GEOLOGY, SEISMOLOGY AND HYDROLOGY OF THE NATIONAL BUREAU OF STANDARDS RESEARCH REACTOR SITE GAITHERSBURG, MARYLAND

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Prepared by: Geotechnical Engineering Group
National Bureau of Standards
Center f Building Technology
Structur. , and Materials Division

REPORT
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RESEARCH NUCLEAR REACTOR SITE
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Table of Contents

List of Tables

List of Figures

REPORT
GEOLOGY, SEISMOLOGY AND HYDROLOGY
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1.0 INTRODUCTION

1.1 Executive Summary

This report presents a discussion of the geology, seismology and hydrology for the National Bureau of Standards Reactor (NBSR) site to provide an understanding of the earthquake exposure and probable ground-water migration path for the NBSR site. It is an update of data presented in NBSR 7, Preliminary Hazards Summary Report dated January 1, 1961, and NBSR 7C, Preliminary Hazards Summary Report, Supplement C dated August 1, 1962 submitted in support of the original license application for the NBSR. The discussion is based on:

a) previous NBS submittals

b) recent USGS geological and seismological maps

c) a comprehensive site selection and evaluation study for sanitary landfill sites performed by Dames and Moore in 1978 in Montgomery County

d) information from reports for the North Anna Power Station.

The rocks underlying the NBSR site consist entirely of the Wissachickon Formation of Precambrian or early Cambrian Age [22]. The formation is derived from ancient sedimentary strata which had been greatly compressed and consists of a great thickness of schist. The upper portion of the basement rocks is weathered to saprolite, a residual soil formed by the chemical decomposition of rocks in situ. Saprolite is composed generally of clay, silt, sand-size fragments of quartz and rock fragments. Textures range from silty sand to sandy clay.

The NBSR site is located within the Piedmont belt defined by King [13]. With the exception of the Triassic rocks found in the region, the textural, mineralogical and structural conditions of most of the Piedmont rock today are the result of the major cycles of tectonic activity outlined in Section 4.3.1 of this report. The Piedmont belt is an area of low-level seismic activity with no strong earthquakes except one of Modified Mercalli intensity VII near the head of Delaware Bay [10]. Considering that few earthquakes in the eastern United States can be shown to be related to specific faults, as are many earthquakes in the west [10], examination of the seismic history of an area in the eastern United States is important to evaluate the earthquake exposure of a site in the eastern United States. The earthquake history of Maryland as presented in table 4.1 and figure 10 indicates that the NBSR site is located in an area which has experienced only a minor amount of earthquake activity. This conclusion is consistent with the recent report by Barstow et al. [1].

Recent work performed by Dames and Moore as part of the Montgomery County landfill site selection and evaluation study has provided much information on the surface water and ground-water hydrology of the NBSR site. Based on Dames and Moore's work [5] it appears that topography rather than geologic structure controls ground-water movement. Drainage is to the south and to the west [22]. The estimated rate of ground-water movement is on the order of .3 ft/day. This estimated rate of movement correlated well with Otton's range of 0.1 to 1.0 foot per day presented in NBSR 7, Preliminary Hazards Summary Report dated January 1, 1961. Additional data on cation exchange capacities from the Dames and Moore study [5] indicate that the values at the NBS site are lower than those referred to in NBSR 7C, Preliminary Hazards Summary Report, Supplement C

dated August 1, 1962. Cation exchange capacities of 2.4 meq/100 grams for Zone A (surficial soils which are approximately five (5) to ten (10) feet thick) and 3.6 meq/100 grams for Zone B (soils below Zone A with thicknesses which range from eleven (11) to sixty (60) feet) are considered reasonable based on the Dames and Moore study.

Because movement of ground-water appears to be slow and ground-water flow through the site can be monitored for anomalous radioactivity should an accident occur, corrective measures should be possible to minimize the deleterious effects of a spill if an accidental release of contaminants necessitates such corrective action.

1.2 Purpose and Scope

The report herein presents a general discussion of the geology, seismology and hydrology for the National Bureau of Standards Reactor (NBSR) Site to provide an understanding of the earthquake exposure and probable groundwater migration path for the NBS research reactor site. A summary of the geology, geohydrology and seismology of the site was prepared for NBS by the U.S. Geological Survey in 1959 [22]. The text of the 1959 report was included as Appendix III of NBSR 7. A second report concerning specifically the rate of movement of ground water in the vicinity of the NBSR Site was included as Appendix II of NBSR 7C [4].

Because of plans by the National Bureau of Standards to increase the power level and renew the license of the NBS research reactor, the geology, seismology and hydrology of the site are being updated to reflect presently available information. The discussion presented herein is based on:

a) previous NBS submittals.

b) recent USGS geological and seismological maps.

c) a comprehensive site selection and evaluation study for sanitary landfill sites performed by Dames and Moore in 1978 in Montgomery County [5].

d) information from reports for the North Anna Power Station.

1.3 Site Location

The site of the NBS research reactor is a 576 acre tract of land in upper Montgomery County, Maryland, approximately one mile southwest of Gaithersburg, Maryland (figure 1). The nearest population centers are Gaithersburg and Rockville, Maryland. The site is located approximately twenty miles northwest of the center of the District of Columbia.

2.0 REGIONAL GEOLOGY (excerpted from [5])

The NBS research reactor site is located within the lower Piedmont physiographic province. The Piedmont terrain is characterized by gently sloping upland areas and broad, relatively shallow valleys [30]. Regionally, the Piedmont Province consists of metamorphic and igneous rocks that have a strong structural grain in a northerly to northeasterly direction. A mantle of saprolite, i.e., soil derived from chemical weathering of rock, covers most of these rocks; outcrops occur on only a minor portion of the land surface. Outcropping rocks in the region studied by Dames and Moore, for a site approximately four miles from the NBS site, consist predominately of quartz-chlorite schist, quartz-muscovite schist, and quartz-feldspar-mica gneiss. In general, the saprolite is predominately silty or sandy in texture with locally significant amounts of clay and abundant residual boulders of quartzite and other weathered rocks. The site area is included in the bedrock map of Montgomery County by Froelich [9]. The dominant lithologies, i.e., schist and gneiss have been described in a summary report by Hopson [12] as comprising the Wissahickon Formation (Western Sequence) and the Sykesville Formation, respectively. Contacts between the two lithologies are elongated along the regional structural trend, N. to N. 20° E., and form irregular stringers and lenses along the regional grain. A major contact between the two lithologies extends from the northeast, between Laytonsville and Brookeville, toward Rockville, the Wissahickon Formation lies to the west and the Sykesville Formation lies to the east. South of Rockville, the country rock is predominantly Wissahickon, with smaller lenses of Sykesville lithologies trending east of Potomac to Cabin John and the Potomac River. These units were differentiated according to lithology on the map by Froelich [9] which depicts

the generalized geology of Montgomery County (figure 2) including the dip and strike of dominant foliation.

In the discussion that follows, the terms "metasiltstone" and "metasandstone" have been used to describe metamorphosed clastic rocks that are recrystallized to a relatively low degree, and "quartzite" to describe those that are either more highly recrystallized, exhibit strongly deformed grains, or both. The term "metasediments" includes "metasandstone" and "metasiltstone". "Schist" is applied to those fine-grained rocks in which no granular structure is discernible and which exhibit schistosity.

2.1 Wissahickon Formation

This unit extends from southeastern Pennsylvania through Maryland, and into Fairfax County, VA. It is well exposed in the gorge of the Potomac River between Great Falls and Glen Echo, forming steep cliffs. Because the units within the Wissahickon Formation are steeply inclined to vertical, the width of the outcrop belt represents a great stratigraphic thickness. From a study of the section exposed along the Potomac, Fisher [7] concluded that the thickness of the unit was considerably in excess of 14,000 feet.

The formation is composed of metasediments which, prior to metamorphism, were probably similar in composition throughout; variations in degree of metamorphism, however, have produced differences in fabric and mineralogy. From Great Falls downstream, the rocks of the Wissahickon Formation show evidence of the highest degree of metamorphism, being composed of coarse-grained mica schist with quartz- and feldspar-rich lenses. Locally, pegmatite injections have altered the adjacent country rock to migmatitic fabrics. In spite of the effects of metamorphism,

however, primary sedimentary structures are apparent. These include bedding, slump structures, and various structures caused by deformation of soft sediments prior to consolidation [12]. Rounded, clastic structures are easily visible in quartzose units, though considerable cementation and recrystallization has occurred in some units. Where outcrops exposing more than a few feet of section occur, graded bedding relationships between quartz-rich (and sometimes quartz- and feldspar-rich) layers and mica-rich layers can be seen. This relationship suggests that the granular, quartz-feldspar-rich layers formed the basal beds of depositional sequences which became progressively finer with time. Such a stratigraphic relationship is typical of cyclical deposition and also of turbidite deposits. The characteristics of the Wissahickon Formation in this regard are discussed in detail by Hopson [12]. Of immediate significance to the present discussion, however, is the likelihood that the original sedimentary layers were probably of considerable lateral extent and continuity. Thus, physical characteristics of the former sedimentary layers, although some metamorphosed to various degrees and structurally disrupted, can be expected to extend in all directions along the old bedding planes.

Along the north- to north-northeast-trending outcrops belt described, the main foliation of the Wissahickon Formation, which was developed parallel to former sedimentary bedding planes, strikes generally parallel to the main trend and dips very steeply to vertically [9]. Thus, former bedding planes now stand nearly on edge and any continuity of physical characteristics inherited from these primary structures extend vertically and along the regional trend.

2.2 Sykesville Formation

Rocks attributed to the Sykesville Formation are described by Hopson [12] as extending in a broad belt from southeastern Carroll County into east-central Montgomery County just east of Rockville, where the belt narrows and pinches out. Farther south, narrow bands appear along the Potomac in the vicinities of Cabin John and Chain Bridge. Hopson [12] described the Sykesville Formation in the area south of Rockville as a semi-continuous mass that extends to the Potomac River, having an intertonguing relationship with the adjacent Wissahickon Formation, and being divided into separate outcrop areas by mafic and quartz-dioritic intrusive bodies. Its apparent stratigraphic thickness in northern Montgomery County is 15,000 feet.

The lithology of the Sykesville Formation was described by Hopson [12] as pebble- and boulder-bearing, arenaceous to pelitic, metamorphic rocks, with various fabrics ranging between medium-grained, weakly gneissoid to strongly foliated gneiss and schist. Contacts among these lithologies are broadly gradational so that a massive, unstratified appearance is generally characteristic of the formation. Contacts between the Sykesville and Wissahickon Formations are gradational, so that the change from one lithology to the other occurs over a zone that may be as much as hundreds of feet in width.

2.3 Saprolite

The upper portion of the crystalline rocks forming the basement is weathered to saprolite, a residual soil formed by the chemical decomposition of rocks in situ. Saprolite is composed generally of clay, silt, sand-size fragments of quartz, and rock fragments. Textures range from silty sand to sandy clay. Commonly, saprolite exhibits original fabrics inherited from the crystalline

parent rock. Where reworking has occurred, however, such textures have been completely or partially obliterated. The contact between saprolite and weathered or fresh rock is gradational in nearly all instances. Therefore, the determination of such contacts is largely subjective.

Because saprolite is a product of weathering, its occurrence or absence in a given area is the result of a number of interacting factors, such as mineralogy of the rock, permeability of the rock to aqueous solutions, and movement of water through the rock. Thus, the thickness of saprolite in an area of rocks with non-uniform properties may cover a considerable range of values.

2.4 Serpentinite

Numerous bodies of serpentinite are described from the outcrop belt of the Wissahickon Formation in central Montgomery County [12]. These bodies are typically in the form of sheets and thick lenses that are concordant with the structure of the country rock. Several occur as an elongated swarm from Gaithersburg to approximately 8 miles to the north; two narrow and slightly sinuous bodies extend from Redlands to approximately 3 miles to the north; and an elongated body approximately 2 miles by 0.5 mile lies between Gaithersburg and Redlands [12].

The serpentinite bodies are considered to have formed during regional metamorphism by alteration from ultramafic rocks. Chlorite schist and talc schist are associated with the bodies and may form rims around the larger bodies.

3.0 SITE GEOLOGY

3.1 Topography and Drainage (excerpted from [22])

The topograhy in the vicinity of the reactor site is undulating and the relief is moderate (figure 3). Altitudes range from 300 feet, in the valley of Muddy Branch, to 520 feet above mean sea level at Gaithersburg. Drainage is to the south and to the west. Drainage to the south is by Muddy Branch and to the west by Long Draught Branch of Seneca Creek. Both streams are tributaries of the Potomac River. Muddy Branch, the easternmost of the tributaries, enters the Potomac near Katie Island at a point about 5.5 miles above Lock 20 at Great Falls.

3.2 Geology

The rocks underlying the NBS reactor site consist entirely of the Wissahickon Formation of Precambrian or early Cambrian Age [22]. The formation is derived from ancient sedimentary strata which have been greatly compressed, resulting in substantial lithologic alteration [22]. A detailed discussion of the formation has been presented in Section 2.0 entitled, "Regional Geology."

3.3 Subsurface Conditions

To aid in the understanding of the subsurface conditions at the NBS Reactor Site, three generalized profiles of subsurface materials have been prepared using the boring logs from a field investigation program consisting of eleven (11) borings performed in 1961. The orientations of the subsurface profiles are shown in figure 4. These profiles consist of four idealized strata (zones A through D) which have been delineated using the descriptions on the boring logs and recent interpretations of subsurface conditions at sites in the vicinity of the NBS Reactor made by Dames and Moore [5] as part of the Montgomery

County site selection and evaluation study for sanitary landfills (figures 5 and 6).

The profiles consist of residual soils grading into relatively unweathered bedrock. The material properties vary within each zone. The zones shown represent an evaluation of the most probable subsurface conditions based upon presently available data. Some variations from the interpreted conditions described below should be expected.

ZONE A - The zone is characterized by a layer of top soil approximately one (1) foot thick overlying silty clay or clayey silt. This zone ranges from five (5) to ten (10) feet thick with the bottom of the strata being determined by the lowest layer of clay or clayey silt. A three (3) foot layer of sandy silt was encountered in this zone in Boring 10-A. According to the 1961 Soil Conservation Service Soil Map for Montgomery County [25], the site of the reactor is underlain by Glenelg and Manor soils (loam, silty clay loam, and silt loam).

ZONE B - This zone is characterized by variable amounts of sand and consists of sandy silt, fine sand, silty sand, and shaley schist (some decomposed). The thickness of this zone ranges from eleven (11) to sixty (60) feet. The extent of this zone is from the bottom of Zone A to the depth in the boring where rock coring began (generally 14 to 63 feet below the surface). Standard Penetration resistance values at the base of Zone B range from 150 to 200 blows per foot. Because the ground-water table generally lies within Zone B, both partially saturated and saturated materials are present. In the borings drilled, the

ground-water table was encountered 2 feet to 23 feet below the ground surface (Elev. 411 to elev. 403).*

ZONE C - This zone forms a transition zone in which the subsurface materials grade from the saprolite of Zone B to the relatively sound bedbrock of Zone D. It consists of gray or yellow-brown shaley schist, often decomposed and often seamy. Zone C begins at the base of Zone B and has a maximum thickness of twenty feet in the borings drilled. The principal criterion used to establish the extent of this zone was the zone where rock coring was done and a recovery ratio of less than seventy (70) percent was achieved.

ZONE D - This zone represents the relatively sound bedrock and is characterized by a gray-green shaley schist, often seamy. Bedrock was generally considered to be that material which was not sampled with conventional soil samplers, required rock coring equipment and the coring operation resulted in a recovery ratio of 70 percent or greater. Not all borings were drilled deep enough to encounter relatively sound bedrock, but it appears that the top of Zone D lies at a depth of 35 to 74 feet below the ground surface.

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* All elevations refer to Mean Sea Level Datum

4.0 SEISMICITY

4.1 General

To provide an understanding of the earthquake exposure for the NBS site, the distribution of historic seismic activity in relation to geologic structures and tectonic provinces will be presented and any structures or regions that are characterized by consistent relations between seismic activity and structural features identified. The basic method of this study will be to compare, for an area within 200 miles of the NBS site, seismicity as shown by the location of epicenters of recorded earthquakes (figure 7), with lithologic, structural, and geophysical features (figure 8) that may have served to generate or control the release of seismic energy. Results of this comparison, depicted as areas of varying amounts of seismic activity and varying degrees of inferred structural control, will then be shown on the seismotectonic map (figure 9).

4.2 Tectonics

The tectonic provinces of the eastern United States, as outlined and described by King [13], are as follows:

I. Central stable region
  - a) Laurentian shield (part of Precambrian Canadian shield)
  - b) Interior lowlands (bordering platforms covered by younger rocks)

II. Appalachian (orogenic) system or tectonic province
  - a) Fold belt (roughly the Valley and Ridge physiographic province)
  - b) Blue Ridge belt (Blue Ridge physiographic province)
  - c) Piedmont belt (Piedmont physiographic province and part of Blue Ridge physiographic province)

d) New England-Maritime belt (extension of belts II a, b, and c north of New Jersey and Pennsylvania)

III. Coastal Plains (postorogenic deposits overlapping the Appalachian system; of subordinate tectonic significance except in Mississippi embayment).

While it is clear from existing structural data, as well as from the distribution of earthquakes, that historic earthquake activity bears no consistent relation to the provinces and subprovinces defined above, this regional system of classification allows discussion of the broad architecture of the upper part of the earth's crust in terms of the origin and historical evolution of regional structural or deformational features. A summary of the structural features in the eastern United States have been discussed in detail by Hadley and Devine [10] and those features which fall in an area within 200 miles of the NBS site are shown on figure 8. The NBS research reactor is located within the Piedmont belt defined by King [13]. Therefore, the history of the Piedmont as presented in the 1969 preliminary report on seismology for the North Anna Power Station [30] and by Hadley and Devine [10] is provided to document the origin of the structural features on figure 8.

4.3 History of the Piedmont

4.3.1 General (excerpted from [30])

Geologic studies, aided by radiometric dating, have disclosed several marked periods of tectonic activity in the Appalachians. This activity occurred through the Paleozoic and into the Mesozoic Era, creating the present structural features of the Piedmont Province.

The rocks of the Piedmont exhibit varying degrees of metamorphism depending upon their location in relation to the axes of major stresses. Generally the axis of major metamorphism has been northeast-southwest. Prior to their metamorphism, the rocks are believed to have been composed of sediments deposited in a vast geosyncline. This geosyncline was probably formed by the down-warping of the Precambrian basement rock.

The initial down-warping and sediment accumulation is believed to have begun in the Precambrian, over one billion years ago. The deposition is believed to have continued until Ordovician time, about 470 million years ago. At this time, deposition was interrupted by uplift and mountain building associated with the Taconic Orogeny. The sedimentary strata were folded, faulted, intruded by granitic masses, and metamorphosed on a regional scale.

Further sediment deposition has been postulated throughout the Paleozoic, between the periods of mountain building. This postulation remains unconfirmed, however, due to a lack of detailed stratigraphic studies.

Again, near the end of Devonian time, as indicated by radiometric dating, further orogenic activity and/or intrusion of large igneous masses occurred. The central axis of the most intense deformation is believed to have been in the rocks of the Inner Piedmont as indicated by the high grade of metamorphism present in the area.

The last period of major folding, faulting and metamorphism is believed to have occurred at the close of the Paleozoic. This stage is called the Appalachian Revolution and occurred from 230 to 280 million years ago. The discovery of post-Devonian granitic plutons, and a minor increase in metamorphism, suggest

that the central axis of intense deformation may have shifted farther to the southeast in the Piedmont Province during this cycle.

With the exception of the Triassic rocks found in the region, the textural, mineralogical and structural conditions of most of the Piedmont rocks today are the result of these major cycles of tectonic activity.

The beginning of the Mesozoic Era marked the last period of major faulting affecting the rocks of the Piedmont. This was a period of extensional faulting rather than the compressional folding and faulting that characterized the earlier periods of tectonic activity. It appears that the Inner Piedmont Zone of high metamorphism was arched in the Triassic, producing basins bordered by deep graben-type faults. The basins were formed on each side of the Inner Piedmont axis. Erosion of the uplifted Paleozoic metamorphic and igneous rocks resulted in large accumulations of terrestrial sediments in these basins. Some faulting and widespread igneous activity persisted throughout the period of deposition. The faulting and igneous activity are believed to have ceased by the end of the Triassic, 180 million years ago.

The region was relatively dormant during Jurassic and Cretaceous times. Generally, extensive erosion occurred during these periods and has continued to the present time. The eroded sediments were deposited farther to the east, in the present day Coastal Plain Province.

4.3.2 Summary of Structural Features (excerpted from [10])

In this section, the structural features broken down according to geologic age are discussed in more detail with particular emphasis on the Piedmont belt.

4.3.2.1 Precambrian Structures

Precambrian rocks underlying a relatively thin cover of Paleozoic rocks are the dominant supracrustal rocks throughout the interior of the United States and Canada. Although largely concealed within the United States, the lithology, age, and distribution of the Precambrian rocks are at least partly known from exposures, drill records, and aeromagnetic and gravity surveys. Structures thus recognized include both local trends and regional features, such as the Lake Superior syncline in Wisconsin, Minnesota, and Iowa and the so-called Grenville metamorphic or orogenic front that has been traced from eastern Canada southward into Michigan and Ohio.

For the most part, major Precambrian structures of the continental interior are not specifically associated with current or historic seismicity. It is not known whether earthquakes have resulted from movements on Precambrian faults or other structural discontinuities, especially in the central United States where scattered smaller earthquakes commonly cannot be related to known features in the Paleozoic or younger rocks. It is notable, however, that such structures seem to have played only a minor or local role in determining the release of seismic energy [14].

Rocks similar in age and Precambrian structural history to those in the eastern part of the continental interior occur also within the Appalachian system from New England to Georgia. Their structural trends have, however, been so strongly overprinted in most places by Paleozoic deformation that no distinctively Precambrian structures can be related to regional seismic activity.

4.3.2.2 Paleozoic Structures

The Appalachian Piedmont belt adjoining the Blue Ridge belt on the southeast is as wide as or wider than the Blue Ridge and is at least as complex structurally. It is well known geologically and consists largely of unfossiliferous sedimentary and volcanic rocks moderately to strongly recrystallized and invaded by many different kinds of felsic and mafic intrusive rocks. The metamorphosed volcanic and sedimentary rocks are probably mostly of early Paleozoic age but may include rocks of late Precambrian age, as well as isolated bodies of older Precambrian rocks. Deformation, metamorphism, and intrusion are believed to have taken place at several times during the Paleozoic. The predominant features are those of supracrustal compression, resulting in folds and faults, regional metamorphism, and emplacement of various intrusive rocks. Rocks in the northeastward continuation of the Piedmont belt in New England range in age from early through middle and late Paleozoic, and their structural history has been at least as complex as that of the Piedmont rocks.

The geologic boundary between the Blue Ridge and Green Mountain belts and the Piedmont belt to the southeast is not well defined. In the southern Appalachians, the geologic boundary has been interpreted as a zone of combined recumbent folding, overthrust faulting, and pre-Triassic high-angle or strike-slip shearing known as the Brevard fault zone [23, 3, 11, 14]. Farther northeast in the central and northern Appalachians, the boundary is even less well defined. For the purposes of this report, the Blue Ridge and Piedmont belts and their equivalents in New England are considered as a single tectonic province.

Rock types and structures characteristic of the Appalachian Piedmont disappear eastward beneath the deposits of the Atlantic Coastal Plain so that

no structurally significant eastern boundary is known in the eastern United States. Evidence from drill holes and aeromagnetic surveys, however, suggests that the rocks of the Florida platform buried beneath the Coastal Plain are significantly different from those of the Piedmont in central Georgia, and therefore a major tectonic province boundary may exist between them.

4.3.2.3 Late Paleozoic (?) and Mesozoic Age Structures

The orogenic events that formed the Appalachian system in the eastern United States were succeeded by a new tectonic regime both in the Appalachian orogenic belt and in the central stable region to the west. This regime was at least partly extensional and, caused high-angle faulting of near-surface rocks, in contrast to the compressional and deep-seated effects of the earlier tectonism. These latter features are divided into two broad groups, a series of fault-block basins of Triassic age entirely within the Appalachian orogenic system, and a group of rift-like fault zones within the central stable region.

Structures known to be Triassic are confined essentially to the Appalachian Piedmont and its New England counterpart. They consist of block-faulted basins in which continental sediments were deposited, in part contemporaneously with the faulting. The deformation was primarily extensional, resulting in tilted and down-dropped basins bordered by graben-type faults. Invasions by basaltic rocks are associated with these movements throughout the Piedmont belt. Neither the sedimentary nor the igneous rocks have been extensively deformed or metamorphosed, as they were formed after Paleozoic deformation and regional metamorphism had ceased completely.

4.3.2.4 Quaternary Structures

The most recent structures, those of Quaternary age or younger, are of course particularly important in a study of the causes of historical seismicity. Several lines of evidence attest to crustal movements during the Quaternary, although quantitative data are scattered and incomplete. One of the best documented crustal movements is the record of upwarping throughout the northeastern part of the continent as a result of deglaciation and unloading of the crust during and after removal of the Labrador ice sheet. These movements were apparently limited to the region north of a line extending roughly from central Minnesota southeastward through Milwaukee, Detroit, New York, and Long Island, and northeastward to Nova Scotia. The central part of this region, in the Hudson Bay area, appears to be still rising relative to sea level at about 7 mm/yr. Isobases of equal uplift during the past 13,000 years and hinge lines marking successive northward shifts of the limit of warping trend approximately parallel to the outer glacial limit and concentric to the former ice cap.

Similar crustal warping, apparently unrelated to glacial unloading, is suggested by recently completed leveling traverses throughout the eastern United States, as reported by Meade [16]. These results indicate crustal updoming during the period 1930-1970 at a rate of 7 mm/yr centered in northwestern Georgia, as well as subsidence along the Atlantic coast north of Cape Hatteras reaching 5 to 6 mm/yr in New England. Elsewhere in the eastern United States, including Florida, changes of elevation appear to be minimal. Regional tilts indicated by the level measurements show a maximum of 6 mm/yr/100 km in New England and 3.5 mm/yr/100 km in northern Georgia and the Carolinas. In comparison, current

tilt rates due to glacial rebound in the Great Lakes region are estimated at only 1.5 mm/yr/100 km [8].

Very different evidence of Quarternary deformation is found in faults that offset surficial materials of late Cenozoic age. These include many examples of faults displacing geologically young features, such as alluvial deposits, till, loess, glaciated bedrock surfaces, and river terraces. Although such features have been widely reported from localities in the Appalachian Piedmont and Coastal Plain, most have been observed only in limited exposures such as road cuts and river banks in unconsolidated materials which are subject to rapid erosion and overgrowth of vegetation. Little information has been available as to their regional extent or tectonic significance. A reported exception is that of the glaciated bedrock surfaces in the Champlain-Hudson valley region; these surfaces show systematic reverse-fault displacements of a millimeter or more on southeast-dipping regional cleavage [21].

In the Mississippi embayment region, faults are known in rocks of Pliocene-Pleistocene age [6, 19, 20]. Faults in loess and alluvium of Pleistocene age have been interpreted as occurring along topographic lineaments which may represent more extensive faults and fractures in the Coastal Plain sediments [15]. For the most part, however, direct evidence indicating that faults are coincident with these features is lacking. With the exception of the vicinity of New Madrid, Missouri, and Reelfoot Lake, Tennessee, no faults or other indications of recent faulting are known to be associated with any historic earthquake.

4.4 Seismic History (excerpted from [10])

A summary of earthquake epicenters for areas within 200 miles of the NBS research reactor site is shown on figure 7. The epicenter plot of figure 7 shows computer plotted locations of epicenters of earthquakes of Modified Mercalli (MM) III or greater intensity which occurred during the period 1800 - 1972.

The epicenter data used for this map were extracted from the working file of the National Earthquake Information Service and do not represent a final edited compilation of eastern United States seismicity. However, subsequent refinement and improvement of locations or maximum intensities were expected to result in only minor changes in the seismic-frequency contours developed for the Hadley and Devine [10] study.

The locations and maximum epicentral intensities of earthquakes were recorded on magnetic tape and plotted from the tape. Locations were fixed to the nearest 0.1 degree of latitude and longitude; the symbol used represents the highest epicentral intensity located at the plotted point.

The contours shown on the epicenter plot were developed by counting the number of epicenters, including repeated events at the same plotted location, within a circle representing $10^4 km^2$ at the original map compilation scale of 1:2,500,000. They were generated by tracing in a somewhat generalized fashion the position of the center of the counting circle while moving it so as to include up to but not more than the 4, 8, 16, 32, and 64 epicenters selected as contour intervals. Because Hadley and Devine [10] wished to emphasize the areal distribution of seismic activity which might be related to geologic structure, rather than the

total seismic energy released, the intensities of individual earthquakes were ignored in contouring seismic frequency.

A study of figure 7 shows that large areas of background or minimal seismic activity are distinguished from epicentral concentrations representing areas that are seismically more active. The upper limit of activity in the background areas is arbitrarily taken as less than 8 epicenters per $10^4 km^2$ (in most places less than 4) and the absence of earthquakes with epicentral intensities greater than VI. Not all such areas are wholly non-seismic, although some areas considerably larger than $10^4 km^2$ have generated no recorded earthquakes. In fact, areas with no epicenters within $10^4 km^2$ could be outlined, but this distinction is believed to be tectonically uninterpretable from a regional point of view.

For meaningful tectonic interpretation, one must turn to the more seismic areas and these, classified according to the level of seismic activity and degree of known structural control, are shown on figure 9.

In establishing the different areas of earthquake activity shown on the seismotectonic map, use is made of three parameters. One parameter is the areal density (seismic frequency) of epicenters, including separate events at the same location. A second parameter is the maximum epicentral intensity, according to the Modified Mercalli scale [31], of any earthquake known to have occurred in the given area. Although magnitude determinations are given for many earthquakes that have occurred since 1960, they are generally not available for earlier events. Moreover, since it is expected that a principal use of the map will be to estimate potential earthquake damage, intensity values are considered to be more useful. The third parameter is the evidence of

structural control on epicenter distribution as determined by the tectonic study. From these parameters, five levels of seismic activity and three categories of structural control were selected (see figure 9).

The seismic areas described herein are intended to represent areas designated by notable seismicity and, in so far as possible, the structural features believed to be casually related to the seismicity. In some areas, notable seismic activity is not associated with any known structural feature, but is distributed so as to indicate rather clearly that the activity is localized along concealed or unidentified faults or other structures. Seismicity, usually of low level, is scattered in many areas so that no localizing fault or other structure is indicated. In a few places, such as central Virginia, seismic activity of intermediate or even high levels cannot, in the light of present information, be considered localized along known structures. In the southern Appalachian fold belt, the level of seismicity is more uniform, but is nowhere well enough defined to indicate individually active structures.

It should be emphasized that the seismic areas show on figure 9 do not have precisely determinable boundaries. Few earthquakes in the eastern United States can be shown to be related to specific faults, as are many earthquakes in the west. Moreover, scatter of epicenters and lack of correlation with geologic structure may be due in part to the scarcity of instrumental data and the resulting inaccuracy in locating epicenters. Where a good correlation seems to exist betweem seismic activity and known structures, or where the distribution of epicenters seems to outline a localizing fault zone or other structure, the seismotectonic map boundaries are drawn to conform rather closely to the geologic

or seismological information available. Elsewhere, boundaries are more generalized and essentially indicate areas where more information is needed to determine the relations between seismic activity and structure.

4.5 Summary and Conclusions [modified from [10])

For seismotectonic purposes, the Blue Ridge and Piedmont form a single unit with complex and incompletely known tectonic features. Within this single unit there is much diversity of structure and of seismic activity but relatively little information on structural control. The most concentrated activity occurs in an east-trending area in central Virginia, within which the seismic frequency is 16 to 32 or higher. Most of the earthquakes in this area have been of MM intensity VI or less, although one near Richmond, Virginia, is reported to have been MM VI-VII [2].

Another area of more than average seismicity in the Blue Ridge-Piedmont province covers parts of western North Carolina and northwestern South Carolina. Structurally the area includes part of the Murphy syncline, much of the great allochthonous terrain of Blue Ridge rocks with its large negative gravity anomaly, and segments of the Brevard fault zone. Northeast of central Virginia, the Piedmont belt is an area of low-level seismic activity with no strong earthquakes except one of intensity MM VII near the head of Delaware Bay. Considering that the NBS reactor site is located within the area between central Virginia and the head of the Delaware Bay, and the earthquakes for the state of Maryland listed in Table 4.1 and shown on figure 10, it can be said that the NBS reactor site is located in an area which has experienced only a minor amount of earthquake activity. This conclusion is consistent with the recent report by Barstow et al. [1].

Table 4.1 Chronological Listing of Earthquakes for the State of Maryland (modified from [28])

DATE			ORIGIN TIME(UTC)			LAT.	LONG.	DEPTH	HYPOCENTER	INTENSITY
YEAR	MONTH	DAY	H	M	S	(N.)	(W.)	(KM)	QUAL	MM
1758	APR	25	02	30	..	38.9	76.5	..	H	...
1828	FEB	24	..	..	..	38.9	76.7*	..	H	...
1876	JAN	30	02	05	..	38.9	76.5*	..	G	...
1876	APR	10	..	..	..	38.5	76.6*	..	H	III*
1877	SEP	01	16	..	..	38.7	76.8*	..	H	III*
1883	MAR	11	23	57	..	39.5	76.4	..	H	IV*
1883	MAR	12	05	..	..	39.5	76.4	..	H	III*
1902	MAR	10	05	..	..	39.6	77.2	..	H	III*
1902	MAR	11	10	30	..	39.6	77.2	..	H	III*
1903	JAN	01	17	30	..	39.6	77.2	..	H	III*
1903	JAN	01	22	45	..	39.6	77.2	..	H	II*
1906	OCT	13	15	..	..	39.2	76.7*	..	H	III
1910	JAN	24	02	20	..	39.6	77.0	..	H	II
1910	APR	24	02	..	..	39.2	76.7*	..	H	III*
1911	APR	08	01	..	..	38.3	75.5 x	..	H	IV
1911	APR	08	04	11	..	38.3	75.5 x	..	H	IV
1928	OCT	15	..	..	..	38.3	75.1*	..	G	IV*
1930	NOV	01	06	34	..	39.1	76.5*	..	G	IV
1930	NOV	01	07	02	..	39.1	76.5*	..	G	III*
1939	JUN	22	23	10	..	39.5	76.6*	..	G	III*
1939	NOV	18	02	33	..	39.5	76.6*	..	G	IV*
1939	NOV	26	05	20	..	39.5	76.6*	..	G	V*
1962	SEP	04	23	40	..	39.5	77.7 x	..	G	IV
1962	SEP	07	14	00	45.9	39.7	78.2	038	C	...

NOTES:

1. The data are listed chronologically in the following categories: date, origin time, N. latitude, W. longitude, depth, hypocenter quality, intensity (Modified Mercalli). Table 1 has some basic limitations in terms of the size of the earthquakes listed. Prior to 1965 all recorded felt earthquakes are listed, after 1965 only felt earthquakes or those with magnitudes above the 2.5-3.0 range are listed; the lower magnitude levels apply mostly to the eastern United States. If no magnitude was computed and the earthquake was felt it was included in the earthquake list. The low magnitude events located in recent years with dense seismograph networks have not been included.

2. Leaders (..) indicate information not available.

3. Latitude and longitude are listed to a hundredth of a degree if they have been pubished with that degree of accuracy, or greater; however, most historical

events have been published only to the nearest degree or tenth of a degree and are therefore listed at this accuracy. An asterisk (*) to the right of the longitude indicates that the latitude and longitude were not given in the source reference, but were assigned by the compilers of the data file. An (x) to the right of the longitude indicates that the event is an explosion, a suspected explosion, rockburst, or a nontectonic event; these have not been plotted on the map.

4. The letter code in the HYPOCENTER, QUAL column is defined below

   a. Determination of the instrumental hypocenters are estimated to be accurate within the ranges of latitude and longitude listed below; each range is letter coded as indicated:

      A 0.0°-0.1°
      B 0.1°-0.2°
      C 0.2°-0.5°
      D 0.5°-1.0°
      E 1.0° or larger

   b. Determination of noninstrumental epicenters from felt data are estimated to be accurate within the ranges of latitude and longitude listed below; each range is letter coded as indicated:

      F 0.0°-0.5°
      G 0.5°-1.0°
      H 1.0°-2.0°
      I 2.0° or larger

5. An asterisk (*) in the INTENSITY, MM column indicates that the intensity was assigned by the compiler on the basis of the available data at the time the catalog was compiled.

5.0 GROUND-WATER HYDROLOGY

5.1 General

This statement on the hydrology of the NBS reactor site has been prepared to update a report by Alfred Clebsch, Jr., entitled, "Rate of Movement of Ground Water and Accidentially Released Radionuclides at a Proposed Reactor Site Near Gaithersburg, Maryland," [4] based on presently available data. The basis for this review was the site evaluation study for Montgomery County performed by Dames and Moore in 1978 [5]. The Dames and Moore study provides a comprehensive hydrologic study of the soils formed on the Wissahickon Formation on which the NBS reactor site is located. At the four sites studied, permeability tests (laboratory and field) were performed at varying depths and the results are reported based on location, depth and soil zone. The information from Site E-57 and Site S-135/271 was used because the site geology for these sites was considered representative of the geologic conditions at the NBS site.

5.2 Regional Ground-Water Hydrology (excerpted from [5])

5.2.1 Hydrological Characteristics of Regional Geological Formations

The NBS reactor site lies within the Lower Piedmont physiographic province, which is composed of metamorphic and igneous rocks. A mantle of saprolite covers most of these rocks, and rock outcrops constitute only a minor portion of the land surface. The exposed rocks consist predominantly of quartz-chlorite schist, quartz-muscovite schist, and quartz-feldspar-mica gneiss. The saprolite is silty or sandy in texture, with locally significant amounts of clay and residual fragments of quartzite and other weathered rocks.

Ground water in the Piedmont occurs almost exclusively in the crystalline rocks and saprolite under unconfined (ground-water table) conditions. Recharge to

the ground-water table is derived from direct infiltration of precipitation. Average annual precipitation in the Maryland Piedmont is approximately 40 inches, of which approximately 8 inches infiltrate to the ground-water table. In general, ground water moves downgradient from topographic highs and eventually discharges to local streams, seeps, and lakes.

The saprolite which typically mantles the crystalline rocks is primarily silty or sandy in texture; therefore, the porosity (defined as the percent of the total volume occupied by voids) of the saprolite is intergranular (or primary). The primary porosity of the unaltered, unfractured crystalline rock is usually very low, seldom exceeding 1 percent [18]. Ground water in the unaltered rocks occurs predominantly in fractures (secondary porosity) resulting from jointing and faulting of the rock. Typically, the size and frequency of fractures decreases with depth below the ground surface. Therefore, the greatest amount of ground water stored in the rocks of the Maryland Piedmont is in the saprolite and the upper few hundred feet of the bedrock.

5.2.2 Ground-Water Use

Ground water in the Maryland Piedmont is used for farm, domestic, commercial, institutional, industrial, and public supplies [18]. Most rural homes and farms in Montgomery County rely on individual wells. The mean yield of the wells used for domestic supplies is about 10 gal/min. Most of these wells extend to depths of less than 300 feet; however, several have been drilled to depths greater than 500 feet [18].

5.3 Site Hydrology

5.3.1 Ground-Water Movement

The direction and rate of ground-water movement is primarily dependent on local topography and the porosity and permeability of the subsurface materials [5]. A topographic map of the NBS site is presented on figure 3. Information on the permeability of the subsurface materials has been obtained from the Dames and Moore site selection study [5].

Permeability values at Site E-57 (located 4 miles northeast of the NBS reactor site) range from 1×10^{-5} cm/sec to 3.2×10^{-3} cm/sec, and increase gradually from Zone B to Zones C and D. At this site, the zone of maximum permeability appears to be the zone of fractured, unweathered bedrock (top of Zone D) and the zone of weathered rock (Zone C) immediately above it. At Site S-135/271, located approximately 9 miles south of the NBS reactor site, permeability values range from 1×10^{-5} cm/sec to 5×10^{-4} cm/sec. The highest value occurred in unweathered bedrock (Zone D) and was assumed to be the jointed zone at the top of the bedbrock. A permeability value of less than 1×10^{-6} cm/sec was recorded below this point and was assumed to be unjointed bedrock. (Since the joint spacing varies from a few inches to 2 or 3 feet, permeability tests run in jointed bedrock may vary in their results, depending on the number of joints crossed by the 2-foot test section.) At Site S-135/271, the permeability values do not show any steady trend from Zone B to Zone D. Table 5.1 shows permeability values from the Dames and Moore tests on Sites E-57 and S-135/271. The results of both field and laboratory tests are shown. The permeability values given in the text above are from field tests because their results are considered more

reliable than the laboratory tests. Laboratory results were frequently less than the field test results by approximately one order of magnitude.

The results of laboratory permeability tests performed by Dames and Moore on samples of soil from Zones A and B indicate that the soil in Zone A may be slightly more permeable than the soil in Zone B (see Table 5.1). The results of laboratory tests given in the Soil Conservation Service report [26] and Otton in NBSR-7 [22] are also listed in Table 5.1. The Dames and Moore values would seem to be the most representative of conditions at the NBS site for several reasons:

1) The results are based on a large number of tests at different depths and locations,
2) The two Dames and Moore sites are relatively near and geologically similar to the NBS site, while the permeability values given by Otton are for soil samples (developed on the Wissahickon Formation) in Baltimore County, and the value given by the Soil Conservation Service is a general value for the Glenelg loam, wherever it occurs in Montgomery County, and
3) The Dames and Moore results represent the more recent work performed.

For Zones B, C, and D, the Dames and Moore results are what is available. The maximum average permeability value from the Dames and Moore study is 3.2×10^{-3} cm/sec (see Table 5.1). This represents a conservative (i.e., high permeability) value for ground-water movement, and was used in computing the rate of ground-water movement at the NBS reactor site. The permeability values for the soil, saprolite, and bedrock all fall within the low to medium permeability range as established by Terzaghi and Peck [27].

"Water table contours based on measurements of water level made January 20, 1961, in foundation borings in the vicinity of the reactor building are shown on figure 11. Bore holes 7-A, 8-A, 10-A, and 3-A are at the corners of the building. Depths to water ranged from 1.7 feet in hole 2-A to 23.0 feet in hole 3-A. All the water levels were in subsoil or decomposed rock [4]."

Since the soil derives its structure from the in-place weathering of the rock, one might expect it to have a higher permeability parallel to the foliation and former bedding planes, and for ground water to flow preferentially along the planes of foliation. However, the Dames and Moore study [5], based on four different sites and approximately 2200 acres mapped with ground-water table contours in Montgomery County, concluded that the ground-water table elevation was controlled by topography rather than by geologic structure. This implies that the permeability of the soil and rock does not vary with direction. The ground-water table contours at the NBS reactor site are more easily related to the topography than to the geologic structure, since the primary ground-water movement is to the west (to a perennial stream) and across the plane of foliation.

"The presence of a perennial stream between the reactor site and the three off-site wells to the west (wells 37, 38, and 39 in Otton's report [22]) effectively eliminates the possibility that cones of depression caused by pumping these wells could extend beneath the reactor building [4]."

The ground-water velocity can be computed from the hydraulic gradient and the permeability. The maximum hydraulic gradient at the reactor site (measured from the groundwater table contours on figure 11) is to the northwest and is 6'/170' or 0.035.

The maximum average permeability value from Dames and Moore's field permeability tests on Sites E-57 and S-135/271 is 3.2×10^{-3} cm/sec (see Table 5.1). The ground-water velocity, v, should be approximately:

$$v = ki = (3.2 \times 10^{-3} \text{ cm/sec}) (0.035)$$

$$= 1.1 \times 10^{-4} \text{ cm/sec}$$

$$= 0.3 \text{ ft/day}$$

This correlates well with Otton's estimate of 0.1 to 1.0 foot per day.

5.3.2 Cation Exchange Capacities

The cation exchange capacity of the soil is a particularly important characteristic indicating the degree to which radionuclides will become adsorbed on or fixed in the solid phase of a soil-water system [4]. Cation exchange capacities have not been determined for samples from the NBS site, but determinations on samples of the same geologic unit (soil and weathered rock of the Wissahickon Formation) from two Dames and Moore sites [5] and from the site of the National Naval Medical Center Reactor [4] are available and should be reasonably representative of conditions at the NBS site. The cation exchange values for these samples are listed in Table 5.2. The Dames and Moore values differ from those obtained at the National Naval Medical Center site. The Dames and Moore values are recommended for use because they were obtained from a larger number of tests, the results are more consistent with each other than those obtained for the Naval Medical Center, and the Dames and Moore results are more conservative, i.e., the cation exchange values are lower.

5.4 Ground-Water Monitoring Program

A routine sampling and analysis program has been in effect since November 1963, and is described in NBSR 9 [17].

5.5 Conclusions

Recent work performed by Dames and Moore as part of the Montgomery County landfill site selection and evaluation study indicate permeability values for surficial soils (Zone A) which are similar to the values reported by Clebsch [4]. Based on the Dames and Moore work it appears that topography rather than geologic structure controls ground-water movement. The estimated rate of ground-water movement is expected to be on the order of .3 ft/day using the maximum hydraulic gradient at the reactor site measured from the ground-water table contours on figure 11 and the maximum average permeability value from the Dames and Moore's field permeability tests. This rate of movement correlates well with the estimate from the earlier work performed by Otton [22] of 0.1 to 1.0 foot per day.

Additional data on cation exchange capacities from the Dames and Moore study indicate that the values at the NBS site are lower than those referred to in Clebsch's report [4]. Cation exchange capacities of 2.4 meq/100 grams for Zone A and 3.6 meq/100 grams for Zone B are considered reasonable based on the Dames and Moore study.

Because movement of ground-water appears to be slow and ground-water flows through the site can be monitored for anomalous radioactivity should an accident occur, corrective measures should be possible to minimize deleterious effects of a spill if an accidential release of contaminants necessitates such corrective action.

Table 5.1 Field and Laboratory Permeability Data

Dames and Moore Landfill Study [5]

Permeability in cm/sec

	SITE E-57		SITE S-135/271	
	Lab	Field	Lab	Field
Zone A	8×10^{-5} (3)		1.3×10^{-4} (5)	
Zone B	1×10^{-5} to 7×10^{-5}	2.6×10^{-4} (10)	3.3×10^{-5} (22)	5×10^{-4}
Zone C		3.2×10^{-3} (3)	1.5×10^{-5} (1)	1×10^{-5} to 5×10^{-4}
Zone D		1.2×10^{-3} (3)		1×10^{-4}* to 5×10^{-4}* $< 1 \times 10^{-6}$**

(n) - indicates an average of n values
* - assumed zone of fractured bedrock
** - assumed zone of sound bedrock

Soil Conservation Service [26]

Zone A 4×10^{-4} to 1.4×10^{-3} cm/sec
(0.6 to 2 in/hr)

NBSR 7 [22]

Zone A 6×10^{-4} to 4×10^{-3} cm/sec
(12 to 93 gpd/ft^2)

NOTE: See text for further explanation of these results

Table 5.2 Cation Exchange Data (^{meq}/100 grams)

Dames and Moore [5]

	Site E-57	Site S-135/271
Zone A	2.75 (1)	2.15 (1)
Zone B	3.60 (4)	3.65 (1)

National Naval Medical Center Reactor [4]

Depth Below Surface	Total Exchange Capacity
2'-6" to 4'-0"	7.6
19'-6" to 21'-0"	15.1
33'-6" to 33'-9"	5.7

NOTE: (n) - indicates that the value given is the average of n values

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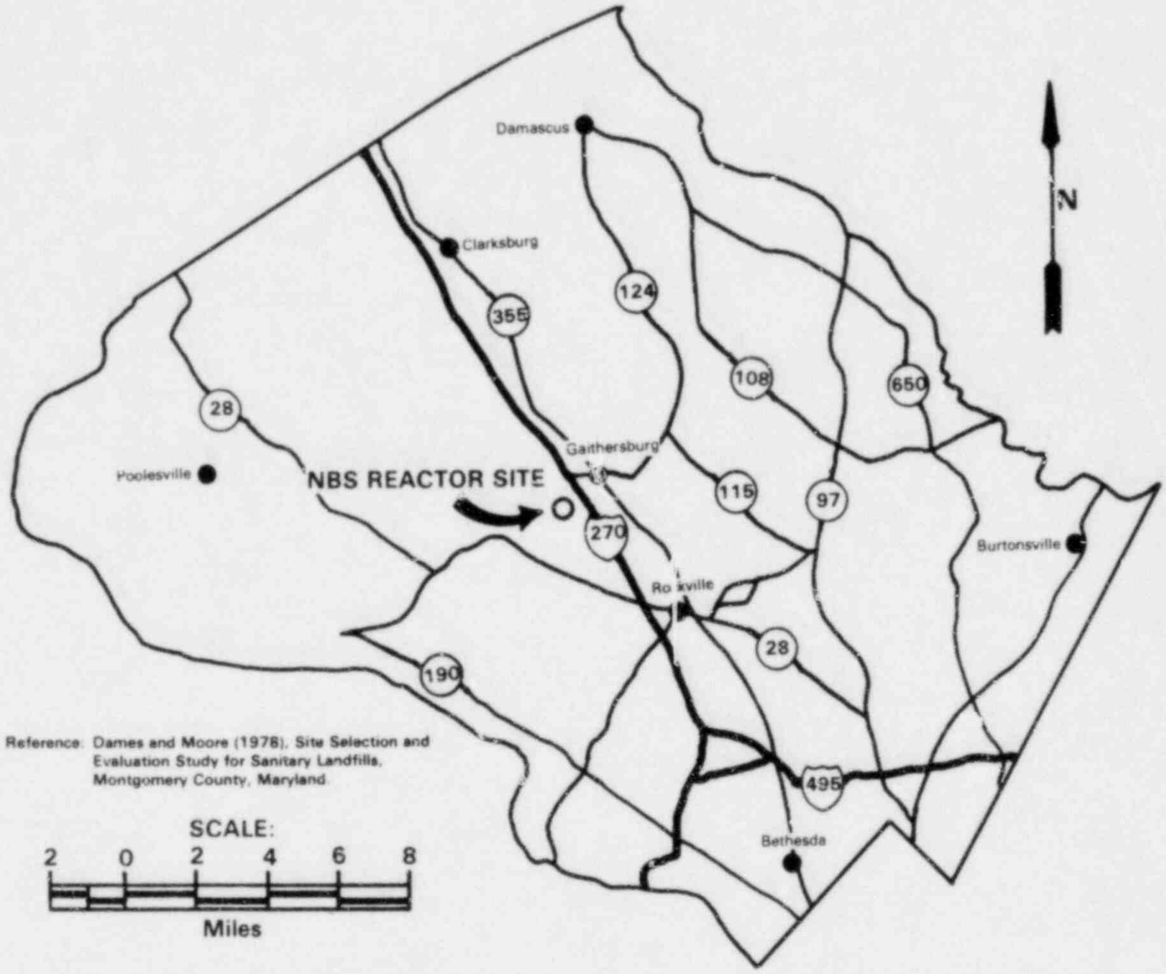


Figure 1. Site vicinity map.

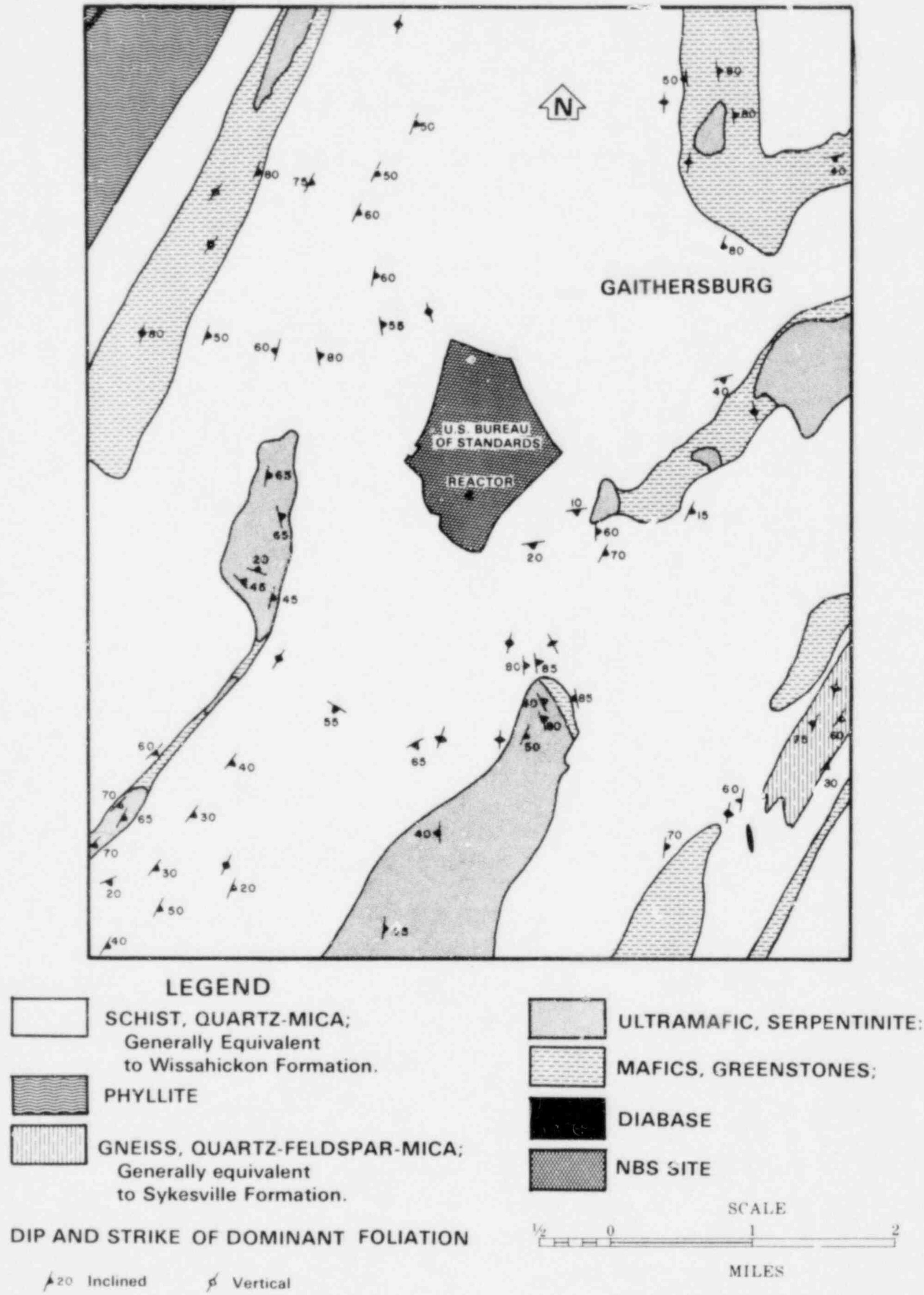
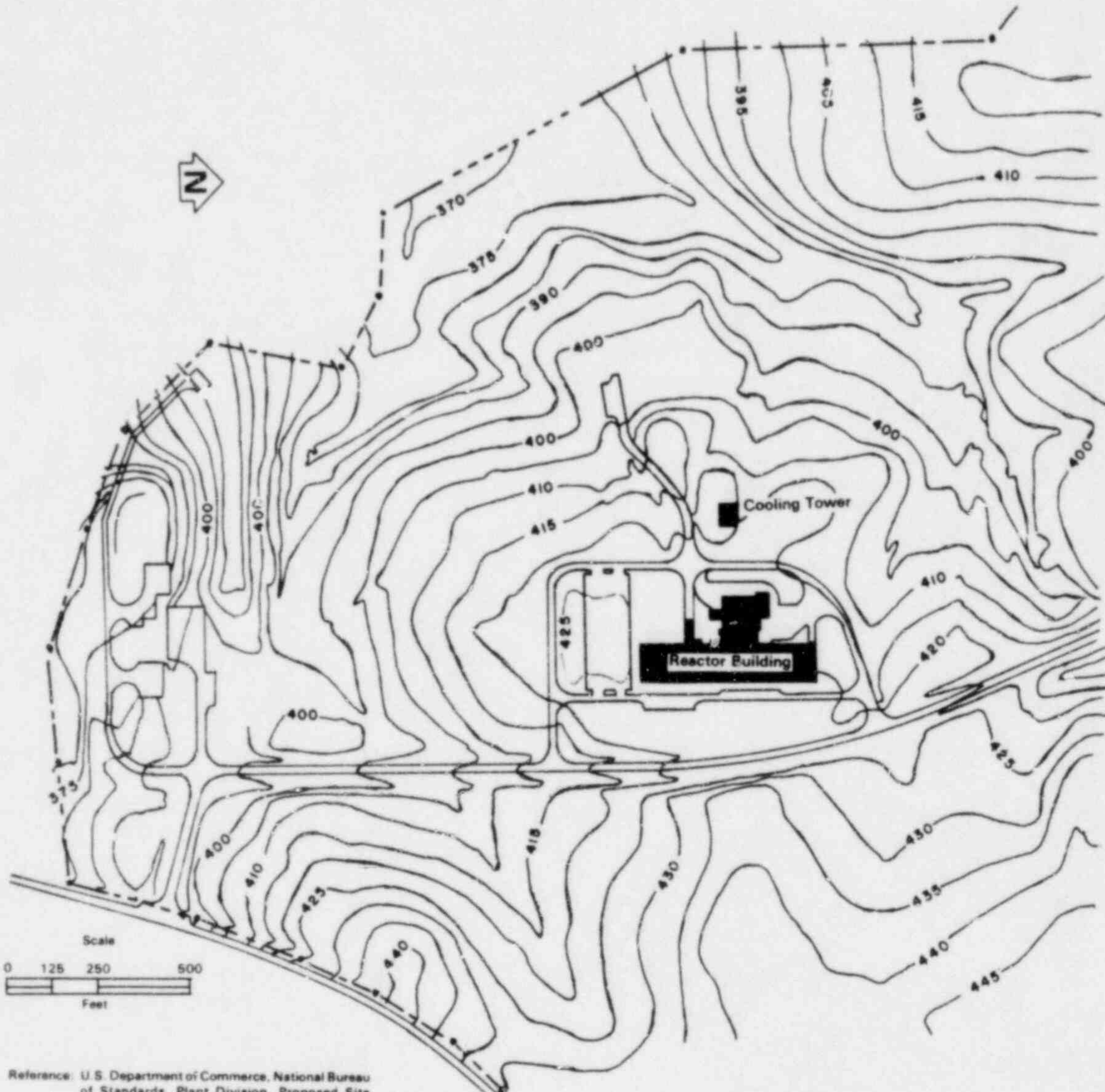


Figure 2. Regional geology.

Lithologic units according to Froelich (1975)



Reference: U.S. Department of Commerce, National Bureau of Standards, Plant Division, Proposed Site Development Plan, Gaithersburg, Maryland, Drawing MP-1P Dated 4-1-77.

Figure 3. Site topography.

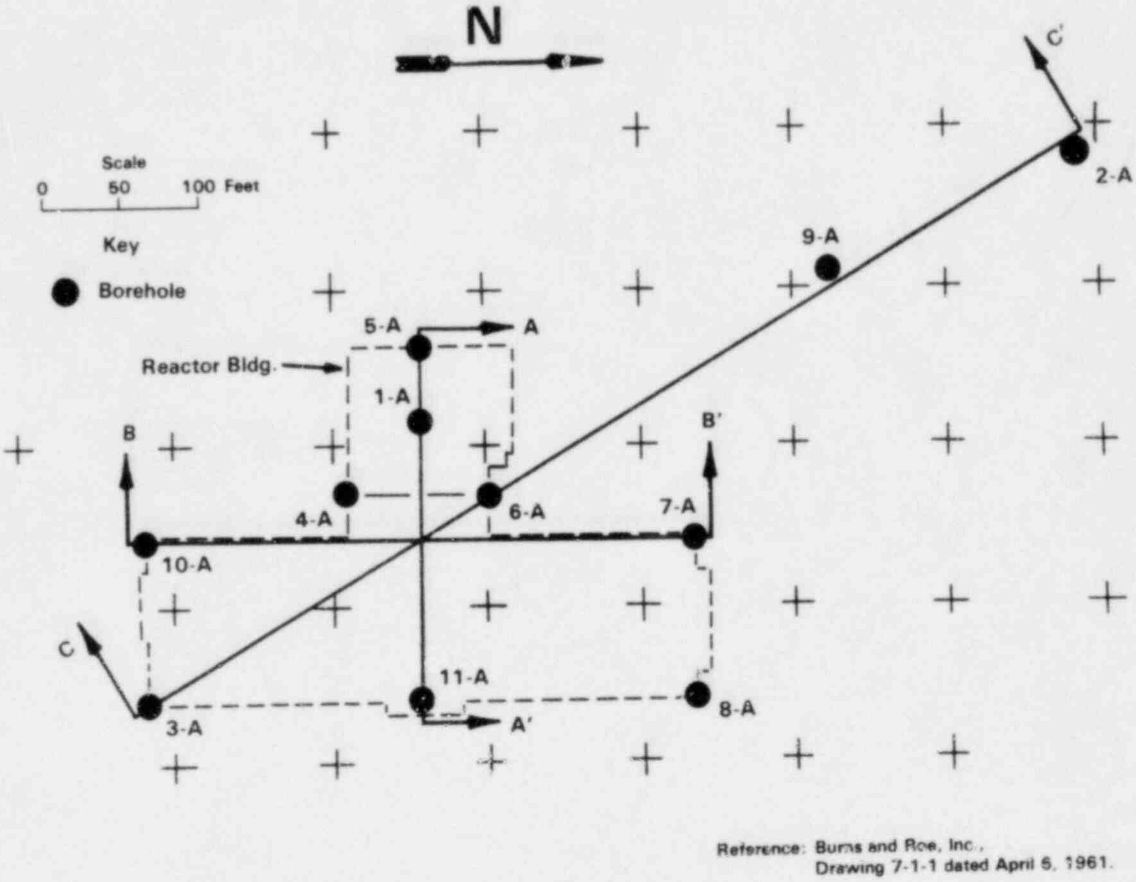


Figure 4. Plot plan showing locations of borings and geologic cross sections.

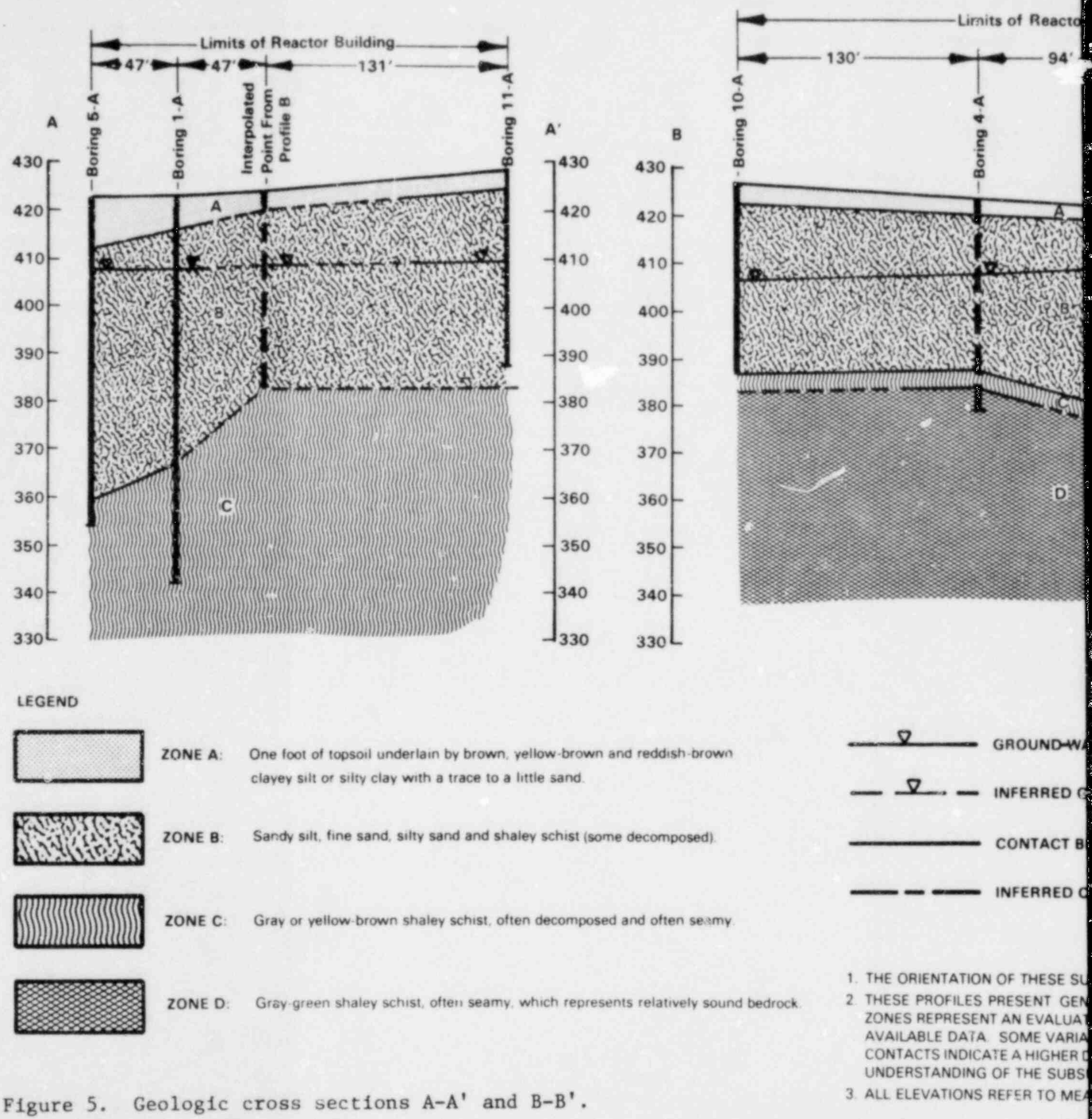
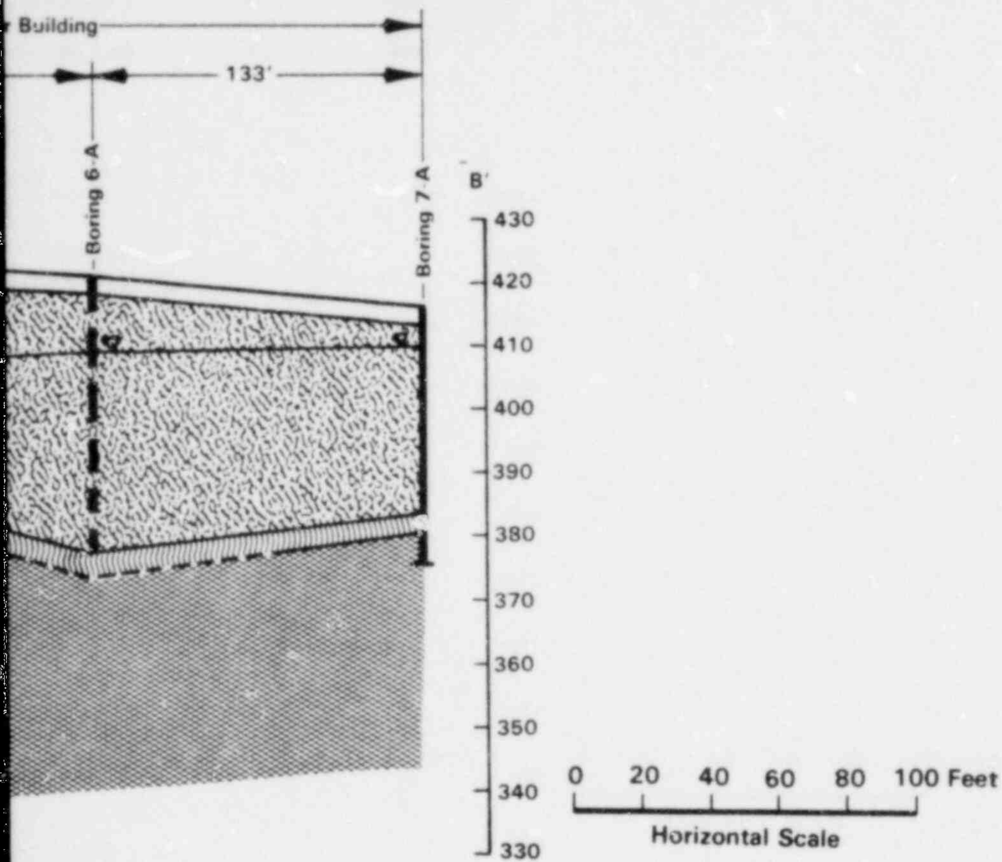


Figure 5. Geologic cross sections A-A' and B-B'.



ATER TABLE.

ROUND-WATER TABLE.

ETWEEN ZONES.

ONTACT BETWEEN ZONES

TEST BORING ON SECTION LINE.

TEST BORING PROJECTED ON SECTION LINE.

NOTES

BSURFACE PROFILES ARE INDICATED ON FIGURE 4.

ERALIZED CROSS-SECTIONS COMPRISED OF FOUR IDEALIZED STRATA (ZONES A THROUGH D). THESE ION OF THE MOST PROBABLE SUBSURFACE CONDITIONS BASED UPON INTERPRETATION OF PRESENTLY TIONS FROM THESE INTERPRETED CONDITIONS SHOULD BE EXPECTED. DASHED SUBSURFACE STRATA EGREE OF INTERPRETATION. THE DISCUSSION IN THE TEXT IS NECESSARY FOR A COMPLETE AND PROPER URFACE CONDITIONS.

AN SEA LEVEL DATUM.

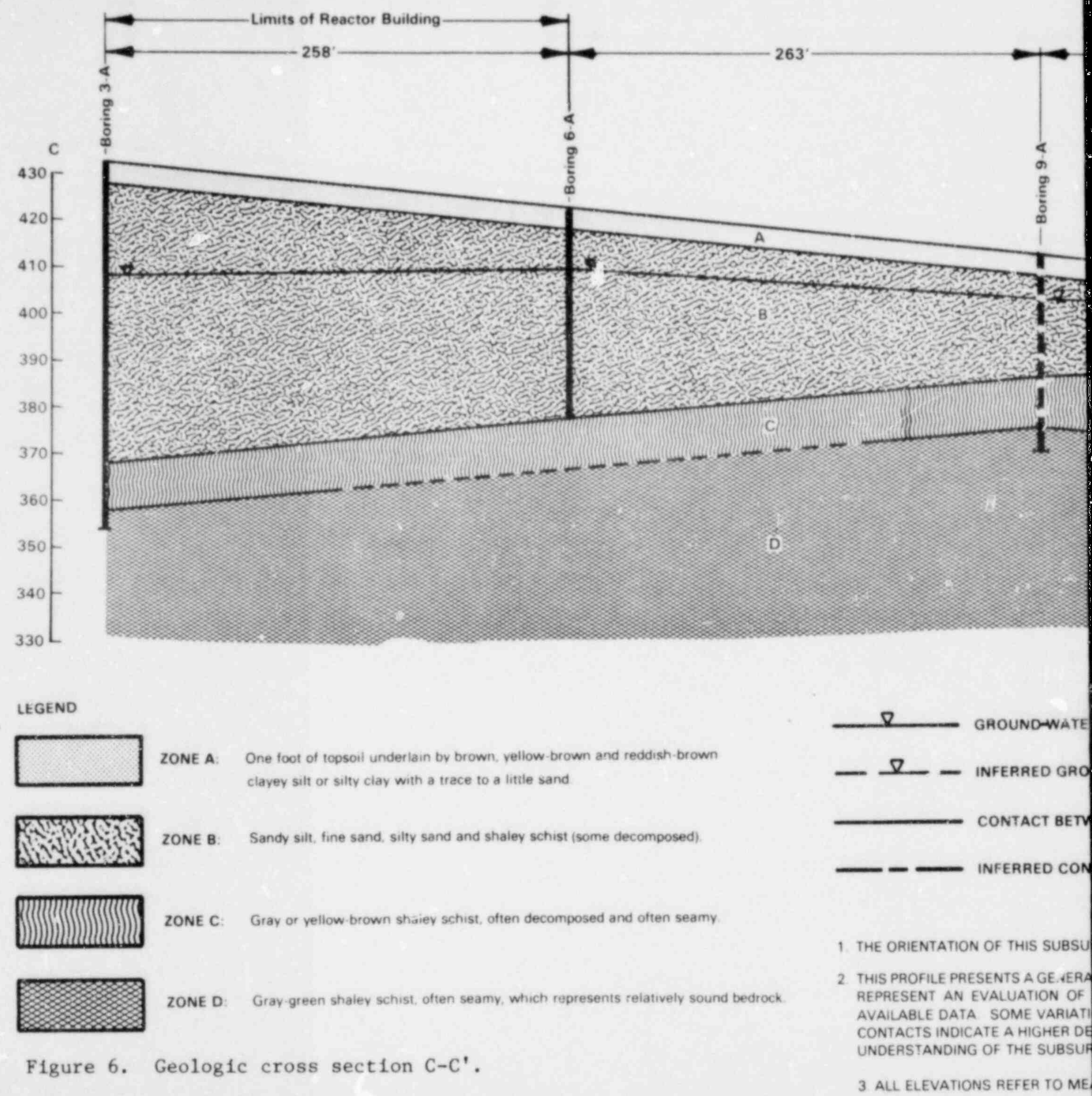
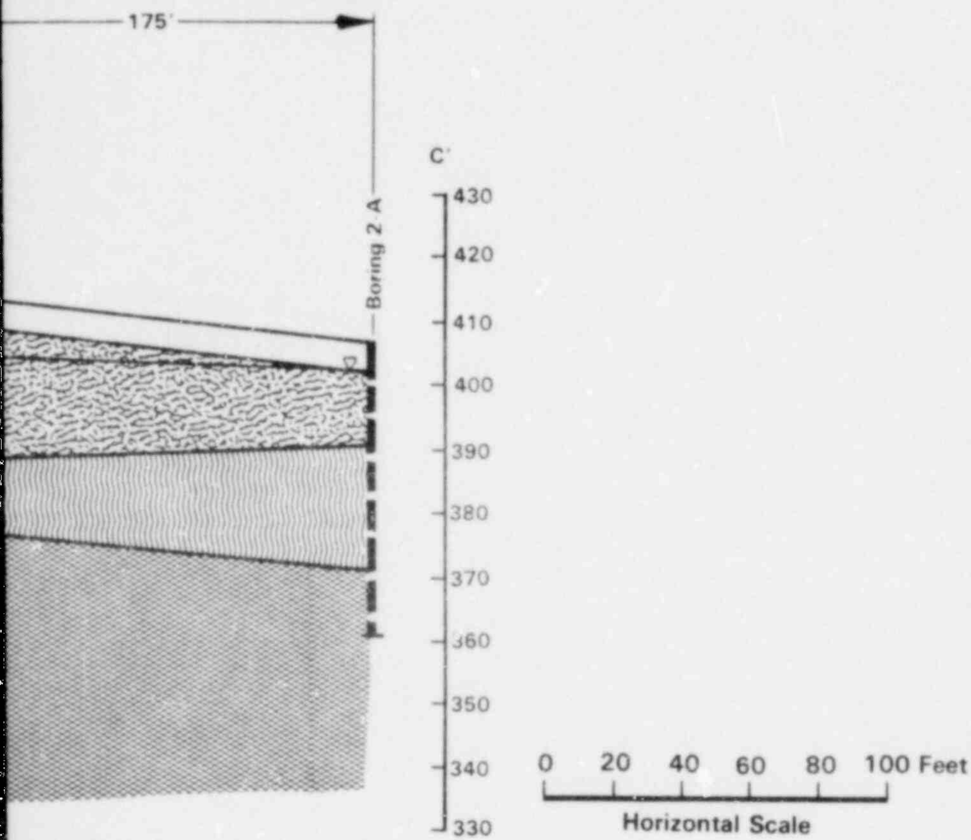


Figure 6. Geologic cross section C-C'.



R TABLE.

UND-WATER TABLE.

VEEN ZONES

TACT BETWEEN ZONES

TEST BORING ON SECTION LINE.

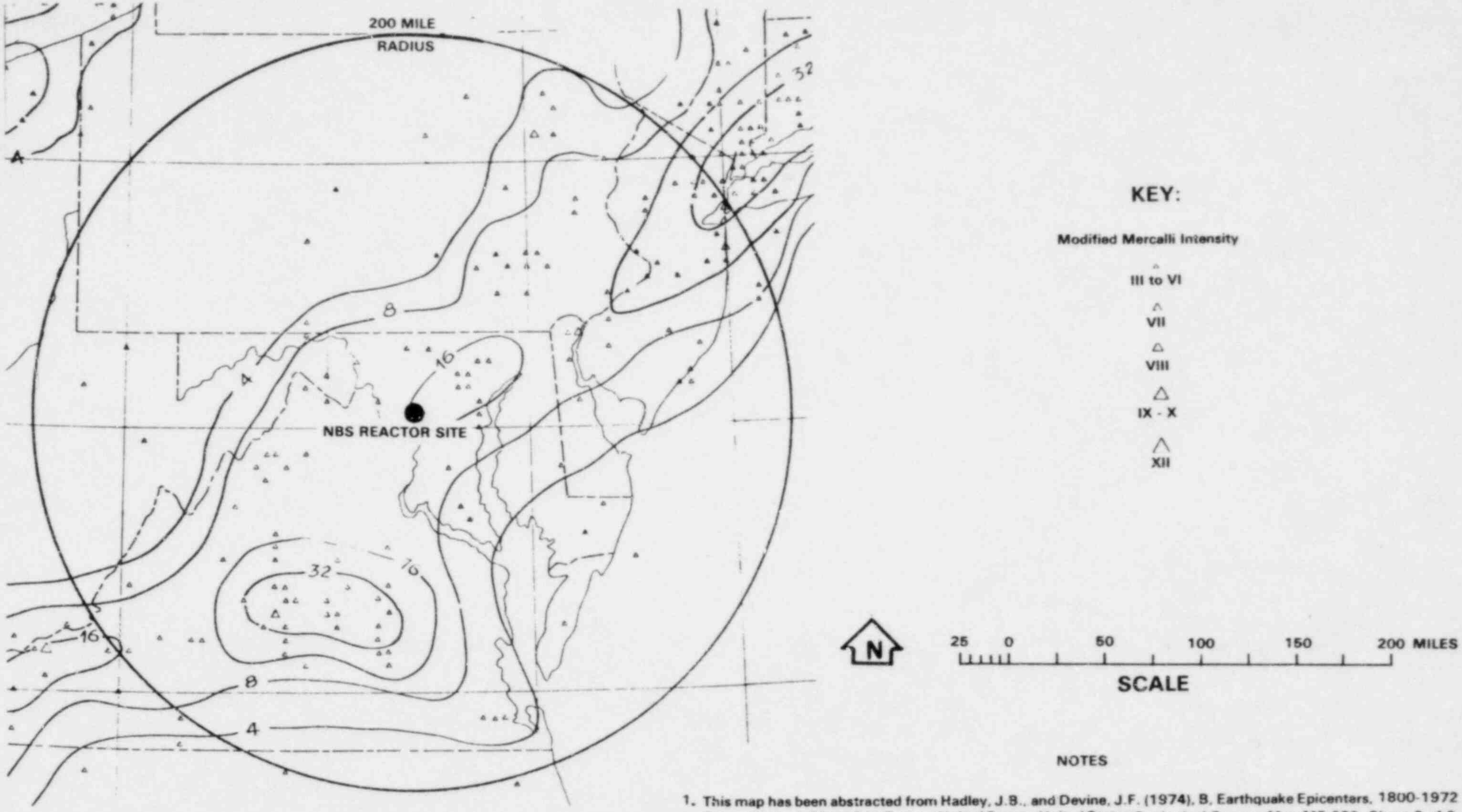
TEST BORING PROJECTED ON SECTION LINE.

NOTES

RFACE PROFILE IS INDICATED ON FIGURE 4.

LIZED CROSS-SECTION COMPRISED OF FOUR IDEALIZED STRATA (ZONES A THROUGH D). THESE ZONES THE MOST PROBABLE SUBSURFACE CONDITIONS BASED UPON INTERPRETATION OF PRESENTLY ONS FROM THESE INTERPRETED CONDITIONS SHOULD BE EXPECTED. DASHED SUBSURFACE STRATA GREE OF INTERPRETATION. THE DISCUSSION IN THE TEXT IS NECESSARY FOR A COMPLETE AND PROPER FACE CONDITIONS.

AN SEA LEVEL DATUM.



NOTES

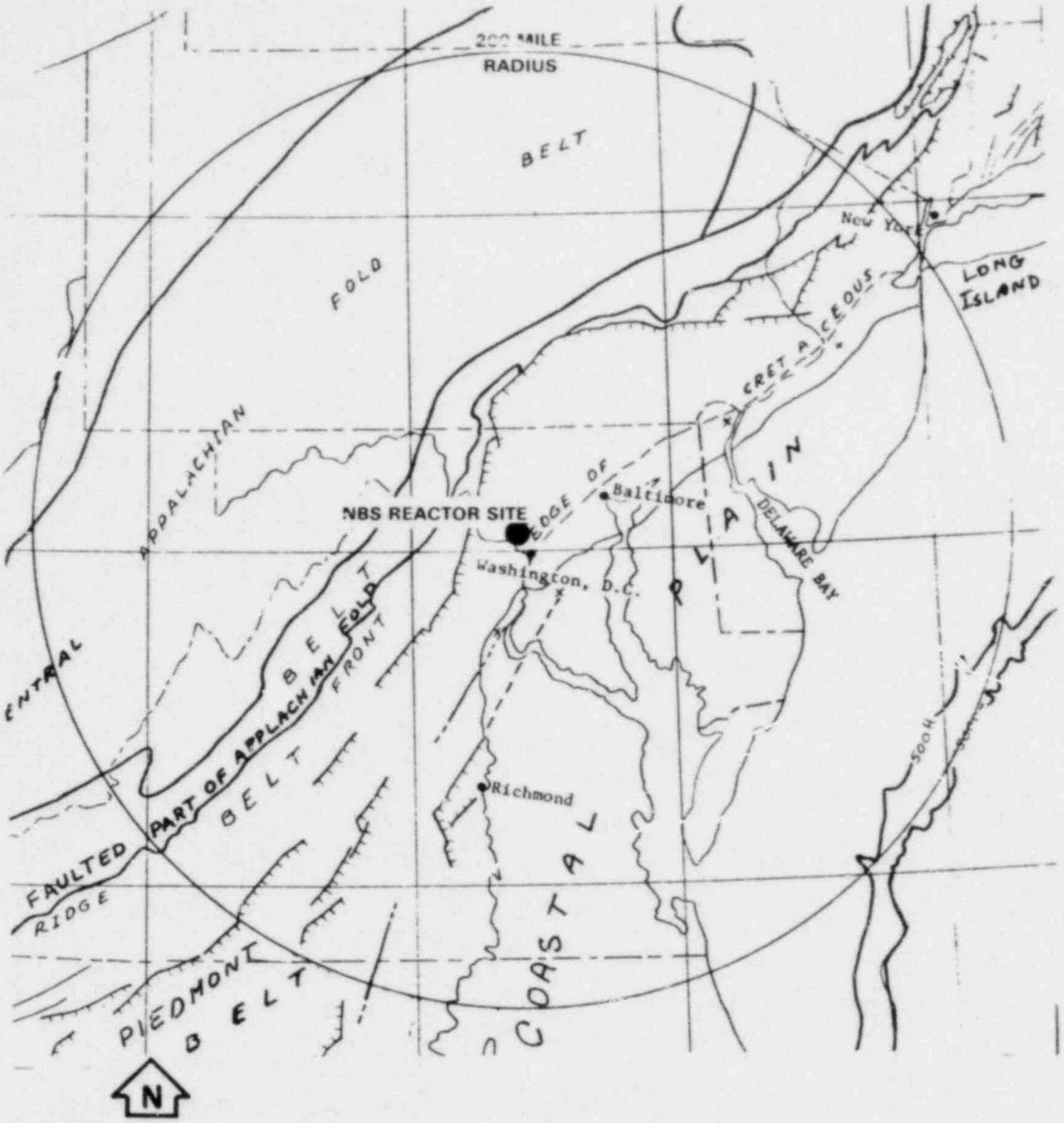
1. This map has been abstracted from Hadley, J.B., and Devine, J.F. (1974), B, Earthquake Epicenters, 1800-1972 Seismotectonic Map of the Eastern United States: United States Geological Survey, Map MF-620, Sheet 2 of 3.

2. The center of each triangular symbol indicates the epicentral location of one or more seismic events, plotted to the nearest 0.1 degree of latitude and longitude. The intensity shown is maximum Modified Mercalli (MM) intensity in the epicentral area of the largest event at the plotted location. Most locations are based on observations of intensity rather than on instrumental records.

—8—

Seismic frequency contours represent the areal distribution of earthquake epicenters with epicentral intensity of MM III and greater, as indicated by the total number per $10^4 km^2$ during the period 1800-1972. Contour intervals are 0-4, more than 4 but less than 8, more than 8 but less than 16, more than 16 but less than 32, more than 32 but less than 64, and more than 64. The contours are considerably generalized and are shown only as a guide for estimating regional seismicity. They have no value for precise location of seismic boundaries.

Figure 7. Regional map of earthquake epicenters.



KEY:

Geologic boundary

Tectonic province boundary
Dashed where concealed by younger deposits

Major anticline or anticlinorium

High-angle fault
Hachures on downthrown side where known; arrows show relative movement.
Dashed where approximately located or covered by younger deposits

Low-angle fault
Sawteeth on upper plate. Dashed where covered by younger deposits

Locally observed folds or faults in Coastal Plain rocks

25 0 50 100 150 200 MILES

SCALE

NOTES

1. This map has been abstracted from Hadley, J.B. and Devine, J.F. (1974), A, Tectonic Map, Seismotectonic Map of the Eastern United States: United States Geological Survey, MAP MF-620, Sheet 1 of 3.

2. Generalization involved in reducing data from maps at scales of 1:62,500 or larger to the 1:2,500,000 scale of the tectonic and basement maps has resulted in discrepencies in some locations amounting to several miles. Therefore, this map should not be used for the precise location of geologic features.

Figure 8. Regional tectonic map.

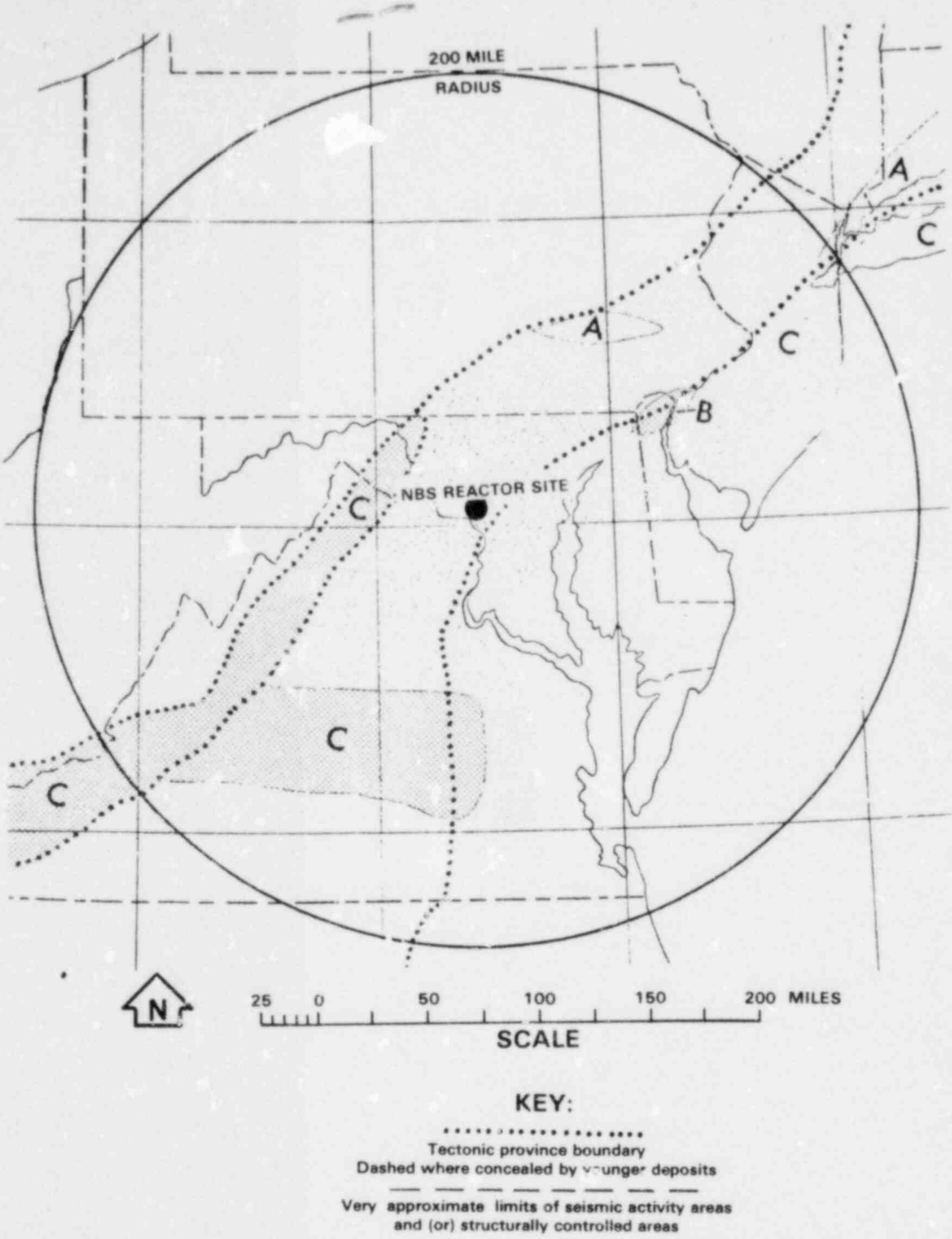


Figure 9. Regional seismotectonic map.

STRUCTURAL CONTROL

SEISMIC ACTIVITY LEVEL			
1			
2	A	B	C
3	A	B	C
4	A	B	C
5	A		C

SEISMIC ACTIVITY LEVEL

Level 1

frequency in epicenters is less than 8 per $10^4 km^2$. Includes large areas in which seismic frequency is l areas of this level are indicated without pattern, because information about historical seismicity is cient to make structural analysis possible.

Level 2

frequency is generally more than 8 but less than 32, and no earthquake in the area has a maximum ntral intensity greater than MM VI. Used locally for are s of seismic frequency higher than 32 around and en areas whos epicentral pattern indicates structural control.

Level 3

generally to areas where seismic frequency is more than 8 but less than 32 and at least one earthquake of ntral intensity VII or VIII is recorded. Commonly restricted to areas where epicentral distribution or relation wn structure indicates a limiting structural factor. Applies also to some areas where seismic frequency or more if not epicenters of intensity greater than VI are recorded, notab in central Virginia and the dack-St. Lawrence area.

Level 4

frequency is 32 or more and earthquakes of intensity VII or VIII have been recorded. Locally extended fault trends into areas of somewhat lower seismic frequency.

Level 5

here one or more epicenters of intensity IX or higher are present and seismic frequency is more than 32. seismic frequency drops below 32 along structural trends, level 3 applies because both maximum ity and seismic frequency decrease. No areas exist where the seismic frequency is less than 32 and earth- of intensity greater than VIII have been recorded.

STRUCTURAL CONTROL

A

which known faults are associated with epicentral alinements or distribution, in such a way as to indicate ovements on the known faults or closely related faults have been the source of recorded earthquakes.

B

which major faults are not known, but epicentral concentration and alinement indicate that movements ecognized or concealed faults have been the source of recorded earthquakes.

C

which major faults are known, but the epicentral distribution does not indicate that they are the source rded earthquakes. Also, areas in which major faults or other seismically active structures are not known cated.

NOTE

has been abstracted from Hadley, J.B., and Devine, J.F. (1974), C, Seismotectonic Map, ctonic Map of the Eastern United States: United States Gelogical Survey, MAP MF-620, Sheet 3 of 3.

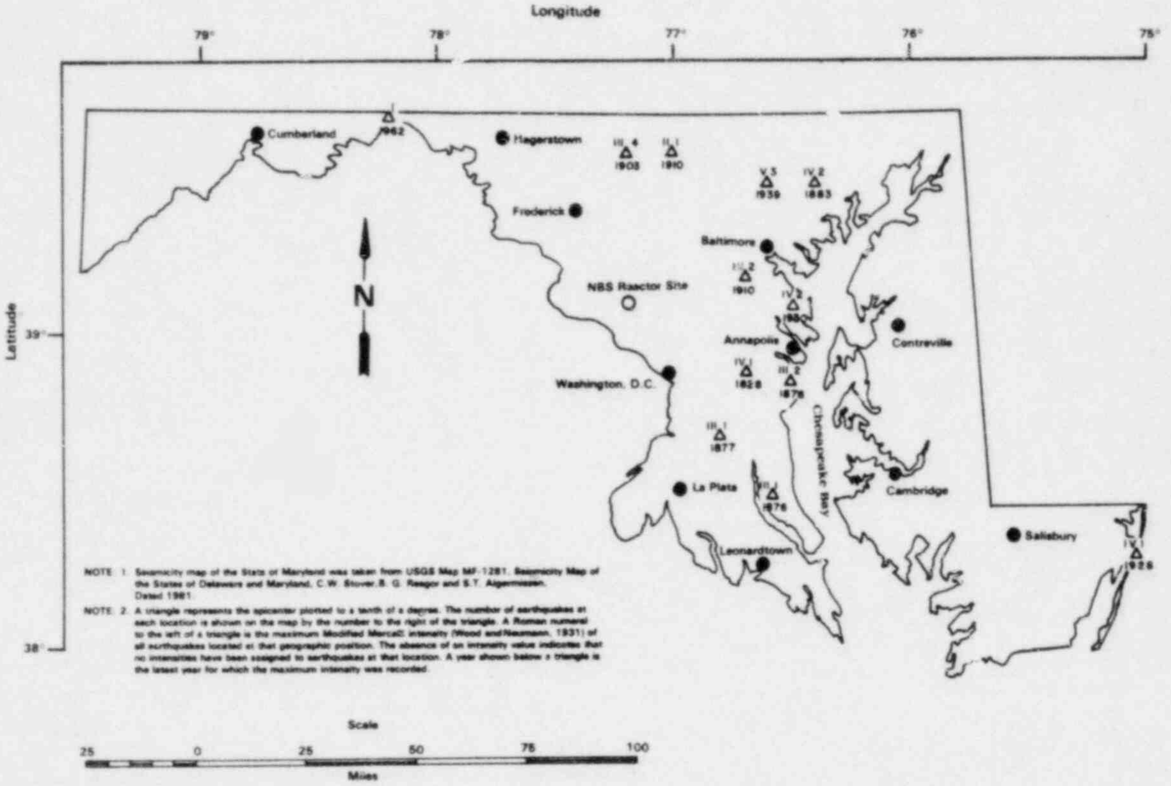
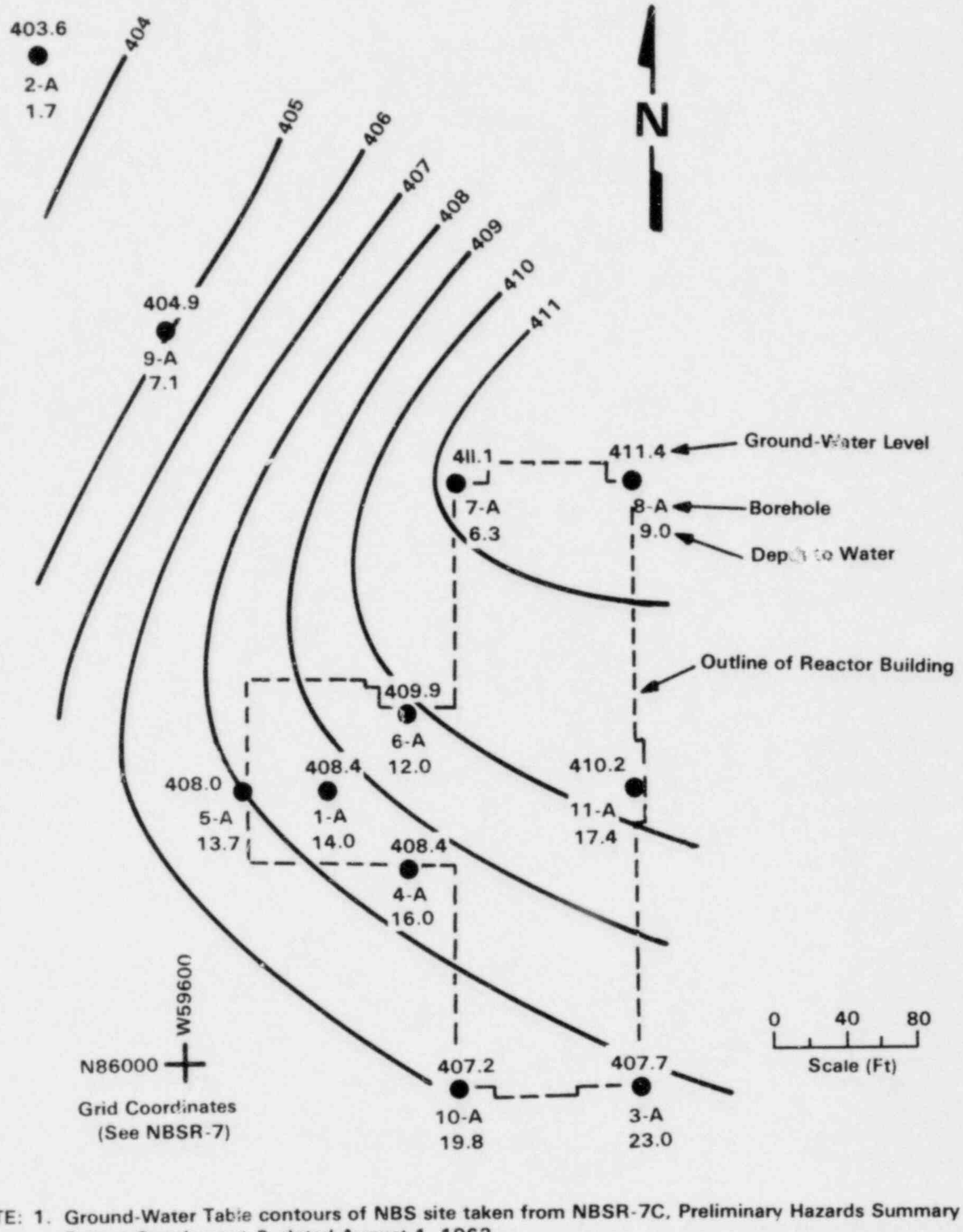


Figure 10. Seismicity map of the state of Maryland.



NOTE: 1. Ground-Water Table contours of NBS site taken from NBSR-7C, Preliminary Hazards Summary Report-Supplement C, dated August 1, 1962.

NOTE: 2. Ground-Water Elevations Refer to Mean Sea Level Datum.

NOTE: 3. Ground-Water Table contours are based on water level measurements in borings on January 20, 1961.

Figure 11. Ground-water table contours at NBSR site.