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A Geophysical and Geological Study of the Farmville Triassic Basin

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A GEOPHYSICAL AND GEOLOGICAL STUDY OF THE FARMVILLE TRIASSIC BASIN

by

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ABSTRACT

The Farmville basin is one of many Triassic basins which are found along the eastern coast of North America, and is the largest of the central string of basins in Virginia. Metavolcanic and metasedimentary rocks of the Chopawamsic Formation, as well as felsic intrusives are the primary lithologies surrounding the basin. A detailed gravity survey was conducted along six roads that trend approximately NW-SE, across the basin. Geologic, gravity, magnetic, and radiometric data were used to develop a kinematic model. Gravity anomalies were isolated using two-dimensional harmonic analysis methods to isolate the local, and regional anomalies. This analysis indicates that all the gravity anomalies are a result of structures that lie within the upper 8 kilometers of crust. Results of gravity modelling indicate that the basin is a fault controlled half-graben with an east dipping border fault, and that the basin is relatively shallow. Maximum depth of the basin, occurs along State Road 636, and is less than 1 kilometer. Modelling further suggests that the deepest portion of the basin is opposite the border fault, and is a result of the master (primary) fault laying underneath the basin rocks. In addition to the kinematic model, this study provides evidence of unique geologic features, such as a diabase/granophyre dike that has a maximum width of 688 meters.

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Finally, I am dedicating this thesis to my two grandfathers, Bruce Thomson and Hatcher James, who passed away before the completion of my thesis.

TABLE OF CONTENTS

LISTING OF TABLES

LISTING OF FIGURES

LISTING OF PLATES

CHAPTER 1

INTRODUCTION

Early Mesozoic sediments were deposited in a series of fault bounded troughs, during the breakup of Pangea. The sediments deposited in the Mesozoic age troughs on the east coast of North America are considered part of the Newark Supergroup (Cornet, 1977). Current and past geological and geophysical surveys and studies have been made of the Mesozoic age troughs. Several theories explaining the origin of Mesozoic age troughs or basins have been proposed by many authors (Russell, 1892; Lindholm, 1978; Ratcliffe and Burton, 1985; Swanson, 1986). The data used to develop and support the formation of smaller basins and/or troughs is based on the mechanisms from larger basins, such as the Newark-Gettysburg (Ratcliffe and Burton, 1985). That is why geologic and geophysical evidence from smaller Mesozoic basins is a necessity if existing "unifying" theories are to be substantiated. "Unifying" theories, such as Lindholm (1978) or Ratcliffe and Burton (1985) imply that a particular sequence of geologic events or mechanisms controlled the formation of all eastern North American Mesozoic basins.

The Farmville Basin is exposed in Buckingham, Prince Edward, and Cumberland Counties, Virginia (Figure 1). The Farmville basin exceeds 43 kilometers in length, and has a

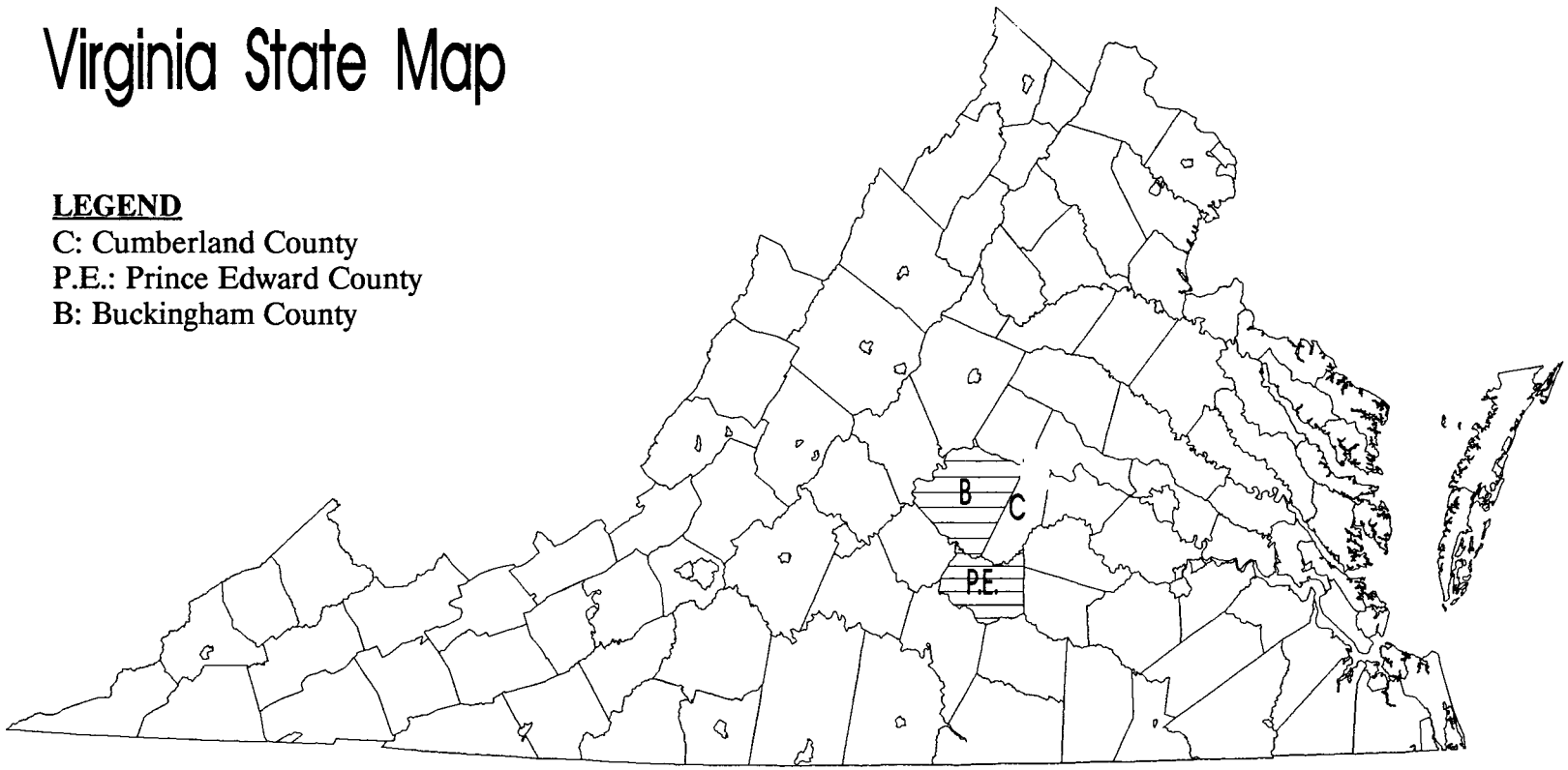
maximum width of 16 kilometers (Figure 2). This basin was chosen for a geological and geophysical study because of its size, and the limited number of detailed geologic and geophysical investigations in the area. Geologic mapping was conducted to obtain a general understanding of the lithologies and structures in the study area. The geophysical surveys provided data that was used to interpret the subsurface lithologic and structural relationships. In addition, the geophysical data was a tool for identifying surface lithologies. This was possible because lithologies in the area have unique gravity-magnetic-radiometric signatures.

This thesis has three primary objectives. The first objective is to define distinct geologic and geophysical features within the study area. To accomplish this objective detailed field mapping and gravity readings were performed along the roads (profiles) shown in Figure 2. The profiles were chosen to reveal the greatest structural information given the constraints of this study. The second objective of this study was to develop a kinematic model to explain the formation of the Farmville Basin. The kinematic model presented is based on field data gathered and analyzed during this study, as well as information from previous studies(Johnson and others, 1985; Marr, 1980a, 1981; Brown, 1969; Wilkes and Lasch, 1979). The final objective was to compare and contrast the kinematic model from this study with existing models.

Figure 1: This figure is the state map of Virginia. The study area is located in the counties highlighted by letters. Counties found in the study area are: Prince Edward, Cumberland, and Buckingham. A more detailed view of the study area is given in Figure 2.

Virginia State Map

LEGEND
C: Cumberland County
P.E.: Prince Edward County
B: Buckingham County



CHAPTER 2

METHODS OF INVESTIGATION

Conclusions of a study are directly affected by the methods used to collect and analyze pertinent data. Gravimetric and geologic field data was gathered during this investigation. After collecting all geophysical and geologic field data, information from a variety of sources was compiled (Marr 1980a, 1981; Brown, 1969; Virginia Division of Mineral Resources Farmville Aeromagnetic Map, 1970a; Virginia Division Of Mineral Resources Dillwyn Aeromagnetic Map, 1970; Virginia Division Of Mineral Resources Farmville Aeroradiometric Map, 1978; Virginia Division Of Mineral Resources Dillwyn Aeroradiometric Map, 1978). All information was analyzed using computer and manual techniques. A hypothesis was developed from these analyzes to explain the mechanisms behind the formation of the Farmville Basin. This chapter is divided into data collection and data analysis.

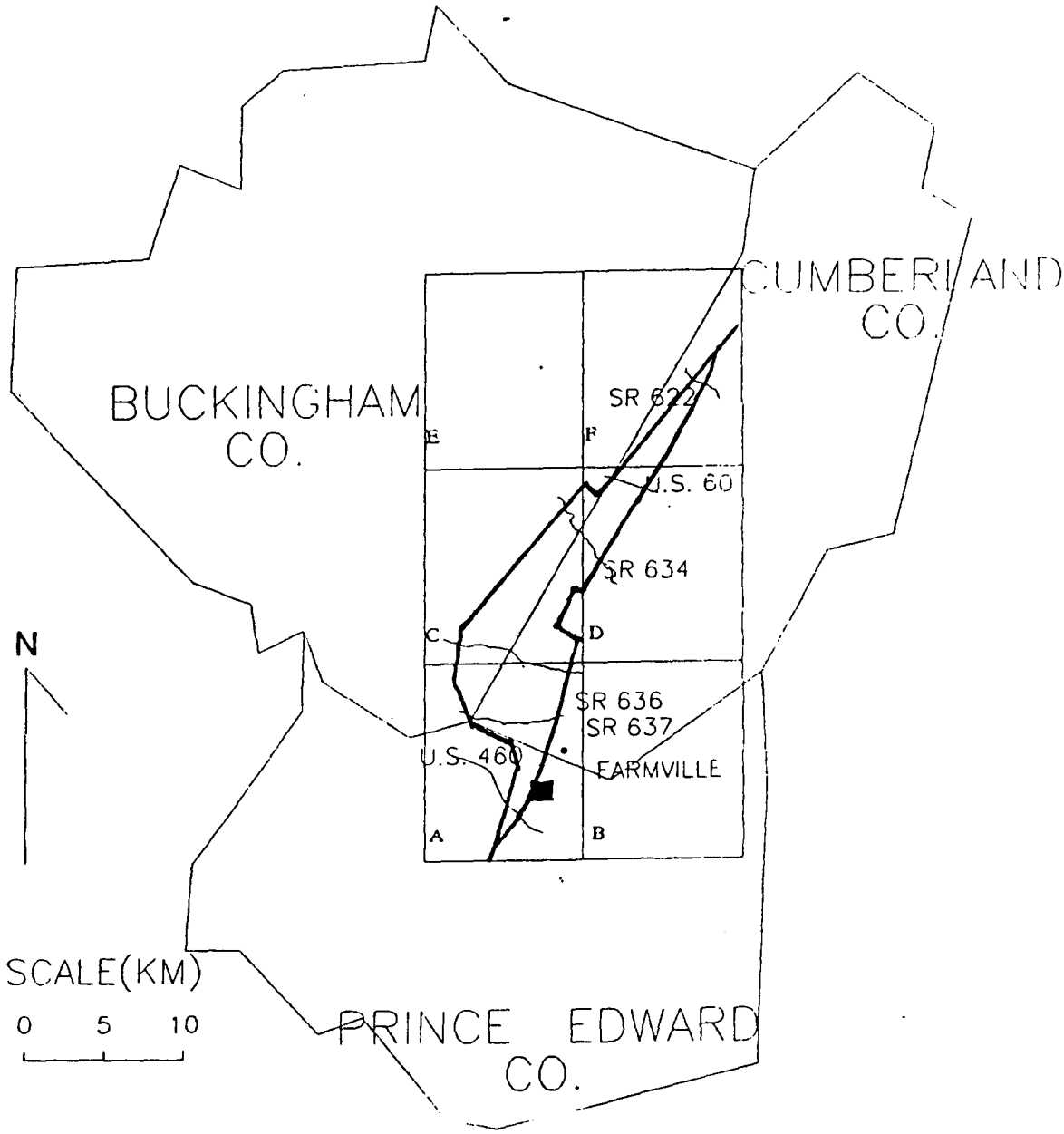
DATA COLLECTION

Established field techniques were used to collect geophysical and geological data. Because field techniques used to collect geophysical and geological data differ they are examined separately.

Figure 2: Shown is a detailed view of the counties in which study area is located. Gravity readings were taken on all roads shown on this map. The letters define the respective 7 1/2 minute quadrangles comprising the study area. The quadrangles comprising the study area are as follows: A: Farmville, B: Rice, C: Willis Mountain, D: Hillcrest, E: Dillwyn, and F: Gold Hill. The bold square within the Farmville quadrangle is the town of Farmville.

Note: State Road 637 does not cross the entire basin, as a result, surveying was conducted off road to connect State Road 637 with Highway 15.

EXPLODED VIEW OF
STUDY AREA



Gravity Data

The field techniques used to collect gravimetric data followed the techniques established by Nettleton (1954). Gravimetric data was gathered along roads trending NW-SE across the basin (Figure 2). The NW-SE trend of the roads is perpendicular to regional geophysical and geologic trends minimizing the affects of regional trends on the local models. A total of 695 gravimetric readings were taken along roads crossing the Farmville Basin. The gravity readings were taken along U.S. Highways 460E and 60, and State Roads 637, 637, 634, and 622 (Figure 2). Each road was surveyed to establish the location and elevation of each gravimetric station. Station elevation was determined using a Geotec-Al 21 automatic level and English Transit Rod. Stations were spaced 61 meters apart. To minimize surveying errors, foresight and backsight readings were taken for each station. Three readings corresponding to the top-middle-bottom cross-hairs of the level were taken for each sighting to determine station spacing. Sighting information was used in conjunction with contour maps to determine station locations. The terminus and beginning of each surveyed road had a benchmark with the exception of State Road 637. In addition, most of the roads had intermediate bench marks allowing errors to be determined for every station. The only exception is State Road 637 (Table 1).

Several benchmarks were available along State Road 637;

however, a benchmark was not available at the road terminus. The nearest benchmark in which to tie to this profile was 7 kilometers from the terminus of State Road 637. A spot elevation was used to end the line. As a result, the last 25 stations on State Road 637 could have a maximum error of +/- 0.3 meters.

Latitude and longitude of gravimetric stations located on the topographic maps were determined using a Numonics 2400 series digitizer. The digitizer cursor was placed over each station and the latitude and longitude, in degrees, were written to an ASCII computer file. Gravity readings were taken at each station in the field, after the above steps.

A LaCoste-Romberg Model-G (#289) gravimeter was used to obtain the gravity measurements. The G-model gravimeter has a range of over 7000 milligals (mgal), a drift rate of less than 1 mgal/month, and a reading accuracy of +/- 0.01 (LaCoste-Romberg, 1978). A gravity reading was taken at the Farmville gravity base station, at the beginning and end of each day. This station was established by Johnson and Ziegler (1972). Using the closed loop technique, a reading was taken periodically at the first station of each loop. Gravimetric readings were reduced to Free Air and Bouguer anomalies using the program GRAVAS FORTRAN (Appendix I-A). The gravity readings from this study, in addition to the published data of Johnson and others (1985), were hand contoured (Plate 1). The

Table 1: Calculated elevation errors for the six roads surveyed.

ELEVATION ERRORS OF SURVEYED ROADS

ROAD SURVEYED	ELEVATION ERROR
U.S. HIGHWAY 460E	-0.14619 cm/station
STATE ROAD 637	+0.30400 m for line
STATE ROAD 636	+0.03056 cm/station
STATE ROAD 634	+0.01111 cm/station
U.S. HIGHWAY 60	+0.00 cm/station
STATE ROAD 622	-0.02586 cm/station

Note: Elevation for State Road 637 could not be calculated for each station because a benchmark was not available at the end of the road.

contour gravity map was digitized using the program DIGIT BAS (Decker, 1987) and contoured at an interval of 1 milligal (mgal) using the program CONTOUR SAS (Appendix II-A). Comparison of the hand drawn and computer generated contour maps showed no discernable differences. This ensured that the computer generated data is a close approximation of the actual gravity field, allowing the data to be used in computer analysis.

Magnetic And Radiometric Data

Magnetic and radiometric data presented in this study was taken from Virginia Division Of Mineral Resources Aeromagnetic 15-minute Maps (Dillwyn, 1970; Farmville, 1970), and Aeroradiometric 15 minute Maps (Dillwyn, 1978; Farmville, 1978). Airborne maps were used instead of ground data because of the extremely erratic readings being obtained from the ground equipment. Both airborne surveys were flown at an altitude of 152 meters above ground level, and used a flight spacing of 0.8 kilometers. The flight lines were flown in an E-W direction. The aeromagnetic and areoradiometric maps are at 1:62,500 scale and are illustrated in Plates 2 and 3, respectively.

Geologic Data

Geologic maps and rectified stream data aided in the development of a kinematic model of the Farmville Basin.

Geologic data was collected during an eight week period in December, January, and February of 1987. The field mapping was done to distinguish different lithologies, to define the basin's margin, and to identify geologic trends (Plate 4). This data was used in determining correlations between geological and geophysical signatures. Field mapping was primarily conducted in streams that parallel the roads shown in Figure 2. The structural features measured included the strike and dip of foliation, bedding, and joints. In addition, lithologic information was recorded for each outcrop.

A rectified drainage map was constructed for the study area (Plate 5). Construction of this map was done to identify significant drainage trends, and to determine if they were geologically controlled. Procedures used in the stream analysis are as follows:

1) Digitizing of permanent streams (blue line) in the Farmville, Willis Mountain, Hillcrest, Rice and Gold Hill 7.5 minute quadrangles.
2) Analysis of data using programs developed to isolate significant azimuthal drainage trends.

Digitization of the stream maps was done using the Numonics 2400 digitizer and the program DIGIT BAS (Decker, 1987). Streams were digitized in a upstream-downstream direction with each stream assigned an identification number. Using the program RECTIFY BAS (Decker, 1988), the digitized streams were divided into straight line segments if the next

stream point varied 5 degrees or more from the previous point.

DATA ANALYSIS

Geophysical and geological data was interpreted using a series of existing programs, and programs specifically developed during the course of this research. The interpreted information was correlated and a kinematic model was developed based on the data. Because the computer programs are crucial to interpretations presented in this study, their purpose and algorithms are explained in the following section.

Reduction Programs

Reduction programs, as defined in this study, are computer programs that perform repetitive corrections to raw data. STATION FORTRAN and GRAVAS FORTRAN are the two reductions programs used to correct the elevation and gravity data, respectively. STATION FORTRAN (I-B) converts station foresight and backsight level readings to elevations. In addition, the program calculates station spacing, total elevation change, and total elevation error for each station. Output from STATION FORTRAN was verified by comparing the program output with hand calculated values for State Road 622. The comparison indicated that STATION FORTRAN generated the correct values and thus was used in determining the same information for the remaining lines.

GRAVAS FORTRAN (I-A) converts dial readings of the

LaCoste Romberg gravity meter (Model G, #289) to Free Air and Bouguer anomalies. The program first converts gravimetric dial readings to observed gravity values. Observed gravity values are corrected for elevation and mass differences between stations. Observed gravity values are then corrected for solar and lunar fluctuations (tides), and instrumental drift. Finally, GRAVAS FORTRAN applies Free Air and Bouguer corrections to the observed data, resulting in the Free Air and Bouguer anomalies for each station. A comparison of the Bouguer anomalies from this study and data from Johnson and Ziegler (1972) was conducted to ensure the gravimeter was properly calibrated. A difference of + 0.02 milligals was determined between the Bouguer values of this study and the Bouguer value of Johnson and Ziegler (1972). The + 0.02 milligal difference remained constant for all the compared readings. This comparison indicates the gravimeter was properly calibrated. The + 0.02 milligal difference between the Bouguer values is attributed to the settling of the base station.

Analysis Programs

Analysis programs, as defined in this study, simplify and group data so that interpretation of the information is possible. UPDW FORTRAN and GRAVMOD FORTRAN are the two analysis programs that were used to interpret the geophysical data. In addition, the programs QUAD BAS, and SNET (Decker,

1988) were used to aid in the analysis of the stream and structural data, respectively.

Two programs were reviewed to isolate regional and local gravimetric anomalies. An evaluation was conducted of each program to determine the best program, because of differences in the methods used to analyze the data. UPDW FORTRAN and UDD FORTRAN (Appendix I-C) use algorithms based on two dimensional harmonic analysis (Bhattacharayya, 1965), and coefficient averaging (Henderson, 1960), respectively. Both programs are able to calculate upward/downward continuation, and 2nd derivative values from potential field data. Each method has advantages and disadvantages; however, after thorough evaluation it was determined the two-dimensional harmonic analysis method was best suited for this study. A complete discussion of the evaluation is given in Appendix I-C. A upward/downward continuation and second derivative map of the gravimetric data was produced using UPDW FORTRAN. The contour maps of the gravity data was produced to obtain evenly spaced gravity nodes. CONTOUR SAS (Appendix I-F) gridded the raw data, then produced a contour map from the data. After examining the contour maps for errors, the gridded data was analyzed using UPDW FORTRAN.

Slight differences exist between modules used to perform upward/downward continuation, and the nTH vertical derivative in UPDW FORTRAN. The theory and methodology of this method is given in Appendix I-C. Two tests were developed to verify

that output from UPDW FORTRAN was correct. Each test used the potential field data of Tasubi (1959).

First, the potential field data of Tasubi (1959) was continued upward +15.9 kilometers, using UPDW FORTRAN. The output generated by UPDW FORTRAN was contoured and compared to the hand calculated values of Tasubi (1959), Appendix I-C. The comparison showed that differences between the two maps is negligible. To test the nTH vertical derivative algorithm of UPDW FORTRAN, the 1st vertical derivative of Tasubi's data was calculated. The data was contoured and compared to the same map in Agarwal's dissertation (1968). The comparison showed little difference between the two maps. Both tests indicated the algorithms used in UPDW FORTRAN produced valid and usable output.

The GRAVMOD FORTRAN program (Appendix I-D) allows the user to create a two-dimensional model of the subsurface geology. The input data is based on surface lithologies and their associated densities. The underlying principle and theory of this program is based on methods developed by Talwani (1964, 1965). Talwani's method allow a geophysist to approximate subsurface geology by polygons of an assigned density. Further explanation of the theory and method are given in Appendix I-D. This program was checked by producing a simple polygonal model. The results of the test proved the program produced accurate results.

In order to analyze the rectified stream data, QUAD BAS

(Appendix I-E) was developed to isolate, and identify significant drainage trends within the area. The program's algorithm is based on a paper by Abdel-Rahman Hay (1978) that deals with sampling and statistical analysis of multimodal orientation data. In this paper, azimuthal trends are identified using randomly spaced circular sampling units call quadrats. Significant trends are then determined using Possoin's distribution. The algorithm was modified in order that the analysis of the data could be done with randomly spaced square quadrats. In addition, equally spaced circular or square quadrat analysis could be chosen with azimuthal trends and significant trends identified for each quadrat. Discussion of the theory involved in this type of analysis is continued in the Appendix I-E.

To help in the analysis of the structural data the program SNET (Decker, 1988) was used. This program projects structural data onto a stereo graphic net, either Wulff or Schmidt. Once projected onto the net the data is contoured, and T statistics can be performed. The program also includes a file and record maintenance option.

Graphing programs were developed to present the analyzed data in an understandable form. The majority of these programs are written in SAS, with the remainder of the graphical programs written in BASIC. These programs include MODEL SAS, TWOLINE SAS, and CONTOUR SAS. Listings of these programs are found in Appendix I-F along with a brief

discussion of the function of each program.

CHAPTER 3

GEOLOGY AND GEOPHYSICS

Current ideas for the formation of the Newark Supergroup rift basins all involve reactivation of Paleozoic age structures. The basin geometry is invariably controlled by the basement fabric (structural grain); however, little research has been done to understand the internal geometry and true three-dimensional shape of the basins'. This study attempts to develop new data that might be used in the evaluation of mechanisms responsible for the formation of the Newark Supergroup.

PREVIOUS WORK

The Farmville Basin is one of many Mesozoic age basins found in the eastern United States. It is the largest of five basins composing the central system of Mesozoic basins in Virginia (Johnson, 1981). The study area is located in the Gold Hill, Willis Mountain, Hillcrest, and Farmville quadrangles (Figure 2). Several geophysical studies and surveys were conducted within the area of study, including aeromagnetic (Virginia Division of Mineral Resources (VDMR), 1970; 15-minute Farmville and Dillwyn maps), aeroradiometric (VDMR, 1978; 15-minute Farmville and Dillwyn maps), and gravity (Johnson et al., 1985) surveys. The airborne

surveys had flight line spacings of 0.8 kilometer at 152 meters above ground level. A regional gravity map (Johnson and others, 1985) covered approximately 5, 15 minute quadrangles and contains 1202 gravity stations including the only published lithologic map of the entire Farmville Basin.

William Barton Rodgers (1859) was the first person to describe the various lithologies in and around the Farmville Basin. Since that time, a majority of geologic studies in the vicinity have been reconnaissance in nature (Russell, 1892; Jonas, 1932; Espenshande and Potter, 1960). Two exceptions are the publications of Brown (1969) and Marr (1980).

A geologic map of the Dillwyn 15-minute quadrangle that includes the Gold Hill 7.5 minute quadrangle was prepared by Brown (1969). A geologic map of the Willis Mountain 7.5 minute quadrangle was prepared by Marr (1980). These two publications account for the majority of the known geology, within the study area. The stratigraphic columns presented in these two publications are different, and thus posed a problem as to the stratigraphic sequence of strata. Table 2 is a proposed stratigraphic column for the study area. This column is based on the publications by Brown (1969) and Marr (1980, 1981), as well as mapping conducted during this investigation. Rocks from oldest to youngest in the stratigraphic column are the Chopawamsic Formation, "Granitic" Gneiss Undifferentiated (Hatcher Complex (?)), Arvonia Formation, Triassic Rocks, Diabase/Granophyre dikes, and Quaternary alluvium.

Table 2: Tentative stratigraphic correlation of lithologies within the study area. The stratigraphic column used for this study is based on stratigraphy of Marr (1980, 1981), Brown (1969), and geologic mapping conducted during this investigation.

ERA	PERIOD	Brown (1969)	Marr (1980)	Present Study
CENOZOIC	QAL	Alluvium	Alluvium	Alluvium
MESOZOIC	JR	Diabase Dikes	Diabase Dikes	Diabase/ Granophyric Diabase
	TR	Newark Supergroup	Newark Supergroup	Newark Supergroup
PALEOZOIC	ORD	Arvonia Formation	Arvonia Formation	Arvonia Formation
		Hatcher Complex	?	"Granitic" Gneisses (Hatcher Complex Equivalent ?)
	?	?	Pegmatite	Pegmatite
	?	Ultramafic Rocks & Hornblende Metadiorite	?	?
	C	Evington Group (?) & Rocks Of Uncertain Age	Chopawamsic Formation	Chopawamsic Formation

Note: The letter abbreviations in this table are defined as follows: C-Cambrian, ORD-Ordovican, TR-Triassic, JR-Jurrasic, and QAL-Quaternary. ?: Unknown

STRATIGRAPHY

The type section of the Chopawamsic Formation lies along Chopawamsic Creek near Quantico, Virginia (Southwick et al., 1971), and is estimated to be 1829 meters thick. Pavlidies (1980), and Conley and Johnson (1975) traced the formation from northern Virginia to the study area. Marr (1980) described the various lithologies within the Chopawamsic Formation, and defined a lower and upper member. Only the upper member is found within the study area. This formation has a maximum age of Early to Middle Cambrian (Tilton, 1970; Higgins, et al., 1977; Glover, 1975), and is comprised primarily of metavolcanic and metasedimetary rocks.

Chopawamsic Formation

The upper member of the Chopawamsic Formation is a biotite gneiss that ranges in thickness from 3 to 31 meters. The unit is interlayered with amphibolite gneiss. The biotite and amphibolite gneisses compose nearly 90 percent of this member. The remaining 10 percent of the upper member is comprised of felsic volcanics (rhyodacites), talc-tremolite schists, and ferruginous quartzites. These rocks are primarily found along the western margin of the basin; although, numerous outcrops are found farther to the south. The following descriptions of the above rocks units were taken from Marr (1980, and 1981) with modifications.

Table 3: General geophysical characteristics of lithologies in the area.

ERA	PERIOD	GEOPHYSCIAL CHARACTERISTICS OF LITHOLOGIES WITHIN STUDY AREA
MESOZOIC	TR | JR	DIABASE/GRANOPHYRIC DIKE 1. High Magnetics 2. High Gravity 3. Low Radiometrics 4. density = 2.88 g/cm^3
	TR	TRIASSIC ROCKS 1. Low Magnetics 2. Low Gravity 3. Low Radiometrics 4. density = 2.55 g/cm^3
PALEOZOIC	ORD	"GRANITIC GNEISS" 1. Low Magnetics 2. Low Gravity 3. High Radiometric 4. density = 2.775 g/cm^3
	C	CHOPAWAMSIC FORMATION 1. High Magnetics 2. High Gravity 3. Low Radiometrics 4. density = 2.845

Note1: The letter abbreviations in this table are defined as follows: C-Cambrian, ORD-Ordovican, TR-Triassic, JR-Jurrasic, and QAL-Quaternary.

Note2: The terms High, and Low are relative terms. In other, words they are relative to the surrounding rock units. For example, if a Triassic Rocks were in lithologic contact with the Chopawamsic Formation then magnetic, gravity, and radiometric readings of the two units would display the characteristics in this figure.

The biotite gneiss is medium to fine-grained, moderately foliated, and light gray to gray in color. Quartzo-feldspathic bands found within this unit are interlayered with biotite layers. Some of the biotite layers contain amphibole. Composition of this unit ranges from granitic gneiss to biotite-quartz-feldspar gneiss. This unit is not resistant to weathering and occupies areas of low topography. Outcrop of the biotite gneiss is predominately limited to the Willis Mountain and Farmville quadrangles. In the field this rock is usually highly weathered; however, fresh outcrops contain pegmatitic bands, ranging in size from a few centimeters to nearly a half a meter. The pegmatitic bands are a distinctive feature of this unit. Generally, quartz veins are absent from this unit; although, veins are concentrated in some areas. This unit usually displays low magnetic, intermediate gravity, and low radiometric values in comparison to the surrounding rocks (Johnson, 1981), Table 3, and grades into an amphibole gneiss.

The amphibole gneiss is medium to coarse-grained, banded, and greenish-black to black in color. The banding in this unit is composed of tremolite-cummingtonite or hornblende-cummingtonite and quartz calcic oligoclase, biotite, epidote, and garnet. Talc-tremolite schistose bodies range in composition from talc-tremolite schist to actinolite-chlorite schist. This unit is generally found west of the basin and is more resistant to weathering than the

biotite gneiss, occurring in areas of rolling topography. The outcrop of this unit is often unweathered. Minor folds are common. Banding is not as distinctive in this unit as in the biotite gneiss. Light-green, quartz-epidote lenses are also characteristic of this unit. High magnetic and gravity values, and low radiometric values are the geophysical characteristic of the unit. Unconformably overlying the Chopawamsic Formation is the undifferentiated "granitic" gneiss.

Granitic-Gneiss Undifferentiated

The "granitic" gneiss is thought to be the equivalent of the Hatcher Complex Undifferentiated (Brown, 1969). Brown (1969) and Mose (1980) assign an age of 454 $\pm$ 9 millon years to the Hatcher Complex. Surface exposure of these rocks occur in the northern and eastern portions of the study area. Generally, these rocks are medium grained, strongly lineated, and light-gray to tan in color. The term "granitic" was used to describe a group of intrusive rocks ranging in composition from granite to quartz diorite. The gneisses have a low resistance to weathering; therefore, are found in areas of low topography. In the field this unit ranges from highly weathered to fresh, and is strongly banded and foliated. No distinguishing characteristics exist, except for the interlocking granular patterns associated with intrusive rocks. When weathered the unit looks very similar to the

granitic gneisses of the Chopawamsic Formation. Geophysical characteristics include low magnetic and gravity values, and high radiometric values. Brown (1969) indicates that basal conglomerates of the Arvonia Formation uncomformably overly the granitic intrusives; therefore, the Arvonia is the younger of the two lithologies.

Arvonia Formation

Fossils indicate that the Arvonia Formation ranges in age from 440 to 460 million years (Mose, 1980; Mose and Nagel, 1983). Within the study area, this formation consists of the following rock units: quartz-mica schist with interlayered micaceous quartzite and quartz mica conglomerate, quartzite and kyanite quartzite, and porphyroblastic garnet mica schist. These rocks are found in the extreme northwestern part of the study area. Marr (1980) describes the conglomeritic quartz-mica schist as medium to coarse grained, moderately foliated and lineated, light-gray to gray schist with blue quartz found in some conglomerates. Kyanite occurs locally as massive lenses and can make up as much as 30 percent of the unit. The quartzite/kyanite quartzite unit is medium to coarse-grained, banded and cross-bedded, and is light-yellow to gray in color (Marr, 1980). This unit is resistant to weathering and found in areas of higher relief. This unit is resistant to weathering and underlies along NE-SE trending linear ridges formed by isoclinal synclines. The highest

magnetic values within the study area are found within this formation. The Arvonia Formation has intermediate radiometric and gravity values as compared to other lithologies within the study area. This formation is not used as a unit in the gravity models, produced in this study, because it lies outside the range of the surveyed gravity lines. An unconformity exists between the Arvonia Formation and the Triassic age rocks.

Newark Group

Unconformably overlying the metamorphic basement are the Triassic rocks of the Newark Supergroup. Basal strata are Carnian in age as determined by Robbins (1985). This age date is based on palynoflora data found in the basin. This places rocks of the Farmville basin, along with rocks in the Richmond and Taylorsville basins, as the oldest rocks in the Newark Supergroup (based on palynoflora data; Cornet, 1978). The rocks show a general fining away from the basin perimeter (Plate 4). According to Smoot (1985), this is indicative of a closed basin. He defines a closed basin as having no drainage outlet. In other words, all surface drainage and groundwater entering the basin evaporates. This is not to say the basin remained closed throughout its entire depositional history, since the erosion of hitherto undetermined strata overlying the presently exposed basin is not known.

Czechowski (1982) suggested that the paleoenvironment

during deposition of these rocks was more arid than the present climate. His conclusions are based on relative percentage of feldspar and lithic fragments in the Triassic rocks as compared with Quaternary stream sands in the basin. He also showed rocks within the basin have undergone less than 45 kilometers of transportation. Breccia-conglomerate, arkosic conglomerate, arkosic sandstone, and siltstone/shale are the four lithologies found in the basin.

The breccia-conglomerate is a fine to medium-grained, brown to reddish-brown rock with angular to subangular clast ranging from pebble to boulder size. In general, clasts are comprised of metamorphic rocks from the Chopawamsic and Arvonia Formations, and "granitic" gneiss undifferentiated. Clast imbrication indicate transportation of sediment comprising this unit was from the northwest (Marr, 1981; Czechowski, 1982).

The arkosic conglomerate is medium-grained and light brown to light gray in color, and has an arkosic sandstone matrix. Clasts are subangular to subrounded ranging from pebble to boulder size, and are predominately metamorphic in composition (Johnson, et al., 1985). Czechowski (1982) suggested that the clasts were transported in a north-south direction with source rocks laying farther than 43 kilometers north of the basin.

The arkosic sandstone is medium-grained, thick-bedded, and brown to light-brown in color with interlayers of

red-brown sandstone, siltstone, and shale (Johnson, et al., 1975). Source of this unit is thought to lie east of the basin (Cezchowski, 1982). Siltstone-shale is the youngest sedimentary unit in the basin. These rocks are light-gray in color and are interbedded with red-brown sandstone, quartz-pebble conglomerate, and dark-gray mudstone and coal. This unit is thought to have been deposited in a lacustrine environment (Cezchowski, 1982). The Mesozoic rocks are distinctive because of their low gravity, magnetic, and intermediate radiometric values. These rocks are cross-cut by diabase/granophyre dikes.

Dikes

The diabase dikes are the youngest rocks of interest in the area and are thought to be late Triassic to Jurassic in age (Marr, 1981). These dikes are medium to fine-grained, and light-gray to dark-gray in color. Several dikes have been found to contain granophyres (Rogan, pers. comm.). The granophyres are found predominately in larger (thicker) dikes. Compositionally, larger dikes seem to be of diabase composition along their margins with granophyre percentages increasing as one progresses towards their center. Two sets of dike trends are recognizable in the area. A majority of the dikes trend between N12^{o}W and N25^{o}W, with a second minor set trending between N and N20^{o}E. Dikes in the area cross-cut Triassic Rocks, and the basin margin. This puts a cross

cutting relationship time constraint on sedimentation.

GEOLOGICAL DATA

The known structures from publications of Brown (1969) and Marr (1980), as well as structural data gained from this study give valuable information as to structures within and outside the basin. Knowing the structural regime of the area puts constraints on gravity models.

Folds

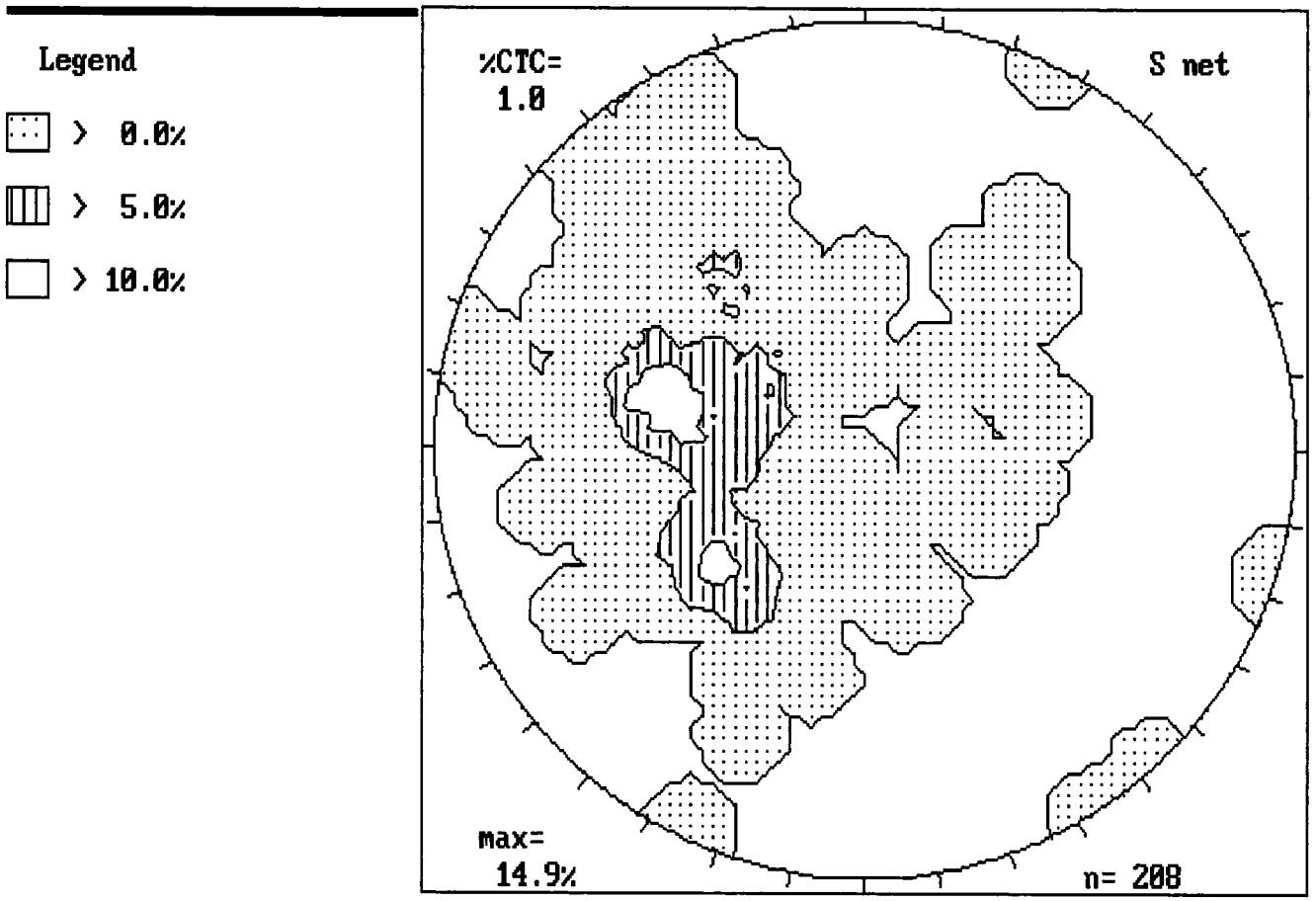
The scope of this thesis is limited to understanding the structural control of Mesozoic events imposed by Pre-Mesozoic structures. Previous studies discuss three phases of folding (Marr, 1980). The cumulative effect of these folding phases is the NE regional trend. Therefore, the geologic information collected during this study is limited in scope.

Foliation

Figure 3 is a compilation of 208 foliation measurements throughout the study area. Two foliation pole maxima are shown on the stereo net. The two maxima are separated by 35 degrees. The dominant pole concentration ('A') is in the NW quadrant of the net. This group of poles are representative of foliation that has an average strike of N15^{o}E and dip of 35 degrees southeast. The secondary concentration of poles ('B')

Figure 3: Contour plot of 208 poles to foliation from this study and the geologic map of Marr (1980). The graph is a contour plot of foliation poles. The maxima represent foliation planes located at N15E 35 degrees SE, and N40W 35 degrees NE. Pole maxima are separated by 35 degrees. The distribution of pole clusters shows that the general modal average foliation plane strikes north-north east and dips to the south east.

One Percent Total Area Contour Of Poles To Foliation



is representative of foliation that has an average strike of N40W and dip of 35 degrees northeast.

Bedding

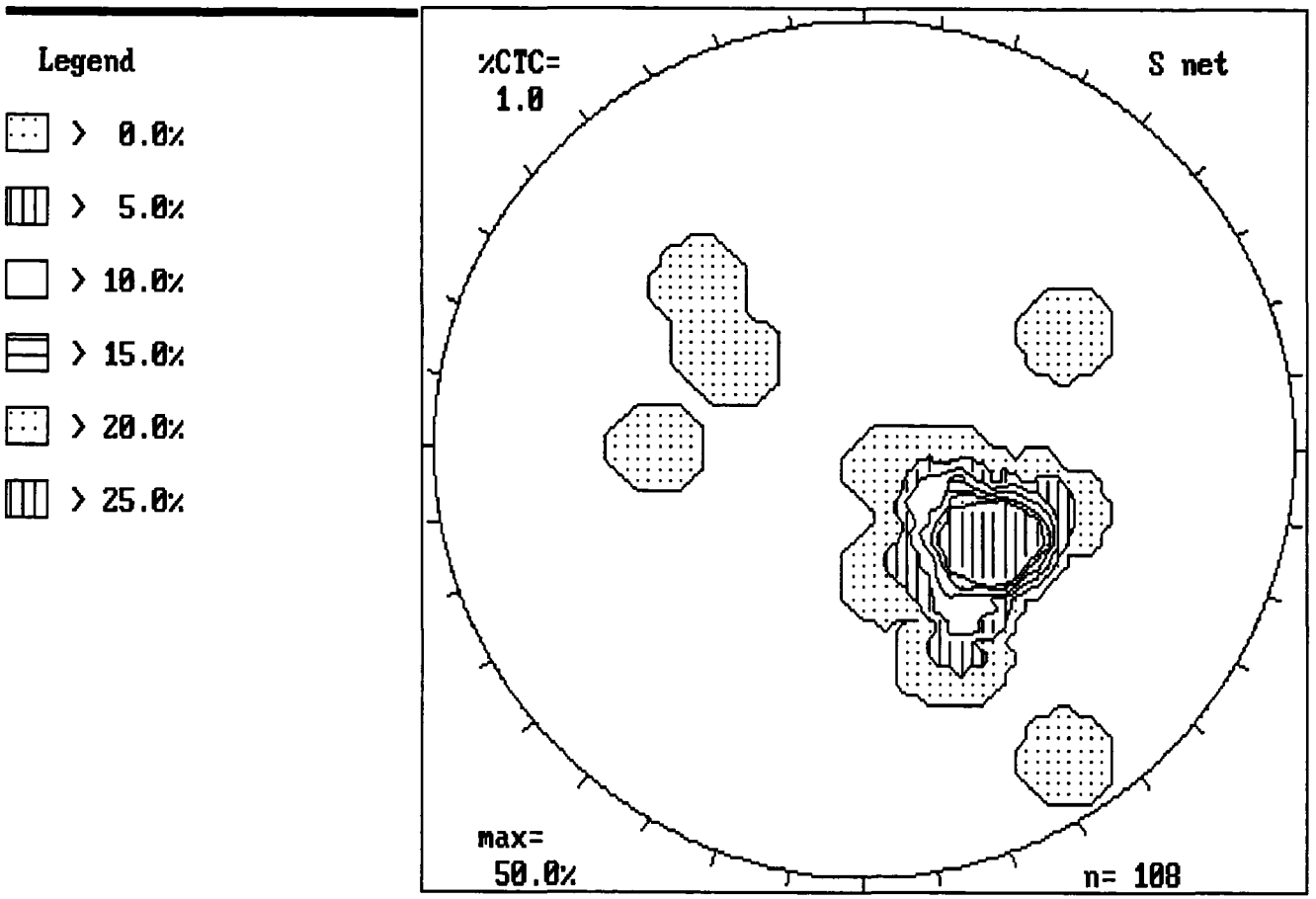
Poles of bedding within the basin show little variance (Figure 4). Bedding within the basin has an average strike of N45E and dip of 30 degrees northwest. Dips within the basin generally decrease from east to west. It should be noted that these dips vary along profile sections. A pattern of steep to shallow to steep is recognizable. This is best documented along the profile on State Road 636 (Plate 4).

Joints

Two systematic joint sets are found within the area (Figure 5). The joint set with poles in the NE quadrant of the stereo net have an average strike of N40W and an average dip of 50 degrees southwest ('A'). A second cluster of joint poles lay near the perimeter of the net in the NW quadrant ('B'). This joint set has an average strike of N70^{o}E and dip of 80 degrees southeast. The contour projection indicates a third joint set may be present. In the NE and SW quadrants of the stereo net there are a group of poles that lie on the net's perimeter. This joint set has an average strike of N20^{o}W and near vertical dips.

Figure 4: Contour plot of 108 poles to bedding taken in the Farmville Basin, during the course of this investigation. The stereo graphic projection is a contour plot of the poles to bedding and indicates that bedding in the basin has an average strike of N45E and dips 30 degrees northwest.

One Percent Total Area Contour Of Poles To Bedding



Rectified Stream Patterns

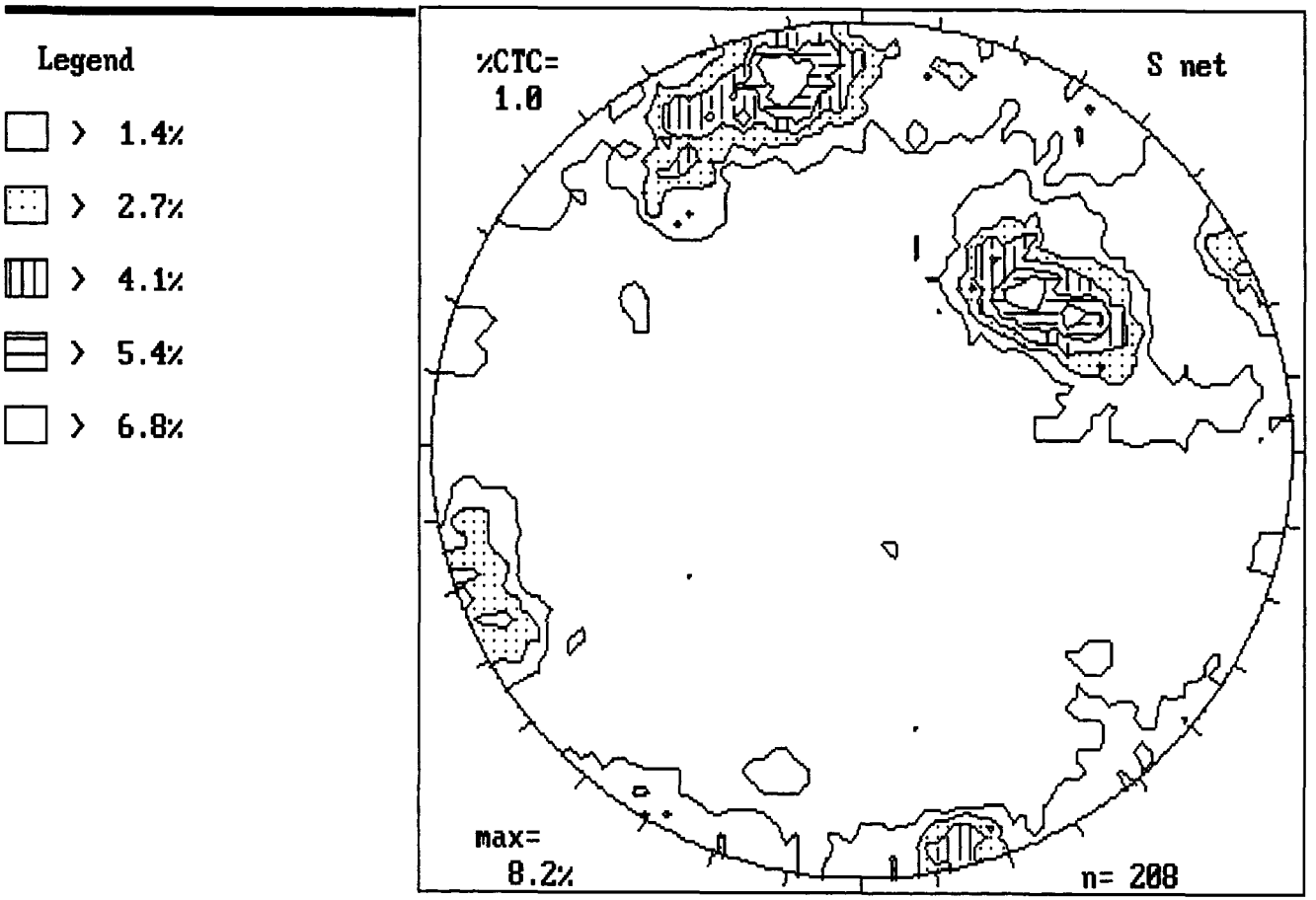
A rectified stream analysis was correlated with geological and geophysical trends to identify significant drainage trends, and to aid in the development of a kinematic model (Plate 5). This analysis is based on the underlying assumption that the stream drainage is structurally controlled. There is no validity to conclusions drawn from this type of analysis without this assumption. In this study, it is assumed streams are structurally controlled because of the near rectilinear stream segments.

Studies of stream patterns have been used in the identification of drainage trends and associated geologic and/or geophysical trends. This enables past geologic events to be reconstructed (Scheidegger, 1980 a, 1980 b; Cox and Harrison, 1979; Venkatakrishnan, 1984).

At least three significant trends have been identified from analysis of rectified stream data (Figure 6). These trends, listed in order of prominence, are NNW to SSE (160 to 180 degrees), NW to SE (120 to 130 degrees), and NE to SW (030 to 040 degrees) The most prominent trend occurs in the azimuthal range of 160 to 180 degrees.

Figure 5: Contour plot of 208 joint poles taken in this study from various areas within the area. From this plot one may interpret two joint sets; one at N40°W-50 degrees SW, and the other at N70°E- 80 degrees SE.

One Percent Total Area Contour Of Poles To Joints



GEOPHYSICAL DATA

Gravity Data

The Bouguer Gravity anomaly map of the Farmville Basin (Plate 1) is prepared from two sets of gravity data. The first contains 700 detailed gravity readings taken along six roads at station spacings of 61 meters (Figure 2). All readings from this set either lie within the basin or within a 1.609 kilometers circumference of the basin's border. An additional 700 gravity readings were obtained from data of Johnson and others (1975). These readings lie outside the 1.609 km circumference of the basin's border.

The gravity map (Plate 1) defines both regional and local anomalies. Regionally, a general pattern of high gravity anomalies is evident on the west, and low anomalies occur on the east side of the basin. A strong NE-SW regional trend is evident on the gravity map. An E-W orientation of the regional trend becomes dominant in the southern portion of the map. Letters A-E, on the map designate local gravity anomalies.

Magnetic Data

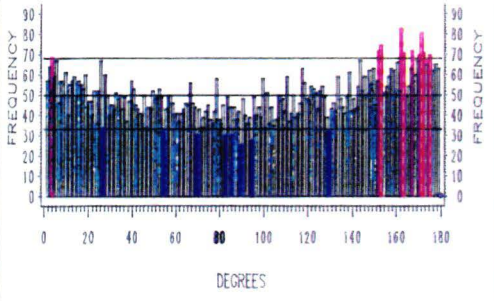
The aeromagnetic map (Plate 2) show distinct regional and local trends (Virginia Division Of Mineral Resources Aeromagnetic 15-minute Maps; Dillwyn, 1970; Farmville, 1970). Magnetic anomalies in the area decrease in a NW-SE transverse. In addition, the anomalies indicate a strong NE-SW trend.

Figure 6: Plot of significant stream trends within the study area. The plots were generated for each 7.5 minute quadrangle within the study area. In addition, one plot has been generated to show the sum total of drainage trends. The degrees at the bottom of plots is the azimuthal range of streams. If peaks lie above the upper deviation bar it is deemed to be significant (Red Bar). Significant troughs lie below the lower deviation bar (Blue Bar).

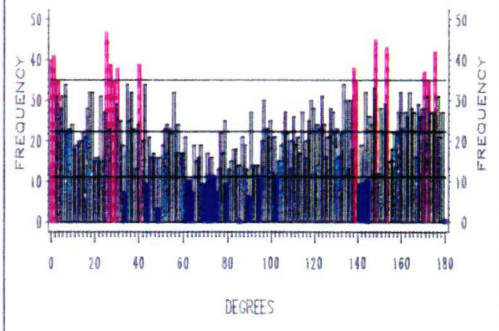
Upper Bar : Upper Third Deviation (Red Bar)
Middle Bar: Zero Deviation (Hollow Bar)
Lower Bar : Lower Third Deviation (Blue Bar)

STREAM TREND ANALYSIS

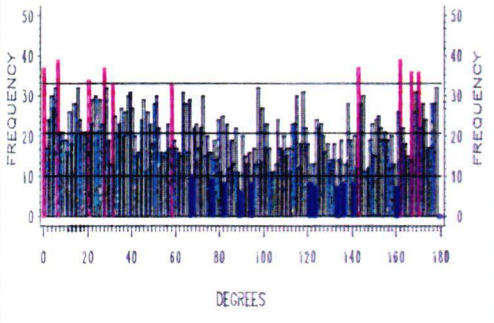
COMBINED



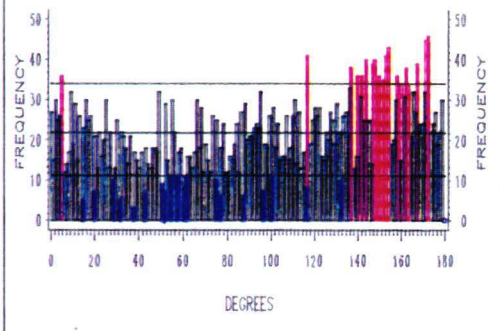
GOLD HILL



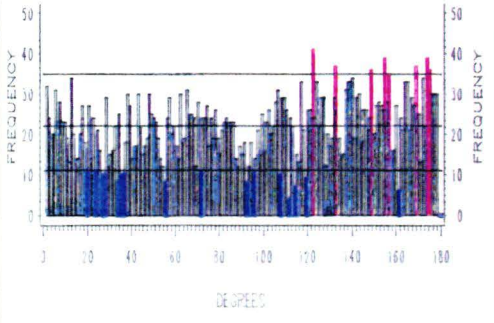
WILLIS MOUNTAIN



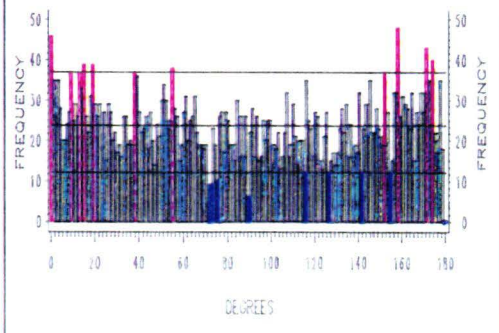
HILLCREST



FARMVILLE



RICE



Linear features and low closures, designated A-C on Plate 2, are the local anomalies identified on the magnetic map.

Radiometric Data

Three domains can be identified on the Radiometric Anomaly map (Plate 3). NW-SE profiles across the basin indicate radiometric anomalies west of the basin have a range of 100 to 200 count-per-second (cps). Radiometric anomalies generally have a range of 300 to 400 cps in the basin, and are higher than 400 cps east of the basin (Virginia Division Of Mineral Resources Aeroradiometric 15 minute Maps (Dillwyn, 1978; Farmville, 1978).

PRELIMINARY GEOLOGIC INTERPRETATION

Before gravity modelling, a geologic interpretation is necessary, using the information presented in this chapter, to properly constrain the models. Without these constraints the gravity models could have an infinite number of solutions. The geologic interpretation will start with regional features, and terminate with a discussion of local features.

Regional Features

The regional NE-SW trend is the one feature common to all the geophysical anomalies, and geologic structures of the area (Plate 1,2,3; Figures 3, 4, 5). No other feature is common to both the geophysical and geological data. By closely examining

Figure 7: This is the Bouguer gravity field, shown on Plate 1, at the continuation level of +0.64 kilometers. The letters on this figure show the location of the following geologic features:

A: Whispering Creek Anticline

B: Diabase/Granophyre Dike

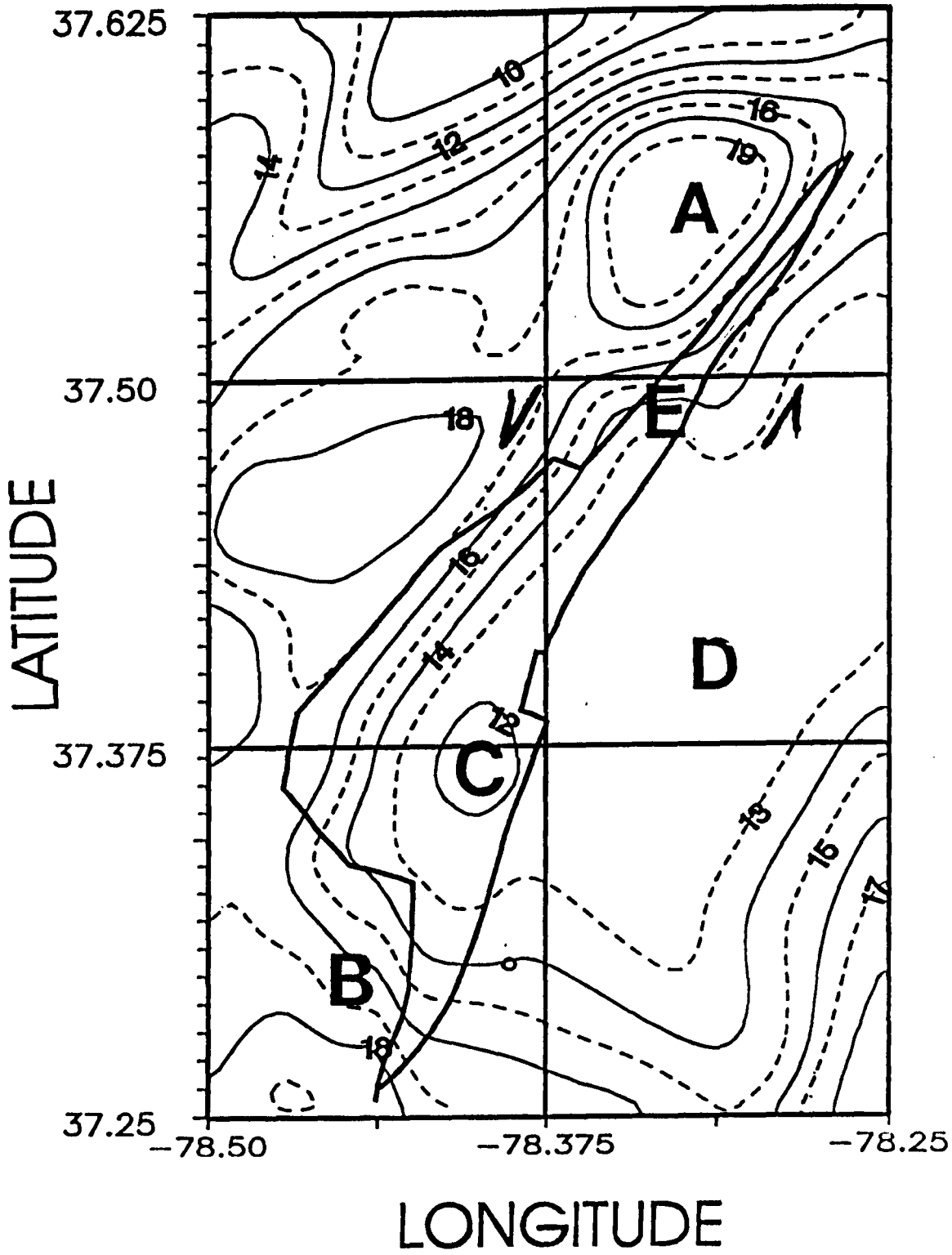
C: Deepest Part Of Basin

D: "Granitic" Gneiss Undifferentiated

E: Possible Shear Zone (direction of shear shown by arrows)

Note: Variation in gravity anomalies indicate that differences in density of the rocks can be seen at this level.

GRAVITY FIELD AT 0.64 KILOMETERS



the geophysical and geological data conclusions pertaining to the regional geology become apparent. Gravity and Magnetic maps are potential field data. This means that they measure the horizontal difference between densities (gravity), or magnetic susceptibilities (magnetic) of the lithology. A difference between two potential field readings indicates differences exist in the property of those rocks.

A wealth of information about the regional geology is contained on the gravity map (Plate 1). By drawing any NW-SE (X-X') profile on the gravity map, it is apparent that there are distinct differences in gravity values, leading to the conclusion that densities of lithologies along such a profile vary. This poses the question, whether the density variations are a result of shallow (< 10 km), or subcrustal features ?

To address this problem, upward continuation of the gravity field (Plate 1) was performed. The upward continuation was done at various levels up to 8 kilometers (Figures 7, 8, 9). This resulted in the isolation of gravity anomalies attributed to density variations at the specified continuation level. This means that an upward continuation performed at 2 kilometers is providing a map of the variation in densities of rocks at a depth of 2 kilometers and higher, while upward continuation at 8 kilometers is providing data on the density of rocks at depth of 8 kilometers and more. It is apparent, from Figures 7, 8, and 9, that most of the gravity anomalies shown on Plate 1 are a result of density variations

Figure 8: This is the Bouguer gravity field, shown on Plate 1, at the continuation level of +2.89 kilometers. The letters on this figure show the location of the following geologic features:

A: Whispering Creek Anticline

B: Diabase/Granophyre Dike

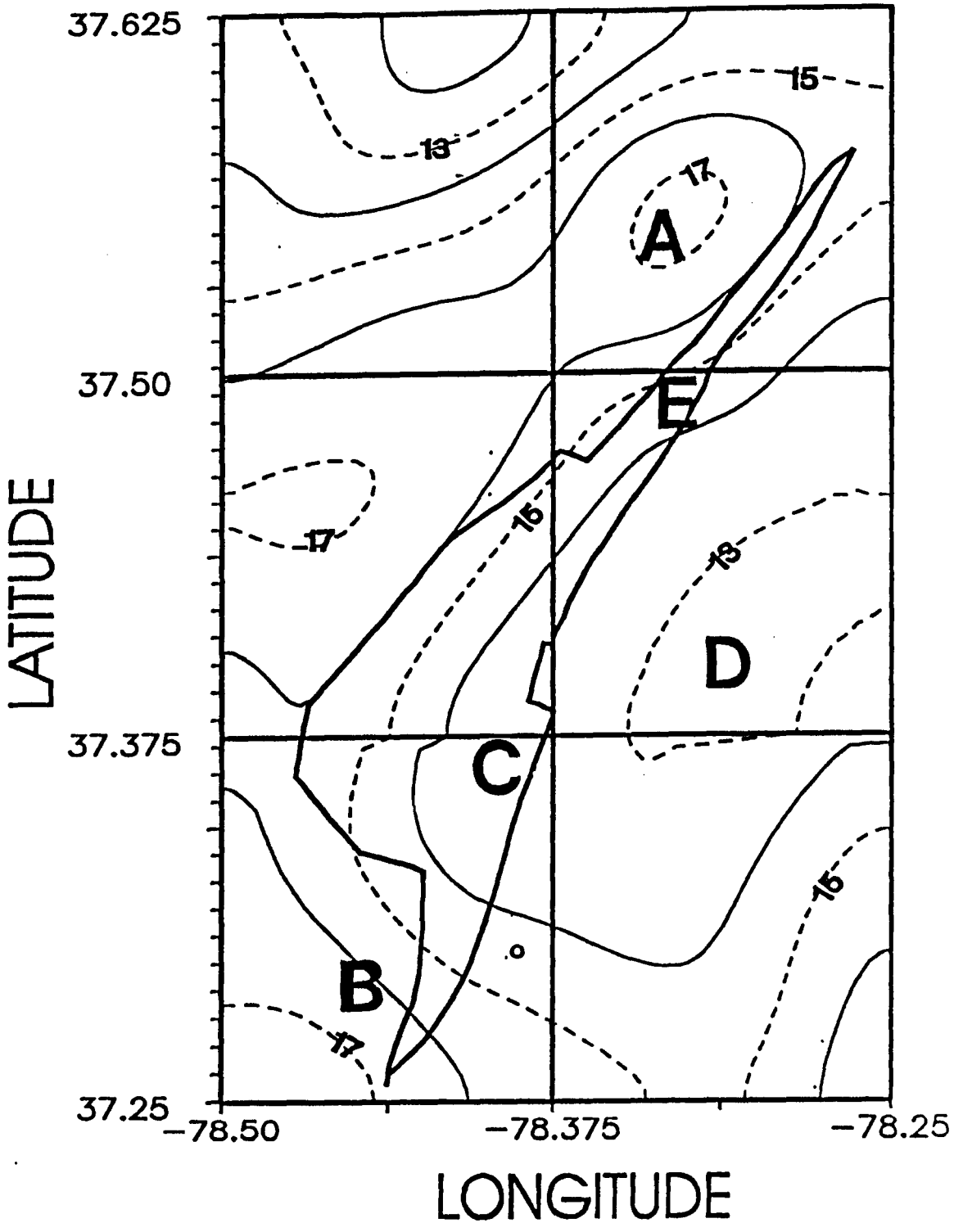
C: Deepest Part Of Basin

D: "Granitic" Gneiss Undifferentiated

E: Possible Shear Zone

Note: Variation in gravity anomalies indicate that differences in density of the rocks can be seen at this level.

GRAVITY FIELD AT 2.89 KILOMETERS



within the upper 8 kilometers of crust. At 8 kilometers, the NE-SW trend is apparent; although, the E-W trend (Plate 1) is no longer apparent in the southern portion of this map.

Magnetic anomalies, like gravity anomalies, show a strong NE-SW trend (Plate 2). In addition, the magnetic values generally decrease along NW-SE (X-X') profiles. This implies that the magnetic susceptibilities of the rocks, along such a profile, are different. With this information it can confidently be concluded that there are distinct lithologic breaks underneath and outside of the basin.

Both gravity and magnetic anomaly maps (Plates 1 and 2) show a definite change in the density and magnetic susceptibilities of rocks along NW-SE profiles. This is supported by the geology. Table 2, shows that there are several distinct lithologies in the study area. The geophysical properties of these rocks are listed in Table 3. The values in Table 3 are useful in approximating the regional surface geology. For example, using the gravity map (Plate 1) a general set of lithologic boundaries can be drawn, using the 15 milligal contour as a lithology break (Figure 10). The 15 milligal contour was chosen as the reference contour because it was present on the 8.00 kilometer continuation map (Figure 9), meaning it is a regional phenomenon. Figure 10 shows four distinct lithologic groups. These groups are from oldest to youngest: Chopawamsic Formation, "Granitic" Gneiss, Arvonia Formation, and Triassic rocks. This map is very close to the

Figure 9: This is the Bouguer gravity field, shown on Plate 1, at the continuation level of +8.00 kilometers. The letters on this figure show the location of the following geologic features:

A: Whispering Creek Anticline

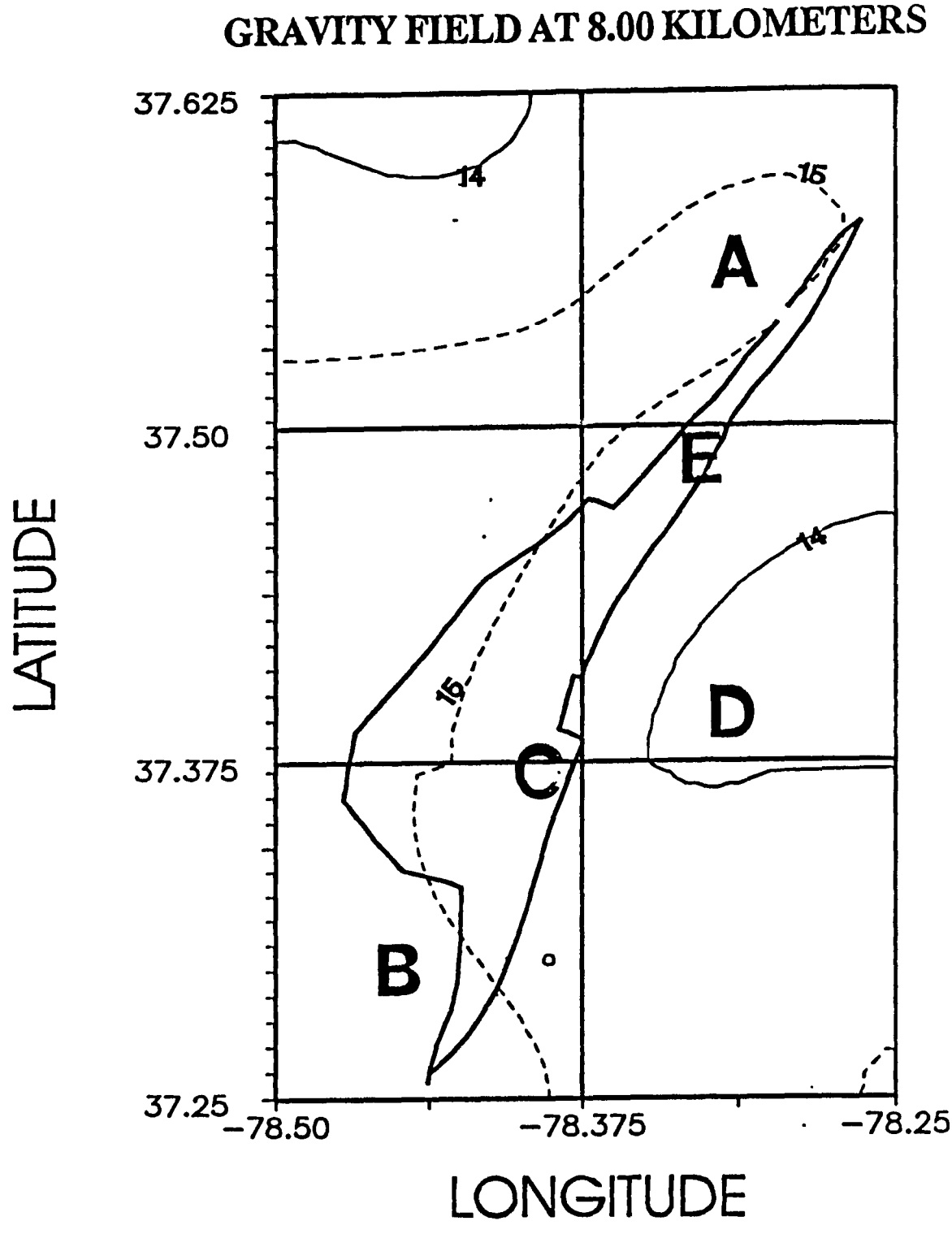
B: Diabase/Granophyre Dike

C: Deepest Part Of Basin

D: "Granitic" Gneiss Undifferentiated

E: Possible Shear Zone

Note: Variation in gravity anomalies indicate that differences in density of the rocks can be seen at this level.


GRAVITY FIELD AT 8.00 KILOMETERS
37.625
37.50
37.375
37.25
LATITUDE
−78.50
−78.375
−78.25
LONGITUDE
14
15
A
E
D
C
B

detail maps of Marr (1980) and Brown (1969). Because of the good correlation, geophysical data was used to make inferences about lithologies shown on Plate 4.

Radiometric data provides further proof that the study area is comprised of the lithologic units defined above (Plate 3). These domains correlate with lithologic units in the area. NW-SE profiles across the basin indicate radiometric anomalies west of the basin have a range of 100 to 200 counts-per-second (cps). Radiometric anomalies generally have a range of 300 to 400 cps in the basin, and are generally higher than 400 cps, east of the basin.

Structurally, foliation, bedding, and joint measurements all have concentration of poles whose average plane strike lies within 25 degrees of the NE-SW regional trend. The dominant foliation pole concentration, has an average strike of N15°E and dip of 35 degrees southeast (Figure 3). The average bedding strike is N45°E and dips 30 degrees northwest (Figure 4). The secondary joint set has an average strike of N70°E and dips 80 degrees southeast (Figure 5). In addition, the rectified stream analysis identified a significant drainage trend in the azimuthal range of 030 to 040 degrees.

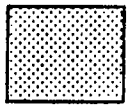
Local Analysis

An examination of local geophysical and geological anomalies is necessary to complete the preliminary geological analysis of the area. Once again, examination of the gravity

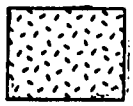
Figure 10: This is the Bouguer gravity field, shown on Plate 1, at the continuation level of +0.64 kilometers. This maps show the four lithologies based on gravity values. The reference line for dividing the lithologies is 15 milligals.

Note: Variation in gravity anomalies indicate that differences in density of the rocks can be seen at this level.

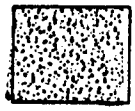
LITHOLOGIES:



CHOPAWAMSIC FORMATION



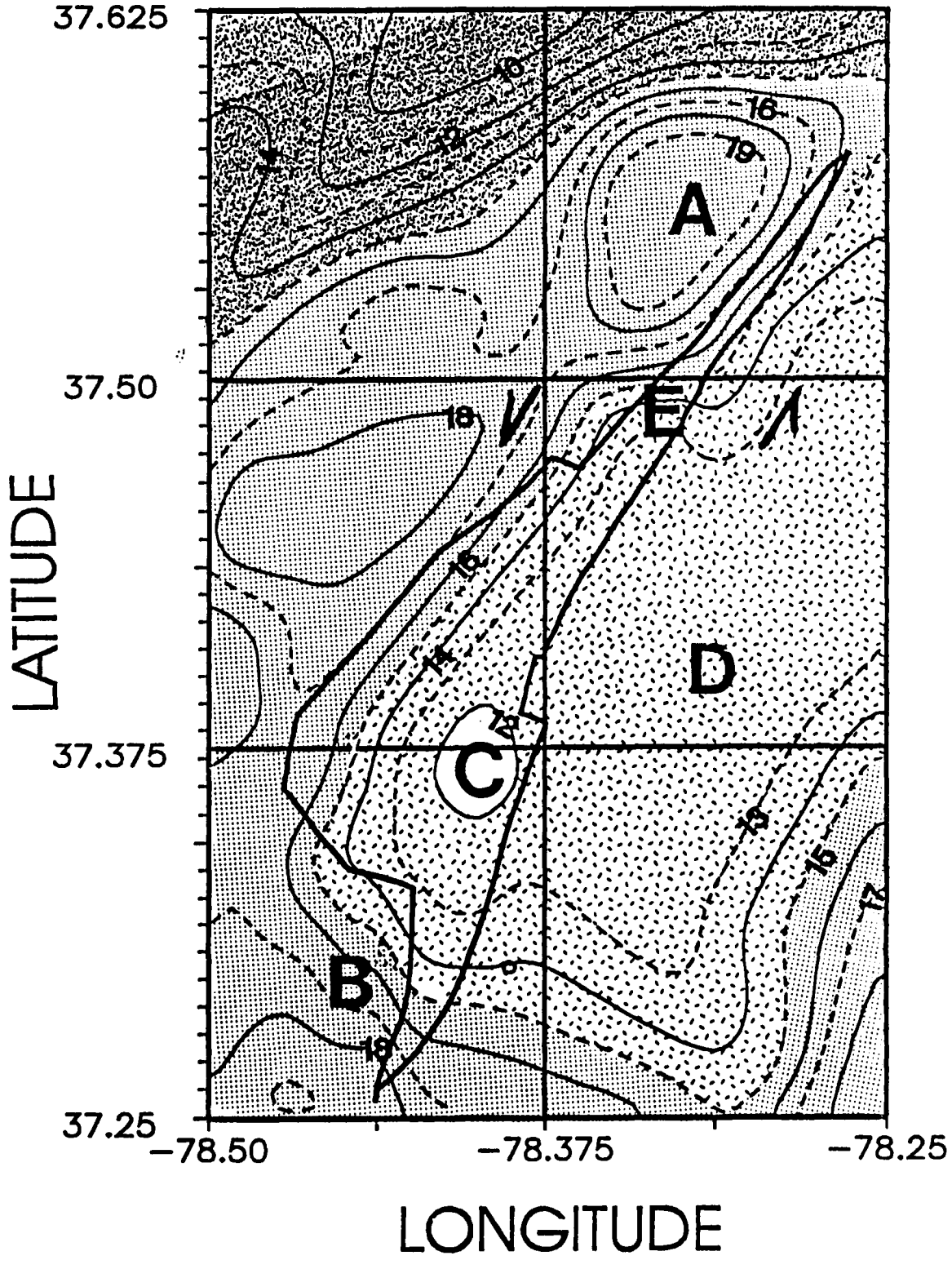
"GRANITIC" GNEISS UNDIFFERENTIATED



ARVONIA FORMATION

TRIASSIC ROCKS

GRAVITY FIELD AT 0.64 KILOMETERS



and magnetic maps indicate localized features. Two local anomalies are common to both the gravity (Plate 1) and magnetic (Plate 2) maps. The first feature is the gravity and magnetic lows found on the eastern margin of the Farmville Basin, marked 'C' respectively. Another common feature to both maps is a NNW-SSE diabase/granophyre dike marked 'B' on both maps.

Labels A-E, on the gravity map (Plate 1), are the locations of localized gravity anomalies. The circular high marked 'A' (Plate 1) is in excess of 21 milligals. This high is attributed to the Whispering Creek Anticline (Brown, 1969) A sharp high amplitude feature marked 'B' on the gravity map is a diabase/granophyre dike that exceeds 488 meters in width, across U.S. Highway 460E. At location 'C' the gravity values decrease below 10.5 milligals. It is at this point where the deepest portion of the basin is believed to exist. The elliptical gravity low 'D' is typical of intrusive bodies (Griffin, 1949). An unusual gravitational anomaly, marked 'E' (Plate 1) is thought to be a remanent of a shear zone. This conclusion is made from the 'Z' pattern displayed by the gravity contours (Plate 1). The 'Z' pattern indicates a left-lateral sense of shear has occurred. If this is a shear zone, then projecting it south indicates it continues underneath the basin.

The upward continuation maps (Figures 7, 8, and 9) give an approximate depth of the local features. As the gravity

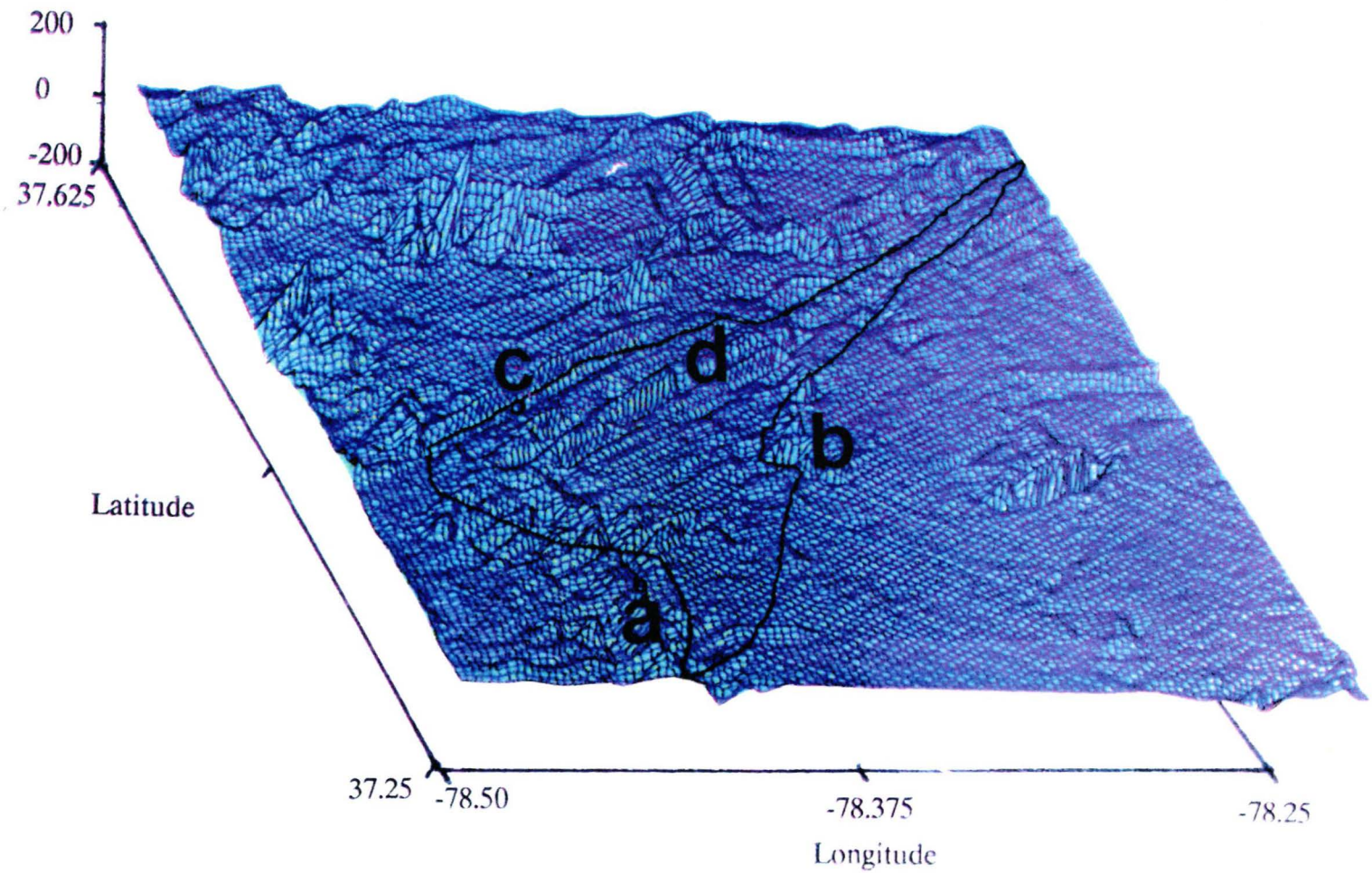
field is continued upward regional features are emphasized, as previously discussed. Remember, the upward continuation is a sampling of the variation of densities at the continuation level; therefore, if a local anomaly is no longer present at a continuation level then the horizontal variation in rocks that caused that anomaly is no longer present. The result is that the maximum depth of a local anomaly can be determined using upward continuation.

At the continuation level of 0.64 kilometers all the localized anomalies are still definable; although, the diabase/granophyre dike ('B', Plate 1) is barely discernable. After the 1 kilometer continuation the circular gravity anomaly, 'C' Plate 1, is no longer present. This suggest that the basin is less than 1.00 kilometer in thickness. If this is the case then no gravity model can have the basin exceeding 1.00 kilometers in depth. Continuing the gravity field to 2.89 kilometers eliminates the dike anomaly, 'B' Plate 1. At the continuation level of 8 kilometers, the gravity map is less sinuous, the Whispering Creek gravity high ('A', Plate 1) is no longer present, and the strong E-W trend in the southern portion of the study area is not present (Figure 9).

Figure 11 is the second vertical derivative of the gravity field. This map has several interesting features. The linear features that lie outside the basin are diabase dikes ('a' and 'b'). On the basin margin and inside the basin are linear highs adjacent to lows ('c' and 'd') which are

Figure 11: Second vertical derivative of the study area gravity field. Locations 'a' and 'b' mark the location of diabase dikes, while the locations 'c' and 'd' mark the location of possible mylonite zones.

Second Vertical Derivative Map



thought to be mylonite zones. This is supported by field evidence at location 'c'. Inside the basin these features are believed to mylonite zones; however, no field evidence was found to support or disprove this hypothesis. No diabase outcrop was found in the vicinity of these highs, eliminating possibility that the linear highs in the basin are a result of diking. Gravity modelling should take into account all features shown on this map.

High frequency magnetic values indicates the presence of dikes and a basin that is relatively shallow. Linear magnetic features present on the magnetic map (Plate 2) are diabase/ granophyre dikes. The area marked 'B' and the linear high east of 'C' on the magnetic map are large dikes. The dike marked 'B' exceeds 488 meters in width across U.S. Highway 460E. The low marked 'C' on the magnetic map (Plate 2) is attributed to the deepest part of the basin.

Field data provides limited insight into local structures of the area, because of the large scale on which it was conducted. One exception is the variation of bedding dips within the basin. Mapping conducted along State Road 636 (Plate 4) shows a variance in dips from shallow to steep to shallow. This phenomenon is a result of some type of localized displacement. The cause of this displacement has to be addressed in any gravity model.

SUMMARY

The study area is dominated by a NE-SW regional trend. This trend is present in the basement structural grain of the rock, as well as the local lithologies. As a result, this trend can be identified on all geophysical and geological maps, data, and analyzes. One implication of this finding is that most of the structures in the area are dependent on this feature.

The relationship of the various lithologies in the area are a second factor to consider in defining the structural controls on the basin geometry. There are five lithologic units in the area; however, only the Chopawamsic Formation, "Granitic" Gneiss Undifferentiated, and Dikes are in surfical contact with the Triassic rocks. Each of these lithologies have unique physical properties (i.e. densities, magnetic susceptibilities, and radioactive elements). It is the unique physical properties of these lithologies that cause a majority of the local anomalies found on the geophysical maps (Plates 1, 2, and 3). These anomalies support the hypothesis that the Farmville Basin covers the lithologic contact between the Chopawamsic Formation and the "Granitic" Gneiss. If this is the case, then the lithologic contact is a possible plane of weakness along which faults could form. Only subsurface modelling can verify this hypothesis.

CHAPTER 4

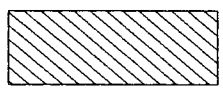
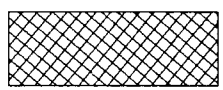
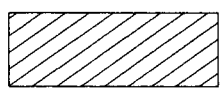
GRAVITY MODELLING

INTRODUCTION

Gravity models are based on data obtained from six profiles that cross-cut the Farmville Basin nearly perpendicular to the regional geophysical and geological trends. Four lithologic units were used to create the gravity models. The modelled lithologies from oldest to youngest are the Chopawamsic Formation, "Granitic" Gneiss Undifferentiated, Triassic rocks, and Diabase/Granophyre dikes. Density listing of the Arvonia Formation is not given because it is not present in the gravity models. Densities for the modelled lithologies are listed in Table 4. These values were calculated from a series of density measurements. The density values for the Triassic rocks were obtained by taking the mean of the density measurements along the southern traverse across the basin (Wilkes and Lasch, 1979). Density measurements were not taken for basin rocks because most of the outcrops were highly weathered. Two categories of dikes are distinguished based on densities. One group of dikes have an average density of 2.99 g/cm^3 and the second group have an average density of 2.89 g/cm_3. Most dikes that cross the gravity profiles contained granophyres; therefore, the density value of 2.89 g/cm^3 was used for modelling.

Table 4: Densities of the lithologies used in the gravity models. This legend is referenced in the gravity models that follow.

LEGEND

	UNIT	DENSITY (g/cm3)
	CHOPAWAMSIC FORMATION	2.845
	GRANITIC GNEISSES	2.775
	TRIASSIC ROCKS	2.55
	MESOZOIC DIKES	2.88

+ : OBSERVED GRAVITY CURVE
*** : THEORETICAL GRAVITY CURVE**
-----: REGIONAL GRAVITY GRADIENT

The assigned density when modelling the "granitic" gneiss is much higher than the measured densities. The density value used for the "granitic" gneiss is from the density values of the Columbia Granite (Keller and others, 1985). The densities assigned to the modelled lithologies remained constant in all profiles. This gave additional constrains to the gravity models.

PROFILES

Figure 2 shows the location of the modelled gravity profiles. Discussion of these models will begin with U.S. Highway 460E continuing north and ending with State Road 622. A description of the lithologies used in the models is given in Table 4. Each of the modelled profiles is comprised of two graphs. The upper graph is a plot of the observed and theoretical Bouguer anomalies. The lower graph is the gravity model that produced the theoretical curve, shown on the upper graph. The regional gravity gradient is represented by the solid line on the upper graph. The regional gradients are related to the deeper structure, and are used to identify local gravitational anomalies. The term "residual" is used to describe the variation of the observed gravity with respect to the regional gradient. In modeling one must keep in mind the basin's geometry, strike and dip orientations of faults and dikes, as well as the density contrast of the various lithologies.

Models indicate two sets of faults are present in the study area. Master faults (solid lines in lower graph on Figures 13-16) are believed to be reactivated Paleozoic faults. The greatest displacement occurred along such faults in the study area. Splay faults (dashed line in lower graph) are believed to be Mesozoic in age, and are thought to have formed along existing planes of weakness (other than faults) in the structural grain of the basement rocks. All faults were drawn on the models after each model was completed. The relative displacement of each fault is shown by the arrows. Each fault is drawn so that the models were as close to being a balanced cross-section, as possible.

U.S. Highway 460E Profile

U.S. Highway 460E crosses the southern portion of the basin. Figure 12 is the gravity model produced for this profile. The profile is 6705 meters in length and modelled to a depth of 3657 meters. A model depth of 2800 meters is shown for this profile to keep uniformity between each profile. A model depth of 2800 meters is possible with this profile because the lithology appear to be homogenous below 2800 meters. The anomaly marked on the profile is attributed to a diabase/granophyre dike, as shown in the model. Location of a dike at this location is supported by outcrop found along U.S. 460E (Plate 4), as well as the geophysical evidence previously discussed. In outcrop, the dike is at least 305

Figure 12: The gravity model developed for the profile U.S. 460E. The lower graph is the geologic model that generated the calculated Bouguer anomalies shown on the upper plot. Letters shown on the gravity profile are representative of the geologic features:

A: "Massive" Diabase/Granophyre Dike Anomaly

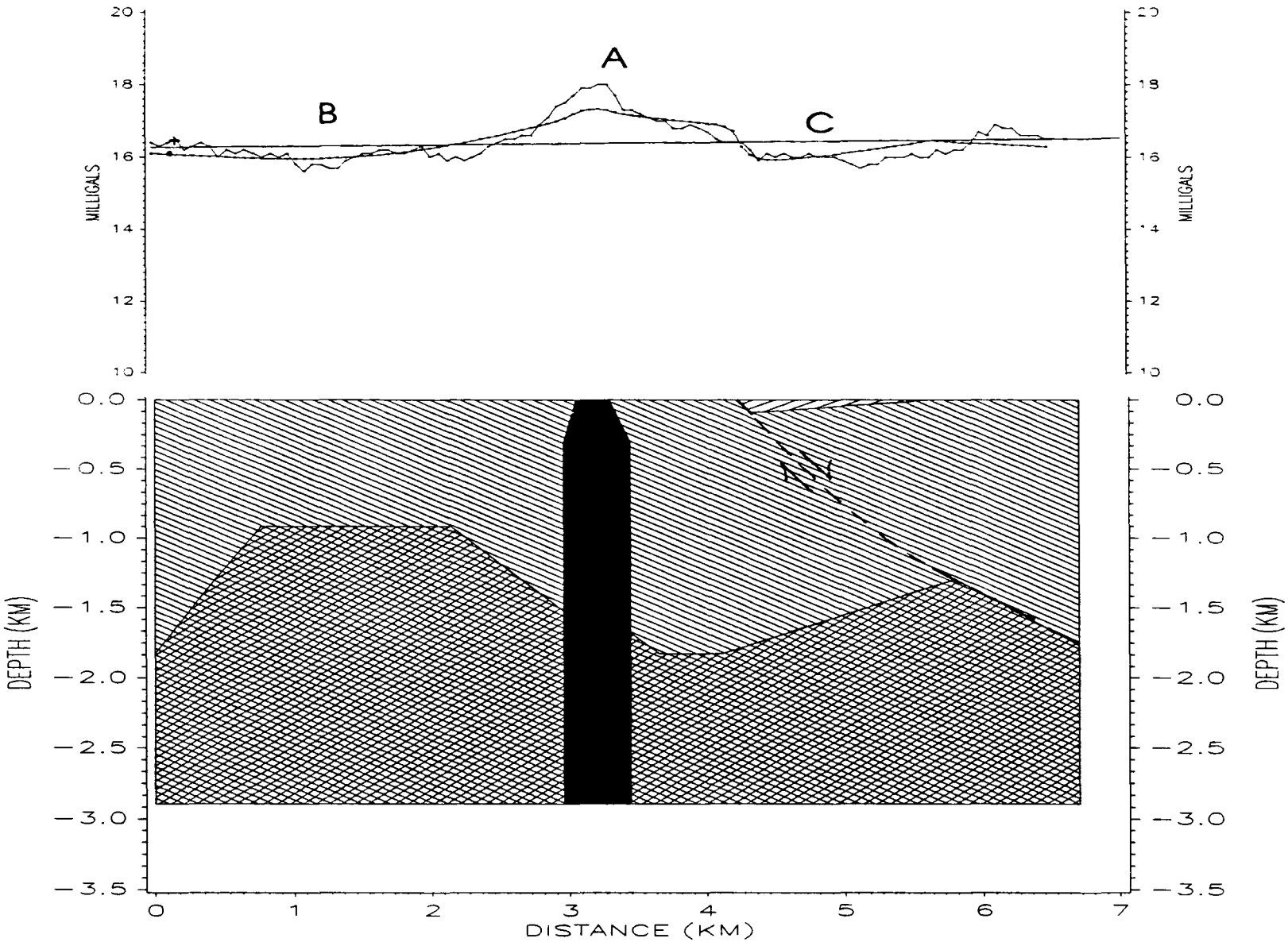
B: "Granitic" Gneiss Anomaly

C: Triassic Basin Anomaly

Arrows: Indicate direction of displacement along fault

Dashed Line: Secondary listric normal faulting

Note: Refer to Table 4 for description of lithologies in models.


A
B
C
MILLIGALS
20
18
16
14
12
10
DEPTH (KM)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
1
2
3
4
5
6
7
DISTANCE (KM)

meters in width. This width increases to 488 meters at depth. Residual lows, marked 'B' and 'C', occur on both sides of the two milligal high. The residual low 'B' is interpreted to be the result of the "granitic" gneiss undifferentiated laying 305 meters below the surface. Triassic rocks of the basin are responsible for the low marked 'C'. Modelling indicates the Chopawamsic Formation is present east of the basin. Length and depth of the basin is 1402 meters, and 91 meters, respectively. The length of the modelled basin is greater than suggested by Johnson and others (1975). Basin width, along this profile, is based on the soil map of Prince Edward County (Henery et. al, 1949). The western border fault, of the basin is defined as a splay fault. This fault dips 35 degrees SE, at the surface, and decreases with depth. A 10 to 15 degree difference exist between the average dip of foliation (45 degrees) and the splay fault. The fault is shown to have normal slip displacement. Palinspastic reconstruction of this profile suggests 5 percent extension has occurred.

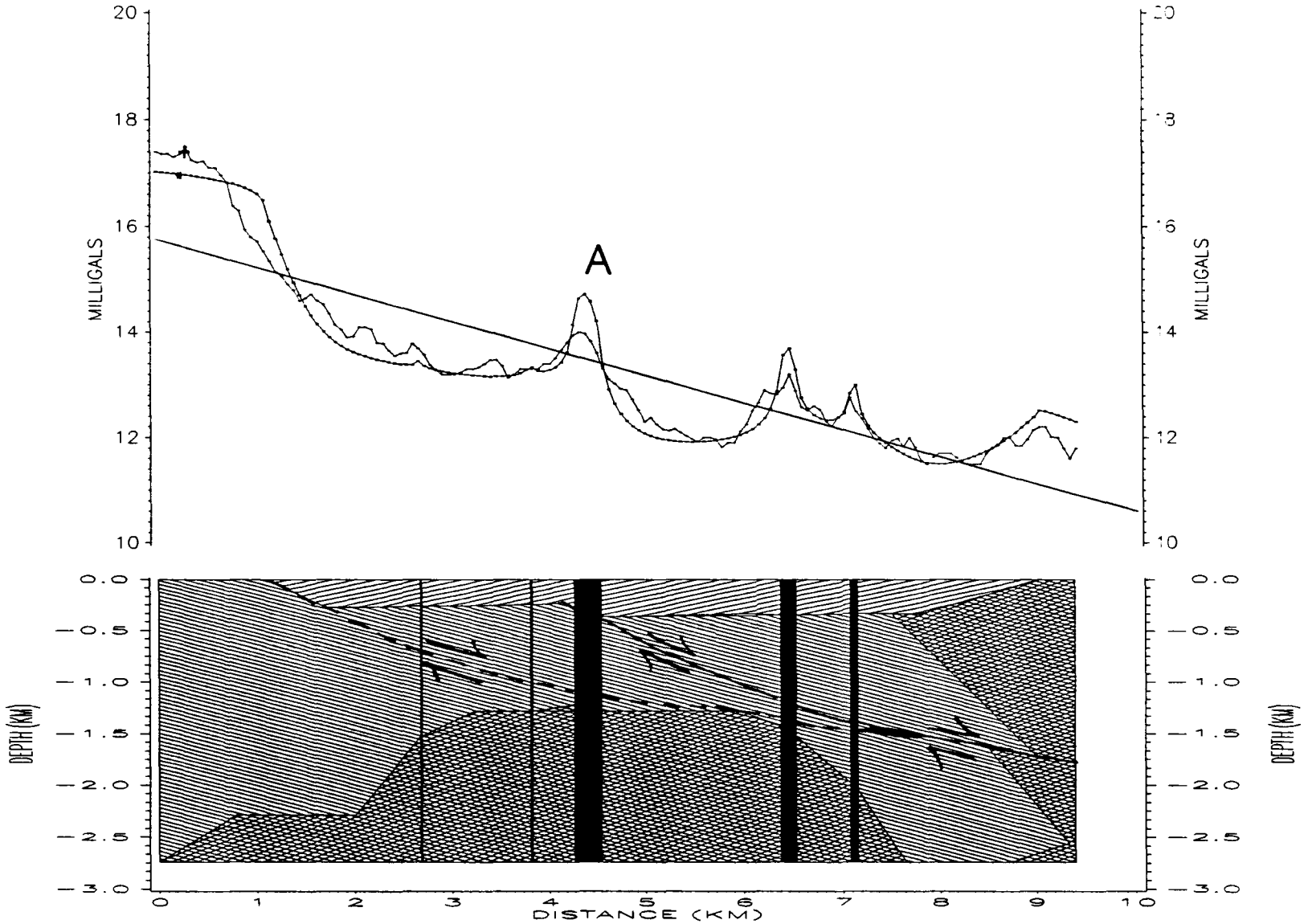
State Road 637 Profile

State Road 637 is 3.2 kilometers north of U.S. Highway 460E (Figure 13). This profile is 9448 meters in length and modelled to a depth of 2743 meters. Observed Bouguer gravity values indicated there are several residual highs interpreted. These highs are interpreted as dikes. Outcrop and float found along the profile support this interpretation. Corresponding

Figure 13: The gravity model developed for the profile State Road 637. The lower graph is the geologic model that generated the calculated Bouguer anomalies shown on the upper plot. Letters shown on the gravity profile are representative of the geologic features:

A: "Massive" Diabase/Granophyre Dike Anomaly
Arrows: Indicate direction of displacement along fault
Dashed Line: Secondary listric normal faulting
Solid Line: Primary listric normal faulting

Note: Refer to Table 4 for description of lithologies in models.


A
MILLIGALS
20
18
16
14
12
10
DEPTH (KM)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
1
2
3
4
5
6
7
8
9
10
DISTANCE (KM)

dike locations are shown on the model. The largest dike is 274 meters in width ('A'), and is the same dike found along profile U.S. 460E. Dike width has decreased 61 meters within 3.2 kilometers. Basin length, along profile State Road 637, is 7925 meters, and is modelled to a depth of 343 meters. Rotational listric type faulting (Wernicke and Burchfield, 1982) is clearly indicated on the model. Both master (solid line) and splay faults (dashed line) are identified in the model, each shows normal slip displacement. Splay faults form the western margin of the basin. At the surface the splay fault dips 24 degrees to the southeast. The master fault is covered by the Triassic rocks. The greatest displacement occurs along the master. Ten percent extension is estimated for this profile, as a result of palinspastic reconstruction.

State Road 636 Profile

State Road 636 is the longest of all modelled profiles. It is 10896 meters in length and is modelled to a depth of 2743 meters (Figure 14). Two broad residual highs, marked 'A' and 'B' on the profile represent high density country rocks occurring along the basins' margin and a 61 meter dike, respectively. This dike contains granophyres and is a continuation of the dike present on profile U.S. Highway 460E and State Road 637. The low, marked 'C', is caused by the Triassic rocks. Basin length is 8229 meters, and is modelled to a depth of 617 meters making it the deepest part of the

Figure 14: The gravity model developed for the profile State Road 636. The lower graph is the geologic model that generated the calculated Bouguer anomalies shown on the upper plot. Letters shown on the gravity profile are representative of the geologic features:

A: Chopawamsic Formation Anomaly

B: "Massive" Diabase/Granophyre Dike Anomaly

C: Triassic Basin Anomaly

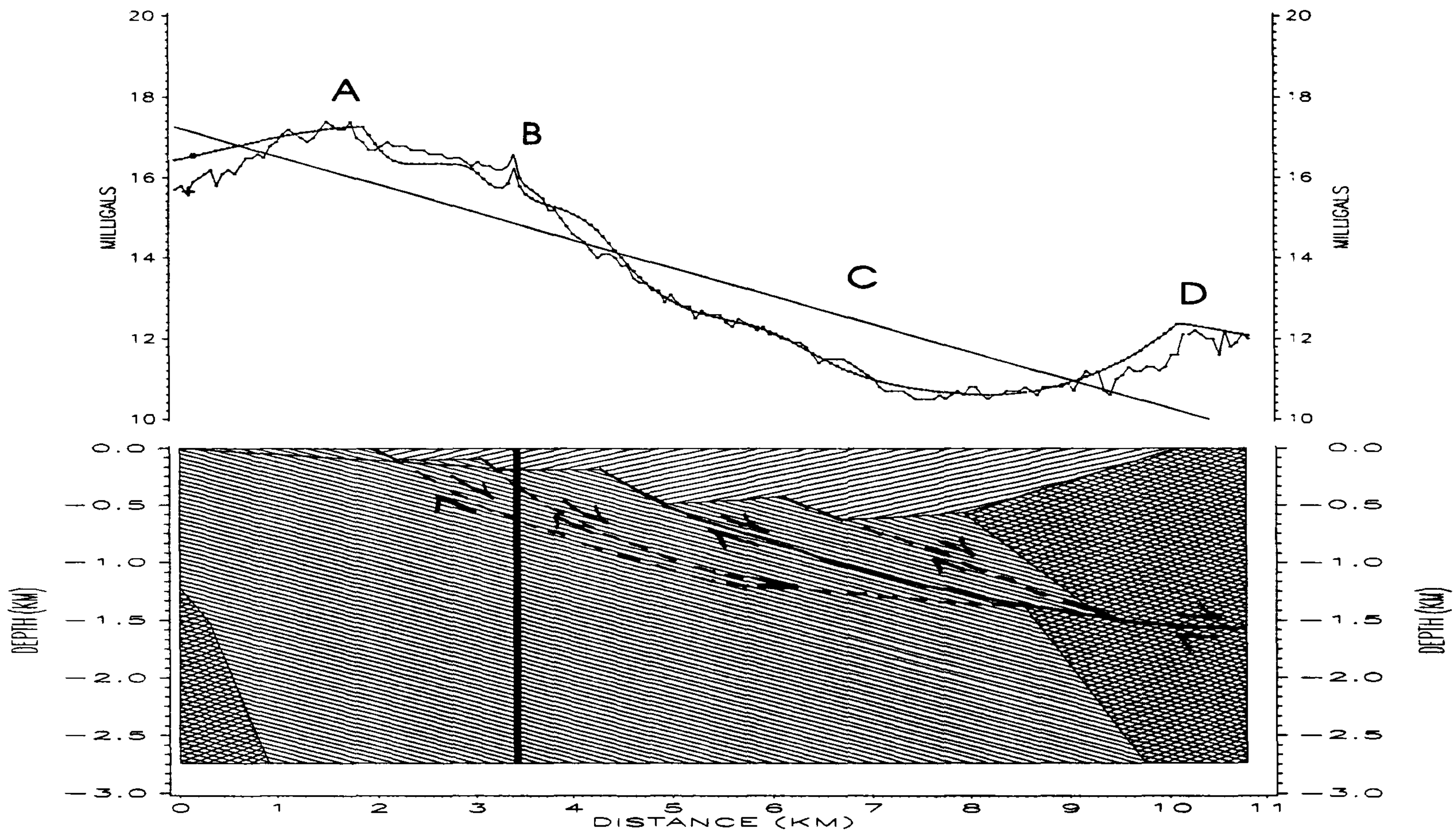
D: "Granitic" Gneiss Anomaly

Arrows: Indicate direction of displacement along fault

Dashed Line: Secondary listric normal faulting

Solid Line: Primary listric normal faulting

Note: Refer to Table 4 for description of lithologies in models.



20
18
16
14
12
10
MILLIGALS
A
B
C
D
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
DEPTH (KM)
0
1
2
3
4
5
6
7
8
9
10
11
DISTANCE (KM)

basin. Unlike existing Mesozoic basin models, the deepest section of the Farmville basin lies along its' eastern margin. This conclusion is supported by the low closures found on both gravity and magnetic contour maps (Plates 1 and 2). Rotational listric normal slip movement is displayed by both the master and splay faults. A splay fault forms the western margin of the basin, dipping 28 degrees to the southeast, on the surface. All faults shallow with depth cross-cutting the foliation. Extension of 15 percent was calculated for this model after palinspastic reconstruction.

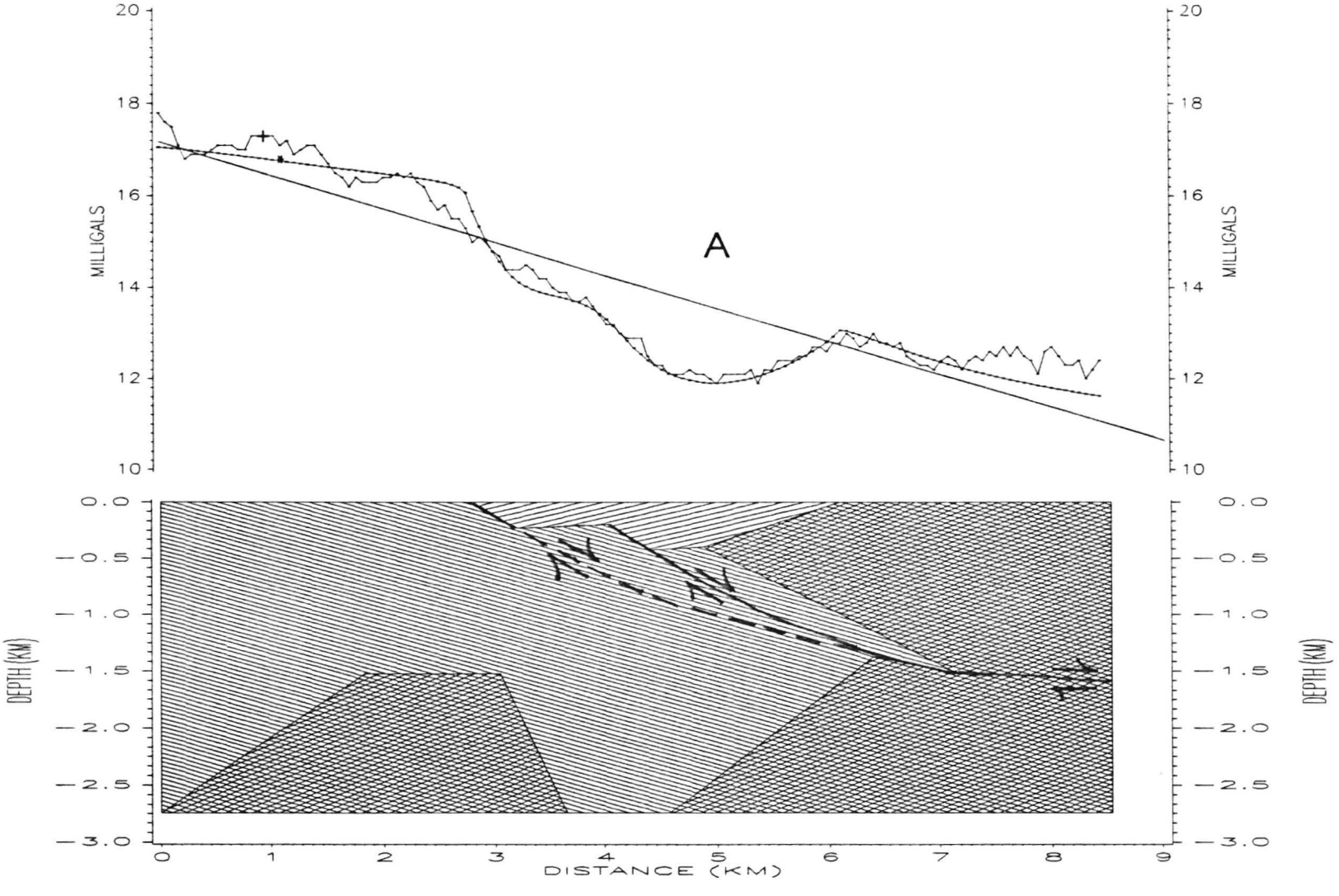
State Road 634 Profile

Figure 15 is the gravity model of State Road 634. The profile is 8500 meters in length and is modelled to a depth of 2743 meters. No sharp high amplitude residuals are present on this profile, meaning that no dikes greater than 50 meters cross the profile. Field evidence supports this aspect of the model. A broad residual low, marked 'A', is caused by the basin. Along this profile the basin is 3554 meters in length and 427 meters in depth. As in previous profiles the deepest part of the basin lies along its eastern margin. Both splay and master faults are present along this profile. The westernmargin of the basin is bounded by a splay fault with the master fault laying underneath the basin rocks. All faults are listric normal slip with the western border fault dipping to the SE at 28 degrees. The palinspastic

Figure 15: The gravity model developed for the profile State Road 634. The lower graph is the geologic model that generated the calculated Bouguer anomaly shown on the upper gravity profile. Letters shown on the gravity profile are representative of the geologic features:

A: Triassic Basin
Arrows: Indicate direction of displacement along fault
Dashed Line: Secondary listric normal faulting
Solid Line: Primary listric normal faulting

Note: Refer to Table 4 for description of lithologies in models.


A
MILLIGALS
20
18
16
14
12
10
DEPTH (KM)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
1
2
3
4
5
6
7
8
9
DISTANCE (KM)

reconstruction of this model indicates a maximum of 10 percent extension has occurred along this profile.

U.S. Highway 60 Profile

The gravity profile and model for U.S. Highway 60 is shown in Figure 16. Profile length is 3353 meters with a modelled depth of 2591 meters. Residual highs are found at the NW and SE ends of this profile. These highs are attributed to the higher density country rocks that surround the basin. The residual low, marked 'A', is a typical pattern of a full graben basin; however, modelling indicates the basin is a true half graben with listric type fault geometry. The basin is 2591 meters in length and 259 meters in depth along this profile. As in the four previous profiles, a splay fault forms the western margin of the basin. The border fault dips 25 degrees to the southeast, decreasing at depth. Unlike the four previous profiles, evidence suggests the master fault lies east of the basin. Palinspastic reconstruction of the profile was difficult because of the individual unit shapes; however, it is estimated that 11 percent of extension has occurred.

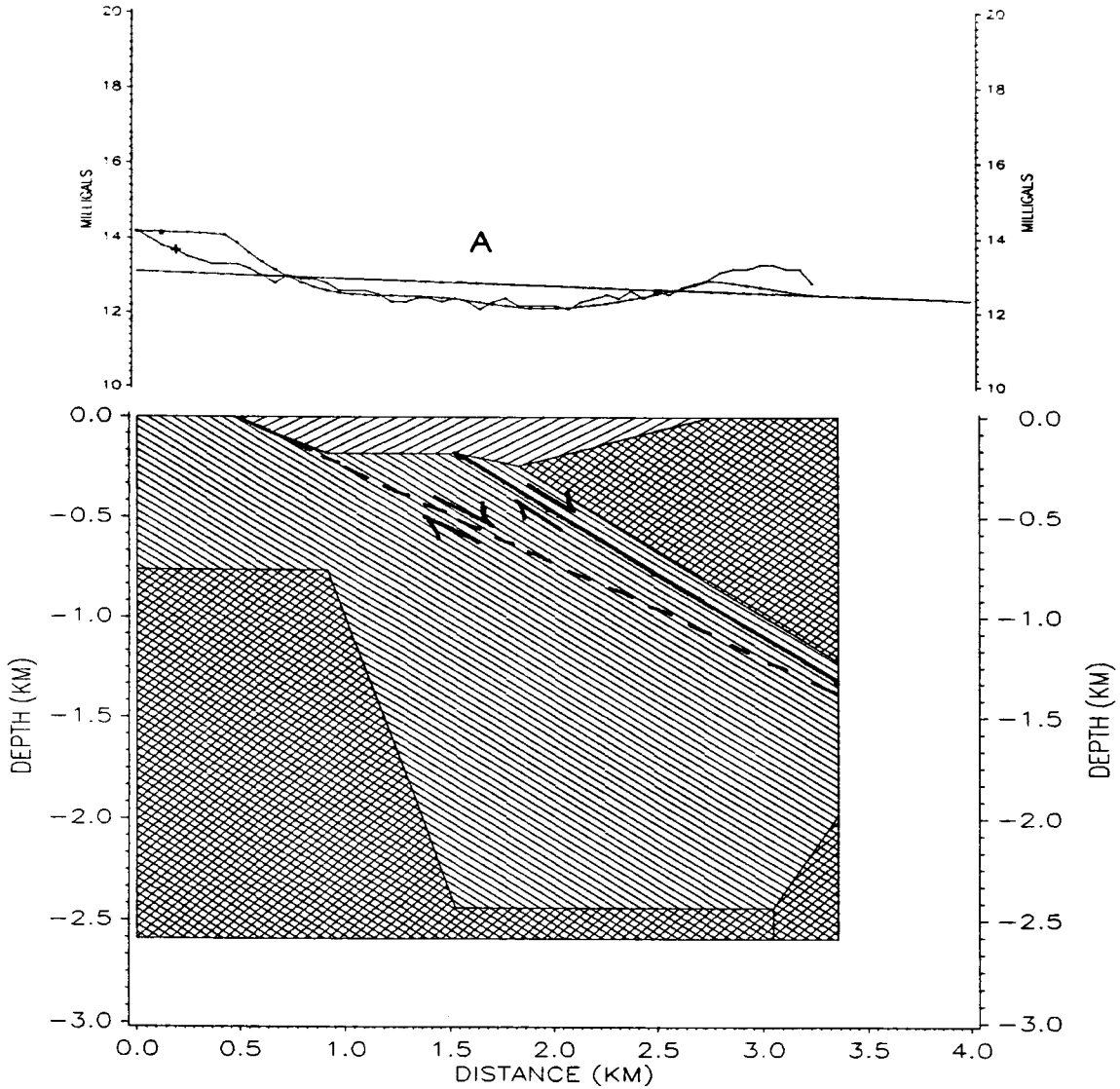
State Road 622

The northern most of the modelled profiles is State Road 622 (Figure 17). This profile has a length of 3231 meters and is modelled to a depth of 3231 meters. The basin is 914

Figure 16: The gravity model developed for the profile U.S. Highway 60. The lower graph is the geologic model that generated the calculated Bouguer anomaly shown on the upper gravity profile. Letters shown on the gravity profile are representative of the geologic features:

A: Triassic Basin
Dashed Line: Secondary listric normal faulting
Solid Line: Primary listric normal faulting

Note: Refer to Table 4 for description of lithologies in models.


20
18
16
14
12
10
MILLIGALS
A
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
DEPTH (KM)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
DISTANCE (KM)

meters and is 122 meters in depth at this location. A splay fault forms the basin's western margin, dipping to the southeast at 26 degrees. The fault indicates normal displacement has occurred. As the fault shallows with depth it cross-cuts the foliation. It is believed that the master fault lies east of the profile section. Outcrop east of this profile showed mylonitic signs; although the highly weathered condition of the rocks proved inconclusive. Reconstruction of this profile indicates this area of the basin has undergone 8 percent extension.

SUMMARY

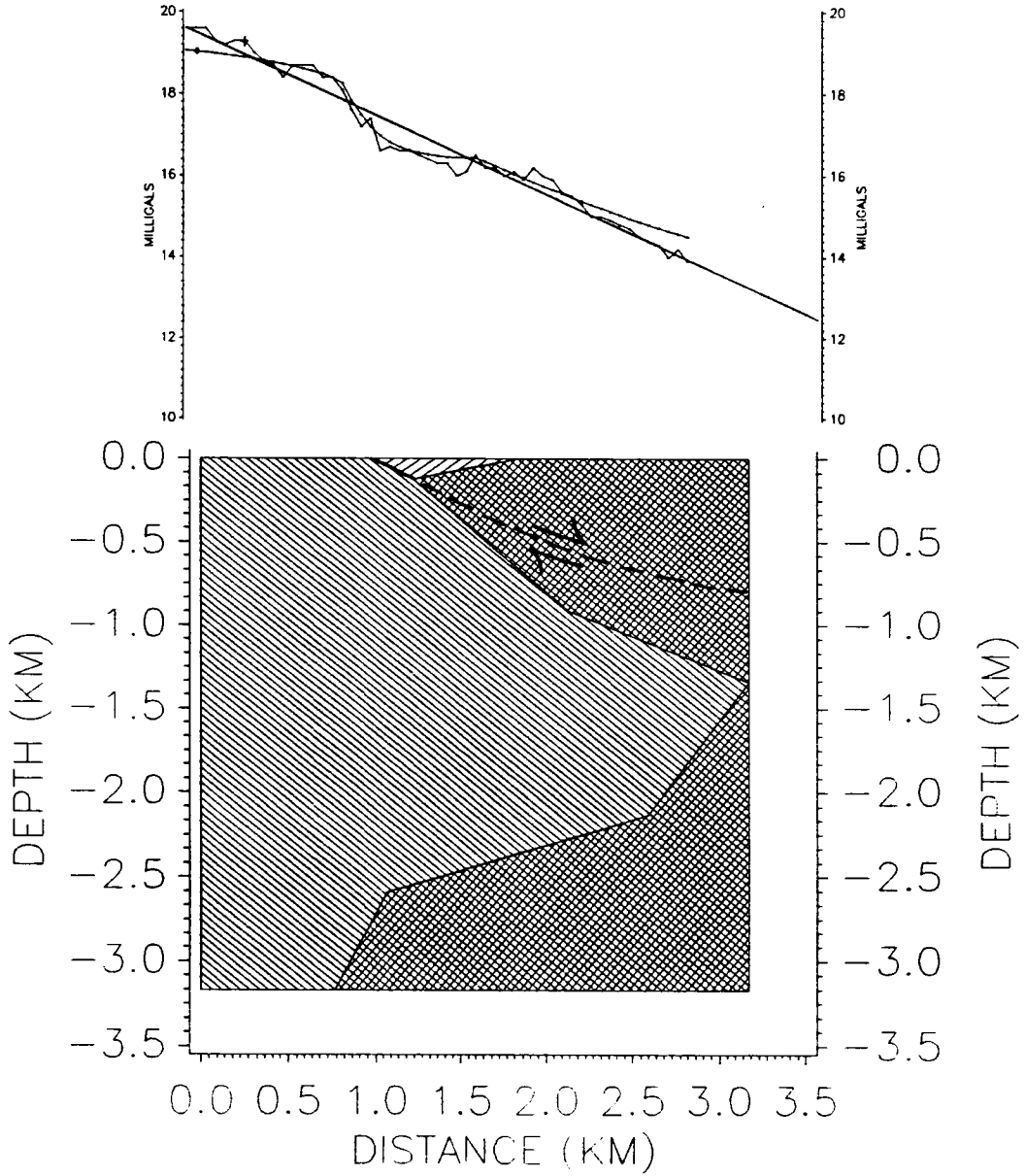
Gravity models show the subsurface relationship of the lithologies present in the area. All models indicate the western margin of the Farmville Basin is bounded by splay faults with the master fault(s) lying beneath or east of the basin. Along U.S. Highway 460E and State Road 622 the master fault lies to the east of the profiles. Modelling further indicates the basin's geometry is of normal, listric, rotational-type faulting described by Wernicke and Burchfield (1982). When averaged, the calculated extension of the individual profiles is 9.8 percent. Indicating that at least 9.8 percent extension has occurred in the study area. It is to be noted that the total extension does not include extension caused by dilation as a result of dike emplacement. Extension

Figure 17: The gravity model developed for the profile State Road 622. The lower graph is the geologic model that generated the calculated Bouguer anomaly shown on the upper gravity profile. Letters shown on the gravity profile are representative of the geologic features:

A: Triassic Basin

Solid Line: Primary listric normal faulting

Note: Refer to Table 4 for description of lithologies in models.


20
18
16
14
12
10
MILLIGALS
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
DEPTH (KM)
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
DISTANCE (KM)

as noted only measures fault slip or horizontal heave.

CHAPTER 5

INTERPRETATION

To explain the geologic processes responsible for the structure and formation of the Farmville Basin, a kinematic model was developed. This model is based on geological and geophysical data presented in this study. The past century has seen the development of numerous theories explaining the formation of Mesozoic basins. "Unifying" theories explaining the formation of the Newark Supergroup are grouped into rift, structural grain, and fault reactivation categories.

PREXISTING THEORIES

Russell (1892) proposed what is known as the Broad Terrane hypothesis, to explain the formation of the Newark Supergroup. He summarized his hypothesis by stating the Newark system of basins are remnants of a broader terrane that, at one time, united all the Newark basins. Russell suggested that sedimentation, orogenic movements, and upheaval occurred. These processes were followed by faulting and dike emplacement.

The theory of continental drift lead Sanders (1963) to propose the broad terrane of Russell was a failed rift. Sanders suggested development of the present day Newark basin is a result of three phases. During phase 1, Pangea began to break-up forming a rift basin along the present day North

American east coast. Sediments from the surrounding terranes filled the basin. As rifting continued the center of the rift was gradually heaved upward because of thermal processes. This upheaval defines the second phase of the Newark Supergroup evolution. As upheaval continued a central ridge developed within the rift. Sediments west of the central dipped west, and sediments east of the ridge dipped east. When the rift failed, 160 million year of erosion began. This period of erosion defines the third phase. During this third phase, the rift was eroded to a point where the only distinguishable features left are the remnant basins of today. Sander suggested that basins with a western border fault lay west of the central ridge and basins with an eastern border fault lay east of the ridge.

STRUCTURAL GRAIN

Lindholm (1978) proposed that the structural grain of basement rocks and their orientation to tensional stresses is the primary mechanism controlling the occurrence and formation of Mesozoic basins. The present day foliation is representative of the ancient structural grain, according to Lindholm (1978). Making this assumption Lindholm discovered that a majority of the Mesozoic basins have border faults dipping the same direction as the surrounding basement foliation. After extensive analysis Lindholm postulated that basins formed in areas where the basement structural grain was nearly perpendicular to tensional stresses. He related this

to the separation of Pangea. Erratic foliation, foliation not suitably oriented to tensional stresses, and/or the dip of the foliation was either to high or to low are the three reasons given to explain why basins did not form.

FAULT REACTIVATION

Ratcliffe and Burton (1985) proposed that the formation of the Newark basin was the result of duplex fault reactivation. They stated that asymmetry, width, and thickness of sediments within some eastern North American Mesozoic half-grabens may be related to the position and attitude of Paleozoic fault systems, in basement rocks, formed by tensional stresses. This theory concludes that all west dipping asymmetric basins, like the Newark basin, formed from reactivation of either concave listric foreland thrust, or convex ramp systems. As an example they chose the Newark basin, and explained that by simple extensional reactivation of a complex system of curvilinear thrust ramp structures one could explain present structures of the basin. The widest and deepest part of the basin occurs where SE extension was normal to the strike of the ancestral thrust ramp complex, according the this theory.

A similar hypothesis was proposed by Swanson (1986). This hypothesis states reactivation of preexisting fault systems of late Paleozoic age is the primary control for Mesozoic basin formation. His sites as examples in Virginia,

the Lakeside fault controlling the formation of the Farmville basin and it's stringers (this fault lies to the east of the basin), the Hylas fault controlling the formation of the Richmond and Taylorsville basins, and the Chatham fault controlling formation of the Danville basin and possibly the Scottsville and Culpeper basins.

STRUCTURAL MODEL

The structural model presented in Figure 18 illustrates several structural and lithologic relationships. The models indicate the "granitic" gneiss undifferentiated varies in depth and form between profile sections. Another conclusion drawn from this model is that rocks of the "granitic" gneiss undifferentiated generally lie east, and rocks of the Chopawamsic Formation generally lie west of the basin's margin, at the surface. The contact between the "granitic" gneisses and Chopawamsic Formation is not exposed at the surface. This contact is covered by the Carnian aged rocks of the Farmville Basin. The model further shows the Farmville basin has a block fault geometry similar to the models published by Wernicke and Burchfield (1982). All the observations presented in this model have supporting geological and geophysical evidence.

An igneous origin explains the variance in depth and form of the "granitic" gneisses. It is often assumed that an

Figure 18: Structural model of the Farmville Basin. This model is intended to show the subsurface relationship of the modelled lithologies.

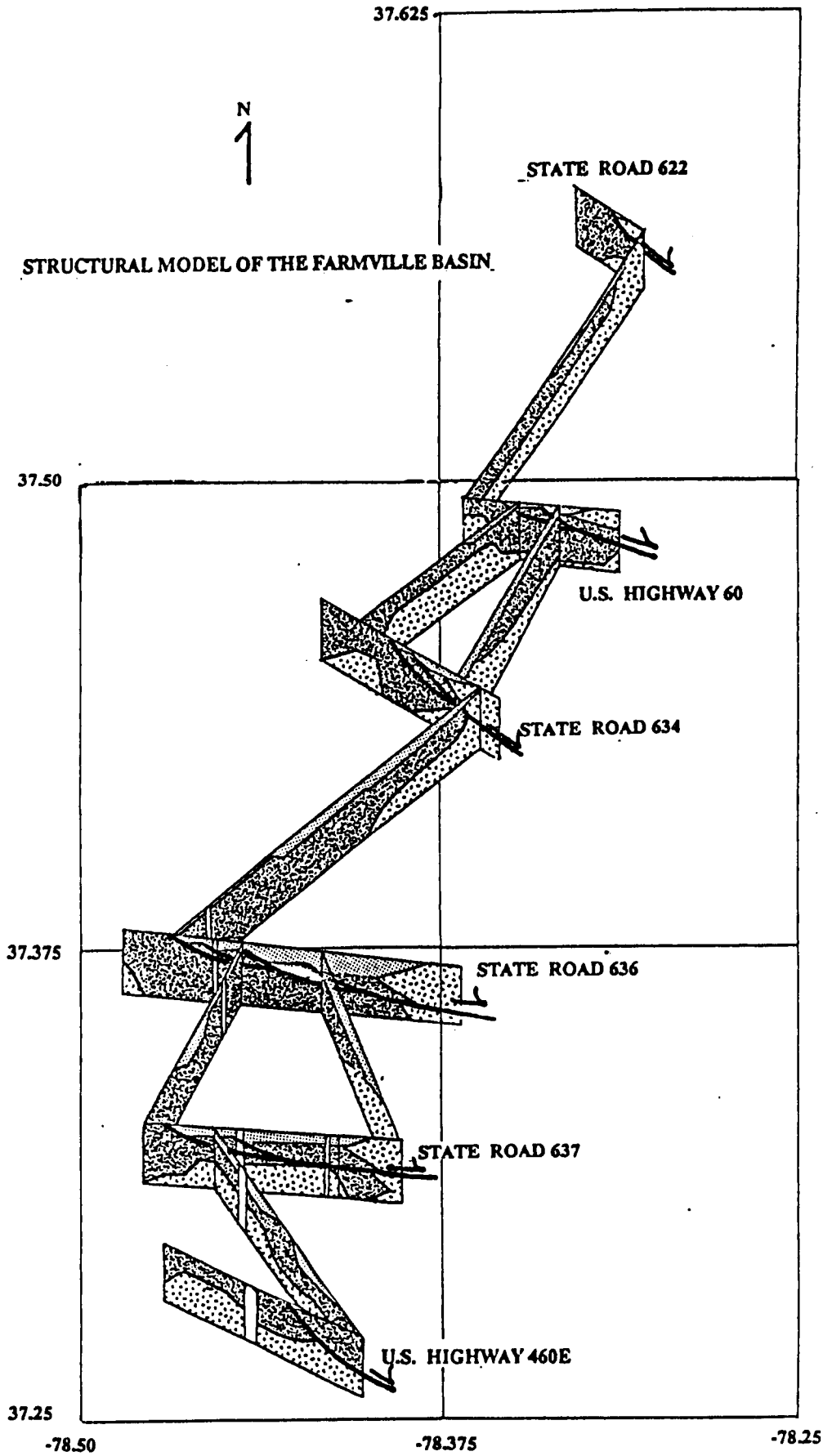
LITHOLOGIES


Chopawamsic Formation


"Granitic" Gneiss Undifferentiated


Triassic Rocks


Diabase/Granophyre Dikes


37.625
N
STATE ROAD 622
STRUCTURAL MODEL OF THE FARMVILLE BASIN
37.50
U.S. HIGHWAY 60
STATE ROAD 634
37.375
STATE ROAD 636
STATE ROAD 637
U.S. HIGHWAY 460E
37.25
-78.50
-78.375
-78.25

intrusive body forms a smooth surface with the country rock. In reality, the contact surface between an intrusive body and the country rock is highly irregular. Only indirect evidence supports the proposed subsurface relationship between the "granitic" gneisses and the Chopawamsic Formation. Although there are an infinite number of solutions in gravity modelling, there are enough geologic constraints on the modelled profiles to ensure a close approximation of the actual subsurface geology.

Geologic and geophysical evidence support that the rocks of the Chopawamsic Formation lie to the west and that the "granitic" gneisses lie to the east of the basin, at the surface. Plate 4 shows these lithologies and their relationship to the basin. Supporting geophysical evidence includes high gravity and magnetic, and low radiometric values west of the basin. East of the basin, geophysical signatures include low gravity and magnetic values, and high radiometric values (Plates 1, 2, 3). The geophysical pattern changes in the southern portion of the study area. In the vicinity of profile U.S. Highway 460E it is known that the Chopawamsic Formation occurs on both sides of the basin, based on field mapping. However, the radiometric anomalies are greater than 400 CPS (indicative of the "granitic" gneisses). In addition, there is a change in the regional gravity gradient from NE-SW to E-W, along the same profile. Based on geophysical evidence, rocks of the "granitic" gneiss undifferentiated should be

present. The structural model indicates the "granitic" gneisses are present, but lie 1000 to 1200 meters below the surface. The model suggest the "granitic" gneisses taper off in a southern direction causing the change in the regional gravity gradient.

The structural model indicates that the Farmville Basin's geometry is controlled by a series of down faulted blocks. Using the classification of Wernicke and Burchfield (1982), this basin is defined as having a listric normal rotational-type fault geometry. Several geological and geophysical relationships would be expected with this type of geometry. Expected geological relationships include near vertical border faults, variations in dips across the basin, and a general trend of dips decreasing toward the shallow part of the basin. Circular gravity and magnetic lows over the deepest part of the basin would be expected. In addition, large mylonite zones, if present, should be recognizable on gravity maps due to their high density.

A listric fault defined by Shelton (1984) should have near vertical dips at the surface and decrease with depth. His definition is based on Basin and Range structures in the western United States. Many of these structures are young relative to Triassic times. If these structures were uplifted and eroded, faults at the erosion surface would begin to shallow; therefore, the more uplift and erosion, the less the dip of the border fault at the surface. This is believed to

be the case for the Farmville Basin where the border fault at the surface generally dips to the SE between 24 and 35 degrees.

The structural model developed indicates that the basin is comprised of a series of down-faulted blocks, separated by what are believed to be mylonite zones. The mylonite zones are reactivated Paleozoic faults and possibly Mesozoic splay faults. The Paleozoic faults lie beneath the basin, and the Mesozoic faults form the basin's western border. Since the deepest part of the basin lies along the eastern portion part of the basin it is concluded that larger displacements occurred along the reactivated Paleozoic faults. This is shown in all the models, and is supported by the low gravity and magnetic closures along State Road 636.

Geological evidence strongly supports this aspect of the model. Strike and dip of bedding within the basin is generally NE-SW at 30 degrees NE; however, there is a large variation in dips across the basin. Three basins with listric rotational type geometry and east dipping border faults are shown in Figures 19, 20, and 21. The first model shows a basin with a rotational geometry soled on one fault. The second and third models show basins with a listric rotational type of geometry. Model 2 shows the deepest part to be nearest the western border fault while Model 3 is representative of a basin that is deepest nearest its eastern margin. Each model has unique features and these are discussed below.

Figure 19: Model 1 shows a basin comprised of a single fault that shallows with depth. Distinguishing characteristics of this model are the dip of basin rocks and the age of the basin rocks increases away from the border.

Legend:

Dark Solid Lines : Dip of Triassic Beds

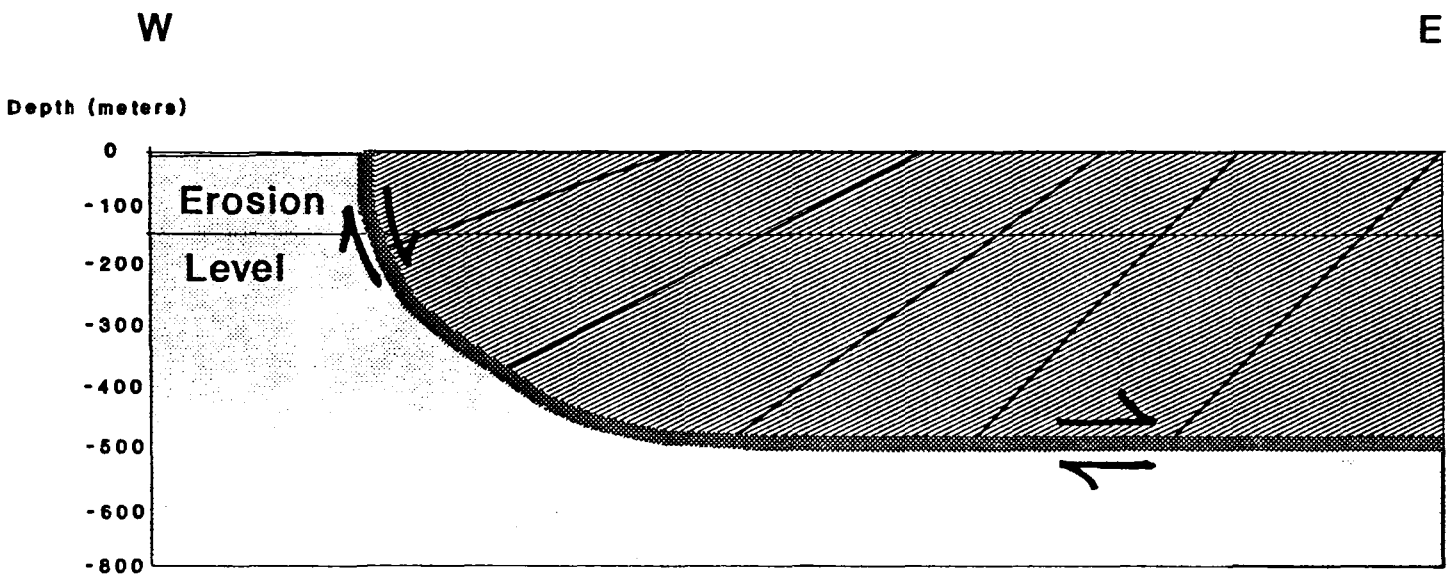
Light Solid Lines: Triassic Rocks

Dotted Area : Country Rock

Angle Cross-Hatch: Master Fault

Arrows : Indicate Fault Displacement

MODEL 1: SINGLE MASTER FAULT



Basins with the geometry shown in model 1 have two distinguishing features (Figure 19). The most recognizable feature of a basin having this geometry is the dip of rocks within the basin increase away from the border fault. The second distinguishing feature is rocks are older in age as one proceeds away from the border fault. As a basin of this type is eroded the dips of rocks become steeper at the surface. Geophysical anomalies of this type of basin are unique. Residual values of the Bouguer and magnetic anomalies would have minimums near the basins' center. Neither rocks of the Farmville Basin nor the gravity data indicate the basin has the geometry of model 1.

Model 2 is the geometric scenario presented for all modelled Mesozoic Basins to date (Figure 20). In this model, the primary fault bounds the basins' western border, with secondary faults covered by the Triassic rocks. Faults divide the basin into a series of blocks that join the master fault. Dip patterns of rocks in such a basin are unique. The dips alternate from shallow to steep to shallow. Overall the dips in the basin decrease away from the border fault. If a mylonite zone bounds the basin then the gravity values sharply decrease at the basins' border fault. Gravity values gradually increase away from the basin border fault. This is attributed to the decrease in basin thickness away from the master fault.

Figure 20: Model 2 shows a basin comprised of a two fault system. The master fault forms the western border of the basin, while splay faults (secondary) are found underneath the basin rocks. All faults shallow with depth. The splay faults eventually join the master fault at depth. The shallow to steep to shallow change in dip patterns along profile section is typical of such basins. The dips generally steepen toward the master fault. If a mylonite zone is present then the Bouguer curve may displays a peak near the border fault perimeter, at the surface.

Legend:

Dark Solid Lines : Dip of Triassic Beds

Light Solid Lines : Triassic Rocks

Dotted Area : Country Rock

Angled Cross-Hatch : Master Fault

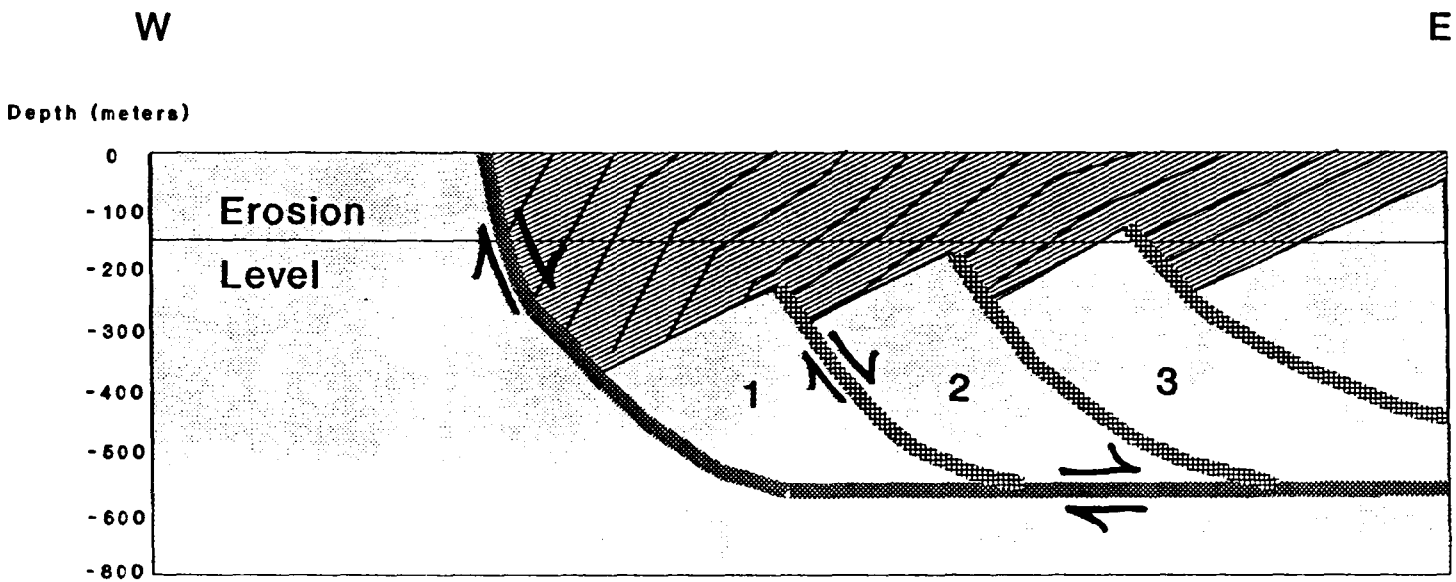
Vertical Cross-Hatch: Splay Fault

1, 2, 3 : Fault Blocks

Arrows : Direction Of Displacement

MODEL 2: LISTRIC FAULTING

Multiple Faults with Primary on Western Border



Model 3 is believed to be representative of the Farmville Basin (Figure 21). In this model, the primary fault lies near the basins' center while secondary faults bound the basin. With this geometry the deepest part of the basin lies on the opposite side of the basins' western border fault. Distinguishing geologic characteristics of this model include dip variations, and a general decrease in dips toward the basin border fault. The lowest gravity anomalies are found over the deepest part of the basin, or nearest the eastern margin.

Figure 21: Model 3 shows a basin comprised of a two fault system. A splay fault forms the western border of the basin, while the master fault(s) are found underneath the basin rocks. All faults shallow with depth. The splay faults eventually join the master fault at depth. The shallow to steep to shallow change in dip patterns along profile section is typical of such basins; however, unlike Model 2 the dips generally steepen toward the eastern portion of the basin (master fault).

Legend:

Dark Solid Lines : Dip of Triassic Beds

Light Solid Lines : Triassic Rocks

Dotted Area : Country Rock

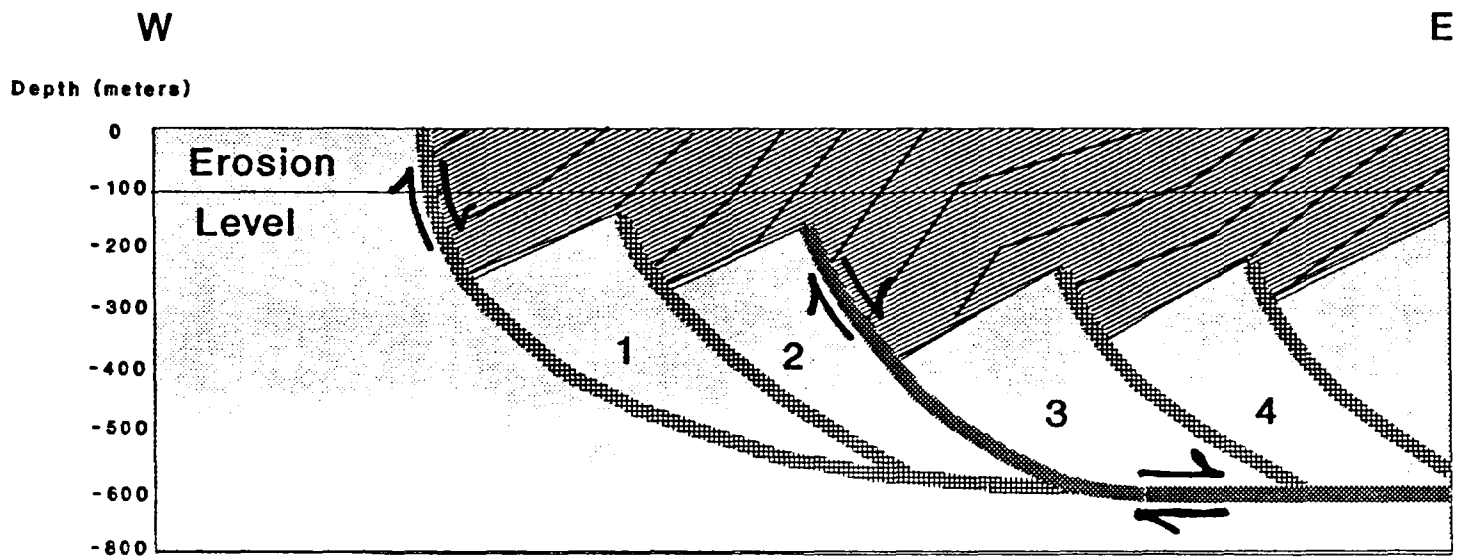
Angled Cross-Hatch : Master Fault

Vertical Cross-Hatch: Splay Fault(s)

1, 2, 3, 4 : Fault Blocks

MODEL 3: LISTRIC FAULTING

Multiple Faults with Primary Underneath Basin



CHAPTER 6

KINEMATIC MODEL

Geologic Evolution

All evidence gathered and analyzed during this study indicates that the present day geometry of the Farmville Basin is a result of Alleghanian, Triassic, and Jurassic structures. The kinematic model developed for the Farmville Basin attempts to explain the evolution of the basin and how the various structures interacted to form the present day basin. Stresses that apparently controlled basin evolution are also examined.

Alleghanian or Preexisting Structures

The Alleghanian orogeny occurred during the Middle Carboniferous to Late Permian (Lefort and Van derVoo, 1980). This orogeny was the result of a collision between North America and Africa. A majority of the regional structural trends found in the study area, are thought to be a result of this orogeny and these are the NE-SW orientation of foliation and folds, as well as the NW-SE orientation of master joints. Foliation and folds were formed as a result of NW-SE directed primary stress or shortening (P1), during the Alleghanian orogeny. A majority of the folds plunge to the SE and are classified as tight isoclinal (Fluety, 1964). In general, foliation dips to the SE between 35 and 45 degrees. Crustal cooling occurred during Post-Alleghanian times, and is

believed to be responsible for the NW-SE joints. This joint set is related to extension or release fracturing, as a result of the cooling. Features formed during the Alleghanian and Post-Alleghanian were the primary structures in determining the geometry of the Farmville Basin.

Basin Formation

Manspeizer and others (1982) suggested the breakup of Pangea began sometime during the Late Permian to Middle Triassic, with the onset of continental uplift. The uplift caused tensional stresses, resulting in graben type structures on both continents. Dooley and Smith (1982) sited evidence to support the conclusions of Manspeizer and others (1982). Van der Voo and others (1976) concluded a counter-clockwise rotation of Africa relative to North America occurred during the Triassic. Venkatarishnan and Lutz (1989) presented a kinematic model of the Richmond basin based on the model of Van der Voo (1976).

Field evidence, basin shape and geophysical modelling suggests that extension was in a NW-SE direction during the formation of the Farmville Basin (Figure 22). This study places P1 in an E15S orientation. This implies P1 (tensional maximum stress) was nearly perpendicular to the NE-SW strike of the foliation, and less than 30 degrees from being parallel with the NW-SE joint set. As extension continued through the

Figure 22: Simplified block diagram illustrates the major structural features and associated stereograms of these structures. Large converging arrows mark the directions of shortening (P1) during the Alleghanian and large diverging arrows mark principal extensional stress (P3) during the Mesozoic times (see text for further details).

STRESSES

P_1 : Primary Stress (convergent arrows - shortening stress)

P_2 : Intermediate Stress

P_3 : Minimum Stress (divergent arrows - extensional stress)

P'_3: Minimum Stress During Dike Emplacement (extensional stress during dike emplacement)

STRUCTURES

T : Thrust Fault

N : Reactivated Thrust Fault

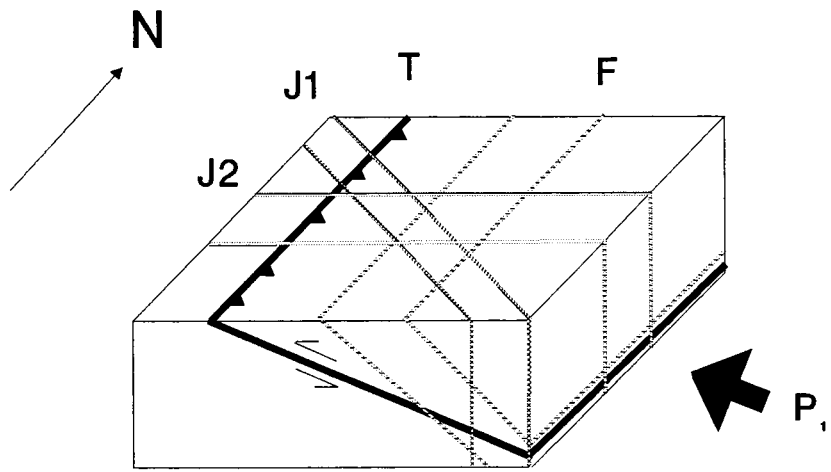
F : Foliation

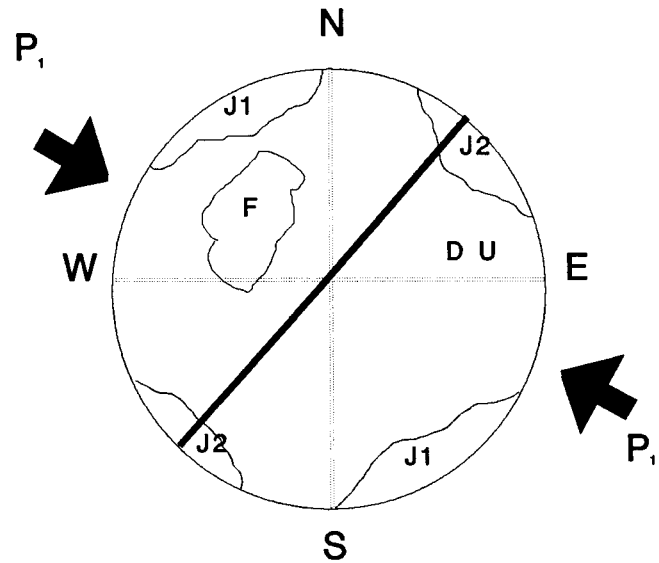
J1 : NE-SW Release Fractures

J2 : E-W Extension Joints

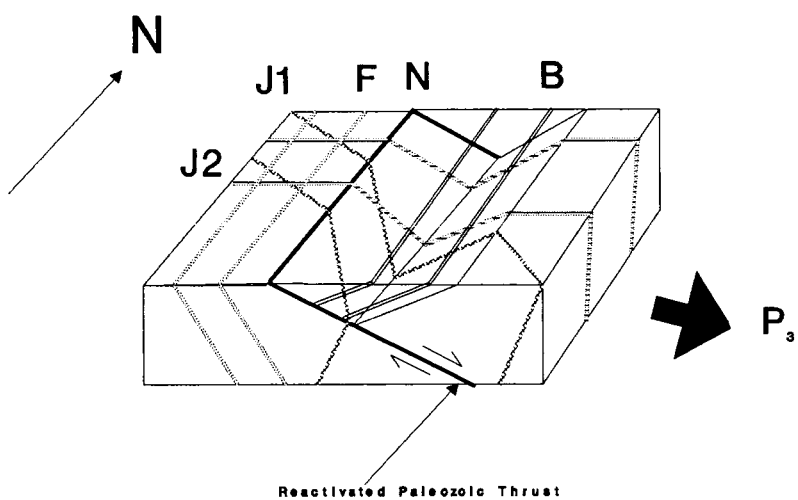
B : Bedding

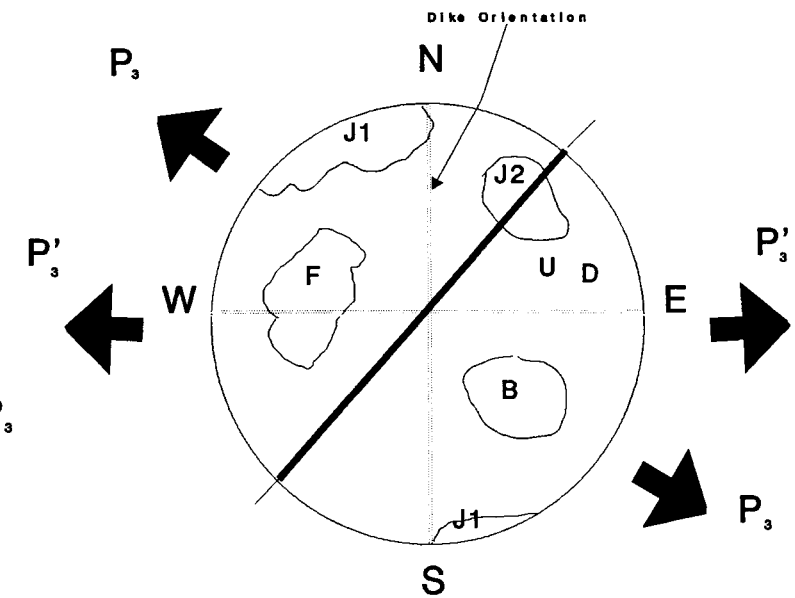
A. POST ALLEGHANIAN STRUCTURES





B. LARNIAN STRUCTURES (BASIN FORMATION)





Carnian, reactivation of the NE-SW fabric occurred forming listric faults. During Mesozoic extension, the NW-SE directed principal extensional stress (P3, corresponding to maximum shortening axis during the Alleghanian) resulted in the reactivation of favorably oriented Paleozoic structures. Alleghanian thrust faults appear to have been reactivated as listric-normal, down-to-the east step faults. Even-though there is no kinematic explanation presently available to suggest why the western most normal fault does not form the basin marginal fault, field evidence suggest that the "master" fault may indeed lie beneath the basin. If this model (Figure 21) is accepted then it is suggested that the basin oversteps the western marginal fault (see also Wernicke and Burchfield, 1982). The geophysical models also support the above interpretation.

Jurassic

As extension continued, changing orientations of the principal extensional stress appears to have resulted in the emplacement of dikes that trend about north-south. Dike orientations range from NNW-SSE to NE-SW. These dikes were part of a "major" igneous event(s) that occurred along eastern North America, Europe, Africa, and South America, during the Jurassic (Dooley and Smith, 1983). It is believed that dikes within the study area were emplaced during the Jurassic; however, radiometric dating of these dikes has not been conducted. Dikes striking in a NE-SW direction parallel the

strike of regional foliation. This indicates that foliation was the structural feature responsible for the NE-SW oriented dike group. The NNW-SSE dike group is thought to have formed along N-S fractures formed as a result of sea-floor spreading. Dikes in the NNW-SSE group were found to have a high concentration of granophyres (Rogan, personal communication, 1987). This lead to the conclusion that the two dike groups were emplaced at different times. Granophyres found in the NNW-SSE dike group indicated the parent magma of this dike group was chemically mature compared to the parent magma of the NE-SW dike group. This implies the NE-SW dike group was emplaced before the NNW-SSE dike group, and lends support to the two phase igneous event suggested by Smith and Noltier (1979). They claim an igneous event occurred at 190 million years and a second igneous event occurred at 170-175 million years. Further field and laboratory analysis is needed to confirm the proposed two phase igneous events proposed in this study.

Post Jurassic

From the Cretaceous to the Holocene tectonic, stresses in the study area are generally attributed to isostatic rebound. This conclusion is supported by the lack of structural features cross-cutting dikes in the area. To test this reasoning, a rectified stream analysis was conducted to determine structural trends. The results of the stream analysis indicates there are three significant trends within

the study area, including a N-S, a NE-SW, and a NW- SE trend. These trends approximate the Pre-Jurassic NE-SW foliation, N-S dikes, and NW-SE joint set. From the evidence gathered during this study it is believed that the present Farmville Basin is a remanent of a much larger basin. It is commonly accepted that as much as 2 kilometers of erosion has occurred in the Piedmont of Virginia (Dooley and Smith, 1982).

COMPARISON WITH OTHER MODELS

One purpose of this study was to compare and contrast the kinematic model of the Farmville Basin with existing models that explain the formation of the Newark-Supergroup. Of existing models, this study presents data to support some aspect of every model with the exception of the Broad Terrane hypothesis (Russell, 1892).

Foliation Control

Strong evidence exist to support the Foliation Control theory of Lindholm (1978). As Lindholm stated, the geometry of a basin and its location was dependent on the Paleozoic foliation, and its orientation to p1, during the break-up of Pangea. This study definitely indicates that preexisting foliation was one factor contributing to the Farmville Basins' geometry. This foliation is thought to have formed during the Alleghanian orogeny. The difference between Lindholm's theory and the kinematic model is that structural features, besides

foliation, contributed to the present day geometry of the Farmville Basin. In addition, mapping in the Farmville Quadrangle showed that the foliation strikes are perpendicular to the western border of the basin (Plate 4). This is a direct contradiction to Lindholm's model.

Paleozoic Fault Control

Swanson (1982) believes the primary factor controlling a basins' geometry and location are Paleozoic Mylonite zones. Though Swanson's model is vague, he believes that the Newark-Supergroup of basins formed along Paleozoic Fault zones. Evidence from this study indicates that Paleozoic age mylonitic zones were critical in determining the Farmville Basins' geometry; however, this was not the only factor contributing to the formation of the basin.

Ratcliffe And Burton (1985)

The strongest similarity between the model of Ratcliffe and Burton (1985), and the model presented in this study is that the geometry of the Farmville basin is a direct result of Paleozoic structures. This study concludes that foliation, joints, and Allegahnian thrust are the structural features most strongly controlling the geometry of the Farmville Basin. In contrast, the duplex reactivation model of Ratcliffe and Burton (1985) proposes reactivation of concave and convex Paleozoic thrust systems as the primary factor controlling a

basin's geometry. The geophysical model does not support a duplex model. Ratcliffe and Burton (1985) proposed the duplex reactivation model can explain the geometry of all Mesozoic Basin in eastern North America. Differences explained above between the duplex reactivation and kinematic model raise doubts as to whether the model of Ratcliffe and Burton (1985) is a unifying model for the formation of basins of the Newark Supergroup. One primary difference is that the geometry of the Farmville Basin is of rotational listric type as defined by Wernicke and Burchfield (1982) and convex and concave fault geometry does not appear to be present.. In other words, the basin is comprised of a series of block faults joining a master decollement at depth. The fault with maximum displacement in the Farmville Basin is believed to lie underneath the basin as opposed to the western margin of a basin (as is the case in the duplex reactivation model). Ratcliffe and Burton (1985) suggest the deepest part of a basin occurs immediately to that east of the border fault. The results of this study and evidence presented in this study clearly shows that the deepest part of the Farmville Basin lies farther to the east of the border thrust (eastern part of the basin). Geophysical evidence from this study suggests that block faults were displaced by cross-faults while no evidence was presented indicating that similar displacements were expected in duplex reactivation model.

CHAPTER 7

CONCLUSIONS

Field geological and geophyscial data obtained during the course of this study show that the Farmville basin is indeed a true half graben. The half graben was formed during NW-SE directional Mesozoic extension. However, unlike the generally accepted and existing models sugesting that basin formation nucleates on one common marginal border fault, this study shows that the fault displays maximum down-dip movement and hence controlling the deepest part of the basin may indeed lie within the central part of the basin. In other words, the Newark Group of Triassic basins need not all be nucleated on a western, down-to-the-east marginal fault. The geophysical models presented also clearly displayed the staircase geometry of reactivated Paleozoic faults. However, amounts of down-dip (to the east) movement varied. The deepest part of the Farmville basin is clearly along the eastern margin of the basin.

Future study would be extremely helpful in clarifying some of the more obscure points in this study. A detailed structural analysis is needed of the basin rocks to determine if cross-faults do exist in the basin. Proving the presence of cross-faults would lend more support to the structural and

kinematic models presented in this study. Other areas of study that would be useful in understanding the formation of the Farmville Basin include, a detailed analysis of dike morphology, and seismic profiles across the modelled gravity profiles.

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APPENDIX I-A

GRAVAS FORTRAN

Gravas Fortran is a used to reduced the gravimetric dial readings to Free Air and Bouguer Anomalies. The algorithm first converts the dial readings from a LaCoste Romberg gravity meter (Model G, #289) to observed gravity values. The program converts observed gravity values for elevation and mass differences between stations, as well as solar and lunar fluctuations (tides), and instrumental drift. Finally, the algorithm applies Free Air and Bouguer corrections to the observed data yielding the Free Air and Bouguer anomalies for each station. This program was originally written by Virginia Division of Mineral Resources, Charlottesville Virginia. The program is listed below:

GRAVAS FORTRAN:

Written By: Virginia Division Of Mineral Resources

```
C    ROUTINE GRAVAS  (AFTER SNOWDEN; FROM VDMR)                          GRA00010
C                                                                        GRA00020
      DIMENSION VIM(72),NBASE(30),BASEG(30)                              GRA00030
      DIMENSION DELT(100),DELG(100),RES(100)                             GRA00040
      DIMENSIONIDATE(190),PHI(190),ALON(190),OBSG(190),H(190),NUM(190)GRA00050
```

```
      DIMENSION HS(190),SURNAM(21)                                      GRA00060
      CHARACTER*6TAG(13),STA1(190),STA2(190),A,B,C,D,E,F,G,Q,R,S,T,U,VGRA00070
      CHARACTER *6 CONVER                                               GRA00080
      CHARACTER * 1 TITLE(67)                                           GRA00090
C     OPEN (UNIT=1,ACCESS='SEQUENTIAL',FILE='CAL')                      GRA00100
C     OPEN (UNIT=2,ACCESS='SEQUENTIAL',FILE='GRAVAS')                   GRA00110
C     OPEN (UNIT=4,ACCESS='SEQUENTIAL',FILE='FINAL')                    GRA00120
      JIMMY=0                                                           GRA00130
      WRITE(6,1141)                                                     GRA00140
1141  FORMAT(10X,44HENTER DESIRED DISTANCE TO START FOR PLOTTING,/,     GRA00150
     +20X,49HIF DISTANCE DESIRED IS 0.0 FEET ENTER -400.0 FEET,/)       GRA00160
      READ(5,*) DIST                                                    GRA00170
C               IF JAG =                                                GRA00180
C                       0 TERMINATE RUN                                 GRA00190
C                       1 DO NOT READ CALIBRATION                       GRA00200
C                       2 READ CALIBRATION TABLE                        GRA00210
C               IF KAG =                                                GRA00220
C                       1 DO NOT READ BASE STNS                         GRA00230
C                       2 READ BASE STNS                                GRA00240
C               IF LAG =                                                GRA00250
C                       1 OMIT OPTION                                   GRA00260
C                       2 READ GMT REJKT CALIM RHO                      GRA00270
C               IF MAG =                                                GRA00280
C                       1 LOOP DRIFT COMPUTATION                        GRA00290
C                       2 LINE DRIFT COMPUTATION                        GRA00300
C               IF NAG =                                                GRA00310
C                      1 INDIVIDUAL LOOP(LINE) COMPUTATION              GRA00320
C                      2 STORE LOOP PENDING INTERLOOP COMPARISON        GRA00330
C                      3 LAST LOOP,STORE,EXECUIT COMPARISON             GRA00340
C               IF IAG =                                                GRA00350
C                       1 IGNORE OPTION                                 GRA00360
C                       2 PUNCH ACIC CARDS                              GRA00370
C                       3 PUNCH NON-ACIC CARDS                          GRA00380
C               IF IFOR =                                               GRA00390
C                       0 PRINT STANDARD TITLE                          GRA00400
C                       1 PRINT ALTERNATE TITLE                         GRA00410
   90 READ (1,100) JAG,KAG,LAG,MAG,NAG,IAG,IFOR                         GRA00420
  100 FORMAT(7I1)                                                       GRA00430
      NOMTYP=0                                                          GRA00440
      IF(JAG) 700,700,150                                               GRA00450
  150 GO TO (300,200),JAG                                               GRA00460
C             TAG IS CALIBRATION TABLE TITLE                            GRA00470
  200 READ (1,225) (TAG(I),I=1,13)                                      GRA00480
  225 FORMAT(13A6)                                                      GRA00490
      READ (1,230) SCALE                                                GRA00500
  230 FORMAT(F8.6)                                                      GRA00510
      DO 250 I=1,9                                                      GRA00520
C             VIM (VALUE IN MILLIGALS) IS CALIBRATION TABLE             GRA00530
      K=I*8                                                             GRA00540
      J=K-7                                                             GRA00550
  250 READ (1,260) (VIM(L),L=J,K)                                       GRA00560
  260 FORMAT(8F10.2)                                                    GRA00570
      IF(SCALE) 285,300,285                                             GRA00580
  285 DO 290 I=1,72                                                     GRA00590
  290 VIM(I)=VIM(I)*SCALE                                               GRA00600
  300 GO TO (400,310),KAG                                               GRA00610
C       NBASE AND BASEG ARE NUMBER AND MGAL VALUE OF BASE STATIONS      GRA00620
  310 READ (1,320) NNBASE                                               GRA00630
  320 FORMAT(I2)                                                        GRA00640
      DO 330 I=1,NNBASE                                                 GRA00650
      IF(IFOR.NE.0) GO TO 345                                           GRA00660
      READ (2,340) NBASE(I),BASEG(I)                                    GRA00670
```

```
  340 FORMAT(I4,2X,F9.3)                                                GRA00680
      GO TO 330                                                         GRA00690
  345 READ (2,346) NBASE(I),BASEG(I)                                    GRA00700
  346 FORMAT(I5,F9.3)                                                   GRA00710
  330 BASEG(I)=BASEG(I)-976000.                                         GRA00720
  400 GO TO (500,410),LAG                                               GRA00730
C         LCT+GMT=GCT                                                   GRA00740
C              REJKT IS REJECTION LIMIT                                 GRA00750
C              CALIM IS CALIBRATION REJECTION LIMIT                     GRA00760
  410 READ (1,420)  GMT,REJKT,CALIM                                     GRA00770
  420 FORMAT(F6.2,2F5.3)                                                GRA00780
      IF(CALIM.LE.0.) CALIM=.15                                         GRA00790
      IF(REJKT.LE.0.) REJKT=.05                                         GRA00800
C             READ LOOP (LINE) TITLE                                    GRA00810
  500 IF(IFOR.NE.0) GO TO 511                                           GRA00820
      READ(2,505) (TITLE(II),II=1,67)                                   GRA00830
505   FORMAT(67A1)                                                      GRA00840
      WRITE(4,510) (TITLE(II),II=1,67)                                  GRA00850
510   FORMAT(1X,67A1)                                                   GRA00860
      GO TO 519                                                         GRA00870
  511 READ (2,512) (SURNAM(I),I=1,8),TYPINS,INSNO,SURNAM(9),SURNAM(10) ,GRA00880
     1NOMTYP,(SURNAM(I),I=11,21)                                        GRA00890
  512 FORMAT(8A6,A3,I3,2A6,I3,11A1)                                     GRA00900
      WRITE (4,513) (SURNAM(I),I=1,8),TYPINS,INSNO,(SURNAM(I),I=9,21)   GRA00910
  513 FORMAT(1H1,45X,5A6/2X,10HLOOP/LINE ,A6,7X,5HDATE ,2A6,7X,11HGRAVIMGRA00920
     1ETER ,A3,I3,7X,9HOBSERVER ,2A6,7X,8HCOMMENT ,11A1)                GRA00930
  519 WRITE (4,225) (TAG(I),I=1,13)                                     GRA00940
  520 CALL STORE(IDATE,PHI,ALON,OBSG,H,NUM,VIM,    GMT,ICOUNT,STA1,STA2GRA00950
     1,IYEAR,HS,IFOR)                                                   GRA00960
  530 CALL TIDE(ICOUNT,NUM,IDATE,OBSG,PHI,ALON,H)                       GRA00970
      CALL DRIFT(ICOUNT,NUM,OBSG,IDATE,REJKT,MAG,NNBASE,NBASE,BASEG,    GRA00980
     1DELT,DELG,RES,RR,DD)                                              GRA00990
      GO TO (550,560,550,550),NAG                                       GRA01000
  550 IF(IFOR.NE.0) GO TO 552                                           GRA01010
      WRITE (4,551) A,B,C,D,E,G,Q                                       GRA01020
  551 FORMAT(1H1,9X,5A6,2X,2A6)                                         GRA01030
      GO TO 554                                                         GRA01040
  552 WRITE (4,553) (SURNAM(I),I=1,5)                                   GRA01050
  553 FORMAT(1H1,45X,5A6)                                               GRA01060
  554 GO TO (555,560,560,555),NAG                                       GRA01070
  555 WRITE (4,225) (TAG(I),I=1,13)                                     GRA01080
  560CALLGRANET(ICOUNT,NUM,STA1,STA2,OBSG,PHI,ALON,H,NNBASE,NBASE,BASEGRA01090
     1G,NOMTYP,JIMMY,NAG,IAG,HS,RR,DD,DIST)                             GRA01100
      IF(NAG.EQ.4)CALLCALIB(ICOUNT,NUM,OBSG,NNBASE,NBASE,BASEG,STA1,STGRA01110
     1A2,NAG,PHI,ALON,H,CALIM,DELT,DELG,RES)                            GRA01120
      IF(NAG.EQ.5) GO TO 560                                            GRA01130
C     GO TO 90                                                          GRA01140
C      CLOSE (UNIT=20)                                                  GRA01150
C      CLOSE (UNIT=21)                                                  GRA01160
C      CLOSE (UNIT=41)                                                  GRA01170
C      CLOSE (UNIT=42)                                                  GRA01180
  700 STOP                                                              GRA01190
      END                                                               GRA01200
C                                                                       GRA01210

C                                                                       GRA01220
C                                                                       GRA01230
      SUBROUTINE STORE(IDATE,PHI,ALON,OBSG,H,NUM,VIM,    GMT,ICOUNT,STAGRA01240
     1 1,STA2,JYEAR,HS,IFOR)                                            GRA01250
C       IDATE = DATE AND TIME OF OBSERVATION                            GRA01260
C      CONVERTS YEAR , DAY , HOUR ,MINUTES TO ONE VARIABLE IDATE IN MINUGRA01270
C         LEAP YEAR TAKEN INTO ACCOUNT , CONVERSION TO GMT             GRA01280
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C      LATITUDE , LONGITUDE CONVERTED TO RADIANS                          GRA01290
C      DIAL READING CONVERTED TO MGALS                                    GRA01300
C *****NUMBER,DATE,TIME,OBS.G,PHI,LAMBDA,HEIGHT ARE STORED                GRA01310
       DIMENSION IDATE(1),PHI(1),ALON(1),OBSG(1),NUM(1),VIM(1)            GRA01320
      DIMENSION HS(1),H(1)                                                GRA01330
       CHARACTER *6 CONVER,CON,CKF, STA1(1),STA2(1)                       GRA01340
       I=1                                                                GRA01350
       CKF='F'                                                            GRA01360
 1000 IF(IFOR.NE.0) GO TO 50                                              GRA01370
      READ (2,1001) NUM(I),STA1(I),STA2(I),IDAY,MONTH,IYEAR,IHOUR,DIA     GRA01380
     1L,IPHI,JPHI,PHI(I),LON,ILON,ALON(I),CONVER,H(I)                     GRA01390
 1001 FORMAT(I5,2A6,I2,I2,I4,I4,F7.3,2I3,F2.0,I4,I3,F2.0,A1,F8.2)         GRA01400
      WRITE (9,1002) STA1(I),STA2(I)                                      GRA01410
1002  FORMAT (5X,2A6)                                                     GRA01420
      GO TO 99                                                            GRA01430
  999 PHI(I)=PHI(I)*0.6                                                   GRA01440
      ALON(I)=ALON(I)*0.6                                                 GRA01450
   50 READ (2,51) NUM(I),STA1(I),STA2(I),IDAY,MONTH,IYEAR,IHOUR,MINUTE ,GRA01460
     1IPHI,PHI(I),LON,ALON(I),CONVER,H(I)                                 GRA01470
   51 FORMAT(I5,2A6,2I2,I4,2I2,F7.3,I3,F5.2,I4,F5.2,A1,F8.2)              GRA01480
      WRITE (9,1002) STA1(I),STA2(I)                                      GRA01490
   99 IF(IYEAR) 105,100,105                                               GRA01500
  100  ICOUNT=I-1                                                         GRA01510
       RETURN                                                             GRA01520
  105  GO TO (110,111,112,113,114,115,116,117,118,119,120,121),MONTH      GRA01530
  110  IDATE(I)=IDAY                                                      GRA01540
       GO TO 125                                                          GRA01550
  111  IDATE(I)=IDAY+31                                                   GRA01560
       GO TO 125                                                          GRA01570
  112  IDATE(I)=IDAY+59                                                   GRA01580
       GO TO 125                                                          GRA01590
  113  IDATE(I)=IDAY+90                                                   GRA01600
       GO TO 125                                                          GRA01610
  114  IDATE(I)=IDAY+120                                                  GRA01620
       GO TO 125                                                          GRA01630
  115  IDATE(I)=IDAY+151                                                  GRA01640
       GO TO 125                                                          GRA01650
  116  IDATE(I)=IDAY+181                                                  GRA01660
       GO TO 125                                                          GRA01670
  117  IDATE(I)=IDAY+212                                                  GRA01680
       GO TO 125                                                          GRA01690
  118  IDATE(I)=IDAY+243                                                  GRA01700
       GO TO 125                                                          GRA01710
  119  IDATE(I)=IDAY+273                                                  GRA01720
       GO TO 125                                                          GRA01730
  120  IDATE(I)=IDAY+304                                                  GRA01740
       GO TO 125                                                          GRA01750
  121  IDATE(I)=IDAY+334                                                  GRA01760
  125  YEAR=IYEAR                                                         GRA01770
      IDATE(I)=IDATE(I)+(IYEAR-1900)/4+1                                  GRA01780
      IF(YEAR/4.-FLOAT(IYEAR/4)) 145,135,145                              GRA01790
  135 IF(MONTH-3) 140,145,145                                             GRA01800
  140 IDATE(I)=IDATE(I)-1                                                 GRA01810
  145 TIME=(FLOAT(IHOUR)/100.0)+0.001                                     GRA01820
      JHR=IFIX(TIME)                                                      GRA01830
      MINUTE=IFIX((TIME-FLOAT(JHR))*100.0)                                GRA01840
      IHOUR=JHR                                                           GRA01850
      IDATE(I)=(IYEAR-1900)*525600+(IDATE(I)-2)*1440+IHOUR*60+IFIX(GMT*6GRA01860
     10.)+720+MINUTE                                                      GRA01870
       IF(CONVER.EQ.CKF)  H(I)=H(I)/3.280833                              GRA01880
      IF(IFOR.EQ.0) GO TO 180                                             GRA01890
      IF(CON.EQ.CKF) HS(I)=HS(I)/3.280833                                 GRA01900
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  180 PHI(I)=DERAD2(IPHI,JPHI,PHI(I))                                    GRA01910
      ALON(I)=DERAD2(LON,ILON,ALON(I))                                   GRA01920
       J=IFIX(DIAL/100.0)                                                GRA01930
       CR=FLOAT(J)*100.0                                                 GRA01940
       R=DIAL-CR                                                         GRA01950
       J=J+1                                                             GRA01960
      OBSG(I)=VIM(J)+R*(VIM(J+1)-VIM(J))/100.                            GRA01970
      JYEAR=IYEAR                                                        GRA01980
       I=I+1                                                             GRA01990
       GO TO 1000                                                        GRA02000
       END                                                               GRA02010

C                                                                        GRA02020
C                                                                        GRA02030
C                                                                        GRA02040
      SUBROUTINE TIDE(ICOUNT,NUM,IDATE,OBSG,PHI,ALON,H)                  GRA02050
C     COMPUTES TIDAL CORRECTION BY LONGMAN METHOD. JGR,VOL.64,NO.12,P.23GRA02060
        DIMENSION PHI(1),IDATE(1),H(1),ALON(1),OBSG(1),NUM(1)            GRA02070
       DATA  SMLA,SMLC1,SMLE,SMLM,OMEGA,AMU,BIGM,BIGS,SMLC,SMLI,SMLAP,CON1GRA02080
      1,CON2,CON3,CON4,CON5,CON6,CON7,CON8,CON9,CON10,CON11,CON12,CON13,  GRA02090
      2CON14,CON15,CON16,CON17,CON18,CON19,CON20,CON21,CON22,CON23,CON24/GRA02100
      36.37827E8,1.495E13,5.489972E-2,7.4804E-2,4.09314616E-1,6.670E-8,GRA02110
      47.3537E25,1.993E33,3.84402E10,8.979719E-2,.260931E-10,.006738,.016GRA02120
      575104,.00004180,.126E-6,4.90822947,3.00052642E-2,7.90246E-6,5.818EGRA02130
      6-8,4.71996657,8399.70914,-1.97803982E-5,3.29673303E-8,5.83515153,  GRA02140
      771.0180412,1.80205245E-4,2.18166156E-7,4.88162793,628.331951,5.279GRA02150
      862E-6,.261799388,4.52360045,33.7571462,3.62640633E-5,3.87850945E-8GRA02160
      9/                                                                 GRA02170
       WRITE (4,71)                                                      GRA02180
   71 FORMAT(///5X,6HSTA NO,14X,4HDATE,10X,12HUNCORR OBS G,10X,9HTIDE COGRA02190
     1RR//20X,14HJULIAN MINUTES,9X,5HMGALS,15X,5HMGALS//)                GRA02200
  200  DO 300 I=1,ICOUNT                                                 GRA02210
       SNPHI=SIN(PHI(I))                                                 GRA02220
       CSPHI=COS(PHI(I))                                                 GRA02230
  205 T=FLOAT(IDATE(I))/52596000.                                        GRA02240
       T2=T**2                                                           GRA02250
       T3=T*T2                                                           GRA02260
  210  BIGC=SQRT(1.0/(1.0+CON1*SNPHI**2))                                GRA02270
       SMLR=BIGC*SMLA+H(I)*100.0                                         GRA02280
       SMLE1= CON2-CON3*T-CON4*T2                                        GRA02290
       SMLAP1=1.0/(SMLC1*(1.0-SMLE1**2))                                 GRA02300
       SMLP1=CON5+CON6*T+CON7*T2+CON8*T3                                 GRA02310
       SMLS=CON9+CON10*T+CON11*T2+CON12*T3                               GRA02320
       SMLP=CON13+CON14*T-CON15*T2-CON16*T3                              GRA02330
       SMLH=CON17+CON18*T+CON19*T2                                       GRA02340
  220  BIGRD=1.0/SMLC1+SMLAP1*SMLE1*COS(SMLH-SMLP1)                      GRA02350
       SMLRD=1.0/SMLC+SMLAP*SMLE*COS(SMLS-SMLP)+SMLAP*SMLE**2*COS(2.0*GRA02360
     1(SMLS-SMLP))+(15.0/8.0)*SMLAP*SMLM*SMLE*COS(SMLS-2.0*SMLH+SMLP)+GRA02370
     2 SMLAP*SMLM**2*COS(2.0*(SMLS-SMLH))                                GRA02380
  225 SMLTO=FLOAT(IDATE(I)-(IDATE(I)/1440)*1440)/60.0                    GRA02390
       SMLT=CON20*(SMLTO     )+ALON(I)                                   GRA02400
       CHI1=SMLT+SMLH                                                    GRA02410
       SMLL1=SMLH+2.0*SMLE1*SIN(SMLH-SMLP1)                              GRA02420
  230  BIGN=CON21-CON22*T+CON23*T2+CON24*T3                              GRA02430
       CSBIGI=COS(OMEGA)*COS(SMLI)-SIN(OMEGA)*SIN(SMLI)*COS(BIGN)        GRA02440
       SNBIGI=SQRT(1.0-CSBIGI**2)                                        GRA02450
       BIGI=ATAN2(SNBIGI,CSBIGI)                                         GRA02460
  235  SNGNU=SIN(SMLI)*SIN(BIGN)/SNBIGI                                  GRA02470
       CSGNU=SQRT(1.0-SNGNU**2)                                          GRA02480
       GNU=ATAN2(SNGNU,CSGNU)                                            GRA02490
       CHI=SMLT+SMLH-GNU                                                 GRA02500
       CSALFA=COS(BIGN)*CSGNU+SIN(BIGN)*SNGNU*COS(OMEGA)                 GRA02510
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      SNALFA=SIN(OMEGA)*SIN(BIGN)/SNBIGI                                GRA02520
      ALFA=2.0*ATAN(SNALFA/(1.0+CSALFA))                                GRA02530
  240 ETA=BIGN-ALFA                                                     GRA02540
      SIGMA=SMLS-ETA                                                    GRA02550
      SMLL=SIGMA+2.0*SMLE*SIN(SMLS-SMLP)+1.25*SMLE**2*SIN(2.0*(SMLS-    GRA02560
     1  SMLP))+3.75*SMLM*SMLE*SIN(SMLS-2.0*SMLH+SMLP)+(11.0/8.0)*SMLM**2*GRA02570
     2 SIN(2.0*(SMLS-SMLH))                                             GRA02580
  245 CSFEE=SNPHI*SIN(OMEGA)*SIN(SMLL1)+CSPHI*(COS(OMEGA/2.0)**2*COS    GRA02590
     1 (SMLL1-CHI1)+SIN(OMEGA/2.0)**2*COS(SMLL1+CHI1))                  GRA02600
  250 CSTHET=SNPHI*SNBIGI*SIN(SMLL)+CSPHI*(COS(BIGI/2.0)**2*COS(SMLL-   GRA02610
     1 CHI)+SIN(BIGI/2.0)**2*COS(SMLL+CHI))                             GRA02620
C THE NEXT TWO STATEMENTS ARE WRITTEN TO TAKE ADVANTAGE OF MACHINES WITHGRA02630
C  LIMITATIONS AS TO THE SIZE OF LARGE NEGATIVE EXPONENTS               GRA02640
  255  GS=AMU*BIGS*SMLR*BIGRD**2*BIGRD*(3.0*CSFEE**2-1.0)               GRA02650
  260 GM=AMU*BIGM*SMLR*SMLRD**3*(3.0*CSTHET**2-1.0)+1.5*AMU*BIGM*SMLRD GRA02660
     1**2*SMLR**2*SMLRD**2*(5.0*CSTHET**3-3.0*CSTHET)                   GRA02670
  270 GOO=(GM+GS)*1200.0                                                GRA02680
      WRITE (4,3000) NUM(I),IDATE(I),OBSG(I),GOO                        GRA02690
 3000 FORMAT(5X,I5,10X,I10,8X,F10.3,13X,F6.3)                           GRA02700
  300  OBSG(I)=OBSG(I)+GOO                                              GRA02710
       RETURN                                                           GRA02720
       END                                                              GRA02730
C                                                                       GRA02740

C                                                                       GRA02750
C                                                                       GRA02760
      SUBROUTINE DRIFT(ICOUNT,NUM,OBSG,IDATE,REJKT,MAG,NNBASE,NBASE,    GRA02770
     1BASEG,DELT,DELG,RES,ZSUM,ZENO)                                    GRA02780
      DIMENSION NUM(1),OBSG(1),IDATE(1),NBASE(1),BASEG(1)               GRA02790
      DIMENSION DELT(1),DELG(1),RES(1),LUM(100)                         GRA02800
C     IF MAG=@                                                          GRA02810
C           1,LOOP COMPUTATION                                          GRA02820
C           2,LINE COMPUTATION                                          GRA02830
      KDAT=IDATE(1)                                                     GRA02840
C          REFERANCE ALL TIMES TO INITAL TIME                           GRA02850
       WRITE (4,69)                                                     GRA02860
   69  FORMAT(//5X,6HSTA NO,14X,4HTIME,14X,4HOBSG,15X,'(CORRECTED FOR   GRA02870
     1 TIDE)'/)                                                         GRA02880
      WRITE (4,1)                                                       GRA02890
    1 FORMAT(10H          )                                           GRA02900
      DO 10 J=1,ICOUNT                                                  GRA02910
   10 IDATE(J)=IDATE(J)-KDAT                                            GRA02920
       DO 12 I=1,ICOUNT                                                 GRA02930
      WRITE (4,15) NUM(I),IDATE(I),OBSG(I)                              GRA02940
   15 FORMAT(5X,I5,13X,I6,11X,F9.3)                                     GRA02950
   12 CONTINUE                                                          GRA02960
      JC=ICOUNT-1                                                       GRA02970
C          REMOVE DRIFT STNS                                            GRA02980
      DO 19 J=1,JC                                                      GRA02990
      IF(NUM(J).NE.0) GO TO 19                                          GRA03000
      IF(NUM(J)-NUM(J+1)) 19,16,19                                      GRA03010
   16 GLAY=OBSG(J+1)-OBSG(J)                                            GRA03020
      LAYT=IDATE(J+1)-IDATE(J)                                          GRA03030
      KK=J+1                                                            GRA03040
      DO 18 K=KK,ICOUNT                                                 GRA03050
      OBSG(K)=OBSG(K)-GLAY                                              GRA03060
   18 IDATE(K)=IDATE(K)-LAYT                                            GRA03070
   19 CONTINUE                                                          GRA03080
C          TEST FOR AND REMOVE ANY LAY-OVERS                            GRA03090
       DO 30 J=1,JC                                                     GRA03100
      IF(NUM(J).EQ.0) GO TO 30                                          GRA03110
      IF(NUM(J)-NUM(J+1)) 30,20,30                                      GRA03120
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   20 GLAY=OBSG(J+1)-OBSG(J)                                          GRA03130
      LAYT=IDATE(J+1)-IDATE(J)                                        GRA03140
      KK=J+1                                                          GRA03150
      NUM(KK)=0                                                       GRA03160
      DO 25 K=KK,ICOUNT                                               GRA03170
      OBSG(K)=OBSG(K)-GLAY                                            GRA03180
   25 IDATE(K)=IDATE(K)-LAYT                                          GRA03190
   30 CONTINUE                                                        GRA03200
      GO TO(31,150),MAG                                               GRA03210
C          TEST FOR REOCCUPATIONS,FORM DELTA G2S AND DELTA T2S         GRA03220
   31 XYSUM=0.                                                        GRA03230
      X2SUM=0.                                                        GRA03240
      XSUM=0.                                                         GRA03250
      YSUM=0.                                                         GRA03260
      L=0                                                             GRA03270
       WRITE (4,39)                                                   GRA03280
   39  FORMAT(///)                                                    GRA03290
      DO 50 I=1,JC                                                    GRA03300
      IF(NUM(I)) 50,50,32                                             GRA03310
   32 K=I+1                                                           GRA03320
      DO 45 J=K,ICOUNT                                                GRA03330
   35 IF(NUM(I)-NUM(J)) 45,40,45                                      GRA03340
   40 L=L+1                                                           GRA03350
      LUM(L)=NUM(J)                                                   GRA03360
      DELG(L)=OBSG(J)-OBSG(I)                                         GRA03370
      DELT(L)=IDATE(J)-IDATE(I)                                       GRA03380
      WRITE (4,941) L,DELG(L),L,DELT(L)                               GRA03390
  941  FORMAT(1H ,5HDELG(,I2,2H)=,F7.3,8X,5HDELT(,I2,2H)=,F8.1)       GRA03400
      XYSUM=XYSUM+DELG(L)*DELT(L)                                     GRA03410
      X2SUM=X2SUM+DELT(L)**2                                          GRA03420
      XSUM=XSUM+DELT(L)                                               GRA03430
      YSUM=YSUM+DELG(L)                                               GRA03440
   45 CONTINUE                                                        GRA03450
   50 CONTINUE                                                        GRA03460
      WRITE (4,600)                                                   GRA03470
  600 FORMAT(1H1,50X,20HD R I F T    P L O T//)                       GRA03480
      CALL PLOT2D(L,DELT,DELG)                                        GRA03490
C          SOLVE FOR BEST FIT LINEAR DRIFT                            GRA03500
      WRITE (4,68)                                                    GRA03510
   68 FORMAT(1H1)                                                     GRA03520
      IPASS=1                                                         GRA03530
      DENO = L+1                                                      GRA03540
      ZENO=DENO                                                       GRA03550
   70 DENOM= DENO*X2SUM-XSUM**2                                       GRA03560
      AC=(DENO*XYSUM-XSUM*YSUM)/DENOM                                 GRA03570
      BINT=(YSUM*X2SUM-XYSUM*XSUM)/DENOM                              GRA03580
C          COMPUTE RESIDUALS , TEST AGAINST REJECTION LIMIT           GRA03590
      II=1                                                            GRA03600
      RSUM=0.                                                         GRA03610
      WRITE (4,800) IPASS,REJKT                                       GRA03620
  800 FORMAT(////13H FIT NUMBER  ,I1,37H  REJECTED VALUES  REJECTION LIMGRA03630
     1IT = ,F5.3,5HMGALS/)                                            GRA03640
      DO 72 I=1,L                                                     GRA03650
      IF(LUM(I)) 72,72,71                                             GRA03660
   71 RES(I)=BINT+AC*DELT(I)-DELG(I)                                  GRA03670
      RSUM=RSUM+RES(I)**2                                             GRA03680
   72 CONTINUE                                                        GRA03690
      IF(IPASS.EQ.1) ZSUM=RSUM                                        GRA03700
      SIGMA=SQRT(RSUM/DENO)                                           GRA03710
      RESMAX=0.                                                       GRA03720
      DO 74 I=1,L                                                     GRA03730
      IF(LUM(I)) 74,74,73                                             GRA03740
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   73 RESMAX=AMAX1(RESMAX,ABS(RES(I)))                                  GRA03750
   74 CONTINUE                                                          GRA03760
      DO 76 I=1,L                                                       GRA03770
      IF(LUM(I)) 76,76,75                                               GRA03780
   75 IF (ABS(RES(I))-RESMAX) 76,77,77                                  GRA03790
   77 IF(ABS(RES(I))-REJKT) 76,76,80                                    GRA03800
   80 II=2                                                              GRA03810
      XYSUM=XYSUM-DELG(I)*DELT(I)                                       GRA03820
      X2SUM=X2SUM-DELT(I)**2                                            GRA03830
      XSUM=XSUM-DELT(I)                                                 GRA03840
      YSUM=YSUM-DELG(I)                                                 GRA03850
      KDELT=DELT(I)                                                     GRA03860
      WRITE (4,900) LUM(I),KDELT,RES(I)                                 GRA03870
  900 FORMAT(1H0,11HSTA NUMBER ,I5,4X,6HTIME =,I5,5X,11HRESIDUAL = ,F7.3GRA03880
     1)                                                                 GRA03890
      LUM(I)=0                                                          GRA03900
      DENO=DENO-1.                                                      GRA03910
   76 CONTINUE                                                          GRA03920
      WRITE (4,1000) IPASS,SIGMA                                        GRA03930
 1000 FORMAT(1H0,14HSIGMA FOR FIT ,I1,3H = ,F8.4)                       GRA03940
C           IF ANY VALUES REJECTED REFIT DRIFT                         GRA03950
      GO TO(120,85),II                                                  GRA03960
   85 IPASS=IPASS+1                                                     GRA03970
      GO TO 70                                                          GRA03980
C     DRIFT COMPUTATION FOR LINE                                        GRA03990
  150 DO 170 I=1,NNBASE                                                 GRA04000
      IF(NUM(1)-NBASE(I)) 160,155,160                                   GRA04010
  155 FIRST=BASEG(I)                                                    GRA04020
  160 IF(NUM(ICOUNT)-NBASE(I)) 170,165,170                              GRA04030
  165 BLAST=BASEG(I)                                                    GRA04040
  170 CONTINUE                                                          GRA04050
      REFDIF=FIRST-BLAST                                                GRA04060
      DIF=OBSG(1)-OBSG(ICOUNT)                                          GRA04070
      AC=(REFDIF-DIF)/FLOAT(IDATE(ICOUNT))                              GRA04080
  120 AII=AC*60.                                                        GRA04090
      WRITE (4,1200) AII                                                GRA04100
 1200 FORMAT(1H0,19HFINAL DRIFT RATE = ,F8.4,16HMILLIGALS / HOUR)       GRA04110
      IF(MAG.NE.1) GO TO 121                                            GRA04120
      WRITE (4,1250) BINT                                               GRA04130
 1250 FORMAT(1X,12HINTERCEPT = ,F8.4,5H MGAL)                           GRA04140
C          APPLY DRIFT CORRECTION AND FORM DELTA G2S WITH RESPECT TO FIGRA04150
  121 DO 125 I=1,ICOUNT                                                 GRA04160
      IF(NUM(I)/1000.GT.0) GO TO 126                                    GRA04170
  125 CONTINUE                                                          GRA04180
  126 GEE=OBSG(I)                                                       GRA04190
      DO 130 I=1,ICOUNT                                                 GRA04200
  130 OBSG(I)=OBSG(I)-GEE    -AC*FLOAT(IDATE(I))                        GRA04210
      WRITE (4,1300)                                                    GRA04220
 1300  FORMAT(////6X,17HCORRECTED DELTA G//)                            GRA04230
      WRITE (4,1400)                                                    GRA04240
 1400 FORMAT (6X,3HSTA,13X,1HG,11X,8HINTERVAL)                          GRA04250
      DO 1700 I=1,ICOUNT                                                GRA04260
      IF(NUM(I)) 1700,1700,1450                                         GRA04270
 1450 WRITE (4,1500) NUM(I),OBSG(I)                                     GRA04280
 1500 FORMAT(5X,I5,5X,F11.3)                                            GRA04290
      J=I+1                                                             GRA04300
 1505 IF(J.GT.ICOUNT) GO TO 1700                                        GRA04310
      IF(NUM(J).GT.0) GO TO 1550                                        GRA04320
 1510 J=J+1                                                             GRA04330
      GO TO 1505                                                        GRA04340
 1550 XINT=OBSG( J )-OBSG(I)                                            GRA04350
      WRITE (4,1600) XINT                                               GRA04360
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 1600 FORMAT(31X,F11.3)                                                 GRA04370
 1700 CONTINUE                                                          GRA04380
      RETURN                                                            GRA04390
      END                                                               GRA04400
C                                                                       GRA04410

C                                                                       GRA04420
C                                                                       GRA04430
      SUBROUTINE  GRANET(ICOUNT,NUM,STA1,STA2,OBSG,PHI,ALON,H,NNBASE,NBASGRA04440
     1E,BASEG,NOMTYP,JIMMY,NAG,IAG,HS,RR,DD,DIST)                       GRA04450
C          COMPUTES MEAN VALUES FOR REOBSERVATIONS                      GRA04460
C          ADDS REFERENCE STATION VALUE TO DELTA G                      GRA04470
      DIMENSION NUM(1),PHI(1),ALON(1),H(1),HS(1),OBSG(1),NBASE(1)       GRA04480
      DIMENSION NUMI(500),PHII(500),ALONI(500),HI(500),STA1I(500),      GRA04490
     1STA2I(500),BASEG(1), OBSGI(500),HSI(500)                          GRA04500
       DIMENSION STA1(1),STA2(1)                                        GRA04510
   39 GO TO(310,400,400,310,15),NAG                                     GRA04520
C     AVERAGING FOR SINGLE LOOP                                         GRA04530
  310 IC=ICOUNT-1                                                       GRA04540
      II=ICOUNT                                                         GRA04550
      DO330 I=1,IC                                                      GRA04560
      IF(NUM(I)) 330,330,315                                            GRA04570
  315 K=I+1                                                             GRA04580
      CN=1.                                                             GRA04590
      SUM=OBSG(I)                                                       GRA04600
      DO325 J=K,ICOUNT                                                  GRA04610
      IF(NUM(I)-NUM(J)) 325,320,325                                     GRA04620
  320 NUM(J)=0                                                          GRA04630
      CN=CN+1.                                                          GRA04640
      SUM=SUM+OBSG(J)                                                   GRA04650
  325 CONTINUE                                                          GRA04660
      OBSG(I)=SUM/CN                                                    GRA04670
  330 CONTINUE                                                          GRA04680
C     ZERO DELTA G                                                      GRA04690
      DO 6 I=1,ICOUNT                                                   GRA04700
      IF(NUM(I)/1000) 6,6,8                                             GRA04710
    6 CONTINUE                                                          GRA04720
    8 GEE=OBSG(I)                                                       GRA04730
      DO 14 J=1,ICOUNT                                                  GRA04740
      HSI(J)=HS(J)                                                      GRA04750
      HI(J)=H(J)                                                        GRA04760
   14 OBSG(J)=OBSG(J)-GEE                                               GRA04770
C     ADD BASE VALUE                                                    GRA04780
   16 DO 30 I=1,ICOUNT                                                  GRA04790
      IF(NUM(I)/1000.LE.0) GO TO 30                                     GRA04800
      DO 25 JA=1,NNBASE                                                 GRA04810
      IF(NUM(I)-NBASE(JA))25,10,25                                      GRA04820
   10 DO 20 J=1,ICOUNT                                                  GRA04830
   20 OBSG(J)=OBSG(J)+BASEG(JA)                                         GRA04840
      GO TO 40                                                          GRA04850
   25 CONTINUE                                                          GRA04860
   30 CONTINUE                                                          GRA04870
   40 GO TO(300,100,100,300),NAG                                        GRA04880
C     STORE DATA FOR COMPARISON                                         GRA04890
  100 JIMMY=JIMMY+1                                                     GRA04900
      IF(JIMMY.NE.1) GO TO 105                                          GRA04910
      SR=0.                                                             GRA04920
      SD=0.                                                             GRA04930
      RM=0.                                                             GRA04940
      II=0                                                              GRA04950
  105 IF(SQRT(RR/DD).GT.RM) RM=SQRT(RR/DD)                              GRA04960
      SR=SR+RR                                                          GRA04970
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      SD=SD+DD                                                          GRA04980
      DO 190 I=1,ICOUNT                                                 GRA04990
      IF(NUM(I)) 190,190,110                                            GRA05000
  110 DO 140 J=1,500                                                    GRA05010
      IF(NUMI(J)) 120,120,130                                           GRA05020
  120 NUMI(J)=NUM(I)+100000                                             GRA05030
      II=II+1                                                           GRA05040
      PHII(J)=PHI(I)                                                    GRA05050
      ALONI(J)=ALON(I)                                                  GRA05060
      HI(J)=H(I)                                                        GRA05070
      HSI(J)=HS(I)                                                      GRA05080
      STA1I(J)=STA1(I)                                                  GRA05090
      STA2I(J)=STA2(I)                                                  GRA05100
      OBSGI(J)=OBSG(I)                                                  GRA05110
      GO TO 190                                                         GRA05120
  130 IF(NUMI(J)-(NUMI(J)/100000)*100000.EQ.NUM(I)) GO TO 150           GRA05130
  140 CONTINUE                                                          GRA05140
      WRITE (4,1000)                                                    GRA05150
 1000 FORMAT(1H1,33X,54HOBSERVATION ARRAYS FILLED,EXECUTE MEANING AND COGRA05160
     1NTINUE)                                                           GRA05170
      GO TO 200                                                         GRA05180
  150 OBSGI(J)=OBSGI(J)+OBSG(I)                                         GRA05190
      NUMI(J)=NUMI(J)+100000                                            GRA05200
  190 CONTINUE                                                          GRA05210
      GO TO (310, 90,200),NAG                                           GRA05220
  200 NSUM=0                                                            GRA05230
      DO 260 I=1,II                                                     GRA05240
      NSUM=NSUM+NUMI(I)/100000                                          GRA05250
      OBSGI(I)=OBSGI(I)/FLOAT(NUMI(I)/100000)                           GRA05260
  260 NUMI(I)=NUMI(I)-(NUMI(I)/100000)*100000                           GRA05270
      SIG=SQRT(SR/SD)                                                   GRA05280
      WRITE (4,2000) NSUM,II,SIG,RM,JIMMY                               GRA05290
 2000  FORMAT(1H1,I10,2X,12HOBSERVATIONS,10X,I4,2X,8HSTATIONS,10X,13HMEANGRA05300
     1 SIGMA = ,F6.3,10X,16HMAXIMUM SIGMA = ,F6.3/60X,I5,2X,5HLOOPS)    GRA05310
      JIMMY=0                                                           GRA05320
      CALL  NOMALY(II,NUMI,STA1I,STA2I,OBSGI,PHII,ALONI,HI,NOMTYP,IAG,HSIGRA05330
     1,DIST)                                                            GRA05340
      NAG=0                                                             GRA05350
      DO 270 J=1,II                                                     GRA05360
  270 NUMI(J)=0                                                         GRA05370
      RETURN                                                            GRA05380
  300 IF(NAG.EQ.4) RETURN                                               GRA05390
   15 CONTINUE                                                          GRA05400
      CALL  NOMALY(II,NUM,STA1,STA2,OBSG,PHI,ALON,HI,NOMTYP,IAG,HSI,DIST)GRA05410
   90 NAG=0                                                             GRA05420
      RETURN                                                            GRA05430
  400 DO 405 I=1,ICOUNT                                                 GRA05440
      IF(NUM(I)/1000.GT.0) GO TO 410                                    GRA05450
  405 CONTINUE                                                          GRA05460
  410 LN=NUM(I)                                                         GRA05470
      GS=0.                                                             GRA05480
      CN=0.                                                             GRA05490
      DO 415 I=1,ICOUNT                                                 GRA05500
      IF(NUM(I).NE.LN) GO TO 415                                        GRA05510
      GS=GS+OBSG(I)                                                     GRA05520
      CN=CN+1.                                                          GRA05530
  415 CONTINUE                                                          GRA05540
      GS=GS/CN                                                          GRA05550
      DO 420 I=1,ICOUNT                                                 GRA05560
      IF(NUM(I).EQ.LN) GO TO 418                                        GRA05570
      OBSG(I)=OBSG(I)-GS                                                GRA05580
      GO TO 420                                                         GRA05590
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        418 OBSG(I)=0.
GRA05600
  420 CONTINUE                                                          GRA05610
      GO TO 16                                                          GRA05620
      END                                                               GRA05630
C                                                                       GRA05640

C                                                                       GRA05650
C                                                                       GRA05660
      SUBROUTINE NOMALY(ICOUNT,NUM,STA1,STA2,OBSG,PHI,ALON,HI,NOMTYP,   GRA05670
     1IAG,HSI,DIST)                                                     GRA05680
C          COMPUTES FREE AIR AND BOUGUER ANOMALIES                     GRA05690
C          PRINTS FINAL OUTPUT TAB                                     GRA05700
C          PUNCHES CARDS                                               GRA05710
      DIMENSION NUM(1),PHI(1),ALON(1),H(1),OBSG(1)                      GRA05720
      DIMENSION HS(1),HI(1),HSI(1)                                      GRA05730
      DIMENSION COEF(11)                                                GRA05740
      CHARACTER *6 SECCON(2),TYP(13), STA1(1),STA2(1)                   GRA05750
      DATA(COEF(I),I=1,11)/.3086,.1119,.2238,.06886,.2225,.04191,.08382,GRA05760
     1.06999,.2248,.03843,.07347/,(TYP(I),I=1,13)/'1','2','3','4','5',' GRA05770
     26','7','8','9','A','B','C','D'/                                  GRA05780
      WRITE (4,1000)                                                    GRA05790
 1000 FORMAT(/25X,69HP R I N C I P A L   F A C T S   A T   G R A V I T YGRA05800
     1   S T A T I O N S//6X,16HSTA NAME AND NUM,5X,8HLATITUDE,3X,9HLONGGRA05810
     2ITUDE,3X,9HELEVATION,2X,9HSUPP ELEV,2X,10HOBSERVED G,2X,8HFREE AIRGRA05820
     3,3X,7HBOUGUER,3X,7HTHEOR G/28X,7HNORTH +,5X,6HEAST +,6X,6H FEET , GRA05830
     45X,6HMETERS,6X,4HMGAL,7X,4HMGAL,6X,4HMGAL,6X,4HMGAL/)             GRA05840
      SECCON(1)='2'                                                     GRA05850
      SECCON(2)=' '                                                     GRA05860
      NOMTYP=NOMTYP+1                                                   GRA05870
      IPAGE=0                                                           GRA05880
      I=1                                                               GRA05890
      DO 500 J=1,ICOUNT                                                 GRA05900
      IF(NUM(J).EQ.0)GO TO 500                                          GRA05910
      CALL RADEG(PHI(J),KDEG,XMIN)                                      GRA05920
      CALL RADEG(ALON(J),JDEG,TMIN)                                     GRA05930
      H(1)=HI(J)                                                        GRA05940
      HS(1)=HSI(J)                                                      GRA05950
      GAMMA=2049.+978049.*(.0052884*SIN(PHI(J))**2-.0000059*SIN(2.*PHI(JGRA05960
     1))**2)                                                            GRA05970
      GO TO (10,15,20,25,30,35,40,45,50,55,60,65,70),NOMTYP             GRA05980
   10 FA=OBSG(J)+COEF(NOMTYP)*H(I)-GAMMA                                GRA05990
      BA=FA-COEF(NOMTYP+1)*H(I)                                         GRA06000
      GO TO 100                                                         GRA06010
   15FA=OBSG(J)+COEF(NOMTYP+1)*HS(I)+COEF(NOMTYP-1)*(H(I)-HS(I))-GAMMAGRA06020
      BA=FA-COEF(NOMTYP)*H(I)                                           GRA06030
      GO TO 100                                                         GRA06040
   20 FA=OBSG(J)-GAMMA                                                  GRA06050
      BA=FA+COEF(NOMTYP+1)*H(I)                                         GRA06060
      GO TO 100                                                         GRA06070
   25 FA=OBSG(J)-COEF(NOMTYP+1)*HS(I)-GAMMA                             GRA06080
      BA=FA+COEF(NOMTYP)*H(I)                                           GRA06090
      GO TO 100                                                         GRA06100
   30 FA=OBSG(J)-COEF(NOMTYP)*HS(I)-GAMMA                               GRA06110
      BA=FA+COEF(NOMTYP-1)*HS(I)                                        GRA06120
      GO TO 100                                                         GRA06130
   35 FA=OBSG(J)+COEF(NOMTYP-5)*H(I)-GAMMA                              GRA06140
      BA=FA-COEF(NOMTYP)*HS(I)-COEF(NOMTYP-4)*(H(I)-HS(I))              GRA06150
      GO TO 100                                                         GRA06160
   40 FA=OBSG(J)+COEF(NOMTYP)*HS(I)+COEF(NOMTYP-6)*(H(I)-HS(I))-GAMMA   GRA06170
      BA=FA-COEF(NOMTYP-1)*HS(I)-COEF(NOMTYP-5)*(H(I)-HS(I))            GRA06180
      GO TO 100                                                         GRA06190
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   45 FA=OBSG(J)+COEF(NOMTYP-1)+COEF(NOMTYP-7)*(H(I)-HS(I))-GAMMA      GRA06200
      BA=FA-COEF(NOMTYP-2)*H(I)-COEF(NOMTYP)*(H(I)-HS(I))             GRA06210
      GO TO 100                                                       GRA06220
   50 FA=OBSG(J)+COEF(NOMTYP-8)-GAMMA                                 GRA06230
      BA=FA-COEF(NOMTYP-3)*H(I)-COEF(NOMTYP-1)*(H(I)-HS(I))           GRA06240
      GO TO 100                                                       GRA06250
   55 FA=OBSG(J)+COEF(NOMTYP-9)*H(I)-GAMMA                            GRA06260
      BA=FA-COEF(NOMTYP-8)*H(I)+COEF(NOMTYP-2)*HS(I)                  GRA06270
      GO TO 100                                                       GRA06280
   60 FA=OBSG(J)+COEF(NOMTYP-10)*H(I)-COEF(NOMTYP-2)*HS(I)-GAMMA      GRA06290
      BA=FA-COEF(NOMTYP-9)*H(I)+COEF(NOMTYP-3)*HS(I)                  GRA06300
      GO TO 100                                                       GRA06310
   65 FA=OBSG(J)+COEF(NOMTYP-11)*H(I)-GAMMA                           GRA06320
      BA=FA-COEF(NOMTYP-2)*H(I)-COEF(NOMTYP-1)*(H(I)-HS(I))           GRA06330
      GO TO 100                                                       GRA06340
   70 FA=OBSG(J)+COEF(NOMTYP-12)*H(I)-GAMMA                           GRA06350
      BA=FA-COEF(NOMTYP-3)*HS(I)-COEF(NOMTYP-11)*(H(I)-HS(I))         GRA06360
  100 OBSG(J)=OBSG(J)+976000.                                         GRA06370
      GAMMA=GAMMA+976000.                                             GRA06380
      H(I)=H(I)*3.280833                                              GRA06390
      WRITE (4,2000) STA1(J),STA2(J),NUM(J),KDEG,XMIN,JDEG,TMIN,H(I), GRA06400
     1HS(I),OBSG(J),FA,BA,GAMMA                                       GRA06410
 2000  FORMAT(5X,2A6,1X,I5,3X,I3,F6.2,2X,I4,F6.2,2X,F10.3,2X,F9.3,1X,F11.GRA06420
     13,2X,F10.3,2X,F10.3,1X,F11.3)                                   GRA06430
      WRITE (6,2001) STA1(J),STA2(J),KDEG,XMIN,JDEG,TMIN,H(I),OBSG(J), GRA06440
     *FA,BA                                                           GRA06450
      WRITE (6,*) FA,BA                                               GRA06460
2001  FORMAT(4X,2A6,1X,I3,F6.2,1X,I4,F6.2,F10.3,1X,F11.3,2X,E9.3,1X,  GRA06470
     *E9.3)                                                           GRA06480
      DIST=DIST+200.                                                  GRA06490
C     IF (BA.EQ.13.3262033) THEN                                      GRA06500
C     PRINT *,'HELLO'                                                 GRA06510
C     DIST=DIST+200.                                                  GRA06520
C     END IF                                                          GRA06530
      TLAT1=KDEG - (XMIN/60.)                                         GRA06540
      TLONG1=JDEG + (TMIN/60.)                                        GRA06550
      WRITE (3,1234) DIST,BA                                          GRA06560
1234  FORMAT(F9.2,2X,F6.2)                                            GRA06570
      IPAGE=IPAGE+1                                                   GRA06580
      IF(IPAGE.LT.50) GO TO 200                                       GRA06590
      IPAGE=0                                                         GRA06600
      WRITE (4,4000)                                                  GRA06610
 4000 FORMAT('1')                                                     GRA06620
      WRITE (4,1000)                                                  GRA06630
  200 CONTINUE                                                        GRA06640
      IF(IAG.EQ.1) GO TO 500                                          GRA06650
      KMIN=IPUNIX(XMIN,2)                                             GRA06660
      JMIN=IPUNIX(TMIN,2)                                             GRA06670
      IH=IPUNIX(H(I),1)                                               GRA06680
      IHS=IPUNIX(HS(I),1)                                             GRA06690
      OBSG(J)=OBSG(J)-976000.                                         GRA06700
      IG=IPUNIX(OBSG(J),2)                                            GRA06710
      IFA=IPUNIX(FA,1)                                                GRA06720
      IBA=IPUNIX(BA,1)                                                GRA06730
      IF(IAG.EQ.3) GO TO 300                                          GRA06740
      WRITE(6,3000)SECCON(1),SECCON(2),KDEG,KMIN,JDEG,JMIN,TYP(NOMTYP)GRA06750
     1,IH,IHS,IG,IFA,IBA,NUM(J)                                       GRA06760
 3000  FORMAT(2A1,I3,I4,2X,I4,I4,1X,A1,1X,I7,1X,I5,1X,I6,1X,I5,1X,I5,14X,GRA06770
     1I4)                                                             GRA06780
      GO TO 500                                                       GRA06790
  300 OBSG(J)=OBSG(J)+976000.                                         GRA06800
      WRITE(6,5000)STA1(J),STA2(J),KDEG,XMIN,JDEG,TMIN,H(I),OBSG(J),FAGRA06810
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     1,BA                                                                GRA06820
 5000  FORMAT(2A6,2X,I3,F6.2,2X,I4,F6.2,2X,F8.2,2X,F10.3,4X,F7.2,4X,F7.2)GRA06830
  500 CONTINUE                                                           GRA06840
      RETURN                                                             GRA06850
      END                                                                GRA06860
C                                                                        GRA06870

C                                                                        GRA06880
C                                                                        GRA06890
      SUBROUTINE  CALIB(ICOUNT,NUM,OBSG,NNBASE,NBASE,BASEG,STA1,STA2,NAG,GRA06900
     1PHI,ALON,H,CALIM,PUBG,Y,V)                                         GRA06910
      DIMENSION NUM(1),OBSG(1),NBASE(1),BASEG(1),STA1(1),STA2(1)         GRA06920
      DIMENSION PHI(1),ALON(1),H(1)                                      GRA06930
      DIMENSION PUBG(1),Y(1),V(1)                                        GRA06940
      WRITE (4,1000)                                                     GRA06950
 1000 FORMAT(46X,38HCALIB IS A DUMMY,NO SCALE WAS COMPUTED)              GRA06960
      NAG=NAG+1                                                          GRA06970
      RETURN                                                             GRA06980
      END                                                                GRA06990
C                                                                        GRA07000
C                                                                        GRA07010
C                                                                        GRA07020
      SUBROUTINE PLOT2D(N,X,Y)                                           GRA07030
C       PLOTS Y AGAINST X.  N IS NUMBER OF POINTS                        GRA07040
C       Y AND X ARE SCALED AGAINST THEIR MAX AND MIN VALUES              GRA07050
C       THE ELEMENTS OF X AND Y ARRAYS ARE NOT ALTERED                   GRA07060
      DIMENSION X(1),Y(1)                                                GRA07070
      CHARACTER *6 P(100)                                                GRA07080
      DO 10 I=1,100                                                      GRA07090
   10 P(I)=' '                                                           GRA07100
      XMIN=0.0                                                           GRA07110
      XMAX=0.0                                                           GRA07120
      YMIN=0.0                                                           GRA07130
      YMAX=0.0                                                           GRA07140
      DO 20 I=1,N                                                        GRA07150
      IF(XMIN.GT.X(I)) XMIN=X(I)                                         GRA07160
      IF(X(I).GT.XMAX) XMAX=X(I)                                         GRA07170
      IF(YMIN.GT.Y(I)) YMIN=Y(I)                                         GRA07180
      IF(Y(I).GT.YMAX) YMAX=Y(I)                                         GRA07190
   20 CONTINUE                                                           GRA07200
      WRITE (4,200) XMIN,XMAX                                            GRA07210
  200 FORMAT(3X,F7.0,92X,F7.0)                                           GRA07220
      XSCALE=(XMAX-XMIN)/99.0                                            GRA07230
      YSCALE=(YMAX-YMIN)/49.0                                            GRA07240
      IF(YMAX) 25,25,27                                                  GRA07250
   27 IF(YMIN) 28,25,25                                                  GRA07260
   28 JYO=-YMIN/YSCALE+1.0                                               GRA07270
      GO TO 26                                                           GRA07280
   25 JYO=0                                                              GRA07290
   26 DO 95 I=1,50                                                       GRA07300
      IF(I.EQ.1) P(1)='+'                                                GRA07310
      IF(I.EQ.1) P(100)='+'                                              GRA07320
      IF(I.EQ.50) P(100)='+'                                             GRA07330
      IF(I.EQ.50) P(1)='+'                                               GRA07340
      IYREF=51-I                                                         GRA07350
      DO 60 J=1,N                                                        GRA07360
      JYTEM=(Y(J)-YMIN)/YSCALE+1.0                                       GRA07370
      IF(JYTEM-IYREF) 60,30,60                                           GRA07380
   30 KJ=(X(J)-XMIN)/XSCALE+1.0                                          GRA07390
   35 P(KJ)='*'                                                          GRA07400
   60 CONTINUE                                                           GRA07410
      IF(IYREF-50) 65,70,65                                              GRA07420
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   65 IF(IYREF-1) 66,75,66                                                GRA07430
   66 IF(JYO) 80,80,67                                                    GRA07440
   67 IF(JYO-IYREF) 80,68,80                                              GRA07450
   68 P(1)='+'                                                            GRA07460
      WRITE (4,690) P                                                     GRA07470
  690 FORMAT(2X,5H0.000,2(50A1))                                          GRA07480
      GO TO 85                                                            GRA07490
   70 WRITE (4,700) YMAX,P                                                GRA07500
  700 FORMAT(F7.3,2(50A1))                                                GRA07510
      GO TO 85                                                            GRA07520
   75 WRITE (4,700) YMIN,P                                                GRA07530
      GO TO 85                                                            GRA07540
   80 WRITE (4,800) P                                                     GRA07550
  800 FORMAT(7X,2(50A1))                                                  GRA07560
   85 DO 90 J=1,100                                                       GRA07570
   90 P(J)=' '                                                            GRA07580
   95 CONTINUE                                                            GRA07590
      RETURN                                                              GRA07600
      END                                                                 GRA07610
C                                                                         GRA07620
C                                                                         GRA07630
C                                                                         GRA07640
      FUNCTION DEGRAD(JDEG,AMIN)                                          GRA07650
C    * * * *  DEGRAD CONVERTS DEGREES + MINUTES (1/102S) TO RADIANS       GRA07660
      ALFA= .174532925199 E-1                                             GRA07670
      BETA=.290888208666 E-3                                              GRA07680
      A=JDEG                                                              GRA07690
      IF(A) 100,200,300                                                   GRA07700
  100 DEGRAD=A*ALFA-AMIN*BETA                                             GRA07710
      GO TO 400                                                           GRA07720
  200 DEGRAD=AMIN*BETA                                                    GRA07730
      GO TO 400                                                           GRA07740
  300 DEGRAD=A*ALFA+AMIN*BETA                                             GRA07750
  400 RETURN                                                              GRA07760
      END                                                                 GRA07770
C                                                                         GRA07780

C                                                                         GRA07790
C                                                                         GRA07800
      SUBROUTINE RADEG(RAD,JDEG,TMIN)                                     GRA07810
C             CONVERTS RADIANS TO DEGREES(SIGNED) AND MINUTES             GRA07820
      TMIN=3437.74677078*RAD                                              GRA07830
      JDEG=TMIN/60.                                                       GRA07840
      TMIN=TMIN-FLOAT(JDEG*60)                                            GRA07850
      IF(JDEG.LT.0) TMIN=-TMIN                                            GRA07860
      RETURN                                                              GRA07870
      END                                                                 GRA07880
      FUNCTION IPUNIX(VAL,IDEC)                                           GRA07890
C        CONVERTS REAL VALUE(VAL) TO ROUNDED INTEGER RETAINING            GRA07900
C         SPECIFIED(IDEC) NO. OF DECIMAL PLACES                           GRA07910
C        USE FOR PUNCHED OUTPUT WITH NO DECIMAL POINT                     GRA07920
      P=VAL*10.**IDEC                                                     GRA07930
      IP=P                                                                GRA07940
      FRACT=P-FLOAT(IP)                                                   GRA07950
      IPUNIX=P                                                            GRA07960
      IF(FRACT) 10,30,20                                                  GRA07970
   10 IF(FRACT+.5) 15,15,30                                               GRA07980
   15 IPUNIX=P-1.                                                         GRA07990
      GO TO 30                                                            GRA08000
   20 IF(FRACT-.5) 30,25,25                                               GRA08010
   25 IPUNIX=P+1.                                                         GRA08020
   30 RETURN                                                              GRA08030
```

```
      END                                                                GRA08040
C                                                                        GRA08050
C                                                                        GRA08060

C                                                                        GRA08070
      FUNCTION DERAD2(J,K,C)                                             GRA08080
C             CONVERTS WHOLE DEG,MIN AND FRACTIONAL SEC TO RADIANS       GRA08090
      DATA X,Y,Z/.174532925199E-1,.290888208666E-3,.4848136811E-5/       GRA08100
      A=J                                                                GRA08110
      B=K                                                                GRA08120
      IF(J.LT.0) GO TO 1                                                 GRA08130
      IF(K.LT.0) GO TO 2                                                 GRA08140
      DERAD2=X*A+Y*B+Z*C                                                 GRA08150
      RETURN                                                             GRA08160
    1 DERAD2=X*A-Y*B-Z*C                                                 GRA08170
      RETURN                                                             GRA08180
    2 DERAD2=Y*B-Z*C                                                     GRA08190
      RETURN                                                             GRA08200
      END                                                                GRA08210
```

APPENDIX I-B

STATION FORTRAN

STATION FORTRAN converts station foresight and backsight level readings to elevations. In addition, the program calculates station spacing, total elevation change, and total elevation error for each line. The program source listing is given below:

```
C Title : Title of Line
C     NA: Total Number Of Station
C  BENCH: Bench Mark Elevation
C CORR1 : Correction Factor 1
C CORR2 : Correction Factor 2
      CHARACTER * 80 TITLE                                              STA00010
      INTEGER SUM                                                       STA00020
      WRITE(6,*) 'TYPE TITLE NAME'                                      STA00030
      READ(5,1011) TITLE                                                STA00040
1011  FORMAT(A80)                                                       STA00050
      WRITE(2,1012) TITLE                                               STA00060
1012  FORMAT(//,A80,//)                                                 STA00070
      READ(1,*) NA,BENCH,CORR1,CORR2                                    STA00080
      SUMB=0.0                                                          STA00090
      SUMF=0.0                                                          STA00100
      BSUM=0.0                                                          STA00110
      FSUM=0.0                                                          STA00120
C                                                                       STA00130
C                                                                       STA00140
C     ELEV=BENCH                                                        STA00150
      DO 100 I=1,NA                                                     STA00160
C                                                                       STA00170
      WRITE(2,1000)                                                     STA00180
1000 FORMAT(1X,'BACKSIGHT',4X,'MEAN',2X,'INTERVAL',4X,'FORESIGHT',4X,   STA00190
     +'MEAN',4X,'INTERVAL',/,1X,'---------',4X,'----',2X,'--------',4X,'STA00200
     +--------',5X,'----',4X,'--------',/)                              STA00210
                                                                        STA00220
C
C B1, B2, B3 : Corresponds To Top-Middle-Bottom Backsight Readings
C F1, F2, F3 : Corresponds To Top-Middle-Bottom Foresight Readings
C
C                                                                       STA00230
      READ(1,*) B1,B2,B3,F1,F2,F3                                       STA00240
C                                                                       STA00250
      BMEAN=(B1+B2+B3)/3.0                                              STA00260
```

```
      FMEAN=(F1+F2+F3)/3.0                                                  STA00270
C                                                                           STA00280
      BDIFF1=B1-B2                                                          STA00290
      BDIFF2=B2-B3                                                          STA00300
      BDIFF3=BDIFF1+BDIFF2                                                  STA00310
      SUMB=SUMB+BDIFF3                                                      STA00320
      FDIFF1=F1-F2                                                          STA00330
      FDIFF2=F2-F3                                                          STA00340
      FDIFF3=FDIFF1+FDIFF2                                                  STA00350
      SUMF=SUMF+FDIFF3                                                      STA00360
C                                                                           STA00370
      BSUM=BSUM+BMEAN+CORR1                                                 STA00380
      FSUM=FSUM+(-1.0*FMEAN)+CORR2                                          STA00390
C                                                                           STA00400
      ELEV=BSUM+FSUM+BENCH                                                  STA00410
      ELV=BSUM+FSUM                                                         STA00420
C                                                                           STA00430
      WRITE(2,1001) B1,F1                                                   STA00440
1001  FORMAT(1X,F8.3,22X,F8.3)                                              STA00450
      WRITE(2,1002) B2,BMEAN,BDIFF1,F2,FMEAN,FDIFF1                         STA00460
1002  FORMAT(1X,F8.3,2X,F8.3,2X,F3.2,8X,F8.3,4X,F8.3,2X,F3.2)               STA00470
      WRITE(2,1003) B3,BDIFF2,F3,FDIFF2                                     STA00480
1003  FORMAT(1X,F8.3,12X,F3.2,8X,F8.3,13X,F3.2)                             STA00490
      WRITE(2,1004) BDIFF3,FDIFF3                                           STA00500
1004  FORMAT(3X,17HSUMS OF INTERVAL:,2X,F6.2,5X,17HSUMS OF INTERVAL:,2X,    STA00510
     +F6.2)                                                                 STA00520
      WRITE(2,1007) SUMB,SUMF                                               STA00530
1007  FORMAT(3X,18HCONT. INTER. SUMS:,1X,F6.2,5X,18HCONT. INTER. SUMS:,1    STA00540
     +X,F6.2)                                                               STA00550
      WRITE(2,1005) BSUM,FSUM                                               STA00560
1005  FORMAT(3X,'CONT. MEAN',/,8X,'SUMS:',F8.3,25X,F8.3,/)                  STA00570
      WRITE(2,1006)  I,ELEV                                                 STA00580
1006  FORMAT(20X,'ELEVATION OF STATION  ',I3,':',2X,F9.3,/)                 STA00590
      WRITE (3,1017) ELEV                                                   STA00600
1017  FORMAT(F9.3)                                                          STA00610
100   CONTINUE                                                              STA00620
C                                                                           STA00630
      SUMB=SUMB*100.                                                        STA00640
      SUMF=SUMF*100.                                                        STA00650
      WRITE(2,1008) SUMB                                                    STA00660
1008  FORMAT(//,3X,33HTOTAL BACKSIGHT DISTANCE(FEET):  ,F10.2)              STA00670
      WRITE(2,1009) SUMF                                                    STA00680
1009  FORMAT(/,3X,33HTOTAL FORESIGHT DIATANCE(FEET):  ,F10.2)               STA00690
      WRITE(2,1010) ELV                                                     STA00700
1010  FORMAT(/,3X,28HTOTAL ELEVATION CHANGE(FEET):  ,F10.2)                 STA00710
      WRITE(2,1014) CORR1,CORR2                                             STA00720
1014  FORMAT(/,3X,25H CORRECTION FARCTORS ARE:,2X,'CORR1:  ',F7.5,          STA00730
     +2X,'CORR2:  ',F7.5)                                                   STA00740
      STOP                                                                  STA00750
      END                                                                   STA00760
```

APPENDIX I-C

COMPARISON OF UPDW/UDD FORTRAN ALGORITHMS

UPDW FORTRAN algorithm is based on the two-dimensional harmonic analysis method of Bhattachararyya (1965). This program was written by Agrwal (1968). It was used to differentiate local and regional gravitational trends. A comparison between the algorithms used in the programs UPDW FORTRAN and UDD FORTRAN (Ruddman and Blakley, 1983) was conducted at the onset of this study. The purpose of this comparison was to determine which algorithm was best for this study. The algorithm used in UDD FORTRAN is based on a method developed by Henderson and Zietz (1949) while the algorithm used in UPDW FORTRAN is based on the method of Bhattachararyya (1965).

The algorithm used in UDD FORTRAN is based on:

Equation 1:

$$\Delta T(h) = \sum_{i=1}^{n-1} \Delta \overline{T}(r_i)\, K(r_i, h) + \Delta \overline{T}(r_n)\, K(r_n, h)$$

Figure 23: Contour map of vertical gravity component over a sphere. Contour interval is 0.40 milligals. This data was used in comparing the algorithms of the programs UPDW and UDD FORTRAN.

where

h : height above surface

$K(r_i,h)$: Continuation and vertical Derivative Coefficients

T(h) : Calculated field

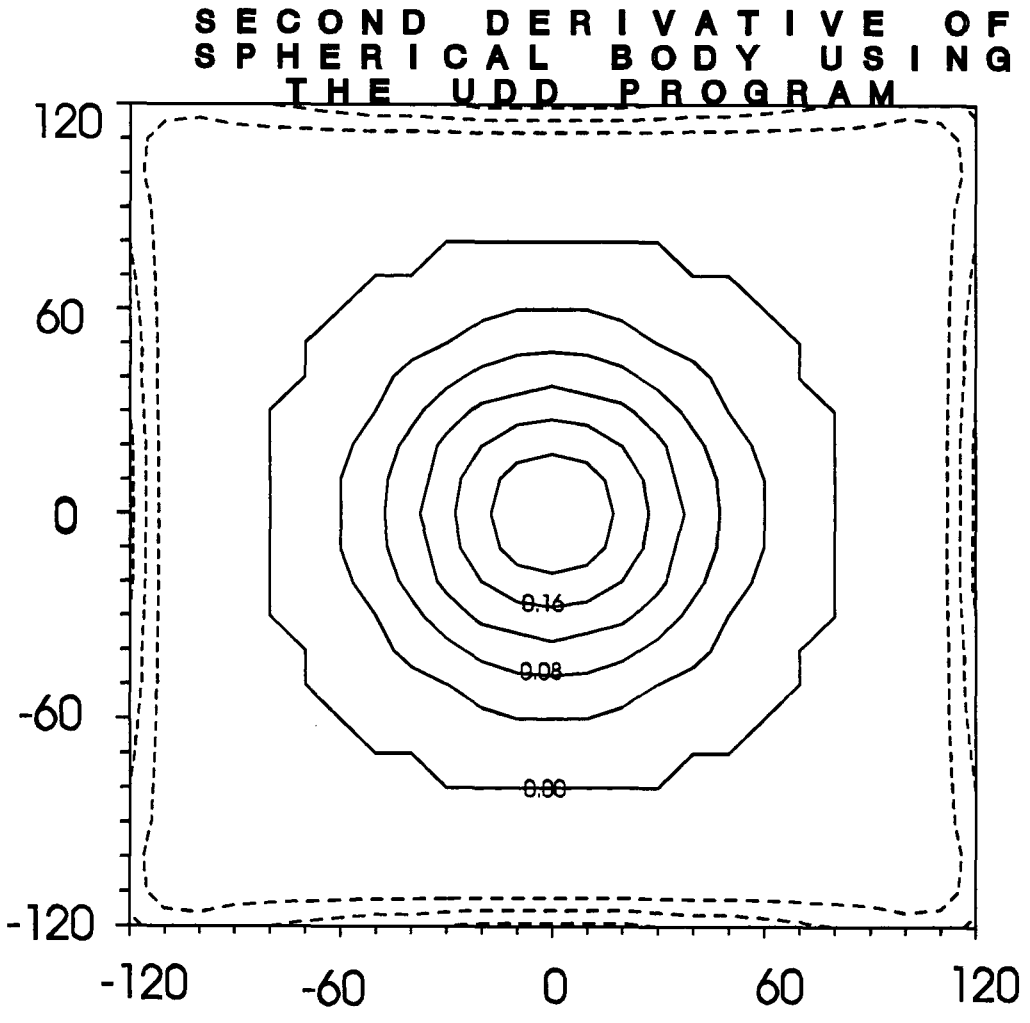
$T(r^i)$: Average value of T on the ith circle of radius r

Using this equation Ruddman and Blackely (1983) developed a UDD FORTRAN that determined the upward and downward continuation of a potential field. In addition, the program can determine the second vertical derivative of a potential field. To use this program the data had to be gridded. Once gridded the potential field can be filtered by continuing it upward or downward, or by taking the 2nd vertical derivative. Filtering is accomplished by using a series concentric rings about each grid point. The radius of these rings is defined as follows:

$$r_i = \text{gridspacing} * n \text{ , where } n=1,2,3,\ldots,k-1.$$

The potential field values that intersect the respective circles are multiplied by the appropriate table of coefficients (Henderson and Zietz, 1949). After this is done for each grid point, values of the operation are summed at the grid points resulting in filtered values.

Figure 24: Contour plot of the second vertical derivative field of the spherical gravity field, using UDD FORTRAN. Contour interval is 0.04 milligals.


SECOND DERIVATIVE OF
SPHERICAL BODY USING
THE UDD PROGRAM
120
60
0
-60
-120
-120
-60
0
60
120
0.16
0.08
0.00

The two-dimesional harmonic analysis method used in the program UPDW FORTRAN (Agarwal, 1968) is based on:

Equation 2:

$$T(x,y,z)=\sum_{m=0}^{m_o}\sum_{n=0}^{n_o}\left[A_{mn}COS\left(2\Pi m\frac{x}{L_x}\right)COS\left(2\Pi n\frac{y}{L_y}\right)+B_{mn}COS\left(2\Pi m\frac{x}{L_x}\right)SIN\left(2\Pi n\frac{y}{L_y}\right)+E_{mn}SIN\left(2\Pi m\frac{x}{L_x}\right)COS\left(2\Pi n\frac{y}{L_y}\right)+F_{mn}SIN\left(2\Pi m\frac{x}{L_x}\right)SIN\left(2\Pi n\frac{y}{L_y}\right)\right]\left[e^{-2\Pi\left(\frac{m^2}{L_x^2}+\frac{n^2}{L_y^2}\right)^{\frac{1}{2}}z}\right]\left[-2\Pi\frac{m^2}{L_x^2}+\frac{n^2}{L_y^2}\,\frac{1}{2}\right]^{r}$$

where

A_{mn}, B_{mn}, E_{mn}, F_{mn}: are coefficients of the solution to the partial differential equation.

m : number of values along x-axis

n : number of values along y-axis

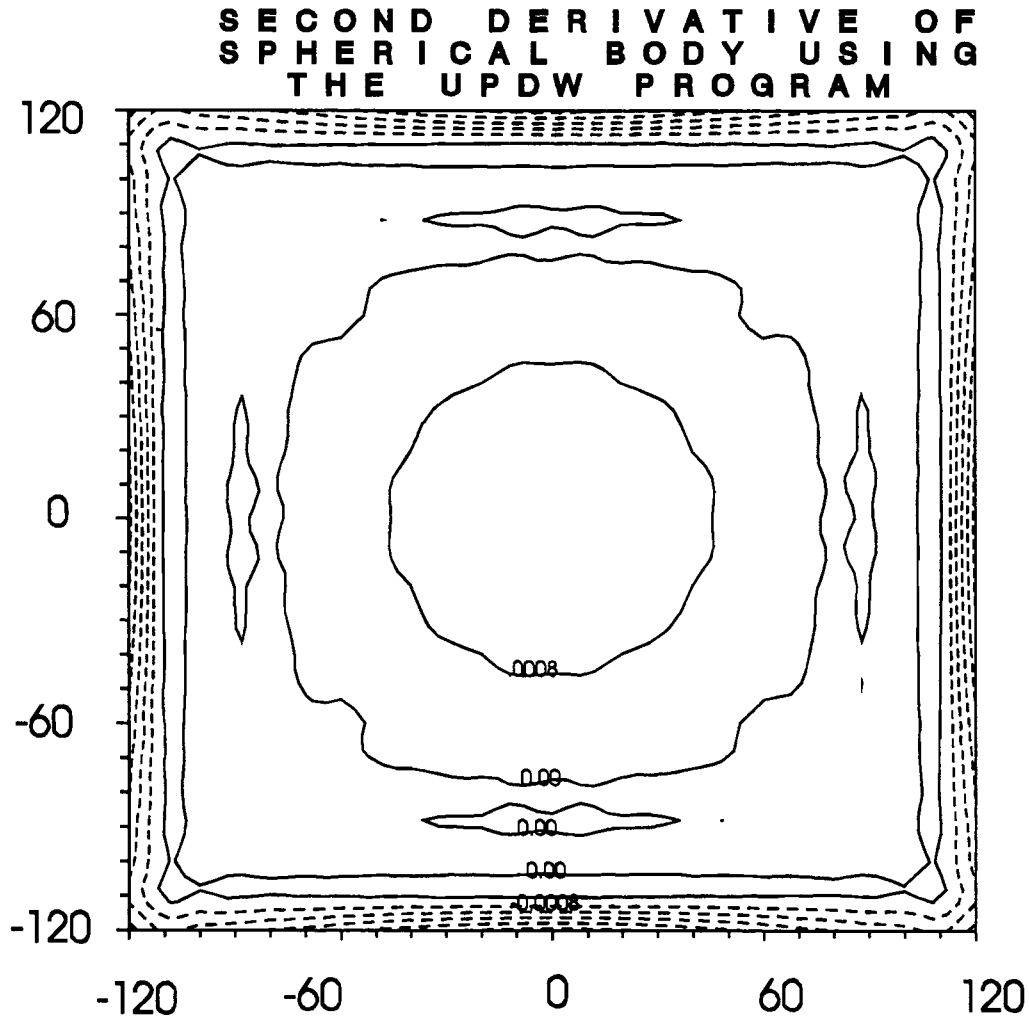
S_x : Uniform spacing along x-axis

S_y : Uniform spacing along y-axis

$L_x=mS_x$: L_x is the Nynquist Frequency

$L_y=nS_y$: Uniform spacing along y-axis

Figure 25: Contour plot of the second vertical derivative of spherical gravity field, using UPDW FORTRAN. Contour interval is 0.04 milligals.


SECOND DERIVATIVE OF
SPHERICAL BODY USING
THE UPDW PROGRAM
120
60
0
-60
-120
-120
-60
0
60
120
.0008
0.00
0.00
0.00
-0.0008

Downward Continuation: Z > 0

Upward Continuation : Z < 0

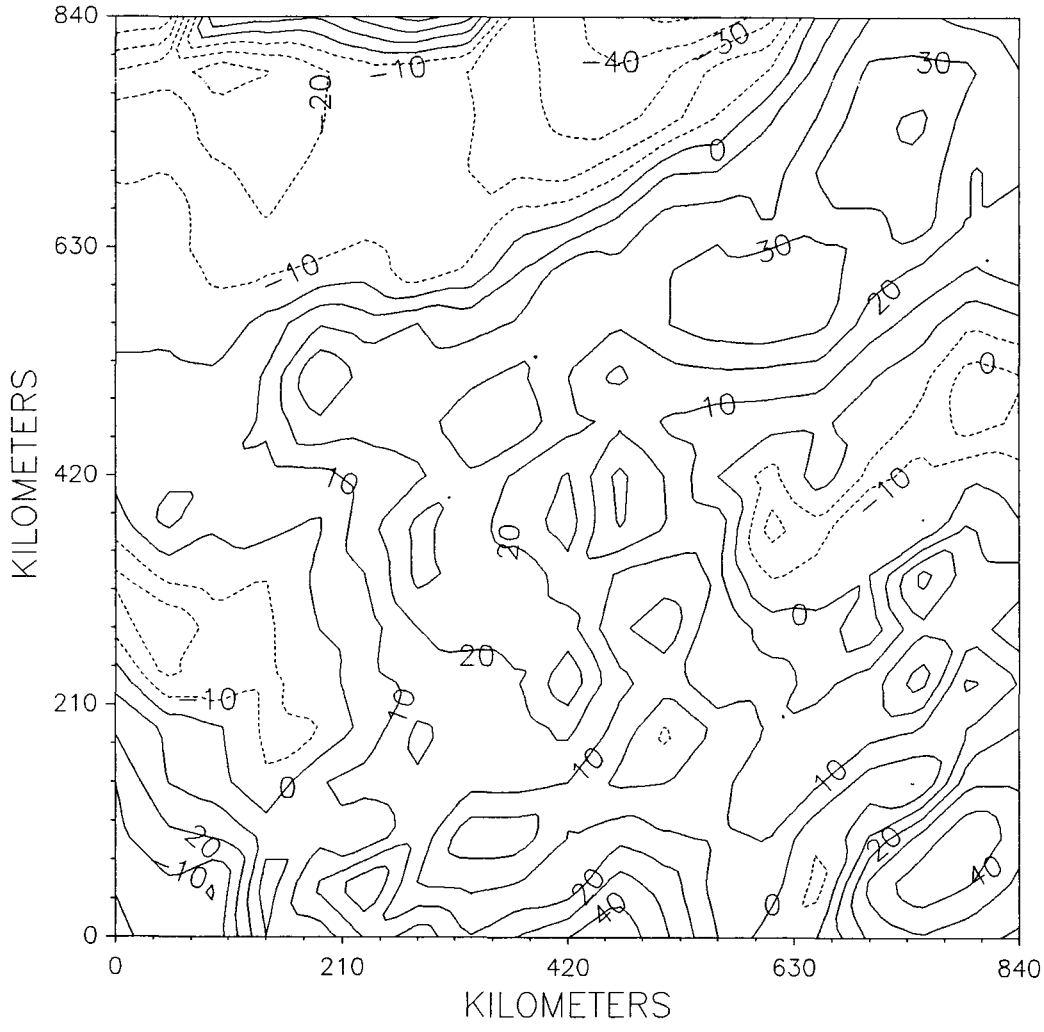
Vertical Derivative : r= 0, 1, 2, 3, ... , n

The two dimensional harmonic analysis method allows the potential field to be continue upward or downward at any level. In addition, this method can determine the nTH vertical derivative of a potential field at the specified level. The coefficients A_{mn}, B_{mn}, E_{mn}, and F_{mn} in the equation 2 are first calculated by the algorithm. These coefficients are the solution to the partial differential equation. Once the coefficients are calculated the upward/downward continuation and/or the vertical derivative of the potential field can be calculated since the remaining values in the equation are known. To calculate the upward or downward continuation of a potential field at the surface assign the appropriate "Z" value and set r to zero. The nTH vertical derivative is calculated in a similar fashion; however, the value of r is greater than one. It is apparent the continuation and nTH vertical derivative use different terms of the same equation when calculating the respective fields.

A theoretically calculated data set was computed for a sphere. This output was used as input for UPDW FORTRAN and UDD FORTRAN, so that a comparison of these programs could

Figure 26: Contour plot of the potential field values listed in a paper by Tasubi (1959).

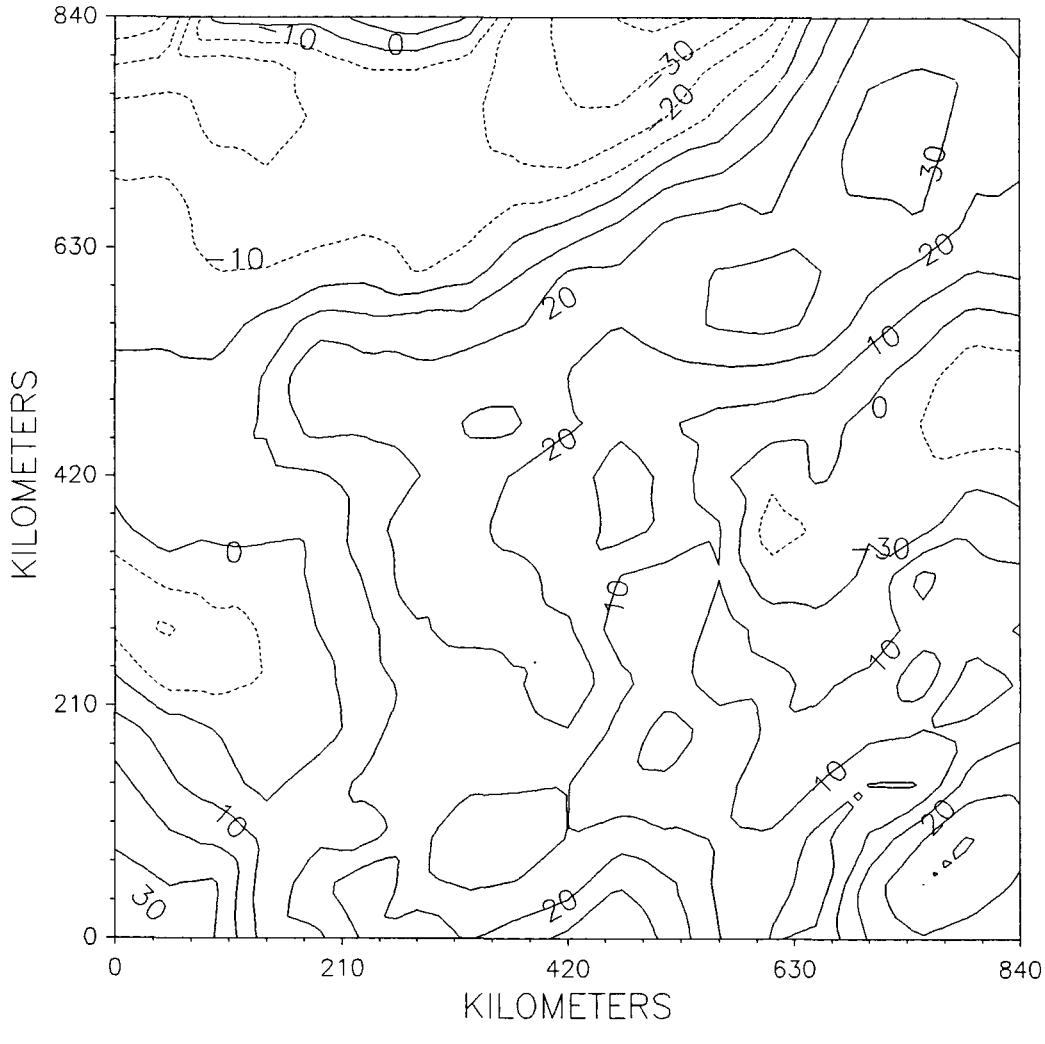
Tasubi Gravity Data (1959)



be conducted (Figure 23). The output from both programs was contoured with the results shown in Figures 24 and 25, respectively. Both maps have concentric rings about their centers. In fact, when the two maps are overlain, like contours, at the maps' center, closely approximate each other. The difference is at the maps edges. These differences are attributed to the algorithms being used. UDD FORTRAN output has a minimum edge effect, while UPDW FORTRAN values are effected at the edge. This aspect of the two methods is the only advantage UDD FORTRAN has over UPDW FORTRAN. A critical advantage UPDW FORTRAN has over UDD FORTRAN is that a continuation field can be continued upward or downward at any level. UDD FORTRAN can continue a field upward or downward only at grid spacing intervals. The maximum a field can be continued upward or downward with UDD FORTRAN is four grid levels. A second advantage of UPDW FORTRAN when compared to UDD FORTRAN is UPDW can process a matrix of potential field values up to 60x60 while UDD can process a maximum matrix of 25x25. The capability of UPDW to process a 60x60 was deemed important because it reduced the time in performing the potential field filtering. For the reasons listed above, UPDW FORTRAN was chosen to perform the analysis of the gravity data in this study. To compensate for the edge effects of UPDW the output was overlapped. A listing of both UPDW and UDD FORTRAN are given below:

Figure 27: Contour plot of the potential field values listed in a paper by Tasubi (1959), continued to a level of +15.9 kilometers.

Upward Continuation Of Tasubi Gravity Data at 15.9 Km.



To verify the output from UPDW FORTRAN the data of Tasubi (1959) was gridded and contoured for analysis (Figure 26). The potential field was continued upward 15.9 kilometers using UPDW FORTRAN. The contour plot of this operation (Figure 27) was compared to the values in Tasubi's paper (1959), and no discernable differences were identified.

UPDW FORTRAN:

Written by: Agarwal (1968)

```
C                                                                       UPD00010
C   THIS PROGRAM CALCULATES THE UPWARD OR DOWNWARD CONTINUATION AT ANY  UPD00020
C HEIGHT OR DEPTH IN A PARTICULAR LOCATION. IT ALSO OBTAINS FIRST,SECONDUPD00030
C OR HIGHEST SET OF DERIVATIVES. USES TWO DIMENSIONAL FOURIER ANALYSIS. UPD00040
C                                                                       UPD00050
C  THIS PROGRAM ALSO OBTAINS 1ST, 2ND, OR HIGHEST SET OF DERIVATIVES.   UPD00060
C                                                                       UPD00070
C  THE GAUSSIAN DISTRIBUTION FOR THE CALCULATIONS USED IN THIS PROGRAM  UPD00080
C  IS AFTER TSUBOI(1959)                                                UPD00090
                                                                        UPD00100
C  Z: UPWARD (-IVE) OR DOWNWARD (+IVE) HEIGHT.                          UPD00110
C                                                                       UPD00120
C  ID=0 FOR NO DERIVITVE                                                UPD00130
C  ID=1 FOR FIRST DERIVITIVE                                            UPD00140
C  ID=2 FOR 2ND DERIVITIVE                                              UPD00150
C  ID=3 FOR 3RD DERIVITIVE AND SO ON                                    UPD00160
C                                                                       UPD00170
C  X1(I,J) IS THE REAL INPUT MATRIX IN SPACE DOMAIN.                    UPD00180
C                                                                       UPD00190
C  X(J) IS THE FINAL SYMMETERIZED DATA, USING GYCLIC PROPORTIES OF      UPD00200
C  FOURIER TRANSFORMS.                                                  UPD00210
C                                                                       UPD00220
C  FOR COMPUTATION PROGRAM USES X(J)+IY(J) WHERE Y(J)=0.0               UPD00230
C  OUTPUT RESULTS ARE GIVEN AS X(J)+IY(J) IN FREQUENCY DOMAIN           UPD00240
C                                                                       UPD00250
C  N(J,K,0) : ARRAY OF DATA IS TOW DIMENSIONAL WITH SIDE J BY K         UPD00260
C  NOPTS: NUMBER OF DATA POINTS (J*K)                                   UPD00270
C  DELT: THE DIGITIZING INTERVAL IN MILES.                              UPD00280
C                                                                       UPD00290
C                                                                       UPD00300
      DIMENSION X(15000),Y(15000),S(15000),N(3),X1(76,76)               UPD00310
C  20 FORMAT(5X,3I5)                                                    UPD00320
   22 FORMAT(1HJ,31X,23HDEGREE OF DERIVATIVE = ,I5,23X,24HSIZE OF OUTPUTUPD00330
     1 MATRIX = ,I5)                                                    UPD00340
   23 FORMAT(1HJ,20X,34HELEVATION OF CONTINUATION FIELD = ,F10.5,5X,37HDUPD00350
     1IGITIZING INTERVAL OF DATA POINTS = ,F10.5)                       UPD00360
C  30 FORMAT(5X,F10.5)                                                  UPD00370
   35 FORMAT(1X,6E11.4)                                                 UPD00380
   36 FORMAT(1X,10E13.4)                                                UPD00390
   45 FORMAT(1HJ)                                                       UPD00400
   40 FORMAT(1H1,60X,10HINPUT DATA)                                     UPD00410
   42 FORMAT(1HT,60X,10H**********)                                     UPD00420
   50 FORMAT(1HT,25X,80(1H*))                                           UPD00430
   60 FORMAT(1X,6HDELT =,F8.3,8X,18HNYQUIST FREQUENCY=,F8.3)            UPD00440
   70 FORMAT(1HJ,22X,15HFREQUENCY =2*J*,F10.6,1X,15HCYCLES PER MILE)    UPD00450
  316 FORMAT(1H1,40X,47HUPWARD OR DOWNWARD CONTINUATION AND DERIVATIVES)UPD00460
  317 FORMAT(41X,47(1H*))                                               UPD00470
  320 FORMAT(1HL,56X,17HREAL (SPACE) PART)                              UPD00480
  325 FORMAT(1HT,56X,17H*****************)                             UPD00490
C
C XMIN : MINIMUM XMIN=MINX-TERV where MINX= minimum x value
C YMIN : MINIMUM YMIN=MINY-TERV where MINY= minimum y value
C TERV : Digitizing Interval
C
```

```
      READ(1,*) ID,XMIN,YMIN,TERV                                       UPD00500
      READ(1,*) DELT                                                    UPD00510
      READ(1,*) Z                                                       UPD00520
      READ(1,*) (N(J),J=1,3)                                            UPD00530
      NOPTS=N(1)*N(2)                                                   UPD00540
      WRITE(6,*) NOPTS, N(1), N(2)                                      UPD00550
      NN=N(1)                                                           UPD00560
      NNN=N(2)                                                          UPD00570
      DO 9 I=1,NN                                                       UPD00580
      READ(1,1235) (X1(I,J),J=1,NNN)                                    UPD00590
C Choose One Format: Current Format gives X, Y, and Z values
C     WRITE(6,1235) (X1(I,J),J=1,NNN)                                   UPD00600
C235  FORMAT(23X,F10.2)                                                 UPD00610
1235  FORMAT(F10.2)                                                     UPD00620
    9 CONTINUE                                                          UPD00630
      WRITE(2,40)                                                       UPD00640
      WRITE(2,42)                                                       UPD00650
      DO 10 I=1,NN                                                      UPD00660
      WRITE(2,36) (X1(I,J),J=1,NNN)                                     UPD00670
      WRITE(2,45)                                                       UPD00680
   10 CONTINUE                                                          UPD00690
      WRITE(2,50)                                                       UPD00700
C                                                                       UPD00710
C SETTING X AS THE FINAL SYMMERTIZED MATRIX OF SIZE (2N-2)*(2N-2). REMEMUPD00720
C BER HERE X IS STORED IN A VECTOR FORM.                                UPD00730
C                                                                       UPD00740
C                                                                       UPD00750
      DO 1 I=1,NN                                                       UPD00760
      DO 2 J=1,NNN                                                      UPD00770
      J1=(2*NN-2)*(I-1)+J                                               UPD00780
      X(J1)=X1(I,J)                                                     UPD00790
    2 CONTINUE                                                          UPD00800
      N1=NN-2                                                           UPD00810
      DO 3 J=1,N1                                                       UPD00820
      J2=J1+J                                                           UPD00830
      X(J2)=X1(I,NN-J)                                                  UPD00840
    3 CONTINUE                                                          UPD00850
    1 CONTINUE                                                          UPD00860
      N2=2*NN-2                                                         UPD00870
      DO 5 K=1,N1                                                       UPD00880
      DO 4 J=1,N2                                                       UPD00890
      J3=J2+J                                                           UPD00900
      X(J3)=X(J3-(4*NN-4)*K)                                            UPD00910
    4 CONTINUE                                                          UPD00920
      J2=J3                                                             UPD00930
    5 CONTINUE                                                          UPD00940
C                                                                       UPD00950
C END OF SYMMETRIZED VECTOR. NOW WE RESET N(1),N(2),NOPTS,ETC.....      UPD00960
C                                                                       UPD00970
      N(1)=2*NN-2                                                       UPD00980
      N(2)=2*NNN-2                                                      UPD00990
      NN=N(1)                                                           UPD01000
      NNN=N(2)                                                          UPD01010
      NOPTS=N(1)*N(2)                                                   UPD01020
      FN=1./(2.*DELT)                                                   UPD01030
      WRITE(2,60) DELT,FN                                               UPD01040
      PRINT *,'FP=',FP,'NOPTS=',NOPTS                                   UPD01050
      FP=FN/(FLOAT(NOPTS))                                              UPD01060
      WRITE(2,70) FP                                                    UPD01070
      CALL ZERO(Y,NOPTS)                                                UPD01080
      CALL ZERO(S,NOPTS)                                                UPD01090
      CALL ARMDFT(N,X,Y,S)                                              UPD01100
```

```
C                                                                       UPD01110
C MULTIPLY FREQ. BY A FACTOR; EXP((1**2+J**2)*(2.0*PI*Z/(NN*DELT))),    UPD01120
C FOR 1=0,2,2.....NN AND J=0,1,2....NNN                                 UPD01130
C                                                                       UPD01140
      DO 121 I=1,NN                                                     UPD01150
      IF(I.GT.(NN/2+1)) GO TO 11                                        UPD01160
      A=I-1                                                             UPD01170
      GO TO 12                                                          UPD01180
   11 A=NN+1-I                                                          UPD01190
   12 CONTINUE                                                          UPD01200
      K=(I-1)*NNN+1                                                     UPD01210
      L=K+NNN-1                                                         UPD01220
      DO 121 J=K,L                                                      UPD01230
      IF(J.GT.((L+K)/2+1)) GO TO 13                                     UPD01240
      B=J-1-(NN*(I-1))                                                  UPD01250
      GO TO 14                                                          UPD01260
   13 B=NN+1-J+(NN*(I-1))                                               UPD01270
   14 CONTINUE                                                          UPD01280
      XYA=(SQRT(A**2+B**2)*2.0*3.14159*Z)/(FLOAT(NN)*DELT)              UPD01290
      CONT=EXP(XYA)                                                     UPD01300
      IF(ID.EQ.0) GO TO 15                                              UPD01310
      CONTDI=(SQRT(A**2+B**2)*(2.0*3.14159)/(FLOAT(NN)*DELT))**ID       UPD01320
   15 CONTINUE                                                          UPD01330
      X(J)=X(J)*CONT                                                    UPD01340
      Y(J)=Y(J)*CONT                                                    UPD01350
      IF(ID.EQ.0) GO TO 121                                             UPD01360
      X(J)=X(J)*CONTDI                                                  UPD01370
      Y(J)=Y(J)*CONTDI                                                  UPD01380
  121 CONTINUE                                                          UPD01390
      J=0                                                               UPD01400
      DO 250 J3=1,NOPTS                                                 UPD01410
      J=J+1                                                             UPD01420
C                                                                       UPD01430
C REPLACE FOURIER COEFFS. BY COMPLEX CONJUGATE                          UPD01440
C                                                                       UPD01450
      F=Y(J)                                                            UPD01460
      Y(J)=-F                                                           UPD01470
  250 CONTINUE                                                          UPD01480
      CALL ZERO(S,NOPTS)                                                UPD01490
      CALL ARMDFT(N,X,Y,S)                                              UPD01500
      J=0                                                               UPD01510
      DO 350 J4=1,NOPTS                                                 UPD01520
      J=J+1                                                             UPD01530
C TAKE COMPLEX CONJUGATE                                                UPD01540
      GG=Y(J)                                                           UPD01550
      Y(J)=-GG                                                          UPD01560
  350 CONTINUE                                                          UPD01570
      J=0                                                               UPD01580
      DO 400 J5=1,NOPTS                                                 UPD01590
      J=J+1                                                             UPD01600
      X(J)=X(J)/FLOAT(NOPTS)                                            UPD01610
      Y(J)=Y(J)/FLOAT(NOPTS)                                            UPD01620
  400 CONTINUE                                                          UPD01630
C                                                                       UPD01640
C RESET NN AND NNN. PICK UP USEFUL SIZE OF RESULTS                      UPD01650
C                                                                       UPD01660
      WRITE(2,316)                                                      UPD01670
      WRITE(2,317)                                                      UPD01680
      WRITE(2,320)                                                      UPD01690
      WRITE(2,325)                                                      UPD01700
      NN=(NN+2)/2                                                       UPD01710
      NNN=(NNN+2)/2                                                     UPD01720
```

```
      DO 7 I=1,NN                                                       UPD01730
      DO 8 J=1,NNN                                                      UPD01740
      X1(I,J)=X((2*NN-2)*(I-1)+J)                                       UPD01750
    8 CONTINUE                                                          UPD01760
    7 CONTINUE                                                          UPD01770
      DO 21 I=1,NN                                                      UPD01780
      WRITE(2,36) (X1(I,J),J=1,NNN)                                     UPD01790
      WRITE(2,45)                                                       UPD01800
   21 CONTINUE                                                          UPD01810
      PRINT *,'NNN=',NNN,'NN=',NN                                       UPD01820
      XMIN1=XMIN                                                        UPD01830
      DO 1375 I=1,NNN                                                   UPD01840
         XMIN1=XMIN1+TERV                                               UPD01850
           YMIN1=YMIN                                                   UPD01860
      DO 1377 J=1,NN                                                    UPD01870
         YMIN1=YMIN1+TERV                                               UPD01880
           WRITE(3,1112) XMIN1,YMIN1,X1(I,J)                            UPD01890
1112  FORMAT(F8.3,1X,F8.3,1X,E16.4)                                     UPD01900
1377  CONTINUE                                                          UPD01910
1375  CONTINUE                                                          UPD01920
      WRITE(2,50)                                                       UPD01930
      WRITE(2,45)                                                       UPD01940
      WRITE(2,45)                                                       UPD01950
      WRITE(2,23) Z,DELT                                                UPD01960
      WRITE(2,45)                                                       UPD01970
      WRITE(2,22) ID,NN                                                 UPD01980
      STOP                                                              UPD01990
      END                                                               UPD02000
      SUBROUTINE ZERO(X,NOPTS)                                          UPD02010
C                                                                       UPD02020
C SETS VECTOR TO ZERO                                                   UPD02030
C                                                                       UPD02040
      REAL X(15000)                                                     UPD02050
      DO 1 J=1,NOPTS                                                    UPD02060
      X(J)=0.0                                                          UPD02070
    1 CONTINUE                                                          UPD02080
      RETURN                                                            UPD02090
      END                                                               UPD02100
       SUBROUTINE AR ID FT (N,X,Y,S)                                    UPD02110
C      ARBITRARY RADIX ONE DIMENSIONAL FOURIER TRANSFORM                UPD02120
C                                                                       UPD02130
       INTEGER N                                                        UPD02140
       REAL X (15000), Y (15000), S(15000)                              UPD02150
C                                                                       UPD02160
       CALL GR ID FT (N,X,Y)                                            UPD02170
       CALL GR ID FS (N,X,Y,S)                                          UPD02180
       RETURN                                                           UPD02190
       END                                                              UPD02200
C                                                                       UPD02210
       SUBROUTINE  GR ID FT (NOPTS,X,Y)                                 UPD02220
C      ONE DIMENSIONAL FOURIER TRANSFORM                                UPD02230
C                                                                       UPD02240
       REAL  X(15000),Y(15000)                                          UPD02250
C                                                                       UPD02260
       INTEGER J,K,M,MR,J1,J2,J3,J4,J5,JT                               UPD02270
       REAL I1,I2,I3,I4,I5                                              UPD02280
       INTEGER P,PMAX,U,V                                               UPD02290
C                                                                       UPD02300
C      NEEDS SORT ID TO RECOVER UNSCRAMBLED FOURIER COEFICIENTS         UPD02310
C                                                                       UPD02320
C      THIS SUBROUTINE REPLACES X + I Y BY ITS FOURIER TRANSFORM WHERE  UPD02330
C      X(F)+IY(F) = SUM T=0,(NOPTS-1) OF (X(T)+IY(T))*EXP(-F*T/NOPTS).  UPD02340
```

```
C                                                                       UPD02350
C      REAL I (PMAX), R (PMAX), C(PMAX,PMAX), S (PMAX,PMAX),            UPD02360
C     1A ((PMAX-1)**2+1), B((PMAX-1)**2+1)                              UPD02370
C                                                                       UPD02380
       REAL I (13), R(13),C(13,13), S(13,13), A(145), B(145)            UPD02390
C                                                                       UPD02400
       PMAX=13                                                          UPD02410
C                                                                       UPD02420
       TWOPI=6.283185307                                                UPD02430
       M=NOPTS                                                          UPD02440
  100  CONTINUE                                                         UPD02450
       IF (M .NE. (M/4)*4) GO TO 400                                    UPD02460
C                                                                       UPD02470
C      FACTORS OF FOUR                                                  UPD02480
C                                                                       UPD02490
       MR=M                                                             UPD02500
       M=M/4                                                            UPD02510
       DO 300 J=1,M                                                     UPD02520
       ARG= TWOPI*FLOAT(J-1)/FLOAT(MR)                                  UPD02530
       C1=COS(ARG)                                                      UPD02540
       S1=SIN(ARG)                                                      UPD02550
       C2=COS(2.0*ARG)                                                  UPD02560
       S2=SIN(2.0*ARG)                                                  UPD02570
       C3=COS(3.0*ARG)                                                  UPD02580
       S3=SIN(3.0*ARG)                                                  UPD02590
       DO 200 K=MR,NOPTS,MR                                             UPD02600
       J1=J+K-MR                                                        UPD02610
       J2=J1+M                                                          UPD02620
       J3=J2+M                                                          UPD02630
       J4=J3+M                                                          UPD02640
       R1=X(J1)+X(J3)                                                   UPD02650
       R2=X(J1)-X(J3)                                                   UPD02660
       I1=Y(J1)+Y(J3)                                                   UPD02670
       I2=Y(J1)-Y(J3)                                                   UPD02680
       R3=X(J2)+X(J4)                                                   UPD02690
       R4=X(J2)-X(J4)                                                   UPD02700
       I3=Y(J2)+Y(J4)                                                   UPD02710
       I4=Y(J2)-Y(J4)                                                   UPD02720
       X(J1)=R1+R3                                                      UPD02730
       Y(J1)=I1+I3                                                      UPD02740
       X(J2)=(R2+I4)*C1+(I2-R4)*S1                                      UPD02750
       Y(J2)=(I2-R4)*C1-(R2+I4)*S1                                      UPD02760
       X(J3)=(R1-R3)*C2+(I1-I3)*S2                                      UPD02770
       Y(J3)=(I1-I3)*C2-(R1-R3)*S2                                      UPD02780
       X(J4)=(R2-I4)*C3+(I2+R4)*S3                                      UPD02790
       Y(J4)=(I2+R4)*C3-(R2-I4)*S3                                      UPD02800
  200  CONTINUE                                                         UPD02810
  300  CONTINUE                                                         UPD02820
       GO TO 100                                                        UPD02830
  400  CONTINUE                                                         UPD02840
       IF (M .NE. (M/2)*2) GO TO 700                                    UPD02850
C                                                                       UPD02860
C      FACTORS OF TWO                                                   UPD02870
C                                                                       UPD02880
       MR=M                                                             UPD02890
       M=M/2                                                            UPD02900
       DO 600 J=1,M                                                     UPD02910
       ARG=TWOPI*FLOAT(J-1)/FLOAT(MR)                                   UPD02920
       C1=COS(ARG)                                                      UPD02930
       S1=SIN(ARG)                                                      UPD02940
       DO 500 K=MR,NOPTS,MR                                             UPD02950
       J1=J+K-MR                                                        UPD02960
```

```
      J2=J1+M                                                          UPD02970
      R1=X(J1)+X(J2)                                                   UPD02980
      R2=X(J1)-X(J2)                                                   UPD02990
      I1=Y(J1)+Y(J2)                                                   UPD03000
      I2=Y(J1)-Y(J2)                                                   UPD03010
      X(J1)=R1                                                         UPD03020
      Y(J1)=I1                                                         UPD03030
      X(J2)=R2*C1+I2*S1                                                UPD03040
      Y(J2)=I2*C1-R2*S1                                                UPD03050
  500 CONTINUE                                                         UPD03060
  600 CONTINUE                                                         UPD03070
      GO TO 400                                                        UPD03080
  700 CONTINUE                                                         UPD03090
      IF (M .NE. (M/3)*3) GO TO 1000                                   UPD03100
C                                                                      UPD03110
C     FACTORS OF THREE                                                 UPD03120
C                                                                      UPD03130
      MR=M                                                             UPD03140
      M=M/3                                                            UPD03150
      A1=COS(TWOPI/3.0)                                                UPD03160
      B1=SIN(TWOPI/3.0)                                                UPD03170
      A2=COS(2.0*TWOPI/3.0)                                            UPD03180
      B2=SIN(2.0*TWOPI/3.0)                                            UPD03190
      DO 900 J=1,M                                                     UPD03200
      ARG=TWOPI*FLOAT(J-1)/FLOAT(MR)                                   UPD03210
C                                                                      UPD03220
C     ABSORB TWIDDLE FACTOR INTO ANALYSIS COEFFICIENTS                 UPD03230
C                                                                      UPD03240
      C21=COS(ARG)                                                     UPD03250
      S21=SIN(ARG)                                                     UPD03260
      C22=C21*A1-S21*B1                                                UPD03270
      S22=C21*B1+S21*A1                                                UPD03280
      C23=C21*A2-S21*B2                                                UPD03290
      S23=C21*B2+S21*A2                                                UPD03300
      C31=COS(2.0*ARG)                                                 UPD03310
      S31=SIN(2.0*ARG)                                                 UPD03320
      C32=C31*A2-S31*B2                                                UPD03330
      S32=C31*B2+S31*A2                                                UPD03340
      C33=C31*A1-S31*B1                                                UPD03350
      S33=C31*B1+S31*A1                                                UPD03360
      DO 800 K=MR,NOPTS,MR                                             UPD03370
      J1=J+K-MR                                                        UPD03380
      J2=J1+M                                                          UPD03390
      J3=J2+M                                                          UPD03400
      R1=X(J1)                                                         UPD03410
      I1=Y(J1)                                                         UPD03420
      R2=X(J2)                                                         UPD03430
      I2=Y(J2)                                                         UPD03440
      R3=X(J3)                                                         UPD03450
      I3=Y(J3)                                                         UPD03460
      X(J1)=R1+R2+R3                                                   UPD03470
      Y(J1)=I1+I2+I3                                                   UPD03480
      X(J2)=R1*C21+I1*S21+R2*C22+I2*S22+R3*C23+I3*S23                  UPD03490
      Y(J2)=I1*C21-R1*S21+I2*C22-R2*S22+I3*C23-R3*S23                  UPD03500
      X(J3)=R1*C31+I1*S31+R2*C32+I2*S32+R3*C33+I3*S33                  UPD03510
      Y(J3)=I1*C31-R1*S31+I2*C32-R2*S32+I3*C33-R3*S33                  UPD03520
  800 CONTINUE                                                         UPD03530
  900 CONTINUE                                                         UPD03540
      GO TO 700                                                        UPD03550
 1000 CONTINUE                                                         UPD03560
      IF (M .NE. (M/5)*5) GO TO 1300                                   UPD03570
C                                                                      UPD03580
```

```
C       FACTORS OF FIVE                                                 UPD03590
C                                                                       UPD03600
        MR=M                                                            UPD03610
        M=M/5                                                           UPD03620
        A1=COS(TWOPI/5.0)                                               UPD03630
        B1=SIN(TWOPI/5.0)                                               UPD03640
        A2=COS(2.0*TWOPI/5.0)                                           UPD03650
        B2=SIN(2.0*TWOPI/5.0)                                           UPD03660
        A3=COS(3.0*TWOPI/5.0)                                           UPD03670
        B3=SIN(3.0*TWOPI/5.0)                                           UPD03680
        A4=COS(4.0*TWOPI/5.0)                                           UPD03690
        B4=SIN(4.0*TWOPI/5.0)                                           UPD03700
        DO 1200 J=1,M                                                   UPD03710
        ARG=TWOPI*FLOAT(J-1)/FLOAT(MR)                                  UPD03720
C                                                                       UPD03730
C       ABSORB TWIDDLE FACTOR INTO ANALYAIS COEFFICIENTS                UPD03740
C                                                                       UPD03750
        C21=COS(ARG)                                                    UPD03760
        S21=SIN(ARG)                                                    UPD03770
        C22=C21*A1-S21*B1                                               UPD03780
        S22=C21*B1+S21*A1                                               UPD03790
        C23=C21*A2-S21*B2                                               UPD03800
        S23=C21*B2+S21*A2                                               UPD03810
        C24=C21*A3-S21*B3                                               UPD03820
        S24=C21*B3+S21*A3                                               UPD03830
        C25=C21*A4-S21*B4                                               UPD03840
        S25=C21*B4+S21*A4                                               UPD03850
        C31=COS(2.0*ARG)                                                UPD03860
        S31=SIN(2.0*ARG)                                                UPD03870
        C32=C31*A2-S31*B2                                               UPD03880
        S32=C31*B2+S31*A2                                               UPD03890
        C33=C31*A4-S31*B4                                               UPD03900
        S33=C31*B4+S31*A4                                               UPD03910
        C34=C31*A1-S31*B1                                               UPD03920
        S34=C31*B1+S31*A1                                               UPD03930
        C35=C31*A3-S31*B3                                               UPD03940
        S35=C31*B3+S31*A3                                               UPD03950
        C41=COS(3.0*ARG)                                                UPD03960
        S41=SIN(3.0*ARG)                                                UPD03970
        C42=C41*A3-S41*B3                                               UPD03980
        S42=C41*B3+S41*A3                                               UPD03990
        C43=C41*A1-S41*B1                                               UPD04000
        S43=C41*B1+S41*A1                                               UPD04010
        C44=C41*A4-S41*B4                                               UPD04020
        S44=C41*B4+S41*A4                                               UPD04030
        C45=C41*A2-S41*B2                                               UPD04040
        S45=C41*B2+S41*A2                                               UPD04050
        C51=COS(4.0*ARG)                                                UPD04060
        S51=SIN(4.0*ARG)                                                UPD04070
        C52=C51*A4-S51*B4                                               UPD04080
        S52=C51*B4+S51*A4                                               UPD04090
        C53=C51*A3-S51*B3                                               UPD04100
        S53=C51*B3+S51*A3                                               UPD04110
        C54=C51*A2-S51*B2                                               UPD04120
        S54=C51*B2+S51*A2                                               UPD04130
        C55=C51*A1-S51*B1                                               UPD04140
        S55=C51*B1+S51*A1                                               UPD04150
        DO 1100 K=MR,NOPTS,MR                                           UPD04160
        J1=J+K-MR                                                       UPD04170
        J2=J1+M                                                         UPD04180
        J3=J2+M                                                         UPD04190
        J4=J3+M                                                         UPD04200
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```
      J5=J4+M                                                           UPD04210
      R1=X(J1)                                                          UPD04220
      I1=Y(J1)                                                          UPD04230
      R2=X(J2)                                                          UPD04240
      I2=Y(J2)                                                          UPD04250
      R3=X(J3)                                                          UPD04260
      I3=Y(J3)                                                          UPD04270
      R4=X(J4)                                                          UPD04280
      I4=Y(J4)                                                          UPD04290
      R5=X(J5)                                                          UPD04300
      I5=Y(J5)                                                          UPD04310
      X(J1)=R1+R2+R3+R4+R5                                              UPD04320
      Y(J1)=I1+I2+I3+I4+I5                                              UPD04330
      X(J2)=R1*C21+I1*S21+R2*C22+I2*S22+R3*C23+I3*S23+R4*C24+I4*S24+    UPD04340
     1R5*C25+I5*S25                                                     UPD04350
      Y(J2)=I1*C21-R1*S21+I2*C22-R2*S22+I3*C23-R3*S23+I4*C24-R4*S24+    UPD04360
     1I5*C25-R5*S25                                                     UPD04370
      X(J3)=R1*C31+I1*S31+R2*C32+I2*S32+R3*C33+I3*S33+R4*C34+I4*S34+    UPD04380
     1R5*C35+I5*S35                                                     UPD04390
      Y(J3)=I1*C31-R1*S31+I2*C32-R2*S32+I3*C33-R3*S33+I4*C34-R4*S34+    UPD04400
     1I5*C35-R5*S35                                                     UPD04410
      X(J4)=R1*C41+I1*S41+R2*C42+I2*S42+R3*C43+I3*S43+R4*C44+I4*S44+    UPD04420
     1R5*C45+I5*S45                                                     UPD04430
      Y(J4)=I1*C41-R1*S41+I2*C42-R2*S42+I3*C43-R3*S43+I4*C44-R4*S44+    UPD04440
     1I5*C45-R5*S45                                                     UPD04450
      X(J5)=R1*C51+I1*S51+R2*C52+I2*S52+R3*C53+I3*S53+R4*C54+I4*S54+    UPD04460
     1R5*C55+I5*S55                                                     UPD04470
      Y(J5)=I1*C51-R1*S51+I2*C52-R2*S52+I3*C53-R3*S53+I4*C54-R4*S54+    UPD04480
     1I5*C55-R5*S55                                                     UPD04490
 1100 CONTINUE                                                          UPD04500
 1200 CONTINUE                                                          UPD04510
      GO TO 1000                                                        UPD04520
 1300 CONTINUE                                                          UPD04530
      IF (M .LE. 1) GO TO 2400                                          UPD04540
C                                                                       UPD04550
C     GENERAL FACTORS                                                   UPD04560
C                                                                       UPD04570
      DO 1400 J=2,PMAX                                                  UPD04580
      P=J                                                               UPD04590
      IF (M .EQ. (M/P)*P) GO TO 1500                                    UPD04600
 1400 CONTINUE                                                          UPD04610
      CALL FCT ERR                                                      UPD04620
 1500 CONTINUE                                                          UPD04630
      JT=(P-1)**2+1                                                     UPD04640
C                                                                       UPD04650
C     SET UP ARBITRARY FACTORS                                          UPD04660
C                                                                       UPD04670
      DO 1600 J=1,JT                                                    UPD04680
      ARG=TWOPI*FLOAT(J-1)/FLOAT(P)                                     UPD04690
      A(J)=COS(ARG)                                                     UPD04700
      B(J)=SIN(ARG)                                                     UPD04710
 1600 CONTINUE                                                          UPD04720
      MR=M                                                              UPD04730
      M=M/P                                                             UPD04740
      DO 2300 J=1,M                                                     UPD04750
      ARG=TWOPI*FLOAT(J-1)/FLOAT(MR)                                    UPD04760
C                                                                       UPD04770
C     ABSORB TWIDDLE FACTOR INTO ANALYSIS COEFFICIENTS                  UPD04780
C                                                                       UPD04790
      DO 1800 U=1,P                                                     UPD04800
      C(U,1)=COS(FLOAT(U-1)*ARG)                                        UPD04810
      S(U,1)=SIN(FLOAT(U-1)*ARG)                                        UPD04820
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      DO 1700 V=2,P                                                     UPD04830
      JT=(U-1)*(V-1)+1                                                  UPD04840
      C(U,V)=C(U,1)*A(JT)-S(U,1)*B(JT)                                  UPD04850
      S(U,V)=C(U,1)*B(JT)+S(U,1)*A(JT)                                  UPD04860
 1700 CONTINUE                                                          UPD04870
 1800 CONTINUE                                                          UPD04880
      DO 2200 K=MR,NOPTS,MR                                             UPD04890
C                                                                       UPD04900
C     GENERAL ANALYSIS                                                  UPD04910
C                                                                       UPD04920
      DO 1900 U=1,P                                                     UPD04930
      JT=J+K-MR+(U-1)*M                                                 UPD04940
      R(U)=X(JT)                                                        UPD04950
      I(U)=Y(JT)                                                        UPD04960
 1900 CONTINUE                                                          UPD04970
      DO 2100 U=1,P                                                     UPD04980
      XT=0.0                                                            UPD04990
      YT=0.0                                                            UPD05000
      DO 2000 V=1,P                                                     UPD05010
      XT=XT+R(V)*C(U,V)+I(V)*S(U,V)                                     UPD05020
      YT=YT+I(V)*C(U,V)-R(V)*S(U,V)                                     UPD05030
 2000 CONTINUE                                                          UPD05040
      JT=J+K-MR+(U-1)*M                                                 UPD05050
      X(JT)=XT                                                          UPD05060
      Y(JT)=YT                                                          UPD05070
 2100 CONTINUE                                                          UPD05080
 2200 CONTINUE                                                          UPD05090
 2300 CONTINUE                                                          UPD05100
      GO TO 1300                                                        UPD05110
 2400 CONTINUE                                                          UPD05120
      RETURN                                                            UPD05130
      END                                                               UPD05140
     SUBROUTINE GR ID FS (NOPTS,X,Y,S)                                  UPD05150
C    UNSCRAMBLING PROGRAM FOR ONE DIMENSIONAL FOURIER COEFFICIENTS      UPD05160
C                                                                       UPD05170
     REAL  X(15000),Y(15000),S(15000)                                   UPD05180
C                                                                       UPD05190
     INTEGER JT                                                         UPD05200
     INTEGER DO, LIM(13), STEP(13), P,PMAX                              UPD05210
     INTEGERA,B,C,D,E,F,G,H,I,J,K,L,M,AL,BL,CL,DL,EL,FL,GL,HL,IL,JL,    UPD05220
    1KL,LL,ML,AS,BS,CS,DS,ES,FS,GS,HS,IS,JS,KS,LS,MS                    UPD05230
C                                                                       UPD05240
C    DIGIT REVERSER FOR USE WITH FOUR  ID . S MUST BE THE SAME SIZE AS  UPD05250
C    X AND Y                                                            UPD05260
C                                                                       UPD05270
C    EQUIVALENCES TO ALLOW INDEXING TO SET PARAMETERS AND ALLOW SCALARSUPD05280
C    FOR USE IN DO LOOPS.                                               UPD05290
C                                                                       UPD05300
     EQUIVALENCE (AS,STEP(1)),(BS,STEP(2)),(CS,STEP(3)),(DS,STEP(4)),   UPD05310
    1(ES,STEP(5)),(FS,STEP(6)),(GS,STEP(7)),(HS,STEP(8)),(IS,STEP(9)),  UPD05320
    2(JS,STEP(10)),(KS,STEP(11)),(LS,STEP(12)),(MS,STEP(13))            UPD05330
     EQUIVALENCE (AL,LIM(1)),(BL,LIM(2)),(CL,LIM(3)),(DL,LIM(4)),       UPD05340
    1(EL,LIM(5)),(FL,LIM(6)),(GL,LIM(7)),(HL,LIM(8)),(IL,LIM(9)),       UPD05350
    2(JL,LIM(10)),(KL,LIM(11)),(LL,LIM(12)),(ML,LIM(13))                UPD05360
C                                                                       UPD05370
C    PMAX IS SET TO AGREE WITH FOUR ID                                  UPD05380
C                                                                       UPD05390
     PMAX=13                                                            UPD05400
C                                                                       UPD05410
C    SET LIMITS AND STEP SIZES FROM INNER LOUPS GOING OUT               UPD05420
C                                                                       UPD05430
     DO=13                                                              UPD05440
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      M=NOPTS                                                          UPD05450
  100 CONTINUE                                                         UPD05460
C                                                                      UPD05470
C     CHECK FOR FACTORS OF FOUR                                        UPD05480
C                                                                      UPD05490
      IF (M .NE. (M/4)*4) GO TO 200                                    UPD05500
      M=M/4                                                            UPD05510
C                                                                      UPD05520
C     REALLY WANT 0-4*M-1 BUT WE GO FROM 1 TO 4*M.  4 STEPS  OF M WITH UPD05530
C     MAXIMUM DISPLACEMENT OF M INITIALLY                              UPD05540
C                                                                      UPD05550
      LIM(DO)=4*M                                                      UPD05560
      STEP(DO)=M                                                       UPD05570
      DO=DO-1                                                          UPD05580
      GO TO 100                                                        UPD05590
  200 CONTINUE                                                         UPD05600
C                                                                      UPD05610
C     CHECK FOR REMAINING FACTORS                                      UPD05620
C                                                                      UPD05630
      IF (M .LE. 1) GO TO 500                                          UPD05640
C                                                                      UPD05650
C     FACTORS OF 2,3,5,7,11,13                                         UPD05660
C                                                                      UPD05670
      DO 300 JT=2,PMAX                                                 UPD05680
      P=JT                                                             UPD05690
      IF (M .EQ. (M/P)*P) GO TO 400                                    UPD05700
  300 CONTINUE                                                         UPD05710
C                                                                      UPD05720
C     ERROR EXIT IF FACTORS ABOVE PMAX ARE NEEDED                      UPD05730
C                                                                      UPD05740
      CALL FCT ERR                                                     UPD05750
  400 CONTINUE                                                         UPD05760
      M=M/P                                                            UPD05770
C                                                                      UPD05780
C     REALLY WANT 0-P*M-1 BUT WE USE 1 TO P*M. P STEPS OF M WITH       UPD05790
C     MAXIMUM INITIAL DISPLACEMENT OF M                                UPD05800
C                                                                      UPD05810
      LIM(DO)=P*M                                                      UPD05820
      STEP(DO)=M                                                       UPD05830
      DO=DO-1                                                          UPD05840
      GO TO 200                                                        UPD05850
  500 CONTINUE                                                         UPD05860
C                                                                      UPD05870
C     FINISH OUT THE DO LOOPS TO MAKE OUTER LOOPS EXECUTE ONLY ONCE    UPD05880
C                                                                      UPD05890
      DO 600 JT=1,DO                                                   UPD05900
      LIM(JT)=1                                                        UPD05910
      STEP(JT)=1                                                       UPD05920
  600 CONTINUE                                                         UPD05930
C                                                                      UPD05940
C     SET JT SO THAT JT RUNS FROM 1 TO NOPTS IN STEPS OF 1 WHILE M WILL UPD05950
C     RUN WITH REVERSE DIGITS                                          UPD05960
C                                                                      UPD05970
      JT=0                                                             UPD05980
      DO 700 A=1,AL,AS                                                 UPD05990
      DO 700 B=A,BL,BS                                                 UPD06000
      DO 700 C=B,CL,CS                                                 UPD06010
      DO 700 D=C,DL,DS                                                 UPD06020
      DO 700 E=D,EL,ES                                                 UPD06030
      DO 700 F=E,FL,FS                                                 UPD06040
      DO 700 G=F,GL,GS                                                 UPD06050
      DO 700 H=G,HL,HS                                                 UPD06060
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      DO 700 I=H,IL,IS                                                  UPD06070
      DO 700 J=I,JL,JS                                                  UPD06080
      DO 700 K=J,KL,KS                                                  UPD06090
      DO 700 L=K,LL,LS                                                  UPD06100
      DO 700 M=L,ML,MS                                                  UPD06110
      JT=JT+1                                                           UPD06120
      S(JT)=X(M)                                                        UPD06130
  700 CONTINUE                                                          UPD06140
C                                                                       UPD06150
C     COPY BACK OUT THE SCRATCH ARRAY                                   UPD06160
C                                                                       UPD06170
      DO 800 JT=1,NOPTS                                                 UPD06180
      X(JT)=S(JT)                                                       UPD06190
  800 CONTINUE                                                          UPD06200
      JT=0                                                              UPD06210
      DO 900 A=1,AL,AS                                                  UPD06220
      DO 900 B=A,BL,BS                                                  UPD06230
      DO 900 C=B,CL,CS                                                  UPD06240
      DO 900 D=C,DL,DS                                                  UPD06250
      DO 900 E=D,EL,ES                                                  UPD06260
      DO 900 F=E,FL,FS                                                  UPD06270
      DO 900 G=F,GL,GS                                                  UPD06280
      DO 900 H=G,HL,HS                                                  UPD06290
      DO 900 I=H,IL,IS                                                  UPD06300
      DO 900 J=I,JL,JS                                                  UPD06310
      DO 900 K=J,KL,KS                                                  UPD06320
      DO 900 L=K,LL,LS                                                  UPD06330
      DO 900 M=L,ML,MS                                                  UPD06340
      JT=JT+1                                                           UPD06350
      S(JT)=Y(M)                                                        UPD06360
  900 CONTINUE                                                          UPD06370
C                                                                       UPD06380
C     COPY BACK OUT OF THE SCRATCH ARRAY                                UPD06390
C                                                                       UPD06400
      DO 950 JT=1,NOPTS                                                 UPD06410
      Y(JT)=S(JT)                                                       UPD06420
  950 CONTINUE                                                          UPD06430
      RETURN                                                            UPD06440
      END                                                               UPD06450
      SUBROUTINE FCT ERR                                                UPD06460
C     FACTORING ERROR                                                   UPD06470
C                                                                       UPD06480
C     FACTORING ERROR IN FOUR ID OR SORT ID.                            UPD06490
C                                                                       UPD06500
C     CURRENTLY TAKEN IF A FACTOR ABOVE 13 IS REQUIRED. (THE ARRAYS     UPD06510
C     ARE NOT BIG ENOUGH TO HANDLE THINGS ABOVE 13.)                    UPD06520
C                                                                       UPD06530
      WRITE (6,100)                                                     UPD06540
      CALL EXIT                                                         UPD06550
  100 FORMAT (1X,15HFACTORING ERROR)                                    UPD06560
      RETURN                                                            UPD06570
      END                                                               UPD06580
      SUBROUTINE AR MD FT (N,X,Y,S)                                     UPD06590
C     ARBITRARY RADIX MULTI DIMENSIONAL FOURIER TRANSFORM               UPD06600
C                                                                       UPD06610
C    FIRST SUBSCRIPT VARIES FASTEST IN KEEPING WITH FORTRAN CONVENTIONSUPD06620
C                                                                       UPD06630
      INTEGER N (10)                                                    UPD06640
      REAL X (15000), Y(15000),S(15000)                                 UPD06650
C                                                                       UPD06660
      CALL GR MD FT (N,X,Y)                                             UPD06670
      CALL GR MD FS (N,X,S)                                             UPD06680
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      CALL GR MD FS (N,Y,S)                                                 UPD06690
      RETURN                                                                UPD06700
      END                                                                   UPD06710
      SUBROUTINE GR MD FT (N,X,Y)                                           UPD06720
C     GENERAL RADIX MULTI DIMENSIONAL FOURIER TRANSFORM                     UPD06730
C                                                                           UPD06740
      INTEGER N(10)                                                         UPD06750
      REAL X(15000),Y(15000)                                                UPD06760
C                                                                           UPD06770
      INTEGER DIMEN,J,JJ,J0,J1,J2,J3,J4,K,M,MR,P,PMAX,PROD,S0,U,V           UPD06780
      REAL ARG,A1,A2,A3,A4,B1,B2,B3,B4,C1,C2,C3,C10,C11,C12,C13,C14,        UPD06790
     1C20,C21,C22,C23,C24,C30,C31,C32,C33,C34,C40,C41,C42,C43,C44,I0,I1,UPD06800
     2I2,I3,I4,R0,R1,R2,R3,R4,S1,S2,S3,S10,S11,S12,S13,S14,S20,S21,         UPD06810
     3S22,S23,S24,S30,S31,S32,S33,S34,S40,S41,S42,S43,S44,TWOPI,XT,YT      UPD06820
C                                                                           UPD06830
      REAL A (19), B(19), C(19,19), I(19),R(19),S(19,19)                    UPD06840
C                                                                           UPD06850
      PMAX=19                                                               UPD06860
C                                                                           UPD06870
      TWOPI=6.283185307                                                     UPD06880
      DIMEN=1                                                               UPD06890
      PROD=1                                                                UPD06900
  100 CONTINUE                                                              UPD06910
      PROD=PROD*N(DIMEN)                                                    UPD06920
      DIMEN=DIMEN+1                                                         UPD06930
      IF (N(DIMEN) .GT. 0) GO TO 100                                        UPD06940
      DIMEN=DIMEN-1                                                         UPD06950
      S0=PROD                                                               UPD06960
      M=PROD                                                                UPD06970
  200 CONTINUE                                                              UPD06980
      S0=S0/N(DIMEN)                                                        UPD06990
      DIMEN=DIMEN-1                                                         UPD07000
  300 CONTINUE                                                              UPD07010
      IF (M/S0 .NE. M/S0/4*4) GO TO 600                                     UPD07020
      MR=M                                                                  UPD07030
      M=M/4                                                                 UPD07040
      DO 500 J=1,M                                                          UPD07050
      ARG=TWOPI*FLOAT((J-1)/S0)/FLOAT(MR/S0)                                UPD07060
      C1=COS(ARG)                                                           UPD07070
      S1=SIN(ARG)                                                           UPD07080
      C2=COS(2.0*ARG)                                                       UPD07090
      S2=SIN(2.0*ARG)                                                       UPD07100
      C3=COS(3.0*ARG)                                                       UPD07110
      S3=SIN(3.0*ARG)                                                       UPD07120
      DO 400 K=MR,PROD,MR                                                   UPD07130
      J0=J+K-MR                                                             UPD07140
      J1=J0+M                                                               UPD07150
      J2=J1+M                                                               UPD07160
      J3=J2+M                                                               UPD07170
      R0=X(J0)+X(J2)                                                        UPD07180
      R1=X(J0)-X(J2)                                                        UPD07190
      I0=Y(J0)+Y(J2)                                                        UPD07200
      I1=Y(J0)-Y(J2)                                                        UPD07210
      R2=X(J1)+X(J3)                                                        UPD07220
      R3=X(J1)-X(J3)                                                        UPD07230
      I2=Y(J1)+Y(J3)                                                        UPD07240
      I3=Y(J1)-Y(J3)                                                        UPD07250
      X(J0)=R0+R2                                                           UPD07260
      Y(J0)=I0+I2                                                           UPD07270
      X(J2)=(R1+I3)*C1+(I1-R3)*S1                                           UPD07280
      Y(J2)=(I1-R3)*C1-(R1+I3)*S1                                           UPD07290
      X(J1)=(R0-R2)*C2+(I0-I2)*S2                                           UPD07300
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      Y(J1)=(I0-I2)*C2-(R0-R2)*S2                                       UPD07310
      X(J3)=(R1-I3)*C3+(I1+R3)*S3                                       UPD07320
      Y(J3)=(I1+R3)*C3-(R1-I3)*S3                                       UPD07330
  400 CONTINUE                                                          UPD07340
  500 CONTINUE                                                          UPD07350
      GO TO 300                                                         UPD07360
  600 CONTINUE                                                          UPD07370
      IF (M/S0 .NE. M/S0/2*2) GO TO 900                                 UPD07380
      MR=M                                                              UPD07390
      M=M/2                                                             UPD07400
      DO 800 J=1,M                                                      UPD07410
      ARG=TWOPI*FLOAT((J-1)/S0)/FLOAT(MR/S0)                            UPD07420
      C1=COS(ARG)                                                       UPD07430
      S1=SIN(ARG)                                                       UPD07440
      DO 700 K=MR,PROD,MR                                               UPD07450
      J0=J+K-MR                                                         UPD07460
      J1=J0+M                                                           UPD07470
      R0=X(J0)+X(J1)                                                    UPD07480
      R1=X(J0)-X(J1)                                                    UPD07490
      I0=Y(J0)+Y(J1)                                                    UPD07500
      I1=Y(J0)-Y(J1)                                                    UPD07510
      X(J0)=R0                                                          UPD07520
      Y(J0)=I0                                                          UPD07530
      X(J1)=R1*C1+I1*S1                                                 UPD07540
      Y(J1)=I1*C1-R1*S1                                                 UPD07550
  700 CONTINUE                                                          UPD07560
  800 CONTINUE                                                          UPD07570
      GO TO 600                                                         UPD07580
  900 CONTINUE                                                          UPD07590
      IF (M/S0 .NE. M/S0/3*3) GO TO 1200                                UPD07600
      MR=M                                                              UPD07610
      M=M/3                                                             UPD07620
      A1=COS(TWOPI/3.0)                                                 UPD07630
      B1=SIN(TWOPI/3.0)                                                 UPD07640
      A2=COS(2.0*TWOPI/3.0)                                             UPD07650
      B2=SIN(2.0*TWOPI/3.0)                                             UPD07660
      DO 1100 J=1,M                                                     UPD07670
      ARG=TWOPI*FLOAT((J-1)/S0)/FLOAT(MR/S0)                            UPD07680
      C10=COS(ARG)                                                      UPD07690
      S10=SIN(ARG)                                                      UPD07700
      C11=C10*A1-S10*B1                                                 UPD07710
      S11=C10*B1+S10*A1                                                 UPD07720
      C12=C10*A2-S10*B2                                                 UPD07730
      S12=C10*B2+S10*A2                                                 UPD07740
      C20=COS(2.0*ARG)                                                  UPD07750
      S20=SIN(2.0*ARG)                                                  UPD07760
      C21=C20*A2-S20*B2                                                 UPD07770
      S21=C20*B2+S20*A2                                                 UPD07780
      C22=C20*A1-S20*B1                                                 UPD07790
      S22=C20*B1+S20*A1                                                 UPD07800
      DO 1000 K=MR,PROD,MR                                              UPD07810
      J0=J+K-MR                                                         UPD07820
      J1=J0+M                                                           UPD07830
      J2=J1+M                                                           UPD07840
      R0=X(J0)                                                          UPD07850
      I0=Y(J0)                                                          UPD07860
      R1=X(J1)                                                          UPD07870
      I1=Y(J1)                                                          UPD07880
      R2=X(J2)                                                          UPD07890
      I2=Y(J2)                                                          UPD07900
      X(J0)=R0+R1+R2                                                    UPD07910
      Y(J0)=I0+I1+I2                                                    UPD07920
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      X(J1)=R0*C10+I0*S10+R1*C11+I1*S11+R2*C12+I2*S12                    UPD07930
      Y(J1)=I0*C10-R0*S10+I1*C11-R1*S11+I2*C12-R2*S12                    UPD07940
      X(J2)=R0*C20+I0*S20+R1*C21+I1*S21+R2*C22+I2*S22                    UPD07950
      Y(J2)=I0*C20-R0*S20+I1*C21-R1*S21+I2*C22-R2*S22                    UPD07960
 1000 CONTINUE                                                           UPD07970
 1100 CONTINUE                                                           UPD07980
      GO TO 900                                                          UPD07990
 1200 CONTINUE                                                           UPD08000
      IF (M/S0 .NE. M/S0/5*5) GO TO 1500                                 UPD08010
      MR=M                                                               UPD08020
      M=M/5                                                              UPD08030
      A1=COS(TWOPI/5.0)                                                  UPD08040
      B1=SIN(TWOPI/5.0)                                                  UPD08050
      A2=COS(2.0*TWOPI/5.0)                                              UPD08060
      B2=SIN(2.0*TWOPI/5.0)                                              UPD08070
      A3=COS(3.0*TWOPI/5.0)                                              UPD08080
      B3=SIN(3.0*TWOPI/5.0)                                              UPD08090
      A4=COS(4.0*TWOPI/5.0)                                              UPD08100
      B4=SIN(4.0*TWOPI/5.0)                                              UPD08110
      DO 1400 J=1,M                                                      UPD08120
      ARG=TWOPI*FLOAT((J-1)/S0)/FLOAT(MR/S0)                             UPD08130
      C10=COS(ARG)                                                       UPD08140
      S10=SIN(ARG)                                                       UPD08150
      C11=C10*A1-S10*B1                                                  UPD08160
      S11=C10*B1+S10*A1                                                  UPD08170
      C12=C10*A2-S10*B2                                                  UPD08180
      S12=C10*B2+S10*A2                                                  UPD08190
      C13=C10*A3-S10*B3                                                  UPD08200
      S13=C10*B3+S10*A3                                                  UPD08210
      C14=C10*A4-S10*B4                                                  UPD08220
      S14=C10*B4+S10*A4                                                  UPD08230
      C20=COS(2.0*ARG)                                                   UPD08240
      S20=SIN(2.0*ARG)                                                   UPD08250
      C21=C20*A2-S20*B2                                                  UPD08260
      S21=C20*B2+S20*A2                                                  UPD08270
      C22=C20*A4-S20*B4                                                  UPD08280
      S22=C20*B4+S20*A4                                                  UPD08290
      C23=C20*A1-S20*B1                                                  UPD08300
      S23=C20*B1+S20*A1                                                  UPD08310
      C24=C20*A3-S20*B3                                                  UPD08320
      S24=C20*B3+S20*A3                                                  UPD08330
      C30=COS(3.0*ARG)                                                   UPD08340
      S30=SIN(3.0*ARG)                                                   UPD08350
      C31=C30*A3-S30*B3                                                  UPD08360
      S31=C30*B3+S30*A3                                                  UPD08370
      C32=C30*A1-S30*B1                                                  UPD08380
      S32=C30*B1+S30*A1                                                  UPD08390
      C33=C30*A4-S30*B4                                                  UPD08400
      S33=C30*B4+S30*A4                                                  UPD08410
      C34=C30*A2-S30*B2                                                  UPD08420
      S34=C30*B2+S30*A2                                                  UPD08430
      C40=COS(4.0*ARG)                                                   UPD08440
      S40=SIN(4.0*ARG)                                                   UPD08450
      C41=C40*A4-S40*B4                                                  UPD08460
      S41=C40*B4+S40*A4                                                  UPD08470
      C42=C40*A3-S40*B3                                                  UPD08480
      S42=C40*B3+S40*A3                                                  UPD08490
      C43=C40*A2-S40*B2                                                  UPD08500
      S43=C40*B2+S40*A2                                                  UPD08510
      C44=C40*A1-S40*B1                                                  UPD08520
      S44=C40*B1+S40*A1                                                  UPD08530
      DO 1300 K=MR,PROD,MR                                               UPD08540
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      J0=J+K-MR                                                          UPD08550
      J1=J0+M                                                            UPD08560
      J2=J1+M                                                            UPD08570
      J3=J2+M                                                            UPD08580
      J4=J3+M                                                            UPD08590
      R0=X(J0)                                                           UPD08600
      I0=Y(J0)                                                           UPD08610
      R1=X(J1)                                                           UPD08620
      I1=Y(J1)                                                           UPD08630
      R2=X(J2)                                                           UPD08640
      I2=Y(J2)                                                           UPD08650
      R3=X(J3)                                                           UPD08660
      I3=Y(J3)                                                           UPD08670
      R4=X(J4)                                                           UPD08680
      I4=Y(J4)                                                           UPD08690
      X(J0)=R0+R1+R2+R3+R4                                               UPD08700
      Y(J0)=I0+I1+I2+I3+I4                                               UPD08710
      X(J1)=R0*C10+I0*S10+R1*C11+I1*S11+R2*C12+I2*S12+R3*C13+I3*S13+     UPD08720
     1R4*C14+I4*S14                                                      UPD08730
      Y(J1)=I0*C10-R0*S10+I1*C11-R1*S11+I2*C12-R2*S12+I3*C13-R3*S13+     UPD08740
     1I4*C14-R4*S14                                                      UPD08750
      X(J2)=R0*C20+I0*S20+R1*C21+I1*S21+R2*C22+I2*S22+R3*C23+I3*S23+     UPD08760
     1R4*C24+I4*S24                                                      UPD08770
      Y(J2)=I0*C20-R0*S20+I1*C21-R1*S21+I2*C22-R2*S22+I3*C23-R3*S23+     UPD08780
     1I4*C24-R4*S24                                                      UPD08790
      X(J3)=R0*C30+I0*S30+R1*C31+I1*S31+R2*C32+I2*S32+R3*C33+I3*S33+     UPD08800
     1R4*C34+I4*S34                                                      UPD08810
      Y(J3)=I0*C30-R0*S30+I1*C31-R1*S31+I2*C32-R2*S32+I3*C33-R3*S33+     UPD08820
     1I4*C34-R4*S34                                                      UPD08830
      X(J4)=R0*C40+I0*S40+R1*C41+I1*S41+R2*C42+I2*S42+R3*C43+I3*S43+     UPD08840
     1R4*C44+I4*S44                                                      UPD08850
      Y(J4)=I0*C40-R0*S40+I1*C41-R1*S41+I2*C42-R2*S42+I3*C43-R3*S43+     UPD08860
     1I4*C44-R4*S44                                                      UPD08870
1300  CONTINUE                                                          UPD08880
1400  CONTINUE                                                          UPD08890
      GO TO 1200                                                        UPD08900
1500  CONTINUE                                                          UPD08910
      IF (M .LE.S0) GO TO 2600                                          UPD08920
      DO 1600 J=2,PMAX                                                  UPD08930
      P=J                                                               UPD08940
      IF (M/S0 .EQ. M/S0/P*P) GO TO 1700                                UPD08950
1600  CONTINUE                                                          UPD08960
      GO TO 2800                                                        UPD08970
1700  CONTINUE                                                          UPD08980
      MR=M                                                              UPD08990
      M=M/P                                                             UPD09000
      DO 1800 U=1,P                                                     UPD09010
      ARG=TWOPI*FLOAT(U-1)/FLOAT(P)                                     UPD09020
      A(U)=COS(ARG)                                                     UPD09030
      B(U)=SIN(ARG)                                                     UPD09040
1800  CONTINUE                                                          UPD09050
      DO 2500 J=1,M                                                     UPD09060
      ARG=TWOPI*FLOAT((J-1)/S0)/FLOAT(MR/S0)                            UPD09070
      DO 2000 U=1,P                                                     UPD09080
      C(U,1)=COS(FLOAT(U-1)*ARG)                                        UPD09090
      S(U,1)=SIN(FLOAT(U-1)*ARG)                                        UPD09100
      DO 1900 V=2,P                                                     UPD09110
      JJ=(U-1)*(V-1)-(U-1)*(V-1)/P*P+1                                  UPD09120
      C(U,V)=C(U,1)*A(JJ)-S(U,1)*B(JJ)                                  UPD09130
      S(U,V)=C(U,1)*B(JJ)+S(U,1)*A(JJ)                                  UPD09140
1900  CONTINUE                                                          UPD09150
2000  CONTINUE                                                          UPD09160
```

```
      DO 2400 K=MR,PROD,MR                                              UPD09170
      DO 2100 U=1,P                                                     UPD09180
      JJ=J+K-MR+(U-1)*M                                                 UPD09190
      R(U)=X(JJ)                                                        UPD09200
      I(U)=Y(JJ)                                                        UPD09210
 2100 CONTINUE                                                          UPD09220
      DO 2300 U=1,P                                                     UPD09230
      XT=0.0                                                            UPD09240
      YT=0.0                                                            UPD09250
      DO 2200 V=1,P                                                     UPD09260
      XT=XT+R(V)*C(U,V)+I(V)*S(U,V)                                     UPD09270
      YT=YT+I(V)*C(U,V)-R(V)*S(U,V)                                     UPD09280
 2200 CONTINUE                                                          UPD09290
      JJ=J+K-MR+(U-1)*M                                                 UPD09300
      X(JJ)=XT                                                          UPD09310
      Y(JJ)=YT                                                          UPD09320
 2300 CONTINUE                                                          UPD09330
 2400 CONTINUE                                                          UPD09340
 2500 CONTINUE                                                          UPD09350
      GO TO 1500                                                        UPD09360
 2600 CONTINUE                                                          UPD09370
      IF (DIMEN .GT. 0) GO TO 200                                       UPD09380
 2700 CONTINUE                                                          UPD09390
      RETURN                                                            UPD09400
 2800 CONTINUE                                                          UPD09410
      DIMEN=DIMEN+1                                                     UPD09420
      WRITE (6,2900) DIMEN,N(DIMEN)                                     UPD09430
      GO TO 2700                                                        UPD09440
 2900 FORMAT (1X,28HFACTORING ERROR IN DIMENSION,I2,10H.  N(DIM)=,I5)   UPD09450
      END                                                               UPD09460
      SUBROUTINE GR MD FS (PTS,X,T)                                     UPD09470
C     GENERAL RADIX MULTI DIMENSIONAL FOURIER SORT                      UPD09480
C                                                                       UPD09490
      INTEGER PTS(10)                                                   UPD09500
      REAL X(15000),T(15000)                                            UPD09510
C                                                                       UPD09520
      INTEGER DIMEN,DO,II,JJ,P,PMAX,S0,S(19),U(19)                      UPD09530
      INTEGERA,B,C,D,E,F,G,H,I,J,K,L,M,N,O,Q,R,V,W,AL,BL,CL,DL,EL,FL,   UPD09540
     1GL,HL,IL,JL,KL,LL,ML,NL,OL,QL,RL,VL,WL,AS,BS,CS,DS,ES,FS,GS,HS,IS UPD09550
     2,JS,KS,LS,MS,NS,OS,QS,RS,VS,WS                                   UPD09560
      EQUIVALENCE (AS,S(1)),(BS,S(2)),(CS,S(3)),(DS,S(4)),(ES,S(5)),    UPD09570
     1(FS,S(6)),(GS,S(7)),(HS,S(8)),(IS,S(9)),(JS,S(10)),(KS,S(11)),    UPD09580
     2(LS,S(12)),(MS,S(13)),(NS,S(14)),(OS,S(15)),(QS,S(16)),           UPD09590
     3(RS,S(17)),(VS,S(18)),(WS,S(19)),(AL,U(1)),(BL,U(2)),(CL,U(3)),   UPD09600
     4(DL,U(4)),(EL,U(5)),(FL,U(6)),(GL,U(7)),(HL,U(8)),(IL,U(9)),      UPD09610
     5(JL,U(10)),(KL,U(11)),(LL,U(12)),(ML,U(13)),(NL,U(14)),(OL,U(15)UPD09620
     6),(QL,U(16)),(RL,U(17)),(VL,U(18)),(WL,U(19))                     UPD09630
C                                                                       UPD09640
      PMAX=19                                                           UPD09650
C                                                                       UPD09660
      DO=19                                                             UPD09670
      DIMEN=1                                                           UPD09680
      S0=1                                                              UPD09690
  100 CONTINUE                                                          UPD09700
      M=PTS(DIMEN)                                                      UPD09710
  200 CONTINUE                                                          UPD09720
      IF (M .LE. 1) GO TO 500                                           UPD09730
      DO 300 J=2,PMAX                                                   UPD09740
      P=J                                                               UPD09750
      IF (M .EQ. M/P*P) GO TO 400                                       UPD09760
  300 CONTINUE                                                          UPD09770
      GO TO 1100                                                        UPD09780
```

```
 400 CONTINUE                                                          UPD09790
     U(DO)=M*S0                                                        UPD09800
     S(DO)=M/P*S0                                                      UPD09810
     M=M/P                                                             UPD09820
     DO=DO-1                                                           UPD09830
     GO TO 200                                                         UPD09840
 500 CONTINUE                                                          UPD09850
     S0=S0*PTS(DIMEN)                                                  UPD09860
     DIMEN=DIMEN+1                                                     UPD09870
     IF (PTS(DIMEN) .GT. 0) GO TO 100                                  UPD09880
     IF (DO .LE. 0) GO TO 700                                          UPD09890
     DO 600 J=1,DO                                                     UPD09900
     U(J)=1                                                            UPD09910
     S(J)=1                                                            UPD09920
 600 CONTINUE                                                          UPD09930
 700 CONTINUE                                                          UPD09940
     JJ=0                                                              UPD09950
     DO 800 A=1,AL,AS                                                  UPD09960
     DO 800 B=1,BL,BS                                                  UPD09970
     DO 800 C=1,CL,CS                                                  UPD09980
     DO 800 D=1,DL,DS                                                  UPD09990
     DO 800 E=1,EL,ES                                                  UPD10000
     DO 800 F=1,FL,FS                                                  UPD10010
     DO 800 G=1,GL,GS                                                  UPD10020
     DO 800 H=1,HL,HS                                                  UPD10030
     DO 800 I=1,IL,IS                                                  UPD10040
     DO 800 J=1,JL,JS                                                  UPD10050
     DO 800 K=1,KL,KS                                                  UPD10060
     DO 800 L=1,LL,LS                                                  UPD10070
     DO 800 M=1,ML,MS                                                  UPD10080
     DO 800 N=1,NL,NS                                                  UPD10090
     DO 800 O=1,OL,OS                                                  UPD10100
     DO 800 Q=1,QL,QS                                                  UPD10110
     DO 800 R=1,RL,RS                                                  UPD10120
     DO 800 V=1,VL,VS                                                  UPD10130
     DO 800 W=1,WL,WS                                                  UPD10140
     II=A+B+C+D+E+F+G+H+I+J+K+L+M+N+O+Q+R+V+W-18                        UPD10150
     JJ=JJ+1                                                           UPD10160
     T(JJ)=X(II)                                                       UPD10170
 800 CONTINUE                                                          UPD10180
     DO 900 J=1,S0                                                     UPD10190
     X(J)=T(J)                                                         UPD10200
 900 CONTINUE                                                          UPD10210
1000 CONTINUE                                                          UPD10220
     RETURN                                                            UPD10230
1100 CONTINUE                                                          UPD10240
     WRITE (6,1200) DIMEN,PTS(DIMEN)                                   UPD10250
     GO TO 1000                                                        UPD10260
1200 FORMAT (1X,28HFACTORING ERROR IN DIMENSION,I2,10H.  N(DIM)=,I5)   UPD10270
     END                                                               UPD10280
```

UDD FORTRAN

Written By: Ruddman and Blackley

```
C   THIS PROGRAM FOLLOWS HENDERSONS TECNIQUE FOR UPWARD AND DOWNWARD    UDD00010
C   CONTINUATION AND FIRST AND SECOND DERIVATIVES.  WRITTEN FOR FORTRAN UDD00020
C   77.  OUTPUT MAPS ARE THE SIZE OF INPUT MAPS. UP TO AND MAXIMUM ARRAYUDD00030
C   OF 25 X 25.                                                         UDD00040
C                                                                       UDD00050
C                                                                       UDD00060
C  DIMENSION STATEMENTS FOR DATA UP TO 25 X 25                          UDD00070
C                                                                       UDD00080
      DIMENSION ISET(20),P(75,75), C(11,19), R(26,26,11),HEAD(70)       UDD00090
      COMMON P,C,R                                                      UDD00100
C  READ IN HEADING AND ISELECT(CONTAINS CODES FOR LIST OF MAPS DESIRED  UDD00110
C  CODES ARE IDENTIFIED LATER IN THIS PROGRAM.                          UDD00120
C                                                                       UDD00130
      READ(1,1) (HEAD(I),I=1,70)                                        UDD00140
1     FORMAT (70A1)                                                     UDD00150
      READ(1,*) (ISET(L),L=1,19)                                        UDD00160
C                                                                       UDD00170
C  READ IN MAXIMUM VALUE OF I. I BEGINS AT 26 AND MUST BE 50 OR LESS. SIUDD00180
C  FOR JMAX. READ IN ON SAME CARD THE VALUE (BASE) TO BE SUBRACTED FORM UDD00190
C  VALUES P(I,J).  NEXT READ A SCALE VALUE TO MODIFY DATA TO FIT THE LIMUDD00200
C  SIZE MAP FORMAT OF F4.0.  P(I,J) DATA IS MULTIPLIED BY THIS SCALE FACUDD00210
C                                                                       UDD00220
      READ(1,*) IMAX, JMAX, BASE, YMIN, XMIN, TERV                      UDD00230
      PRINT *, IMAX, JMAX, BASE                                         UDD00240
      READ(1,*) SCALE                                                   UDD00250
C                                                                       UDD00260
C    READ OM P(I,J) DATA. SUBTRACT BASE. MULTIPLY BY SCALE. PRINT HEADINUDD00270
C    AND PLOT ON MAP TYPE OUTPUT.  MAP IS PRINTED FROM P(26,26) TO P(IMAUDD00280
C    IF DATA IS LESS THAN 25 X 25 A BLANK IS PRINTED IN THE SPACES TO FIUDD00290
C    THE MAP.                                                           UDD00300
C                                                                       UDD00310
      READ(1,1111) ((P(I,J), I=26,IMAX), J=26,JMAX)                     UDD00320
C111  FORMAT(12X,F8.2)                                                  UDD00330
1111  FORMAT(F8.6)                                                      UDD00340
C                                                                       UDD00350
C                                                                       UDD00360
      DO 6 J=26,JMAX                                                    UDD00370
      DO 5 I=26,IMAX                                                    UDD00380
5     P(I,J)=(P(I,J)-BASE)*SCALE                                        UDD00390
6     CONTINUE                                                          UDD00400
C                                                                       UDD00410
      WRITE(2,7)                                                        UDD00420
7       FORMAT(1H1)                                                     UDD00430
C                                                                       UDD00440
      WRITE(2,101) (HEAD(I),I=1,70)                                     UDD00450
101     FORMAT(20X,70A1,/)                                              UDD00460
C                                                                       UDD00470
      WRITE(2,8) BASE, SCALE                                            UDD00480
8     FORMAT(20X,'INPUT DATA LESS BASE OF ',F6.2,3X,'MULTIPLIED BY SCAUDD00490
     +LE OF',F5.2,/)                                                    UDD00500
C                                                                       UDD00510
      DO 9 J=26,JMAX                                                    UDD00520
       WRITE(2,222)                                                     UDD00530
222     FORMAT(4X,24(1H*,4X),1H*)                                       UDD00540
       WRITE(2,10) (P(I,J),I=26,IMAX)                                   UDD00550
10      FORMAT(2X,25(F4.0,1X),/)                                        UDD00560
C                                                                       UDD00570
```

```
          IF (IMAX.LT.50) THEN                                          UDD00580
             WRITE(2,601)                                               UDD00590
601           FORMAT(1H1)                                               UDD00600
          END IF                                                        UDD00610
9       CONTINUE                                                        UDD00620
C                                                                       UDD00630
          IF (JMAX.LT.50) THEN                                          UDD00640
             LMAX=50-JMAX                                               UDD00650
              DO 603 LL=1,LMAX                                          UDD00660
603              WRITE(2,604)                                           UDD00670
604                FORMAT(4X,24(1H*,4X),1H*,//)                         UDD00680
          END IF                                                        UDD00690
C                                                                       UDD00700
C      NEXT SECTION PREPARES REGIONS BEYOND EDGE OF MAP TO BE USED IN ANUDD00710
C      APPROACH IS TO FILL THE SURROUNDING SPACE BY EXTENDING EACH EDGE UDD00720
C       NORMAL TO THE MAP FOR 25 UNITS.                                 UDD00730
C                                                                       UDD00740
        IMAX1=IMAX + 1                                                  UDD00750
        IMAX25= IMAX +25                                                UDD00760
        JMAX1= JMAX + 1                                                 UDD00770
        JMAX25= JMAX + 25                                               UDD00780
C                                                                       UDD00790
          DO 14 J=26,JMAX                                               UDD00800
          DO 15 I=1,25                                                  UDD00810
15         P(I,J)=P(26,J)                                               UDD00820
            DO 16 I=IMAX1,IMAX25                                        UDD00830
16           P(I,J)=P(IMAX,J)                                           UDD00840
14       CONTINUE                                                       UDD00850
C                                                                       UDD00860
         DO 17 I=26,IMAX                                                UDD00870
         DO 18 J=1,25                                                   UDD00880
18        P(I,J)=P(I,26)                                                UDD00890
           DO 19 J=JMAX1,JMAX25                                         UDD00900
19       P(I,J)=P(I,JMAX)                                               UDD00910
17       CONTINUE                                                       UDD00920
C                                                                       UDD00930
C                                                                       UDD00940
         DO 20 I=1,25                                                   UDD00950
         DO 21 J=1,25                                                   UDD00960
21        P(I,J)=P(26,26)                                               UDD00970
20       CONTINUE                                                       UDD00980
C                                                                       UDD00990
C                                                                       UDD01000
         DO 22 I=IMAX1, IMAX25                                          UDD01010
         DO 23 J=1,25                                                   UDD01020
23        P(I,J)=P(IMAX,26)                                             UDD01030
22       CONTINUE                                                       UDD01040
C                                                                       UDD01050
C                                                                       UDD01060
         DO 24 I=1,25                                                   UDD01070
         DO 25 J=JMAX1,JMAX25                                           UDD01080
25        P(I,J)=P(26,JMAX)                                             UDD01090
24       CONTINUE                                                       UDD01100
C                                                                       UDD01110
C                                                                       UDD01120
         DO 26 I=IMAX1,IMAX25                                           UDD01130
         DO 27 J=JMAX1,JMAX25                                           UDD01140
27        P(I,J)=P(IMAX,JMAX)                                           UDD01150
26       CONTINUE                                                       UDD01160
C                                                                       UDD01170
C  CALCULATION OF AVERAGE VALUE OF DATA ON RINGS CENTERED AT EACH MAP POUDD01180
C  CALL THESE R(I,J,K), WHERE K=1 TO 11.                                UDD01190
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C                                                                       UDD01200
        M=0                                                             UDD01210
        DO 28 I=26,IMAX                                                 UDD01220
         M=M+1                                                          UDD01230
         N=0                                                            UDD01240
        DO 29 J=26,JMAX                                                 UDD01250
        N=N+1                                                           UDD01260
C                                                                       UDD01270
        R(M,N,1)=P(I,J)                                                 UDD01280
C                                                                       UDD01290
        R(M,N,2)=(P(I,J+1)+P(I,J-1)+P(I+1,J)+P(I-1,J))/4.0              UDD01300
C                                                                       UDD01310
        R(M,N,3)=(P(I+1,J+1)+P(I+1,J-1)+P(I-1,J+1)+P(I-1,J-1))/4.0      UDD01320
C                                                                       UDD01330
        R(M,N,4)=(P(I+2,J+1)+P(I+2,J-1)+P(I-2,J+1)+P(I-2,J-1)+          UDD01340
     *P(I+1,J+2)+P(I+1,J-2)+P(I-1,J+2)+P(I-1,J-2))/8.0                  UDD01350
       IF(I.EQ.26.AND.J.EQ.26) THEN                                     UDD01360
       PRINT *, P(I+2,J+1),P(I+2,J-1),P(I-2,J+1),P(I-2,J-1),P(I+1,J+2)  UDD01370
     *,P(I+1,J+2),P(I-1,J+2),P(I-1,J-2),R(M,N,4)                        UDD01380
       END IF                                                           UDD01390
C                                                                       UDD01400
        R(M,N,5)=(P(I+2,J+2)+P(I+2,J-2)+P(I-2,J+2)+P(I-2,J-2))/4.0      UDD01410
C                                                                       UDD01420
        R(M,N,6)=(P(I+2,J+3)+P(I+2,J-3)+P(I-2,J+3)+P(I-2,J-3)+          UDD01430
     *P(I+3,J+2)+P(I+3,J-2)+P(I-3,J+2)+P(I-3,J-2))/8.                   UDD01440
C                                                                       UDD01450
        R(M,N,7)=(P(I+5,J)+P(I-5,J)+P(I,J+5)+P(I,J-5)+P(I+3,J+4)        UDD01460
     *+ P(I+3,J-4)+P(I+4,J+3)+P(I+4,J-3)+P(I-4,J+3)+P(I-4,J-3)+         UDD01470
     *P(I-3,J+4)+P(I-3,J-4))/12.                                        UDD01480
C                                                                       UDD01490
        R(M,N,8)=(P(I+7,J+1)+P(I+1,J+7)+P(I+7,J-1)+P(I+1,J-7)+          UDD01500
     *P(I-7,J+1)+P(I-1,J+7)+P(I-7,J-1)+P(I-1,J-7)+P(I+5,J+5)+          UDD01510
     *P(I+5,J-5)+P(I-5,J+5)+P(I-5,J-5))/12.                             UDD01520
C                                                                       UDD01530
        R(M,N,9)=(P(I+10,J+6)+P(I+10,J-6)+P(I+6,J+10)+P(I+6,J-10)       UDD01540
     *+P(I-10,J+6)+P(I-10,J-6)+P(I-6,J+10)+P(I-6,J-10))/8.              UDD01550
C                                                                       UDD01560
        R(M,N,10)=(P(I+7,J+15)+P(I+15,J+7)+P(I-7,J+15)+P(I-15,J+7)      UDD01570
     *+P(I+7,J-15)+P(I+15,J-7)+P(I-7,J-15)+P(I-15,J-7))/8.              UDD01580
C                                                                       UDD01590
        R(M,N,11)=(P(I,J+25)+P(I,J-25)+P(I-20,J+15)+P(I-15,J+20)        UDD01600
     *+P(I-20,J-15)+P(I-15,J-20)+P(I+20,J+15)+P(I+15,J+20)+             UDD01610
     *P(I+20,J-15)+P(I+15,J-20)+P(I+25,J)+P(I-25,J))/12.                UDD01620
C                                                                       UDD01630
29      CONTINUE                                                        UDD01640
28      CONTINUE                                                        UDD01650
C                                                                       UDD01660
C   FOR EACH MAP THERE IS A SET OF COEFFICIENTS       C(K,L), WHERE  K UDD01670
C   RING NUMBER AND L IS THE CODED INTGER FOR THE DESIRED MAP. CODES AREUDD01680
C   'ONE' IF THE MAP IS DESIRED, OR 'ZERO' IF IT IS NOT.  CODES ARE EN- UDD01690
C   TERED ON THE ISELECT INPUT FROM COLUMNS 1 TO 19.  THE FOLLOWING LISTUDD01700
C   GIVES THE CODES.  THUS, A 'ONE' IN COLUMN 1 REQUESTS A MAP CONTINUEDUDD01710
C   UPWARD ONE GRID UNIT.  A 'ZERO' IN COULMNS W WILL SUPPRESS THE MAP  UDD01720
C   THAT IS CONTINUED UPWARD 2 GRID UNITS, ETC.                         UDD01730
C                                                                       UDD01740
C                                                                       UDD01750
C   COEFFICENTS FOR UPWARD CONTINUATION 1. CODE L=1.                    UDD01760
C                                                                       UDD01770
       C(1,1)=.11193                                                    UDD01780
       C(2,1)=.32193                                                    UDD01790
       C(3,1)=.06062                                                    UDD01800
       C(4,1)=.15206                                                    UDD01810
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      C(5,1)=.05335                                                    UDD01820
      C(6,1)=.06586                                                    UDD01830
      C(7,1)=.06650                                                    UDD01840
      C(8,1)=.05635                                                    UDD01850
      C(9,1)=.03855                                                    UDD01860
      C(10,1)=.02273                                                   UDD01870
      C(11,1)=.03015                                                   UDD01880
C                                                                      UDD01890
C                                                                      UDD01900
C  COEFFICENTS FOR UPWARD CONTINUATION 2, CODE L=2                     UDD01910
C                                                                      UDD01920
      C(1,2)=.04034                                                    UDD01930
      C(2,2)=.12988                                                    UDD01940
      C(3,2)=.07588                                                    UDD01950
      C(4,2)=.14559                                                    UDD01960
      C(5,2)=.07651                                                    UDD01970
      C(6,2)=.09902                                                    UDD01980
      C(7,2)=.11100                                                    UDD01990
      C(8,2)=.13051                                                    UDD02000
      C(9,2)=.07379                                                    UDD02010
      C(10,2)=.04464                                                   UDD02020
      C(11,2)=.05998                                                   UDD02030
C                                                                      UDD02040
C COEFFICENTS FOR UPWARD CONTINUATION 3. CODE L=3                      UDD02050
C                                                                      UDD02060
      C(1,3)=.01961                                                    UDD02070
      C(2,3)=.06592                                                    UDD02080
      C(3,3)=.05260                                                    UDD02090
      C(4,3)=.10563                                                    UDD02100
      C(5,3)=.07146                                                    UDD02110
      C(6,3)=.10226                                                    UDD02120
      C(7,3)=.12921                                                    UDD02130
      C(8,3)=.13635                                                    UDD02140
      C(9,3)=.10322                                                    UDD02150
      C(10,3)=.06500                                                   UDD02160
      C(11,3)=.08917                                                   UDD02170
C                                                                      UDD02180
C COEFFICIENTS FOR UPWARD CONTINUATION 4. CODE L=4                     UDD02190
C                                                                      UDD02200
      C(1,4)=.01141                                                    UDD02210
      C(2,4)=.03908                                                    UDD02220
      C(3,4)=.03566                                                    UDD02230
      C(4,4)=.07450                                                    UDD02240
      C(5,4)=.05841                                                    UDD02250
      C(6,4)=.09173                                                    UDD02260
      C(7,4)=.12915                                                    UDD02270
      C(8,4)=.15474                                                    UDD02280
      C(9,4)=.12565                                                    UDD02290
      C(10,4)=.08323                                                   UDD02300
      C(11,4)=.11744                                                   UDD02310
C                                                                      UDD02320
C  COEFFICIENTS FOR UPWARD CONTINUATION 5. CODE L=5                    UDD02330
C                                                                      UDD02340
      C(1,5)=.00742                                                    UDD02350
      C(2,5)=.02566                                                    UDD02360
      C(3,5)=.02509                                                    UDD02370
      C(4,5)=.05377                                                    UDD02380
      C(5,5)=.04611                                                    UDD02390
      C(6,5)=.07784                                                    UDD02400
      C(7,5)=.11986                                                    UDD02410
      C(8,5)=.16159                                                    UDD02420
      C(9,5)=.14106                                                    UDD02430
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      C(10,5)=.09897                                                    UDD02440
      C(11,5)=.14458                                                    UDD02450
C                                                                       UDD02460
C COEFFICIENTS FOR DOWNWARD CONTINUATION 1. CODE L=6                    UDD02470
C                                                                       UDD02480
      C(1,6)=4.8948                                                     UDD02490
      C(2,6)=-3.0113                                                    UDD02500
      C(3,6)=.0081                                                      UDD02510
      C(4,6)=-.5604                                                     UDD02520
      C(5,6)=-.0376                                                     UDD02530
      C(6,6)=-.0689                                                     UDD02540
      C(7,6)=-.0605                                                     UDD02550
      C(8,6)=-.0534                                                     UDD02560
      C(9,6)=-.0380                                                     UDD02570
      C(10,6)=-.0227                                                    UDD02580
      C(11,6)=-.0302                                                    UDD02590
C                                                                       UDD02600
C   COEFFIECIENTS FOR DOWNWARD CONTINUATION 2. CODE L=7                 UDD02610
C                                                                       UDD02620
      C(1,7)=16.1087                                                    UDD02630
      C(2,7)=-13.2209                                                   UDD02640
      C(3,7)=.4027                                                      UDD02650
      C(4,7)=-1.9459                                                    UDD02660
      C(5,7)=.0644                                                      UDD02670
      C(6,7)=-.0596                                                     UDD02680
      C(7,7)=-.0522                                                     UDD02690
      C(8,7)=-.0828                                                     UDD02700
      C(9,7)=-.0703                                                     UDD02710
      C(10,7)=-.0443                                                    UDD02720
      C(11,7)=-.0600                                                    UDD02730
C                                                                       UDD02740
C  COEFFICIENTS FOR DOWNWARD CONTINUATION 3. CODE L=8                   UDD02750
C                                                                       UDD02760
      C(1,8)=41.7731                                                    UDD02770
      C(2,8)=-38.2716                                                   UDD02780
      C(3,8)=1.7883                                                     UDD02790
      C(4,8)=-4.7820                                                    UDD02800
      C(5,8)=.5367                                                      UDD02810
      C(6,8)=.1798                                                      UDD02820
      C(7,8)=.1342                                                      UDD02830
      C(8,8)=-.0560                                                     UDD02840
      C(9,8)=-.0900                                                     UDD02850
      C(10,8)=-.0639                                                    UDD02860
      C(11,8)=-.0891                                                    UDD02870
C                                                                       UDD02880
C COEFFICIENTS FOR DOWNWARD CONTINUATION 4. CODE L=9                    UDD02890
C                                                                       UDD02900
      C(1,9)=92.5362                                                    UDD02910
      C(2,9)=-89.7403                                                   UDD02920
      C(3,9)=5.1388                                                     UDD02930
      C(4,9)=-9.9452                                                    UDD02940
      C(5,9)=1.7478                                                     UDD02950
      C(6,9)=.8908                                                      UDD02960
      C(7,9)=.6656                                                      UDD02970
      C(8,9)=.0718                                                      UDD02980
      C(9,9)=-.0890                                                     UDD02990
      C(10,9)=-.0802                                                    UDD03000
      C(11,9)=-.1173                                                    UDD03010
C                                                                       UDD03020
C COEFFICIENTS FOR DOWNWARD CONTINUATION 5. CODE L=10                   UDD03030
C                                                                       UDD03040
      C(1,10)=183.2600                                                  UDD03050
```

```
      C(2,10)=-183.9380                                                 UDD03060
      C(3,10)=11.8804                                                   UDD03070
      C(4,10)=-18.6049                                                  UDD03080
      C(5,10)=4.2324                                                    UDD03090
      C(6,10)=2.4237                                                    UDD03100
      C(7,10)=1.7777                                                    UDD03110
      C(8,10)=.3606                                                     UDD03120
      C(9,10)=-.0571                                                    UDD03130
      C(10,10)=-.0921                                                   UDD03140
      C(11,10)=-.1444                                                   UDD03150
C                                                                       UDD03160
C COEFFICIENTS FOR FIRST DERIVATIVE ON SURFACE. CODE L=11               UDD03170
C                                                                       UDD03180
      C(1,11)=1.87282                                                   UDD03190
      C(2,11)=-1.13625                                                  UDD03200
      C(3,11)=-.05949                                                   UDD03210
      C(4,11)=-.30210                                                   UDD03220
      C(5,11)=-.05857                                                   UDD03230
      C(6,11)=-.07597                                                   UDD03240
      C(7,11)=-.07072                                                   UDD03250
      C(8,11)=-.05758                                                   UDD03260
      C(9,11)=-.03905                                                   UDD03270
      C(10,11)=-.02286                                                  UDD03280
      C(11,11)=-.05020                                                  UDD03290
C                                                                       UDD03300
C  COEFFICIENTS FOR FIRST DERIVATIVE DOWN 1. CODE L=12                  UDD03310
C                                                                       UDD03320
      C(1,12)=6.62394                                                   UDD03330
      C(2,12)=-5.62446                                                  UDD03340
      C(3,12)=.12727                                                    UDD03350
      C(4,12)=-.88750                                                   UDD03360
      C(5,12)=.00361                                                    UDD03370
      C(6,12)=-.04856                                                   UDD03380
      C(7,12)=-.04007                                                   UDD03390
      C(8,12)=-.04575                                                   UDD03400
      C(9,12)=-.03615                                                   UDD03410
      C(10,12)=-.02233                                                  UDD03420
      C(11,12)=-.05000                                                  UDD03430
C                                                                       UDD03440
C COEFFICIENTS FOR FIRST DERIVATIVE DOWN 2. CODE L=13                   UDD03450
C                                                                       UDD03460
      C(1,13)=16.98074                                                  UDD03470
      C(2,13)=-16.05517                                                 UDD03480
      C(3,13)=.76135                                                    UDD03490
      C(4,13)=-1.98701                                                  UDD03500
      C(5,13)=.23820                                                    UDD03510
      C(6,13)=.09219                                                    UDD03520
      C(7,13)=.07475                                                    UDD03530
      C(8,13)=-.00768                                                   UDD03540
      C(9,13)=-.02726                                                   UDD03550
      C(10,13)=-.02077                                                  UDD03560
      C(11,13)=-.04934                                                  UDD03570
C                                                                       UDD03580
C COEFFICIENT FOR FIRST DERIVATIVE DOWN 3. CODE L=14                    UDD03590
C                                                                       UDD03600
      C(1,14)=36.11116                                                  UDD03610
      C(2,14)=-35.96237                                                 UDD03620
      C(3,14)=2.17080                                                   UDD03630
      C(4,14)=-3.83054                                                  UDD03640
      C(5,14)=.76745                                                    UDD03650
      C(6,14)=.42646                                                    UDD03660
      C(7,14)=.32573                                                    UDD03670
```

```
      C(8,14)=.06859                                                    UDD03680
      C(9,14)=-.01084                                                   UDD03690
      C(10,14)=-.01812                                                  UDD03700
      C(11,14)=-.04832                                                  UDD03710
C                                                                       UDD03720
C COEFFICIENTS FOR FIRST DERIVATIVE DOWN 4. CODE L=15                   UDD03730
C                                                                       UDD03740
      C(1,15)=67.88049                                                  UDD03750
      C(2,15)=-69.68033                                                 UDD03760
      C(3,15)=4.76651                                                   UDD03770
      C(4,15)=-6.69004                                                  UDD03780
      C(5,15)=1.74330                                                   UDD03790
      C(6,15)=1.05352                                                   UDD03800
      C(7,15)=.77613                                                    UDD03810
      C(8,15)=.19699                                                    UDD03820
      C(9,15)=.01469                                                    UDD03830
      C(10,15)=-.01433                                                  UDD03840
      C(11,15)=-.04693                                                  UDD03850
C                                                                       UDD03860
C COEFFICIENT FOR 2ND DERIVATIVE ON THE SURFACE. CODE L=16.             UDD03870
C                                                                       UDD03880
      C(1,16)=2.82994                                                   UDD03890
      C(2,16)=-2.49489                                                  UDD03900
      C(3,16)=.05173                                                    UDD03910
      C(4,16)=-.39446                                                   UDD03920
      C(5,16)=.00932                                                    UDD03930
      C(6,16)=-.00732                                                   UDD03940
      C(7,16)=.00304                                                    UDD03950
      C(8,16)=.00219                                                    UDD03960
      C(9,16)=.00040                                                    UDD03970
      C(10,16)=.00004                                                   UDD03980
      C(11,16)=.00                                                      UDD03990
C                                                                       UDD04000
C   COEFFICIENTS FOR 2ND DERIVATIVE DOWN 1. CODE L=17                   UDD04010
C                                                                       UDD04020
      C(1,17)=7.08408                                                   UDD04030
      C(2,17)=-6.93715                                                  UDD04040
      C(3,17)=.36265                                                    UDD04050
      C(4,17)=-.80764                                                   UDD04060
      C(5,17)=.13050                                                    UDD04070
      C(6,17)=.07231                                                    UDD04080
      C(7,17)=.06502                                                    UDD04090
      C(8,17)=.02312                                                    UDD04100
      C(9,17)=.00565                                                    UDD04110
      C(10,17)=.00103                                                   UDD04120
      C(11,17)=.00043                                                   UDD04130
C                                                                       UDD04140
C COEFFICIENTS FOR 2ND DERIVATIVE DOWN 2. CODE L=18.                    UDD04150
C                                                                       UDD04160
      C(1,18)=14.15751                                                  UDD04170
      C(2,18)=-14.51327                                                 UDD04180
      C(3,18)=.96018                                                    UDD04190
      C(4,18)=-1.42970                                                  UDD04200
      C(5,18)=.35907                                                    UDD04210
      C(6,18)=.22256                                                    UDD04220
      C(7,18)=.17330                                                    UDD04230
      C(8,18)=.05501                                                    UDD04240
      C(9,18)=.01239                                                    UDD04250
      C(10,18)=.0021                                                    UDD04260
      C(11,18)=.00085                                                   UDD04270
C                                                                       UDD04280
C COEFFICIENTS FOR 2ND DERIVATIVE DOWN 3. CODE L=19                     UDD04290
```

```
C                                                                       UDD04300
      C(1,19)=24.74755                                                  UDD04310
      C(2,19)=-26.02351                                                 UDD04320
      C(3,19)=1.92719                                                   UDD04330
      C(4,19)=-2.30269                                                  UDD04340
      C(5,19)=.72474                                                    UDD04350
      C(6,19)=.46253                                                    UDD04360
      C(7,19)=.3392                                                     UDD04370
      C(8,19)=.09985                                                    UDD04380
      C(9,19)=.02070                                                    UDD04390
      C(10,19)=.00322                                                   UDD04400
      C(11,19)=.00122                                                   UDD04410
C                                                                       UDD04420
C  THIS SECTION MAKE THE FINAL CALCULATIONS FOR THOSE MAPS SELECTED BY   UDD04430
C  USER IN HIS ISELECT CODE.                                            UDD04440
C                                                                       UDD04450
      DO 30 L=1,19                                                      UDD04460
       LEVEL=L                                                          UDD04470
        IF (ISET(L)) 30,30,555                                          UDD04480
C                                                                       UDD04490
555    WRITE(2,1113)                                                    UDD04500
1113   FORMAT(////////////////////////////////////)                      UDD04510
C                                                                       UDD04520
       WRITE(2,7)                                                       UDD04530
        WRITE(2,101) (HEAD(I),I=1,70)                                   UDD04540
C                                                                       UDD04550
          IF (L.EQ.1) THEN                                              UDD04560
             WRITE(2,171)                                               UDD04570
          ELSE IF (L.EQ.2) THEN                                         UDD04580
             WRITE(2,172)                                               UDD04590
          ELSE IF (L.EQ.3) THEN                                         UDD04600
             WRITE(2,173)                                               UDD04610
          ELSE IF(L.EQ.4) THEN                                          UDD04620
             WRITE(2,174)                                               UDD04630
          ELSE IF(L.EQ.5) THEN                                          UDD04640
             WRITE(2,175)                                               UDD04650
          ELSE IF(L.EQ.6) THEN                                          UDD04660
             WRITE(2,176)                                               UDD04670
          ELSE IF(L.EQ.7) THEN                                          UDD04680
             WRITE(2,177)                                               UDD04690
          ELSE IF(L.EQ.8) THEN                                          UDD04700
             WRITE(2,178)                                               UDD04710
          ELSE IF(L.EQ.9) THEN                                          UDD04720
             WRITE(2,179)                                               UDD04730
          ELSE IF(L.EQ.10) THEN                                         UDD04740
             WRITE(2,180)                                               UDD04750
          ELSE IF (L.EQ.11) THEN                                        UDD04760
             WRITE(2,181)                                               UDD04770
          ELSE IF(L.EQ.12) THEN                                         UDD04780
             WRITE(2,182)                                               UDD04790
          ELSE IF(L.EQ.13) THEN                                         UDD04800
             WRITE(2,183)                                               UDD04810
          ELSE IF(L.EQ.14) THEN                                         UDD04820
             WRITE(2,184)                                               UDD04830
          ELSE IF(L.EQ.15) THEN                                         UDD04840
             WRITE(2,185)                                               UDD04850
          ELSE IF(L.EQ.16) THEN                                         UDD04860
             WRITE(2,186)                                               UDD04870
          ELSE IF(L.EQ.17) THEN                                         UDD04880
             WRITE(2,187)                                               UDD04890
          ELSE IF(L.EQ.18) THEN                                         UDD04900
             WRITE(2,188)                                               UDD04910
```

```
            ELSE                                                        UDD04920
               WRITE(2,189)                                             UDD04930
            END IF                                                      UDD04940
          DO 33 I=26,IMAX                                               UDD04950
          DO 34 J=26,JMAX                                               UDD04960
           P(I,J)=0.0                                                   UDD04970
          DO 35 K=1,11                                                  UDD04980
C                                                                       UDD04990
           Q1=C(K,L)*R(I-25,J-25,K)                                     UDD05000
35        P(I,J)=P(I,J)+Q1                                              UDD05010
34       CONTINUE                                                       UDD05020
33       CONTINUE                                                       UDD05030
C                                                                       UDD05040
C  NEXT SECTION PRINTS ALL MAPS IN SAME FORMAT AS INPUT MAP.            UDD05050
C                                                                       UDD05060
          DO 36 J=26,JMAX                                               UDD05070
          WRITE(2,223)                                                  UDD05080
223       FORMAT(4X,24(1H*,4X),1H*)                                     UDD05090
          WRITE(2,37) (P(I,J),I=26,IMAX)                                UDD05100
37        FORMAT(2X,25(F4.0,1X),/)                                      UDD05110
          IF (IMAX.LT.50) THEN                                          UDD05120
           WRITE(2,701)                                                 UDD05130
701        FORMAT(1H1)                                                  UDD05140
          END IF                                                        UDD05150
36         CONTINUE                                                     UDD05160
C                                                                       UDD05170
          XMIN1=XMIN                                                    UDD05180
          DO 122 J=26,JMAX                                              UDD05190
            XMIN1=XMIN1+TERV                                            UDD05200
              YMIN1=YMIN                                                UDD05210
          DO 123 I=26,IMAX                                              UDD05220
            YMIN1=YMIN1+TERV                                            UDD05230
              WRITE(3,1112) XMIN1,YMIN1,P(I,J)                          UDD05240
1112    FORMAT(F7.1,1X,F7.1,1X,F8.2)                                    UDD05250
123      CONTINUE                                                       UDD05260
122      CONTINUE                                                       UDD05270
          IF (JMAX.LT.50) THEN                                          UDD05280
            LMAX=50-JMAX                                                UDD05290
             DO 703 LL=1,LMAX                                           UDD05300
703         WRITE(2,704)                                                UDD05310
704         FORMAT(4X,24(1H*,4X),1H*,//)                                UDD05320
          END IF                                                        UDD05330
705       CONTINUE                                                      UDD05340
30        CONTINUE                                                      UDD05350
          STOP                                                          UDD05360
C          WRITE(2,91)                                                  UDD05370
C1         FORMAT(1X,'ERROR, TOO LARGE L VALUE')                        UDD05380
171      FORMAT(20X,'MAP CONTINUED UPWARD 1 GRID UNIT',//)              UDD05390
172      FORMAT(20X,'MAP CONTINUED UPWARD 2 GRID UNIT',//)              UDD05400
173      FORMAT(20X,'MAP CONTINUED UPWARD 3 GRID UNIT',//)              UDD05410
174      FORMAT(20X,'MAP CONTINUED UPWARD 4 GRID UNIT',//)              UDD05420
175      FORMAT(20X,'MAP CONTINUED UPWARD 5 GRID UNIT',//)              UDD05430
176      FORMAT(20X,'MAP CONTINUED DOWNWARD 1 GRID UNIT',//)            UDD05440
177      FORMAT(20X,'MAP CONTINUED DOWNWARD 2 GRID UNIT',//)            UDD05450
178      FORMAT(20X,'MAP CONTINUED DOWNWARD 3 GRID UNIT',//)            UDD05460
179      FORMAT(20X,'MAP CONTINUED DOWNWARD 4 GRID UNIT',//)            UDD05470
180      FORMAT(20X,'MAP CONTINUED DOWNWARD 5 GRID UNIT',//)            UDD05480
181      FORMAT(20X,'MAP OF FIRST DERIVATIVE ON SURFACE',//)            UDD05490
182      FORMAT(20X,'MAP OF FIRST DERIVATIVE DOWN 1 GRID UNIT',//)      UDD05500
183      FORMAT(20X,'MAP OF FIRST DERIVATIVE DOWN 2 GRID UNIT',//)      UDD05510
184      FORMAT(20X,'MAP OF FIRST DERIVATIVE DOWN 3 GRID UNIT',//)      UDD05520
185      FORMAT(20X,'MAP OF FIRST DERIVATIVE DOWN 4 GRID UNIT',//)      UDD05530
```

```
186    FORMAT(20X,'MAP OF SECOND DERIVATIVE ON SURFACE',//)          UDD05540
187    FORMAT(20X,'MAP OF SECOND DERIVATIVE DOWN 1 GRID UNIT',//)    UDD05550
188    FORMAT(20X,'MAP OF SECOND DERIVATIVE DOWN 2 GRID UNIT',//)    UDD05560
189    FORMAT(20X,'MAP OF SECOND DERIVATIVE DOWN 3 GRID UNIT',//)    UDD05570
       END                                                           UDD05580
```

APPENDIX I-D

ANALYSIS OF GRAVMOD FORTRAN

GRAVMOD FORTRAN is designed to give the modeler a two dimensional approximation of the subsurface geology, for a selected traverse. The model is comprised of polygons that approximate the subsurface geology. Each polygon is assigned a density, based on the known geology. The contrast densities used in the program are the difference between the polygonal density and the value 2.67 g/cm^3 (average crustal density). In addition, the number of polygonal sides, polygonal coordinates, traverse length, station spacing, number of stations, and observed Bouguer anomalies are the other input variables.

The program uses the input variables to generate a series of theoretical Bouguer curves, along the traverse, for each polygon. Theoretical anomalies are summed, after the last polygonal curve is calculate, at each station. A theoretical Bouguer curve for the model is the result of this summation. To test the validity of a model the theoretical and Bouguer curves are compared. If the sum of the residuals values between curves is a low value the model is accepted;

otherwise, the input is modified and the process is repeated. In this study, a model was accepted if a majority of the residuals values were less than 0.5 milligals.

GRAVMOD FORTRAN is based on an algorithm first introduced by Talwani and others (1959). This algorithm is based on the equation 2:

$$A(0,0)=2G\Delta P\sum_{j=1}^{n}\left[\frac{x_j z_{j+1}-x_{j+1}z_j}{(x_{j+1}-x_j)^2+(z_{j+1}-z_j)^2}\right]$$
$$\left[\frac{z_{j+1}-z_j}{2}\ln\left(\frac{x_{j+1}^2+z_{j+1}^2}{x_j^2+z_j^2}\right)+\right.$$
$$\left.(x_{j+1}-x_j)\left(\arctan\left(\frac{x_{j+1}}{z_{j+1}}\right)-\arctan\left(\frac{x_j}{z_j}\right)\right)\right]$$

where

A(0,0) : Gravity anomaly at point 0,0

G : Newton's Gravitational constant

delta P: Density contrast between polygonal unit and 2.67 g/cm^3.

n : Number of polygons

X_j, Z_j : X and Z coordinates of the polygon

This equation provides interesting insight to the limitations of the algorithm. This method assumes an infinite extension of the geologic formation along strike. Because of this assumption, variations of lithology along strikes are not modelled. This is the primary reason, that residual values

between theoretical and observed Bouguer curves often are not equal to zero. A second limitation of this method is that an infinite number of models exists that satisfy the criteria of acceptance. This is because the polygonal density and polygonal shape are unknowns, in the geologic sense. Remember from linear algebra if an equation has two unknowns then the number of solutions is infinite. This is why it is imperative to have geologic constraints, such as lithologic densities, and structures for the traverse. These constraints make the number of possible solutions finite because they limit the possible number of unknowns. Lastly, Talwani's method does not accurately predict the boundary values of the model.

GRAVMOD FORTRAN

```
C     ROUTINE GRAVMOD (MODIFIED FROM PARASNIS,1973,PG.380)                    GRA00010
C     MODIFIED FOR IBM NOWROOZI 1985                                          GRA00020
C     PROGRAM TO CALCULATE THE GRAVITY ANOMOLY ALONG A GROUND                 GRA00030
C     PROFILE AT RIGHT ANGLES TO THE STRAKE OF A TWO-DIMENSIONAL              GRA00040
C     FEATURE OF ARBITRARY, UNIFORM CROSS-SECTION.                            GRA00050
C                                                                             GRA00060
C     ANY NUMBER OF K(<36) MODELS CAN BE HANDLED. EACH MODEL MUST             GRA00070
C     HAVE THE FOLLOWING PARAMETER SET:                                       GRA00080
C          NCOR: NUMBER OF POLYGON CORNERS                                    GRA00090
C          NCR: NUMBER OF POLYGON CORNERS + 1                                 GRA00100
C         XS,XF:(XS<XF) CORRDINATES OF END POINTS OF PROFILE (NEAR-           GRA00110
C                EST MDX MUST BE POSITIVE.)                                   GRA00120
C          D:CALCULATION INTERVAL (METERS)                                    GRA00130
C         X(),Z():X-Z CORRDINATES OF EACH CORNER OF THE POLYGON, MOV-         GRA00140
C                 ING CW. EACH CORRDINATE IS ON A SEPERATE LINE.              GRA00150
C          N:NUMBER OF DATA POINTS                                            GRA00160
C     OUTPUT IS A TABLE OF X(METERS) VS GRAVITY ANOMOLY (MGALS)               GRA00170
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCGRA00180
C                                                                             GRA00190
       CHARACTER * 1 C(30,128),LAY,HAY,BAY                                    GRA00200
       DIMENSION X(33),Z(33),A(500),G(35,500),S(500),TITL(80),R(500)          GRA00210
     +,S1(500),DDD(500,3)                                                     GRA00220
C                                                                             GRA00230
       READ(1,*) XS,D,XF,N                                                    GRA00240
       XS=NINT(XS)/3.281                                                      GRA00250
       D=NINT(D)/3.281                                                        GRA00260
       XF=NINT(XF)/3.281                                                      GRA00270
C                                                                             GRA00280
       DATA C/3840 * ' '/LAY/'1'/HAY/'2'/BAY/'3'/                             GRA00290
c      DATA (C(15,I),I=1,128)/128 * '-'/                                      GRA00300
c      DATA (C(I,1),I=1,30)/30 * '¦'/                                         GRA00310
C                                                                             GRA00320
C                                                                             GRA00330
C      READ IN TITLE AND PARAMETERS                                           GRA00340
C                                                                             GRA00350
       READ(1,1) (TITL(I),I=1,80)                                             GRA00360
1      FORMAT(80A1)                                                           GRA00370
C      K=NUMBER OF MODELS                                                     GRA00380
       READ(1,*) K                                                            GRA00390
C      READ LIMIT VALUES                                                      GRA00400
       READ(1,*) XMIN,XMAX                                                    GRA00410
C     XS=STARTING POINT; D=INTERVALS; XF=END POINT; N=(XF-XS)/D +1             GRA00420
       WRITE(2,3) (TITL(I),I=1,80)                                            GRA00430
3      FORMAT(80A1)                                                           GRA00440
       WRITE(2,2) K,N,XS,D,XF                                                 GRA00450
2     FORMAT('///',5X,'K=',I5,5X,'N=',I5,3X,'XS=',F5.2,3X,'D=',F5.2           GRA00460
     +,5X,'XF=',F9.2)                                                         GRA00470
C                                                                             GRA00480
C      CALCULATE ANOMALY FOR EACH MODEL                                       GRA00490
C                                                                             GRA00500
       PRINT *,K,XS,XF,D,N                                                    GRA00510
       DO 50 M=1,K                                                            GRA00520
       RHO=0.0                                                                GRA00530
       P=XS                                                                   GRA00540
       READ(1,*) NCOR,RHO                                                     GRA00550
C       PRINT *, NCOR,RHO                                                     GRA00560
       WRITE(2,4) NCOR,RHO,M                                                  GRA00570
4      FORMAT('///','NCOR=',I5,10X,'RHO=',F5.2,10X,'MODEL=',I5)               GRA00580
       READ(1,*) (X(I),Z(I),I=1,NCOR)                                         GRA00590
```

```
      DO 121 I=1,NCOR                                                    GRA00600
      X(I)=NINT(X(I))/3.281                                              GRA00610
      Z(I)=NINT(Z(I))/3.281                                              GRA00620
121   CONTINUE                                                           GRA00630
      WRITE(2,6)                                                         GRA00640
6     FORMAT('///','       XCOR                    ZCOR          ')      GRA00650
      WRITE(2,7) (X(I),Z(I),I=1,NCOR)                                    GRA00660
7     FORMAT(5X,F10.2,15X,F10.2)                                         GRA00670
      WRITE(2,2000)  M                                                   GRA00680
      IF (P.GT.XF) GO TO 50                                              GRA00690
      DO 40 I=1,N                                                        GRA00700
      S(I)=0.0                                                           GRA00710
      CALL PRISMG(P,0.0,X,Z,NCOR,ANOM)                                   GRA00720
      ANOM=ANOM*1000.0*RHO                                               GRA00730
      WRITE(2,2001) P,ANOM                                               GRA00740
      A(I)=P                                                             GRA00750
      G(M,I)=ANOM                                                        GRA00760
      P=P+D                                                              GRA00770
40    CONTINUE                                                           GRA00780
50    CONTINUE                                                           GRA00790
C                                                                        GRA00800
C     STACK ANOMALIES INTO ONE PROFILE MODEL                             GRA00810
C                                                                        GRA00820
      WRITE(2,8) K                                                       GRA00830
8     FORMAT('1','SUMMATION OF ALL K = ',I5,5X,'MODELS',30X,'OBSERVED GGRA00840
     +RAVITY VALUES')                                                    GRA00850
C                                                                        GRA00860
      CHUD=-200.                                                         GRA00870
      AMIN=0.0                                                           GRA00880
      AMAX=0.0                                                           GRA00890
      BMIN=0.0                                                           GRA00900
      BMAX=0.0                                                           GRA00910
      DO 60 I=1,N                                                        GRA00920
      S(I)=0.0                                                           GRA00930
      CHUD=CHUD+200.                                                     GRA00940
      DO 70 J=1,K                                                        GRA00950
      S(I)=S(I)+G(J,I)                                                   GRA00960
70    CONTINUE                                                           GRA00970
      IF (CHUD.LT.XMIN.OR.CHUD.GT.XMAX) THEN                             GRA00980
      R(I)=0.0                                                           GRA00990
      WRITE(2,2001) A(I), CHUD, S(I), R(I)                               GRA01000
      WRITE(3,2003) CHUD,S(I),R(I)                                       GRA01010
      ELSE                                                               GRA01020
      READ(1,*) R(I)                                                     GRA01030
      WRITE(2,2001) A(I), CHUD, S(I), R(I)                               GRA01040
      WRITE(3,2003) CHUD,S(I),R(I)                                       GRA01050
2003  FORMAT(1X,E8.3,2X,F9.3,2X,F9.3)                                    GRA01060
      END IF                                                             GRA01070
      BMIN=MIN(BMIN,A(I))                                                GRA01080
      BMAX=MAX(BMAX,A(I))                                                GRA01090
      AMIN=MIN(AMIN,S(I),R(I))                                           GRA01100
      AMAX=MAX(AMAX,S(I),R(I))                                           GRA01110
60    CONTINUE                                                           GRA01120
C                                                                        GRA01130
      PRINT *,'AMIN=',AMIN,'AMAX=',AMAX,'BMIN=',BMIN,'BMAX=',BMAX       GRA01140
      DO 123 I=1,N                                                       GRA01150
      CALL PLOT1(A(I),S(I),C,30,128,LAY,AMIN,AMAX,BMIN,BMAX)             GRA01160
      CALL PLOT1(A(I),R(I),C,30,128,HAY,AMIN,AMAX,BMIN,BMAX)             GRA01170
C     CALL PLOT1(A(I),S1(I),C,30,128,BAY,AMIN,AMAX,BMIN,BMAX)            GRA01180
123   CONTINUE                                                           GRA01190
C                                                                        GRA01200
      CALL OOUT(C,30,128,D,AMIN,AMAX)                                    GRA01210
```

```
       STOP                                                              GRA01220
1000   FORMAT (I3)                                                       GRA01230
1001   FORMAT (3F10.0,I6)                                                GRA01240
1002   FORMAT (2F10.0)                                                   GRA01250
1003   FORMAT (I3,F10.0,8A5)                                             GRA01260
2000   FORMAT ('//',' MODEL',I3,'//',4X,' X(METERS)',7X,'     ','/',4X, GRA01270
     +' G(MGAL)-',5X,'-----------')                                      GRA01280
2001   FORMAT (15X,F10.1,2X,F7.1,11X,F10.4,10X,F10.4,10X,F10.4)          GRA01290
C                                                                        GRA01300
       END                                                               GRA01310
C                                                                        GRA01320
C                                                                        GRA01330
C                                                                        GRA01340
C                                                                        GRA01350
C     SUBROUTINE PRISMG                                                  GRA01360
C                                                                        GRA01370
C     PROGRAM TO CALCULATE GRAVITY ANOMALY OF ARBITRARY POLYGONAL        GRA01380
C     SHAPE WITH UNIFORM DENSITY AT POSITION (XOB,ZOB). ANOMALY IN       GRA01390
C     GALS: Z POSITIVE UP: XCOR AND ZCOR ARE ARRAYS CONTAINING THE       GRA01400
C     CORNERS OF THE POLYGON. LAST CORNER=FIRST CORNER.                  GRA01410
C     REF: GEOPHYSICS V48 # 7,PG 999-1010 (1005-6)                       GRA01420
C                                                                        GRA01430
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCGRA01440
       SUBROUTINE PRISMG(XOB,ZOB,XCOR,ZCOR,NCR,ANOM)                     GRA01450
       DIMENSION XCOR(1), ZCOR(1), X(40), Z(40)                          GRA01460
       REAL A                                                            GRA01470
       FACTOR=1.334E-5                                                   GRA01480
       NCOR1=NCR-1                                                       GRA01490
       DO 1000 I=1,NCR                                                   GRA01500
       X(I)=XCOR(I)-XOB                                                  GRA01510
       Z(I)=ZOB-ZCOR(I)                                                  GRA01520
1000   CONTINUE                                                          GRA01530
       ANOM=0.0                                                          GRA01540
       DO 2000 I=1,NCOR1                                                 GRA01550
       IF (X(I).EQ.0.0.AND.Z(I).EQ.0.0) GO TO 2000                       GRA01560
       IF (X(I+1).EQ.0.0.AND.Z(I+1).EQ.0.0) GO TO 2000                   GRA01570
       THETA1=ATAN2(Z(I),X(I))                                           GRA01580
       THETA2=ATAN2(Z(I+1),X(I+1))                                       GRA01590
       IF (ABS(THETA1-THETA2).LT.1.E-6) GO TO 2000                       GRA01600
       IF (Z(I).EQ.Z(I+1)) GO TO 2                                       GRA01610
       C1=COS(THETA1)                                                    GRA01620
       C2=COS(THETA2)                                                    GRA01630
       IF(X(I).EQ.X(I+1)) GO TO 3                                        GRA01640
       PHI=ATAN2(Z(I+1)-Z(I),X(I+1)-X(I))                                GRA01650
       CP=COS(PHI)                                                       GRA01660
       SP=SIN(PHI)                                                       GRA01670
       TP=SP/CP                                                          GRA01680
       A=X(I+1)+Z(I+1)*(X(I+1)-X(I))/(Z(I)-Z(I+1))                       GRA01690
       S1=SIN(THETA1)                                                    GRA01700
       S2=SIN(THETA2)                                                    GRA01710
       IF (X(I+1).EQ.0.0) GO TO 4                                        GRA01720
       IF (X(I).EQ.0.0) GO TO 5                                          GRA01730
       IF ((S1-C1*TP)/(S2-C2*TP)) 10,11,11                               GRA01740
11    ANOM=A*SP*CP*(THETA1-THETA2+TP*ALOG((S1-C1*TP)/(S2-C2*TP)))+ANOM   GRA01750
10     GO TO 2000                                                        GRA01760
2      ANOM=ANOM+Z(I)*(THETA2-THETA1)                                    GRA01770
       GO TO 2000                                                        GRA01780
3      IF (C1/C2) 12,13,13                                               GRA01790
13     ANOM=ANOM+X(I)*ALOG(C1/C2)                                        GRA01800
12     GO TO 2000                                                        GRA01810
4      IF (S1-C1*TP) 14,15,15                                            GRA01820
15     ANOM=ANOM+A*SP*CP*(THETA1-1.570796327+TP*ALOG(S1-C1*TP))          GRA01830
```

```
14    GO TO 2000                                                        GRA01840
5     IF (S2-C2*TP) 16,17,17                                            GRA01850
17   ANOM=ANOM+A*SP*CP*(THETA2-1.570796327+TP*ALOG(S2-C2*TP))           GRA01860
16    GO TO 2000                                                        GRA01870
2000  CONTINUE                                                          GRA01880
      ANOM=FACTOR*ANOM                                                  GRA01890
      RETURN                                                            GRA01900
      END                                                               GRA01910
C                                                                       GRA01920
C                                                                       GRA01930
C                                                                       GRA01940
C                                                                       GRA01950
      SUBROUTINE PLOT1(X1,Y1,GP,NA,NF,HELP,AMIN,AMAX,BMIN,BMAX)         GRA01960
      CHARACTER * 1 GP(NA,NF), HELP                                     GRA01970
      REAL X2, Y2                                                       GRA01980
      Y2=NINT((Y1-AMIN)/(AMAX-AMIN)*NA)+1                               GRA01990
      X2=NINT((X1-BMIN)/(BMAX-BMIN)*NF)+1                               GRA02000
C      PRINT *, Y2,X2                                                   GRA02010
      IF (Y2.GE.1.AND.Y2.LE.NA.AND.X2.GE.1.AND.X2.LE.NF) THEN           GRA02020
      GP(Y2,X2)=HELP                                                    GRA02030
      END IF                                                            GRA02040
      RETURN                                                            GRA02050
      END                                                               GRA02060
C                                                                       GRA02070
      REAL FUNCTION FUNMIN(X,NC,NR,NL,NM)                               GRA02080
      REAL X(NC,NR)                                                     GRA02090
      FUNMIN=X(1,NL)                                                    GRA02100
      DO 100 I=NL,NM                                                    GRA02110
      DO 100 J=1,NC                                                     GRA02120
      IF (FUNMIN.GT.X(J,I)) FUNMIN=X(J,I)                               GRA02130
100   CONTINUE                                                          GRA02140
      RETURN                                                            GRA02150
      END                                                               GRA02160
C                                                                       GRA02170
C                                                                       GRA02180
      REAL FUNCTION FUNMAX(X,NC,NR,NL,NM)                               GRA02190
      REAL X(NC,NR)                                                     GRA02200
      FUNMAX=X(1,NL)                                                    GRA02210
      DO 100 I=NL,NM                                                    GRA02220
      DO 100 J=1,NC                                                     GRA02230
      IF (FUNMAX.LT.X(J,I)) FUNMAX=X(J,I)                               GRA02240
100   CONTINUE                                                          GRA02250
      RETURN                                                            GRA02260
      END                                                               GRA02270
C                                                                       GRA02280
      SUBROUTINE OOUT(X,NA,NF,D,AMIN3,AMAX3)                            GRA02290
      CHARACTER * 1 X(NA,NF)                                            GRA02300
      DIMENSION T(21)                                                   GRA02310
      INTEGER Y1                                                        GRA02320
C                                                                       GRA02330
      WRITE(2,500)                                                      GRA02340
      PRINT *,'AMAX=',AMAX3,'AMIN=',AMIN3                               GRA02350
      DO 100 I=NA,6,-6                                                  GRA02360
       IF (I.EQ.NA) THEN                                                GRA02370
        Y1=NINT(AMAX3)                                                  GRA02380
       ELSE                                                             GRA02390
        Y1=Y1-NINT(((AMAX3-AMIN3)/FLOAT(NA))*6)                         GRA02400
      END IF                                                            GRA02410
C                                                                       GRA02420
      WRITE(2,1000) Y1, (X(I,J),J=1,NF)                                 GRA02430
C                                                                       GRA02440
       DO 100 J=I-1,I-5,-1                                              GRA02450
```

```
        WRITE(2,2000) (X(J,K),K=1,NF)                                    GRA02460
100    CONTINUE                                                          GRA02470
C                                                                        GRA02480
C                                                                        GRA02490
       RETURN                                                            GRA02500
C                                                                        GRA02510
500   FORMAT(///////,50X,'THEORITICAL AND OBSERVED BOUGER ANOMALIES',//)GRA02520
1000   FORMAT(I4,128A1)                                                  GRA02530
2000   FORMAT(4X,128A1)                                                  GRA02540
       END                                                               GRA02550
```

APPENDIX I-E

ANALYSIS OF QUAD BAS

QUAD.BAS was developed by Decker and James (1988) to statistically analyze rectified stream data. The algorithm of this program is based the quadrat presence/absence method proposed by Abdel-Rahman and Hay (1978). Prior to the quadrat presence/absence method the two most common techniques for sampling geological fractures was the quadrat length and quadrat frequency methods.

The quadrat length method sums the lengths of all fractures in a specified orientation class interval. A rose diagram of the summed lengths could then be plotted. This method does not distinguish between one long fracture and several shorter independent fractures in the same orientation class. Statistical analysis of the fracture data using this method is complex and yield random results.

The quadrat frequency method counts the total number of fractures in a specified orientation class, regardless of length. As a result, different trends are distinguished, and because the data are true frequencies of individuals statistical tests based on frequencies are possible. Abdel-Rahman and Hay (1979) point out that this method does not give a true representation of the population because the individual fractures in a quadrat may represent a cluster of fractures related to a small scale geologic event.

The quadrat presence/absence method determines whether a certain orientation class is present or absent using a sample size of 50 or more random quadrat sample units. Using this methodology, a single fracture may be counted more than once if it falls in more than one sampling quadrat. This means there is a higher probability that a long fracture will be counted more than once resulting in the close approximation to the pattern of fracture lengths. Using this method data can be statistical analyzed quickly while minimizing measurement errors.

The algorithm used in QUAD.BAS is based on the Possion equation below:

$$p(n) = \frac{e^{-x} x^{n}}{n!}$$

where

n : number of points falling in any one class category

e : base of the natural logarithm

x : mean of the number of observations in each class (Total number of observations, N, divided by number of classes)

The program QUAD BAS is located on the diskette along with several input files name *.STR (* means all files ending with the prefix STR).

QUAD BAS

```
DECLARE SUB writm1 (class1, class2, pp!, mm)
DECLARE SUB writm (class, pp!, mm)
DECLARE SUB tails (meen!, level!, tn!, pn!)
DECLARE SUB prob (x!, n!, p!)
DECLARE SUB quadrat (qx!, qy!, qr!, q!())
DECLARE SUB group (meen!, pn!, tn!, tot!())

' -------------------------  QUADRAT.BAS  -------------------------------
' ---------------  Circular statistics using Poisson distributions ------
' program to create data set of quadrats from any given 'lineament' file
' data must be in x1,y1 - x2,y2 format
'
 RESET: SCREEN 2: CLOSE : KEY OFF
 CONST pi# = 3.1415927#, pi2# = pi * 2, rad# = pi / 180
     DIM q(361), tot(361)

'get name of file to work on
begin0: CLS : PRINT : PRINT
INPUT "[DD:\path] filename . ext = "; ifil$
'ON ERROR GOTO handle1
begin: OPEN ifil$ FOR INPUT AS #1
'ON ERROR GOTO handler
     GOTO skip1

' error handler for file name
handle1: BEEP: LOCATE 10, 5
     IF ERR = 53 THEN PRINT "That file was not found" ELSE PRINT "error #"; ERR
     RESUME begin0

'skip error handler above
skip1: CLS :
     LOCATE 3, 10: PRINT " Determining graphic limits of "; ifil$
     LOCATE 6, 37: PRINT "n= 1";
' begin with a lower and upper set from the data
          ct% = 1
     INPUT #1, x1, Y1, x2, y2
     llx = x1: urx = x2
     IF x2 < x1 THEN llx = x2: urx = x1
     lly = Y1: ury = y2
     IF y2 < Y1 THEN lly = y2: ury = Y1
getlim: IF EOF(1) THEN CLOSE #1: GOTO step2
          ct% = ct% + 1
     LOCATE 6, 40: PRINT ct%
     INPUT #1, x1, Y1, x2, y2
' lower x
  IF llx > x1 THEN llx = x1
  IF llx > x2 THEN llx = x2
' lower y
  IF lly > Y1 THEN lly = Y1
  IF lly > y2 THEN lly = y2
' upper x
  IF urx < x1 THEN urx = x1
  IF urx < x2 THEN urx = x2
' upper y
  IF ury < Y1 THEN ury = Y1
  IF ury < y2 THEN ury = y2
```

```
     GOTO getlim

step2:

     vy% = 190
       dx = ABS(llx - urx) ' total change in X
       dy = ABS(ury - lly) ' total change in Y
      cdd = dy / dx
      vx% = 310 - CINT(181 / cdd)
  IF vx% < 0 THEN vx% = 9: vy% = 190 - CINT(181 * cdd)

' setup screen for map
      SCREEN 1, 0: CLS
     VIEW (vx%, 9)-(310, vy%), , 2
     WINDOW (llx, lly)-(urx, ury)

     LOCATE 1, 1: PRINT SPC(39);
     LOCATE 1, 1: PRINT "Is data in 1> 360 or 2>180 format"
getfmt:   a$ = INPUT$(1)
       dfmt% = VAL(a$)
       IF dfmt% <> 1 AND dfmt% <> 2 THEN BEEP: GOTO getfmt
     arend% = 360 / dfmt% - 1

' check for type of analysis
     LOCATE 1, 1: PRINT SPC(39);
     LOCATE 1, 1: PRINT "1> whole or 2> quadrat analysis"
getan:   a$ = INPUT$(1)
       ana% = VAL(a$)
       IF ana% <> 1 AND ana% <> 2 THEN BEEP: GOTO getan
 IF ana% = 1 THEN
       nq = 1
     IF dx > dy THEN qr = dx ELSE qr = dy
     qr = qr / 2
      qx = .5 * dx + llx
      qy = .5 * dy + lly
      paflg% = 1
          GOTO comence
 END IF

     LOCATE 1, 1: PRINT SPC(39);
     LOCATE 1, 1: INPUT "# of quadrats= ", nq
     LOCATE 1, 1: PRINT SPC(39);
     LOCATE 25, 1: PRINT "dx="; dx; "  dy="; dy;
     LOCATE 1, 1: INPUT "radius of quardat= ", qr
 IF qr > dx / 10 THEN qr = dx / 10
     LOCATE 1, 1: PRINT SPC(39);
     LOCATE 25, 1: PRINT SPC(39);


' determine qx and qy for quadrat center
comence: RANDOMIZE TIMER
     FOR iq = 1 TO nq
ON ana% GOTO skpq, quad

quad: LOCATE 25, 1: PRINT "quadrat #"; iq;
redo: qx = RND(1) * dx + llx
      qy = RND(1) * dy + lly

' display quadrat
     LOCATE 1, 1: PRINT "qx="; qx; "  qy="; qy

'     CLS 1 ' clear graphics screen only
```

```
     LINE (qx - qr, qy - qr)-(qx + qr, qy + qr), 1, B
skpq:
  CALL quadrat(qx, qy, qr, q())

' change q() to presence/absence and check for empty set if paflg%=0
 IF paflg% = 1 THEN GOTO skppa
     chk = 0
     FOR i = 0 TO arend%
      IF q(i) > 0 THEN q(i) = 1: chk = 1
     NEXT i
  IF chk = 0 THEN
     LINE (qx - qr, qy - qr)-(qx + qr, qy + qr), 0, B
   GOTO redo
  END IF

' keep track of all data [in the case of once through no problem
skppa: FOR i = 0 TO arend%
     tot(i) = tot(i) + q(i)
       NEXT i
     NEXT iq

 SCREEN 0

' now the probability shit
' get n
  ntot = 0
     FOR i = 0 TO arend%
      ntot = ntot + tot(i)
     NEXT i

    SCREEN 2: CLS
    LOCATE 10, 20: PRINT "Which Probability Level Do You Desire ?"
    LOCATE 11, 30: INPUT " ex. 99 or 95 :", level
      level = 1 - level / 100
     meen = (ntot / arend%)
     LOCATE 15, 20: PRINT "Mean value is......", meen


 CALL tails(meen, level, tn, pn)

 CLS
     LOCATE 5, 10: PRINT "Peak =  "; pn
     LOCATE 7, 10: PRINT "Trough ="; tn
     a$ = INPUT$(1)



' display data set
    CLS : LOCATE 10, 10: PRINT "Do you want a hardcopy of the data set ?  [Y/N]"
    a$ = UCASE$(INPUT$(1))
 IF a$ <> "Y" THEN GOTO noprt
getpv: LOCATE 15, 10: PRINT "1> all data or 2> just peaks and troughs"
    pval = VAL(UCASE$(INPUT$(1)))
    IF pval <> 1 AND pval <> 2 THEN BEEP: GOTO getpv
          CLS : LOCATE 10, 35: PRINT "working"
' print header info
    LPRINT "                    Azimuthal data from "; ifil$
  IF ana% = 1 THEN LPRINT "             Whole data frequency analysis"
  IF aUME begin0

 SUB group (meen, pn, tn, tot())
 SHARED arend%, ntot
```

```
'this program looks for significant peaks and groups them into larger classes
'with max. class determined by user

 LOCATE 15, 10: INPUT "please give maximum class grouping desired:  ", max
' outer loop determines significant peaks around which to group

  FOR i = 0 TO arend%
    IF tot(i) < pn GOTO 1
     ii = 0: ll = 1: mm = 1: lll = 0: iii = 0
     g1 = tot(i)
      meen = ntot / (360 / 1)
      CALL prob(meen, g1, pp)
      CALL writm(i, pp, mm)

'this loop finds the groupings about the significant peaks

   FOR j = i TO (i + max)
      ii = ii + 1
       IF (i - ii) >= 0 THEN kk = i - ii
       IF (i - ii) < 0 THEN kk = (360 + i) - ii

    mm = mm + 1

'to correct for counting above 359 or below zero

     IF (j + ll) > 359 THEN ll = -360

'test to see which class has higher frequency on either side of peak
    'to save time, two if statements are used to check for troughs before
    'grouping is done

     IF lll = -999 GOTO stepp2
      IF tot(j + ll) <= tn THEN lll = -999
      IF tot(j + ll) > tot(kk) THEN
         g1 = g1 + tot(j + ll)
         meen = ntot / (360 / mm)
 'calcualte probability of occurrence for this grouping
 '        PRINT "g1="; g1; "j="; j; "meen="; meen; "tot="; tot(j + ll)
 '        a$ = INPUT$(1)
         CALL prob(meen, g1, pp)
 'write to printer the results of test
         CALL writm(j + ll, pp, mm)
         ii = ii - 1
         GOTO 2
       END IF

' check for troughs

stepp2: IF iii = -999 GOTO step3
        IF tot(kk) <= tn THEN iii = -999
        IF tot(j + ll) < tot(kk) THEN
          g1 = g1 + tot(kk)
          meen = ntot / (360 / mm)
'calcualte probablitiy of occurrence for this grouping
          CALL prob(meen, g1, pp)
' write results to printer
          CALL writm(kk, pp, mm)
          ll = ll - 1
          GOTO 2
      END IF

' check to see if two classes either side of grouping are equal
```

```
stna% = 2 THEN LPRINT "        using "; nq; " quadrats with a "; qr; " radius."
    LPRINT CINT((1 - level) * 100); "% critical values        min peak="; pn; "
 max trough="; tn
    LPRINT

     FOR i = 0 TO arend%
 ON pval GOTO pall, ptp

ptp: IF tot(i) >= pn OR tot(i) <= tn THEN GOTO pall
     GOTO skpprt

pall: LPRINT USING "     ###"; i;
      LPRINT USING "    ########"; tot(i);

' mark peaks and troughs
  IF tot(i) >= pn THEN
     LPRINT "   +"
  ELSEIF tot(i) <= tn THEN
     LPRINT "   -"
  ELSE LPRINT " "
  END IF
skpprt: NEXT i
' now determine grouping of the various peaks
noprt: CALL group(meen, pn, tn, tot())



' make a file of angular data for plotting in the rose program
    OPEN "\000\poisson.roz" FOR OUTPUT AS #2
     FOR i = 0 TO arend%
      FOR j = 1 TO tot(i)
      PRINT #2, i
      NEXT j
     NEXT i

 SCREEN 2

     END

handler: CLS : LOCATE 5, 1: PRINT "Error handler"
     LOCATE 6, 1: PRINT "error= #"; ERR
      a$ = INPUT$(1)
      RESDECLARE SUB makeang (ang!, dlen!)
DECLARE SUB smooth (sdat!())
DECLARE SUB autocor ()
DECLARE SUB crosscor ()
' -------------   ROSE corr.BAS  -------------------
' program to plot a rose diagram to the screen
' also does some simple statistics
' -----  written by Bill Decker  6/21/87  ---- modified 6/29/88

 COMMON SHARED nf
   RESET
     CONST pi# = 3.141592654#, pi2# = 2 * pi, hpi# = pi / 2, rad# = pi / 180
   DIM dat(361, 2), pdat(361, 2, 2), bdat(361), stot(2), tot(2)
   SCREEN 2: KEY OFF: CLS

' constants and counters
begin:   tot(1) = 0: tot(2) = 0: stot(1) = 0: stot(2) = 0: cbar = 0: sbar = 0:
nf = 1
```

```
   FOR i = 0 TO 360
    dat(i, 1) = 0
    dat(i, 2) = 0
    pdat(i, 1, 1) = 0: pdat(i, 2, 1) = 2
    pdat(i, 1, 2) = 0: pdat(i, 2, 2) = 2
    bdat(i) = 0
   NEXT i

' get data format
20 PRINT : PRINT
     PRINT "Is the data in   <1> 360  or  <2> 180 degree format?"
     a$ = INPUT$(1)

dfmt = VAL(a$)
     IF dfmt < 1 OR dfmt > 2 THEN BEEP: GOTO 20

' get increment
30 PRINT : PRINT
 PRINT "   Increment for rose diag. construction  "
 INPUT "    equal subdivision of 360 degrees    = ", inc
  inc = ABS(inc)
 IF inc = 0 THEN GOTO 30
 IF 360 MOD inc <> 0 THEN BEEP: GOTO 30 ' not an even subdivision of 360

'double increment if 180 degree format
'*****************************************************************
     inc = inc * dfmt

inf: CLS : LOCATE 3, 15: PRINT "INPUT DD [path]  NAME . EXT  for input file "
           LOCATE 5, 20: INPUT "Filename: ", flin$(nf)

     LOCATE 10, 5: PRINT "Is data <A> angular or <L> linear (x1-y1 x2-y2) ?"
getform:  a$ = UCASE$(INPUT$(1))
          IF a$ = "A" THEN datflg = 2: GOTO 70
          IF a$ = "L" THEN
          datflg = 1
' get length weighting
   PRINT : PRINT
   PRINT "Use length weighted formula?  [Y/N]"
   lw$ = UCASE$(INPUT$(1))

   IF lw$ <> "Y" THEN minl = 0: maxl = 1000: GOTO 70 'skip min/max if no length
weighting
' set minimum length
     PRINT : PRINT
     INPUT "Input minimum length ", minl
```

APPENDIX I-F

REMAINING PROGRAMS

The remaining programs mentioned in this paper are listed below:

TWOLINE SAS: This program is used to plot two simultaneous curves on the same graph.

```
OPTIONS MPRINT ;
%MACRO GPH(DATTA);
  /* INTIALIZE AXIS LABELS */
   %LET XTIT=DISTANCE (KM);
   %LET YTIT=MILLIGALS;
   %LET TIT2=THEORETICAL AND BOUGUER;
   %LET TIT3=      ANOMALIES        ;
   %LET DESC=THEORECTICAL/BOUGUER  VS DIST;
   %LET XSCALE=15;

 /* INTIALIZE PAGE TITLE */

  %IF &DATTA=IN.D622 %THEN %DO;
      %LET TIT1=STATE ROAD 622;
      %LET NAM=SR622;
      %LET INC=0.5;
  %END;
  %IF &DATTA=IN.D60 %THEN %DO;
      %LET TIT1=   U.S. 60   ;
      %LET NAM=US60;
      %LET INC=0.5;
  %END;
  %IF &DATTA=IN.D634 %THEN %DO;
      %LET TIT1=STATE ROAD 634;
      %LET NAM=SR634;
      %LET INC=1.0;
  %END;
  %IF &DATTA=IN.D636 %THEN %DO;
      %LET TIT1=STATE ROAD 636;
      %LET NAM=SR636;
      %LET INC=1.0;
  %END;
  %IF &DATTA=IN.D637 %THEN %DO;
      %LET TIT1=STATE ROAD 637;
      %LET NAM=SR637;
      %LET INC=1.0;
  %END;
  %IF &DATTA=IN.D460 %THEN %DO;
      %LET TIT1=   U.S. 460   ;
```

```
      %LET NAM=US460;
      %LET INC=1.0;
  %END;

   DATA MOD;
     SET &DATTA;
      DIST=(DIST/3.2808)/1000;
   RUN;
/*Find the maximum x value */

   PROC MEANS DATA= MOD  NOPRINT;
    VAR DIST;
     OUTPUT OUT=MOD1 MAX=MAXX ;
   RUN;

   DATA MOD2;
     set mod1;
      MAXX= ROUND(MAXX,.5)+.5;
      CALL SYMPUT('MAX',MAXX);
      %LET XMAX=&MAX;
  run;
/* use sas annotate graphic macros*/
/* %label and %line are listed in the Model SAS program
DATA ANNO;
%DCLANNO;
LENGTH TEXT $40;
%LABEL(50,75,"&TIT2",BLACK,0,0,4.0,SIMPLEX,5);
%LABEL(50,72,"&TIT3",BLACK,0,0,4.0,SIMPLEX,5);
%LABEL(20,25,'+',BLUE,0,0,2.0,SIMPLEX,5);
%LABEL(22,25,'BOUGUER ANOMALY',BLACK,0,0,2.0,SIMPLEX,6);
%LABEL(60,25,'*',RED,0,0,2.0,SIMPLEX,5);
%LABEL(62,25,'THEORETICAL ANOMALY',BLACK,0,0,2.0,SIMPLEX,6);
%LINE(42,21,43,21,BLACK,1,3);
%LABEL(50,21,'REGIONAL TREND',BLACK,0,0,2.0,SIMPLEX,5);
RUN;
 /* GET READY FOR PLOTTING */
    SYMBOL1 V=PLUS C=BLUE I=JOIN;
    SYMBOL2 V=STAR C=RED I=JOIN;
    SYMBOL3 V=NONE C=BLACK W=3 I=RL;

PROC GPLOT DATA=MOD;*OUT=IN.gpHH ANNOTATE=ANNO;
AXIS1 LABEL=(H=2.5 C=BLACK F=SIMPLEX  "&XTIT")
    VALUE=(H=2.5 F=SIMPLEX C=BLACK) color=black
    ORDER=0 TO &XMAX BY &INC LENGTH=10 CM;
AXIS2 LABEL=(H=2.5 F=SIMPLEX C=BLACK J=L A=90 "&YTIT")
      VALUE=(H=2.5 C=BLACK F=SIMPLEX)
      ORDER=10 TO 20 BY 2 COLOR=BLACK
      LENGTH=10 CM;
PLOT1 BANOM*DIST=1 TANOM*DIST=2 / NOLEGEND
                            HAXIS=AXIS1 OVERLAY
                            VAXIS=AXIS2
                            NAME="&NAM"
                            DES="&DESC";
PLOT2 BANOM*DIST=3/VAXIS=AXIS2;
RUN;
%MEND GPH;

GOPTIONS DEV=TEK4010 GEPILOG='18'X GPROLOG='1B0C' GPROTOCOL=GSAS7171
         NOTEXT82 HPOS=100 VPOS=100
         COLORS=(BLACK RED BLUE GREEN YELLOW PURPLE BROWN ORANGE);
%GPH(IN.D622);
%GPH(IN.D60);
```

```
%GPH(IN.D634);
%GPH(IN.D636);
%GPH(IN.D637);
%GPH(IN.D460);
```

CONTOUR SAS: This program contours three dimensional data in a X, Y, Z format.

```
GOPTIONS NOTEXT82 DEVICE=ZETA836C
HSIZE=9.0
VSIZE=15.0
ROTATE;
CMS FI GOOD DISK GMAP DATA B;
DATA AREA;
     INFILE GOOD;
      INPUT X Y Z;
RUN;
PROC G3GRID DATA=AREA OUT=GPH;
   GRID Y*X=Z / PARTIAL
              NEAR=25
              AXIS1=37.26 TO 37.600 BY .01
              AXIS2=-78.49 TO -78.26 BY .010;
RUN;
TITLE1 J=C H=3 F=NONE C=BLACK
'CONTOUR GRAVITY MAP OF FARMVILLE BASIN';
FOOTNOTE2 J=C H=1 F=NONE C=BLACK 'CONTOUR LINE ';
PROC GCONTOUR  DATA=GPH;
     PLOT Y*X=Z/LEVELS=10 TO 20 BY .5;
RUN;
```

MODEL SAS: This program is used to generate the gravity models shown in this study. Note all graphic macros listed below were written by SAS Institue, Cary North Carolina.

```
OPTIONS MPRINT DQUOTE;

%MACRO SEQUEN(SEQ);
IF UPCASE("&SEQ")='AFTER' OR UPCASE("&SEQ")=:'A'  THEN WHEN="A";
                                                  ELSE WHEN = "B";
%MEND SEQUEN;
%MACRO  SYSTEM(XS,YS,HS);
XSYS = "&XS"; YSYS = "&YS";  HSYS = "&HS";
%MEND SYSTEM;

%MACRO DCLANNO;
  length function color style      $ 8.;
  length xsys ysys hsys            $ 1.;
  length when position             $ 1.;
  retain xsys ysys hsys;

  x= .; y= .;
  style=" "; position = "5"; color = " "; function= " ";
```

```
  %system(4,4,4);
  %sequen(BEFORE);
%MEND DCLANNO;

%MACRO POLY(X1,Y1,COLR,PATTERN,LINTYP);
 X=&X1;
 Y=&Y1;
 LINE= &LINTYP;
 STYLE = &PATTERN;
 COLOR = &COLR;
FUNCTION ="POLY    "; OUTPUT;
%MEND POLY;
%MACRO POLYCON(X1,Y1,COLIN);
 X=&X1;
 Y=&Y1;
COLOR=&COLIN;
FUNCTION ='POLYCONT'; OUTPUT;
%MEND POLYCON;
%MACRO FRAME(COLIN,LINTYP,WIDTH,PATTERN);
 X=.;
 Y= .;
  IF "&COLIN"=: '*' THEN; ELSE COLOR="&COLIN";
  STYLE="&PATTERN";
  LINE=&LINTYP;
  SIZE=&WIDTH;
FUNCTION ='FRAME   '; OUTPUT;
%MEND FRAME;
%MACRO PUSH;
X=.;
Y=.;
FUNCTION='PUSH    '; OUTPUT;
%MEND PUSH;

%MACRO SWAP;
X=.;
Y=.;
FUNCTION='SWAP    '; OUTPUT;
%MEND SWAP;

%MACRO CNTL2TX;
X=.;
Y=.;
FUNCTION='CNTL2TXT'; OUTPUT;
%MEND CNTL2TX;

%MACRO TXT2CNT;
X=.;
Y=.;
FUNCTION="TXT2CNTL"; OUTPUT;
%MEND TXT2CNT;

%MACRO POP;
X=.;
Y=.;
FUNCTION="POP     "; OUTPUT;
%MEND POP;

%MACRO DRAW2TX(COLIN,LINTYP,WIDTH);
X=.;
Y=.;
SIZE=&WIDTH;
LINE=&LINTYP;
```

```
  IF "&COLIN"=: '*' THEN; ELSE COLOR="&COLIN";
FUNCTION="DRAW2TXT"; OUTPUT;
%MEND DRAW2TX;


%MACRO LINE(X1,Y1,X2,Y2,COLIN,LINTYP,WIDTH);
%MOVE(&X1,&Y1);
%DRAW(&X2,&Y2,&COLIN,&LINTYP,&WIDTH);
%MEND LINE;

%MACRO MOVE (X1,Y1);
X=&X1;
Y=&Y1;
FUNCTION= "MOVE    "; OUTPUT;
%MEND  MOVE;
%MACRO DRAW(X1, Y1, COLIN, LINTYP, WIDTH);
X=&X1;
Y=&Y1;
LINE  = &LINTYP;
SIZE  = &WIDTH;
   IF "&COLIN" =:  '*' THEN ; ELSE COLOR = "&COLIN";
FUNCTION = "DRAW  "; OUTPUT;
%MEND  DRAW;
%MACRO LABEL(X1, Y1, TXT, COLTXT, ANG, ROT, HGT, FONT, POS);
X=&X1;
Y=&Y1;
ANGLE= &ANG;
ROTATE= &ROT;
SIZE= &HGT;
STYLE= "&FONT";
TEXT= &TXT;
  IF "&POS" =: '*' THEN;  ELSE POSITION = "&POS";
   IF "&COLTXT" =: '*' THEN ; ELSE COLOR = "&COLTXT";
FUNCTION = "LABEL  ";  OUTPUT;
%MEND  LABEL;
%MACRO RECT(X1,Y1,X2,Y2,COLIN,LINTYP, WIDTH );
%MOVE (&X1, &Y1);
%DRAW (&X2, &Y1, &COLIN, &LINTYP, &WIDTH);
%DRAW (&X2, &Y2, &COLIN, &LINTYP, &WIDTH);
%DRAW (&X1, &Y2, &COLIN, &LINTYP, &WIDTH);
%DRAW (&X1, &Y1, &COLIN, &LINTYP, &WIDTH);
%MEND  RECT;
%MACRO BAR (X1, Y1, X2, Y2, COLOR, BARTYP, PATTERN );
%MOVE  (&X1, &Y1);
X= &X2;
Y= &Y2;
LINE  = &BARTYP;
STYLE  ="&PATTERN"
  IF "&COLOR" =: '*'  THEN ; ELSE COLOR = "&COLOR";
FUNCTION  = "BAR   "; OUTPUT;
%MEND   BAR;
%MACRO MODEL(DATTA);
   %LOCAL MAX YSCALE MINXY;
  /* INTIALIZE AXIS LABELS */
   %LET XTIT=DISTANCE (KM);
   %LET YTIT=DEPTH (KM);
   %LET TIT2=GRAVITY MODEL;
   %LET DESC=GRAVITY MODEL;
   %LET XSCALE=15;

 /* INTIALIZE PAGE TITLE */
```

```
%IF &DATTA=IN.MOD622 %THEN %DO;
    %LET TIT1=STATE ROAD 622;
    %LET NAM=SR622;
    %LET INC=0.5;
%END;
%IF &DATTA=IN.MOD60 %THEN %DO;
    %LET TIT1=   U.S. 60   ;
    %LET NAM=US60;
    %LET INC=0.5;
%END;
%IF &DATTA=IN.MOD634 %THEN %DO;
    %LET TIT1=STATE ROAD 634;
    %LET NAM=SR634;
    %LET INC=1.0;
%END;
%IF &DATTA=IN.MOD636 %THEN %DO;
    %LET TIT1=STATE ROAD 636;
    %LET NAM=SR636;
    %LET INC=1.0;
%END;
%IF &DATTA=IN.MOD637 %THEN %DO;
    %LET TIT1=STATE ROAD 637;
    %LET NAM=SR637;
    %LET INC=1.0;
%END;
%IF &DATTA=IN.MOD460 %THEN %DO;
    %LET TIT1=   U.S. 460   ;
    %LET NAM=US460;
    %LET INC=1.0;
%END;
 DATA CONVERT;
    SET &DATTA;
     XX=XX/3280.8;
     YY=YY/3280.8;
 RUN;
 PROC MEANS DATA= CONVERT NOPRINT;
  VAR XX;
   OUTPUT OUT=MOD1 MAX=MAXX ;
 RUN;

 PROC MEANS DATA= CONVERT NOPRINT;
  VAR YY;
   OUTPUT OUT=MOD2 MIN=MAXY ;
 RUN;

 DATA MOD3;
   set MOD1;
    MAXX= ROUND(MAXX,.5)+.5;
    CALL SYMPUT('MAX',MAXX);
    if maxx > 5 then call symput('inc','1');
    else call symput('inc','.5');
   set MOD2;
    MAXY= ROUND(ABS(MAXY),.5)+.5;
    YSCALE=(MAXY*&XSCALE)/MAXX;
    MINXY=-1*MAXY;
    CALL SYMPUT('MINXY',MINXY);
    CALL SYMPUT('YSCALE',YSCALE);
run;
/* GET READY FOR PLOTTING */
   SYMBOL1 V=NONE;

   DATA DAT1;
```

```
    XX=0;
    YY=0;
    RUN;

    DATA ANNO(DROP =ID XX YY RHO RHO1 RH1 RH2 RH3 RH4 PATTERN);
    LENGTH CLR $8.;
    %DCLANNO;
    %SYSTEM(2,2,4);
    %SEQUEN(AFTER);
     SET CONVERT;
     CALL SYMPUT('RHO',RHO);
     CALL SYMPUT('RHO1',RHO1);
     CALL SYMPUT('ID',ID);
     RH1=-0.12;RH2=0.18;RH3=0.21;RH4=0.11;
     CALL SYMPUT('RH1',RH1);
     CALL SYMPUT('RH2',RH2);
     CALL SYMPUT('RH3',RH3);
     CALL SYMPUT('RH4',RH4);
     ID1=4;
     CALL SYMPUT('ID1',ID1);

      IF SYMGET('RHO') =SYMGET('RH1') THEN DO;
        PATTERN='M3N035'; CLR="GREEN";
      END;
      IF SYMGET('RHO') =SYMGET('RH2') THEN DO;
        PATTERN='M4N320';   CLR="PURPLE";
      END;
      IF SYMGET('RHO') =SYMGET('RH3') THEN DO;
        PATTERN='S';  CLR="RED";
      END;
      IF SYMGET('RHO') =SYMGET('RH4') THEN DO;
         PATTERN='M4X320';  CLR="ORANGE";
      END;
    IF SYMGET('RHO')  NE SYMGET('RHO1') THEN DO;
       %POLY(XX,YY,CLR,PATTERN,1);
       OUTPUT;
    END;
    ELSE IF SYMGET('RHO') = SYMGET('RHO1') THEN DO;
      %POLYCON(XX,YY,BLACK);
    OUTPUT;
    END;
 RUN;
TITLE1;
PROC GPLOT DATA=DAT1 ANNOTATE=ANNO;*OUT=IN.GPHH;
AXIS1 LABEL=(H=2.5 C=BLACK F=SIMPLEX  "&XTIT")
   VALUE=(H=2.5 F=SIMPLEX C=BLACK)
   ORDER=0 TO &MAX BY &INC LENGTH=10 CM COLOR=BLACK;
AXIS2 LABEL=(H=2.5 C=BLACK F=SIMPLEX J=L A=90 "&YTIT") COLOR=BLACK
      VALUE=(H=2.5 C=BLACK F=SIMPLEX)
      ORDER=&MINXY TO 0 BY .5
      LENGTH=10 CM;
PLOT1 XX*YY / NOLEGEND
            HAXIS=AXIS1 OVERLAY VMINOR=5
            VAXIS=AXIS2 HMINOR=10
                     NAME="&NAM"
                     DES="&DESC";
PLOT2 XX*YY/VAXIS=AXIS2 VMINOR=5;
RUN;
%MEND MODEL;
GOPTIONS DEV=TEK4010 GEPILOG='18'X GPROLOG='1B0C' GPROTOCOL=GSAS7171
         NOTEXT82 HPOS=100 VPOS=100 NODISPLAY;
```

```
%MODEL(IN.MOD622);
%MODEL(IN.MOD60);
%MODEL(IN.MOD634);
%MODEL(IN.MOD636);
%MODEL(IN.MOD637);
%MODEL(IN.MOD460);
```

APPENDIX II

LISTING OF GRAVITY DATA

PROFILE

A. U.S. HIGHWAY 460E

B. STATE ROAD 637

C. STATE ROAD 636

D. STATE ROAD 634

E. U.S. HIGHWAY 60

F. STATE ROAD 622

U.S. HIGHWAY 460E GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA	NAME AND NUM	LATITUDE NORTH +	LONGITUDE EAST +	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
2	BASE 1031	37 17.80	-76 23.89	399.700	0.000	979932.676	26.173	14.840	979842.260
25	10000	37 18.70	-76 27.61	454.240	0.000	979933.167	31.927	16.434	979844.000
26	10100	37 18.70	-76 27.56	453.140	-230.620	979933.167	31.786	16.331	979844.000
27	10200	37 18.66	-76 27.53	452.630	**********	979933.250	31.646	16.409	979844.000
28	10300	37 18.67	-76 27.46	453.010	3.125	979933.312	31.936	16.467	979843.937
29	10400	37 18.65	-76 27.45	453.660	4.255	979932.937	31.696	16.226	979843.937
30	10500	37 18.62	-76 27.41	454.450	5.320	979933.000	31.666	16.366	979843.937
31	10600	37 18.62	-76 27.36	455.190	0.000	979933.062	31.669	16.444	979843.674
32	10700	37 18.60	-76 27.34	456.140	**********	979932.812	31.664	16.326	979843.674
33	10800	37 18.64	-76 27.31	457.000	0.000	979932.800	31.667	16.060	979843.612
34	10900	37 18.67	-76 27.26	457.760	**********	979932.562	31.825	16.212	979843.612
35	11000	37 18.67	-76 27.23	458.490	0.000	979932.800	31.788	16.188	979843.612
36	11100	37 18.65	-76 27.20	459.530	**********	979932.800	31.818	16.245	979843.612
37	11200	37 18.63	-76 27.16	460.410	0.000	979932.250	31.623	16.120	979843.750
38	11300	37 18.62	-76 27.13	461.410	4.016	979932.125	31.767	16.029	979843.750
39	11400	37 18.60	-76 27.11	461.710	1.023	979932.125	31.662	16.114	979843.687
40	11500	37 18.60	-76 27.06	461.800	**********	979932.125	31.623	16.013	979843.687
41	11600	37 18.46	-76 27.05	461.270	0.000	979932.187	31.672	16.139	979843.687
42	11700	37 18.47	-76 27.01	460.390	-1660.079	979931.937	31.676	16.676	979843.687
43	11800	37 18.43	-76 26.98	458.510	0.000	979931.750	31.557	16.619	979843.625
44	11900	37 18.42	-76 26.96	456.890	0.000	979932.062	31.352	16.603	979843.625
45	12000	37 18.38	-76 26.93	453.260	**********	979932.187	31.288	16.629	979843.562
46	12100	37 18.37	-76 26.69	449.710	**********	979932.312	31.106	16.764	979843.500
47	12200	37 18.33	-76 26.66	446.930	0.005	979932.500	30.987	16.747	979843.500
48	12300	37 18.30	-76 26.64	441.450	**********	979932.937	31.050	16.893	979843.437
49	12400	37 18.27	-76 26.63	436.690	**********	979933.250	30.936	16.842	979843.375
50	12500	37 18.23	-76 26.60	431.660	-50.820	979933.562	30.676	16.749	979843.312
51	12600	37 18.20	-76 26.60	426.260	**********	979933.675	30.667	16.144	979843.312
52	12700	37 18.17	-76 26.76	420.560	0.000	979934.250	30.580	16.236	979843.250
53	12800	37 18.13	-76 26.74	414.830	0.000	979934.562	30.266	16.230	979843.187
54	12900	37 18.12	-76 26.73	408.480	**********	979934.812	30.064	16.132	979843.187
55	13000	37 18.08	-76 26.71	402.610	-2800.084	979935.125	29.647	16.118	979843.125
56	13100	37 18.05	-76 26.70	396.480	0.000	979935.562	29.612	16.290	979843.062
57	13200	37 18.03	-76 26.68	390.530	**********	979936.937	29.628	16.220	979843.062
58	13300	37 18.00	-76 26.66	384.320	**********	979936.062	29.268	16.100	979843.000
59	13400	37 17.97	-76 26.64	378.470	**********	979936.375	29.042	16.127	979842.937
60	13500	37 17.95	-76 26.63	372.410	-1860.092	979936.562	28.716	16.010	979842.937
61	13600	37 17.92	-76 26.61	366.430	0.000	979936.937	28.563	16.054	979842.875
62	13700	37 17.68	-76 26.60	360.740	0.000	979937.187	28.300	15.896	979842.812
63	13800	37 17.67	-76 26.58	354.630	-748.312	979936.562	28.189	15.867	979842.812
64	13900	37 17.63	-76 26.56	348.950	0.000	979936.000	28.055	15.783	979842.750
65	14000	37 17.60	-76 26.54	344.418	**********	979936.375	28.083	16.342	979843.687
66	14100	37 17.78	-76 26.61	341.850	**********	979936.625	28.163	16.464	979843.625
67	14200	37 17.72	-76 26.60	341.220	2.004	979936.687	28.213	16.871	979843.562
68	14300	37 17.67	-76 26.46	353.610	0.000	979936.000	24.760	16.682	979843.500
69	14400	37 17.62	-76 26.46	360.000	**********	979937.812	29.321	17.012	979843.437
70	14500	37 17.60	-76 26.43	368.260	0.000	979937.500	28.760	17.167	979843.437
71	14600	37 17.57	-76 26.41	375.710	-2404.066	979937.250	30.264	17.438	979843.375
72	14700	37 17.53	-76 26.38	383.220	0.000	979936.937	30.657	17.846	979843.312
73	14800	37 17.50	-76 26.38	390.670	-2048.506	979936.625	31.005	17.760	979843.250
74	14900	37 17.47	-76 26.34	396.940	0.000	979936.312	31.549	17.973	979842.187
75	15000	37 17.45	-76 26.33	404.460	0.000	979936.675	31.731	17.834	979842.187
76	15100	37 17.42	-76 26.32	409.870	0.000	979936.687	32.063	16.864	979842.125
77	15200	37 17.38	-76 26.31	414.860	-2106.064	979936.312	32.263	16.113	979842.126
78	15300	37 17.36	-76 26.28	419.670	0.000	979934.687	32.072	17.762	979842.062
79	15400	37 17.33	-76 26.26	423.160	**********	979934.062	31.819	17.366	979842.000
80	15500	37 17.30	-76 26.25	428.700	**********	979933.675	31.822	17.402	979842.000
81	15600	37 17.27	-76 26.21	427.660	**********	979933.562	31.886	17.304	979841.937
82	15700	37 17.25	-76 26.20	429.300	0.000	979933.312	31.800	17.166	979841.875
83	15800	37 17.22	-76 26.18	430.060	**********	979933.125	31.749	17.041	979841.875
84	15900	37 17.20	-76 26.16	429.920	**********	979933.187	31.780	17.117	979841.812
85	16000	37 17.18	-76 26.13	428.670	1.044	979933.000	31.666	16.933	979841.812
86	16100	37 17.15	-76 26.09	427.660	**********	979933.062	31.827	16.836	979841.750
87	16200	37 17.13	-76 26.06	426.710	0.000	979933.250	31.630	17.010	979841.750
88	16300	37 17.10	-76 26.05	423.250	**********	979933.187	31.313	16.677	979841.687
89	16400	37 17.08	-76 26.01	420.750	**********	979933.250	31.178	16.636	979841.687
90	16500	37 17.07	-76 25.98	416.070	**********	979933.187	30.977	16.616	979841.626
91	16600	37 17.05	-76 25.95	416.260	**********	979933.250	30.989	16.632	979841.626
92	16700	37 17.02	-76 25.91	412.760	**********	979933.250	30.834	16.456	979841.562
93	16800	37 17.00	-76 25.89	409.820	1.044	979933.437	30.633	16.446	979841.562
94	16900	37 16.96	-76 25.86	406.890	0.000	979933.437	30.319	16.341	979841.500
95	17000	37 16.97	-76 25.84	404.260	0.000	979933.312	29.835	16.044	979841.500
96	17100	37 16.95	-76 25.81	401.730	**********	979933.562	29.876	16.176	979841.500
97	17200	37 16.93	-76 25.78	398.760	1.044	979933.625	29.674	16.073	979841.437
98	17300	37 16.92	-76 25.74	396.360	0.000	979933.812	29.694	16.176	979841.437
99	17400	37 16.90	-76 25.74	393.720	0.000	979933.675	29.523	16.094	979841.376
100	17500	37 16.87	-76 25.68	391.100	-2867.158	979934.000	29.441	16.102	979841.376
101	17600	37 16.85	-76 25.64	388.560	**********	979934.250	29.448	16.196	979841.312
102	17700	37 16.82	-76 25.61	386.070	1.043	979934.187	29.228	16.061	979841.250
103	17800	37 16.78	-76 25.58	383.620	0.000	979934.375	29.216	16.138	979841.250
104	17900	37 16.75	-76 25.54	380.680	**********	979934.437	29.061	16.077	979841.187
105	18000	37 16.73	-76 25.51	378.260	**********	979934.500	28.900	15.999	979841.187
106	18100	37 16.70	-76 25.48	375.910	0.000	979934.500	28.758	15.937	979841.125
107	18200	37 16.68	-76 25.46	373.170	**********	979934.562	28.678	15.850	979841.062
108	18300	37 16.65	-76 25.43	370.800	**********	979934.750	28.664	15.828	979841.062
109	18400	37 16.62	-76 25.39	367.880	**********	979934.812	28.462	15.698	979841.000
110	18500	37 16.58	-76 25.36	365.360	**********	979935.125	28.541	16.078	979840.937
111	18600	37 16.57	-76 25.36	362.810	**********	979935.187	28.359	16.024	979840.937
112	18700	37 16.53	-76 25.33	360.400	**********	979935.312	28.227	16.045	979840.875
113	18800	37 16.52	-76 25.31	357.740	**********	979935.562	28.386	16.184	979840.812

STATE ROAD 637 - GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA	NAME AND NUM	LATITUDE NORTH +	LONGITUDE EAST +	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
2	BASE 1031	27 17.60	-76 22.69	388.700	0.000	979832.676	26.172	14.840	979842.880
1	1000	27 20.98	-76 26.64	466.910	-142.312	979836.667	33.336	17.411	979847.260
2	2000	27 20.82	-76 26.61	466.060	0.000	979836.667	33.318	17.410	979847.167
3	3000	27 20.64	-76 26.60	462.890	**********	979836.625	33.067	17.272	979847.167
4	4000	27 20.46	-76 26.64	462.000	**********	979836.612	33.178	17.280	979847.126
5	5000	27 20.62	-76 26.66	469.020	2.004	979836.612	33.360	17.317	979847.063
6	6000	27 20.76	-76 26.63	464.070	0.000	979837.042	33.404	17.336	979847.000
7	7000	27 20.73	-76 26.61	449.660	**********	979837.376	32.918	17.255	979844.937
8	8000	27 20.72	-76 26.60	443.260	0.000	979837.675	32.814	17.096	979844.939
9	9000	27 20.70	-76 26.46	436.210	-2404.864	979838.000	32.031	17.166	979844.678
10	10000	27 20.66	-76 26.46	434.670	0.000	979836.642	31.886	17.207	979844.612
11	11000	27 20.63	-76 26.43	413.660	-3043.504	979835.260	31.361	17.234	979844.612
12	12000	27 20.60	-76 26.41	401.060	0.000	979839.937	30.916	17.238	979844.760
13	13000	27 20.57	-76 26.39	388.700	0.000	979840.750	30.479	17.322	979844.667
14	14000	27 20.63	-76 26.38	382.730	0.000	979840.437	30.677	17.163	979844.612
15	15000	27 20.67	-76 26.38	401.330	**********	979838.675	30.761	17.083	979844.678
16	16000	27 20.66	-76 26.32	402.350	-3104.664	979838.612	30.648	17.130	979844.612
17	17000	27 20.65	-76 26.29	403.060	0.000	979838.500	30.662	16.988	979844.612
18	18000	27 20.65	-76 26.26	405.610	**********	979839.260	30.666	16.766	979844.612
19	19000	27 20.65	-76 26.22	421.370	**********	979837.476	30.788	16.337	979844.612
20	20000	27 20.65	-76 26.20	411.660	**********	979838.437	30.386	16.276	979844.612
21	21000	27 20.67	-76 26.16	402.690	0.000	979838.562	29.673	16.232	979844.678
22	22000	27 20.65	-76 26.13	389.190	**********	979838.667	29.306	16.762	979844.612
23	23000	27 20.62	-76 26.09	381.030	**********	979839.062	29.027	16.698	979844.612
24	24000	27 20.60	-76 26.06	389.370	1.044	979839.062	29.220	16.440	979844.760
25	25000	27 20.64	-76 26.04	384.860	**********	979838.562	29.041	16.472	979844.760
26	26000	27 20.67	-76 26.02	402.810	0.000	979837.612	29.970	16.231	979844.667
27	27000	27 20.68	-76 26.00	412.030	**********	979837.062	30.167	16.117	979844.667
28	28000	27 20.63	-76 27.96	407.190	**********	979837.250	29.911	16.023	979844.667
29	29000	27 20.60	-76 27.95	389.860	**********	979837.500	29.486	14.868	979844.628
30	30000	27 20.60	-76 27.48	384.640	**********	979837.375	29.243	14.648	979844.628
31	31000	27 20.60	-76 27.46	383.440	**********	979837.750	29.021	14.635	979844.628
32	32000	27 20.60	-76 27.43	384.020	**********	979837.687	29.232	14.740	979844.662
33	33000	27 20.64	-76 27.40	388.160	1.044	979837.312	29.168	14.688	979844.662
34	34000	27 20.66	-76 27.74	393.070	0.000	979837.500	27.671	14.464	979844.662
35	35000	27 20.66	-76 27.71	390.760	0.000	979837.437	27.691	14.353	979844.662
36	36000	27 20.64	-76 27.66	386.430	**********	979836.812	27.666	14.081	979844.662
37	37000	27 20.67	-76 27.63	386.260	1.044	979836.750	27.426	13.921	979844.662
38	38000	27 20.67	-76 27.56	387.070	0.000	979841.000	26.212	14.056	979844.662
39	39000	27 20.67	-76 27.61	382.000	0.000	979841.250	26.864	14.072	979844.662
40	40000	27 20.65	-76 27.60	382.390	-2867.189	979841.260	26.063	14.067	979844.662
41	41000	27 20.65	-76 27.64	329.030	**********	979840.625	26.061	13.639	979844.662
42	42000	27 20.63	-76 27.63	337.750	1.044	979840.062	26.310	13.781	979844.600
43	43000	27 20.63	-76 27.39	349.310	0.000	979838.375	26.486	13.662	979844.600
44	44000	27 20.62	-76 27.36	363.230	0.000	979836.937	26.600	13.667	979844.600
45	45000	27 20.62	-76 27.36	367.160	**********	979836.625	26.769	13.676	979844.600
46	46000	27 20.60	-76 27.34	366.030	**********	979837.676	26.134	13.642	979844.600
47	47000	27 20.60	-76 27.32	361.630	0.000	979839.062	26.632	13.646	979844.600
48	48000	27 20.60	-76 27.28	362.040	**********	979836.375	26.671	13.683	979844.600
49	49000	27 20.62	-76 27.26	371.130	**********	979838.062	26.471	13.613	979844.600
50	50000	27 20.63	-76 27.22	376.120	**********	979837.625	26.490	13.662	979844.600
51	51000	27 20.68	-76 27.20	381.000	**********	979837.250	26.676	13.666	979844.662
52	52000	27 20.67	-76 27.16	381.060	**********	979836.437	26.726	13.661	979844.662
53	53000	27 20.66	-76 27.13	401.350	**********	979838.675	27.016	13.336	979844.662
54	54000	27 20.66	-76 27.09	410.140	**********	979836.187	27.193	13.304	979844.662
55	55000	27 20.66	-76 27.06	411.760	**********	979836.187	27.200	13.246	979844.628
56	56000	27 20.68	-76 27.03	412.270	**********	979836.125	27.202	13.240	979844.628
57	57000	27 20.68	-76 26.98	411.610	**********	979836.125	27.220	13.190	979844.628
58	58000	27 20.67	-76 26.96	404.330	**********	979838.562	27.026	13.226	979844.662
59	59000	27 20.63	-76 26.96	401.260	**********	979836.625	26.668	13.164	979844.600
60	60000	27 20.60	-76 26.96	400.660	**********	979835.687	26.026	13.270	979844.600
61	61000	27 20.58	-76 26.95	398.160	**********	979835.937	26.813	13.333	979844.637
62	62000	27 20.57	-76 26.95	396.110	**********	979836.437	26.822	13.288	979844.637
63	63000	27 20.57	-76 26.91	376.260	**********	979837.000	26.181	13.268	979844.637
64	64000	27 20.36	-76 26.88	371.620	0.000	979837.500	25.804	13.413	979844.376
65	65000	27 20.35	-76 26.84	364.650	1.044	979837.812	25.943	13.431	979844.376
66	66000	27 20.33	-76 26.83	355.250	0.000	979838.562	25.847	13.470	979844.376
67	67000	27 20.33	-76 26.81	345.750	0.000	979839.125	25.864	13.462	979844.376
68	68000	27 20.33	-76 26.78	342.710	**********	979839.250	25.863	13.384	979844.376
69	69000	27 20.33	-76 26.75	344.640	0.191	979838.937	24.865	13.311	979844.376
70	70000	27 20.33	-76 26.73	344.188	1.044	979838.625	24.672	13.132	979844.376
71	71000	27 20.33	-76 26.70	326.220	0.000	979839.937	24.440	13.246	979844.376
72	72000	27 20.33	-76 26.68	316.230	0.000	979840.562	24.144	13.293	979844.376
73	73000	27 20.30	-76 26.64	312.090	**********	979840.625	23.928	13.264	979844.312
74	74000	27 20.30	-76 26.63	310.150	**********	979841.062	23 901	13.326	979844.312
75	74000	27 20.26	-76 26.68	308.700	0.000	979841.125	23.459	13.327	979844.312
76	77000	27 20.27	-76 26.64	310.210	**********	979841.062	23.972	13.392	979844.250
77	78000	27 20.27	-76 26.60	321.420	0.000	979840.375	24.213	13.351	979844.250
78	79000	27 20.27	-76 26.48	325.480	0.000	979840.437	24.744	13.646	979844.250
79	80000	27 20.27	-76 26.43	327.460	**********	979839.750	25.266	13.736	979844.250
80	81000	27 20.27	-76 26.39	354.430	**********	979836.625	26.090	13.665	979844.250
81	82000	27 20.26	-76 26.36	375.650	**********	979837.687	26.766	13.957	979844.250
82	83000	27 20.23	-76 26.33	376.520	0.000	979837.500	26.667	13.873	979844.250
83	84000	27 20.20	-76 26.29	376.490	0.000	979837.562	26.714	13.907	979844.187
84	85000	27 20.16	-76 26.26	370.670	**********	979837.562	26.292	13.661	979844.125
85	86000	27 20.15	-76 26.23	371.630	**********	979837.250	26.108	13.627	979844.125
86	87000	27 20.17	-76 26.20	376.900	1.044	979836.687	25.994	13.143	979844.125
87	88000	27 20.16	-76 26.16	375.760	0.000	979836.625	25.613	12.897	979844.125
88	89000	27 20.20	-76 26.11	372.620	**********	979836.687	25.606	12.691	979844.187
89	90000	27 20.20	-76 26.08	368.260	**********	979837.000	25.623	12.672	979844.187
90	91000	27 20.20	-76 26.05	366.160	0.000	979836.937	25.161	12.679	979844.187
91	92000	27 20.18	-76 26.01	366.180	**********	979836.750	25.046	12.596	979844.125
92	93000	27 20.16	-76 25.98	368.270	**********	979836.437	24.910	12.344	979844.125
93	94000	27 20.15	-76 25.95	364.660	0.000	979836.750	24.649	12.418	979844.125

STATE ROAD 637 - GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA NAME AND NUM	LATITUDE NORTH +	LONGITUDE EAST +	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
84 88888	37 20.30	-78 25.91	361.120	-748.312	978936.760	24.662	12.336	978946.167
84 88888	37 20.30	-78 25.86	366.310	0.000	978936.812	24.366	12.146	978946.167
87 87000	37 20.30	-78 25.83	365.000	**********	978937.125	24.326	12.217	978946.167
84 88888	37 20.30	-78 25.80	353.000	**********	978937.125	24.160	12.128	978946.167
84 99000	37 20.30	-78 25.74	348.430	2.004	978937.260	23.926	12.004	978946.167
100 10000	37 20.30	-78 25.70	346.110	0.000	978937.312	23.716	11.911	978946.167
101 10100	37 20.30	-78 25.66	343.300	**********	978937.625	23.630	11.868	978946.167
102 10200	37 20.30	-78 25.61	337.700	0.000	978937.837	23.527	13.008	978946.167
103 10300	37 20.30	-78 25.58	330.940	-2404.064	978936.126	23.062	11.796	978946.167
104 10400	37 20.30	-78 25.52	323.230	0.000	978936.667	22.831	11.906	978946.167
105 10500	37 20.30	-78 25.48	317.320	-2048.588	978939.062	22.736	11.912	978946.167
106 10600	37 20.30	-78 25.45	313.000	0.000	978939.562	22.880	12.174	978946.167
107 10700	37 20.30	-78 25.39	313.900	0.000	978939.612	23.177	12.471	978946.167
108 10800	37 20.30	-78 25.36	315.600	0.000	978939.676	23.368	12.626	978946.167
109 10900	37 20.30	-78 25.33	319.446	**********	978939.937	23.784	12.685	978946.167
110 11000	37 20.16	-78 25.28	322.040	0.000	978939.626	23.784	12.603	978946.138
111 11100	37 20.17	-78 25.23	321.140	**********	978939.167	24.176	12.662	978946.138
112 11200	37 20.17	-78 25.20	344.360	**********	978936.427	25.061	13.160	978946.138
113 11300	37 20.16	-78 25.14	361.770	**********	978937.760	24.701	12.703	978946.138
114 11400	37 20.16	-78 25.11	366.010	0.000	978937.427	24.603	12.629	978946.138
115 11500	37 20.20	-78 25.06	368.320	**********	978937.260	24.742	12.661	978946.167
116 11600	37 20.20	-78 25.01	361.700	**********	978937.062	24.606	12.646	978946.167
117 11700	37 20.22	-78 24.96	368.000	1.046	978936.812	24.416	12.152	978946.167
118 11800	37 20.22	-78 24.88	366.040	**********	978937.062	24.320	12.179	978946.167
119 11900	37 20.23	-78 24.83	366.010	0.000	978937.260	24.484	12.362	978946.260
120 12000	37 20.25	-78 24.69	366.000	**********	978937.312	24.606	12.433	978946.260
121 12100	37 20.25	-78 24.66	369.370	**********	978937.376	24.600	12.643	978946.260
122 12200	37 20.27	-78 24.64	366.220	**********	978937.125	24.213	12.767	978946.260
123 12300	37 20.25	-78 24.61	366.910	**********	978936.667	24.660	12.646	978946.260
124 12400	37 20.25	-78 24.76	367.440	**********	978936.437	24.744	12.212	978946.260
125 12500	37 20.25	-78 24.73	367.070	**********	978936.260	24.645	12.030	978946.260
126 12600	37 20.23	-78 24.70	364.480	1.046	978936.260	24.308	11.678	978946.260
127 12700	37 20.23	-78 24.66	364.000	0.000	978936.167	24.210	11.796	978946.260
128 12800	37 20.23	-78 24.61	366.370	0.000	978936.312	24.486	11.893	978946.260
129 12900	37 20.23	-78 24.56	367.240	**********	978936.000	24.312	11.786	978946.260
130 13000	37 20.23	-78 24.52	371.760	1.046	978935.875	24.631	11.981	978946.260
131 13100	37 20.26	-78 24.48	372.600	0.000	978935.667	24.452	11.747	978946.260
132 13200	37 20.26	-78 24.45	370.950	0.000	978935.500	24.115	11.463	978946.260
133 13300	37 20.27	-78 24.41	371.410	-2687.108	978935.500	24.164	11.456	978946.260
134 13400	37 20.27	-78 24.38	372.800	**********	978936.626	24.423	11.704	978946.260
135 13500	37 20.27	-78 24.34	378.610	1.046	978936.437	24.497	11.690	978946.260
136 13600	37 20.26	-78 24.29	376.640	0.000	978936.437	24.698	11.746	978946.312
137 13700	37 20.26	-78 24.25	376.688	0.000	978936.167	24.464	11.664	978946.312
138 13800	37 20.26	-78 24.21	380.100	**********	978935.000	24.477	11.610	978946.312
139 13900	37 20.26	-78 24.16	381.900	**********	978934.476	24.487	11.448	978946.312
140 14000	37 20.26	-78 24.12	384.000	0.000	978934.760	24.667	11.467	978946.312
141 14100	37 20.26	-78 24.08	386.380	**********	978934.812	25.013	11.766	978946.312
142 14200	37 20.30	-78 24.03	394.470	**********	978934.500	25.262	11.800	978946.312
143 14300	37 20.32	-78 24.00	402.020	**********	978934.260	25.706	11.894	978946.376
144 14400	37 20.32	-78 23.98	407.080	**********	978933.937	25.885	12.000	978946.376
145 14500	37 20.32	-78 23.91	407.410	**********	978933.667	25.667	11.762	978946.376
146 14600	37 20.36	-78 23.86	406.980	**********	978933.937	25.700	11.852	978946.376
147 14700	37 20.37	-78 23.83	407.810	**********	978934.062	25.900	12.091	978946.437
148 14800	37 20.36	-78 23.80	410.260	**********	978934.062	26.102	12.198	978946.437
149 14900	37 20.40	-78 23.76	413.420	**********	978933.812	26.263	12.163	978946.500
150 15000	37 20.42	-78 23.71	416.420	**********	978933.500	26.173	11.870	978946.500
151 15100	37 20.43	-78 23.68	420.400	**********	978933.312	26.332	11.893	978946.500
152 15200	37 20.43	-78 23.64	423.660	**********	978932.937	26.261	11.816	978946.500
153 15300	37 20.45	-78 23.61	422.100	**********	978932.812	25.965	11.681	978946.562
154 15400	37 20.46	-78 23.56	424.480	**********	978933.167	26.042	12.046	978946.562
155 15500	37 20.46	-78 23.53	427.820	**********	978933.250	26.022	12.240	978946.562
156 15600	37 20.46	-78 23.48	440.830	**********	978933.667	27.063	12.847	978946.562
157 15700	37 20.46	-78 23.46	448.110	0.000	978932.000	27.714	12.398	978946.562
158 15800	37 20.46	-78 23.41	466.000	1.046	978931.626	27.865	12.347	978946.562

STATE ROAD 636 - GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA NAME AND NUM	LATITUDE NORTH °	LONGITUDE EAST °	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
2 BASE 1031	27 17.60	-78 23.69	200.700	0.000	979832.676	26.173	16.666	979862.200
1 100	27 23.42	-78 29.04	866.200	-748.312	979832.662	34.066	16.684	979850.612
2 200	27 23.40	-78 28.02	867.830	0.000	979832.800	36.121	16.750	979850.612
3 300	27 23.36	-78 26.96	860.470	**********	979832.312	36.070	16.647	979850.612
4 400	27 23.37	-78 26.95	866.910	**********	979832.612	35.187	16.610	979850.750
5 500	27 23.37	-78 26.91	863.200	2.004	979833.426	34.690	16.028	979850.750
6 600	27 23.35	-78 26.86	866.870	0.000	979834.126	34.749	16.164	979850.750
7 700	27 23.33	-78 26.84	863.870	**********	979834.312	34.765	16.195	979850.750
8 800	27 23.33	-78 26.80	865.630	0.000	979833.812	34.607	16.001	979850.667
9 900	27 23.30	-78 26.76	865.690	-2404.066	979833.812	34.613	16.056	979850.667
10 1000	27 23.30	-78 26.71	866.170	0.000	979833.687	35.129	16.238	979850.667
11 1100	27 23.30	-78 26.66	867.630	-2049.508	979833.375	35.146	16.128	979850.667
12 1200	27 23.30	-78 26.63	868.820	0.000	979834.250	34.850	16.330	979850.667
13 1300	27 23.30	-78 26.60	837.760	0.000	979834.937	34.653	16.611	979850.667
14 1400	27 23.30	-78 26.58	824.870	0.000	979834.126	34.748	16.812	979850.667
15 1500	27 23.30	-78 26.53	833.010	**********	979834.437	34.768	16.641	979850.667
16 16000	27 23.30	-78 26.50	830.050	-2195.066	979834.437	34.815	16.561	979850.667
17 17000	27 23.26	-78 26.45	829.200	0.000	979834.750	34.662	16.513	979850.625
18 18000	27 23.26	-78 26.39	826.140	**********	979834.000	34.621	16.475	979850.625
19 19000	27 23.27	-78 26.35	824.460	**********	979834.312	35.006	17.116	979850.625
20 20000	27 23.23	-78 26.34	823.010	**********	979834.437	35.057	17.219	979850.562
21 21000	27 23.22	-78 26.31	822.760	0.000	979834.312	34.884	17.124	979850.562
22 22000	27 23.20	-78 26.29	825.130	**********	979834.062	34.813	17.003	979850.500
23 23000	27 23.16	-78 26.26	827.490	**********	979835.750	34.675	16.864	979850.500
24 24000	27 23.16	-78 26.22	816.240	1.048	979835.562	34.613	17.003	979850.500
25 25000	27 23.16	-78 26.18	807.000	**********	979837.375	34.641	17.245	979850.500
26 26000	27 23.17	-78 26.14	809.250	0.000	979838.000	34.454	17.426	979850.500
27 27000	27 23.17	-78 26.11	806.890	**********	979838.062	34.152	17.273	979850.500
28 28000	27 23.17	-78 26.08	808.220	**********	979838.250	33.903	17.160	979850.500
29 29000	27 23.18	-78 26.06	802.220	**********	979838.750	33.676	17.228	979850.437
30 30000	27 23.18	-78 26.00	809.420	**********	979838.062	33.721	17.270	979850.437
31 31000	27 23.18	-78 27.96	806.060	**********	979838.937	33.237	17.000	979850.437
32 32000	27 23.18	-78 27.91	802.690	**********	979838.937	32.873	16.651	979850.437
33 33000	27 23.18	-78 27.86	870.190	1.048	979839.000	32.771	16.734	979850.437
34 34000	27 23.16	-78 27.83	867.020	0.000	979839.126	32.686	16.688	979850.437
35 35000	27 23.17	-78 27.78	868.390	0.000	979839.376	32.669	16.798	979850.000
36 36000	27 23.17	-78 27.74	863.160	**********	979839.562	32.662	16.686	979850.000
37 37000	27 23.16	-78 27.70	860.660	1.048	979839.687	32.503	16.798	979850.000
38 38000	27 23.20	-78 27.64	866.960	0.000	979839.812	32.434	16.787	979850.000
39 39000	27 23.20	-78 27.61	864.660	0.000	979839.937	32.356	16.788	979850.000
40 40000	27 23.22	-78 27.68	865.160	-2887.188	979839.937	32.222	16.698	979850.062
41 41000	27 23.22	-78 27.64	863.660	**********	979840.000	32.126	16.699	979850.062
42 42000	27 23.22	-78 27.61	862.220	1.048	979840.126	32.127	16.703	979850.562
43 43000	27 23.22	-78 27.48	861.260	0.000	979840.062	31.972	16.676	979850.562
44 44000	27 23.22	-78 27.45	862.290	0.000	979840.000	32.007	16.677	979850.562
45 45000	27 23.22	-78 27.41	865.630	**********	979840.187	31.930	16.603	979850.062
46 46000	27 23.22	-78 27.38	866.860	**********	979840.250	31.762	16.614	979850.562
47 47000	27 23.22	-78 27.33	867.860	0.000	979840.250	31.776	16.607	979850.562
48 48000	27 23.22	-78 27.28	868.000	**********	979840.000	31.880	16.611	979850.562
49 49000	27 23.22	-78 27.25	863.390	**********	979839.812	31.662	16.438	979850.562
50 50000	27 23.20	-78 27.20	864.180	**********	979839.625	31.636	16.339	979850.500
51 51000	27 23.20	-78 27.16	862.670	**********	979839.750	31.796	16.357	979850.500
52 52000	27 23.16	-78 27.13	868.780	**********	979840.000	31.522	16.264	979850.500
53 53000	27 23.17	-78 27.09	835.670	**********	979840.687	31.196	16.241	979850.500
54 54000	27 23.15	-78 27.06	837.300	**********	979840.750	30.662	16.172	979850.437
55 55000	27 23.15	-78 27.01	837.000	**********	979840.375	31.131	16.158	979850.437
56 56000	27 23.13	-78 26.98	847.020	**********	979839.937	31.646	16.298	979850.437
57 57000	27 23.12	-78 26.93	848.210	**********	979840.125	31.672	16.546	979850.437
58 58000	27 23.12	-78 26.88	841.660	**********	979839.937	31.075	16.011	979850.437
59 59000	27 23.10	-78 26.84	837.670	**********	979840.000	30.737	15.816	979850.375
60 60000	27 23.10	-78 26.81	836.820	**********	979841.125	29.941	15.726	979850.376
61 61000	27 23.10	-78 26.76	836.660	**********	979842.187	29.104	15.564	979850.376
62 62000	27 23.10	-78 26.73	848.700	**********	979842.562	24.716	15.460	979850.376
63 63000	27 23.12	-78 26.70	860.260	0.000	979842.812	26.206	15.233	979850.437
64 64000	27 23.12	-78 26.66	872.630	1.048	979842.250	27.662	15.173	979850.437
65 65000	27 23.12	-78 26.63	864.670	0.000	979842.562	27.432	15.001	979850.437
66 66000	27 23.10	-78 26.60	865.100	0.000	979842.250	27.218	14.746	979850.376
67 67000	27 23.10	-78 26.56	864.830	**********	979842.125	27.025	14.592	979850.376
68 68000	27 23.10	-78 26.51	868.240	0.181	979842.750	27.012	14.493	979850.376
69 69000	27 23.10	-78 26.46	877.740	1.048	979842.126	27.301	14.617	979850.376
70 70000	27 23.08	-78 26.43	866.310	0.000	979841.375	27.344	14.166	979850.376
71 71000	27 23.06	-78 26.39	865.940	0.000	979841.250	27.181	14.016	979850.376
72 72000	27 23.07	-78 26.34	862.320	**********	979841.500	27.128	14.068	979850.312
73 73000	27 23.07	-78 26.29	860.210	**********	979841.626	27.036	14.064	979850.312
74 74000	27 23.05	-78 26.26	873.330	0.000	979841.937	26.762	14.018	979850.312
75 75000	27 23.05	-78 26.21	872.070	**********	979841.812	26.498	13.806	979850.312
76 76000	27 23.03	-78 26.16	872.120	0.000	979841.750	26.449	13.787	979850.312
77 77000	27 23.03	-78 26.14	874.670	0.000	979841.376	26.306	13.827	979850.312
78 78000	27 23.02	-78 26.11	876.500	**********	979840.937	26.306	13.397	979850.250
79 79000	27 23.02	-78 26.08	861.760	**********	979840.750	26.378	13.354	979850.250
80 80000	27 23.02	-78 26.05	868.850	**********	979840.312	26.266	13.201	979850.250
81 81000	27 23.00	-78 26.01	852.860	0.000	979840.000	26.612	13.240	979850.250
82 82000	27 22.98	-78 25.96	869.860	0.000	979839.187	26.562	12.965	979850.187
83 83000	27 22.97	-78 25.98	865.740	**********	979838.937	26.694	12.886	979850.187
84 84000	27 22.95	-78 25.89	811.320	**********	979838.437	26.954	12.925	979850.187
85 85000	27 22.92	-78 25.84	812.960	1.048	979838.187	26.922	12.637	979850.126
86 86000	27 22.90	-78 25.81	809.800	0.000	979838.375	26.817	12.636	979850.126
87 87000	27 22.87	-78 25.76	863.350	**********	979838.375	26.261	12.493	979850.062
88 88000	27 22.83	-78 25.74	867.260	**********	979838.875	26.228	12.474	979850.000
89 89000	27 22.82	-78 25.70	868.400	0.000	979838.937	26.133	12.447	979850.000
90 90000	27 22.80	-78 25.66	864.030	**********	979839.437	25.724	12.595	979849.937
91 91000	27 22.76	-78 25.66	876.620	**********	979840.062	25.448	12.623	979849.937
92 92000	27 22.77	-78 25.64	870.610	0.000	979840.062	25.840	12.603	979849.876
93 93000	27 22.73	-78 25.61	872.610	0.000	979839.875	25.853	12.267	979849.876
94 94000	27 22.70	-78 25.60	868.250	**********	979839.500	25.636	12.466	979849.812
95 95000	27 22.66	-78 25.66	881.940	**********	979838.687	25.771	12.604	979849.750
96 96000	27 22.65	-78 25.64	886.120	**********	979838.187	25.690	12.311	979849.750
97 97000	27 22.63	-78 25.61	886.760	**********	979838.062	25.636	12.235	979849.687
98 98000	27 22.62	-78 25.66	887.500	**********	979838.125	25.636	12.276	979849.687
99 99000	27 22.58	-78 25.66	889.110	**********	979837.875	25.758	12.166	979849.626

STATE ROAD 636 - GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA NAME AND NUM		LATITUDE NORTH +	LONGITUDE EAST +	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
100	10000	27 22.67	-79 25.41	402.260	**********	979027.662	25.780	12.060	979040.626
101	10100	27 22.65	-79 25.38	407.260	0.000	979027.167	26.633	12.062	979040.662
102	10200	27 22.66	-79 25.36	407.040	**********	979027.167	26.664	11.976	979040.662
103	10300	27 22.63	-79 25.33	407.060	**********	979027.062	26.776	11.882	979040.662
104	10400	27 22.62	-79 25.29	406.620	- 0.000	979026.937	26.642	11.982	979040.662
105	10500	27 22.62	-79 25.26	411.980	**********	979026.626	26.847	11.784	979040.662
106	10600	27 22.60	-79 25.23	416.670	**********	979026.126	26.642	11.624	979040.600
107	10700	27 22.60	-79 25.20	416.000	**********	979026.076	26.693	11.636	979040.600
108	10800	27 22.60	-79 25.16	416.000	**********	979026.126	26.736	11.627	979040.600
109	10900	27 22.44	-79 25.09	414.670	**********	979026.126	26.632	11.662	979040.600
110	11000	27 22.44	-79 25.06	413.220	1.066	979026.187	26.673	11.476	979040.600
111	11100	27 22.47	-79 24.98	414.510	**********	979026.126	26.670	11.523	979040.627
112	11200	27 22.46	-79 24.95	415.560	**********	979026.937	26.626	11.441	979040.627
113	11300	27 22.45	-79 24.91	416.960	0.000	979026.626	26.600	11.391	979040.627
114	11400	27 22.43	-79 24.88	420.460	0.000	979026.437	26.642	11.202	979040.627
115	11500	27 22.42	-79 24.84	421.640	**********	979026.187	26.486	11.078	979040.276
116	11600	27 22.42	-79 24.81	422.530	**********	979026.000	26.406	10.980	979040.276
117	11700	27 22.42	-79 24.76	426.460	**********	979026.687	26.332	10.911	979040.276
118	11800	27 22.40	-79 24.73	426.560	0.000	979026.000	26.260	10.781	979040.276
119	11900	27 22.40	-79 24.66	426.900	0.000	979026.376	26.362	10.733	979040.276
120	12000	27 22.40	-79 24.64	431.160	0.000	979026.260	26.434	10.731	979040.276
121	12100	27 22.40	-79 24.60	432.360	0.000	979026.187	26.464	10.717	979040.276
122	12200	27 22.38	-79 24.56	433.760	0.000	979026.937	26.397	10.601	979040.276
123	12300	27 22.36	-79 24.51	436.760	**********	979026.760	26.376	10.514	979040.276
124	12400	27 22.34	-79 24.46	436.080	**********	979026.562	26.446	10.506	979040.276
125	12500	27 22.36	-79 24.43	442.410	**********	979026.312	26.600	10.511	979040.276
126	12600	27 22.37	-79 24.38	445.840	**********	979026.062	26.661	10.476	979040.212
127	12700	27 22.36	-79 24.34	446.360	**********	979026.126	26.767	10.462	979040.212
128	12800	27 22.36	-79 24.31	446.330	**********	979026.062	26.656	10.467	979040.212
129	12900	27 22.33	-79 24.28	444.970	**********	979026.250	26.626	10.480	979040.250
130	13000	27 22.32	-79 24.26	436.760	**********	979026.626	26.644	10.463	979040.250
131	13100	27 22.30	-79 24.21	433.810	**********	979026.612	26.397	10.401	979040.250
132	13200	27 22.28	-79 24.16	430.960	1.048	979026.126	26.488	10.761	979040.167
133	13300	27 22.28	-79 24.11	426.030	0.000	979026.312	26.382	10.783	979040.126
134	13400	27 22.23	-79 24.08	426.570	0.000	979026.187	26.186	10.648	979040.126
135	13500	27 22.23	-79 24.05	426.330	0.000	979026.126	26.002	10.696	979040.126
136	13600	27 22.23	-79 24.01	422.860	0.000	979026.437	26.088	10.622	979040.126
137	13700	27 22.22	-79 23.96	419.210	0.000	979026.562	26.025	10.624	979040.126
138	13800	27 22.23	-79 23.93	416.960	**********	979026.876	26.664	10.697	979040.126
139	13900	27 22.23	-79 23.88	416.990	**********	979026.126	26.626	10.762	979040.126
140	14000	27 22.23	-79 23.84	419.370	**********	979026.260	26.698	10.701	979040.126
141	14100	27 22.23	-79 23.81	466.640	0.000	979026.437	26.766	10.811	979040.126
142	14200	27 22.23	-79 23.76	467.030	0.000	979026.437	26.617	10.736	979040.126
143	14300	27 22.23	-79 23.73	466.880	0.000	979026.437	26.674	10.632	979040.126
144	14400	27 22.23	-79 23.68	466.520	**********	979026.062	26.678	10.610	979040.126
145	14500	27 22.23	-79 23.64	466.440	**********	979026.437	26.718	10.767	979040.126
146	14600	27 22.23	-79 23.60	411.130	**********	979026.250	26.646	10.623	979040.126
147	14700	27 22.20	-79 23.56	413.640	**********	979026.126	26.648	10.643	979040.062
148	14800	27 22.16	-79 23.51	416.130	0.000	979026.000	26.667	10.664	979040.062
149	14900	27 22.17	-79 23.46	416.210	0.000	979026.626	26.616	10.662	979040.000

STATE ROAD 634 - GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA	NAME AND NUM	LATITUDE NORTH +	LONGITUDE EAST +	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
2	BASE 1031	37 17.60	-76 23.48	399.700	0.000	979932.676	28.123	14.640	979842.260
1	1000	37 26.63	-76 22.61	473.220	-749.312	979944.126	33.025	17.765	979856.667
2	2000	37 26.63	-76 23.60	469.970	0.000	979944.167	33.670	17.640	979856.667
3	3000	37 26.62	-76 23.64	466.660	**********	979946.167	33.413	17.600	979856.667
4	4000	37 26.60	-76 23.63	466.170	**********	979947.937	33.000	17.145	979856.626
5	5000	37 26.77	-76 23.63	463.940	2.004	979947.662	32.666	16.765	979856.626
6	6000	37 26.78	-76 23.46	463.440	0.000	979947.667	32.666	16.861	979856.662
7	7000	37 26.73	-76 23.43	466.920	**********	979947.675	32.894	16.907	979856.662
8	8000	37 26.70	-76 23.39	462.710	0.000	979944.167	32.266	16.646	979856.600
9	9000	37 26.67	-76 23.26	447.990	-2404.066	979944.626	32.302	17.023	979856.437
10	10000	37 26.62	-76 23.26	444.980	0.000	979944.676	32.218	17.161	979856.437
11	11000	37 26.60	-76 23.26	446.060	-2049.504	979944.760	32.262	17.063	979856.376
12	12000	37 26.57	-76 23.24	444.530	0.000	979944.500	32.278	17.081	979856.312
13	13000	37 26.53	-76 23.24	449.670	0.000	979944.312	32.335	16.982	979856.250
14	14000	37 26.50	-76 23.23	443.640	0.000	979944.626	32.184	17.046	979856.187
15	15000	37 26.46	-76 23.23	436.600	**********	979949.126	32.219	17.263	979856.187
16	16000	37 26.46	-76 23.21	436.290	-2108.064	979949.250	32.176	17.291	979856.126
17	17000	37 26.43	-76 23.20	435.700	0.000	979949.312	32.177	17.316	979856.126
18	18000	37 26.38	-76 23.20	437.660	**********	979948.167	32.260	17.220	979856.062
19	19000	37 26.36	-76 23.20	442.260	**********	979946.626	32.225	17.140	979856.000
20	20000	37 26.32	-76 23.26	440.990	**********	979946.750	32.267	17.226	979857.937
21	21000	37 26.28	-76 23.26	436.060	0.000	979948.562	31.666	16.926	979857.876
22	22000	37 26.27	-76 23.23	434.020	**********	979948.750	31.906	17.026	979857.876
23	23000	37 26.23	-76 23.21	434.630	**********	979948.612	31.893	17.062	979857.812
24	24000	37 26.22	-76 23.16	434.320	1.044	979948.612	31.666	17.063	979857.812
25	25000	37 26.20	-76 23.14	436.520	**********	979948.500	31.807	16.910	979857.812
26	26000	37 26.20	-76 23.11	434.110	**********	979948.427	31.694	16.666	979857.812
27	27000	37 26.18	-76 23.06	425.640	**********	979948.750	31.926	16.902	979857.750
28	28000	37 26.16	-76 23.03	421.440	**********	979948.675	30.727	16.283	979857.750
29	29000	37 26.17	-76 23.00	416.110	**********	979948.612	30.436	16.177	979857.750
30	30000	37 26.17	-76 22.96	415.000	**********	979949.260	30.646	16.266	979857.750
31	31000	37 26.16	-76 22.91	413.740	1.044	979949.250	30.430	16.216	979857.687
32	32000	37 26.12	-76 22.69	413.660	0.000	979949.126	30.266	16.277	979857.687
33	33000	37 26.06	-76 22.69	410.730	0.000	979949.312	30.256	16.248	979857.626
34	34000	37 26.03	-76 22.91	412.490	**********	979949.167	30.466	16.289	979857.562
35	35000	37 26.02	-76 22.96	416.010	1.044	979949.000	30.827	16.272	979857.500
36	36000	37 27.97	-76 22.96	411.220	0.000	979949.250	30.466	16.660	979857.437
37	37000	37 27.97	-76 23.00	407.260	-2887.199	979948.437	30.276	16.366	979857.437
38	38000	37 27.93	-76 23.01	407.000	**********	979949.500	30.276	16.496	979857.376
39	39000	37 27.92	-76 23.03	406.470	1.044	979948.250	30.262	16.250	979857.376
40	40000	37 27.67	-76 23.03	410.030	0.000	979948.937	30.163	16.196	979857.312
41	41000	37 27.66	-76 23.01	407.070	0.000	979948.612	30.611	16.627	979857.250
42	42000	37 27.62	-76 23.00	397.200	**********	979948.126	29.261	16.732	979857.250
43	43000	37 27.76	-76 22.96	392.030	**********	979948.437	29.120	16.769	979857.187
44	44000	37 27.76	-76 22.86	392.430	0.000	979948.126	28.826	16.644	979857.126
45	45000	37 27.73	-76 22.86	393.760	**********	979948.000	28.916	16.466	979857.126
46	46000	37 27.70	-76 22.81	397.700	**********	979948.562	28.912	16.347	979857.062
47	47000	37 27.66	-76 22.68	398.620	**********	979948.126	28.671	16.046	979857.062
48	48000	37 27.65	-76 22.68	398.190	**********	979948.167	28.679	16.088	979857.000
50	50000	37 27.60	-76 22.61	396.770	**********	979947.937	28.321	14.788	979856.937
51	51000	37 27.57	-76 22.60	397.010	**********	979947.812	28.264	14.723	979856.876
52	52000	37 27.52	-76 22.74	396.170	**********	979947.500	27.966	14.486	979856.812
53	53000	37 27.52	-76 22.74	395.460	-749.312	979947.562	27.944	14.466	979856.812
54	54000	37 27.50	-76 22.70	394.250	0.000	979947.562	27.672	14.426	979856.750
55	55000	37 27.46	-76 22.63	391.760	**********	979947.750	27.679	14.617	979856.750
56	56000	37 27.47	-76 22.60	387.720	**********	979947.612	27.692	14.366	979856.687
57	57000	37 27.46	-76 22.64	386.620	2.004	979947.612	27.610	14.267	979856.687
58	58000	37 27.43	-76 22.64	382.570	0.000	979947.937	27.366	14.219	979856.687
59	59000	37 27.43	-76 22.63	378.660	**********	979947.937	26.984	14.036	979856.687
60	60000	37 27.40	-76 22.61	374.320	0.000	979947.937	26.726	13.690	979856.626
61	61000	37 27.37	-76 22.60	372.550	-2404.066	979944.167	26.664	13.959	979856.562
62	62000	37 27.33	-76 22.46	366.990	0.000	979944.126	26.336	13.744	979856.500
63	63000	37 27.32	-76 22.46	365.440	-2049.504	979944.250	26.186	13.666	979856.500
64	64000	37 27.28	-76 22.46	363.740	0.000	979944.437	26.179	13.773	979856.437
65	65000	37 27.27	-76 22.41	360.760	0.000	979944.376	25.912	13.607	979856.437
66	66000	37 27.25	-76 22.36	357.230	**********	979944.376	25.676	13.382	979856.376
67	67000	37 27.22	-76 22.34	354.060	-2108.064	979944.376	25.328	13.254	979856.376
68	68000	37 27.20	-76 22.31	352.410	0.000	979944.437	25.223	13.204	979856.312
69	69000	37 27.16	-76 22.29	352.330	**********	979944.250	25.074	13.067	979856.312
70	70000	37 27.16	-76 22.26	353.570	**********	979944.000	24.961	12.922	979856.312
71	71000	37 27.17	-76 22.26	357.460	**********	979947.667	25.056	12.664	979856.312
72	72000	37 27.13	-76 22.23	360.360	0.000	979947.500	25.167	12.667	979856.250
73	73000	37 27.12	-76 22.20	363.150	**********	979944.937	24.864	12.676	979856.187
74	74000	37 27.08	-76 22.16	364.610	**********	979944.626	24.724	12.296	979856.187
75	75000	37 27.05	-76 22.15	364.000	1.044	979944.562	24.695	12.260	979856.126
76	76000	37 27.03	-76 22.13	361.270	**********	979944.562	24.466	12.144	979856.062
77	77000	37 27.00	-76 22.11	357.800	0.000	979944.750	24.339	12.135	979856.062
78	78000	37 26.97	-76 22.09	353.670	**********	979944.937	24.203	12.140	979856.000
79	79000	37 26.95	-76 22.06	350.760	**********	979947.187	24.209	12.244	979855.937
80	80000	37 26.93	-76 22.05	348.620	**********	979947.125	24.022	12.126	979855.937
81	81000	37 26.90	-76 22.01	347.950	**********	979947.125	23.980	12.093	979855.876
82	82000	37 26.88	-76 22.00	346.810	**********	979947.062	23.906	11.977	979855.876
83	83000	37 26.85	-76 21.98	345.680	1.044	979947.062	23.781	11.961	979855.812
84	84000	37 26.82	-76 21.95	344.420	0.000	979947.250	23.675	12.126	979855.750
85	85000	37 26.80	-76 21.93	343.600	0.000	979947.250	23.634	12.118	979855.750
86	86000	37 26.77	-76 21.91	343.180	**********	979947.250	23.642	12.134	979855.687
87	87000	37 26.73	-76 21.89	341.800	1.044	979947.250	23.726	12.077	979855.626
88	88000	37 26.70	-76 21.86	341.210	0.000	979947.375	23.657	12.218	979855.626
89	89000	37 26.65	-76 21.86	338.800	0.000	979947.062	23.661	11.891	979855.562
90	90000	37 26.62	-76 21.84	336.830	-2887.199	979947.062	23.677	12.223	979855.500
91	91000	37 26.60	-76 21.84	330.540	**********	979947.675	23.602	12.226	979855.437
92	92000	37 26.67	-76 21.85	324.630	0.000	979944.375	23.479	12.407	979855.437
93	93000	37 26.85	-76 21.63	316.040	0.000	979944.667	23.240	12.391	979856.376
94	94000	37 26.82	-76 21.63	311.630	**********	979949.126	23.076	12.447	979856.312

STATE ROAD 634 - GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA NAME	AND NUM	LATITUDE NORTH °	LONGITUDE EAST °	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
95	95000	37 26.46	-78 21.60	304.750	*********	979949.500	22.904	12.610	979955.212
96	96000	37 26.47	-78 21.76	307.250	0.000	979949.937	23.026	12.469	979955.250
97	97000	37 26.46	-78 21.72	298.970	*********	979950.562	22.669	12.765	979955.250
98	98000	37 26.42	-78 21.70	296.510	*********	979950.687	22.596	12.744	979955.187
99	99000	37 26.40	-78 21.66	297.230	*********	979950.500	22.344	12.646	979955.187
100	10000	37 26.36	-78 21.64	298.000	*********	979950.687	22.629	12.606	979955.125
101	10100	37 26.37	-78 21.61	298.310	*********	979950.562	22.641	12.772	979956.125
102	10200	37 26.33	-78 21.66	295.380	*********	979950.375	23.112	13.027	979955.062
103	10300	37 26.32	-78 21.64	308.850	*********	979949.500	23.491	12.864	979955.062
104	10400	37 26.30	-78 21.61	321.670	*********	979944.500	23.696	12.731	979955.000
105	10500	37 26.26	-78 21.48	333.300	*********	979947.812	24.165	12.617	979955.000
106	10600	37 26.27	-78 21.45	346.600	*********	979947.187	24.831	13.003	979956.000
107	10700	37 26.25	-78 21.40	361.690	*********	979946.062	25.128	12.766	979954.937
108	10800	37 26.23	-78 21.36	376.480	*********	979945.187	25.666	12.647	979954.937
109	10900	37 26.23	-78 21.31	384.900	*********	979944.562	26.022	12.694	979954.937
110	11000	37 26.20	-78 21.26	386.740	*********	979944.437	26.130	12.670	979954.875
111	11100	37 26.16	-78 21.25	387.370	*********	979944.126	26.704	12.402	979954.875
112	11200	37 26.17	-78 21.23	385.980	0.000	979944.125	26.677	12.412	979954.812
113	11300	37 26.13	-78 21.20	384.900	1.048	979944.000	26.636	12.311	979954.812
114	11400	37 26.12	-78 21.16	386.480	0.000	979943.937	26.606	12.324	979954.750
115	11500	37 26.06	-78 21.15	391.440	0.000	979943.437	26.843	12.192	979954.687
116	11600	37 26.05	-78 21.14	397.390	*********	979943.250	25.939	12.365	979954.687
117	11700	37 26.02	-78 21.13	403.650	0.191	979943.037	26.283	12.519	979954.625
118	11600	37 26.00	-78 21.13	410.490	0.000	979942.375	26.427	12.426	979954.562
119	11900	37 25.97	-78 21.11	416.510	0.000	979941.812	26.467	12.251	979954.562
120	12000	37 25.93	-78 21.09	421.140	*********	979941.667	26.761	12.417	979954.500
121	12100	37 25.90	-78 21.09	423.640	*********	979941.562	26.937	12.448	979954.437
122	12200	37 25.87	-78 21.09	427.190	0.000	979941.187	27.000	12.430	979954.375
123	12300	37 25.83	-78 21.06	429.140	*********	979941.312	27.310	12.672	979954.375
124	12400	37 25.82	-78 21.08	431.650	0.000	979941.000	27.269	12.550	979954.312
125	12500	37 25.76	-78 21.06	433.800	0.000	979941.000	27.496	12.702	979954.250
126	12600	37 25.75	-78 21.09	434.970	*********	979940.687	27.347	12.612	979954.250
127	12700	37 25.72	-78 21.11	437.160	*********	979940.687	27.501	12.691	979954.187
128	12800	37 25.70	-78 21.13	439.690	*********	979940.312	27.530	12.623	979954.125
129	12900	37 25.67	-78 21.13	442.200	0.000	979940.000	27.509	12.427	979954.125
130	13000	37 25.63	-78 21.13	443.370	0.000	979939.625	27.253	12.131	979954.062
131	13100	37 25.67	-78 21.09	444.710	*********	979939.875	27.774	12.606	979953.937
132	13200	37 25.55	-78 21.06	445.770	1.048	979939.875	27.664	12.662	979953.937
133	13300	37 25.53	-78 21.03	446.740	0.000	979939.687	27.614	12.676	979953.937
134	13400	37 25.52	-78 21.00	447.690	*********	979939.375	27.644	12.368	979953.875
135	13500	37 25.50	-78 20.86	448.650	*********	979939.312	27.636	12.332	979953.875
136	13600	37 25.50	-78 20.93	452.020	0.000	979939.187	27.612	12.384	979953.875
137	13700	37 25.50	-78 20.89	456.600	*********	979938.500	27.587	11.984	979953.875
138	13800	37 25.47	-78 20.86	459.430	*********	979938.500	27.673	12.203	979953.812
139	13900	37 25.35	-78 20.86	464.840	0.000	979938.812	27.958	12.448	979953.625

U.S. HIGHWAY 60 - GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA	NAME AND NUM	LATITUDE NORTH +	LONGITUDE EAST +	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
2	BASE 1031	37 17.80	-76 23.69	399.700	0.000	979932.875	26.172	14.540	979842.250
6	21100	37 28.07	-76 19.01	290.310	-749.312	979954.312	22.730	12.618	979858.675
5	20900	37 28.04	-76 19.05	291.550	0.000	979954.687	23.164	13.230	979854.937
4	20700	37 28.04	-76 19.09	291.700	**********	979954.687	23.179	13.302	979864.937
3	20500	37 28.00	-76 19.13	289.540	**********	979954.675	23.177	13.304	979864.937
2	20300	37 29.02	-76 19.16	284.840	2.004	979955.187	23.023	13.234	979869.000
1	20100	37 29.03	-76 19.21	276.720	0.000	979955.500	22.744	13.234	979869.000
1	11900	37 29.05	-76 19.30	276.620	**********	979954.062	21.265	11.752	979869.000
2	19700	37 29.07	-76 19.34	279.100	0.000	979955.437	22.666	13.146	979869.062
3	19600	37 29.06	-76 19.38	279.720	-2404.055	979955.250	23.470	12.930	979869.062
4	19300	37 29.10	-76 19.43	280.050	0.000	979955.062	22.331	12.780	979869.062
5	19200	37 29.10	-76 19.46	280.000	-2049.500	979955.000	22.331	12.764	979869.062
6	18900	37 29.12	-76 19.51	276.410	0.000	979954.812	21.873	12.317	979869.125
7	18700	37 29.12	-76 19.56	281.950	0.000	979954.812	22.209	12.692	979869.125
8	18500	37 29.13	-76 19.60	282.610	0.000	979954.625	22.081	12.442	979869.125
9	18300	37 29.15	-76 19.64	284.440	**********	979954.812	22.304	12.661	979869.187
10	18100	37 29.15	-76 19.68	286.720	-2104.044	979954.562	22.290	12.646	979869.187
11	17900	37 29.17	-76 19.73	287.210	0.000	979954.625	22.422	12.636	979869.187
12	17700	37 29.16	-76 19.76	288.328	**********	979954.375	22.203	12.443	979869.187
13	17500	37 29.20	-76 19.81	289.650	**********	979954.250	22.268	12.361	979869.250
14	17300	37 29.20	-76 19.86	292.650	0.000	979954.000	22.242	12.364	979869.250
15	17100	37 29.22	-76 19.89	298.600	**********	979953.937	22.786	12.671	979869.250
16	16900	37 29.23	-76 19.93	304.620	**********	979953.562	22.924	12.639	979869.312
17	16700	37 29.23	-76 19.96	306.840	1.044	979953.250	23.027	12.494	979869.312
18	16500	37 29.25	-76 20.01	312.010	**********	979953.000	23.042	12.400	979869.312
19	16300	37 29.27	-76 20.06	313.090	0.000	979953.000	23.120	12.442	979869.312
20	16100	37 29.27	-76 20.08	312.070	**********	979952.676	22.869	12.246	979869.312
21	15900	37 29.26	-76 20.13	309.480	**********	979952.750	22.806	11.952	979869.375
22	15700	37 29.30	-76 20.16	308.740	**********	979953.187	22.874	12.145	979869.375
23	15500	37 29.30	-76 20.21	307.840	**********	979953.437	22.449	12.156	979869.375
24	15300	37 29.32	-76 20.26	295.920	**********	979953.625	22.083	11.990	979869.375
25	15100	37 29.33	-76 20.30	288.720	**********	979954.125	21.664	11.668	979869.437
26	14900	37 29.33	-76 20.34	279.110	1.046	979954.812	21.618	12.098	979869.437
27	14700	37 29.35	-76 20.40	278.940	0.000	979955.250	21.724	12.312	979869.437
28	14600	37 29.37	-76 20.43	278.940	0.000	979955.375	21.880	12.439	979869.500
29	14300	37 29.37	-76 20.46	278.260	**********	979955.562	22.082	12.631	979869.500
30	14100	37 29.38	-76 20.51	283.230	1.044	979955.687	22.836	13.176	979869.500
31	13900	37 29.36	-76 20.54	284.060	0.000	979955.250	23.421	13.391	979869.500
32	13700	37 29.40	-76 20.60	305.710	0.000	979954.647	23.968	13.443	979869.500
33	13500	37 29.42	-76 20.64	315.150	-2567.199	979954.147	24.277	13.526	979869.562
34	13300	37 29.43	-76 20.68	322.500	**********	979953.687	24.478	13.479	979869.562
35	13100	37 29.43	-76 20.73	326.610	1.048	979953.312	24.474	13.466	979869.562
36	12900	37 29.45	-76 20.76	331.690	0.000	979953.062	24.488	13.342	979869.625
37	12700	37 29.47	-76 20.80	331.750	0.000	979952.750	24.364	13.050	979869.625
38	12600	37 29.47	-76 20.85	331.710	**********	979952.676	24.477	13.183	979869.625
39	12300	37 29.46	-76 20.89	336.630	**********	979953.062	24.982	13.548	979869.625
40	12100	37 29.50	-76 20.93	342.840	0.000	979953.000	25.505	13.892	979869.687
42	11700	37 29.52	-76 21.01	346.410	**********	979952.312	25.276	13.493	979869.687
43	11600	37 29.53	-76 21.06	347.310	**********	979952.376	25.325	13.488	979869.687
44	11300	37 29.53	-76 21.09	344.530	**********	979952.562	25.345	13.495	979869.687
45	11100	37 29.55	-76 21.14	343.400	**********	979952.676	25.486	13.744	979869.750
46	10900	37 29.57	-76 21.18	342.010	**********	979953.125	25.585	13.667	979869.750
47	10700	37 29.58	-76 21.23	340.620	**********	979953.375	25.649	14.031	979869.812
48	10500	37 29.66	-76 21.26	339.300	**********	979953.687	25.834	14.262	979869.812

STATE ROAD 622 - GRAVITY READINGS

PRINCIPAL FACTS AT GRAVITY STATIONS

STA	NAME	AND NUM	LATITUDE NORTH +	LONGITUDE EAST +	ELEVATION FEET	SUPP ELEV METERS	OBSERVED G MGAL	FREE AIR MGAL	BOUGUER MGAL	THEOR G MGAL
2	BASE	1031	37 17.50	-76 23.69	399.700	0.000	979932.675	26.173	16.540	979942.250
1		1000	37 33.44	-76 17.63	346.030	-748.312	979964.625	31.323	19.585	979965.750
2		2000	37 33.45	-76 17.63	336.940	0.000	979965.062	31.090	19.584	979965.687
3		3000	37 33.62	-76 17.64	329.900	**********	979965.437	30.903	19.552	979965.625
4		4000	37 33.67	-76 17.64	321.690	**********	979965.500	30.305	19.326	979965.562
5		5000	37 33.63	-76 17.64	316.430	2.004	979965.750	29.984	19.166	979965.500
6		6000	37 33.62	-76 17.63	308.660	0.000	979966.312	29.641	19.307	979965.500
6		6000	37 33.62	-76 17.63	301.250	**********	979966.625	29.497	19.222	979965.500
7		7000	37 33.60	-76 17.60	294.690	0.000	979966.750	29.072	19.016	979965.437
8		8000	37 33.47	-76 17.54	287.370	-2404.056	979966.937	28.554	18.785	979965.375
9		9000	37 33.45	-76 17.53	280.010	0.000	979967.250	28.163	18.633	979965.375
10		10000	37 33.43	-76 17.51	276.220	-2049.606	979967.187	27.829	18.408	979965.312
11		11000	37 33.40	-76 17.48	275.080	0.000	979967.437	28.046	18.677	979965.312
12		12000	37 33.37	-76 17.46	276.160	0.000	979967.437	28.041	18.686	979965.250
13		13000	37 33.35	-76 17.45	271.640	**********	979967.562	27.663	18.614	979965.187
14		14000	37 33.32	-76 17.43	266.280	-3108.864	979967.562	27.462	18.360	979965.187
15		15000	37 33.26	-76 17.40	257.060	0.000	979968.125	27.157	18.390	979965.125
16		16000	37 33.27	-76 17.38	250.690	**********	979968.125	26.679	18.029	979965.125
17		17000	37 33.26	-76 17.34	247.240	**********	979967.812	25.958	17.626	979965.062
18		18000	37 33.23	-76 17.31	244.766	**********	979967.562	25.643	17.186	979965.062
19		19000	37 33.22	-76 17.26	242.370	0.000	979967.875	25.617	17.260	979965.062
20		20000	37 33.20	-76 17.25	243.610	**********	979967.000	24.904	16.666	979965.000
21		21000	37 33.18	-76 17.20	249.600	**********	979966.812	25.219	16.706	979965.062
22		22000	37 33.20	-76 17.16	255.570	1.044	979966.250	25.276	16.659	979965.000
23		23000	37 33.17	-76 17.11	261.470	**********	979965.875	25.476	16.840	979965.000
24		24000	37 33.17	-76 17.09	268.060	0.000	979965.375	25.619	16.476	979964.937
25		25000	37 33.15	-76 17.05	275.600	**********	979964.812	25.774	16.364	979964.937
26		26000	37 33.15	-76 17.01	285.140	**********	979964.125	25.861	16.256	979964.937
27		27000	37 33.15	-76 16.96	295.390	**********	979963.562	26.373	16.256	979964.937
28		28000	37 33.13	-76 16.93	301.810	**********	979962.812	26.240	16.943	979964.937
29		29000	37 33.13	-76 16.88	316.370	**********	979962.062	26.669	16.099	979964.937
30		30000	37 33.12	-76 16.85	321.760	1.044	979962.000	27.398	16.424	979964.875
31		31000	37 33.10	-76 16.80	321.330	0.000	979961.812	27.145	16.188	979964.875
32		32000	37 33.08	-76 16.76	320.020	0.000	979961.750	27.023	16.108	979964.875
33		33000	37 33.07	-76 16.73	326.340	**********	979961.187	27.067	16.064	979964.812
34		34000	37 33.05	-76 16.70	329.090	1.044	979961.062	27.229	16.008	979964.812
35		35000	37 33.03	-76 16.68	326.810	0.000	979960.375	27.307	15.816	979964.750
36		36000	37 33.02	-76 16.64	324.130	0.000	979960.875	27.579	16.162	979964.750
37		37000	37 33.00	-76 16.60	334.760	-2827.189	979960.562	27.350	15.923	979964.750
38		38000	37 32.96	-76 16.58	340.550	**********	979960.125	27.476	15.660	979964.687
39		39000	37 32.95	-76 16.53	344.140	0.000	979959.562	27.293	15.555	979964.625
40		40000	37 32.93	-76 16.48	344.610	0.000	979959.312	27.281	15.463	979964.625
41		41000	37 32.92	-76 16.46						
42		42000	37 32.90	-76 16.43	350.170	**********	979956.875	27.313	15.270	979964.625
43		43000	37 32.86	-76 16.40	356.310	**********	979956.000	27.120	14.899	979964.562
44		44000	37 32.87	-76 16.36	362.630	0.000	979957.687	27.357	14.955	979964.562
45		45000	37 32.87	-76 16.31	368.510	**********	979957.000	27.320	14.854	979964.562
46		46000	37 32.87	-76 16.26	364.220	**********	979957.437	27.155	14.732	979964.562
47		47000	37 32.85	-76 16.23	361.610	**********	979957.000	27.025	14.665	979964.562
48		48000	37 32.80	-76 16.21	368.770	**********	979957.000	26.938	14.463	979964.437
49		49000	37 32.77	-76 16.20	368.660	**********	979956.812	26.815	14.344	979964.437
50		50000	37 32.75	-76 16.18	365.390	**********	979956.687	26.678	14.213	979964.375
51		51000	37 32.72	-76 16.16	368.670	**********	979956.125	26.490	13.916	979964.312
52		52000	37 32.66	-76 16.14	370.410	**********	979956.187	26.733	14.100	979964.312

APPENDIX III

LISTING OF GEOLOGIC DATA

Below are a listing of structural readings taken during the course of this investigation. The legend that follows is a reference to where the readings were taken.

LEGEND

Location

629: B, C, D, E: The location of these readings are from State Road 629 in the Gold Hill quadrangle, at Winston Lake. The readings are from SE to NW away from Winston Lake along the blue line valley leading toward State Road 629.

R.R.: N, S, 2N, 3N, 3S: The location of these readings are from the Railroad Cut approximately 1/2 mile west of the Farmville Train Station. The train station is located off business 460 in Farmville, Virginia (Farmville Triangle).

R.C: 1, 2, 3, 5: The location of these readings are from Rock Creek, off of U.S. Highway 60. Readings 1, 2, and 3 are from the creek south of U.S. 60, while the fifth location was along the creek north of U.S. 60. Rock Creek is located in the northern portion of the Hillcrest Quadrangle, at the U.S.

Highway 60 Bridge.

US60 : The location of these readings are from a blue line creek that parallels U.S. Highway 60 at the Buckingham and Cumberland County crossing. The creek is located north of U.S. Highway 60 in the Hillcrest quadrangle.

634 : The location of these readings are from a blue line creek south of State Road 634 in the western portion of the Hillcrest quadrangle. The stream starts at the base of Bridge 289 along State Road 634 approximately 2 kilometers west of Browns Store on State Road 45.

636 : 1, 100, 17DC, PC: The location of these readings are from creeks that run along State Road 636. Locations 1, 100, and 17DC are from Dry Creek starting at Raines Tavern and ending where Dry Creek crosses State Road 600. All readings are located in the north east portion of the Farmville quadrangle. The readings at the PC location are from Perkins Creek. The readings start at Bridge 366 along State Road 636 in the Willis Mountain quadrangle and continue west until Perkins Creek forks.

460: E and W: The location of these readings are from creeks that parallel U.S. Highway 460, in the southern portion of the

Farmville quadrangle. The E location readings start at a blue line stream that starts at the intersection of U.S. Highway 460 and U.S. Route 15. The stream lies south of U.S. 460E, and terminates at Buffalo Creek. The W location readings start at a blue line stream that begins at the intersection of U.S. 460 and State Road 45. The stream lies north of U.S. 460 and terminates at Little Buffalo Creek.

Plant : The location of these readings is at the City Of Farmville Treatment Plant, off of U.S. Highway 460 business in the Farmville quadrangle.

638 : The location of these readings is from the Ganaway Creek north of the Appomattox River in the south western portion of the Farmville quadrangle. The readings start where Ganaway Creek crosses State Road 683 and continue southward until the Buckingham and Cumberland county line.

KFC : The location of these readings is from an outcrop located at the Kentucky Fried Chicken off of U.S. Highway 460 business in the City of Farmville.

CAMP : 1, 2, 3: The location of these readings are from a creek located north of the Bear Creek campground in the Gold Hill quadrangle. The readings start at the terminus of the creek, at the dam, and continue until the creek forks.

Marr : 2 : Theses locations all come from strikes and dips on the geologic map of the Willis Mountain quadrangle (Marr, 1980).