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Tectonic history and setting of a seismogenic intraplate fault system that lacks microseismicity: The Saline River fault system, southern United States

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ABSTRACT

Although the northwest-striking Saline River fault system of southeastern Arkansas is not defined by microseismicity, it is associated with sand blows and shows evidence of Pleistocene and Holocene surface ruptures, suggesting a significant seismogenic potential. This fault system is within the northern Gulf of Mexico interior coastal plain, a region only recently recognized as containing seismogenic faults. To better characterize this active fault system, we reconstructed its post-Paleozoic history using petroleum and coal industry wire-line well log and seismic reflection subsurface data.

The Saline river fault system initiated as a series of northwest-striking grabens during Triassic/Jurassic uplift and incipient Gulf of Mexico rifting along the basement Alabama–Oklahoma transform margin of the North American Proterozoic craton. During post-rift subsidence, these grabens were buried by Gulf sediments until mid-Cretaceous uplift and igneous activity resulted in minor extensional reactivation of graben faults. Faulting style changed from extension to transpression during the Late Cretaceous due to compression of eastern North America as the North Atlantic rapidly widened and due to thermal weakening of the Alabama–Oklahoma transform lithospheric discontinuity as it obliquely crossed a mantle hot spot. In the Late Cretaceous, graben faults experienced contractional reactivation and steep, deeply-rooted transpressional faults developed within and parallel to the graben system. These transpressional faults locally displace Eocene, Pleistocene, and Holocene sediments.

Fault activity continues on the Saline River fault system due to thin crust along the Alabama–Oklahoma transform and to high heat flow, which act together to weaken the crust and promote seismogenic tectonism. The fault system may lack appreciable microseismicity because the aftershock sequence of the last large earthquake has had time to dissipate.

1. Introduction

A foremost question in neotectonics and seismic hazard assessment concerns the controls on locations of intraplate deformation, and nowhere is this question debated more than mid-continent North America. Evidence is growing that the New Madrid seismic zone within the Reelfoot rift (Fig. 1A inset), once considered the only significant seismic source zone in the central United States, may not be unique in the region and that long-term deformation and seismic activity may migrate through a linked system of structures across a broad area of the continent extending far outside the Reelfoot rift (Slemmons, 1989; Stein et al., 2009). The southern edge of the North American craton, Thomas' (1991) Alabama–Oklahoma transform (AOT), is a fundamental discontinuity in the continent's crust and could be expected to be such a locus of intraplate strain accumulation beyond the Reelfoot rift proper.

The northwest-striking Saline River fault system (SRFS), named for the river it follows through the coastal plain of Arkansas, is not evident on seismicity maps. It was originally recognized due to an asymmetric distribution of river terraces and tributaries suggesting active ground tilting (Cox, 1994). Several locations of surface ruptures and associated sand blow fields have since been described (Cox et al., 2000, 2007, 2010, 2012). The tectonic significance of the SRFS stems from this evidence for strong Quaternary paleo-earthquakes and from its correspondence to the AOT (Fig. 1). In this report, we describe the structure of the SRFS and episodes of recurrent fault activity along the AOT corridor since the breakup of Pangea that gave rise to this structure. Study of the tectonic evolution of the region can provide important insight into why the SRFS shows Quaternary activity and may contribute to an improved general understanding of why some intraplate faults are active.

2. Study area

We conducted a subsurface study of the structure and geologic history of the SRFS along the northern Gulf of Mexico interior coastal

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plain in an area of southeast Arkansas that spans the AOT (Fig. 1). In this area, the AOT occupies the hinge zone between the Monroe uplift and the Desha basin. The Monroe uplift is a Late Cretaceous feature, and the Desha basin initially formed in Late Cretaceous, but subsidence was greatest during Paleocene (Cushing et al., 1964; Ewing, 1991; Sohl et al., 1991).

The study area is well suited for characterizing deformation involving Paleozoic "basement" rock and Mesozoic/Cenozoic sedimentary cover due to available petroleum exploration seismic reflection profiles and well logs and because it is north and east of a Jurassic salt horizon that has caused most of the deformation of the Coastal Plain to the south and west of our study area, obscuring deformation not related to salt tectonics (Ewing, 1991). Well data alone are too sparse to map subsurface faults in the study area because it is north of oil and gas production fields, but many of the faults can be mapped with confidence by integrating well log data with seismic reflection profiles. Oil and gas fields along the AOT corridor to the south of our study area in Mississippi have many more well logs available, but the presence of Jurassic salt both masks the sub-salt basement on seismic reflection profiles due to attenuation of seismic energy and greatly complicates the shallow structure through salt diapirism and related faulting and folding (Ewing, 1991).

3. Regional tectonic and stratigraphic framework

Late Proterozoic and early Paleozoic rifting and breakup of the supercontinent Rodinia established the southern margin of the North American craton as a northwest-striking transform fault margin from southwestern Alabama to eastern Oklahoma (AOT) (Thomas, 1991). This transform margin of the craton, now buried at a ~20 km depth below Ouachita orogen thrust sheets and subsequent sedimentary strata, is characterized by a more abrupt change in crustal thickness (from 40 to 25 km over a 50 km distance) than is typical across Atlantic-type extended rift margins (Harry and Londono, 2004; Mickus and Keller, 1992; Thomas, 1991, 2011). During the late Paleozoic assembly of the supercontinent Pangea, the Ouachita collisional fold and thrust belt conformed to this transform margin (Thomas, 2006). Shortening of the sedimentary cover by Ouachita thrusting and folding is greatest in a northwestward direction along the northeast-trending segment of the orogen exposed in Oklahoma and in the subsurface in Texas (Fig. 1A inset), revealing that the culminating Pennsylvanian (Atokan Stage) movement was northwestward and involved dextral transpressional convergence along the AOT (Arbenz, 1989; Viele, 1995; Whitaker and Engelder, 2006). Post-orogenic, mildly deformed middle Pennsylvanian (Desmoinesian Series) to middle Permian (Guadalupian Series) shallow marine clastics and carbonates several kilometers thick were deposited in a basin ("successor basin" of Thomas, 2004) on the southern flank of the Ouachita orogen (Lowrie et al., 1993; Thomas, 1988; Woods et al., 1991).

The opening of the Gulf of Mexico during the breakup of Pangea began with Triassic uplift and extensional faulting along the Gulf-ward edge of the Ouachita thrust front (Dickinson et al., 2010; Lowrie et al., 1993; Salvador, 1991; White et al., 1999). Most authors agree that the Yucatan block rifted away from Texas and Louisiana with a component of counterclockwise rotation, but the location of the pole for this rotation is a point of debate because magnetic anomalies of the seafloor spreading fabric are not discernible, probably due to thick sediments (Bird et al., 2005; Mickus et al., 2009; Pilger, 1981; Salvador, 1987; Sawyer et al., 1991).

Topographic highs of this extended terrain were subject to erosion for a significant period during the Upper Triassic and Lower Jurassic (230 to 195 Ma) as terrigenous clastic red beds accumulated in the study area before initial Middle Jurassic marine incursion and deposition of evaporites by 160 Ma (Salvador, 1991) (Fig. 2). This evaporite environment was followed by widespread marine transgression and carbonate ramp development by 155 Ma. A series of deltaic sequences prograded across the carbonate ramp in Late Jurassic and Early Cretaceous until 120 Ma when platform carbonate deposition prevailed until 100 Ma (Imlay, 1949; Salvador, 1991) (Fig. 2).

Just to the west and south of the study area, a system of grabens formed at the up-dip limit of buried Jurassic salt as sediment progressively accumulated (Fig. 1). These grabens opened from the Jurassic to at least Miocene time due to Gulf-ward sliding of the post-salt sediment sequence along a detachment fault in Jurassic salt (Cloos, 1968; Ewing, 1991; Jackson and Seni, 1983) and are not part of our study.

During the mid-Cretaceous (100 to 90 Ma), an area of the northern Gulf interior coastal plain centered on southeast Arkansas, but including southwest Arkansas, north Louisiana, and west-central Mississippi, was uplifted and eroded during the South Arkansas Uplift/Cretaceous igneous event (SAU, Fig. 1A inset) (Bornhauser, 1958; Ewing, 1991; Salvador, 1991) that has been attributed to this region passing over the Bermuda hotspot (Cox and VanArsdale, 1997, 2002; Nunn, 1990; Van Arsdale, 2009). The Monroe Uplift experienced accentuated uplift and erosion during this epeirogenic event (Fig. 1A). Igneous activity accompanied the South Arkansas Uplift from 100 to 90 Ma in central Arkansas and migrated southeastward to the Jackson dome at Jackson, Mississippi by 75 Ma (Baksi, 1997; Cox and VanArsdale, 2002; Dockery et al., 1997; Eby and Vasconcelos, 2009; Morris, 1987; Sundeen and Cook, 1977; Tilton et al., 1987; Zartman, 1977; Zartman and Howard, 1987). The Lower Cretaceous sedimentary sequence and parts of the Jurassic/Triassic sequence (totaling as much as 3 km thick in the northern interior coastal plain) were eroded from the study area during this uplift (Ewing, 1991; Imlay, 1949).

The mid-Cretaceous unconformity caused by this episode of erosion is buried around the margins of the uplift by 95 to 90 Ma conglomerates, but they are thin or absent in the study area. The mid-Cretaceous South Arkansas uplift episode was followed by punctuated and accelerating subsidence and sedimentation. The area of greatest uplift and erosion experienced the greatest subsidence and became the Desha Basin (Mississippi Embayment depocenter) (Fig. 1A).

Late Cretaceous deposition (95 to 65 Ma) was marked by multiple transgressive/regressive cycles of fluvio-deltaic clastics and chalk/marl intervals (Fig. 2) (Salvador, 1991; Spooner, 1935). Thinning of Upper Cretaceous strata over the Monroe uplift records its rejuvenation from 80 to 70 Ma due to inflation by continuing magma intrusion in that area (Ewing, 1991; Sohl et al., 1991). Late Paleocene to mid-Eocene (55 to 45 Ma) rejuvenation of the Sabine Arch in eastern Texas and western Louisiana is unrelated to the South Arkansas Uplift, but rather is far-field foreland deformation of the Laramide orogen (Laubach and Jackson, 1990).

The Desha Basin experienced its greatest subsidence rate and continued to be the Mississippi Embayment depocenter for fluvio-deltaic and marine sediments during the Paleocene and Eocene (65 to 35 Ma) (Cushing et al., 1964; Onellion, 1956; Wilbert, 1953). Maximum subsidence rates obtained approximately 55 Ma. There are no Oligocene through Pliocene sediments in the study area. Quaternary sediments include Pleistocene and Holocene alluvia of the Arkansas and Saline Rivers, Bayou Bartholomew and their tributaries as well as thin eolian deposits (Saucier and Snead, 1989) (Fig. 2).

Late Cenozoic and active tectonism in southeast Arkansas and the Monroe uplift area is indicated by geomorphology (Burnett and Schumm, 1983; Cox, 1994; Schumm et al., 1982), shallow seismic reflection and trenching studies (Cox et al., 2000, 2012), and land-based geodetic surveys (Meade, 1975; Officer and Drake, 1981). Interpolated vertical velocities from analysis of continuous GPS measurements (Calais et al., 2006) suggest ~2 mm/yr of modern down-to-the-northeast movement across the AOT from Mississippi to Oklahoma. Furthermore, prior to engineered modifications of the river in the 19th century, the only place the water surface on the Lower Mississippi River had a downstream increase in slope (including the river reach that crosses the New Madrid seismic zone) was where it crossed the AOT near the Arkansas–Louisiana line (Biedenharn