THE OUACHITA SYSTEM IN NORTHERN MEXICO

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Abstract. The Ouachita system in northern Mexico can be subdivided into four unique tectonostratigraphic provinces: the foreland, the frontal zone, the interior zone, and the Coahuila terrane. Each province is defined by specific lithologic characteristics, structural styles, and regional Bouguer gravity anomalies. The Ouachita foreland is characterized by a carbonate dominated shelf which was disrupted during the late Paleozoic by several basement cored uplifts. The frontal zone is a northwest migrating foredeep and fold-thrust belt; clastic sediments derived mainly from the fold-thrust belt filled the foredeep and were subsequently deformed as the fold-thrust belt migrated. The interior zone is the metamorphic core of the migrating fold-thrust belt and is characterized by a distinctive positive Bouguer gravity anomaly. The Coahuila terrane is a composite terrane which includes a late Paleozoic volcanic arc and a piece of exotic continental crust which was probably affixed to North America during the final stages of the Ouachita orogeny and then left behind during the opening of the Gulf of Mexico.

INTRODUCTION

For the past 25+ years the trend and character of the Ouachita orogenic belt in Mexico have posed nagging problems for geologists working on the paleotectonic history of the southern margin of North America [Flawn and Diaz, 1959; King, 1975]. Most workers have extended the Ouachita frontal zone westward from the Marathon region of west Texas to central Chihuahua, Mexico, as postulated by Flawn et al. [1961] on the basis of lithologic similarities in the two areas, but no one has felt confident extrapolating the trend of the interior zone more than a few kilometers into Mexico.

Recent geologic and geophysical studies in northern Mexico have raised questions about the validity of extending the frontal zone into central Chihuahua and have provided a basis for extending the interior zone almost 100 km into Coahuila. In light of these new findings it is now possible to reevaluate the entire public data base for the Ouachita system in northern Mexico. For the most part, this study is restricted to the portions of Chihuahua, Coahuila, and Nuevo Leon which lie north of the postulated trace of the Mojave-Sonora megashear. However, it is important to note that changes in late Paleozoic paleogeography may have important implications for the megashear.

One of the biggest problems encountered by geologists studying the pre-Mesozoic history of northern Mexico is the limited number of Paleozoic and Precambrian outcrops. Wells have provided information in several critical areas, but as a whole the data base is small, and data points are often widely scattered and unevenly distributed (Figure 1). We have attempted to minimize this problem by dividing the upper Paleozoic rocks of the region into several tectonostratigraphic provinces and, where possible, tying the known surface geology to regional gravity anomaly patterns. Considering the lack of seismic data and the limited amount of well data available, this technique seems to provide the best
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REGIONAL GEOPHYSICS

The only substantial geophysical data set in the area is the gravity data base compiled by Smith [1986]. In his study, Smith [1986] analyzed over 14,000 readings and processed these data with a variety of filters. In this study we have employed his residual anomaly map. In preparing this map a second order polynomial surface, representing a gradual west to east variation in lithospheric structure, was removed from the original Bouguer anomaly values. The removal of this regional trend is a straightforward process which significantly improves the resolution of local anomalies. In order to emphasize the regional features of interest here, anomalies with wavelengths less than 50 km were eliminated by filtering, and the resulting map is shown in Figure 2. Many anomalies on this map correlate well with known geologic features, and these anomalies provide an improved picture of the nature and extent of these features.

REGIONAL GEOLOGY

The Ouachita Foreland

The Ouachita foreland in northern Mexico and the southwestern United States was dominated by marine and nonmarine platform sedimentation for much of the Paleozoic [Cook and Bally, 1975]. Between the Late Devonian and Late Permian,
basement cored blocks created the Ancestral Rocky Mountains, and their associated basins, in a roughly triangular region cornered by the Wichita Uplift of Oklahoma and Texas, the Pathfinder Uplift of south central Wyoming, and the Sierra del Nido block of west central Chihuahua [Kluth and Coney, 1981; Handschy, 1986].

Paleozoic rocks in northern Sonora and northwestern Chihuahua form the western extension of the carbonate shelf sequence in southern New Mexico and west Texas [Greenwood et al., 1977], and the southern extension of the Cordilleran miogeocline [Bridges, 1971; Stewart et al., 1984]. To the southwest, stratigraphic correlations in Sonora suggest that the carbonate-dominated shelf extended at least into the south central portion of the state [King, 1939; Bridges, 1971], but some of these correlations are based on outcrops on different sides of the Mojave-Sonora megashear and are thus suspect. To the southeast, the pre-Permian rocks exposed between Placer de Guadalupe and Sierra el Carrizalillo closely resemble the equivalent-age rocks in the Franklin mountains 300 km to the north [Bridges, 1962; Dyer, 1986], suggesting that the carbonate-dominated shelf extended at least as far south as the Tascotal uplift prior to the Permian.

During the earliest Permian the shelf sequence in northwestern Chihuahua was disrupted by uplift of the Diablo platform, Florida-Moyotes uplift, and Bavispe shelf (Figure 3) and by increased subsidence and deposition in the intervening Orogrande and Pedregosa basins [Thompson et al., 1978; Wilson, 1971; Tovar, 1969]. The Pedregosa basin can be extended from southwestern New Mexico to central Chihuahua on the basis of latest Pennsylvanian through Early Permian turbidites west of Nuevas Casas Grandes, in the number 1 Villa Ahumada well, at Sierra del Cuervo, and at Sierra el Carrizalillo [Thompson et al., 1978; Mellor and Breyer, 1981; Torres-Roldan and Wilson, 1986; J. L. Wilson, 1986, personal communication].

The presence of a previously unidentified foreland uplift in west central Chihuahua, the Sierra del Nido block, is indicated by east directed paleocurrents and slump structures [Handschy, 1986] and an apparent unroofing sequence [Mellor and Breyer, 1981] in
Lower Permian submarine fan deposits at Sierra del Cuervo. The Sierra del Nido block was originally defined using gravity and magnetic data and is interpreted as a cratonic block of Precambrian (?) granitic crust beneath the eastern edge of the Sierra Madre Occidental [Aiken et al., 1981; Goodell et al., 1985]. Additional indirect evidence for an Early Permian uplift in western Chihuahua comes from a Lower Cretaceous conglomerate at Sierra de la Mojina which is composed exclusively of late Precambrian metamorphic and Early Permian rhyolite clasts, implying that the Paleozoic sedimentary sequence was absent in the source area [Denison et al., 1971; Bridges, 1971]. Although the exact source area for the conglomerate is unknown, the freshness of the clasts and preliminary clast imbrication measurements indicate a source immediately to the west.

In the Placer de Guadalupe area (Figure 1), Lower Permian rocks are composed of shallow water carbonate reefs, coarse- to fine-grained clastics, and a few intercalated rhyolite flows [Bridges, 1962]. Approximately 20 km to the south, in Sierra el Carrizalillo, the age equivalent rocks are dominated by turbidites [Torres-Roldán and Wilson, 1986]. This dramatic change in depositional environment indicates that the shelf edge which separated the southern extension of the Pedregosa Basin from the shelf environments of the Tascotal Uplift was located between Placer de Guadalupe and Sierra el Carrizalillo. The Tascotal Uplift (Figure 3), which...
was first defined on the basis of well data from the Big Bend area of west Texas, can be extended to the Placer de Guadalupe area on the basis of its gravity signature (Figure 2). North of the Tascotal Uplift, in the Marfa Basin, over 3 km of Lower Permian clastics constrain the timing of uplift and basin formation to Early Permian [Luff, 1981].

The Ouachita Frontal Zone

Totally dominating the Marathon basin and thrust over the eastern ends of the Tascotal uplift and Marfa basin are the intensely deformed, deepwater clastics of the Ouachita frontal zone [Flawn et al., 1961; Luff, 1981]. Between the Early Mississippian and Early Permian the frontal zone in the Marathon area was characterized by several pulses of tectonism and sedimentation [King, 1937, 1977]. During each pulse, deformation initiated in the south. Loading by thrust sheets and their derivative sediments created a foredeep along the northern edge of the growing mountain belt. Sedimentary rocks deposited in the foredeep were in turn overridden and deformed by the northward migration of the thrust belt. For the most part, the syntectonic sediments in the Marathon region are submarine fan deposits which thin northward onto the carbonate-dominated shelf of the Ouachita foreland [McBride, 1970]. The frontal zone in west Texas is known from surface exposures in the Marathon area and at the Solitario Uplift (Figure 1) and from wells in the Val Verde, Marathon and Marfa Basins. Rocks of the frontal zone have not been documented at the surface in Mexico.

In 1961, Flawn and his colleagues tentatively extended the frontal zone from the Marathon region to just north of Sierra del Cuervo on the basis of similarities in age and lithology. This extrapolation showed the Placer de Guadalupe area to be within or behind the frontal zone. Bridges [1962] later proved this extrapolation unlikely by demonstrating that the stratigraphy of the area closely resembled the carbonate dominated shelf sequence of the foreland, not the clastic sequence of the foredeep. By examining facies relationships associated within Lower Permian reefs near Mina Plomosas, just south of Placer de Guadalupe, Bridges [1971] was also able to show that the clastic foredeep of the Ouachita frontal zone should lie southeast of Mina Plomosas. These findings prompted L.W. Bridges (personal communication, 1984) to redraw the frontal zone so that it passed south of Placer de Guadalupe and then turned northwest to pass through Sierra del Cuervo.

In Sierra del Cuervo, several major thrust faults which involve both Lower Permian submarine fan deposits and Precambrian crystalline rocks dominate the pre-Cretaceous structures. All of the faults and their associated folds are vergent toward the east southeast and were probably active during the middle Permian [Handschy, 1986]. Although the Lower Permian lithologies strongly resemble equivalent facies in the Marathon region and the apparent timing of deformation corresponds well with Ouachita orogenesis, the direction of tectonic transport is almost perpendicular to that predicted by the frontal zone as drawn by Flawn et al [1961, p. 100]. As noted earlier, the Lower Permian submarine fan deposits at Sierra del Cuervo apparently represent unroofing of a basement cored uplift, the Sierra del Nido block, to the west and is postulated that the subsequent basement-involved east southeast directed thrusting was caused by movement of the same uplift [Handschy, 1986]. This style of foreland deformation is analogous to that observed on seismic lines across the southwest edge of the Wind River Uplift in Wyoming and is believed to represent the southern extension of the Ancestral Rock Mountains into central Chihuahua [Handschy et al., 1985].

The Interior Zone

The interior zone of the Ouachita system, as defined by numerous wells in western and central Texas, is a relatively narrow zone of variably sheared metasedimentary rocks which range in age from Early Pennsylvanian to middle Permian [Denison et al., 1977]. Coincident with the interior zone is a distinctive gravity high known as the interior zone maximum [Kruger and Keller, 1986]. This anomaly can be easily traced from southwestern Arkansas to the Big Bend area of Texas where it abruptly turns south and continues for almost 100 km into Coahuila [Ahuja and Aiken, 1984; Keller and Smith, 1985].

Prior to these recent gravity studies it was virtually impossible to trace the extension of the interior zone into northern Mexico. Previous authors [e.g., Kellum et al., 1936] have suggested that the Ouachita orogenic belt formed the basement beneath the Cretaceous Coahuila platform, but definitive proof has been lacking. By using the interior zone maximum as a reference it is now possible to evaluate the paleotectonic setting of several small outcrops in Coahuila which have long been recognized as intriguing pieces of the Ouachita puzzle in Mexico.

The only known outcrop of the interior zone in northern Mexico is a sequence of fine-grained metasedimentary rocks in Sierra de Carmen just a few miles across the border from the Big Bend area of Texas [Flawn et al., 1961]. Flawn and Maxwell [1958] first recognized these pre-Cretaceous metamorphics as probable interior zone rocks and Denison et al. [1969; Denison et al., 1977] later showed that the age of metamorphism (263±5 m.y. by K/Ar and 275±20 m.y. by Rb/Sr) is similar to that of interior zone rocks in the subsurface of Texas. Further to the south, similar fine-grained, highly sheared, low grade metamorphic rocks have been reported from five PEMEX wells, the number 2-A Peyotes, number 101 Chapa, number 1 Ceralvo,
Carabajal, and Minas Viejas [Flawn et al., 1961; Wilson et al., 1984]. When these localities are plotted on a regional gravity map the strong correlation between the Sierra del Carmen outcrop and the interior zone maximum is obvious and it becomes apparent that the wells are located east of the interior zone (Figure 2).

The Coahuila Terrane

In Coahuila, a series of elliptical gravity lows, adjacent and parallel to the eastern edge of the interior zone maximum, form a distinctive north-south trend for approximately 200 km through central Coahuila (Figure 2). The most prominent of these lows is coincident with the Potrero de La Mula area (Figure 1). The basement rocks exposed at Potrero de La Mula and Sierra Fuente are composed of Late Triassic (213±14 m.y.; Rb/Sr), I-type granite [Jones et al., 1984]. Farther to the south, similar ages have been reported for granodiorite intrusions in the Acatita-Las Delicias area [205±4 m.y.; K/Ar, Denison et al., 1969] and in the Valle San Marcos [242±2 m.y.; Rb/Sr, Jones et al., 1982]. In the Acatita valley these Triassic plutons cut a thick sequence of Late Pennsylvanian through Late Permian volcaniclastic sedimentary rocks [King et al., 1944; McKee and Jones, 1984, Cunningham, 1975]. Prior to intrusion of the granodiorite the entire sequence was folded and thrust toward the west [King et al., 1944].

The composition, intrusive relationships, and gravity signature of this linear belt just east of the interior zone maximum are fairly typical of volcanic arcs (both island and continental margin), and many authors [e.g., Walper and Rowett, 1972; Cunningham, 1975; Rowett and Hawkins, 1975] have inferred the presence of a late Paleozoic arc in the region. The proximity of this postulated arc to the interior zone and the direction of Late Permian and/or earliest Triassic thrusting at Las Delicias suggest that the arc was thrust against the interior zone prior to intrusion of the Triassic plutons.

The origin of this arc, with respect to the North American Plate, is still unclear. If the interior zone reflects the position of the Paleozoic plate margin as postulated by Keller and Smith [1985], the arc must have been accreted to the North American Plate. South and east of Potrero de La Mula four PEMEX wells, the number 1 Barril Viejo, number 1 Garza, number 1 Paila, and number 1 La Perla also encountered pre-Cretaceous basement (Figure 1). The first three wells bottomed in igneous rocks which are presumably equivalent to the outcrops at Potrero de La Mula, Las Delicias, and in the Valle San Marcos [Flawn et al., 1961; Wilson et al., 1984]. The number 1 La Perla, however, bottomed in granitic gneiss which Denison et al. [1969] dated as 358±60 m.y. old using Rb/Sr. All of these wells lie considerably south and east of the postulated position of the Paleozoic margin of the North American Plate and are inferred to be exotic. Conforming to the nomenclature of Campa and Coney [1983] the arc and the Paleozoic crystalline basement east of the arc are lumped together as the Coahuila terrane (Figure 3).

DISCUSSION

Based on the data outlined above, we have constructed a revised paleogeographic map of the Ouachita system in northern Mexico (Figure 3). Although this map provides a consistent interpretation of a wide variety of geological and geophysical data, there are many uncertainties, and as more data become available, improvements will undoubtedly be necessary.

Recent plate tectonic reconstructions for the region [e.g., Anderson and Schmidt, 1983; Pindell, 1985] show the Maya block juxtaposed against southern Coahuila prior to the opening of the Gulf of Mexico. This idea is supported by the presence of mid-Paleozoic crystalline basement in the number 1 La Perla and beneath the Yucatan peninsula [Lopez-Ramos, 1975; Kesler et al., 1974; Marshall, 1974] and implies that a fragment of the Maya block remained with the North American Plate during the opening of the Gulf of Mexico.

Ouachita orogenesis in the south central United States probably involved thrusting of an island arc and/or the South American Plate margin over the passive southern margin of the North American Plate [Graham et al., 1975; Wickham et al., 1976]. In Mexico, however, it appears that plate interactions may have been more complicated. In central Chihuahua, Permian rhyolites at Placer de Guadalupe and Sierra de la Mojina [Bridges, 1962; de Cserna et al., 1968; Denison et al., 1971] suggest the possibility of an active North American Plate margin in the region during the latest Paleozoic. The extremely small data base makes any interpretation speculative, but these rhyolites are probably related to the Ouachita system, since there is no definitive evidence for an active margin along the west coast of Mexico during the Permian.

CONCLUSIONS

The Ouachita system in northern Mexico can be subdivided into four major regions: (1) The Ouachita foreland, which is characterized by basement cored uplifts and their associated basins; (2) The frontal zone, which includes both the fold-thrust belt and its associated foredeep; (3) The interior zone, which represents the metamorphic core of the Ouachita orogen and may approximate the Paleozoic continental margin; and (4) The Coahuila terrain, which is composed of a late Paleozoic through earliest Mesozoic volcanic arc and a remnant of the Maya block which was thrust against North America during the Late Permian.
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