U-Pb detrital zircon geochronology of the Upper Paleocene to Lower Eocene Wilcox Group, east-central Texas

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ABSTRACT

Arrival of Laramide uplift sediments to the Texas Gulf Coastal Plain and northwestern Gulf of Mexico during the early Paleocene is recorded in strata of the Wilcox Group as a significant increase in sediment accumulation and with the appearance of 65–52 Ma detrital zircons that correspond with the timing of late Laramide uplift. New U-Pb dating of detrital zircons by laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) for samples obtained from the Lower Paleocene Tehuacana Member through the Lower Eocene Queen City Formation in east-central Texas identifies the Hooper Formation of the Wilcox Group as the oldest stratigraphic unit to contain 65–52 Ma ages. Late appearance of 65–52 Ma detrital zircons in the Hooper Formation is correlated with unroofed Laramide magmatic intrusions or nearly syndepositional volcaniclastic sources; whereas older detrital zircons are inferred to be derived primarily from sedimentary cover and basement rocks exposed during uplift of Laramide blocks.

Potential source region and Gulf Coastal Plain detrital zircon data support a relatively similar paleodrainage area and sediment sources for east-central Texas Tehuacana Member to Carrizo Formation and central Louisiana Wilcox Group data, and for east-central Texas Queen City Formation and central Louisiana middle-upper Claiborne Group data. South Texas Wilcox Group data contrast with data from these samples and support a different paleodrainage area and sediment sources for the south Texas region. We propose that headwaters sourced from southeastern Wyoming to the southern Rocky Mountain region delivered sediments to east-central Texas and central Louisiana during the Paleocene to Middle Eocene. Pronounced Mesoproterozoic and Neoproterozoic detrital zircons in the lower Claiborne Group of east-central Texas and the middle-upper Claiborne Group of central Louisiana are attributed to new or unroofed recycled sediments with Grenvillian age detrital zircons incorporated from the Ouachita region and other proximal locations in the preexisting paleodrainage area. The inferred paleodrainage area for east-central Texas and central Louisiana includes most of the Rocky Mountain Laramide uplift blocks, has a southern boundary separating it from a south Texas paleodrainage, and an eastern boundary roughly coincident with the Mississippi embayment, which separates it from Appalachian Mountains drainages.

INTRODUCTION

Upper Paleocene and Lower Eocene strata comprising the Wilcox Group and overlying Claiborne Group occur along the Gulf Coastal Plain from southwestern Texas to central Alabama. Wilcox Group and Claiborne Group strata are an important economic resource in the Texas Gulf Coastal Plain and northwestern Gulf of Mexico. Both groups contain important aquifers (Thorkildsen and Price, 1991), and the east-central Texas region contains a significant percentage of total Texas Wilcox Group lignite coal reserves (Kaiser et al., 1980). Additionally, deep-water amalgamated channel systems and associated deposits of the Wilcox Group equivalent are important hydrocarbon targets in the northwestern Gulf of Mexico (Meyer et al., 2005). These resources have made Paleocene and Eocene strata subject to various geologic studies, including those related to sedimentary provenance (Hutto et al., 2008; Mackey et al., 2012). Previous U-Pb age dating of detrital zircons from Paleocene and Eocene strata along the northwestern Gulf Coastal Plain includes areas in south Texas (Mackey et al., 2012), east-central Texas (Hutto et al., 2009), central Louisiana (Craddock and Kylander-Clark, 2013), and a regional study extending from southwestern Texas to central Alabama (Blum and Pecha, 2014). This study advances efforts to further characterize these strata along the Gulf Coastal Plain by providing U-Pb age data for 12 sandstone samples from closely spaced stratigraphic horizons in east-central Texas. Samples were obtained from locations between Bastrop and Freestone Counties of east-central Texas where strata crop out in and in close proximity to the Colorado, Brazos, and Trinity River Valleys (Figs. 1 and 2), all of which are located in the Houston embayment structural basin. Sandstone samples are from the Lower Paleocene Tehuacana Member at the top of the Kincaid Formation of the Midway Group to the Lower Eocene Queen City Formation of the lower Claiborne Group. Sample location details are available in Supplemental Item 1.

Sediment delivery to the Texas Gulf Coastal Plain and northwestern Gulf of Mexico during the early Paleogene is characterized by a substantial increase of clastic sediment volume during the Late Paleocene, followed by an overall decline of sediment delivery until the Late Eocene (Galloway and Williams, 1991; Galloway et al., 2011). Wilcox Group and lower Claiborne Group sediments were deposited during a phase of clastic sediment delivery representing the first and greatest Paleogene cycle of tectonic-influenced deposition (Winker, 1982). This phase corresponds with timing of late Laramide orogenesis (Cather and Chapin, 1990; Lawton, 2008) and continued development of the Western...
Cordillera (DeCelles, 2004). Extended sediment deposition on the margins of the Gulf of Mexico resulted in an overall transition from open marine shelf settings during the Early Paleocene to nonmarine settings by the Oligocene, modulated by variation of sediment supply, subsidence, and eustatic sea level (Yancey and Davidoff, 1991; Davidoff and Yancey, 1993). Shelf-margin outbuilding was accompanied by sediment accumulation in large fluvial and deltaic depositional systems (Fisher and McGowen, 1967; Edwards, 1981; Ayers and Lewis, 1985; Galloway et al., 2000) and development of submarine canyons through which sediments were transported to the deep-water Gulf of Mexico (Hoyt, 1959; Galloway et al., 1991). New radiometric age dates from Paleocene and Lower Eocene sandstone samples deposited in shallow marine and fluvial settings in east-central Texas advance the initial regional work of Hutto et al. (2009), which identified 80–53 Ma age detrital zircons in Calvert Bluff and Carrizo Formation strata that are considered to be derived from areas affected by late Laramide uplift. Analyses of additional Paleocene to Lower Eocene Wilcox Group strata reported similar young detrital zircon ages (62–54 Ma) from the Mississippi embayment to south-central Texas (Blum and Pecha, 2014). However, much of these data in east-central Texas are derived from undifferentiated Wilcox Group strata, with the Simsboro Formation being the oldest identified unit. Closely spaced stratigraphic age data from this study are the first to constrain the relative arrival time of these young detrital zircons to the east-central Texas region.

The Laramide orogeny (80–55 Ma) is considered to have resulted from regional northeast-southwest compressional forces and crustal shortening related to flat-slab subduction of the Farallon plate beneath the North American plate (Dickinson and Snyder, 1978; DeCelles, 2004), although other models exist (English and Johnston, 2004). This resulted in an area east of the Sevier fold and thrust belt characterized by intermontane basins (Dickinson et al., 1988) and associated asymmetric basement-cored uplifts that characterize Laramide-style deformation (Dickinson and Snyder, 1978; Lawton, 2008).
Paleocene and Eocene Texas stratigraphic nomenclature has historically been subdivided into major transgressive and regressive successions bound by major breaks in lithology (Sellards et al., 1932; Stenzel, 1938; Hargis, 1986). In east-central Texas, lower Paleogene lithostratigraphic units are the Midway, Wilcox, and Claiborne Groups. The Paleocene component of the Midway Group generally consists of abundant shale with minor sandstone beds and includes in its uppermost section the Tehuacana Member of the Kincaid Formation and the Wills Point Formation (Gardner, 1935). These formations were deposited in an open marine setting represented by two overall shallowing-upward successions below the Wilcox Group (Kellough, 1959). The Wilcox Group contains abundant sandstone and shale and has extensive lignite deposits. The Seguin Formation marks its lowermost boundary and is overlain by the Hooper, Simsboro, and the Calvert Bluff Formations (Sellards et al., 1932; Stenzel, 1938). Wilcox Group depositional settings range from shallow marine, estuarine, fluvial-deltaic, and coastal plain settings (Sellards et al., 1932; Stenzel, 1938; Ayers and Lewis, 1985; Yancey and Davidoff, 1991). The overlying Lower Eocene Claiborne Group generally consists of interbedded sandstone and shale and comprises the Carrizo, Reklaw, and Queen City Formations from base to top (Sellards et al., 1932; Eargle, 1968). These units were deposited in shallow marine, shoreface, coastal plain, and interdeltic embayment and constructive deltaic settings (Sellards et al., 1932; Stenzel, 1938; Guevara and Garcia, 1972; Yancey et al., 2010).

### ANALYTICAL METHODS

Sample preparation and analyses were conducted at the Department of Geology and Geophysics at Texas A&M University. Sandstone samples from each stratigraphic horizon were collected from outcrop sections after well-weathered surfaces or surfaces potentially containing float were removed in order to avoid sample contamination. Samples were fully disaggregated, sieved, and elutriated, with the resultant sample grain size ranging between 63 and 300 μm. Elutriated samples were oven dried for at least 12 h at 75 °C before further processing. Sorted aliquots of each sample were then concentrated into heavy and light mineral fractions by methylene iodide (MEI) heavy liquid separation. Detrital zircons were individually picked and mounted in epoxy pucks for further processing. Sorted aliquots of each sample were then concentrated into heavy and light mineral fractions by methylene iodide (MEI) heavy liquid separation. Detrital zircons were individually picked and mounted in epoxy pucks for further processing. Sorted aliquots of each sample were then concentrated into heavy and light mineral fractions by methylene iodide (MEI) heavy liquid separation. Detrital zircons were individually picked and mounted in epoxy pucks for further processing. Sorted aliquots of each sample were then concentrated into heavy and light mineral fractions by methylene iodide (MEI) heavy liquid separation.

- **Present elevation of the entire central Rockies and adjacent parts of the Great Plains was reached concurrently during the Late Eocene** (Fan et al., 2014a, and basin floors attained much of their elevation during the Early Eocene to Early Oligocene (Fan et al., 2014b). To address paleodrainage and sediment sources with respect to regions such as those affected by Laramide uplift, comparisons are made between composite U-Pb detrital zircon age spectra from four potential source regions in the western United States and northern Mexico and from three regions along the Texas and Louisiana Gulf Coastal Plain (Fig. 3). Potential source region data represent Mesozoic through Paleogene strata and were compiled from previous geochronologic studies into a northeastern Mexico region (Lawton et al., 2009), a southwestern region (Dickinson et al., 2009; Davis et al., 2010; Mauel et al., 2011; Spencer et al., 2011), and a southern (Dickinson and Gehrels, 2008) and northern (Fan et al., 2011; Fuentes et al., 2011; May et al., 2013) Rocky Mountain region. Gulf Coastal Plain samples comprise data from south Texas (Mackey et al., 2012), central Louisiana (Craddock and Kylander-Clark, 2013), and east-central Texas (this study).

#### Figure 2. Generalized east-central Texas stratigraphic column (after Sellards et al., 1932; Stoeser et al., 2005; and others) with sampled units indicated. See Supplemental Item 1 (see footnote 1) for sample location details. Middle Calvert Bluff Formation and lower Carrizo Formation samples from Hutto et al. (2009).
Figure 3. Location of potential source region and Gulf Coastal Plain data in the United States and Mexico. Physiographic highs potentially influential on sediment drainage to the northwestern Gulf of Mexico are indicated in brown, with tan or dashed features indicating uncertainty of relief and/or extent. Physiographic features adapted from (Sellards et al., 1932; Budnik, 1986; DeCelles, 2004; Flowers et al., 2008; Lawton, 2008; Galloway et al., 2011 and references therein). SOB—Sevier orogenic belt; CFR—Colorado Front Range; MH—Mogollon Highlands; LFTB—Laramide fold-thrust belt; LU—Llano uplift; SMA—San Marcos arch; AWM—Amarillo-Wichita Mountains; OM—Ouachita Mountains; AM—Appalachian Mountains; EBPA/PA/TA—El Burro-Peyotes arches, Picachos arch, Tamaulipas arch; southwestern region (Dickinson et al., 2009; Davis et al., 2010; Mauel et al., 2011; Spencer et al., 2011); northeastern Mexico region (Lawton et al., 2009); northern Rocky Mountain region (Fan et al., 2011; Fuentes et al., 2011; May et al., 2013); southern Rocky Mountain region (Dickinson and Gehrels, 2008); Louisiana Wilcox Group and Claiborne Group (Graddock and Kylander-Clark, 2013); south Texas Wilcox Group (Mackey et al., 2012); east-central Texas (this study).
LA-ICP-MS was performed in the Texas A&M University Radiogenic Isotope Geochemistry Laboratory. A precise timing of LA-ICP-MS and TIMS (Thermal Ionization Mass Spectrometry) U-Pb zircon ages for similar sample populations support that LA-ICP-MS was able to produce data within <1% (one standard uncertainty) (Chang et al., 2006), although limitations of the LA-ICP-MS method are included in various publications (Feng et al., 1993; Fryer et al., 1997; Chu et al., 2002). Methods for such evaluations and evaluation were modified after those developed by the Radiogenic Isotope and Geochemistry Laboratory (RIGL) at Washington State University (WSU) and the Arizona LaserChron Center (Hebert et al., 2004). Data processing focused primarily on text developed by RIGL at Washington State University. High-resolution LA-ICP-MS was performed using an Element XR single sector mass spectrometer and Analyte Exite Excimer laser ablation system at the Texas A&M University Radiogenic Isotope Geochemistry Laboratory. A minimum of 300 detrital zircon grains were mounted per sample, with ~150 analyses performed. The respective size of zircon standards and NIST glass standards included the number of standards mounted in an epoxy pump. LA-ICP-MS procedures are described in Supplemental Item 2 and were modeled after those developed by the Radiogenic Isotope and Geochemistry Laboratory at Washington State University (Chang et al., 2006) and the University of Arizona LaserChron Center (Gehrels et al., 2006). Isolot 3.0 software (Ludwig, 2003) was used to create probability density plots, histograms, concordia plots, and to determine the youngest detrital zircon age for each respective sample. Detrital zircon age data were also assessed using the Kolmogorov-Smirnov (K-S) statistical test, which tests the null hypothesis that two distributions were derived from the same parent population. K-S test results and Isolot products not included in this report are available in Supplemental Item 3.

**DETRITAL ZIRCON GEOCHRONOLOGY**

Apparent ages, isotopic ratios, and associated 1σ absolute error values from 206Pb/238U, 207Pb/235U, and 207Pb/206Pb data were obtained after LA-ICP-MS data processing of detrital zircons from each sandstone sample. All samples show minimal to no detrital zircon ages between 500 and 700 Ma, which provides a natural break in data sets at which to place the cutoff between the 206Pb/238U age (<600 Ma) and 207Pb/206Pb age (>600 Ma) as our best interpretation of the zircon crystallization age for concordant or nearly concordant analyses. See Supplemental Item 4 for all radiometric age data. Of the ~150 analyses performed by LA-ICP-MS per sample, the number of usable detrital zircon data per sample with respect to a 10% discordant age filter varied between 94 and 140 ages. These U-Pb age data are displayed in individual and composite probability density plots for qualitative comparison.

Fractionation factors of primary zircon standards and ages of secondary zircon standards plotted with respect to analysis date reveal that despite change of fractionation factors, the overall relative standard deviation of secondary zircon standard ages was 3.23–5.28%. This supports a similar range of uncertainty regarding the reproducibility of east-central Texas detrital zircon ages. Further information regarding fractionation and secondary zircon standards relating to the relative reproducibility of detrital zircon age data are included in Supplemental Item 2 (see footnote 2).

**EAST-CENTRAL TEXAS SAMPLES**

Detrital zircon U-Pb age data (n = 1297) from east-central Texas are presented in composite probability density plots representing all 12 Paleocene and Lower Eocene sample horizons (Figs. 4 and 5). Figures 6 and 7 reveal the distribution of detrital zircon ages in individual sample horizons. Qualitative observation of east-central Texas composite probability density plot peaks, peak shoulders, and valleys allows designation of eight primary detrital zircon age ranges that were used for comparative purposes. Boundaries separate age ranges with clustered ages or where data are scattered or relatively absent, and boundary age numbers correspond with maximum and minimum ages of detrital zircons in each age range. These age ranges are 3217–1970 Ma, 1958–1530 Ma, 1518–1303 Ma, 1293–843 Ma, 799–676 Ma, 652–265 Ma, 251–134 Ma, and 130–52 Ma.

Age ranges of Precambrian detrital zircons reveal a major difference between samples of younger and older strata. A stratigraphic interval containing samples from the Tehuacana Member of the Kincaid Formation, the Wilcox Group, and the Carrizo Formation contains abundant detrital zircons with ages between 1958 Ma and 1530 Ma. Detrital zircons in this age range comprise nearly 38% of all sample ages. In contrast, the Queen City Formation contains abundant (51% of all sample ages) 1293–843 Ma age detrital zircons with mode peaks at 1099 Ma and 1221 Ma and the least amount (16%) of 1958–1530 Ma detrital zircons. These two age ranges and a 1518–1303 Ma age range account for most of the Precambrian detrital zircons, with the 3217–1970 Ma age range representing a minor amount. Precambrian–Paleozoic ages (652–265 Ma) in sample age spectra are also minor, and there is a relatively consistent absence of 799–676 Ma detrital zircon ages in all samples. These minor age ranges contain too few data points for use in robust determination of provenance.

The distribution of detrital zircon ages younger than 300 Ma is relatively consistent among samples (Fig. 7). There are two multi-modal detrital zircon age ranges that are populated in all samples (251–134 Ma and 130–52 Ma), but few detrital zircon ages are between 150 Ma and 105 Ma. The 251–134 Ma age range has mode peaks at 153 Ma and 168 Ma that appear in most samples or contains a single peak with an intermediate age. The 130–52 Ma age range has mode peaks at 94 Ma, 75 Ma, and 57 Ma. Only the Sequin Formation and one Calvert Bluff Formation sample do not contain the older peak. These two samples lacking the 94 Ma peak also have a mode peak shifted more than ±3 Ma from the 75 Ma peak. The youngest mode in the 130–52 Ma age range spans the 65–52 Ma age interval that corresponds in time with late stages of Laramide uplift (Dickinson et al., 1988; DeCelles, 2004). Paleocene and Early Eocene ages between 65 Ma and 52 Ma comprise 19% of the 130–52 Ma age range. The oldest stratigraphic occurrence of 65–52 Ma ages is in the Hoober Formation of the Wilcox Group. These ages are present in younger Wilcox Group samples except for two Simsboro Formation samples. They are also absent from the Queen City Formation of the lower Claiborne Group. Inconsistency in occurrence of detrital zircons in the Wilcox and Claiborne Groups may be attributed to natural bias or vagaries of sample selection and preparation (Sircombe et al., 2001; Cawood et al., 2003; Fedo et al., 2003; Vermeesch, 2004; Moehl and Samson, 2006; Hay and Dempster, 2008; Slama and Kosler, 2012). The youngest detrital zircons account for just several percent of the total sample set. Despite their occasional absence, the presence of detrital zircons with ages that approximate the depositional age of the sampled sedimentary deposit has importance in study of provenance.
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**Figure 4.** Probability density plot and associated histogram of composite detrital zircon age data for all 12 east-central Texas samples. Age ranges are overlain for reference. Age labels identify pronounced probability density plot peaks and valleys of each age range. \( n \)—number of ages. From oldest to youngest, each consecutive lower boundary of an age range corresponds with its youngest respective value (e.g., 1970, 1530, etc.) because no data are present between age ranges.

**Figure 5.** Probability density plot and associated histogram of composite detrital zircon age data of all 12 east-central Texas samples for ages younger than 300 Ma. Age ranges are overlain for reference. \( n \)—number of ages. See Figure 4 caption for age label and age range boundary details.
GULF COASTAL PLAIN SAMPLES

Ages of the majority of detrital zircons in the east-central Texas region of the Gulf Coastal Plain correspond with the timing of major igneous and metamorphic events in North America, including those related to assembly of the southern and eastern Laurentian shield (Yavapai Province [1800–1720 Ma]; Mazatzal Province [1720–1600 Ma]; Granite-Rhyolite Province [1550–1350 Ma] [Bennett and DePaolo, 1987; Karlstrom and Bowring, 1988; Whitmeyer and Karlstrom, 2007 and references therein]; the Grenville Province [1300–950 Ma] [Eriksson et al., 2004; Park et al., 2010]; and the Cordilleran arc (<300 Ma) of the tectonically active western margin of the continent [Tobisch et al., 1986; Busby-Spera, 1988; Dunne et al., 1998; Saleeby et al., 2008; Gehrels et al., 2009; Miller et al., 2009; LaMaskin, 2012]. Identifying the source of detrital zircons based on comparison of measured ages of known basement terranes is complicated by the possibility of sediment recycling, where grains may be eroded, transported, and deposited numerous times in sites far from the original source (Eriksson et al., 2004; Dickinson et al., 2009). To address sediment sources and paleodrainage implications, comparison was made between compiled detrital zircon data from potential source regions in the Western Cordillera and data from the Texas and Louisiana Gulf Coastal Plain (Figs. 8–11). Composite probability density plots of the east-central Texas region include Tehuacana Member; Se—Seguin Formation; H-PC—Hooper Formation, Polecat Creek; H-DR—Hooper Formation, Dennison Ranch; Si-B—Basal Simsboro Formation, Route 14 roadcut; Si-LP—Simsboro Formation, Luminant Pit; Si-TQ—Simsboro Formation, Thornton Quarry; Si-KM—Simsboro Formation, Rosse Mine; CB-BS—Calvert Bluff Formation, Black Shoals; CB-BBM—Calvert Bluff Formation, Big Brown Mine; Cz—Carrizo Formation; and QC—Queen City Formation.
East-central Texas (Teh-Cz) and lower Claiborne Group Queen City Formation detrital zircon age assemblages are very similar to Wilcox Group and middle-upper Claiborne Group assemblages of central Louisiana. Both areas show a distinct change between the Wilcox Group and Claiborne Group (Figs. 10 and 11). East-central Texas Queen City Formation and central Louisiana middle-upper Claiborne Group data both contain a less pronounced 1958–1530 Ma age range and a more pronounced 1293–843 Ma age range compared to older samples. Apart from young (65–52 Ma) detrital zircon ages being minimal or entirely absent in these younger strata, east-central Texas and central Louisiana data have relatively similar 251–52 Ma age distributions. In contrast, south Texas Wilcox Group data are distinct compared to equivalent Gulf Coastal Plain samples to the northeast. East-central Texas (Teh-Cz) and central Louisiana Wilcox Group data each contain a relatively similar distribution of Precambrian ages (Figs. 8 and 9) that contrast with less pronounced 1958–1530 Ma ages in the south Texas Wilcox Group, and south Texas Wilcox Group samples contain a distribution of 150–105 Ma ages that is minimal to absent in central Louisiana and east-central Texas data. Additionally, a similar distribution of 130–52 Ma ages in central Louisiana and east-central Texas contrasts with south Texas data, which lacks a relatively pronounced 75 Ma peak. Young 65–52 Ma age detrital zircons with a defined 57 Ma age peak occur in east-central Texas (Teh-Cz) and central Louisiana Wilcox Group data, but they are poorly represented in south Texas Wilcox Group data.

<table>
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<th>Age (Ma)</th>
<th>Data Set</th>
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<td>(52–130)</td>
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<td>(134–251)</td>
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<tr>
<td>(265–652)</td>
<td>GC, Cz, CB-BBM, CB-BS, Si-KM, Si-LP, Cz, Cz</td>
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Figure 7. Normalized probability density plots of detrital zircon age spectra younger than 300 Ma for 12 sample horizons in east-central Texas. Samples are arranged vertically with respect to stratigraphic level. n—number of ages. Interpreted east-central Texas age ranges are overlain for comparison. See Figure 6 caption for sample label details.
DISCUSSION

Previous literature and comparison of potential source region and Gulf Coastal Plain data yield an interpretation of paleodrainage and inferred constraints during the Paleocene and Early Eocene for sediments delivered to the northwestern Gulf of Mexico (Fig. 12). An interpreted northward Paleogene drainage from the McCoy Mountains Formation of southwestern Arizona to the Colton Formation in northeastern Utah (Davis et al., 2010) defines the paleo drainage extent in the southwestern United States. Previously interpreted Late Paleocene and Early Eocene paleodrainage to south Texas infers a paleodrainage divide that follows the approximate path of major physiographic highs along the Mexico and United States border (Galloway et al., 2011). Detrital zircons with 150–105 Ma ages in south Texas Wilcox Group data and the Paleogene Difunta Group that defines the northeastern Mexico source region (Lawton et al., 2009) are considered to be sourced from the Peninsular Range Batholith and Alisitos arc of southern California and the Baja Peninsula (Lawton et al., 2009; Mackey et al., 2012). This interpretation is compatible with data shown here (Figs. 8 and 9) and extends the reach of sediment drainage to the south Texas Wilcox Group into northwestern Mexico.

The Llano uplift and San Marcos arch (Sellards et al., 1932) in west-central Texas define an approximate divide between fluvial systems draining into the Texas regions, which is consistent with previously interpreted Late Paleocene and Early Eocene fluvial pathways to northwestern Gulf of Mexico depocenters (Galloway et al., 2011). Further drainage limitations in the western United States follow a general path along basement structures with presumed physiographic relief from Arizona toward the Colorado Front Range and northward toward the Black Hills of South Dakota (Mackey et al., 2012). This interpretation highlights a divide that may discount northern Rocky Mountain region data as a source of east-central Texas and central Louisiana sediments. Northern Rocky Mountain region data are comparable to some Gulf Coastal Plain data, but similar age components are present in regions farther south that had shorter and simpler paths to northwestern Gulf of Mexico depocenters.
Mountain region composite probability density plots were previously compiled in Craddock and sample reference details. South Texas Wilcox Group, Louisiana Wilcox Group, and both Rocky Teh—Tehuacana Member through Carrizo Formation data. See Figure 3 for location and number of samples. Interpreted east-central Texas age ranges are overlain for comparison.

Figure 9. Normalized composite probability density plots of detrital zircon age spectra younger than 300 Ma for potential source regions and Gulf Coastal Plain locations. n — number of ages; s — number of samples. Interpreted east-central Texas age ranges are overlain for comparison. Teh-Cz—Tehuacana Member through Carrizo Formation data. See Figure 3 for location and sample reference details. South Texas Wilcox Group, Louisiana Wilcox Group, and both Rocky Mountain region composite probability density plots were previously compiled in Craddock and Kylander-Clark (2013).

Additionally, northeasterly drainage from the northern Rocky Mountains toward the Cannonball embayment during this time (Cherven and Jacobs, 1985; Galloway et al., 2011) until the Eocene (Smith et al., 2008; Smith et al., 2014) reduces the likelihood of this region as a sediment contributor.

Central Louisiana Wilcox Group and middle-upper Claiborne Group paleodrainage extents have been previously modeled after modern Mississippi River catchment, attributing the majority of Louisiana Wilcox Group sediments to Yavapai-Mazatzal basement and Sevier-Laramide sedimentary basins of southwestern Wyoming and northern and eastern Colorado (Craddock and Kylander-Clark, 2013). This interpretation suggests separate paleodrainage areas for the east-central Texas and central Louisiana regions during deposition of Wilcox and Claiborne Group sediments, a conclusion not supported by our data. Late Paleocene through Middle Eocene interpretations by Galloway et al. (2011) also separate east-central Texas region and central Louisiana region catchment while incorporating drainage from the interior lowlands and Appalachian Basin region, and Blum and Pecha (2014) extend paleodrainage limits to include sediments from the Cordilleran arc batholiths of California and Idaho. Based on potential source region and Gulf Coastal Plain detrital zircon data, we propose a model for a relatively similar Paleocene and Early to Middle Eocene paleodrainage area between the time of upper Midway Group through lower Claiborne Group deposition in east-central Texas and Wilcox and middle-upper Claiborne Group deposition in central Louisiana, and exclude sediment contribution from the Appalachian Basin region.

D detrital zircon age components from each source region appear to overlap with Gulf Coastal Plain data, with Triassic to Early Eocene data being the most unique between source regions (Fig. 9). Inferences on sediment sources for some Early Cretaceous, Paleocene, and Eocene age components were limited, as these data were not available or underrepresented in two of the four source region data sets (southwestern region and southern Rocky Mountain region). While arrival of 65–52 Ma age detrital zircons in the Hooper Formation is late relative to the timing of initial Laramide uplift-derived sediment delivery to the Gulf of Mexico (recorded by the increase in sediment delivery to the upper Wills Point Formation), it provides strong evidence linking Wilcox Group sediments to a Laramide uplift source. These young grains could originate from newly unroofed Laramide magmatic intrusions in areas such as the Colorado Mineral Belt (Chapin, 2012) or from nearly syndepositional volcaniclastic sources produced during Laramide uplift. Older associated detrital zircons are inferred to be derived primarily from sedimentary cover and basement rocks exposed by uplift of Laramide blocks. We propose that east-central Texas (Teh-Cz) and central Louisiana Wilcox Group samples both had major sediment derivation from the southern Rocky Mountain region and received additional sediment from parts of northern New Mexico, the Colorado Front Range, and southeastern Wyoming. Major sediment derivation from the southwestern United States and northern Mexico suggested for the south Texas Wilcox Group (Mackey et al., 2012) is consistent with comparisons between south Texas data and components of southern Rocky Mountain, southwestern, and northeastern Mexico source region data. These detrital zircon age data and interpreted paleodrainage extents highlight a unique paleodrainage and sediment sources for the south Texas region with respect to equivalent-age Gulf Coastal Plain samples to the northeast. Young (65–52 Ma) ages in one south Texas Wilcox Group sample (Carrizo Formation) are attributed to sources in northern Mexico (McDowell et al., 2001), not the central or southern Rocky Mountains, and are also present in the Paleocene Potrerillos Formation of the Difunta Group in northeastern Mexico (Lawton et al., 2009). Implications of youngest detrital…
zircon data obtained in east-central Texas with ages essentially the same as the depositional age of the enclosing strata are beyond the scope of the present study. These data will be incorporated into ongoing work using volcanic ash beds and isotope dilution–thermal ionization mass spectrometry (ID-TIMS) analyses to revise the Gulf Coast Paleocene–Eocene stratigraphic framework (e.g., Heintz et al., 2014).

The pronounced presence of detrital zircons with 1293–843 Ma ages in Claiborne Group data is distinctly different from older samples. However, similarity of age assemblages in central Louisiana Wilcox Group and east-central Texas (Teh-Cz) data, and in east-central Texas Queen City Formation and central Louisiana middle-upper Claiborne Group data supports largely the same paleodrainage area and sediment sources during respective times of deposition. This is highlighted by the similar incorporation of 1293–843 Ma age detrital zircons in the Lower Eocene Queen City Formation of the lower Claiborne Group in east-central Texas and the Middle Eocene Sparta, Cook Mountain, and Cockfield Formations of the middle-upper Claiborne Group in central Louisiana (Fig. 11). Either the drainage basin acquired a new geographic source area at those times, or erosion uncovered and incorporated into river sediment load an older sediment source containing 1293–843 Ma age detrital zircons. Grenville Province zircons are of equivalent age (1300–950 Ma) to the pronounced 1293–843 Ma age range in Claiborne Group data, and zirconium-rich (Moecher and Samson, 2006) Grenvillian basement is exposed in the Appalachian-Ouachita orogenic belt and associated foreland basins (Todd and Folk, 1967; Gleason et al., 2002; Eriksson et al., 2004; Park et al., 2010). A shift from garnet-epidote–enriched heavy-mineral assemblages in central Louisiana Wilcox Group strata to kyanite-staurolite–enriched assemblages in younger Claiborne Group strata has been used to support derivation of recycled Grenvillian age (1300–950 Ma) detrital zircons from the Appalachian Basin.

Figure 10. Normalized composite probability density plots of all detrital zircon age spectra for east-central Texas (Teh-Cz), Queen City Formation, and central Louisiana Wilcox Group and middle-upper Claiborne Group samples. n—number of ages; s—number of samples. Interpreted east-central Texas age ranges are overlain for comparison. Teh-Cz—Tehuacana Member through Carrizo Formation data. See Figure 3 for location and sample reference details. Louisiana Wilcox Group and Claiborne Group plots taken from Craddock and Kylander-Clark (2013).

Figure 11. Normalized composite probability density plots of detrital zircon age spectra younger than 300 Ma for east-central Texas (Teh-Cz), Queen City Formation, and central Louisiana Wilcox Group and middle-upper Claiborne Group samples. n—number of ages; s—number of samples. Interpreted east-central Texas age ranges are overlain for comparison. Teh-Cz—Tehuacana Member through Carrizo Formation data. See Figure 3 for location and sample reference details. Louisiana Wilcox Group and Claiborne Group plots taken from Craddock and Kylander-Clark (2013).
Figure 12. Interpreted paleodrainage to the northwestern Gulf Coastal Plain and Gulf of Mexico during the Paleocene and Early to Middle Eocene. Physiographic highs potentially influential on sediment drainage to the northwestern Gulf of Mexico are indicated in brown, with tan or dashed features indicating uncertainty of relief and/or extent. Physiographic features adapted from Sellards et al., 1932; Budnik, 1986; DeCelles, 2004; Flowers et al., 2008; Lawton, 2008; Galloway et al., 2011 and references therein). SOB—Sevier orogenic belt; CFR—Colorado Front Range; MH—Mogollon Highlands; LFTB—Laramide fold-thrust belt; LU—Llano uplift; SMA—San Marcos arch; AWM—Amarillo-Wichita Mountains; OM—Ouachita Mountains; AM—Appalachian Mountains; EBPA/PA/TA—El Burro-Peyotes arches, Picachos arch, Tamaulipas arch. Drainage divide indicated by red dashed lines (adapted from Galloway et al., 2011; Mackey et al., 2012; Craddock and Kylander-Clark, 2013). Yellow dashed line indicates assumed maximum shoreline position during Paleocene-Eocene time (adapted from Galloway et al. [2011]). Question mark (?) denotes uncertain extent of an associated feature. Generalized routes of sediment transport to the northwestern Gulf of Mexico indicated by dashed blue lines and arrows. Map does not depict the extent of the Baja Peninsula before pre-Miocene time (Dickinson and Lawton, 2001; Lawton et al., 2009).
region (Craddock and Kylander-Clark, 2013). Enrichment of kyanite-staurolite is also noted in lower Claiborne Group strata in Bastrop and Leon Counties in east-central Texas, including parts of the Carizzo Formation, the Newby Member of the Reklaw Formation, and the Queen City Formation (Todd and Folk, 1957; McCarley, 1981, and references therein). While the presence of kyanite-staurolite–enriched samples and 1293–843 Ma detrital zircon ages may suggest an easterly derived source component for the Queen City Formation of east-central Texas and the middle-upper Claiborne Group of central Louisiana, recycled Grenvillian detrital zircons are prominent in Pennsylvanian (Gleason et al., 2007), Permian (Soreghan and Soreghan, 2013), and Cenomanian (Blum and Pecha, 2014) strata of Texas. They are also present in other regions such as in Mesozoic and Paleogene strata in parts of the Colorado Plateau (Dickinson and Gehrels, 2008) and the northern Rocky Mountains (Fan et al., 2011; Fuentes et al., 2011; May et al., 2013). Xu et al. (2015) show that Grenville age detrital zircons deposited in Louisiana have discordant U-Pb and U-Th/He ages that indicate recycling through the Colorado Plateau area before deposition in Louisiana, and Blum and Pecha (2014) attribute Grenvillian age detrital zircons in the Cenomanian Woodbine Formation in Oklahoma and Texas to erosion of Upper Paleozoic foreland-basin strata in the Ouachita region. Although inclusion of the Appalachian Basin region in paleodrainage area interpretations is popular (Galloway et al., 2011; Craddock and Kylander-Clark, 2013; Blum and Pecha, 2014), the possibility of sediment sourcing due to increased or new exposure of basement or of previously covered sedimentary deposits with once-easterly derived heavy-mineral assemblages is equally viable as a source of the 1293–843 Ma detrital zircons. We hypothesize that by the time of Queen City Formation deposition, central Louisiana and east-central Texas regions were receiving a decreased sediment load from eroded Laramide uplift blocks after Reklaw transgression (Galloway and Williams, 1991; Craddock and Kylander-Clark, 2013) and an increased sediment contribution from the Ouachita region and other proximal locations in the preexisting paleodrainage area that contained exposed Grenvillian basement and/or recycled sediments. This could account for a diminished amount of young 65–52 Ma detrital zircons and incorporation of more metamorphic heavy minerals and Grenvillian age zircons.

## CONCLUSIONS

Detrital zircon data reveal an earliest arrival time of young detrital zircons (65–52 Ma) to the Hooper Formation of the Wilcox Group in east-central Texas. Late arrival of these young detrital zircons provides strong evidence linking Wilcox sediments to a Laramide uplift source such as unroofed Laramide magmatic intrusions or nearby syndepositional volcaniclastic sources. Older associated detrital zircons are inferred to be derived primarily from sedimentary cover and basement rocks exposed by uplift of Laramide blocks. This study presents evidence suggesting that river systems draining areas affected by Laramide uplift from southeastern Wyoming to the southern Rocky Mountain region transported sediments down a fairway between the Llano uplift and the Ouachita Mountains and into their respective depocenters in east-central Texas and central Louisiana. East-central Texas (Teh-Cz) data show close similarity with central Louisiana Wilcox Group data and support largely the same paleodrainage area and sediment sources, whereas both of these data sets contrast with south Texas Wilcox Group data and indicate a separate overall paleodrainage area and sediment sources for this location.

Close similarity of age assemblages in east-central Texas (Teh-Cz) and central Louisiana Wilcox Group data, and in east-central Texas Queen City Formation and central Louisiana middle-upper Claiborne Group data suggests a relatively similar Paleocene and Early-Middle Eocene paleodrainage area and sediment sources. The presence of pronounced Grenvillian age detrital zircons during lower and middle-upper Claiborne Group deposition in east-central Texas and central Louisiana, respectively, is attributed to increased or new exposure of basement or previously covered sedimentary deposits from the Ouachita region and other proximal locations within the preexisting paleodrainage area. Less pronounced Grenvillian ages in east-central Texas (Teh-Cz) and central Louisiana Wilcox Group data supports a lack of sediment input from the Appalachian Basin region. During deposition of younger Claiborne Group sediments, incorporation of sediments with abundant Grenvillian age zircons from within the preexisting paleodrainage area is viable alternative to sourcing directly from the Appalachian Basin region, and may suggest a false paleodrainage signal from this region during the Early and Middle Eocene.

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