STATE OF DELAWARE

UNIVERSITY OF DELAWARE

DELAWARE GEOLOGICAL SURVEY

OPEN FILE REPORT 2 2

PRELIMINARY REPORT ON SEISMIC EVENTS IN NORTHERN DELAWARE

BY

ROBERT R. JORDAN
THOMAS E. PICKETT
KENNETH D. WOODRUFF

NEWARK, DELAWARE

APRIL, 1972

PRELIMINARY REPORT ON SEISMIC EVENTS IN NORTHERN DELAWARE

INTRODUCTION

Earthquakes are an unfamiliar phenomenon in Delaware. Because of the great public and scientific interest in the seismic events that have recently affected northern Delaware, this Open File Report has been prepared to present currently available information concerning the earthquakes and the investigation pursued by the Delaware Geological Survey. This is not a final scientific explanation of the events.

To many persons it is shocking to realize that the earth that they regard as stable is, in fact, an active body. The present earth is a product of 4.5 billion years of history, during which time most geologic forces have acted so slowly as to be almost imperceptible. Therefore, sudden movements are disturbing.

Earthquakes are the vibrations caused by relatively sudden slippage of deeply buried rocks. Earthquakes occur in a vast range of sizes; many are too small to be felt and others cause great damage. The events in Delaware that are described on these pages were relatively small and, although they warrant further study, which may lead to some precautionary measures, they do not represent cause for alarm.

ACKNOWLEDGMENTS

The outstanding cooperation achieved during this investigation is a tribute to many persons and agencies. We are grateful to the many individual citizens of Delaware who provided us with their observations of the events.

We particularly wish to thank the following people and institutions for their many forms of assistance:

William G. Turner, Commissioner, Wilmington Department of Public Works

James F. Lander, Director, National Earthquake Information Center, Rockville, Maryland, National Oceanic and Atmospheric Administration (NOAA)

Wendell V. Mickey, Chief, Vibration and Engineering Branch, NOAA, Boulder, Colorado

James N. Jordan, Geophysicist, NOAA, Boulder, Colorado

John West, Instrumentation Specialist, NOAA, Las Vegas, Nevada

Marc Sbar, Lamont-Doherty Geological Observatory, Palisades, New York

Francis T. Wu, Department of Geology, State University of New York at Binghamton

Robert E. Sheridan, Department of Geology, University of Delaware, Newark

Mrs. Americo Carucci and Miss Marlene Carucci, 8th Street, Wilmington

Wilmington Department of Parks and Recreation, Canby and Delamore Parks

University of Delaware, Goodstay Center, Wilmington, and Morris Property, Newark

St. Thomas of the Apostle Church, Wilmington

Veterans Administration Center, Elsmere

Delaware Department of Administrative Services, Division of State Buildings and Grounds, Buena Vista

E. I. duPont de Nemours Experimental Station, Wilmington.

The names of all persons rendering assistance cannot be listed in this brief report; however, their assistance is acknowledged with gratitude.

GEOLOGY

Earthquakes were felt in both the Piedmont and Coastal Plain Provinces of New Castle County, Delaware (see Table 1).

The Piedmont contains Lower Paleozoic metamorphic and igneous rocks (see Figure 1). The Wissahickon Formation, in the northwestern part of the State, is a biotite-quartz-plagioclase feldspar schist with migmatite zones. Structures in this formation generally strike northeast. Mr. John C. Miller, Delaware Geological Survey, has interpreted lineations on aerial photographs as traces of inclined, tabular fracture zones that strike

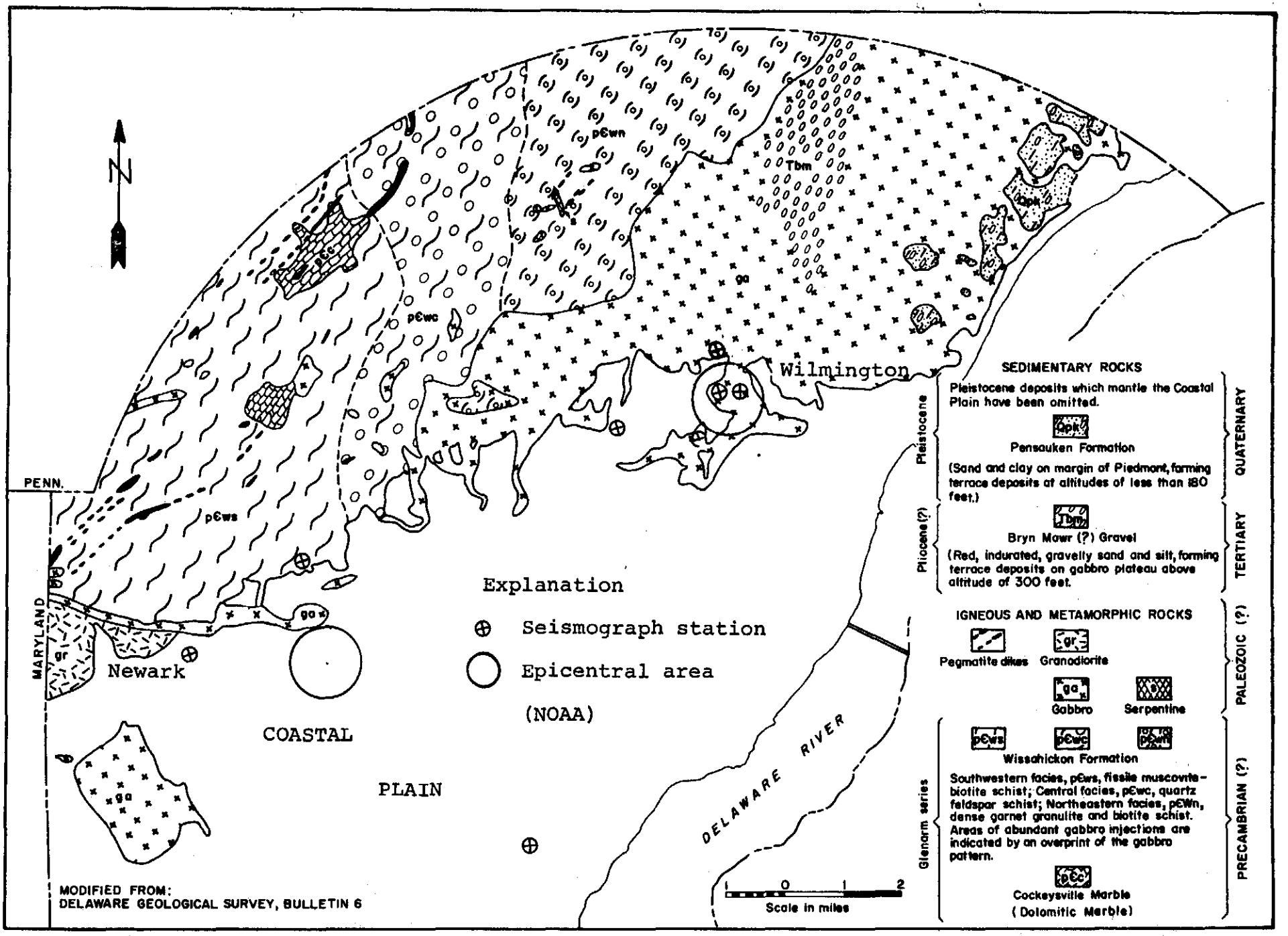

FIGURE 1. GEOLOGIC MAP OF THE PIEDMONT PROVINCE IN NEW CASTLE COUNTY.

essentially northwest (personal communication). Miller interprets these fracture zones as the result of extensional forces due to regional uplift.

The Cockeysville Formation is a granular marble seen in outcrop only a few places north of Newark.

The Wilmington Complex, in the northeastern part of the State, comprises several rock types and is dominated by a dense gray crystalline rock described as a banded gneiss (Ward, 1959).

The Fall Zone separates the Piedmont rocks from the sediments of the Coastal Plain. This zone contains many small faults, but their sizes and dates of last movements are not well understood. Research presently underway by Dr. Nenad Spoljaric, Delaware Geological Survey, should clarify the geology of the Fall Zone (Spoljaric, 1972).

The Coastal Plain in the area contains unconsolidated sands, gravels, and clays from Lower Cretaceous to Pleistocene in age.

SUMMARY OF EVENTS PRIOR TO INSTRUMENTATION OF WILMINGTON AREA

The "Every Evening" newspaper for Wilmington, October 9, 1871, reports an earthquake that was a sudden tremor accompanied by an audible "boom." The reports are similar to modern ones except that the 1871 event was strong enough to knock down a few brick chimneys and crack a few windows in southwest Wilmington. There was some panic, particularly among school children who had to be restricted from running out of the classroom.

The Earthquake Information Bulletin (NOAA, 1971) summarized the 1871 event:

> At Wilmington, Delaware's largest city, chimneys toppled, windows broke, and residents were quite bewildered by the unusual event. Lighter damage was sustained in northern Delaware at Newport, New Castle, and Oxford (Pa.). Earth noises, variously described as "rumbling" and "explosive," accompanied the shock in several areas.

This event was estimated to have been intensity VII. The same article records an earthquake of less than

intensity V in the Dover area in March, 1879 and another, similar event in May, 1906 near Seaford. A small event in the lower Delaware Bay area was noted in December, 1937.

Some residents report remembering minor tremors felt in 1944 near Wilmington. Others report "vibrations" for the last several years which were dismissed as "sonic booms," "blasting," or "testing at Aberdeen Proving Grounds." A few reports in 1972 from the seashore area of Sussex County and Salem County, New Jersey have been received. The intensity in all cases is apparently less than 2.5.

The latest incidents apparently started on July 14, 1971 when residents of southwestern Wilmington reported "booms." This is the area bounded by 8th Street to Maryland Avenue, and Jackson Street to Bancroft Parkway. The reports were investigated by City and utility company officials who were concerned that they be caused by sewer or natural gas. No trace of gas or damage was found.

Hundreds of reports were received by the Department of Public Works, the Fire Department, and others from the same area of southwestern Wilmington on December 29, 1971, January 2, 6, 22, and 23, 1972. The "booms" felt like "a truck hitting the house," "furnace blowing up," "distant thunder," "shore batteries." No damage to houses was reported although the vibrations accompanying the "booms" rattled window panes and crockery.

Gas was again believed to be a possible cause. No trace of gas was found by Public Works officials, although the smell of gas was reported by a few residents preceding the January 6 events.

The Diamond State Telephone Company and the Delmarva Power and Light Company reported no damage. It was conjectured that pranksters using explosives were responsible, but no evidence of this was found.

INITIAL CONTACTS OF DGS WITH OTHER AGENCIES

The Delaware Geological Survey first became involved when Robert Lewis of the Office of Public Information, University of Delaware, telephoned on January 3, 1972 to report that he had been contacted by WCAU-TV in Philadelphia concerning the tremors.

The Survey contacted Mr. George L. Ryan, Deputy Commissioner of the Wilmington Department of Public Works.

He and Mr. John H. Doherty, also of Public Works, who was on the scene during the events of January 2, confirmed numerous reports of unexplained tremors. Utilities were unaffected.

The Delaware Geological Survey contacted the Franklin Institute, Princeton University, Franklin and Marshall College, Lamont-Doherty Geological Observatory, and the National Oceanic and Atmospheric Administration (NOAA) in order to learn if the events were recorded on seismographs in the area. It was learned that regional coverage is minimal and some of the existing stations are out of order. The event had not been recorded.

On January 4, 1972, contact was established with the National Earthquake Information Center in Rockville, Maryland. Mr. James F. Lander, the Director, was very helpful in checking the records and offering information on the nature of earthquakes. However, no positive information on the Delaware events was found.

On January 10, 1972, Mr. Richard Goldsmith, Liaison Officer of the U. S. Geological Survey in Beltsville, Maryland, was telephoned. It was determined that the USGS could not offer direct assistance in such matters.

Mr. William G. Turner, Commissioner of Public Works for Wilmington, invited Jordan and Pickett to a meeting on January 10, 1972 with representatives from Delmarva Power and Light Company, Department of Public Safety and Fire, and Diamond State Telephone Company. The phenomena were discussed and the possibility of a natural explanation was considered. Jordan and Pickett agreed to study the problem further.

Mr. William Belford, Executive Office of the President, Office of Emergency Preparedness, expressed interest by telephone to Pickett on January 27, 1972. He used the information supplied on the telephone as a news item for their in-house "Situation Summary."

FIELD INVESTIGATIONS

Following correlation of felt reports for the event of January 2, several localities in and around the Wilmington area were visited in an attempt to detect any possible earth movements. Outcrops of crystalline rock in Delamore Park and in a quarry near the Alapocas area showed no obvious evidence of recent movement. Other areas visited included a City of

TABLE 1. SUMMARY OF FELT REPORTS

Date	Geographic Range	Time	Notes
7/14/71	S.W. Wilmington	?	Cause undetermined
1/2/72	S.W. Wilmington	2:08 AM, 7-9 PM	Probable earthquake
1/6/72	S.W. Wilmington	10:45-11:45 PM	"
1/22/72	S.W. Wilmington	1:40 AM, 8:35 PM	"
1/23/72	S.W. Wilmington	2:22 AM	"
2/10/72	Smyrna-Elkton-Carneys Point, NJ-Wilmington	7:16:30 PM	Earthquake magnitude 2
2/11/72	Hockessin-Talleyville	10-11 AM	Earthquake
2/14/72	Elm Street, Wilmington	5:45 PM	Cause undetermined
2/17/72	Landenburg	9:45, 11:28 AM	"
2/21/72	Lincoln Street, Wilmington	9:49 PM	"
2/22/72	S.W. Wilmington	2, 4:30, 11 AM, 9 PM	"
2/23/72	Penny Hall, Univ. of Del.	2:11 PM	"
2/23/72	Bethany Beach	10:30 AM	"
2/25/72	Fairhill, MD; Newark	Between 10:50-11:05 AM	"
3/3/72	Arbor Park, Newark, Heritage Park	4:30 PM	Quarry blast at 4:24 PM
3/7/72	Brookside	11:20 AM	Cause undetermined

Wilmington reservoir in the 1500 block of Eighth Street and the Penn Central Railroad yards at the foot of Seventh Avenue. Again, no evidence of earth movement was seen.

Recording stream gages in nearby streams, rain gages, and observation well records were all checked for any evidence of earth tremors with the cooperation of the USGS office at Dover, Delaware. No anomalous readings were noted on any of these instruments at times of reported tremors.

Many residents of the Newark-Wilmington area were interviewed and their observations recorded.

INSTRUMENTATION

On the evening of January 27, Mr. James N. Jordan, Mr. James F. Lander, Mr. Wendell V. Mickey, and Mr. John West, all with NOAA, arrived in Wilmington with instrumentation for two seismic monitoring stations.

During January 28-29 temporary monitors supplied by NOAA were established at the University of Delaware Goodstay Center on Pennsylvania Avenue in Wilmington, and at the Veterans Administration Hospital in Elsmere. Instrumentation in both cases was a short period, vertical motion seismometer feeding into an amplifier and galvanometer-type drum recorder ("Helicorder," Teledyne Geotech).

Additional instrumentation was obtained from Lamont-Doherty Geological Observatory and from the State University of New York at Binghamton (SUNY). On January 29 and 30, Mr. Marc Sbar and Dr. Francis T. Wu established seismic stations at the following locations:

1. St. Thomas of the Apostle Church at Fourth Street and Bancroft Parkway,

2. a private residence at 1633 West Eighth Street,

3. the E. I. duPont Experimental Station at Chestnut Run,

4. the University of Delaware Goodstay Center.

The additional station at the Goodstay Center was for the purpose of comparing responses with the NOAA monitor

already in operation there. Other localities were visited for placement of a possible monitor but were judged too noisy for satisfactory results. The duPont location also proved to be unsatisfactory because of high background noise and on January 30, after a day of operation, the instrument at this location was moved to Canby Park within the City of Wilmington.

The instrumentation at St. Thomas' Church was that provided by Lamont-Doherty and consisted of a Mark Products 1-4 seismometer, a Develco amplifier, and a Sprengnether timing system. The other three monitors provided by SUNY employed Geospace short period seismometers, Electro-tech SPA-1 amplifiers, Develco timing systems, and Sprengnether drum recorders.

Monitoring by NOAA continued until February 2. At that time, after a study of all available data, NOAA personnel concluded that the events reported prior to the monitoring were indeed earthquakes of a small magnitude, probably less than 2.5 on the Richter Scale. No events were reported during the period January 28 to February 2 that were large enough to be felt. However, some very minor events may have been recorded at the Goodstay Center during this time. This information was released in a press conference held in Wilmington on February 2 prior to the departure of NOAA personnel.

Because of other commitments, NOAA staff removed their instrumentation on February 2. However, the four monitors provided by Lamont-Doherty and SUNY remained, under a temporary loan agreement with the Delaware Geological Survey. The Survey then took over full-time operation of the remaining monitors.

EVENT OF FEBRUARY 10, 1972

No events of apparent significance occurred during the monitoring period until February 10. Beginning at about 7:25 p.m. EST on that day, local police and radio stations began receiving reports of apparent widespread tremors centered in the Newark-Wilmington area. However, some felt reports were received as far away as Carneys Point, New Jersey, and Elkton, Maryland. Records collected from all four seismographs the next day confirmed that an event had occurred at 7:16:30 p.m. EST (0016:30 Greenwich Mean Time, Feb. 11). The seismic records were forwarded to NOAA, Lamont-Doherty, and SUNY for further study. Because of the "tightness" of the seismic monitoring network, the frequency of the seismic

waves, and the lack of background data, it was not possible to locate the epicenter of the event. However, NOAA concluded that the epicenter was probably between Newark and Wilmington (Figure 1) along the Fall Zone (J. N. Jordan, personal communication). The S-P interval was about three seconds and the focus seemed to be about 10 kms. The magnitude was estimated at about 2.0. This event apparently had an unusually large felt area for a tremor of such small magnitude. Reports were received from as far away as Smyrna, Delaware, about 28 miles to the south of Newark. At the laundry building of the State Correctional Institute near Smyrna, large amounts of ground water entered the basement through a floor drain and flooded the basement to a depth of six feet. However, the exact time of damage could not be placed closer than within several hours of the tremor.

The following day, a number of felt reports for a tremor of lesser intensity was received for the area in and around Hockessin. These reports may be observations of aftershocks for the February 10 event. No clear confirmation of the February 11 reports was seen on the seismographs.

FURTHER MONITORING AND INVESTIGATION

Following the event of February 10, it became apparent that the epicenter of tremors was shifting and that the arrangement of the present seismic network was not entirely suitable for accurate interpretation of the records. Also, both background noise and routine maintenance were problems at some stations. Consequently, the station at 1633 West Eighth Street was discontinued on February 14 and moved to Penny Hall at the University of Delaware. The instrument at Canby Park was moved to State property at Buena Vista, Delaware. Both of these locations are in the Coastal Plain, although the University of Delaware location is less than one-half mile from the crystalline rock outcrops in the Piedmont. The monitor at St. Thomas' Church was removed on March 1 and reinstalled on the University of Delaware Morris Property located about three miles northeast of Newark, near Delaware Route 2. All of these relocations resulted in some reduction of background noise and easier access for servicing. The Morris Property location proved to be the most favorable of all the sites in terms of background noise and should be considered as a site for a permanent installation.

PRELIMINARY CONCLUSIONS

Based on the monitoring results and study of available felt reports, it was concluded by both the Delaware Geological Survey and other agencies involved in this study that minor earthquakes had been occurring. All of these had an apparent magnitude of about 2.5 or less on the Richter Scale and were no immediate cause for alarm. One puzzling aspect was the wide felt areas and low intensity for some events as recorded on the seismographs. However, the instrument settings and relative high background noise may have decreased the recorded intensities. It was also possible that several small events which appeared on some seismographs late in the evening were not felt and thus went unreported by the general public.

The epicenter of all events seemed to be along the Fall Zone within a few miles of the Newark-Wilmington area. While such seismic activity is not rare in this part of the country, it is possible that some intensification has occurred in the last one or two years. Improved communications and more public awareness of such natural happenings makes this difficult to determine with accuracy. NOAA estimated that such activity might possibly migrate to the southwest. It is possible that the intensity of any future event could be as high as that of the 1871 event, an estimated 7 on the modified Mercalli scale.

RECOMMENDATIONS

Instrumentation. Due to the lack of suitable background data on the seismicity of the northern Delaware area and the lack of seismograph coverage, it is recommended that a permanent seismograph be installed in the Newark-Wilmington area. Specifically, the station would fill the following needs:

1. Low intensity earthquakes, not detected at seismographs some distance away could be detected and studied. This would give information on depths, epicenters, and possible hazards.

2. A local station would fill a "gap" in general seismic coverage of the eastern U.S.

3. A seismic station would be an invaluable teaching and research aid to both students and the general public. It would also serve to answer questions raised by both citizens and public officials who

want information on possible seismic events. Lately, the Delaware Geological Survey has averaged several requests a day for such information.

4. Data on the seismicity of an area should be an input into the emergency operations plans of the State. In view of recent events, some reevaluation of natural disaster priorities might be considered.

On March 23, 1972, all instrumentation was removed and returned to the proper owner because of the need for such equipment in other parts of the country. Approximately seven weeks of nearly continuous records were obtained which provided, among other things, much needed background data on suitability of various sites for long-term monitoring. During this time some progress was also made on securing equipment for a permanent station. The efforts of the following individuals are gratefully acknowledged in this regard:

Governor Russell W. Peterson
U. S. Representative Pierre S. duPont
State Senator Everette Hale
Col. James W. McCloskey, Delaware Division of Civil Defense
Dr. Edward A. Trabant, University of Delaware
Dr. Donald F. Crossan, University of Delaware
Mr. Leonard M. Murphy, NOAA

REFERENCES

Every Evening (newspaper), Wilmington, 1871, October 9.

Howell, J. V., 1960, Glossary of Geology and Related Sciences: American Geological Institute, Washington, D. C., 325 p.

NOAA, 1971, Earthquake Information Bulletin: Nat. Ocean. & Atmos. Admin., v. 3, no. 3, p. 28-29.

Spoljaric, Nenad, 1972, Geology of the Fall Zone: Delaware Geol. Survey Rept. of Invest. No. 19 (in press).

Ward, R. F., 1959, Petrology and metamorphism of the Wilmington Complex, Delaware, Pennsylvania, and Maryland: Geol. Soc. America Bull., v. 70, p. 1425-1458.

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.