

A late refugium for *Classopollis* in the Paleocene Lower Wilcox Group along the Texas Gulf Coast

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ABSTRACT

We report a new ecological refugium for the Cheirolepidiaceae family (pollen form genus *Classopollis*) in the Paleocene Lower Wilcox Group in the Gulf Coast of southeastern Texas based on palynological analysis of four wells. The Cheirolepidiaceae were once thought to have gone extinct at the Cretaceous–Paleogene (K/Pg) boundary or earlier in North America; however, similar ecological refugia for this family in the Paleocene have previously been reported in China, Argentina, and potentially the Rocky Mountains of the United States. The highest relative abundances of *Classopollis* pollen were found in delta front, lagoon, and shoreface depositional paleoenvironments marked by high mud-fraction Sr/Ba (a geochemical proxy for salinity), and abundances generally increased down section in older Paleocene strata. The high relative abundance of *Classopollis* pollen in the well samples, the rarity of reworked Mesozoic palynomorphs, the generally good preservation of *Classopollis* pollen, and the similarity of *Classopollis* fluorescence spectra to other in situ Paleocene pollen all provide strong evidence for the survival of the Cheirolepidiaceae family in the coastal salt marshes of Texas through at least the late Paleocene.

INTRODUCTION

The Paleocene–Eocene Wilcox Group in the southeastern United States is a thick sedimentary sequence that represents the first significant influx of Laramide-derived siliciclastic material into the Gulf of Mexico (Galloway et al., 2000); it is an important producer of hydrocarbons and coal and has potential as a future reservoir for carbon capture and storage (e.g., Shelton et al., 2014; Swanson et al., 2015). The palynology of the Wilcox Group has been well studied, ranging from early academic research (e.g., Elsik, 1968) to modern industrial biostratigraphy (e.g., Zarra et al., 2019). A question of dispute in the literature has existed for decades (e.g., Nichols and Traverse, 1971): Are occurrences of *Classopollis* pollen in the Wilcox Group Paleogene survivors or reworked from Cretaceous strata? Here, we present data derived from an ongoing,

multidisciplinary research project on the Lower Wilcox Group of Texas supporting the survival of *Classopollis* into the Paleocene.

Fossil pollen, including *Classopollis*, is often identified using “form genera,” which exist as a separate form of classification from plant macrofossils. Fossil pollen referable to *Classopollis* was first found associated with macrofossils of *Cheirolepsis muensteri* in the conifer family Cheirolepidiaceae by Hoerhammer (1933). Eventually, this type of pollen grain was given the name *Classopollis*, although other synonymous names have been used in the literature (e.g., Srivastava, 1976). All *Classopollis* specimens in the study have been identified as *Classopollis classoides*, the type species of the genus (Fig. 1). Fossil remains of the Cheirolepidiaceae, which include macrofossils as well as *Classopollis* pollen, are globally common, particularly at low latitudes, from the Late Triassic to the Cretaceous, but there has been a long debate over whether the Cheirolepidiaceae survived the end-Cretaceous mass extinction, and, if so, the

geographic areas in which they survived (e.g., Srivastava, 1976; Pocknall and Nichols, 1996; Barreda et al., 2012; Berry, 2022a, 2022b).

Based on the broad, mainly low-latitude paleogeographic distribution of Cheirolepidiaceae in the Mesozoic, the anatomy of Cheirolepidiaceae megafossils, and the depositional environments where *Classopollis* pollen is common, the Cheirolepidiaceae generally preferred hot, arid environments and were at least in part halophytes (i.e., salt-tolerant) (Upchurch and Doyle, 1981; Alvin, 1982; Traverse, 2007). The Cheirolepidiaceae at least in part preferred low-lying water-margin environments, with some probably also present in more upland arid environments (Srivastava, 1976). Although it appears that the Cheirolepidiaceae survived the end-Cretaceous mass extinction in some areas, the evidence for the survival of the Cheirolepidiaceae in North America has been ambiguous until now (Berry, 2022b). Kroege (1995) interpreted Paleocene occurrences of *Classopollis* as contemporaneous components of a brackish or salt marsh flora along the coastline of the Cannonball Sea in North Dakota. Nichols and Fleming (2002), on the other hand, interpreted Paleocene *Classopollis* pollen from Colorado as present at the time of deposition, but potentially transported from arid upland habitats to the depositional site.

DATA AND METHODS

Well cutting and core chip samples (~10 g/sample) were collected from four onshore wells in Karnes County and DeWitt County in southeastern Texas (Fig. 1). Drill cuttings were collected from the Edmond Olinick #1 well (17 samples), and core chips were collected from the Jerome Olinick #16 well (27 samples), Lawrence Keseling #1 well (30 samples), and

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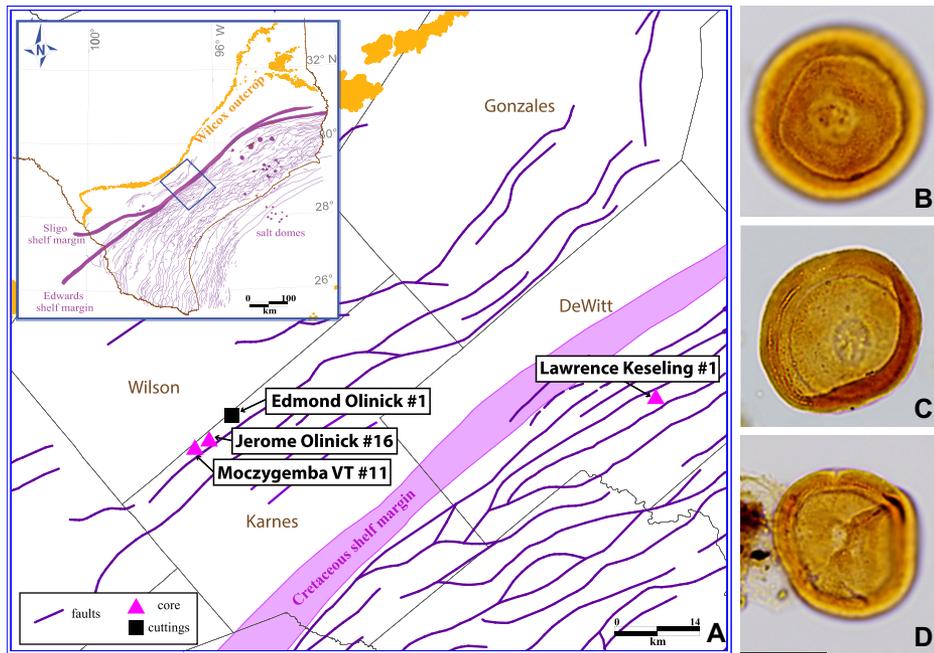


Figure 1. Map and *Classopollis* pollen. (A) Location of four wells analyzed (global positioning system [GPS] coordinates are provided in Supplemental Material [see text footnote 1]). (B–D) Images of *Classopollis classoides* pollen from four studied wells. Scale bar = 10 μ m.

Moczygemba VT #11 well (38 samples). Samples from all four wells were processed for palynological analysis using mineral acid techniques as summarized by Riding (2021); in addition, samples from the Lawrence Keseling #1 and Moczygemba VT #11 wells were also processed for nanofossil analysis using a double slurry method (Watkins and Bergen, 2003). Quantitative counts for both disciplines were made using a modified cascade count (Styzen, 1997). The palynological biostratigraphy is based primarily on the zonation presented by Zarra et al. (2019) for the deep-water Wilcox Group, and the nanofossil biostratigraphy is based on Martini (1971) and Agnini et al. (2014), calibrated to Geologic Time Scale (GTS) 2016 ages (Ogg et al., 2016). In some sections, the nanofossil recovery was too poor for biostratigraphic interpretation (as is typical for the Wilcox Group), and only the palynological biostratigraphy is available.

Energy-dispersive X-ray fluorescence (ED-XRF) data were acquired for the Jerome Olinick #16 and Moczygemba VT #11 cores at the Bureau of Economic Geology, The University of Texas at Austin, with regular, high-resolution (5 cm) sampling. Major and trace elements were collected using a Bruker Tracer 5G with a deWitt helium purge unit and yellow filter at 15 kV for 15 s and 45 kV for 45 s, respectively. Elemental ratios linked to salinity (Sr/Ba) were compared with *Classopollis* relative abundances as a percentage of the total pollen and plant spores by averaging Sr/Ba values ($n = 7$) from clastic mudstone (Si/Al <4.6) immediately above and below the palynological sample depths. Data and

methodology for the fluorescence spectroscopy are provided in the Supplemental Material.¹

RESULTS AND DISCUSSION

The palynological assemblages in all four wells indicated a marginal marine environment, which is consistent with facies descriptions from previous sedimentological and stratigraphic research (Olariu and Zeng, 2018; Zhang et al., 2019). The terrestrial palynomorph assemblages are diverse and typical for the Lower Wilcox Group, with high abundances of Betulaceae/Myricaceae-type pollen, Juglandaceous *Caryapollenites/Momipites* pollen, and *Thomsonipollis magnificus* pollen in all wells; the relative abundances in Moczygemba VT #11 well samples are typical (Fig. 2). These assemblages likely represent a regional signal from the marshes, swamps, and warm temperate to tropical lowland forests in the vicinity, although some of the assemblage probably represents long-distance fluvial and eolian transport from the continental interior.

The relative abundance of *Classopollis* generally increased down section (see Supplemental Material). In the Moczygemba VT #11 well, *Classopollis* abundances over 5% were only observed in the deepest Lower Selandian samples. *Classopollis* abundances in the Upper Selandian to Thanetian samples were variable

¹Supplemental Material. Well information, *Classopollis* abundance, biostratigraphic interpretation, and geochemical data. Please visit <https://doi.org/10.1130/GEOL.S.24993288> to access the Supplemental Material; contact editing@geosociety.org with any questions.

but generally lower than the Lower Selandian section, averaging $\sim 1.2\%$. The Lawrence Keseling #1 well contained the youngest samples, Upper Thanetian in age, with an average *Classopollis* abundance of $\sim 0.4\%$. The lower section of Lawrence Keseling #1, interpreted as Selandian in age based on the palynological biostratigraphy, had an average *Classopollis* abundance of $\sim 1.8\%$. The Jerome Olinick #16 well is Selandian to Thanetian in age based on palynological biostratigraphy; *Classopollis* abundances were quite variable, but again the highest relative abundances were found in the older samples. The Edmond Olinick #1 drill cutting samples included Selandian/Thanetian samples from the Lower Wilcox Group as well as three samples from the underlying Midway Group; average *Classopollis* abundances in the Lower Wilcox Group section were $\sim 0.7\%$, and relative abundances in the Midway Group were $\sim 1.6\%$.

The total number of reworked Mesozoic pollen in the assemblages is uncertain because some species are present in both Mesozoic and Paleogene sections. However, we are confident that reworked Mesozoic palynomorphs are extremely rare in these sections because other common Cretaceous species that became extinct before the Paleogene are either absent or present in very low abundances. The few clearly reworked Mesozoic palynomorphs are mainly Cretaceous dinoflagellate cysts (e.g., *Apteodinium granulatum*, *Dinogymnium* spp.). If reworked Mesozoic fossils were common in the assemblages, we would expect to regularly observe other reworked taxa, including species that became extinct before the Cretaceous–Paleogene (K/Pg) mass extinction and species that were common in the Mesozoic but rare in the Paleogene (e.g., Nichols and Johnson, 2002; Kumar, 2019).

The coloration of palynomorphs can be an indicator of reworking if the original burial depth and thermal maturity of the reworked palynomorphs were greater than the contemporaneous palynomorphs; higher thermal maturity tends to result in a darkening of the pollen grain (e.g., Goodhue and Clayton, 2010). Palynomorph preservation can also be an indicator of reworking; palynomorphs that have been eroded out of sediments and redeposited in younger sediments have more opportunities for mechanical fragmentation, oxidation, and bacterial degradation than in situ pollen, and they are generally not as well preserved as the contemporaneous assemblage. The average color and state of preservation of *Classopollis* grains in these samples (Fig. 1) were not significantly different than the clearly contemporaneous Paleocene assemblage and indicated an in situ origin for the *Classopollis* grains.

Fluorescence emission spectra were analyzed to determine whether *Classopollis* pollen had a significantly different spectral signature

Moczygamba VT #11

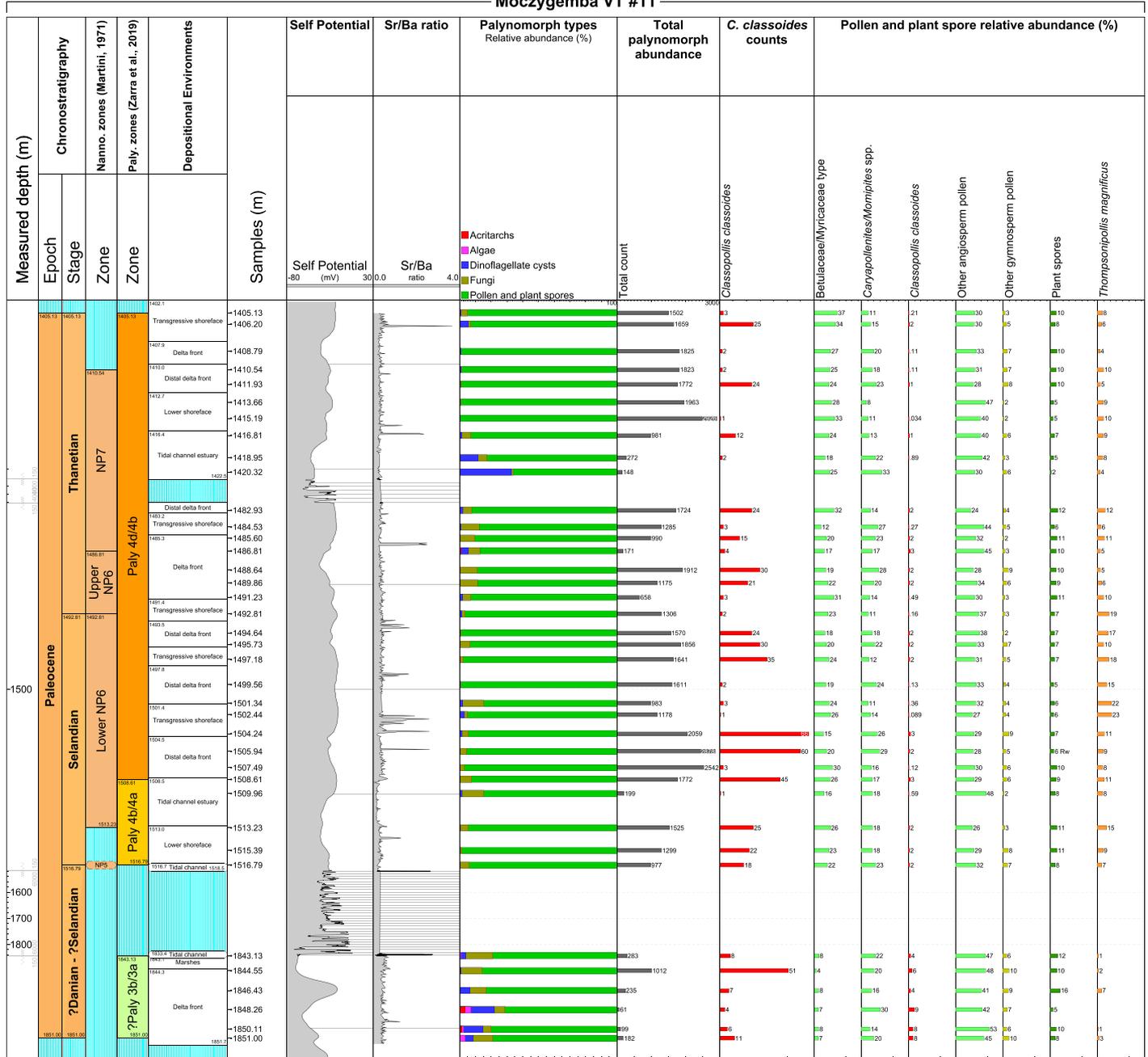


Figure 2. Stratigraphic chart of Moczygamba VT #11 well. Depth scaling varies to minimize stratigraphic thickness of uncored section. Nanno.—nannofossil; Paly.—palynology.

than other in situ Paleocene pollen. Fresh pollen fluoresces in the green part of the visible light spectrum, but fossil pollen is subjected to heat and oxidation during diagenesis, which progressively shift spectra toward the red end of the spectrum and eventually extinguish fluorescence auto-emission. Fluorescence spectroscopy has previously been used to identify reworked pollen based on a red-shifted spectrum relative to in situ pollen (e.g., Hoyle et al., 2018). High-resolution emission spectra from *Classopollis* pollen and other in situ Paleocene pollen (Fig. 3D) were very similar, consistent with the in situ presence of *Classopollis* pollen in

the Paleocene section of Texas; low-resolution spectra of additional pollen are included in the Supplemental Material.

Nichols and Traverse (1971) considered *Classopollis* as part of a “marine influence assemblage” in the Wilcox Group, which also included marine algae, bisaccate pollen, and Amaranthaceae pollen; we tested this relationship by comparing *Classopollis* abundances with mudstone Sr/Ba (Fig. 3), building on previous research by Hessler et al. (2017) that quantified changes in paleoclimate using geochemical ratios in the Wilcox Group. With sustained salt-water influence, the Sr/Ba ratio in terrigenous

sediment generally increases with transport and deposition into brackish or marine environments (e.g., Wei and Algeo, 2020; Dashtgard et al., 2022). Here, *Classopollis* relative abundances correlated positively with mudstone Sr/Ba in the Jerome Olinick #16 and Moczygamba VT #11 cores, where the highest *Classopollis* relative abundances were generally found in delta front, lagoon, and shoreface depositional environments. The correlation between high *Classopollis* relative abundance and mudstone Sr/Ba was tied to the environment of pollen origin (e.g., lagoon, arid upland) more than the environment of final deposition (e.g., delta front,

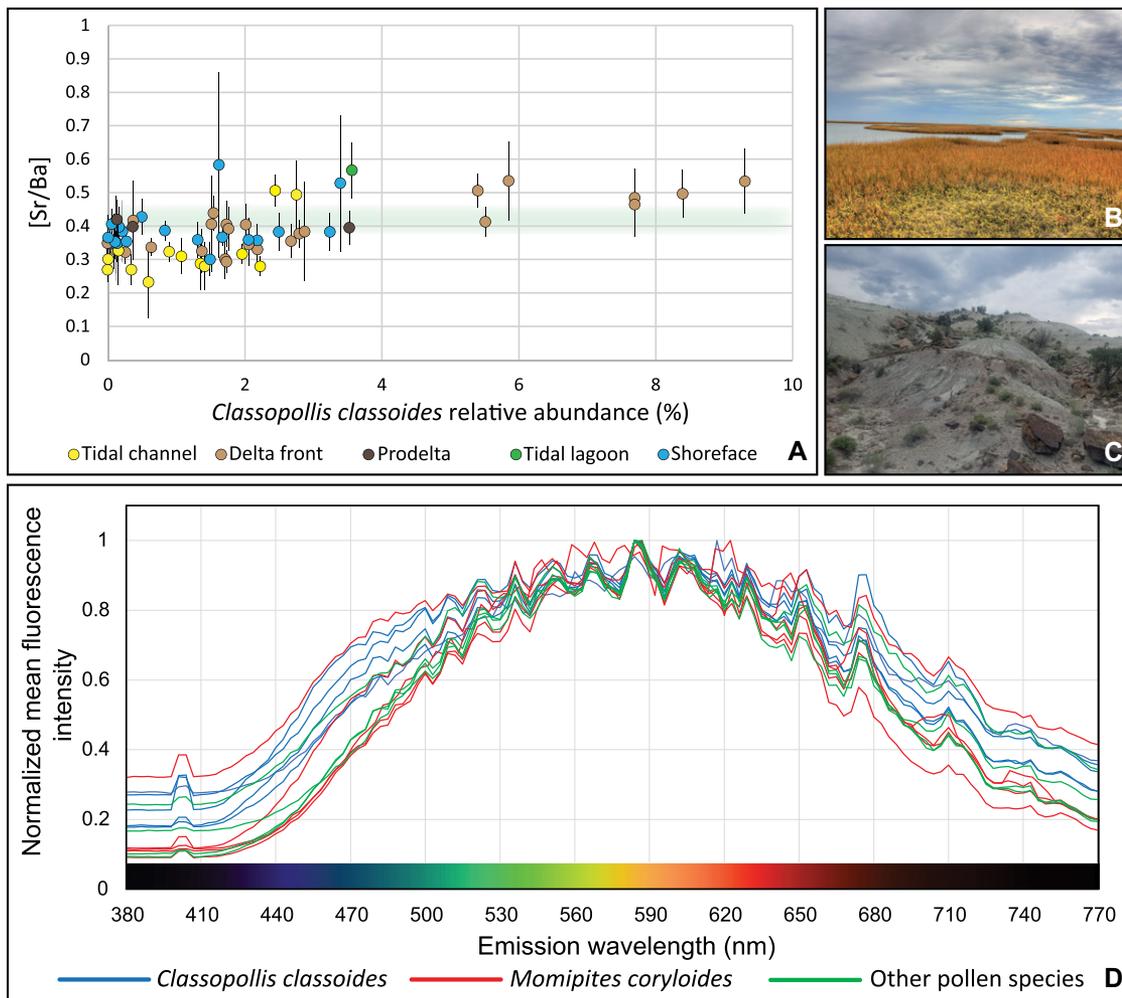


Figure 3. *Classopollis* pollen, geochemistry, and depositional environments. (A) Comparison of *Classopollis* abundance with depositional environments and Sr/Ba ratios. (B) Potential modern salt marsh analog for Wilcox Group *Classopollis* habitat at Galveston Island State Park (photograph by Yinan Chen under Creative Commons Public Domain Dedication). (C) Potential modern arid upland analog for Wilcox Group *Classopollis* habitat in Fremont County, Colorado (photograph by Vann Smith). (D) Normalized fluorescence spectroscopy of *Classopollis classoides* and other pollen species.

shoreface). The apparent prevalence of *Classopollis* in the delta-front facies is interpreted as a secondary function of erosion and transport, preservation potential, mudstone abundance, and stratigraphic distribution.

The association of *Classopollis* with higher-salinity depositional environments, including probable in situ tidal lagoon beds, supports previous paleoecological interpretations from other areas that considered in situ Paleocene *Classopollis* specimens as indicative of coastal salt marsh environments (Fig. 3B; Berry, 2022b), with high abundances in distal environments being the result of erosion and transport of lagoonal sediment and pollen into deltaic systems. Alternatively, the *Classopollis* pollen could have been transported from more arid uplands in the continental interior (Fig. 3C), as Nichols and Fleming (2002) suggested for Paleocene *Classopollis* specimens from the Denver Basin of Colorado. The pollen assemblages are indicative of a mainly proximal pollen source area, with taxa common to more temperate, inland environments (like bisaccate gymnosperm pollen) observed only rarely. Thus, we consider a coastal source for the *Classopollis* pollen more likely.

CONCLUSIONS

Palynological analysis of the Paleocene Lower Wilcox Group in four wells located in southeastern Texas revealed the consistent presence and high relative abundance of *Classopollis* pollen in the assemblages. We interpret these *Classopollis* grains as contemporaneous in age with the time of sedimentary deposition (i.e., not reworked). This interpretation is based on their common and persistent presence in multiple wells, the rarity of other clearly reworked Mesozoic palynomorphs, and the similarity in color, state of preservation, and fluorescence spectra of *Classopollis* grains with respect to contemporaneous Paleocene palynomorphs. The generally decreasing abundance of *Classopollis* in younger sections in multiple wells indicates a gradual decline in abundance followed by complete extinction either in the late Paleocene or Eocene; Fairchild and Elsik (1969) identified the last appearance datum of *Classopollis* in the Ypresian along the northern Gulf of Mexico coastal plain. The extinction of the Cheirolepidiaceae due to global warming or increased aridity in the early Eocene is considered unlikely, as the family is generally interpreted as thermophilic and xeric. Berry (2022b) discussed hypotheses

for the cause of the final global extinction of the Cheirolepidiaceae, including competition from angiosperms and ecological specialization resulting in habitat contraction and range fragmentation.

In summary, we interpret the *Classopollis* pollen in the Lower Wilcox Group as derived from contemporaneous Paleocene Cheirolepidiaceae conifers, probably from a nearby coastal salt marsh environment. Compelling evidence for the survival of the Cheirolepidiaceae past the K/Pg boundary in Argentina and China, including a short-lived “*Classopollis* spike” immediately following the K/Pg mass extinction, has been summarized by Berry (2022b). This is not to say that all early Paleogene occurrences of *Classopollis* in the United States are in situ; Korasidis et al. (2022) investigated reworked pollen in Paleocene–Eocene thermal maximum (PETM) strata from Wyoming and observed that the *Classopollis* grains were generally darker in color and more poorly preserved than the in situ PETM assemblage, which are both indicators of reworking (Vera Korasidis, 2023, personal commun.). Although we are not the first researchers to interpret Wilcox Group occurrences of *Classopollis* pollen as in situ (e.g., Elsik, 1968;

Fairchild and Elsik, 1969), improved biostratigraphic control, quantitative palynological abundance analysis from multiple wells, the inclusion of geochemical proxies and fluorescence spectroscopy, and a better understanding of the post-Cretaceous paleogeographic and paleoecological distribution of the Cheirolepidiaceae allow us to state with reasonable confidence that the coastal salt marshes of Texas served as a late refugium for *Classopollis* in the Paleocene.

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