Journal of the Arkansas Academy of Science

Volume 34 | Article 23

1980

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John H. McBride
University of Arkansas, Fayetteville

RELATION OF MAGNETIC AND GRAVITY FIELD DATA TO SELECTED STRUCTURAL ELEMENTS OF THE CENTRAL PORTION OF THE ARKOMA BASIN

JOHN H. McBRIDE
Department of Geology
University of Arkansas
Fayetteville, Arkansas 72701

ABSTRACT

In order to acquire a greater understanding of some of the major basement structural features characteristic of the Arkoma basin, magnetic and gravity data have been collected and analyzed for a selected area. Several anomalies exist and are found to be associated with faulting or major fracturing in the Precambrian basement. Modelling of source bodies based on magnetic and gravity values provides quantitative estimates of the depth as well as the geometry of basement structural geology.

INTRODUCTION

The Arkoma basin is an arcuate, east-west trending structural trough bounded on the north by the Boston Mountain plateau and on the south by the Ouachita Mountain fold belt. Structural geology studies in the central portion of the Arkoma basin in Arkansas have dealt primarily with the mapping of surface structure as well as mechanical well log correlation of lenticular, gas-producing sandstone bodies of the Atoka Formation. Very little information has been published regarding the structural configuration of the Precambrian igneous basement. In order to provide an initial, quantitative view of some of the major structural elements of the igneous basement, ground magnetic and gravity field surveys have been conducted in a selected portion of the Arkoma basin of Arkansas.

LOCATION AND REGIONAL GEOLOGY

The area of study is located in the Arkansas River Valley and includes the southernmost part of the Boston Mountain plateau south of the Mulberry fault. Using the General Land Office Grid System the location is given as follows: townships 10, 11, north, ranges 25, 26, west; one additional township is included for magnetic field coverage: township 9, range 25 (see Fig. 1). Included are portions of Franklin and Johnson counties. The general topography of the land becomes gentler toward the Arkansas River but more rugged and dissected to the north.

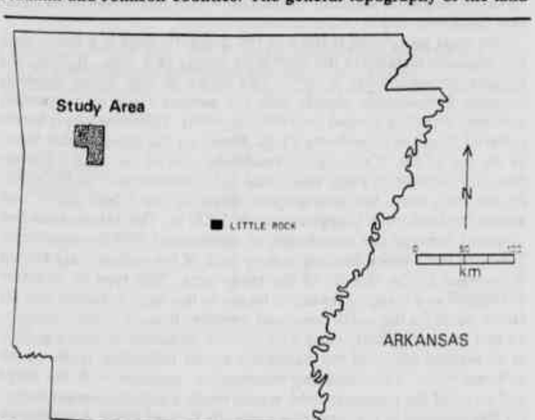

Figure 1. Location of study area.

In the vicinity of the study area, the Arkoma basin is bounded on the north by the northern Arkansas structural platform (Chinn and Konig, 1973). Among the prominent structural features of this platform is a pattern of northeast-trending lineaments which are visible on LANDSAT and RADAR imagery (Tolman, 1979). The Fayetteville and Drakes Creek faults are part of this pattern. These faults show a variable amount of vertical displacement along their trace (0-92 m) and are downthrown to the southeast. This variability in vertical displacement has been explained through movements related to solutioning of carbonate rock at depth (Quinn, 1973). The Arkoma basin was once part of the large Ouachita geosyncline, and is now one of seven structural basins that lie along the northern margin of the Ouachita Mountain System. Depths to basement increase southward to an estimated 9,200 m along the frontal zone of the mountains (Branan, 1968).

The Paleozoic carbonate section is composed of Cambrian through Pennsylvanian age limestone and dolomite. Sandstone and shale represent the principal lithologies of the Pennsylvanian System. The Pennsylvanian age Atoka Formation is by far the thickest unit in the study area and is composed of shale with subordinate amounts of siltstone and sandstone.

The common surface structures of the Arkoma basin include box-shaped synclines separated by narrow anticlines (Viele, 1973), regional monoclines, zones of normal faulting, and zones of imbricate thrust faulting (Diggs, 1961). In the study area, normal faulting is dominant over reverse faulting. Well records indicate that depths to basement increase in a southerly direction. Arkansas Western Gas Company penetrated the granitic basement at 7,467 ft below the surface in the Woolsey No. 1 well located in sec. 13, T.10N., R.27W., Franklin County. This location is less than a mile west of the study area.

Diggs (1961) concluded that the tectonic framework of the Arkoma basin represents the effects of tensional stress produced by the uplift of the northern Arkansas structural platform followed by the effects of compressional stress caused by the Ouachita orogeny on the south. The first emergence of the northern Arkansas structural platform occurred during the late Devonian. During the middle and late Pennsylvanian period subsidence accelerated, and the basin dropped rapidly along south-dipping normal faults (Viele, 1973).

GEOPHYSICAL SURVEYS AND DATA REDUCTION

The ground magnetic field survey was conducted by making observation stations at approximately one-mile intervals. Base stations were established and periodically revisited in order to account for diurnal variation in the geomagnetic field. A total field measuring proton procession magnetometer, with a sensitivity of ±1 gamma was used throughout the study. A two-dimensional display of the total geomagnetic field was produced from the survey results and is shown in Fig. 2.

A gravity field survey was made in order that gravity data could be integrated with the magnetic field data to provide a more unique view. Stations for gravity measurements were spaced at an average of two miles, although some irregularity exists depending on the distribution of surveyed points of known elevation. Base stations were established and periodically rechecked in order to compute local tidal variations. A Worden gravity meter (Prospector Model) was used in conducting the survey.

For each gravity station reading a tidal drift, Free-air, Bouguer, latitude, and terrain correction was applied. A datum elevation of 92 m above sea level was selected for this investigation. The density of the assumed Bouguer slab was chosen to be 2.50 g/cc. The results of the calculations are replotted and the points contoured to produce a complete Bouguer gravity map (Fig. 3). In order to reduce the effect of the regional gravity field and enhance local anomalies, the complete Bouguer gravity field was continued downward one km (3,282 ft) below the surface. The downward continuation was done automatically using a FORTRAN computer program developed by Rudman and Blakely (1975) which is based on an algorithm presented by Henderson (1960).

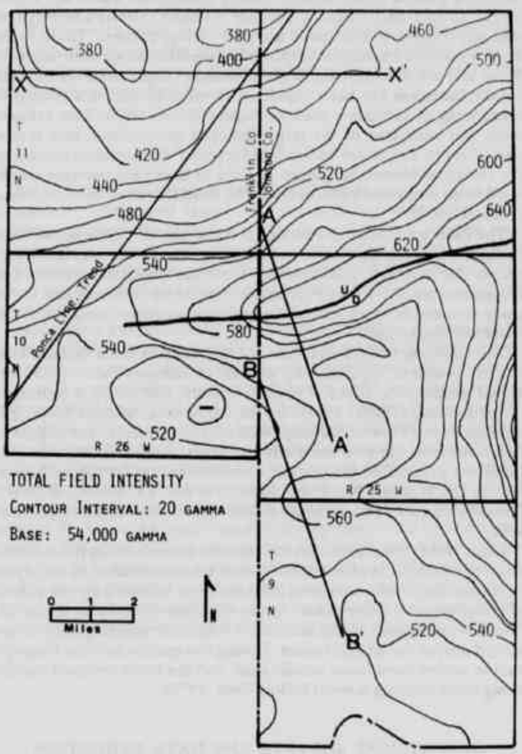

Figure 2. Total field magnetic intensity map showing location of cross sections and structural features.

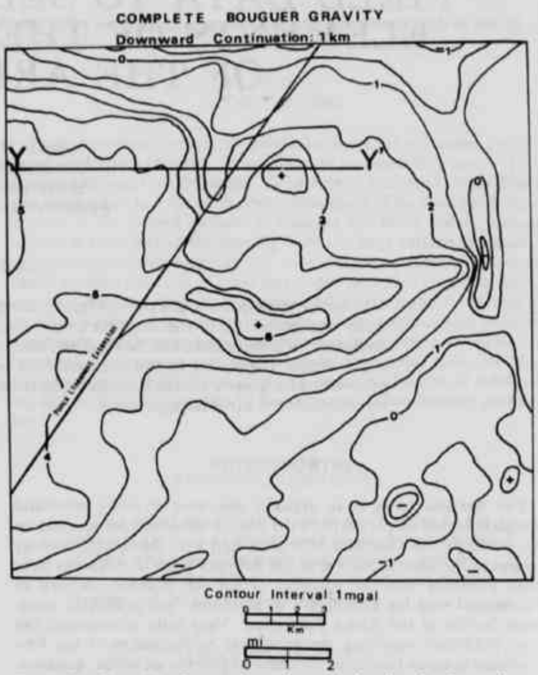

Figure 3. Complete Bouguer gravity map showing the Ponca lineament extension. Location given by T.10-11N., R.25-26W.

GEOLOGIC INTERPRETATION

In the study area and vicinity a deepening of the basin occurs to the south. This is evidenced by a general decrease in the amplitude of magnetic field anomalies and a corresponding decrease in the intensity of the magnetic field in the region immediately south of the study area (McBride, 1980). This is particularly noticeable in T.9N., R.25W. The sharp steepening of the magnetic field near the eastern boundary of T.10N., R.25W. is caused by the existence of a positive having a magnetic anomaly maximum which lies seven miles to the east (McBride, 1980).

The most prominent feature of the magnetic field is a linear positive anomaly situated in the northwest corner of T.10N., R.25W. and striking approximately N.70°E. The strike of this linear magnetic anomaly corresponds closely with the surface trace of a generally east-west trending normal fault (Haley, 1976). This structure is herein referred to as the Strawberry Fault. Based on the stratigraphic throw of the top of the "Cecil Spiro" sandstone unit of the Atoka Formation, the Strawberry Fault was found to be downthrown to the south. In the study area, the stratigraphic throw of the "Cecil Spiro" unit across the fault trace is approximately 1,230 m. This information was obtained through the correlation of mechanical well log signatures. Down-to-basin block faulting in deep beds of the sedimentary section is common in the vicinity of the study area. This type of structure developed as a result of tensional forces as the basin subsided and the Ozark uplift on the north remained positive (Branan, 1968). Buchanan and Johnson (1968), using well records, postulate as much as 1000 m of vertical offset of the basement across individual faults of the Arkoma basin. The preceding information, together with the shape and trend of the magnetic field, would imply a suprabasement source for this anomaly in the form of a vertically faulted block downthrown to the south. Since the magnetic susceptibility of the local sedimentary section is negligible relative to igneous rock, the configuration of the magnetic field is nearly independent of material overlying the basement.

The method of direct interpretation used for the Strawberry fault anomaly was developed by Qureshi and Nalaye (1978) and is based on a vertical block fault. Following Koulomzine et al. (1970), the origin is found analytically by locating conjugate points on the field curve after which the symmetrical and asymmetrical components are analyzed separately. In this way the source can be identified and the geometry of the block determined.

In Fig. 4 the magnetic field is displayed along the section A-A'. Based on the above interpretation procedure, the depth to the block apex was found to be 1,070 m and the vertical displacement of the igneous basement 670 m. The magnetic anomaly profile, oriented perpendicular to the face of a horizontal step (Grant and West, 1965) with the above dimensions, is shown in Figure 4 for comparison. The magnetic susceptibility associated with the theoretical anomaly is 0.0020 emu which is close to the average figure for granitic rock (Dobrin, 1976). This value then gives an estimate for the magnetic susceptibility of the igneous basement. A problem arises as to the explanation of a basement fault having less displacement (670 m) than the overlying Strawberry fault (1,230 m). That the Precambrian igneous basement fault coincides with the Strawberry fault in the sedimentary section indicates basement faulting was important in controlling faulting in the overlying sediments. However, the fact that the vertical displacement in the basement is much less than the throw in the upper part of the Atoka Formation is interpreted to imply that basement faulting did not completely control development of the Strawberry fault in the sedimentary section.

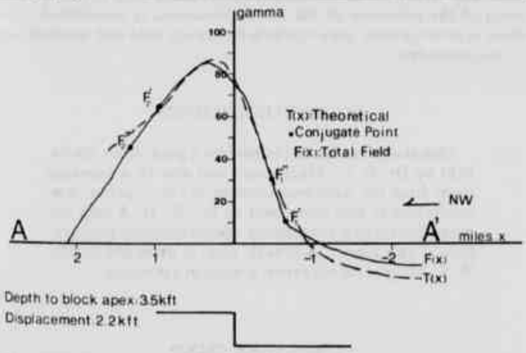

Figure 4. Profile A-A' (see Figure 2) comparing observed and theoretical magnetic field anomalies associated with a fault.

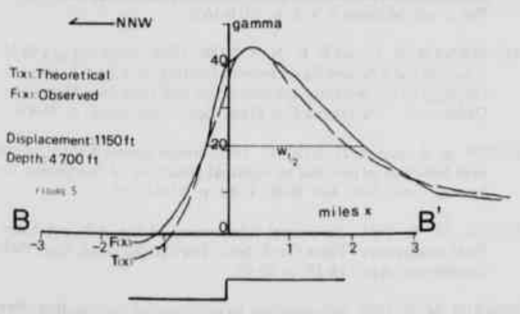

Figure 5. Profile B-B' (see Figure 2) comparing observed and theoretical magnetic field anomalies associated with a fault.

Another positive, linear magnetic anomaly exists near the south of T.10N., R.25W. which is much less in magnitude than the Strawberry fault anomaly but similar in shape. The strike of the anomaly is approximately equal to that of the Strawberry fault anomaly to the north, N.70°E. These two linear highs are separated by a trough-like, anomalous low in the magnetic field. The minimum value of total magnetic intensity in this area is less than 54,500 gamma. The configuration of the magnetic field here suggests a model based on a vertical basement fault downthrown to the north. We examine a profile along the line B-B'.

Grant and West (1965) give a simple method of interpretation based on a thin horizontal step. This method uses a technique of measuring certain characteristic estimators from the total field anomaly from which are obtained values for the geometrical parameters involved. These estimates are the half-width and the amplitude of the field curve. In this example estimations were obtained and the corresponding theoretical magnetic anomaly curve plotted for comparison and revision based on a magnetic susceptibility of 0.0020 emu. The results of the curve superposition are shown in Fig. 5. Based on this work the depth of the top of the upthrown block on the south is 1,450 m and the vertical displacement 340 m. No corresponding fault having a similar orientation has been found to exist on the surface (Merewether and Haley, 1969).

The orientation of two thusly described basement block faults, having parallel strikes, implies the existence of a basement graben structure. Such a structure would have evolved as a result of tensional forces associated with the Ozark uplift and Arkoma basin subsidence.

The final area to be discussed involves the influence of major northeast-trending lineaments visible on small scale imagery on the earth's magnetic and gravity fields. The Ponca lineament strikes subparallel to the Fayetteville fault and Drakes Creek fault lineaments and can be traced on satellite imagery a minimum distance of 81 km (Smith, 1977). The Ponca lineament trend direction intersects the northwest section of the study area (see Figs. 2 and 3). The Mulberry fault strikes generally east-west and exists less than two miles north of the study area. South of the Mulberry fault the Ponca lineament does not readily appear as a topographically defined feature on satellite imagery. From this situation a controversy immediately arises concerning the geologic significance of "extending" the Ponca lineament southward into the Arkansas Valley where it seems to disappear.

In order to define the physical and geologic character of the Ponca lineament, Smith (1977) developed a series of east-west magnetic and gravity field profiles across the Ponca lineament in the vicinity of Ponca, Newton County, Arkansas. It was found that to the west of the Ponca lineament a minimum in the vertical component of the magnetic field consistently appears. The magnitude of these minima is approximately 75 gamma. The complete Bouguer gravity data show a well-developed minimum having a magnitude of three mgal coinciding with the trace of the Ponca lineament. This gravity low is probably related to a negative density contrast produced by a vertical zone of fractured rock. Based on the geophysical data, Smith (1977) concluded that the Ponca lineament is associated with a low density fracture and/or shear zone developed parallel to the lineament and penetrating the Precambrian basement as well as the overlying Paleozoic sedimentary section. It is also postulated that no vertical displacement on the basement has occurred.

In the northwest corner of the present study area a pronounced low in the magnetic field develops just to the west of the Ponca lineament trend direction (see Fig. 2). Profile X-X' (Fig. 6) shows the total magnetic field on the surface and continued downward one km in an east-west direction, intersecting the lineament trend direction. At a continuation downward of one km a minimum centers about the lineament direction. Also the displacement of the total magnetic field at this level is now approximately 100 gamma. This is comparable to the anomaly magnitude in the vicinity of Ponca, Arkansas. A downward continuation of one km is equivalent to a field observed roughly 780 m above the basement which is close to the basement depth near Ponca, Arkansas. The general configuration of the magnetic field near the lineament trend in the study area, together with the dis-

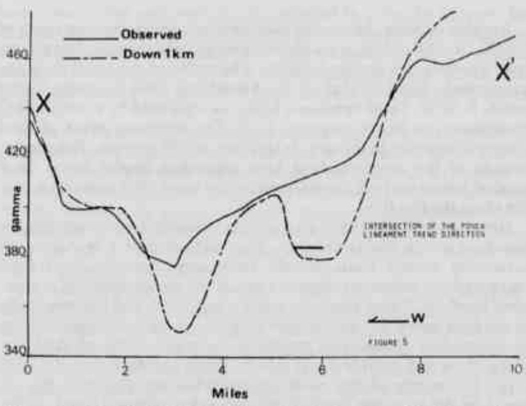

Figure 6. Profile X-X′ (see Figure 2). Influence of the Ponca lineament on the surface magnetic field and its downward continuation.

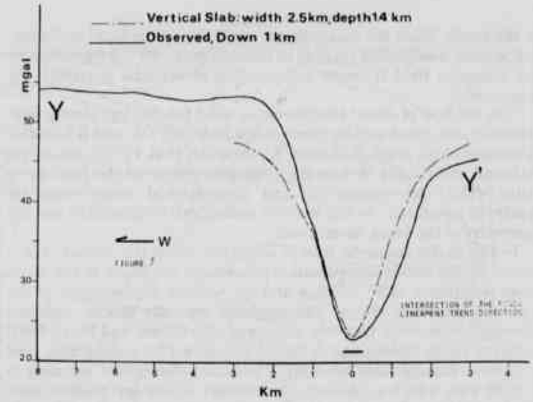

Figure 7. Profile Y-Y′ (see Figure 3) comparing observed and theoretical anomalies over the Ponca lineament.

cussed similarities suggests that the Ponca lineament has an associated fracture zone south of where it diminishes at the Mulberry fault.

In order to examine this problem more closely, a complete Bouguer gravity map (Fig. 3) has been prepared. The gravity field has been continued downward one km so as to enhance local anomalies and subdue the regional field. On this map the Ponca lineament trend direction is also indicated and coincides with a trough-like low in the gravity field of magnitude approximately three mgal. This is the same value given by Smith (1977) for the Ponca, Arkansas area. Fig. 7 gives the gravity anomaly across the direction along the profiles Y-Y′. Assuming a low density vertical slab (Nettleton, 1976) to represent a vertical fracture or shear zone, a comparison of the observed field with a theoretical field is used (Fig. 7). Based on this comparison, it is concluded that the fracture zone initiates at a depth of 1.4 km (4,594 ft) and has a width of 2.5 km (1.55 miles). A density contrast of 0.04 g/cc is required to achieve these figures. A depth of 1.4 km places the top of the low density vertical slab above the surface of the Precambrian basement but within the Cambrian-Ordovician dolomite. Assuming fracturing has occurred, a density contrast of 0.04 g/cc in rock ranging 2.65-2.75 g/cc in density (i.e., granite and dolomite) would yield a fracture porosity of 1.5%. Schumacher (1979) reported on the results of a gravity study of an area in the Arkoma basin which included the Drakes Creek fault lineament. In this study, it was concluded that the Drakes Creek fault lineament is associated with a low density fracture zone having dimensions similar to those derived for the Ponca lineament fracture zone. Based on the foregoing discussion it is then concluded that the Ponca lineament has an associated structure trending in the same direction and represented by a low density fracture or shear zone with no vertical displacement. This fracture zone exists in the Precambrian basement and possibly in the lower Paleozoic sedimentary section.

CONCLUSIONS

The magnetic and gravity methods of subsurface investigation are useful in refining existing knowledge of the structural elements within the Arkoma basin. The southward sloping basement surface is interupted by east-west trending faults. The Strawberry fault is a normal fault in the overlying sediments and is downthrown to the south with a significant amount of throw. This fault corresponds to an elongated magnetic anomaly which is related to a basement block fault downthrown to the south. This basement block fault is genetically related to the overlying Strawberry fault. However, displacement on the basement fault is significantly less than the throw on the associated Strawberry fault. South of the Strawberry fault area there exists an anomalous low in the magnetic field terminated on the south by a second, but lesser elongated magnetic anomaly. This anomaly is also related to a basement block fault but in this case downthrown to the north. This arrangement of basement faults produces a graben-like structure. In the northwest corner of the study area the subsurface trend of the extension of the Ponca lineament is established. This trend is substantiated quantitatively by gravity data and qualitatively by magnetic data.

ACKNOWLEDGEMENTS

This study was funded in part by a grant from NASA held by Dr. H. C. MacDonald and also by a separate grant from the Arkansas Geological Commission. Appreciation is also expressed to Dr. R. H. Konig for many instructive suggestions concerning the preparation of this report. A "thank you" is extended to Dr. W. L. Manger for his expert graphical assistance.

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