First State Geology

RESEARCH DELAWARE GEOLOGICAL SURVEY SERVICE EXPLORATION

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Earthquakes 1993

By Richard N. Benson

On February 26, 1993, a 2.7-magnitude (Richter Scale) earthquake was felt near Cherry Hill, New Jersey, and was the first of 23 small quakes within the mid-Atlantic region recorded through May 18 by the three seismographs in northern New Castle County operated by the Delaware Geological Survey.

Two areas experienced multiple events. From March 10 to April 8, nine earthquakes were recorded in the Columbia, Maryland, area with magnitudes ranging from 1.0 to 2.7. These prompted many telephone calls to Maryland officials. As the DGS has the seismograph network closest to the Columbia area, we were asked by our counterparts at the Maryland Geological Survey to provide data on the events. Subsequently, the Baltimore and Washington news media contacted DGS staff for information and interviews. More recently, the Reading, Pennsylvania, area was the location of 9 or 10 events of magnitudes <1.5 to 2.8 recorded from May 10 to May 18.

Single earthquakes of magnitudes <2.0 were detected near Bel Air, Maryland, on March 21 and the next day near Lancaster, Pennsylvania. On May 15, a coastal New Jersey event (just off the map shown here) was estimated to be of 2.6 magnitude.

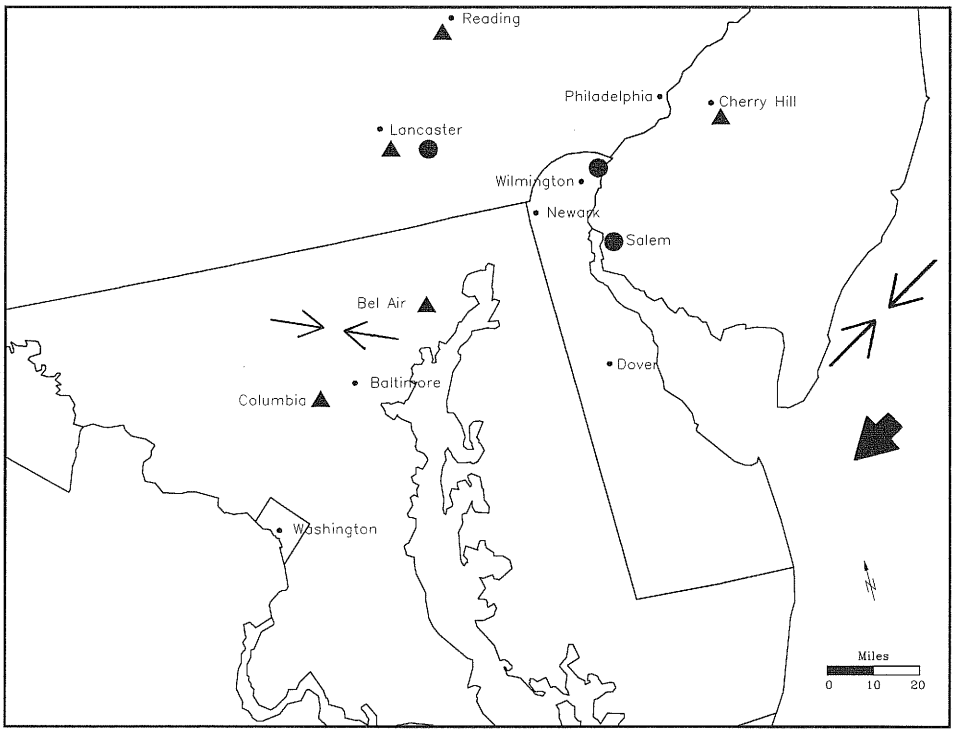
A quake of magnitude 2 is about the lowest limit normally felt by humans. At magnitudes >4-5 sleepers may be awakened and small objects are upset, and at >5-6 some minor damage may occur. However, in the eastern U. S., smaller magnitudes produce larger intensities than this, and slight damage may occur at magnitudes around 4. The Richter Scale is logarithmic; therefore, a recording of 6, for example, indicates ground motion 10 times as large as a recording of 5.

Earthquakes in the northeastern United States generally occur in the upper half of the earth's crust. The focal depths determined from a sampling of earthquake records for this region tend to cluster in a zone between 5 and 15 km beneath the earth's surface; the deepest generally are at 20 km and the shallowest are about 1 km deep.

An earthquake occurs when blocks of the earth's crust on either side of a fracture termed a fault suddenly break or "snap" to new positions. The earth's crust is constantly under stress as a result of forces operating on the earth's outer brittle layer, the lithosphere, which is subdivided into several tectonic plates. Friction along active fault planes keeps the blocks of crust from moving past one another continuously, but under constantly applied stress, the strains in the blocks build to a point until rupture occurs releasing energy in the form of body waves that travel in all directions through the earth from the focal point of the earthquake. Body waves that reach the earth's surface generate surface waves which usually have the strongest vibrations and probably cause most of the damage done by earthquakes.

There are two types of body waves — compressional, called primary or P waves, and shear, called secondary or S waves. As a P wave travels through the earth it pushes particles of material ahead of it closer together but behind it the particles rebound to positions farther apart from one another than when the material was at rest. S waves, on the other hand, displace material in directions at right angles to their paths of travel.

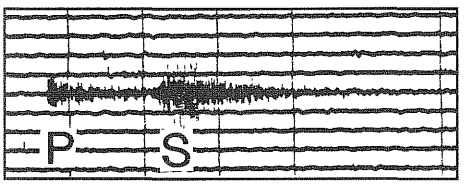
Because P waves travel through the earth at higher velocities than S waves,



Locations of recent earthquakes in the mid-Atlantic region. Solid triangles mark areas of 1993 events; solid circles identify earlier events recorded within the last few years. Large single arrow indicates direction of absolute motion of the mid-plate of the North American Plate (after Zoback and Zoback, 1991). Large inward-pointing arrows show the orientation of the average compressive tectonic stress field of the region; small inward-pointing arrows indicate the local variation of NW-SE compression (after Zoback and Zoback, 1989).

they are the first to be detected by seismographs. With knowledge of the velocity of P and S waves, the difference in arrival times between the P and S waves on a seismogram can be used to measure the distance between the seismograph and the epicenter of the earthquake, which is the location on the earth's surface directly above the focal point. The seismogram shown here for the March 14 Columbia, Maryland, earthquake of magnitude 2.7 indicates a 17.7- second difference in the arrival times of the P and S waves. This calculates to a distance of about 150 km between the seismograph and the epicenter, which could be anywhere on a circle of that radius centered on the seismograph location. In order to locate the epicenter, there must be at least two more circles centered on other seismograph locations that intersect the first circle to define a single point. For the example shown, four seismograph stations were used to locate the epicenter near Columbia.

Earthquake activity in the northeastern United States is quite low compared to that of the boundaries of Earth's tectonic plates, which are located several thousand kilometers from this region. In the broad intraplate region of the North American Plate, researchers, using a variety of methods, have measured the tectonic stress field and have concluded that the central and eastern United States, most of Canada, and possibly much of the western North Atlantic basin to within about 250 km of the Mid-Atlantic Ridge are under a uniform compressive stress field. Faulting (earthquakes) occurring under these conditions is dominated by reverse faults (one block of the earth's crust moves up and over another block along an inclined fault plane) and strike-slip faults (blocks move past one another along a near vertical fault plane). The compression has an average ENE-WSW orientation that is also remarkably near parallel with the WSW direction of absolute plate motion of this large midplate province (see map). The uniformity of the stress field suggests that it arises from forces that either drive (ridge push) or resist (basal drag) plate motions. A local variation of the uniform stress pattern is observed in eastern Virginia and Maryland where reverse faults of Miocene and younger age indicate apparent northwest-southeast compression (see map). A fault plane solution of the Wilmington earthquake of February 28, 1973, also suggests northwest-southeast compression.



DGS seismogram of the 2.7-magnitude earthquake of March 14 near Columbia, Maryland. The difference in the arrival times of the P and S waves is 17.7 seconds.

In California, faults responsible for earthquakes are well-known, but for the northeastern U. S., earthquake faults are difficult to identify. Faults that have been mapped at the earth's surface were zones of weakness under pre-existing stress regimes in the geologic past, and researchers commonly explain northeastern United States earthquakes as the result of these ancient zones of weakness being reactivated if favorably oriented in the present-day stress field. Leading candidates are faults inherited from the extensional stress fields that characterized continental rifting and eventual breakup of the supercontinent of Pangea during the early Mesozoic Era, followed by the separation of Africa and Europe from North America. These faults, in turn, may have been inherited from zones of weakness created during the compressional tectonics that characterized the Appalachian mountain- building episodes of the Paleozoic Era.

Possible zones of weakness that may be responding to the current ENE-WSW compressive stress field or the local NW-SE compression in the mid-Atlantic region include Mesozoic rift basin border faults (see previous issue of *First State Geology);* faults associated with a series of Mesozoic diabase dikes extending from the area of Columbia, Maryland, to Lancaster, Pennsylvania; the Fall Zone which marks the boundary between the Piedmont and Atlantic Coastal Plain provinces; and, possibly, the Delaware Bay Fracture Zone of the western North Atlantic basin that if extended into continental crust would trend northwestward beneath Delaware Bay.

In addition to information provided for this article by the DGS staff and a press release from the Maryland Geological Survey, several chapters authored by researchers specializing in earthquake seismology and tectonics were consulted from: *Geophysical Framework of the Continental United States*, Geological Society of America Memoir 172, 1989; *Neotectonics of North America*, Decade Map Volume, Geological Society of America, 1991; and *Journal of Geophysical Research,* v. 97, no. B8, 1992.

Publications on earthquakes in Delaware are DGS Information Series No. 5, Report of Investigations No. 39, Open File Reports 2, 3, and 4, and *Bulletin of the Seismological Society of America,* Vol. 65, no. 1, 1975. Informative pamphlets published by the U. S. Geological Survey are "Earthquakes" and "The Severity of an Earthquake."

Hydrology News

By A. Scott Andres

Ground-Water Recharge Mapping

Ground-water recharge potential maps and reports have been completed for the Seaford and Dover areas and for the Atlantic Coastal Plain portion of New Castle County. The maps depict areas that have been defined by their ability to transmit water into the shallow Columbia aquifer. Currently, recharge mapping is being conducted in Sussex County in the area covered by the Sharptown, Laurel, and Trap Pond 7.5-minute topographic maps. In addition, work is proceeding on evaluating the maps as potential tools for predicting shallow ground-water quality.

Fossil Vertebrates Identified from the Calvert Formation near Smyrna

By Kelvin W. Ramsey and Richard N. Benson

As reported in the 1992 issues of *First State Geology,* excavation of a wetlands mitigation site, now graded and seeded, as part of the new Route 1 construction south of Smyrna exposed two shell beds of the Calvert Formation. The lower shell bed has yielded the best collection of early Miocene fossil vertebrate remains in eastern North America outside of Florida. It has also produced an impressive collection of fossil mollusks (clams and snails), numbering about 130 species, many of which are newly discovered.

Following is a preliminary list of fossil vertebrates provided by paleontologists Robert Emry, Robert Purdy, Dave Bohaska, and colleagues at the Smithsonian Institution.

- 23 species of cartilaginous fishes (sharks, skates, rays)
- 6 species of bony fishes
- 2 species of salamanders
- 1 species of a lizard
- 4 species of snakes
- 1 species of a crocodile
- 2 species of fresh-water turtles
- 1 species of a terrestrial turtle
- 2 or 3 species of birds
- 2 species of horses
- 2 species of peccary (pig)
- 1 species of a small deer-like animal
- 1 species of a rabbit
- 3 species of rodents (pocket mouse, beaver, squirrel)
- 2 species of insectivores
- 1 species of a chalicothere (a horse-like animal with clawed feet)
- 1 species of a rhinoceros
- 4 species of carnivores (cat, bear, seal, mink)
- 1 species of a sirenean (sea cow)
- 4 species of cetaceans (whales, porpoises)
- 1 species of a bat

Two groups of siliceous microfossils occurring in a silt interval between the upper and lower shell beds provide information on the age of the Calvert exposed at the site. Radiolarians identify the *Stichocorys wolffii* Zone which is estimated to represent the early Miocene

time interval between 19.2 and 17.4 million years ago. Also found was the diatom *Actinoptychus heliopelta* which has been estimated to be no younger than about 17.8 or 17.9 million years but as old as 22-23 million years. The fact that at several Delaware sites *A. heliopelta* occurs at or even above the highest occurrence of radiolarians identifying the *S. wolffii* Zone indicates that this important diatom index species could be as young or younger than about 17.4 million years. The narrowest age range assignable to the fossil site near Smyrna, therefore, is that of the *S. wolffii* Zone, 17.4-19.2 million years.

Report of the Coastal Storm of December 10-14, 1992

A report on the coastal storm of December 10-14, 1992, has been published by the Delaware Geological Survey. Open File Report 37, "Summary Report, the Coastal Storm of December 10-14, 1992, Delaware and Maryland," authored by Kelvin W. Ramsey and John H. Talley of the Delaware Geological Survey and Darlene V. Wells of the Maryland Geological Survey, presents a compilation of the weather and tide data for the storm as well as geologic observations of the effects of the storm along the coast.

The storm was typical of "northeasters" that produce flooding along the Delaware coast. The severity of the storm was lessened by the fact that it proceeded up the Chesapeake Bay and moved from land to offshore. As a result, Delaware's coast was not in the northeast quadrant of the storm until it moved offshore. The duration of the storm over several days, coinciding with an astronomical high tide and rainfall, contributed to flooding of coastal marshes and some additional coastal washover in areas most severely affected, particularly Dewey Beach.

This report represents the beginning of a cooperative effort with the Maryland Geological Survey to compile and report data for coastal storms that affect the upper Delmarva Peninsula. Data and observations from Maryland were provided by the Maryland Geological Survey and are included in the report.

STATEMAP Proposal

By Thomas E. Pickett

As a result of the enactment of the National Geologic Mapping Act of 1992 (Public Law 102-285), a call for proposals was made by the U. S. Geological Survey this spring for state geological surveys engaged in geologic mapping. This component of the law, termed STATEMAP, is the first opportunity to participate in the new national effort to cover the United States with accurate, large-scale geologic maps.

In April, the DGS submitted a proposal that would match efforts by DGS geologists with federal funds for field work and laboratory analyses needed for a map of the Seaford, Delaware, area. The area was selected on the bases of an existing extensive subsurface database, location within the State of Delaware priority watershed of the Nanticoke River, the location of several Superfund sites within the area, and location near a population and industrial center. In addition, the distribution of late Tertiary and Quaternary surficial deposits in the area is of key interest in testing several stratigraphic and depositional models for the Coastal Plain history of Delaware. The plan was approved by the Delaware State Mapping Advisory Committee.

If funded, the study would take one year to complete the field and laboratory part of the project and to make a draft copy of the map (by summer of 1994). The map will show the distribution of surficial stratigraphic units along with cross-sections showing the subsurface stratigraphic relationships.

Honorary Membership in AAPG for Jordan

Robert R. Jordan, Director, received an Honorary Membership Award from the American Association of Petroleum Geologists, the world's largest geoscience organization with over 32,000 members in 112 countries, at its annual convention in New Orleans, April 25-28.

The award for distinguished service to the science of petroleum geology and the association was specifically for Jordan's outstanding contributions to the understanding of geology of the Atlantic Coastal Plain Province and for his leadership in public policy.

Jordan and Carucci Honored for Combined 70 Years of Service and Talley for 20 Years.

Robert R. Jordan, Director and State Geologist and Marlene A. Carucci, Executive Secretary, were among those honored by the University of Delaware at the Annual Service Awards Dinner, May 4. Six persons, including Jordan and Carucci, were recognized for 35 years of service and one for 40 years.

The DGS pair are probably unique in that they both started work at the DGS within weeks of each other in the spring of 1958 and have maintained a continuous working relationship ever since. Robert Jordan had just graduated from Hunter College and Marlene Carucci had just graduated from Padua Academy in Wilmington. Johan J. Groot was then State Geologist and hired both. Jordan was appointed State Geologist and Director in 1969 when Groot left to work for the United Nations. Carucci was appointed Executive Secretary in 1981. Jordan ranks third in the nation in longevity for time served as state geologist at the same survey and probably second for total time served as survey staff and state geologist combined. Figures are not available, but we suspect that Ms. Carucci's tenure also has national ranking.

At the same awards dinner John H. Talley was recognized for 20 years of service. Talley joined the DGS upon graduation from the University of Delaware and earned his M.S. in geology from Franklin and Marshall while employed full time. He was appointed Associate Director for Hydrology and Geophysics in 1992 upon retirement of Kenneth D. Woodruff.

Cartographic Corner

By W. S. Schenck

New topographic (primary) maps have begun to arrive and are available at the Delaware Geological Survey. The thirteen Sussex County quadrangles that have been completed and printed by the U. S. Geological Survey are Milton, Lewes, Cape Henlopen, Fairmount, Rehoboth Beach, Frankford, Bethany Beach, Whaleysville, Pittsville, Delmar, Hebron, Sharptown, and Seaford West.

The next quadrangles to be printed will cover New Castle County. Quadrangles in review now are Kennett Square, Wilmington North, Marcus Hook, Newark West, Newark East, Wilmington South, Elkton, Saint Georges, Delaware City, Middletown, and Taylors Bridge. The Dover Project (Kent County) is in the photogrammetric phase of the mapping process at the USGS Mid-Continent Mapping Center in Rolla, Missouri.

The new quadrangles are the first tangible products of the DGS/USGS topographic Joint Funded Agreement initiated 5 years ago by specific appropriations of the General Assembly, matched by federal funds, to remap the entire State of Delaware.

The new maps have five-foot contours, are on the new North American Datum of 1983, and have a conversion to change National Geodetic Vertical Datum of 1929 (NGVD29) topography to new North American Vertical Datum of 1988 (NAVD88). The new maps also retain outbuilding classification (non-inhabitable structures shown in open outline) and include names of most subdivisions and mobile home parks.

Following publication of each quadrangle, hypsography as a digital layer will become available for use in conjunction with existing USGS Digital Line Graph (DLG)

data in Geographic Information Systems (GIS). Layers covering Sussex County quadrangles will be ready by fall 1993.

Publications

Recent DGS Publications

Open File Reports

No. 37 Summary Report, the Coastal Storm of December 10-14, 1992, Delaware and Maryland: K. W. Ramsey, J. H. Talley (DGS), Darlene V. Wells (Maryland Geological Survey), 29 p.

Other Publications by DGS Staff

Robert R. Jordan, and Chandler, F. W., 1992, Note 59, Records of Stratigraphic Commission 1988-1990: American Association of Petroleum Geologists Bulletin, v. 76, p. 1933-1934.

Robert R. Jordan, 1992, Report of Delegation to North American Commission on Stratigraphic Nomenclature: American Association of Petroleum Geologists Bulletin, v. 76, p. 1959.

Kelvin W. Ramsey, 1992, Coastal response to late Pliocene climate change: middle Atlantic Coastal Plain, Virginia and Delaware, *in* Fletcher, C. H., III, and Wehmiller, J. F. (eds.), *Quaternary Coasts of the United States: Marine and Lacustrine Systems*, Tulsa, SEPM (Society of Sedimentary Geology) Special Publication No. 48, p. 121-127.

Nenad Spoljaric, Preface, *in* Srivastava, R. A. K. (ed.), 1986, *Glauconite: Form and Function:* New Delhi, India, Today and Tomorrow's Printers and Publishers, 267 p.

Staff Notes

Robert R. Jordan received a certificate of appreciation from the Department of the Interior for significant contributions to the Outer Continental Shelf Policy Committee. He is the current chairman of that committee, which is advisory to the Secretary of the Interior. Also, Jordan has been nominated as a candidate for President-elect of the American Institute of Professional Geologists.

Congratulations to **Kelvin W. Ramsey** who received a University of Delaware Service Award for completion of 5 years at the DGS.

Presentations

A. Scott Andres, "Nitrate Contamination of Ground and Surface Waters, Coastal Sussex County, Delaware," at the Second USA/CIS Joint Conference on Environmental Hydrology and Hydrogeology, American Institute of Hydrology, Washington, D.C., May 18.

Richard N. Benson, "Eastern U. S. Mesozoic Rift Basins in the Context of Onshore and Offshore Oil and Gas Exploration," spring seminar series, University of Delaware Department of Geology, March 18.

Roland E. Bounds, "1993 Tucson Mineral Show," Lower Bucks County Mineral Society, April 12, and Delaware Valley Lapidary and Mineral Society, April 27.

Thomas E. Pickett, Field trip leader to Miocene fossil deposits, Calvert County, Maryland, sponsored by Delaware Nature Society, May 22-23.

Kelvin W. Ramsey, "Discovery by Accident - The Smyrna Fossil Discovery," spring seminar series, University of Delaware Department of Geology, March 4.

William S. Schenck, "Services of the DGS Cartographic Information Center and the Work of the Delaware State Boundary Commission," Delaware Association of Professional Land Surveyors, May 13.

Externally Funded Projects

A. Scott Andres from University of Delaware Water Resources Center for GIS analysis of nitrates in ground water (with John Mackenzie, Carmine Balascio, and Radolfo Tanjuakio of the College of Agricultural Sciences) July 1993 - June 1994, and ground-water modeling for wellhead protection under hydrological and geological uncertainties (with Alex Cheng, College of Engineering) July 1993 - June 1994; from DNREC for ground-water recharge mapping in the Trap Pond, Laurel, and Sharptown areas.

First State Geology is published by the Delaware Geological Survey, a State agency established by an Act of the Delaware General Assembly in 1951 and organized as a unit of the University of Delaware.
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