GRAVITY CONSTRAINTS ON THE SUBSURFACE STRUCTURE OF THE PULASKI-STAUNTON THRUST SHEET, ROCKBRIDGE COUNTY, VIRGINIA

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Introduction

Fold and thrust belts dominate the structural style of the Valley and Ridge province of the Central Appalachian Mountain System. The major thrust faults of the region have been mapped based primarily on surficial expressions of the faults and related stratigraphic successions of rock units represented in each thrust sheet. The Pulaski-Staunton fault is a major regional scale thrust which is exposed in the southern Great Valley of Virginia. In the study area, the Pulaski-Staunton fault trends northeast-southwest between the towns of Lexington and Buena Vista, Virginia.

The Pulaski-Staunton thrust sheet is a sequence of relatively dense carbonates that has been displaced more than 12 miles (Dean and Kulander, 1986) and overlies the less dense Martinsburg Formation that provided the plane of weakness for the thrusting event. The subsurface geometry of the fault and the affected strata has been inferred primarily by surficial mapping techniques and seismic data collected by the COCORP project. The complicated nature of the thrust belts has limited the interpretation of the subsurface by these techniques. During the summer of 1993, I participated in several gravity surveys with three other students and a faculty advisor. These surveys crossed various structures which were anticipated to have measurable gravity anomalies. This study is an attempt to model the subsurface structure of the Pulaski-Staunton thrust sheet using the gravity data from one of these surveys. The primary goals in modeling the measured and reduced gravity data are to determine the geometry of the fault and constrain the geometry of the rock units in and beneath the thrust sheet. The results obtained from this modeling will be the first to use densely sampled, terrain-corrected gravity in this region.

Field Methods

The gravity anomaly over the Pulaski-Staunton fault was not expected to be more than a few mGals due to the small density contrasts between the rock units involved. The total density range is between 2.65 to 2.77 g/cm^3 (Byerly, 1973; Dean and Kulander, 1978). Topography alone produces gravity changes of 0.2 mGal per meter. Since gravity measurements have a precision of 0.02 mGal, elevation changes between stations must be measured to within 10 centimeters. For this reason, all gravity stations were surveyed using a Leitz SET4 Electronic Total Station. This device consists of a theodolite and an electronic data collector to record measured angles and distances and convert them to Cartesian coordinates of northing, easting, and elevation. Horizontal and vertical angles are measured to a precision of 5" of arc, and distances up to 1 kilometer to a precision of 0.003 meters. Azimuthal orientation of the survey was approximated in the field using a Brunton compass.

The gravity stations were surveyed on the median of Route 60 between Lexington and Buena Vista (Fig. 1). This four lane divided highway was ideal for the survey because it crosses perpendicular to the strike of the fault and the stratigraphic units involved. The flat topography of the highway allowed several gravity stations to be surveyed from one instrument station and minimized the terrain corrections close to the stations. Each station was flagged and numbered so that it could be reoccupied at a later time for gravity measurements. A total of 69 gravity stations were surveyed 50 to 100 meters apart, forming a traverse approximately 6 kilometers in length. Because of local topography and turns in the road, the theodolite had to be moved after every few shots. Back shots were used in order to reestablish the orientation of the theodolite.

The data were downloaded into a Macintosh Quadra 700 computer. An X-Y plot of station locations was generated and overlaid on a scanned topographic map. True azimuthal orientation of the survey was established by rotating the overlay to match selected stations with their known map positions. Absolute elevations of several control points were determined using contour lines on the topographic map. Absolute elevations of the remaining stations were calculated using the relative elevations measured in the survey.

Gravity was measured using Trinity University's LaCoste-Romberg Model G gravity meter. Because the instrument is essentially a horizontal pendulum, the meter must be accurately leveled using a pair of perpendicular bubble levels. These bubble levels are sensitive to sudden changes in temperature, so a large red golf umbrella was used to shield them from direct sunlight. When taking each gravity reading, the last turn of the nulling screw was made in the same direction to minimize error caused by mechanical play in the screw. The time of day of each reading was recorded so that drift corrections could be applied.

Two types of drift occur during a gravity survey. Tidal drift is caused by tidal forces on the solid earth. Mechanical drift of the instrument results from physical changes in the instrument's spring. The effect of drift was minimized by remeasuring gravity at temporary base stations at intervals of less than two hours to determine total drift. Frequent reoccupation of gravity stations allowed linear drift to be assumed so that the stations measured within loops could be corrected. To confirm the reliability of the gravity values, the entire traverse was measured twice over a five day period. Measurements at all stations were reproducible with less than 0.05 mGal difference after the effects of drift were removed.

Data Reduction

The reduction and correction of gravity data was done with Microsoft Excel™ spreadsheets. The first step in the reduction was to convert the gravity meter dial readings to actual mGal values. This was done using a calibration table, unique to Trinity's instrument, provided by the manufacturer. After the data were converted to mGals, the empirical corrections were applied. At this point, the gravity values represent the data set that would be obtained if all of the stations were measured at the same instant with identical gravity meters.

Measured gravity values change with latitude because of the ellipticity and rotation of the earth. Because the survey spanned a small range of latitudes, a linear variation of 0.786 mGals per meter of northing at the latitude of Lexington can be assumed. Gravity values also vary as distance from the station to center of the earth changes. In order to account for changes in elevation, a free-air correction was applied (Sharma, 1986).

The free-air correction assumes that no material has been added under the gravity meter as elevation increases, so the obvious effects of the mass of rocks comprising the terrain are neglected. The Bouguer correction compensates for this added mass. The first part of the Bouguer correction assumes that the material beneath the station is an infinite slab between the station's elevation and sea level. A second part of the correction takes into account the regional terrain. Because the relief in the Great Valley and Blue Ridge is substantial, ranging from several hundred to one thousand meters, it was necessary to calculate terrain corrections for each station. All terrain corrections are additive because both positive and negative relief lower measured gravity readings. Terrain corrections were determined using Hammer charts (Hammer, 1939) created to map scale on transparencies and overlaid on topographic maps. Average elevations were estimated for Hammer zones D through I, to a distance of 4453 meters from each gravity station. The inner 53 meters, represented by Hammer zones A through C, were assumed to contribute no terrain due to the conveniently flat topography of the highway. Average elevations for the zones sector were input into a spreadsheet that calculated the terrain correction for each station.

The line surveyed for gravity is roughly perpendicular to the Pulaski-Staunton fault, but deviations from the perpendicular required that the station locations be projected onto a straight line normal to the fault. This was accomplished using a vector dot-product to project all points onto a line defined by two of the points which approximated the perpendicular. Once the terrain corrected gravity was projected onto a line, a gravity profile was created. Figure 2 shows the raw calibrated gravity data projected onto a line and each of the corrections applied to the data set including the free-air anomaly, Bouguer anomaly, and terrain corrected gravity.

Analysis

A computer modeling program, Grav2D, was used to created preliminary two dimensional models of the subsurface structure along the gravity profile. Surficial geologic mapping (Spencer, 1992) provided surface constraints on the contacts between units and the trace of the Pulaski-Staunton fault. Starting from Lexington, an eastward traverse of the measured line begins on the Ordovician Edinburg limestone. The next unit encountered is the Ordovician Martinsburg shale, which forms the footwall of the fault. Outcrops on the hanging wall of the fault suggest the existence of an asymmetric syncline between the interstate and Buena Vista, consisting of the Cambrian Elbrook and Conococheague carbonate formations. Using these basic surficial relationships, a preliminary gravity model was created (Fig. 3). Densities of units from Byerly (1973) and Dean and Kulander (1978) were used and adjusted within the reported ranges in order to produce a model which best fits the gravity data.

The major feature on the gravity profile is a low over the Martinsburg Formation reflecting the low density of this unit. Gravity abruptly increases when the line crosses the Pulaski-Staunton fault onto the more dense Cambrian carbonates. Although surficial expressions of the fault indicate that it dips gently near the surface, the gravity data appears to require a relatively steep fault near the surface. This short wavelength feature cannot be caused by structure, even by abrupt density changes, deeper than 1.5 kilometers.

Although the model shown in Figure 3 fits the general amplitude of the anomaly, additional modeling is underway to fit the very short wavelength anomaly observed over Pulaski-Staunton fault. Adjustments in densities, dips, and thicknesses of the units, along with stacking of carbonate units beneath the Martinsburg Formation are possible modifications to the preliminary model presented here.

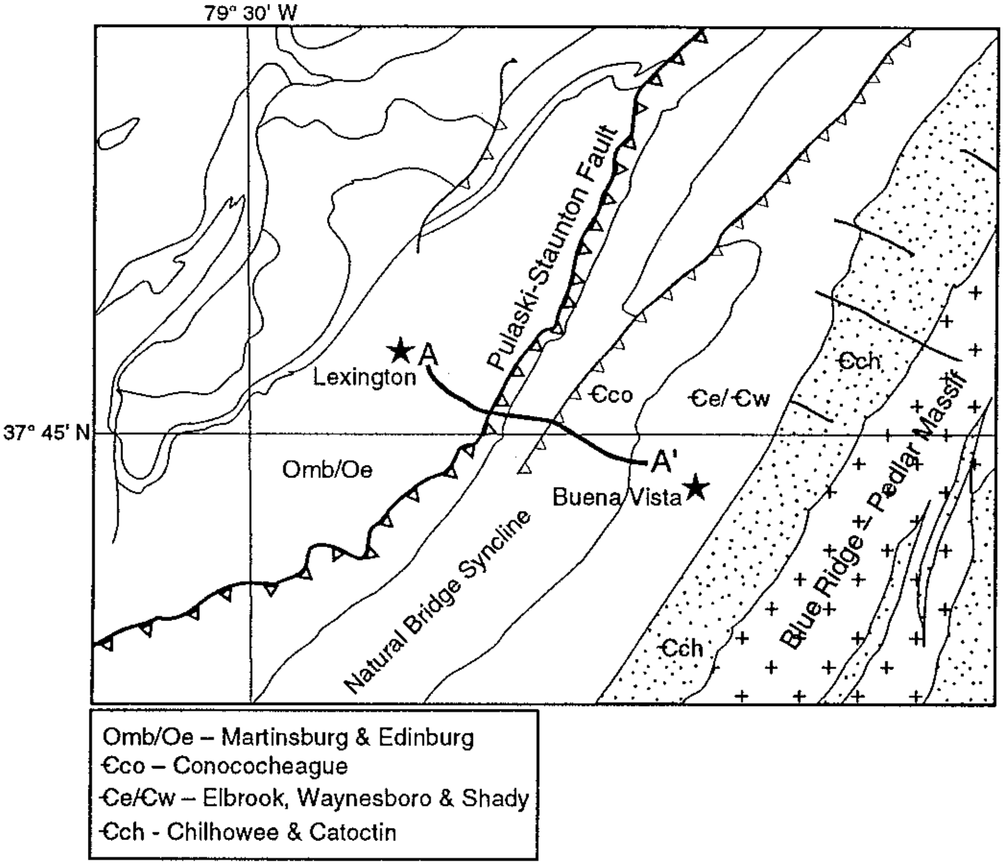

Figure 1. Geologic location map showing the measured gravity line, A-A', crossing the Pulaski-Staunton Fault between Lexington and Buena Vista, Virginia.

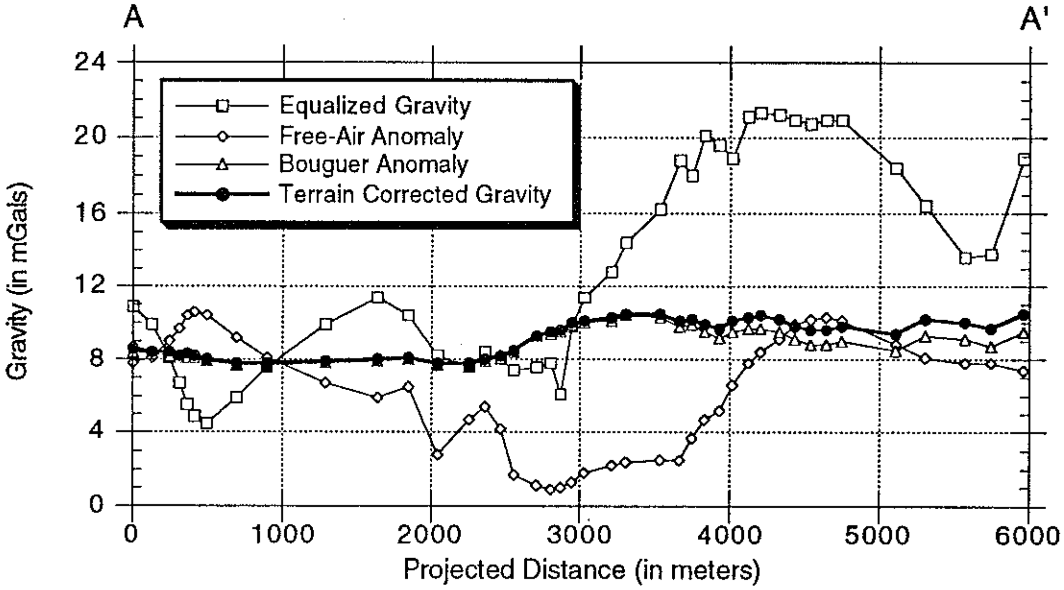

Figure 2. Gravity data along the survey line A-A' showing the equalized values after drift correction, along with the values after each additional correction. The terrain corrected values are used in the modeling procedure.

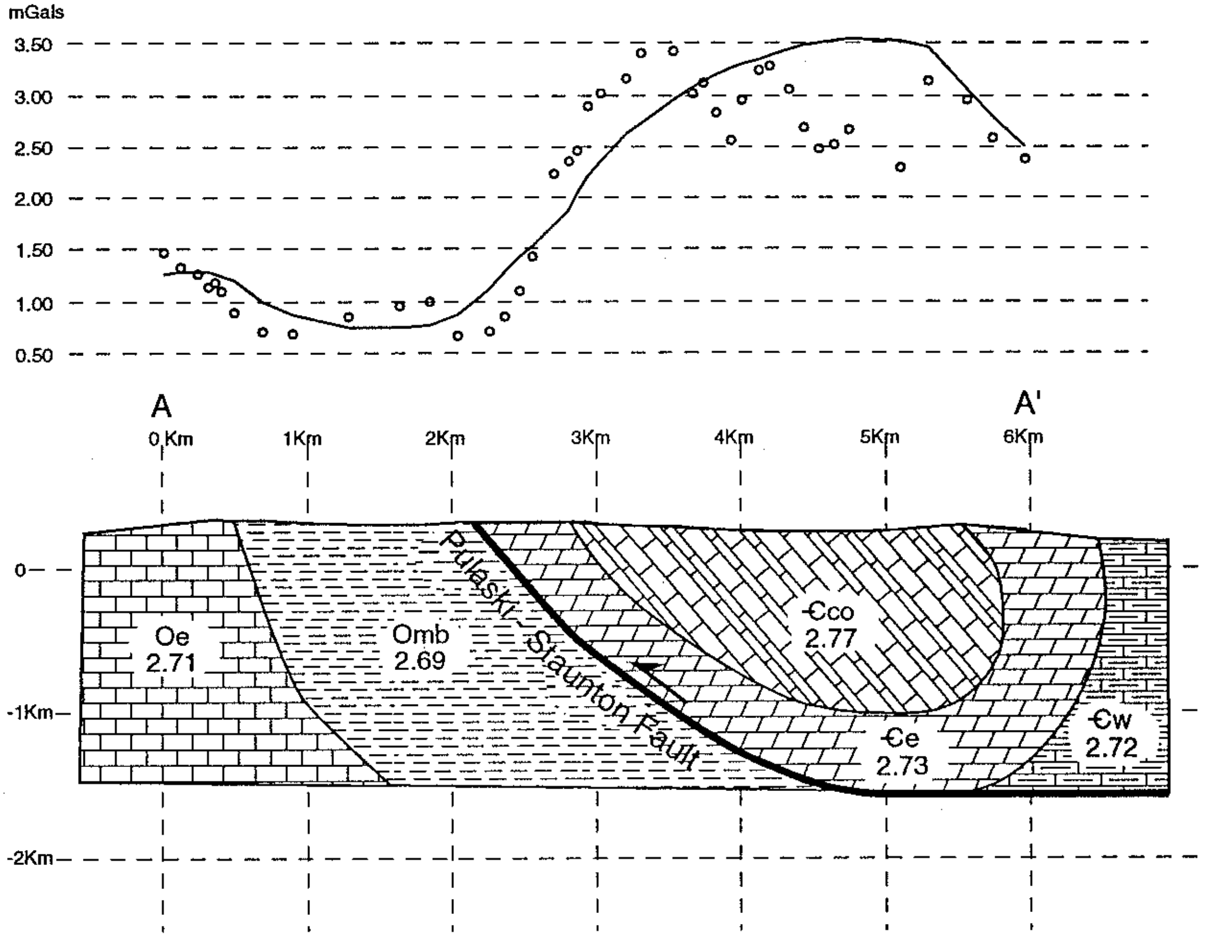

Figure 3. Preliminary model of the subsurface geology along A-A' based on gravity data. The observed gravity values and synthetic gravity curve are shown in the upper graph. The geologic model used to generate the synthetic gravity curve is shown. The model densities for each unit are shown beneath unit's symbol. The surface contacts of the units and the Pulaski-Staunton Fault are based on field mapping by Edgar Spencer (1992). This model shows the Elbrook and Conococheague formations in an asymmetric syncline in the Pulaski-Staunton thrust sheet. The near surface dip of the fault used in this model is greater than that observed in outcrop north of our survey line but still does not adequately model the steep rise in gravity observed across the trace of the fault. Additional modeling involving duplicated carbonate units at shallow depth may produce a better fit to the data. The short wavelength of the anomaly over the fault requires a source at depths less than 1.5 km.

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