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Offshore extent of Gondwanan Paleozoic strata in the southeastern United States: The Suwannee suture zone revisited

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ABSTRACT

The recognition of the Suwannee terrane in southeastern North America was a critical step in advancing our current understanding of the tectonic evolution of ocean basins. Unfortunately, further clarification of the boundaries of the Suwannee terrane has proven difficult due to the thick coastal plain cover, limited well log analyses, and a paucity of seismic reflection data onshore. We present the results from a new compilation and analysis of legacy marine seismic reflection, refraction and well data from offshore the southeastern United States, which reveals in the subsurface a previously unmapped lower Paleozoic sedimentary section spanning the continental shelf from Florida to North Carolina. Previously only identified in two deep offshore wells (COST GE-1 and Transco 1005-1), this Paleozoic platform sequence is identified in seismic reflection profiles as a package of low-frequency, sub-horizontal, laterally-continuous reflectors which are clearly discordant with and distinct from the overlying Mesozoic and Cenozoic stratigraphy above the post-rift unconformity (PRU). The inferred base of the Paleozoic sequence is marked by the downward diminution of parallel seismic reflectors, as well as an increase in seismic velocities to >6 km/s observed on numerous offshore seismic refraction surveys. While clearly deformed in some areas, these Paleozoic strata are generally sub-horizontal, range in thickness from 4 to 6 km, and can be mapped continuously over an area in excess of 130,000 km^2. Similar sedimentary rocks have been recognized from onshore exploration wells in Florida since the 1930s, and were subsequently identified to be part of the Suwannee basin within the larger exotic Suwannee terrane of Gondwanan affinity. Recognition of the presence and extent of these Gondwanan strata offshore implies: (1) the inferred position of the Suwannee suture zone offshore lies >200 km further north, approximately along the boundary between the Carolina terrane and the Charleston terrane; (2) previously identified terranes (Brunswick, Charleston, Suwannee, Northern Florida) are likely distinct crustal blocks, but their amalgamation predates deposition of the overlying Paleozoic section of the Suwannee basin; (3) collectively, this crust represents the Gondwanan continent based on the size and presence of a stable platform stratigraphy, nominally doubling the size of the last sutured terrane, the Suwannee terrane.

1. Introduction

Recognition of Paleozoic strata of Gondwanan (non-Laurentian) affinity in the subsurface of southeastern North America was a critical observation leading to Wilson's (1966) seminal work on the opening and closing of ocean basins. Termed the Suwannee basin by King (1961), this sequence of early- to mid-Paleozoic strata was originally identified through extensive onshore petroleum exploration drilling during the first half of the 20th century in northern Florida, and southern Georgia and Alabama (Applin, 1951; Barnett, 1975; Fig. 1A). Subsequent clarification of the regional extent of the Suwannee basin and identification of the boundaries of the associated Suwannee terrane have proven difficult due to the thick coastal plain cover, limited analyses of deep well penetrations, and lack of extensive seismic reflection data onshore (Williams and Hatcher, 1983; Tauvers and Muehlberger, 1987; Horton et al., 1989; Mueller et al., 2014).

Offshore data collection initiated in the 1950s with a series of refraction profiles aiming to characterize the crustal structure of the southeastern United States Atlantic margin (Hersey et al., 1959; Sheridan et al., 1966). Following the initial refraction surveys, the United States Geological Survey (USGS) and various research cruises, completed seismic reflection and refraction surveys between the 1960s and 1980s. In the 1970s, offshore petroleum exploration accelerated data collection leading to the acquisition of the "legacy industry Atlantic margin" dataset, which included extensive 2D seismic reflection surveys, and the completion of seven exploration wells offshore the southeastern United States. Two of these seven wells reside just offshore northern Florida and drilled a similar sequence of Paleozoic strata correlated to the onshore Suwannee basin rocks (Poppe and Dillon, 1989; Poppe

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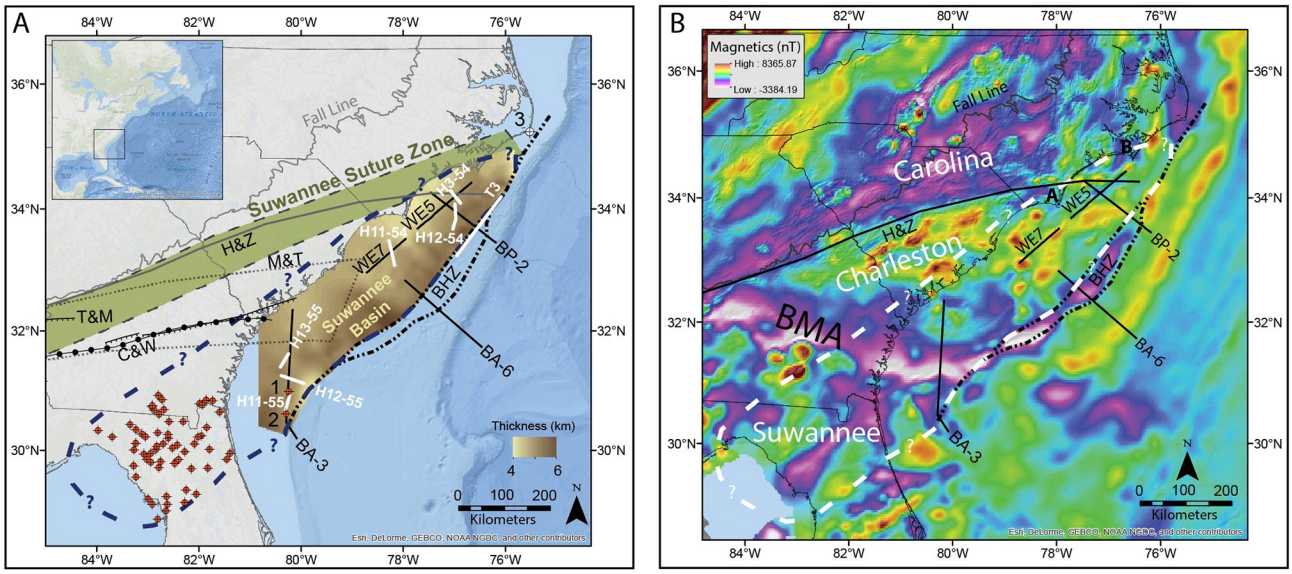

Fig. 1. (A) Map of southeastern North America illustrating revised extent of Suwannee basin (navy dashed line), re-defined location of Suwannee suture zone, previously interpreted positions of suture, and location of data referred to in text. Isochore (brown) indicates mappable extent and thickness (4–6 km) of Suwannee basin rocks. Seismic reflection profile locations (BA-3, BA-6, WE-007-7 (WE7), WE-007-5(WE5), and BP-2) shown as black lines; refraction surveys (Hersey et al., 1959 (H) and Trehu et al., 1989 (T)) shown as white lines. Abbreviations for previous suture interpretations: C&W (Chowns and Williams, 1983); T&M (Tauvers and Muehlberger, 1987); M&T (Thomas, 2010; Mueller et al., 2014); H&Z (Higgins and Zietz, 1983). Onshore wells penetrating Suwannee basin strata in northern Florida and southern Georgia shown by red well symbols. Offshore wells 1 (Transco 1005-1) and 2 (COST GE-1) tie to profile BA-3. Well 3 (Hatteras Light No.1) encountered granitic basement, marking the northeastern extent of identifiable Suwannee basin strata. Fall line marks western boundary of coastal plain sediments. BHZ (dot-dashed line) offshore identifies "Basement Hinge Zone" (modified after Hutchinson et al., 1995). (B) Magnetic anomaly map (EMAG2, 2009) of southeastern North America and previously interpreted exotic terranes (Carolina, Charleston, and Suwannee). Locations of seismic reflection profiles (black) illustrated offshore as well as the revised extent of the Suwannee basin highlighted in white dashed line. Abbreviations: A - Cape Fear; B - Cape Lookout . BMA - Brunswick Magnetic Anomaly. H&Z - Carolina–Mississippi fault (Higgins and Zietz, 1983) is a dextral strike slip fault separating the Carolina Terrane and Charleston terrane previously interpreted to be the location of the Alleghanian suture. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

et al., 1995; Fig. 1A). After the mandatory 25 years of confidentiality, the Bureau of Ocean and Energy Management (BOEM) has recently released the Atlantic legacy industry dataset.

Integration of four decades of refraction profiles, 2-D seismic reflection surveys, including the much denser legacy dataset, in addition to well penetrations, demonstrate the presence of Paleozoic strata of inferred Suwannee basin origin across the continental shelf. The mappable extent of the Suwannee basin is limited to the continental shelf, bounded to the east by the Basement Hinge Zone (BHZ), and stretches from onshore Florida to offshore Cape Lookout, North Carolina (Fig. 1A).

Implications of the revised Gondwanan-affinity Suwannee basin rocks offshore include (1) the inferred position of the Suwannee suture zone is now constrained in the east to lie much further north, along the boundary between the Carolina and Charleston terranes (Fig. 1A and B), (2) previously identified terranes (Charleston, Brunswick, Suwannee, Northern Florida) and their inferred boundaries (e.g. Brunswick Magnetic Anomaly) may yet be distinct crustal blocks, but their amalgamation predates deposition of the overlying Paleozoic section of the Suwannee basin (Fig. 1B); and (3) the size and presence of the Suwannee basin offshore suggest that the underlying crust represents a continuous piece of Gondwanan continental lithosphere, nominally doubling the size of the previously interpreted Suwannee terrane.

1.1. Suwannee basin

Extensive petroleum exploration in the early 1900s led to the identification of Paleozoic sedimentary rocks in the subsurface of the southeastern United States. The basin containing these Paleozoic sedimentary rocks in Florida, Georgia and Alabama was first termed the "Suwannee River Basin" by Braunstein (1957), and was later contracted to the "Suwannee basin" by King (1961). Chowns and Williams (1983) proposed to abandon the term "Suwannee basin" due to confusion with the younger and unrelated feature, the Suwannee Strait. However, other authors have continued use of the term "Suwannee basin" to identify the region that contains Paleozoic sedimentary rocks (Nelson et al., 1985; Poppe et al., 1995; Pollock et al., 2012). Therefore, this study continues use of the term "Suwannee basin" in reference to the area containing Gondwanan Paleozoic sedimentary strata, highlighted by the onshore well penetrations in Fig. 1.

The Suwannee basin Paleozoic strata are lithologically and faunally distinct from equivalent-age sequences in the Appalachian foreland and correlated to similar age sedimentary rocks and faunal assemblages in the conjugate West African basins (Wilson, 1966; Arden, 1974; Dillon and Sougy, 1974; Barnett, 1975; Pojeta et al., 1976; Poppe et al., 1995). Subsequent dating of detrital zircons from the Suwannee basin sedimentary rocks revealed ages of typical Gondwanan orogenic events, generally not observed in southeastern Laurentian zircon records (Mueller et al., 1994; Mueller et al., 2014).

The Paleozoic strata consist of Lower Ordovician quartzites and Middle Ordovician to Middle Devonian fossiliferous shales and sandstones overlying a complex terrain of pre-Cambrian felsic volcanic and intrusive rocks (Applin, 1951; Barnett, 1975; Chowns and Williams, 1983). Using seismic refraction, reflection, and gravity data, the thickness of the Paleozoic strata onshore is estimated to be 2.5–3 km, however onshore wells have only penetrated the upper ~600 m of the sedimentary sequence (Arden, 1974; Chowns and Williams, 1983; Thomas et al., 1989; Pollock et al., 2012). The Paleozoic sedimentary rocks represent a typical continental platform sequence with a mixed source of continental derived sands and marine muds, suggesting that the Suwannee basin was deposited on Gondwanan continental crust (Arden, 1974; Duncan, 1998).

Scientists have previously used the mappable extent of Suwannee basin Paleozoic rocks and associated Gondwanan affinity basement onshore to help delineate the boundaries of the associated Suwannee terrane. Similar methods using well and seismic reflection data offshore could provide additional constraints on the boundaries of the Suwannee terrane. Paleozoic strata penetrated by two offshore wells, Transco 1005-1 and Continental Offshore Stratigraphic Test (COST) Georgia