UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

Geologic Interpretation of Basement Rocks of the Atlantic Coastal Plain

by

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and

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Open-File Report 85-655

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standard and stratigraphic nomenclature.

1. Reston, VA

1985

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PREFACE

Crystalline rock masses overlain by a hydrologic system where water flow can be readily predicted and water use is unlikely because of high salinity are possible candidates as host rocks for repositories for high level radioactive waste. The potential advantages of such systems were first described by Bredehoeft and Maini (1981) and later discussed by the National Academy of Science (1983). Studies of buried crystalline bodies, and buried crystalline rock masses are not now under active consideration as repository hosts by the Department of Energy (DOE).

Before the concept of utilizing buried crystalline rocks as repository host rocks can be a part of a formal land screening process, like those DOE has carried out for other rock types such as salt, various questions about the feasibility of the concept need to be addressed. This report is one of a series of feasibility studies conducted by the U.S. Geological Survey (USGS). The first (Davis,1984), based on existing compilations of data, identified two regions in the eastern United States where the conditions described in the original suggestion of Bredehoeft and Maini (1981) appear to be met. These regions are: (1) portions of the Atlantic Coastal Plain from New York to North Carolina and including parts of Georgia, and (2) the west flank of the Cincinnati arch in parts of Ohio, Indiana and Kentucky. Davis also pointed out that much uncompiled data bearing on the feasibility of the buried crystalline rock concept existed for the two regions and suggested that additional feasibility studies be carried out. This report represents a continuation of the work of Davis (1984) for the Atlantic Coastal Plain and deals with the nature of the pre-Cretaceous basement. A companion report by Lloyd and others (in press) discusses the hydrology of the sedimentary rocks immediately overlying the basement.

INTRODUCTION

Knowledge of the rocks that form the basement of the Atlantic Coastal Plain (ACP) was for many years limited to the samples returned by deep drilling for groundwater and petroleum. The distribution of these wells is highly uneven (Figure 1). Data from various geophysical investigations has become increasingly significant and now may equal the well data in terms of total information content. Particularly important is the nearly complete aeromagnetic coverage of good quality because of the even data distribution, and gravity data because of its use in indicating plutonic rocks. The quality of the gravity data is less even than the magnetic data but is good in certain areas. Large and important features are revealed in the potential field data which are totally unexplained by the drillhole samples. Some potential field features show excellent correlation with lithologies observed in wells and may represent sources present at the basement surface. Seismic reflection profiles are becoming more important but coverage in the Coastal Plain is limited largely to Georgia and South

Carolina. The basement geology maps of the Atlantic Coastal Plain (plates 2 and 4) are an interpretation of the geologic and geophysical data. Significant differences of interpretation of the basement geology are common among various workers.

GEOLOGIC DATA

Several sources of geologic data have been utilized. Geologic mapping in the Piedmont along the edge of the Coastal Plain onlap can be used to extrapolate the geology into the adjacent subsurface basement. Shallow water wells which have struck basement provide additional lithologic control along the inner edge of the Coastal Plain. Oil test wells, scientific test wells, and groundwater monitoring wells are the source of basement samples for the deep basement terrain.

The geologic data from basement rocks varies widely in quality. Most reliable and least abundant are core samples which allow accurate observations of grain size, texture, mesoscopic structures, and lithologic variability. Most of these characteristics are difficult or impossible to obtain from cuttings, the most common type of source material. Cuttings are frequently contaminated by rock fragments from higher in the hole. Where there is uncertainty about whether basement has been reached, rock fragments which appear to represent crystalline basement may actually be crushed lithic grains from lower members of the Coastal Plain sedimentary section. Cuttings studied in thin section by geologists represent the next level of reliability below core samples. Least reliable and most common are descriptions of basement from shallow water wells by persons of unknown qualifications.

New and revised petrographic analyses of selected basement rocks by G.W. Leo are included in a section of this report. All available descriptions of basement rocks from drillholes in the Atlantic Coastal Plain, from Georgia to Massachusetts, have been extracted from the literature and other sources and are included in a separate report (Daniels, in press).

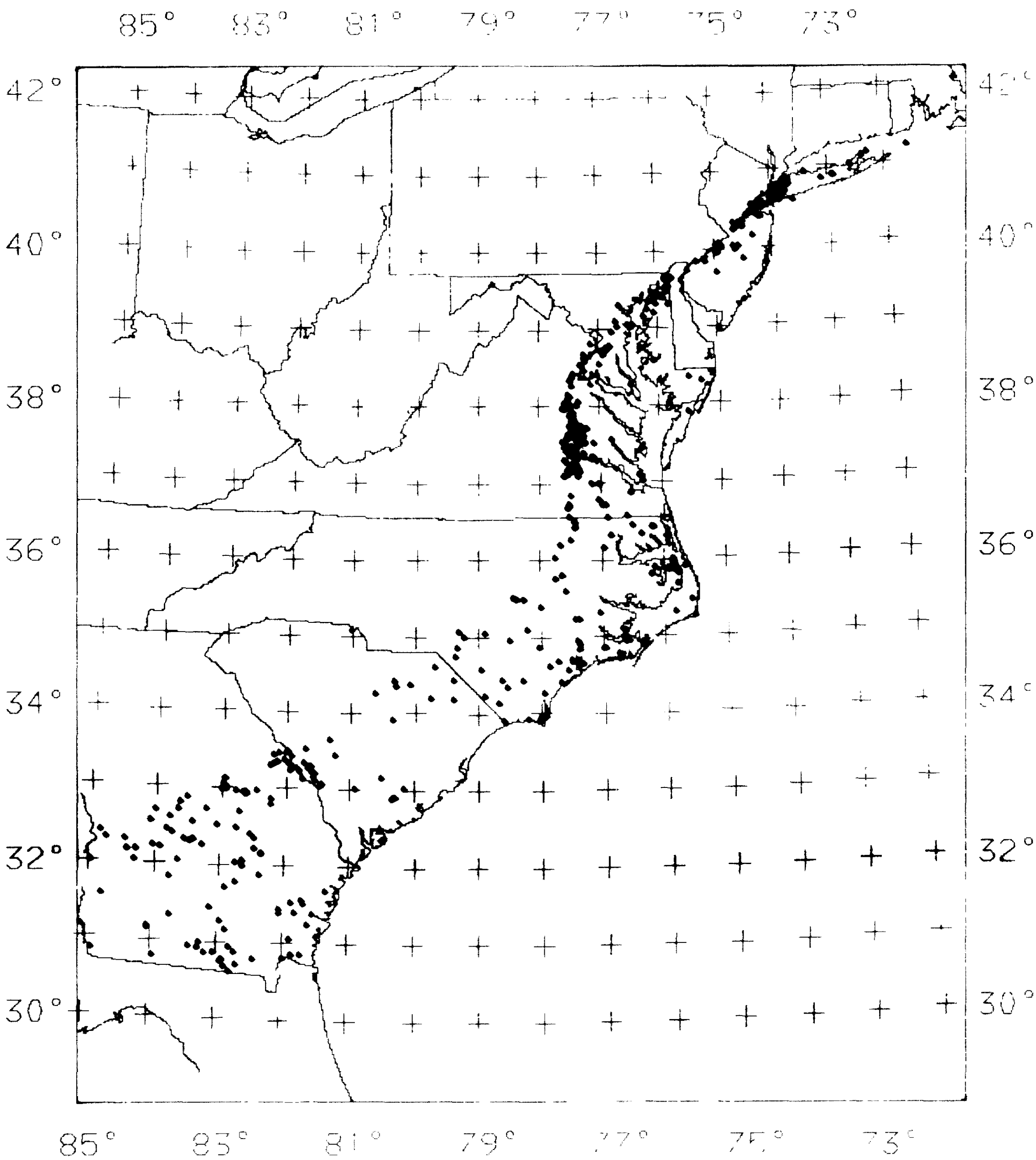

Figure 1. Map showing the location of wells and drillholes in the Atlantic Coastal Plain which are known to have returned samples of the pre-Cretaceous basement rocks.

GEOPHYSICAL DATA

Aeromagnetic maps of the Atlantic Coastal Plain are available from the U.S. Geological Survey in a wide variety of formats and scales. Maps utilized in this investigation are the state aeromagnetic maps published at a scale of 1:1,000,000 with color-coded magnetic intensity for Georgia (Zietz and others, 1980a), South Carolina (Zietz and others, 1982), North Carolina (Zietz and others, 1984), Virginia (Zietz and others, 1977), and Maryland, Delaware, and New Jersey (Zietz and others, 1980b). The latter map was used in conjunction with a newer aeromagnetic survey (U.S. Geological Survey, 1979) and unpublished aeromagnetic data.

No 1:1,000,000 scale Bouguer gravity maps which cover the entire Atlantic Coastal Plain have been published for direct comparison with the magnetic maps, although part of the area is covered by Haworth and others (1980), and larger scale maps are available (Johnson, 1973, 1975). To remedy this lack, two machine-contoured Bouguer gravity maps at 1:1,000,000 were prepared from digital gravity data (plates 1 and 3). The digital data set was compiled from the data supplied by the U.S. Defense Mapping Agency, U.S. Geological Survey, and several master's theses (Sugarman, 1981; Maguire, 1980; Chapin, 1981). The resulting density of gravity stations is shown in inset maps on plates 1 and 3. The contour maps were produced using small grid size (1 km) and small contour interval (1 mgal) to best display gravity gradients which are pertinent to the interpretation of gravity anomalies due to subsurface plutons.

The interpretation of the basement of the Coastal Plain is divided into two sections for convenience: Georgia to North Carolina and Virginia to New York. Plates 2 and 4 are interpretive maps of the basement geology. Geology of the Piedmont adjacent to the Coastal Plain is derived from Georgia Geological Survey (1976), Bramlett and others (1982), Snoke and others (1980), Bell and Popenoe (1976), Farrar (1985), Bobyarchick (1978), Farrar (1984), Weems (1981), Pavlides (1980), Drake and Froelich (1977), Cleaves and others (1968), Delaware Geological Survey (1976), Lyttle and Epstein (in press),and Rodgers (1985).

SOUTHERN AREA: GEORGIA AND THE CAROLINAS

EARLY MESOZOIC BASINS

Pre-Mesozoic crystalline rocks of the southern Piedmont continue southeastward beneath the Coastal Plain cover toward the continental shelf. In Georgia, about 20 to 50 km southeast of the Coastal Plain onlap limit, these rocks are replaced by a broad subsurface terrane of rift rocks of probable early Mesozoic age, which constitutes the South Georgia basin (Daniels and others, 1983). None of the rift rocks encountered have been dated but the association of red-beds, diabase and basalt is characteristic of the Newark Supergroup rocks (Froelich and Olsen, 1984) of the early Mesozoic basins of the exposed Piedmont. Mapping the covered boundaries of this basin is complicated by the presence of inliers of crystalline rock. Even though the number of wells into the basin is large, it is still inadequate to constrain the boundaries very closely. Narrow linear magnetic anomalies characteristic of deformed metamorphic rocks are abruptly terminated in eastern Georgia along a line which passes between wells to foliated crystalline rocks and wells to redbeds and diabase. The magnetic line is interpreted as the faulted northern boundary of the South Georgia basin and locally the border of the Riddleville basin (Daniels and others, 1983). Two inliers of crystalline rocks have been identified in Georgia and South Carolina along the northern edge of the basin using well data. In addition, magnetic depth to source measurements led to the identification of another crystalline inlier in eastern Georgia not previously indicated by well data. Both the Riddleville and Dunbarton basins, which were originally mapped by their aeromagnetic lows (Siple, 1958; Daniels and Zietz, 1978), are peripheral sub-basins within the South Georgia basin and are partly defined by the crystalline inliers. These two sub-basins appear to tilt in opposite directions. Northward deepening to a major fault along the north side is indicated for the Riddleville basin by magnetic depth estimates (Daniels and others, 1983) and seismic reflection (Cook and others, 1981; Peterson and others, 1984). These interpretations are supported by recent drilling which located the northern edge of the basin and revealed the amount of displacement along this boundary. One well which bottomed in chlorite schist without passing through redbeds is 4 km north of another well in the basin, which reached chlorite schist after penetrating 2225 m of redbeds (D. Prowell, oral communication, 1983). This indicates that the basin edge dips at least 30 degrees and is probably fault bounded.

Nelson and others (1985) have interpreted new seismic reflction profiles in western Georgia which cross the South Georgia basin. These profiles indicate that a large half graben lies central to the basin and thins to the north. Maximum basin fill appears to exceed 5 km.

The southern limits of the South Georgia basin are irregular and not evident in the potential field data. They are defined by a terrain of unmetamorphosed to lightly metamorphosed rhyolitic rocks in apparent association with several granites in the Southeast Georgia embayment. Radiometric measurements on these rocks give an extremely wide range of ages but stratigraphic evidence suggests that at least some of the rocks are Proterozoic Z or earliest Paleozoic (Chowns and Williams, 1983), and may be equivalent to the low-grade rocks of the Georgia Piedmont, the Belair and Carolina slate belts (Higgins, 1984).

In North Carolina and eastern South Carolina the subsurface crystalline rocks extend the full width of the Coastal Plain and are interrupted only by two small and poorly defined basins of apparent early Mesozoic rocks, the Florence, South Carolina basin (Darton, 1896; Siple, 1958; Popenoe and Zietz, 1977) and an unnamed basin in northeastern North Carolina (Richards, 1945; Daniels and Zietz, 1978).

CRYSTALLINE BASEMENT ROCKS

The southern Appalachian Piedmont adjacent to the Coastal Plain from Georgia to North Carolina includes six lithotectonic belts. From southwest to northeast these are the Uchee belt, the Carolina slate belt, the Kiokee belt, the Belair belt, the Raleigh belt and the eastern slate belt. In general the slate belts and Belair belt are greenschist facies rocks of volcanic, volcaniclastic, and epiclastic origin with minimal recrystallization and deformation. The Uchee, Kiokee, and Raleigh belts are generally amphibolite grade feldspathic gneisses, amphibolites and schists with rare original textures, more intense deformation, and more abundant granitic plutons.

The subsurface crystalline basement rocks in Georgia and the adjacent region in South Carolina are a mixed assemblage of foliated amphibolite and greenschist facies rocks and minor felsic plutonic rocks. This assemblage is similar to rocks in the adjacent Piedmont represented by the Uchee, Kiokee, and Belair belts. The majority of subsurface metamorphic samples are of mafic to intermediate composition, including amphibolites and chlorite-hornblende schists. The metamorphic grade appears to generally decrease gradually northeastward, although the scarcity of subsurface data in South Carolina prevents continuity with the data in North Carolina. Low-grade Belair belt rocks crop out in the more deeply incised stream valleys which expose basement along the edge of the Georgia Coastal Plain (Prowell, 1978). In outcrops in eastern Georgia, Belair rocks have been thrust over the Kiokee belt to the north along the Augusta fault (Bramlett and others, 1982). The southern subsurface boundary of the Belair belt is largely inferred from aeromagnetic patterns. The remainder of the subsurface is probably an extension of the Uchee belt. Kiokee belt rocks are exposed as far as the vicinity of Columbia, South Carolina (Snoke and others, 1980), and are partly covered by Coastal Plain sediments on the southeast and may have little subsurface extent. Carolina slate belt rocks are continuously exposed from Columbia northward along the edge of the Piedmont into North Carolina (Bell and Popenoe, 1976) and terminate in Virginia.

The subsurface width of pre-Mesozoic metamorphic rocks reaches a maximum of 220 km in North Carolina, and nearly all subsurface samples are low grade (greenschist facies), similar to rocks in the three low-grade slate belts of the Piedmont. Subsurface amphibolite grade metamorphic rocks are scarcer but most are associated with a area of abundant plutonic rocks extending from Cape Fear north, called the Hatteras terrane (Daniels and Zietz, 1978). There are no geophysical indications of this terrane. The boundary was drawn specifically to enclose the higher-grade rocks (plate 2).

Because of the predominence of low-grade metavolcanic rocks in the subsurface directly adjacent to like rocks along the edge of the Piedmont it seems probable that a very large continuous low-grade Avalon terrane (Williams and Hatcher, 1983) underlies a large part of the Coastal Plain of North Carolina and eastern South Carolina.

Plutonic Rocks

Granitic plutons are relatively evenly distributed in the Piedmont near the onlap edge of the Coastal Plain. Nearly all of these have been dated by radiometric means as late Paleozoic (Fullagar and Butler, 1979). A large proportion of these are closely associated with negative gravity anomalies. Beneath most of the Coastal Plain a similar distribution of granitic rocks is observed, even allowing for the uneven sampling of deep wells. One exception is an area with a major concentration of plutonic rocks that occurs along the North Carolina coast within the area defined as the Hatteras terrane. Of the 25 wells within this area, 14 recovered granitic rocks, 6 returned diorites, and 5 amphibolite grade metamorphic rocks. Most of the published radiometric dates for subsurface granites in the the Georgia to North Carolina Coastal Plain come from this terrane. The following whole rock Rb/Sr dates, all with large ranges of uncertainty, have been reported; 610 my (well 43) (Denison and others, 1968), 583 my (well 46) (Russell and others, 1981), 685 my (well 49) (unpublished 1972 date reported in Daniels and Zietz, 1978), 585 my (well 52) (Denison and others, 1968), for granites north of Cape Hatteras, and 630 my for quartz monzonite from the southwestern part of the Hatteras terrane (Russell and others, 1981). Two of the dated Hatteras area samples may have come from the same pluton. This range of dates suggests that this terrane is Avalonian.

Williams and Hatcher (1983) postulate the existence of a three fold division of subsurface terranes beneath the Coastal Plain of Georgia and the Carolinas. Their Tallahassee/Suwannee terrane begins in southernmost Georgia and includes Florida. Their Avalon terrane occupies the inner Coastal Plain and is continuous with the exposed Piedmont. They differentiate a coastward Brunswick terrane by longer magnetic wavelengths. In North Carolina the Avalon-Brunswick boundary follows a northerly trending arc bisecting the Coastal Plain. However, there is no indication of a major boundary in the subsurface rocks or in the radiometric dates for these rocks, few as they are. Similar low-grade metasedimentary and metavolcanic rocks are found on both sides of their proposed boundary, and Avalonian age granites in the Hatteras terrane occur in both of these areas. The change in magnetic signature in North Carolina that they describe may be attributed to the increasing depth to basement, or to the increase in the slope of the basement surface which also occurs at about the location of their boundary (Gleason, 1981). The slope change slightly increases the eastward dampening of the aeromagnetic anomalies. If the magnetic changes can be explained by increasing depth to basement the evidence indicates that Avalon terrane is probably continuous to the coast. Brunswick terrane may be restricted to southern Georgia and South Carolina.

Gravity and Magnetic evidence

The gravity field of the southeastern Atlantic Coastal Plain is punctuated by a series of closed lows, a pattern which is similar to that of the Piedmont. Most of such lows in the Piedmont are closely associated with midsize to the largest of the exposed late Paleozoic granitic plutons. The following plutons are examples: the Petersburg in Virginia; the Rolesville, Castalia, Landis, and Churchland in North Carolina; the Winnsboro-Rion, Liberty Hill, Pageland and Lowrys in South Carolina; the Siloam and Danburg in Georgia (pluton names from Speer and others, 1980). Several plutons are significant exceptions. Factors which would diminish the amplitude of the gravity anomaly of a pluton include, small vertical extent (possible examples are the Elberton and Lilesville plutons), or a lack of density contrast with country rocks (example- Cherryville pluton ?). Recognition of anomalies associated with small plutons may be hindered by inadequate gravity data. Superposition of a large amplitude gravity anomaly such as the Appalachian gravity gradient may also suppress a local anomaly. A few gravity lows in the Piedmont are not associated with exposed granite but with felsic metavolcanic rocks of the Uwharrie Formation and with parts of the Durham and Wadesboro basins in North Carolina. In general, based on the examples of the Piedmont, the favored interpretation of a significant gravity low in the Coastal Plain is a granitoid pluton or plutonic complex. Some gravity lows of the Coastal Plain have been used to target subsurface granites as a source of low-grade geothermal energy. Several granite bodies have been verified beneath the lows by drilling to the basement. Two of these sites are at Dort, North Carolina (Becker, 1981), and Springfield, South Carolina (Speer, 1982). These and other significant gravity lows are identified in Table 1 (North Carolina) and Table 2 (South Carolina) and evaluated as candidates for granitic plutons which may be present at the basement surface. The factors considered in the evaluation include anomaly amplitude (a function of total mass), horizontal gradient magnitude (a function of depth as well as mass and density contrast), presence of magnetic anomalies with sharp gradients within the gravity low (an indication of metamorphic rocks rather than granite). The lows with positive indications of a granitic pluton at the basement surface are mapped as such on plate 2. This analysis is not intended to suggest that granite is not present in other areas. Several reliably documented basement granite samples are located within gravity highs (wells 15, 25, 35, 44, plate 2). Other samples are located where gravity values are average (wells 36, 37, 38, 43) or just slightly low. Some of these samples may have come from plutons in which the factors listed above are important.

Far fewer basement samples are of mafic plutonic rocks. Yet the potential field data show a significant presence of these rocks as intense magnetic anomalies and corresponding gravity anomalies. These anomalies are identified and evaluated in Table 3. Four closely spaced wells (39, 40, 41, 42) which struck diorite rich in magnetite correlate closely with positive magnetic anomalies. Several other diorites (24, 34, 48) are not associated with magnetic anomalies reflecting variations also observed with exposed diorites.

Table 1. Gravity lows within the Coastal Plain of North Carolina which granitic sources can be interpreted. Bouguer relief is estimated visually from contour maps. Anomaly numbers refer to plate 2.

Map Loc #	Place name	Bouguer Minimum	Bouguer Relief	Description/Evaluation
1.	Kitty Hawk, NC	-45 mgal	40 mgal	Gravity low of large dimensions and relief. Gravity gradients are high indicating a source near the basement surface. Magnetic relief is very low internal to the low. Anomaly extends offshore to the NNE and connects with a free air anomaly of -55 mgal off Cape Henry, VA (Grow and others, 1976). Of the 8 wells to basement which lie within the low, 6 struck granite, (4 with Avalonian radiometric dates), strongly indicating a granitic batholithic complex (Watkins and others, 1985).
2.	Dort, NC	-22 mgal	9 mgal	A relatively small, circular gravity low with sharp gradients overlaps the Virginia state line. Magnetic anomalies are muted within the low. Basement rocks were cored in the center of the low and granite lithologically similar to the Petersburg granite was recovered (Becker, 1981). The gravity low associated with the Petersburg is of large areal extent, continues southeast of the exposed granite in a broad arc, and terminates in the Coastal Plain within 15 km of the Dort anomaly. A late Paleozoic U-Pb zircon age, which has been reported for the Petersburg by Wright and others, 1975, suggests the speculation of a similar age for the Dort granite, based on the lithologic and gravity similarities.
3.	Rocky Mount,	-32 mgal	12 mgal	Oval gravity low with moderate gradients; station spacing fair. The probable outline NC of the pluton is defined by a distinct area in which short wavelength magnetic anomalies are relatively absent (Farrar, 1980b). Ten water wells within the area defined by the magnetic map struck granite, but none of the driller's desciptions are verifiable. The pluton is exposed at the edge of the Coastal Plain where it has been mapped by Farrar (1980b).
4.	Holly Springs,	-29 mgal	11 mgal	Circular gravity low with sharp gradients suggests that the source lies at the NC basement surface. Station spacing is adequate. Flat magnetic field within gravity low. Two wells returned granite and quartz diorite within low. Good indication of small granitic pluton.
5.	Croatan, NC	-37 mgal	10 mgal	Similar to #3 except that there are no wells to basement within the anomaly. Gravity gradients are high in spite of poor station spacing. Some short wavelength magnetic anomlies lie within the gravity low. Somewhat weaker indication of a basement pluton than #3.
6.	Padgett, NC	-42 mgal	? mgal	Gravity gradients are sharp along the northeast edge of the anomaly but are low elsewhere. Station spacing is very poor. The low coincides with some linear, short wavlength magnetic anomalies. Granite was recovered from one well and biotite gneiss with granitic veins in a second. With better gravity control this low might show sharper gradients, smaller dimensions and stronger evidence of a basement pluton.
7.	Wrightsville	-60 mgal	? mgal	This gravity low is mostly offshore and is defined by only a few gravity stations Beach, NC onshore. Offshore the low is roughly circular, with a Bouguer minimum of less than -60 mgal, 25 km from the coastline (Krivoy and Eppert, 1977) and closely corresponds to a circular, low gradient, magnetic area (Klitgord and Behrendt, 1977). Even though there are no basement samples, a granitic pluton is strongly indicated but with only a small fraction underlying the onshore region.
8.	Bolivia, NC	-32 mgal	? mgal	Poorly constrained gravity low. Some short wavelength magnetic anomalies. No wells to basement within the low. The evidence for a granitic pluton is weak with the existing widely spaced gravity stations.
9.	Lumberton, NC	-37 mgal	27 mgal	A broad gravity low shows sharp gradients only locally. Gravity stations are widely spaced. Numerous short wavelength magnetic anomalies indicate metamorphic rocks lie at the basement surface. In a corehole to basement near the center of the anomaly, felsic to intermediate metavolcanics were recovered (Becker, 1980). A seismic reflection line in the same area indicates that a pluton is present at a depth of 3.5 km with the floor at 17 km (Pratt and others, 1985).

Table 2. Gravity lows within the Coastal Plain of South Carolina for which granitic sources can be interpreted. Bouguer relief is estimated visually from contour maps. Anomaly numbers refer to plate 2.

Map Loc #	Place name	Bouguer Minimum	Bouguer Relief	Description/Evaluation
10.	Georgetown, SC	-35 mgal	35 mgal	This very large gravity low extends well offshore (Long and others, 1976; Krivoy and Eppert, 1976). An associated peripheral low of -12 mgals lies just north. Magnetic anomalies terminate against the gradients of both gravity lows. Few short wavelength magnetic anomalies lie within the gravity low. Most of these are may be generated by early Mesozoic diabase dikes (Daniels and others, 1983). No wells have returned basement samples within the low. Granodiorite intruding schist was cored at Brittains's Neck, SC, and is the closest basement sample to the gravity lows. The granodiorite could be related to the inferred pluton. The indications are strong for a pluton at the top of the basement.
11.	Sumter, SC	-22 mgal	11 mgal	A well controlled arcuate gravity low with moderate gradients coincides with an area of subdued magnetic gradients. An interpretation of a granitic pluton at the basement surface is mildly supported by a report of uncertain validity of granite recovered from one well (Siple, 1958) within the low.
12.	Springfield,	-46 mgal	20 mgal	This circular gravity anomaly defined by good gravity data has sharp gradients, a SC large amplitude, and low central magnetic gradients. Granite was cored in the center of the low and dated radiometrically at 372 ma. (Speer, 1982). The evidence is strong for a deep-rooted granitic pluton with a diameter at the basement surface of about the dimensions of the low.
13.	Columbia, SC	-22 mgal	7 mgal	Low gravity gradients and corresponding low magnetic gradients. Granite is exposed within the low at the edge of the Piedmont. The gravity low maps an area of possible subsurface extension of the pluton. No subsurface samples are available. The low gravity relief indicates other types of sources are also probable.
14.	Graniteville,	-33 mgal	? mgal	Sharp gravity gradient on west contrasts with low gradients elsewhere. Numerous SC short wavelength magnetic anomalies within the gravity low suggest the presence of metamorphic rocks. Like #12, granite is exposed within part of the low by streams which cut through the Coastal Plain sediments. "Granite" has been reported from a a well at Aiken, SC (Siple, 1958). Area of the gravity low may be underlain by predominately granite mixed with metamorphic rocks.

Table 3. Magnetic and gravity highs within the Coastal Plain of Georgia, South Carolina, and North Carolina for which mafic plutonic sources can be interpreted. Bouguer relief is estimated visually from contour maps. Magnetic data from surveys flown with flight-lines spaced 1 mile (1.6 km) a art and at 500 ft (152 m) above terrain. Gravity station spacing variable. Anomaly numbers refer to plate 2.

Map Loc #	Place name	Bouguer Relief	Magnetic Relief	Description/Evaluation
15.	Pamlico, NC	8 mgal	400 nT	Moderate amplitude magnetic anomaly and partly coincident with a gravity anomaly of larger dimensions. The magnetic anomaly overlies two wells which recovered diorite in the basement. Two other wells with diorite coincide with a smaller 200 nT magnetic anomaly just to the south and which significantly avoids two wells which struck granite nearby. The corellation with the magnetic anomalies is good; with gravity the corellation is uncertain even though the station spacing is adequate. The diorite samples contain abundant magnetite. The magnetic anomalies are interpreted as diorite plutons at the basement surface.
16.	Pooles Crossroads,	9 mgal	900 nT	Small, nearly circular magnetic high. Magnetic depth to source estimates place this SC body at the top of the basement. The gravity station spacing is good. No basement samples are available. Strong indication of a gabbroic pluton.
17.	Kline, SC	18 mgal	2100 nT	Circular magnetic and nearly coincident gravity high. A magnetic depth to source calculation indicates that the source lies at a depth of about 3000 ft (910 m) or about 1700 ft (530 m) below the pre-K surface. The overlying rocks may be early Mesozoic sedimentary rocks (Daniels and others, 1983). Gravity station spacing is adequate. No basement samples are available. The high intensity part of the anomaly probably maps the extent of a gabbroic pluton which intrudes foliated metamorphosed mafic rocks beneath a Mesozoic basin.
18.	St. Helena	> 12 mgal	1000 nT	Perfectly circular positive magnetic anomaly with central low. Magnetic depth to Sound, SC source estimates place the top of this body at the pre-K surface. Similar in shape and amplitude to the magnetic anomaly over the Concord, NC gabbro-syenite complex (Daniels and others, 1983). The gravity anomaly is poorly defined as no gravity measurements have been made in the central part of the magnetic anomaly where it is occupied by water. No basement samples are available. A gabbroic pluton at the top of the basement is strongly indicated.
19. 20. 21.	Tift Co., GA	25 mgal 28 mgal 32 mgal	1000 nT 1100 nT 1000 nT	Three nearly circular magnetic anomalies with coincident gravity anomalies, each about 25 km in diameter are interpreted as gabbroic plutons in the basement. Magnetic depth to source calculations place the tops of these bodies below the top of the basement. Three deep wells in the area recovered basement samples which are part of a terrain of felsic volcanic rocks and associated granites (Chowns and Williams, 1983); well GGS-468 recovered granite within anomaly 19; well GGS-107 returned rhyolitic tuff within anomaly 20; well GGS-3127 between anomalies 20 and 21, struck porphyritic rhyolite. None of these samples can be the source for the magnetic and gravity anomalies The gabbroic sources must lie well below the level of the basement surface.

BASEMENT FAULTS

The expectation of encountering evidence of basement faulting in drillhole samples is small. Yet such evidence was found in one sample, well 42 within the Hatteras terrane which is a mylonitic quartz diorite. The boundaries between many of the major lithotectonic belts of the Piedmont in part coincide with mylonite zones and faults (Nutbush Creek, Augusta faults; Farrar, 1985; Bramlett and others, 1982) and zones of high ductile strain with some shear and brittle faulting (Modoc zone; Bramlett and others, 1982). The zones of mylonite and high strain are closely associated with groups of long, narrow, linear, aeromagnetic anomalies which, in part, have been the means by which these zones have been traced in the Piedmont and in the Coastal Plain (Daniels, 1974; Hatcher and others, 1977). Other linear features in the aeromagnetic data were traced by Daniels and others (1983) some of which are reproduced on plate 2. Certainly many basement faults are associated with the subsurface early Mesozoic basins and some of these have been delineated by seismic surveys in the Charleston, South Carolina region (Hamilton and others, 1983; Schilt and others, 1983).

NORTHERN AREA: VIRGINIA TO LONG ISLAND

DIFFERENCES BETWEEN SOUTHERN AND NORTHERN AREAS

Several significant differences between the southern and northern areas are apparent from regional tectonic and geologic maps.

1. Slope of the basement: From Fredericksburg, VA north to New York the slope of the basement in the inner Coastal Plain is at a maximum. The steeper slopes are in places partly due to normal faulting in the Cretaceous parallel to the present Fall Line (Mixon and Newell, 1977).

2. Width of the exposed crystalline rocks in the Appalachian Orogen: The width is at a minimum of about 75 km at Washington, DC and at New York, NY. This compares with the maximum of about 300 km which occurs at Augusta, GA. The area of minimum width corresponds with the area of maximum slope of the basement under the Coastal Plain.

3. Post metamorphic granitoid plutons in the Piedmont: Abundant in the region from Macon, GA to Richmond, VA. and scarce in the region from Washington to New York.

These observations corellate with a northwestward incursion of Coastal Plain sediments in the northern area making the Fall Line much closer to the edge of the North American craton.

Because of less favorable petroleum target areas in the northern region, fewer deep oil tests have been drilled resulting in a poorer knowledge of the deeper basement in the region.

EARLY MESOZOIC BASINS

Subsurface unmetamorphosed, consolidated, redbed and/or basalt and diabase, which may be correlated with exposed Newark group rocks, are widespread in the northern area with the most occurances in Virginia.

Newark and Hartford basins

Along the edge of the Coastal Plain adjacent to the Newark basin ten shallow wells recovered Newark-like rocks, extending the basin a short distance beneath the Coastal Plain. Diabase in two of these wells (Kasabach and Scudder, 1961) is probably the subsurface continuation of the Palisades sill.

The possibility of a continuation of the Hartford basin beneath Long Island Sound and Long Island was suggested by Wheeler (1938). The idea hinged upon the report of sandstone similar to rocks in the Hartford basin from a well drilled to basement in 1914 at Duck Island on the north shore of Long Island. The reliability of this data is unknown. Three wells struck crystalline basement very close to the Duck Island well and appear to severely restrict the size of a basin there if it exists (D. Pierce, personal communication, 1985). No other wells on Long Island are known to have returned Newark-like rocks. However, marine seismic lines which cross the Long Island Platform south of Long Island, show strong evidence of extensive rift grabens of presumed early Mesozoic age (Hutchinson and Klitgord, 1984), so that there is ample reason to suspect the presence of these rocks in the subsurface of Long Island.

Taylorsville Trend

The Taylorsville basin as shown by Weems (1980) is structurally similar to and on strike with the Richmond basin to the south, but appears smaller as it is cut off by the onlap of the Coastal Plain. A group of 7 wells just northeast of the basin, penetrate the Coastal Plain striking similar Newark-like lithologies in the basement. Continuation of the Taylorsville basin for varying distances to the northeast has been postulated (Spangler and Peterson, 1950; McKee and others, 1959; Mixon and Newell, 1977; Weems, 1980) as far as the Brandywine, Maryland area. Wells at Bowling Green and King George, Virginia (Cederstrom 1945; Johnson, 1973), LaPlata, MD (Hansen, 1978) and a group of wells at Brandywine, MD (Jacobeen, 1972) all returned Newark-like lithologies to form a remarkably straight trend. The length of this subsurface trend exceeds 140 km beyond the exposed part of the Taylorsville basin, and is comparable in length to the Danville or Culpeper basins. Whether this represents one continuous basin or a series of smaller basins is unknown at this time. The width is also unknown from well data but is probably comparable to that of the Richmond and Taylorsville basins.

As noted by Mixon and Newell (1977), both the Richmond and Taylorsville basins and these wells all lie on a prominent, linear, east-sloping gravity gradient. The Hylas mylonite zone also lies along this gradient, bounding the Richmond and Taylorsville basins on the west. The association of the Hylas zone, the gravity gradient, and the west edge of the basins suggests an inherited zone of weakness which forced the occurence of the basins along this trend.

Studley and Petersburg basins

In the area east of the Richmond basin, ten wells have struck redbeds, which Weems (1980) has assigned to his Studley basin. One of these wells penetrated 1600 feet of sedimentary rocks and bottomed in gneiss. Four wells struck similar redbeds to the south in an area just east of Petersburg, VA and are here considered to be a separate basin called the Petersburg basin. In the interpretation of Shomo (1982) the two basins are joined. Wells striking subsurface granite limit the possible extent of the Studley and Petersburg basins on the west. Wells in the two basins lie on the eastern edge of an extensive gravity low probably generated by Petersburg type granite which may underlie both basins. The eastern boundary of the basins has been drawn to follow the strong gravity gradient there in a manner similar to the Richmond and Taylorsville basins and the gravity gradient on their western flanks. Local highs of the basement structure contours seem to coincide with the basins, suggesting post Jurassic reverse faulting which may have been reactivated in the Tertiary (Shomo, 1982), similar to the inferred structures at Brandywine, MD (Mixon and Newell, 1977).

Isolated Newark rocks- Virginia-Maryland

Probable early Mesozoic rocks were recovered from three wells which form an arc midway across the Coastal Plain in Virginia and Maryland at basement depths between 1500 and 2500 feet below sea level. Jurassic olivine diabase was cored in the northernmost of the three wells at Lexington Park, Maryland (38.26 N - 76.46 W degrees, well St.M-Df 84, Hansen and Wilson, 1984); sandstones were recovered in King William and Nansemond Counties, Virginia (W-515, at 37.55 N - 76.81 W degrees, and W-3316, at 36.57 N - 76.58 W degrees, Hubbard and others, 1978). Although widely separated in a north-south direction, their equivalent positions relative to the Fall Line (70-90 km east) and structures defined by the geophysics suggest a structural trend of independent basins. A small hypothetical basin envelope has been drawn around each with a trend reflecting the grain of the potential field maps. This is a trend along which future wells will probably recover more early Mesozoic basin rocks.

Other Possible Early Mesozoic Rocks

In three deep wells on the Eastern Shore of Virginia and Maryland (Hammond, Bethards, and Taylor wells; 64, 66, 67 on plate 4) which were drilled into crystalline basement rocks, a basal sequence of redbeds, ranging in thickness from 116 to 546 feet, was encountered immediately overlying the basement. The age of these rocks has been a source of controversy, with some workers assigning early Mesozoic ages based on lithlogic similarity to Newark supergroup rocks (Anderson, 1948; Onuschak, 1972). Robbins and others (1975), however, concluded that these rocks should be assigned a Cretaceous age based on limited palynological data and interpretation of geophysical logs.

CRYSTALLINE BASEMENT ROCKS

Piedmont crystalline rocks adjacent to the Coastal Plain in the northern area differ from the southern area chiefly by the scarcity of greenschist facies metamorphic rocks and the general highly deformed nature of most of the metamorphic rocks. Greenschist facies rocks of the Eastern Slate belt extend from North Carolina north into Virginia to about the vicinity of Petersburg, (Bobyarchick, 1978). From this point northward to Rhode Island the metamorphic grade is dominently amphibolite. In the subsurface, low-grade rocks are found in Virginia north to Crisfield, Maryland, reflecting a distribution similar to the exposed rocks.

Goochland Terrane

Immediately to the west of the Richmond-Taylorsville basins lies a Piedmont terrane of amphibolite grade metamorphic rocks, about 30 km wide, which appears to be bounded on the west by the Spotsylvania magnetic lineament (Pavlides, 1980). Farrar (1984) has called this assemblage of rocks the Goochland terrane. The chief unifying characteristic of this terrane is, according to Farrar, widely distributed relict granulite facies mineral assemblages. The rocks of this terrane are deformed into a series of three domes which lie on the eastern edge of this terrane (Weems, 1981; Farrar, 1984). The domes are cored by the Proterozoic State Farm gneiss, which is structurally overlain by the Sabot amphibolite, and by rocks called the Maidens gneiss (Farrar, 1984). The Maidens gneiss may be equivalent to the Po Gneiss described by Pavlides (1980). A pervasive feldspathic quartzite may occupy the structural position of the Sabot amphibolite in part of the area (R. Weems, personal communication, 1985). A distinctive linear, positive, asymmetrical gravity anomaly of about 15 milligals, coincides with the Goochland terrane in the type area. The anomaly has a steep gradient on the southeast side and the maximum coincides with the position of the domes. A broad, low-amplitude magnetic high is associated with the gravity anomaly. The source of the gravity anomaly must be a thick section of mafic rocks lying beneath the State Farm gneiss. The gravity anomaly continues to the northeast into the Coastal Plain maintaining fairly constant character, indicating that the Goochland rocks continue in the subsurface. The anomaly extends into Maryland where a deep well at Douglas Point on the Potomac River recovered biotite gneisses and amphibolite, lithologies compatible with the Maidens or Po gneiss. The anomaly ends just northeast of the District of Columbia where the amplitude and sharp eastern gradient diminish. Of particular interest is a similar distinctive gravity anomaly and a similar magnetic anomaly, which occurs in the eastern shore of Maryland but which is not continuous with the Goochland anomaly. The Eastern Shore anomaly is interpreted as a terrane that is possibly equivalent to the Goochland Terrane. The Eastern Shore gravity anomaly appears to continue into Delaware and New Jersey although with the loss of definition, possibly due to the lower density of gravity stations in these states. The terrane terminates at the location of a deep well at Island Beach State Park, New Jersey, where a migmatitic gneiss was cored in the basement. As noted by Southwick (1964), this gneiss could equally well fit descriptions of rock from several provinces, such as the Manhattan Prong, the Hartland Formation in southwestern Connecticut, gneisses from southeastern Connecticut, or the Baltimore gneiss domes. The speculative correlation with the very distant Goochland terrane is based strictly on the geophysical similarities and trends.

Low grade Avalonian terrane

The eastern Slate belt in North Carolina has been mapped as far north as the southern end of the Richmond basin, though interrupted by granitic bodies (Bobyarchick, 1978). In the shallow part of the Coastal Plain, a few wells have returned rocks indicating low metamorphic grade. In the deeper basement area of Virginia and Maryland, samples from three wells constitute the evidence for continuation of this terrane: rhyolite or meta-rhyolite at Fort Monroe, Hampton, VA (Darton, 1902); carbonate-rich meta-argillite with biotite porphroblasts in the Taylor well on the eastern shore of Virginia (Onuschak, 1972); fine-grained bedded metavolcaniclastic rock at Crisfield, Maryland (Gleason, 1979). The low-grade terrane is bounded by amphibolite grade rocks on the eastern shore of Maryland in the Hammond 1 well and in the Bethards 1 well; Anderson, 1948). The boundary was drawn in a northwesterly direction simply to follow the trend evident in the gravity. Subsurface metamorphic rocks from this point north to the end of Long Island all seem to be amphibolite grade.

Mafic rocks

A prominent linear gravity anomaly, with about 30 milligals relief, first described by Johnson (1973), traverses the low-grade terrain, mostly in Virginia but including 40 km in Maryland, in a northerly and NNE direction. A mixed pattern of magnetic highs and lows coincides with the envelope of the gravity anomaly. LeVan and Pharr (1963), called the series of magnetic anomalies the Sussex-Currioman Bay trend, here renamed the Sussex-Leonardtown anomaly to include the continuation in Maryland. Five wells have penetrated basement within the limits of the gravity anomaly. Although detailed petrographic descriptions of the samples are not available, lithologic descriptions include foliated mafic metavolcanic rocks and meta-ultramafic(?) rocks, gabbro, metadiorite, and phyllite (Hubbard and others, 1978; Gernand, 1984; Leo, this report). The amplitude of the gravity anomaly is large enough that gabbro may constitute a major part of the source. Affinity with the mafic rocks of the Baltimore Complex is a possibility.

Two breaks in the Sussex-Leonardtown gravity/magnetic anomaly suggest faulting has offset the causative body. At the southern end of the magnetic anomaly (Zietz and others, 1977), a sharp bend with apparent left-lateral offset of several kilometers, suggests displacement along a northwest-trending line. At the northern end, the gravity and magnetic anomalies are shaply truncated along a north-south line. Lesser amplitude gravity/magnetic anomalies lie to the east of this line (Taylor Island magnetic anomaly of Hansen, 1978) suggesting continuation of the source rocks, though shifted south and with lesser thickness. Hansen (1978) investigated basement faulting along the anomaly with a seismic reflection survey in St. Marys Count, Maryland. A 250 foot up-to-the-southeast offset of the basement surface at Hillville, Maryland was clearly detected, which coincides very closely with the north-south truncation line, suggesting that Cretaceous or younger reactivation of an older basement fault has occurred.

Glenarm-Baltimore Complex Terrane

North of the Spotsylvania Lineament, a heterogeneous terrane of Piedmont metamorphic rocks lies adjacent to the edge of the Coastal Plain and is largely occupied by a Paleozoic package of rocks called the Glenarm Supergroup (usage of Muller and Chapin, 1984). In the Maryland Piedmont it consists of the sequence comprising the Setters Formation, Cockeysville Marble, and the much larger Wissahickon Group, all of which overlie the Proterozoic Baltimore Gneiss. The Glenarm rocks are complexly deformed with the gneiss into a series of mantled domes (Muller and Chapin, 1984). In Virginia the Wissahickon Group is the dominant lithology.

East and southeast of the Baltimore gneiss domes lies an allochthonous terrane of highly varied lithologies which includes metagabbro and metaperidotite of the Baltimore Mafic Complex, metavolcanic rocks of the James Run Formation and metaplutonic rocks of the Relay Quartz Diorite and Port Deposit gneisses, and other rocks (Muller and Chapin, 1984). The numerous bodies of metamorphosed gabbro and peridotite in the Virginia-Maryland-Pennsylvania-Delaware Piedmont are regarded by Drake and Morgan (1981) as allocthonous fragments of a dismembered ophiolite.

Metagabbro and other mafic rocks of the Baltimore Complex are typically associated with positive gravity anomalies of large amplitude. Although the metagabbro is high in iron, the associated magnetic field is not uniformly high but is marked by small but intense positive anomalies and also some low to moderate magnetic anomalies. Serpentinized ultramafic rocks of the Piedmont are typically, but not uniformly, associated with intense magnetic anomalies, but rarely have an associated positive gravity anomaly due to the moderate density of serpentine.

Sub-Coastal Plain extent of Glenarm-Baltimore Complex Rocks

Low amplitude, linear magnetic and gravity anomalies produced by the metavolcanic rocks of the Chopawamsic and James Run units appear to plunge beneath the Coastal Plain from the south and north respectively and may join in the region east of Washington, DC. The gravity anomalies associated with the mafic units of the Baltimore Complex extend into the Coastal Plain, but only for short distances. However, several other separate gravity anomalies with associated magnetic anomalies are present and indicate similar rocks, with one such anomaly spanning Chesapeake Bay. The source of the western end of this anomaly in southeastern Baltimore County, was interpreted by Bromery (1968) as gabbro. Serpentinite was recovered from a well on the eastern shore within the anomaly (Otton and Mandle, 1984) suggestive of the Baltimore Complex. As the Baltimore Complex is considered to be allocthonous, the rocks which are the sources for these anomalies may also be fragments of the same allocthon. The same may be true for the source rocks of the Sussex-Leonardtown anomaly in Virginia and southern Maryland.

Gravity and magnetic anomalies at Wilmington, Delaware are associated with mafic rocks and anorthosite of the Wilmington Complex (Woodruff and Thompson, 1975) and indicate that the Complex is much larger than the rocks currently exposed and extends to the south and southwest under the Coastal Plain. The anomalies enclose gabbro exposed in three monadnocks which emerge from the Coastal Plain south of Newark, Delaware, and gabbro and serpentinite recovered from shallow wells (Maguire, 1980). Rocks similar to the Wilmington complex may be found in the basement of the New Jersey Coastal Plain, 15 km south of Raritan Bay where moderate amplitude magnetic/gravity anomalies occur. Sugarman (1981) modelled the anomalies as a mafic body which may lie at or just below the basement surface.

The great concentration of mafic-ultramafic complexes, which may be ophiolite fragments, in the Maryland Piedmont and beneath the adjacent Coastal Plain, is unusual in the Appalachian Orogen and is repeated only in Quebec and Newfoundland. Each of these localities is a reentrant of the North American Craton (Williams, 1978).

In the northern half of the New Jersey Coastal Plain, most wells have struck what is usually described as "Wissahickon (?)" schists and mica gneisses reflecting the familiarity of drillers with the nearest exposed basement, the Wissahickon rocks of the Philadelphia area. Two of the deeper wells in New Jersey have been described in more detail and are consistent with Glenarm rocks: the New Brooklyn well (72, plate 4) in which sillimanite bearing quartz-plagioclase-biotite-muscovite schist and gneiss was reported, and the Butler Place test well (73, plate 4) which returned dolomitic marble (US Geological Survey, 1967). Dolomitic marbles are characteristic of both the Cockeysville marble from the Baltimore area and the Inwood marble from Manhattan Island in New York City, (Muller and Chapin, 1984; C. Baskerville, personal communication, 1985). Linear magnetic anomalies connect the site of the Butler Place well with Raritan Bay to the north, and the anomaly trend, if continued, would connect with Manhattan Island. The Inwood marble appears to be the stronger correlation considering the shorter distance and the magnetic trends. Wissahickon rocks from the Philadelphia area probably continue east and northeast into the New Jersey Coastal Plain and merge with the Manhattan rocks. South of the Butler Place well is an area of subdued magnetic field and regionally lower gravity, in which basement lithology is unknown from well data. This area may be underlain by the Glenarm-Manhattan rocks, or by granitic rocks. In southwestern New Jersey, abundant magnetic anomalies suggest typical Glenarm patterns.

Long Island

Most wells to bedrock in Long Island are clustered in the western area where basement is shallow. In northwest Queens County, the basement in many wells is described as either Fordham gneiss or Ravenswood granodiorite and are probably part of the Manhattan Prong. Granitic rocks are abundant farther east as well as granitic gneiss, mica schist and biotite gneiss. These are the principal descriptions for basment rocks for all of Long Island. The potential field data suggest several broad divisions that follow northeasterly trends and may correlate with exposed major geologic divisions in Connecticut. To the east of the Manhattan prong, a broad magnetic low area is aligned with the region in Connecticut underlain by the pelitic schists of the Hartland Formation (the Rowe-Hartland belt of Harwood and Zietz (1976)) and the Hartford basin. The gravity field within this same magnetic low region on Long Island is composed of a western low and an eastern high. The gravity low may be produced by extensive granitic rocks. No basement rocks have been described for the area of the gravity high.

The easternmost geophysical zone is composed of multiple magnetic highs coincident with a broad gravity low. The trend and "grain" of magnetic anomalies in eastern Long Island, Long Island Sound, and southeastern Connecticut shows that crystalline rocks within these areas are of a single structural province. Avalonian metamorphic and plutonic rocks crop out along the north shore of Long Island Sound and south of the Honey Hill Fault in southeastern Connecticut (Rodgers, 1985). Rocks found in the basement in Suffolk County, Long Island include quartz-plagioclase gneiss, two-mica granite (75, plate 4), schist, and biotite granite gneiss (76, plate 4), lithologies which are all characteristic of the Avalonian Terrane in Connecticut. A core sample of the biotite granite gneiss from the basement near Jamesport, Long Island is very similar to the Potter Hill granite gneiss unit exposed in southeastern Connecticut (R. Goldsmith, USGS, personal communication, 1985). The intensity of individual magnetic anomalies in Long Island are lower than those under the Sound or in Connecticut, possibly due only to the greater depth to the source rocks there. The magnetic and gravity trends and the similar lithologies suggest that the southeastern New England Avalonian terrane includes the eastern part of Long Island.

PLUTONIC ROCKS

In the Piedmont adjacent to the Coastal Plain, from Fredericksburg, Virginia south, granitoid plutons are relatively abundant, some, such as the Petersburg granite being of batholithic dimensions. This terrane plunges beneath the Coastal Plain and evidence from wells and potential field data suggests that granitoid plutons are abundant in the subsurface at least to central Delaware.

Of all the granitoid bodies of the southeastern Piedmont, the Petersburg pluton may rank as the largest if consideration is also given to its sub-coastal plain extent. The large number of shallow wells which struck granite in the Richmond-Petersburg area and the potential field data define its probable limits. Bobyarchick (1978) differentiated massive and foliated phases of the Petersburg. Boundaries between these phases generally follow northwest trends. Northwest trends are also evident in the potentail field maps. The gravity and magnetic maps suggest further that the exposed and covered Petersburg granite may be divisable into three areas, each of which could be an individual pluton. A zircon age of 330 my was determined by Wright and others (1975) for samples obtained in two of these areas of the Petersburg granite. These divisions are described in Table 4 along with other negative gravity anomalies which are evaluated as possible subsurface plutons.

Table 4. Gravity lows within the Coastal Plain of Virginia, Maryland, Delaware, New Jersey, and New York for which granitic sources can be interpreted. The approximate Bouguer relief is estimated visually from contour maps. Anomaly numbers refer to plate 4.

Map Loc #	Place name	Bouguer Minimum	Bouguer Relief	Description/Evaluation
1A.	Richmond, VA	-3 mgal	15 mgal	Northern anomaly of the Petersburg granite. About 35 % of this gravity anomaly is exposed and mapped as Petersburg granite. Over 40 shallow water wells struck granite beneath the Coastal Plain. The amplitude indicates a thinner body than anomalies 1B & 1C. The magnetic field is subdued.
1B.	Petersburg, VA	-24 mgal	35 mgal	Central anomaly of the Petersburg granite. About 20 % of this anomaly is exposed mostly along stream valleys where Coastal Plain sediments have been stripped. About 30 shallow wells have struck granite within the area of this anomaly. A regional magnetic low corresponds closely with the gravity low. The amplitude of this anomaly and of the magnetic low indicate that a deeply rooted pluton underlies this anomaly. The pluton probably also floors the Templeton basin.
1C.	Gray, VA	-25 mgal	35 mgal	Southern anomaly of the Petersburg granite. About 20 % of the area of this anomaly is exposed, mainly along stream valleys along the edge of the Coastal Plain. Only 2 wells struck basement rocks within the anomaly and these recovered granite. This anomaly differs from anomalies 1A & 1B by the elongate shape and the SE trend, which is unusual for this part of the Appalachian orogen. The trend is parallel to the boundaries between the massive and foliated phases mapped by Bobyarchick (1978). Anomaly C differs also by the correspondingly larger amplitude magnetic anomalies. The magnetic anomalies might be produced either by phases of varying composition within the pluton or by a thin roof of country rocks. The shape and pattern of these anomalies suggest greater deformation of the pluton. The amplitude of the gravity anomaly indicates a deeply rooted pluton like anomaly B.
2.	Franklin, VA	-6 mgal	5 mgal	A small gravity anomaly with an associated flat magnetic field. The principal indication of a granitic pluton is from well W-2719 in which pink granite was reported as the basement rock (Johnson, 1975).
3.	Portsmouth, VA	-47 mgal	35 mgal	This circular anomaly is sharply defined with an associated circular magnetic low. The conspicuous gravity anomaly and high thermal gradient in the Coastal Plain sediments provided the target for US Department of Energy drillhole to basement in which granite was cored. Rb/Sr radiometric dating gave a Permian age (263 my) for this rock (Russell and others, 1985). Corehole confirms existence of granitoid pluton at the top of the basement.
4.	Messick, VA	-28 mgal	5 mgal	A small, poorly defined gravity low and associated magnetic low surrounds a well to basement which recovered granite (NASA well, Johnson, 1973). Weak geophysical evidence of a pluton.
5.	New Kent, VA	-20 mgal	10 mgal	This large, elongate gravity low of moderate ampltude suggests granitic basement. Magnetic anomalies associated with the gravity low suggest that pre-Cretaceous erosion may not have completely unroofed the inferred pluton. The magnetic trends do not conform exactly to the shape and trend of the gravity anomaly unlike anomaly 1C suggesting that the anomalies may be caused by metamorphic roof rocks. No wells have been drilled to basement within this anomaly. Moderate indication of a basement granitoid pluton.
6.	Mathews, VA	-17 mgal	7 mgal	A poorly defined gravity low and associated magnetic low. Only one well to basement lies within the low, W-180, which recovered granite (Cederstrom, 1945).

Table 4. Continued

Map Loc #	Place name	Bouguer Minimum	Bouguer Relief	Description/Evaluation
7.	Colonial Beach,	-16 mgal	15 mgal	Broadly elongate negative gravity and magnetic anomalies with NNE trend are sharply VA limited by strong gradients on either side but poorly defined at ends. The position of this anomaly suggests affinity with the Petersburg plutons. No wells have struck an identifiable basement rock within the low. Moderate geophysical indication of granitoid pluton at the basement surface.
8.	Chesapeake Bay	-35 mgal	20 mgal	A broad gravity low with a relatively featureless magnetic field. The eastern edge is poorly defined due to the scarcity of gravity stations. The western edge is defined by land gravity data of adequate density. Dysart and others (1983) judge from the gravity and high heat flow at Smith Point in Virginia, that the source of the anomaly is a granitoid pluton.
9.	Eastern Shore	-33 mgal	20 mgal	An exceptionally broad, northeast trending region of generally low gravity, is poorly defined on the south, with a relatively featureless magnetic field. The area extends across Delaware Bay to include the gravity low at the southern tip of New Jersey. The lack of sharp magnetic and gravity gradients is partly due to the significant depth to basement. Gneissic quartz monzonite was cored from the basement at Cambridge, Maryland (well 68, plate 4), (Trapp and others, 1982). The basement in the Dickenson #1 well at Cape May, New Jersey was described as gneiss (Maher, 1971) and weathered gneiss/schist (H. Kasabach, written communication, 1986). The large area and weak definition of this anomaly give mild support to the interpretation of a large terrane of predominately granitic rocks.
10.	Queens Co, NY	-22 mgal	40 mgal	This sharply defined gravity low in western Long Island is coincident with a flat magnetic field. The basement rock was cored at Rockaway Park and described by Roberts (1948) as a two-mica granite. Several other wells for which the documentation is less thorough, reported granite within and outside the low. The geophysical evidence is strong for one or more granitic plutons.

SUMMARY

The interpretations advanced in this report are intended to provide working hypotheses as to the nature of the basement of the Atlantic Coastal Plain.

1. Early Mesozoic rift basins are widely distributed under the Coastal Plain. Well data are the principal means of locating subsurface basins as the potential field data are useful identifying tools only where the basins are thick and the country rocks are either uncommonly dense and/or magnetic. Doubt has often been expressed about the reliability of many of the descriptions or the assignment of consolidated sedimentary rocks to the Newark supergroup. Yet the large number of wells of this type, the frequent association with basalt or diabase, and the coherent spacial grouping, lend credence to the early Mesozoic interpretation.

In Georgia, where no Mesozoic basins are found in the Piedmont, the largest of all the basins, either exposed or covered, is found beneath the Coastal Plain. The South Georgia basin is unusual for its size and its location as a transition between Atlantic and Gulf of Mexico rifting. Two sub-basins within the South Georgia basin are currently known in Georgia and South Carolina, the Riddleville and Dunbarton basins. Other sub-basins are known in Florida and southern Alabama. Eventually it will probably be shown to be segmented into many more parts. In contrast to the South Georgia basin, most of the inferred subsurface basins to the north appear to be small, although the data usually do not place tight constraints on their size.

2. Avalonian basement of low metamorphic grade is inferred to be widespread in the Coastal Plain of the Carolinas and Virginia, although only in North Carolina is the documentation substantial. A few isolated, single well occurences of amphibolite grade rocks are scattered throughout the low grade terrane. Metamorphic grade is particularly difficult to determine where lithologic descriptions are sketchy. The low-grade terrane may continue northward approximately to Maryland.

3. Amphibolite grade metamorphic rocks seem to dominate the crystalline basement of the Coastal Plain in Georgia and also from Maryland to Long Island. The Hatteras Terrane in North Carolina and the rocks of eastern Long Island may both be Avalonian rocks of amphibolite grade. The gravity and magnetic signature of the Goochland terrane indicates that it extends from the outcrop in central Virginia to just east of Washington, DC. Other linear gravity/magnetic anomalies in eastern Maryland continuing to southern New Jersey, resemble the the Goochland anomalies and suggest similar source rocks and structure. Glenarm rocks probably occupy much of subsurface southern New Jersey. Magnetic trends and a key dolomitic marble indicate that Manhattan Prong rocks may continue due south into New Jersey and either merge with the Glenarm rocks or form a bordering terrane on the southeast.

4. Large volumes of granitoid rocks are inferred in the basement of the region from South Carolina to southern Delaware. If correct, many of the indicated plutons may be late Paleozoic judging from the abundance of plutons of this age in the adjacent Piedmont. Radiometric dating of granitoid basement samples, at Portsmouth, Virgina and Springfield, South Carolina, confirm the existence of two occurances of late Paleozoic ages. Granitoid plutons of Avalonian age are present in the North Carolina basement and may be distributed throughout the same region. The interpretation relies heavily upon analysis of the gravity data. Yet a significant number of granitoid basement samples in the Hatteras terrane are not associated with gravity lows. It may be that gravity is indicating mostly the post-metamorphic plutons and that those with no gravity indication are Avalonian plutons. Post-metamorphic granitoid plutons are probably scarce in the subsurface Glenarm terrane.

Granitoid rocks are abundantly represented in the well data. However, granite may be overreported because of the generally suspected tendency of drilling crews to describe crystalline basement as "granite". Some of the ways in which this analysis may err are as follows: (1) misplacement of boundaries of granitic plutons where contacts have gentle dips; (2) omission of thin plutons with modest gravity anomalies, (3) omission of plutons which are smaller than the gravity station spacing, (4) omission of highly deformed granitic plutons with complex geometry, (5) misinterpretation of plutons which are present in the subsurface but which do not lie at the top of the basement, (6) misinterpretation of granite where the source may be other low density rock such as a thick sequence of either sedimentary rocks or felsic volcanic rocks.

5. Circular, coincident, gravity and magnetic anomalies that indicate undeformed mafic intrusive complexes dominated by gabbroic rocks, occur in Georgia, where they do not reach the top of the basement, and in South Carolina.

Gravity/magnetic anomalies point to the presence of abundant mafic-ultramafic rocks beneath the Maryland and Delaware Coastal Plain which are probably closely related to nearby rocks of the Baltimore and Wilmington complexes.

The large amplitudes of the prominent Sussex-Leonardtown gravity and magnetic anomalies suggest that gabbroic rocks may be the dominent source rock. Well samples indicate a mixed assemblage including gabbro, mafic metavolcanic and ultramafic rocks, which are similar to lithologies in the Baltimore Complex.

PETROGRAPHIC ANALYSIS OF SELECTED BASEMENT SAMPLES

FROM THE ATLANTIC COASTAL PLAIN

by

G.W. Leo

The presence of a diversified crystalline basement under the Atlantic Coastal Plain between Georgia and Long Island has been confirmed by numerous well and core drill records. These rocks are of interest in the context of deep disposal of high-level radioactive wastes inasmuch as they have potential hydrologic advantages over exposed crystalline rocks (Davis, 1984).

The purpose of this section is to present new or revised lithologic and petrologic data on the crystalline basement, including granitoid crystalline rocks, penetrated by wells and boreholes. In the case of granitoid rocks, the size and shape of associated buried plutons is estimated on the basis of geophysical data. The zone of particular interest is that where depth to bedrock is between 1000 and 4000 ft. (plates 2 and 4) (Davis, 1984). Petrographic analyses of basement rocks, mostly within but also beyond the 1000-4000 ft. depth zone, are shown in Table 5. Most analyses are based on thin sections of very small rock chips and as such may not be entirely representative of basement rock at each location. Most samples studied in this report have been graciously provided by the state geological surveys of the respective states.

Information regarding the lithologic and petrographic character of the basement rock varies greatly from state to state. By far the best data base on the crystalline basement rocks is that for North Carolina, where thin sections or rock chips from cores were available for a large fraction of the total number of wells. Described localities where first-hand petrographic data are unavailable, have been selected on the basis of the completeness of the descriptions in the literature. The order of discussion of specific localities or groups of localities is as nearly as feasible from southwest to northeast.

Table 5. Locations, depths, and descriptions of crystalline "basement" rocks encountered in selected wells and boreholes in the Atlantic Coastal Plain (see fig. 1). Sequence of sample locations is generally southwest to northeast; TD=total depth; NA=not available.

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
				GEORGIA	
1	GGS-193	Houston Co.; 32°26'25"N, 83°49'00"W	1494 TD; depth into basement NA	Foliated quartz-plagioclase-biotite-(K-feldspar) gneiss with accessory graphite and magnetite; probably paragneiss.	
2	GGS-194	Houston Co.; 32°24'05"N, 83°44'00"W	1698 TD; 13 into basement	Biotite monzogranite, approximately equal proportions quartz, sericitized sodic plagioclase and K-feldspar. 5% red-brown biotite; looks low-grade metamorphic.	May be part of gneiss of loc. 193.
3	GGS-3105	Dodge Co.; 32°15'28"N, 83°17'21"W	4466 TD; 1763 into basement	Coarse-grained biotite granite; quartz 35, microcline 50, plagioclase 12, biotite 3, hornblende tr.; deuterically altered (Chowns, pers. comm., 1977).	
4	GGS-468	Coffee Co.; 31°42'15"N, 82°53'38"W	4130 TD; 20 into basement	Graphic, fine-grained granophyre; quartz-plagioclase-K-feldspar-myrmekite, <5% partly chloritized biotite.	
5	GGS-7	Bibb Co.: 32°42'12"N, 83°39'12"W	509 TD; 13 into basement	Moderately foliated and sheared meta-tonalite consisting of quartz, plagio-clase and chlorite with accessory epidote apatite and magnetite.	
6	GGS-789	Treutlen Co.; 32°21'41"N, 82°28'23"W	3180 TD	Medium-grained, weakly foliated quartz-plagioclase-biotite garnet schist; varies from unaltered to moderately altered.	
7	GGS-964	Treutlen Co.; 32°21'26"N, 82°28'23"W	3253 TD; 450 into basement	Olivine-rich diabase; varies from unaltered to largely serpentinized.	
				SOUTH CAROLINA	
8	SAL-1	Barnwell Co.; 33°26.2'N, 81°14.2'W	1149 TD; 87 into basement	Gray to pink, medium-grained, equi-granular biotite monzogranite. Color index 5-8, substantially altered in upper 85 ft (Speer, 1982). Referred to as Springfield pluton.	Related to subcircular gravity low approx. 25 km in diameter. U-Pb zircon age 372 m.y. (Speer, 1982).
9	MRN-78	Marion Co.; 34°51'27"N, 79°19'30"W	1228 TD; 70 into basement	Medium- to coarse-grained, panidiomorphic granite intruding gray pelitic schist along sharp contacts.	Related to irregularly shaped gravity low 20 x 30 km in maximum dimensions

Table 5, Continued

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
				NORTH CAROLINA	
11	NC 155A	Robeson Co.; 34°34'11"N, 78°56'02"W	1284 TD; 876 into basement	Strongly foliated metavolcanic rocks ranging from leucocratic to melanocratic. Protolith thought to be sodium-rich tuffs (keratophyre in part?) (Becker, 1980).	Rb-Sr whole-rock isochron age, 314 ± 22 m.y.; $^{87}Sr/^{86}Sr_0$ = 0.7090. Biotite- whole-rock pairs yield 241-247 m.y. Supported by gravity low at this locality.
14	NC 17-1	Bladen Co.: 34°26'05"N 78°16'30"W	765 TD; 115 into basement	Moderately altered diabase with well-preserved primary texture; consists of felted plagioclase prisms with interstitial biotite, chlorite and epidote, the latter also in crosscutting veins. Rock is metamorphosed to low greenschist facies.	
16	NC 129-1	New Hanover Co.: 33°58'25"N 77°55'10"W	1558 TD; 22 into basement	Fine-grained, moderately altered and recrystallized basalt or andesite (not diabase). Plagioclase with interstitial chlorite and epidote. Low to intermediate greenschist metamorphism.	
18	NC 19C	Brunswick Co.; 33°56.9'N, 79°00.0'W	1864 TD: 310 into basement	Intermediate to mafic gneiss of tonalitic composition, biotite-hb-qtz-plagioclase. with amphibolite layers 1-10 cm thick Pervasively fractured and retrogressively metamorphosed to green-schist facies grade.	An unusually complete description of this rock, complete with EMP mineral analyses, is given by Farrar (1980a).
19	NC 141A	Pender Co.; 34°23'57"N 77°04'42"W	1347 TD; 1 into basement	Biotite-hb amphibolite, qtz + plag 20%; well developed metamorphic texture; rock is mafic volcanic at amphibolite facies grade, virtually unaltered.	
20	NC 141-2	Pender Co.; 34°40'30"N 77°42'30"W	1000 TD; 50 into basement	Fine- to medium-grained, moderately altered leucogranite, hypidiomorphic-granular texture, K-feldspar, plagioclase, quartz, 2% muscovite and tourmaline.	
21	NC 133-1	Onslow Co.; 34°32'50"N, 77°33'00"W	1497 TD; 80 into basement	Biotite-quartz-epidote schist with sericitized interstitial feldspar(?) Metamorphism is biotite grade, sericite is secondary. Metamorphosed argillaceous sediment, possibly with tuffaceous component.	

Table 5, Continued

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
22	NC 133-12	Onslow Co.; approx 15 km N 20 E of 133-1 (no co-ordinates given	1402 TD; penetration into basement NA	Low-grade sandstone consisting of of well-sorted quartz (80%) with interstitial chlorite and muscovite and disseminated magnetite; clear primary layering; associated fine-grained marble with 5% quartz.	
23	NC 133-13	Onslow Co.; 34°40'20"N, 77°30'20"W	1414 TD; approx. 60 into basement	Chips range from quartz-rich metasediment with fine-grained mosaic texture through quartz-chlorite-(epidote)-(carbonate) rock to fine-grained marble with 5% quartz. Overall similarity to 133-12; mixed low-grade metasedimentary rocks with subordinate volcanic component.	
24	NC 133-14	Onslow Co.; 34°41'30"N, 77°30'30"W	1370 TD; 3 into basement	Fine-grained meta-quartz diorite consisting of plagioclase, quartz, amphibole, biotite, sphene and opaques. Texture distinctly crystalloblastic; the actinolitic amphibole and olive brown-biotite are probably metamorphic. However there is relict hypidiomorphic fabric. Color index estimated 35.	This relatively mafic, and metamorphosed, rock is distinct from the granite (141-2) 20 km. west, and almost certainly is not co-magmatic. A reasonable guess is that it's older.
25	NC 133A	Onslow Co.; 34°39.11'N, 77°19.23'W	1954 TD; 286 into basement	hornblende-(clinopyroxene)-(biotite)-quartz monzonite, somewhat altered, with development of calcite, chlorite, rutile, and zeolites; weakly foliated and intruded by lamprophyre dikes.	Whole-rock Rb-Sr isochron age, 633 $\pm$ 58 m.y. Biotite- whole rock Rb-Sr pairs, 371 and 340 m.y. For these and other data see Speer, 1980.
26	NC 133-7	Onslow Co.; 34°49'30"N, 77°23'55"W	1328 TD; penetration into basement NA	Highly altered intermediate to mafic metavolcanic rock (tuff?) consisting of sericite, epidote, chlorite, quartz, and semiopaque and opaque material. Alteration could be hydrothermal or reflect low greenschist facies metamorphism.	
27	NC 133-4	Onslow Co.; 34°54'00"N, 77°23'45"W	1433 TD: approx. 100 into basement	Very fine-grained quartz-sericite-chlorite-epidote aggregate with scattered opaques (presumed magnetite). Possibilities: volcanic tuff, retaining some original glassy matrix, or metamorphosed siltstone. Basically similar to some fragments of 133-13.	

Table 5, Continued

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
28	NC 103-1	Jones Co.; 35°56'15"N, 77°24'30"W	1218 TD; 5 into basement	Clastic, fine-grained, moderatedly sorted rock consisting of quartz, plagioclase biotite, sericite, chlorite, calcite, and cryptocrystalline groundmass. No pore space; low-grade metamorphism (biotite grade). Probably volcanogenic; metatuff or metagraywacke.	
34	NC 49-2	Craven Co.; 34°50'55"N, 76°57'54"W	2430 TD; 61 into basement	Medium-grained quartz diorite or tonalite consisting dominantly of quartz and plagioclase (An_{25}) with 3% biotite and 2% opaques. Texture is hypidiomorphic (not crystalloblastic) in contrast to 133-14.	This rock is more likely a component of the Hatteras granitic suite than the apparently older quartz diorite (133-14) to the west.
35	NC 31-9	Carteret Co.; 34°43'50"N, 76°34'30"W	4975 TD; 37 into basement	Medium grained, moderately altered monzogranite, plagioclase and K-feldspar 1:1 5% partly chloritized biotite and opaques.	
36	NC 31-8	Carteret Co.: 34°53'55"N 76°22'00"W	5607 TD; approx. 50 into basement	Medium-grained, moderately altered leucogranite, altered biotite and opaques; plagioclase and K-feldspar 1:1.	
37	NC 31-3	Carteret Co.: 34°55'50"N 76°38'05"W	4123 TD; 17 into basement	Slightly altered, medium-grained leucogranite; K-feldspar > plagioclase: hypidiomorphic texture. 1% opaques sole mafic constituent.	Sample is very similar to 31-8, and is also comparable to 31-9.
38	NC 31-6	Carteret Co.; 34°58'45"N 76°38'00"W	4010 TD; 10 into basement	Essentially identical to 31-3.	
39	NC 31-4	Carteret Co.; 34°58'50"N, 76°39'00"W	3962 TD; 29 into basement	Fine-grained diorite consisting of plagioclase (normally zoned An_{30-68}) 60%, green hornblende and deep red-brown biotite ca. 15% each, quartz <5%, opaque and secondary epidote 5%. Panidiomorphic texture.	This rock is clearly unrelated to preceding granites, apparently forms a discrete mass to the north-west. Note it is not metamorphosed like 133-14 but is compositionally similar.
40	NC 31-5	Carteret Co.; 34°57'15"N, 76°39'35"W	3961 TD; 17 into basement	Diorite generally similar to 31-4.	In all probability these two samples, less than 5 km apart, are from the same body.

Table 5, Continued

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
41	NC 137-1	Pamlico Co.; 35°04'35"N, 76°39'00"W	3667 TD; 20 into basement	Considerably altered biotite-hornblende-quartz diorite; plagioclase (An_{30}) 70%, quartz 10%, biotite 10%, hornblende 5%, opaques + sphene + epidote 5%. Medium-grained, hypidiomorphic granular texture, distinct from 2 preceding samples.	May be related to diorite of 31-4/31-5, but is a less mafic rock.
42	NC 137-2	Pamlico Co.; 35°05'15"N, 76°40'35"W	3436 TD; approx. 30 into basement	Highly sheared quartz diorite with approximately same mineralogy as preceding sample but containing more epidote, sericite, and unidentified cryptocrystalline material.	
43	NC 95-9	Hyde Co.; 35°18'25"N, 75°49'45"W	7300 TD; approx. 60 into basement	Moderately altered plagioclase (An_{32})-quartz-K-feldspar granitoid with < 2% biotite and secondary sericite. K-feldspar is < 10%, hence rock appears to be a trondhjemite or leucogranodiorite.	Somewhat anomalous composition relative to granites of region, but nevertheless could be comagmatic.
44	NC 55-1	Dare Co.; 35°15'00"N, 75°31'45"W	10,054 TD; approx. 200 into basement	Fine-grained, somewhat altered, sheared monzogranite with approximately equal proportions of quartz, plagioclase (An_{37}) and K-feldspar; chloritized biotite 5.	This and following 8 samples are beyond 4000 ft. maximum depth. Rock is generally of same composition as granites to the southwest.
46	NC 55-9	Dare Co.; 35°39'36"N 75°46'40"W	6230 TD; 120 into basement	Medium-grained, rather altered muscovite-biotite granite with about equal proportions of quartz, plagioclase (An_{5-20}) and perthitic K-feldspar. Muscovite + chloritized biotite 5%, strongly sericitized and chloritized cordierite(?) 10%, apatite and zircon.	Stumpy Point pluton, a cordierite-biotite granite according to Speer (1981).
47	NC 55-14	Dare Co.; 35°48'19"N, 75°47'48"W	5560 TD; approx. 30 into basement	Moderately altered monzogranite, plagioclase + K-spar (80). quartz (15), chloritized biotite (<5)	Location is 15 km N of 55-9.
48	NC 55-6	Dare Co.: 35°51'50"N, 75°55'30"W	5144 TD; 20 into basement	Metadiorite consisting of albite (An_0), epidote and altered hornblende, little or no quartz. Rock is low greenschist facies; primary diabasic texture and albite twinning well preserved. Both green (actinolitic?) and deep red-brown hornblende present.	Could be related to diorites 31-4/31-5.

Table 5, Continued

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
49	NC 55-10	Dare Co.· 35°51'48"N, 75°51'04"W	5780 TD; approx. 350 into basement	Monzogranite generally similar to 55-14, almost devoid of mafic constituents (1% muscovite + chloritized biotite).	Location 10 km NW of 55-14.
51	NC 55-15	Dare Co.; 35°56'38"N, 75°52'20"W	5260 TD: 50 into basement	Somewhat sheared and altered, medium-grained granite with K-feldspar 45%, plagioclase 25%, quartz 25%, and muscovite + pale yellow tourmaline 5%.	Generally similar to 55-10, and quite possibly part of the same mass.
53	NC 177-1	Tyrrell Co.; 35°53'33"N, 76°09'35"W	4198 TD; 300 into basement	Slightly sheared, moderately altered, slightly foliated fine- to medium-grained graywacke consisting of quartz, plagioclase, K-feldspar, green biotite, possibly chlorite and carbonate with cryptocrystalline matrix of same constituents. Low greenschist facies metamorphism.	
54	NC 177-2	Tyrrell Co.; 35°47'56"N, 76°12'20"W	4242 TD; 178 into basement	Well-sorted quartz-rich metasedimentary rocks ranging texturally from granofels (low mica content) to phyllite (15% muscovite ± biotite). Accessories include opaques, apatite and tourmaline. Generally similar to #177-1 except for lower feldspar content.	
55	NC 53-1	Currituck Co.; 36°18'10"N, 75°55'30"W	4553 TD: 35 into basement	Relatively coarse-grained quartz-muscovite-biotite staurolite-(tourmaline) schist. Fragments too sparse to get representative mode of this rock.	Both coarser grain size, relative to 177-1 and 177-2, as well as presence of staurolite indicate higher metamorphic grade northward along this(?) belt.
56	NC 29-2	Camden Co.; 36°24'40"N, 76°10'30"W	3741 TD; 920 into basement	Rhyolitic vitric-crystal tuff, with devitrified groundness and phenocrysts of quartz and K-feldspar; eutaxitic texture well preserved despite considerable alteration including large carbonate patches. Rock is virtually unmetamorphosed.	Whole-rock Rb-Sr determination of 408 ± 40 (Denison and others, 1967).
57	NC 73-1	Gates Co.; 36°26'N, 76°30'W	2150 TD; 20-30 into basement	Volcanic rock, intermediate composition probably dacite); altered devitrified groundmass of quartz, sericite, epidote and opaques, few relict feldspar phenocrysts, also quartz aggregates. Indicates greenschist facies metamorphism; degree of recrystallization greater than in 29-2.	

Table 5, Continued

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
58	NC 91-1	Hertford Co.; 36°19'10"N, 76°50'10"W	1278 TD; 33 into basement	Tuffaceous siltstone or fine-grained metamorphosed sandstone consisting of well-sorted quartz-feldspar mosaic and 30% metamorphic biotite and epidote as well as carbonate and disseminated opaques. Rock could be regarded as calc-silicate granofels.	Sample is generally compatible with other low-grade sedimentary rocks in this broad belt.
59	NC 73A	Gates Co.: 36°31.9"N, 76°52.7' W	1355 TD; 265 into basement	Monzogranite-granodiorite consisting of plagioclase (An_{20}) 37%, quartz 30%, K-feldspar 20%, biotite 10%, hornblende <1%, and traces of epidote, sphene, and opaques (Becker, 1981).	The granite shows indications of mild ductile deformation and two stages of brittle deformation resulting in two sets of fractures (Becker, 1981). It is closely similar to the Petersburg granite.
				VIRGINIA	
60	CP 25A	Suffolk Co.; 36°51.01'N, 76°29.83'W	NA, 175 into basement	Coarse-grained, inequigranular granitoid corresponding to monzogranite; quartz, K-feldspar, oligoclase and biotite, plus secondary quartz, carbonate and muscovite and numerous accessories including fluorite, thorite and uraninite (Russell and others, 1985).	Whole-rock Rb-Sr isochron age of 263 ± 24 Ma considered crystallization age; $^{87}Sr/^{86}Sr_0$= 0.7076 ± 0.0012. (Russell and others, 1985).
61	W-158	York Co.; 37°00'15"N, 76°18'23"W	NA	Rhyolite (Darton, 1902); could be rhyolitic tuff, metamorphosed to greenschist facies.	
63	W-3876	Charles City Co.; 37°19'55"N, 77°05'55"W	NA	Grayish green, medium-grained, moderately sheared and fractured metadiorite consisting dominantly of plagioclase, and hornblende mostly replaced by chlorite and epidote. Metamorphic grade is greenschist facies.	
64	W-3180	Accomac Co.: 37°57'03"N, 75°31'01"W	6279 TD; 90 into basement	Evenly laminated argillite consisting of alternating carbonate-rich (up to 85%), and carbonate-poor bands and also containing fine-grained quartz, feldspar, and biotite porphyroblasts and <1% opaque minerals (D'Appolonia, 1980).	
				MARYLAND	
65	SOM-Dd 47	Somerset Co.· 38°00'58"N, 75°49'32"W	5562 TD;	Fine-grained, gray-green quartz-albite-epidote-chlorite phyllite derived from mafic volcanic rocks (Gleason, 1979)	Depth to top of basement uncertain.

Table 5, Continued

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
66	WOR-CE 12	Worcester Co.; 38°17'55"N, 75°17'27"W	7178 TD; 38 into basement	Medium- to fine-grained gabbro, partly serpentinized and traversed by carbonate-bearing joints; locally brecciated with disseminated pyrite. (Anderson, 1948).	
67	WI-Cg 37	Wicomico Co.; 38°20'48"N, 75°29'13"W	5568 TD; 70 into basement	Deeply weathered chlorite-bearing schist with small pegmatite veinlets overlying a moderately altered and locally fractured quartzo-feldspathic biotite gneiss intruded by feldspar-rich pegmatite (Anderson, 1948).	
68	DO-CE 88	Dorchester; 38°34'02"N, 76°03'21"W	3337 TD; 33 into basement	Medium-grained, nonporphyritic monzo-granite, slightly gneissic, consisting of quartz 39%, oligoclase 34%, micro-cline 18%, biotite 10%, and accessory apatite and zircon (Trapp and others, 1982).	
69	CE-EC 17	Cecil Co.; 39°24'18"N, 76°01'30"W	1107 TD; 79 into basement	Quartzo-feldspathic, graphitic mica schist, extensively sheared and fractured; alternates with coarser-grained gneiss of same general composition. (Edwards and Hansen, 1979).	
70	HAR-Dg 3	Harford Co.; 30°26'43"N, 76°04'15"W	777 TD; 65 into basement	Intermediate to mafic metavolcanics under-lain by more or lesa gneissic granite with biotite as principal mafic constituent (Edwards and Hansen, 1979).	
71	CE-Dc 2	Cecil Co.; 39°27'16"N, 76°00'30"W	936 TD; 151 into basement	Quartz-plagioclase-muscovite-biotite schist, locally garnet-bearing; one sample has 5% sillimanite. Moderately altered and fractured (Edwards and Hansen, 1979)	Mineralogy suggests volcaniclastic to epiclastic source.
				DELAWARE: NO SIGNIFICANT WELLS	
				NEW JERSEY	
72	III	Camden Co.; 39°41.55'N, 74°56.85'W	2090 TD; depth into basement NA	Dark gray, even-textured and medium grained, well-foliated, biotite-rich schist and gneiss (USGS Map I-514A, 1967).	
73	IV	Burlington Co.; 39°51.85"N, 74°30.3'W	2284 TD; 11 into basement	Impure marble consisting of carbonate (40%) phlogopitic mica and chlorite (20%) and a clay-chlorite matrix (USGS Map I-514A).	

Table 5, Continued

Map Loc. No.	Sample/ Well No.	Location	Depth (ft)	Description/Petrography	Comments
74	Island Beach State Park	Ocean Co.; 39°48'15"N, 74°05'45"W	3891 TD; 8 into basement	Migmatitic gneiss consisting of a well-foliated, dark gray medium-grained paleosome of garnet-microcline-biotite quartz gneiss, and neosome comprising granitic, concordant to cross-cutting igneous-textured stringers of alaskite and pegmatite (Southwick, 1964).	A 235-m.y. K-Ar age on biotite probably reflects Alleghanian metamorphism.
			NEW YORK		
75	S-33379 T	Suffolk Co.; 40°49'32"N, 73°05'59"W	1580 TD; depth into basement NA	Tan, fine- to medium-grained saprolitic granitoid containing quartz, muscovite, biotite, and highly altered feldspar.	
76	S-56981 T	Suffolk Co.: 40°59'37"N, 72°35'49"W	160 TD; 15 into basement	Slightly altered, weakly to moderately foliated, medium to coarse-grained granitic gneiss, locally pegmatoid. Consists of: microcline 45%, sodic plagioclase 20%, quartz 32%, plus 3% biotite, muscovite and garnet (Pierce and Taylor, 1975).	A K-Ar age of 254±9 m.y. determined on biotite probably reflects Alleghanian metamorphism.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the following persons and institutions for the contribution of samples of basement rocks and/or lithologic descriptions of basement rocks: North Carolina Geological Survey, Raleigh, NC; Georgia Geological Survey, Atlanta, GA; R. Shiver and R. Cheek, North Carolina Division of Environmental Management, Groundwater Section, Wilmington and Raleigh, NC; J. Sampair, North Carolina Geological Survey, Raleigh, NC; J. Gernand, Earth Sciences and Resource Institute, Columbia, SC; D.G. Ziegler, Southeastern Exploration and Production Co., Dallas, TX; D.S. Pierce, Stone and Webster Engineering Corp., Boston, MA; J. Soren, USGS, Water Resources Division, Syosset, NY; H. Meisler, USGS, Water Resources Division, Trenton, NJ; R.L. Waite, USGS, Water Resources Division, Doraville, GA; D.C. Prowell, USGS, Geologic Division, Doraville, GA; A.J. Froelich, USGS, Geologic Division, Reston, VA.

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