DP-1559

EXECUTIVE SUMMARY

REVIEW OF POTENTIAL HOST ROCKS FOR RADIOACTIVE WASTE DISPOSAL IN THE SOUTHEASTERN UNITED STATES

H. W. BLEDSOE, JR.
I. W. MARINE

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

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ABSTRACT

The geology of the southeastern United States was studied to recommend areas that should be considered for field exploration in order to select a site for a radioactive waste repository. The region studied included the Piedmont Province, the Triassic Basins, and the Atlantic Coastal Plain in Maryland, Virginia, North Carolina, South Carolina, and Georgia. This study was entirely a review of literature and existing knowledge from a geotechnical point of view and was performed by subcontractors whose individual reports are listed in the bibliography. No field work was involved. The entire study was geotechnical in nature, and no consideration was given to socioeconomic or demographic factors. These factors need to be addressed in a separate study.

For all areas, field study is needed before any area is further considered. A total of 29 areas are recommended for further consideration in the Piedmont Province subregion: one area in Maryland, 8 areas in Virginia, 4 areas in North Carolina, 6 areas in South Carolina, and 10 areas in Georgia. Of the 14 exposed and 5 buried or hypothesized basins identified in the Triassic basin subregion, 6 are recommended for further study: one basin in Virginia, 3 basins in North Carolina, and 2 basins in South Carolina. Four potential candidate areas are identified within the Atlantic Coastal Plain subregion: one in Maryland, one in North Carolina, and 2 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 southeastern United States. For the purposes of this study, this area 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 characteristics and suitability for disposal of solidified high-level radioactive waste.

The results of the study of the Southern Piedmont by Acres American, Inc. of Buffalo, New York, is given in DP-1567; that of the Southeastern Coastal Plain by Ebasco Services, Inc. of Greensboro, North Carolina, in DP-1568; and that of the Southern Triassic basins by Dames and Moore of Atlanta, Georgia, in DP-1569. Because of the geologic complexity of the Piedmont and its generally high potential for waste storage, the general study 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 this summary report (DP-1559).

All the reports listed above were sent to the State Geologists of the states involved for their technical review prior to publication. Their detailed technical or editorial points are incorporated as necessary into the respective report to which they apply. The substantive portions of the reviews are published with comments in an appendix to this report.

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REVIEW OF POTENTIAL HOST ROCKS FOR RADIOACTIVE WASTE DISPOSAL IN THE SOUTHEASTERN UNITED STATES

1.0 INTRODUCTION AND SCOPE

A demonstrated solution to the problem of the permanent disposal of high-level waste from the nuclear fuel cycle is considered very important to the acceptance of nuclear power as an energy alternative. The light water reactor nuclear fuel cycle necessitates the terminal disposal of nuclear wastes. The fuel cycle (Figure 1) consists of several steps, the first of which is mining the uranium. The uranium then passes through several steps to convert it to fuel, which is placed in a reactor. There it generates heat to produce steam to generate electricity. After the fuel has been discharged from the reactor, it is placed in a fuel storage pool. From this point, the spent fuel can either be disposed of by some method or reprocessed. If reprocessed, the waste from this operation must be disposed of also. In either case the waste, either spent fuel or from reprocessing, must be isolated from the biologic environment for many centuries.

The major question that has delayed a demonstrated solution has not been one of the technology to treat or handle the waste, but of where to dispose of the radioactive waste so that it will not constitute a public risk. A number of alternatives have been suggested and investigated in various degrees including:

- extraterrestrial disposal
- seabed disposal
- ice sheet disposal
- deep geologic disposal

The alternative that appears to offer the most promising capability for long-term isolation of waste, and the one that has received the most attention and detailed investigation, is that of permanent disposal in the geologic environment; specifically, the placement of the waste in a mined cavity in the subsurface that would isolate it from the biosphere for sufficient time to make the risk to man insignificant. Rock types under investigation as possible host media are salt, basalt, granite, argillaceous formations, limestone, chalk, and tuff. The rock type that has received the most consideration is rock salt (both bedded and domal).

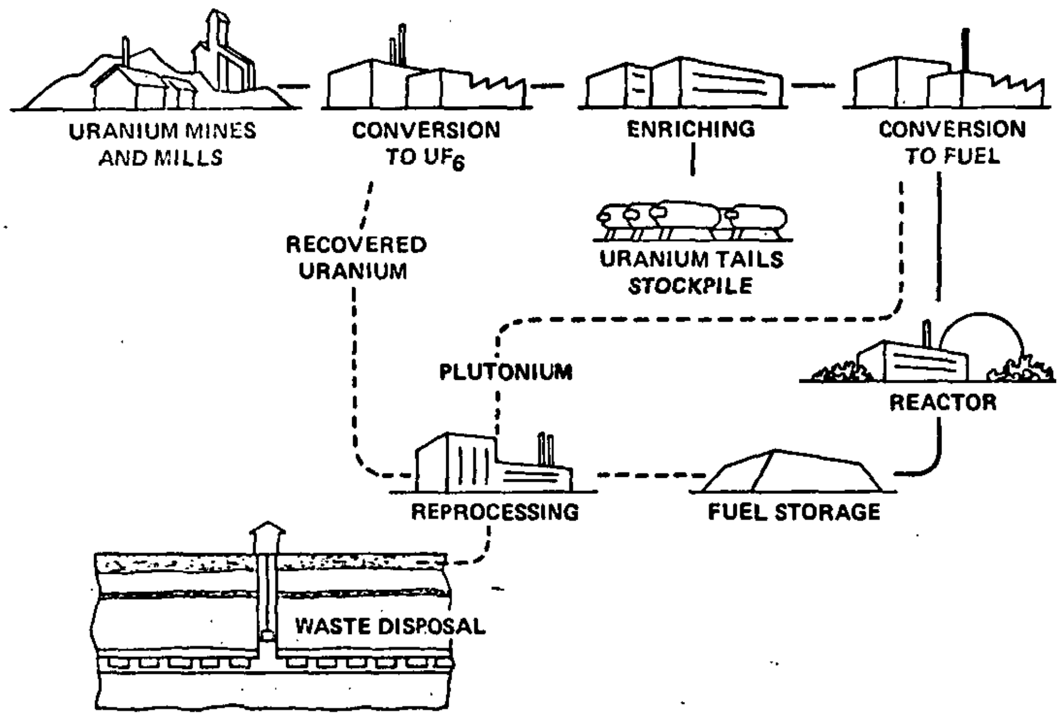

FIGURE 1. The Nuclear Fuel Cycle

Demonstrating the safety of placing waste in the geologic environment is the subject of the National Waste Terminal Storage (NWTS) program. The NWTS program was instituted in 1976. The objective is to provide federal facilities (repositories) in various deep geologic formations at multiple locations in the United States, in which commercial or government produced radioactive waste can safely be stored. The planned program consists of a general development sequence.

- Identification of formations of interest
- Regional survey of existing knowledge
- Selection of field-study areas
- Field studies in selected areas to confirm regional information
- Selection of potential sites
- Detailed confirmation studies
- In-situ tests
- Pilot repository construction

A particular area or formation may be eliminated from further consideration by results obtained during any phase.

Part of the NWTS program is being coordinated by the Office of Nuclear Waste Isolation (ONWI) of Battelle in Columbus, Ohio. As part of this national program, the Savannah River Laboratory (SRL) conducted a literature study of the southeastern United States with the aim of designating areas with sufficiently high geotechnical potential to warrant consideration for field investigation.

The potential host rocks studied in the Southeast were: argillaceous rocks such as mudstone, shale and clay; intrusive igneous rocks such as those of the granite and gabbro families; and metamorphic rocks such as gneiss, schist, and phyllite. The subregions covered by these studies are the Piedmont Province, the Triassic sedimentary basins, and the Atlantic Coastal Plain Province in the coastal states from Maryland to Georgia (Figure 2).

Regional geologic literature reviews of the three subregions were conducted under separate contracts issued by SRL. Acres American, Inc. conducted the initial review of the Piedmont Province; Dames & Moore investigated the Triassic basins; and Ebasco Services, Inc. reviewed the southeastern Atlantic Coastal Plain Province. However, due to the complexity of rocks within the Piedmont Province, supplemental studies were conducted on a state by state basis by professors of geology from leading southeastern universities. Dr. William R. Brown of the University of Kentucky reviewed the Piedmont Province in Maryland and Virginia. Dr. J. Robert Butler of the University of North Carolina reviewed the North Carolina Piedmont Province. Dr. Donald T. Secor, Jr. of the University of South Carolina reviewed the South Carolina Piedmont Province. Dr. David B. Wenner and Kenneth A. Gillon of the University of Georgia reviewed the Georgia Piedmont Province.

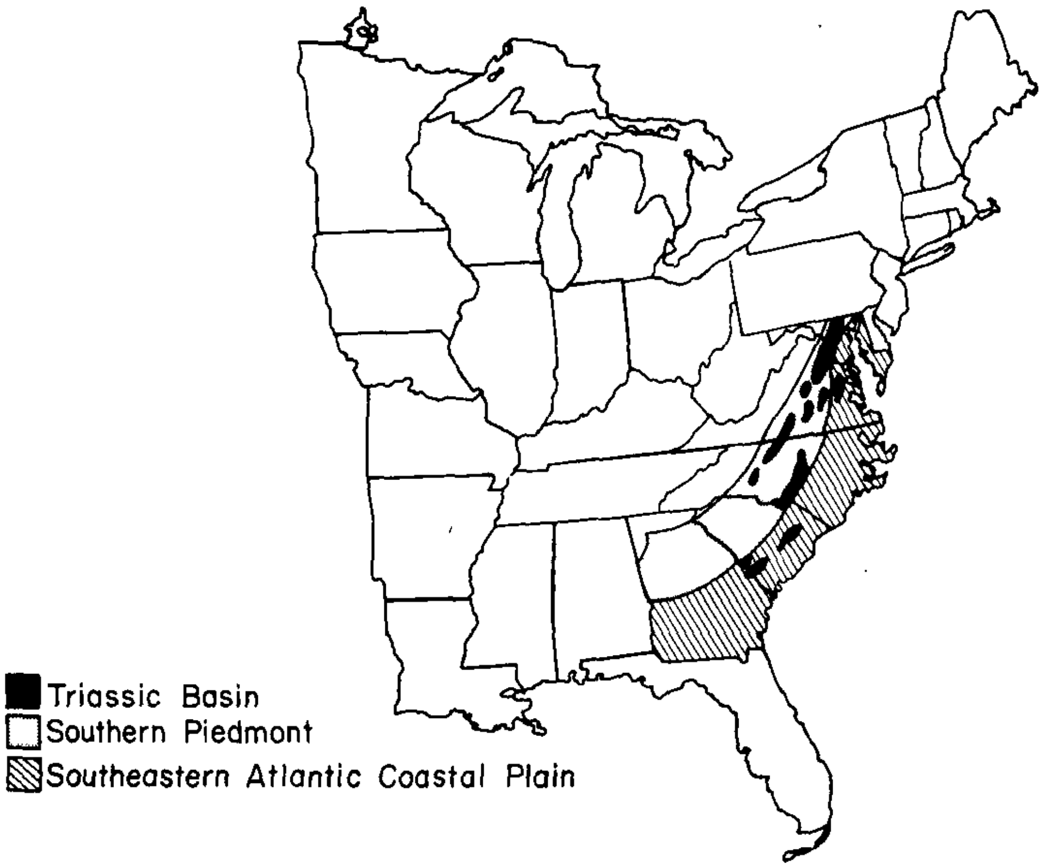

FIGURE 2. Geologic Subregions Studied in the Southeastern United States

This report summarizes the approach and findings of these studies whose primary objective was to review the present knowledge on the subregions and to identify potential host rocks and candidate areas for additional geologic field studies. The investigations in the southeastern United States reported in this summary are limited to regional reconnaissance by literature studies. No field studies are included.

Socioeconomic and field studies would represent other phases in a progressive study to determine the suitability and safety of establishing a repository in these rocks to contain radioactive waste and prevent it from reaching the biosphere.

Engineering, construction, and socioeconomic restraints associated with the development and operation of an underground storage repository are not considered within this report but will have to be addressed in future studies.

The immediate purpose of this study was to provide the basic geologic and hydrologic data on potential host rocks within each subregion such as depth, thickness, homogeneity, fracture density, etc. This work included a review of published and unpublished geologic reports and maps including theses and industrial studies. State and Federal Geological Surveys were consulted for their most recent work in the subregions, and discussions were held with persons knowledgeable in the geology of the subregions. Follow-on tasks would consist of surface geological, geophysical, and hydrological testing to confirm the conceptual model of the area. From this testing, a site would be selected for more site-specific tests.

2.0 CRITERIA AND ROCK CHARACTERISTICS

2.1 Criteria

The objective of placing radioactive waste in a geologic environment is to contain and isolate the waste from the biosphere and to insure that radionuclides from the waste cannot migrate to the biosphere in amounts which will exceed applicable dose limits. Each prospective repository location must be carefully studied and evaluated to establish the unique geologic aspects peculiar to that specific area. The relative suitability of a specific site within a candidate area can be determined only after its characteristics are determined from detailed field investigations.

The selection of an area that might contain a suitable site for a radioactive waste repository requires the existence of a geologic formation possessing certain physical and chemical characteristics, hydrologic properties, and structural stability.

The following list of important geologic and hydrologic characteristics which are applicable to any region or rock type were developed and provided to the subcontractors to aid in the selection of candidate field-study areas after the information on potential host rocks in the Southeast were obtained. These criteria were used during the reviews of the subregions of the Southeast.

- The areal extent and thickness of the geologic formation should be sufficient to contain the necessary structures for a repository, and to ensure containment of the waste. Because this study did not focus on siting a repository but on locating areas suitable for field study, the size of the designated areas were several times larger than required to contain a repository. As a rough guide, it was suggested that the recommended areas be larger than 100 square kilometers.

- The depth below ground surface should be sufficient to isolate the formation from any externally imposed environmental changes and deep enough to be in a region of extremely slow ground-water circulation. On the other hand, the depth should not be so great as to impose extremely large in-situ rock stresses on the facility. As a rough guide, it was suggested that the host rock should be between 300 and 1500 m deep.

- The formation should be homogeneous. Homogeneity is desirable because it enhances the ability to extrapolate information obtained during the exploration phase. Zones of heterogeneity also tend to be avenues of ground-water migration.

- Bedding in sedimentary rocks should be relatively flat. Flat lying bedding indicates little structural deformation. Extrapolation of geologic and hydrologic characteristics is more difficult in structurally deformed areas.

- The area should be tectonically stable and be located in a zone of low seismicity, removed from active or capable faults. With the exception of the areas around Charleston, South Carolina, seismicity was not a major consideration in the southeastern United States.

- The formation should have properties that would ensure a stable excavation. In general, most metamorphic and igneous rocks in the Piedmont Province subregions fulfill this consideration. More attention needs to be given to stability in the Triassic Basin subregions; and in the Atlantic Coastal Plain, stability becomes a major consideration.

- The geologic host formations should be of extremely low permeability and be surrounded by formations that permit no unacceptable leakage to the biosphere. These conditions should be simple and determinable. This information was generally not available for the depths of interest. Commonly, even indirect information from which a qualitative evaluation of the permeability could be made was not available. Even though these criteria are of great importance, they could not always be applied using information available from literature studies.

- The chemical exchange characteristics of the formation should favor containment. Ion exchange information was generally lacking on specific rocks, thus was not an influencing consideration in selecting study areas. In general, however, host rocks with high clay content have greater ion exchange capabilities than rocks with low clay content.

- The thermal conductivity of the rock should be high. In general, this information was not available in detail for specific host rocks and so was not an influencing consideration in selection of areas. The thermal conductivity of the crystalline rocks is generally higher than that of clay-rich rocks.

- The formation should be resistant to chemical or mechanical alterations. In general, the rocks studied do not show large differences in chemical resistance. However, the rocks of the Piedmont are far more resistant to mechanical deterioration than the rocks of the Coastal Plain and are somewhat more resistant than the rocks of the Triassic basins.

- The area should not possess high in-situ stresses. Information on in-situ stresses is not generally available and will have to be determined during a subsequent phase of investigation.

- The area should not contain minerals or other resources of current or projected value. Information on current and estimated reserves of mineral resources is generally available and was used in evaluating the areas.

- The area should be removed from high exposure to current or projected activities of man. This subject was not addressed in this geotechnical study, except as it may relate to mineral resources. A subsequent socioeconomic study of the recommended areas should properly address this subject.

These criteria were expanded (where necessary) by the subcontractors to apply to the individual characteristics of the subregions being investigated.

It should be realized that, in most cases, specific information could not be obtained from a literature review and only with detailed field work can these considerations be properly addressed. However, it was necessary to establish these general guidelines for consideration in pursuing this investigation.

2.2 Generic Characteristics of Rock Types

Each of the potential types of host rocks has its own respective physical and chemical properties that influence the design of a mined underground repository. These characteristics not only vary from rock type to rock type but also are site-specific.

Crystalline rocks of interest are primarily massive siliceous rocks of either magmatic or high-grade metamorphic origin. These rock types consist essentially of quartz, alkali feldspar (microcline, orthoclase, perthite), plagioclase feldspar, and mica. The advantages for repository development in these rocks include: the absence of bedding, high strength, low primary permeability, general homogeneity, and the probable thermal stability due to their original high temperature of formation. Homogeneity of large bodies of crystalline rock, especially large granite plutons, is a very desirable feature because homogeneity simplifies design, increases predictability of properties, and enhances stability of an excavation. Also, large volumes within these rock bodies can be found that are relatively free of economic mineralization, thus minimizing the possibility of exploration or exploitation activities.

Disadvantages of crystalline rocks are: 1) they may have fractures, joints, or shear zones that lower the strength of the overall rock mass and also provide passageways for water flow, 2) well-developed foliation planes in gneisses may make the rock mass behave anisotropically.

Argillaceous rocks are sedimentary deposits consisting of a mixture of clay, silt, and sand sized sediments which may be soft and unlithified (soil-like) or relatively hard and lithified (rock-like). In this study, the term "argillaceous rock" includes clays, silts, shales, siltstone, mudstone, claystone, and argillaceous sandstone. The diffent names are based primarily on the percentages of the clay and silt-size particles and the degree of induration or cementation. Favorable physical and chemical properties of argillaceous rocks include: low permeability, relatively high plasticity, high ion exchange capacity, and (for some formations) persistent vertical and lateral homogeneity.

Disadvantages of argillaceous rocks are: 1) relatively low strength; 2) the possibility of structural instability, such as heaving, associated with the presence of montmorillonite clay; and 3) combustible gases associated with some organic shales. In some circumstances, the presence of contiguous sand beds that may be aquifers or oil or gas reservoirs could encourage well drilling. Some areas contain many thousands of feet of argillaceous material, but are characterized by abrupt vertical and lateral changes in thickness, texture, and composition. This heterogeneity makes extrapolation between widely spaced data points difficult and uncertain.

The storage of nuclear waste in deep geologic formations requires the excavation and construction of large-diameter shafts for transporting men, materials, and nuclear waste, as well as supplying ventilation. The maximum depth and suitability of the host formation for acceptable isolation is site dependent. The maximum depth is governed by the relationship of the lithostatic pressures (the weight of the rock column above the storage facility) to the overall host-rock strengths. Lithostatic pressures increase with increasing depth. As depth is increased, these pressures approach the compressive strength of the host rock and the stability of the repository openings could be endangered. The major factor in determining rock competence for shaft excavation and mine stability is not the laboratory strength of the rock, but the presence of discontinuities in the rock mass, e.g., bedding planes, foliations, and the joint and fracture systems. Massive, lower-strength material is more desirable than a high-strength material that has a high density of joints, fractures, or shears.

Construction of shafts and a mined repository is appreciably more difficult in unconsolidated material such as that in the Atlantic Coastal Plain. The lack of induration of sediments directly above the mine and around the shafts could cause surface subsidence. Another consideration in the design, construction, and operation of a facility in certain areas of the Atlantic Coastal Plain is "squeezing ground," a phenomenon which occurs when the confining pressure on sediments is released by excavation. As the confining pressure is reduced, pore pressure causes sediments to "squeeze" into the excavated area. Also, thick sand aquifers may be encountered during shaft excavation, creating engineering difficulties.

Geotechnical conditions will exert a major influence on the design and construction of the waste facility and on the amount of waste that can be stored. The rock surrounding and overlying the repository will react in response to the stresses imposed by the mined excavation and by the thermal loading of the waste. The mined opening will cause the surrounding rock to move inward depending on its strength, while thermal loading will expand the rock causing heaving. Thus, the strength and other physical properties have a large influence on the suitability of the rock.

The most important property, however, is the permeability of the rock mass because movement of groundwater is the most likely avenue of escape for radionuclides contained in the disposal facility. Except for general characteristics of various rock types, there is little site-specific information on this topic in the literature. These properties must be determined by a field exploration program. The most that can be achieved with a literature study is to indicate areas where the potential of finding suitable conditions may be higher than elsewhere.

3.0 DESCRIPTION OF SUBREGIONS

The region under investigation is the southeastern United States including portions of the states of Maryland, Virginia, North Carolina, South Carolina, and Georgia. The study region lies within two physiographic provinces, the Piedmont Province and the Atlantic Coastal Plain, and includes the series of northeast-trending Triassic Basins located within both provinces. The following is a brief description of the geology of these three broad subregions.

3.1 Piedmont Province of the Southeast

The geologic history and tectonic framework of the Southeastern Piedmont Province is complex and only partially understood. The tectonic history has been complicated by multiple periods of deformation, metamorphism, and intrusion which occurred at varying times in different parts of the Piedmont. Table 1 is a generalized timetable of the major recognized events. The earliest post-Grenville (<1000 m.y.) age deformations appear to be related to the Virgilinian orogenic event that occurred during the late Precambrian Era or the early Cambrian Period. This event produced folding, volcanic, and plutonic activity. The next major deformation occurred during Ordovician and Silurian times and is related to the Taconic orogeny. The Taconic orogeny was followed by the Acadian orogeny in the Devonian to early Carboniferous Periods. A compressional event accompanied by local thrusting, mylonitization, metamorphism, and plutonic activity occurred in the southern Appalachians in late Carboniferous (Pennsylvanian) or Permian time and is called the Alleghenian Orgeny.

In the early Triassic Period, when extensional forces related to the postulated rifting of Africa from North America predominated, widespread zeolitization occurred. By late Triassic or early Jurassic time, fault basins accumulating terrestrial sediments were widely developed, and diabase igneous intrusions were abundant. Since Triassic time, the region has undergone periodic uplift and erosion.

The structure of the Piedmont Province has been complicated by multiple periods of deformation and metamorphism which have obscured many of the older premetamorphic structural features. Generally, the rocks of the Piedmont Province are mapped as a series of large anticlinoria and synclinoria which trend in a northwest-southeast direction. Large faults that have been mapped

TABLE 1

General Ages of Tectonic, Metamorphic, and Igneous Events in the Southeastern Piedmont Province

Era		*Period*	*Major Orogenic Events*	*Recognized Plutonic Events*	*Major Metamorphic Periods*
Cenozoic		Quaternary and Tertiary			
Mesozoic	100	Cretaceous			
		Jurassic			
	200	Triassic			
Paleozoic		Permian			
	300	Carboniferous	Alleghenian	Throughout Piedmont	Regional Amphibolite Grade Metamorphism
	400	Devonian	Acadian	Inner Piedmont	Greenschist Grade Metamorphism
		Silurian		Charlotte Belt	
		Ordovician	Taconian		Greenschist and Amphibolite Grade
	500	Cambrian		Charlotte and Carolina Slate Belt	Amphibolite Grade Metamorphism of Charlotte Belt
Precambrian	600		Virgilinian		
	700				
	900				
	1000		Grenvillian		

are generally considered to be post-metamorphic and post-folding (Hatcher, 1972). The major pre-Triassic (>230 million years ago) faults are the Brevard Zone, Towaliga, Goat Rock, Gold Hill, and a recently mapped fault system that passes beneath segments of the Atlantic Coastal Plain in the Carolinas, and continues into Virginia (Figure 3). Normal faults commonly bound the Triassic Basins in the Piedmont Province.

Igneous activity within the southern Piedmont occurred over a wide time period during the Paleozoic era (Table 1). Intrusive activity occurred before, during, and after regional metamorphism. Based on age data, the major plutonic activity occurred between approximately 595 and 250 million years ago. The oldest and youngest plutons are in the southeast portion of the Piedmont Province with the oldest plutons found in the Charlotte Belt. Most of the Late Paleozoic granite intrusions (325 to 265 m.y.) in the Charlotte and Carolina Slate Belts have not been deformed; however in the Kiokee Belt, Late Paleozoic granites were highly deformed during regional amphibolite facies metamorphism.

The Piedmont Province generally falls within Seismic Zone 2 (Uniform Building Code), indicating an area that may be subject to moderate damage corresponding to an intensity of VII on the Modified Mercalli (MM) scale. Generally, the Piedmont Province is considered to have low-to-moderate seismicity. There are no known active faults within the region, and no seismic activity has been associated with any mapped structural feature.

The crystalline rocks of the Piedmont Province are divided into a number of northeast-trending belts that generally follow the regional structural features (King, 1955). The belts are defined on the basis of rock type, structure, and metamorphic grade or mineral facies. From west-to-east, the major belts are the Inner Piedmont, Kings Mountain, Charlotte, and Carolina Slate, but there are a number of smaller belts recognized locally. The boundaries between the belts are not always sharp, but may be gradational in character. These belts and their locations are shown in Figure 4 and will be discussed generally from west-to-east.

Brevard Zone. The Brevard Zone represents a major zone of cataclasis of regional extent, characterized by one or more ductile and one or more brittle deformations. The zone extends for about 500 km (300 mi), from the Atlantic Coastal Plain overlap in Alabama to northwestern North Carolina, where it changes character and merges with other tectonic units. The Brevard Zone defines the western boundary of the Piedmont Province.

Inner Piedmont Belt. The Inner Piedmont Belt is the widest of the belts. It is bordered by the Brevard Zone on the west and by the Kings Mountain Belt on the eaasst (where present). The belt extends from Georgia through most of North Carolina. It has not

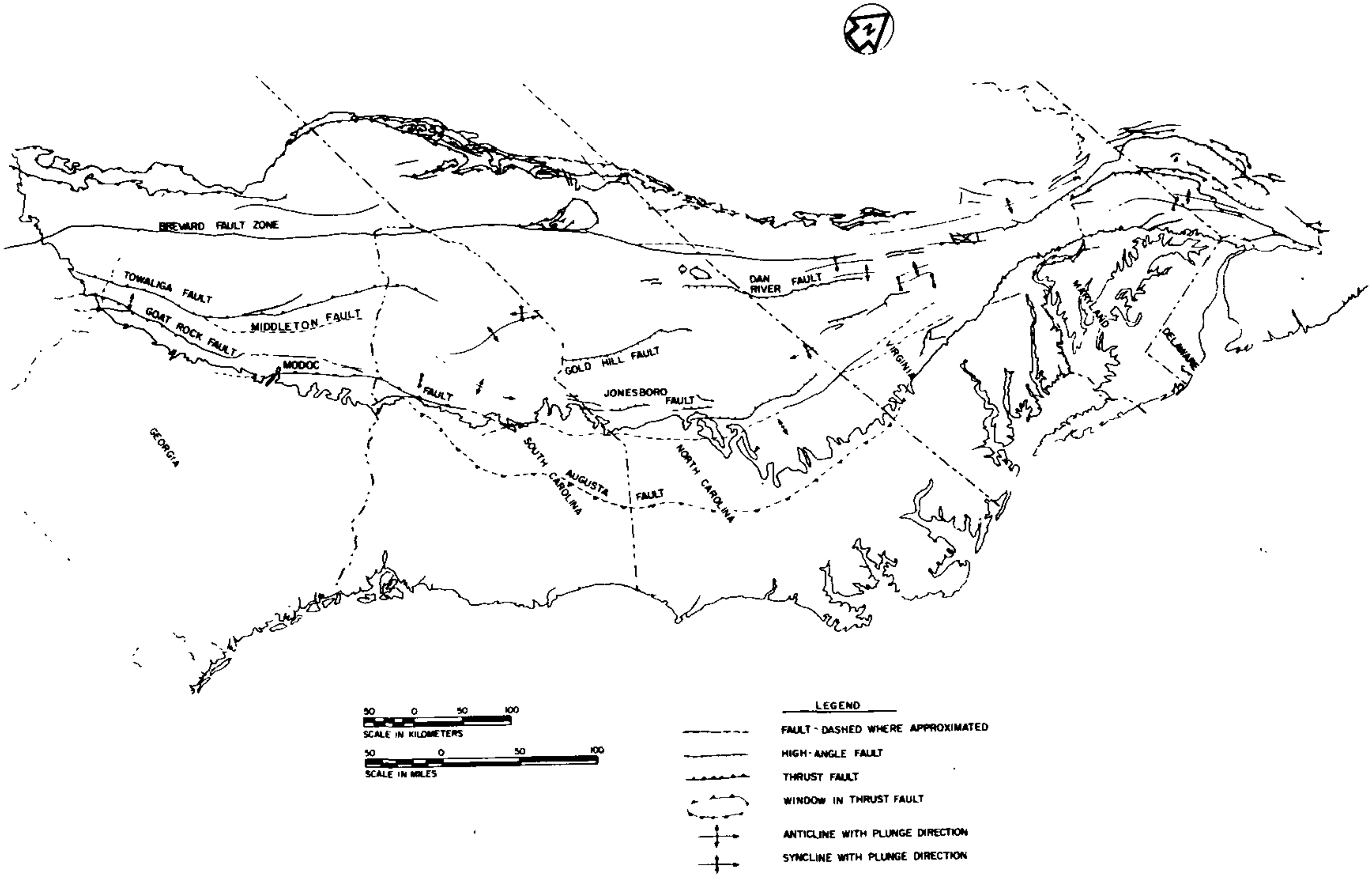

FIGURE 3. Generalized Tectonic Map of the Southeastern United States

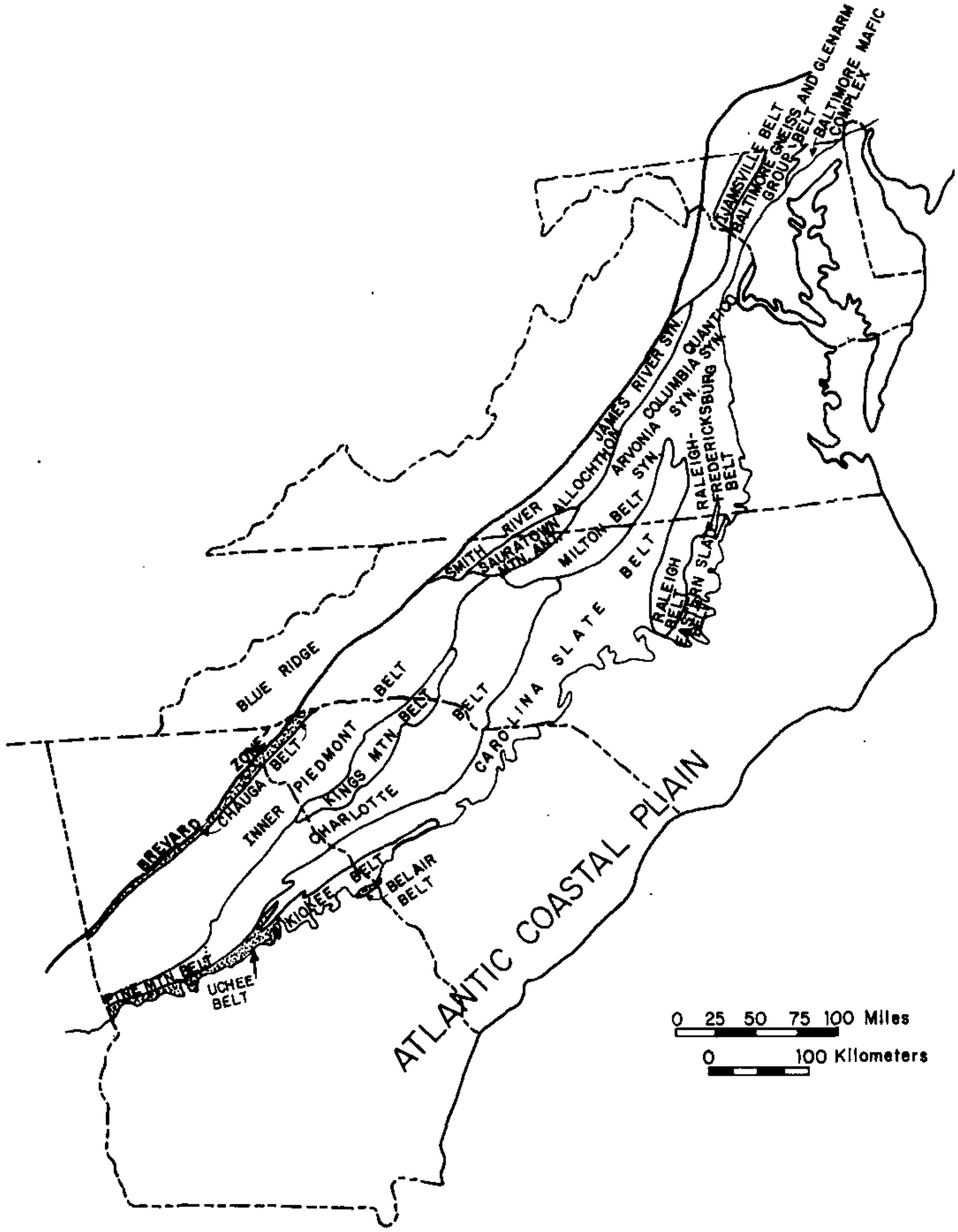

FIGURE 4. Metamorphic Belts in the Southeastern Piedmont Province

been recognized as such in Virginia, but its rocks may be represented in the Smith River allochthon. The belt is composed of two general rock types (Hatcher, 1972). One rock type is a belt of low-to-medium grade metasedimentary and metavolcanic rocks, mainly graphitic phyllite, chlorite-muscovite phyllite, impure marble, quartzite and quartz feldspathic augen gneiss; and which lies immediately southwest of the Brevard Zone, and narrows southward into Georgia and Alabama. The other rock type is a wider belt of deformed and high-grade granitic gneisses, amphibolite-hornblende gneiss, biotite gneisses, schists, and metagraywackes.

Kings Mountain Belt. The Kings Mountain Belt lies in the central part of the Piedmont Province, primarily in South Carolina and North Carolina. The belt includes metamorphic rocks that range from siliceous and calcareous metasediments to feldspathic, micaceous, and hornblende schists and gneisses. Three types of instrusive igneous rocks (quartz monzonite, biotite granites, and diabase) occur in this belt. The metamorphic rocks of this belt are medium-to-low grade. The Kings Mountain Belt probably extends across North and South Carolina, but its continuity is obscured by major intrusive bodies and metamorphic alteration.

Charlotte Belt. The Charlotte Belt comprises a broad central part of the Piedmont Province from Georgia to Virginia. Generally, 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. Foliation of the granitoid rocks probably represents 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. Locally, the grade of regional metamorphism rises to the staurolite-kyanite subfacies. 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. The youngest intrusive rocks include gabbro, diorite, and syenite. The belt also contains swarms of mafic dikes that may have been feeders for volcanic flows.

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

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 southern Virginia southwestward to central Georgia. The age of these rocks is generally considered to be of early Paleozoic age

(550 million years ago). The belt is generally bounded on the west by medium-grade metamorphic rocks belonging to the Charlotte Belt, and to the east by the unconsolidated sediments of the Atlantic Coastal Plain. Rocks of the Carolina Slate Belt compose much of the eastern Piedmont Province and crop out in large sections 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. Most were emplaced during middle to late Paleozoic time.

In addition to these major belts described by King (1955), there are a number of less extensive belts defined by local workers. These belts are described from north-to-south and from west-to-east. Their locations are shown on Figure 4.

Ijamsville Belt. The Ijamsville Belt extends in a northeastward direction across the state of Maryland just east of Frederick Valley. Rocks within this belt consist mainly of argillaceous phyllites and impure quartzite with lesser amounts of greenstone, metarhyolite, and marble.

Baltimore Gneiss and Glenarm Group Belt. This is the largest single belt in the Maryland Piedmont Province, extending northeastward across the state and lying between the Ijamsville Belt on the west and the Baltimore mafic complex on the east. The dominant feature of this belt is the cluster of seven mantled gneiss domes which occur along or near the crest of the Baltimore-Washington anticlinorium in the eastern part of the belt. Felsic and mafic igneous intrusions occur scattered throughout the belt.

Baltimore Mafic Complex. The Baltimore mafic complex lies to the east of the Baltimore gneiss and consists basically of variably metamorphosed felsic to ultramafic, plutonic, and volcanic rocks along the southeastern part of the Maryland Piedmont Province from Bethseda, Maryland, (north of Washington, D.C.) northeastward into Pennsylvania.

Arvonia, Columbia, and Quantico Synclinoria. The Arvonia, Columbia, and Quantico synclinoria are located in the central and extreme northeastern Piedmont Province of Virginia. They are narrow complex belts of graphitic slate and schist. The largest and best known is the Arvonia synclinorium located in the central Piedmont Province and extending a distance of approximately 74 km (46 mi). The Columbia synclinorium and the Quantico synclinorium are located generally northeast of the Arvonia synclinorium.

James River Synclinorium. The James River synclinorium, located in the westernmost Piedmont Province of Virginia, is a low-grade metamorphic zone underlain by phyllites, schists, impure marbles, quartzites, and metavolcanics (greenstone).

Smith River Allochthon. The Smith River allochthon is a very large, fault-bounded block of the Piedmont Province. It lies mostly in Virginia, but extends a short distance into North Carolina. Rocks in this allochthon are mostly high-rank gneiss, schist, and amphibolite, intruded by felsic and mafic plutons.

Sauratown Mountains Anticlinorium. The Sauratown Mountains anticlinorium lies mainly in North Carolina, but extends about 19 km (12 mi) into Virginia. This large anticlinorium is bounded on the northwest by the Smith River allochthon, and on the east and southeast by the Dan River Triassic Basin and the Charlotte Belt, and on the southwest by the Inner Piedmont. Lithologically, the anticlinorium contains granites, gneisses, schists, and quartzites intruded by granitic plutons.

Raleigh Belt. Metamorphic rocks within the Raleigh Belt of North Carolina generally fall within the greenschist facies. The belt is bounded on the west and northwest by the Carolina Slate Belt and the Deep River Triassic Basin, and on the east by the Eastern Slate Belt. Dikes and sills of granite, pegmatite, and aplite are abundant. The huge Rolesville Batholith occupies nearly half of the belt in North Carolina.

The Raleigh-Fredericksburg Belt of Virginia is essentially a northward continuation of the Raleigh Belt and the Eastern Slate Belt of North Carolina, and includes the late Paleozoic plutons of the easternmost Piedmont Province of Virginia. In central Virginia, beyond the end of the Carolina Slate Belt, it merges with and is not readily separable from the Charlotte Belt to the west.

Eastern Slate Belt. The Eastern Slate Belt in North Carolina is a zone of low-rank metasedimentary and metavolcanic rocks located east of the Raleigh Belt and is bounded on the east by the Atlantic Coastal Plain. Rocks within the belt are similar to those found in the Carolina Slate Belt and consist mainly of volcaniclastics including some mafic flows, conformable granitic bodies, and mafic-ultramafic complexes.

Milton Belt. The Milton Belt is an area of the Piedmont Province in north-central North Carolina and adjacent Virginia that was formerly considered part of the Charlotte Belt. The Milton Belt is characterized by strongly foliated gneiss and schist, commonly showing compositional layering and having felsic composition. The belt is bounded on the southeast by the Carolina Slate Belt and on the northwest by the Dan River Triassic Basin.

The southwestern boundary is placed where gneiss and schist units give way to mafic-to-felsic intrusive rocks characteristic of the Charlotte Belt. The major structure is interpreted as a large, refolded, antiformal nappe that is rooted near the boundary of the Carolina Slate Belt.

Chauga Belt. The Chauga Belt is a relatively small feature located in northwestern South Carolina and northern Georgia. The belt is bounded on the northwest by the Brevard Zone and on the southeast by the Inner Piedmont Belt. The basic structure of the Chauga Belt is that of a multiply-deformed synclinorium. The belt contains a sequence of low-to-medium grade metasedimentary and metaigneous rocks that grade into and are continuous with the mylonitic rocks in the Brevard Zone.

Kiokee Belt. The Kiokee Belt is a complex zone of amphibolite facies metasedimentary and felsic metaigneous rocks that extend along the Fall Line in South Carolina from the vicinity of Lake Murray into eastern Georgia. The belt is bounded to the north by the Modoc Fault, a major zone of cataclasis.

Belair Belt. The Belair Belt is a small zone of greenschist facies metasedimentary and metavolcanic rocks that crop out along the Savannah River in Georgia and South Carolina. The belt lies adjacent to higher grade rocks of the Kiokee Belt to the northwest.

Pine Mountain Belt. This belt outcrops as an antiformal structure in central Georgia and is bounded by the Towaliga Fault to the northwest and Goat Rock fault to the southeast. It is composed of amphibolite grade gneisses, schists, and quartzites lying uncomformably upon a basement of orthogneisses and charnockites.

Uchee Belt. The Uchee Belt is a narrow zone of amphibolite grade migmatitic gneisses, amphibolites, and schists located south of the Pine Mountain Belt in western and central Georgia. The rocks are similar in composition to those of the Inner Piedmont Belt north of the Pine Mountain Belt.

3.2 Triassic Basins of the Southeast

The Triassic basins along the east coast of North America are long, narrow, northeast-trending structural troughs that occur from Florida to Nova Scotia. The basins have generally been filled with thousands of feet of continental clastic deposits of alluvial, lacustrine, and paludal origin. Fourteen exposed Triassic basins within the subregion are reported in the literature along with several buried or hypothesized basins. In addition, there are several localities where probable Triassic rocks have either been encountered in deep borings or infered by geophysical methods. The locations of the major Triassic basins are shown on Figure 5.

The sedimentary rocks of the Triassic basins are generally considered to belong to the Upper Triassic Newark Group. They are continental clastic deposits derived from the Paleozoic and Precambrian metamorphic and igneous rocks bordering the basins. The lithologies of the various basins are generally similar. The sediments are predominantly red in color and consist mainly of fanglomerates, conglomerates, arkosic sandstones, siltstones, claystones, shales, and argillites with minor amounts of limestone and coal. The sediments are characterized by abrupt vertical and lateral changes in color, thickness, texture, and composition. Dikes and sill-like masses of diabase are common. Interbedded with the Triassic sediments from the Culpeper Basin north are basalt flows and associated tuffs.

All of the basins that have been investigated in detail are bordered on one or both sides by major normal faults. The strata are tilted toward a major border fault, with local reversals and variations in dip noted near faults and/or large intrusions. The basins are broken into smaller subbasins by longitudinal faults that generally parallel the border faults, and by cross-faults that trend more or less normal to the axis of the basin. It is generally believed that most of the faulting, other than the border faults, occurred after most of the sediments were deposited. The faults are commonly the locations of diabase dikes which intruded the sediments during late Triassic or Early Jurassic time.

From the North Carolina-South Carolina border northward, most of the basins are located within the Piedmont Province and are subaerially exposed. The surrounding Piedmont rocks consist of Precambrian and Early Paleozoic igneous and metamorphic rocks, except in Maryland and where Cambrian and Ordovician carbonates bound parts of the basin. The small Crowburg Basin in northern South Carolina is the southernmost exposure of Triassic rocks in the eastern United States.

Known or suspected buried basins are also found eastward of the exposed outcrops. These Triassic deposits occur beneath younger Atlantic Coastal Plain and Continental Shelf sediments. Geophysical and drillhole data indicate that these basins are found at depths from less than 305 meters (1,000 feet) to more than 1830 meters (6,000 feet) below the ground surface.

The Triassic rocks are more easily eroded than the surrounding pre-Triassic crystalline and metamorphic rocks and are therefore expressed topographically as trough-like lowlands 15 to 16 meters (50 to 200 feet) below the elevations of the adjacent uplands. The dikes which cut the Triassic sedimentary rocks generally form low ridges and divides and, in some areas, have an important influence on drainage patterns.

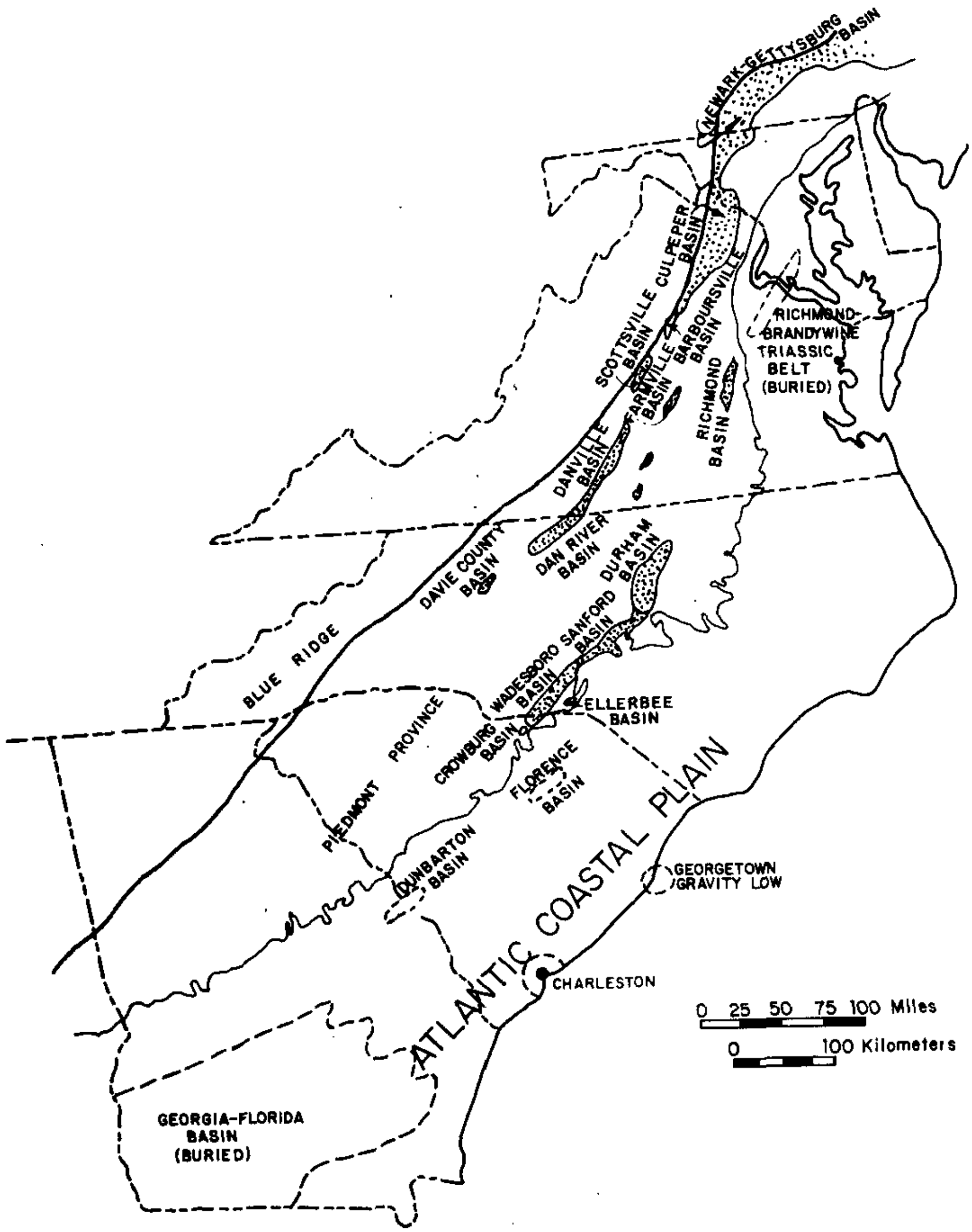

FIGURE 5. Triassic Basins of the Southeastern United States

The Triassic basins of the southeastern United States generally fall within Seismic Zone 2 (Uniform Building Code), indicating an area that may be subject to moderate damage and corresponding to the Modified Mercalli (MM) scale of Intensity VII. There are no known active faults associated with the Triassic basins, and no seismic activity has been correlated with any geologic structures within the basins.

3.3 Atlantic Coastal Plain of the Southeast

The southeastern Atlantic Coastal Plain is formed by gently seaward-dipping Mesozoic and younger sedimentary sequences of sands, clays, and limestones that lie above Triassic/Jurassic rocks or the pre-Mesozoic crystalline basement. The oldest Atlantic Coastal Plain formations are exposed to the west and northwest along the Fall Line. Progressively younger units crop out in roughly parallel bands in a seaward direction, although beds dip and thicken locally in other directions. The regional dip is toward the southeast although there are local variations. Le Grand (1961) noted common characteristics of the sedimentary strata to be: (1) downdip change in lithologic character of many formations from coarse clastic to fine clastic to carbonate facies, (2) downdip thickening of formations, (3) a downdip increase in the number of beds, (4) the unconsolidated nature of the sands and clays except at great depths, and (5) decreasing porosity and permeability with depth.

The surface of the Atlantic Coastal Plain consists of a series of broad, gently eastward-sloping terraces that roughly parallel the present shore line and are separated from one another by steeper scarps. The terraces decrease in elevation, degree of dissection, and age from west to east. The scarps which separate the terraces are highly dissected and not everywhere recognizable. The Atlantic Coastal Plain deposits and the terraces are generally indicative of the intermittent warping and submergence. The alternate emergence and submergence of the land mass from about Jurassic time onward resulted in a thick accumulation of terrestrial, marginal marine, and marine sediments.

There is little geologic structure found in the southeastern Atlantic Coastal Plain. Most of the structures are controlled by the pre-Cretaceous basement. Large, broad, regional features exist such as the Salisbury Embayment, Cape Fear Arch, the Southeast Georgia Embayment, and the Southwest Georgia Embayment (Figure 6). The Peninsular Arch of Florida extends into southern Georgia, where it has been referrred to as the Central Georgia Uplift. It separates the Southwest and Southeast Georgia Embayments.

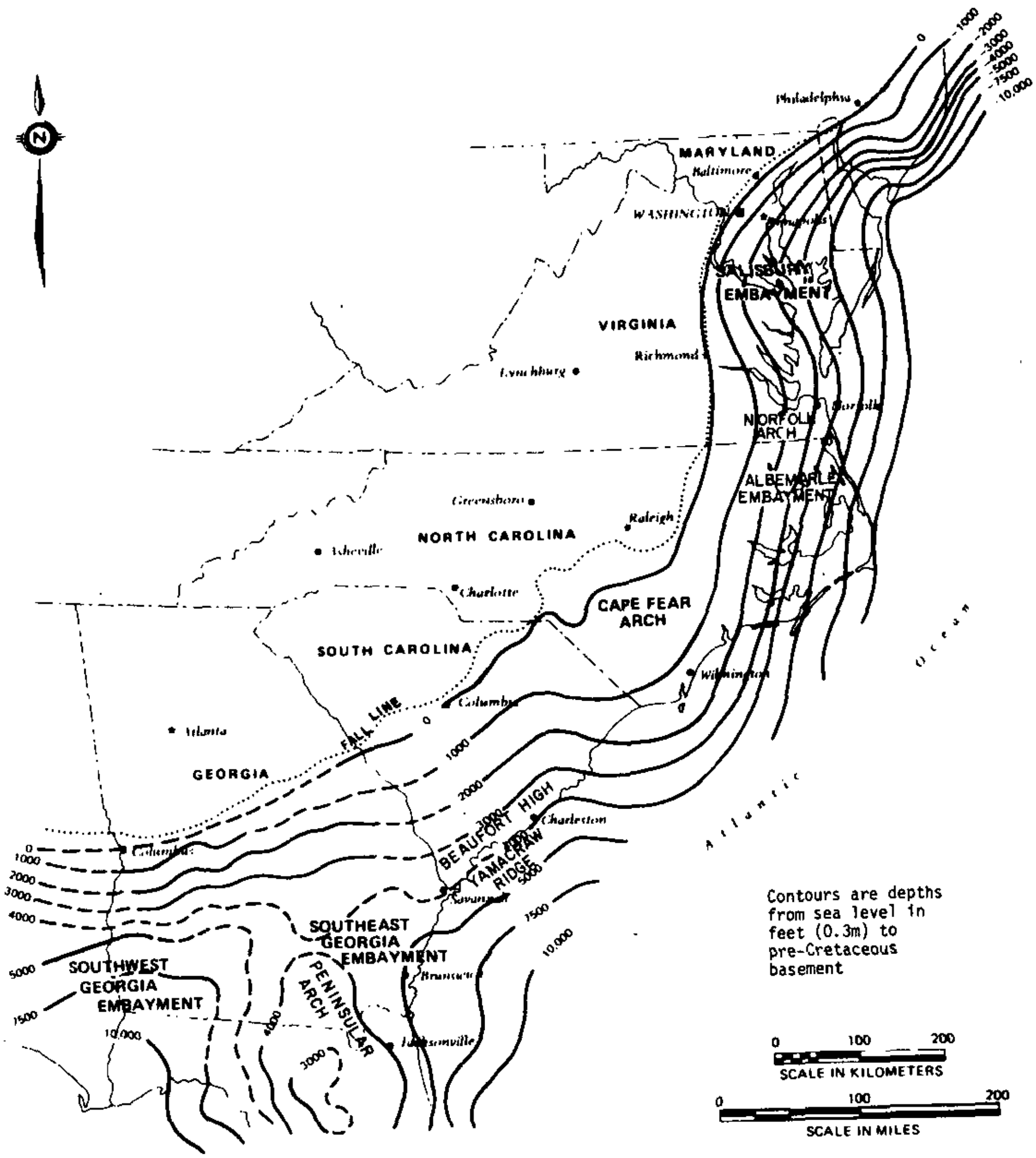

FIGURE 6. Structure of the Southeastern Atlantic Coastal Plain

Numerous structural features of local extent have been named (Figure 6) and discussed in the literature. These include (1) the Norfolk Arch or Fort Monroe High, a northwest-southeast striking feature in the lower James River area of Virginia; (2) the Albemarle Embayment in northeastern North Carolina; (3) the Yamacraw Ridge, a northeast-southwest striking basement ridge near the coast in the vicinity of the Georgia-South Carolina border; (4) the Beaufort (Burton) High, a flat-crested Miocene ridge paralleling the coast between the Savannah River and Charleston, South Carolina; and (5) the Gulf Trough, an elongate belt of thick Miocene sediments extending from the Southwest Georgia Embayment northeastward into Georgia.

Faults of regional extent have not been recognized in the Atlantic Coastal Plain sediments. Those faults that are observed in surface exposures are limited mostly to the area near the Fall Line. Several faults have been postulated in the sedimentary strata on the basis of lineaments observable on maps and remote sensing imagery; however, positive verification in the field is still under investigation.

The southeastern Atlantic Coastal Plain region has shown very low historical seismicity with the exception of the Charleston, South Carolina, area. The earthquake activity in the Charleston area has been declining since the large earthquake of 1886.

4.0 IDENTIFICATION OF POTENTIAL FIELD-STUDY AREAS

The identification of candidate areas within the three subregions required the meeting of the broad criteria described in Section 2.0 plus any additional criteria important to a specific subregion or rock type. This section describes the application of those criteria to the subregions and describes the areas identified by this process.

4.1 Piedmont Province Subregion

The Southeastern Piedmont Province is underlain by variably metamorphosed igneous and sedimentary rock types. Because of its complexity, along with widespread vegetative cover, deep weathering, scarcity of outcrops, and almost complete lack of fossils, knowledge of geological details is incomplete.

Criteria for the selection of favorable rock units within the Piedmont Province relate chiefly to the hydrogeological, dimensional, structural, mechanical, and chemical characteristics of the rock units. Seismicity of the region is considered low and not an important factor. The most important considerations are the hydrogeologic characteristics. Unfortunately, knowledge concerning the hydrology of Piedmont rocks at depths below a few hundred feet is very sparse. It is known that groundwater flow in Piedmont rocks is generally restricted to interconnected joints, fractures, and shear zones. However, in general, groundwater movement decreases with increasing depth in all lithologic types. Rock units that consist of steeply dipping intermixed lithologies might be expected to provide preferred pathways for relatively deep subsurface water migration. Thus, areas of steeply dipping rocks should be avoided in selecting field-study areas.

Hydrologic data at depth in igneous and metamorphic rocks similar to those underlying the Piedmont Province are available from deep mines in the Lake Superior region. These data show that most mines are completely dry with no evidence of running, seeping, or moving water reported at depths exceeding 1000 m (3000 ft) (Yardley, 1975). At depths less than 1000 m (3000 ft), minor seepages occur, that increase with decreasing depth. These observations suggest that a repository in any type of igneous or metamorphic rock may be free from circulating groundwater if located at depths below 1000 m (3000 ft).

The identification of potential study areas within the Piedmont Province has been directed chiefly toward igneous and metaigneous plutons, primarily because the pluton boundaries are relatively easy to determine and because these plutons tend to be more homogeneous than other rock types. Plutonic igneous rocks tend to have high strength characteristics and are mineralogically stable under high temperature and pressure. They are also generally resistant to chemical and mechanical alteration. Thermal conductivity is higher in most igneous rocks than in most sedimentary rocks with the exception of salt and quartzose sandstones.

Slates, schists, and phyllites of the Piedmont Province are generally not considered for candidate study areas because of undesirable structural characteristics that might cause difficulties in excavation and heterogenieties that would make exploration difficult.

Potential field-study areas within the Piedmont Province (shown on Figure 7 and described in Table 2) were identified and evaluated in terms of the criteria set forth earlier.

4.1.1 **Maryland** (Acres American, 1980; Brown, 1980)

Only one geologic unit was identified within the Maryland Piedmont Province for consideration as a candidate field-study area. This was the diamictite facies of the Wissahickon Formation. All other rock bodies were considered either too small in areal extent, too heterogeneous (and thus unpredictable), or are so strongly and thinly foliated that openings in them would be prohibitively difficult to develop and maintain.

Diamictite Facies. The diamictite facies of the Wissahickon Formation is a granite-like metasedimentary gneiss characterized by scattered pebble-to-boulder-size detrital rock fragments. The unit is a belt up to approximately 6 km (4 miles) wide extending from southeastern Carrol County south-southwestward to the vicinity of Washington, DC, a distance of approximately 65 km (40 miles) (Figure 7). Another belt crops out along the Atlantic Coastal Plain overlap northwest of Baltimore. Southwestward another belt extends, although possibly not continuously, a distance of at least 60 km (38 miles) into northern Virginia. The unit has an apparent stratigraphic thickness of approximately 4,570 m (15,000 feet) in Howard and Montgomery Counties.

The diamictite facies is described as being massive, strikingly uniform, and remarkably unfractured. It is essentially a metamorphosed conglomeratic sandstone containing rounded granules and pebbles of quartz and metamorphic rock fragments.

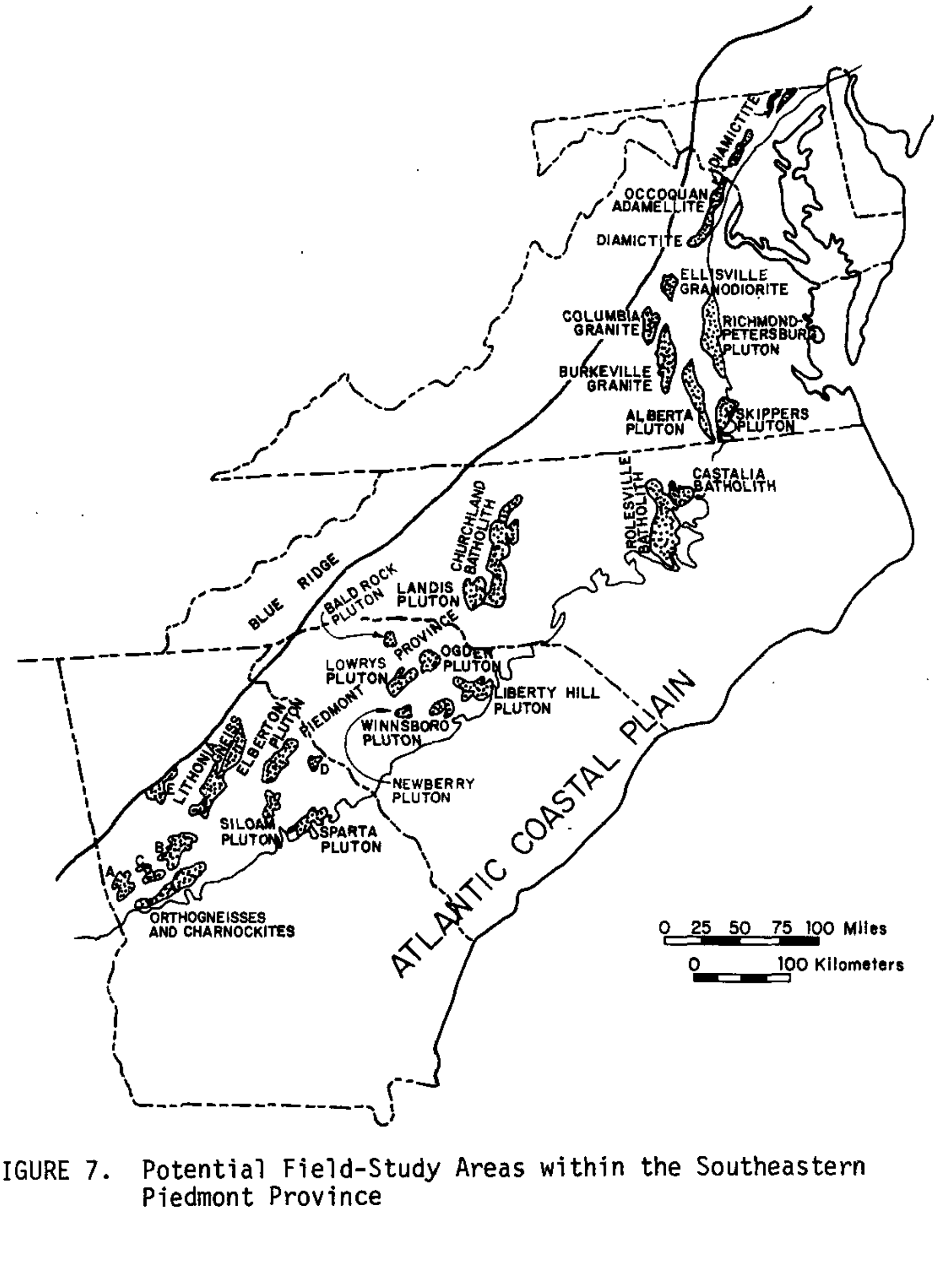

FIGURE 7. Potential Field-Study Areas within the Southeastern Piedmont Province

TABLE 2

Potential Field Study Areas in the Southeastern Piedmont

State	*Candidate Study Area*	*Location*	*Size*	*Lithology*	*Depth to Host Formation*	*Thickness of Host Formation*	*Age*
Maryland	Wissahickon Formation Diamictite Facies	Carrol, Howard, Anne Arundel, Prince George and Montgomery Counties, Maryland	$\approx$415 km^2 (160 mi^2)	Granite-like metasedimentary gneiss	Outcrop	Estimated up to 4570 m (15,000 ft)	Late Precambrian
Virginia	Richmond-Petersburg Pluton	Near Doswell, Virginia	$\approx$2710 km^2 (1050 mi^2)	Granite to quartz monzonite	Outcrop. Eastern limit buried beneath Coastal Plain sediments	Unknown	330-350 m.y.
	Skippers Pluton	Southern Dinwiddie County, Virginia, into North Carolina	$\approx$780 km^2 (300 mi^2)	Granite	Outcrop. Eastern limit buried beneath Coastal Plain sediments	Unknown	460 m.y.
	Alberta Pluton	Southeastern Amelia County, Virginia, into North Carolina	$\approx$1690 km^2 (650 mi^2)	No published descriptions of the rock (granite)	Outcrop	Unknown	Undated
	Occoquan Adamellite	Near Occoquan Creek, Virginia	$\approx$195 km^2 (75 mi^2)	Adamellite and granite gneiss. Some granodiorite and tonalite	Outcrop	Unknown	560 m.y.
	Ellisville Granodiorite	Louisa County, Virginia	$\approx$310 km^2 (120 mi^2)	Biotite granodiorite	Outcrop	Unknown	Undated; intrudes Late Precambrian to Early Cambrian Evington Group
	Columbia Granite	Goochland, Fluvanna, Buckingham, and Cumberland Counties, Virginia	$\approx$780 km^2 (300 mi^2)	Granite and tonalite	Outcrop	Unknown	547 m.y.
	Cumberland-Burkeville Granite	Cumberland and Lunenburg Counties, Virginia	$\approx$520 km^2 (200 mi^2)	Biotite granite. Strongly gneissic and interlayered with hornblende gneiss near borders	Outcrop	Unknown	Undated; probably more than one intrusive body of different ages
	Wissahickon Formation Diamictite Facies	Northeastern Virginia	$\approx$910 km^2 (350 mi^2)	Granite-like metasedimentary gneiss	Outcrop	Estimated up to 4570 m (15,000 ft)	Late Precambrian

TABLE 2 (page 2)

State	*Candidate Study Area*	*Location*	*Size*	*Lithology*	*Depth to Host Formation*	*Thickness of Host Formation*	*Age*
North Carolina	Rolesville Batholith	Wake and Franklin Counties, North Carolina	≈1700 km^2 (650 mi^2)	Biotite granite	Outcrop	Unknown	Uncertain; probably middle to late Paleozoic
	Castalia Batholith	Franklin and Nash Counties, North Carolina	≈312 km^2 (125 mi^2)	Granite (adamellite)	Outcrop	Unknown	≈316 m.y.
	Churchland Batholith	Rowan, Davie, Davidson, Forsyth, and Guilford Counties, North Carolina	326 km^2 (130 mi^2)	Porphyritic granite	Outcrop	Unknown	≈282 m.y.
	Landis Pluton	Rowan, Iredell, Mecklinburgh, and Cabarrus Counties, North Carolina	>300 km^2 (100 mi^2)	Porphyritic granite	Outcrop	Unknown	≈300 m.y.
South Carolina	Liberty Hill Pluton	Kershaw, Lancaster, and Fairfield Counties, South Carolina	≈360 km^2 (144 mi^2)	Biotite-amphibole granite; quartz monzonite; porphyritic granite and biotite granite	Outcrop	Unknown	≈300 m.y.
	Winnsboro Plutonic Complex	Fairfield County, South Carolina	≈234 km^2 (90 mi^2)	Granite and quartz monzonite (adamellite)	Outcrop	Unknown	≈300 m.y.
	Ogden Pluton	York and Chester Counties, South Carolina	≈100 km^2 (40 mi^2)	Gabbro	Outcrop	Unknown	≈413 m.y.
	Lowrys Pluton	Chester County, South Carolina	≈160 km^2 (64 mi^2)	Granite and porphyritic biotite-muscovite granite	Outcrop	Unknown	≈400 m.y.
	Bald Rock Pluton	Union and Cherokee Counties, South Carolina	≈330 km^2 (132mi^2)	Porphyritic biotite granite	Outcrop	Unknown	≈388 m.y.
	Newberry Pluton	Newberry and Fairfield Counties, South Carolina	≈280km^2 (112 mi^2)	Granite	Outcrop	Unknown	Undated

TABLE 2 (page 3)

State	*Candidate Study Area*	*Location*	*Size*	*Lithology*	*Depth to Host Formation*	*Thickness of Host Formation*	*Age*
Georgia	Elberton Pluton	Elbert and Oglethorpe Counties, Georgia	≳550 km^2 (220 mi^2)	Granite	Outcrop	Unknown	Uncertain;
	Siloam Pluton	Green County, Georgia	≳220 km^2 (85 mi^2)	Porphyritic	Outcrop	Unknown	≳270 m.y.
	Sparta Pluton	Hancock and Warren Counties, Georgia	>390 km^2 (150 mi^2)	Granite	Outcrop	Unknown	≳300 m.y.
	Lithonia Gneiss	DeKalb, Rockdale, Newton, Gwinnett, Walton, Barrow, Jackson, and Banks Counties, Georgia	>600 km^2 (240 mi^2)	Granitic orthogneiss	Outcrop	Unknown	≳480 m.y.
	Orthogneisses and Charnockites of the Pine Mountain Belt	Talbot, Upson, Lamar, and Monroe Counties, Georgia	>550 km^2 (220 mi^2)	Biotite-garnet orthogneiss. Intruded by charnockite plutons (gabbro-hypersthene granite)	Outcrop	Unknown	Grenville Age 1,000 m.y.
	Unnamed Plutons in Georgia Piedmont	A. Troup and Harris Counties, Georgia	≳100 km^2 (40 mi^2)	Granite	Outcrop	Unknown	No data
		B. Spalding, Pike and Meriwether Counties, Georgia	>390 km^2 (150 mi^2)	Granite	Outcrop	Unknown	No data
		C. Meriwether County, Georgia	≳100 km^2 (40 mi^2)	Granite	Outcrop	Unknown	No data
		D. Wilkes and Lincoln Counties, Georgia	>100 km^2 (40 mi^2)	Granite	Outcrop	Unknown	No data
		E. Fulton County, Georgia	>100 km^2 (40 mi^2)	Granite	Outcrop	Unknown	No data

4.1.2 **Virginia** (Acres American, 1978; Brown, 1980)

Rock units which appear to offer the best potential for consideration as candidate field-study areas in the Piedmont Province of Virginia include the larger granitic plutons and the metasedimentary diamictite facies of the Wissahickon Formation. The granitic plutons include three plutonic bodies of the Petersburg Granite (Richmond-Petersburg, Skippers, and Alberta Plutons), Occoquan Adamellite, Ellisville Granodiorite, Columbia Granite, and the Cumberland-Burkeville Granite. The remainder of the Virginia Piedmont Province is underlain by igneous bodies that appear to be too small for consideration, or schists, gneisses, phyllites, quartzites, metavolcanic rock, or other rock types that are too heterogeneous or have physical properties that would make repository development difficult.

Richmond-Petersburg Pluton (Petersburg Granite). The Richmond-Petersburg Pluton extends from near Doswell, 32 km (20 miles) north of Richmond, southward to beyond the Nottoway River in Sussex County, Virginia, a total distance of approximately 113 km (70 miles). The width of the body is about 24 km (15 miles) in the vicinity of Petersburg. The eastern extent of the pluton is buried beneath the nearly flat-lying Atlantic Coastal Plain sediments.

Lithologically, the pluton varies from a two-mica granite to quartz monzonite and from nonfoliated to foliated. Near its borders, this pluton contains numerous xenoliths of gneissic country rock and it is intruded by felsic, mafic, and pegmatite dikes.

Jointing is well developed and vertical sets are common. Joints are sufficiently widely spaced to permit quarrying of large dimension stone, and the unit has been extensively quarried.

Skippers Pluton (Petersburg Granite). The Skippers Pluton extends from southern Dinwiddie County, Virginia, southward to North Carolina, a distance of about 47 km (29 miles). This hook-shaped body has a maximum width of at least 19 km (12 miles). The eastern limit of the pluton is buried beneath the flat-lying Atlantic Coastal Plain sediments. Lithologically, the rock is a gray-to-pink fine-grained granite that is locally quarried for crushed stone. There are two vertical joint sets.

Alberta Pluton (Petersburg Granite). The Alberta Pluton has a maximum width of about 16 km (10 miles) and extends from southeastern Amelia County, Virginia, southward to the Virginia-North Carolina state line, a distance of over 74 km (46 miles). There are no published studies of this pluton.

Occoquan Adamellite. The Occoquan adamellite unit is approximately 5 to 10 km (3 to 6 miles) wide and 16 km (10 miles) long. Lithologically, the unit contains fairly abundant granodiorite and minor tonalite but is dominantly adamellite in composition. Locally, the unit has a moderate-to-strong metamorphic foliation and well-developed lineation. The adamellite intrudes the Wissahickon Formation.

Ellisville Granodiorite. The Ellisville granodiorite is a roughly heart-shaped pluton located in west-central Louisa County, Virginia. The body is approximately 24 km (15 miles) by 13 km (8 miles) in areal extent. Lithologically, the rock is a massive biotite granodiorite consisting mainly of plagioclase feldspar, potash feldspar, biotite, and quartz, but varies from porphyritic to gneissic. It intrudes the late Precambrian to early Cambrian Age formations.

Columbia Granite. The Columbia granite is a broad V-shaped body approximately 60 km (38 miles) long by 13 km (8 miles) wide, which extends across the James River in the vicinity of Columbia, Virginia. The rock ranges from granite to tonalite and is medium-to coarse-grained and commonly porphyritic. Foliation varies from moderate to strong. Xenoliths occur in places, and locally granitic rock is interlayered with hornblende gneiss.

Cumberland-Burkeville Granite. The Cumberland-Burkeville granite is approximately 16 km (10 miles) wide and 42 km (26 miles long in Cumberland and Lunenburg Counties, Virginia. This formation is poorly known and probably includes more than one intrusive body, possibly of different ages. Locally, especially near its borders, the unit is foliated and interlayered with hornblende gneiss. In some areas, the rock is nearly massive and has been quarried for at least 150 years.

Diamictite Facies of the Wissahickon Formation. This diamictite is most extensively found in Maryland; however, the unit extends southwestward from the Maryland-Virginia border at least 60 km (38 miles) into northeastern Virginia, where it attains an outcrop width of as much as 16 km (10 miles). Although it contains granules and pebbles of quartz and feldspar and a variety of small to very large fragments of a variety of metamorphic rocks, mainly schist and metagraywacke, its matrix is so uniform that it was long considered a magmatic granite. The rock is strikingly uniform and extremely free of fractures.

4.1.3 North Carolina (Acres American, 1980; Butler, 1980)

The literature studies identified a total of four granitic bodies within the North Carolina Piedmont Province as possessing overall characteristics favorable for consideration as candidate study areas. Areas excluded from further consideration based on structural complexity, small size, insufficient depth, and inhomogeneous rock type.

Rolesville Granite Batholith. The Rolesville Batholith, located in the eastern Piedmont Province of north-central North Carolina east of Raleigh is one of the largest in the southern Appalachians, with an area of approximately 1700 km^2 (650 $miles^2$). Lithologically, the unit is typically a medium-grained biotite granite, but other variations are commonly seen. The border zones are highly variable, but the center of the pluton is more massive and homogeneous.

Castalia Granite Batholith. The Castalia Batholith is a nearly separate northeast lobe of the Rolesville Batholith. The intrusion has an area of approximately 312 km^2 (125 $miles^2$) and is divided into two lobes by a belt of gneisses with granitic rocks and pegmatites. The rock is generally a massive, homogeneous, medium-grained granite (adamellite). This batholith has intruded metasedimentary and metavolcanic rocks of the Raleigh Belt.

Churchland Granite Batholith. The Churchland Batholith located in the central Piedmont Province of North Carolina has an outcrop area of approximately 326 km^2 (130 $miles^2$). Lithologically, the rock is a massive, homogeneous, coarsely porphyritic granite, but locally it has a flow foliation and contains biotite-rich zones.

Landis Pluton. The Landis Pluton is also located in the central Piedmont Province of North Carolina, south-southwest of the Churchland pluton. The pluton appears to be associated with the Churchland body. The unit has been described as a coarse-grained to porphyritic granite with a ground mass consisting of feldspar, quartz, and biotite. The Landis Pluton has an area of greater than 300 sq. km (~100 sq. mi).

4.1.4 South Carolina (Acres American 1980; Secor, 1980)

Based on a literature survey of the Piedmont Province of South Carolina, a total of four igneous plutons were identified as meeting the overall criteria for consideration as potential field-study areas. Other areas in the South Carolina Piedmont Province were excluded from consideration mainly on the basis of proximity to major structural features (faults, shear zones, etc.), structural complexity, small size, inhomogeneity, and anisotropy.

Liberty Hill Pluton. The Liberty Hill Pluton located in Kershaw, Lancaster, and Fairfield Counties of north-central South Carolina was intruded along the border between the Carolina Slate

Belt and the Charlotte Belt, and has a surface area of approximately 360 km^2 (144 mi^2). Geophysical and geological studies indicate the pluton tapers inward with a depth of approximately 6 km. The pluton, which is probably the largest mass of relatively homogeneous rock in the South Carolina Piedmont Province, has three textural phases: a very coarse biotite-amphibole granite and quartz monzonite, a porphyritic border phase, and a fine-to-medium grained biotite granite that intruded the western part of the pluton as large dikes and/or plugs. The pluton contains numerous large xenoliths and thin aplite and pegmatite dikes. Northwest-trending Mesozoic diabase dikes cut both the country rock and the pluton. Zones of fracturing and alternation are commonly observed in drill holes. Traces of copper and molybdenum mineralization have been reported in the pluton but are of no immediate economic importance.

Winnsboro Plutonic Complex. The Winnsboro plutonic complex is a large granite and quartz monzonite (adamellite) intrusion located along the border between the Carolina Slate Belt and the Charlotte Belt in Fairfield County, South Carolina. The body is roughly circular in shape, but has a complex outcrop pattern due to numerous large concordant enclaves of country rock. The pluton is actually made up of several partly connected irregular- to crescent-shaped bodies and is made up of several compositional phases. The Winnsboro Pluton extends to a depth of several kilometers based on geophysical studies. The Rion Pluton which covers approximately 70 km^2 (24 $miles^2$) is the central core of the complex. Around most of its circumference, the Rion Pluton is separated from the other bodies by a screen of country rock. The border phase of the Winnsboro Pluton contains numerous xenoliths and an inward-dipping flow foliation that suggests that the Winnsboro complex has the shape of a funnel with the Rion Pluton located in the central and deepest part of the complex. The complex has been intruded by Paleozoic lamprophyric dikes and Mesozoic diabase dikes. Both horizontal and vertical fractures are present at depth, but these are filled with zeolites and pyrite, respectively.

Ogden Pluton. The Ogden Pluton is the largest and most homogeneous of the postkinematic gabbro instrusions in the South Carolina Piedmont Province, covering an area of approximately 100 km^2 (40 $miles^2$) in the southern portion of York and northern Chester Counties. The pluton is believed to be a steep-sided stock extending to considerable depth. Lithologically, the rock consists of a medium-grained gabbro containing plagioclase, augite, olivine, and hypersthene as essential minerals, with accessory hornblende, magnetite, biotite, pyrite, and spinel. There are no known economic mineral deposits associated with the Ogden Pluton aside from possible use as crushed stone.

Lowrys Pluton. The Lowrys Pluton is a large granitic complex covering an area of approximately 160 km^2 (64 $miles^2$) in northwestern Chester County, South Carolina. The pluton consists of a central region of coarse-grained porphyritic biotite-muscovite granite surrounded by a fine-grained granitic border facies. Lowrys Pluton was recommended for consideration as a candidate study area because both geological and geophysical evidence indicates the presence of a large mass of relatively undeformed granite.

Bald Rock Pluton. The Bald Rock Pluton is a large, circular-shaped, granitic body covering approximately 330 km^2 (132 mi^2) in north-central Union County and in southern Cherokee County, South Carolina. Lithologically, the unit is dominantly a coarse-grained, porphyritic, biotite granite. The unit has been dated as 388 m.y., but shows little or no evidence of having been deformed. Although it is poorly exposed, the available information suggests that the pluton is extremely homogeneous. The northern and northwestern boundaries of the pluton are gradational with sill-like sheet intrusions of granite interlayered with schist. Joints are widely spaced and in many places are filled with minerals. The apparent absence of an associated gravity anomaly may indicate that the Bald Rock Pluton is relatively thin.

Newberry Pluton. The Newberry Pluton is an irregular-shaped body, that is elongated parallel to the regional strike. This pluton covers approximately 280 km^2 (112 mi^2) in central Newberry County and in west-central Fairfield County, South Carolina. Although there is some disagreement concerning its exact shape (probably because of poor exposures), the available data suggest that there is an extensive body of fine-grained homogeneous granite in the central part of the pluton just to the north of the town of Newberry. The western part of the pluton contains numerous large enclaves or xenoliths of country rock, and the eastern part contains a distinct flow foliation. Petrographically, the Newberry Pluton resembles the Rion adamellite of the Winnsboro plutonic complex. Dikes of gabbro, basalt, and pegmatite have been observed to cut the pluton. The associated negative gravity anomaly of 5 to 10 mgals suggests the pluton extends to depths of at least a few kilometers.

4.1.5 Georgia. (Acres American, 1980; Wenner and Gillon, 1980)

A review of the available data on the Piedmont Province of Georgia concluded that the granites of the large post-metamorphic plutons and large, homogeneous, orthogneissic units best meet the criteria for consideration as potential candidate study areas. Virtually all other rock types (including most metavolcanic and metasedimentary units) have one or more unacceptable physical or mechanical properties. Most rocks of this type are steeply dipping and contain numerous lithologic variations. These variations could provide potential zones for influx and migration of ground water, thus making these rocks hydrologically unsuitable. Also, most lack sufficient unit-dimensional continuity to be acceptable. The areas identified as generally favorable are discussed below.

Elberton Pluton. The Elberton Pluton, located in Elbert and Oglethorpe Counties, Georgia, is a large body of medium-grained, light-gray to pinkish, equigranular granite that is exceedingly homogeneous (both chemically and petrographically) over its entire outcrop area. The outcrop area exceeds 550 km^2. Recent detailed mapping suggests that the pluton widens just below the surface and extends to considerable depth. Paleomagnetic anistropy measurements indicate that the Elberton Pluton acted as a stable hinge-block between two major fault zones (the Towaliga and Middleton) and has rotated about 30°. This unit is one of the major sources of dimension stone in the country. Most active quarries are located near the northern end of the body.

Siloam Pluton. The Siloam Pluton, located in Greene County, Georgia, consists dominantly of a coarsely porphyritic granite characterized by large perthitic phenocrysts. The pluton is approximately 10 km (6 mi) south of the Elberton Pluton and is located between two major fault zones, the Middleton and Modoc.

Sparta Pluton. The Sparta Pluton, located primarily in Hancock and Warren Counties, Georgia, is in all probability a composite pluton that consists of a variety of textural rock types that dominantly include both a porphyritic, coarse-grained granite and an equigranular, medium-to-fine-grained granite. The body has a relatively large surface-outcrop and is probably sparsely jointed and fractured as evidenced by an average density of flat-rock outcrops. This pluton is located south of the Modoc Fault Zone. There are no active quarries within the pluton. The southern boundary of the pluton is obscured by Atlantic Coastal Plain sediments.

Lithonia Gneiss. The Lithonia gneiss which outcrops in Dekalb, Rockdale, Newton, Gwinnett, Walton, Barrow, Jackson, and Banks Counties, Georgia, appears to meet the general criteria for consideration as a candidate study area. The unit is an exceedingly homogeneous, medium-grained, upper amphibolite-grade, granitic orthogneiss having alternating light and dark bands. The rock is composed of oligoclase, microcline, quartz, biotite, and muscovite, with occasional stringers of garnet and tourmaline. Also, this unit has the greatest density of flat-rock outcrops of any gneissic or granitic unit in the Georgia Piedmont Province, which suggests a minimal density of joints and fractures. It can be expected that rock units that outcrop extensively should have a relatively low density of joints and fractures, because most rocks with a large number of vertically dipping fractures and joints would be expected to be preferentially weathered to substantial depths.

Orthogneisses and Charnockites of the Pine Mountain Belt. These rocks constitute a major exposure of Grenville-age basement rock in the Pine Mountain Belt of Georgia. Outcrops are seen mainly in Talbot, Upson, Lamar, and Monroe Counties. The Woodland gneiss unit consists of a moderately foliated, granulite-grade, biotite-garnet orthogneiss that has been locally intruded by charnockite plutons ranging from hypersthene gabbros to hypersthene granites. The units of this belt have relatively extensive outcrop areas and are known to be exceedingly poor water producers. However, numerous surficial joints and fractures are suggested by the deep weatherings of these units. The uncertainty and nature of a bordering thrust fault existing in this belt would have to be evaluated further.

Unnamed Plutons in Georgia Piedmont. Several unnamed plutons in the Georgia Piedmont Province are judged to meet the overall criteria for consideration as candidate study areas. These areas are designated by letters on Figure 7. Three plutons of relatively large surface areas exist just north of the Pine Mountain Belt. One (A) is located mainly in Troup and Harris Counties, another (B) in Meriwether, Pike, and Spalding Counties, and a third (C) in south-central Meriwether County. However, little information exists on the nature of these three granite bodies. These three plutons possibly have a paucity of jointing as evidenced by a high average-density of flat-rock outcrops. An unnamed pluton (D), located east of the Elberton Pluton in Lincoln and Wilkes Counties in easternmost Georgia adjacent to the Georgia-South Carolina border, and an unnamed pluton (E), located mainly in Fulton County, fulfill the criteria. These bodies were designated as favorable for consideration as candidate study areas because of their apparent massive structure and composition. However, there are little to no specific data available on these plutons.

4.2 Triassic Basins Subregion (Dames and Moore, 1980)

The investigation identified a total of 14 exposed Triassic basins within the study area that are large enough in size to have been named and reported in varying degrees of detail in the literature. Of the 14 exposed basins (Figure 5), eight are of sufficient size to be considered as possible candidate areas (Newark-Gettysburg Basin, Culpeper Basin, Richmond Basin, Danville Basin, Dan River Basin, Durham Basin, Sanford Basin, and Wadesboro Basin). The remaining 6 basins (Barboursville, Scottsville, Farmville, Davie County, Ellerbe, and Crowburg) are small, all less than 91 square kilometers (35 square miles) in surface area and are considered too site-specific for the identification of candidate study areas.

There are five buried basins, or hypothesized basins, or areas where Triassic(?) material has either been encountered in deep borings or whose presence is suggested by geophysical investigations, that may be of sufficient areal extent to be considered as possible candidate areas (Figure 5). These are, from north to south, the Richmond-Brandywine Triassic Belt, Florence Basin, Georgetown Gravity Low, Dunbarton Basin, and the Georgia-Florida Triassic(?) Basin(s). Other basins are too small in area, or too hypothetical to be considered candidate study areas. In addition, the Charleston area is not considered a candidate study area because Triassic basalts encountered at a depth of approximately 580 meters (1,900 feet) are in an area of extensive seismic activity, unknown structure, and possible active faulting.

Based on the general criteria (outlined in Section 2.0) for selection of candidate areas for radioactive waste repositories, a total of six basins were identified as favorable areas for possible detailed investigations (Figure 8). These basins are the Danville, Dan River, Durham, Wadesboro, Florence, and Dunbarton Triassic Basins (Table 3). Few of these basins have been investigated at the depths compatible with the development of a repository (300 to 900 meters) with the exception of the buried Dunbarton Basin. There are essentially no data in the literature concerning the depth, rate, and direction of subsurface water movement in the deep Triassic rocks. Also data pertaining to the engineering and geochemical properties at depth are lacking.

All of the candidate areas contain significant fractions of clay and silt-sized materials and are moderately-to-well indurated resulting in relatively low effective porosity and permeability values. None of the candidate areas contain known active or potentially active faults. Where inactive faults occur, they appear to be widely spaced. None of the candidate areas are located within high-risk seismic zones, and nearby seismic events have not been correlated with candidate area structure. Mining, mineral exploration, and solutioning (or potential solutioning) are all minimal-to-nonexistent within the candidate areas. Known and potential mineral resources are considered compatible with repository siting.

4.2.1 Danville Basin Candidate Area

The Danville Basin, located in Virginia, is considered to be a candidate area for additional study based on available geologic data. Published geologic data indicate that the areal extent of

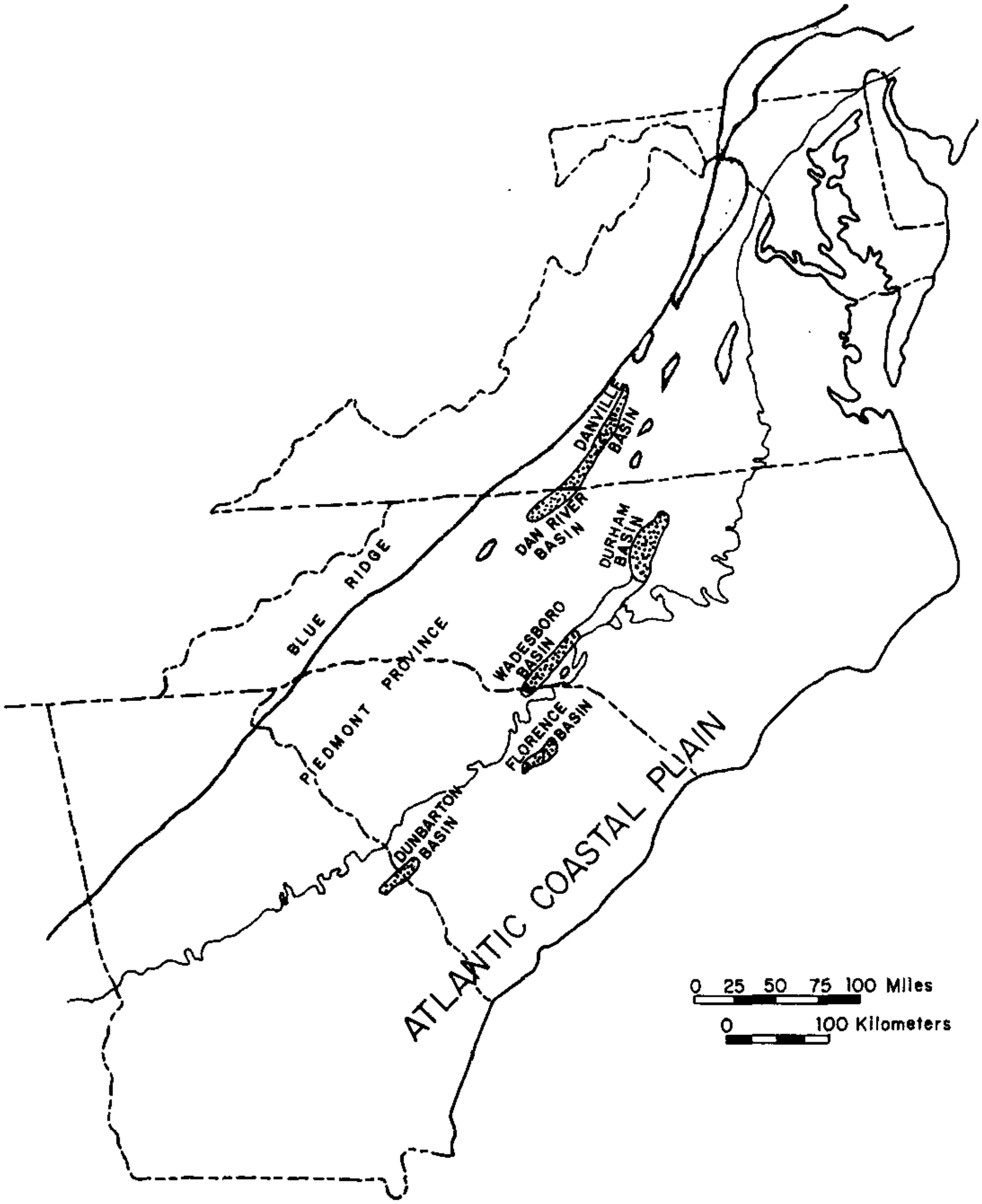

FIGURE 8. Potential Field-Study Areas of the Southeastern Triassic Basins

Table 3

Potential Field Study Areas in the Southeastern Triassic Basins

Candidate Study Area	*Location*	*Size*	*Lithology*	*Depth to Host Formation*	*Thickness of Host Formation*	*Age*
Danville Basin	Pittsylvania and Campbell Counties, Virginia	492 km^2 (190 mi^2)	Interbedded claystones, shales, sandstones, and conglomerates	Outcrop	Estimated $\approx$4,570 m (15,000 ft)	Triassic
Dan River Basin	Stokes and Rockingham Counties, North Carolina	388 km^2 (150 mi^2)	Interbedded claystones, siltstones, sandstones, and conglomerates	Outcrop	Estimated $\approx$1,525 m (5,000 ft)	Triassic
Durham Basin	Granville, Lee, Durham, Orange, Wake, and Chatham Counties, North Carolina	1580 km^2 (610 mi^2)	Interbedded fanglomerates, conglomerates, sandstones, siltstones, shales, and argillites	Outcrop	Estimated $\approx$3,050 m (10,000 ft)	Triassic
Wadesboro Basin	Anson, Union, Richmond, and Montgomery Counties, North Carolina	1115 km^2 (430 mi^2)	Interbedded fanglomerates, conglomerates, sandstones, siltstones, and claystones	Outcrop	Estimated $\approx$610 to 1150 m (2000 to 3800 ft)	Triassic
Buried Florence Basin	Vicinity of Florence, South Carolina	$\approx$1040 km^2 (400 mi^2)	Interbedded sandstones and claystones (no good descriptions available)	183-213 m (600-700 ft)	Estimated >210 m (700 ft)	Triassic
Buried Dunbarton Basin	Barnwell County, South Carolina	>648 km^2 (250 mi^2)	Interbedded arkosic sandstones, sandstones, mudstones, claystones, and siltstones	305 m (1000 ft)	Estimated $\approx$915 to 1525 m (3,000 to 5,000 ft)	Triassic

the basin is approximately 492 square kilometers (190 square miles) in Pittsylvania and Campbell counties, Virginia. The basin is approximately 120 kilometers (75 miles) long and ranges to greater than 9 kilometers (6 miles) in width. The maximum thickness of the Triassic sediments within the basin (including claystones, shales, sandstones, and conglomerates) has been estimated by stratigraphic means to be approximately 4,570 meters (15,000 feet).

Although the Danville Basin seems to be moderately fractured and faulted, producing a series of smaller sub-basins, there appear to be areas lacking in structure which are sufficiently large for repository construction requirements.

Small to moderate groundwater resources have been developed within the Triassic rocks of the Danville Basin. The occurrence and movement of groundwater in the basin probably occurs principally along bedding planes or in secondary openings such as joints and fractures in the rock, as the primary porosities of the Triassic sediments are low.

Development of mineral resources within the Triassic rocks of the Danville Basin is limited. Relatively shallow deposits of clay are extracted for use in the manufacture of brick and ceramic ware. Some quarrying of stone for building purposes also takes place. No mineable coal deposits have been identified or developed within the basin.

4.2.2 Dan River Basin Candidate Area

The Dan River Basin is located in Stokes and Rockingham counties, North Carolina, and is separated from the Danville Basin only by the State Line. The basin is approximately 72 kilometers (45 miles) long with a maximum width of 9.6 kilometers (6 miles) and covers approximately 388 square kilometers (150 square miles). The subsurface of the basin has not been studied in great detail.

The Dan River Basin contains an abundance of argillaceous sediments. The average dip of the Triassic strata is 30° to the northwest; but locally, the dips range between 13° and 70°. Based on surface measurements the maximum sediment thickness is estimated to be 4,570 meters (15,000 feet). However, gravity data indicate the strata does not exceed 1,525 meters (5,000 feet). A boring drilled near the North Carolina-Virginia state line was still in Triassic sediments at a depth of 1,432 meters (4,700 feet).

The Triassic sediments consist of interbedded conglomerates, sandstones, siltstones, and claystone characterized by abrupt lateral and vertical changes in color, texture, composition, and thickness. The sediments are poorly sorted and exhibit low permeabilities. Faults have cut the basin into smaller sub-basins. These faults are commonly associated with diabase dikes. The fault-density appears to be sufficiently low to not preclude the basin from consideration as a candidate area.

Specific data on the geohydrologic characteristics of the strata are lacking. Movement of groundwater is principally in secondary openings such as joints and fractures. Dikes tend to act as barriers to the movement of groundwater. The groundwater system has not been extensively developed because of the relatively low yields.

Clays for manufacturing bricks and light-weight aggregates are the most important natural resources. Coal is present in the basin in the area of Walnut Cove, but no economic deposits have been identified.

4.2.3 Durham Basin Candidate Area

The Durham Basin covers approximately 1,580 square kilometers (610 square miles) in Granville, Lee, Durham, Orange, Wake, and Chatham counties, North Carolina. It is approximately 84 kilometers (52 miles) long with a maximum width of 32 kilometers (20 miles).

The north and central portions of the basin are considered more favorable for development than the extreme southern portion of the basin. The southern portion of the basin may contain appreciable thicknesses of organic shales of the Cumnock Formation and possibly some thin coal seams.

The basin is estimated to contain a thickness of up to 3,050 meters (10,000 feet) of poorly sorted continental clastic deposits consisting of fanglomerates, conglomerates, sandstones, shales, siltstones, and argillites. These sediments have low primary porosity and permeability. The movement of groundwater is mainly through secondary openings such as faults, fractures, and joints. The average well-yield from the Durham Basin is approximately 0.44 liters per sec (7 gpm). The well-yield per meter of depth generally decreases with increasing depth, indicating that the permeability at the depths considered feasible for a repository may be quite low.

The sediments strike northeast and generally dip to the southeast at about 15° to 20°. The dips are generally steeper on the western side of the basin and flatten out with depth. Gravity data indicate the deepest parts of the basin are the northeastern and southeastern portions.

Faulting has cut the basin into smaller horsts and grabens. The density or degree of faulting and fracturing could influence the movement of groundwater at the depth of a repository. However, data appear to indicate that the sediments become less permeable with depth, signifying fewer faults and fractures.

Montmorillonite is the major clay mineral present in the near-surface sediments. The presence of montmorillonite at depth would be advantageous from an ion exchange point, but would be detrimental because of the amount of water that could be released from this mineral under heat and pressure.

The most important natural resources are the clay and shale deposits presently being mined for the manufacture of brick and tile products. The construction of a repository should not significantly affect these natural resources.

4.2.4 Wadesboro Basin Candidate Area

The Wadesboro Basin, located primarily in North Carolina, is considered to be a candidate area for additional study. The entire basin is approximately 64 kilometers (40 miles) long and has a maximum width of 16 kilometers (10 miles), covering an area of approximately 1,115 square kilometers (430 square miles). In general, that portion of the basin south of the Pee Dee River located in Anson County, North Carolina, is considered geologically more favorable than the area north of the Pee Dee River. The Wadesboro Basin south of the Pee Dee River occupies an area of approximately 518 square kilometers (200 square miles).

The basin contains a significant thickness of poorly sorted clastic sediments including abundant amounts of silt- and clay-sized material. Lithologically, the sediments are heterogeneous and comprise fanglomerates, conglomerates, sandstones, siltstones, and claystones characterized by rapid variations in thickness, color, texture, composition, and areal extent. However, all lithologies have low porosity and permeability owing to the poor sorting and high clay content. The Triassic strata generally strike N 33° E and dip to the southeast at about 20°. The exact thickness of the Triassic deposits is not known for certain because no deep boring data are available. However, gravity data indicate the strata are approximately 610 meters (2,000 feet) thick north of the Pee Dee River and increase to 1,158 meters (3,800 feet) south of the river. North of the river, sediment thicknesses are affected by the Pekin cross-structure and other cross faults. There is a fairly heavy concentration of diabase dikes in the immediate vicinity of the Pee Dee River. This area should be avoided. In general, the structure of the southern portions of the Wadesboro Basin appears adequate for the location of a repository.

Practically no published data are available on the geohydrologic characteristics of the Triassic sediments within the basin. A few wells indicate yields ranging from 0.06 to 7.82 liters per sec (1 to 124 gpm). Groundwater production in the region is not great.

There are no known natural resources of economic importance with the exception of the clays and shales for manufacturing of bricks and tiles. The coal and organic shale deposits of the Cumnock Formation have not been identified in the basin and are believed to have been either eroded away or never deposited.

4.2.5 Florence Basin Candidate Area

The buried Florence Basin located in the Atlantic Coastal Plain in the vicinity of Florence, South Carolina, is considered a favorable candidate area for possible additional study. Little data have been collected from the basin with the exception of a few water wells drilled into the Triassic rocks. The best estimates of the size of the basin, based on geophysical data, indicate that it is at least 64 kilometers (40 miles) in length and has a maximum width of 21 kilometers (13 miles). There are no estimates of the thickness of the Triassic sediments or evidence of any structure within the basin. The basin is overlain by between 183 and 213 meters (600 and 700 feet) of Atlantic Coastal Plain sediments. The basin is directly overlain by the Tuscaloosa Formation of Cretaceous age which consists of crossbedded sand and gravel intercalated with lenses of silt and clay. These deposits overlying the Triassic sediments contain aquifers which are sources of water.

Except for the overlying aquifers in the Atlantic Coastal Plain sediments, no known significant natural resources or economic deposits exist within the Florence Basin area. A critical requirement for construction of a repository within the basin would be to avoid contamination of the overlying aquifers. Relatively impermeable layers occur within this basin which would tend to isolate a repository from the overlying Atlantic Coastal Plain aquifers.

4.2.6 Dunbarton Basin Candidate Area

The buried Dunbarton Basin, located primarily in South Carolina, is considered to be a candidate area for additional study. The buried Triassic rocks, the underlying and surrounding crystalline basement rocks, and the overlying Atlantic Coastal Plain sediments have been investigated utilizing exploratory wells, seismic reflection and refraction studies, and magnetic and gravitational techniques. The Dunbarton Basin is the only East Coast Triassic basin that has been subjected to field explorations for the acquisition of data pertaining to the subsurface storage of radioactive waste.

The Dunbarton Triassic rocks are located beneath approximately 305 meters (1000 feet) of Atlantic Coastal Plain sediments and continue to depths which exceed those feasible for repository construction. The majority of the Triassic basin rocks are situated within the most favorable depth range for a repository. The rocks are well indurated, very poorly sorted, exhibit low fracture-densities, and contain significant amounts of clay and silt particles, all of which serve to restrict the quantity and flow of groundwater. The clayey Triassic sediments would impede the migration of groundwater to the overlying more permeable Atlantic Coastal Plain rocks. The Atlantic Coastal Plain deposits contain aquifers, some of which are quite permeable.

There is no indication that intrusive dikes occur within the basin. Some evidence indicates the presence of ancient faults within the Triassic rocks, but none of these features extend into the overlying Atlantic Coastal Plain deposits. The possibility of a hydraulic connection from the Triassic rocks to the Atlantic Coastal Plain aquifers is remote.

Montmorillonite occurs in low concentrations near the upper contact but is apparently absent in the rest of the basin. The principal clay is illite. The overlying Atlantic Coastal Plain deposits contain appreciable quantities of clay, chiefly kaolinite.

Except for aquifers located within the Atlantic Coastal Plain sediments, there are no significant or critical natural resources or economic deposits in the Dunbarton Basin area. Within the vicinity of the Dunbarton Basin, the Atlantic Coastal Plain aquifers are utilized for industrial and domestic purposes. A critical requirement for the construction of a Dunbarton Basin repository would be to avoid contamination of the overlying aquifers.

4.3 Atlantic Coastal Plain Subregion (Ebasco Services, 1980)

Four potential candidate areas have been identified within the Atlantic Coastal Plain subregion. The potential areas (Figure 9 and Table 4), two in Georgia, one in North Carolina, and one in Maryland, were identified mainly from data for chronostratigraphic units described by Brown and others (1972) for the middle Atlantic Coastal Plain (Maryland, Virginia, and North Carolina) and by Brown and others (1978) for the southern Atlantic Coastal Plain (South Carolina and Georgia). Pre-Cretaceous basement rocks were evaluated independently using selection criteria as consistent as possible with those for younger rocks.

In addition to the general evaluation criteria outlined in Section 2.0, the following specific characteristics of the Atlantic Coastal Plain subregion were also considered:

- The potential host rock should lie below the maximum fresh-water depth of approximately 457 m (1500 ft) in the middle Atlantic Coastal Plain or below the 10,000 mg/L NaCl isochlor in the southern Atlantic Coastal Plain.
- The potential host rock should not contain groundwater whose NaCl concentration decreases with increasing thickness of the host rock.
- The potential host rock should have a sand-shale ratio less than 1.
- The potential host unit should contain less than 25 percent limestone; any limestone beds present should be less than 7.6 m (25 ft) thick.
- The potential host rock should not be located near an abrupt change in facies to material whose relative permeability is markedly higher than that of the host rock.
- The potential host unit should contain 75 to 100 percent shale or clay with at least one shale or clay layer more than 15.2 m (50 ft) thick.
- The potential host unit should not be located above a chronostratigraphic unit containing more than 50 percent limestone.

Specific application of the selection criteria to the geologic formations within the subregion depends on the nature of the available subsurface data.

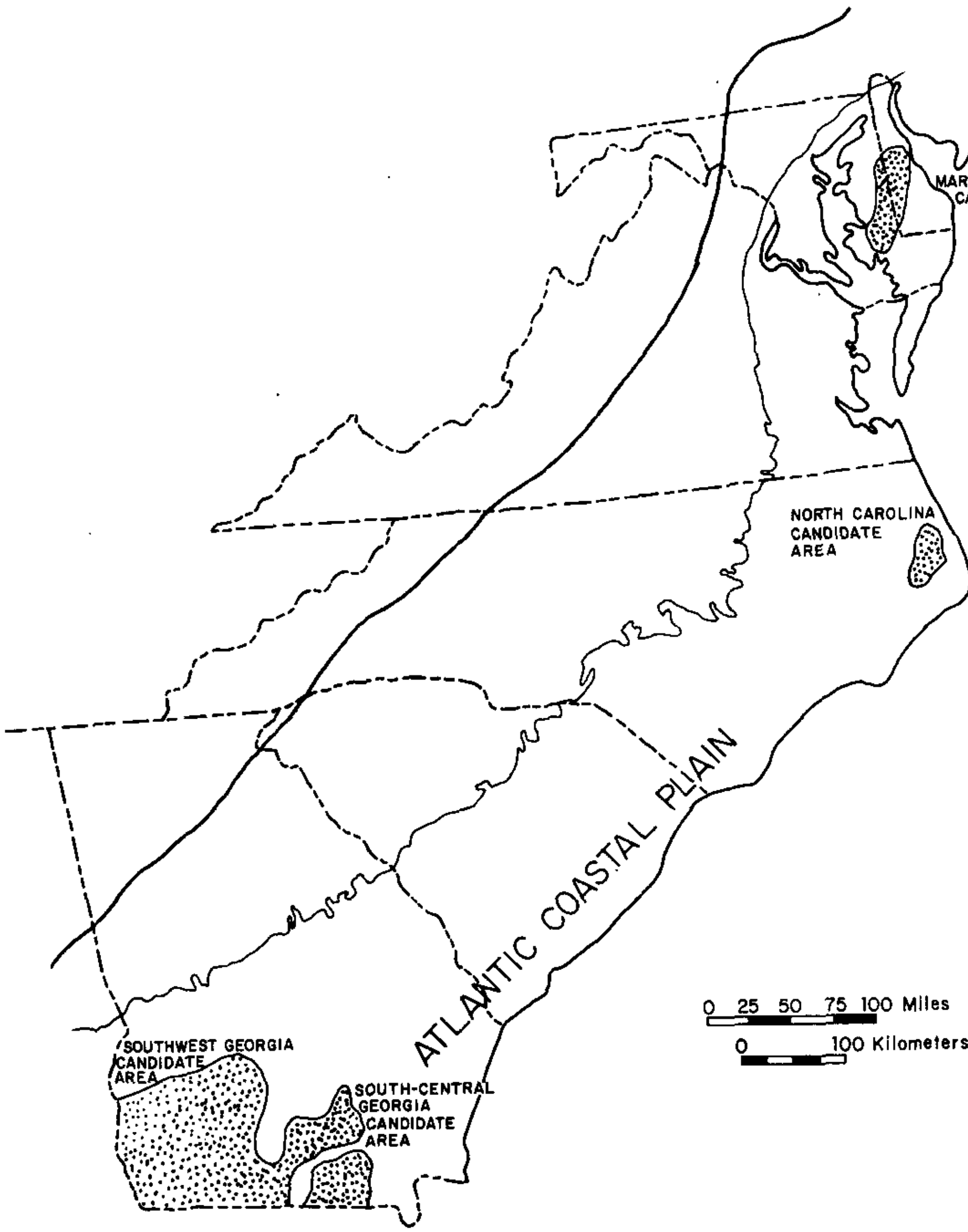

FIGURE 9. Potential Field-Study Areas within the Southeastern Atlantic Coastal Plain

TABLE 4

Potential Field Study Areas in the Southeastern Atlantic Coastal Plain

Candidate Study Area	*Location*	*Size*	*Lithology*	*Altitude/Depth to top of Host Formation*	*Thickness of Host Formation*	*Age*
Maryland Candidate Area	Caroline, Dorchester, and Talbot Counties	3120 km^2 (1200 mi^2)	Unit F: Alternating beds of fine sands and clays. Some thin layers of coarse sand	-274 to -488 m (-900 to -1600 ft)	244 to 305 m (800 to 1000 ft)	Lower Cretaceous
North Carolina Candidate Area	Hyde and Dare Counties	624 km^2 (240 mi^2)	Unit B: Micaceous shale and clay	-458 to -625 m (-1500 to -2050 ft)	61 to 107 m (200 to 350 ft)	Upper Cretaceous
			Unit G: Interbedded shale, fine to medium sand, and limestone	-1067 to -1341 m (-3500 to -4400 ft)	274 to 366 m (900 to 1200 ft)	Lower Cretaceous
Southwest Georgia Candidate Area	Southwest corner of the state; all or parts of twenty counties	18460 km^2 (7100 mi^2)	Unit E: Micaceous shale interbedded with sand, sandstone, and limestone	-762 to -1067 m (-2500 to -3500 ft)	30 to 91 m (100 to 300 ft)	Upper Cretaceous
			Unit G: Micaceous shale and fine to coarse quartz sand and sandstone. Possibly some limestone	-1067 to -1524 m (-3500 to -5000 ft)	152 to 305 m (500 to 1000 ft)	Lower Cretaceous
			Unit H: Micaceous sandy clay, clayey sand and sandstone. Gravel lenses	-1280 to -1768 m (-4200 to -5800 ft)	31 to 305 m (100 to 1000 ft)	Lower Cretaceous Late Jurassic(?)
South-Central Georgia Candidate Area	Echols and Clinch Counties	1950 km^2 (750 mi^2)	Shales intercalated with siltstone and sandstone	-1128 to 1250 m (3700 to 4100 ft)	>107 m (350 ft)	Early Paleozoic

Except for the Charleston, South Carolina, area, the southeastern Atlantic Coastal Plain is of low seismicity. Seismic considerations are therefore not restrictive criteria in selecting candidate field exploration areas in the southeastern Atlantic Coastal Plain except in the region around Charleston, South Carolina.

4.3.1 Maryland Candidate Area

The Maryland candidate area is located in the central part of the Delmarva Peninsula in the Eastern Shore Region of Caroline, Dorchester, and Talbot Counties. The candidate host rock in this area is the uppermost Lower Cretaceous chronostratigraphic unit, Unit F, as defined by Brown and others (1972). It consists of 75 to 100 percent clay with interbedded thin sand layers and has a very low relative intrinsic permeability. The thickness of Unit F ranges from approximately 244 m (800 ft) to 305 m (1000 ft) and the altitude of its top is from -274 m (-900 ft) to -488 m (-1600 ft). Only that part of Unit F below -457 m (-1500 ft) is considered potential host rock. The unit is part of a broadly homoclinal, seaward- dipping wedge of Cretaceous and Cenozoic clastic sediments which fill a trough in the pre-Cretaceous basement surface. Fresh-water aquifers occur in the sediments above the potential host unit. The land overlying he potential host unit is a low-lying, gently-rolling, terraced plain of low relief. The natural resources of the area are mostly soil and water with mineral resources limited to shallow deposits of sand and gravel.

4.3.2 North Carolina Candidate Area

The North Carolina candidate area comprises the northeastern corner of Hyde County and all but the coastal margin of the Dare County mainland. Two chronostratigraphic units of Cretaceous age, Units B and G, are the candidate host rocks. They are separated by rocks of unacceptable lithology, permeability, or thickness. The Upper Cretaceous unit, Unit B, is almost all clay and has a very low relative intrinsic permeability. The unit thickens eastward from 61 m (200 ft) to about 107 m (350 ft) and the altitude of its top decreases from -458 m (-1500 ft) to -625 m (-2050 ft). The Lower Cretaceous unit, Unit G, consists of 75 to 100 percent shale interlayered with siltstone, sand, and limestone. The relative intrinsic permeability of the unit is very low. The unit thickens eastward from 274 m (900 ft) to 366 m (1200 ft) and its top decreases in altitude from -1067 m (-3500 ft) to -1341 m (-4400 ft). These units are part of a more than 1524 m (5000 ft) thick sequence of Cretaceous and Cenozoic marine to marginal marine sediments. The structure of this sedimentary sequence is broadly homoclinal toward the sea, but its detailed structure is poorly known. The land surface in the area is of very low elevation, swampy, and largely forested. Natural resources of the area are limited mainly to groundwater and forest land. Uneconomic beds of phosphatic sand are common in the middle Miocene Formations at a depth of approximately 183 m (600 ft).

4.3.3 Southwest Georgia Candidate Area

The southwest Georgia candidate area is located in the southwest corner of the state and includes all or parts of twenty counties. The candidate host rocks are two chronostratigraphic units of Cretaceous age, Unit E and G, and another of Cretaceous or Late Jurassic age, Unit H. The uppermost Cretaceous unit, Unit E, consists mostly of micaceous shale intercalated with thin layers of sand and sandstone and lenses of limestone and has a sand-shale ratio generally less than 0.6. Its thickness ranges from less than 30 m (100 ft) in the northern part of the area to more than 91 m (300 ft) in the southern part. The altitude of its top decreases from around -762 m (-2500 ft) in the northwest to lower than -1067 m (-3500 ft) in the southeast. The middle unit, Unit G, consists of micaceous shale, quartz sand, and sandstone, with sand-shale ratios commonly less than 0.5. Its thickness ranges from 152 m (500 ft) to 305 m (1000 ft) over most of its extent. The altitude of its top ranges from approximately -1067 m (-3500 ft) in the northeast to -1524 m (-5000 ft) in the southwest. The lowermost unit, Unit H, consists of micaceous sandy clay, clayey sand and sandstone, and less commonly, lenses of gravel. The altitude of its top ranges from -1280 m (-4200 ft) to -1768 m (-5800 ft). It thickens from less than 31 m (100 ft) in the northeast to more than 305 m (1000 ft) in the southwest. Several structural features interrupt the regional southeastward dip of the upper part of the section. However, there is generally no firm evidence for the existence of faults in the area. As with the other areas in the southeastern Atlantic Coastal Plain, soil, surface water, and groundwater are probably the most valuable natural resources. Mineral resources known to be present in the area include deposits of Fuller's earth (clay), limestone, peat, sand, and phosphate.

4.3.4 South-Central Georgia Candidate Area

The south-central Georgia candidate area comprises all of Echols County and the central portion of Clinch County. The candidate host rocks are early Paleozoic in age and consist of hard, slaty, black-to-gray carbonaceous fissile shales that are irregularly interlensed with thin layers of siltstone and fine-grained sandstone. For the most part, the strata are horizontally bedded and essentially unmetamorphosed. This unit occupies the highest part of the Peninsular Arch in the pre-Cretaceous basement. In thecandidate area, these rocks are found at depths ranging from 1128 m (3700 ft) to 1250 m (4100 ft below the ground surface. Their total thickness and geometry are unknown, but more than 107 m (350 ft) have been penetrated by drilling. The area has few natural resources other than pine forest, groundwater, and marginally economic phosphorite deposits.

5.0 CONCLUSIONS

This study brings together an extensive amount of data on the geology and distribution of potential host rocks within the southeastern United States. Available data on the structure, stratigraphy, lithology, depth, thickness, mineralogy, hydrogeology, geochemistry, seismicity, natural resources, and physical characteristics of the Piedmont, Triassic, and Coastal Plain rocks were collected and reviewed.

These reconnaissance surveys determined whether these broad subregions contained a potential host rock that:

1) has sufficient areal extent,

2) has at least the minimum thickness necessary for a storage facility,

3) does not exceed the maximum depth for optimum emplacement,

4) is not within the range of regional tectonics and seismicity that would impose any undue restrictions on repository design,

5) has generally favorable hydrologic characteristics, and

6) contains negligible quantities of valuable mineral resources.

From these surveys, some 39 areas were identified as possessing generally favorable characteristics for repository development.

Additional studies of these 39 recommended areas should include socio-economic and demographic factors to determine those areas that appear to have a greater overall potential for repository development.

6.0 REFERENCES

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Yardley, D. H. (1975). Hydrology of Somc Deep Mines in Precambrian Rocks. Office of Waste Isolation, Report Y/OWI/Sub-4367-1, Union Carbide Corp., Oak Ridge, Tenn.

7.0 APPENDIX - REVIEWS BY STATE GEOLOGISTS

This report, as well as the seven supporting reports, were sent to the State Geologists of the 5 states in the region for their technical review prior to publication. Their detailed technical or editorial points are incorporated as necessary into the respective reports to which they apply. The more substantive comments are included in this Appendix. One common comment by several State Geologists expressed concern over geotechnical stability of a mined waste disposal facility in the Coastal Plain sediments.

STATE OF MARYLAND

MARYLAND GEOLOGICAL SURVEY
THE JOHNS HOPKINS UNIVERSITY
MERRYMAN HALL
BALTIMORE, MARYLAND 21218

September 3, 1980

Dr. I. W. Marine, Research Associate
Savannah River Laboratory
E. I. Du Pont De Nemours & Company
Aiken, South Carolina 29801

Dear Dr. Marine:

I appreciate your providing the Survey with draft copies of the regional radioactive waste disposal reports. As you are aware two Maryland Candidate Areas are identified in the reports, the diamictite facies of the Wissahickon Formation (Piedmont) and "Unit F" of the Potomac Group (Coastal Plain).

If we disregard socioeconomic factors and apply only geotechnical criteria at this stage of the selection progress, then perhaps the Piedmont area may be reasonably considered for additional field study. Indications are that the diamictite facies is lithologically fairly homogeneous and that it is relatively unfractured. Moreover, the formation is presumably quite thick. If one includes socioeconomic factors, however, the area underlain by the diamictite would probably lose its candidate area status.

On the other hand I doubt if any serious consideration should be given to the upper Potomac Group sediments (Patapsco Formation) underlying Dorchester, Talbot, and Caroline Counties on Maryland's Eastern Shore. The Potomac Group is a fluvio-deltaic complex and lacks lithologic homogeneity. Although parts of the section may be dominantly clayey, the areal continuity of individual beds is hard to demonstrate. Additionally, fresh water Patapsco aquifers are known to occur in the Candidate Area, at least in the upper part of the unit. In any event I would not characterize the unit as being "in a region of extremely slow ground-water circulation." Furthermore, increasing interest is being shown in low-termperature geothermal applications, which may qualify the brackish aquifers of the Patapsco Formation as a "resource of current or projected value." For these reasons I view the Coastal Plain site as a poor Candidate Area selection.

COMMONWEALTH of VIRGINIA

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

DIVISION OF MINERAL RESOURCES
NATURAL RESOURCES BUILDING
McCORMICK ROAD
BOX 3667, CHARLOTTESVILLE, VA. 22903
(804) 293-5121
ROBERT C. MILICI, COMMISSIONER AND STATE GEOLOGIST

September 12, 1980

Mr. I. W. Marine
Research Associate
E. I. DuPont De Nemours & Company, Inc.
Atomic Energy Division
Savannah River Laboratory
Aiken, South Carolina 29801

Dear Mr. Marine:

Here are our comments on your reports concerning the National Waste Storage Program. Don Le Van reviewed the Executive Summary, Gene Rader reviewed the Coastal Plain report, and Jim Conley commented on the Triassic Basin and Piedmont reports.

The report should be very helpful to us should we become involved in selecting potential sites for low level radioactive waste disposal.

Please call upon us if we may assist you further.

Sincerely,

Bob Milici

Robert C. Milici
State Geologist

RCM/kr

Enc.

MAJOR COMMENTS BY VIRGINIA DIVISION OF MINERAL RESOURCES

Executive Summary DP-1559

1. p. 14 - As applicable dose-limit standards may be revised, the only acceptable plan should be one that ensures that NO radionuclides can migrate to the biosphere.

2. p. 15 - Virginia has experienced numerous seismic events in the past, e.g., see Bollinger, 1978, enclosed.

3. p. 15 - How is "unacceptable leakage" defined and determined? Is any leakage acceptable?

4. NOTE: Information on additional areas of buried strata of probable Triassic age revealed by drilling in King William County is reported in "Virginia Minerals," Vol. 7, No. 3, p. 6-7, enclosed.

5. p. 49 - Mineral resources in Danville Basin: Intensive exploration and leasing for uranium are currently taking place in and adjacent to the Danville Basin. Also Triassic clay materials are used as raw material for lightweight aggregate, and Triassic rocks are quarried for the production of crushed stone.

6. Excavation of a deep repository in the Coastal Plain would require unusual design or construction considerations because of unconsolidated or poorly consolidated sediments and presence of aquifers. See p. 20.

Comment on Dames and Moore Report DP-1567 (Triassic Basins)

7. p. 5-3 - The writer rules out highly fractured rocks, but what about a mylonite which would have no porosity or permeability?

Comment on W. R. Brown report DP-1561 (Piedmont of VA and MD)

8. p. 28 - Lynchburg in the gneiss domes is the Bassett Formation, and the so-called Catoctin is also Bassett.

SRL COMMENTS ON MAJOR POINTS FROM REVIEW BY VIRGINIA DIVISION OF MINERAL RESOURCES

Executive Summary; DP-1559

Item	SRL Comment
1	It is difficult to quantify "No" for use as a criteria. Federal agencies, such as the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA) are currently in the process of defining the applicable limits.
2	As Bollinger states, the earthquake activity in Virginia has been low but persistent. According to risk studies, quoted by Bollinger, Virginia is not a zone of high seismic risk.
3	Quantitative definitions of "unacceptable leakage" are being defined by the Nuclear Regulatory Commission and the Environmental Protection Agency.
4	This information on a buried Triassic basin in King William County was included in the Triassic Report (DP-1569). However, because of the small amount of information on the extent of this basin, it was not discussed in the Executive Summary.
5	Additional evaluations of the most recent trends in mineral leasing would be made in any area designated for further study. Surface quarrying would not ordinarily be considered detrimental to a deep repository.
6	The comment is correct.
7	The word "fracture" has a double meaning. In structural geology, it is used to mean evidence of a break in rock, which may have been healed by subsequent geologic processes. In hydrogeology, the term "fracture" refers to a present crack in the rock that will transmit water. In this report, "fracture" is used in the hydrogeologic sense.
8	The comment is acknowledged.

COMMONWEALTH of VIRGINIA

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
NATURAL RESOURCES BUILDING
McCORMICK ROAD
BOX 3667, CHARLOTTESVILLE, VA. 22903
(804) 293-5121
ROBERT C. MILICI, COMMISSIONER AND STATE GEOLOGIST

September 8, 1980

MEMORANDUM

TO: Robert Milici

FROM: Eugene Rader

SUBJECT: Review of potential host rock for radioactive waste disposal in the southeastern United States, Southeastern Coastal Plain subregion.

The site selection criteria stated on page 6 and 7 appear to be objective and scientifically sound, except for number 6. Chronostratigraphic units are not a useful concept in this type of study. It would be more useful to consider only lithostratigraphic units.

Pre-Mesozoic basement rocks include metasedimentary rocks and mylonites in addition to the rock types listed on page 15. The use of shale and sandstone for Eocene deposits is incorrect; clay and sand is more appropriate. Thin Oligocene deposits (6 to 10 ft.) are locally present in Virginia. Post-Miocene sediments in Virginia include the Yorktown (Hazel, 1977) and Bacon Castle of Pliocene age which are in part marine (see pages 20, 21 and 24). The assumption that all red beds are Triassic may be in error (page 22 - 23).

The formations and ages listed in Table 2 are either incorrect or not complete. The following corrections should be made:

Series	Formation
Pliocene	Bacons Castle and Yorktown
Miocene	"Virginia St. Marys", St. Marys, Choptank, and Calvert
Oligocene	unnamed unit
Eocene	Chickahominy, Nanjemoy, and Marlboro

Paleocene	Aquia
Upper and Lower	Potomac Group

On Figure 4A potential areas based on lithology and ground water requirement are shown. Those areas along the fall line in Virginia contain considerable sand and gravel and lie in the fresh water zone and therefore should not be considered potential areas.

The objective application of the stated selection criteria eliminates the entire Virginia coastal plain from consideration.

SRL COMMENT ON MAJOR POINTS FROM REVIEW BY VIRGINIA DIVISION OF MINERAL RESOURCES

These comments on the Coastal Plain are acknowledged.

North Carolina Department of Natural Resources & Community Development
James B. Hunt, Jr., Governor
Howard N. Lee, Secretary

DIVISION OF
LAND RESOURCES
Stephen G. Conrad, Director
Box 27687, Raleigh 27611
Telephone 919 733-3833

September 15, 1980

Mr. I. W. Marine, Research Associate
E. I. du Pont de Nemours & Company
Atomic Energy Division
Savannah River Laboratory
Aiken, SC 29801

Dear Mr. Marine:

Thank you for your recent letter and the attached reports concerning regional studies of the Southeastern United States as part of the National Waste Terminal Storage Program. These geotechnical reports appear to fulfill their purpose of identifying broad areas that may be favorable for development of a radioactive waste repository.

In reviewing the portions of the reports dealing with North Carolina geology we have found them to be essentially correct based on the current state of knowledge.

As indicated in your letter no socioeconomic factors have been taken into consideration to this point. It is apparent that when factors such as population density are considered, several of the eight areas in North Carolina should be eliminated from the list.

We hope these comments are of assistance and we are looking forward to continuing cooperation.

Yours very truly,

Stephen G. Conrad

Stephen G. Conrad, Director

SGC:EPA:pfg

Geological Survey Section—733-2423, Geodetic Survey Section—733-3836; Land Quality Section—733-4574; Planning and Inventory Section—733-3833;
Land Resources Information Service—733-2090

SRL COMMENT ON REVIEW BY THE NORTH CAROLINA DIVISION OF LAND RESOURCES

Socio-economic factors will have to be studied before an area can be considered for further study.

STATE OF SOUTH CAROLINA
SOUTH CAROLINA GEOLOGICAL SURVEY
HARBISON FOREST ROAD
COLUMBIA, SOUTH CAROLINA 29210

EUGENE A. LAURENT, PH.D., DIRECTOR
DIV. OF RESEARCH AND STATISTICAL SERVICES
BUDGET AND CONTROL BOARD

NORMAN K. OLSON
STATE GEOLOGIST
(803) 758-6431

September 16, 1980

Dr. I. Wendell Marine
Research Associate
E. I. duPont deNemours & Company, Inc.
Savannah River Laboratory
Aiken, South Carolina 29801

Dear Wendell:

As a follow-up of my letter of August 15 to you, I'm enclosing review (and partial edit) comments on some of the eight radioactive waste publications you sent, and which were prepared as part of the National Waste Terminal Storage Program.

Some publications from the group you sent were reviewed by various geologists on our staff. As understood, we are keeping the reports in our library and sending you individual copies of comments on selected reports (abbreviated title) as follows:

DP-number	Title	Reviewer
1559	Executive Summary	Staff (see comments on individual reports)
1563	S.C. Piedmont	Nystrom
1567	SE U.S.--Piedmont	Maybin
1568	SE U.S.--Coastal Plain	Zupan
1569	Triassic basins	Olson

The other three reports--covering Va.-Md., N.C. and Ga.--were not included in our review comments. Thank you for sending those reports, anyway.

We appreciate the opportunity of reviewing these reports. We hope you'll continue to call on us and other geologists and hydrologists in South Carolina.

Cordially,

Norman K. Olson
State Geologist

NKO:ny
cc: Honorable Allen R. Carter
Mr. David Reid
Dr. Eugene A. Laurent
Mr. Robert E. Leak
Mr. Clair P. Guess, Jr.
Mr. Donald A. Duncan
Dr. William W. Hambleton

REVIEWS BY THE SOUTH CAROLINA GEOLOGICAL SURVEY

Review of DP-1563 - P. J. Nystrom, Jr. - 8/21/80

1. p. 41; 7.3 Ogden Pluton

   The Ogden Pluton is large but very poorly exposed. I don't see how anyone could determine how homogeneous the pluton really is without core drilling and no one has yet done that. Some of the other large gabbros such as the Mt. Carmel, Dutchman's Creek, and Greenwood show considerable internal variability in rock composition.

2. p. 45; Conclusions

   What about the large Santuck Pluton in Union County?

3. The Pageland Pluton was eliminated as a target area because it is partially concealed. Being in part covered by Coastal Plain sediments, it cannot be examined as thoroughly as some of the other plutons. Nevertheless, much of the pluton is exposed and as it is a sister pluton to the Winnsboro and Liberty Hill, like those approved plutons it might make a suitable body of rock for a repository. I wonder if the Pageland Pluton should be eliminated so soon as a potential site.

Suggested Corrections for DP-1567 - A. H. Maybin, III - 9/80

4. pp. 3-3 - Comment on origin of Kings Mountain Belt rocks.

   Some are volcanic in origin; see Horton and Butler, 1977, "Guide to the Geology of Kings Mountain Belt in the Kings Mountain Area, North Carolina and South Carolina," in Field Guides of GSA, SE Section Meeting, Winston-Salem, North Carolina, pp. 76-143, GSA-SE Sect., USA.

SRL COMMENTS ON REVIEWS BY THE SOUTH CAROLINA GEOLOGICAL SURVEY

Piedmont of South Carolina; DP-1563

1. Core drilling would have to be done at an early stage were this gabbro pluton to remain viable.

2. The report was revised to mention that the structural complexity and small size of the Santuck Pluton eliminated it from consideration.

3. The report was revised to mention that the Pageland Pluton is 60 percent concealed by Coastal Plain sediments, and this fact caused it not to be considered further.

Piedmont of South Carolina; DP-1567

4. No Comment

Review of DP-1568 - Alan-Jon Zupan - 8/19/80

5. General Comment:

   The discussion of S.C. Coastal Plain geology is outdated; therefore, is inaccurate.

   Specific Comments:

   p. 18 - Rocks of Late Cretaceous..., south central South Carolina,.... These sediments are partially, if not wholly, Tertiary. Also "Rocks" should be "Sediments."

   pp. 18-19 - They crop.... S.C. has numerous outcrops and exposures of Paleocene sediments.

   p. 20 - 3.2.8 Miocene - The Miocene discussed is probably the Duplin which is now recognized as Pliocene. Also, the name Duplin has recently been eliminated in favor of Yorktown.

   Table 4: This table is out-of-date (1962) and inaccurate
   No Pliocene (Yorktown)
   No Oligocene (Cooper)
   Should be Warley Hill/Congaree. Description is wrong.
   No Paleocene (Black Mingo is both Paleocene and Eocene)
   Tuscaloosa should be Middendorf and new description.
   Cape Fear should be added w/description.
   Triassic should be added w/description.

   Figure 1: Geology of S.C. inaccurate.

Review (and partial edit) comments on DP-1569: Triassic Basin Subregion.

	Page	Para	Line	Remarks
6.	3-34	6	6	...there are no data ...(be sure to verify this statement with Dr. G. A. Bollinger, VPI&SU, Blacksburg. His extensive knowledge of SE seismicity should be used as well as some of his papers in the Bibliography.)
7.	3-89	1	6	Clastic dikes filled with sand and clay are common (Siple, 1967).

SRL COMMENTS ON REVIEWS BY THE SOUTH CAROLINA GEOLOGICAL SURVEY (Cont'd)

Coastal Plain of South Carolina; DP-1568

5. Terminology of the South Carolina Coastal Plain stratigraphy is currently undergoing revision, largely by the State Geological Survey. Not all of this work has yet been published, and thus it is difficult to use. It is not believed that the differences in terminology would affect the conclusions of the study.

Triassic Basins; DP-1569

6. The focus of this report is on the Triassic basins, and there is no specific reference to the correlation of seismicity with the Triassic basins in the Bollinger references.

7. The text has been changed.

South Carolina Department of Health and Environmental Control

2600 Bull Street
Columbia, S. C. 29201

October 9, 1980

Dr. I. Wendell Marine
Research Associate
E. I. duPont deNemours & Company, Inc.
Savannah River Laboratory
Aiken, South Carolina 29801

Dear Wendell:

I appreciate the opportunity to review the draft reports on the potential host rocks for radioactive waste disposal as they relate to ground-water protection in S.C. The reports are well-written and objective and I agree with the conclusions.

There is one major point I would like to make however. Whereas the review of such potential in the Coastal Plain Subregion addresses the potential for impact on aquifers in that area, the Piedmont counterpart seems to pass over the facts that fractures are documented, others are probable, and these fractures yield or have the potential to yield significant amounts of ground water to wells, i.e., the plutons themselves or at least the upper parts could be designated as aquifers. I realize that this review is general in nature and is to be the basis for future field testing, but it is recommended that these facts be mentioned early on as having no less significance than the other criteria.

Again, I appreciate this opportunity and if there is any way I can help, please let me know.

Sincerely,

Donald A. Duncan, Director
Ground-Water Protection Division

DAD/dhw

SRL COMMENT ON REVIEWS BY THE SOUTH CAROLINA DEPARTMENT OF HEALTH AND ENVIRONMENTAL CONTROL

The extremely low permeability of the plutons at depth needs to be demonstrated before they can continue to be considered as viable areas for more detailed exploration.

JOE D. TANNER
Commissioner

J. LEONARD LEDBETTER
Division Director

Department of Natural Resources

ENVIRONMENTAL PROTECTION DIVISION
270 WASHINGTON STREET, S. W.
ATLANTA, GEORGIA 30334

Reply To:
Georgia Geologic Survey
Room 400
19 Martin Luther King, Jr., Dr., S.W.
Atlanta, Georgia 30334
(404)656-3214

September 16, 1980.

Mr. I.W. Marine,
Research Associate,
E.I. Du Pont de Nemours & Company,
Atomic Energy Division,
Savannah River Laboratory,
AIKEN, S.C. 29808.

Dear Mr. Marine,

The Georgia Geologic Branch of the Environmental Protection Division appreciates the opportunity to review several geologic studies of the Southeastern United States as part of the National Waste Terminal Storage Program. It is our understanding that the purpose of these studies was to review the geologic literature and to identify broad geologic areas that appeared to be geologically compatible for development as a radioactive waste repository. We also understand that placement of radioactive wastes would be in mined cavities (i.e. retrievable); and that liquid or slurry injection is not being considered as part of this study.

The remainder of this letter, therefore, will provide our comments to these literature studies. Our comments, however, will be directed at the geological conditions of the Candidate Areas within or immediately adjacent to Georgia. We will not comment on geological conditions or Candidate Areas outside of Georgia. In addition, it is important to remember that geological suitability represents only one aspect of host rock evaluation. For example, the Lithonia Gneiss, which was identified as a Candidate Area in the Piedmont of Georgia lies within the heavily populated metropolitan Atlanta area; and, as such, obviously is not appropriate for a radioactive waste repository.

Specific comments are as follows:

(A) In general, the work of several of the consultants is out-of-date. References in the Executive Summary indicate that the reports were submitted to Du Pont in excess of two years ago (i.e. spring and summer of 1978). At about this same time (1978), the State of Georgia initiated a number of new studies, many of which addressed the State's ground-water regime. Thus, there is considerable new hydrologic and geo-

2/....

logic data that simply were not available to the consultants; for example:

(1) The Lithonia Gneiss and several other igneous plutons of the Georgia Piedmont have now been mapped in detail and their general configuration are delimited in several maps and reports.

(2) The U.S. Geological Survey is now in the final stages of completing a hydrogeological investigation of the Piedmont in the vicinity of Atlanta. Statistical summaries of well yields for various Piedmont lithologies have been developed; and can be correlated to similar lithologies elsewhere in the Piedmont.

(3) The general lithostratigraphy of the Georgia Coastal Plain has been redefined. Of particular importance is the documentation of facies change across the State as well as in a down-dip direction.

(4) The Georgia Geologic Survey and the U.S. Geological Survey are engaged in several detailed hydrogeological investigations in the Coastal Plain. The Dunbarton Triassic Basin, the Southwest Georgia Candidate Area, and the South-Central Georgia Candidate Area are within several of the study areas.

(5) Recent work by the U.S.G.S. suggests that faults, which could act as pathways for fluid movement, are quite common in the Georgia Coastal Plain. Because Coastal Plain faults appear to be much more common than previously had been anticipated, the Geologic Division of the U.S.G.S. has assigned a person full-time to search out Coastal Plain faults in Georgia.

(B) Prior to 1970, the fresh-water aquifers were used mainly in the traditional industrial centers such as Albany, Jesup, Savannah, Brunswick, St. Marys, as well as a few other areas. For most of the remainder of rural South Georgia, the aquifers were little used. However, in the past ten years, use of ground-water for irrigation purposes has increased from virtually nil to an estimated 520 million gallons per day in 1980. More significantly, the 520 million gallons per day is an annualized value; actual pumpage is several billion gallons per day in the summer with little or no pumpage in the winter. Consequently, the aquifers of rural South Georgia often are under severe hydrologic stress with water leaking both upward and downward through confining units. Moreover, the growth rate of irrigation usage of ground-water is on the order of 15 to 20 percent per year. Obviously, with such an accelerated growth rate of irrigation pumpage, the aforementioned hydrologic stresses will magnify; and it is reasonable

3/....

SRL COMMENTS ON REVIEWS BY GEORGIA DEPARTMENT OF NATURAL RESOURCES: ENVIRONMENTAL PROTECTION DIVISION

Item	Comment
(A)	The three basic reports on the Piedmont, Coastal Plain, and Triassic Basins bear an imprint date of Summer, 1978. Additional studies of the Piedmont were completed in the Fall of 1979.
(A-1)	The author of the Georgia Piedmont report was aware of the concurrent studies by the State of Georgia and included as much of this information as was available in the Fall of 1979.
(A-2)	These quantitative data (as developed around Atlanta) were not available. However, similar work by LeGrand and Mundorff,[1] in the Charlotte, North Carolina area, and by Marine and Rasmussen,[2] in the Wilmington, Delaware area, was made available to the consultants.

1) LeGrand, H. E. and M. J. Mundorff, 1952, "Geology and Ground Water in the Charlotte Area, North Carolina," North Carolina Department of Conservation and Development Bull. 63.

2) Marine, I. W., and W. C. Rasmussen, 1955, "Preliminary Report on the Geology and Ground-Water Resources of Delaware," Delaware Geolog. Surv. Bull. No. 4, pp. 91-94.

Item	Comment
(A-3, 4,5)	The results of these studies will be valuable when they are available.
(B)	Hydrogeological studies and projections of water use will be an important part of any further studies of more restricted areas.

to assume that interaquifer ground-water flow will become a common phenomena. In other words, the existance of confining units such as clays or the lack of present day hydraulic interconnection should not be interpreted to indicate that radioactive waste buried beneath the Georgia Coastal Plain will remain isolated from the biosphere.

(C) The Piedmont Province - Several igneous plutons of the Georgia Piedmont are mentioned as Candidates for further study. In this regard, it is important to note that the plutons range in age from Precambrian to Late Paleozoic; and that the older plutons typically have undergone several phases of tectonic activity and hence are more likely to be fractured (i.e. more transmissive to ground-water flow). Also, recent geologic mapping of xenoliths (correlative with metamorphic formations on the flanks of the igneous bodies) through the plutons suggests that the plutons may be much thinner than had been previously believed and perhaps more or less saucer-shaped. If this is the case, then uniform non transmissive rock suitable for radioactive waste burial may not exist at the appropriate depths.

(D) The Dunbarton Triassic Basin - The Dunbarton Basin probably extends southwesterly from the Savannah River Plant area to Washington County where the Triassic has been the object of several oil/gas tests. Throughout this entire area, the Dunbarton apparently is overlain by an extensive weathered clay zone of Cretaceous-age. In turn, the clay is overlain by sands and gravels. These sands and gravels are prolific and transmissive aquifers and are being increasingly used for irrigation purposes.

The arguments presented that the Triassic strata are hydraulically separate from Cretaceous aquifers are suspect; namely:

(1) The variation of ground-water chemistry between the Triassic and Cretaceous is to be expected. Even if the Triassic and Cretaceous were hydraulically interconnected, the very large volume of water moving through the Cretaceous aquifers would simply dilute and mask upward leakage from the Triassic. Thus, variation in ground-water chemistry should not be considered as being indicative of hydraulic separation.

(2) The presence of the weathered zone forming an impermeable aquiclude between the Triassic and Cretaceous is unlikely. The coarse character of the Cretaceous sediments suggests a high energy depositional environment. Thus, any weathered zone would be expected to be erratic, thin (and transmissive), and perhaps locally breached. Recent drilling by the U.S.G.S. at Wrightsville, Georgia indicates that the clayey weathered zone is faulted (i.e. slickensides were observed) and possibly transmissive. Also, as previously mentioned, interaquifer flow (i.e. from the Tri-

4/....

SRL COMMENTS (Cont'd)

Item	Comment
(C)	Considerable thought was given to this subject during the course of these investigations. It is the opinion of the author of the Georgia Piedmont study, (DP-1564) that the early tectonic episodes were ductile in character and therefore did not result in an increase in brittle fractures with an increase in the age of the pluton. Hard evidence of whether older plutons are more fractured than younger plutons does not exist. Therefore, plutons are not removed from consideration simply because of their age.
(C)	The shape of the plutons was also given considerable thought. It was well recognized that plutons might be saucer or funnel shaped. In general, the thickness of the plutons was estimated using geophysics. This information indicated that different plutons have different shapes and thicknesses. Some plutons were rejected on the basis of this information.
(D)	The oil and gas tests in Washington County penetrate Triassic sediments, but to our knowledge there is as yet no evidence that these sediments are part of the Dunbarton basin.
(D-1)	The difference in chemistry was not used as evidence of hydraulic separation of these two bodies of rock.
(D-2)	Although drilling in the Dunbarton Basin shows the presence of a weathered zone at the top of the Triassic sediment, its permeability has not been tested. It is unlikely that this weathered zone has a permeability as low as that of the parent Triassic rock. Hydraulic isolation would be afforded by the large thickness of low permeability Triassic rock rather than by the thin weathered zone.

assic to the Cretaceous) should be anticipated in response to hydrologic stresses induced by irrigation pumpage.

Mine cavern burial of high-level radioactive wastes in the Dunbarton Triassic Basin underlying the Savannah River Plant was the subject of DOE/EIS-0023. In Governor Busbee's letter of January 11, 1980 to Ms. Ruth Clausen of the United States Department of Energy, it was noted that specifically because of the potential for contamination of the Tuscaloosa Aquifer, the State of Georgia was opposed to bedrock storage at the Savannah River Plant (i.e. within Triassic-aged strata of the Dunbarton Basin). A copy of Governor Busbee's letter is attached.

(E) Southwest Georgia Candidate Area - Chronostratigraphic Units E, G, and H are stratigraphically equivalent to Aquifer A_7 (refer to Georgia Geologic Survey Hydrologic Atlas #3), which is the lowermost Coastal Plain Unit of Southwest Georgia. Use of a shale within this sequence as a waste repository would mean that an adit (mine shaft) would have to be lowered several thousand feet through some of the most prolific, transmissive, and highly used fresh water aquifers in the county. Also, the adit would pass through fine-grained sands that readily liquify (i.e. turn into quicksand).

The deep Cretaceous host rock shales typically are poorly sorted and hence would be relatively transmissive; thus water would be expected to flow through them into any excavated cavern. Any such water would be highly saline and would have to be pumped up to the surface (and through fresh water aquifers) and then reinjected elsewhere. Such dewatering has the potential for contaminating fresh water aquifers over multi-county areas. We also question whether a cavern in a partially consolidated clay would remain open at a depth of several thousand feet, especially if water were infiltrating into the void. It is our opinion that the combined lithostatic and hydrostatic stresses would be too great to excavate a cavern and that the shale would continually flow as a plastic or be eroded into the cavity.

In reviewing the various geologic reports provided to us as well as the much more extensive technical data in our files, we question whether it is engineeringly feasible to construct a cavern in a deeply buried Coastal Plain shale. All of our geologic knowledge of the area suggests that such an excavation would present high unacceptable risks for cavern failure as well as ground-water leakage due to sediment permeability.

(F) South Central Georgia Candidate Areas - The early Paleozoic Black Shales underlying Echols and Clinch Counties have definite African affinities and probably represent a portion

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SRL COMMENTS (Cont'd)

Item	Comment
(E)	Construction and maintaining the stability of a disposal facility in the Coastal Plain would present difficulties not present in the metamorphic or Triassic host rocks.

← Poor sorting ordinarily means low permeability and correspondingly low water-transmission rates.

of the African Plate that was carried along with the North American Plate during Mesozoic *sea-floor spreading*. Therefore, such shales probably have undergone multiple phases of deformation and are heterogeneous, fractured and faulted. In other words, they would be expected to bè transmissive and hydraulically interconnected with Coastal Plain aquifers. Also, as mentioned in the review of the Southwest Georgia Candidate Area; dewatering and engineering problems should be expected.

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In summary, we must stress that high-level radioactive wastes should *be isolated* from the ground-water regime. When considering that the Georgia Coastal Plain contains multiple and prolific fresh-water aquifers and that interaquifer communication is to be expected, we believe that all of the identified Coastal Plain sites present unacceptable geological risks in that the Coastal Plain aquifers would be susceptible to contamination.

Very truly yours,

J. Leonard Ledbetter

J. Leonard Ledbetter
Director.

JLL:bb
enc.

cc: Commissioner Joe B. Tanner
Governor G. Busbee

SRL COMMENTS (Cont'd)

Item	Comment
(F)	Whether the Early Paleozoic shale was at one time part of the African Plate is, perhaps, not as important as whether it was involved in the continental structure.