

OUACHITA OROGENIC COMPLEX, CENTRAL TEXAS GEOPHYSICAL MEASUREMENTS AND BASEMENT OFFSET

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ABSTRACT

The outline of the buried Ouachita orogenic belt in Texas follows an ancient continental edge that has been involved in lithosphere plate interaction since late Precambrian time. Gravity and magnetic measurements along the Central Texas portion of the trend, combined with limited seismic and well information, indicate that the complex has been offset along a persistent zone of weakness during its history. The offset relationship of the gravity and magnetic anomaly patterns and their relationship in turn to the geology of this zone of weakness indicates a series of basement displacements through time. A broad negative gravity anomaly is related to the overthrust package developed during the collision phase; broad magnetic anomalies are related to slivers of basement caught up in the collision; a belt of positive gravity anomalies is related to a concentration of dense rocks created during the collision phase; or to a mantle welt created during the pull-apart phase; and short wavelength dipole magnetic anomalies are related to shallow volcanics extruded during this pull-apart phase. The detail in these patterns may provide a framework for interpretation of basement uplift and fracture patterns involved in the offset zone.

INTRODUCTION

The outline of the buried Ouachita orogenic belt in Texas (Fig. 1) follows an ancient continental edge that has been repeatedly involved in lithosphere plate interaction since late Pre-Cambrian time (King, 1975; Walper, 1977; Keller and Cebull, 1973; Flawn, 1961). Gravity and magnetic measurements along the Central Texas portion of the Ouachita trend, combined with limited seismic (Rozendal and Ers-kine, 1971) and well (Flawn, 1961) information indicate that the complex may have been offset along a persistent zone of weakness during its history. The offset relationship of gravity and magnetic anomaly patterns, and their relationship in turn to the geology of this zone of weakness is the subject of this paper.

GEOLOGIC FRAMEWORK

The Ouachita development in Central Texas was the most recent of a series of collisions involving a plate, or plates, of as yet unresolved nature (King, 1975; Walper, 1977) with the North American plate edge - the Llano block. The result of the Ouachita event was a package of overthrusts bordered at the edge by a strongly deformed interior zone (Flawn, 1961). Subsequent departure of the attacking plate resulted in a zone of marginal rifting parallel to the boundary, and a sharp deepening at the outside edge of the interior zone - which marked the limit of the embryonic Gulf of Mexico. Subsequent phases of deformation may be related to Laramide influence, the continued development of spreading in the Gulf of Mexico, and adjustment of the basin as sediments continued to load the margin.

The geology of the region, then, may be considered as a record of plate interaction. The results of early periods of collision and rifting may be found in the Pre-Cambrian rocks of the Llano (King, 1975); later in buried metamorphic rocks (Flawn, 1961; Nicholas and Rozendal, 1975) and finally in the Mesozoic rocks of the Gulf of Mexico's shelf edge (Wilson, 1975).

Igneous rocks, involved with the marginal rifting phase are found from Arkansas to South Texas (Lonsdale, 1927; Simmons, 1967). In Central Texas, the rocks are basalts extruded in shallow seas, usually involved with late Cretaceous Austin and Taylor sediments. These volcanics were initially discovered in the subsurface by frustrated farmers seeking water, but finding oil (Udden and Bybee, 1916) trapped in the fractured flows.

The study area may be characterized as the site of repeated plate collision marked most recently by overthrust followed by relics of marginal rifting associated with the spreading that created the present Gulf of Mexico. In cross-section this would appear now as a "taffy-pull" with marked activity at the boundary.

GEOPHYSICAL MEASUREMENTS

Orogenic belts developed along collision boundaries may be traced in the subsurface by gravity and magnetic measurements. Broad negative Bouguer gravity anomalies outline the thickened sediment section of the overthrust package, while the dense rocks involved in the crustal section of the interior zone create a narrower band of higher amplitude positive anomalies (Watkins, 1961; Flawn, 1961). Where this complex includes igneous or mafic metamorphic rocks, magnetic anomalies are found as well (Steenland, 1973).

Regional potential field measurements in Central Texas follow the expected pattern. Figure 2 is a regional Bouguer gravity anomaly map of the Ouachita and Wichita-Muenster trends in Texas and Oklahoma (Exploration Service Inc., 1964). The relative positive anomalies are the more clearly defined. Elongate bands follow the approximate coastward edge of the metamorphosed Paleozoic rocks and are in the range of tens of milligals. The Wichita-Muenster trend is outlined by an even narrower band of positive Bouguer anomalies.

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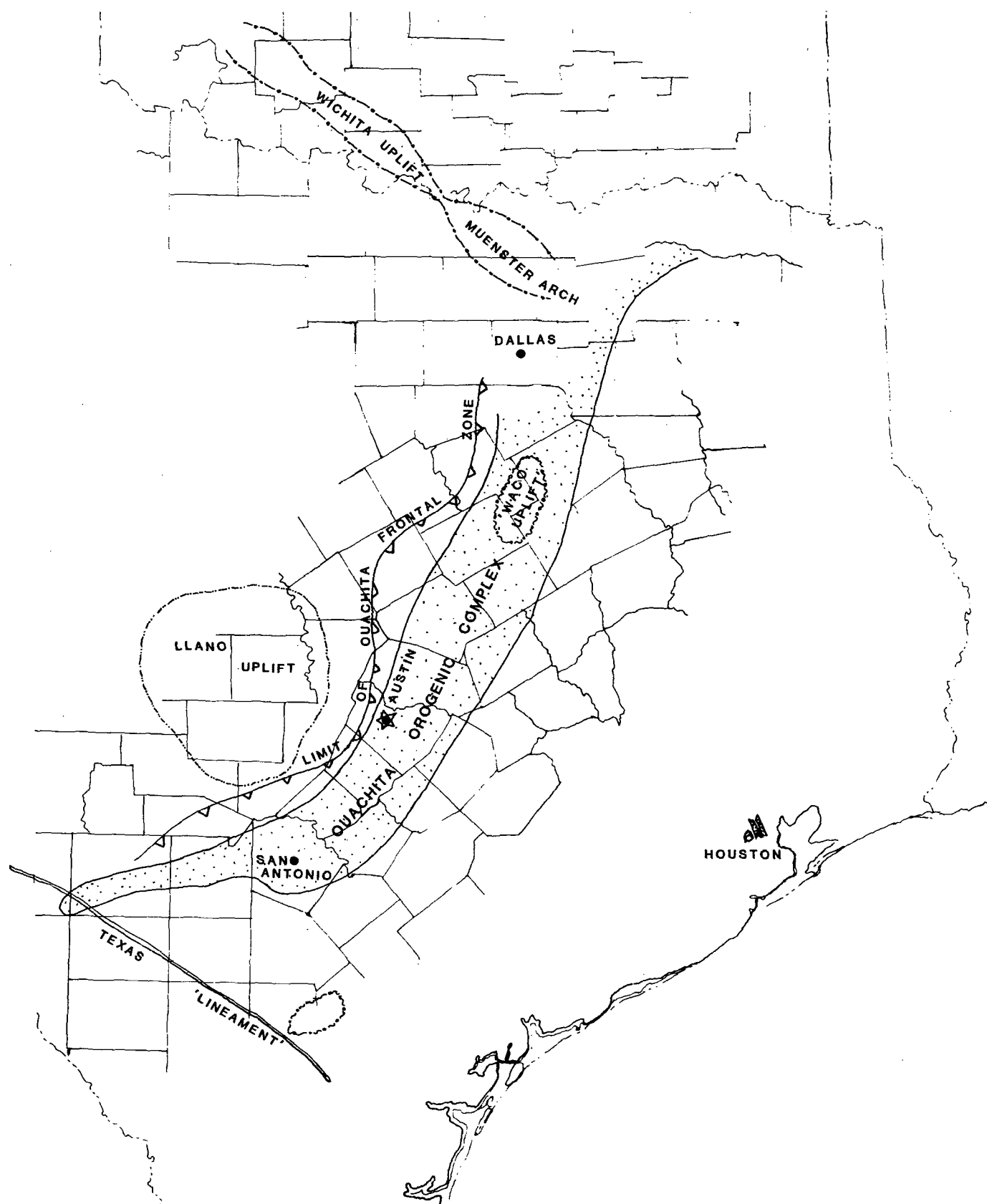


Figure 1. Structural features involved with the Ouachita trend, Central Texas. Limits defined by gravity gradients (Figure 2). Compiled from sources listed in text.

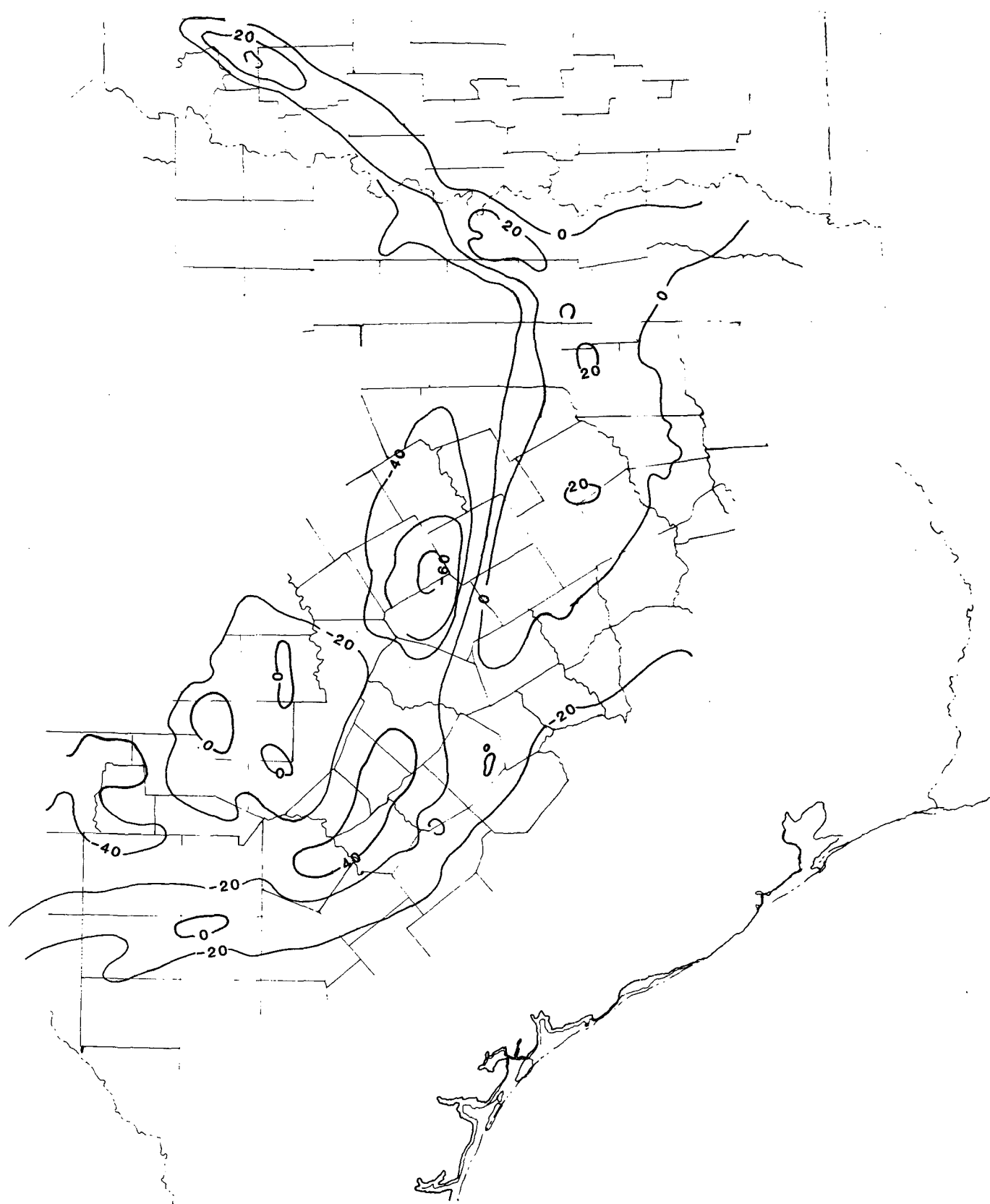


Figure 2. Regional Bouguer gravity of the Ouachita complex and associated tectonic elements. Contour interval is 20 milligals. (After Exploration Surveys, Inc., 1964).

The anomalies are certainly associated with a positive horizontal density variation, but their source is a matter of conjecture. The Ouachita anomalies are clearly related to the collision and pull-apart process, but could be caused by 1) a late Paleozoic island arc (Nettleton, 1949), 2) mafic material from the deep crust caught up in the interior zone during collision (Watkins, 1961), or 3) an upward migration of the Moho during marginal rifting. Pruatt (1975) and Wickham et al. (1975) have modeled the Wichita Uplift as an aulacogen. This would be a failed arm of a triple junction meeting at the Ouachita complex. The Muenster Arch may be one expression of this feature. The negative anomalies are more diffuse and comingled with the signatures of pre-existing sedimentary basins found on the ancient craton. The anomaly complex turns sharply from west to south at Dallas-Fort Worth (Crosby, 1971) where it intersects the Wichita-Muenster trend. The gravity pattern turns sharply again to the west, just south of the Llano Uplift - which emphasizes the long term stability or "buttress" effect of the Llano crust.

Total field magnetic anomalies along the Ouachita trend generally parallel the gravity pattern. These anomalies are positive, on the order of tens of gammas and approximately 5 to 10 km in wavelength. An example is shown in the aeromagnetic map of the Dale area shown in Figure 3. The measurements were made using a Geometrics 803 proton magnetometer with a sensitivity of 1 gamma flown at 430 meters above sea level. The lines were spaced from

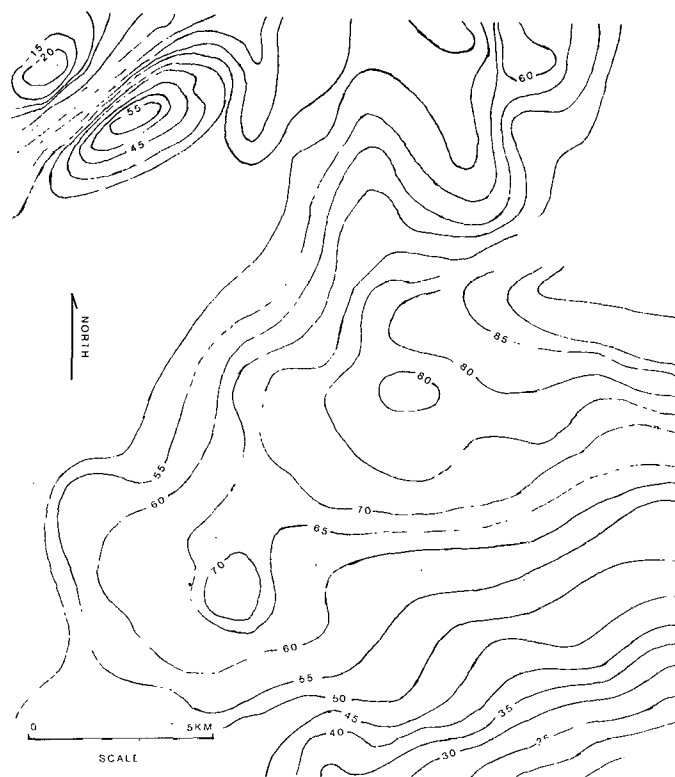


Figure 3. Total field aeromagnetic residual map of the Dale area. Contour interval is 5 gammas. Residual is referred to IGRF 1980. Flight elevation is 430 meters above sea level.

300 to 700 meters and flown perpendicular to the Ouachita trend. The data is shown in the form of a residual map with the IGRF 1980 removed. The broad positive anomaly is sub-parallel to the Ouachita trend as defined by Bouguer gravity. Depth calculations place the source within or near the surface of the stack of metamorphic rocks related to the late Paleozoic collision. The source, however, requires a magnetic susceptibility contrast that is too great to be explained by metamorphosed Paleozoic sediments. It could be due to slivers of mafic material such as oceanic crust involved with the Ouachita collision. As such, the sources of the broad magnetic anomalies may be generically related to each of the possible sources of the positive gravity anomalies listed in the previous paragraph, but the magnetic sources must be much shallower in the section. Figure 3 also shows an example of a short wavelength dipolar anomaly, associated in this case with the basalt flow, or "serpentine plug" responsible for the Dale oil fields. These anomalies range from a few to several tens of gammas and are generally displaced to the continent side of the broad wavelength magnetic anomalies.

Seismic reflection measurements on the Central Texas Ouachita trend are complicated by the multiple thrust sheets and normal faults of the orogen. Rozendal and Erskine (1971) and Nicholas and Rozendal (1975) have presented a seismic section in Hill and Limestone Counties that clearly shows an anticlinal structure at approximately 2 seconds with deeper reflections at 3 seconds between this feature and the craton. The seismic section is tied to a well drilled at its crest, the Shell #1 Ethel Barrett (Rozendal and Erskine, 1971). The well penetrated metamorphic rocks at 3,904 feet and igneous rock dated as Precambrian at 19,780 feet. The reflector is interpreted to be a massive marble encountered at 13,595 feet. The structure parallels the trend and is approximately coincident with the band of Bouguer positive gravity. In addition, at least a part of this anticlinal feature is nearly coincident with one of the large magnetic anomalies that parallel the interior zone. Steenland (1973) suggested that the anomaly is due to Precambrian rocks elevated to a 10,000 depth by thrusting. This anticline is one of several documented positive features found along the Ouachita trend (Nicholas and Rozendal, 1975; Duval and Martin, 1977).

In summary, the Ouachita trend is manifest at the surface in a series of gravity, magnetic, and seismic features that generally follow the orogen from the Louisiana-Arkansas area to South Texas.

INTERPRETATION OF GEOPHYSICAL MEASUREMENTS ALONG THE COLORADO RIVER

The Ouachita orogenic complex is apparently offset on a grand scale in the Dallas-Fort Worth area and to the south of San Antonio (Fig. 1) (Muehlberger, 1965; King, 1975). A number of lesser offsets are suggested as well by a variety of geophysical evidence. Steenland (1967) described an apparent wrench fault indicated by aeromagnetic measurements in the Hueco Mountains near El Paso - a possible western extension of Ouachita related activity. Wheeler

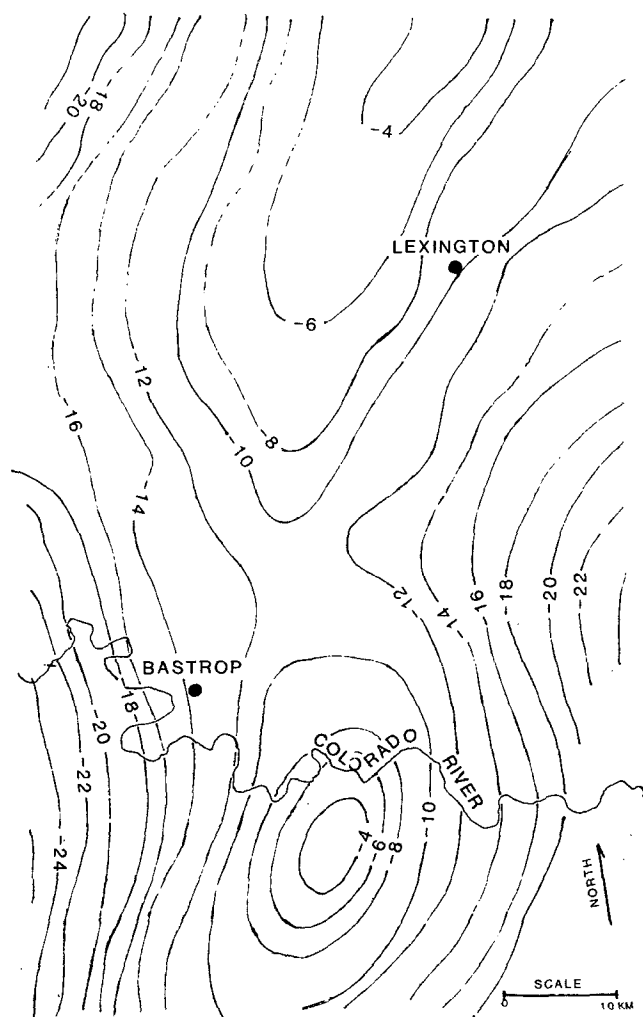


Figure 4. Detailed Bouguer gravity map of the Ouachita interior zone in the vicinity of the Colorado River. Contour interval is 2 milligals. (Values are not tied to regional base.) (Data from National Oceanic and Atmospheric Administration.)

(1980) used LANDSAT, as well as other geophysical evidence, to develop a case for cross-strike structural discontinuities in the Appalachian orogen. Frierson and Amsbury (1974) suggested a persistent zone of weakness along the Colorado River as indicated by satellite imagery. Geophysical measurements along the Central Texas portion of the Ouachita orogenic complex tend to support Frierson and Amsbury's observations.

The regional gravity pattern indicates several potentially offset zones. Detailed gravity data made available by the National Oceanic and Atmospheric Administration (National Geophysical and Solar-Terrestrial Data Center, 1978) were contoured at a 2 milligal contour interval in the vicinity of the Colorado River (Fig. 4). A particularly interesting feature is the apparent left lateral offset of the relative positive Bouguer anomaly of approximately 20 km. The broad positive magnetic anomalies (Fig. 3) in the region are also discontinuous, but the character of the offset is not clearly defined.

The long term nature of this apparent zone of weakness may be indicated by the pattern of igneous rocks extruded in late Cretaceous time. This pattern is shown by a map of "serpentine plug" oil fields (Fig. 5) compiled from a number of sources (primarily Lonsdale, 1927; and Simmons, 1967) and confirmed in part by magnetic measurements. These igneous rocks are offset in the same sense as the gravity pattern, and by approximately the same amount.

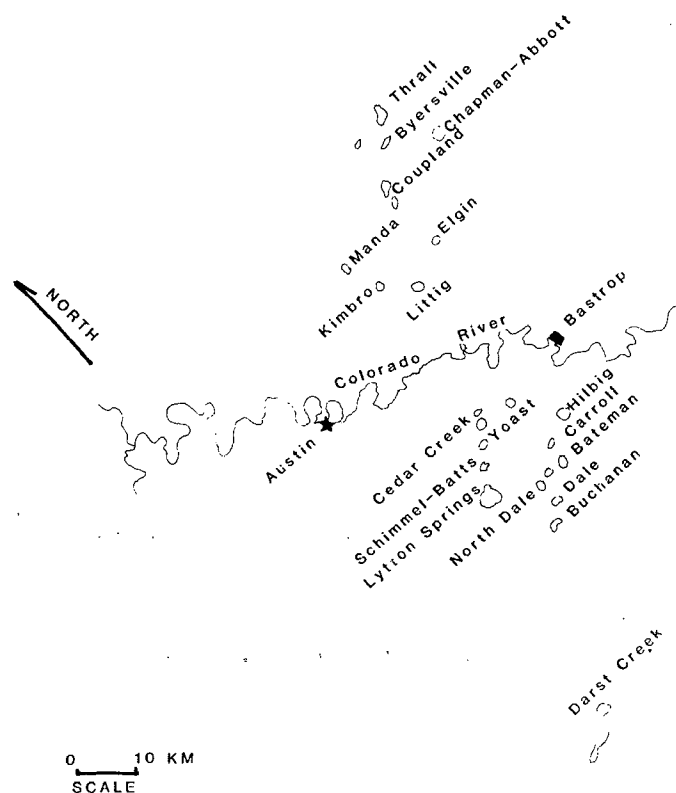


Figure 5. Map showing oil fields with igneous involvement in vicinity of Figure 4 portion of Colorado River. Compiled primarily from Lonsdale, 1927; and Simmons, 1967.

A possible scenario for the offset in the vicinity of the Colorado River is shown in Figure 6, a schematic diagram from the viewpoint of the Llano block. The Llano has served as a "buttress", overthrust by parts of the Ouachitas section. The process might have begun with initial development of a zone of weakness during Precambrian tectonic activity. The area could have then been offset again during the development of the Ouachita orogenic complex. Following this, the zone of weakness could have persisted, allowing igneous rocks to reach the surface in the Balcones-Luling area during Austin and Taylor time.

In conclusion, it appears that the Ouachita trend in Central Texas is the product of a complicated history as indicated by gravity, magnetic, seismic and geologic evidence. These same measurements may be used to provide evidence about the detailed structure along the trend.

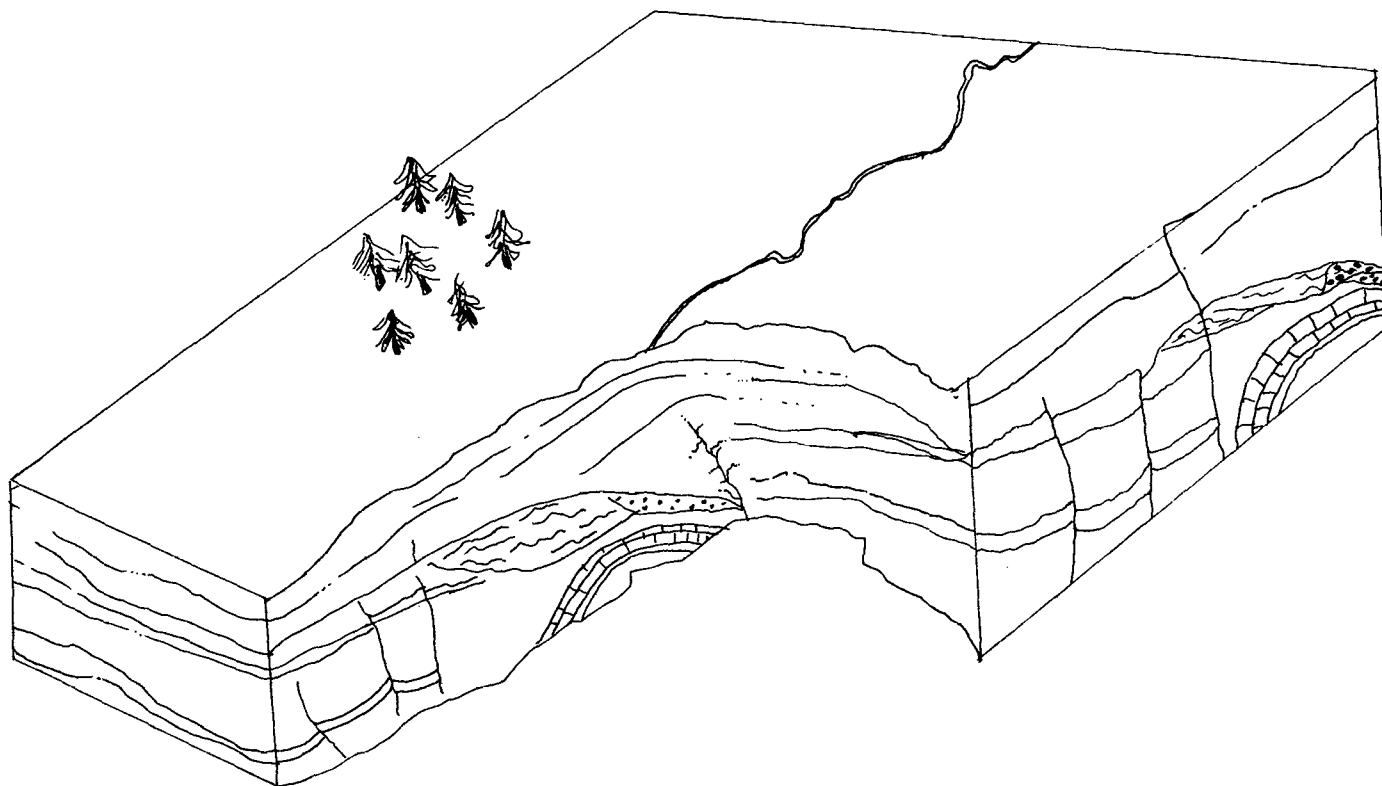


Figure 6. Schematic section of possible Ouachita offset scenario from the perspective of the Llano block. The thrust package and interior zone are offset and the Colorado River area is a persistent zone of weakness.

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