Regional Geologic Implications of the Gravity and Magnetic Fields of a Part of Eastern Tennessee and Southern Kentucky

GEOLOGICAL SURVEY PROFESSIONAL PAPER 516-A

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By JOEL S. WATKINS

GEOPHYSICAL FIELD INVESTIGATIONS

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Interpretation of aeromagnetic and gravity anomalies in terms of fault tectonics, basement rock units, and regional geology

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[Plates are in pocket]

REGIONAL GEOLOGIC IMPLICATIONS OF THE GRAVITY AND MAGNETIC FIELDS OF A PART OF EASTERN TENNESSEE AND SOUTHERN KENTUCKY

By Joel S. Watkins

ABSTRACT

Aeromagnetic and gravity surveys have been made of an area encompassing approximately 10,000 square miles in eastern Tennessee and southern Kentucky. Data from these surveys have been compiled as a Bouguer gravity anomaly map having a 5-mgal contour interval and an aeromagnetic anomaly map having a contour interval of 20 and 100 gammas.

Differences in character and magnitude of the gravity and magnetic anomalies suggest that basement rocks in this area comprise five major lithologic units. Boundaries of three of the five units trend more northward than surface structural features. The northerly trend apparently reflects the pre-Appalachian structural grain in the area. A northeast-striking basement contact with a steeply dipping contact plane truncates northward-trending units. This contact is thought to be a basement fault that was active prior to or during an early phase of sedimentation in the Appalachian geosyncline. The inferred fault has no surface expression in exposed strata, however.

Near-surface strata are overthrust from southeast to northwest in much of the area. Absence of magnetic and gravity anomalies along traces of major thrust faults indicates that the thrust faults either die out within the sedimentary section or coalesce into a sole fault or faults which extend southeastward beneath the great overthrusts of the Blue Ridge. Two major tear faults, the Jacksboro and Emory River, have magnetic and gravity anomalies along their traces. Basement movement along the Jacksboro fault has the same sense of motion and approximately the same amount of motion as the surface fault, but the basement fault seems to be much longer than the surface fault.

Analysis of magnetic anomalies and available well data indicates that the basement surface in the Valley and Ridge province lies generally above 15,000 ft below sea level. The surface appears relatively flat in the area, but may rise slightly along the boundary of the Valley and Ridge and Blue Ridge provinces.

A northeast-striking basement lineament parallels the western margin of the Valley and Ridge province from west-central Alabama to northern Tennessee. In the area of investigation, this lineament seems to be a transition zone separating a tectonically active Appalachian crustal block from a stable cratonic block. The basement surface rises immediately northwest of the zone in an area where intensity of thrust faulting and folding decreases. Thinning and facies changes may inhibit formation of thrust planes in the Cambrian shale over the rising basement surface and thus cause the change in intensity of deformation.

INTRODUCTION

Aeromagnetic and gravity surveys in eastern Tennessee and southern Kentucky have been interpreted in an effort to delineate basement lithologies, basement structural features, and to ascertain the interrelationships between basement and surface structural features. The area investigated comprises about 10,000 square miles and includes approximately equal parts of the Cumberland Plateau and Valley and the Ridge province as well as a small part of the Blue Ridge province. Structural features range from intensively faulted and folded rocks to relatively undeformed horizontal strata. Figure 1 shows the location of the area and some of the larger structural elements.

ACKNOWLEDGMENTS

I wish to thank Isidore Zietz for guidance in the interpretation of the aeromagnetic map. R. A. Laurence and L. D. Harris estimated basement elevations from well data in eastern Tennessee. Zvi Yuval assisted in the gravity field work and determined the densities from cores which Dr. Wallace de Laguna of the Oak Ridge National Laboratory graciously allowed us to use. Dr. E. T. Luther, Assistant State Geologist of Tennessee, advised and assisted in many respects.

GEOLOGY

Ages of the rocks in the area of investigation range from late Precambrian to Pennsylvanian, with the exception of stream deposits and one intrusion of unknown age. No basement rocks crop out in the area except this intrusion. Age, induration, and complexity of structure generally decrease from southeast to northwest. Overall, the stratigraphic section consists of coarse clastic rocks of late Precambrian and Early Cambrian ages below carbonate rocks, most of which were deposited during Cambrian, Ordovician, and Mississippian times. Finer grained clastic rocks deposited during middle and late parts of the Paleozoic era com-

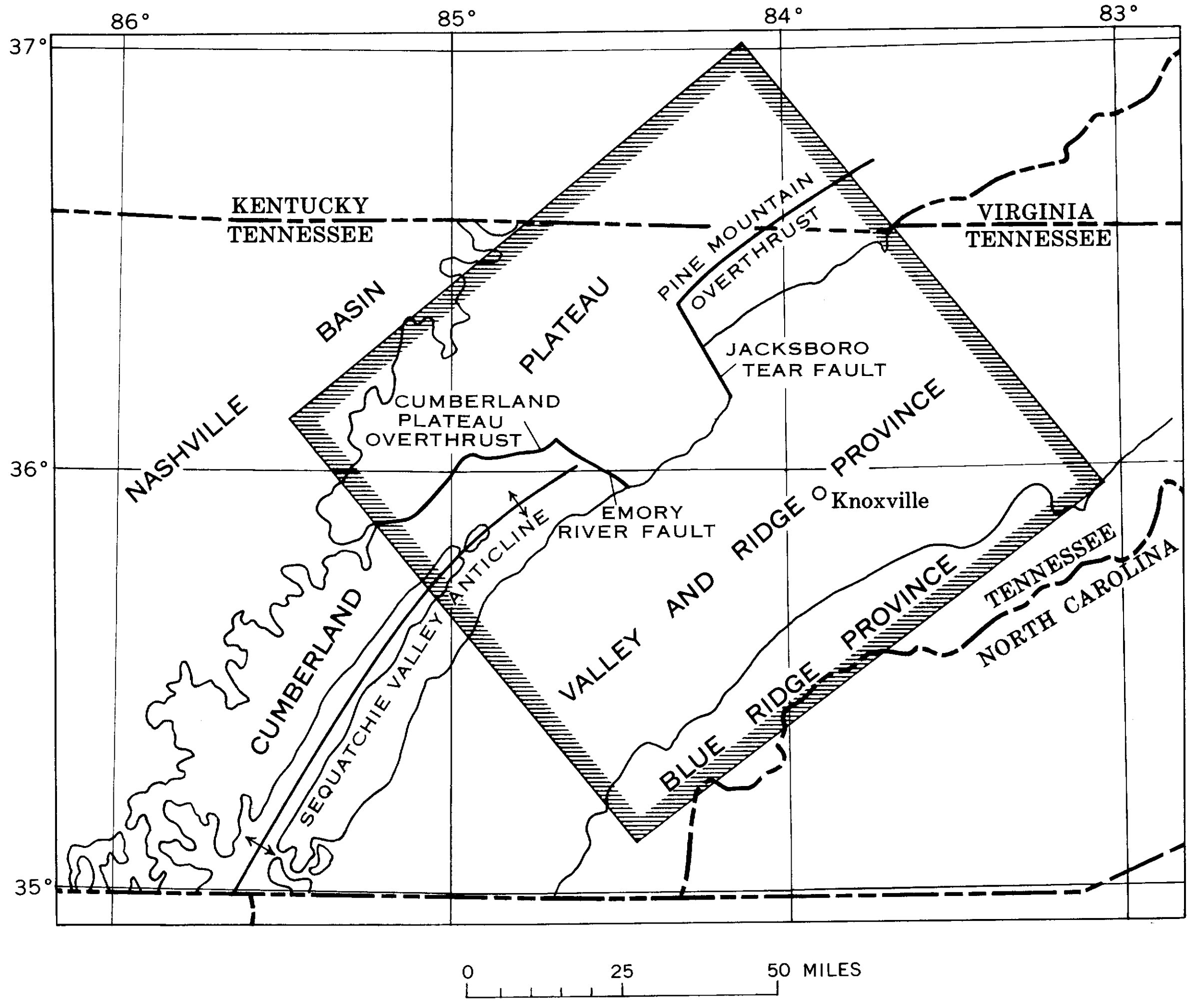


Figure 1.—Location of aeromagnetic and gravity surveys and generalized structural geology based on Rodgers (1952) and Wilson and others (1956) Shaded border encloses the area of the report.

plete the section. Plate 1 includes generalized surface geology compiled from Rodgers (1952), Wilson and others (1956), Hamilton (1961), Jillson (1929), and Pond (1933), and Butts (1940). Although the boundary between rocks of Cambrian and Ordovician ages lies near the base of the Knox Group, its exact location has not been determined everywhere in the area; the location has therefore been inferred in much of Plate 1. The entire Chilhowee Group has been assigned a Cambrian age, although its lower formations may actually be latest Precambrian.

ROCKS OF PRECAMBRIAN AGE

Rocks of unquestioned Precambrian age include the Ocoee Series and rocks of equivalent age, and the so-called injection complex. A profound unconformity separates the injection complex from the overlying rocks (King, 1949; Stose and Stose, 1944). The injection complex consists of a vast gneiss intruded by granite plutons in many places and, on a lesser scale, by ultramafic intrusives. No injection-complex rocks crop out within the area of investigation, but they may be present at depth.

According to King and others (1958) the Ocoee Series lies unconformably above the injection complex and consists predominantly of finely to coarsely clastic rocks with some limestone and dolomite beds near its top. Its total thickness probably exceeds 30,000 feet.

ROCKS OF PALEOZOIC AGE

The oldest diagnostic fossils in the area are found in the upper part of the Chilhowee Group, a unit consisting primarily of conglomerate, shale, and sandstone. The Chilhowee Group has been thrust over younger rocks in the southeastern part of the area, and erosion-resistant members form high ridges bordering the east side of the Valley and Ridge province. These ridges prevented eastward continuation of low-level flying necessary for the radiation survey and thus mark the eastern margin of the surveyed area in many places.

Cambrian formations above the Chilhowee Group consist mainly of limestone, dolomite, and shale, as do succeeding formations of Ordovician age. The most widely distributed unit in the area is the Knox Group of Cambrian and Ordovician age. Rocks of the Knox Group contain zinc deposits near Jefferson City, Tenn., and are also noteworthy for their very dense dolomite members. One major red-bed unit, the Juniata Formation of Ordovician age, extends into the area from Virginia and grades laterally southwestward into marine limestone and shale.

Rocks of Silurian or Devonian age contain more coarsely clastic rocks than those of Cambrian or Ordovician age. The Clinch Sandstone forms prominent ridges. Rocks of Mississippian age are more calcareous than rocks of Silurian, Devonian, or Pennsylvanian age, and yield most of the oil produced in Tennessee.

Most rocks of Pennsylvanian age are restricted to the Cumberland Plateau. The lower part of the Pennsylvanian sequence consists of massive sandstone and equal amounts of shale, but the upper sequence contains more shale than sandstone. All coal produced in Tennessee comes from rocks of Pennsylvanian age (Wilson and others, 1956).

OTHER ROCKS

Safford in 1869 noted the occurrence of a small intrusive body in Union County, Tenn. The rock is a mica-peridotite (Gordon, 1927; Hall and Amick, 1944) intruded into Rockwood Formation of Silurian age and Hancock Limestone of Silurian and Devonian age. One margin of the outcrop lies along the trace of the Wallen Valley fault. Analysis of aeromagnetic anomalies by Johnson (1961) shows that the body appears to be elliptical in plan and dips steeply northwest. No other intrustive bodies have been recognized in the area of investigation. At least 15 or more bentonite beds occur within Ordovician limestone units (Fox and Grant, 1944; Rodgers, 1952; Wilson, 1949), and one bed occurs in the Chattanooga Shale (Hass, 1948). The source of the bentonite has not been found.

Low-grade sedimentary iron ore was mined in the 19th century from members of the Rockwood Formation of Silurian age, and some Ordovician sandstone includes iron deposits which were economic in past years. Ore deposits are associated with metasedimentary rocks, volcanic flows, and igneous intrusions in the Blue Ridge of eastern Tennessee and North Carolina. Magnetic anomalies do not seem to correlate with these iron-bearing rocks in the area of investigation.

STRUCTURE

Thrust faults in the Blue Ridge province along the Tennessee-North Carolina boundary clearly involve dislocations of basement rocks, but thrust faults along the margin of the Cumberland Plateau apparently do not. Rocks between the Blue Ridge and Cumberland Plateau comprise the main body of the folded, thrust-faulted, and, in some cases, cross-faulted belt of the Appalachian geosyncline. The origin and nature of the thrust faults lying in this belt have been disputed almost since their discovery by H. D. and W. B. Rodgers in the late 1830's (John Rodgers, 1949). Attempts to understand the nature of the faulting contributed to the geosynclinal theory by Dana (1873), to the concept of competence of strata of Willis (1893), and to much other speculation. Discovery of fensters in Powell Valley by Butts (1927) helped Rich (1934) reach his famous conclusion that some thrust planes lie mainly in incompetent beds and that the basement rocks beneath the thrusts are relatively undistributed. Most contemporary investigators think that faults and folds of the Valley and Ridge province similarly lack basement "roots" (Rodgers, 1949).

The Cumberland Plateau, although it includes the Pine Mountain thrust fault, the Cumberland Plateau overthrust, and the Sequatchie Valley anticline, consists mainly of nearly horizontal, undisturbed strata. Dislocation along the Pine Mountain thrust fault may be several miles, but movement along the Cumberland Plateau overthrust is small, and the Sequatchie Valley anticline is broad and simple compared with folds of the Valley and Ridge province. Cross sections in figure 2 show location and direction of deformation of major faults of the Cumberland Plateau, Valley and Ridge, and Blue Ridge provinces.

Few deep wells have been drilled in the Valley and Ridge province of the southern Appalachians, and none penetrate the basement; therefore no exact depth of basement is available. Basement lithologies are likewise unknown, not only for the Valley and Ridge province but for most of the Cumberland Plateau.

DATA

Aeromagnetic intensities (pl. 2) were compiled by standard U.S. Geological Survey procedures from surveys directed by Peter Popenoe in 1959 and J. R. Henderson in 1957. Flight lines were generally about 2 miles apart, and the flight elevation was 500 feet above ground except where noted otherwise. The southeast margin of the survey is irregular because the survey stopped at the first high range of mountains of the Blue Ridge. In some places, therefore, the area includes none

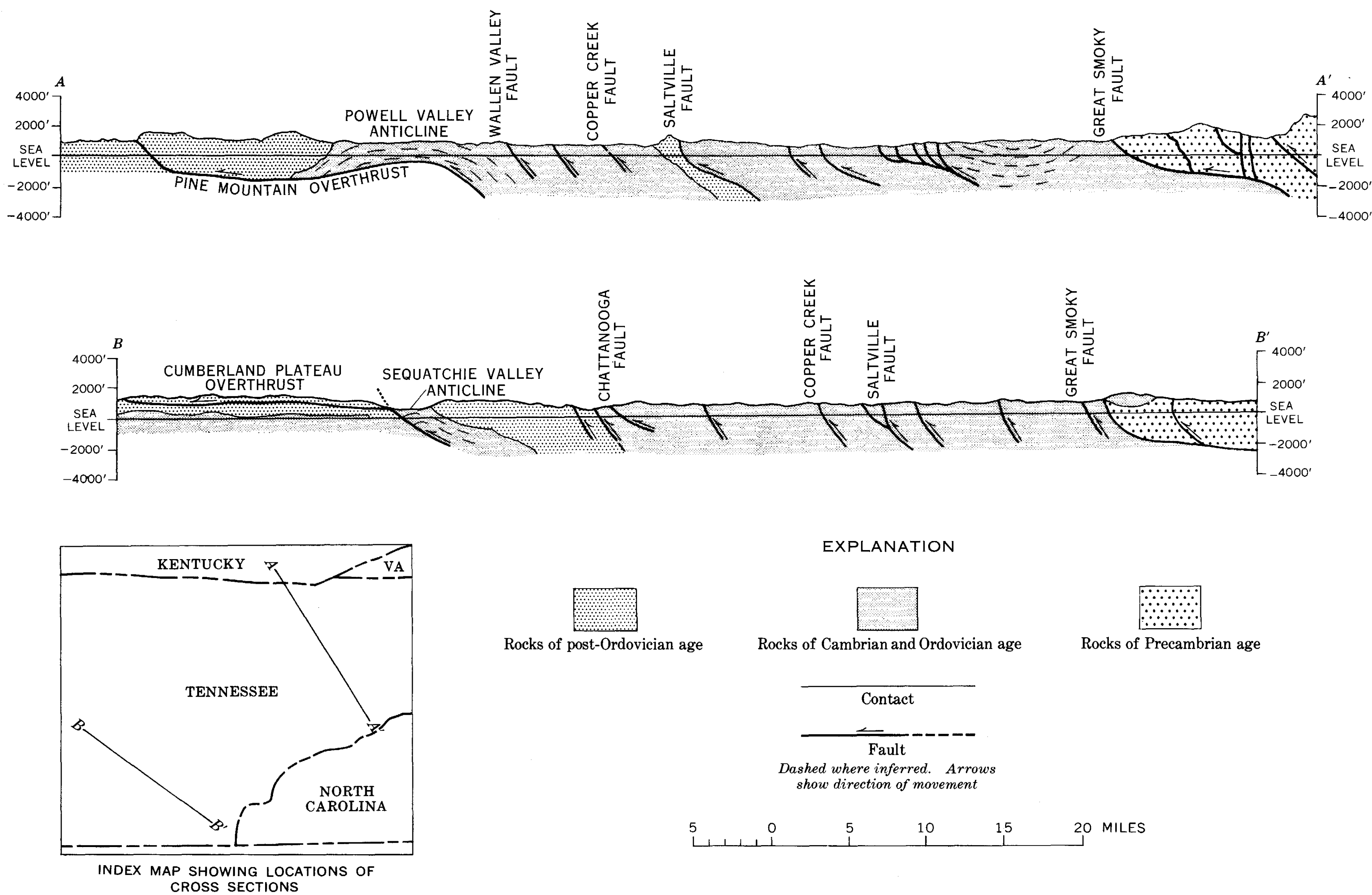


FIGURE 2.—Schematic cross sections across eastern Tennessee showing geologically inferred structural conditions. Generalized from Rich (1934), Rodgers (1952), Wilson and Stearns (1959), and Hamilton (1961).

of the Blue Ridge province, but in others, such as the extreme southern corner of the area, the survey extends about 10 to 15 miles into the Blue Ridge province.

Bouguer gravity anomalies (pl. 1) were calculated by using a density of 2.67 g per cc. The principal facts for the gravity stations have been placed on open file (Watkins and Yuval, 1962). Gravity data were corrected for effects of the terrain within 20 km of the stations by a digital computer (Kane, 1962); terrain corrections do not not exceed 7 mgal in any part of the survey, and only a small fraction of the corrections exceed 2 mgal.

During study of the Bouguer gravity anomaly map (pl. 1), it became evident that removal of a regional gradient from the data would facilitate interpretation of the gravity anomalies. The regional gradient, which decreases from northwest to southeast, is caused by a large negative gravity anomaly associated with the Appalachian geosyncline. The negative anomaly is several hundreds of miles wide and more than 1,000 miles in length. Possible causes of this anomaly are beyond the scope of this paper, but some aspects of the problem have been considered by Woollard (1939) and Griscom (1963).

The following procedure was used to estimate the value of the regression surface (or regional gradient): First, the latitude and longitude were converted from degrees, minutes, and seconds to degrees and fractions of degrees. (For purposes of computation, the latitude and longitude were considered orthogonal. No serious error is introduced because the divergence of the meridians and the curvature of the earth's surface is small within the area of investigation.) Then, third-, sixth-, and ninth-degree least-square regression surfaces of the function $x=f(y,z)$ were computed wherein x is the complete Bouguer anomaly at a point and y and z are the latitude and longitude of the point. The calculations were made on a digital computer (B-220) using a program devised by the U.S. Geological Survey.

The computed values of the surface at each of the points were subtracted from the observed Bouguer values at the points, and the differences (or residuals) were plotted and contoured. The areal extents of anomalies on the contoured residual maps were compared with the extents of anomalies on the aeromagnetic map. Anomalies derived from the third- and sixth-degree surfaces correlated well with those of the aeromagnetic map, but the ninth-degree residual anomalies correlated best and were used for interpretation. Figure 5 shows ninth-degree residual anomalies.

Regression analysis generates false anomalies when the size of undulations of the computed surface approaches the size of the residual anomalies being studied. Consequently, the ninth-degree surface was contoured and inspected. It was found that the surface decreases uniformly from about +10 mgals along the northwest boundary to approximately −65 mgals along the southeast boundary. The +10- to −40-mgal contours, inclusive, are concave northwest. The −50- and −60-mgal contours lie along the margins of a broad, elongate northeast-southeast-trending minimum whose axis seems to lie immediately southeast of the area. Consequently, the extreme southwest ends of the −50- and −60-mgal contour lines are concave southeast, and the northeast end of the −60-mgal contour line is concave southward. Curvature of the surface, however, is everywhere so small that it cannot generate false anomalies.

DENSITIES AND SUSCEPTIBILITIES

Figure 3 shows densities measured from cores consisting chiefly of limestone and shale of early Palezoic age but including some dense dolomite of the Knox Group at the base of one core. The core material of the Sprague-Henwood well had been stored for several years prior to measurements, but the material from the Joy 1 well was fresh. Dehydration during storage probably caused the slightly decreased mean density of the Sprague-Henwood cores inasmuch as the collars of the two wells lie at nearly equivalent positions in the geologic section in a valley on the Oak Ridge National Laboratory reservation. Additional densities are as follows:

Densities of some carbonate rocks in east Tennessee

[Determined by Tennessee State Highway Department, E. T. Luther, written commun., 1962]

Unit	Age	Samples	Mean density (g per cc)
Chicamauga Limestone	Ordovician	9	2.70
Holston Formation	do	1	2.72
Lenoir Limestone	do	3	2.70
Athens Shale (limestone facies)	do	1	2.69
Knox Group, undivided	Ordovician and Cambrian	11	2.73
Mascot Dolomite	Ordovician	3	2.77
Copper Ridge Dolomite	Cambrian	1	2.71
Maynardville Limestone	do	5	2.71
Maryville Limestone	do	1	2.79
Shady Dolomite	do	1	2.83
Total number samples		36	
Mean density			2.72

Sedimentary rocks such as those cropping out in the area are not generally sufficiently magnetic to warrant measurement of their susceptibilities. The basement rocks in the area are not penetrated by wells, and therefore no samples are available for measurements. Magnetic susceptibilities mentioned in this report were estimated from the anomalies by a method described by Vacquier and others (1951).

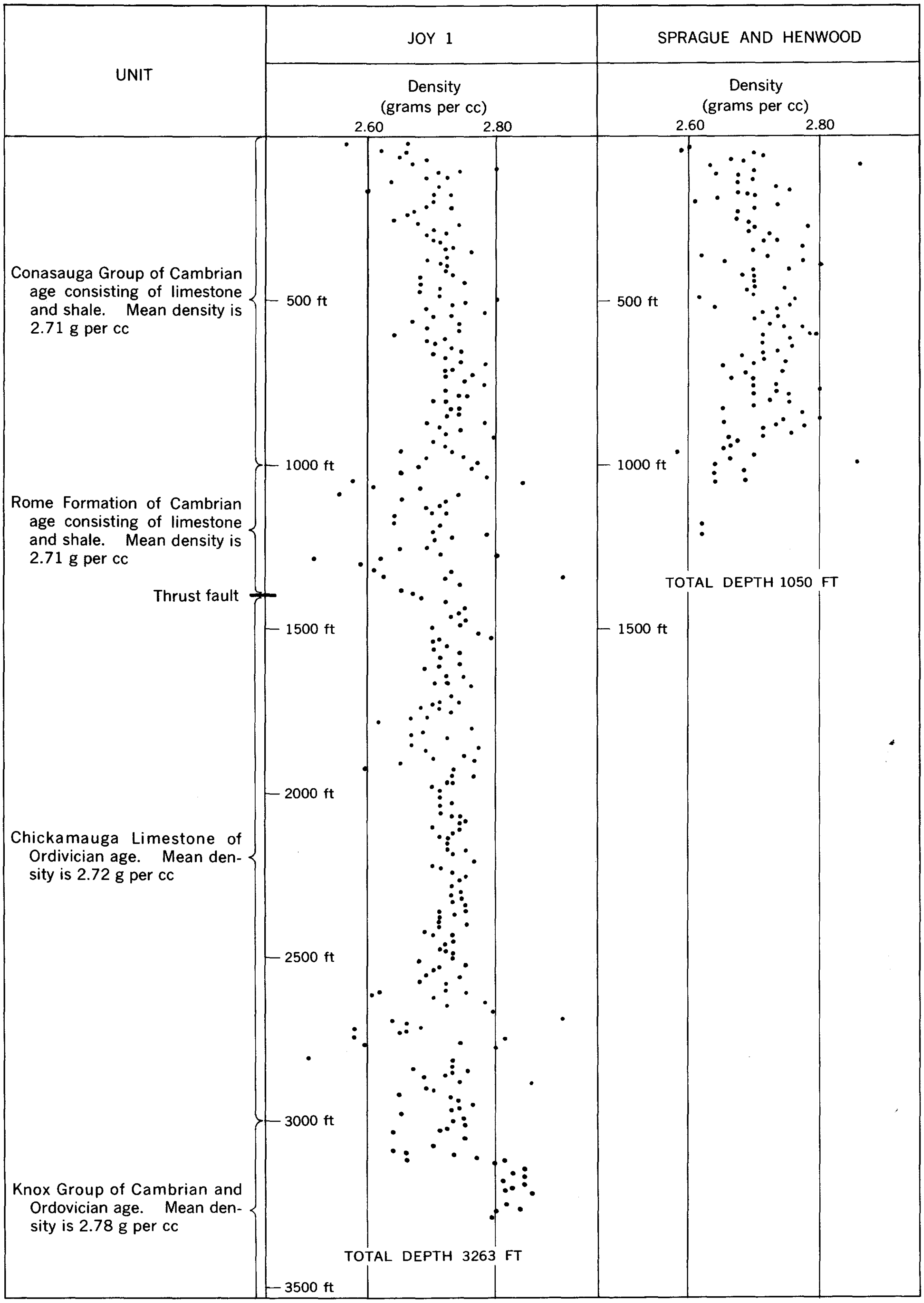


FIGURE 3.—Densities determined from cores of wells near Oak Ridge, Tenn. Geologic contacts identified by Wallace de Laguna of the Oak Ridge National Laboratory.

INTERPRETATION

UPPER BASEMENT ROCKS

Rocks in the area of investigation causing gravity and magnetic anomalies have been divided into five coanomalous units. A coanomalous unit is defined as a geologic rock unit inferred from two or more areally coincident geophysical anomalies. Gross characteristics of anomalies associated with an extensive unit are relatively uniform over the entire unit. Character of localized anomalies within the unit may deviate from the general pattern, however. Anomalies and inferred coanomalous units in the area of investigation are shown in figures 4 and 5.

The lowest gravity anomalies in areas of exposed basement rocks are generally associated with felsic igneous and metamorphic rocks. Magnetic anomalies associated with felsic rocks are generally low to intermediate relative to those of most other igneous and metamorphic rocks. These facts suggest that coanomalous units 2 and 3 consist primarily of felsic rocks. Gravity anomalies of unit 3 are slightly greater and the magnetic anomalies slightly lower than those of unit 2. (The greater magnetic anomaly over unit 2 may be due to "edge effect". See fig. 6.) The contact of units 2 and 3 appears gradational. Coanomalous unit 2 is structurally important and will be discussed below.

Coanomalous unit 1 has a higher residual gravity anomaly but a lower magnetic anomaly and, by inference, a higher density but a lower susceptibility than units 2 and 3. Barnes (1953) reports that the Packsaddle Schist of the Llano Uplift in Texas has a density exceeding that of adjacent felsic rocks by almost 0.2 g per cc and a susceptibility which is approximately 540×10^{-6} emu (electromagnetic units) less than the average of the nearby granite bodies. Anomalies of unit 1 can be explained by assigning this unit a lithology similar to that of the Packsaddle Schist.

The anomalies of coanomalous unit 5 are smooth, regular, and large compared with anomalies of units 1, 2, and 3. These characteristics, and the known peridotite plug associated with unit 5 suggest a gabbroic intrusion. The peridotite plug intrudes Silurian and Devonian rocks and outcrops over unit 5. No evidence indicates that the principal mass of unit 5 intrudes overlying Paleozoic sedimentary rocks, however.

The anomalies of unit 4 are high and complex. Unit 4 also includes many nearly circular magnetic highs which suggest intrusions of plugs or stocks. The character of the anomalies and the analysis of anomaly magnitudes (R. W. Johnson, Jr., written commun., 1961) suggest a province of iron-rich volcanic rocks surrounding plugs and stocks which served as conduits for the volcanic material.

MAGNETIC GRADIENT

The most prominent feature on the magnetic anomaly map is a linear gradient striking northeast and separating unit 2 from unit 1. The distinctness of the anomaly implies that the contact dips steeply, but the direction of dip cannot be determined. Anomalies for interfaces dipping 30° NW., 30° SE., and vertically are superimposed on the observed anomaly in figure 6.

The linearity, length, and steep dip of the contact suggest that it is a major fault. However, no unequivocable evidence of motion has been observed at the surface although five of nine earthquakes recorded in east Tennessee during the past 100 years (Heck, 1958) occurred within 15 miles of the gradient. Depth estimates indicate that elevation of the basement surface does not change radically across the contact, and, hence, the gradient may be caused by a pregeosynclinal zone of weakness along which occasional minor adjustments continue to occur.

PREGEOSYNCLINAL TRENDS

Boundaries of units 3, 4, and 5 and some individual magnetic anomalies within the major units (pl. 2) have trends which are more northerly than Appalachian structural trends. These northerly trends parallel trends of the Allegheny axis (Kay, 1942) and Waverly Arch (Woodward, 1961) north of the area of investigation.

THRUST FAULTS

Some geologists (Willis, 1893; Longwell, 1945) have believed that rocks would be crushed and crumbled before the compressive force of thrusting becomes large enough to overcome the frictional drag along a gently dipping fault plane. They consequently concluded that outcropping fault planes must be steep at depth. Proponents (Rich, 1934) of gently dipping fault planes point out that frictional drag is minimized when the fault plane lies mostly in a water-saturated shale bed and that outcropping thrust faults in the area of investigation do actually appear to lie within shale formations. The nearly horizontal fault planes presumably either die out at depth or join a sole fault extending southeastward.

The Saltville fault is perhaps the longest single thrust fault in the southern Appalachians. It extends at least from Dalton, Ga., through the area and 130 miles northeast into Virginia (Rodgers, 1952), a distance of approximately 300 miles. At the point where line *A–A′* (pl. 1) crosses the Saltville fault, rocks of Cambrian age are adjacent to rocks of Mississippian age, and the stratigraphic separation is approximately 6,500 feet (L. D. Harris, oral commun., 1962).

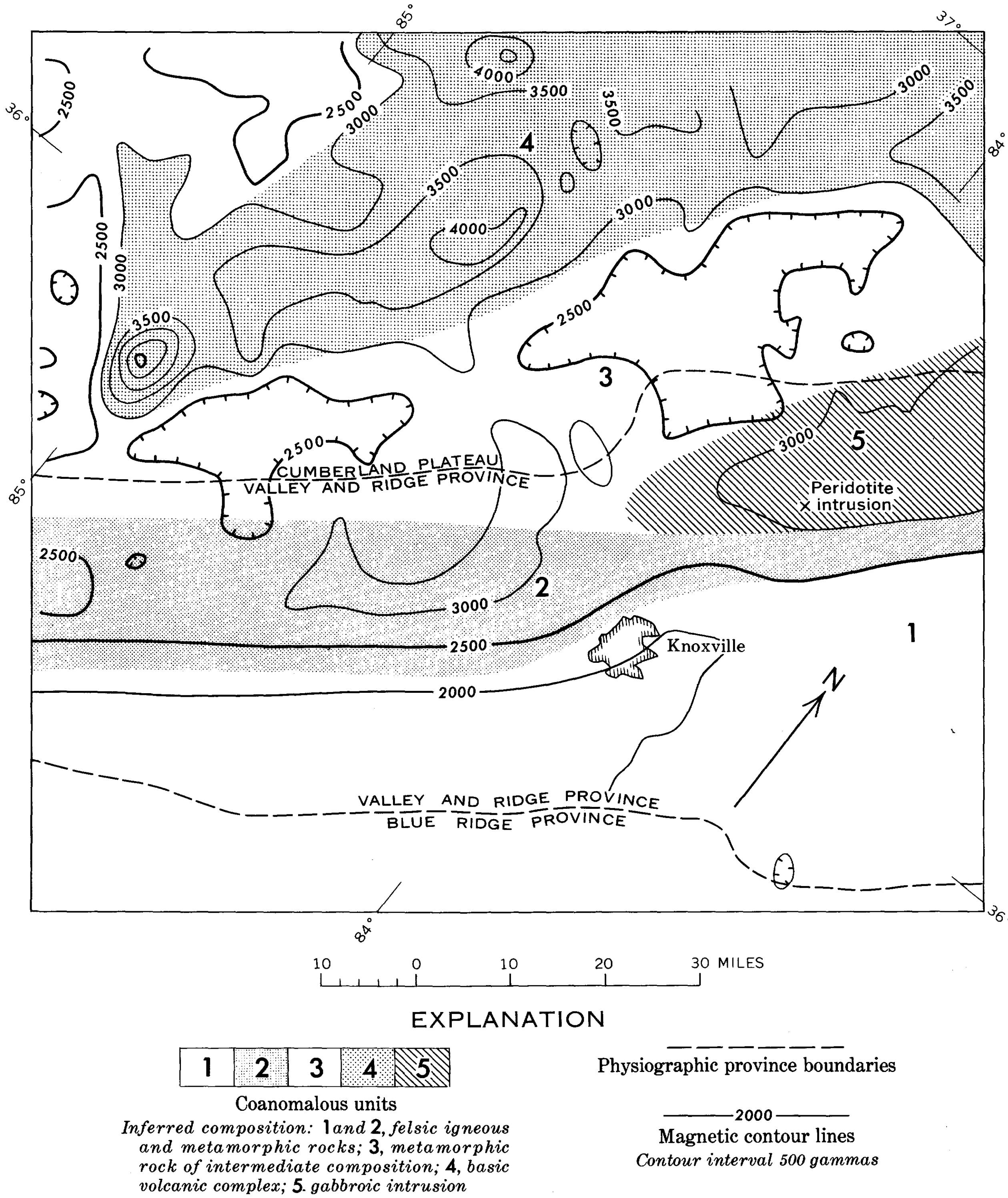


FIGURE 4.—Generalized aeromagnetic map of the area of investigation showing physiographic provinces and coanomalous units.

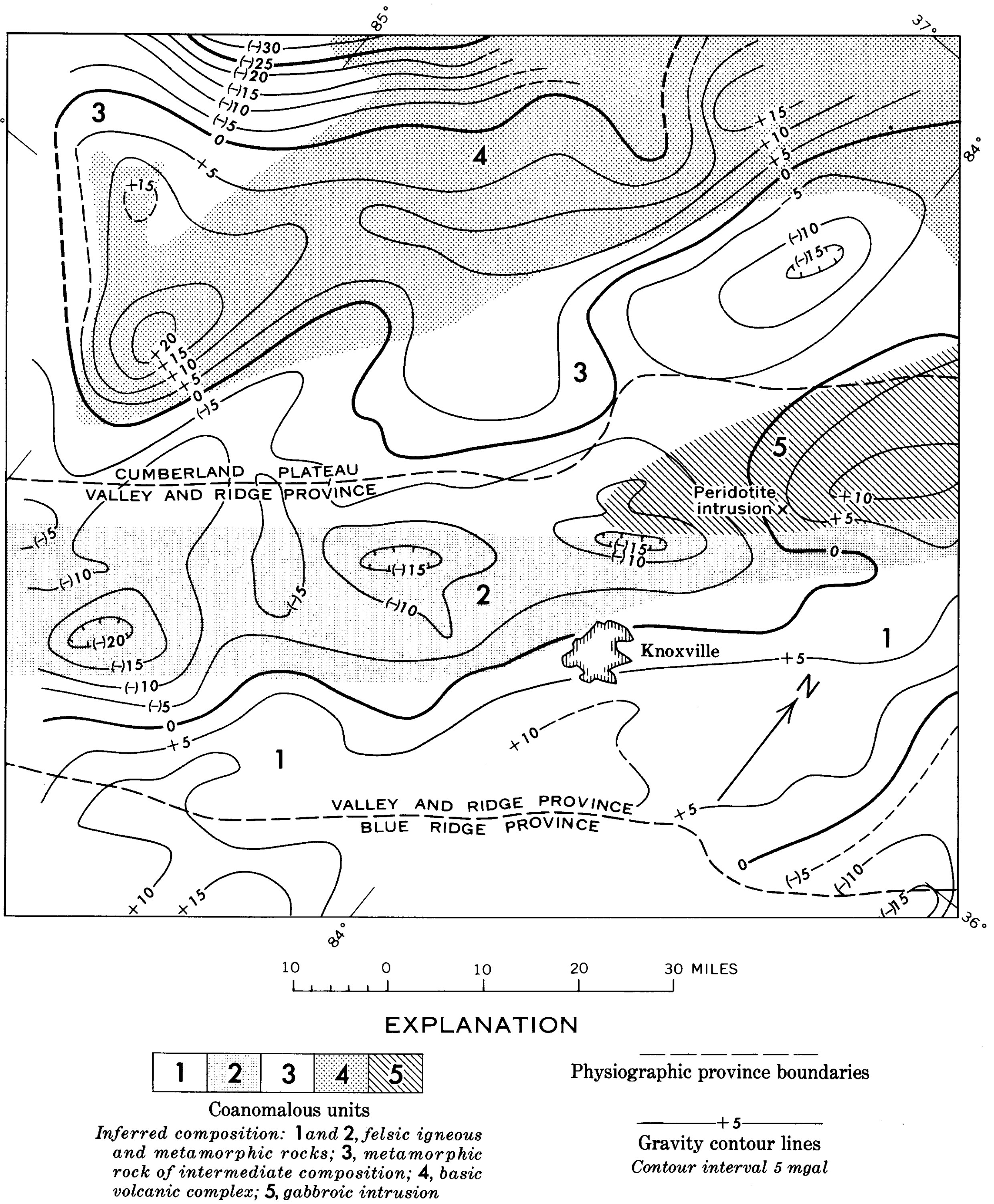


FIGURE 5.—Residual Bouguer gravity anomaly map after removal of ninth-degree least-square-fitted surface showing physiographic provinces and coanomalous units.

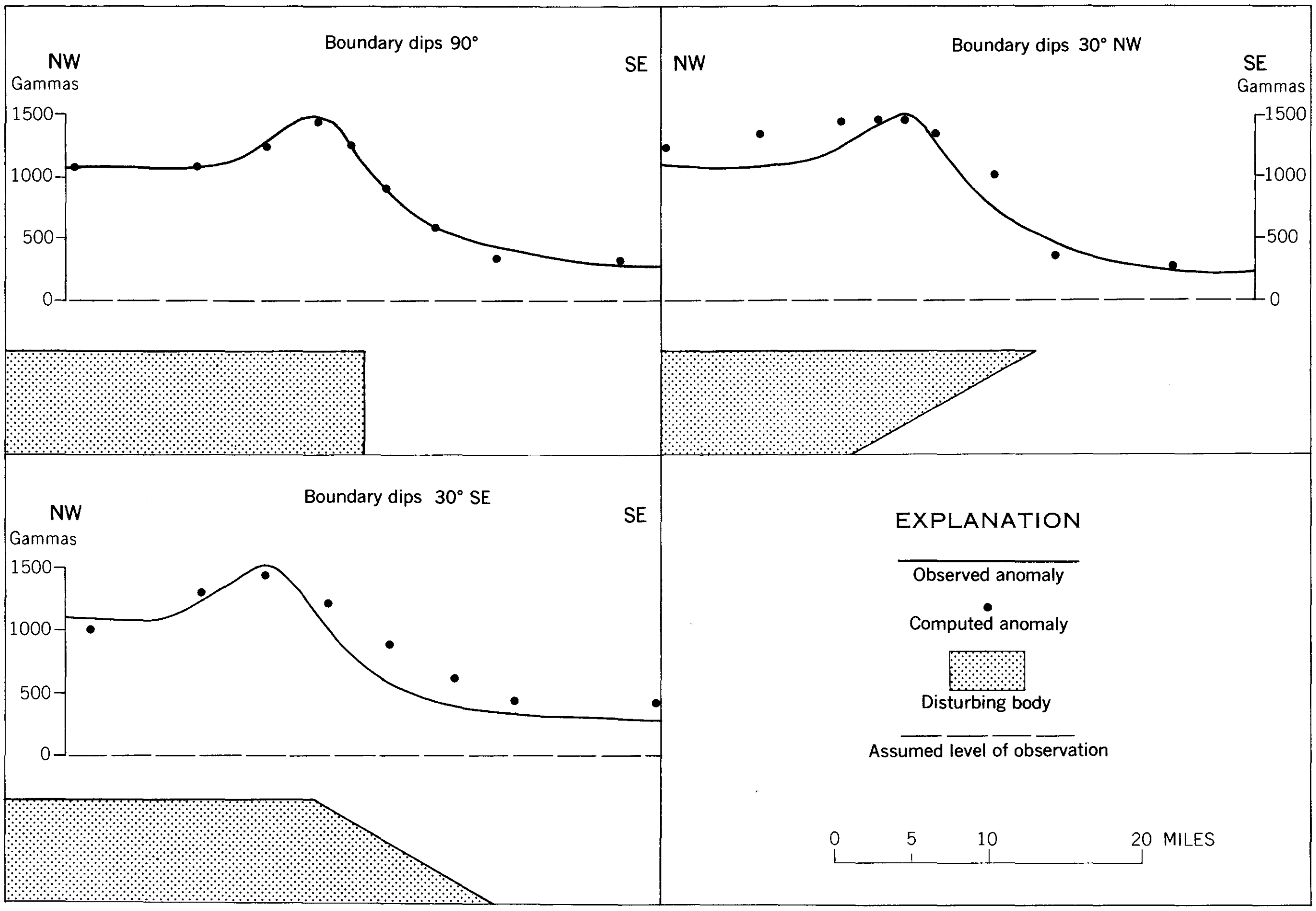


FIGURE 6.—Comparison of computed magnetic anomalies, resulting from a body whose southeastern boundary dips 90°, 30° NW., and 30° SE., with values observed across the magnetic gradient in the southeast part of the area.

If density and magnetic susceptibility of basement rocks in the hanging wall differ significantly from density and susceptibility of sedimentary rocks in the footwall of the Saltville fault and if the Saltville fault dips steeply into the basement rather than flattens at depth, then gravity and magnetic anomalies will occur along the fault. Let us, therefore, estimate the density and susceptibility of basement and sedimentary rocks.

The residual gravity anomaly associated with unit 1 indicates that basement rocks of unit 1 have a slightly higher mean density than most other basement rocks in the area. Woollard (1959) and Worzel and Shurbert (1955) estimate that the mean crustal density exceeds 2.80 g per cc. These figures may be slightly higher than the mean uppercrust density in the area of investigation; nevertheless, the density of rocks of unit 1 probably lies between 2.80 and 2.90 g per cc. Data tabulated on page A5 and shown in figure 3 indicate that the average density of the carbonate part of the sedimentary section in eastern Tennessee is slightly greater than 2.70 g per cc. The clastic part of the sedimentary section has a lower density than the carbonate part. Consequently, the average density of the sedimentary section is probably less than 2.70 g per cc, and the density contrast of basement and sedimentary rocks is probably about 0.15 g per cc.

Line *A–A′* lies on the edge of a small anomaly within unit 1 which allows direct estimation of a minimum susceptibility contrast (Vacquier and others, 1951) of $1{,}333 \times 10^{-6}$ emu between the anomaly-producing body and adjacent basement rocks. It has been previously observed that sedimentary rocks in the area are virtually nonmagnetic. Therefore, the susceptibility of the anomaly-producing body must exceed the susceptibility of the sedimentary rocks by at least $1{,}333 \times 10^{-6}$ emu.

Figure 7 shows anomalies observed along line *A–A′* and those computed on the basis of the preceding estimates of density and susceptibility contrasts. The failure of computed anomalies to match observed anomalies indicates that basement rocks are not displaced by the Saltville fault as assumed. Comparison of plates 1 and 2 reveals no anomalies which can be correlated with

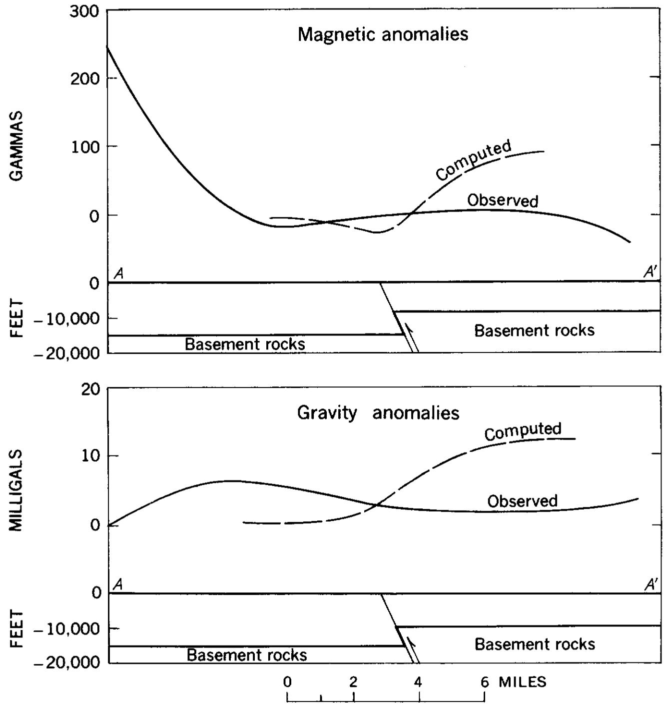


FIGURE 7.—Observed magnetic and gravity anomalies across the Saltville fault and anomalies computed by assuming that the Saltville fault displaces basement rocks. Location of line *A–A'* is shown in plate 1.

surface thrust faults for significant distances. These facts indicate that outcropping thrust faults do not penetrate the basement beneath the Valley and Ridge province.

JACKSBORO AND EMORY RIVER FAULTS

The Jacksboro fault, according to Wilson and others (1956), is a high-angle left-lateral fault along its outcrop which flattens northeast in the subsurface and merges with the Pine Mountain fault. Horizontal separation may be be as much as 10 miles, but vertical separation is only about 500 feet. The Emory River fault is similar to the Jacksboro fault except that it is a right-lateral fault and its horizontal separation is generally less than 1 mile.

The Jacksboro and Emory River tear faults are conspicuous in an area of dominant thrust faulting, and it is obvious that the mechanics of their deformation differ from those of the thrust faults. Inspection of the Bouguer anomaly map (pl. 1) shows that the area between the Emory River and Jacksboro faults has a pronounced positive gravity anomaly associated with it. Changes within the sedimentary section cannot cause such a large anomaly; it must be due either to increased basement elevation or to changes in basement lithology. The magnetic field (pl. 2) between the tear faults also differs from that of surrounding areas. Flight elevation, however, was different over much of this area, and hence the apparent change in magnetic character of the field may be partly due to the increased elevation of the plane relative to basement.

Northeast and southwest boundaries of the gravity anomaly coincide approximately with the trace of the faults. Magnetic anomalies are discontinuous near the Jacksboro fault trace, and some magnetic contours have inflection points near the Emory River fault.

The magnetic gradient previously discussed has an inflection point on the southeast projection of the trace of the Jacksboro fault. Magnetic contours are also inflected on the northwest projection of the surface trace. Relative motion of the flexure of the magnetic gradient is left lateral, the same as that of the Jacksboro fault.

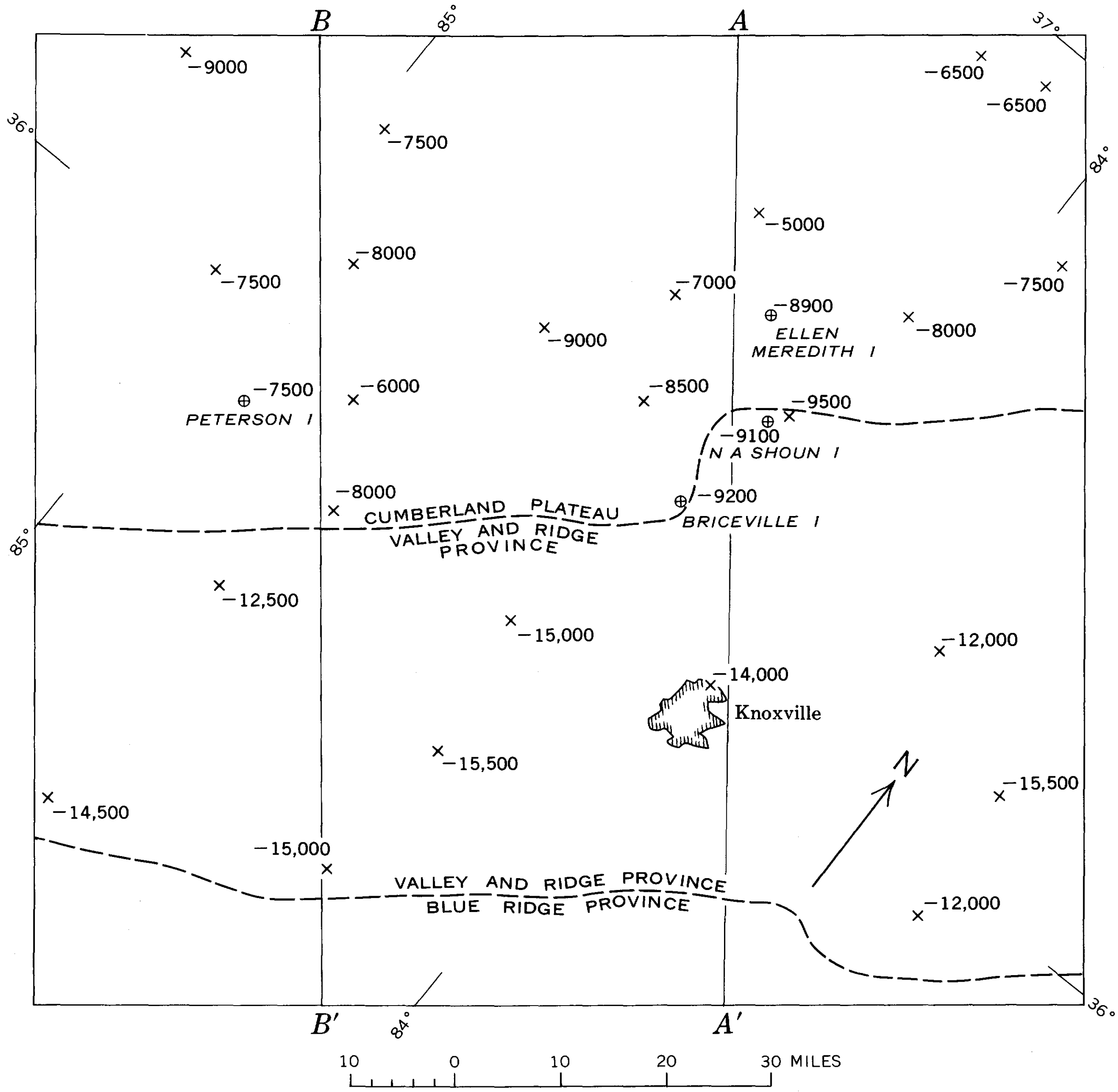
The relationships of anomalies and structural features suggest that basement faults underlie the Emory River and Jacksboro faults. These basement faults obviously cannot have caused the Cumberland Plateau overthrust and the Pine Mountain fault, but tear faulting, if active during sedimentation or lithification, may have created zones of weakness which were subsequently fractured by surficial stresses such as those causing adjoining thrusts.

If rocks northeast of the Jacksboro fault or southwest of the Emory River fault were already compressed, it is possible that basement faulting along the tear faults triggered the adjoining thrusts.

ELEVATION OF BASEMENT SURFACE

Depths to basement in the area were estimated from well data and magnetic anomalies. Estimates of depths from magnetic anomalies were made using a method described by Vacquier and others (1951). Five wells penetrate the sedimentary section deeply enough to justify their use in estimations of basement depth. Of the five, only UFG 8801–T in Bell County, Ky., passed completely through the Rome Formation. It stopped, however, in "basal sand" beneath the Rome Formation and did not actually penetrate basement rocks. Total depth to basement was inferred from observations of the thickness and character of the basal sand in other wells in Kentucky (Thomas, 1960). L. D. Harris (oral commun., 1962) estimated the basement elevations from data of the N. A. Shoun 1 and Briceville 1 wells, and R. A. Laurence (written commun., 1963) estimated basement elevations from data (Milhous, 1959) of the Ellen Meredith 1 and Peterson 1. Locations of wells, estimated and inferred elevations of the basement, and magnetic anomalies are shown in figure 8.

The estimates show relatively shallow basement depths beneath the Cumberland Plateau as expected from geologic inference. The basement deepens grad-



EXPLANATION

−9200
BRICEVILLE I

Well location, name, and inferred basement elevation in feet

−9000

Location of magnetic anomaly and inferred basement elevation in feet

Datum is sea level

FIGURE 8.—Inferred elevation of the basement surface in the area of investigation. Lines *A–A′* and *B–B′* show locations of cross sections in figure 10.

ually toward the Valley and Ridge province where depths are relatively uniform or perhaps rise slightly near the boundary between the Blue Ridge and Valley and Ridge provinces.

BASEMENT LINEAMENT

A lineament extending approximately 440 miles from west-central Alabama to a point about 15 miles southeast of Middlesboro, Ky., can be identified on the gravity anomaly map of the United States (American Geophysical Union and U.S. Geological Survey, in press). The lineament appears as a discontinuous zone of gravity minimums and seems to have an average width of about 15 miles. It can also be identified on an earthquake map of the United States (Heck, 1958) as an earthquake belt separating a zone of moderate earthquake activity in the Valley and Ridge and Blue Ridge provinces from a zone of negligible earthquake activity immediately northwest of the Valley and Ridge province. If those earthquake epicenters whose locations can be estimated only to $\pm 1°$ of latitude or longitude are excluded, 9 to 15 earthquakes recorded in Alabama, northwest Georgia, and eastern Tennessee since 1850 had epicenters within 15 miles of the axis of the zone of gravity minimums.

The lineament has no clear tectonic expression on the surface of the ground; however, the courses of three major rivers, the Powell, Tennessee, and Black Warrior, lie about 10 to 20 miles west of and parallel to the axis of the lineament for many miles in their respective watersheds. The Sequatchie Valley anticline in Alabama parallels the lineament, but structural features in Tennessee cut across the lineament, generally at small angles. The most remarkable characteristic of the lineament is that, for its entire length, its axis lies within 20 miles of the boundary between the Valley and Ridge province and the Cumberland Plateau. Earthquake epicenters, axis of gravity minimums, and major structural features are shown in figure 9.

The gravity minimums are most evident in the area of investigation where the lineament coincides with unit 2. However, unit 2 is very narrow in the northeastern half of the area and cannot be identified with confidence north of the area of investigation on the basis of its gravity anomalies. A possible continuation of the lineament north of the area can be inferred from the earthquake epicenters, but the lineament is either discontinuous or changes direction in the vicinity of the northeast boundary of the area of investigation.

In the area of investigation, the elongate shape of unit 2 and the large number of earthquakes near the unit suggests that it is a transition zone between two major crustal blocks. The irregular shape of the magnetic anomalies and the relative intensities of the magnetic and gravity anomalies associated with unit 2 suggest that its composition is felsic and that the rocks within the unit are intruded and possibly intensely deformed.

The basement block northwest of unit 2 has a relatively high elevation (fig. 10) and negligible seismic activity, and it is overlain by relatively undeformed sedimentary rocks. These characteristics suggest that this crustal block is structurally related to the stable craton of the interior of the continent.

The basement block southeast of unit 2 is characterized by moderate seismic activity. It is overlain by moderately deformed sedimentary rocks, and its surface is relatively deep. These characteristics suggest that this block is, or at least was, more mobile than the northwest block.

DEGREE OF DEFORMATION AND DEPTH TO BASEMENT

Figure 10 shows that the degree of deformation can be correlated to some extent with basement depths. The zone of weak deformation includes all of the Cumberland Plateau and also includes that part of the Valley and Ridge province northwest of the Wallen Valley fault. Much of the weakly deformed zone lies over relatively shallow basement. The zone of moderate deformation corresponds to the remainder of the Valley and Ridge province and lies entirely over relatively deep basement. No depth estimates could be made in the parts of the Blue Ridge province where intensity of deformation is greatest.

Thinning of Cambrian shale units over and immediately northwest of unit 2 is thought to be the factor which controlled location of the boundary between the weakly deformed and moderately deformed zones. The Cambrian shale units, principally the Rome Formation and the Conasauga Shale, are the incompetent rocks wherein the sole fault is thought to be located. These shale beds can be considered as the "lubricants" of the thrust faults.

Rodgers (1952) observes that the source of detrital material in the Rome Formation and the Conasauga Shale lies northwest of the exposures in the Valley and Ridge province. The higher basement northwest of unit 2 may or may not have been part of the source area, but it is a logical place to expect thinning and increased clastic content of the shale. Either thinning or facies change within the shale beds would increase friction and consequently inhibit formation of thrust faults within them. Thinning or facies change in overlying dolomite of the Knox Group, which Rodgers (1952) describes as "controlling struts" of the thrust faulting, might decrease the ability of the dolomite to

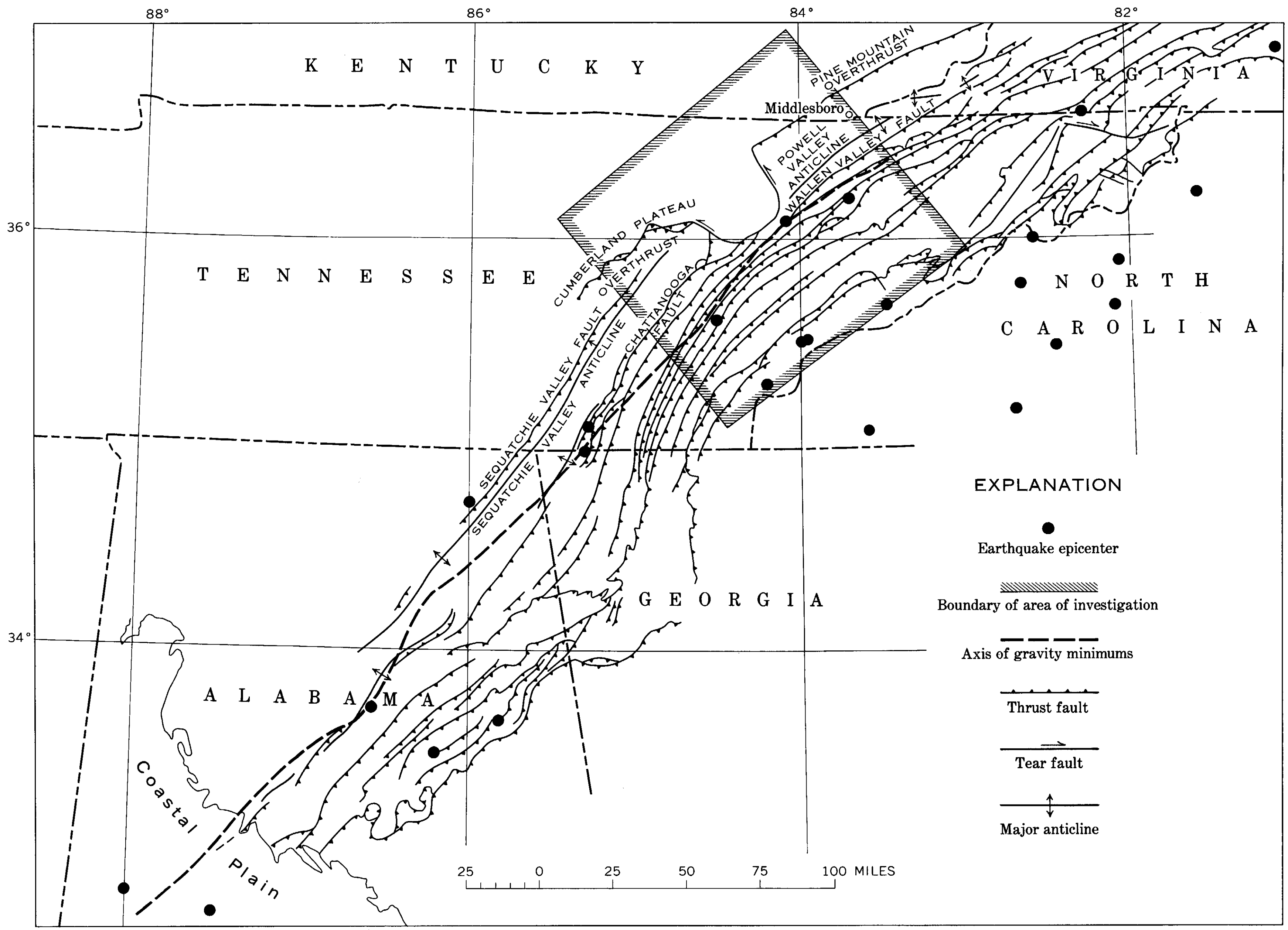


Figure 9.—Structural geology and geophysical-data map showing thrust faults in and bordering the Valley and Ridge province in the southern Appalachians, earthquake epicenters, axis of Bouguer gravity anomaly minimums, and some tear faults and anticlines. Geology after U.S. Geological Survey and American Association of Petroleum Geologists (1962).

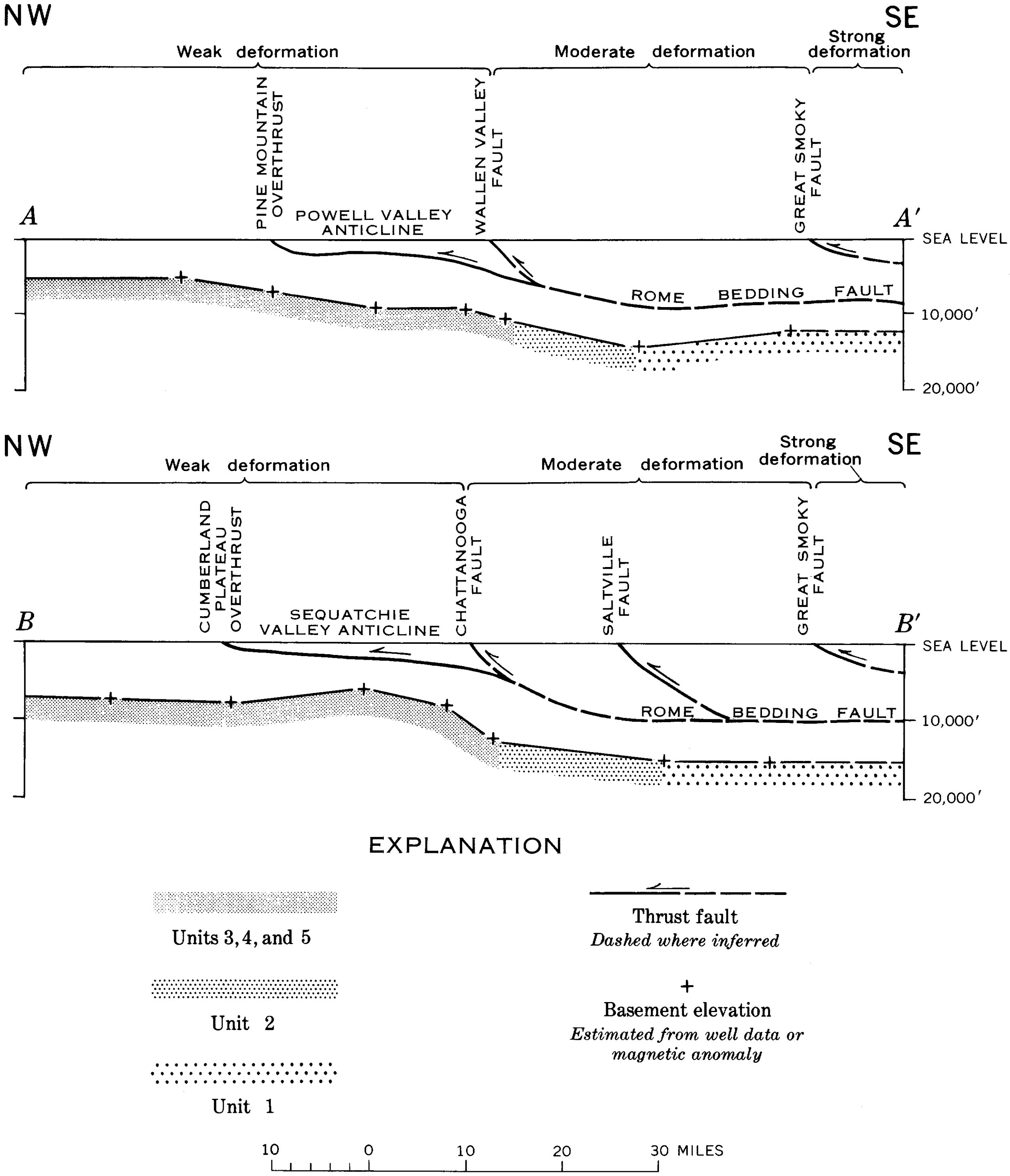


FIGURE 10.—Cross sections showing relationship of zones of deformation, inferred basement elevations, inferred basement lithologic units, and known or inferred structural features in overlying sedimentary rocks. Locations of cross sections are shown in figure 8.

transmit stresses and consequently constitute as important a thrust-fault inhibitor as thinning and facies changes in the shale.

The Cumberland Plateau overthrust northwest of Sequatchie Valley and the Pine Mountain fault northwest of Powell Valley lie in shales of Devonian and Mississippian ages. These thrusts are undeformed when compared with those southeast of the Wallen Valley fault and the Chattanooga fault. The Pine Mountain fault and the Cumberland Plateau overthrust seem unrelated to basement elevation or structure except in the vicinity of the Sequatchie Valley and Powell Valley anticlines where a basement arch may underlie the surface anticlines. Harris and Zietz (1962) have considered the structural implication of such a ridge beneath the Powell Valley anticline in southwestern Virginia.

SUMMARY

Basement rocks in the area of investigation consist of at least five major lithologic units whose approximate boundaries have been located. Three of the five units trend more northward than contemporarily exposed surface structural features and indicate that the pre-Appalachian structural grain of the craton was more northerly than outcropping Appalachian structural feature. A major basement contact with a steeply dipping contact plane extends across the area. The contact is thought to be a basement fault.

The Jacksboro and Emory River faults, which are the two major tear faults in the area, each have gravity and magnetic discontinuities associated with them. The discontinuities suggest that basement faults underlie the surface fault traces. The inferred basement faults, surface tear faults, and surface thrust faults seem structurally related, but the relationship is not clear. Absence of anticipated anomalies implies that surface thrust faults either die out within the sedimentary section or coalesce into a sole fault or faults which must extend nearly horizontally along bedding planes southeastward beneath the great overthrusts cropping out along the western margin of the Blue Ridge province.

The basement surface beneath the Valley and Ridge province lies higher than previously suspected, averaging less than 15,000 feet below sea level. The surface may rise slightly along the boundary of the Valley and Ridge and Blue Ridge provinces.

A major basement lineament parallels the western margin of the Valley and Ridge province. This lineament seems to be a transition zone separating a tectonically active Appalachian crustal block from a stable cratonic block. The absence of intense thrust faulting and folding in the Cumberland Plateau is believed to be the result of thinning of the Paleozoic sedimentary section immediately west of the transition zone.

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