GRAVITY SURVEY OF BUCHANAN, VIRGINIA GEOPHYSICAL EXPLORATION OF THE PULASKI-STAUNTON THRUST

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Introduction

The Central Appalachians are characterized by distinctive parallel linear physiographic features that reflect five structural and lithologic provinces. From east to west these provinces are the Piedmont, the Blue Ridge, the Great Valley, the Valley and Ridge, and the Appalachian Plateau. The highest peaks in the range are in the Blue Ridge province. Structure in the Blue Ridge region is a northeast-plunging anticlinorium of Grenville age high-grade gneisses and lower Paleozoic age granitiod plutons that are thrust over the rocks of the Valley and Ridge. The Valley and Ridge is a sedimentary fold and thrust belt representing the foreland of the Appalachian orogen. The region is dominated by thin-skin deformation and disharmonic folding and little overall metamorphism. The dominant structures in the region are late Paleozoic (Alleghenian) in age. The gravitational attractions of bodies in the crust offer important clues to the geologic interpretation of the Purgatory and Short Hills areas of western Virginia.

Goals

The main goal of this study is to constrain the geologic interpretation of the Renick Run region using gravity data. Furthermore, an additional objective of the study is an analysis of the structural relationships between the Short Hills syncline and the Purgatory anticline, believed to be a fault bend fold (Bartholomew and others, 1982).

Field Methods

Surveying

Accuracy is paramount in our survey because the density contrasts are extremely small and amplitudes of any anomaly are small relative to the influences of terrain. Extensively detailed surveying and gravity readings therefore, characterized the study. A gravity meter measures the difference in gravity between locations to a precision of 0.01 milliGal (mGal), furthermore, one meter of elevation has the capacity to change the gravity approximately 0.2 mGal. Therefore, it is important in a gravity study to survey each station to determine its elevation to within 10 centimeters. Before entering the field, an analysis was performed to determine the possible problems associated with specific areas. The feasibility of each measurement was also assessed in light of the time constraints of our study. Overall, four lines were surveyed utilizing five persons over a period of three weeks.

The survey used a Lietz SET4 Total Station with a SDR electronic data collector to pinpoint a series of points that are relative to a particular known point. This instrument measures distances with an infrared beam reflected from a target prism and is accurate to 0.003 m at a distance of 1 km. Horizontal and vertical angles are measured electromechanically to a precision of 5" of arc. If there was no previously surveyed reference point such as a benchmark, the procedure for beginning the line became more involved. A backshot approximately north, obtained using a Brunton compass, was necessary to begin the line. The data was reduced using the SDR data collector's topography program, which processed station locations by northing, easting, and elevation with a precision of 0.01 m. Each day, data was downloaded from the SDR onto a Macintosh Quadra computer. Precise asmithal orientations were obtained by plotting and rotating these data points on previously scanned maps.

After determining an acceptable base station, the Total Station was erected and subsequent stations were shot at distances ranging from 50-600 meters. Sighting problems constrained surveying distances and thus, not every surveyed station was used for gravity. At each new station, erection of the Total Station, backshots to known locations, and shots of new stations were performed. Each station was flagged or spiked with station numbers attached. Spiking is relatively permanent and reoccupation was not a problem.

Station Locations

The surveying technique involved extensive planning in order to make the measuring of gravity as easy as possible. Although not every survey station was occupied for gravity, the ability for a more detailed analysis was possible by returning to previously unoccupied stations to confine any perceived anomaly. Exactly one hundred stations were established in a line that crosses perpendicular to the surficially mapped structure of the region. Care was taken in surveying to achieve a flat area devoid of any nearby scarps which would substantially influence gravity readings.

The first base station was established at the intersection of State Route 623 and U.S. Route 11. From there, stations were established along Renick Run in a northwest direction for approximately 3.5 miles. The benchmark at the Mt. Joy Church at the corner of State Route 622 and State Route 611 served as a base reference. Figure 2 shows the approximate location of the Renick Run survey.

Gravity Measurements

A LaCoste and Romberg Model G gravity meter was used for the survey. At each gravity station, the date, time, station number, and gravity reading was recorded into a field book. This was done to establish an empirical direction of drift. On average, each station was occupied twice.

At each gravity station, a schedule of procedures was necessary for consistent and accurate readings. Leveling of the gravimeter was done by placing a concave aluminum plate onto the ground and then setting the meter on it. The meter was leveled using two built-in perpendicular levels. Because of the sensitivity of the levels to sunlight, an umbrella was used to shade the reader and the meter. After leveling, the pendulum was unlocked and the screw on the meter was then rotated to obtain a reading. In every instance, the screw was rotated in the same direction so as to eliminate the effect of mechanical play in the mechanism.

There are several influences that cause temporal variations in the instrument readings. Tidal forces and instrument drift resulting from relaxation of the zero-length spring are both factors requiring correction. The gravity stations were occupied at 8-10 minute intervals and tie-ins were done approximately every hour. This was possible due to vehicle transportation of the instrument. Several new base stations were established to limit travel time as well as any jolting of the gravimeter. About 50 percent of the stations were used as gravity stations and the rest were used primarily for the surveying process. This exemplifies the detailed surveying as well as the discrimination used in choosing proper gravity stations. Furthermore, after the first base station for the line was determined, gravity was taken at least two times by the same person in order to maintain consistency.

Data Reduction

All of the preliminary gravity data reduction was done in Virginia on a Macintosh Quadra using Excel 4.0 software. The final reductions were done at Whitman College using a Macintosh Centris 650. Because each gravimeter is different, there is a calibration curve for each individual meter. This curve is used to convert meter dial readings into actual milliGals. For our specific meter the calibration is approximately 1.

After conversion to milliGals, the effects of instrument drift and tidal drift were removed from the data by assuming a linear drift from each successive base station reading. The process was then repeated by merging each data set.

The free-air correction was then applied to the data to compensate for the effects of latitude and elevation (Burger, 1993). We corrected for latitudinal variation using a Chebychev approximation of the Gravity Formula 1967 of the International Association of Geodesy:

$$g=(978\ 031.85)(0.005\ 278\ 895\ \sin^2\phi+0.000\ 023\ 462\ \sin^4\phi)\ \text{mGal}$$

where ϕ is the latitude in radians. It is also important to correct for the elevation since gravitational force varies with the distance from the center of the earth. This is derived using Newton's law of gravitation:

$$\Delta g=(-0.03086)(\text{elevation in meters})\text{mGal}$$

The simple Bouguer correction is used to account for the rock mass variations directly under the gravimeter due to changes in elevation. In our survey, as well as most regional surveys, a density of 2.67 g/cm^3 was employed for the density of the slab of uniform material of infinite extent. This value may change with further study on calculated densities of the units in the Renick Run region. Figure 1 is the preliminary Bouguer anomaly for the Renick Run line. Distance is from the intersection of State Route 623 and U.S. Route 11.

There are two anomalies exhibited in figure 1. The first is the dip in the line resulting from the contracting densities of the Cambrian Elbrook on the Pulaski-Staunton thrust and the Ordovician Beekmantown Dolomite. The second anomaly is a result of the Short Hills syncline and anticline pair towards the northwest end of the line.

Terrain corrections for this data is necessary for the influence of topography on readings taken within the proximity of these features. A large amount of relief exists in the area, yet by using a Hammer chart and Excel 4.0 spreadsheet, terrain only accentuates the anomaly and often cancels out. At time of printing, the terrain correction has not been completed for the entire line, as it is a tedious and often boring task. After reduction, modeling of the final gravity is done using Grav 2D software on a Macintosh Centris 650.

Discussion

We hope to constrain the geology of the subsurface in the area in and around Purgatory Mt. It is believed to be a southwest plunging anticline formed in Silurian clastic rocks of the Tuscarosa and the Rose Hill Formations. This fold plunges to the southwest and is overlain by the Lower Cambrian Elbrook dolomite thrust onto the Silurian on the Pulaski-Staunton Thrust (Spencer, 1993). The anomaly over the Pulaski-Staunton Fault provides an opportunity to model the thickness of the thrust sheet using the contrasting densities between the Cambrian units and the Ordovician units. Approximately 10 km to the northeast there is a southwest plunging syncline formed in undivided Silurian rocks and cored by Devonian shales. The Cambrian Elbrook Formation is exposed to the west of Purgatory Mountain, which indicates that the Pulaski-Staunton Fault is folded and Purgatory Mountain is a fault-bend fold (Bartholomew, et al., 1982).

About 10 km to the northeast of the Purgatory anticline are the Short Hills, an associated southwest plunging syncline and anticline pair with similar plunge and trend. The large positive anomaly produced by this fold results from the thickening of the Ordovician units in this area. A structural analysis of these folds based on gravity modeling should shed light on the small scale imbricate faults associated with the Pulaski-Staunton Fault. It may also be possible to accurately constrain the relationships between the folds of the Short Hills and Purgatory Mt.

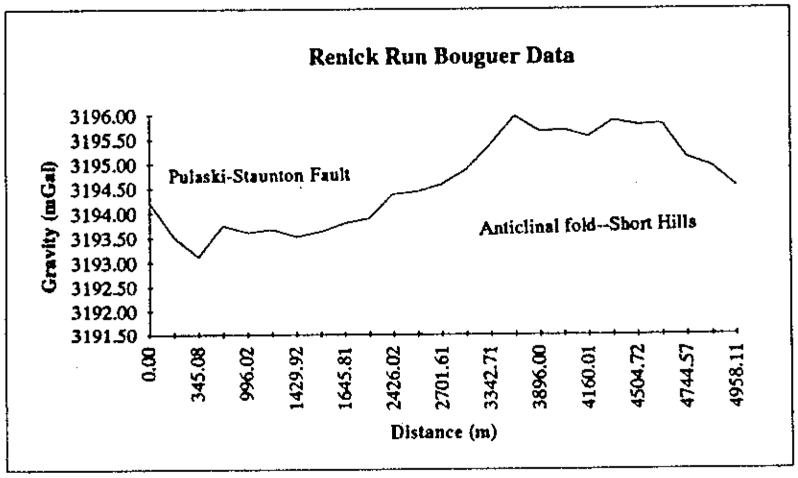

Figure 1 Preliminary Bouguer data for Renick Run. The anomalies shown above have not been terrain corrected, yet both are correlative to surficial mapping of structural features by Spencer, 1968 and Bick, 1987.

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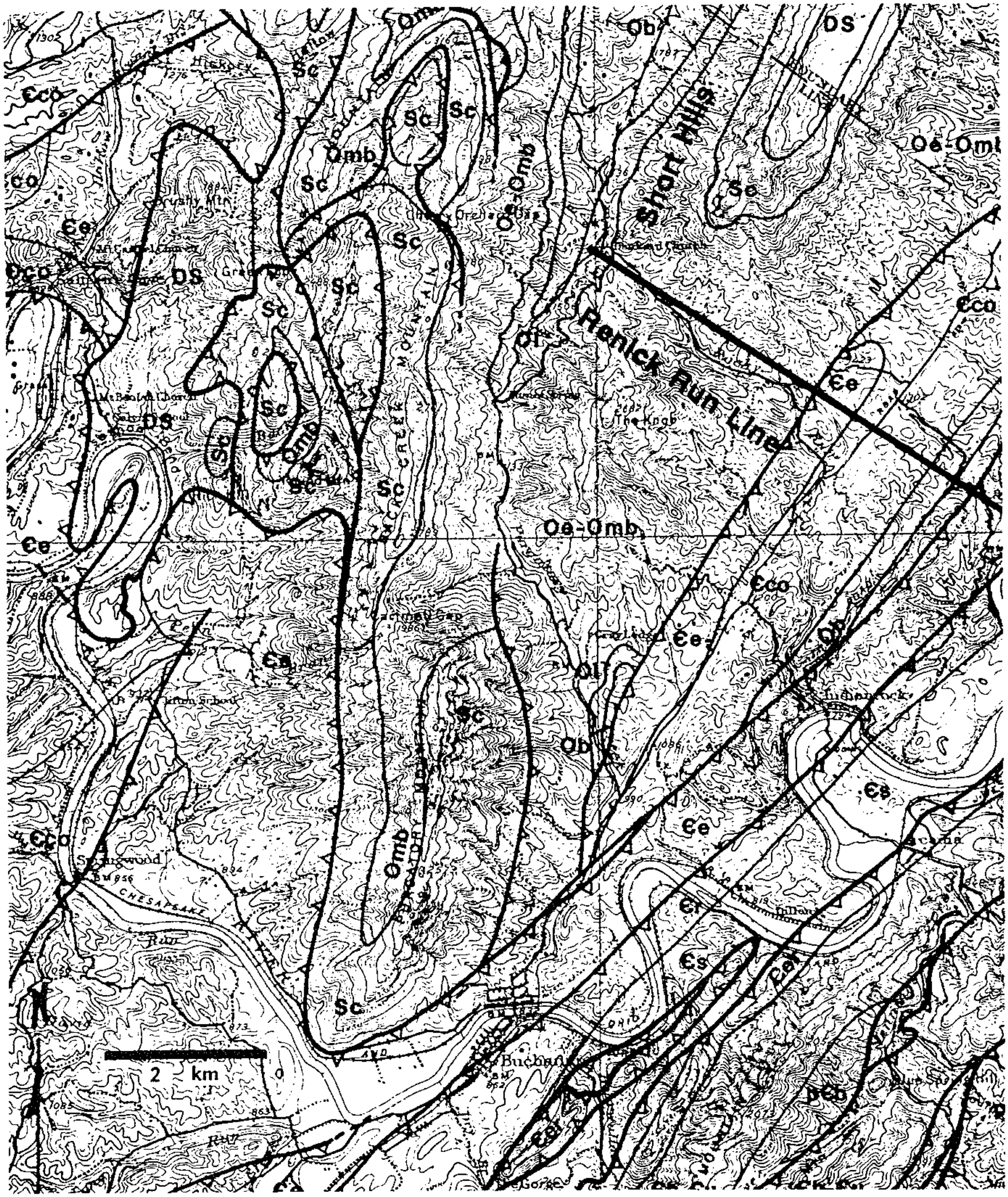

Figure 2 Sketch map of the Renick Run area showing Purgatory Mountain as well as the Short Hills region. Structure shown on this map has been modified after Spencer, 1968 and Bick, 1987.