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REVIEW OF POTENTIAL HOST ROCKS FOR RADIOACTIVE WASTE DISPOSAL IN THE SOUTHEAST UNITED STATES - SOUTHERN PIEDMONT SUBREGION

ACRES AMERICAN INCORPORATED
Buffalo, New York

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808

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ABSTRACT

A literature study was conducted on the geology of the Southern Piedmont province in the states of Maryland, Virginia, North Carolina, South Carolina, and Georgia. The purpose was to identify geologic areas potentially suitable for containment of a repository for the long-term isolation of solidified radioactive waste. The crystalline rocks of the Southern Piedmont province range in age from Precambrian to Paleozoic, and are predominantly slates, phyllites, argillites, schists, metavolcanics, gneisses, gabbros, and granites. These rock units were classified as either "favorable," "potentially favorable," or "unfavorable" as potential study areas based on an evaluation of the geologic, hydrologic, and geotechnical characteristics. No socio-economic factors were considered. Rocks subjected to multiple periods of deformation and metamorphism, or described as highly fractured, or of limited areal extent were generally ranked as unfavorable. Potentially favorable rocks are primarily the high-grade metamorphic gneisses and granites. Sixteen areas were classified as being favorable for additional study. These areas are primarily large igneous granite plutons as follows: the Petersburg granite in Virginia; the Rolesville-Castallia, Churchland, and Landis plutons in North Carolina; the Liberty Hill, Winnsboro, and Ogden plutons in South Carolina; and the Siloam, Elberton, and six unnamed granite plutons in Georgia.

PREFACE

The disposal of radioactive waste in the proper geologic environment offers a high potential for isolating the waste from man's environment for the period of time required for the waste to decay to innocuous levels. As part of the National Waste Terminal Storage Program, the Savannah River Laboratory has responsibility for studies related to the storage of waste in the geologic environment in the Southeast. For the purposes of this study, the Southeast consists of the igneous and metamorphic rocks of the Piedmont, the sands and clays of the Coastal Plain, and the mudstones and shales of the Triassic basins from Maryland to Georgia. To implement these studies, a literature review of each of these three geologic provinces was performed by subcontract. The purpose of these reviews was to designate areas that, from a geotechnical point of view, offer a potential for field exploration to investigate their charcteristics and suitability for disposal of solidified high-level radioactive waste. This report covers the Southern Piedmont subregion and was prepared by Acres American, Inc., of Buffalo, New York. Because of the geologic complexity of the Piedmont and its generally high potential for waste storage, the general study reported herein was complemented by four detailed studies of literature and existing knowledge by experts in the local geology. These reports are on the piedmont of Virginia and Maryland (DP-1561), North Carolina (DP-1562), South Carolina (DP-1563), and Georgia (DP-1564). From all of these supporting studies, the Savannah River Laboratory prepared a summary report (DP-1559) which designates the areas favorable for field exploration.

This report is a general study of the Southern Piedmont by Acres American, Inc. The study is being published by the Savannah River Laboratory to make it generally available. However, the conclusions reached are those of Acres American, and they are responsible for its content.

I. W. Marine
Savannah River Laboratory
October 7, 1980

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1 - INTRODUCTION

1.1 - Objective

This report presents the results of a geotechnical investigation undertaken by Acres American Incorporated, Buffalo, New York, to identify geologic formations within the crystalline rocks of the southern Piedmont for subsequent study to determine their suitability for storage of radioactive waste.

The work was performed for E. I. DuPont de Nemours & Company, Savannah River Laboratory, Aiken, South Carolina under contract order number AX450039L.

1.2 - Scope

The subregion studied included the southern Piedmont province (as defined by physiography and structure) which falls within the States of Maryland, Virginia, North Carolina, South Carolina and Georgia, an area of over 116,000 sq. km. (45,000 square miles). The subregion is bordered on the east by the Fall Line, which is defined by the contact between the Piedmont rocks and the unconsolidated Cretaceous and Tertiary (140-2 million years ago) sediments of the Coastal Plain, and on the west by the Blue Ridge, a complex series of Precambrian (>600 million years ago) and Cambrian (600-500 million years ago) age rocks. The Triassic age (230-180 million years) basins which transect the crystalline Piedmont rocks were excluded from the scope of this study, but are covered by a parallel study by others.

The scope for this study was set out by Savannah River Laboratory in their Request for Proposal dated September 21, 1977, which is reproduced in Appendix A.

The geology within the subregion was reviewed to identify potential host rocks that may be favorable for exploration for the long-term storage of radioactive wastes. The study was based solely on overall geologic, geotechnical, and geohydrologic suitability of the rock. No consideration was given to socioeconomic or nontechnical restraints. Such areas were considered political, and thus not within the scope of this study.

The methods employed by Acres in defining rock suitability included:

(a) a literature survey of published and unpublished material,

(b) discussions with State and Federal Geologic Surveys and other persons knowledgeable of the study area.

No field work was undertaken for this study.

The ultimate intent of this study was to identify candidate study areas and to compile background information in the form of a bibliography on these areas that could be utilized in further studies to more closely define and locate suitable localities for field studies for the disposal of radioactive wastes.

2 - SUMMARY

This study identified potential host rocks within the southern Piedmont in the States of Maryland, Virginia, North Carolina, South Carolina, and Georgia that may be favorable for further investigation for underground disposal of radioactive waste material. The study entailed:

- a review of the regional geology, hydrogeology, seismicity, and natural resources

- establishment of a criteria for defining "potentially favorable" and "favorable" host rocks, and

- a review and categorization of all the individual rock units within the subregion for their overall suitability.

The crystalline Piedmont rocks range in age from Precambrian (>600 million years ago) to middle-late Paleozoic (400-230 million years ago), and are predominantly slates, phyllites, argillites, schists, metavolcanics, gneisses, and granites. The southern Piedmont has experienced multiple periods of regional metamorphism, hard rock deformation, and igenous intrusive activity during the Paleozoic and Mesozoic era (600-60 million years ago). The Piedmont is, therefore, a complex and diversified assemblage of rock units.

The criterion developed for this study identified potential host rocks within the southern Piedmont that may be considered for further investigation for underground disposal of radioactive waste. The criterion was based wholly on the rocks' hydrogeologic, geotechnical and geologic acceptability with no consideration given to socioeconomic or nontechnical factors.

These three technical criteria were subdivided into those properties and conditions that were considered the most crucial in assuring the long-term stability and containment of radioactive waste material. These included:

Hydrogeology: Permeability
Hydraulic Gradient

Geotechnical:
Physical and Mechanical Properties
Unconfined Compressive Strength
Modulus of Elasticity
Rock Quality
Joint Spacing
In-situ Stress

Geology: Unit Dimension
Structural Complexity
Lithology

The rocks within the subregion of study were classified by origin as:

Igneous
Metamorphic
Volcanic and Metavolcanic
Sedimentary

Each individual rock unit was tabulated; described by age, type, and petrologic description (where available); and classified as being either "acceptable", "marginally acceptable" or "unacceptable" for each of the individual properties and/or condition listed above. These classifications were assigned by the Acres geologist based on a review of the geologic literature and discussions with the various state geologists.

The overall favorability of the unit was then determined based on an evaluation of the classifications of the rock's properties and/or conditions. The rock units were classified as either "favorable", "potentially favorable" or "unfavorable", as potential "study areas". Only those rocks that appeared as the most suitable were given the "favorable" ranking.

Because of the large area of study and its diversified geology, it was impossible to collect and review all the available geologic literature pertaining to the Piedmont rocks. Consequently, additional data and studies could change the classification of several of these rock units.

A total of sixteen areas were classified as being the most "favorable" for additional study. These units, ranging from Virginia to Georgia, were primarily the large, younger syn- or post-metamorphic, igneous granitic plutons. These rocks appeared to demonstrate the most suitable geotechnical, hydrogeologic, and geologic properites and conditions for housing a radioactive waste repository. Additional studies, however, will be required within these chosen rock bodies to accurately define their extent, chemical, physical, and thermal properties, as well as the deep hydrologic regime before the final suitability of the rock can be determined.

A total of 23 rock types or units were classified as being "potentially favorable". These rocks, which were primarily the high-grade metamorphic gneisses and granites, cover a large portion of the southern Piedmont. As defined within the criteria, these rocks would require extensive study to locate a suitable rock mass within these rocks for housing a radioactive waste repository.

3 - REGIONAL GEOLOGY

3.1 - Physiography

The Piedmont physiographic province is a broad upland of moderate altitude with several lowlands scattered through the region, bordered on the west by the Blue Ridge Province* and overlapped on the east by the sediments of the Coastal Plain (see Plate 1). The province trends in a northeasterly direction extending 1350 km (840 miles) from Alabama to Central New Jersey, varying in width from 60 km (40 miles) in northern Virginia to nearly 240 km (150 miles) in the Carolinas.

Regional slopes in the Piedmont Province are generally eastward. General altitude increase from north to south ranging from 90-120m (300 to 400 feet) in Maryland to 550m (1800 feet) in Georgia. The eastern boundary between the Piedmont Province and the Coastal Plain is commonly referred to as the Fall Line. This line marks the contract between the resistant rocks of the Piedmont and the unconsolidated Cretaceous and Tertiary sediments of the Coastal Plain.

Many portions of the Piedmont are covered by a deep saprolite soil which in places is as much as 30m (100 feet) thick. This thick saprolite is evidence that the Piedmont has been exposed to extensive long-term weathering. The gently rolling terrain of the Piedmont has given the appearance of being a peneplain. The lack of structural or lithologic control of drainage is common throughout the province. Generally streams tend to cross-cut the regional structure, flowing from west to east and southeast towards the Atlantic Ocean. Numerous monadnocks are present along the province's western boundary.

*The boundary between the Blue Ridge and the Piedmont has been placed by some geologists at the Brevard Fault Zone (Reed & Bryant, 1964; Hatcher, 1971a) while others consider the rocks west of the Brevard in Georgia and Alabama as part of the Piedmont (Crawford and Medlin, 1970). This study has considered the Brevard Zone as marking the western boundary of the Piedmont Province.

The Piedmont rocks are deformed and metamorphosed rocks of late Precambrian to late Paleozoic age (650-230 million years ago), which overlie older Precambrian (>650 million years ago) basement gneisses (see Section 3.3). Several Triassic, sedimentary basins occur in a general northeast-southwest direction within the province. These Triassic basins were formed by a down-faulting, with the boundary faults generally following the structural trends in the older rocks.

Numerous diabase dikes intrude many of the earlier Piedmont rocks.

3.2 - Piedmont Subdivisions

3.2.1 - Introduction

The rocks of the Piedmont have been subdivided in several northeast trending belts that follow the regional structural features. These belts have been defined on the basis of similar topography, structure, rock type and metamorphic grade. Boundaries between belts are generally gradational in nature. The stratigraphic relationship of the belts suggest that they represent zones of different grades of regional metamorphism and rock composition.

The most common subdivision of the Piedmont (King, P.B., 1955) has been into the Inner Piedmont Belt, Kings Mountain Belt, the Charlotte Belt and the Carolina Slate Belt. These belts are discussed in detail in the following sections, and their locations are shown on Plate 2.

3.2.2 - Inner Piedmont

The Inner Piedmont comprises the widest belt within the Piedmont. It is bounded by the Kings Mountain Belt on the east, and the Brevard Fault Zone to the west.

The belt is composed of two general rock types (Hatcher, 1972); (1) a belt of low-to-medium grade metasedimentary and metavolcanics which lies immediately southwest of the Brevard Zone and narrows southward into Georgia and Alabama and consists of graphitic phyllite, chlorite-muscovite phyllite, impure marble, and quartz feldspathic augen to quartzite Henderson Gneiss, and, (2) the more abundant and extensively deformed and metamorphosed granitic gneisses, amphibolite-hornblende gneiss, biotite gneisses, schists and metagraywackes.

3.2.3 - Kings Mountain Belt

The Kings Mountain Belt (Plate 2) lies in the central part of the Piedmont in South Carolina and south-central North Carolina.

The belt is largely comprised of metamorphic rocks that range from siliceous and calcareous metasediments to feldspathic, micaceous, and hornblende schists and gneiss of uncertain origin. The belt has three basic types of intrusive igneous rocks: quartz monzonite granites, biotitic granites and diabase.

The metamorphic rocks of this belt are of medium-to-low grade. The belt probably extends across both North and South Carolina, but its continuity is obscured by major intrusive bodies and metamorphic alteration.

3.2.4 - Charlotte Belt

The Charlotte Belt comprises a broad central part of the Piedmont. The belt lies between the Carolina Slate Belt to the southeast and the Kings Mountain Belt to the northwest (King, 1955). This belt contains more granite than other belts, and granitoid textures are common in intrusive plutons. The granitoid rocks are highly foliated with apparent remnants of bedding of the original sedimentary and volcanic rocks. The granitoid paragneiss is commonly a fine-grained, epidote-bearing gneiss and migmatite of the albite-epidote amphibolite facies (Overstreet, 1970). Locally the grade of regional metamorphism rises to the staurolite-kyanite subfacies and, adjacent to parts of large plutons, the grade rises to the sillimanite-almandine subfacies. Three episodes of intrusive activity are evident in the Charlotte Belt (see Section 3.3). These younger intrusive rocks consist of gabbro, diorite and syenite (Butler, 1966).

In summary, the Charlotte Belt is a zone of moderate to high metamorphic grade between two belts of lower grade rocks.

3.2.5 - Carolina Slate Belt

The Carolina Slate Belt is a lower rank assemblage of metasedimentary and metavolcanic rocks, including metagraywacke, tuffaceous argillites, quartzite, and metasiltstone (Hatcher, 1972).

The belt extends for more than 650 km (400 miles) from Virginia southwestward to central Georgia. The age of these rocks are unknown but are generally considered to be of early Paleozoic age (550 million years ago). The belt is bounded on the west by medium-grade, metamorphic rocks of the Charlotte Belt and to the east by the unconsolidated Cretaceous and Tertiary sediments of the Coastal Plain. Rocks of the Slate Belt compose much of the eastern Piedmont and crop out in large regions of Virginia, North Carolina and South Carolina. The belt has been intruded by granitic rocks of Paleozoic age. These intrusive masses are generally circular to oval in plan and are conspicuous features of both the Carolina Slate Belt and the Charlotte Belt. They were probably emplaced during middle to late Paleozoic time (see Section 3.3).

3.3 - Tectonic History

The tectonic history of the southern Piedmont has been complicated by multiple periods of deformation, metamorphism, and intrusion.

The rocks have been metamorphosed at least twice since the late Precambrian (650 million years ago) (Reed and Bryant, 1964). The earliest and most severe orogenic activities to affect the southern Piedmont commenced during the early Paleozoic (500-650 million years ago) (Hatcher, 1972) causing extensive regional metamorphism and isoclinal folding. The metamorphic intensity of this event was greatest in the Inner Piedmont and the Charlotte Belts where the rocks reached the sillimanite grade and were extensively remobilized.

The last regional metamorphic event affecting the southern Piedmont probably occurred between 420 and 380 million years ago (Hatcher, 1972). The metamorphic intensity of this event was less than the earlier event, causing predominantly retrogression (Hatcher, 1972). Accompanying the metamorphism was large-scale overthrusting and folding. It was during this phase that the major fault systems to include the Brevard Zone, Towaliga, Goat Rock and Gold Hill faults were probably formed (Hatcher, 1972) (see Section 3.4). The mapped series of large plunging anticlinoria and synclinoria that trend across the southern Piedmont in a general northeast-southwest direction probably are an overprint of this last major compressive event.

Igneous activity within the southern Piedmont occurred over a wide time period with the earliest being about 1 billion years ago (Ranking, et al, 1969). Paleozoic (230-650 million years ago) intrusive activity occurred pre-, syn-, and post-regional metamorphism. Based on age dating of plutons throughout the southern Piedmont, Fullagar (1971a) concluded all of the plutonic activity occurred between 595 and 300 million years ago, and that the activity could be divided into three episodes: 595 to 520 million years ago, 415 to 385 million years ago, and 300 million years ago. The oldest and youngest plutons are in the southeast portion of the Piedmont with the oldest plutons found in the Charlotte Belt. To the west of the Blue Ridge there was folding between 230 and 300 million years ago, but this apparently was not accompanied by intrusive activity in the Piedmont.

The last major tectonic event affecting the southern Piedmont was a shift from a compressive to a tensional stress regime during the Permian to Triassic (280-190 million years ago) (Jurassic?) period. This tensional regime caused large scale normal faulted Triassic basins. These basins subsequently were filled with terrigenous sediments. Associated with this last major tectonic event was the intrusion of diabase dikes and sills that are common throughout the Piedmont.

Geologists now attribute plate tectonics as the primary mechanism for the tectonic evolution of the southern Piedmont. Although the interpretation of the model is controversial, the plate tectonic concept provides the most plausible mechanism for the generation of orogenic belts.

One of the more recent tectonic models for the evolution of the southern Piedmont is that presented by Hatcher (1972). Hatcher identified four distinct phases of developmental history of the southern Piedmont. Phase I, being the earliest phase of post-Grenville time, involved the erosion of the previously formed Grenville Mountains and deposition of the erosion products in several interconnected basins along the continental margin. Further east (seaward) there was sea-floor volcanic activity, and perhaps the development of an island arc-trench subduction zone system. Deposition began in late Precambrian on the previously deformed and intruded Grenville basement. Up to 12,800m (42,000 feet) of sediments were deposited in some basin areas. All the sediments were poorly sorted, such as those found in the Carolina Slate Belt. With the diminishing of the source area to the west the sediment changed to cleaner and better sorted. The westward clastic source ceased for a short period during the early Cambrian (650 million years ago) but reappeared and persisted as a low-relief source of fine clastics through the late Cambrian (500 million years ago) time.

The eastern Piedmont probably was a series of volcanic islands that persisted well into the Paleozoic. Phase II, commencing in the middle Ordovician (470 million years ago), marked the first major period of regional metamorphism. Hatcher attributed this early Paleozoic folding and metamorphism to a westward-moving lithospheric plate being consumed in a subduction zone located to the east of the Carolina Slate Belt. The heat generated in the subduction zone caused widespread metamorphism and granitization in the hottest portions of the zone (Inner Piedmont). Compressive stresses exerted by the plates produced the isoclinal and recumbent folding. This phase was accompanied by synkineatic pluton intrusions.

Phase III marked the second period of large-scale compression, low-grade metamorphism, major faulting and some intrusive activity. Hatcher relates this event to the collision of the southeastern North America plate and the Africa plate. The culmination of the collision probably produced large scale over-thrusting of the Blue Ridge and folding and faulting throughout the southern Piedmont.

Phase 4 was the last major period of tectonism in the southern Piedmont. The tensional stress regime formed during this period was caused by the decoupling and spreading of the continents to their present day position.

3.4 - Structure

As stated in Section 3.3, the structure of the Piedmont has been complicated by multiple periods of deformation and metamorphism which have obliterated many of the older pre-metamorphic structural features.

Plates 3 and 4 are a regional tectonic map of the Piedmont and a generalized cross section. Generally the rocks of the Piedmont are mapped as a series of large anticlinoria and synclinoria which trend in a northwest-southeast direction. Localized folding ranges from broad and open to tightly compressed, symmetric to assymetric, upright to overturned. Cleavage within the Piedmont crystalline rocks ranges from closely spaced slaty cleavage to non-existent in the more massive units.

The large faults that have been mapped in southern Piedmont, and are shown on Plate 3, are generally considered to be post-metamorphic and post-folding in age (Hatcher, 1972). The major mapped pre-Triassic (230 million years ago) faults of the southern Piedmont are the Brevard Zone, Towaliga, Goat Rock, Gold Hill Faults as well as a series of recently mapped faults along the eastern Piedmont. Several of the larger Triassic faults are also shown on Plate 3. These faults which predominately form the boundary of the Triassic basins are outside the scope of this study, and have not been included in this discussion.

The largest and most pronounced structure within the southern Piedmont is the Brevard Fault Zone which forms the boundary between the Blue Ridge and the Piedmont. The known length of the zone is more than 520 km (325 miles) and its width is generally less than 5 km (3 miles). The fault is remarkably straight and independent of the structures of the Blue Ridge and Piedmont. The zone is readily distinguished on Landsat imagery (N.J. Trask, et al, 1977) and gravity maps. The zone has had a long and complicated history. Mapping across the zone shows gross contrasts on opposite sides in structural patterns and rock composition. The age and origin of the Brevard is unknown. Reed, et al (1970) postulate that movement of the Brevard started as early as the early Paleozoic (570 million years ago) and continued through the middle Paleozoic (400 million years ago) after the climax of regional metamorphism. Some authors have argued that the zone has experienced northwestward thrust faulting, others have favored strike-slip faulting, while still others have argued a combination of both movements (Hatcher, 1971a; Reed and Bryant, 1964; Reed, Bryant and Myers, 1970). The zone was active as a shear zone as long as 346 million years ago (Odom and Fullagar, 1973). Several undisturbed Mesozoic (230-65 million years ago) age dikes which cross cut the structure, indicate that the zone (at least in part) had ceased to be active by that time.

The Towaliga and Goat Rock Faults form the northwest and southeast sides of the Kings Mountain Belt. Clarke (1952) suggested that the Towaliga, Goat Rock and Brevard may be the surface traces of a single folded fault. Later work by Bentley and Neathery (1970) show some support for this hypothesis based on aeromagnetic data. Recent aeromagnetic and aeroradioactivity maps (Bentley, et al, 1974a, 1974b) show that these faults extend northeast across Georgia and possibly into South Carolina (Howell, 1976). They continue southwestward beneath the Coastal Plain of Alabama.

The Gold Hill Fault is a zone of shearing and cataclasis along the Charlotte-Carolina Slate Belt, from near the North Carolina-South Carolina border northeastward for approximately 135 km (80 miles). Sundelius (1970) shows it to be sharply discordant, dipping steeply and cutting across the layering and structure of the Slate Belt rocks on the southeast.

Recent geologic mapping, interpretation, and field checking of aeromagnetic data by Hatcher, et al, (1977), has led them to suggest the existence of a series of closely associated faults and splays extending from Alabama to Virginia along the eastern Piedmont. Based heavily on interpretation of magnetic data, these authors postualte an extensive eastern Piedmont fault system which extends northeastward from the Goat Rock Fault, passing beneath segments of the Coastal Plain in the Carolinas, and continuing into Virginia. Hatcher, et al, (1977) places the movement history of these faults to be similar to that of the Brevard Fault (see Plate 3).

Within the crystalline rocks of the Piedmont are a series of unmetamorphosed Triassic rocks which are found in a series of downfaulted basins. These basins are bounded on one or both sides by large normal faults which closely follow structural trenches in the older crystalline rock.

None of the mapped faults in the southern Piedmont are believed to be active. There is no known seismic activity associated with any mapped structural features within this part of the Piedmont.

3.5 - Seismicity

Seismic events in the southeastern U.S. are geographically randomly scattered with the exception of several areas of clustered earthquake epicenters. The establishment of the world-wide seismograph network in the early 1960's has made it possible to more accurately define earthquake epicenter locations and magnitude. Historical records of earthquakes in the southeast date back 300 years to the earliest colonial settlement and the location of most earthquakes have been based on published and unpublished records of felt effects. Many of the early recordings are highly subjective, depending on an individual's sensitivity and activity at the time of the earthquake. Prior to 1850, much of the southeast was sparsely populated and earthquake occurrences tended to be biased around the few centers of population. Thus, many of the early earthquake epicenters may possibly have been located tens of miles from their actual point of occurrence. Due to the absence of seismography records, there is a general lack of information concerning earthquake ground motions and durations.

The method that has been most frequently used in classifying earthquakes, and the one used in this report, has been the Modified Mercalli (MM) Intensity scale given in Table 1. This is a scale of I to XII which measures the earthquakes' effect on people, man-made structures and on the earth's surface. The measure of intensity depends on many factors which include a structure's design, foundation conditions, and the type and quality of construction, as well as the objectivity of human observation.

A plot of earthquakes of intensity V or greater for the southeast is shown in Plate 5 while a list of the earthquake events with their location, intensity and magnitude (where available) is given in Table 2.

A review of the epicenter map shows several apparent "clusters" of earthquakes in the southeast. These are in the vicinity of Giles County, Virginia, along the Tennessee-North Carolina border area, and at Charleston, South Carolina. It is worth noting that none of these areas fall within the Piedmont. The largest earthquake ever recorded in the southeast U.S. the Charleston Earthquake of August 31, 1886, which had an estimated epicenter intensity of X (MM).

The Piedmont generally falls within Seismic Zone 2 (Uniform Building Code), indicating an area that may be subject to moderate damage and corresponding to intensity VII (MM). As a whole, the Piedmont is considered to have low to moderate seismicity. There are no known active faults within the Piedmont and no earthquakes are known to be associated with any mapped structural or tectonic features.

3.6 - Hydrogeology

The Piedmont rocks have all been subjected to varying degrees of metamorphism (see Section 3.3) which has resulted in recrystallization and interlocking of mineral grain boundaries which, for all practical purposes, has eliminated water access between grain boundaries. As a result, water movement within the Piedmont rocks is essentially restricted to connected open fractures, shear zones and joints (Herrick and LeGrand, 1949).

Unfortunately, there is little available data on groundwater flows within Piedmont rocks at depths in excess of 300m (1,000 feet). Hydrogeologic studies that have been performed in the Piedmont have generally been restricted to the upper consolidated soil and fractured rock. It is expected that with increasing depth, joints and fractures become fewer and tighter, resulting in more restricted groundwater flows (Snow, 1968). However, joints, shears, and fractures are common in all crystalline Piedmont rocks and the transmissibility to groundwater within the various rocks will depend on rock type, chemical and physical composition, and tectonic history. Older rocks that have been subjected to multiple periods of deformation may tend to be more highly fractured than younger, intrusive rocks. Similarly, the more massive high-grade metamorphic rocks (granites and gneisses) that have been recrystallized and compacted are expected to have lower permeabilities than the lower grade metamorphic rocks.

The regional groundwater table throughout the Piedmont is generally a subdued replica of the topography. Groundwater gradients are dictated by topographic expressions with regional movement being from the higher elevation towards lower elevations.

Locally, deep groundwater circulation is affected by rock types and structural discontinuities. Areas with faults and contact zones between igneous and metamorphic rocks will generally produce substantially higher groundwater yield in comparison to other areas within the region (Herrick and LeGrand, 1949).

In general, it is to be expected that the large younger igneous intrusive rocks and the more massive high-grade metamorphic rocks would be most likely to have the lowest permeabilities of all the Piedmont rocks.

3.7 - Natural Resources

The Piedmont is endowed with a variety of rocks and minerals that have been of economic importance since colonial days. Both metallic and non-metallic minerals are found within the province.

The metallic minerals are principally associated with the igneous and metamorphic rocks. Minerals, including chromite, copper, gold and silver, iron, lead and zinc, manganese, molybdenum, nickel, tin, titanium and tungsten occur in limited quantities throughout the Province, while some high-grade magnetite is found locally. The Piedmont is not considered a large producer of metallic minerals, and only small localized mines are currently in operation. However, because of its similarity to important metal mining districts in Canada, the Carolina Slate Belt (see Section 3.2.5) has been the target of recent exploration, and has been considered to have potential for the discovery of sulfides deposits to include copper, lead and zinc (Wilson, 1976). However, no major deposits have been found to date.

The largest and most productive mining within the Piedmont are the nonmetallic resources. This industry is highly diversified and found throughout the Province. The principal non-metallic resources are:

- Feldspar - Mica
- Lithium
- Crushed Stone
- Dimension Stone
- Talc and Pyrophyllite
- Asbestos
- Gemstones

The potential effect on current and future development of natural resources within the Piedmont rocks must be thoroughly assessed for the siting of a waste repository.

4 - CRITERION FOR SELECTING POTENTIAL GEOLOGIC FIELD STUDY AREAS

4.1 - Introduction

This section discusses the technical criteria used in identifying potential host rocks that may be favorable for exploration for underground disposal of waste material. The criteria are based on the concept that a host rock for a proposed repository site must have adequate chemical and physical properties to insure long-term geologic containment of any stored radioactive waste such that the radionuclides would be isolated and thus dispersion into the biosphere in hazardous amounts would be prevented.

Generally, qualitative rather than quantitative parameters have been used in these criteria because:

(a) no regulatory guidelines for deep disposal of radioactive wastes have yet been developed;

(b) the required effective period of isolation of the waste material from the biosphere has not been determined; and

(c) the effects of radioactive waste/rock interaction for the Piedmont rocks has not been determined.

A suitable host rock for housing a radioactive waste repository must ultimately demonstrate favorable hydrogeology, geology and geotechnical conditions. This study utilized these three disciplines in defining favorable rock units within the southern Piedmont. Rock units having favorable properties were referred to as "potential study areas" which indicates that they provide the highest potential for locating a suitable rock mass within that body for siting a repository.

The study areas have been designated solely on their technical acceptability with no consideration being given to socioeconomic or nontechnical factors at this time. It is realized that land-use conflicts are a political consideration that will have to be addressed at an early phase of any subsequent studies undertaken to evaluate the "potential study areas". Obvious conflicts with urban areas, national parks, densely populated areas, etc., will eliminate many technically acceptable rocks from further consideration.

The three technical criteria--hydrogeology, geotechnical conditions and geology were subdivided into those properties and conditions that were considered most crucial to assure the long-term stability and containment of radioactive waste material. These included:

I Hydrogeology: Permability
Hydraulic Gradient

II Geotechical:

Physical and Mechanical Properties

Unconfined Compressive Strength
Modulus of Elasticity
Rock Quality
Joint Spacing
In-situ Stress

III Geology: Unit Dimension
Structural Complexity
Lithology

The thermal properties of a rock, including its thermal conductivity, specific heat capacity and geothermal gradient, are important in the ultimate selection of a potential host rock. However, for this study a rock's thermal properties have not been considered because:

- these properties are poorly defined for Piedmont rocks,

- the majority of the otherwise favorable rock units considered in this study are believed to fall within acceptable ranges of thermal properties and,

- the degree and duration of thermal loading is related to the type to be disposed which is unknown at this time.

4.2 - Hydrogeology

The primary vehicle for migration of radionuclides from a repository to the biosphere is the groundwater system. Thus, to insure the long-term isolation of radionuclides from the biosphere, the hydrogeology of potential sites must be thoroughly understood. Hydrogeologic conditions, including groundwater flow patterns, rock mass permeability, hydraulic gradients, linear velocity and the content and retention of radionuclides within the rock, must be thoroughly evaluated.

The groundwater flow pattern (upward, downward or lateral movement) is crucial to the siting potential of a repository. The host rock must safeguard the waste from disseminating into the biosphere. Such data in the Piedmont are generally scarce, and available only within a few hundred meters of the ground surface. It is generally difficult to extrapolate near surface data to depths. However, certain geological characteristics (e.g., nature and orientation of joints, foliation, mechanical properties and tectonic history of rocks, etc.) can help guide the initial selection of potentially favorable hydrogeological areas. In light of the absence of hydrogeological data, intensive investigations will have to be carried out during any future field study program.

As stated in Section 3.6, the groundwater flow within the Piedmont rocks is generally restricted to connecting joints, fractures, and shear zones within the rock bodies. It is, therefore, important to identify those rock bodies that are massive and homogeneous with minimal jointing, fracturing, and shearing. Rocks that may meet this criteria in the Piedmont are the younger, intrusive granitic rocks and the more massive, less foliated, high-grade metamorphic rocks (i.e., granites and gneisses). Many of the Precambrian and early Paleozoic rocks of the Piedmont have been subjected to multiple periods of metamorphism and hard rock deformation causing their intense fracturing, shearing and alteration resulting in higher rock permeabilities.

Some systematic jointing of a rock mass (resulting from cooling of the rock mass or from regional stresses) are expected to be found in the younger Piedmont intrusive and high-grade metamorphic rocks. In general, however, because of these rocks younger age and/or metamorphic history, the degree of fracuturing and jointing is expected to be appreciably less than that of the older Piedmont rocks. Both the spacing and openness of joints and fractures seen on the surface are expected to decrease with depth due to increasing confining stresses and decreased effects of weathering (Snow, 1968).

Thus, the crystalline rocks that appear to demonstrate the most favorable hydrogeology for housing a nuclear repository within the southern Piedmont are the large, young, granitic plutonic and massive high-grade metamorphic rocks that are believed to extend to depth.

4.3 - Geotechnical

The geotechnical parameters which are considered to be of importance in assessing the overall suitability of a host rock for storage of radioactive waste include both physical and mechanical properties. The host rock should provide the following conditions to ensure the overall integrity of a waste repository:

(a) adequate rock properties to assure long-term stability of mined chambers

(b) adequate rock composition such that any alteration of the host rock caused by radiogenic heat, radiation, or air and/or water would not adversely affect repository stability

(c) adequate physical properties to assure no deterioration of the original low permeability of the rock.

Table 3 provides a general range of key physical and mechanical properties considered important in the selection of a potential host rock for exploration for radioactive waste disposal. These ranges, which are qualitatively stated and are referenced to accepted engineering parameters (Appendix A), cover a variety of rock types. These values are only intended to provide general guidelines in defining overall rock suitability. Rocks that deviate from these ranges should not necessarily be excluded from further consideration.

Generally, the mechanical properties of rocks with complex structural geology vary throughout the individual rock unit. Many of the Piedmont metamorphic rocks, including phyllites, slates and volcanic rocks, have anisotropic properties resulting from the variations in these physical-chemical properties. These rocks may exhibit low compressive strength, overall poor rock quality, locally adverse in-situ stress conditions and relatively high natural moisture content. Because of these poor qualitites, many of these rock types are expected to undergo deterioration in strength on exposure to air and these rock types were therefore generally considered unfavorable for housing a radioactive waste repository.

The most favorable Piedmont rock types that fall within the desirable ranges of physical and mechanical conditions outlined in Table 3 are the younger granites, gabbros, granodiorites and some gneisses. Many of these rocks are massive and isotropic in nature, and are of high rock quality with excellent mechanical properties for excavating and sustaining large underground openings.

4.4 - Geology

A host rock must not only be of sufficient lateral and vertical dimensions to house a repository but large enough to provide a "buffer zone" that would effectively prevent the migration of radionuclides to the biosphere. The size of a host rock body is obviously dependent on the amount of waste to be stored and the mined chamber configuration which may be dictated by the rock's physical, chemical, mechanical and thermal properties. Thus, the larger and more homogeneous the rock mass, the greater the opportunity for siting a repository within the rock mass at a sufficient distance from geologic contact zones or other discontinuities that may have relatively high permeabilities.

The vertical extent and continuity of individual rock units within the Piedmont are poorly defined. As previously stated, the intent of this study was to locate potentially favorable host rock bodies suitable for exploration for a radioactive waste repository. Thus, only those large, massive mapped rock bodies of 100 sq.km (40 square miles) and larger in size that were believed to be continuous to depths in excess of 300m (1,000 feet) were considered as favorable study areas. Smaller units, which demonstrated satisfactory geotechnical and hydrogeologic conditions, were generally eliminated from further consideration because of insufficient size for excavation for a repository and provision of a buffer zone within the same rock type. However, additional work on these small units may subsequently indicate that some of them have excellent potential for exploration.

Many of the mapped units within the Piedmont are a grouping of diversified lithologies. Some of these lithologies may meet the criteria for exploration for a waste repository; however, the areal and vertical extents of these individual lithologies are unknown. Additional work in these areas may identify additional study areas with potential for exploration.

The seismicity of the southern Piedmont was assessed (as discussed in Section 3.5) and no obvious correlation between earthquakes within the Piedmont and geologic structures or tectonic features (i.e., faults or folds) was identified. There are no known active faults within the study areas. Seismicity within the Piedmont is considered to be low to moderate with earthquakes occurring more or less randomly within the Province, and as a result, seismicity is not considered a major limiting criterion for site selection in the Piedmont. Underground structures, as contrasted to surface facilities, have additional support that minimize and dampen the impact of earthquake vibrations. No insurmountable seismic design problems are anticipated for either the mined chambers or above ground facilities. However, the seismiscity of areas close to historic epicenters must be addressed in subsequent studies.

5 - REVIEW OF POTENTIAL GEOLOGIC FIELD STUDY AREAS

5.1 - Introduction

This section contains a discussion of the methodology used in applying the criteria outlined in Section 4, to select potential study areas for radioactive waste disposal. The crystalline Piedmont rocks in Maryland, Virginia, North Carolina, South Carolina and Georgia were individually assessed as to their potential for study areas.

5.2 - Criteria Application

Due to the limited scope and large geographic area covered by this study, a consistent review, classification, and grouping of rock types within the southeast states was required.

Based on the criteria established in Section 4 for the selection of potential host rocks for radioactive waste disposal, the Piedmont rocks were grouped by their original and overall suitability as:

Igneous Plutonic
Metamorphic
Sedimentary
Volcanic and Metamorphic Volcanic

Each state was reviewed on an individual basis, since most of the geologic literature, stratigraphic nomenclature, and maps were limited by state boundaries. Each state geologic map was reproduced and used as the point of reference in defining the individual rock units or types within each state.

Different philosophies in geologic mapping were used in constructing the various geologic state maps. Maryland, Virginia and North Carolina, for the most part, classified rocks by their formation names, while the South

Carolina and Georgia maps were based on grouping of rocks by type. These variations in mapping created difficulty and, in some cases, inconsistencies in correlating rocks across state boundaries. Each individual rock formation or type within the state was tabulated and described by age, type and petrologic description (where available), and classified for its overall hydrogeologic, geologic, and geotechnical suitability, as defined by the criteria (see Section 4).

This was accomplished with the use of the following five major categories that were used for rapid classification of individual rock units:

- Hydrogeology
- Physical and Mechanical Properties
- Geology
  Unit Areal Dimension
  Structure
  Lithology

Each rock formation or type was individually assessed for its overall suitability under each of these headings and was classified as either "acceptable", "marginally acceptable", or "unacceptable" in each category. When no data was available, this fact was indicated. Classification was based on rock descriptions as found in the literature and discussions with members of the various state geological surveys.

An "acceptable" classification meant that, with currently available information, the specific rock unit appeared to demonstrate favorable properties and/or conditions for exploration for a waste repository as defined by the criteria. A "marginally acceptable" rank classified those rocks that may be found to demonstrate locally acceptable conditions following more detailed studies. As previously stated, many of the rocks in the Piedmont have been grouped by rock type rather than by formation. Since a differentiation of potentially suitable rock formations within these groups was not within the scope of this study, these rocks were generally marked as "marginally acceptable" under the lithology category and either "acceptable" or "marginally acceptable" under the lithology category and either "acceptable" or "marginally acceptable" under the Unit Areal Dimension category depending on the general rock description and its areal extent. Rocks that were subjected to multiple periods of deformation and metamorphism and described as being fractured were generally ranked as "unacceptable" under the structure category. The age, type, and general history of a rock unit was individually assessed in defining the rock's ranking under the hydrogeology and physical and mechanical properties categories. The scope of this study was to grossly categorize and identify potential field study areas. Thus, subsequent field studies may well identify locally "unacceptable" properties and/or conditions within an "acceptable" ranked unit, or vice versa.

Upon completion of categorizing each individual rock unit within a state, the amount, type, and impact of the "marginally" and "unacceptable" condition(s) were individually assessed and each rock unit was classified overall as either "favorable", "potentially favorable" or "unfavorable". Those rocks classified as "favorable" were considered to indicate the highest potential for finding a suitable rock mass within the rock body. Those rocks that were classified as "potentially favorable" were those rocks that appeared to indicate acceptable properties and/or conditions; however, extensive time and effort would be required to locate suitable study areas within these units. For this reason these rocks were considered to provide a lower degree of confidence for locating a study area than the "favorable" units. Those rocks that were considered totally unsuited were classified as "unfavorable".

The categories having the greatest impact on defining the overall favorability of a rock was its Unit Areal Dimension and Hydrogeology. Many otherwise suitable rocks not having sufficient surface areal size, as defined by the criteria, were given an "unfavorable" ranking. Supplemental information may show these rocks to increase in area with depth which could change their overall classification to a "favorable" ranking. Rocks described as being highly fractured and deformed were generally ranked "unfavorable" for hydrogeologic conditions.

In the case where a rock ranked as "favorable" was mapped in more than one area of a state, then only those rock bodies meeting the 100 sq. km (40 square miles) areal dimension criterion were selected for field study areas unless the body was in contact with other "favorable" or "marginally favorable" rock units.

Rock units of this size were considered to provide:

- a higher degree of confidence that the rock was continuous to depths in excess of 300 m (1,000 feet),
- a sufficient area for potential repository(ies), and,
- sufficient area for an adequate buffer zone between a proposed repository and the contact zones.

5.3 - Maryland

5.3.1 - General Geology

The Maryland Piedmont extends from the Coastal Plain westward to the Blue Ridge, a distance of approximately 65 km (40 miles). The stratigraphic sequence of the Maryland Piedmont consists of the Precambrian (>600 million years ago) basement (Baltimore Gneiss) which is overlain by the metamorphosed stratified rocks of the Glenarm series, a sequence of late Precambrian schists, gneisses, marbles and metagraywackes of the Setters Quartzite and Cockeysville Marble and the Wissahickon formations. Mapping the Glenarm rocks is difficult because of their complex sedimentary facies relationships, variable metamorphic grade, intense and repeated deformation, and the lack of distinctive lithologic units (Fisher, 1970). The sedimentary sequence of the Maryland Piedmont rocks reflect a long and complex history of sedimentary depostion. Mapping of structures along the Potomac (Fisher 1970) reveals a complex history of deformation with evidence of syndeposition and post-deposition folding interspersed with periods of metamorphism.

Across the Maryland Piedmont, the grade of regional metamorphism changes progressively, from the chlorite zone in the west to the kyanite and sillimanite zones in the east. There is also a varied assemblage of plutonic rocks, consisting of ultramafic and gabbroic rocks, as well as a wide range of granitic rocks (Hopson, 1964). The southeast section of the Maryland Piedmont is made up of gneisses, quartzites, schists, and granites or mafic rocks, while the northwest is underlain by phyllites, slates and much less altered formations. Unaltered Triassic rocks crop out along the bend in the Potomac River in the vicinity of Rushville, Maryland.

5.3.2 - Potential Field Study Areas

Based on the criteria presented in Section 4, Maryland Piedmont rock units were evaluated for potential field study areas (see Table 4) and are shown on the State Geologic Map, Plate 6.

Because of the inadequate areal dimensions and/or complex metamorphic and structural history of the rock units, no "favorable" study areas were found within the State of Maryland. Several "potentially favorable" study areas that were identified include:

- Sykesville Boulder Gneiss (wbg)
- Baltimore Gneiss (p€bg)
- Woodstock Quartz Monzonite (Pzw)
- Baltimore Gabbro Complex (bgb)

Although the Woodstock was considered insufficient in areal dimensions, it was included as "potentially favorable" because of its immediate proximity to the larger Baltimore Gneiss formation.

The Sykesville Formation (wbg) extends in a broad belt from the southeastern corner of Carroll County into east-central Montgomery County. The rock consists of a heterogeneous group of pebble-and-boulder-bearing arenaceous to pelitic metamorphic rocks (Hopson, 1964). The rock ranges from a medium-grained weakly gneissic granite to a nearly massive rock that resembles dark, impure quartzite. Foliations range from very weak to strong. Large inclusions of metagraywackes, mica schist, amphibolites, calc-silicates, ultramafics, and gneisses to granites are found within the rock mass.

The Baltimore Gneiss (p€bg), which is the oldest rock in the Maryland Piedmont, crops out in seven anticlinal domes and along the Coastal Plain (see Plate 6). The Baltimore Gneiss rocks include a wide variety of rocks of varying ages and origins. It is a complex assemblage of quartzo-feldspathic gneisses, amphibolites, migmatites, and gneissic granitic rocks and is extremely varied in texture and structure (Hopson, 1964).

The Woodstock Quartz Monzonite (Pzw) is a very small oval intrusive stock of massive biotite quartz monzonite which intrudes the center of a Baltimore Gneiss dome (see Plate 6). Quarrying operations show a well-developed horizontal sheet structure and vertical near-surface jointing. The rock has a well-developed hypidiomorphic granular texture showing the normal magmatic crystallization sequence (Hopson, 1964).

The Baltimore Gabbro Complex (bgb) is a large mass of mafic and ultramafic rock that crops out in the western part of Baltimore City and adjacent parts of Baltimore County and extends southward into Howard County. Hopson (1964) interprets the Baltimore Gabbro as an intrusion of magma at the earliest stage of orogeny which was subsequently caught up in compressional folding, gneiss doming and regional metamorphism during the late stages of its crystallization. Recent theory is that the Baltimore Gabbro was emplaced on multiple thrust slices. The thickness of the unit is unknown, but if the thrusting hypothesis is correct, the rock may not be of sufficient thickness to meet the criteria for a radioactive repository.

As is the case with the majority of the Piedmont rocks, there is no information concerning the deep hydrogeologic regime of these rock units. Based on their history and origin, it is expected that they are continuous to depths of 300-1200m (1,000 to 4,000 feet). Additional studies and investigations may identify suitable portions of these units as being potentially favorable for further study.

No other Maryland Piedmont rocks warranted further consideration because of their limited areal extent or adverse chemical, physical, structural or lithologic properties.

5.4 - Virginia

5.4.1 - General Geology

The Virginia Piedmont lies within the middle of the State and ranges in width from 50 km (30 miles) at the Virginia-Maryland border to nearly 320 km (200 miles) at the Virginia-North Carolina border. The Piedmont is bounded on the east by the Coastal Plain and on the west by the Virginia Blue Ridge Complex, a series of Precambrian (>600 million years ago) granites and gneisses. The Piedmont includes a diverse assemblage of Paleozoic (600-230 million years ago) granites, granodiorites, augen-gneisses, granite gneisses and metamorphic rocks consisting of schists, slates, phyllites, quartzites, marbles, metamorphosed arkoses and conglomerates, greenstones, diorites and gabbros, with metamorphosed volcanic rocks. Cutting all of these rocks are a series of Triassic age (200 million years ago) basins which generally trend along the regional structure, northeast-southwest.

Like the remainder of the southern Piedmont, the Virginia Piedmont has experienced a complex series of tectonic and metamorphic activity which commenced in the Precambrian and continued through the Mesozoic.

Normal faults are found in association with the Triassic basins throughout the Virginia Piedmont, while Pre-Mesozoic thrust faulting can be found along the Piedmont-Blue Ridge Complex. None of these faults are considered active. However, any fault located in proximity to a "favorable" study area should be investigated to define its local effects on the groundwater regime.

5.4.2 - Potential Field Study Area

Based on the criteria presented in Section 4, Virginia Piedmont rock units were evaluated for potential field study areas (see Table 5) and are shown on the State Geological Map, Plate 7.

The only "favorable" study area identified in the state of Virginia was the:

Petersburg Granite (Pzpb)

The Petersburg is a large batholithic intrusive which extends from Hanover County, southward into North Carolina (Bloomer, 1939). The Petersburg intrudes amphibolite-grade metamorphosed sedimentary and volcanic rocks of uncertain age. The intrusion is bordered on the west by Triassic basins and on the east by the Coastal Plain. Lithologically, the Petersburg consists of three distinct facies; a gray to pink, medium-grained granite; a blue, relatively fine-grained facies; and a porphyritic granite. The rock is primarily composed of quartz, potassium feldspar, oligoclase and biotite. Dating of zircons from the Petersburg gives an age of approximately 330 million years ago (Wright, et al, 1975). Petrographic and field relations indicate that the Petersburg was probably only slightly affected by metamorphism indicating that it may mark a minimum age of metamorphism within the Virginia Piedmont (see Section 3.3).

Structural features within the Petersburg are vague. Three joint sets (2 horizontal and 1 vertical) have been mapped in the unit. The extent and effects of the Triassic faulting on the west side of the intrusion must be assessed in further studies of the area.

Three rock units classified as "potentially favorable" were the:

Granite gneisses (grgn)
Granites (gr)
Redoak Granite (PzpGro)

The granite gneisses (grgn) are described in the Hylas and Midlothian Quadrangles (Goodwin, 1970) as being relatively uniform, even banded, and well-foliated. In some cases the granite gneiss is integrated with dark gray, fine- to medium-grained, biotite rich, intensively foliated, schistose textured giotite gneisses. The age of these rocks may be Precambrian (>650 million years). The gneisses are jointed and in many places have well-developed foliations. Pegmatite dikes up to 1m (3 feet) width occur within the rock.

The granites (gr) of undetermined age, are described as being biotite and muscovite granite, granodiorite and quartz monzonite. This unit includes the Columbia granite. The composition of this rock type varies locally, with the unit being more massive in the northern section of the state. South of the James River, the rock becomes badly fractured and foliated (personal communications, Virginia Geological Survey).

The Redoak Granite (PzpGro) is a biotite and muscovite granite, granite gneiss with feldspar and chlorite granodiorite. These rocks are found in the south-central section of the state and extend into North Carolina. These rocks are considered "potentially favorable" if considered as part of the granites (gr) mapped in North Carolina (see Section 5.5).

The varied properties and condition of these rock bodies has warranted a classification of "potentially favorable". As previously stated, extensive time and effort would be required to locate a suitable repository locally within these rock masses.

The hydrogeology within these rock units is unknown. As in other states within the southern Piedmont, no deep wells have been drilled to define the hydrogeologic regime and/or rock mass permeability. Although many of the rock bodies are jointed, it is expected that permeability will decrease with depth.

5.5 - North Carolina

5.5.1 - General Geology

The North Carolina Piedmont covers approximately 40 percent of the State, extending from the Coastal Plain westward to the Blue Ridge, and includes the Carolina Slate Belt, the Charlotte Belt, Kings Mountain Belt and the Inner Piedmont Belt. A detailed description of these belts is presented in Section 3.2 and shown on Plate 2. In summary, the Carolina Slate Belt occupies a large part of the North Carolina Piedmont and is divided into two segments by a series of Triassic basins. The largest or western segment transects the middle part of the state, structurally trending in a northeast-southwest direction. The eastern segment, which contacts the Coastal Plain, consists of volcanic sedimentary formations composed of slates, breccias, tuffs and flows that, in places, have been intruded by granitic plutons.

The Charlotte Belt, which contacts the Carolina Slate Belt on the west, contains more granites than the other belts with abundant granitoid rocks and intrusive plutons.

Rocks of the Kings Mountain Belt, which forms an elongated section in the west central part of the state, are generally less metamorphosed than the adjacent belts and retain a remnant of their original sedimentary characteristics. These rocks are mostly quartzites, schists, conglomerates and marbles.

The western Inner Piedmont Belt is the oldest and least understood of the Piedmont Belts. The rocks of this belt have been highly metamorphosed which has made their origin, sequence and geologic history difficult to decipher.

The North Carolina Piedmont has had at least 3 periods of intrusive events; 595-520, 415-385 and 300 million years ago. The early Paleozoic intrusives (595-620 million years ago), which are found in the Inner Piedmont Belt, have been highly deformed and subjected to retrogradation from subsequent tectonic and metamorphic events. The youngest intrusive rocks (approximately 300 million years ago) have intruded the metamorphosed rocks of the Charlotte and Carolina Slate Belts (Fullagar, 1971a). These younger plutons are generally post or syn-metamorphism.

Several major faults have been mapped within the North Carolina Piedmont. These include the Jonesboro Fault, Gold Hill Fault, the Brevard Fault Zone. Other faults are inferred beneath the Coastal Plain (see Section 3.3 and Plate 3). The Jonesboro Fault is of Triassic age (180 million years ago) and forms the east side of the Triassic basin. The Gold Hill Fault is a zone of shearing and cataclasis within the Charlotte-Carolina Slate Belt that extends from North Carolina-South Carolina border northeastward for approximately 135km (80 miles).

The Brevard Fault Zone (see Plate 3), marking the boundary between the Piedmont and the Blue Ridge Province, extends for more than 520km (325 miles) with a width of 5km (3 miles). The history and movement of the fault is complex with movement probably consisting of a combination of strike-slip and thrusting.

All of these faults are Paleozoic to Mesozoic in age. Movement of these faults was believed to have terminated by the Mesozoic period. No recent seismicity is known to be associated with these structures. However, any fault located near a proposed study area should be fully investigated for its potential adverse effect on the local hydrogeologic regime.

5.5.2 - Potential Field Study Area

Based on the criteria presented in Section 4, North Carolina rock units were evaluated for potential field study areas (see Table 6) and are shown on the State Geological Map, Plate 8.

The classification of rocks on the state geologic map for North Carolina are based on rock type, rather than specific formations and units. This simplification of grouping many rock types of various ages, composition and tectonic history into one classification made specific rock unit selection difficult. The identification of "favorable" study areas within these broad groups could only be done based on general rock descriptions provided in the literature and discussions held with knowledgeable persons. Only those areas that appeared to be the most desirable for exploration and cover an area in excess of 100 sq. km (40 square miles) were classified as "favorable". All other rock types were classified as either "potentially favorable" or "unfavorable". As previously stated in Section 4, many suitable areas within "potentially favorable" areas may be found during further work.

The most favorable rock category identified in North Carolina is the igneous plutonic granites (gr). These cover a large geographic area, ranging from the Coastal Plan to the Blue Ridge. Within this category are three plutonic bodies which were considered as "favorable" study areas. These were the:

Rolesville Batholith
Churchland Pluton
Landis Pluton

The Rolesville Batholith covers an area of approximately 1700 square km (650 square miles) (Butler and Ragland, 1969) east of Raleigh in the eastern Piedmont of north-central North Carolina. The majority of the batholith is comprised of a medium- to coarse-grained, foliated granite. The northeast side of the batholith is generally unfoliated, coarse-grained quartz monzonite constituting a nearly separate lobe, called the Castalia Pluton (Becker and Farrar, 1977). The batholith has intruded metasedimentary and metavolcanic rocks of granitic gneisses, muscovite and muscovite-biotite schists. The age of the Castalia Pluton has been dated as 316$\pm$ 6 million years (Julian, 1972). Jointing is common but not excessive. Where exposed, the granite appears in either ridge or dome-shaped masses. Residual soils cover ranges from less than 1 metre to as much as 12 metres (up to 40 feet.)

The Churchland and Landis Plutons, located in the Central Piedmont Granite Belt, have been mapped by Butler and reported in Heffner and Ferguson (1978) as post metamorphic (300 million years old) intrusives (see Plate 8). These plutons are described as being coarse-grained to porphyritic in texture with ground mass consisting of feldspar, quartz, and biotite. A complex relationship exists between the granites in this area and the diorites. Detailed work would be required to accurately define the age and structural relationships within this area.

Rocks classified as "potentially favorable" study areas in North Carolina included the:

- Granites (gr) in the central and western Piedmont
- Diorite - gabbros (digb)
- Henderson Granite Gneiss (hgg)
- Granite gneiss complex (gnc)
- Whiteside Granite (wg)

The granties (gr) mapped within the central and western Piedmont of North Carolina vary in area, age, and composition. Granites exposed in the north-central part of the Piedmont have been described as being locally crushed and broken with the development of a schistose or gneissic structure extensively intruded by basic dikes (Stuckey, 1958).

Granites in the south-central North Carolina Piedmont vary in composition from granites to diorites. Many of these granites have considerable gneisses and schists in association with them and are medium to highly jointed and fractured.

The granites of the western Piedmont Belt are generally medium to fine-grained biotite granite consisting of orthoclase, plagioclase, quartz, biotite, a little muscovite, and minor accessory minerals. They vary from massive granites to gneissic and schistose rocks.

The diorite-gabbro (di gb) is confined largely to the central Piedmont and is generally associated with the granites. The rocks of this unit range locally from diorite to gabbro. The rock is coarse-textured and is distinctly massive with closely spaced joints. It is composed of hornblende or pyroxene, plagioclase, and varying amount of quartz and accessory minerals. The rock is generally covered by thick soil covers (Stuckey, 1958).

The Henderson Granite Gneiss (hgg) is an older granite gneiss found in the southwest portion of the Inner Piedmont of North Carolina. The age of this rock has been dated at 538 million years (Odom and Fullagar, 1973). The rock has pronounced gneissoid structures. Mineralogically, the rock consists of orthoclase, plagioclase, quartz, muscovite, and biotite. This unit has been greatly altered by metamorphism. Weathering of the Henderson Granite Gneiss varies widely (Stuckey, 1958).

The granite gneiss complex (gnc) is described as a medium to very coarse gneissic granite, containing mica gneiss, mica schist and hornblended gneiss. The unit also contains granite gneisses similar to the Henderson Granite Gneiss and younger granites (Stuckey, 1958).

The Whiteside Granite (wg) is exposed in the southwest portion of the Inner Piedmont. The areal extent of this unit in North Carolina does not meet the criterion for this study; however, since it extends into South Carolina, it is considered to be a "potentially favorable" study area. The granite is a light-gray, even-grained, massive rock, consisting of orthoclase, plagioclase, quartz, muscovite, biotite and minor amounts of magnetite, ilmenite, and garnet (Stuckey, 1958). The granite has intruded older rocks and appears to parallel foliations.

5.6 - South Carolina

5.6.1 - General Geology

The South Carolina Piedmont includes the western half of the state and contains over 95 percent of the crystalline rocks within the state. The Blue Ridge occupies the extreme western tip of the state and is separated from the Piedmont by the Brevard Fault Zone.

As in other southern Piedmont states, the South Carolina Piedmont is poorly understood due to a thick cover of saprolite and the scarcity of detailed geologic mapping.

The South Carolina Piedmont includes the Carolina Slate Belt, Charlotte Belt, Kings Mountain Belt and Inner Piedmont Belt. A detailed discussion of these belts is presented in Section 3.2. In summary, the eastern-most of these belts consists of the low-grade metamorphic rocks of the Carolina Slate Belt. The rocks of this belt are mostly in the muscovite-chlorite and biotite-chlorite subfacies of the greenschist facies. Large plutons, some metamorphosed and some apparently unmetamorphosed, are present in the belt. The belt extends from the Costal Plain northwestward merging with the gneisses, schists, and granitoid rocks of the Charlotte belt.

The broad Charlotte Belt extends from the Carolina Slate Belt northwestward to the Kings Mountain Belt. This belt contains more granites than the other belts. Local metamorphic grades rise to the starolite-kyanite and sillimanite-almandine subfacies of the almandine-amphibolite facies (Overstreet, 1970). The belt is also notable for its swarms of mafic dikes. The Charlotte Belt is a zone of moderate metamorphic grade between two belts of lower-grade rocks.

The Kings Mountain Belt consists of sericite schist, hornblende schist, quartzites and marbles. These rocks trend in a narrow belt through the central part of the South Carolina Piedmont.

The widest of all the belts in South Carolina is the Inner Piedmont Belt. This belt is bounded by the Kings Mountain Belt on the southeast and the Brevard Fault Zone on the northwest. The belt has a high degree of metamorphism which has made its origin, sequence and geologic history difficult to decipher.

Three episodes of igneous intrusions are recognized in the South Carolina Piedmont (Overstreet & Bell, 1965). Butler and Ragland (1969) have divided three episodes into pre-, syn-, and post-metamorphism.

The first episode, and least known, may have taken place in either late Precambrian or Cambrian time (595-520 million years ago). The second, and strongest, probably occurred during the Silurian (415-385 million years ago), occurring pre- and syn-late stage metamorphism, and the third and last episode probably occurred during the Carboniferous (300-250 million years ago). The rocks of most interest for this study are the granitic intrusions of the last episodes. These are, for the most part, large felsic plutons, circular to oval in plan and found in the Carolina Slate and Charlotte Belts.

The South Carolina Piedmont has been deformed into a series of synclinoria and anticlinoria, trending in a general northeastsouthwest direction. The province is cut by several major fault systems to include the Brevard Zone, Towaliga and Goat Rock and Gold Hill Faults, as well as the several recently mapped faults along the Fall Line and beneath the Coastal Plain. A description of these faults is presented in Section 3.4 and shown on Plate 3.

5.6.2 - Potential Field Study Areas

Based on the criteria presented in Section 4, the South Carolina Piedmont rock units were evaluated for potential field study areas (see Table 7) and are shown on the State Geological Map Plate 9.

As stated in Section 5.2, the South Carolina geological map was based on grouping of rock type rather than by formation or units, which posed some difficulties in identifying specific "favorable" and "potentially favorable" rock bodies (i.e. plutons) within the rock types.

Based on a literature survey and discussions with knowledgeable persons, three igneous plutons were identified as "favorable" study areas in South Carolina. These were the:

- Liberty Hill Pluton
- Winnsboro Complex
- Ogden Pluton

The Liberty Hill Pluton (Plate 9) which lies in north-central South Carolina in Kershaw, Lancaster and Fairfield Counties, has been dated at approximately 300 million years old (Fullagar, 1971a). The pluton, which appears to be post metamorphic in origin, has 3 textural phases: a very coarse biotite-amphibole granite and quartz monzonite, a porphyritic border phase, and a fine-to-medium grained biotite granite which intruded the western part of the pluton as large dikes and/or plugs (Costain, et al, 1977). This pluton intrudes rocks of the Carolina Slate Belt, forming a discordant contact with the surrounding country rock.

Magnetic modeling of the Liberty Hill Pluton performed by Dunbar and Speer (1977) is consistent with an assymetric shape tapering inward with depth. Mapping suggests that the northwest boundary of the pluton is a normal fault that may be an extension of the Wadesboro Triassic basin (Bell and Popenoe, 1976). Further investigation of this feature would be required in additional studies.

The Winnsboro Complex which has been dated at approximately 300 million years old (Fullagar, 1971a), is also considered a post metamorphic igneous intrusive. The complex consists of two plutons. The rock is a medium-to-coarse grained granite, quartz syenite and quartz monzonite. Most of the complex lies within the Charlotte Belt whereas the southern border is in contact with the Carolina Slate Belt (Wagener, 1970).

Both the Liberty Hill Pluton and the Winnsboro Complex are currently under investigation by the Department of Energy for the evaluation of geothermal energy resources in the southeastern United States (Costain, et al, 1976-1977).

The Ogden Pluton, located in the southern portion of York and northern Chester Counties, has been mapped as middle Paleozoic (413 million years ago). The age of this gabbroic igneous intrusive body suggests that it was intruded pre- or syn- the last period of metamorphism. The rock is massive and locally intruded by augite syenite and syenite pegmatite.

Rocks considered "potentially favorable" in South Carolina are:

- Yorkville and Toluca Quartz Monzonites (Py & Otm)
- Fine-grained Granite (POf) - Lowry's Pluton
- Porphyritic Granite (POp) - Lowry's Pluton
- Granitoid Gneiss (ЄpЄg)
- Henderson Gneiss (DOhg)
- Biotite Granite Gneiss (DOgg)
- Biotite Gneiss and Migmatite (DpЄm)
- Cherryville Quartz Monzonite (PMcq)

The Yorkville and Toluca Quartz Monzonites (Py & Otm) are Paleozoic age porphyritic, massive to gneissic biotite quartz monzonites with the Toluca being garnetiferous. These rocks crop out in the north and north-central parts of the South Carolina Piedmont belt. Normally these rocks would have been classified as "unfavorable" because of their small area extent; however, due to their proximity to other potentially suitable rock types, they have been given a "potentially favorable" ranking.

The fine-grained granite (POf) and the porphyritic granite (POp) are massive, biotite granites, biotite-muscovite granites, quartz monzonites and porphyritic granites. These rocks crop out in a northeast-southwest trend within the Charlotte Belt. The rocks include several of the older (pre-metamorphic) plutons dated around 400 million years old (Wright, et al, 1975).

The granitoid gneiss (ЄpЄg) is a Cambrian group of undifferentiated granitoid gneisses, gneissic granodiorites, gneissic granites, biotite-muscovite schists and biotite-muscovite gneisses. This rock type includes a wide assemblage of rocks comprising the Charlotte and Carolina Slate Belts. Because of the diversified grouping of these rocks, extensive work would be required if locating suitable host rock bodies within this rock group.

The Henderson Gneiss (DOhg), Biotite Granite Gneiss (DOgg) and the Biotite Gneiss and Migmatite (DpЄm) are varying granitic and gneissic rock types found within the Inner Piedmont Belt. These rocks have been subjected to high-grade metamorphism and multiple deformation causing a wide variation in chemical composition and structure.

5.7 - Georgia

5.7.1 - General Geology

The Georgia Piedmont is a wide belt of metamorphic and igneous rocks which trend in a northeast-southwest direction across the northwest portion of the state. The province, as defined in this study, is bounded on the west by the Brevard Zone and on the east and southeast by the Fall Line (see Plate 2). The Province includes portions of the Inner Piedmont, Charlotte and Carolina Slate Belts (see Section 3.2).

These rocks have been subjected to at least two periods of metamorphism. The metamorphic grade is low on the west and rises rapidly towards the southeast, remaining high all the way to the Fall Line.

Potassium/Argon age dates on the metamorphic rocks give ages of 250 million years, which appears to be the date of the last regional metamorphic event. Dates on rocks further to the west, which were less affected by the last metamorphism, tend to show older ages.

The Georgia Piedmont is cut by several major faults. These include the Brevard Zone, Towaliga Fault, and Goat Rock Fault (Plate 3). These faults are discussed in detail in Section 3.3. In summary, the Brevard Zone is traceable for more than 520 km (325 miles) with a width generally less than 5 km (3 miles). The zone has had a long and complicated history with movement along the zone starting during the early Paleozoic (500 million years ago) and continuing through the middle Paleozoic (390 million years ago). The type of movement along the zone has been argued as being either strike-slip, thrusting, or a combination of both. Undisturbed Mesozoic age (200 million years ago) dikes which cross-cut the zone date its last known period of movement.

The Towaliga Fault dips to the northwest while the Goat Rock Fault dips to the southeast. These fault zones are traceable across Georgia, eventually disappearing beneath the Coastal Plain in Alabama. The apparent line of continuance of these faults suggests their last movement was post-metamorphic.

The Georgia Piedmont has had at least three periods of volcanism:

(1) pre-Mesozoic (>230 million years ago)
(2) Triassic or Jurassic (230-140 million years ago) and
(3) Upper Cretaceous or Lower Tertiary (85-50 million years ago) (Hurst, 1970).

The pre-Mesozoic metavolcanics consist mainly of mestabasalts and metadacites and dikes ranging in composition from rhyolite to gabbro. This intrusive series was regionally metamorphosed towards the close of the Paleozoic (250 million years ago). The Triassic and Jurassic rocks are diabase dikes and possibly granophyric porphyries and hornblende andesites. These have not been metamorphosed.

5.7.2 - Potential Field Study Areas

Based on the criteria presented in Section 4, the Georgia Piedmont rock units were evaluated for potential field study areas (see Table 8), and are shown on the State Geological Map, Plate 10.

As was the case in South Carolina, the Georgia geological map was based on grouping of rocks by type rather than by formation. This posed some difficulty in identifying "favorable" and "potentially favorable" rock bodies within the rock type and correlating rock units across state boundaries.

The most "favorable" geological field study areas in Georgia are the:

- Siloam Pluton (gr1b)
- Elberton Pluton (gr2a)
- Other igneous granitic rock bodies (gr1, gr2, gr1a, gr1b)

These rocks are classified on the state geological map as undifferentiated granites, biotite granites and porphyritic and non-porphyritic granites. For the most part these rocks are pre-metamorphic or syn-metamorphic intrusive plutonic granites which have been intruded into older schists and metamorphic rocks.

The Elberton Pluton (gr2a), located in Oglethorpe and Elbert Counties, is described as a medium-grained light-gray granite, with its structure varying from gneissoid biotitic to massive. There are few data on this granite body; however, Rb-Sr dates on nearby plutons give ages of approximately 270-300 million years (Jones and Walker, 1973).

The Siloam Pluton (grlb) located in Greene County, is described as a medium-coarse-grained, light-gray granite (Watson, 1902). The pluton has been dated at 269± 3 million years old (Jones and Walker, 1973).

The granite in Warren and Hancock Counties (Sparta Pluton) is a coarse-grained porphyritic granite. Dates on this rock give ages of 535± 25 million years (Fullagar, 1971a).

Other "favorable" rock bodies are unnamed granite rocks in Douglas, Coweta, Spalding, Meriwether, Pike, Troup, Wikes, and Lincoln Counties (see Plate 10). These bodies have been designated as "favorable" study areas because of their large apparent massive structure and composition. Subsequent studies may show several of these older rock bodies to be severely altered and deformed by tectonic events giving them unfavorable hydrogeologic, mechanical and physical rock properties.

The "potentially favorable" rocks identified in the State of Georgia include a wide assemblage of the high-grade metamorphic granites and gneisses. The Georgia geologic map groups these rocks into three major categories:

- Granite gneiss (ggl, gg3-6) - undifferentiated, muscovite, amphibolite and calc-silicate granite gneisses and granite gneiss/granite

- Gneiss (fgl-4) - biotite, biotite-hornblende with amphibolite, undifferentiated, biotite with mica schist-amphibolite and biotite with amphibolite gneisses.

- Gneiss (bgl-4) - biotite, biotite-amphibolite, biotite-hornblende-granite and biotite with mica schist gneisses.

As stated in Section 4, these rocks may locally offer acceptable rock properties and conditions as a host rock for a radioactive waste repository; however, extensive time and effort would be needed to locate and evaluate a suitable rock mass within these bodies.

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TABLES

TABLE 1

MODIFIED MERCALLI (MM) EARTHQUAKE INTENSITY SCALE (abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings. Standing motor cars may rock slightly.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed. Standing motor cars rocked noticeably.

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; unstable objects overturned. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction. Shock noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings; great in poorly built structures. Fall of chimneys, stacks, columns. Persons driving motor cars disturbed.

IX. Damage considerable even in specially designed structures; well-designed frame structures thrown out of plumb. Buildings shift off foundations. Ground cracked conspicuously.

X. Some well-built wooden structures destroyed; ground badly cracked; rails bent. Landslides and shifting of sand and mud.

XI. Few if any (masonry) structures remain standing. Broad fissures in ground.

XII. Damage total. Waves seen on ground surface.

TABLE 2

EARTHQUAKE INTENSITIES OF V AND GREATER - SOUTHEAST UNITED STATES

No.	Year	Month	Day	Lat.	Long.	Epicenter Intensity (MM)
1	1758	04	25	38.900N	076.500W	V
2	1774	02	21	37.200N	077.400W	VII
3	1827	08	07	38.300N	085.800W	VI
4	1844	11	28	36.000N	084.000W	VI
5	1852	04	29	36.600N	081.600W	VI
6	1855	02	02	37.000N	078.600W	V
7	1857	12	19	32.900N	080.000W	V
8	1871	10	09	39.700N	075.500W	VII
9	1872	06	17	33.100N	083.300W	V
10	1874	02	10	35.700N	082.100W	V
11	1874	04	17	35.700N	082.100W	V
12	1875	06	18	40.200N	084.000W	VII
13	1875	11	02	33.800N	082.500W	VI
14	1875	12	23	37.600N	078.500W	VII
15	1877	11	16	35.500N	084.000W	V
16	1879	03	26	39.200N	075.500W	V
17	1879	12	13	35.200N	080.800W	V
18	1882	02	09	40.600N	084.200W	V
19	1883	03	11	39.500N	076.400W	V
20	1883	03	12	39.500N	076.400W	V
21	1884	01	18	34.300N	078.000W	V
22	1884	09	19	40.700N	084.100W	VI
23	1885	01	03	39.200N	077.500W	V
24	1885	08	06	36.200N	081.600W	V
25	1885	10	10	37.700N	078.800W	VI
26	1886	09	01	32.900N	080.000W	
27	1886	10	22	32.900N	080.000W	VI
28	1886	10	22	32.900N	080.000W	VII
29	1886	11	05	32.900N	080.000W	VI
30	1889	03	08	40.000N	076.000W	V
31	1897	05	03	37.100N	080.700W	VI
32	1897	05	31	37.300N	080.700W	VIII
33	1897	10	22	37.000N	081.000W	V
34	1897	12	18	37.700N	077.500W	V
35	1898	02	05	37.000N	080.700W	VI

TABLE 2 (Cont'd)

No.	Year	Month	Day	Lat.	Long.	Epicenter Intensity (MM)
36	1899	02	13	37.000N	081.000W	V
37	1899	04	30	38.500N	087.000W	VII
38	1901	05	17	39.300N	082.500W	V
39	1902	05	29	35.100N	085.300W	V
40	1902	10	18	35.000N	085.300W	V
41	1903	01	24	32.100N	081.100W	VI
42	1904	03	05	35.700N	083.500W	V
43	1905	01	27	34.000N	086.000W	VII
44	1905	01	28	34.000N	086.000W	VII
45	1906	05	08	38.700N	075.700W	V
46	1907	02	11	37.700N	078.400W	VI
47	1907	04	19	32.900N	080.000W	V
48	1908	05	31	40.600N	075.500W	VI
49	1908	08	23	37.500N	077.900W	V
50	1909	04	02	39.400N	078.000W	VI
51	1910	05	08	37.700N	078.400W	V
52	1911	04	20	35.200N	082.700W	V
53	1912	06	12	33.000N	080.200W	VII
54	1912	06	20	32.000N	081.000W	V
55	1913	01	01	34.700N	081.700W	VII
56	1913	03	28	36.200N	083.700W	VII
57	1913	04	17	35.300N	084.200W	V
58	1914	01	24	35.600N	084.500W	V
59	1914	03	05	33.500N	083.500W	VI
60	1914	09	22	33.000N	080.200W	V
61	1915	10	29	35.800N	082.700W	V
62	1916	02	21	35.500N	082.500W	VI
63	1916	08	26	36.000N	081.000W	V
64	1916	10	18	33.500N	086.200W	VII
65	1917	06	29	32.700N	087.500W	V
66	1918	04	10	38.700N	078.400W	VI
67	1918	06	22	36.100N	084.100W	V
68	1919	09	06	38.800N	078.200W	VI
69	1920	12	24	36.000N	085.000W	V
70	1921	01	26	40.000N	075.000W	V

TABLE 2 (Cont'd)

No.	Year	Month	Day	Lat.	Long.	Epicenter Intensity (MM)
71	1921	08	07	37.800N	078.400W	V
72	1924	10	20	35.000N	082.600W	V
73	1924	12	26	37.300N	079.900W	V
74	1926	07	08	35.900N	082.100W	VI
75	1926	11	05	39.100N	082.100W	VII
76	1927	06	10	38.000N	079.000W	V
77	1927	06	16	34.700N	086.000W	V
78	1928	03	07	35.600N	086.900W	
79	1928	10	30	37.500N	077.500W	
80	1928	11	03	36.000N	082.600W	VI
81	1929	01	03	33.900N	080.300W	
82	1929	03	08	40.300N	084.200W	
83	1929	10	28	34.300N	082.400W	
84	1929	12	27	38.100N	078.500W	VI
85	1930	06	26	40.500N	084.000W	
86	1930	07	11	40.700N	083.200W	
87	1930	08	30	35.900N	084.400W	
88	1930	09	03	33.000N	080.200W	
89	1930	09	15	37.500N	077.500W	
90	1930	09	29	40.300N	084.200W	
91	1930	10	16	36.000N	084.000W	
92	1930	11	01	39.200N	076.500W	
93	1930	12	01	33.400N	087.000W	
94	1930	12	10	34.300N	082.400W	
95	1931	05	05	33.700N	086.600W	V-VI
96	1931	09	20	40.400N	084.200W	VII
97	1933	12	19	33.000N	080.200W	IV-V
98	1935	01	01	35.116N	083.633W	V
99	1937	03	02	40.400N	084.200W	VII
*100	1937	03	09	40.400N	084.200W	VIII
101	1938	07	15	40.366N	078.233W	VI
102	1939	05	05	33.700N	085.800W	V
103	1939	11	15	39.600N	075.200W	V
104	1939	11	18	39.500N	076.500W	
105	1945	06	13	35.000N	084.500W	V

*Instrumentally Located

TABLE 2 (Cont'd)

No.	Year	Month	Day	Lat.	Long.	Epicenter Intensity (MM)
*106	1945	07	26	34.500N	081.500W	V
107	1952	06	20	39.750N	082.250W	VI
108	1952	11	19	32.800N	080.000W	V
109	1954	01	22	35.300N	084.400W	V
110	1956	09	07	35.500N	084.000W	VI
111	1957	04	23	34.500N	086.750W	VI
112	1957	05	13	35.700N	082.000W	VI
113	1957	06	23	36.500N	084.500W	V
114	1957	07	02	35.500N	083.500W	VI
115	1957	11	24	35.500N	083.500W	VI
116	1958	03	05	34.200N	077.700W	V
117	1958	10	20	34.500N	082.700W	V
118	1958	10	23	37.500N	082.500W	
119	1959	04	23	37.500N	080.500W	VI
120	1959	08	03	33.000N	079.500W	VI
121	1959	08	12	35.000N	087.000W	VI
122	1959	10	26	34.500N	080.200W	VI
123	1960	03	12	33.000N	079.000W	V
124	1960	04	15	35.700N	084.000W	V
125	1960	07	23	33.000N	080.000W	V
126	1962	09	07	39.700N	078.200W	V
127	1963	05	04	32.200N	079.700W	IV
128	1963	10	10	39.800N	078.200W	
129	1963	10	28	36.700N	081.000W	V
130	1963	12	05	37.200N	087.000W	
131	1964	02	13	40.500N	077.900W	
*132	1964	02	18	34.800N	085.500W	V
*133	1964	03	13	33.200N	083.400W	V
*134	1964	05	12	40.200N	076.500W	VI
*135	1964	11	25	37.400N	081.500W	
136	1965	04	26	37.300N	081.600W	
137	1965	09	08	34.700N	081.200W	
138	1965	09	09	34.700N	081.200W	
139	1965	09	10	34.700N	081.200W	
140	1965	09	12	34.700N	081.200W	

*Instrumentally Located

TABLE 2 (Cont'd)

No.	Year	Month	Day	Lat.	Long.	Epicenter Intensity (MM)
*141	1966	05	31	37.600N	078.000W	V
*142	1967	04	08	39.555N	082.489W	V
*143	1967	10	23	33.400N	080.700W	
*144	1967	12	16	37.400N	081.600W	
*145	1968	03	08	37.280N	080.840W	IV
*146	1968	09	22	34.000N	081.500W	IV
147	1969	05	22	39.694N	078.192W	
148	1969	11	19	37.400N	081.000W	VI
*149	1969	11	20	37.400N	081.000W	VI
150	1969	12	11	37.800N	077.400W	V
151	1969	12	13	35.100N	083.000W	V
152	1970	05	27	39.650N	078.157W	
*153	1970	07	30	37.012N	082.248W	
*154	1970	07	30	37.012N	082.248W	
155	1970	08	11	38.400N	082.300W	IV
156	1970	09	10	36.100N	081.400W	V
157	1971	02	18	39.662N	078.212W	
158	1971	02	19	37.128N	083.249W	
159	1971	03	05	40.623N	078.167W	
160	1971	04	01	37.365N	081.629W	
*161	1971	05	19	33.339N	080.558W	V
162	1971	07	31	33.370N	080.659W	III
163	1971	09	12	38.073N	077.444W	V
*164	1971	10	09	35.862N	083.468W	V
165	1972	01	09	37.357N	081.604W	
*166	1972	02	03	33.476N	080.434W	V
167	1972	05	20	37.014N	082.241W	
168	1972	12	08	40.145N	076.223W	IV
*169	1973	02	28	39.718N	075.441W	VI
*170	1973	10	30	35.750N	084.000W	V
*171	1973	11	30	35.799N	083.962W	VI
172	1973	12	19	32.983N	080.260W	
*173	1974	03	23	38.917N	077.780W	
*174	1974	04	27	41.004N	075.955W	
*175	1974	05	30	37.382N	080.419W	V

*Instrumentally Located

TABLE 2 (Cont'd)

No.	Year	Month	Day	Lat.	Long.	Epicenter Intensity (MM)
*176	1974	06	05	38.600N	084.770W	
*177	1974	08	02	33.872N	082.488W	V
*178	1974	10	20	39.095N	081.593W	V
*179	1974	10	28	33.790N	081.920W	IV
*180	1974	11	05	33.730N	082.220W	III
*181	1974	11	22	32.900N	080.145W	VI
*182	1974	12	03	33.950N	082.500W	III
*183	1975	02	16	39.050N	082.422W	
*184	1975	05	02	35.921N	084.446W	III
*185	1975	05	14	35.947N	085.249W	
*186	1975	08	29	33.820N	086.600W	VI
*187	1975	11	11	37.193N	080.839W	IV
188	1975	11	16	34.258N	080.567W	
*189	1975	11	25	34.873N	082.958W	IV
*190	1976	01	19	36.883N	083.825W	VI
*191	1976	01	30	39.683N	078.170W	
192	1976	02	04	35.004N	084.752W	VI
*193	1976	06	19	37.362N	081.624W	
194	1976	07	03	37.217N	081.095W	
*195	1976	09	13	36.604N	080.810W	VI
*196	1976	12	27	32.223N	082.463W	V
*197	1977	01	18	33.069N	080.199W	
*198	1977	02	27	37.897N	078.628W	V
*199	1977	05	31	32.951N	080.244W	
*200	1977	06	17	40.707N	084.582W	VI

*Instrumentally Located

Data Obtained From:

Earthquake Data Center
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Boulder, Colorado

Duke Power Company
Preliminary Safety Analysis Report - Catawba Station
(Docket # 50-413)

TABLE 3

PHYSICAL AND MECHANICAL ROCK PROPERTIES

(a) Physical and Mechanical Properties and Conditions	Desirable Range
(1) Compressive Strength	Medium to very high*
(2) Modulus of Elasticity	Medium to high*
(3) Rock Quality	Good to excellent**
(4) Rock Material Strength	Strong to very strong*
(5) Joint Spacing	Wide to very wide**
(6) In-situ Stresses	Very low to low tectonic residual stresses at 300 to 1200 m (1,000-4,000 feet) depths, respectively*** (Horizontal stresses up to 1.5 times the vertical stresses).

* Related to stability of underground chamber.

** Related to permeability, stability and support requirements of underground chamber. Should require minimal support to eliminate long-term dependence on artificial support systems.

*** Related to post-mining stress level which must be less than the strength of the rock for stability of chamber.

(a) Refer to Appendix A for more details of desirable ranges.

TABLE 4 SHEET 1 OF 5

GEOLOGICAL REVIEW OF ROCK UNITS -
MARYLAND
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
O = Marginally Acceptable
U = Unacceptable
- = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Rock Properties & Conditions: Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Rock Unit Classification: Potentially Favorable	Rock Unit Classification: Unfavorable	Remarks
IGNEOUS PLUTONIC ROCKS											
Pzp	Pegmatite Dikes	Paleo.: Quartz-Albite-microcline-perthite - muscovite granite pegmatites associated with gneiss domes	-	-	U	U	U			X	
Pzg	Guilford Quartz Monzonite	Paleo.: Biotite-muscovite-quartz monzonite; occurs as discontinuous lenticular bodies	-	O	U	O	O			X	
Pze	Ellicott City Granodiorite	Paleo.: Ranges from biotite granodiorite along margin of body to quartz monzonite in core	-	O	U	O	O			X	
Pzw	Woodstock Quartz Monzonite	Paleo.: Massive biotite-quartz monzonite	-	#	U	#	#		X		
gm	Georgetown Mafic Complex	Late Paleo. to Late Precamb.: Poorly exposed complex of tonalite, quartz diorite, gabbro, amphibolite, and undifferentiated basic rocks	-	-	U	U	U			X	
bgb	Baltimore Gabbro Complex	Early Paleo. to Late Precamb.: Hypersthene gabbro with subordinate amount of olivine gabbro, norite, anorthositic gabbro and pyroxenite; slightly to moderately deformed	-	O	#	O	O		X		
METAMORPHIC ROCKS											
Pzpd	Port Deposit Gneiss	Paleo.: Moderately to strongly deformed intrusive complex composed of gneissic biotite-quartz diorite, hornblende-biotite quartz diorite, and biotite granodiorite; all rocks foliated and some strongly sheared	-	-	U	U	U			X	
Pzgg	Gunpowder Granite	Paleo.: Remobilized Baltimore gneiss; quartz monzonite with biotite schlieren	-	-	U	U	U			X	

TABLE 4 SHEET 2 OF 5

GEOLOGICAL REVIEW OF ROCK UNITS –
MARYLAND
PIEDMONT PROVINCE

LEGEND:

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SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions		Geology			Rock Unit Classification			
			Hydrogeology	Physical & Mechanical Prop.	Areal Dimension	Structure	Lithology	Favorable	Potentially Favorable	Unfavorable	Remarks
METAMORPHIC ROCKS (Cont'd)											
Pzgd	Quartz Gabbro and Quartz Diorite Gneiss	Paleo.: Mixed rock zone of uralitized, quartz bearing gabbro to weakly gneissic pyroxene-hornblende-biotite quartz diorite	–	–	U	U	U			X	
Pzn	Norbeck Quartz Diorite	Paleo.: Ranges from weakly foliated quartz diorite to strongly gneissic and schistose rock with recrystallized textures	–	#	U	#	#			X	
Pzk	Kensington Quartz Diorite	Paleo.: Moderately to strongly deformed; igneous textures generally destroyed; ranges from quartz diorite to granodiorite; comprises thin concordant sheets or wedges along plunging crest of Baltimore anticlinorium	–	–	U	O	U			X	
Pzmg	Muscovite Quartz Monzonite Gneiss	Paleo.: Well foliated to nearly massive quartz monzonite gneiss; generally even textured but locally porphyritic	–	–	U	U	–			X	
um	Ultramafic Rocks	Early Paleo. to Late Precamb.: Chiefly serpentinite with partly to completely altered dunite, peridotite, pyroxinite, and massive to schistose soapstone; talc-carbonate rock and altered gabbro are common	–	U	U	U	U			X	
ug	Ultramafic and Gabbroic Rocks	Early Paleo.: Mixed metagabbro, serpentinite, metapyroxinite, and actinolite-, chlorite-, and epidote-bearing schists	–	U	U	U	U			X	
mgb	Metagabbro and Amphibolite	Early Paleo.: Weakly to strongly lineated metagabbro and epidote amphibolite	–	–	U	U	U			X	
uf	Urbana Formation	Late Precamb.: Sericite-chlorite phyllite, metasiltstone, and quartzite; thin lenses of impure marble and calcareous phyllite occur locally	–	U	U	U	U			X	

TABLE 4 SHEET 3 OF 5

GEOLOGICAL REVIEW OF ROCK UNITS - MARYLAND
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
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SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Structure	Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
METAMORPHIC ROCKS (Cont'd)											
sq	Sugarloaf Mountain Quartzite	Late Precamb.: Massive quartzite interbedded with softer sericitic quartzite, slate, and phyllite	-	-	U	U	U			X	
wm	Wakefield Marble	Late Precamb.: Marble	-	U	U	U	U			X	
if	Ijamsville Formation	Late Precamb.: Phyllite and phyllitic slate, with interbedded metasiltstones and metagraywackes; pumaceous blebs locally	-	U	U	U	U			X	
ms	Marburg Schist	Late Precamb.: Muscovite -chlorite-albite-quartz schist; intensely cleaved and closely folded; contains interbedded quartzites	U	U	U	U	U			X	
wu	Wissahickon Formation (undivided)	Late Precamb.: Muscovite-chlorite-albite schists, muscovite-chlorite schist, chloritoid schist, and quartzite, intensely folded and cleaved	U	U	U	U	U			X	
wups	Upper Pelitic Schist (Wissahickon Fm)	Late Precamb.: Albite-chlorite-muscovite-quartz schist with sporadic thin beds of laminated micaceous quartzite	-	-	U	U	U			X	
wmg	Metagraywacke (Wissahickon Fm)	Late Precamb.: Rhythmically interbedded chlorite-muscovite graywacke and chlorite-muscovite schist	-	U	U	U	U			X	
wbg	Sykesville Boulder Gneiss (Wissahickon Fm)	Late Precamb.: Thick bedded to massive, pebble and boulder bearing, arenaceous to pelitic, metamorphic rock; typically a garnet-oligoclase-mica-quartz gneiss; locally an intensely foliated gneiss or schist	-	O	#	O	O		X		
wlps	Lower Pelitic Schist (Wissahickon Fm)	Late Precamb.: Biotite-oligoclase-muscovite-quartz schist with garnet, staurolite, and kyanite; some semipelitic schist and weakly schistose psammitic granulite	-	U	U	U	U			X	
cm	Cockeysville Marble	Late Precamb.: Metadolomite, calc-schist, and calcite marble are predominent; gneiss and calc-silicate marble widespread but minor	-	U	U	U	U			X	

TABLE 4 SHEET 4 OF 5

GEOLOGICAL REVIEW OF ROCK UNITS - MARYLAND
PIEDMONT PROVINCE

LEGEND:

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SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Structure	Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
METAMORPHIC ROCKS (Cont'd)											
sf	Setters Formation	Late Precamb.: Upper member: Feldspathic mica schist and mica gneiss; Middle member: Impure quartzite interstratified with thin beds of mica schist; Lower member: Feldspathic mica schist; locally granitized	-	U	U	U	U			X	
p€bq	Baltimore Gneiss	Precamb.: Biotite-quartz-feldspar gneiss and biotite-hornblende gneiss; amphibole widespread but subordinate; texturally varied; granite gneiss, veined gneiss, augen gneiss, bonded gneiss; and migmatite, in places complexly intermingled	-	0	#	0	0		X		
scm	Sams Creek Metabasalt	Late Precamb.: Massive to schistose, amygdaloidal metabasalt	-	U	U	U	U			X	
lmr	Libertytown Metarhyolite	Late Precamb.: Metarhyolite with feldspar phenocrysts; interbedded amygdaloidal meta-andesite; both rhyolite and andesite interbedded with phyllitic slates	-	U	U	U	U			X	
SEDIMENTARY ROCKS											
srl	Silver Run Limestone	Late Precamb.: Thin bedded, finely crystalline schistose limestone and calcareous slate	-	U	U	U	U			X	
€f	Frederick Limestone	Camb.: Slabby, thin bedded limestone and minor shale	-	U	U	U	U			X	
O€g	Grove Limestone	Camb. to Ord.: Thick bedded limestone; dolomite beds in lower part; highly quartzose at base	-	U	U	U	U			X	

TABLE 4 SHEET 5 OF 5

GEOLOGICAL REVIEW OF ROCK UNITS -
MARYLAND
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
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U = Unacceptable
- = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
VOLCANIC ROCKS											
vc	Volcanic Complex of Cecil County	Late Precamb.: Metamorphosed andesitic and dacitic volcanic rocks (greenstone, greenschist, quartz amphibolite, and schistose felsite), amygdules and volcano-clastic textures locally preserved	-	U	U	U	U			X	
OTHER ROCKS											
Qal	Quaternary Alluvium	Not included in this study									
TRd	Triassic Dikes and Sills-Diabase	Not included in this study									
TRno	New Oxford Formation (Sandstones, siltstone, etc.)	Triassic - not included in this study									
TRg	Gettysburg Shale	Traissic - not included in this study									
TRgc	New Oxford Formation (Quartzite)	Triassic - not included in this study									
Kp	Potomac Group (Coastal Plain)	Not included in this study									

TABLE 5 SHEET 1 OF 3

GEOLOGICAL REVIEW OF ROCK UNITS –
VIRGINIA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
O = Marginally Acceptable
U = Unacceptable
– = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
IGNEOUS PLUTONIC ROCKS											
Pzlw	Leatherwood Granite	Paleoz. & Precamb.: Biotite-muscovite granite, locally porphyritic	–	–	U	–	O			X	
Pzp€ml	Melrose Granite	Paleoz. & Precamb.: Biotite-muscovite granite, and augen gneiss	–	–	U	O	O			X	
Pzpb	Petersburg Granite	Paleoz. & Precamb.: Microcline-biotite granite, and chloritic granodiorite	–	#	#	#	#	X			
Pzp€ro	Redoak Granite	Paleoz. & Precamb.: Biotite and muscovite granite, granite gneiss with feldspar phenocrysts and chloritic granodiorite	–	O	#*	O	O		X		*Acceptable with extension into North Carolina
gr	Granite	Uncertain Age: Biotite and muscovite granite, granodiorite and quartz monzonite, includes the Columbia granite and some mica schist and gneiss	–	O	#	O	O		X		
qd	Quartz Diorite	Uncertain Age: Diorite with some blue quartz	–	–	U	–	–			X	
METAMORPHIC ROCKS											
Oa, Obr	Arvonis Formation	Paleoz.: Slate, phyllite and schists, conglomerates Obr – Bremo quartzite member	U	U	#	U	U			X	
Pze	Evington Group	Paleoz.: Muscovite, chlorite, paragonite. quartz phyllite and schist interbedded with graywacke volcanic greenstone and marble. Includes: Chandler formation, Joshua schist, Arch marble, Pelier schist, Mount Athos formation and Slippery Creek greenstone	U	U	#	U	U			X	
€p€c	Catoctin Formation	Paleoz.: Basic lava flows, schists and gneisses composed of chlorite, plagioclase, amphibole and epidote, local arkose, conglomerate, phyllite	–	U	#	U	U			X	
p€ly	Lynchburg Formation	Paleoz.: Phyllite, quartzite, graywacke and conglomerate; a – Alum phyllite, quartz, muscovite phyllite with chlorite and biotite	–	U	#	U	U			X	

TABLE 5 SHEET 2 OF 3

GEOLOGIC REVIEW OF ROCK UNITS - VIRGINIA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
O = Marginally Acceptable
U = Unacceptable
\- = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
METAMORPHIC ROCKS											
PzpЄst	Shelton Granite Gneiss	Paleoz. & Precamb.: Granite gneiss, augen gneiss and mylonite	U	-	#	U	-			X	
am	Amphibolite	Uncert.: Amphibolite and amphibole rich foliates	-	-	U	U	-			X	
grgn	Granite Gneiss	Uncert.: Biotite and muscovite granite gneiss	-	O	#	O	O		X		
ghgn	Granite and Hornblende Gneiss	Uncert.: Interlayered mica, quartz, feldspar gneiss and hornblende, feldspar, mica gneiss	-	-	#	U	U			X	
hgb	Hornblende Gabbro and Gneiss; Talc	Uncert.: Amphibole-chlorite schist, chloritic hornblende gneiss; and some amphibolite, chloritic diorite, and hornblende diorite; and kyanite schist and kyanite quartzite	-	U	U	U	U			X	
m [mgn, mp, msch]	Metamorphosed Sedimentary Rocks	Uncert.: Includes metamorphosed sedimentary and interlayered igneous rocks that overlie the Virginia Blue Ridge Complex, mp - phyllite; msch - schist and mgn - gneiss; and kyanite schist and kyanite quartzite	-	U	#	U	U			X	
SEDIMENTARY ROCKS											
lm	Limestone and Marble (Metamorphic)	Uncert.: Includes equivalent of Cockeysville marble in Loundoun and Fauquier Counties, Everona limestone in Central Virginia, limestone and marble in Pittsylvania County	-	-	U	-	-			X	

TABLE 5 SHEET 3 OF 3

GEOLOGICAL REVIEW OF ROCK UNITS -
VIRGINIA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
O = Marginally Acceptable
U = Unacceptable
- = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
IGNEOUS VOLCANIC ROCKS											
Pzp€vs	Virgilina Group	Paleoz. & Precamb.: PzpCvg - Altered andesitic flows and tuffs, PzpCvs - Slate, quartz-sericite schist, phyllite and arkose	U	U	U	U	U			X	
v	Metamorphosed volcanic and sedimentary rocks	Uncert.: Extrusive, igneous rocks and interlayered sedimentary rocks. Includes Peters Creek quartzite from Prince William to Buckingham Counties	U	U	U	U	U			X	
g	Greenstone Volcanics	Uncert.: Basic lava flows, tuff and slate commonly altered to chlorite bearing rocks	U	U	U	U	U			X	
COASTAL PLAIN SEDIMENTS											
Tu, Tc, Ta, Kpt, Kptx		Not included in this study.									
TRIASSIC FORMATIONS											
₮d	Igneous rocks within Triassic Basin	Triassic - not included in this study.									
₮ns, ₮o, ₮df, ₮v, ₮n		Triassic - not included in this study.									

TABLE 6 SHEET 1 OF 2

GEOLOGICAL REVIEW OF ROCK UNITS -
NORTH CAROLINA
PIEDMONT PROVINCE

LEGEND:

\# = Acceptable
O = Marginally Acceptable
U = Unacceptable
\- = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Rock Properties & Conditions: Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Rock Unit Classification: Potentially Favorable	Rock Unit Classification: Unfavorable	Remarks
IGNEOUS PLUTONIC ROCKS											
wg	Whiteside Granite	Paleoz.: Muscovite-biotite granite, slightly schistose.	-	-	*U	O	-		X		*Acceptable with extension into South Carolina
cqm	Cherryville Quartz Monzonite	Paleoz.: Massive to weakly foliated muscovite-biotite-quartz monzonite.	-	U	U	U	-			X	
tqm	Toluca Quartz Monzonite	Paleoz.: Foliated biotite-quartz monzonite.	-	U	U	U	-			X	
di gb	Diorite-Gabbro	Paleoz.(?): Massive to weakly foliated, mostly plagioclase, hornblende and pyroxene, di-diorite predominates, gb-gabbro predominates.	-	O	#	O	O		X		
mag	Mt. Airy Granite	Paleoz.(?): Massive, biotite-quartz monzonite.	-	#	U	O	O			X	
sy	Syenite	Paleoz.(?): Massive to weakly foliated augite syenite.	-	#	U	#	#			X	
gr	Granite	Paleoz.(?): Massive to weakly foliated, even-grained to porphyritic granitic rocks.	# O	# O	#	# O	# O	X	X		Includes a wide range of granites with variable ranges
METAMORPHIC ROCKS											
kmg	Kings Mountain Group	Lr. or Upp. Camb.(?): Quartzite, marble, conglomerate and schist.	U	U	-	U	U			X	
hgg	Henderson Granite Gneiss	Precamb.(?): Granite gneiss, locally augen gneiss, contains lenses of hornblende gneiss, mica gneiss, and mica schist.	-	O	#	O	O		X		
gnc	Granite Gneiss Complex	Precamb.(?): Contains granite gneiss, mica gneiss, mica schist and hornblende gneiss.	-	O	#	O	O		X		
hgn	Hornblende Gneiss	Precamb.(?): Chiefly hornblende gneiss and schist with interbeds of mica gneiss and mica schist.	-	O	#	U	U			X	

TABLE 6 SHEET 2 OF 2

GEOLOGICAL REVIEW OF ROCK UNITS -
NORTH CAROLINA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
0 = Marginally Acceptable
U = Unacceptable
- = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Rock Properties & Conditions: Physical & Mechanical Prop.	Rock Properties & Conditions: Geology: Areal Dimension	Rock Properties & Conditions: Geology: Structure	Rock Properties & Conditions: Geology: Lithology	Rock Unit Classification: Favorable	Rock Unit Classification: Potentially Favorable	Rock Unit Classification: Unfavorable	Remarks
METAMORPHIC ROCKS (Cont'd)											
msh	Mica Schist	Precamb.(?): Chiefly mica schist, includes mica gneiss and a wide variety of other gneisses and schists.	-	U	#	U	U			X	
mgn	Mica Gneiss	Precamb.(?): Chiefly mica gneiss, includes mica schist and a wide variety of other gneisses and schists.	-	U	#	U	U			X	
VOLCANIC ROCKS											
ar	Bedded Argillites (Volcanic slate-Carolina Slate Belt)	Precamb. or Lwr. Paleoz.(?): Bedded volcanic slate, containing lenses of acid and basic fragmental and flow material.	-	U	#	-	U			X	
mvs	Mafic Volcanics (Carolina Slate Belt)	Precamb. or Lwr. Paleoz.(?): Chiefly basic tuffs, breccias and flows, in part of sedimentary origin; also felsic fragmental and flow material and lenses of bedded slate.	U	U	#	U	U			X	
fvs	Felsic Volcanics (Carolina Slate Belt)	Precamb. or Lwr. Paleoz.(?): Chiefly acid tuffs, breccias and flows, in part of sedimentary origin; also mafic fragmentals and flow material and lenses of bedded slate; along eastern edge of Piedmont lenses of gneiss, schist and phyllite.	U	U	#	U	U			X	
OTHER ROCKS											
℞d	Diabase Dike	Not included in this study.									
Kt	Tuscaloosa Formation	Not included in this study.									
My	Yorktown Formation	Not included in this study.									
℞u	Undifferentiated Triassic	Not included in this study.									

TABLE 7 SHEET 1 OF 4

GEOLOGIC REVIEW OF ROCK UNITS -
SOUTH CAROLINA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
O = Marginally Acceptable
U = Unacceptable
– = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
IGNEOUS PLUTONIC ROCKS											
Psy	Augite Syenite	Paleo.- Porphyritic, massive, augite syenite	–	#	U	–	#			X	
Pgp	Gabbro, Pyroxenite, Norite	Paleo.- Massive: May be in layered or composite bodies; locally intruded by augite syenite (Psy), syenite pegmatite - composes Ogden Pluton	–	#	#	#	#	X			
Py & Otm	Yorkville Quartz Monzonite Toluca Quartz Monzonite	Ord. - Perm.: Porphyritic, massive to gneissic biotite quartz monzonite, Toluca formation is garnetiferous	–	#	U	–	O		X		
POc	Coarse-grained Granite	Ord. - Perm.: Biotite-muscovite granite, and quartz monzonite; locally porphyritic; locally gneissic; includes porphyritic granodiorite in some areas - composes Liberty Hill and Winnsboro Plutons.	–	#	#	#	#	X			
POf	Fine-grained Granite	Ord. - Perm.: Massive; biotite granite, biotite-muscovite granite, and quartz monzonite	–	#	O	#	#		X		
POp	Porphyritic Granite	Ord. - Perm.: Porphyritic biotite-muscovite granite	–	O	#	O	O		X		
POu	Granite Undivided	Ord. - Perm.: Massive to gneissic biotite granite and biotite-quartz monzonite; grades in composition to gneissic biotite granodiorite; locally strongly gneissic	–	–	U	U	U			X	
MOd	Mafic dike swarms	Ord. - Miss.: Equigranular to porphyritic, massive to foliated mafic dikes occuring in swarms; principally un-metamorphosed to metamorphosed basalt, andesite, pyroxinite, and gabbro; local ultramafic rocks	U	U	U	U	U			X	
PMcq	Cherryville Quartz Monzonite	Miss. - Perm.: Massive to weakly foliated muscovite-biotite-quartz monzonite	–	O	U	O	O		X		
Ogs	Gabbro and Soapstone	Ord.: Massive to foliated hornblende gabbro, metapyroxenite, and soapstone; locally intruded by dikes of pegmatite and granite	U	U	U	U	U			X	

TABLE 7 SHEET 2 OF 4

GEOLOGIC REVIEW OF ROCK UNITS -
SOUTH CAROLINA
PIEDMONT PROVINCE

LEGEND:

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0 = Marginally Acceptable
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\- = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
IGENOUS PLUTONIC ROCKS (Cont'd)											
Oot	Oligoclase Tonalite	Ord.: Massive to gneissic oligoclase tonalite; contains angular inclusions of biotite schist; staurolite, garnet, with kyanite locally present	-	U	U	U	U			X	
METAMORPHIC ROCKS											
MOs	Sericite Schist	Ord. - Miss.: Laminated sericite schist, sericite phylite, quartz-mica schist, biotite schist, biotite gneiss	-	U	U	U	U			X	
MOh	Hornblende Schist	Ord. - Miss.: Hornblende schist, hornblende gneiss, actinolite schist, and chlorite schist, rare layers of marble; closely associated spatially with sericite schist	-	U	U	U	U			X	
MOvs	Muscovite Schist	Ord. - Miss.: Muscovite-biotite-chlorite schist, sericite phylite, includes some intensely sheared rocks, possibly some phyllonite and blastomylonite; cut by numerous quartz veins, locally contains garnet, kyanite and staurolite	U	U	U	U	U			X	
MOvg	Quartz-Microcline Gneiss	Ord. - Miss.: Quartz-microcline gneiss with meta-crysts of microcline; interlayered stringers of hornblende gneiss	-	-	U	-	U			X	
MOvm	Amphibolite	Ord. - Miss.: Amphibolite, hornblende schist, hornblende gneiss, actinolite schist, and chlorite schist; includes some diorite, meta-gabbro, biotite gneiss, and numerous dikes	U	U	U	U	U			X	
MOmg	Mica Gneiss	Ord. - Miss.: Layered biotite gneiss, biotite schist, hornblende schist, and hornblende gneiss; granitic layers common	-	-	#	U	U			X	
€pcg	Granitoid Gneiss	Upper Precamb. and Camb.: Undivided granitoid gneisses, gneissic granodiorite, gneissic granite, biotite-muscovite schist, and biotite-muscovite gneiss	-	0	#	0	0		X		

TABLE 7 SHEET 3 OF 4

GEOLOGIC REVIEW OF ROCK UNITS -
SOUTH CAROLINA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
0 = Marginally Acceptable
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\- = Unknown

SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Rock Properties & Conditions: Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Rock Unit Classification: Potentially Favorable	Rock Unit Classification: Unfavorable	Remarks
METAMORPHIC ROCKS (cont'd)											
DOhg	Henderson Gneiss	Ord. to Dev.: Porphyritic muscovite-biotite gneiss; locally equigranular and massive	-	-	0	0	0		X		
DOgg	Biotite Granite Gneiss	Ord. - Dev.: Biotite granite gneiss	-	-	#	0	0		X		
Mgm	Gaffney Marble	Miss.: Banded to schistose, phlogopite and hornblende bearing marble	U	U	U	U	U			X	
MOiq	Quartzite	Ord. - Miss.: Quartzite, biotite quartzite, and muscovite quartzite: occurs as small thin, lenticular or tabular masses	-	-	U	U	U			X	
MpЄs	Biotite Schist	Upper Precamb. - Miss.: Scaly biotite-oligoclase schist, with thin layers of biotite gneiss, granitoid, quartz schist, quartzite, marble, calc-silicate rocks, and hornblende schist	U	U	#	U	U			X	
DpЄh	Hornblende Gneiss	Upper Precamb. - Dev.: Hornblende gneiss, hornblende schist, amphibolite, and biotite-hornblende-oligoclase gneiss; metamorphosed gabbro, diorite, and pyroxenite; rare small lenses of soapstone and serpentine; thin discontinuous layers of marble and calc-silicate rocks; some interlayered biotite schist, biotite gneiss, and granite gneiss	-	U	0	U	U			X	
DpЄm	Biotite Gneiss and Migmatite	Upper Precamb. - Dev.: Layered, and garnetiferous biotite-sillimanite-oligoclase gneiss and biotite oligoclase-quartz gneiss; several strongly banded granitoid layers; thin layers of biotite, sillimanite schist common; local hornblende and biotite-hornblende-oligoclase gneisses; rare thin layers of quartzite and marble, folded	-	0	#	0	0		X		
MOvu	Argillite	Ord. - Miss.: Laminated argillite; tuffaceous argillite, and graywacke; includes felsic and mafic agglomerates, breccias, tuffs, and volcanic flows	U	U	#	U	U			X	

TABLE 7 SHEET 4 OF 4

GEOLOGIC REVIEW OF ROCK UNITS -
SOUTH CAROLINA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
O = Marginally Acceptable
U = Unacceptable
- = Unknown

			Rock Properties & Conditions					Rock Unit Classification			
					Geology						
SYMBOL	FORMATIONS	AGE AND DESCRIPTION	Hydrogeology	Physical & Mechanical Prop.	Areal Dimension	Structure	Lithology	Favorable	Potentially Favorable	Unfavorable	Remarks
SEDIMENTARY ROCKS											
Qal	Quaternary Alluvium	Not included in this study									
Oku	Coastal Plain Rocks	Not included in this study									
OTHER ROCKS NOT INCLUDED											
Ŧpd	Phyllonite and Blastomylonite	Not included in this study									
Ŧs	Consolidated Sedimentary Rocks	Not included in this study									

TABLE 8 SHEET 1 OF 2

GEOLOGICAL REVIEW OF ROCK UNITS - GEORGIA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
O = Marginally Acceptable
U = Unacceptable
– = Unknown

SYMBOL	DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
IGNEOUS PLUTONIC ROCKS										
gr1, gr1a, gr1b	Granite (Undiff., non-porphyritic, porphyritic)	#	#	#	#	#	X			
gr2, gr2a	Granite with gneissic granite	#	#	#	#	#	X			
gr4	Charnockite	–	–	U	#	–			X	
mp1, mp2	Gabbro/amphibolite	–	–	U	U	–			X	
d	Diabase	–	–	U	U	–			X	
um	Ultramafic rock undiff.	–	–	U	U	U			X	
METAMORPHIC ROCKS										
gg1, gg3, gg4, gg5, gg6	Granite gneiss (undiff., muscovite, amphibolite and calc-silicate granite gneiss, granite gneiss/granite)	–	O	#	O	O		X		
fg1, fg1a, fg2, fg3, fg4	Gneiss (biotite, biotite-hornblende with amphibolite, undiff., biotite with mica schist-amphibolite, biotite with amphibolite, respectively)	–	O	#	O	O		X		
bg1, bg2, bg3, bg4	Gneiss (biotite, biotite-amphibolite, biotite-hornblende-granite, biotite with mica schist, respectively)	–	O	#	O	O		X		
mm1, mm2, mm3, mm4, mm5, mm6, mm8, mm9, mm11	Hornblende gneiss with amphibolite and biotite gneiss, local presence of quartz sericite and mica schist and mica hornfels	–	O	#	O	O		X		
pms1, pms2, pms3, pms3a, pms4, pms5, pms6, pms6a, pms6b, pms6c, pms6d, pms6e, pms7	Mica schist with amphibolite, gneiss, sericite, schist, sericite phyllite	–	U	#	U	U			X	
pp1a	Meta-argillite, phyllite	–	U	U	U	U			X	

TABLE 8 SHEET 2 OF 2

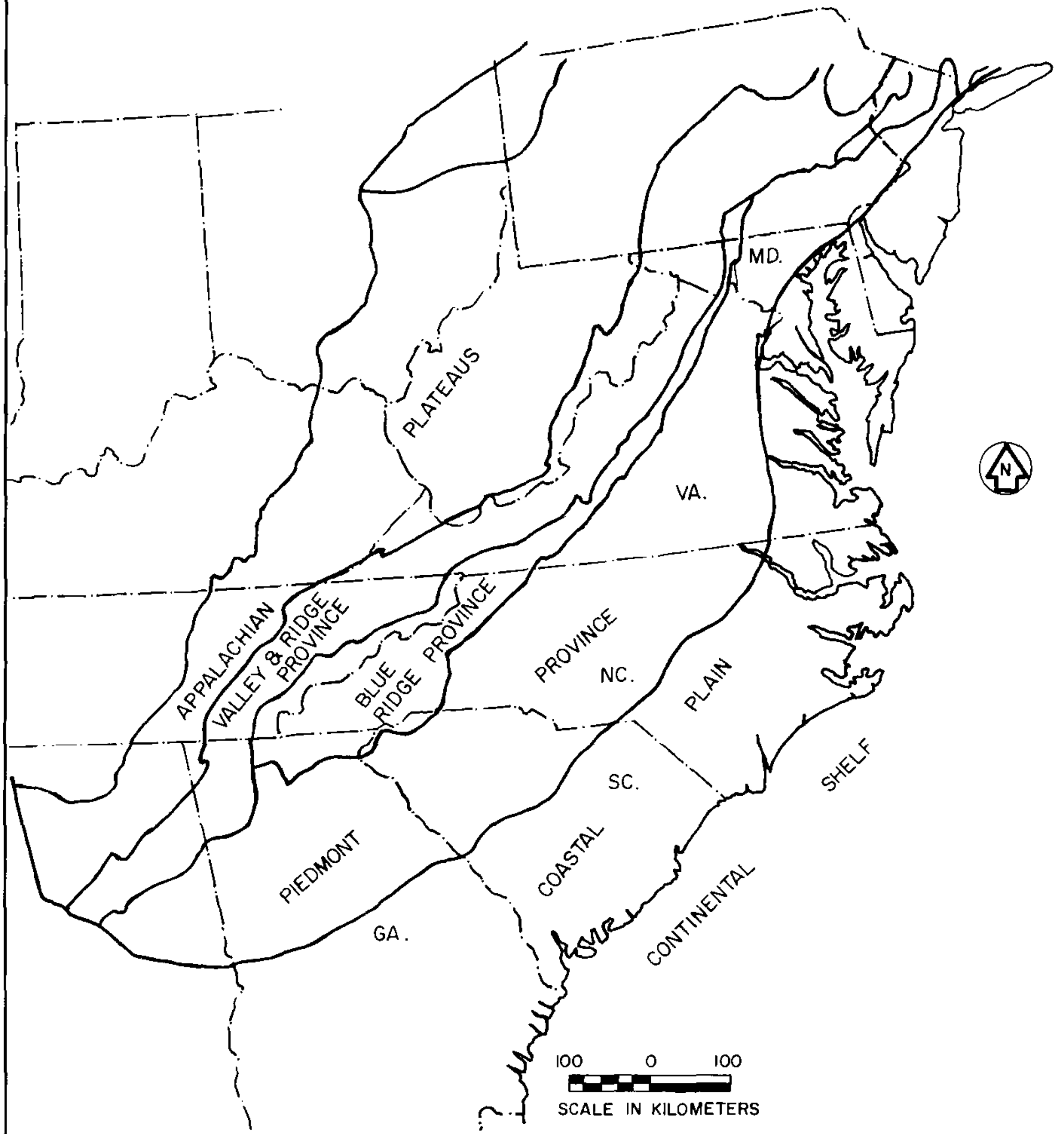
GEOLOGICAL REVIEW OF ROCK UNITS - GEORGIA
PIEDMONT PROVINCE

LEGEND:

# = Acceptable
O = Marginally Acceptable
U = Unacceptable
- = Unknown

SYMBOL	DESCRIPTION	Rock Properties & Conditions: Hydrogeology	Physical & Mechanical Prop.	Geology: Areal Dimension	Geology: Structure	Geology: Lithology	Rock Unit Classification: Favorable	Potentially Favorable	Unfavorable	Remarks
METAMORPHIC ROCKS (Cont'd)										
pg1, pg2, pg3	Garnet-mica schist with gneiss and amphibolite	-	U	U	U	U			X	
pa1, pa2, pa2a, pa2b, pa2c	Sillimanite schist with gneiss and amphibolite	-	U	U	U	U			X	
q1, q1a, q1b, q1c, q1d, q2, q3	Quartzite with mica schist amphibolite, metagraywacke, phyllite and biotite-garnet gneiss	-	U	U	U	U			X	
c1, c2	Mylonite and flinty crush rock respectively	U	U	U	U	U			X	
VOLCANIC ROCKS										
v1	Mafic to intermediate metavolcanic rocks	-	U	U	U	U			X	
v2, v3	Metadacite, felsic metavolcanics, respectively	-	-	U	U	U			X	
v4	Undiff. metavolcanics/sericite phyllite, meta-argillite, quartz mica schist	-	U	U	U	U			X	
v5	Meta-argillite, sericite phyllite and metavolcanics	-	U	U	U	U			X	

PLATES



FROM:
FENNEMAN, N.M., 1938
PHYSIOGRAPHY OF EASTERN UNITED STATES,
MC GRAW - HILL BOOK COMPANY, INC., 714 P.

ACRES

SAVANNAH RIVER LABORATORY

POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT

PHYSIOGRAPHIC MAP

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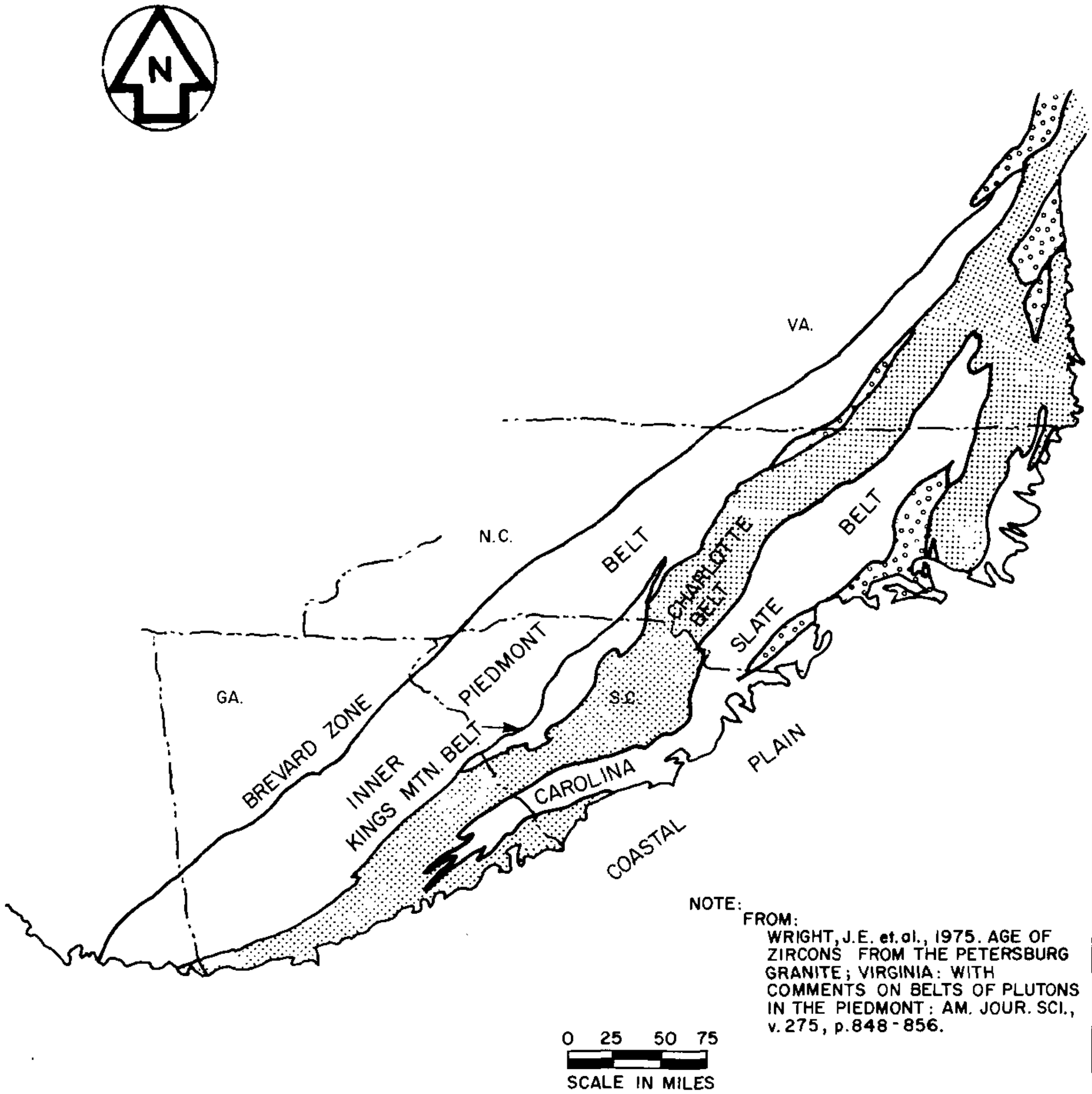
PLATE 1



NOTE:
FROM:
WRIGHT, J.E. et.al., 1975. AGE OF ZIRCONS FROM THE PETERSBURG GRANITE; VIRGINIA: WITH COMMENTS ON BELTS OF PLUTONS IN THE PIEDMONT: AM. JOUR. SCI., v. 275, p.848-856.

LEGEND

Ꞧ TRIASSIC BASIN

ACRES

SAVANNAH RIVER LABORATORY

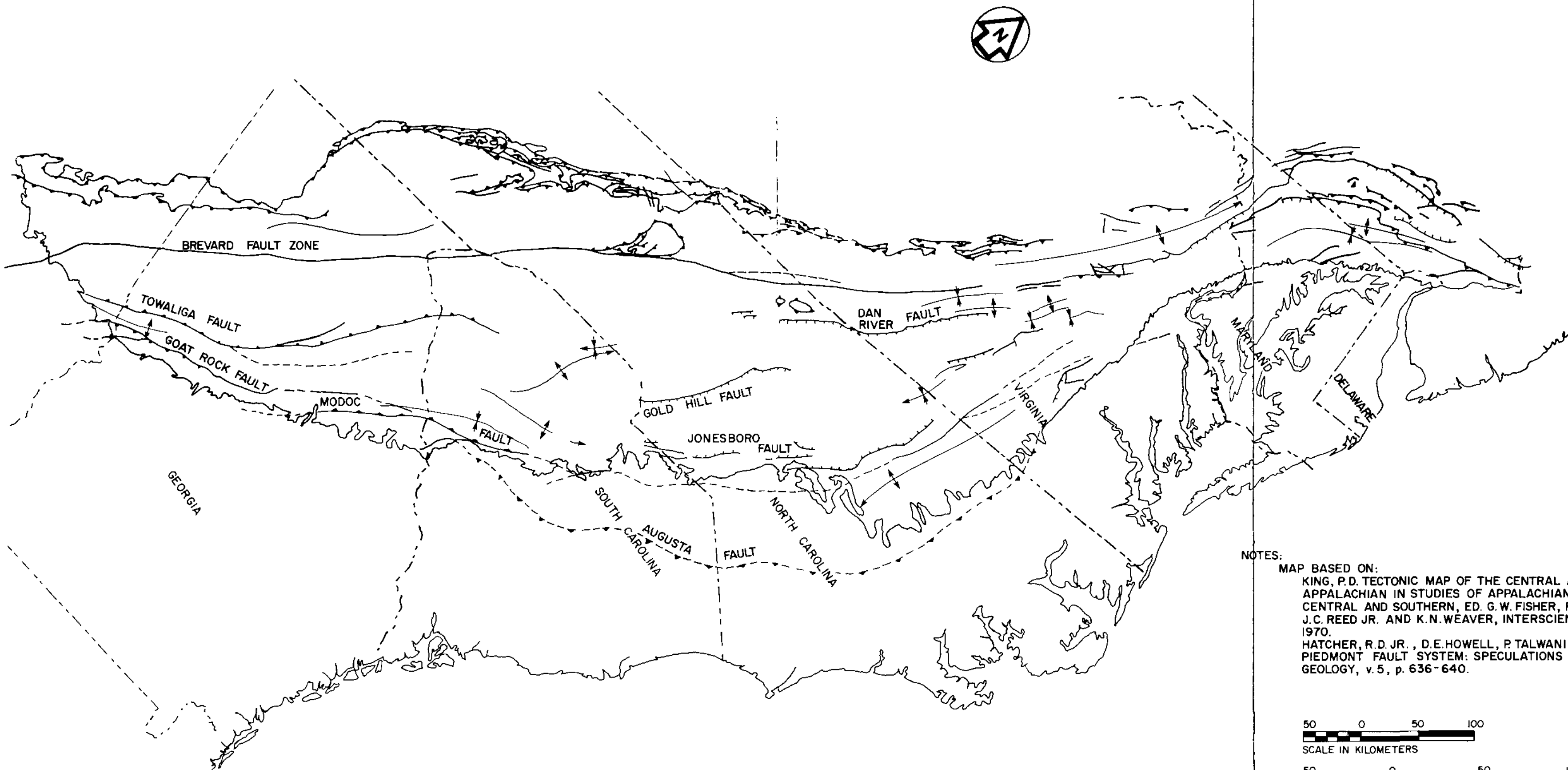
POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT

SOUTHERN PIEDMONT SUBDIVISIONS

ACRES AMERICAN INCORPORATED

JUNE 1978

PLATE 2



NOTES:
MAP BASED ON:
KING, P.D. TECTONIC MAP OF THE CENTRAL AND SOUTHERN APPALACHIAN IN STUDIES OF APPALACHIAN GEOLOGY: CENTRAL AND SOUTHERN, ED. G.W. FISHER, F.J. PETTIJOHN, J.C. REED JR. AND K.N. WEAVER, INTERSCIENCE PUBLISHERS, 1970.
HATCHER, R.D. JR., D.E. HOWELL, P. TALWANI, 1977, EASTERN PIEDMONT FAULT SYSTEM: SPECULATIONS ON ITS EXTENT, GEOLOGY, v. 5, p. 636-640.

50 0 50 100
SCALE IN KILOMETERS

50 0 50 100
SCALE IN MILES

GEOLOGIC LEGEND

- FAULT - DASHED WHERE APPROXIMATED
- HIGH-ANGLE FAULT
- THRUST FAULT
- WINDOW IN THRUST FAULT
- ANTICLINE WITH PLUNGE DIRECTION
- SYNCLINE WITH PLUNGE DIRECTION

ACRES

SAVANNAH RIVER LABORATORY

POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT

TECTONIC MAP OF SOUTHERN PIEDMONT

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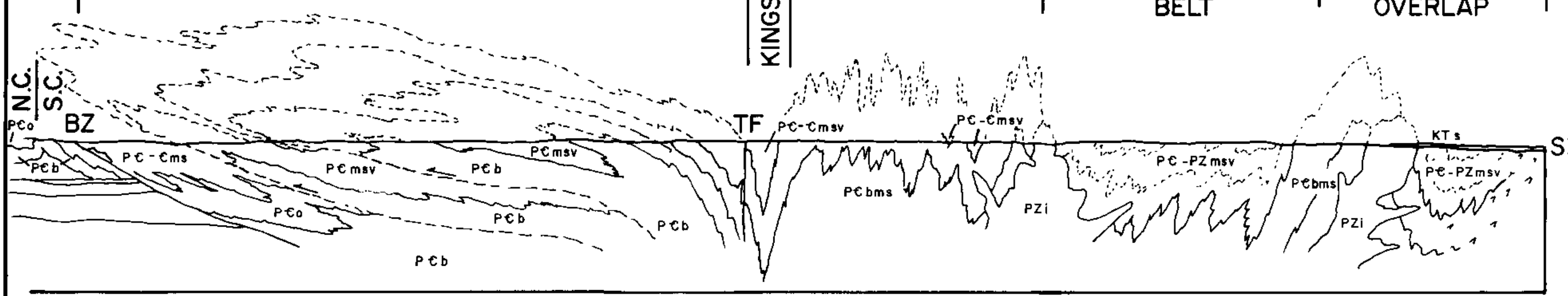
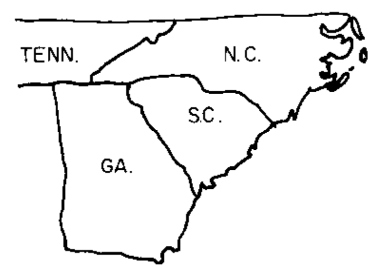
PLATE 3



10 5 0 5 10
SCALE IN MILES
0 5 10 15 20 25
SCALE IN KILOMETERS

LEGEND

BZ	BREVARD ZONE
TF	TOWALIGA FAULT
PЄb	EARLIER PRECAMBRIAN BASEMENT ROCKS.
PЄbms	EARLIER TO LATE PRECAMBRIAN BASEMENT AND METASEDIMENTARY AND METAVOLCANIC ROCKS.
PЄo	OCOEE SERIES
PЄmvs	LATE PRECAMBRIAN METASEDIMENTARY AND METAVOLCANIC ROCKS.
PЄ-Єms, PЄ Єmsv	LATE PRECAMBRIAN AND CAMBRIAN METASEDIMENTARY AND METAVOLCANIC ROCKS.
PZi	PALEOZOIC INTRUSIVE ROCKS.
(solid line with arrow)	THRUST FAULT (PHASE 3 DEFORMATION)
(dashed line with arrow)	TECTONIC SLIDE (PHASE 2 DEFORMATION)



LOCATION MAP

NOTE:
CROSS-SECTION FROM:
HATCHER, R. D., JR., 1972, DEVELOPMENTAL MODEL FOR THE SOUTHERN PIEDMONT, G.S.A. BULL., V.83, P. 2735 - 2760

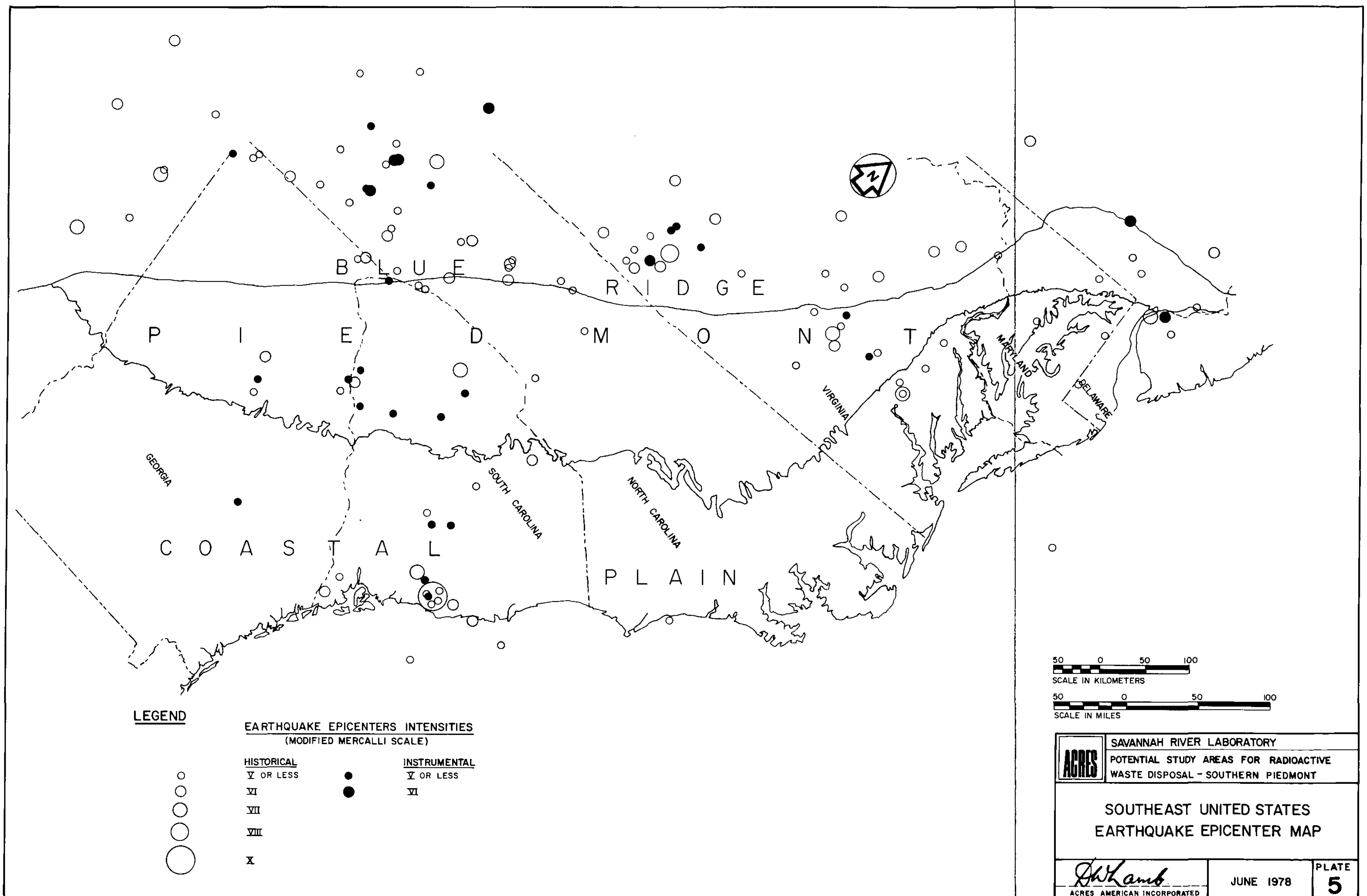
ACRES AMERICAN INCORPORATED

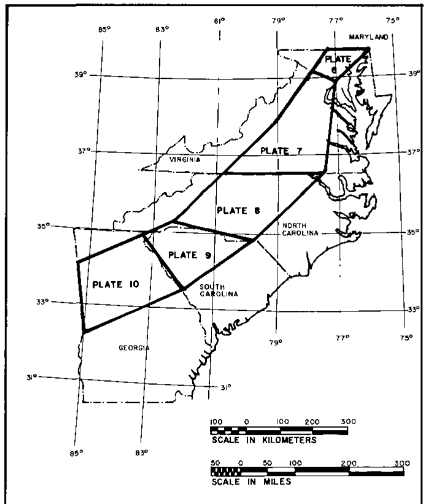
SAVANNAH RIVER LABORATORY
POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT

CROSS SECTION SOUTHERN PIEDMONT

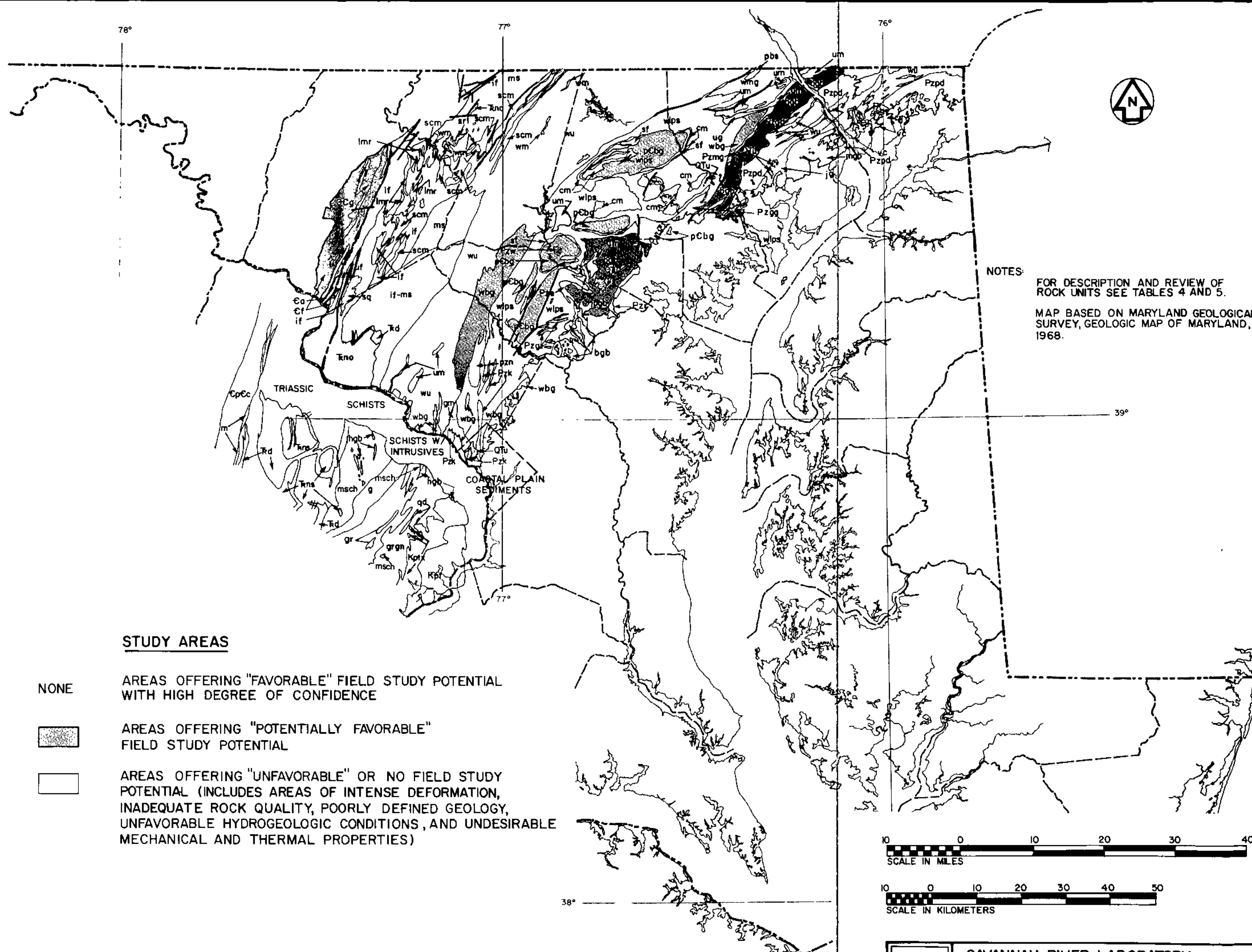
JUNE 1978

PLATE 4


B L U E
R I D G E
P I E D M O N T
C O A S T A L
P L A I N
GEORGIA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
MARYLAND
DELAWARE
N
LEGEND
EARTHQUAKE EPICENTERS INTENSITIES
(MODIFIED MERCALLI SCALE)
HISTORICAL
V OR LESS
VI
VII
VIII
X
INSTRUMENTAL
V OR LESS
VI
50 0 50 100
SCALE IN KILOMETERS
50 0 50 100
SCALE IN MILES
ACRES
SAVANNAH RIVER LABORATORY
POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT
SOUTHEAST UNITED STATES EARTHQUAKE EPICENTER MAP
ACRES AMERICAN INCORPORATED
JUNE 1978
PLATE 5



INDEX MAP



NOTES: FOR DESCRIPTION AND REVIEW OF ROCK UNITS SEE TABLES 4 AND 5.

MAP BASED ON MARYLAND GEOLOGICAL SURVEY, GEOLOGIC MAP OF MARYLAND, 1968.

LEGEND

ROCK TYPES

GENERAL CATEGORIES OF ROCK TYPE BASED ON ORIGIN

- IGNEOUS PLUTONIC
- METAMORPHIC
- SEDIMENTARY
- VOLCANIC & METAMORPHOSED VOLCANIC
- FAULT
- COUNTY BOUNDARY
- MAJOR URBAN AREAS

STUDY AREAS

NONE — AREAS OFFERING "FAVORABLE" FIELD STUDY POTENTIAL WITH HIGH DEGREE OF CONFIDENCE

AREAS OFFERING "POTENTIALLY FAVORABLE" FIELD STUDY POTENTIAL

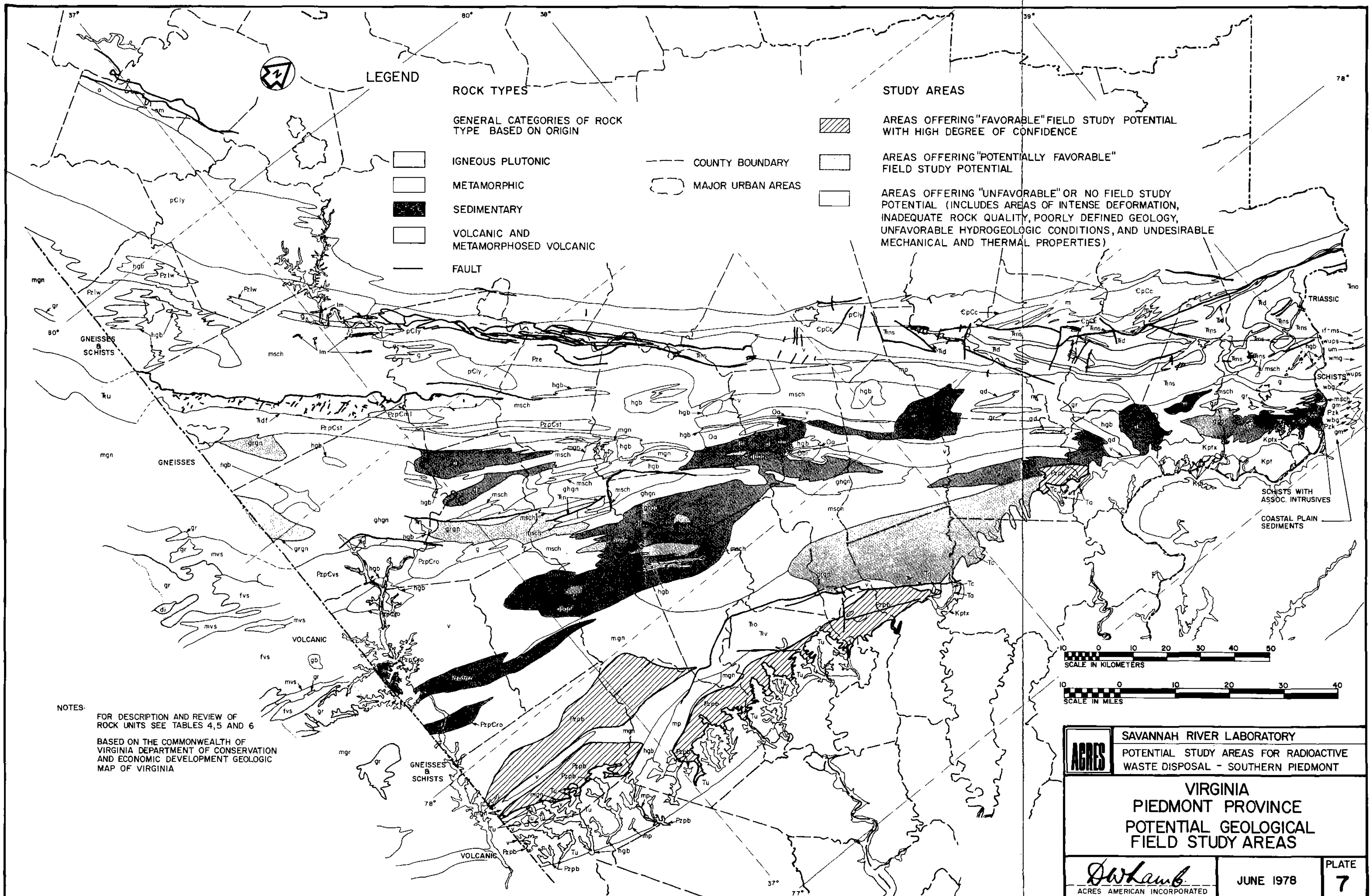
AREAS OFFERING "UNFAVORABLE" OR NO FIELD STUDY POTENTIAL (INCLUDES AREAS OF INTENSE DEFORMATION, INADEQUATE ROCK QUALITY, POORLY DEFINED GEOLOGY, UNFAVORABLE HYDROGEOLOGIC CONDITIONS, AND UNDESIRABLE MECHANICAL AND THERMAL PROPERTIES)

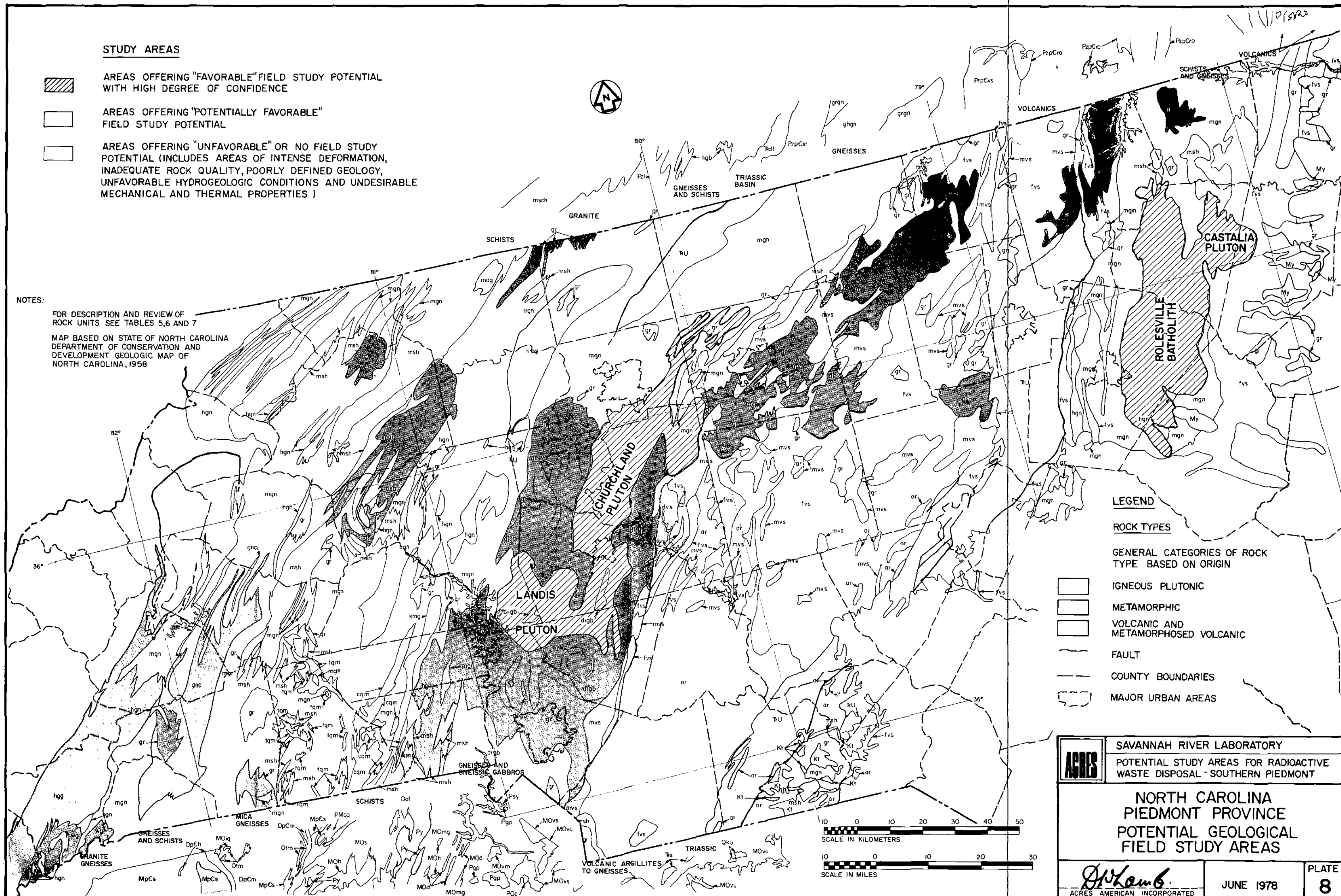
ACRES — SAVANNAH RIVER LABORATORY

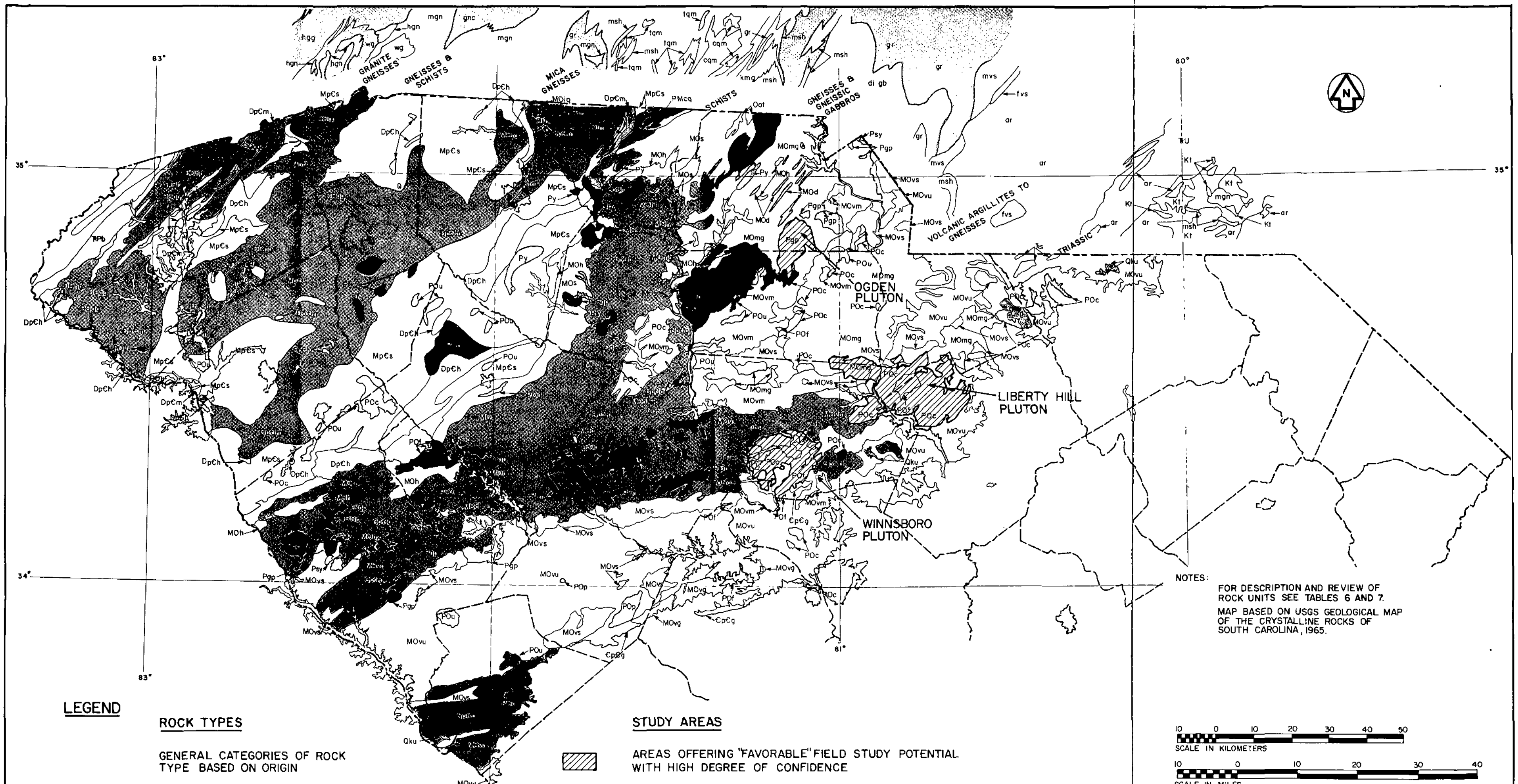
POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT

MARYLAND PIEDMONT PROVINCE POTENTIAL GEOLOGICAL FIELD STUDY AREAS

ACRES AMERICAN INCORPORATED | JUNE 1978 | PLATE 6


LEGEND
ROCK TYPES
GENERAL CATEGORIES OF ROCK TYPE BASED ON ORIGIN
IGNEOUS PLUTONIC
METAMORPHIC
SEDIMENTARY
VOLCANIC AND METAMORPHOSED VOLCANIC
FAULT
COUNTY BOUNDARY
MAJOR URBAN AREAS
STUDY AREAS
AREAS OFFERING "FAVORABLE" FIELD STUDY POTENTIAL WITH HIGH DEGREE OF CONFIDENCE
AREAS OFFERING "POTENTIALLY FAVORABLE" FIELD STUDY POTENTIAL
AREAS OFFERING "UNFAVORABLE" OR NO FIELD STUDY POTENTIAL (INCLUDES AREAS OF INTENSE DEFORMATION, INADEQUATE ROCK QUALITY, POORLY DEFINED GEOLOGY, UNFAVORABLE HYDROGEOLOGIC CONDITIONS, AND UNDESIRABLE MECHANICAL AND THERMAL PROPERTIES)
GNEISSES & SCHISTS
GNEISSES
VOLCANIC
TRIASSIC
SCHISTS
SCHISTS WITH ASSOC. INTRUSIVES
COASTAL PLAIN SEDIMENTS
NOTES:
FOR DESCRIPTION AND REVIEW OF ROCK UNITS SEE TABLES 4,5 AND 6
BASED ON THE COMMONWEALTH OF VIRGINIA DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT GEOLOGIC MAP OF VIRGINIA
SCALE IN KILOMETERS
10 0 10 20 30 40 50
SCALE IN MILES
10 0 10 20 30 40
SAVANNAH RIVER LABORATORY
ACRES
POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT
VIRGINIA
PIEDMONT PROVINCE
POTENTIAL GEOLOGICAL FIELD STUDY AREAS
DWLamb
ACRES AMERICAN INCORPORATED
JUNE 1978
PLATE
7


STUDY AREAS
AREAS OFFERING "FAVORABLE" FIELD STUDY POTENTIAL WITH HIGH DEGREE OF CONFIDENCE
AREAS OFFERING "POTENTIALLY FAVORABLE" FIELD STUDY POTENTIAL
AREAS OFFERING "UNFAVORABLE" OR NO FIELD STUDY POTENTIAL (INCLUDES AREAS OF INTENSE DEFORMATION, INADEQUATE ROCK QUALITY, POORLY DEFINED GEOLOGY, UNFAVORABLE HYDROGEOLOGIC CONDITIONS AND UNDESIRABLE MECHANICAL AND THERMAL PROPERTIES)
NOTES:
FOR DESCRIPTION AND REVIEW OF ROCK UNITS SEE TABLES 5,6 AND 7
MAP BASED ON STATE OF NORTH CAROLINA DEPARTMENT OF CONSERVATION AND DEVELOPMENT GEOLOGIC MAP OF NORTH CAROLINA, 1958
LANDIS PLUTON
CHURCHLAND PLUTON
CASTALIA PLUTON
ROLESVILLE BATHOLITH
GNEISSES AND SCHISTS
TRIASSIC BASIN
GRANITE
SCHISTS
GNEISSES
VOLCANICS
SCHISTS AND GNEISSES
GNEISSES AND GNEISSIC GABBROS
MICA GNEISSES
GRANITE GNEISSES
VOLCANIC ARGILLITES TO GNEISSES
TRIASSIC
LEGEND
ROCK TYPES
GENERAL CATEGORIES OF ROCK TYPE BASED ON ORIGIN
IGNEOUS PLUTONIC
METAMORPHIC
VOLCANIC AND METAMORPHOSED VOLCANIC
FAULT
COUNTY BOUNDARIES
MAJOR URBAN AREAS
SCALE IN KILOMETERS
SCALE IN MILES
SAVANNAH RIVER LABORATORY
ACRES
POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT
NORTH CAROLINA PIEDMONT PROVINCE
POTENTIAL GEOLOGICAL FIELD STUDY AREAS
ACRES AMERICAN INCORPORATED
JUNE 1978
PLATE 8



NOTES: FOR DESCRIPTION AND REVIEW OF ROCK UNITS SEE TABLES 6 AND 7.
MAP BASED ON USGS GEOLOGICAL MAP OF THE CRYSTALLINE ROCKS OF SOUTH CAROLINA, 1965.

LEGEND

ROCK TYPES

GENERAL CATEGORIES OF ROCK TYPE BASED ON ORIGIN

- IGNEOUS PLUTONIC
- METAMORPHIC
- SEDIMENTARY
- COUNTY BOUNDARIES
- MAJOR URBAN AREAS

STUDY AREAS

- AREAS OFFERING "FAVORABLE" FIELD STUDY POTENTIAL WITH HIGH DEGREE OF CONFIDENCE
- AREAS OFFERING "POTENTIALLY FAVORABLE" FIELD STUDY POTENTIAL
- AREAS OFFERING "UNFAVORABLE" OR NO FIELD STUDY POTENTIAL (INCLUDES AREAS OF INTENSE DEFORMATION, INADEQUATE ROCK QUALITY, POORLY DEFINED GEOLOGY, UNFAVORABLE HYDROGEOLOGIC CONDITIONS, AND UNDESIRABLE MECHANICAL AND THERMAL PROPERTIES)

ACRES

SAVANNAH RIVER LABORATORY

POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT

SOUTH CAROLINA PIEDMONT PROVINCE
POTENTIAL GEOLOGICAL FIELD STUDY AREAS

D.L. Lamb
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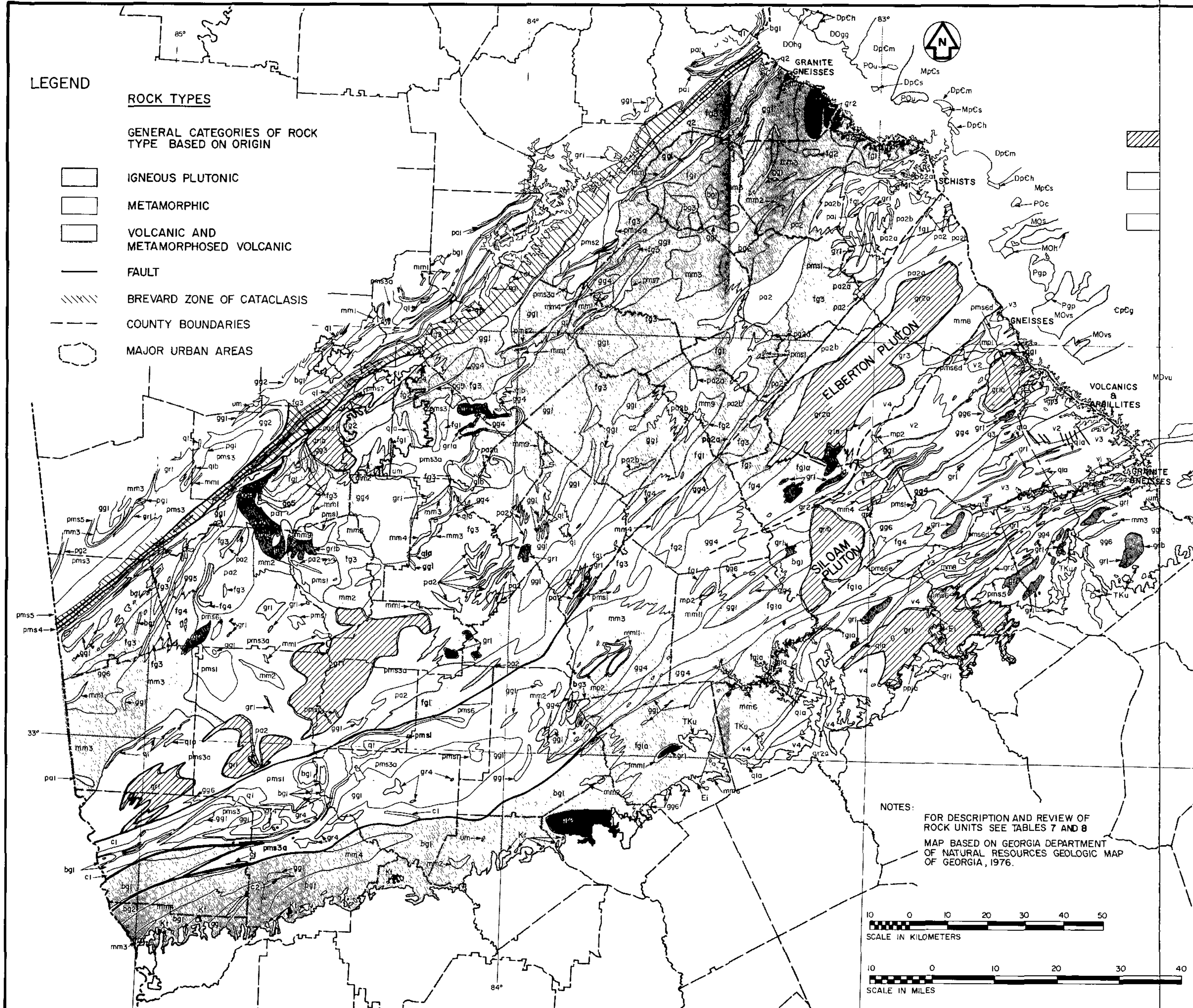
PLATE 9



STUDY AREAS

- AREAS OFFERING "FAVORABLE" FIELD STUDY POTENTIAL WITH HIGH DEGREE OF CONFIDENCE
- AREAS OFFERING "POTENTIALLY FAVORABLE" FIELD STUDY POTENTIAL
- AREAS OFFERING "UNFAVORABLE" OR NO FIELD STUDY POTENTIAL (INCLUDES AREAS OF INTENSE DEFORMATION, INADEQUATE ROCK QUALITY, POORLY DEFINED GEOLOGY, UNFAVORABLE HYDROGEOLOGIC CONDITIONS AND UNDESIRABLE MECHANICAL AND THERMAL PROPERTIES)

ACRES

SAVANNAH RIVER LABORATORY

POTENTIAL STUDY AREAS FOR RADIOACTIVE WASTE DISPOSAL - SOUTHERN PIEDMONT

GEORGIA PIEDMONT PROVINCE

POTENTIAL GEOLOGICAL FIELD STUDY AREAS

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PLATE 10

BIBLIOGRAPHY

BIBLIOGRAPHY

This section contains a partial bibliography of Piedmont geologic literature. The intent of this bibliography is to provide a basis for additional studies in those areas designated as showing "favorable" or "potentially favorable" siting potential for deep geologic disposal of radioactive wastes.

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APPENDICES

APPENDIX A

PHYSICAL AND MECHANICAL PROPERTIES OF ROCK

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PHYSICAL AND MECHANICAL PROPERTIES OF ROCK

The qualitative descriptions of the various physical and mechanical properties of rock listed in Table 3 are defined quantitatively in this Appendix. The numerical values given are taken from recognized engineering references but, in the context of this report, are intended to indicate orders of magnitude and provide guidelines for further studies.

COMPRESSIVE STRENGTH*

Description	Uniaxial Compressive Strength	
	MPa	lbf/in^2
Very High	>220	>32,000
High	110 - 220	16,000 - 32,000
Medium	55 - 110	8,000 - 16,000
Low	28 - 55	4,000 - 8,000
Very Low	>28	>4,000

MODULUS OF ELASTICITY*

On the Basis of Modulus Ratio ($E_t/\sigma_{a(ult)}$)

Description	Modulus Ratio**
High Modulus Ratio	>500
Average (Medium) Ratio	200 - 500
Low Modulus Ratio	>200

*After: Deere, D.U. & R.P. Miller, 1966, *Engineering classification and index properties for intact rock*, Tech. Rept. No. AFWL-TR-65-116, Air Force Weapons Lab., Kirtland Air Force Base, New Mexico.

**Modulus Ratio = $E_t/\sigma_{a(ult)}$ where Et = tangent modulus at 50% ultimate strength

$\sigma_{a(ult)}$ = ultimate uniaxial compressive strength

Rock Density

The density of a substance is the mass per unit volume and reflects the nature of the atoms in the structure and manner in which they are packed together. The more dense a rock, the more mass per unit volume is provided in offering shielding against radioactivity. In general, igneous and metamorphic rocks are more dense than sedimentary rocks. Below is a list of some of the more common rocks and their approximate densities:

Rock	Specific Gravity
Gabbro	2.97
Basalt	2.87
Diorite	2.87
Anorthosite	2.75
Granite	2.66
Rhyolite	2.49

Rock Quality

Rock quality is here defined by Rock Quality Designation (RQD) and is based on a modified core recovery procedure which, in turn, is based indirectly on the number of fractures and the amount of softening or alteration in the rock mass as observed in the rock cores from a drill hole. RQD is obtained by summing up the total length of sound rock core recovered from a single core run (usually 150 cm (60 ins)), and expressing that sum as a percentage of the total core run. Sound core is defined as those pieces of core which are 10 cm (4 ins) or more in length and which are hard and sound.

RQD	Description of Rock Quality
0-25	Very Poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

*After: Deere, 1966

Rock Material Strength*

Description	Field Estimation of Hardness
Very Strong	Very hard rock - more than one blow of geological hammer required to break specimen.
Strong	Hard rock - hand-held specimen can be broken with single blow of geological hammer.
Moderately Strong	Soft rock - 5mm (¼") indentations with sharp end of pick
Moderately Weak	Too hard to cut by hand into a triaxial specimen.
Very Weak Rock or Hard Soil	Brittle or tough, may be broken in the hand with difficulty.

*After: Report by the Geological Society Engineering Group, Working Party; the Description of Rock Masses for Engineering Purposes: Quat. J. Engng. Geol., 1977, v. 10, No. 4, p. 355-388.

Joint Spacing*

Descriptive Term	Spacing of Joints	
Very Close	<5 cm	<2 ins
Close	5 - 30 cm	2 - 12 ins
Moderately Close	30 - 100 cm	1 - 3 feet
Wide	1 - 3m	3 - 10 feet
Very Wide	>3m	>10 feet

*After: Deere, 1966