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Intraplate magmatism related to opening of the southern Iapetus Ocean: Cambrian Wichita igneous province in the Southern Oklahoma rift zone

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ABSTRACT

Southern Oklahoma and adjacent parts of Texas contain an extensive igneous province emplaced during Early Cambrian rifting within the Southern Oklahoma rift zone. The rift zone was initiated in association with the opening of the southern Iapetus Ocean during Rodinia supercontinent breakup and later became the site of a series of linked uplifts and basins as a result of late Paleozoic inversion. Igneous rocks within the rift are referred to as the Wichita province and are present mostly in the subsurface, although critical exposures occur in the Wichita and Arbuckle Mountains in southwestern and southern Oklahoma. Wells drilled into basement in the region provide a wealth of information on the distribution and relations of the major igneous units in the upper crust, and geophysical data provide important constraints on deeper levels of the rift zone.

The upper parts of the igneous rift fill comprise the Carlton Rhyolite Group, which has an estimated subsurface areal extent of ~40,000 km^2, and the related Wichita sheet granites, which intrude the lower parts of the rhyolite succession. These rocks have A-type characteristics and were emplaced after intrusion, tilting and uplift of a large tholeiitic layered mafic complex; smaller bodies of gabbro also intruded the layered complex after it was tilted. U—Pb zircon and $^{40}Ar/^{39}Ar$ geochronology indicates the felsic rocks and at least some of the mafic units were emplaced in a relatively narrow time frame at ~539—530 Ma. Basalts and intermediate lavas are present only in the subsurface. Our new work shows these lavas to have tholeiitic to mildly alkaline compositions and to be more extensive than previously realized, forming thick successions that both underlie and are intercalated with the rhyolites. Diabase dikes were intruded into older crust during initial opening of the rift, and a suite of late diabase intrusions also cuts the rhyolites and granites, indicating that mafic magma was supplied to the rift throughout its igneous history. Geophysical data show that an enormous mass of mafic rock occupies deeper parts of the rift, extending to depths of at least 10 km beneath the surface. The total volume of igneous rock emplaced within the rift is estimated to be in excess of 250,000 km^3.

Detailed studies of Carlton Rhyolite exposures in the Wichita Mountains, complemented by work on drill cuttings from basement wells, indicate that lava flows up to 400 m thick make up major parts of the rhyolitic succession. The generally limited exposures of these rhyolite lavas in the Wichita Mountains are interpreted to be remnants of laterally extensive flow units similar to those documented from other A-type felsic provinces. Trace element abundances define three distinct geochemical groups of rhyolite, suggesting derivation from three different sources or magma reservoirs. Flows belonging to the different geochemical groups are intercalated in the Wichita Mountains exposures, which may indicate that laterally extensive flows from separate magma chambers came to rest on top of one another during accumulation of the rhyolitic volcanic pile.

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1. Introduction

Opening of the Iapetus Ocean during breakup of the Rodinia supercontinent was preceded and accompanied by Neoproterozoic to Cambrian intraplate magmatism at numerous sites along the eastern margin of the Laurentian craton (Aleinikoff et al., 1995; Cawood et al., 2001; Tollo et al., 2004). There is less evidence for similar magmatism

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along the southeastern margin of Laurentia. One notable exception occurs in southern Oklahoma and adjacent parts of Texas, the location of a major rift zone (Fig. 1) containing an extensive, largely bimodal igneous assemblage that is typically considered to be Early Cambrian in age but may also extend back into the late Neoproterozoic. These rocks are grouped together as the Wichita province (Ham et al., 1964), and they represent one of the largest magmatic episodes associated with the opening of Iapetus anywhere along the eastern or southern Laurentian margins. In spite of this, the Wichita province has received only limited attention in the literature on large igneous provinces (LIPs). Here we summarize important aspects of the rift-related igneous rocks and present some results of our work in progress on the geophysical signature and volcanic fill of the rift zone.

2. Geological setting

The early work of Shatski (1946) recognized the large structures in southern Oklahoma as an inverted aulacogen penetrating into the craton interior at a high angle to the Paleozoic continental margin. Hoffman et al. (1974) considered this aulacogen to represent the failed arm of a rift–rift–rift triple junction, with the other two arms evolving into sites of seafloor spreading as Iapetus began to open. More recently, Thomas (1991, 2011) has argued against the failed-rift-arm model and has instead interpreted the magmatism in southern Oklahoma to have occurred in a leaky transform fault zone associated with a pronounced offset in the Paleozoic continental margin. In the present paper we refer to this major, west-northwest-trending structural feature in southern Oklahoma and adjacent parts of Texas as the Southern Oklahoma rift zone, in order to avoid genetic connotations now commonly associated with the term aulacogen. It should also be noted that the leaky transform and rift interpretations are not mutually exclusive, because transtension is common in developing rifts.

An older basin containing Proterozoic strata ~12 km thick occurs in the subsurface to the south of the Southern Oklahoma rift zone (Pratt et al., 1992), raising the possibility that the latter feature developed along a pre-existing line of structural weakness in the craton. Felsic igneous rocks of the ~1.4 Ga southern midcontinent granite–rhyolite province form the main subsurface basement units to each side of the Southern Oklahoma rift zone (Rohs and Van Schmus, 2007; Van Schmus et al., 1996) and are locally exposed along the northern rift margin in the Arbuckle Mountains (Ham et al., 1964). Additional evidence that the rift zone follows an older line of weakness comes from the presence of west-northwest-trending microgranite and diabase dikes in the Arbuckles that cut the Proterozoic crystalline rocks and are considered by Denison (1982, 1995) to be close in age to those rocks.

Inversion of the Southern Oklahoma rift zone occurred in the Pennsylvanian and Early Permian, related either to collisional Ouachita orogenesis along the southeastern continental margin, or to far-field

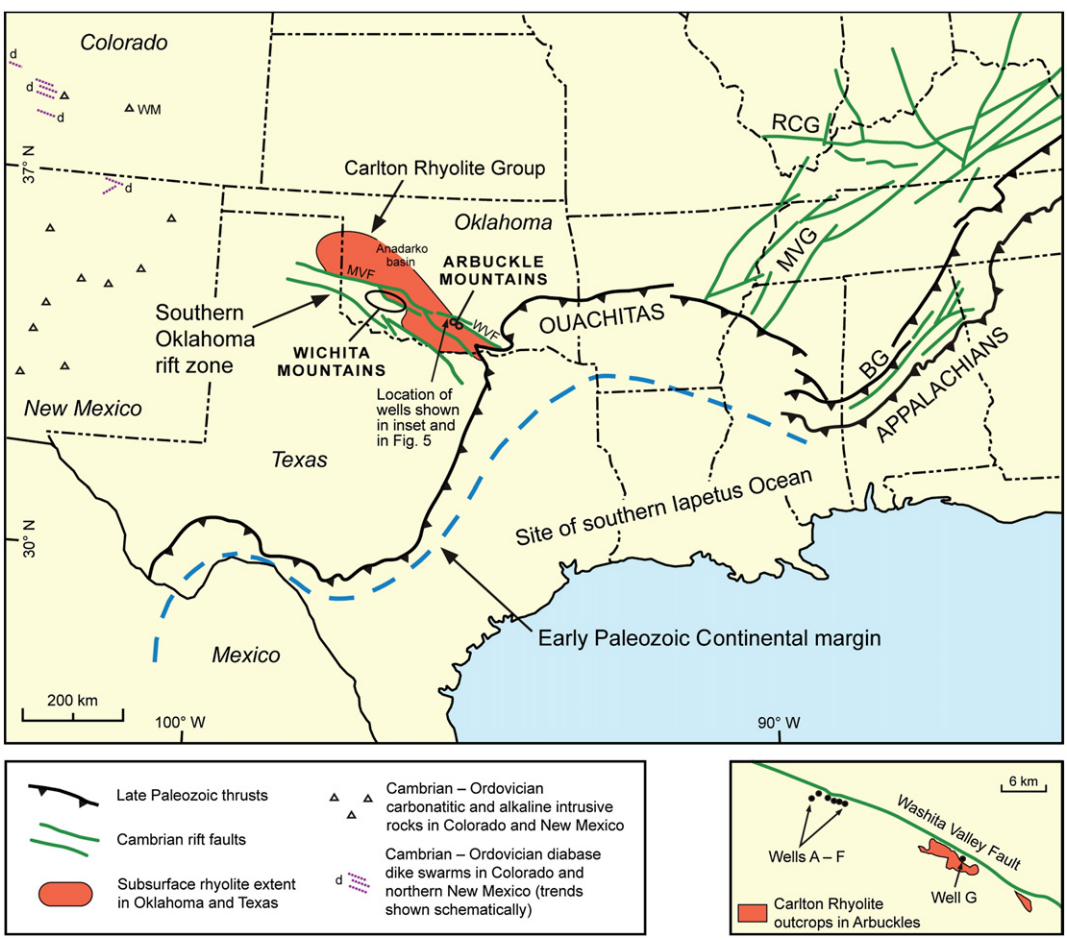

Fig. 1. Cambrian rift zones in southeastern North America related to opening of the Iapetus Ocean. Approximate outlines of outcrops of Cambrian igneous rocks in the Wichita and Arbuckle Mountains in southern Oklahoma are indicated. Inset in lower right shows locations of wells depicted in Fig. 5 relative to the Washita Valley fault and rhyolite outcrops in the Arbuckle Mountains. Main figure modified from McConnell and Gilbert (1990); faults from Thomas (1991) and Northcutt and Campbell (1998); subsurface rhyolite extent modified from Ham et al. (1964); early Paleozoic continental margin from Keller and Stephenson (2007); diabase dike swarms and carbonatitic and alkaline rocks in Colorado and New Mexico from Larson et al. (1985) and McMillan and McLemore (2004); schematic dike trends from Reed (1984) and Larson et al. (1985). WM: Wet Mountains; MVF: Mountain View fault; WVF: Washita Valley fault; BG: Birmingham graben; MVG: Mississippi Valley graben; RCG: Rough Creek graben.

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