PS The Critical Role of Ichnology in Recognizing the True Last Big Marine Transgression of the Western Interior Sea: Paleocene Ferris Formation, Southern Wyoming*

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Abstract

Based on the presence of mineable coal beds, channel form sandstone bodies, freshwater mollusks, terrestrial pollen, and leaf fossils, the latest Cretaceous-Paleogene (~66-62 Ma) Ferris Formation (FF) in southern Wyoming's Hanna Basin (HB) was interpreted to be entirely nonmarine since its initial description in 1918. In the 1990s, sedimentary structures common in tidal environments were described in sandy fluvial bars of the Paleocene section, but a lack of marine ichnofossils in these coarse-grained deposits, coupled with historical reconstructions of a completely nonmarine regional setting made interpretation of marine influence highly controversial. The first unambiguously marine ichnofossil, *Bergaueria perata*, was identified by George Pemberton in 1998 and led to more extensive ichnological investigation of the FF into the early 2000s. Abundant fossil leaves were systematically collected and documented as part of a separate study of the FF in the early 2000s and are best preserved in very fine-grained sand, silt, and mudstone lenses. A renewed, integrated and systematic investigation of fossil leaf and ichnofossil sites began in 2018 and focused on incorporating a total evidence approach to documenting changes in marine and continental depositional environments during the Paleocene. To date, this effort has revealed new insights, clarified some previously unresolved observations, and lead to the following conclusions: 1) over half of the entire Torrejonian section (370 m of 700 m) of the FF is composed of restricted marine deltaic, estuarine, bay, and lagoon deposits, 2) marine deposits of the Cannonball Sea can now be confidently mapped as far south and west as the central HB during the early Torrejonian (~63.5-64.5 Ma), 3) fossil leaves and logs are most abundantly and completely preserved in silty and sandy delta front and mouth bar deposits that also contain abundant marine ichnofossils (*Rhizocorallium*, *Arenicolites*, *Cylindrichnus*, *Rosselia*, *Skolithos*, *Psilonichus*, and *Bergaueria*), 4) cooler temperatures as indicated by leaf fossils in the FF relative to time-equivalent strata in Colorado are consistent with ameliorating effects of the Western Interior Sea, and 5) detailed ichnological analysis provides the critical key (more so even than sedimentology) to recognizing marine influence and flooding events in strata that are seemingly dominated by more easily identifiable features (e.g., coal beds, sandy barforms, and abundant terrestrial fossils).

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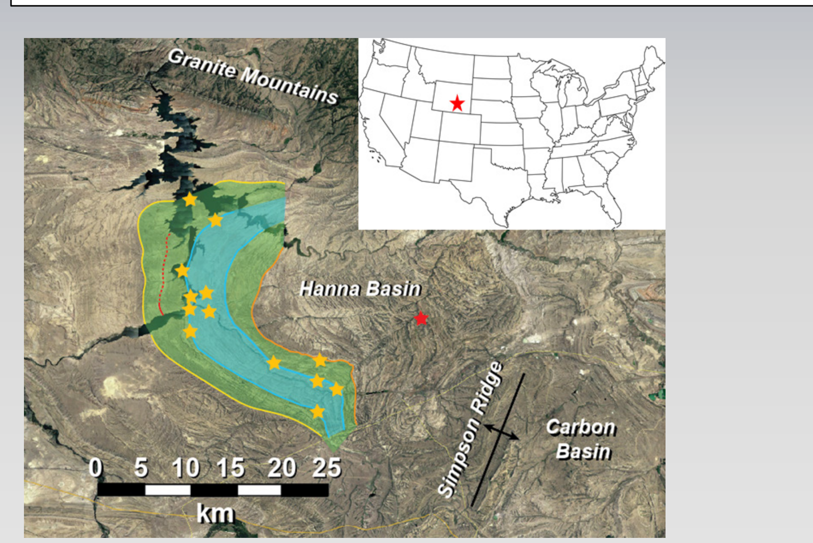
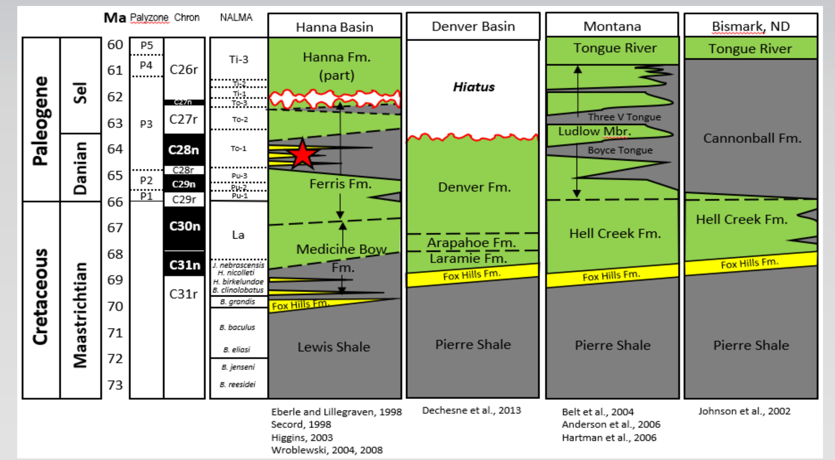
Abstract

Based on the presence of mineable coal beds, channelform sandstone bodies, freshwater mollusks, terrestrial pollen, and leaf fossils, the latest Cretaceous-Paleogene (~66-62 Ma) Ferris Formation (FF) in southern Wyoming's Hanna Basin (HB) was interpreted to be entirely nonmarine since its initial description in 1918. In the 1990s, sedimentary structures common in tidal environments were recognized in fine-grained portions of the section, but a lack of marine ichnofossils in these coarse-grained deposits, coupled with historical reconstructions of a completely nonmarine regional setting made interpretation of marine influence highly controversial. The first unambiguously marine ichnofossil, *Bergaueria perata*, was identified by George Pemberton in 1998 and led to more extensive ichnological investigation of the FF into the early 2000s. Abundant fossil leaves were systematically collected and documented as part of a separate study of the FF in the early 2000s and are best preserved in very fine-grained sand, silt, and mudstone lenses. A renewed, integrated and systematic investigation of fossil leaf and ichnofossil sites began in 2018 and focused on incorporating a total evidence approach to documenting changes in marine and continental depositional environments during the Paleocene. To date, this effort has revealed new insights, clarified some previously unresolved observations, and lead to the following conclusions: 1) over half of the entire Torrejonian section (370 m of 700 m) of the FF is composed of restricted marine deltaic, estuarine, bay, and lagoon deposits, 2) marine deposits of the Cannonball Sea can now be confidently mapped as far south and west as the central HB during the early Torrejonian (~63.5-64.5 Ma), 3) fossil leaves and logs are most abundantly and completely preserved in silty and sandy delta front and mouth bar deposits that also contain abundant marine ichnofossils (*Rhizocorallium*, *Arenicolites*, *Cylindrichnus*, *Rosselia*, *Skolithos*, *Psilonichnus*, and *Bergaueria*), 4) cooler temperatures as indicated by leaf fossils in the FF relative to time-equivalent strata in Colorado are consistent with ameliorating effects of the Western Interior Sea, and 5) detailed ichnological analysis provides the critical key (more so even than sedimentology) to recognizing marine influence and flooding events in strata that are seemingly dominated by more easily identifiable features (e.g., coal beds, sandy bedforms, and abundant fossil leaves).

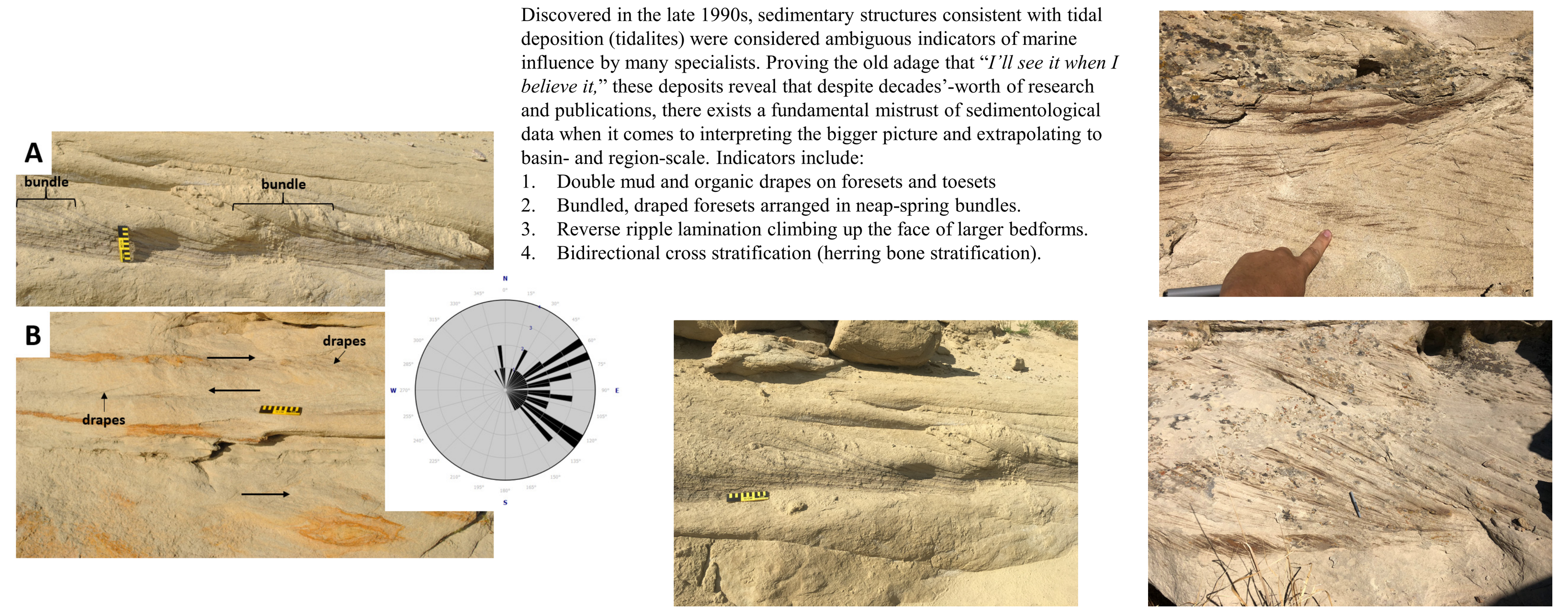




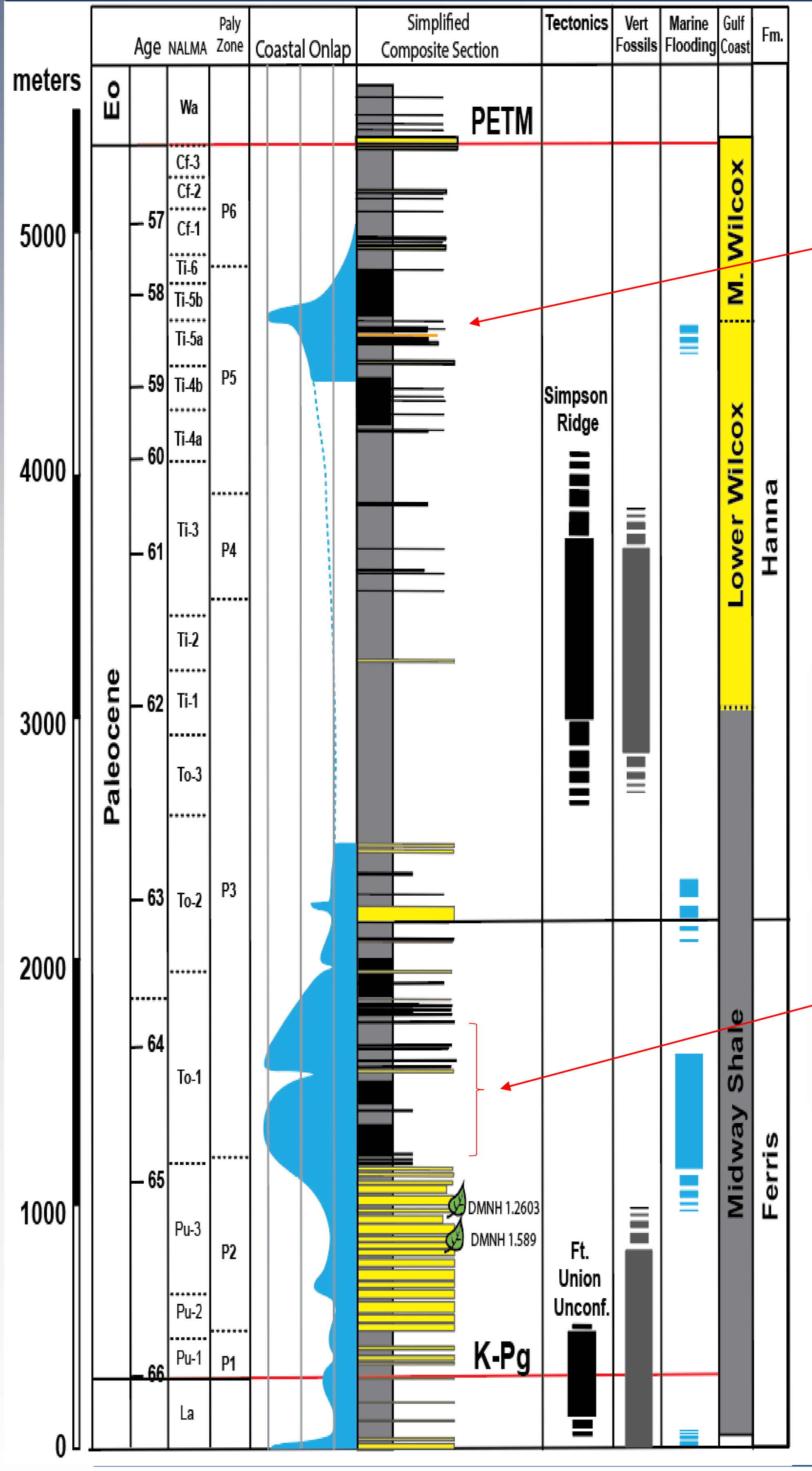
Sedimentological Indicators of Tidal Processes

Discovered in the late 1990s, sedimentary structures consistent with tidal deposition (tidalites) were considered ambiguous indicators of marine influence by many specialists. Proving the old adage that "*I'll see it when I believe it,*" these deposits reveal that despite decades'-worth of research and publications, there exists a fundamental mistrust of sedimentological data when it comes to interpreting the bigger picture and extrapolating to basin- and region-scale. Indicators include:

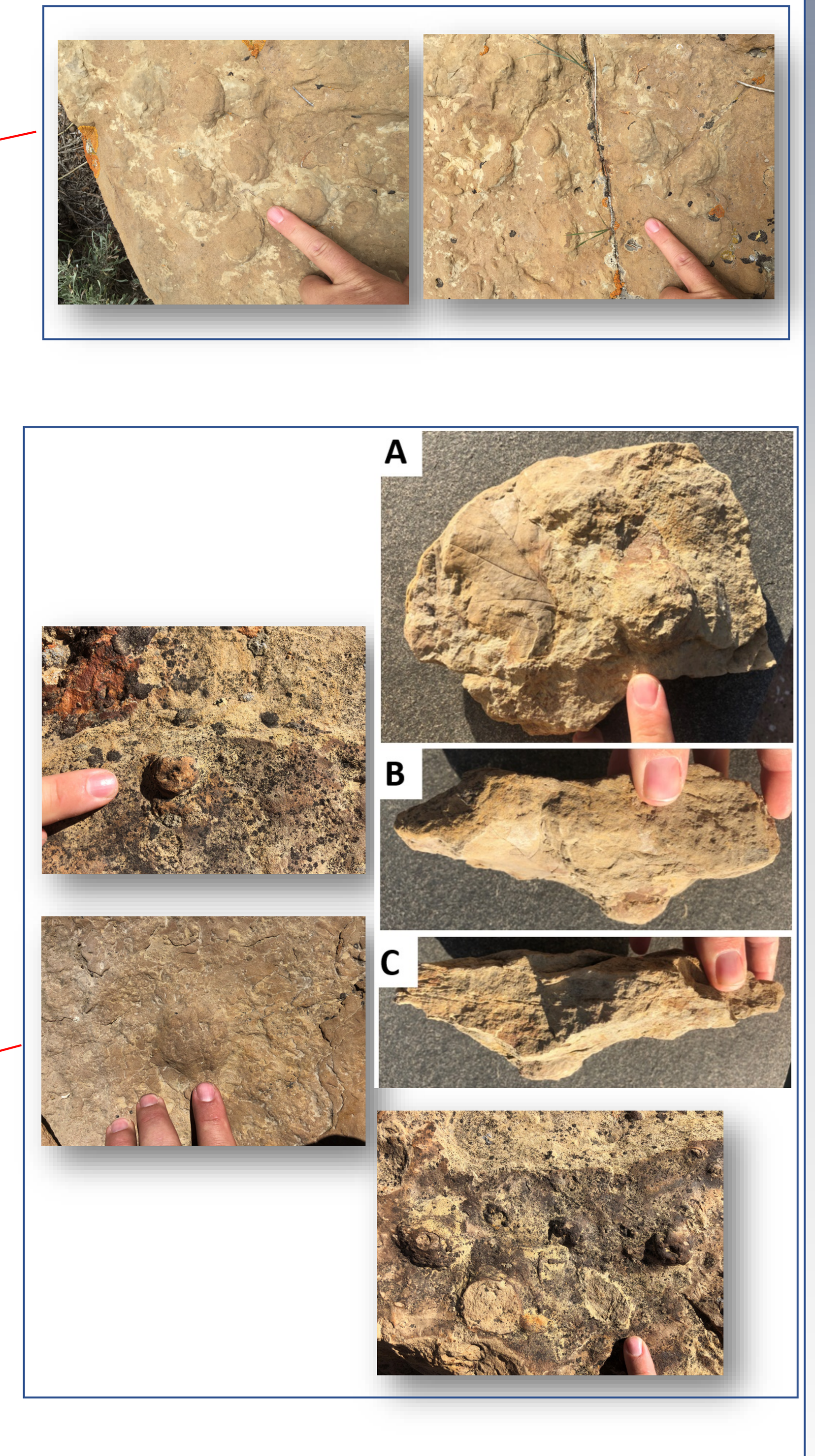
1. Double mud and organic drapes on foresets and toesets
2. Bundled, draped foresets arranged in neap-spring bundles.
3. Reverse ripple lamination climbing up the face of larger bedforms.
4. Bidirectional cross stratification (herring bone stratification).



Paleocene Anemones of Wyoming



The first marine ichnofossils to be discovered in the Paleocene Ferris Formation were *Bergaueria perata*. Since the initial specimen was collected in 1994, many additional examples have been located and documented, including some in the ca. 58-59 Ma Hanna Formation. Anemones tolerate a wide range of salinities and are common faunal components of many deltaic systems, including bayhead deltas like these and shelf edge deltas like those in the Permian Kookfontein Fm.of the Karoo Basin.



The starlet sea anemone (*Nematostella vectensis*) can tolerate salinities from 2 to 52 parts per thousand (ppt) in southern England, and seems to breed best at around 11 ppt. It is typically buried up to the crown in fine silt or sand, with its tentacles flared out on the surface of the sediment. When not feeding, the tentacles are retracted into the column

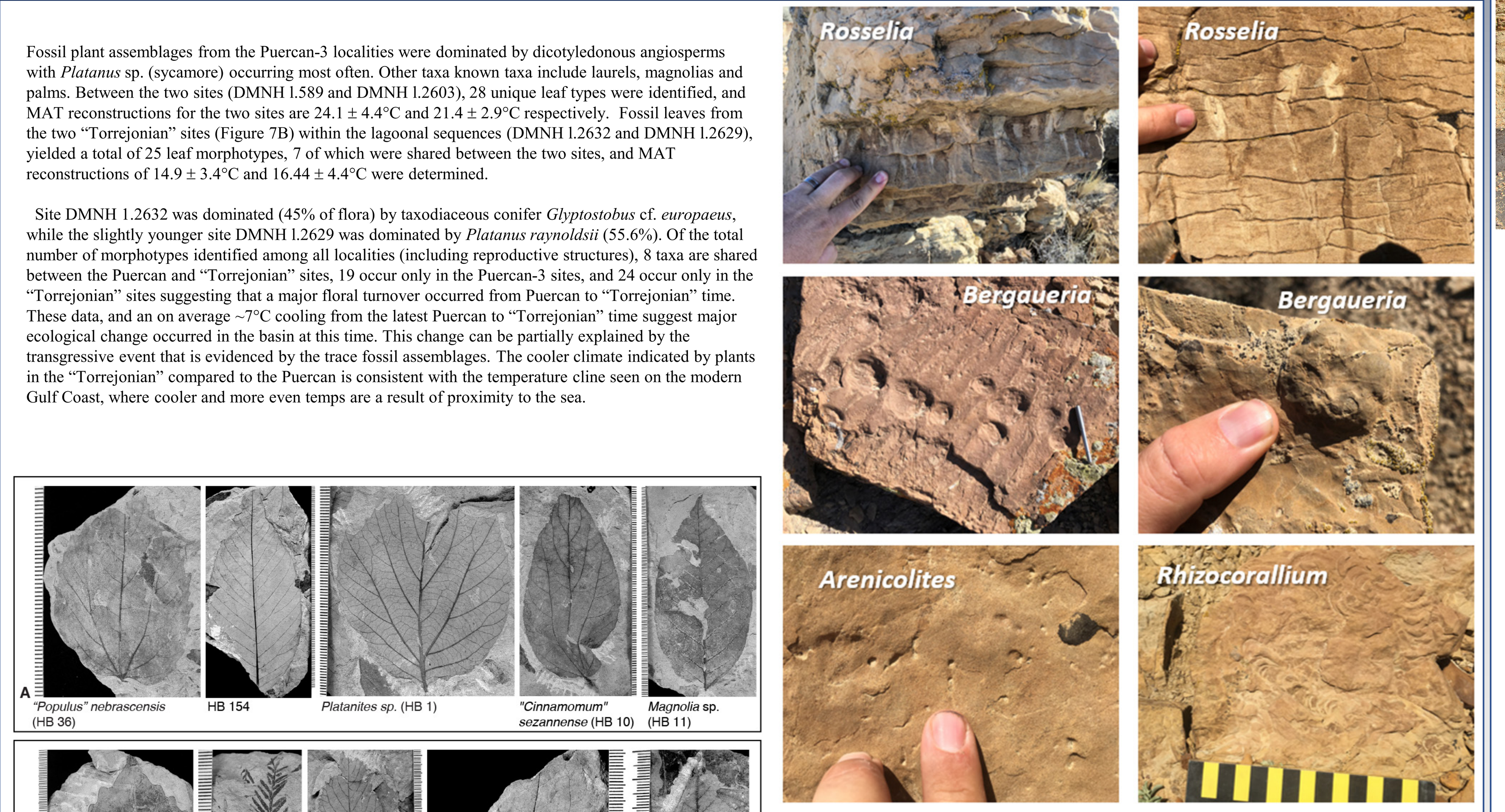
Introduction

The last big marine transgression of the Western Interior Sea (WIS) is generally considered to have occurred in the early Maastrichtian (~73 Ma), during deposition of the Almond Formation (Merletti et al., 2018). Marine body fossils and offshore deposits have not been recognized in Paleocene deposits outside of the Cannonball Formation in the western Dakotas and eastern Montana, fostering the long-held, though incorrect belief that Paleocene transgression of the WIS was a localized event. Recently documented transgressive to highstand deposits 500 km to the southwest in south-central Wyoming reveal a significantly more regional Paleogene flooding event (Figure 1). Tidal deposits and marine ichnofossils in the Puercan-Torrejonian (~65-64 Ma) Ferris and Tiffanian (~58-59 Ma) Hanna formations of south-central Wyoming's Hanna Basin (Figure 2) have been documented previously (e.g., Wroblewski, 2004, 2008), but now are systematically combined all available biogenic and sedimentologic data sets into a "total combined evidence" analysis of the succession, boosting the extent of marine flooding. Paleocene sediment routing to the Gulf of Mexico Wilcox Group during the Paleocene and Eocene has highlighted the importance of the Hanna Basin for accurately reconstructing regional paleogeography and drainage patterns during this dynamic time (Sharman et al., 2017). The unusual cooccurrence of marine ichnofossils and standing fossil trees and tree trunks presents a unique opportunity to directly integrate paleobotanical and ichnological data sets with sedimentology and regional tectonics. Fossil leaves are proven proxies for reconstructing subtle shifts in paleoclimate over time and space, reflecting changes in coastal proximity and the paleogeography of the WIS. Ichnofossils are uniquely suited to record marine flooding events (1000's-10,000's years) and transgressive-regressive cycles (10,000's-100,000's years) that drive their formation. Without them, the true last big transgression of the WIS that occurred 9 my later than conventionally reported, would be unrecognized.

Marine Ichnofossils and Leaves in Bayhead Delta and Lagoon Deposits

Fossil plant assemblages from the Puercan-3 localities were dominated by dicotyledonous angiosperms with *Platanus* sp. (sycamore) occurring most often. Other taxa known taxa include laurels, magnolias and palms. Between the two sites (DMNH 1.589 and DMNH 1.2603), 28 unique leaf types were identified, and MAT reconstructions for the two sites are 24.1 ± 4.4°C and 21.4 ± 2.9°C respectively. Fossil leaves from the two "Torrejonian" sites (Figure 7B) within the lagoonal sequences (DMNH 1.2632 and DMNH 1.2629), yielded a total of 25 leaf morphotypes, 7 of which were shared between the two sites, and MAT reconstructions of 14.9 ± 3.4°C and 16.44 ± 4.4°C were determined.

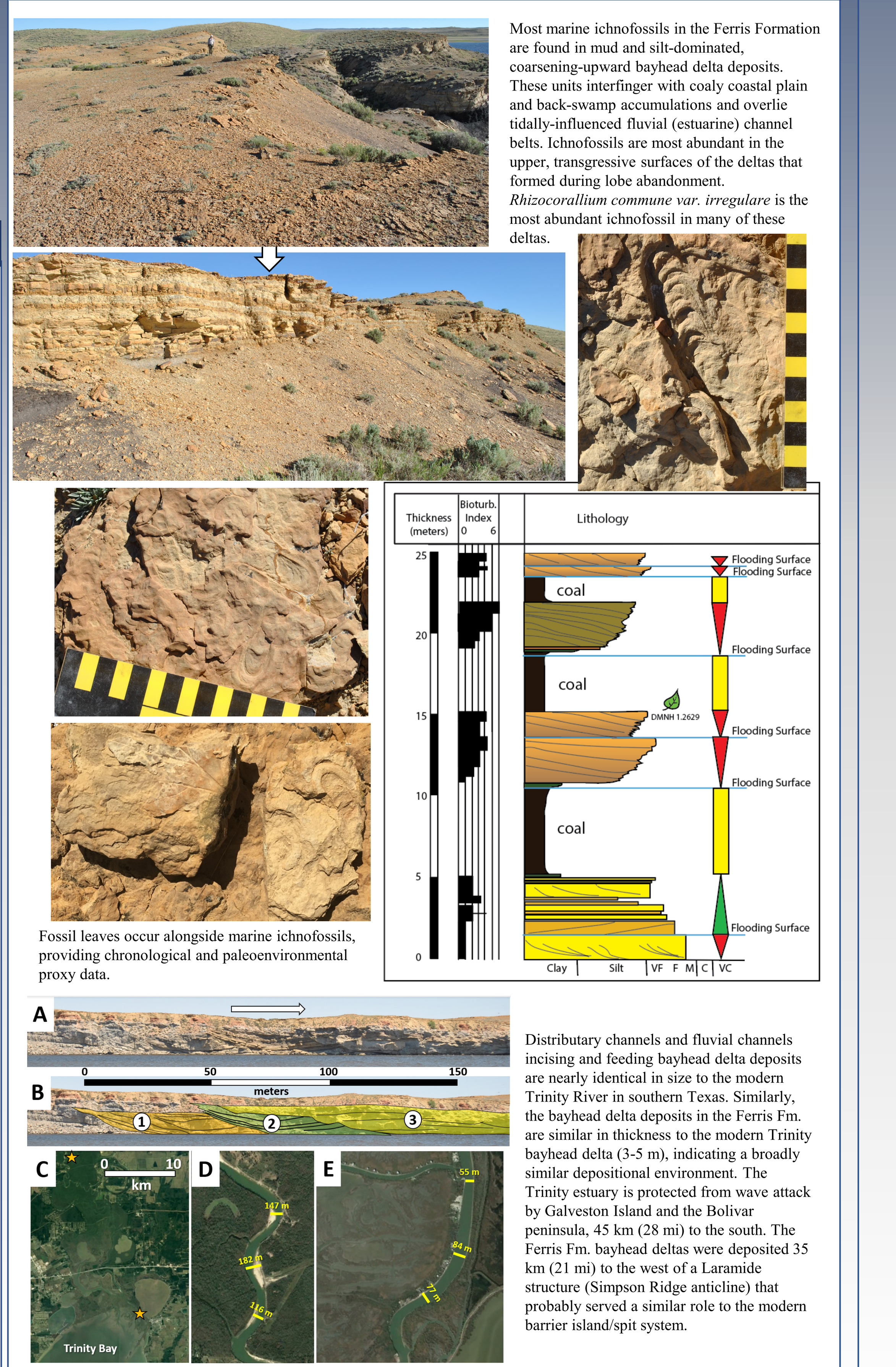
Site DMNH 1.2632 was dominated (45% of flora) by taxodiaceous conifer *Glyptostrobus* cf. *europaeus*, while the slightly younger site DMNH 1.2629 was dominated by *Platanus raynoldsii* (55.6%). Of the total number of morphotypes identified among all localities (including reproductive structures), 8 taxa are shared between the Puercan and "Torrejonian" sites, 19 occur only in the Puercan-3 sites, and 24 occur only in the "Torrejonian" sites suggesting that a major floral turnover occurred from Puercan to "Torrejonian" time. These data, and an on average ~7°C cooling from the latest Puercan to "Torrejonian" time suggest major ecological change occurred in the basin at this time. This change can be partially explained by the transgressive event that is evidenced by the trace fossil assemblages. The cooler climate indicated by plants in the "Torrejonian" compared to the Puercan is consistent with the temperature cline seen on the modern Gulf Coast, where cooler and more even temperatures are a result of proximity to the sea.



A moderate diversity of marine ichnofossils has been thoroughly documented in the Ferris Fm. and is abundantly preserved in clay, silt, and very fine-grained sandstone beds of bayhead deltas, estuarine channels, and distributary mouth bars throughout a 370 m-thick interval of the 700 m-thick Torrejonian section. This stratigraphic interval also includes the thickest coal seams that until recently, were being surface-mined by Arch Mining Company. The most abundant ichnotaxa are *Rhizocorallium*, *Arenicolites*, *Skolithos*, and *Bergaueria*, with *Rosselia*, *Cylindrichnus*, *Thalassinoides*, *Psilonichnus*, and *Ophiomorpha* present is lesser numbers.

Depositional context indicates that these traces were constructed by animals in a marginal marine, back-barrier system of bays and lagoons rather than an offshore, open marine shelf setting. Similar assemblages of incipient trace fossils are found in the bays and estuaries of the modern Texas coastline such as Trinity, Galveston, and Matagorda. The close association of brackish water deposits with coals in the Ferris Fm., is consistent with accumulation in a coastal mire-deltaic complex with abundant interdistributary bays and terminal deltaic splays and mouth bars. A parallel is to be found in the Triassic coal-bearing strata of western Germany, where marginal marine intervals are used to correlated coal seams (Jessen, 1950; Knaust, 2017). In the Ferris Fm., these flooding intervals represent major marine flooding events during the first ~1/3 of the Paleocene and the most significant transgressions since the early Maastrichtian, though of only slightly less westward extent.

Bayhead Deltas



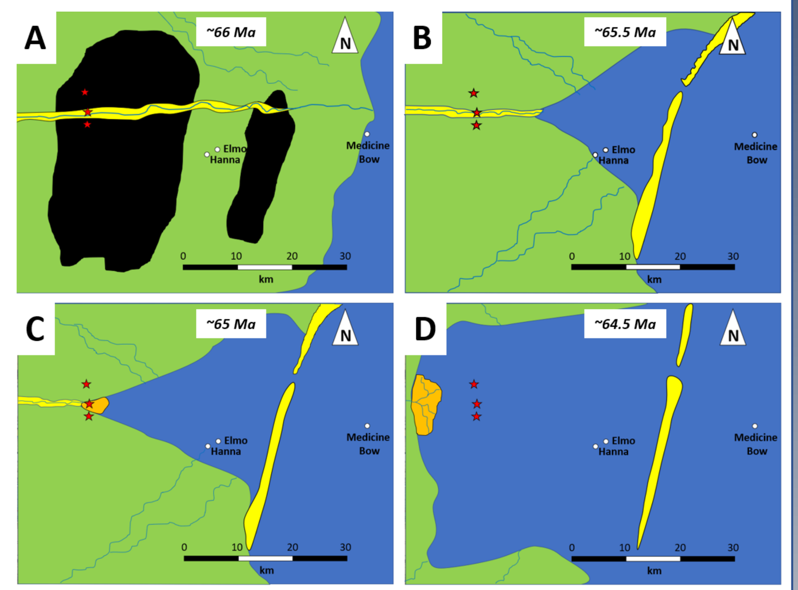
Most marine ichnofossils in the Ferris Formation are found in mud and silt-dominated, coarsening-upward bayhead delta deposits. These units interfinger with coaly coastal plain and back-swamp accumulations and overlie tidally-influenced fluvial (estuarine) channel belts. Ichnofossils are most abundant in the upper, transgressive surfaces of the deltas that formed during lobe abandonment. *Rhizocorallium commune var. irregulare* is the most abundant ichnofossil in many of these deltas.

Fossil leaves occur alongside marine ichnofossils, providing chronological and paleoenvironmental proxy data.

Distributary channels and fluvial channels incising and feeding bayhead delta deposits are nearly identical in size to the modern Trinity River in southern Texas. Similarly, the bayhead delta deposits in the Ferris Fm. are similar in thickness to the modern Trinity bayhead delta (3-5 m), indicating a broadly similar depositional environment. The Trinity estuary is protected from wave attack by Galveston Island and the Bolivar peninsula, 45 km (28 mi) to the south. The Ferris Fm. bayhead deltas were deposited 35 km (21 mi) to the west of a Laramide structure (Simpson Ridge anticline) that probably served a similar role to the modern barrier island/spit system.

Sediment Routing to the Gulf Coast Wilcox and Local Paleogeography

During accumulation of the Midway Shale, the WIS was still present and sequestering sediment in south-central Wyoming. Deposition of the lower Wilcox Group coincided roughly with uplift of Simpson Ridge anticline and absence of marine influence on local deposition. Paradoxically, no large fluvial channel belts are present in the lower Wilcox-equivalent, dominantly lacustrine Hanna Formation (roughly equivalent to the lacustrine Waltman Shale in the Wind River Basin), indicating that the Hanna Basin was not a major fairway to the Gulf Coast. Instead, major fluvial drainage from the Green River Basin, Colorado, Utah, and possibly Nevada, New Mexico, and Idaho probably passed south, through Colorado during the Eocene. Sediment distribution during the Paleocene is consistent with drainage into or near the Hanna Basin area, where rapid subsidence and periodic rises in relative sea level trapped sediment in coal-bearing deltas, coastal plain, and restricted marine embayments.



Conclusions

Ichnofossils are the key to detailed mapping and logging of marine and brackish water deposits in the Paleocene Ferris Formation. We advocate the "total-combined evidence" approach to reconstructing depositional environments. Previous lithological and biogenic data sets contributed to stratigraphic analyses of channelform sands, coal beds, and mudstones and paleontological investigations of abundant leaves, logs, vertebrates, and some freshwater molluscs, but largely failed to include detailed sedimentology and ichnology. At first glance, these studies strongly indicate entirely continental, freshwater settings. Only when detailed sedimentology (e.g., mudstone facies) and rigorous ichnological analysis are included, does the complex relationship between marine flooding surfaces, brackish water bays, and tidally influenced fluvial systems become apparent. Combined with paleobotanical data, the simple identification of a sequence of such transgressive events reveals the tremendous influence of marine flooding on continental life. The simple identification of *Bergaueria perata* by Dr. George Pemberton was the spark that ignited and continues to fuel this ongoing research.

Acknowledgements

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