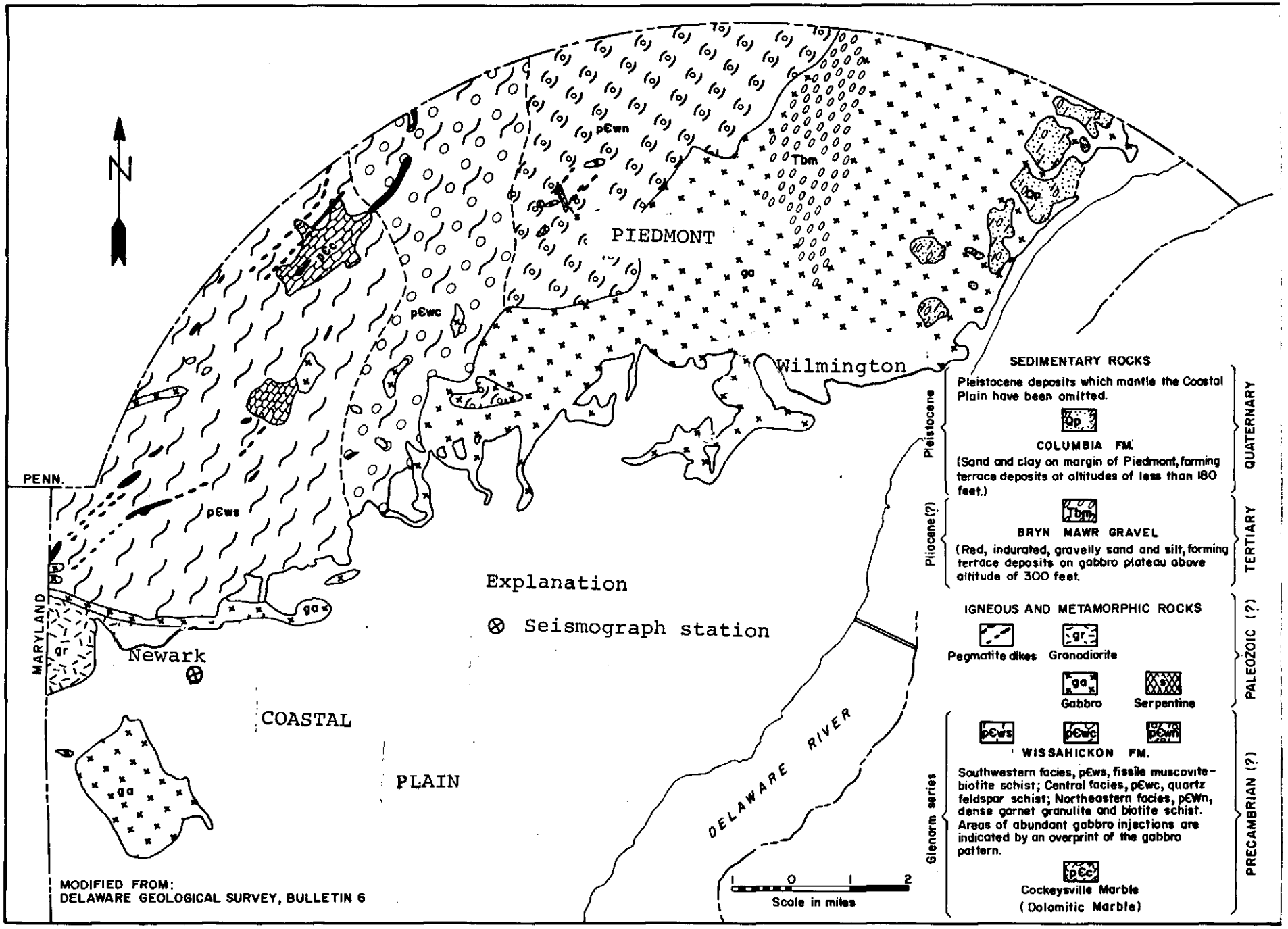

FIGURE 1. GEOLOGIC MAP OF THE PIEDMONT PROVINCE IN NEW CASTLE COUNTY.

University of Delaware during the late summer and early fall of 1972. This equipment was on loan from the National Oceanic and Atmospheric Administration (NOAA) and is being retained as a spare field unit.

OTHER EVENTS

In April, 1972, Jordan et al. reported on confirmed or probable small earthquakes that had been noted, primarily, in southwestern Wilmington on August 14, 1971, January 2, 6, 22, and 23, and February 10 and 11, 1972. Since the issuance of that report, several additional small events have occurred.

On August 13, 1972 a very small local earthquake with a peak intensity possibly as high as IV was noted in southwestern Wilmington. This occurred at about 9:09 p.m. EDT (0109 GMT, 8/14/72) and appeared to have been followed by a weaker event at about 9:55 p.m. EDT (0155 GMT, 8/14/72). There was no damage. The earthquake was accompanied by a loud sound reported as explosion-like or rumbling. The DGS seismograph station had not yet been established and there were no operational seismographs elsewhere within range of detection.

"Booming" noises and vibrations were again reported from southwestern Wilmington on November 27 and 29, 1972. These events, which were quite weak but produced startling noises, were recorded by the DGS seismograph. The event on November 27 happened at 11:15 p.m. EST (0415 GMT, 11/28/72) and that of the 29th at 8:46 a.m. EST (1353 GMT). These were the first local events recorded by the newly established station.

INVESTIGATION METHODS

Delaware Geological Survey personnel were awakened by the earthquake on the morning of February 28, 1973. John H. Talley and Boris J. Bilas immediately made a check of the seismograph record. The instrument had registered the earthquake at 0321:37 EST (0821:37 GMT) with a probable magnitude higher than anything occurring in the area since the 1871 Wilmington event. Figure 2 shows a portion of the record with time "moving" left to right. The earthquake starts abruptly, and the pen is kept from going off scale for the first 45 seconds only by a dampening apparatus. After one minute the machine is still recording vibrations. Hundreds of calls were received in the next few hours by police and other local officials and agencies. Coordination

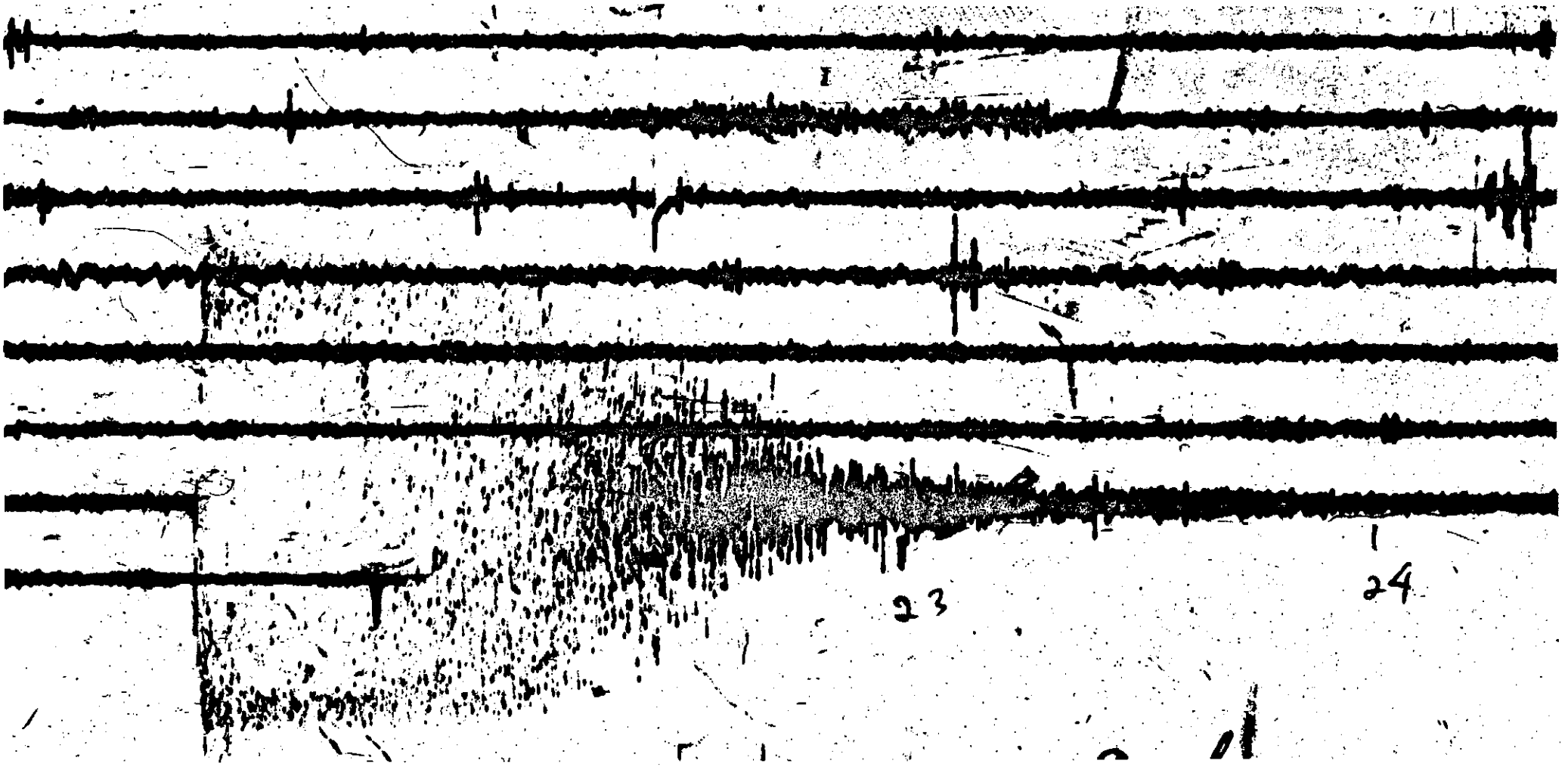

Figure 2. Seismograph recording of February 28, 1973 event, vertical component. Location of instrument - Penny Hall, University of Delaware, Newark, Delaware.

was established with NOAA and Lamont-Doherty and it was learned that the event had been recorded on other seismographs in the eastern United States. Preliminary calculations placed the epicenter either near Norristown, Pa. or just southeast of Philadelphia. However, further work that same day by both NOAA and Lamont-Doherty indicated that the epicenter was probably located within an area bounded by Chester, Pa., West Chester, Pa., and Wilmington, Del. By late afternoon on the 28th, thousands of calls had been received by local officials and the Delaware Geological Survey. The Survey held a press conference on the afternoon of the 28th to discuss the available data and to ask the aid of the press in distributing felt report forms. During the next three to four days approximately 2,500 felt report forms were distributed by the Delaware Geological Survey and several cooperators. In addition, the Wilmington Morning News and Evening Journal, the Newark Weekly Post, the Penns Grove Record, and the University of Delaware Review and Faculty Newsletter ran copies of the felt report forms with requests for local residents to submit them to the Survey. Cable television Channel 5 televised a copy of the form. The combined coverage of these media is estimated at about 158,000. Local radio and television stations and the Baltimore Sun papers cooperated in urging residents to report information to the DGS. NOAA also mailed 3,000 of their own forms to local post offices for distribution to Federal employees in the area.

Dr. Marc Sbar, Lamont-Doherty Geological Observatory and Mr. Chris Stephens, Cornell University, began setting up portable instrumentation for aftershock monitoring on the night of March 1. Four instruments were available and were placed at the following locations for variable periods of time:

Marsh Road, Wilmington, Del.
Haddon Heights, N. J.
Penns Grove, N. J.
Riverview, N. J.
Chadds Ford, Pa.
Oxford, Pa.
Polly Drummond Hill near Newark, Del.
Appleton Road, south of Kemblesville, Pa.

Seven aftershocks were recorded in the period from March 1 through March 4. Reports indicate that a few people may have felt one or more aftershocks but for the most part the aftershocks were too small to be felt. (See Appendix for exact location of temporary monitoring stations and times of aftershocks.)

Plotting of data from felt reports continued until it was thought a reasonable picture of the intensities involved was obtained. The preliminary results obtained from plotting intensities assigned to felt report forms are shown on Figure 3.

EFFECTS OF THE EARTHQUAKE

Study of the 3,742 written felt reports sent to the DGS plus field interviews and observations indicate that the February 28 earthquake produced intensities of IV on the Modified Mercalli Scale in an elongate northeast-southwest pattern from north of Baltimore, Maryland through Philadelphia, Pennsylvania (Figure 3). Intensities of V are general in parts of Wilmington, suburban New Castle County, and Claymont, Delaware and a few peak intensities of VI were reached in that area (Figure 4). As the event occurred at 3:21 a.m. only about 10% of those reporting were awake and observations of the duration of the event and such phenomena as swinging and shifting objects were hampered.

About 70% of persons within 31 miles (50 kilometers) of the epicentral area noted rattling of windows, doors, and small objects. Approximately 20% of the reports within this radius note the shifting of small objects and about 5% the overturning of similar items. The effects were more severe and felt over a longer distance in the Piedmont Province (Figure 1) than in the Coastal Plain. Almost 10% of those reporting from the Piedmont within 15 miles (25 kilometers) of the epicenter experienced cracked plaster, windows, walls, or ground. This also occurred at greater distances and on the Coastal Plain, but infrequently. Greater than two-thirds of the observers perceived a rapid, vibrating motion; the remainder felt a slower, swaying action. As would be expected, the severity of the motion decreased with distance from the epicenter, but significantly greater numbers of persons located within the Piedmont than on the Coastal Plain near the epicenter thought the motion was "violent."

Almost two-thirds of those within 15 miles and more than half within 31 miles of the epicenter noted the type and frequency of the earthquake noise. A greater proportion of those close to the event reported the noise to be explosive or a "boom," as opposed to the rumble that predominated at greater distances. More than one-third of those in the inner zone in the Piedmont noted the extreme loudness of the noise. Many found this to be the most frightening aspect of the earthquake and several noted that this event was more startling than much larger

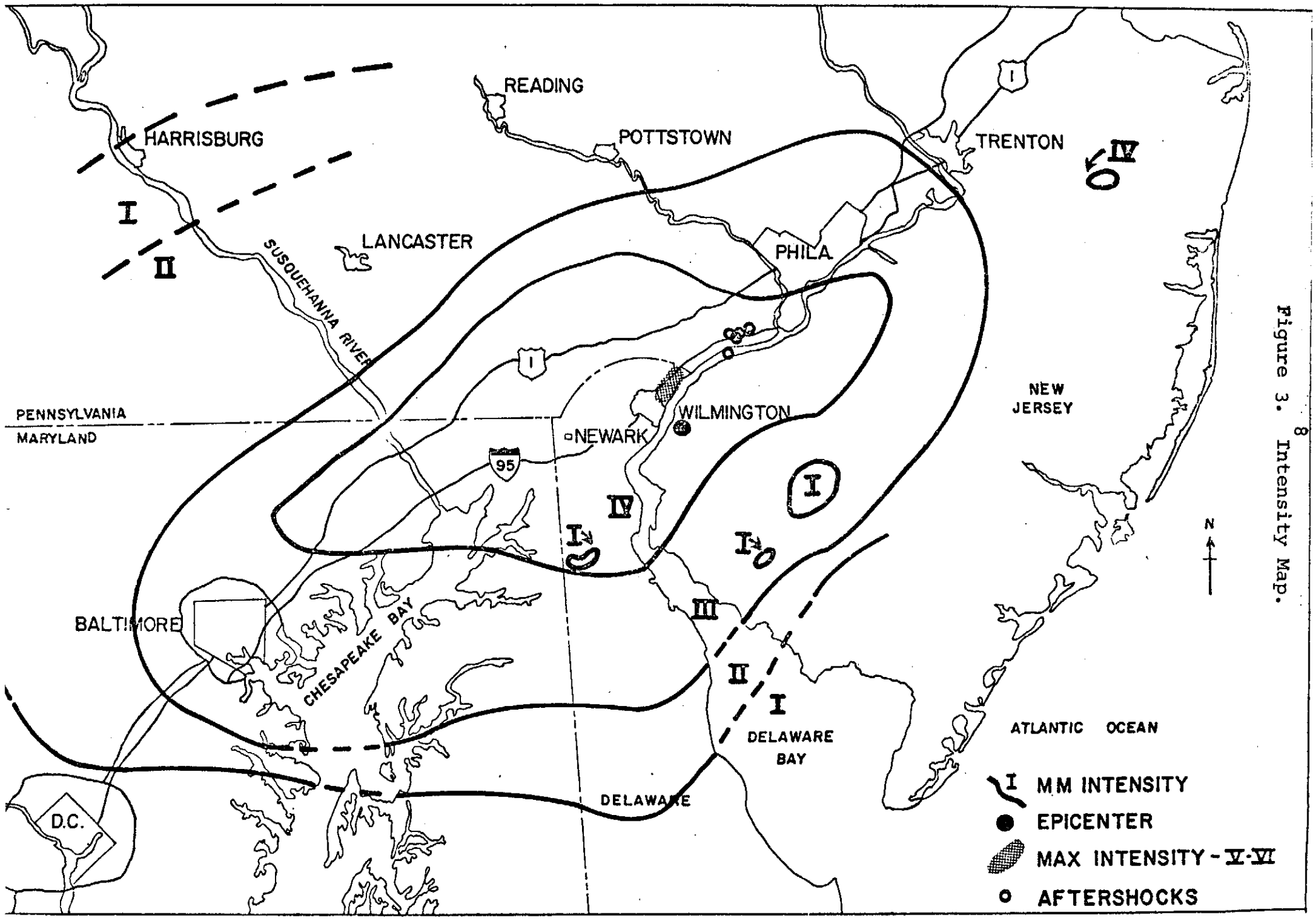

Figure 3. Intensity Map.

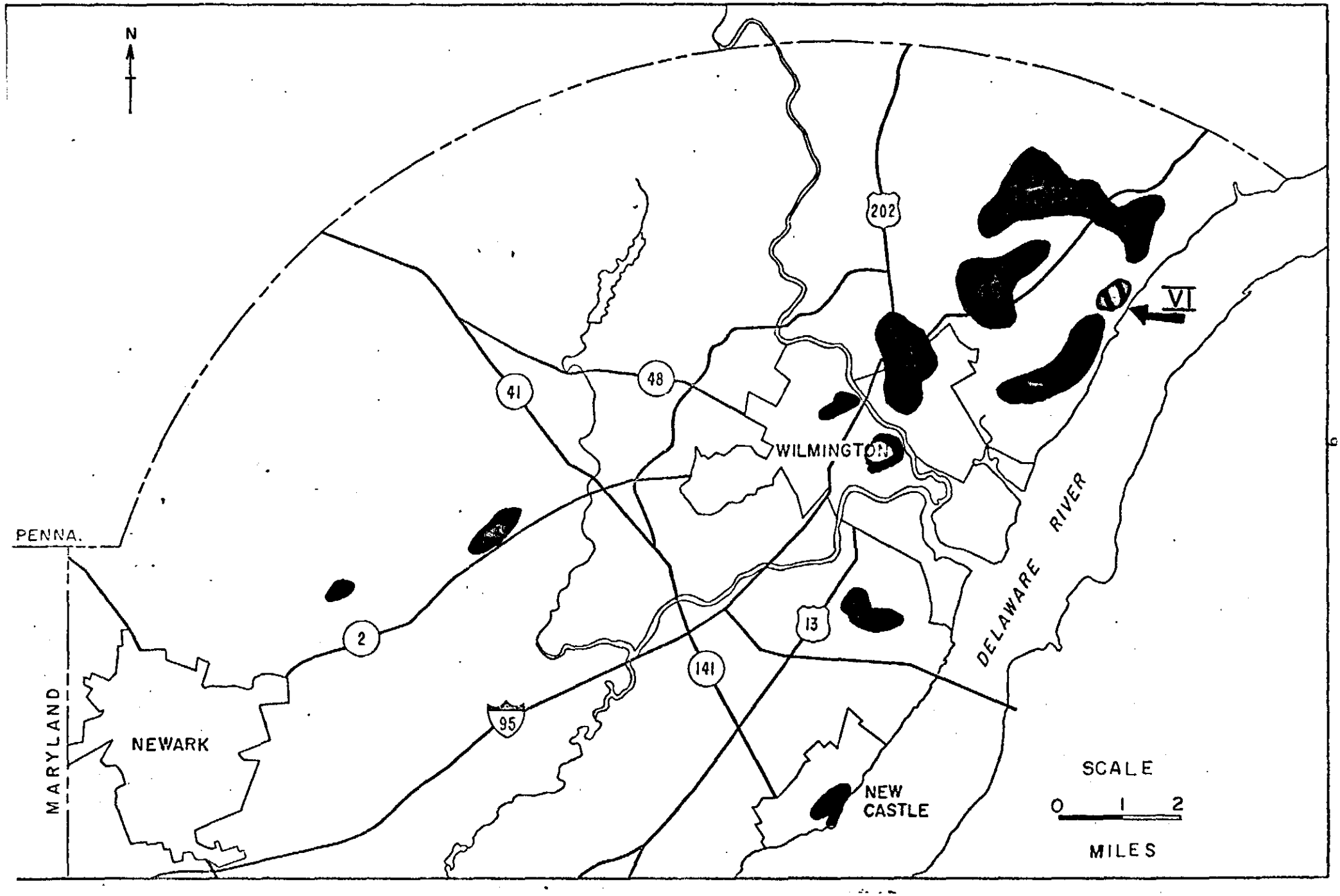

Figure 4. AREAS OF INTENSITY V IN DELAWARE

earthquakes that they had experienced elsewhere because of the intense noise. Apparently, based largely on the sound perceived, about 35% of those within 31 miles were able to associate a direction with the vibrations of the earthquake. When plotted against the final epicenter location, many of these observations were quite accurate.

At intensities of VII to VIII and greater, earthquakes are dangerous. The event of February 28 was, fortunately, below this threshold. The many felt reports and some checks of utilities and major structures in the immediate area indicate that there was no serious damage and no injuries are known.

CONCLUSIONS

The February 28 event had a magnitude of 3.8 and a maximum consistent intensity of V (Modified Mercalli Scale) with a few reports assigned an intensity of VI. The epicenter location as determined by Lamont-Doherty Geological Observatory and Cornell University from aftershock monitoring was about 39°51.0' and 75°20.3' or north of Chester, Pa. near or in the Delaware River (Figure 3). The epicenter location as determined by NOAA was slightly farther south and also in or near the Delaware River. Origin time was calculated as 0821:31.2 GMT and the focus as under 10 kilometers. Further attempts are being made to refine the epicenter location. The event was most strongly felt in the vicinity of Claymont, Delaware.

It should be noted that an epicenter cannot be located as a single point and that determination of its location within a radius of a few miles represents a high level of precision, especially considering the scarcity of instrumentation within this area.

It is quite clear that earthquakes do occur in northern Delaware. The history of the region and the nature of the phenomenon indicate that there will be additional earthquakes in the future. It is impossible to predict now when such events might occur, only that they will occur.

Recent earthquakes in Delaware have been of small to moderate size. It has been over 101 years since the last damaging earthquake. That 1871 event, which reached an estimated intensity of VII, may provide a reasonable indication of what would be a large earthquake for Delaware.

Because of a very different geologic structure, the scale of seismic activity in Delaware and the surrounding area is very much smaller than that in truly active regions such as portions of the West Coast of the United States. However, the earthquake of February 28 produced justified concern in this area and much remains to be learned about the seismicity of the East Coast so that thorough investigation and continuing vigilance are warranted.

RECOMMENDATIONS

Because of the continuing seismic activity in the northern Delaware area and the public awareness and interest in this activity, it is suggested that an investigation be made to determine the susceptibility of specific types of construction and facilities in this area to earthquakes of the type recently experienced. This will require the combined efforts of geologists, seismologists, and engineers. The Delaware Geological Survey is presently seeking ways that this might be done and has been encouraged by Governor Tribbitt to proceed in this direction. The present seismic monitoring station at the University of Delaware yielded valuable information about the November 28 and 29, 1972 and February 28, 1973 events and support of this station should be continued as planned. Some additional portable equipment should be considered to decrease local dependence on borrowed equipment.

Increasingly detailed geologic mapping programs, such as those now underway by the Delaware Geological Survey, should provide additional understanding of the geology of the area and perhaps eventually aid in predicting the nature of future events. It has become apparent that such mapping should give additional emphasis to local and regional structure and an overall regional synthesis of the geology.

APPENDIX

Terminology

The following terms are pertinent to the discussion of earthquakes. Definitions have been taken from the Glossary of Geology and Related Sciences (American Geological Institute, 1960), except for those designated (*).

Earthquake -	Perceptible trembling to violent shaking of the ground produced by the sudden displacement of rocks below the earth's surface.
Epicenter -	The point on the earth's surface directly above the focus of an earthquake.
Felt area* -	Geographic area over which an earthquake is felt (felt report).
Focus -	The true center of an earthquake, within which the strain energy is first converted to elastic wave energy.
Intensity -	A number describing the effects of an earthquake on man, man-made structures, and the earth's surface.
Magnitude -	A quantity characteristic of the total energy released by an earthquake.
Modified Mercalli Scale* -	An arbitrary scale of 12 degrees which expresses the intensity of an earthquake. The intensity is roughly proportional to the logarithm of the acceleration.
P-wave -	A seismic body wave, advancing by alternating compressions and rarefactions in an elastic medium.
S-wave -	A transverse body wave which travels through the interior of an elastic medium.
Seismology -	The science of earthquakes, in all that relates to their forces, duration, lines of direction, periodicity, and other characteristics.

Seismograph - Instrument which records seismic waves.

Seismometer - Detecting device which receives seismic impulses.

Seismogram - The record made by a seismograph.

Tremor - An earthquake having small intensity.

Richter Scale* - A logarithmic scale which expresses the magnitude of an earthquake. The magnitude is related to total elastic energy released.

"Modified Mercalli" Scale of Earthquake Intensities

I. Not felt, except by very few, favorably situated.

II. Felt only on upper floors, by a few people at rest. Swinging of some suspended objects.

III. Quite noticeable indoors, especially on upper floors, but many people fail to recognize it as an earthquake; standing automobiles may sway; vibrations feel like those of a passing truck.

IV. Felt indoors by many during day, outdoors by few; it at night, awakens some; dishes, windows, and doors rattle, walls creak; standing cars may rock noticeably. Sensation like heavy truck striking a building.

V. Felt by nearly all, many wakened; some fragile objects broken, and unstable objects overturned; a little cracked plaster; trees and poles notably disturbed; pendulum clocks may stop.

VI. Felt by all; many run outdoors; slight damage; heavy furniture moved; some fallen plaster.

VII. Nearly everyone runs outdoors; slight damage to moderately well-built structures, negligible to substantially built, but considerable to poorly built; some chimneys broken; noticed by automobile drivers.

VIII. Damage slight in well-built structures; considerable in ordinary substantial buildings, with some collapse; great in poor structues. Panels thrown out of line in frame structures; chimneys, monuments, factory stacks thrown down; heavy furniture overturned; some sand and mud ejected, wells disturbed; automobile drivers disturbed.

IX. Damage considerable even in well-designed buildings; frame structures thrown out of plumb; substantial buildings greatly damaged, shifted off foundations; partial collapse; conspicuous ground cracks; buried pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed or knocked off their foundations; rails bent, ground cracked; landslides on steep slopes and river banks; water slopped over from tanks and rivers.

XI. Few if any masonry structures left standing; bridges destroyed; underground pipes completely out of service, rails bent greatly; broad cracks in ground and earth slumps and landslides in soft ground.

XII. Damage total; waves left in ground surface, and lines of sight disturbed; objects thrown upward into the air.

RECORDED AFTERSHOCKS FOR FEBRUARY 28 EVENT

Date	Time GMT	Time EST	Recorded at
3/1/73	2057	3:57 p.m.	LEV-I
3/2/73	1123	6:23 a.m.	RIV
	1857	1:57 p.m.	SAN
3/3/73	0712	2:12 a.m.	LEV-II
	1620	11:20 a.m.	SAN
	2235	5:35 p.m.	PNG
3/4/73	0256	9:56 p.m.	PNG

LOCATIONS OF PORTABLE STATIONS RECORDING AFTERSHOCKS

Station Designation	Area	Coordinates
LEV-I LEV-II	Appleton Rd., south of Kemblesville, Pa.	39°43'05" x 75°49'24" 39°43'34.8" x 75°49'39.0"
PNG	Penns Grove, N. J.	39°44'17" x 75°21'02"
RIV	Riverview, N. J.	39°44'33" x 75°28'12"
SAN	Chadds Ford, Pa.	39°51'47" x 75°35'36"

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