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A Geophysical Study of the Easternmost Piedmont: Brunswick County, Virginia

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A GEOPHYSICAL STUDY OF
THE EASTERNMOST PIEDMONT:
BRUNSWICK COUNTY, VIRGINIA

BY

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Approved by:

Dr. Ali A. Nowroozi (Advisor)

ABSTRACT

A GEOPHYSICAL STUDY OF THE EASTERNMOST PIEDMONT: BRUNSWICK COUNTY, VIRGINIA

Mark A. Corbin
Old Dominion University, 1989
Director: Dr. Ali A. Nowroozi

Gravity and magnetic models indicate that a steeply dipping, mylonitic shear zone recognized by reconnaissance mapping in the easternmost Piedmont of Brunswick County, Virginia is a listric fault. A pronounced 3 to 5 mgal Bouguer anomaly high is associated with the fault zone. A band of N10°E trending aeromagnetic anomalies delineate the areal extent of the fault zone. The fault zone flattens eastward over a short distance to a depth of 15 kms where it joins a near horizontal surface that cuts across the region. This surface is herein interpreted to be a décollement. The fault zone of this study is interpreted to be a part of the Eastern Piedmont Fault System (EPFS) of Hatcher et al (1977). Listric geometry of this fault suggests it is a splay off the master décollement responsible for the Appalachian fold and thrust belt to the west. Inclusion of the fault of this study in the EPFS suggests that EPFS faults may also be listric.

ACKNOWLEDGMENTS

The following acknowledgments are meant to give credit to all who supported this work during its various stages. First and foremost I would like to thank my parents Donald and Carroll Corbin for their unfailing encouragement throughout my college career. Also, special thanks go to Kathleen Paasch for her love and encouragement in the field and at home.

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To Charles James for help in all aspects of a geophysical study of this type. To Brett Waller for sharing of ideas and companionship in the field. To Bill Decker for providing several of the programs mentioned in this study as well as teaching me SAS programming. To the staff at Old Dominion University Graphics for help in drafting many of the figures contained in this report. To Patrick Considine, Andy Watkins, Phillip Rogan, Bill Friedmann, and Dave Hagar for help with data collection.

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INTRODUCTION

Understanding of Appalachian tectonics is hindered by a lack of modern field data from the Piedmont of southeastern Virginia. For this reason a detailed geophysical study was conducted in Brunswick County, Virginia. Brunswick County makes an excellent area for detailed field studies because the county is located between the Carolina Slate Belt to the west, the Eastern Slate Belt to the east, the Raleigh Belt to the south, and the Goochland terrane and Richmond Triassic Basin to the north (Figure 1).

Several reasons exist for undertaking this study. First, this portion of the Virginia Piedmont is an area lacking in adequate modern geologic data. Only two published geologic maps, both at small scale, exist for this area (Calver, 1963; Bobyarchick, 1979). Second, the area is bisected by a previously unmapped mylonitic shear zone (Waller and Corbin, 1988). The Hylas fault to the north (Bobyarchick and Glover, 1978), and the Hollister fault to the south (Boltin and Stoddard, 1987), have both been extensivly studied, and are known to be part of the eastern Piedmont fault system (Figure 2) of Hatcher et al (1977). However, the extrapolation of the eastern Piedmont

Figure 1. Distribution of "Alleghanian granites" and major Piedmont terranes (From Williams, 1978).

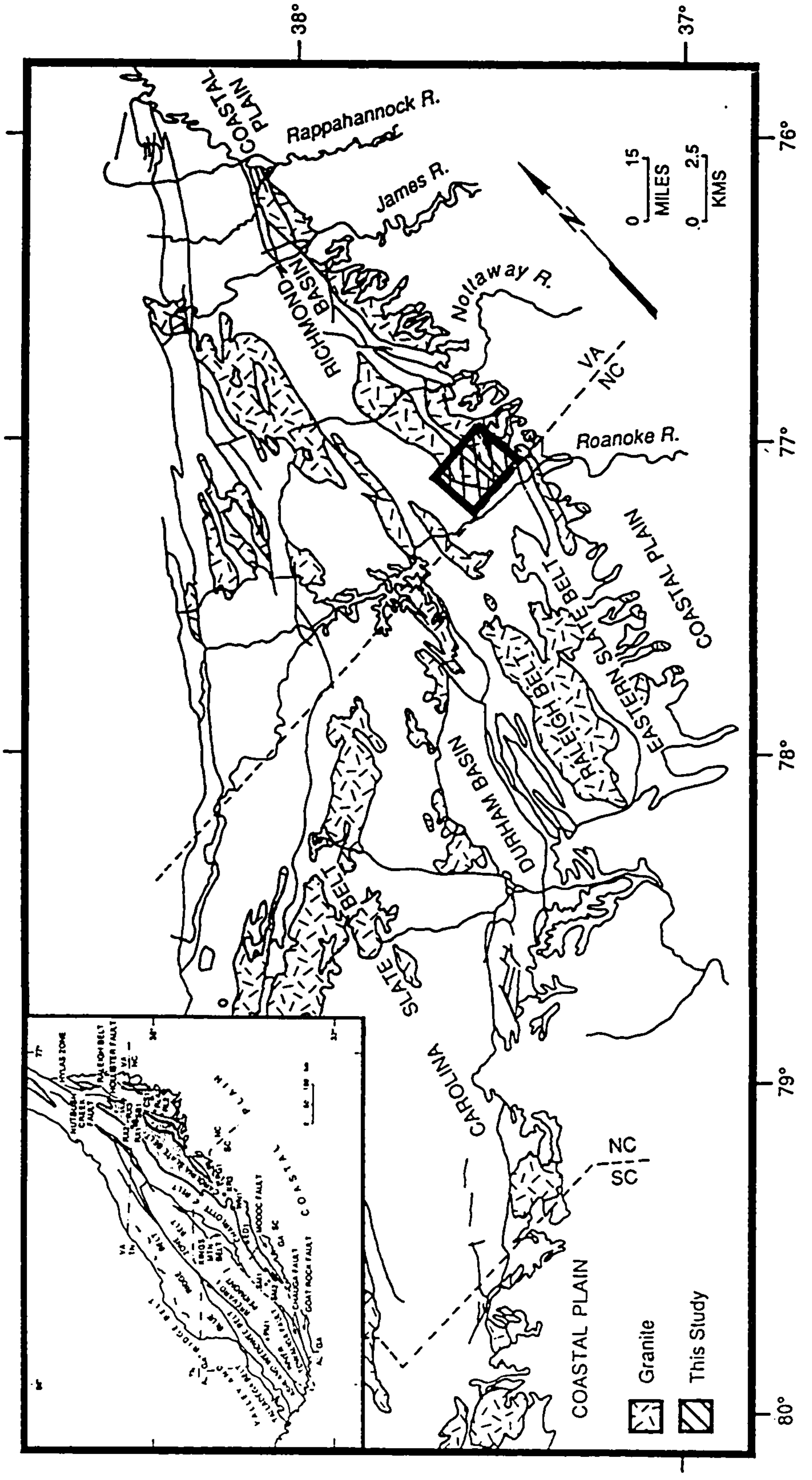
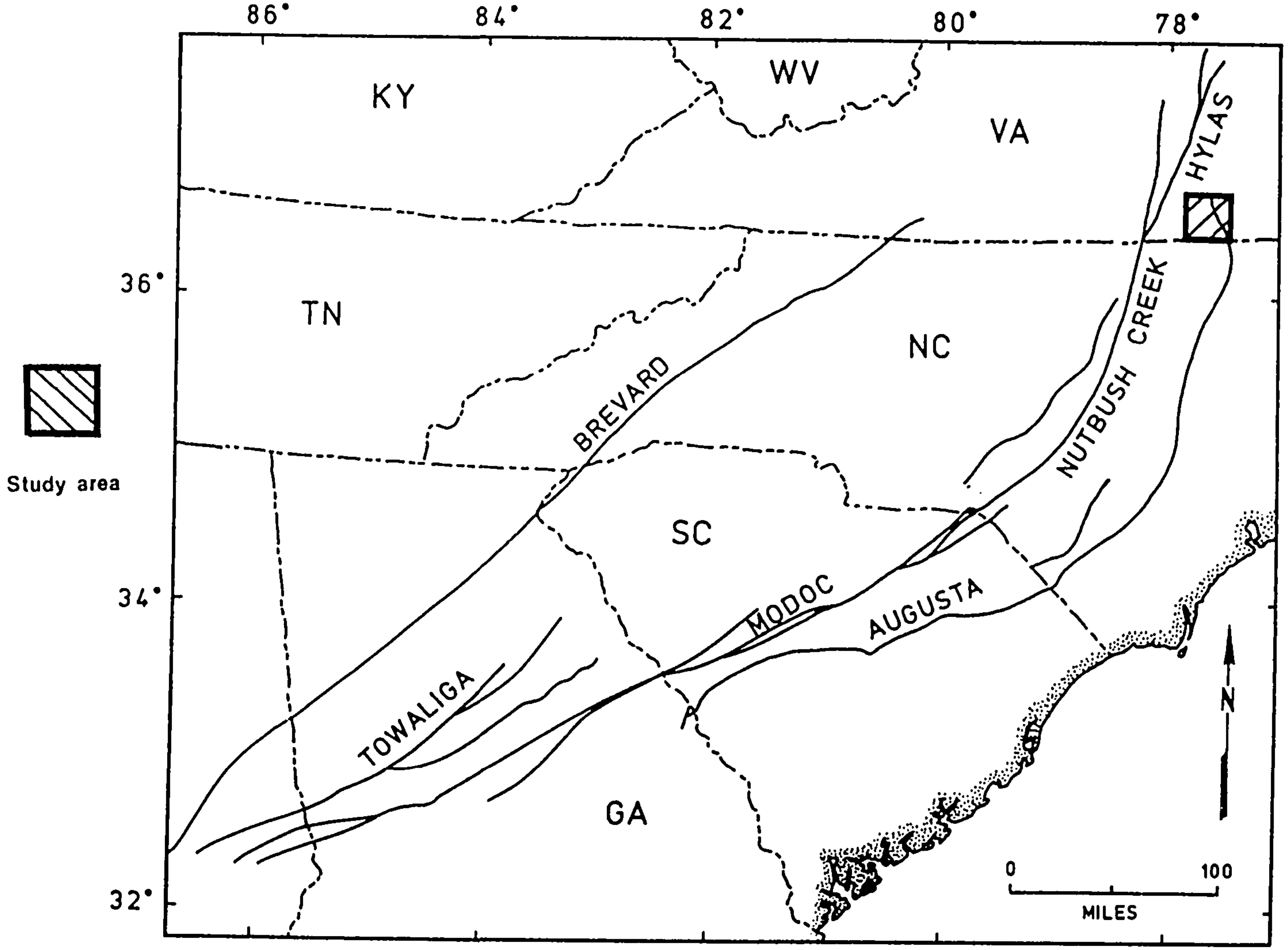

38°
37°
76°
77°
78°
79°
80°
COASTAL PLAIN
Rappahannock R.
James R.
Nottaway R.
Roanoke R.
RICHMOND BASIN
VA
NC
SC
0 15 MILES
0 25 KMS
N
EASTERN SLATE BELT
COASTAL PLAIN
RALEIGH BELT
DURHAM BASIN
SLATE BELT
CAROLINA
COASTAL PLAIN
Granite
This Study

Figure 2. Eastern Piedmont Fault System (From Hatcher et al, 1977).


86°
84°
82°
80°
78°
36°
34°
32°
KY
WV
VA
TN
NC
SC
GA
HYLAS
NUTBUSH CREEK
BREVARD
MODOC
AUGUSTA
TOWALIGA
N
0
100
MILES
Study area

fault system through this part of the eastern Piedmont has never been attempted. Thus, documenting the trend and subsurface structure of the fault is important to understanding regional tectonics. Fault geometry is the key to understanding the tectonics of the eastern Piedmont fault system.

Third, the area contains two granitic bodies of possible "Petersburg Granite" affinity. These granites belong to the "300 m.y." post-metamorphic igneous plutons of Fullagar and Butler (1979). Other plutons assigned to this rock suite in Georgia and North Carolina were modeled using geophysics (Waskom and Butler, 1971; Lynn, Hale, and Thompson, 1981; Fraizer amd Dainty, 1982; Pratt et al, 1985). Determining the mode of emplacement, the tectonic setting, and knowing whether the granitic bodies in Brunswick County are rooted or not is important for a better understanding of the geology of the eastern Piedmont.

Geophysical techniques have been used extensivly to study depth and subsurface shape of plutons, determine fault type, and geologic variations (Steenland, 1962; Behrendt, Popenoe, and Mattick, 1969; James et al, 1968; Issacson and Smithson, 1976; Brisbin and Green, 1980; Reilly, 1980; Bollinger and Sibol, 1985; Keller et al, 1985; Bott and Tantrigoda, 1987; Williams and Finn, 1987). The present study is the first of its kind in this area of Virginia.

Because good exposures in the Piedmont are lacking, very little is known about the geology in these poorly exposed areas. Geophysics offers a viable alternative method to study the tectonics of this area.

LOCATION

Brunswick County is located in southeastern Virginia. This study encompasses the southern third of the county and covers approximately 100 kms^2 of terrain (Figure 3). The study area is bounded by the Virginia - North Carolina border to the south, the Meherrin River limits the northern margin, the Brunswick - Greensville county line limits the eastern margin, and longitude 78° West line limits the western margin. The area is located approximately twenty miles west of Emporia, Virginia, and is south of US Highway 58 near Lawrenceville, Virginia.

Two east - west lines, S-1 and N-1, were surveyed for this study (Figure 4). An additional survey line PN-1 was available for use (Waller, M.S. Thesis, in prep.).

PHYSIOGRAPHY

Brunswick County is located on the eastern edge of the Piedmont province of Virginia. The region contains igneous and metamorphic rocks of many ages. The eastern portion of

Figure 3. Location of study area.

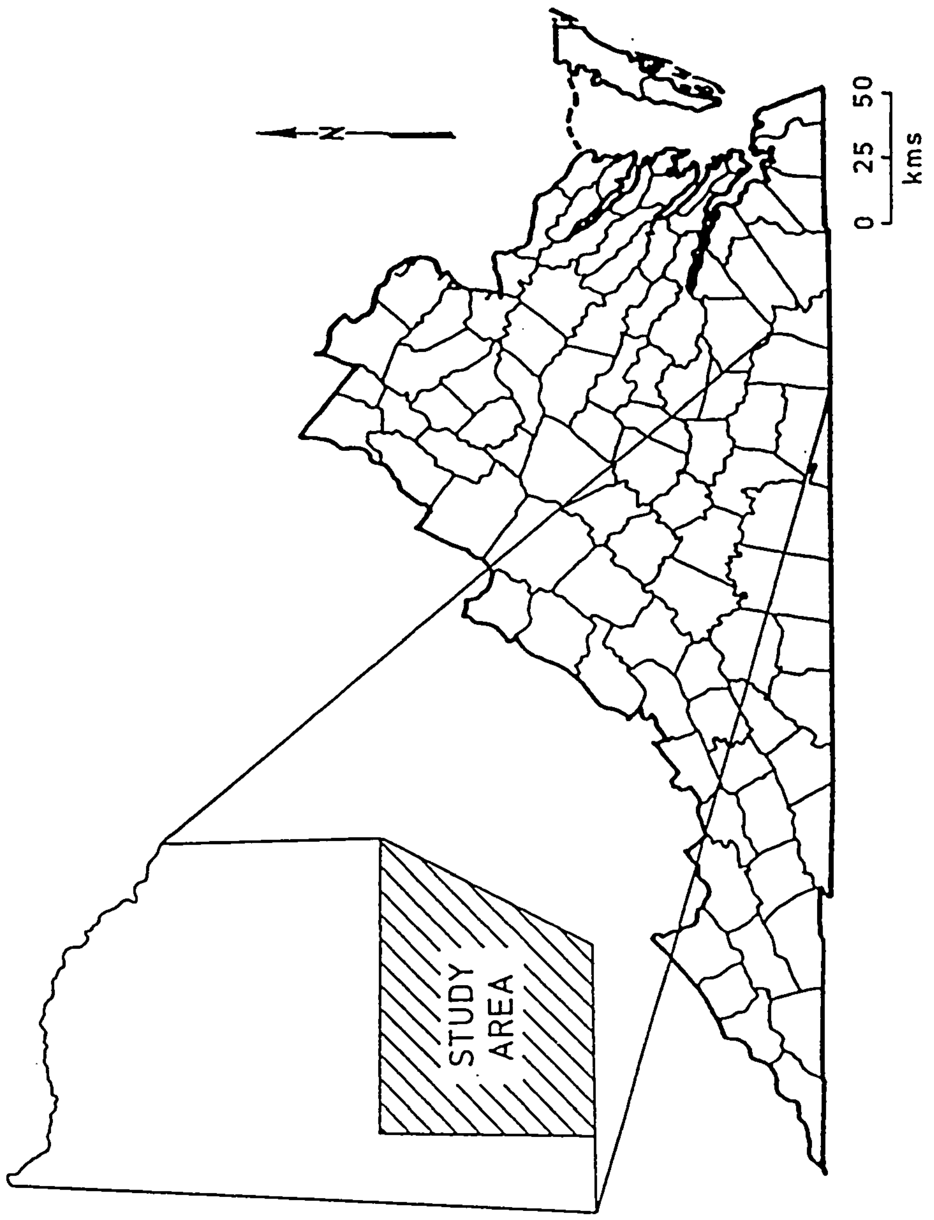
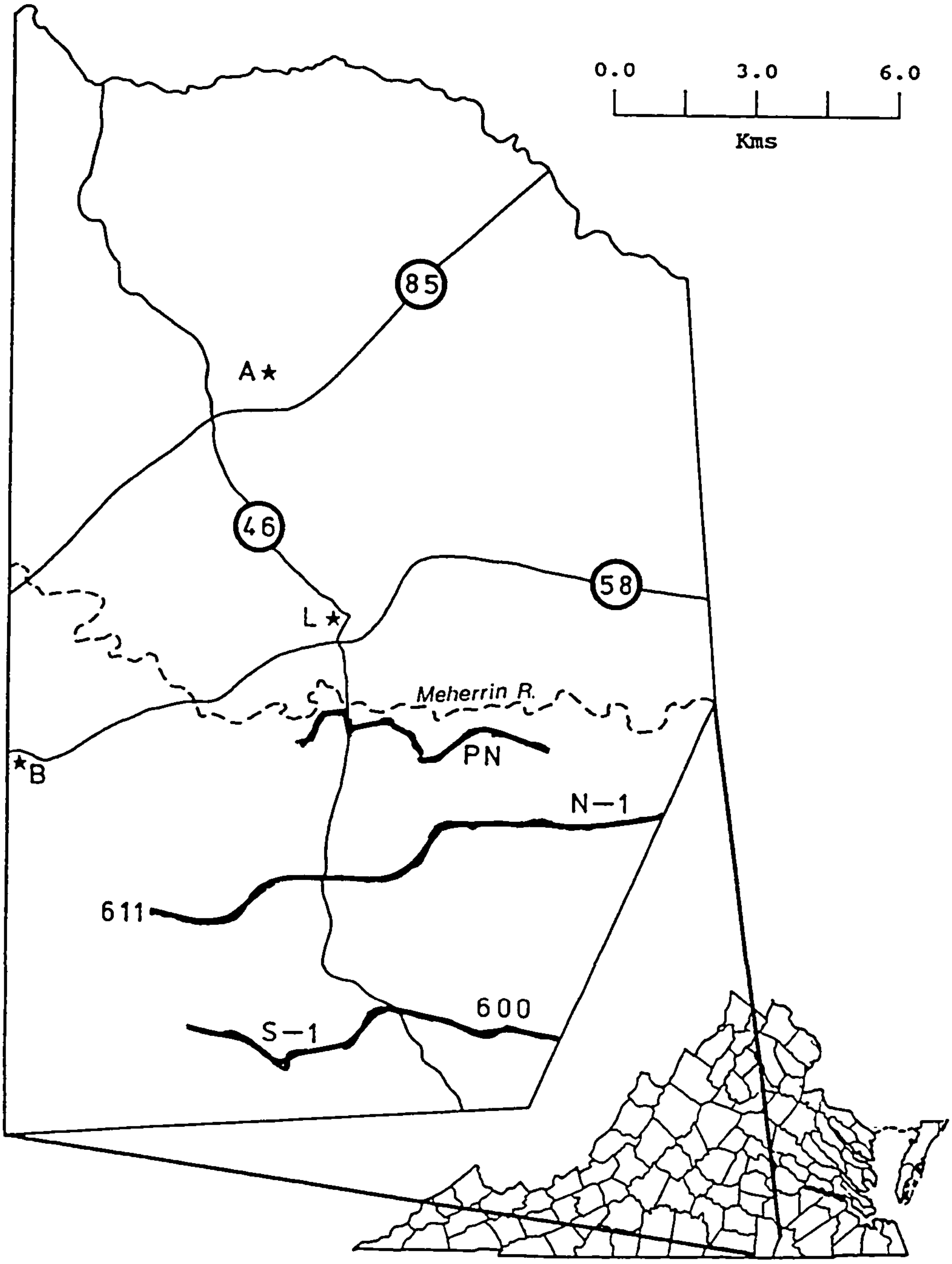

N
0 25 50
kms
STUDY AREA

Figure 4. Brunswick County, Virginia location of geophysical survey lines S-1, N-1, and Pn-1.


0.0
3.0
6.0
Kms
85
A
46
58
L
Meherrin R.
PN
B
N-1
611
600
S-1

the county is overlain by a sequence of Cretaceous and Tertiary age deposits of the Coastal Plain province.

The county is characterized by gentle relief and rolling topography. Average regional elevations are generally less than 100 m. above mean sea level.

PURPOSE

The purpose of this study is to determine the subsurface geometry of the granite and intervening shear zone in Brunswick County, Virginia using geophysical techniques. An indication of the mode of emplacement of the pluton(s) can be inferred, from the relationship between fault and pluton geometry.

The intent is to compare the geophysical models generated in this study with several existing tectonic models of the region (Thomas, 1983; Harris and Bayer, 1979, Cook et al, 1979). Integration of the developed geophysical models into the larger tectonic framework of the region is the ultimate goal of this study.

RESEARCH OBJECTIVES

This study was conducted with the following objectives in mind.

1) The collection of geophysical data. This included the determination of station elevations using engineering surveying methods, and measurement of gravity and radiometric values.

2) Definition of major lithologic and tectonic boundaries using radiometric and aeromagnetic data. (Clarifying lithologic contacts is a vital step in producing a tectonic model of the region and definition of contacts is of utmost importance in an area where exposure is poor.)

3) Modelling of gravity data to obtain information on the crustal structure of southern Brunswick County, Virginia.

4) Plotting of gravity data to produce contour maps. Additional data is available from Waller (M.S. Thesis in prep.) and the Virginia Gravity Network (Johnson and Ziegler, 1977).

5) An interpretation of the geophysical models developed in this study into a tectonic model of regional significance.

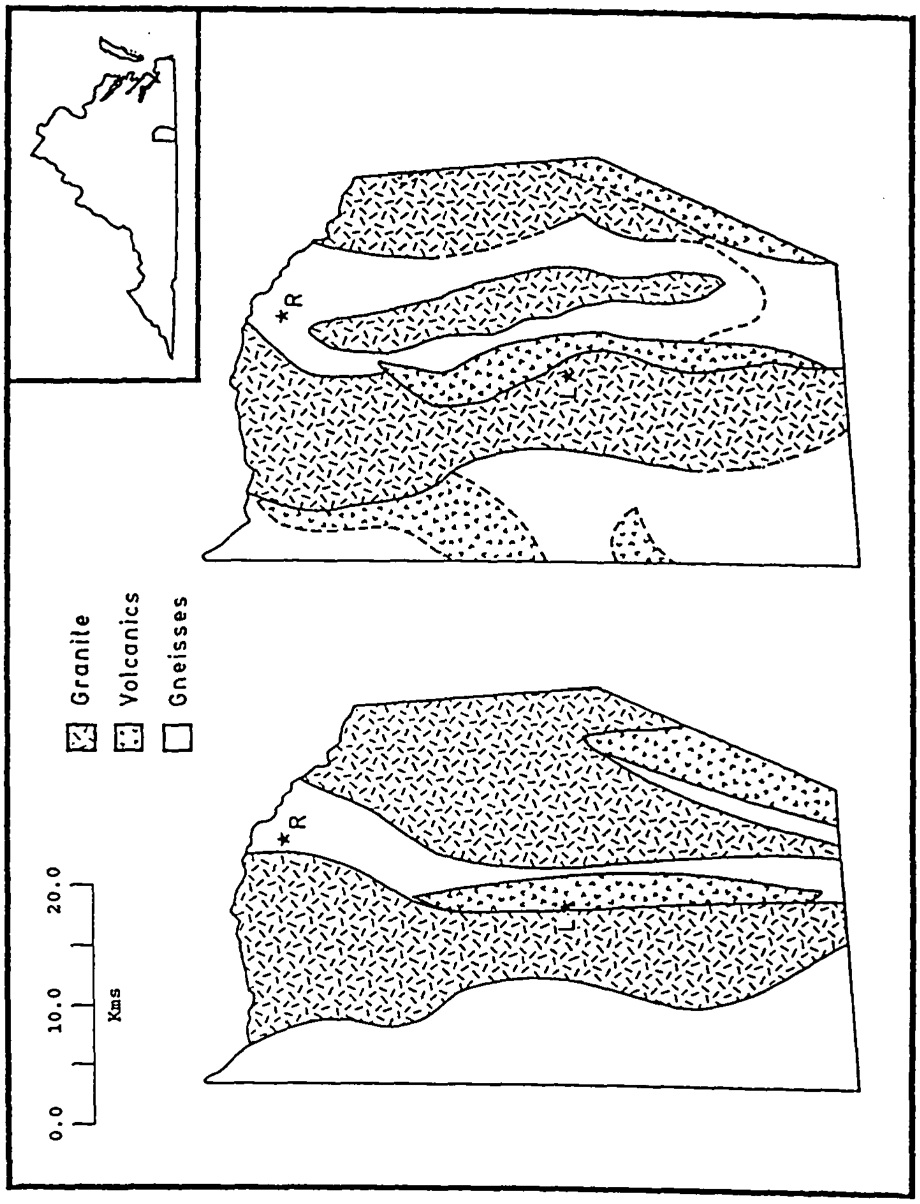
PREVIOUS WORK

Detailed geologic mapping has not been conducted in Brunswick County, Virginia. Brunswick County is included in two general geologic maps (Calver, 1963; and Bobyarchick, 1979). These maps are compared in Figure 5. Koehler (1982) mapped the southern portion of this study area in limited detail. Diment et al (1965) completed a study on the anomalous heat flow present in the granitic rocks in southern Brunswick County, Virginia.

Brunswick County has been the subject of even less geophysical investigations. No published detailed ground surveys have been conducted in the county. The area was included in Johnson's (1975) study of the Bouguer gravity of southeastern Virginia. Aeromagnetic maps have been open-filed (Virginia Division of Mineral Resources, 1975) for the area, but have not been analyzed.

Regionally, several studies are of significance in understanding the regional geology of Brunswick County. To the north, Bobyarchick and Glover (1978) studied the deformation of the Hylas Fault zone in the eastern Piedmont near Richmond. Venkatakrishnan (1983) studied the

Figure 5. Comparison of the geology of Brunswick County, Virginia; R=Rawlings, L=Lawrenceville (modified from Calver, 1963 and Bobyarchick, 1979).


Granite
Volcanics
Gneisses
0.0
10.0
20.0
Kms
R
L

implications of collisional tectonics and its effect on the geology of the eastern Piedmont. Reilly (1980) conducted a geophysical and geological study of central Virginia and determined the depth of the master décollement. Bollinger and Sibol (1985) studied the same region using seismic reflections and Keller, Robinson, and Glover (1985) studied the area using gravity. Both studies gave similar results as Reilly (1980).

To the south, Boltin and Stoddard (1987) studied the relationship of major tectonic terranes. Farrar (1985a; 1985b) and Parker (1968) extensively studied the stratigraphy, structure, and tectonics of northeastern North Carolina. Watkins et al (1985) conducted a geophysical investigation of the gravity field in Albemarle County, North Carolina.

GEOLOGIC SETTING

Piedmont geology can be described as a mixture of tectonic terranes of uncertain origin. The Tectonic Map of the Appalachian Orogen (Williams, 1978; Figure 1) shows that the area consists of contrasting units. The rock units range in age from pre-Cambrian (Grenville 1.1 Ga age) to the most recent (Cenozoic sediments). Many of the tectonic terranes are considered to be allocthonous. A number of authors have spent their entire careers trying to unlock the relationships between these widely differing rocks. Many arguments remain over how and where these terranes originated.

One commonality that binds most of the studies is that the present configuration of tectonic units in the southeastern United States is tied to the presence of major shear zones. It is generally accepted that these shear zones represent the boundaries between the major tectonic units of the piedmont. Several theories describe the type of motion that has occurred (strike-slip vs. thrusting). A discussion of the major tectonic units will be covered in detail in a later section.

Prevalent throughout the piedmont (and of primary importance to this study) of the southeastern United States are "300 my" or "Alleghanian" granites of Fullagar and Butler (1979). These plutonic rocks are the direct result of continent-continent convergence and subduction between North America and Africa during the late Paleozoic. The granitic plutons of this study have previously been described as having "Petersburg" affinity (Calver, 1963; Bobyarchick, 1979). The type locale for the Petersburg granite is located near Richmond, Virginia. The Petersburg granite was described by Bloomer (1939) as a gray to pink medium grained granite, and by Wright et al (1975) as a medium grained quartz monzonite. The granites of this study are predominantly composed of quartz, plagioclase, and potassium-feldspar with accessory amounts of biotite. The potassium-feldspar is usually in the form of megacrysts which are generally aligned parallel with the foliation of the country rocks (to be discussed below).

Of particular importance in the study of Wright et al (1975) is the inclusion of a sample from the Skippers locality. This sample was collected from an area due east of this study (see figure 2 in Wright et al, 1975). This is the best documented description of a granite in this vicinity. For a more detailed discussion of the granites of this study see Wright et al (1975), Bobyarchick

(1979), and Bloomer (1939). Also, for a more detailed discussion of the granites of the southeastern Piedmont see Fullagar and Butler (1979), Sinha and Zietz (1982), and Whitney and Wenner (1980).

The Geologic Map of Virginia (Calver, 1963; figure 5) shows a thin belt of metavolcanics between the two granites of this study. More recently Bobyarchick (1979) concurred with the above map. However, Waller and Corbin (1987) have shown that the metavolcanic unit is a mylonite.

The mylonitic character of the zone between the two granites becomes the key to understanding the geology of Brunswick County, Virginia. A volcanic origin as suggested by previous workers implies an eruptive origin for the rocks separating the two granites. It is difficult to visualize a scenario where intrusive granites are separated by extrusive vocanic rocks. This would suggest that the two granites are indeed separate plutons. Due to the linearity of the zone it would seem unlikely that the volcanic rock represents a roof pendant of country rock. The juxtaposition of intrusive granite and extrusive volcanics seems irreconcilable.

On the other hand, mylonitic rocks are formed by high ductile strain occurring in a region. Ductile strain is often expressed as a fault zone. Therefore, the presence of mylonitic rocks could be reconciled with one large pluton separated by a shear zone.

The composition of the mylonite is extremely important especially considering its occurence between the two granites. Preliminary investigations have shown that the composition of the mylonite is very similar to that of the surrounding granites (Waller, M.S. Thesis in prep.). The rock is predominantly composed of quartz and plagioclase groundmass. Unlike the surrounding granites the potassium-feldspar is not as dominant and may have been destroyed.

The composition of the mylonite suggests that the zone was formed syn- or post-kinematically with the emplacement of the pluton. Further supporting this idea is the coincidence between the foliation present in the granite (represented by the alignment of porphyritic potassium-feldspar) and the direction of foliation in the mylonite (N10E). Foliation is ubiquitous throughout the granite.

The presence of mylonitic shear zones that cross-cut granite plutons is well documented in the Hollister shear zone that cuts the Butterwood Creek pluton to the south of this study (Stoddard et al, 1987). Final movement in the shear zone within this study area must be no older than about the 330 m.y. age date of the Petersburg granite (Wright et al, 1975). No younger age for movement on the shear zone is known at this time.

The mylonite zone in Brunswick County appears to be the northern extension of the Hollister shear zone of northeastern North Carolina (Figure 6). Several features of the Brunswick zone are similar to the Hollister zone.

The mylonite in Brunswick County trends roughly N10E as determined from reconnaissance mapping and analysis of the aeromagnetic maps. This correlates quite well with the trend of the Hollister zone.

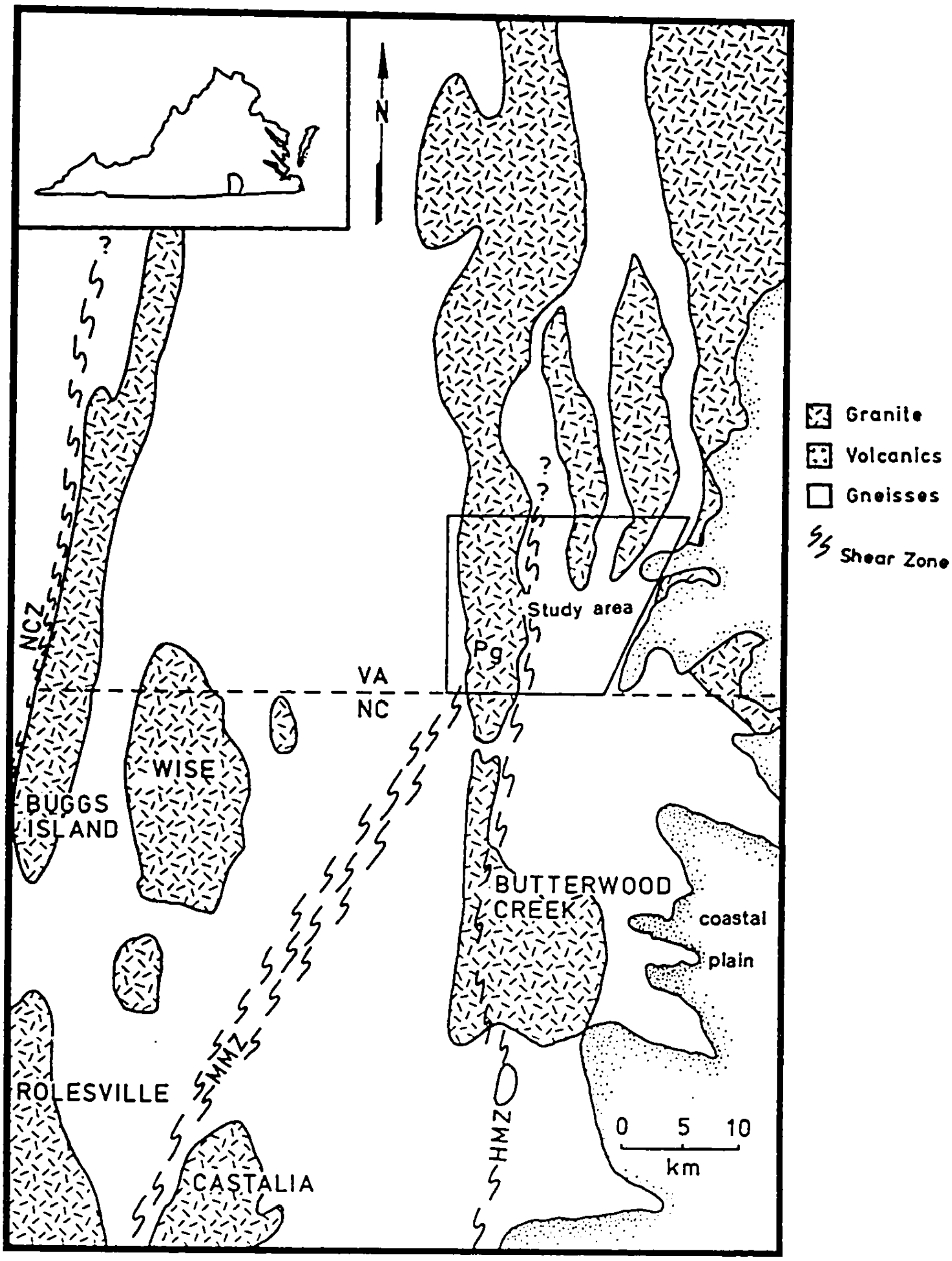
The Hollister mylonite zone varies in character over its length (Stoddard et al, 1987; Farrar, 1985). The deformation zone is narrow when cutting granites (0.5 km). The zone becomes much more diffuse (2.0 km) when not confined by granites. Reconnaissance observations in Brunswick County show a similar pattern. The shear zone of this study is 0.5 to 1.0 km wide in the area north of this study and becomes more diffuse to the south.

It appears likely the Brunswick mylonite zone is a northward extension of the Hollister zone based on these observations (and the spatial closeness of the two zones).

Both of the above units post-date several major tectonic terranes of the southern Piedmont. These terranes are the Carolina Slate Belt, the Raleigh Belt, and the Eastern Slate Belt.

Of the terranes, the Carolina Slate Belt is the best documented. The major units are late pre-Cambrian to

Figure 6. Relationship of faults and granites of northeastern North Carolina and southeastern Virginia to study area; HMZ=Hollister mylonite zone, MMZ=Macon mylonite zone, NCZ=Nutbush Creek zone (From Stoddard et al, 1987).


N
Granite
Volcanics
Gneisses
Shear Zone
Study area
Pg
VA
NC
NCZ
WISE
BUGGS ISLAND
BUTTERWOOD CREEK
coastal plain
ROLESVILLE
MMZ
HMZ
CASTALIA
0 5 10
km

Paleozoic in age. The main lithologic components of the Carolina Slate Belt are metasediments and metavocanic rocks. Glover and Sinha (1973) estimate that 50 percent of the Carolina Slate Belt is volcanically derived sediments and 50 percent are the result of volcanic flows and pyroclastic activity. The volcanic rocks indicate a predominance of explosive volcanism. The Carolina Slate Belt volcanics are dominated by felsic rocks (80%). The Carolina Slate Belt rocks in Virginia are considered to be more mafic (Glover and Sinha, 1973). This association of rock types is probably due to island arc activity (Long, 1979). This interpretation fits with the prevailing ideas of the tectonic evolution of the Piedmont. These ideas are that collision of micro-continents (island arcs, continental fragments, and seamounts) preceded the final closure of the Iapetus Ocean in Paleozoic times (Sinha and Zietz, 1982; Farrar, 1985b).

Most geologic maps show the Carolina Slate Belt extending northward into southern Virginia. The contact between the Carolina Slate Belt and the Raleigh Belt is the Nutbush Creek mylonite zone. This mylonite zone is either a major strike-slip zone separating tectonic terranes or is the surface trace of a major décollement separating overthrusted units (Farrar, 1985b). Tectonic maps of the region indicate that the Carolina Slate Belt terminates in south-central Virginia northwest of the study area. Descriptions of the rocks of the Carolina Slate Belt are available in Long (1979) and Glover and Sinha (1973).

The Raleigh Belt is the key terrane in the region. Although its exact age is uncertain it is overlain by a volcanogenic sequence of probable Precambrian to late Paleozoic age. This suggests (though not conclusively) that the rocks of the Raleigh Belt are Precambrian. The dominant structural features of the Raleigh Belt are the Wake-Warren antiform, which divides the Raleigh Belt in half, and the numerous fault zones already mentioned (Figure 6).

The major rock types in the Raleigh Belt are gneisses and schists which form the core of the antiform. Of particular importance to this study is the Macon's Formation which is the probable major unit bounding the western pluton of Brunswick County, Virginia. The predominant rock type of this unit are muscovite-quartz-biotite-potassium feldspar-plagioclase gneiss.

The Raleigh Belt has what appears to be an unusually high concentration of plutonic bodies, with granites forming the majority of these bodies. Of the granites, most appear to fall into the "Alleghanian" grouping of Fullagar and Butler (1979). The higher concentration of granites supports the contention that the Raleigh Belt rocks are indeed older and of deeper origin. Granitic plutons would be expected to be concentrated in a deeper crustal unit (Pitcher, 1978).

Reconnaissance mapping of the study area indicates that the geology is similar to that mapped by Bobyarchick (1979). This shows that most of the unit mapped as granite on the eastern side of the Hollister shear (in Virginia) is in fact gneiss (Figure 5). However, two distinct gneisses are present. It appears that the "layered" gneiss of Bobyarchick is the northward extension of the Littleton gneiss. The composition of the gneisses is dominantly granitic. Calver (1963) and Grundy (1982) mapped the gneiss as granite. The lithologies and densities of the eastern gneisses and the granites are remarkably similar. Detailed discussions of both the Raleigh Belt and the Littleton gneiss may be found in Parker (1968), Farrar (1985a), and Stoddard et al (1987).

The final major tectonic terrane of significance to this study is the Roanoke Rapids complex of the Eastern Slate Belt. The rocks of this unit occur in the easternmost portion of the study area. Farrar (1985a) describes the Roanoke Rapids complex as one of the largest volcanic-plutonic associations in the Eastern Slate Belt. The rocks of the Roanoke Rapids complex can generally be described as metavolcanic rocks with interlayered volcanically derived metasedimentary rocks (Stoddard et al, 1987). The rocks of this unit have been metamorphosed to the lower greenschist facies. Metasandstones are the dominant metasedimentary rock in northeastern North Carolina. Field reconnaissance also shows this to be the case in Brunswick County. Detailed descriptions of the rocks of the Roanoke Rapids complex and the Eastern Slate Belt are found in Stoddard et al (1987), Farrar (1985a), and Parker (1968).

Many workers have remarked at the similarities between the rocks of the Eastern Slate Belt and the Carolina Slate Belt. It is generally assumed that the two terranes were formed in the same manner. Whether they are of the same origin is a question for speculation.

Prevalent throughout the region is a combination of Coastal Plain sediments, terrace deposits, and river alluvium. The Coastal Plain sediments represent the thin western edge of Cenozoic age marine deposits. Terrace deposits are Pleistocene in age and ubiquitous throughout the region. River alluvium is recent and is generally restricted to the Meherrin river and its tributaries.

TECTONICS

The eastern Piedmont fault system is the key to the tectonics of the region. To understand the tectonics of the area it is important to determine how the fault system interacts with the major terranes. In the Piedmont of southeastern Virginia and northeastern North Carolina, the major terranes are the Carolina Slate Belt, Eastern Carolina Slate Belt, the Raleigh Belt, and the various plutonic bodies that intrude these blocks (Figure 1).

The eastern Piedmont fault system of Hatcher et al (1977) is a series of observed faults and interpreted extensions in the southern Piedmont from Georgia to Virginia (Figure 2). They postulated that this system of faults comprised a series of wrench faults that confined escaping blocks. Movement of these blocks resulted from collisional tectonics due to an impinging block. The movement is similar to the model of Tapponier and Molnar (1976). Many of their extensions were based on speculation or on aeromagnetic lineaments.

Two lines of thought have developed concerning the faults present in southeastern Virginia and northeastern

North Carolina. If it is accepted that the Eastern Carolina Slate Belt is correlative with the Carolina Slate Belt, then the presence of the Raleigh Belt poses a problem. A model must explain why an older, more highly metamorphosed unit is surrounded by younger rocks of markedly different origin. Two of the concepts with the widest acceptance will be discussed. The implications of these models towards the Eastern Piedmont fault system and the geology of southern Brunswick County will also be discussed.

The major structural features of this region are the bounding(?) mylonitic shear zones (Nutbush Creek, Macon, and Hollister; Figure 6). Hatcher et al (1977) extends the Nutbush Creek shear zone up to 100 kilometers into Virginia. If the Hollister shear zone is an extension of the Augusta fault (southeastern Georgia), then the area of this study becomes vital to any connection of the Augusta fault with the Hylas Fault zone to the north (Bobyarchick, 1981) via the Hollister zone (Figure 2).

Farrar (1984) proposed that the Raleigh Belt represented a southward extension of the Goochland terrane of Bobyarchick and Glover (1978). Such a continuation would make the Goochland terrane one of the largest segments of Grenville age (1.1 ga) rocks in the eastern Piedmont. Acceptance of this concept raises further questions. Does this terrane represent true North American continental basement, or is it merely an accreted fragment? The presence of Slate Belt rocks (of presumably younger age) surrounding the Raleigh Belt provide some constraints.

If the Raleigh Belt is an extension of the Grenville Goochland terrane, the question needs to be answered "Why are older rocks of the Raleigh Belt surrounded by the younger rocks of the Slate Belt?". Farrar (1985b) proposes that the younger Carolina Slate Belt rocks were thrust over the Raleigh Belt. This implies that the rocks of the Raleigh Belt are true continental basement and not a continental fragment. However, it is possible that they represent an allocthonous unit thrust over a lower décollement. Given the assumed westward direction of tectonic transport of allocthonous blocks, the necessity that there is continental basement to the east of the present position of the Raleigh Belt becomes important.

It is not clear from Farrar's work (1985b) if his décollement is indeed the same feature as shown by Cook et al, (1979). The décollement from COCORP data is meant to be a regional feature upon which all Piedmont terranes have been thrust. Farrar's décollement may represent a more local thrust surface. It is unlikely that his surface is correlative with the COCORP décollement.

Conversely, Bobyarchick (1981) proposed that thrusting was of minor importance and that strike slip motions along the major faults were the result of collisional tectonics.

He proposes a model with motions similar to those in the Anatolian region of Turkey.

In this model it is envisioned that the various tectonic terranes were being "squeezed" south along the eastern Piedmont fault system in response to collision to the north. The probable cause of this motion is assumed to be the initial collision between Africa and North America. The terranes "escaped" south due to a lack of confining blocks in that direction.

The contradictions between these two ideas are obvious. Farrar's model calls for shallower dipping fault zones that splayed off a décollement between the Raleigh Belt and the Slate Belt. It is implied that the major boundary faults of the Raleigh Belt (Nutbush Creek and Hollister) must at least become listric at depth. Bobyarchick's model calls for steeply dipping wrench faults along which tectonic blocks moved transverse to one another. By implication, the faults in this case must be major crustal breaks which are deep seated.

Recent seismic and magnetic data have been interpreted to suggest that the root zone for the major Appalachian décollement is to the west beneath the Inner Piedmont province (Hatcher and Zietz, 1980; Iverson and Smithson, 1982, 1983; Nelson, et al, 1985). Conversely, several major studies using COCORP data have extended the décollement as far east as the Atlantic Coastal Plain (Harris and Bayer, 1979; Cook et al, 1979; Cook, et al 1981). This is the key factor in determining which hypothesis is valid. If the décollement is rooted beneath the Inner Piedmont then it is unlikely that the Raleigh Belt is basement. If the décollement extends beneath this study then it is unlikely that the faults are deep crustal faults.

By comparing the two models with that developed for the shear zone in this study, it will be shown which model is appropriate for this portion of Virginia.

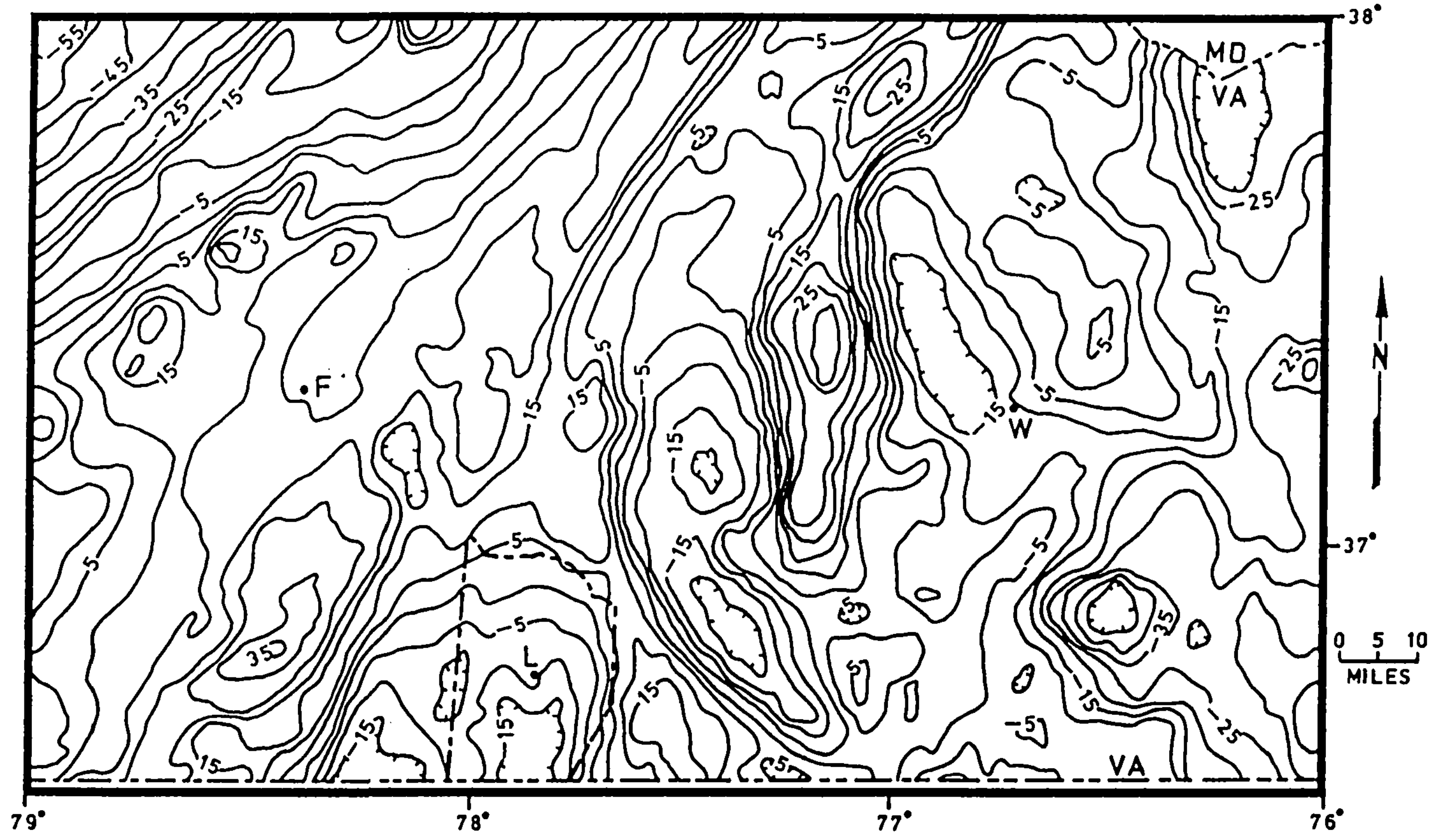
REGIONAL GEOPHYSICS

For a discussion of the regional aspects of the geophysical setting of Brunswick County, Virginia, attention will be turned to the relationship between the county and the major gravity and magnetic trends in the state. The importance of the correlation of major geophysical trends and established geology will be shown as well as the interrelationship between regional and local trends.

Examination of the regional gravity and magnetic fields (compare Figures 7 and 8) shows a general correlation between magnetic and gravity highs. Figure 7 is the Bouguer gravity map of the southeastern portion of Virginia modified from Johnson (1977). It includes gravity data between 79° West and 76° West longitude, and the Virginia - North Carolina border and 38° North latitude. Brunswick County is outlined to show the relationship between data attained in this study and the regional gravity. Figure 8 is the aeromagnetic field for the same portion of Virginia (Zietz et al, 1977).

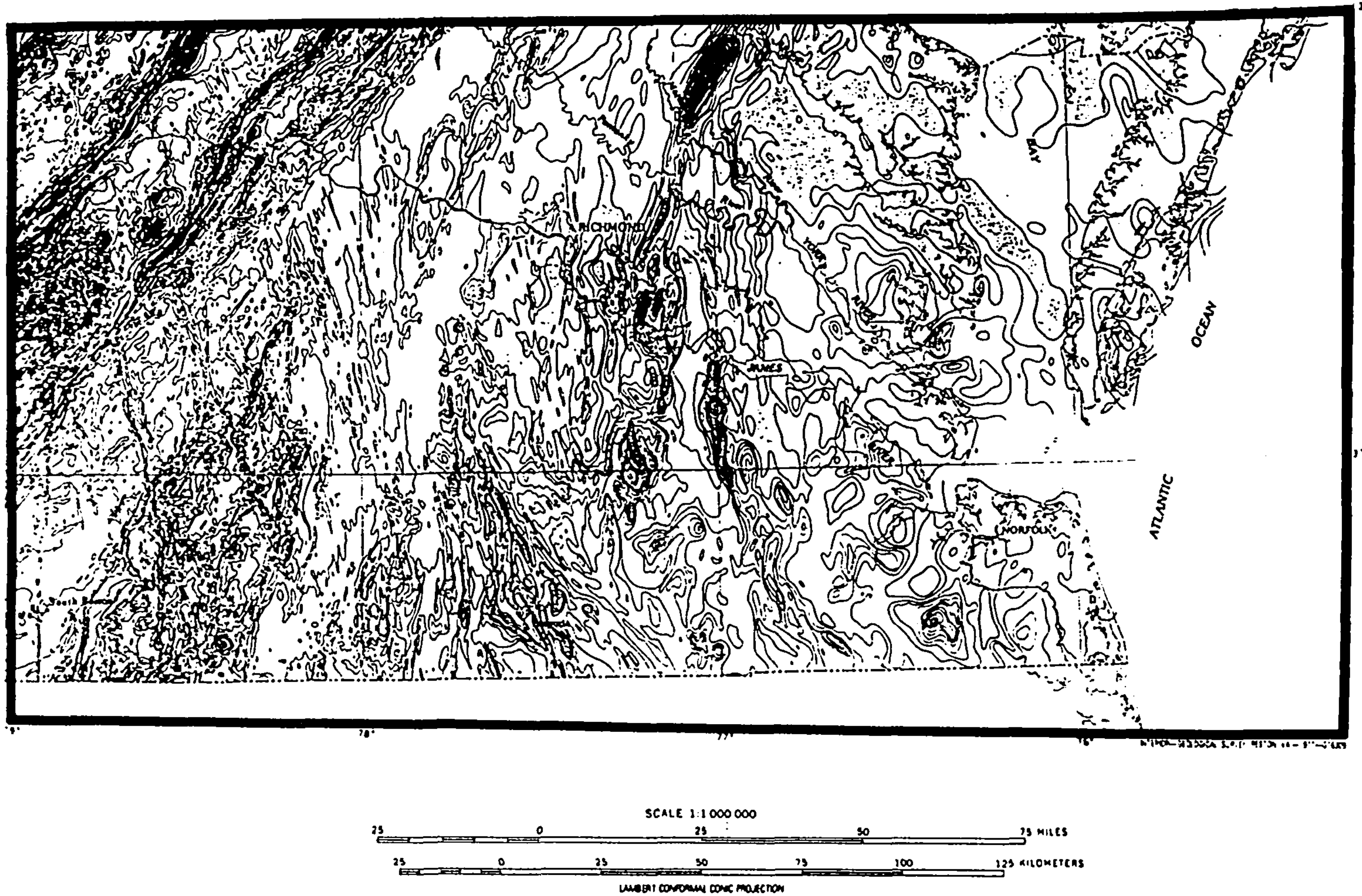
The anomalous patterns on the Bouguer gravity map are much smoother and broader than the magnetic anomalies for

Figure 7. Bouguer Gravity Map of southeastern Virginia; F=Farmville, L=Lawrenceville, W=Williamsburg (from Johnson, 1977).



Contour Interval : 5 milligals

Figure 8. Aeromagnetic Map of southeastern Virginia. (From Zietz et al, 1977).



Contour Interval : 100 gammas

the same region. This is generally true of most areas (Telford et al, 1976) regardless of geology. East to west the gravity field across the region can be described as a series of alternating broad wavelength low and high Bouguer gravity zones. Gravity anomalies are large scale (on the order of 30 to 50 kms wide), and linear (up to 75 kms long). Conversely, the aeromagnetic pattern is much more erratic. No clear east to west trend is apparent. However, the aeromagnetic values east of 77° West longitude are less erratic. Aeromagnetic anomalies are characterized by short wavelength, high amplitude patterns. No clear zonation of the anomalies exists, although anomalies tend to align themselves linearly.

GRAVITY

Regionally, the gravity pattern shows clear zonation of anomalies throughout the region. Anomalous patterns are the result of regional crustal changes. Therefore, observation of regional Bouguer gravity anomalies is an excellent means of defining the extent of major tectonic units in southeastern Virginia.

West to east the Bouguer gravity field is characterized by several major anomalies. In the northwest corner of Figure 7, a gravity gradient exists between 79° and 78°

west, and 37° 30" and 38° north. Values change sharply from a minimum of -40 to 10 milligals over a distance of 40 kms. Thomas (1983) has associated this gravity gradient with a cryptic continental suture. This probably represents the suture zone between the pre-Taconic continental margin and outlying allocthonous terranes.

Just southeast of the gravity gradient is a zone of relatively smooth gravity contours. The zone appears centered in the Farmville area (Figure 7). This zone runs northwest - southeast for approximately 75 kms. Gravity values are consistent between 10 and 20 milligals. This zone most likely correlates with the northward extension of the Carolina Slate Belt into Virginia. The relatively uniform pattern is consistent with the idea that the Carolina Slate Belt represents a complete terrane with an island arc origin (Glover et al, 1983). The presence of a Triassic age sedimentary basin near Richmond probably enhances the smooth nature of the Bouguer gravity in this area.

Along the Virginia - North Carolina border near 78° west longitude is a "semicircular" pattern of negative gravity anomalies. The zone is approximately 45 kms wide and extends northward from the state border 45 kms. The zone represents a -20 milligal anomaly. This area coincides quite well with the northward extension of the Raleigh Belt into Virginia. The negative character of this zone is due either to the dominant granitic composition of the Raleigh Belt (Farrar, 1984; Parker, 1968; Stoddard et al, 1987), or it possibly represents an area of thinned crust, or a combination of both. Northeast of Brunswick County, the low is a larger, arcuate pattern of negative gravity. The zone arcs northward from the Virginia - North Carolina border to Richmond, Virginia. It is a 30 to 40 kms wide zone. Gravity values reach a minimum of less than 20 milligals. The zone correlates well with the the "Petersburg granite" near Richmond. The values are in the range expected for a granitic batholith of this size and dimension. The southward extension of the negative pattern also correlates well with the proposed southward extension of the Petersburg granite (Bobyarchick, 1979, Calver, 1963). Separating the two negative zones mentioned above is a smaller zone located near 77° 30" and the Virginia - North Carolina border. The gravity pattern is nearly circular in shape and has a positive signature. Gravity values reach a maximum of greater than 15 milligals in this area. The positive gravity signature and the location of the zone are coincidental with the northward extension into Virginia of the metasedimentary and metavolcanic rocks of the Roanoke Rapids complex. This complex is a part of the Eastern Slate Belt (Stoddard et al, 1987; Williams, 1978) which is believed to have an origin similar to the Carolina Slate

Belt.

East of the negative anomaly associated with the Petersburg granite is a north - south trending gravity high. Located approximately along 77° north longitude and between 37° and 38° north latitude, the zone is roughly 15 to 25 kms wide. This is the central gravity high of Virginia (Davidson, 1985). The high has been previously associated with high density intrusives (Johnson, 1975). The central gravity high seems to separate the alternating high and low patterns to the west from more subdued gravity patterns to the east. This suggests, but does not prove, a major crustal break occurs in this area.

East of 77° west longitude is an area of "flat" gravity. Values are consistently in the range of 0 to -20 milligals. Possible explanations for this region are a crust of uniform density, the gravity field is suppressed due to the overlying Coastal Plain sediments, or the pattern is the result of a series of Triassic age sedimentary basins. Without drillhole data, interpretation of the map is tenuous. An exception to the flat pattern occurs in the southeastern portion of the state. Near 76° 30" west and 37° north is a deep, negative gravity anomaly distinct from the surrounding field. The anomaly is circular and attains a minimum of -45 milligals. The gravity signature is a classic indicator of a buried granitic pluton. Russell et al (1985) reached this same conclusion with drill data and the geophysical signature.

AEROMAGNETICS

Figure 8 is a portion of the Aeromagnetic Map of Virginia (Zietz et al, 1977). The area displayed is bounded on the west by 79° west longitude, on the east by 76° west longitude, on the north by 38° north latitude, and on the south by the Virginia - North Carolina border.

Unlike the gravity map of the same portion of Virginia, correlations of magnetic patterns with major tectonic units is uncertain. The aeromagnetic patterns give indications of changes in regional foliations. The only significant change in magnetic character occurs east of 77° west longitude. To the west, magnetic contours indicate a field that is highly erratic and variable. However, to the east the magnetic contours are much smoother with broader anomalies. In all probability the onlap of non-magnetic Coastal Plain sediments is suppressing the "normal" signature that occurs over the crystalline rocks of the piedmont.

Several magnetic trends are significant. Two parallel, northeast - southwest trending magnetic highs occur in the northwest corner of the map. Both trends appear to be related to the Blue Ridge province. However, the possibility that the trends are the result of the same geologic feature that causes the gravity gradient can not be ruled out.

Although magnetic values are not specific to tectonic units (i.e. the range of magnetic anomalies associated with the Raleigh Belt in Virginia are similar to those associated with the Eastern Slate Belt), there does appear to be a change in the trend of individual magnetic anomalies and the trend of foliations within the tectonic units. An excellent example of this phenomena is found by the comparison of magnetic patterns associated with the Raleigh Belt and the Carolina Slate Belt. In the Raleigh Belt (centered on 78° W), the magnetic patterns trend north-south and are linear. Juxtaposed against this is the pattern associated with the Carolina Slate Belt (centered on 78° 30' W). In this case the magnetic pattern trends northeast southwest, is less linear (i.e. circular), and of shorter amplitude.

A correlation appears to exist between the arcuate series of magnetic highs located near Richmond and the central gravity high. Similar to the central gravity high, the magnetic highs extend across the area and terminate where the gravity high also terminates.

Several linear magnetic highs trend in the area near 78° 30" west and 37° north. They correlate with major diabase dikes which cut across southern Virginia.

METHODS OF STUDY

A wide variety of techniques were utilized over the course of this study. Field research included 30 days surveying data points, taking gravity and radiometric readings, as well as conducting a reconaissance geology survey. Office techniques included digitizing aeromagnetic and regional gravity data, computer modelling of gravity and magnetic data, and analysis of local gravity and aeromagnetic fields. The research began in the fall of 1987 with an initial reconnaissance survey of the area. This occurred over several days in the fall of 1987. Southern Brunswick County was observed for suitable survey roads, the presence of benchmarks, and lithologic contacts.

STATION ELEVATION

Of primary concern to gravity investigations is the elevation and location of each data point. In an area such as the Piedmont where the terrain is subdued, the elevation and latitude corrections are most important to gravity work. Most descriptions of proper field technique call for precision of 5.0 cms for elevation and location within 10 m (Telford et al, 1976).

Three wire line surveying was the method utilized in this study for station accuracy. This is a standard surveying technique used by the Army Corps of Engineers among others. Station elevations were recorded using the TOPCON model AT-F3 transit and level. Foreshots and backshots were recorded at each station to enhance accuracy. A station spacing of 118 m (400 ft) was chosen (for geologic as well as logistic reasons). Both north and south geophysical lines (N-1 and S-1, see Figure 4) had USGS benchmarks for control.

Exact elevations for gravity reductions were determined using program STATION.FORTRAN provided by Charles James (M.S. Thesis in prep.). Longitude and latitude were determined by digitizing USGS topographic maps on which field stations were located. The data was digitized with a model 2400 Numonics Digitizer. The program used for digitizing, DIGIT.BASIC, was provide by William Decker.

GRAVITY

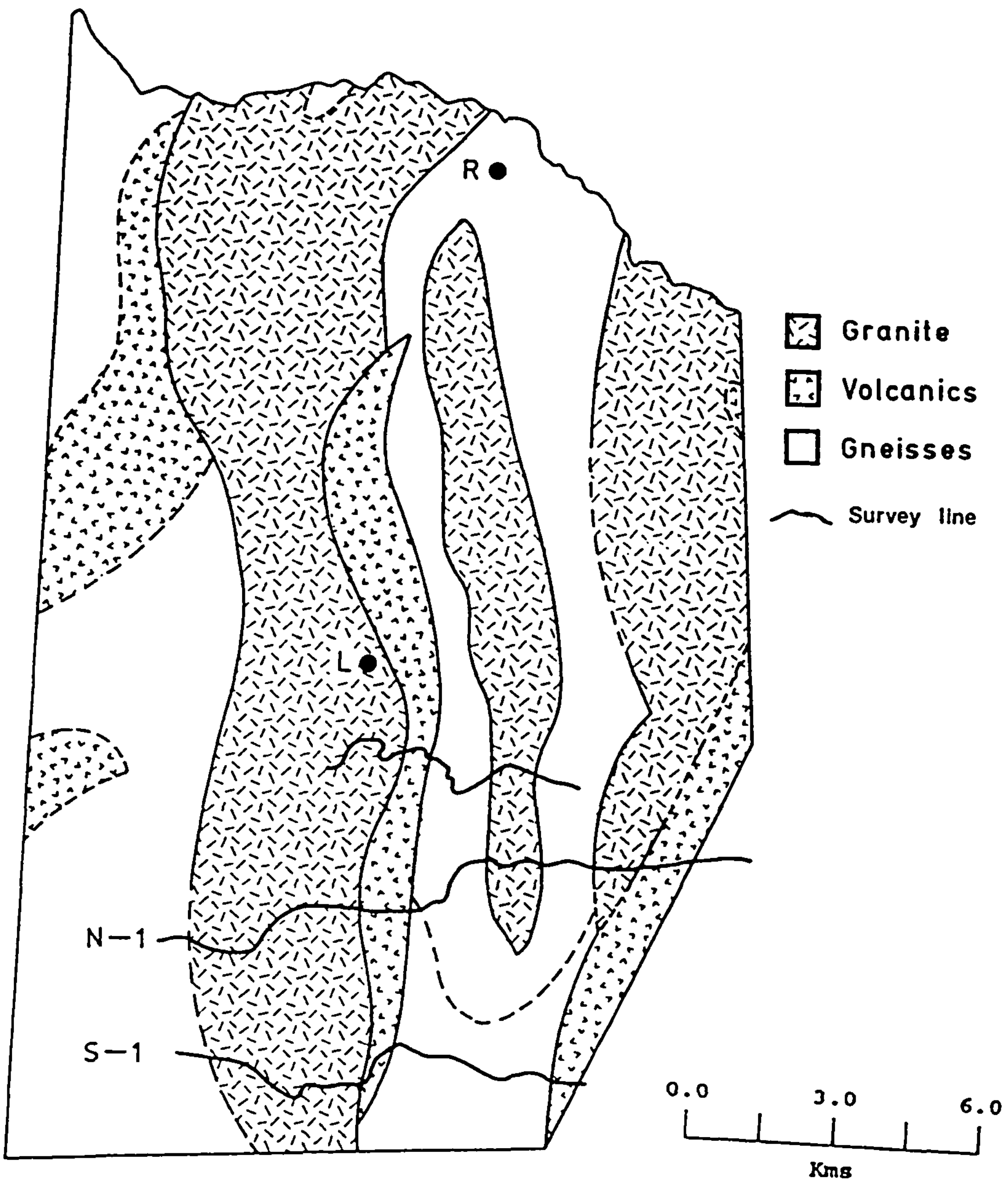
The gravity survey is the most important facet of this study. The use of gravity for modeling the subsurface geometry of granitic batholiths is well documented (Bott and Smithson, 1967). The gravity field of southern Brunswick County was analyzed by several techniques. They are 1) analysis of regional trends, 2) ground based gravity profiling and associated modeling, and 3) gravity contouring and associated analytical techniques.

Many large scale regional features can be determined from the Bouguer Gravity Map of Virginia (Johnson, 1977). Johnson (1975) determined several trends from the portion of this map centered on southeastern Virginia without making inferences about geological correlations. The field between 78° West longitude and the coastline, and the Virginia - North Carolina border and 38° North latitude was analyzed for trends (Figure 7). The Bouguer gravity field for this portion of Virginia was digitized on the Numonics 2400 digitizer. The digitized data was uploaded to an IBM 3090 mainframe computer. The gravity field was analyzed using a modification of Agarwal's (1968) upward and downward continuation program called UPDW1.FORTRAN. The resulting fields were then compared with known surface geology of the region.

Subsurface modelling was conducted of the geology and gravity data that was collected along two cross-strike survey lines. Both lines (N-1 and S-1) are plotted on a geologic map (Figure 9; from Bobyarchick, 1979). The lines totaled approximately 45 kms. Readings were taken at 118 m (400 ft.) intervals. The station interval was chosen to enhance the resolution of modelling the fault zone. Line lengths were chosen to maximize depth of penetration of the models. Gravity values were recorded using a LaCoste-Romberg Model G gravimeter. Daily drift corrections were determined by re-occupying selected stations every few hours. Calibration and tidal variations were determined by occupying the base station at the Emporia Courthouse every morning and evening during the survey. The value for the Emporia base station was established as part of a state base network (Johnson and Ziegler, 1977). The base station is located at 36° 41' 04" W and 77° 32' 12" N, is at an elevation of 35.036 meters (118.773 feet), and has a true gravity value of 979.9004 cm/s^2 (Bouguer value of 17.746 milligals). Gravity reductions were determined using a modified version of Snowden's (1970) program GRAVAS.FORTRAN. Due to the nature of the topography in this portion of the Piedmont (variations in the range of 30 to 60 m), a terrain correction is not necessary. Bouguer gravity values were modelled using program GRAVMOD.FORTRAN modified by Nowroozi

Figure 9. Superposition of survey lines and geology; R=Rawlings, L=Lawrenceville (Bobyarchick, 1979).

BRUNSWICK COUNTY, VIRGINIA



from Parasnis (1973). Estimates of unit densities were determined either by laboratory methods or by literature research (Table 1).

A Bouguer gravity map of the southern third of Brunswick County was prepared for analysis. Additional gravity data was available and used from another study in this region (line Pn; Figure 4 for location; Waller, M.S. Thesis in prep.). Regional data was also available from Johnson (1975). All values were plotted on a base map, contoured, digitized, recountoured mechanically (for comparison with hand contouring and for computer analysis), and analyzed using UPDW1.FORTRAN. This was done for two reasons. One, to extrapolate the two - dimensional, across strike models discussed above into the third dimension. And two, to get a feel for any possible trends that might be missed by a study of the regional field.

RADIOMETRICS

The radiometric method was included primarily as an aid in field reconnaissance mapping of the area. Radiometric and aeroradiometric studies are valuable techniques in geologic studies (Cassidy, 1981; Johnson, 1979). Unfortunately, no aeroradiometric data is available for any portion of Brunswick County.

TABLE I

DENSITIES

UNIT	DENSITY
Layered Gneiss	2.65
Western Granite	2.62
Mylonite	2.72
Eastern Gneiss	2.64
Metavolcanics	2.71
Basement (unknown)	2.60

Densities compiled from Telford et al (1976), Reilly (1980), and Keller, Robinson, and Glover (1985).

Radiometric readings were taken at each gravity station. This was done to enhance the comparison of techniques. The total count field readings were made using a gamma-ray spectrometer. The instrument is capable of reading total count gamma radiation and can differentiate between potassium, uranium, and thorium radiation. A more complete description of the theory behind the gamma-ray spectrometer is found in Telford et al, (1976).

The composition of road asphalt in southern Brunswick County is an unknown factor influencing gamma radiation readings. For this reason, radioactivity readings were observed offset from the gravity stations. In general, readings were taken 10 m perpendicular to the edge of the road surface yet close to the gravity stations.

Initial field work with the spectrometer suggested that measurements of uranium and thorium would be of little use to this study since the radiation levels from these elements were low in Brunswick, County. Also, variations in the readings appeared to be insignificant. This was true at counting intervals of 1.0 seconds, 10 seconds, 100 seconds, and 1000 seconds. Both the total count and potassium readings showed significant results. Not only were readings high enough to be significant, but variations across the area were also important. It was determined that counting at 100 seconds would expedite the survey without significantly decreasing the accuracy.

MAGNETICS

The magnetic method was the least productive of the geophysical methods used in this study. The instrument used was an OMNI IV proton procesion magnetometer. A detailed description of the theory and function of the proton procesion magnetometer is described in Telford et al (1976 p. 133).

The magnetic survey was made by taking readings that were offset from the road. The possibility exists that magnetic minerals are in the road aggregates. In general, readings were taken 10 m perpendicular to the gravity station as in the radioactivity survey.

High tension powerlines and automobiles both strongly influence local magnetic fields. It was planned that carefully placed stations could negate these effects. It is not known to what degree the presence of buried power and utility lines nearby affected the survey.

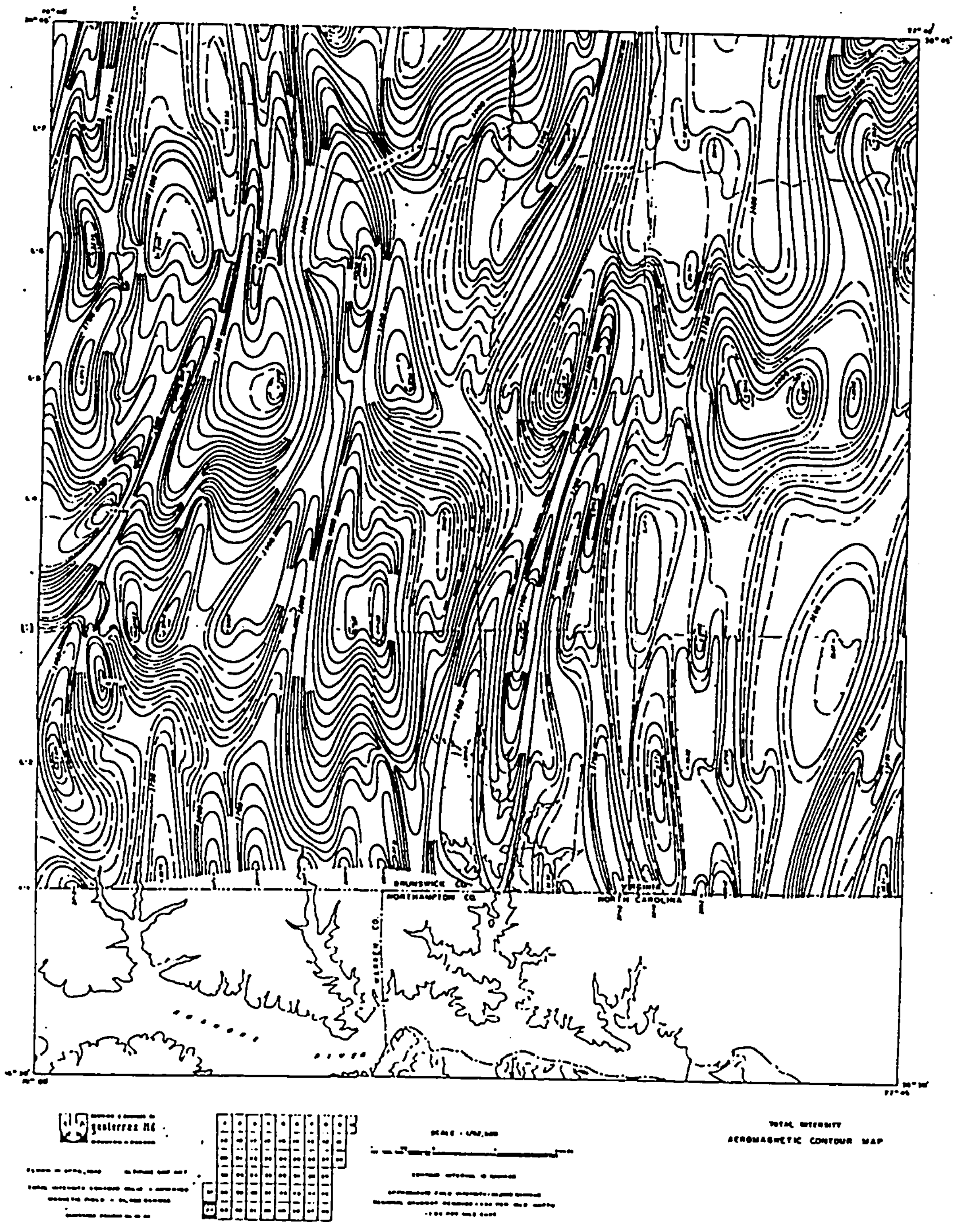
Observation of the total magnetic field at a typical station shows that field variations are great. These variations cannot be explained by observed or presumed geologic influences. It is for this reason that the ground magnetic data was not included as a primary investigative tool. The data was useful in the detection of highly magnetic diabase dikes which are prevalent throughout the area (Stoddard et al, 1987).

AEROMAGNETIC

Available aeromagnetic data was utilized to aid in interpretation because of the near surface influences and inconsistent ground magnetic readings. Both the Aeromagnetic Map of Virginia (Zietz et al, 1977) and the White Plains 15 minute aeromagnetic map (Virginia Division of Mineral Resources, 1975) were included for analysis. The aeromagnetic data was initially to be included only for analysis of regional trends and for creation of east-west profiles to be used for subsurface modelling. Because of the utility of the program UPDW1.FORTRAN in analyzing the gravity fields, similar analysis was performed on the White Plains 15-minute aeromagnetic map (Figure 10). Only the western two-thirds of this map covers the project area.

Most interpretation routines used to study upward and downward continuation, and second derivative analysis are written to analyze only the vertical component of the potential field (hence the suitability of these routines for gravity analysis). Most aeromagnetic maps show total

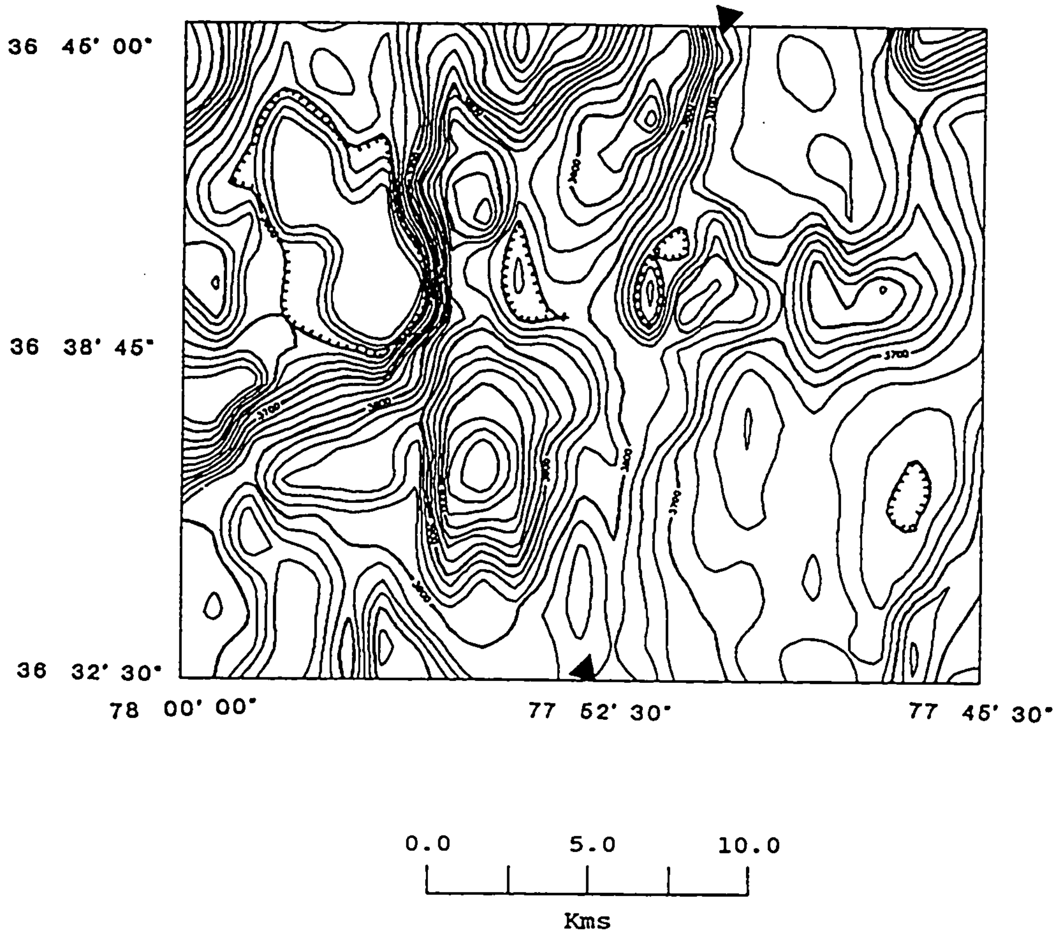
Figure 10. White Plains 15-minute aeromagnetic map.


BRUNSWICK CO.
NORTHAMPTON CO.
VIRGINIA
NORTH CAROLINA
TOTAL INTENSITY
AEROMAGNETIC CONTOUR MAP

field intensity. An assumption was made for the analysis that the total intensity field approximately equals its vertical component. Thus, the assumption is that the horizontal component of the total intenstiy field is negligible. Vacquier et al (1951) made this assumption in a landmark publication of aeromagnetic interpretation. Steenland (1962) also made the same assumption in his analysis of the Paradox basin.

As with the gravity data, digitization had to precede the analysis of the aeromagnetic field. Comparison of the published aeromagnetic data and the digitized version included (Figure 11) show that computerized plotting of the data remains true to form. Analysis and plotting of the end product utilized the IBM 3090 mainframe and published SAS GRAPHICS software available through Old Dominion University Computing Services.

Figure 11. Digitized version of the White Plains 15-minute aeromagnetic map; arrows denote trend of shear zone.


36 45' 00"
36 38' 45"
36 32' 30"
78 00' 00"
77 52' 30"
77 45' 30"
0.0
5.0
10.0
Kms

RESULTS AND INTERPRETATION

AEROMAGNETICS

Comparison of Figure 10 and Figure 11 shows that computer contouring accurately duplicated the original data. The original data (Figure 10) is contoured at 100 gamma intervals. The values range from a low of 3400 gammas to a high of 4100 gammas. A regional magnetic field of 51,400 gammas was removed from the data. The survey lines were flown at 150 m (500 feet) above terrain with a line spacing of 3 kms (2 miles).

Three distinct magnetic zones are observed on the White Plains aeromagnetic map. The zones are separated into a western third, a central third, and an eastern third. The central and eastern thirds are separated by a narrow, en-echelon magnetic pattern. The western third is characterized by an area of low magnetic signatures (3400 to 3600 gammas) when compared to the rest of the map. The central third has a relatively high magnetic signature (3800 to 4100 gammas). The eastern third is characterized by intermediate values and a much smoother pattern (3600 to 3800 gammas). The zone separating the central and eastern thirds is an en-echelon sequence of sharp magnetic anomalies trending roughly N10°E.

Several subtle correlations exist between the patterns mentioned above and the general geology of Bobyarchick (1979; Figure 5). Field reconnaissance as well as a detailed study in the northern portion of this study (Waller, M.S. Thesis in prep.) indicates that Bobyarchick's map closely approximates the geology of southern Brunswick County.

The high magnetic central zone correlates well with the western granite of this study. Granitic plutons are not normally associated with magnetic highs (Telford et al, 1976). A possible explanation for the high magnetic signature of this granite is that it is surrounded by metamorphosed rocks which have been depleted of magnetic minerals. Field reconnaissance indicates that several diabase dikes occur within the boundary of the western granite. Diabase is often associated with high magnetic anomalies.

The eastern magnetic zone correlates with the gneisses. The smooth pattern and intermediate values are characteristic of an area which has undergone extensive metamorphism. The gneisses present in this area (granitic and layered gneisses; Figure 5) have undergone metamorphism. The western magnetic zone has the lowest magnetic values of the study area. This zone correlates with the northward continuation of the Raleigh Belt gneisses. These rocks are metamorphosed to at least amphibolite grade (Stoddard et al, 1987) and possibly granulite grade (Farrar, 1984).

The most significant feature on the White Plains aeromagnetic map is the zone of N10°E trending, slightly en-echelon magnetic anomalies (Figure 11). The zone is characterized by associated high and low magnetic anomalies (3600 to 4100 gammas) concentrated along a belt 1.0 to 1.5 km wide. The trend and location of the N10°E zone correlates with the previously unmapped mylonitic shear zone (Waller and Corbin, 1988; Waller, M.S. Thesis in prep.).

ANALYSES

Digitizing aeromagnetic data allows for an analyses by several means. The program TREND.FORTRAN (modified from Davis, 1973) was utilized to separate the regional and residual portions of the magnetic field. Program UPDW1.FORTRAN was utilized for second derivative analysis as well as upward and downward continuation of the magnetic field.

Separation of the regional and residual portions of the magnetic field is vital to differentiating between the anomalies resulting from local geology and, those that result from deep crustal changes. Figure 12 shows the regional trend that was removed from the White Plains map. A second order polynomial surface was fitted to the aeromagnetic data. A correlation of 0.45 occurs between the regional surface and the actual data. This is well within acceptable limits for this type of analysis (Davis, 1973). Figure 13 shows the residual magnetic field that results from program TREND.FORTRAN. Comparison with Figure 11 indicates that most of the magnetic anomalies are the result of near surface geology and not major crustal changes.

The aeromagnetic field for the White Plains map was continued upward for additional analysis of regional trend. Upward continuation tends to eliminate the smaller anomalies due to local, or near surface geology. The field was continued upward to 5 kms using the program UPDW1.FORTRAN. Figure 14 shows how the aeromagnetic field would appear at 5 kms. At this height it appears that the magnetic character of the area has been smoothed but the effect of the western granite is significant. Comparison with Figure 12 shows that the regional trend is smooth.

A second derivative analysis was performed on the aeromagnetic field. Second derivative analysis enhances the near surface effects of a potential field at the expense of

Figure 12. Regional aeromagnetics, White Plains map.

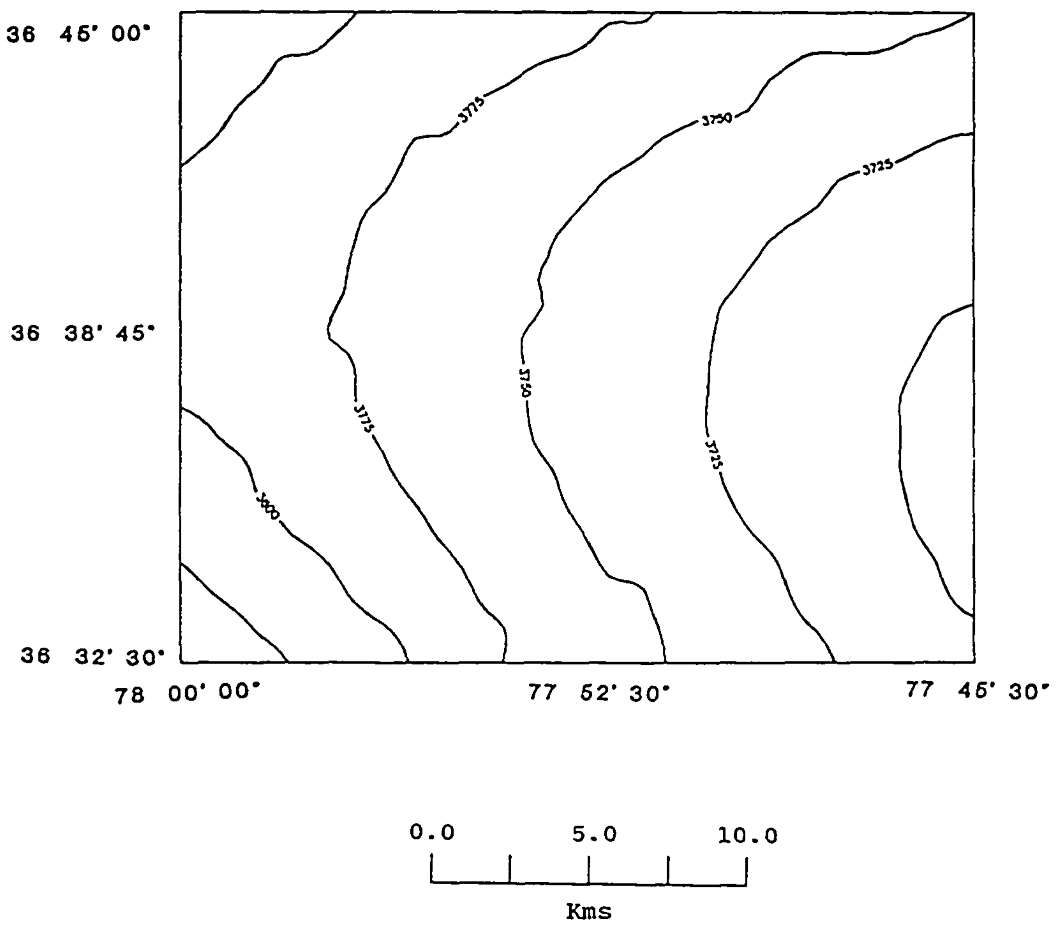

36 45' 00"
36 38' 45"
36 32' 30"
78 00' 00"
77 52' 30"
77 45' 30"
3775
3750
3725
3800
0.0
5.0
10.0
Kms

Figure 13. Residual aeromagnetics, White Plains map; arrows denote trend of shear zone.

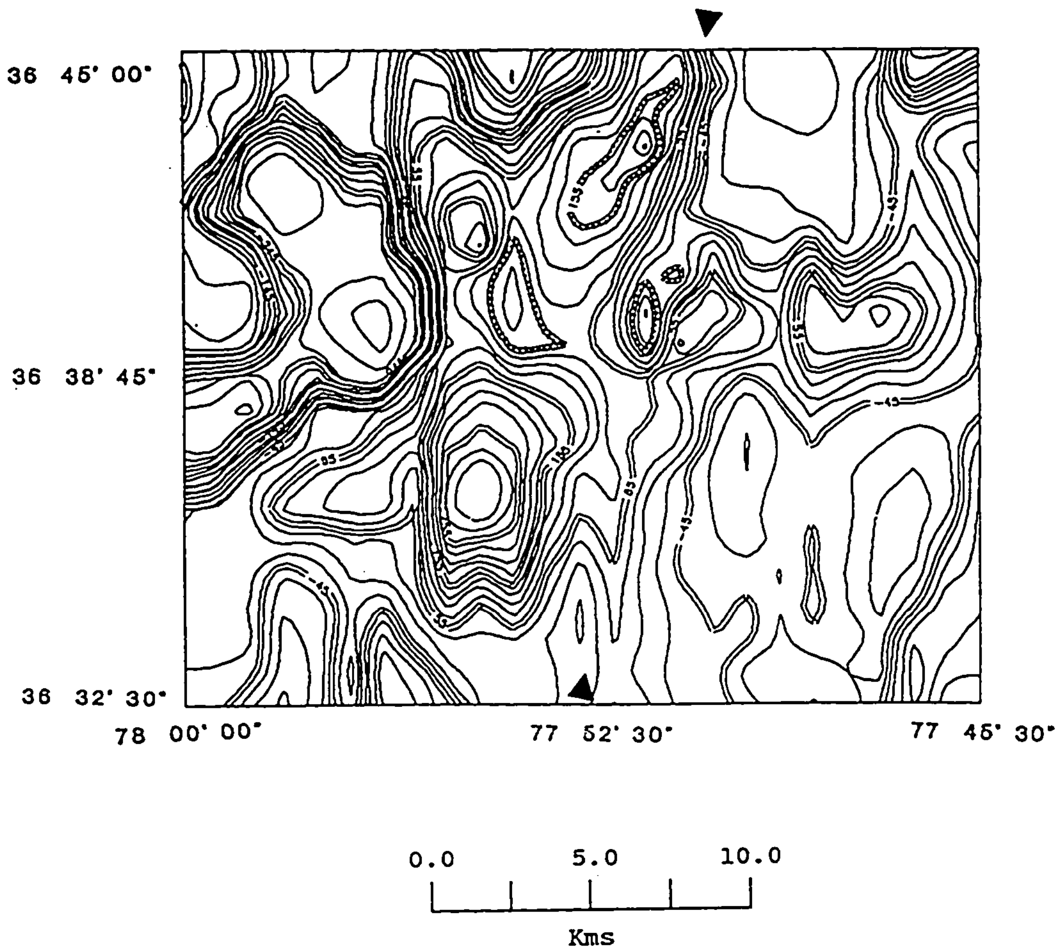
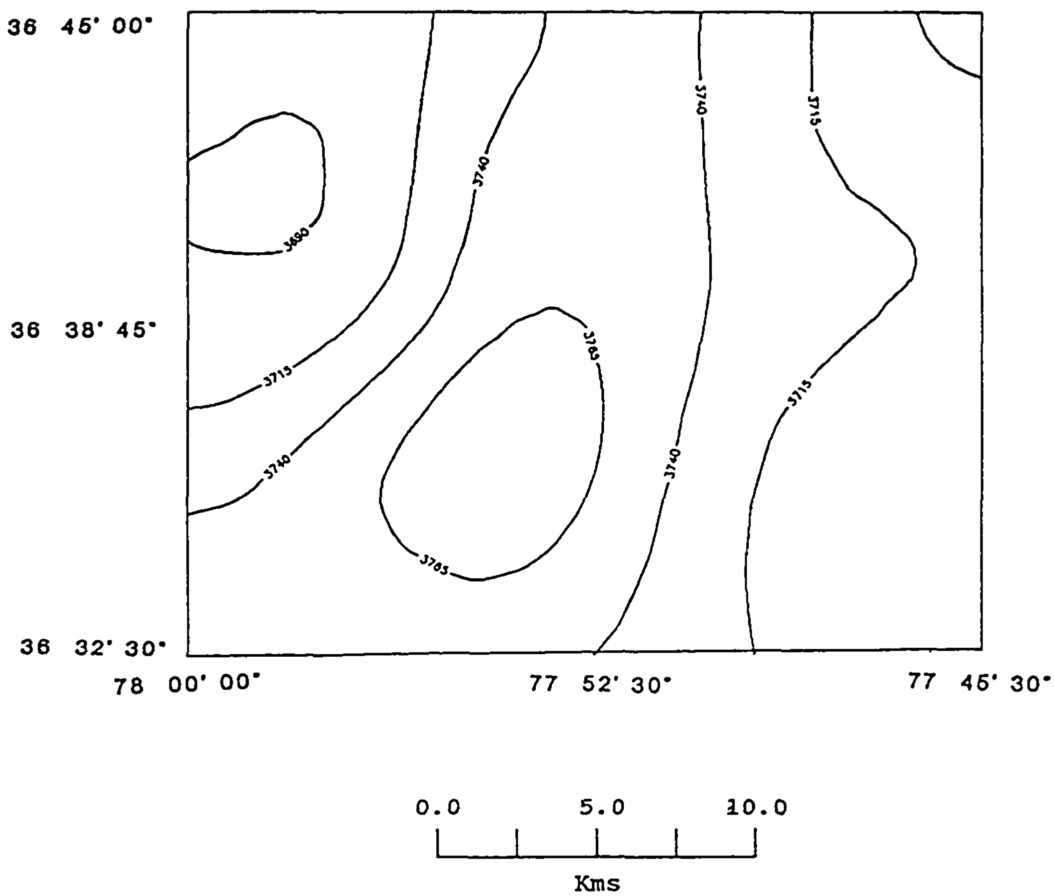

36 45' 00"
36 38' 45"
36 32' 30"
78 00' 00"
77 52' 30"
77 45' 30"
0.0
5.0
10.0
Kms

Figure 14. Aeromagnetic field continued upward to 5.0 kms.


36 45' 00"
36 38' 45"
36 32' 30"
78 00' 00"
77 52' 30"
77 45' 30"
3690
3715
3740
3765
0.0
5.0
10.0
Kms

the deeper crust. Figure 15 shows the second derivative field for the White Plains aeromagnetic map after analysis by program UPDW1.FORTRAN.

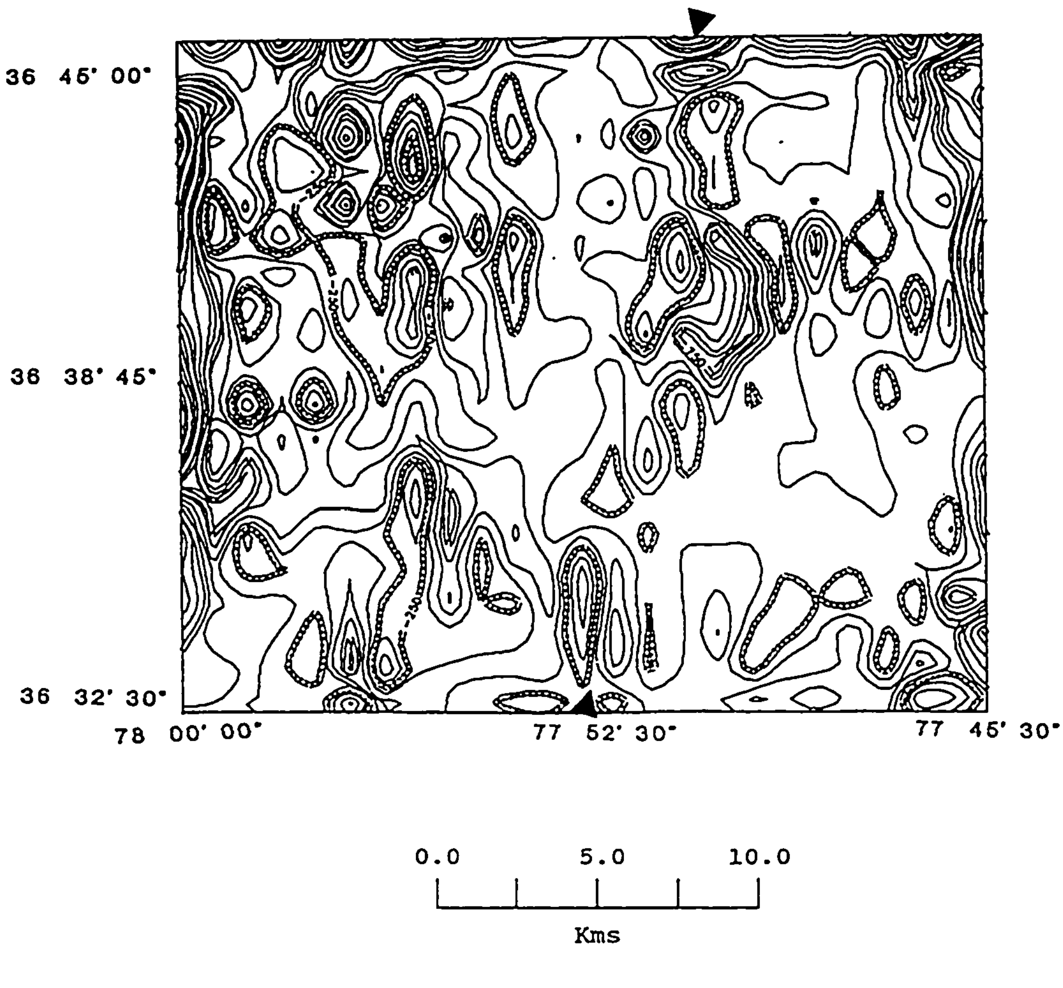
It is important to observe the pattern of the anomalies and not field values when observing Figure 15. The analysis of the aeromagnetic field is meant to be qualitative.

The analysis eliminated the zonation that is present in the total magnetic field (Figure 10). Most of the map is now characterized by a near zero, relatively flat pattern. This suggests that most of the geology causing the anomalies probably extends to mid crustal depths. The magnetic signature of most of the geology does not result from the near surface.

One notable exception to the smooth pattern exists. In the central portion as shown in Figure 15 the smooth pattern is broken by a series of high and low anomalies. The pattern extends across the map in a somewhat en-echelon, N10° E trend. An excellent correlation exists between the anomalous zone and the mylonitic zone.

Several speculations can be made about the mylonitic zone based on its aeromagnetic signature. Based on the magnetic trend, the zone appears to extend completely across the map area. Previous field workers had terminated the extent of the metavolcanic unit (now known to be mylonitic) north of Lake Gaston and the Virginia - North Carolina

Figure 15. Second derivative, White Plains map; arrows denote trend of shear zone.


36 45' 00"
36 38' 45"
36 32' 30"
78 00' 00"
77 52' 30"
77 45' 30"
0.0
5.0
10.0
Kms

border. However, the aeromagnetic signature suggests that the unit could be extended at least to the Virginia - North Carolina border (represented on aeromagnetics by the southern boundary). Reconnaissance mapping has indicated the presence of shear related rocks (primarily breccia) in the vicinity of Lake Gaston just south of this study area.

The enhancement of the mylonitic unit by second derivative analysis suggests that the magnetic signature of the zone is due to near surface geology. This does not suggest that the unit is restricted to the near surface, but that its magnetic source is near surface.

GRAVITY MODELLING

Two dimensional modelling was performed on the gravity data. Bouguer gravity values were determined from field readings along two east - west survey lines (N-1 and S-1; see Figure 4). Program GRAVMOD.FORTRAN was used to model the subsurface. Geologic contacts and unit densities were determined by methods previously discussed. The relatively deeper structure of the county is shown by northen line (N-1). The shallow structure, particularly the mylonitic unit is shown by southern line (S-1).

Line N-1

Figure 16 shows the Bouguer gravity on the northern line (N-1). Bouguer gravity increases from -20 milligals in the west to 15 milligals in the east, indicating either an increase in density to the east or changing crustal thickness.

Figure 17 is a two-dimensional, density contrast model of the subsurface geology along line N-1. The model covers approximately 30 kms west to east and extends to a depth of 25 kms, though detail is lost beneath 20 kms.

Most lithologic units in Figure 17 are a combination of field reconnaissance observations and the previous geologic work of Bobyarchick (1979). The units from west to east 1) layered gneiss (Raleigh belt ?), 2) western granite (Petersburg ?), 3) mylonite, 4) granite gneiss, 5) layered gneiss (Littleton gneiss ?), and 6) metavolcanics and metasediments (Roanoke Rapids block). Diabase dikes are present throughout the region and are present in the study area. The unit beneath the horizontal surface at 15 km is a low density unit of either Grenville basement or Paleozoic shelf affinity.

The mylonite unit is best modelled as a steeply dipping unit near the surface which becomes listric to the east at depth. The shear joins the horizontal surface at a depth of 15 kms. All surface geology is also terminated by the

Figure 16. Bouguer gravity profile; Line N-1; arrow shows location of shear zone.

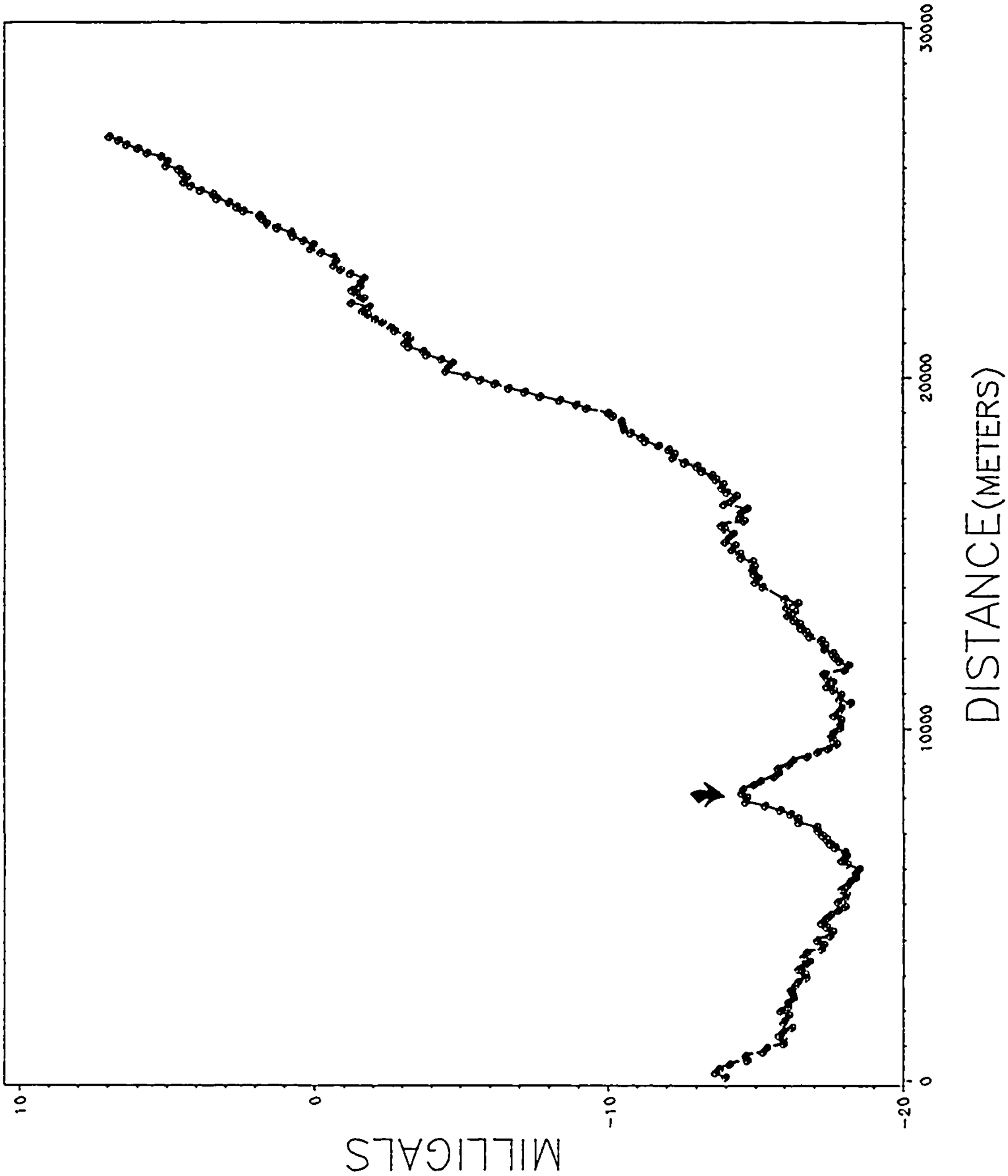
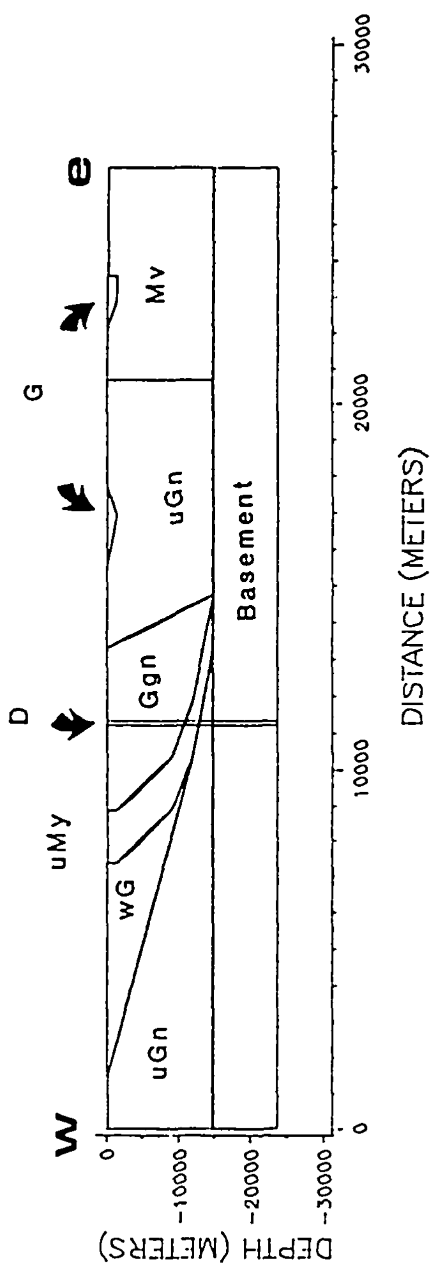

MILLIGALS
10
0
-10
-20
DISTANCE(METERS)
0
10000
20000
30000

Figure 17. Gravity model; line N-1; uGn = undifferentiated gneisses, wG = western Granite, uMy = mylonite, D = diabase, Ggn = granitic gneiss, G = granite, Mv = metavolcanics.



W
e
uMy
D
G
uGn
wG
Ggn
uGn
Mv
Basement
DEPTH (METERS)
0
-10000
-20000
-30000
DISTANCE (METERS)
0
10000
20000
30000

horizontal surface at 15 kms.

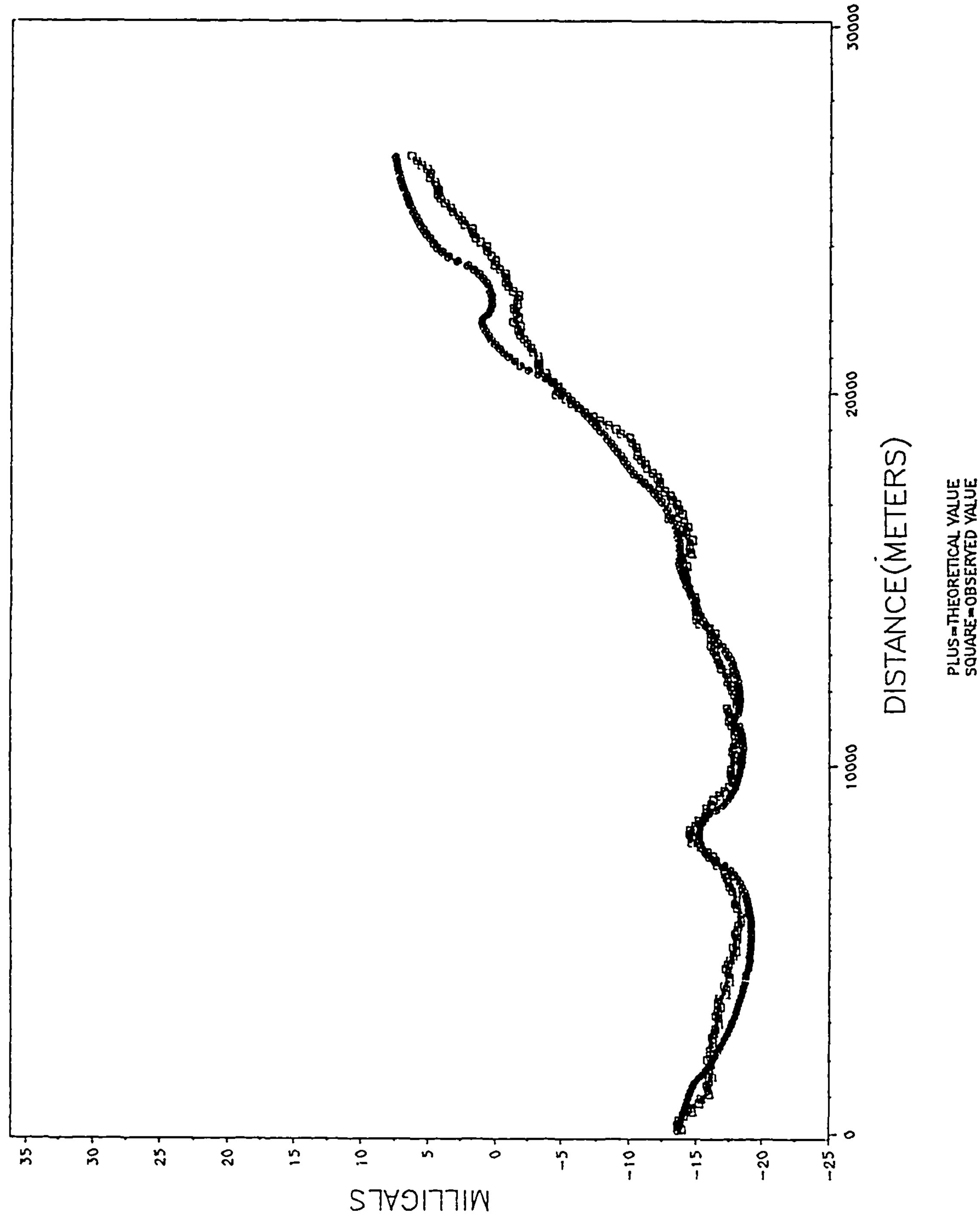
In this model, the eastern gneiss and eastern granite (Figure 5) are modelled as one unit. Both of these units have approximately the same density and are indistinguishable by gravitational methods. This suggests that the two units may be genetically related.

Going from west to east, the contact of the eastern gneiss becomes slightly more of a dense layered gneiss and may represent a gradational change. Bobyarchick (1979) mapped this contact as speculative. In the model the contact is sharp but it likely represents a transitional zone.

Finally, the horizontal surface at 15 kms is proposed to be a décollement. In this model the surface geology has been transported some unknown distance from the east and is allocthonous.

Figure 18 is a plot of the observed versus theoretical Bouguer gravity generated by the model for line N-1. With few exceptions, the values generated by this model closely approximate the observed gravity collected for this study. A wide range of fault types were used to model the mylonitic zone. Over 20 different variations of mylonite geometry were modelled. No other model matched the observed gravity so well.

Figure 18. Theoretical versus observed gravity; line N-1.


MILLIGALS
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
10000
20000
30000
DISTANCE(METERS)
PLUS=THEORETICAL VALUE
SQUARE=OBSERVED VALUE

Line S-1

Figure 19 is a plot of the Bouguer gravity values collected along southern line S-1. Gravity decreases from the west to the east from a value of -13 milligals to 20 milligals. A slight gravity high occurs at approximately 10 kms. This high is likely associated with the mylonite unit. Roughly the eastern half of the gravity profile has been augmented with Bouguer values taken from the Gravity Map of Virginia (Johnson, 1977).

Figure 20 is a two dimensional, density contrast model of the subsurface geology along line S-1. Figure 4 shows this line to be approximately 15 kms south of line N-1 along the Virginia - North Carolina border. Modelling in this area is vital to understanding the relationship between the mylonite here and shear zones to the south. The model covers 30 kms west to east and extends to a depth of 25 kms, although detail is lost below 15 kms. The 12 kms of gravity data collected in this study has been augmented on the east by an equal amount of regional Bouguer gravity. The model is centered on the mylonite - western granite contact.

As with line N-1, geologic units are defined using field reconnaissance observations and Bobyarchick's (1979) geologic map of the area. The units of concern are from west to east 1) layered gneiss, 2) western granite, 3) mylonite, and 4) layered gneiss.

Figure 19. Bouguer gravity profile; line S-1; arrow shows location of shear zone.

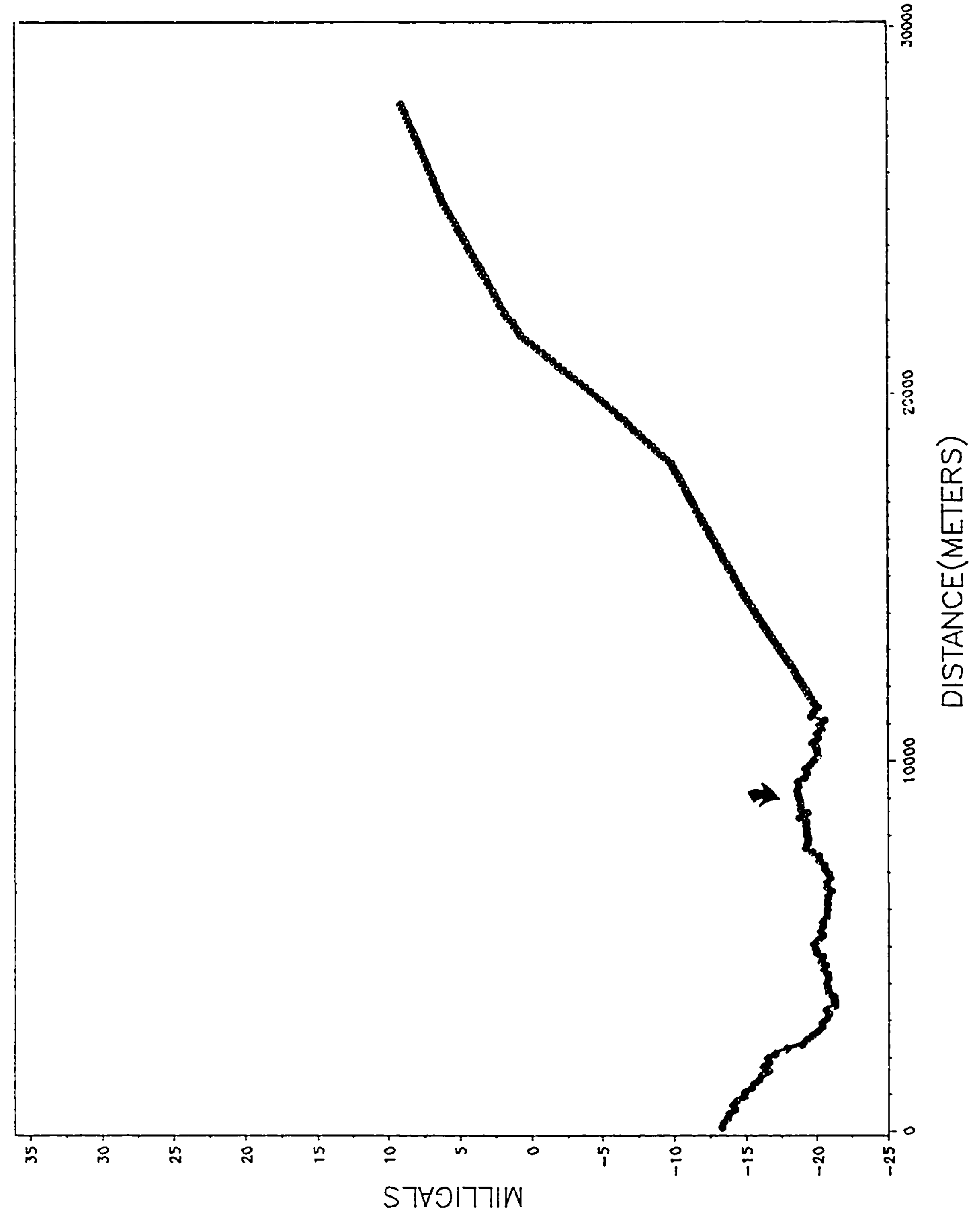
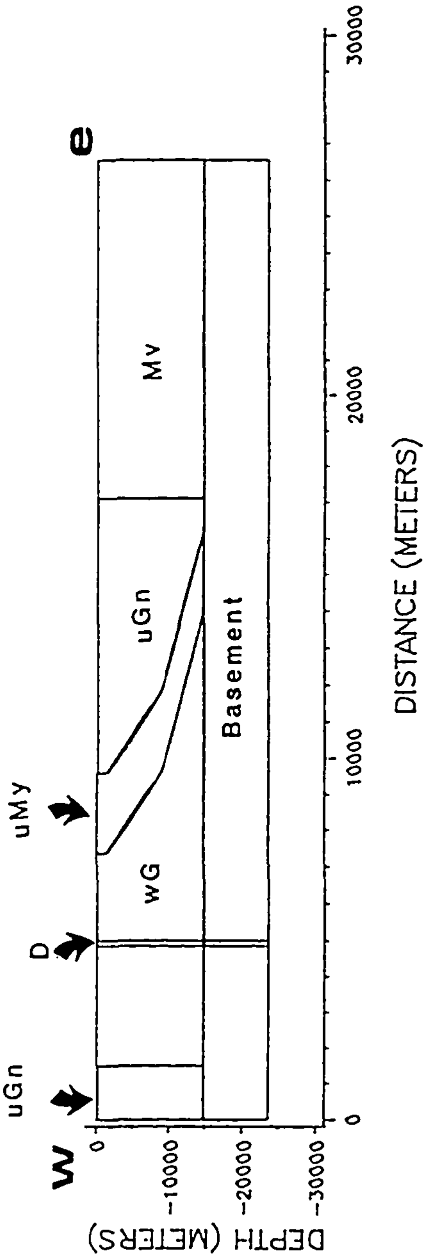

MILLIGALS
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
DISTANCE(METERS)
0
10000
20000
30000

Figure 20. Gravity model; line S-1; uGn = undifferentiated gneisses, wG = western Granite, uMy = mylonite, D = diabase, G = granite, Mv = metavolcanics.

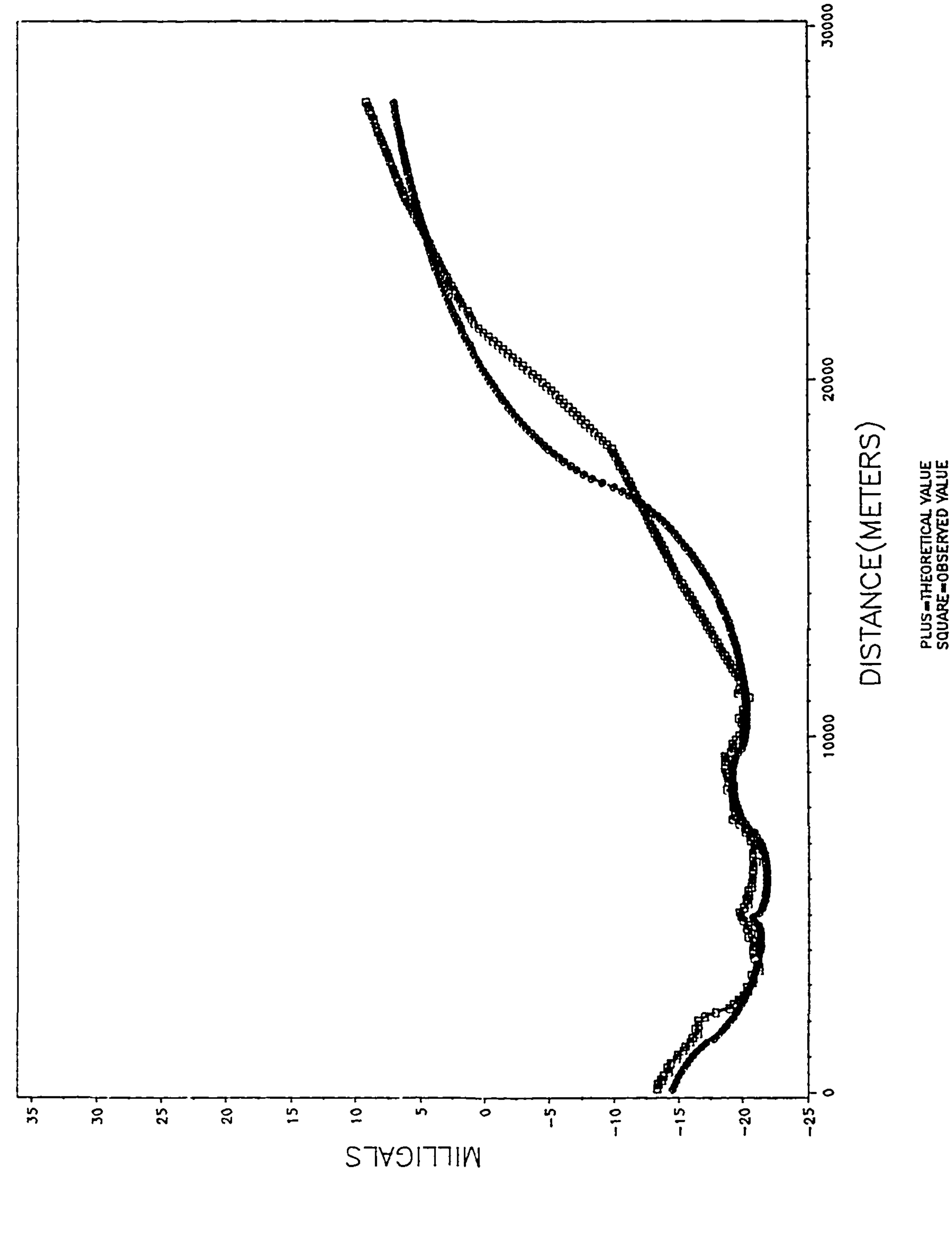

W
e
uGn
D
uMy
wG
uGn
Mv
Basement
0
-10000
-20000
-30000
DEPTH (METERS)
0
10000
20000
30000
DISTANCE (METERS)

In Figure 20 the mylonite is modelled as being wider and less dense. This agrees well with field observations that the intensity of mylonite development decreases to the south. As before, the unit is modelled as becoming listric to the east with depth. The zone eventually joins the horizontal surface at a depth of 15 kms.

The mylonitic zone probably represents a fault zone that splayed off the major detachment. The horizontal surface represents a décollement in the north. The observed geology at the surface is allocthonous along this horizontal detachment zone. The direction of motion along either fault was not determined in this study. It is generally accepted that the direction of transport of the so called "suspect terranes" was from the east (Cook et al, 1979; Bobyarchick, 1981).

Figure 21 is a plot of the observed Bouguer gravity values versus the theoretical gravity generated from the model in Figure 20. The fit between the two curves is not as good as that for the northern line N-1. The more diffuse nature of the mylonite in this region tends to obscure the gravity signature. The lack of fit between the gravity in the eastern half of the profile is due to the lack of detail available with the augmented data. Still, this model accuratly mimicks the gentle increase in gravity to the east.

Figure 21. Theoretical versus observed gravity; line S-1.



MILLIGALS
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
10000
20000
30000
DISTANCE(METERS)
PLUS=THEORETICAL VALUE
SQUARE=OBSERVED VALUE

MAGNETIC MODEL

A single two dimensional magnetic model was generated for the study area. Because ground magnetics were erratic, aeromagnetic data was utilized for the model. A two dimensional profile was taken from the White Plains aeromagnetic map (Figure 10). The east - west profile was taken at approximately 36° 36' N latitude which is approximately midway between gravity lines N-1 and S-1.

Figure 22 is the aeromagnetic profile across the White Plains aeromagnetic map. Magnetic values range from a low of 3400 gammas to a high of 4100 gammas. Magnetic values represent variations in the total field intensity with 51,400 gammas removed from the local field.

The magnetic method is included as a check against the gravity model. Its usefulness is mainly showing that the models developed for gravity can effectively model the magnetic field.

Figure 23 is a general adaptation of the gravity models developed earlier. The model shows the mylonite as a listric splay fault off a major horizontal detachment. A theoretical magnetic field is generated using program MAGMOD.FORTRAN. Because of the difficulty of field determinations of magnetic susceptibilities, values are estimated from knowledge of the general geology

Figure 22. Magnetic profile.

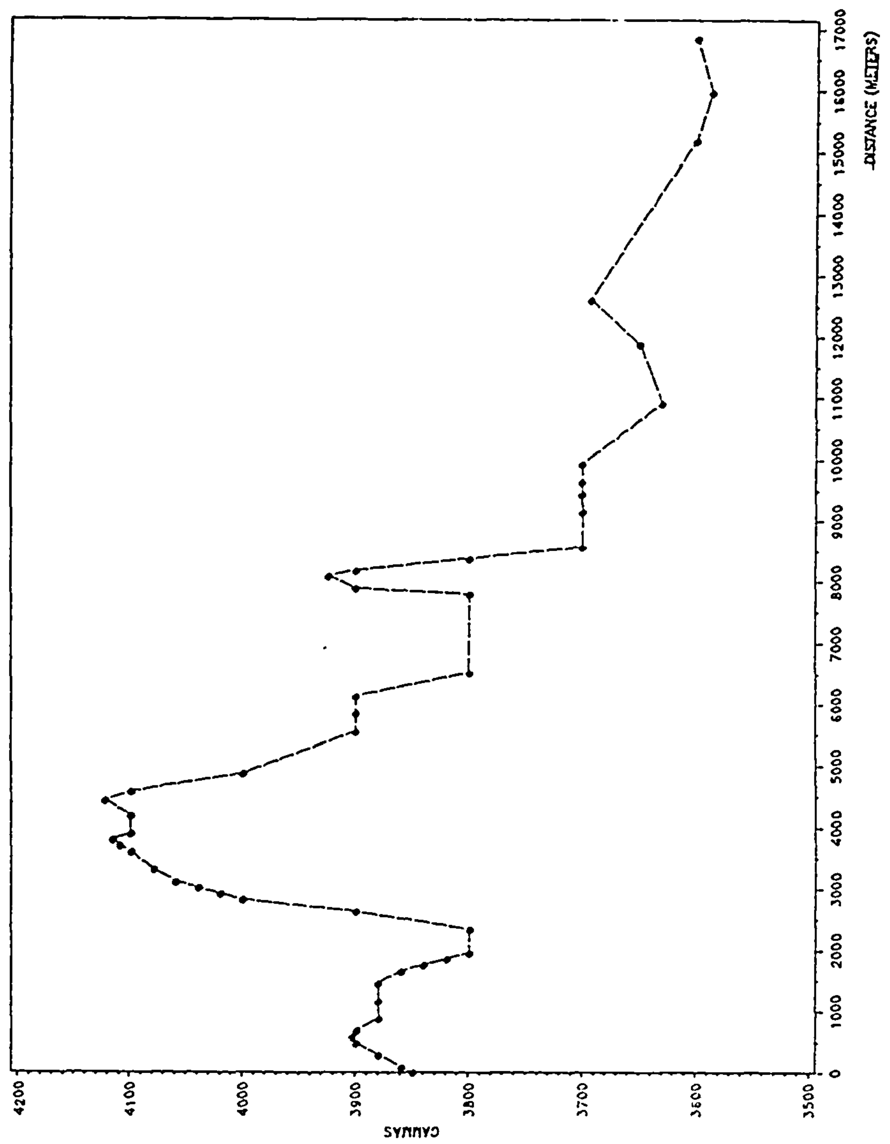
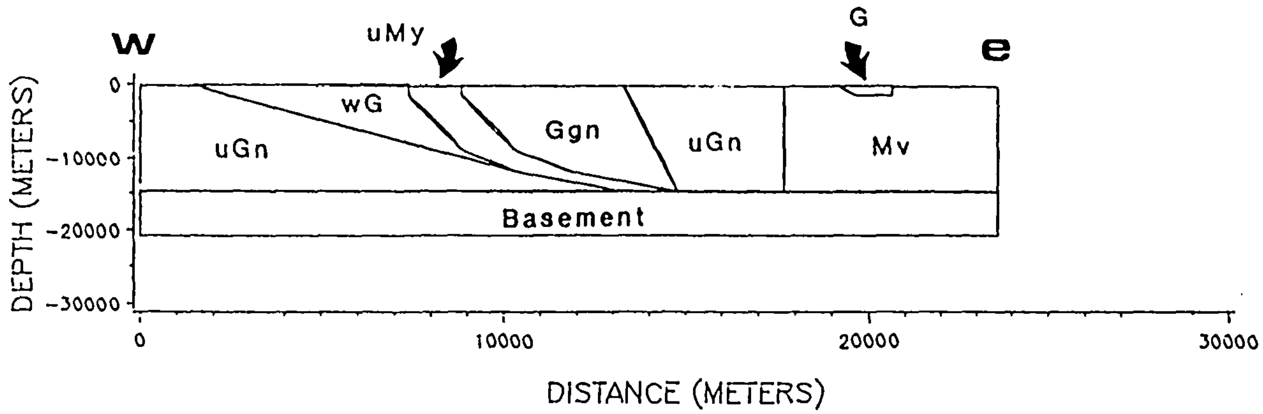

GAMMAS
4200
4100
4000
3900
3800
3700
3600
3500
DISTANCE (METERS)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000

Figure 23. Magnetic model; uGn = undifferentiated gneisses, wG = western Granite, uMy = mylonite, D = diabase, Ggn = granitic gneiss, G = granite, Mv = metavolcanics.


w
uMy
G
e
0
-10000
-20000
-30000
DEPTH (METERS)
wG
uGn
Ggn
uGn
Mv
Basement
0
10000
20000
30000
DISTANCE (METERS)

(Bobyarchick, 1979) and from published susceptibilities for average rocks (Telford et al, 1976). Magnetic susceptibilities for the modeled units are given in Table 2.

Figure 24 is a plot of the theoretical versus observed magnetic field generated by the model in Figure 23. One drawback to the method is the lack of detail that can be modelled using magnetics. However, comparison with the observed field shows a general correlation between levels and trend.

As speculated earlier, the field in this area can be modelled by magnetic zones. The western area is an area of lower magnetic susceptibilities. This corresponds with the gneisses present west of the main granitic body. The central third can be modelled as the unit possessing the highest susceptibility. The cause of the unusually high susceptibility of a normally low susceptability rock (granite) is unknown. The eastern third is modelled as a unit of intermediate susceptibility. Variations in geology across the area are represented by slight variations in magnetic signature.

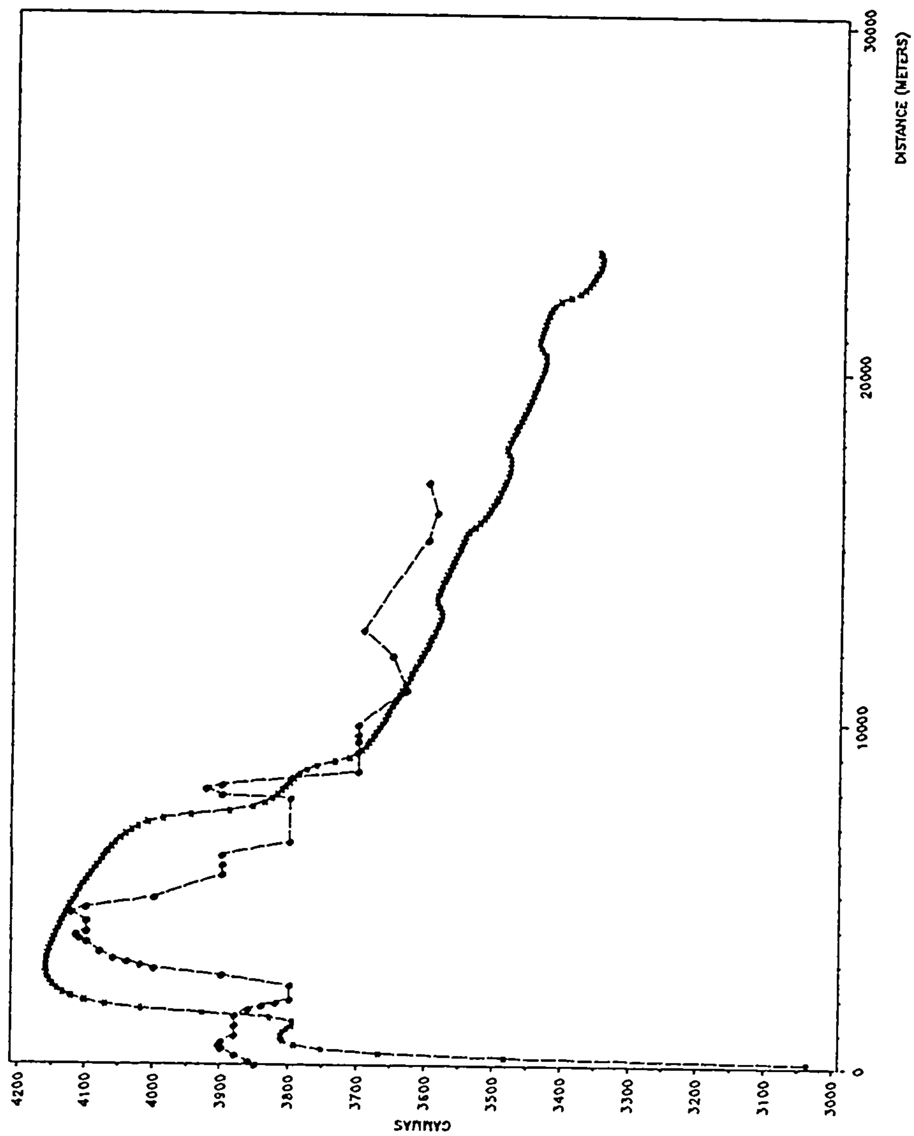
The two-dimensional model developed from gravity data generates a theoretical magnetic profile that closely approximates a two-dimensional profile taken from the local aeromagnetic field. A more general picture is the result and the important features are maintained.

TABLE II

MAGNETIC SUSCEPTABILITIES
(From Telford et al, 1976)

UNIT	SUSCEPTABILITY (emu)
Layered gneiss	0.0160
Western granite	0.0180
Mylonite	0.0175
Eastern gneiss	0.0170
Metavolcanics	0.0170
Basement (unknown)	0.0170

Figure 24. Theoretical versus observed magnetics.


DISTANCE (METERS)
0
10000
20000
30000
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
4100
4200

LOCAL GRAVITY FIELD

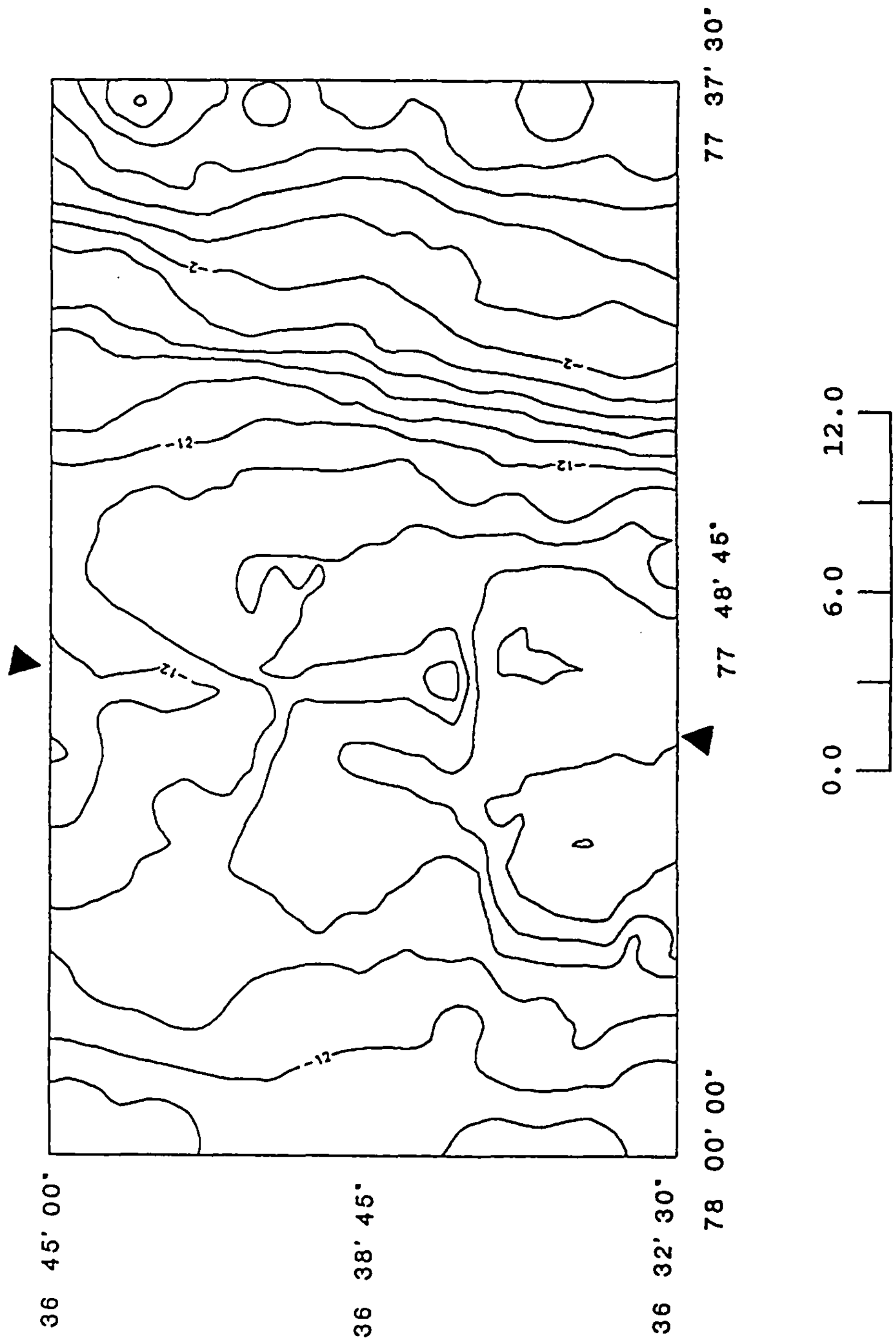
A local Bouguer gravity map was produced for the southern third of Brunswick County. The map covers six topographic maps of the study area. They are the Powellton, Ante, Valentines, White Plains, Gasburg, and Barley 15 minute USGS quadrangles. The total area is greater than 720 sq kms (320 sq. miles).

Data was available from the previously modeled gravity lines (N-1 and S-1). Additional data was available from Johnson (1975) and from a smaller survey line (Pn-1) near the Meherrin river (Waller, M.S. Thesis in prep.).

Figure 25 is a computer contoured version of the local Bouguer gravity field. The data is contoured at 1.0 milligal intervals. The local field suggests that at least gravimetrically the degree of mylonitization decreases to the south (located at approximately 77° 50'W and trending roughly N10°E). The positive gravity anomaly associated with the mylonite in Figure 16 and Figure 19 appears to decrease to the south. The density contrast between the mylonite and the surrounding units decreases to the south. The nature of the relationship between the positive anomaly and the mylonite unit to the north is unknown.

The strong negative anomaly associated with the western granite appears to be continuous across the area (north to

Figure 25. Bouguer gravity map, Brunswick County, Virginia; arrows denote trend of shear zone.

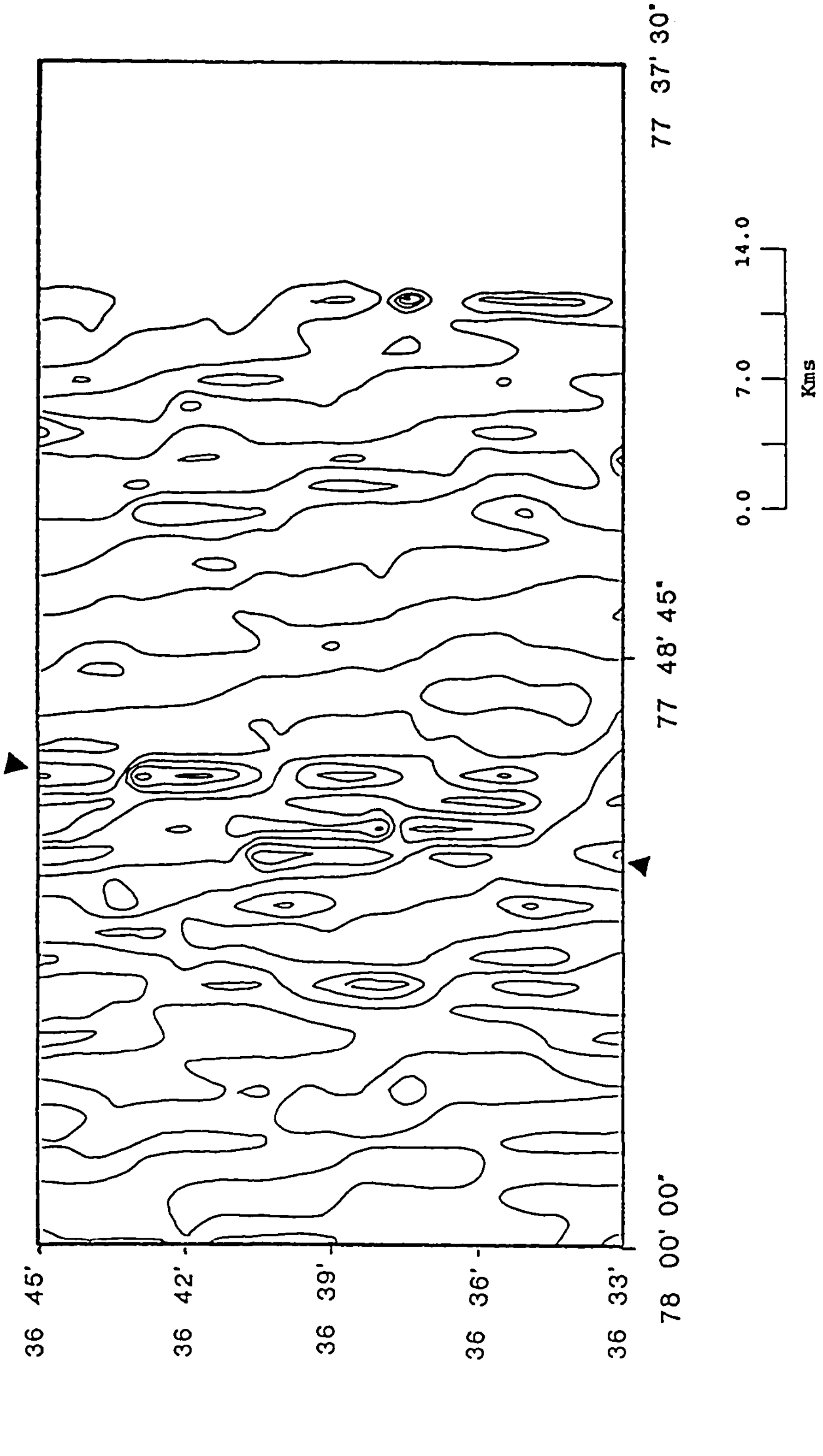

36 45' 00"
36 38' 45"
36 32' 30"
78 00' 00"
77 48' 45"
77 37' 30"
-12
-2
0.0
6.0
12.0
Kms

south). A narrowing of the low appears to be occurring in the south near the state line and a slight decrease in values occurs to the north. The relationship between the gravity field and the western granite to the north is unknown.

Figure 26 is the second derivative map of the Bouguer gravity field in Figure 25. The field was analyzed in the same manner as the aeromagnetic data. The data is contoured at an interval of 50 milligals.

The anomalous pattern east of longitude 78° 42' is an effect due to the sparseness of data points in this area and should be ignored. In general the field can be described as flat with very few anomalous patterns. An exception to this general rule is in the area near 78° 52' west. The pattern is defined by a "tighter" anomalous pattern. The zone of anomalies stretches across the region from north to south. The zone derived from the second derivative analysis of the gravity field and the zone from the second derivative analysis of the aeromagnetic field show remarkable similarities. Both are located in approximately the same area. Both zones cross the study area from north to south. Both zones are defined by a "tighter" pattern of anomalies in an area charaterised by flat anomalies. The main difference is that the aeromagnetic zone is narrower than the gravity zone.

Figure 26. Second derivative of local Bouguer gravity field; arrows denote trend of shear zone.


36 45'
36 42'
36 39'
36 36'
36 33'
78 00' 00"
77 48' 45"
77 37' 30"
0.0
7.0
14.0
Kms

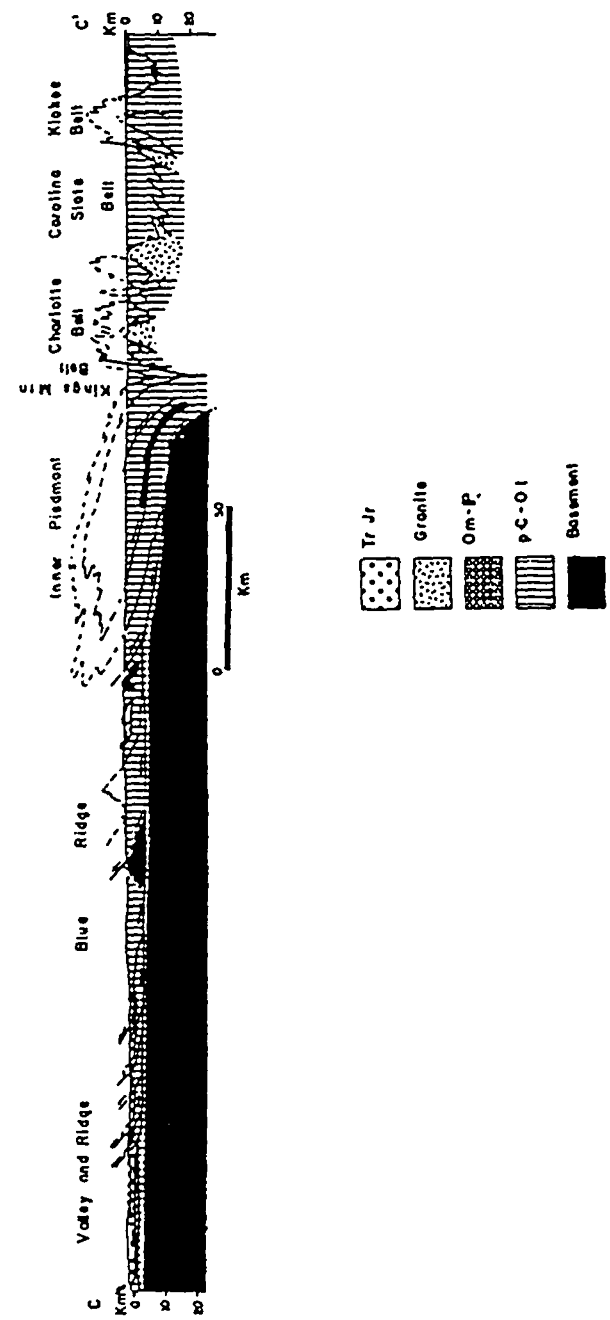
DISCUSSION

A tectonic interpretation of the area in southern Brunswick County is the main objective of this report. The models presented give a clear and consistent picture of the subsurface of Brunswick County. The previously unmapped mylonitic shear zone is best modelled as a listric splay off a major décollement at a depth of 15 km. The surface geology is determined to be allocthonous and presumably thrust into position from the east. The geology beneath the décollement was not be determined in this study. However, the density assigned would be consistent with either Grenville age basement or shelf clastics. Surface studies suggest that there is a dextral component to movement along this shear. The regional implications of these data will be discussed.

Previously, two simplified theories of eastern Piedmont development were applied to the region. These theories concern the nature of subsurface fault geometry. The prevailing, and obviously contradictory, models are strike-slip vs thrust fault.

Figure 27 is an example of the strike-slip model for

Figure 27. Strike slip model for eastern Piedmont development (From Thomas, 1983).


C
C'
Valley and Ridge
Blue Ridge
Inner Piedmont
Kings Mtn Belt
Charlotte Belt
Carolina Slate Belt
Kiokee Belt
Km
0
10
20
Tr Jr
Granite
Om-P
pC-Ot
Basement

Piedmont development in the southeastern United States from Thomas (1983).

Figure 28 is an example of the thrust fault, or décollement, model for Piedmont development in the southeastern United States from Harris and Bayer (1979).

Comparison of both models with the geophysical models developed for Brunswick County presents favorable evidence to the décollement model in southeastern Virginia. The possibility that the model is applicable only to Virginia is remote. The models contained in this report gives evidence for the development of the eastern Piedmont above the master décollement.

By showing the applicability of the décollement model in southern Brunswick County, an arguement has been put forward in favor of the thrust fault model. The depth of the proposed décollement agrees remarkably well with several seismic studies to the north (Bollinger and Sibol, 1985; Harris et al, 1982) and to the south (Cook et al, 1979). It also appears likely that the décollement present in the southeastern United States is the eastern extension of the master décollement responsible for thrusting in the Valley and Ridge Province (Harris and Bayer, 1979).

Figure 29 is a model for Piedmont development above a master décollement and is patterned from a model developed by Bobyarchick (1988). This model includes all aspects of

Figure 28. Décollement model for eastern Piedmont development. AP = Appalachian Plateau, VR = Valley and Ridge, BR = Blue Ridge, P = Piedmont, CP = Coastal Plain, CS = Continental Shelf, pPz = pre-Paleozoic terranes, Pz = Paleozoic sliver (From Harris and Bayer, 1979).

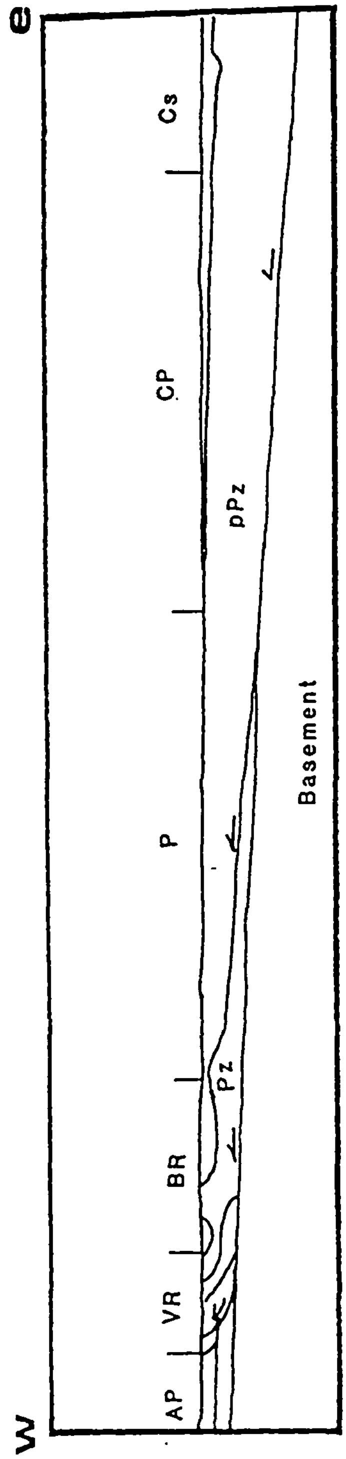
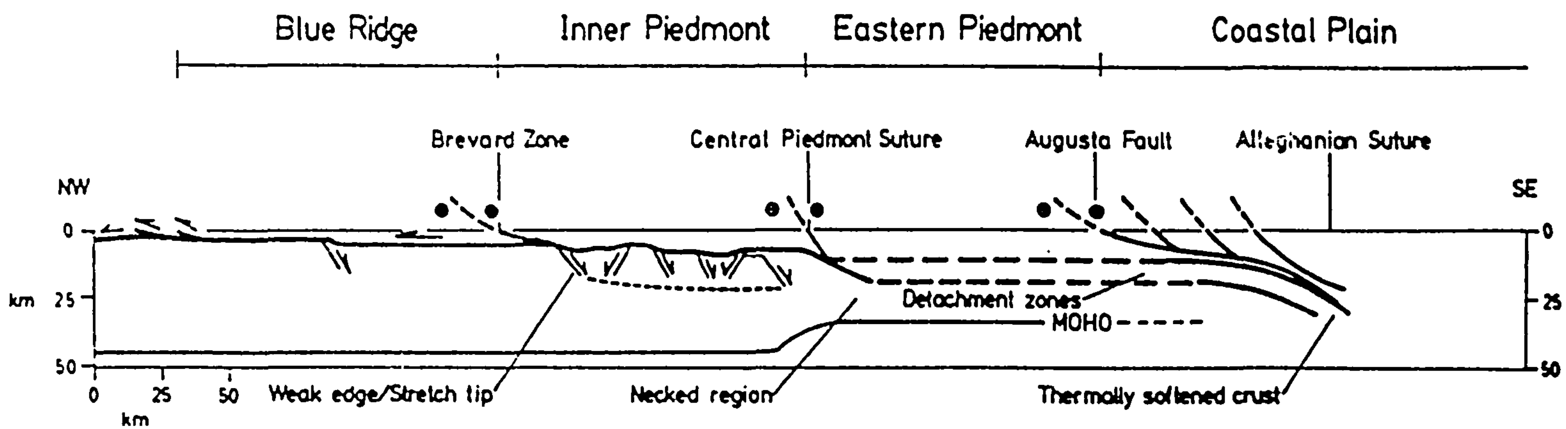

e
Cs
CP
pPz
Basement
P
Pz
BR
VR
AP
w

Figure 29. Tectonic model for Brunswick County, Virginia (From Bobyarchick, 1988).


Blue Ridge
Inner Piedmont
Eastern Piedmont
Coastal Plain
Brevard Zone
Central Piedmont Suture
Augusta Fault
Alleghanian Suture
NW
SE
0
km 25
50
0
25
50
0 25 50
km
Detachment zones
MOHO
Weak edge/Stretch tip
Necked region
Thermally softened crust

the geophysical models in this report. The model presents a dextral sense of motion present on the mylonite zone. In this case the dextral motion represents a later stage reactivation of the thrust fault. The exact timing of the movements is unknown.

The main body of granite in this report is allocthonous as are all other surface units in the area. Based on gravity models the granite extends to a depth between five and ten kms. The juxtaposition of the granite against the fault zone, the elongate shape of the granite, and the coincidence of the foliation of the granite with the strike of the Brunswick shear all suggest that the granite was emplaced near the time of shearing. A similar model is proposed by Guineberteau and others (1987). This portion of Virginia had to be at a sufficient depth to allow for the formation of both granite and mylonite textures, although not necessarily at the same time. It is possible that other examples of shear influenced granite emplacement occur throughout the southeastern Piedmont.

The eastern granite of Calver (1963) is not nearly as extensive as previously thought. The extent of the actual pluton is much closer to that of Bobyarchick (1979). The relationship between the eastern granite and the granitic gneiss presents an excellent target for future studies.

It appears likely that the Brunswick shear of this study represents a northward extension of the Hollister shear of northeastern North Carolina. This makes documentation of the northward extension of the shear into northern Brunswick and western Dinwiddie counties important. It is possible that the Hylas shear zone west of Richmond, Virginia curves to the east south of the Richmond Triassic basin. The area north of Brunswick County could provide evidence of a relationship between the two shear zones.

This study indicates that the Brunswick shear zone is recognizable by detailed gravity surveys. In this case the mylonite of the shear zone gives two isolated positive gravity signatures surrounded (and probably masked) by the main, semi-circular, negative anomaly of the study area. However, the positive signature appears to decrease to the north and disappears completely to the south near the state line. The nature of the gravity field in North Carolina is unknown because no studies of this type have been conducted in that area. The lithologies surrounding the shear play an important role in the anomalous gravity signature.

The shear zone also has a significant aeromagnetic signature. A pattern of N10°E trending anomalies is clearly coincident with the mylonite. The continuous nature of the pattern is clear evidence that the shear continues southwardinto North Carolina and northward into northern Brunswick County.

Why the aeromagnetic pattern continues to the south, while the gravity signature does not, is unclear. The granite may have restricted the shearing to a narrow area, increasing the degree of mylonitization and causing a higher density. To the south where granite does not occur, shearing spreads over a wider area, resulting in less mylonitization and a lower density than to the north. The shear must represent a fundamental break between two units of differing magnetic susceptibilities through the length of the region. Thus, the aeromagnetic pattern should be constant across the area while the gravity pattern would be expected to decrease where the shear is spread over a wider area. This is exactly the pattern seen in southern Brunswick County, Virginia.

CONCLUSION

Brunswick County, Virginia is transected by a nearly north - south trending, hitherto unmapped, steeply dipping mylonitic shear zone (Waller and Corbin, 1988). Geophysical modelling and reconnaissance geological mapping suggests that the shear zone has regional significance. The preferred conclusion is that the shear is a northward continuation of the Hollister fault zone (Farrar, 1984; Stoddard et al, 1987) present in Halifax and Warren counties, North Carolina.

The mylonite zone is defined by a N10°E trending band of en-echelon aeromagnetic anomalies. This anomalous magnetic zone is characterized by an alternating high and low pattern roughly one to one and one-half kilometer wide (1.0-1.5 mile). The location, width, and trend of the aeromagnetic anomalies correlates well with the field-mapped position of the mylonite zone.

Removal of the regional magnetic trend from the local field suggests that the anomalous patterns are due to local near surface geology. Second derivative analysis of the local aeromagnetic field confirms this conclusion.

The granite located to the west of the mylonite zone appears to have an uncharacteristically high aeromagnetic signature. This anomalous signature may be due to the higher magnetic susceptibility of a large diabase dike or alternatively, the surrounding units may have been magnetically depleted by metamorphism. The gneisses, which are ubiquitous throughout the area, are characterized by a broad wavelength, aeromagnetically low patterns.

The mylonite zone is also defined by a distinct gravity pattern. On two-dimensional profiles the zone is represented by a 3-5 milligal high. Anomalies associated with the mylonite appear to decrease in magnitude to the south. As with the aeromagnetic anomalies, gravity anomalies over the mylonite zone are one to one and one-half km wide.

The overall gravity signature of the study area is a broad, low-amplitude, semicircular, negative Bouguer anomaly pattern. The field ranges from a minimum of -20 milligals (centered roughly on the western granite) and increases gently to +10 to +15 milligals towards the western and eastern borders of Brunswick County respectively.

Detailed gravity modelling suggests that the shear zone is nearly vertical at the surface, but is listric to the east at depth.

Gravity modelling suggests that the shear zone flattens in a short distance and becomes near horizontal at a depth of 15 km. At this point the shear zone merges with a horizontal surface that occurs across the region. The horizontal surface at 15 km likely represents a major décollement that influenced the tectonic development of the area. Magnetic models confirm these conclusions.

Bobyarchick (1988) proposed a model that best matches the fault geometry. He suggested that the major décollement responsible for thrusting and folding west of the Piedmont extends eastward beneath the Coastal Plain. In his model, the faults of the eastern Piedmont fault system (Hatcher et al, 1977) are splay faults off the décollement. If the shear zone of this study is an extension of the Hollister zone, then it represents a major northern continuation of the eastern Piedmont fault system and this would concur with Bobyarchick's model. The idea of a multi-leveled décollement beneath the Piedmont and Coastal Plain is not supported from the data obtained in this study.

Acceptance of the décollement model for the eastern Piedmont of Virginia implies that the granitic bodies present in this area are not rooted at depth. As with all rocks present above the décollement they are most likely allocthonous and were transported to their present position from the east.

Glover and Gates (1987) state that the Hylas fault zone, north of this study area, is a deep crustal zone of delamination. To the east, the Carolina terrane (comprising the Chopawamsic, Charlote, Carolina Slate, Raleigh, and Eastern Slate Belts) was speculated to have been thrust upon the Goochland terrane to the west (Glover et al, 1987). If the Hylas is the northern continuation of the Nutbush Creek fault (Hatcher et al, 1977), the presence of a décollement east of this deep crustal delamination is contradictory. The décollement would have to abut against the Hylas/Nutbush Creek zone. Although not impossible, it is unlikely that this is the case. The Hylas fault zone could be a northern continuation of the Hollister fault zone. However, the geophysical models of this study suggest that the Hollister is a listric to the east fault and is incompatible with a deep crustal Hylas fault. A third possibility is that the deep crustal Hylas connects with an unmapped shear zone located to the east. The décollement of this study could be rooted within this zone. Having the décollement rooted in this area could help explain the presence of Roanoke Rapids rocks (Goochland Raleigh Belt; Farrar, 1984) south and east of this study. A final possibility exists that the Hylas is not a crustal delamination but is in fact a listric fault. In this case the area north of this study and south of the Richmond Basin should be investigated for possible connections.

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APPENDIX A

THESIS FIELD DATA
LINE N-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
1	392.077	36 37 58	77 55 42	-13.9225
2	386.627	36 37 57	77 55 39	-13.6245
3	382.843	36 37 58	77 55 34	-13.7280
4	389.660	36 37 58	77 55 29	-14.0766
5	385.430	36 37 59	77 55 23	-14.6750
6	376.030	36 37 58	77 55 17	-14.6129
7	372.393	36 37 57	77 55 13	-15.2136
8	368.303	36 37 57	77 55 10	-15.3661
9	365.350	36 37 57	77 55 04	-15.9276
10	362.207	36 37 57	77 55 01	-15.8851
11	358.343	36 37 57	77 54 57	-15.7691
12	354.523	36 37 59	77 54 53	-15.9213
13	358.027	36 38 01	77 54 49	-16.2079
14	363.410	36 38 04	77 54 46	-15.9159
15	359.160	36 38 08	77 54 46	-15.9824
16	354.970	36 38 12	77 54 46	-16.0975
17	352.903	36 38 16	77 54 44	-15.8211
18	353.840	36 38 19	77 54 39	-16.0719
19	354.697	36 38 22	77 54 35	-16.0733
20	349.953	36 38 24	77 54 32	-16.2498
21	349.213	36 38 27	77 54 28	-16.2289
22	352.943	36 38 29	77 54 23	-16.1823
23	355.283	36 38 31	77 54 20	-16.2941
24	361.443	36 38 34	77 54 17	-16.4129
25	362.633	36 38 37	77 54 14	-16.6615
26	357.923	36 38 38	77 54 11	-16.6305
27	353.583	36 38 41	77 54 07	-16.4454
28	356.723	36 38 44	77 54 03	-16.6071
29	361.293	36 38 47	77 53 59	-16.7891
30	357.937	36 38 50	77 53 55	-16.5766
31	356.857	36 38 52	77 53 50	-16.6931
32	359.983	36 38 52	77 53 47	-17.1976
33	362.457	36 38 52	77 53 43	-17.2745
34	360.327	36 38 52	77 53 38	-17.0641
35	365.143	36 38 52	77 53 34	-17.4683
36	360.780	36 38 52	77 53 29	-17.5510
37	353.183	36 38 53	77 53 25	-17.3738
38	349.003	36 38 53	77 53 21	-17.2017
39	346.187	36 38 53	77 53 16	-17.3507
40	344.777	36 38 54	77 53 11	-17.5150

THESIS FIELD DATA
LINE N-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
41	348.713	36 38 53	77 53 05	-17.7658
42	351.227	36 38 54	77 53 00	-17.9925
43	345.957	36 38 55	77 52 53	-17.7383
44	345.913	36 38 54	77 52 47	-17.9870
45	346.896	36 38 53	77 52 40	-18.0538
46	348.493	36 38 53	77 52 37	-17.8750
47	350.583	36 38 50	77 52 31	-18.0628
48	352.530	36 38 52	77 52 29	-18.1757
49	360.547	36 38 51	77 52 23	-18.3553
50	367.847	36 38 50	77 52 17	-18.3521
51	374.000	36 38 50	77 52 12	-18.4626
52	367.077	36 38 52	77 52 14	-18.0722
53	357.350	36 38 50	77 52 08	-17.8684
54	355.993	36 38 49	77 52 02	-18.0397
55	347.730	36 38 49	77 51 56	-17.9917
56	337.310	36 38 49	77 51 50	-17.6556
57	332.857	36 38 48	77 51 45	-17.4798
58	333.667	36 38 48	77 51 39	-17.3609
59	328.597	36 38 47	77 51 33	-17.2317
60	329.160	36 38 47	77 51 28	-17.0856
61	331.503	36 38 47	77 51 25	-17.0350
62	325.083	36 38 47	77 51 20	-16.4657
63	322.003	36 38 46	77 51 16	-16.3988
64	319.693	36 38 46	77 51 12	-16.1708
65	313.043	36 38 46	77 51 08	-15.8170
66	307.510	36 38 44	77 51 04	-15.3093
67	304.800	36 38 43	77 51 01	-14.6395
68	295.950	36 38 42	77 50 55	-14.6687
69	278.360	36 38 41	77 50 49	-14.4819
70	267.900	36 38 41	77 50 45	-14.5526
71	264.393	36 38 43	77 50 41	-14.9031
72	266.910	36 38 44	77 50 36	-15.1343
73	277.267	36 38 46	77 50 32	-15.6116
74	279.120	36 38 46	77 50 27	-15.7629
75	281.030	36 38 47	77 50 22	-15.7429
76	284.647	36 38 49	77 50 18	-16.1025
77	295.477	36 38 49	77 50 14	-16.2534
78	302.247	36 38 49	77 50 10	-16.7043
79	298.400	36 38 49	77 50 05	-17.0802
80	300.860	36 38 49	77 50 02	-17.4287

THESIS FIELD DATA
LINE N-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
81	311.170	36 38 49	77 49 58	-17.7210
82	312.060	36 38 49	77 49 53	-17.6113
83	311.773	36 38 50	77 49 47	-17.5484
84	316.553	36 38 50	77 49 42	-17.6011
85	327.260	36 38 50	77 49 35	-17.8406
86	328.227	36 38 52	77 49 32	-17.8314
87	330.827	36 38 55	77 49 29	-17.8534
88	333.920	36 38 58	77 49 27	-17.6447
89	338.093	36 39 01	77 49 24	-17.7759
90	335.837	36 39 02	77 49 20	-17.8934
91	333.177	36 39 08	77 49 16	-18.1762
92	328.297	36 39 07	77 49 14	-17.8301
93	322.664	36 39 10	77 49 10	-17.8707
94	319.097	36 39 11	77 49 06	-17.6105
95	312.267	36 39 14	77 49 02	-17.4142
96	318.934	36 39 18	77 48 59	-17.5697
97	327.678	36 39 21	77 48 56	-17.4066
98	335.321	36 39 25	77 48 53	-17.3003
99	343.081	36 39 29	77 48 50	-17.9915
100	344.821	36 39 32	77 48 47	-18.1141
101	349.654	36 39 35	77 48 46	-17.8069
102	350.294	36 39 40	77 48 45	-17.6500
103	342.294	36 39 43	77 48 44	-17.5696
104	339.208	36 39 47	77 48 43	-17.3336
105	341.378	36 39 50	77 48 43	-17.3346
106	333.774	36 39 53	77 48 42	-17.1891
107	329.001	36 39 56	77 48 40	-16.8077
108	326.618	36 39 59	77 48 35	-16.6959
109	329.468	36 40 01	77 48 31	-16.5350
110	319.295	36 40 03	77 48 26	-16.4543
111	316.511	36 40 04	77 48 21	-16.2686
112	314.931	36 40 04	77 48 17	-16.0705
113	315.915	36 40 05	77 48 11	-16.3065
114	324.691	36 40 05	77 48 07	-16.0406
115	329.401	36 40 05	77 48 02	-16.4129
116	328.136	36 40 06	77 47 56	-15.9753
117	332.338	36 40 07	77 47 50	-15.2128
118	328.665	36 40 03	77 47 45	-14.9609
119	328.775	36 40 03	77 47 39	-15.0454
120	322.631	36 40 01	77 47 34	-14.9095

THESIS FIELD DATA
LINE N-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
121	320.565	36 39 58	77 47 29	-14.8658
122	324.311	36 39 56	77 47 25	-14.9109
123	326.051	36 39 56	77 47 21	-14.8492
124	315.881	36 39 57	77 47 16	-14.4852
125	317.964	36 39 59	77 47 11	-14.4084
126	311.074	36 39 59	77 47 06	-14.1627
127	309.398	36 40 01	77 47 02	-14.2582
128	305.188	36 40 01	77 46 58	-13.9694
129	304.345	36 40 02	77 46 53	-14.0643
130	308.668	36 40 02	77 46 47	-14.2194
131	293.642	36 40 02	77 46 44	-13.9098
132	294.835	36 40 02	77 46 40	-13.7963
133	311.198	36 40 02	77 46 35	-14.5674
134	302.115	36 40 02	77 46 31	-14.4535
135	299.905	36 40 01	77 46 31	-14.4778
136	307.528	36 40 03	77 46 20	-14.6632
137	293.972	36 40 03	77 46 16	-13.9044
138	295.749	36 40 02	77 46 11	-14.1457
139	304.352	36 40 01	77 46 06	-14.3180
140	304.485	36 39 59	77 46 01	-13.9970
141	308.039	36 39 57	77 45 56	-12.7914
142	314.192	36 39 56	77 45 52	-13.8533
143	310.346	36 39 56	77 45 49	-13.6275
144	306.133	36 39 56	77 45 44	-13.4664
145	306.656	36 39 57	77 45 40	-13.1626
146	300.406	36 39 58	77 45 35	-12.9877
147	285.512	36 39 59	77 45 33	-12.5670
148	276.539	36 40 01	77 45 29	-12.1768
149	271.199	36 40 01	77 45 23	-12.2212
150	272.996	36 40 02	77 45 17	-12.0311
151	272.719	36 40 02	77 45 11	-11.6766
152	278.065	36 40 02	77 45 06	-11.2390
153	283.695	36 40 02	77 45 02	-11.1038
154	277.722	36 40 02	77 44 52	-10.7723
155	280.272	36 40 02	77 44 48	-10.5136
156	286.835	36 40 01	77 44 43	-10.4688
157	293.452	36 40 00	77 44 39	-10.3989
158	292.759	36 39 59	77 44 34	-10.0989
159	285.605	36 39 58	77 44 29	-9.9407
160	278.495	36 39 55	77 44 26	-9.2231

THESIS FIELD DATA
LINE N-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
161	270.599	36 39 53	77 44 22	-8.8846
162	274.698	36 39 52	77 44 17	-8.3292
163	269.462	36 39 49	77 44 11	-7.6683
164	253.903	36 39 49	77 44 06	-7.1571
165	254.083	36 39 49	77 44 01	-6.6054
166	258.343	36 39 48	77 43 58	-6.1247
167	263.479	36 39 47	77 43 53	-5.6444
168	273.306	36 39 47	77 43 47	-5.1835
169	281.529	36 39 47	77 43 43	-4.4678
170	288.266	36 39 48	77 43 37	-4.5451
171	291.416	36 39 49	77 43 31	-4.6564
172	290.436	36 39 50	77 43 26	-4.2829
173	279.566	36 39 50	77 43 23	-3.7989
174	276.566	36 39 52	77 43 17	-3.6666
175	279.506	36 39 52	77 43 14	-3.1821
176	290.046	36 39 54	77 43 09	-3.0441
177	301.146	36 39 55	77 43 05	-3.2102
178	293.719	36 39 54	77 43 02	-3.1009
179	289.159	36 39 53	77 42 58	-2.7029
180	286.152	36 39 53	77 42 51	-2.5435
181	279.326	36 39 53	77 42 45	-2.2734
182	277.789	36 39 53	77 42 41	-2.0268
183	277.013	36 39 53	77 42 35	-1.7442
184	273.883	36 39 56	77 42 29	-1.5686
185	270.686	36 39 57	77 42 22	-1.7958
186	268.510	36 39 58	77 42 16	-1.2277
187	271.113	36 39 58	77 42 10	-1.6240
188	269.073	36 39 59	77 42 05	-1.4096
189	267.150	36 39 59	77 42 02	-1.2167
190	268.470	36 39 59	77 41 58	-1.4885
191	269.527	36 39 59	77 41 55	-1.5317
192	270.240	36 39 59	77 41 50	-1.6480
193	267.640	36 40 01	77 41 45	-1.1824
194	270.327	36 40 01	77 41 41	-0.8309
195	275.593	36 40 02	77 41 37	-0.6127
196	280.263	36 40 03	77 41 33	-0.6748
197	285.327	36 40 03	77 41 29	-0.5950
198	284.353	36 40 03	77 41 23	-0.1854
199	284.217	36 40 04	77 41 18	0.1643
200	293.673	36 40 07	77 41 08	0.0863

THESIS FIELD DATA
LINE N-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
201	289.677	36 40 07	77 41 04	0.4205
202	289.343	36 40 08	77 41 00	0.7486
203	291.263	36 40 11	77 40 54	0.8137
204	283.513	36 40 11	77 40 47	1.2731
205	278.373	36 40 12	77 40 34	1.6525
206	277.376	36 40 12	77 40 38	1.8051
207	281.450	36 40 11	77 40 33	1.9047
208	279.193	36 40 11	77 40 29	2.4281
209	283.730	36 40 13	77 40 25	2.6629
210	279.947	36 40 15	77 40 19	2.9096
211	277.343	36 40 16	77 40 14	3.3349
212	273.990	36 40 18	77 40 10	3.4899
213	272.243	36 40 19	77 40 04	3.8934
214	266.743	36 40 21	77 39 59	4.2062
215	257.717	36 40 22	77 39 55	4.4700
216	250.417	36 40 23	77 39 51	4.3596
217	244.610	36 40 25	77 39 46	4.5171
218	240.797	36 40 26	77 39 40	4.6579
219	239.410	36 40 27	77 39 35	5.0622
220	238.307	36 40 29	77 39 32	5.0231
221	231.140	36 40 32	77 39 28	5.2344
222	214.147	36 40 35	77 39 22	5.6943
223	195.387	36 40 37	77 39 16	6.0197
224	191.317	36 40 38	77 39 12	6.3797
225	203.577	36 40 38	77 39 07	6.6593
226	213.943	36 40 38	77 39 02	6.9739

THESIS FIELD DATA
LINE S-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
1	357.355	36 35 14	77 56 50	-13.2739
2	352.602	36 35 11	77 56 54	-13.3707
3	349.922	36 35 09	77 56 40	-13.6320
4	344.495	36 35 08	77 56 37	-13.7849
5	335 345	36 35 08	77 56 32	-14.1953
6	329.675	36 35 06	77 56 26	-14.0312
7	328.295	36 35 05	77 56 22	-14.3018
8	324.495	36 35 05	77 56 20	-14.8008
9	334.622	36 35 03	77 56 16	-14.8939
10	330.432	36 35 02	77 56 10	-15.3439
11	332.642	36 35 02	77 56 07	-15.5297
12	339.715	36 35 03	77 56 02	-15.8839
13	335.048	36 35 04	77 56 00	-16.0713
14	316.368	36 35 04	77 55 58	-16.4689
15	312.208	36 35 02	77 55 51	-16.2557
16	305.738	36 35 01	77 55 44	-16.5243
17	299.245	36 35 01	77 55 37	-16.4779
18	294.072	36 35 02	77 55 28	-17.0126
19	284.899	36 35 02	77 55 20	-17.8071
20	291.442	36 35 02	77 55 14	-18.9116
21	293.622	36 35 02	77 55 13	-19.2157
22	303.549	36 35 02	77 55 08	-19.5977
23	303.502	36 34 59	77 55 06	-20.0051
24	312.698	36 34 57	77 55 02	-20.2887
25	311.752	36 34 55	77 54 59	-20.2745
26	318.046	36 34 53	77 54 55	-20.6663
27	315.666	36 34 51	77 54 51	-20.7819
28	314.669	36 34 47	77 54 47	-20.5761
29	328.422	36 34 40	77 54 40	-21.2071
30	334.579	36 34 36	77 54 36	-21.1881
31	330.306	36 34 32	77 54 35	-21.1133
32	323.119	36 34 26	77 54 32	-20.8160
33	319.002	36 34 22	77 54 28	-20.6797
34	317.472	36 34 20	77 54 23	-20.6696
35	308.815	36 34 19	77 54 19	-20.7499
36	311.662	36 34 13	77 54 14	-20.7209
37	314.842	36 34 09	77 54 10	-20.3813
38	311.152	36 34 05	77 54 06	-20.5697
39	304.122	36 34 03	77 54 01	-20.2628
40	303.452	36 34 02	77 53 55	-20.3527

THESIS FIELD DATA
LINE S-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
41	294.075	36 34 26	77 53 36	-19.9404
42	276.601	36 34 27	77 53 32	-19.8002
43	280.711	36 34 26	77 53 26	-19.6814
44	288.061	36 34 22	77 53 26	-20.0046
45	286.898	36 34 25	77 53 16	-20.3368
46	276.588	36 34 25	77 53 11	-20.2212
47	273.278	36 34 23	77 53 07	-20.3712
48	275.874	36 34 23	77 53 03	-20.3735
49	271.048	36 34 25	77 52 57	-20.6043
50	266.051	36 34 27	77 52 50	-20.6330
51	262.301	36 34 28	77 52 50	-20.6792
52	259.691	36 34 29	77 52 46	-20.6896
53	251.648	36 34 29	77 52 41	-20.7150
54	231.451	36 34 28	77 52 36	-20.7320
55	230.604	36 34 28	77 52 35	-20.9625
56	248.731	36 34 28	77 52 29	-20.6720
57	236.691	36 34 26	77 52 25	-20.6756
58	217.024	36 34 25	77 52 21	-20.9073
59	205.138	36 34 25	77 52 16	-20.8226
60	208.408	36 34 25	77 52 11	-20.5518
61	221.514	36 34 26	77 52 07	-20.5001
62	204.514	36 34 28	77 52 02	-20.1435
63	203.691	36 34 29	77 51 57	-20.0889
64	206.691	36 34 31	77 51 52	-19.5687
65	219.158	36 34 35	77 51 47	-19.1982
66	246.282	36 34 37	77 51 43	-19.3171
67	257.762	36 34 37	77 51 39	-19.3713
68	266.885	36 34 39	77 51 35	-19.2221
69	275.132	36 34 40	77 51 32	-19.2384
70	265.962	36 34 43	77 51 30	-19.1802
71	269.662	36 34 47	77 51 28	-19.1909
72	274.382	36 34 46	77 51 24	-18.7358
73	274.231	36 34 51	77 51 21	-19.2348
74	281.642	36 34 55	77 51 19	-18.8428
75	275.048	36 34 58	77 51 16	-18.8003
76	281.742	36 35 01	77 51 14	-18.6723
77	287.672	36 35 05	77 51 11	-18.6029
78	291.362	36 35 10	77 51 09	-18.5641
79	293.885	36 35 14	77 51 05	-18.6562
80	300.839	36 35 15	77 51 01	-18.5708

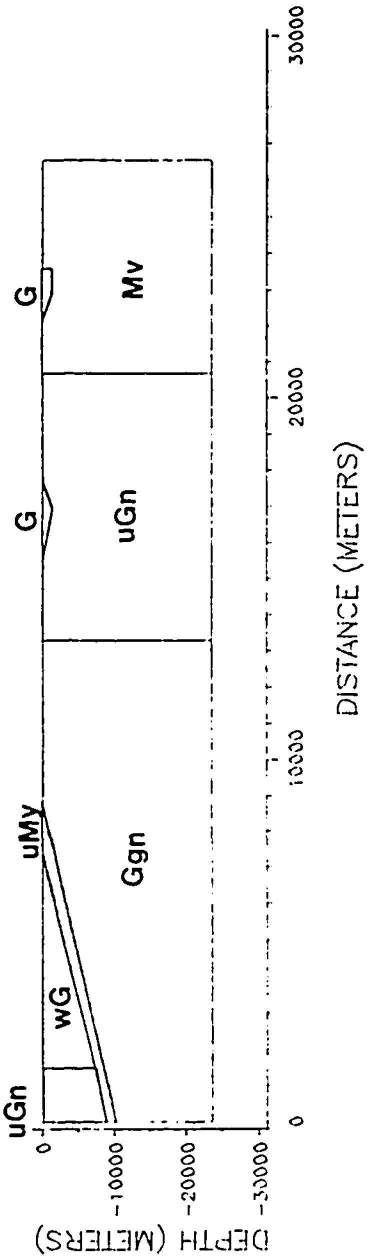
THESIS FIELD DATA
LINE S-1

Station Number	Elev. (Ft.)	Long.	Lat.	Bouguer Gravity
81	299.299	36 35 18	77 50 55	-19.0959
82	298.955	36 35 22	77 50 51	-19.2321
83	306.542	36 35 22	77 50 50	-19.1581
84	314.042	36 35 23	77 50 47	-19.4754
85	316.862	36 35 25	77 50 43	-19.7357
86	327.015	36 35 26	77 50 38	-19.9991
87	333.738	36 35 26	77 50 34	-17.8534
88	325.195	36 35 26	77 50 29	-20.0191
89	318.532	36 35 26	77 50 25	-19.8928
90	314.832	36 35 25	77 50 19	-19.6647
91	318.771	36 35 25	77 50 16	-20.0411
92	328.735	36 35 25	77 50 10	-19.9737
93	334.385	36 35 24	77 50 05	-20.2992
94	331.008	36 35 23	77 50 01	-20.2124
95	326.055	36 35 21	77 49 56	-20.4853
96	323.058	36 35 17	77 49 52	-19.6177
97	325.448	36 35 17	77 49 47	-19.7306

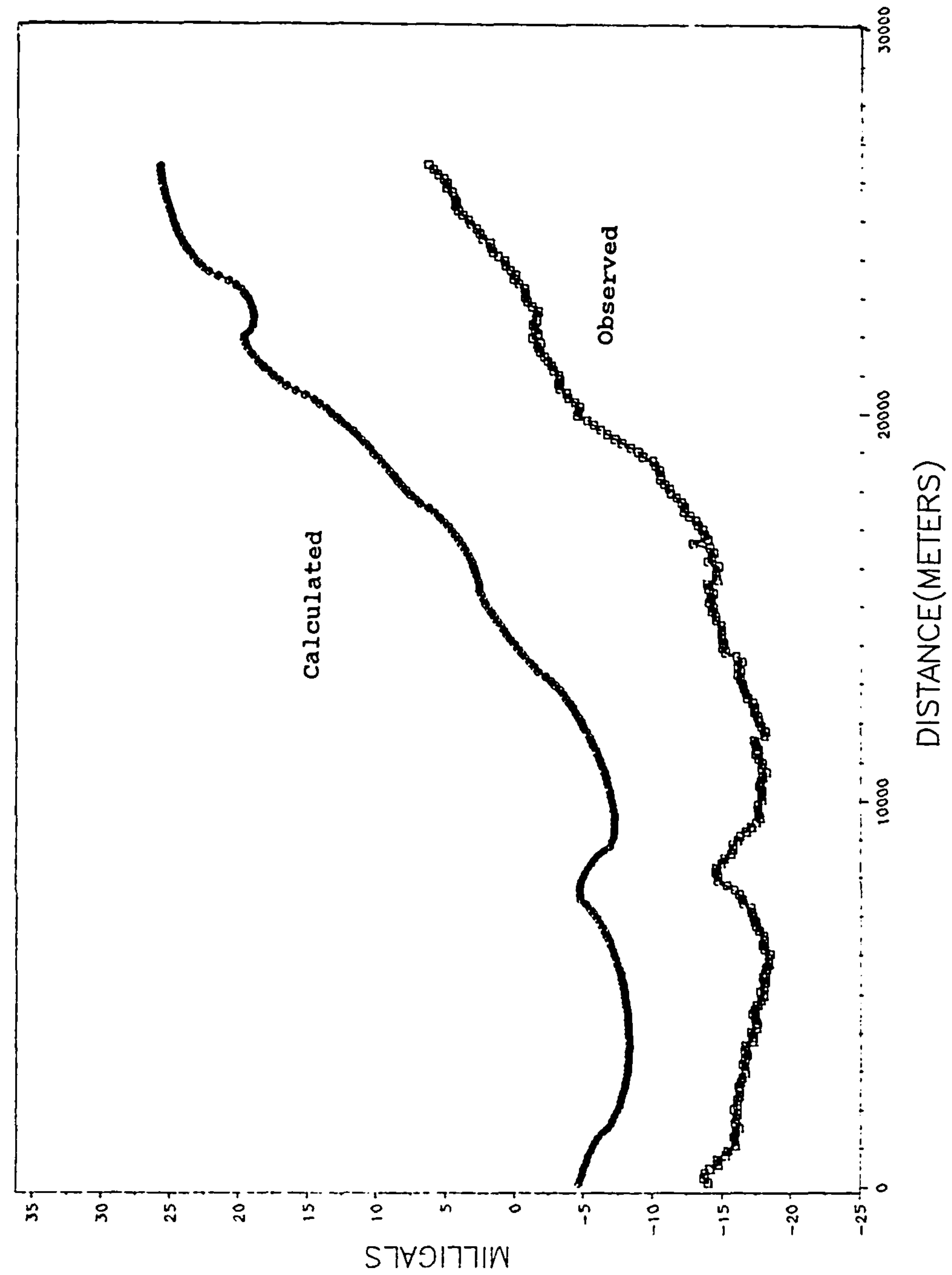
APPENDIX B
FAILED MODELS

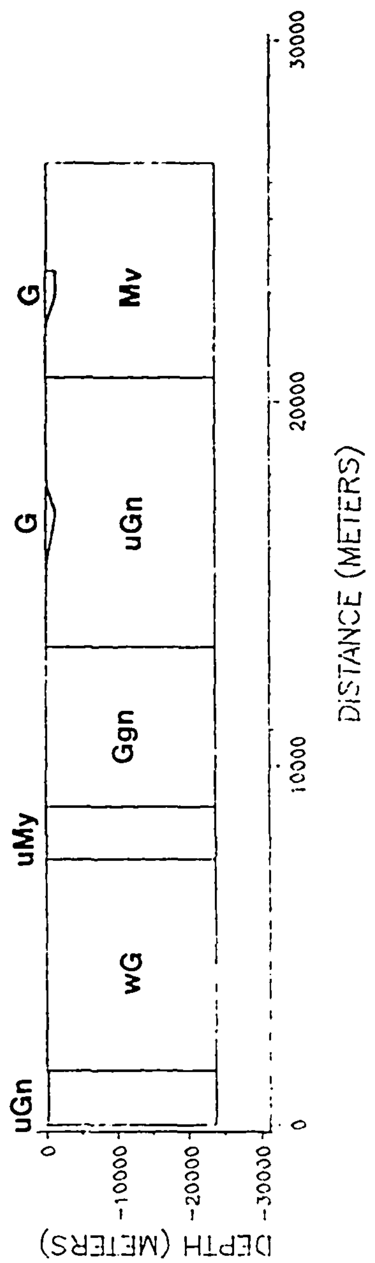
Many different configurations of the geology of Brunswick County were modelled as was the model presented in the body of this report. While surface geological contacts and unit densities were maintained constant the subsurface attitude of the shear zone was varied widely. West dipping, vertical, and east dipping faults were modelled in combination with thick skinned versus thin skinned crust.

Below are several examples of geophysical models with corresponding plots of observed versus calculated Bouguer gravity. The models are presented in the following order 1) west dipping, deep crustal shear zone, 2) vertical, deep crustal shear zone, 3) east dipping, deep crustal shear zone and, 4) west dipping shear zone with décollement at 15 kilometers. In each case the model was rejected. Models 1,2, and 3 failed because the calculated gravity values were 5-10 milligals higher than observed gravity values. Also, the shape of the anomaly calculated by each model for the shear zone did not match the observed anomnaly. Model 4 failed for similar reasons. In this case the calculated gravity values were 5-10 milligals lower than the observed gravity.

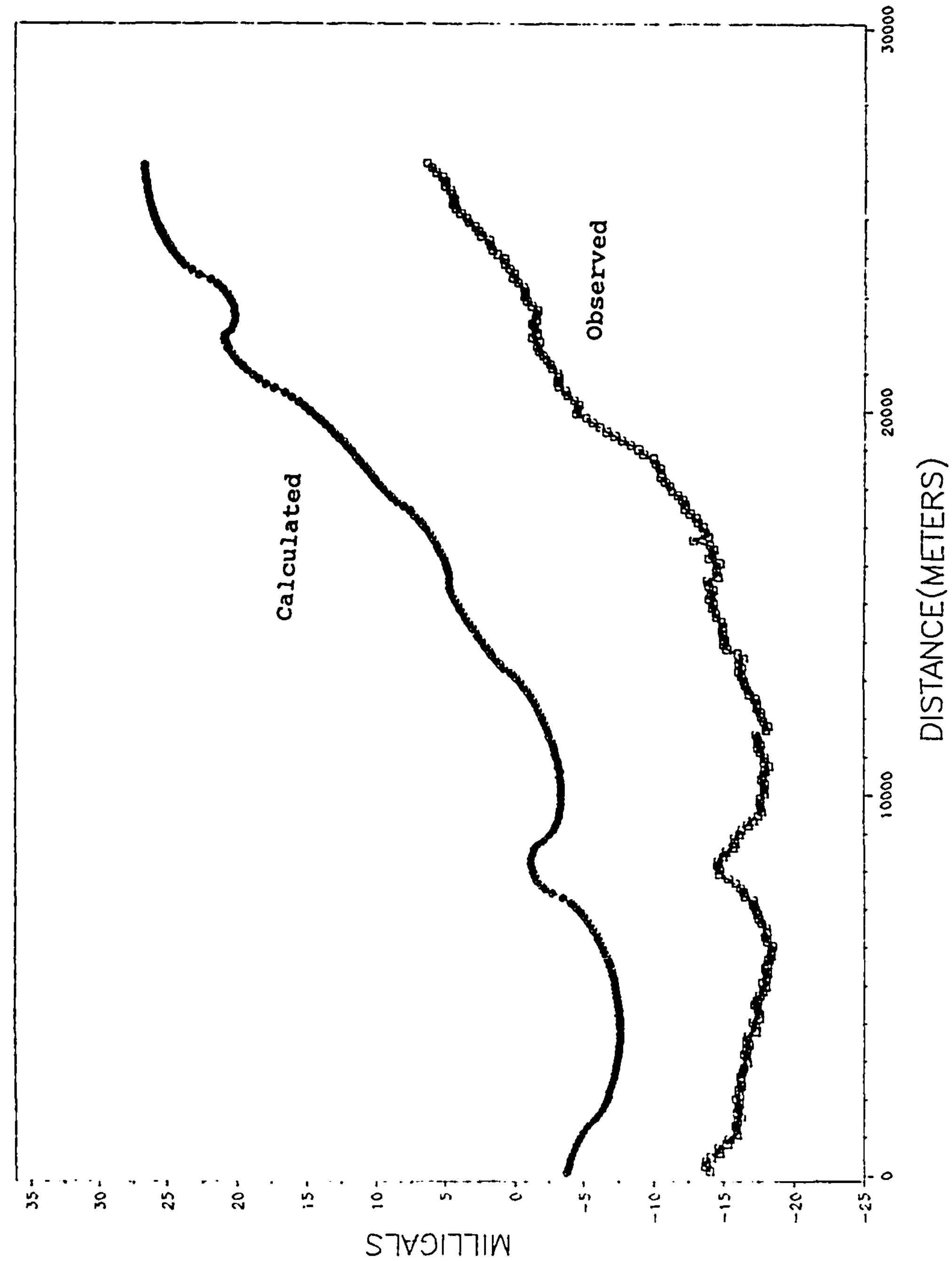

uGn
wG
uMy
Ggn
G
uGn
G
Mv
0
-10000
-20000
-30000
DEPTH (METERS)
0
10000
20000
30000
DISTANCE (METERS)

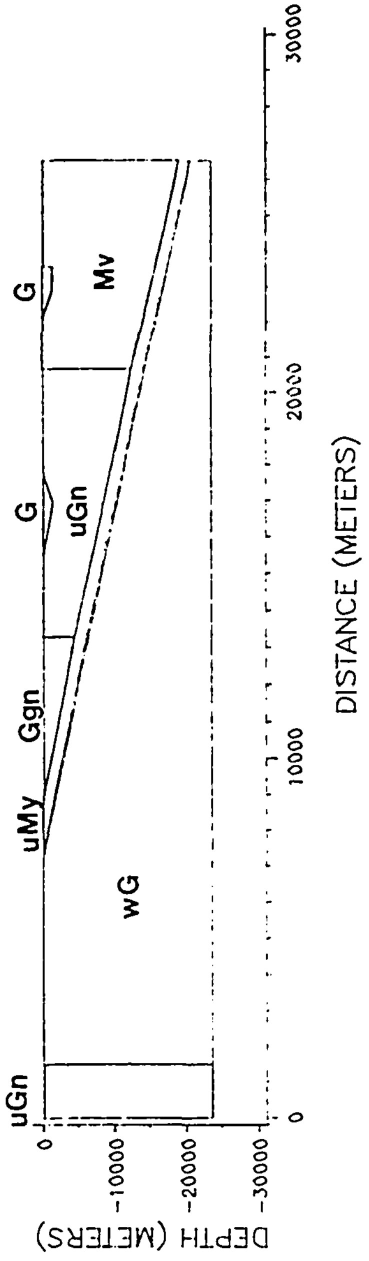
1


Calculated
Observed
DISTANCE(METERS)
0
10000
20000
30000
MILLIGALS
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25


uGn
wG
uMy
Ggn
G
uGn
G
Mv
0
-10000
-20000
-30000
DEPTH (METERS)
0
10000
20000
30000
DISTANCE (METERS)

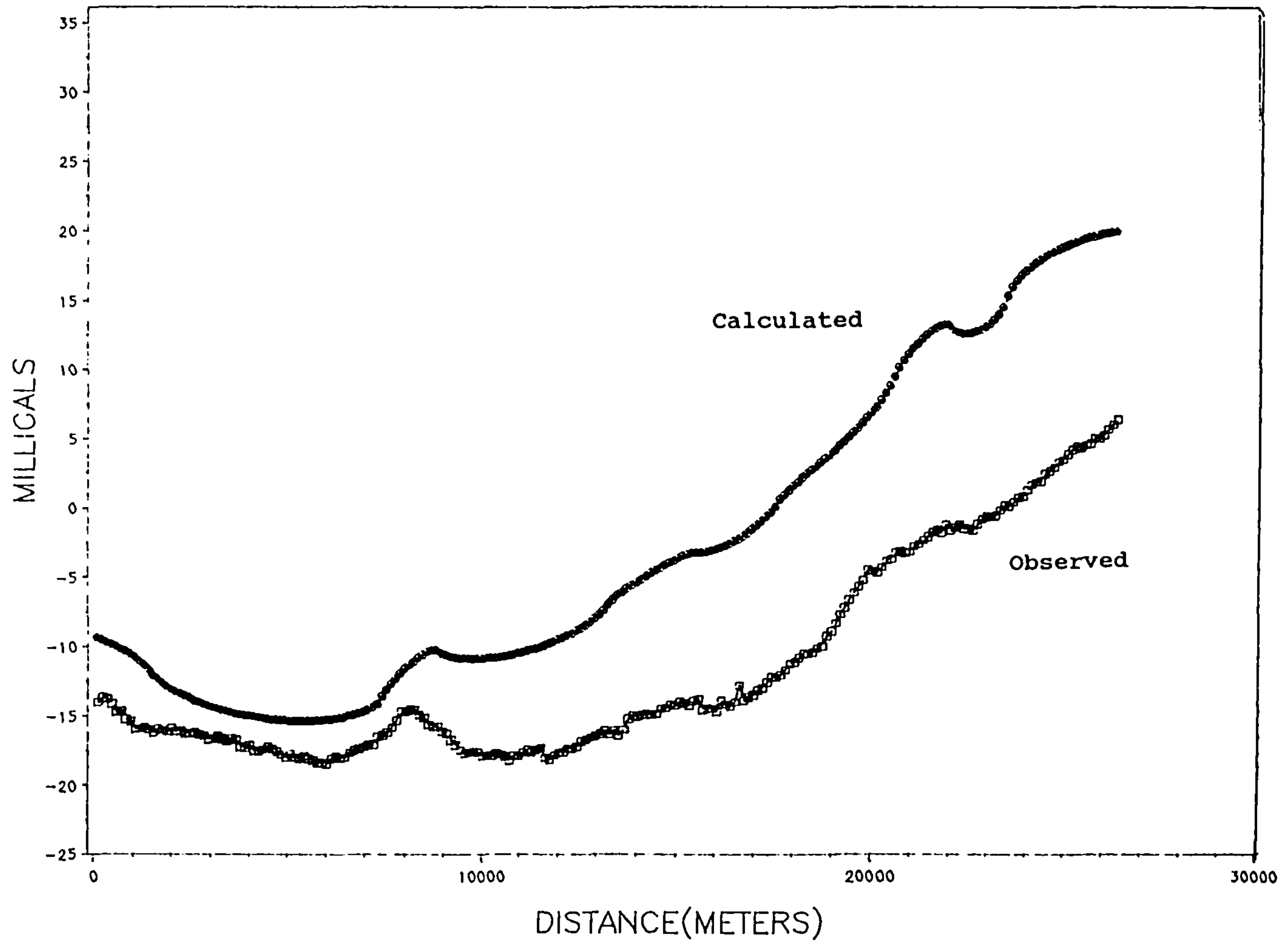
2

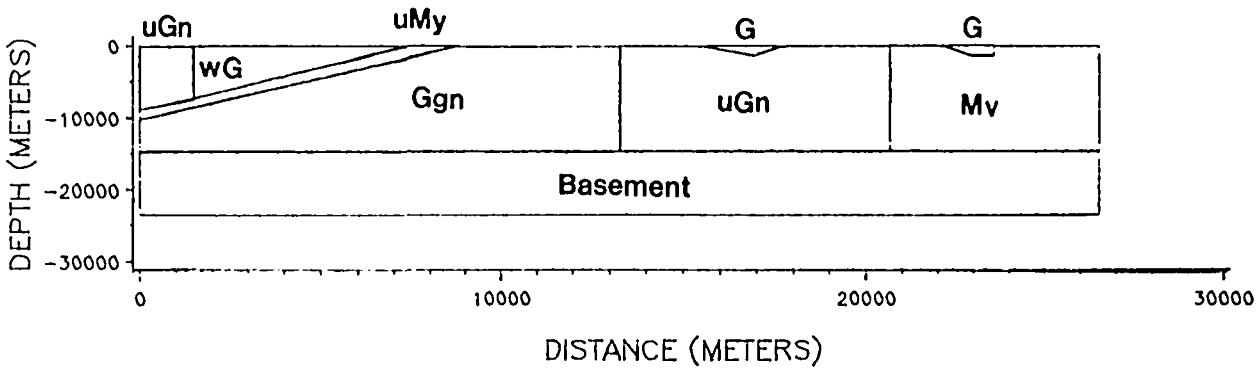

Calculated
Observed
DISTANCE(METERS)
MILLIGALS
0
10000
20000
30000
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25



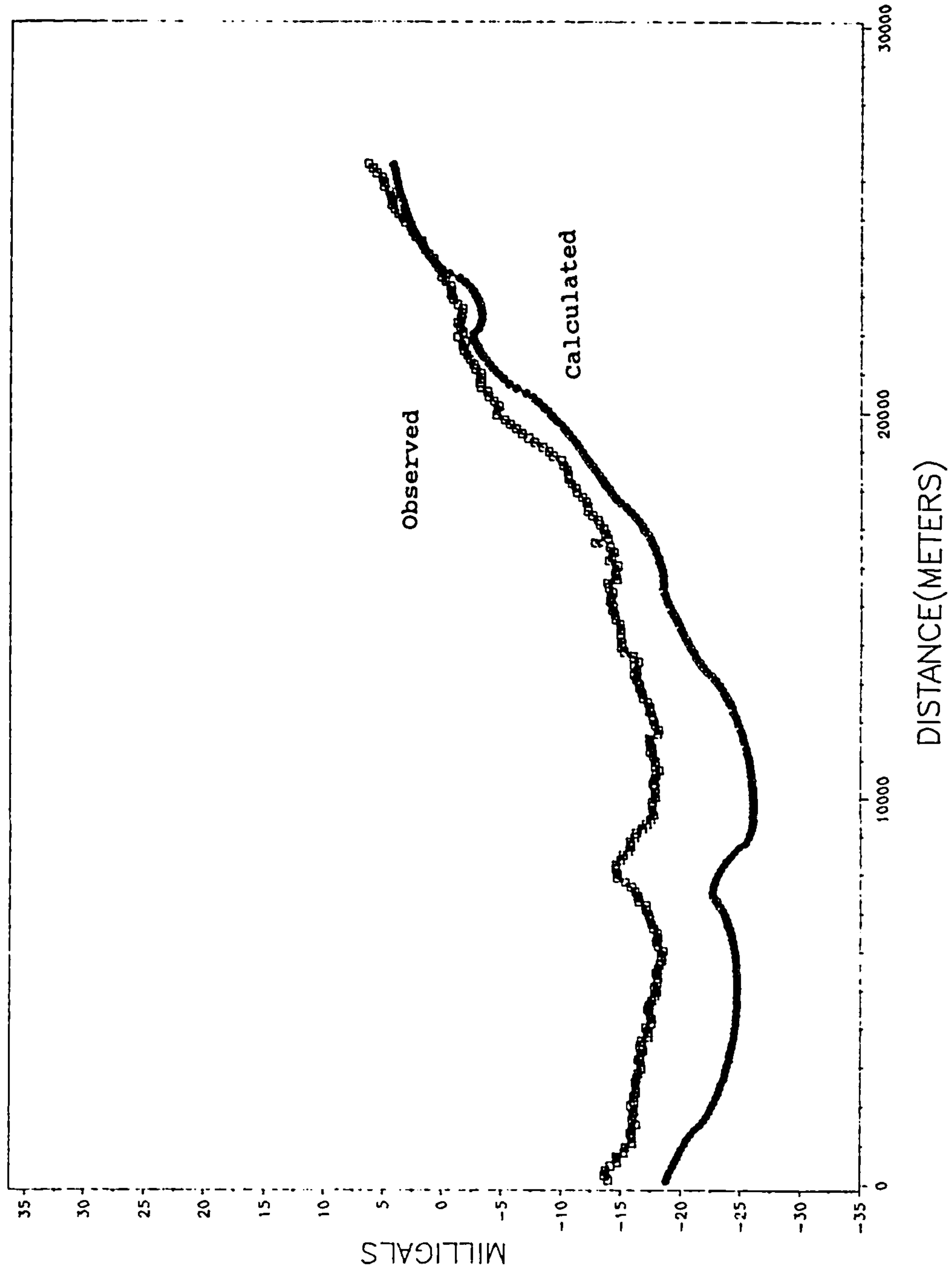
uGn
uMy
Ggn
G
uGn
G
Mv
wG
0
-10000
-20000
-30000
DEPTH (METERS)
0
10000
20000
30000
DISTANCE (METERS)

3


Calculated
Observed
MILLICALS
DISTANCE(METERS)
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
10000
20000
30000


uGn
wG
uMy
Ggn
G
uGn
G
Mv
Basement
0
-10000
-20000
-30000
DEPTH (METERS)
0
10000
20000
30000
DISTANCE (METERS)

4


Observed
Calculated
MILLIGALS
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
0
10000
20000
30000
DISTANCE(METERS)