U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
WEST VIRGINIA GEOLOGICAL AND ECONOMIC SURVEY

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I–2364–H
SHEET 1 OF 2

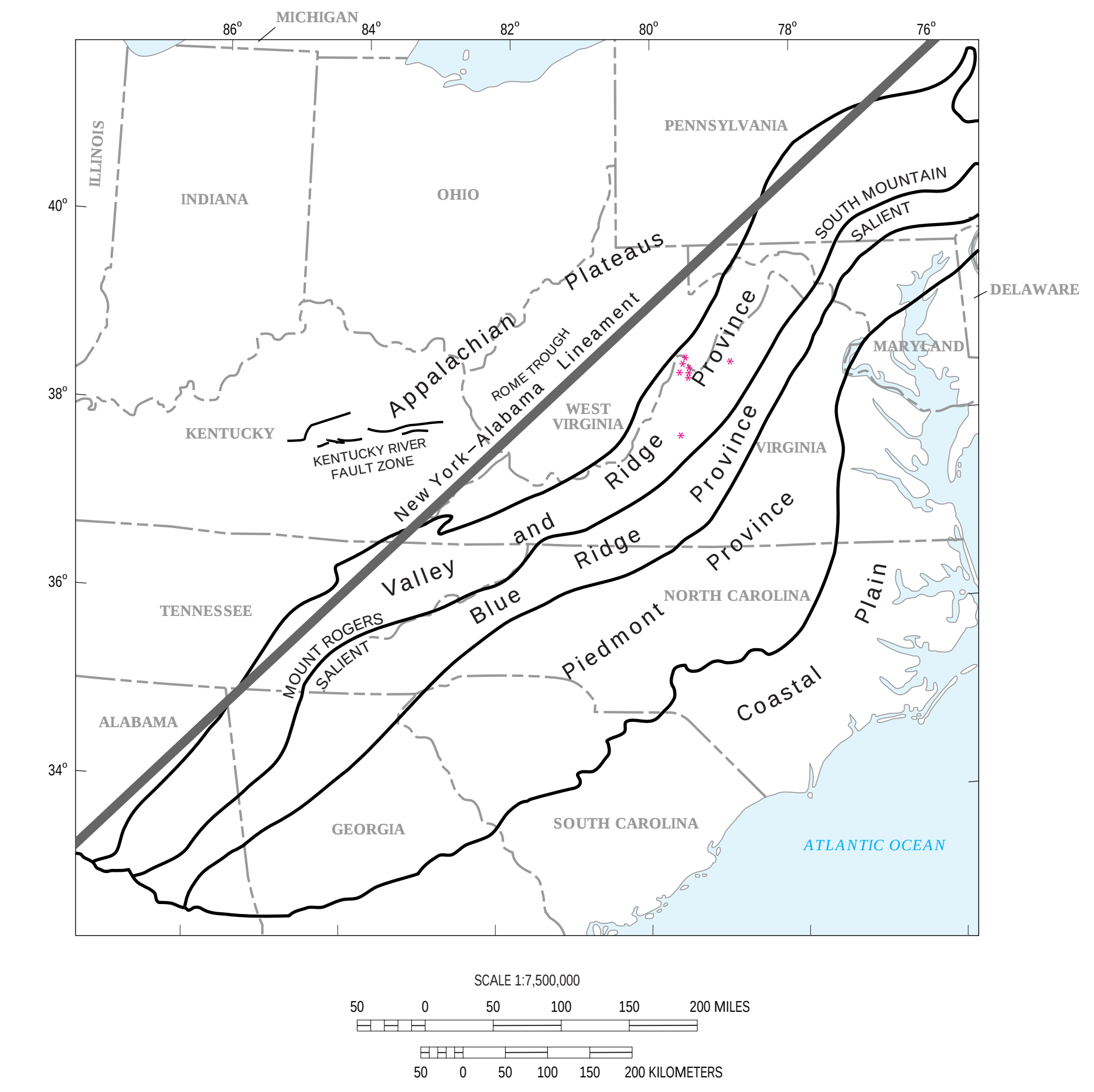

Figure 1. Index map of part of the Appalachian basin and adjacent area showing major physiographic provinces, tectonic features, and intrusive bodies discussed in text (adapted from Bayer, 1983). Symbols (∗) along southeast border of West Virginia and Virginia indicate small intrusive bodies.

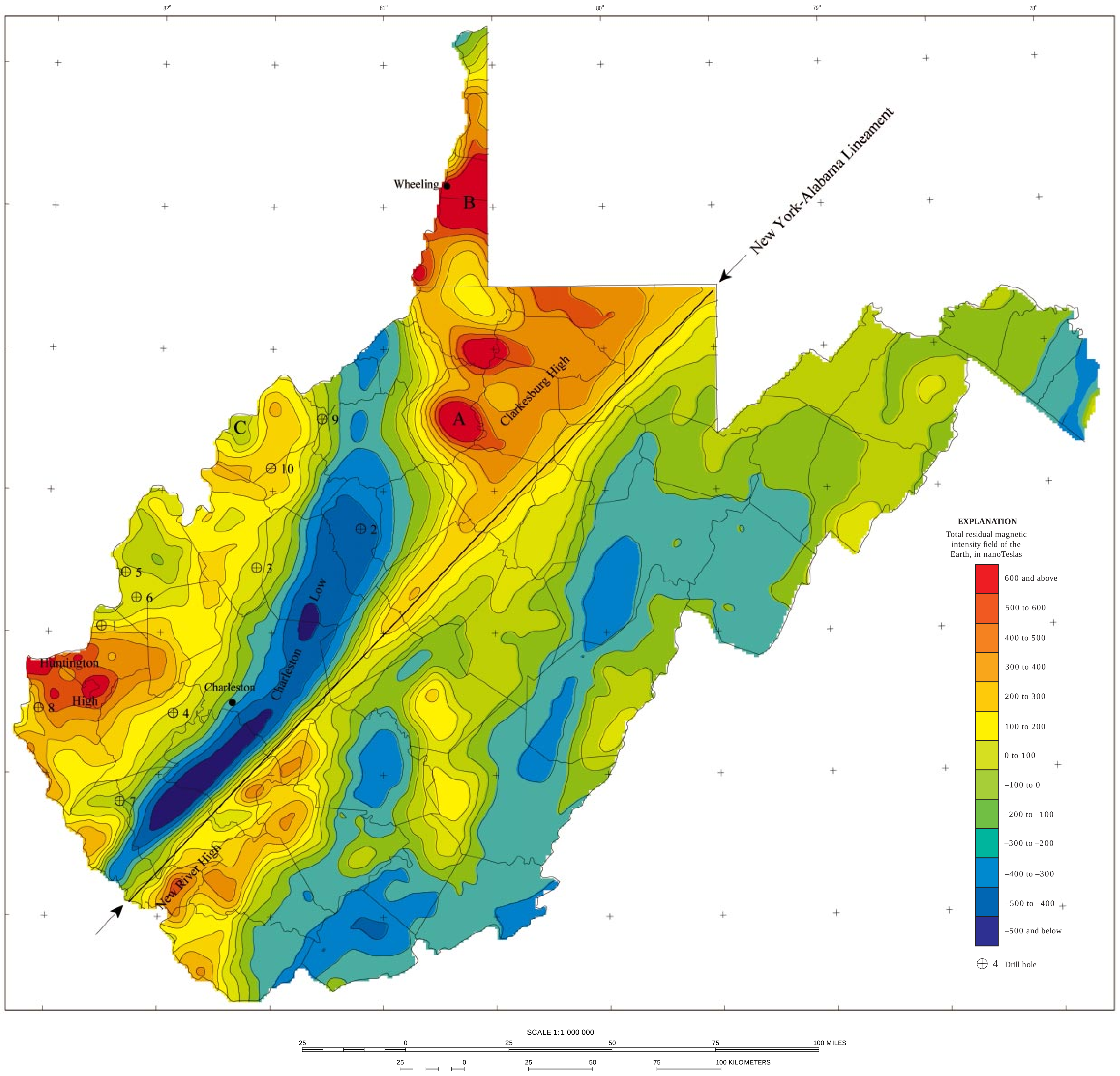

Figure 2. Residual aeromagnetic map of West Virginia showing county boundaries, location of drill holes penetrating basement rocks shown in table 1, and anomalous features (labeled) or areas (lettered A, B, and C) discussed in text.

Figure 4. Distribution of the 4,092 gravity measurement stations used to compile the Bouguer gravity map, figure 3.

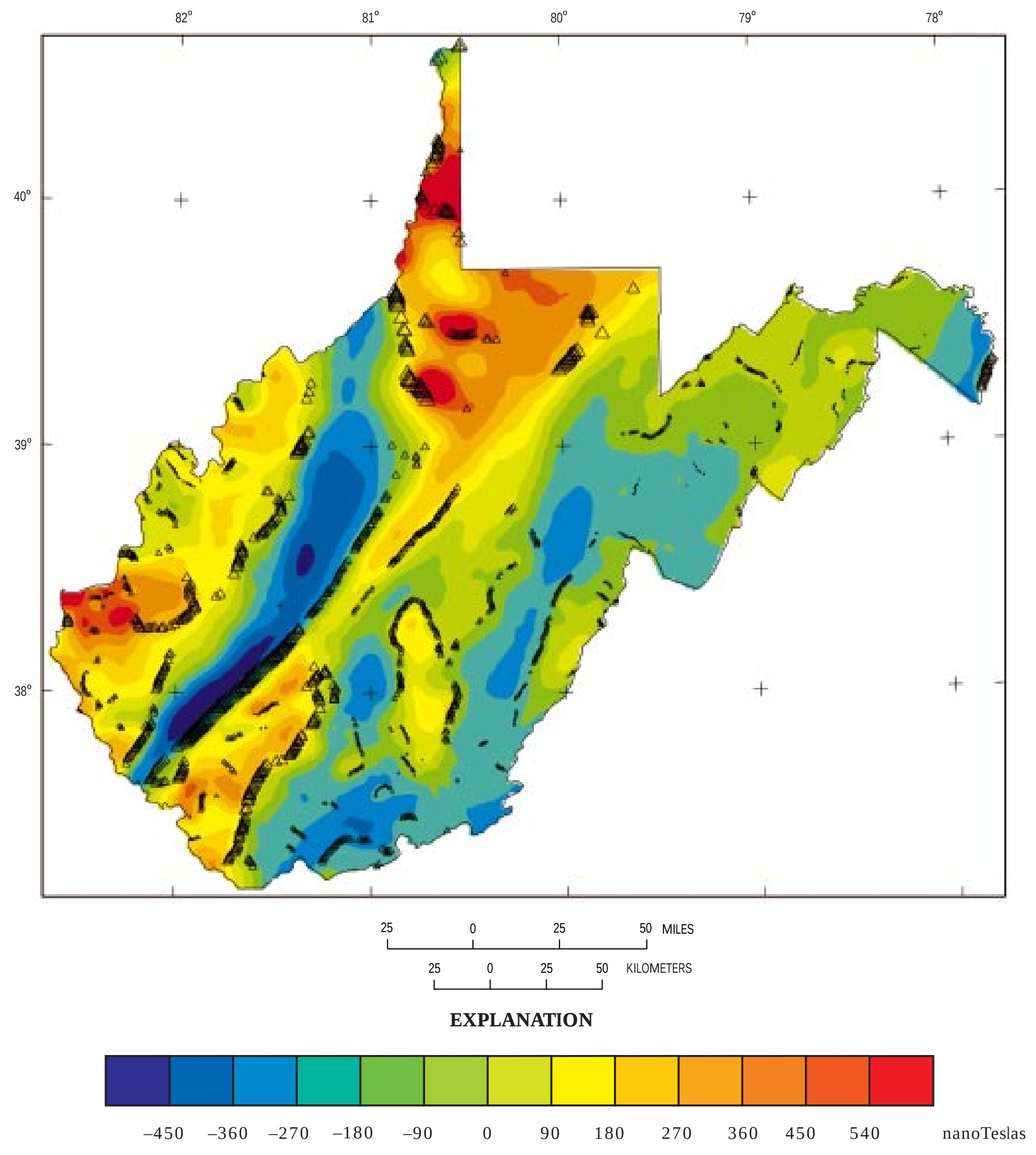

Figure 5. Residual magnetic map showing magnetic boundaries outlining subsurface areas of anomalous magnetization in West Virginia. Symbols mark solutions of boundary calculations using method of Blakely and Simpson (1986).

DISCUSSION

INTRODUCTION

The magnetic and gravity maps of West Virginia show anomalies or disturbances in the Earth's magnetic and gravity fields. These maps are part of a series of geologic, geochemical, structural, and geophysical maps compiled at the scale of 1:1,000,000 for mutual comparison and are produced in cooperation with the West Virginia Geological and Economic Survey. All maps of the series present the mineral resources and pertinent background earth science information of West Virginia. Because the magnetic and gravity anomaly maps are produced at a small scale, they show only anomalous features that are larger than 20 square miles. Smaller anomalous features appear on anomaly maps previously published at the scale of 1:250,000 (U.S. Geological Survey, 1974a,b, 1976, 1978; Kulander and Dean, 1987).

West Virginia lies within the Appalachian Plateaus and the Valley and Ridge Province (see fig. 1) and northwest of the exposed crystalline rocks of the Blue Ridge and Piedmont Province (Bayer, 1983). The Appalachian Plateaus and Valley and Ridge Province comprise the Appalachian basin, which contains a thick sequence of Paleozoic sedimentary rocks that are folded and faulted; deformation is stronger to the east in the Valley and Ridge Province than in the Appalachian Plateaus. Most of West Virginia occupies a broad recess of subdued folding between two arcuate salients of the Appalachian fold belt, the South Mountain salient to the north and the Mount Rogers salient to the south (Rankin, 1976; see fig. 1). The basement of Precambrian igneous and metamorphic rocks that underlies the Appalachian basin is poorly known; in West Virginia the basement is penetrated by only ten deep drill holes (fig. 2 and table 1), all in the western part of the state (Schwietering and Roberts, 1988; Schwietering, unpub. data, 1991).

On the basis of drilling and seismic reflection data (Cardwell and others, 1968; Bayley and Muehlberger, 1968; Cardwell, 1977; Pohn, 1994), the basement rocks underlying West Virginia are buried to depths of about 7,000 to 36,000 ft below sea level. These rocks are metamorphosed intrusive and sedimentary rocks of Middle Proterozoic (Grenville) age, which has been determined by K-Ar dating on biotite at 950±150 Ma from similar rocks exposed in Canada (Moore and others, 1986). Basement rocks in West Virginia that have been intersected by deep wells include gneisses and intrusive rocks classified as syenite, granite, granodiorite, and tonalite, most of which are highly weathered near the top of the basement surface (table 1). Ammerman and Keller (1979) have postulated that basalt flows may occur in the basement in the deepest parts of the Rome trough (fig. 1); however, no such flows have been intersected in deep wells.

Ages of 870 Ma (Bass, 1960, map number 9 in fig. 2 and table 1) and 939 Ma (Heald, 1981, map number 7 in fig. 2 and table 1) were obtained by rubidium-strontium and potassium-argon dating of biotite from basement rocks. Similar ages have been determined from cores of basement rocks in adjacent parts of Ohio and Kentucky (Summerson, 1962; Ammerman and Keller, 1979). All ages fall between 1100 Ma and 800 Ma, the period of the Grenville orogeny, when a broad swath of the eastern part of ancestral North America was extensively intruded and metamorphosed during the collision of North America and a continental mass to the southeast (Moore and others, 1986). Following a half billion years of erosion of the orogenic region, the Rome trough (Woodward, 1961; McGuire and Howell, 1963) developed as part of an intra-continental rift system extending from western Tennessee to Pennsylvania (Webb, 1980).

MAGNETIC ANOMALY DATA

The residual aeromagnetic anomaly map (fig. 2) was compiled from data obtained in a joint program of the U.S. Geological Survey and the West Virginia Geological and Economic Survey (U.S. Geological Survey, 1978). The small panhandle in the northernmost part of the state was flown in north-south traverses two miles apart at an altitude of 1,000 ft above ground (Popenoe and others, 1964). The remainder of the state was flown in northwest-southeast traverses, also two miles apart at an altitude of 1,000 ft above ground (U.S. Geological Survey, 1974a,b, 1976). The two-mile flightline spacing is comparable to the distance between the airborne magnetometer and the top of the Precambrian basement rocks in the western part of the state to ensure adequate coverage of those rocks. The northwest-southeast orientation of flightlines is approximately perpendicular to the general Appalachian trends.

All data have been digitally merged into a single gridded data set having a 2-km (approximately 1.25-mi) interval (Hildenbrand and others, 1983). The data were plotted on a Lambert Conformal Conic projection using a central meridian of 81^{o} W. longitude and base latitude of 0^{o}, and contours were generated using the computer software program of Godson and Webring (1982). Anomalies were generated by subtracting from the measured total magnetic field values the International Geomagnetic Reference Field of 1965, which was adjusted to the time and altitude of the surveys (Fabiano and Peddie, 1969).

GRAVITY ANOMALY DATA

The complete, terrain-corrected, Bouguer gravity anomaly map (fig. 3) was digitally derived from data maintained by the Defense Mapping Agency (DMA) of the Department of Defense and the National Geodetic Survey (Hittelman and others, 1992) and from Masters degree dissertations (Lemmon, 1982; Doyle, 1984; Schrantz, 1984). Data from the DMA files included measurements by Kulander and Dean (1978), Hendry (1981), and the Army Map Service (unpub. data, 1966). Stations for which the location or elevation were found incorrect were discarded. A total of 4,092 gravity stations (fig. 4) were used to compile the gravity data shown in figure 3.

All gravity values were adjusted to conform to the International Gravity Standardization Net of 1971 (Morelli and others, 1974). Complete Bouguer gravity anomaly values were computed using the 1967 theoretical gravity formula (International Association of Geodesy, 1971) and a reduction density of 2.67 g/cm^3. Terrain corrections were calculated using an algorithm (Plouff, 1977), which uses digital terrain data spaced at 30 seconds of latitude and longitude for the region extending radially outward 0.895 to 167 km from the station. The terrane correction included a correction for the Earth's curvature. Reduction procedures are described in greater detail by Cordell and others (1982).

A grid interval of 0.635 km was chosen for convenience of computer plotting and was interpolated from the irregularly spaced Bouguer gravity anomaly values using a computer program (Webring, 1981) on the basis of minimum curvature (Briggs, 1974). The data were plotted using the same projection as figure 2.

POTENTIAL FIELD DERIVATIVE MAPS

Two potential field derivative maps were made by calculating boundary points following the method of Cordell and others (Cordell, 1979; Cordell and Grauch, 1982; Blakely and Simpson, 1986): one map was derived from the digital grid of magnetic anomaly data (fig. 5) and the other map was derived from the digital grid of gravity anomaly data (fig. 6). These boundary maps show in plan view the approximate boundaries of anomalously magnetic or dense bodies of subsurface rocks that are assumed to have steeply dipping sides. Derivation of the boundary points from gravity anomaly data is straightforward: the points represent maximum values of the horizontal gradient of gravity anomalies and the points tend to outline subsurface regions of anomalous density (Cordell, 1979; Cordell and Grauch, 1982; Blakely and Simpson, 1986). Scatttered boundary point solutions have been minimized by applying a moving average filter (7-km radius) to the data set before calculating the boundary point solutions. Derivation of boundary points from magnetic anomaly data is more complicated. A pseudogravity anomaly grid was first computed from the magnetic anomaly data (Baranov, 1957) in order to correct the data for skewness associated with magnetic inclination. Next the horizontal gradient of this pseudogravity anomaly grid was computed. The resulting boundary points represent the maximum values of the horizontal gradient of the pseudogravity anomalies, and the points tend to outline subsurface regions of anomalous magnetization. A comparison of the distribution of magnetic and gravity boundary points shows the extent to which subsurface regions of anomalous density spatially correlate with those of anomalous magnetization.

The boundaries outlining the anomalously magnetic regions in figure 5 have more closely spaced points than those outlining density regions in figure 6, in part because the original magnetic measurements were regularly spaced, whereas the original gravity measurements were not. The difference in spacing also depends on the more sharply delineated magnetization boundaries in comparison to the density boundaries, because magnitudes of magnetization variation are commonly orders of magnitude larger than those of density variation. A lack of correspondence between magnetic and gravity boundaries can be caused by several factors, which may include the following: (1) the anomalous regions may not have steeply sided edges, (2) subsurface basement that has anomalous magnetization may not have anomalous density, or vice versa, and (3) subsurface regions of high magnetization delineated by boundary points refer almost exclusively to basement rocks at the scale of the present study, whereas subsurface density regions refer to both basement rocks and overlying sedimentary rocks.

MAGNETIC PROPERTY MEASUREMENTS

Magnetic properties of two deep drill hole samples of Precambrian tonalite/ granodiorite were measured (map number 7 in fig. 2 and table 1). Both samples were strongly magnetic, having, respectively, apparent susceptibilities of 2.01 and 4.57×10^{-2} SI (International system) units; remanent magnetizations of 1.3 and 3.6 amperes per meter (A/m); Koenigsberger ratios (Q) of remanent-to-induced magnetization of 1.4 and 1.8; and remanent magnetization inclinations of 62 and 78 degrees. The samples have a maximum total magnetization of 1.6 and 4.1 A/m, assuming codirectional induced and remanent magnetization because of the steepness of the remanent magnetization inclinations. The only sample for which the vertically upward (versus vertically downward) core orientation is known has a normally polarized remanent magnetization and, thus, a normally polarized total magnetization. In summary, our results indicate that remanent magnetization in deeply buried Precambrian intermediate plutonic rocks may be an important contributor to the aeromagnetic anomalies.

GEOLOGIC INTERPRETATION

Morphological Similarities of the Anomalous Fields

The magnetic and gravity anomaly maps (figs. 2 and 3) are broadly similar. On both maps, the anomalous field is low in the southeast and rises to a northeast-trending ridge that transects the central part of the state. This ridge broadens to a triangular shape where the state joins Pennsylvania. Another high is present at the westernmost part of the state on both maps. These gross morphological similarities of the two anomalous fields reflect large subsurface magnetization and density sources that generally conform with the Appalachian structural trend. There is an apparent inverse correlation of some of the magnetic and gravity anomalies west of the New York–Alabama lineament. The magnetic high in the panhandle (B in fig. 2) coincides with a gravity low (B in fig. 3), and, to the southwest, the area north of the Huntington magnetic high coincides with a gravity low (C in figs. 2 and 3), but poor gravity coverage in both areas make such correlations uncertain. The groupings of boundary points shown in figures 5 and 6 generally do not coincide (although some of the boundaries are parallel), implying that the most conspicuous magnetization contrasts in the basement do not coincide with major density contrasts. We infer that the source of most of the regional magnetic anomalies is not dense gabbroic or ultramafic rocks, but rather is metamorphic and plutonic rocks of intermediate composition and normal density.

The variety of magnetic features shown in the magnetic anomaly map (fig. 2) is characteristic of a heterogeneous complex of crystalline basement rocks. The gradients of the magnetic anomalies are broad and smooth. Because the horizontal extent and steepness of the magnetic gradient are a measure of the distance between the detector and the source of the anomaly, the magnetic patterns delineated in figure 2 are caused primarily by deeply buried rocks of the Precambrian basement and not by the overlying sedimentary rocks of the Appalachian basin.

Minor Magnetic Variations

Analog records made during the magnetic survey have a number of minor variations, most of which are too small to contour at this map scale. Several are associated with industrial development, such as power plants, oil and gas fields, and mine workings. In adjacent Virginia (fig. 7), several small negative anomalies may be associated with reversely magnetized mafic dikes of unknown age. These dikes may have been emplaced during rifting and the opening of the Atlantic in Mesozoic time or during an episode of Eocene igneous activity, which has been dated in nearby areas of Virginia (Johnson and others, 1971; Dennison and Johnson, 1971).

The New York–Alabama Lineament

West Virginia is bisected from southwest to northeast by an alignment of gradients (fig. 2) known as the New York–Alabama lineament (King and Zietz, 1978). South of the latitude of Charleston, the gradient separates an irregularly shaped area of large magnetic anomalies on the southeast from a very deep magnetic low on the northwest. North of the latitude of Charleston, the gradient is lower and broader in magnitude than to the southwest, but it is just as linear. This gradient defines a fundamental discontinuity in the basement rocks underlying the Paleozoic sedimentary rocks of the Appalachian basin in West Virginia.

The New York–Alabama lineament occurs along the northwest flank of the regional Appalachian gravity low of the eastern United States (Haworth and others, 1980) and appears to separate different overall gravity patterns. To the southeast, the gravity trends tend to be northeast parallel to the regional gravity low, whereas to the northwest, the trends are more northerly and seem directly related to basement lithology.

The New York–Alabama lineament roughly parallels the western edge of the strong deformation of the rather sinuous Appalachian fold belt to the east (Valley and Ridge Province, fig. 1). The lineament is tangential to the arcuate folded and thrusted Paleozoic rocks adjacent to the South Mountain salient and the arcuate thrust slices adjacent to the Mount Rogers salient (Rankin, 1976). This suggests that the crustal block on the northwest acted as a buttress for the Appalachian deformation. The lineament is more sharply defined and continuous in West Virginia than elsewhere along its length, perhaps because the magnetic properties of the basement rocks on either side contrast so abruptly due to a possible large-scale transcurrent fault.

Inferred Basement Lithology

Northwest of the New York–Alabama lineament, two large blocks of magnetic rocks are separated by a broad magnetic low that trends south to southwest from eastern Ohio to Kentucky. This low is labeled the Charleston low in figure 2. From east of Charleston to the south, the lineament and the Charleston low are parallel. The gravity map (fig. 3) has a low that is similar in shape and trend to the Charleston magnetic low, but the gravity low is offset to the west about 12.5 miles (20 km). The gravity low must be caused by a different lithologic unit, although both magnetic and gravity lows may have been controlled by Appalachian deformation.

A triangular high magnetic area northeast of the Charleston low has the low to the west and the New York–Alabama lineament to the southeast. This high is labeled the Clarkesburg high in figure 2. The magnetic configuration of the Clarkesburg high indicates a considerable diversity in the basement rocks beneath it. The knoblike highs and deep circular lows in the west probably are caused by plutons intruding a moderately magnetic country rock. In the boundary map (fig. 5), this plutonic region is bounded on the east by a broken line of plus symbols that trend north-northeast and are on line with the linear southeastern side of the Charleston low; this alignment of features may be fault controlled. The gravity map also shows this inferred plutonic terrane, but not as clearly because fewer gravity measurements were taken. The gravity patterns also are more variable west of the magnetic Clarkesburg high. The closed gravity high and coinciding southernmost circular magnetic high (A, figs. 2 and 3), indicate a body of dense magnetic rock, such as a gabbro. This area also coincides with a cluster of high titanium values in the geochemical analysis of stream sediments of West Virginia (see the titanium isopleth map in this series by Watts and others, 1993). However, the magnetic anomalies do not indicate that the source could be shallower than the basement. The coincident magnetic high and gravity low over the northern panhandle at Wheeling (B, figs. 2 and 3) suggest a pluton of magnetic granitic composition.

Another probable basement plutonic terrane is indicated by the diverse magnetic anomaly pattern northeast of the Huntington high (fig. 2). In the northern part a weak circular magnetic high partially outlines a central low (C, fig. 2). This feature coincides with a closed gravity low in figure 3. Drill hole 10 penetrates a granite gneiss (table 1). These data may indicate a compositionally zoned metamorphosed granitic pluton. The circular magnetic anomaly with a much greater amplitude at Huntington (fig. 2) also has a central low, but has

MAGNETIC AND GRAVITY ANOMALY MAPS OF WEST VIRGINIA

By

E.R. King, D.L. Daniels, W.F. Hanna, and S.L. Snyder

1998