Palynology of the Upper Cretaceous (Turonian) Ferron Sandstone Member, Utah, USA: identification of marine flooding surfaces and Milankovitch cycles in subtropical, ever-wet, paralic to non-marine palaeoenvironments

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The Upper Cretaceous Ferron Sandstone Member of the Mancos Shale Formation in Utah includes coal and gas deposits and is an important outcrop analogue to study reservoir characterisation of fluvial–deltaic petroleum systems. Numerous sedimentological and sequence stratigraphic studies of the Notom fluvial–deltaic wedge have been conducted recently; however, palynological analyses had not previously been undertaken. Here, we present palynological data from 128 samples collected in the Notom wedge of the Ferron Sandstone Member outcropping in south-central Utah. The purpose of this study is to use palynological analysis to refine the broader depositional environments, evaluate the climatic setting, and to build a biostratigraphic palynological framework. The dominance of terrestrial palynomorphs, especially the high yield of moisture-loving cryptogam spores, indicates a primarily ever-wet depositional environment characteristic of hydromorphic floodplain palaeosols formed in subtropical to tropical climates. Although dinoflagellates are rare, four intervals with occurrences of marine cysts indicate periods of increased marine/tidal influence associated with previously identified flooding surfaces within Milankovitch-scale parasequences of the largely non-marine stratal succession. These flooding surfaces confirm correlations from regional high-resolution sequence stratigraphic studies and allow correlative marine parasequences and system tracts to be extended within floodplain-dominated stratal successions. The presence of Nyssapollenites albertensis pollen places the interval studied within the Nyssapollenites albertensis Interval Zone (Nichols 1994), constraining the age of the Ferron Sandstone Member to the latter part of the Cenomanian and the early Coniacian. This largely agrees with the bentonite- and ammonite-derived Turonian age proposed in previous studies.

Keywords: palynology; Upper Cretaceous (Turonian); Ferron Notom; Cretaceous Western Interior Seaway; sequence stratigraphy

1. Introduction

Studying fluvial–deltaic outcrops is fundamental to understanding how such formations are formed and to apply the knowledge gained to the reservoir characterisation of fluvial–deltaic petroleum systems. Here, we focus on the Upper Cretaceous Ferron Sandstone Member of the Mancos Shale Formation, a well-known host of coal and gas deposits Bhattacharya & Tye (2004). Within the Ferron, three major deltaic wedges have been defined, including the Notom, Last Chance and Vernal sub-members. Recent high-resolution stratigraphical analysis of the Notom delta system (Li et al. 2010; Zhu et al. 2012) demonstrates six 100,000-year-duration Milankovitch-frequency sequences based largely on outcrop correlation of marine parasequences and overlying incised valley systems. Detailed pedostratigraphical analysis of the associated non-marine successions suggests high-frequency sequences can also be recognised (Famubode 2014).

The Ferron Sandstone Member was deposited along the Cretaceous Western Interior Seaway (KWIS) during the Turonian (Peterson & Ryder 1975, Cobban et al. 2006), a time interval known to be the warmest period of the Cretaceous, as indicated by composite oxygen isotopic records (e.g. Huber et al. 2002, MacLeod et al. 2013). The Turonian age also marked the highest sea level seen during the Mesozoic and Cenozoic. During the Turonian, the KWIS coastline ran through central Utah, and much of the western half of the state consisted of coastal environments (Figure 1). The Ferron Sandstone Member has been informally divided into three separate clastic wedges. From oldest to youngest, these are the Notom delta, the Vernal delta and the Last Chance delta. But none

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Figure 1. Palaeogeographical location map illustrating the three deltas that built the Ferron Sandstone Member: the Notom, Last Chance and Vernal deltas, along the Cretaceous Western Interior Seaway during the Turonian (base map ©Ron Blakey, Colorado Plateau Geosystems, Inc.).
of these units is an official stratigraphical or lithostratigraphical unit. It is generally agreed that the Vernal, Last Chance and Notom delta complexes were built as a consequence of northeast progradation of fluvial deltaic deposits into the western margin of the seaway (Figure 1; Gardner 1995, Ryer & Anderson 2004). Here, we will refer to the studied section as the Ferron Sandstone Member, with the understanding that the work presented herein is on the oldest clastic wedge (the Notom delta informal unit) of the Ferron Sandstone Member. This section provides an ideal sequence for understanding coastal/deltaic deposition under extreme greenhouse climatic conditions.

Other penecontemporaneous fluvial–deltaic wedges of the KWIS include the Upper Cretaceous Cardium Formation in Alberta, Canada, the Frontier Formation in Wyoming, and the Gallup Sandstone Formation in New Mexico (Gardner 1995, Li & Zhu 2014).

The Ferron Sandstone Member was deposited above the Late Cenomanian to Lower Turonian Tununk Shale Member of the Mancos Formation (Figure 2). Based on ammonites, the Notom delta wedge of the Ferron Sandstone Member has been estimated to be Middle to Upper Turonian in age (Peterson & Ryder 1975, Cobban et al. 2006). The Ferron Sandstone Member is disconformably overlain by the Santonian Blue Gate Shale Member of the Mancos Shale Formation (Figure 2; Peterson & Ryder 1975, Fielding 2010).

The Ferron Sandstone Member outcrop sampled for this study is exposed in the Henry Mountains in south-central Utah (Figure 3). On the basis of lithological characteristics, the Ferron Sandstone Member studied here was previously divided into two informal units, the Lower Ferron–Notom and the Upper Ferron–Notom Peterson & Ryder (1975). Shelf and shoreline sandstones and marine shale beds are common in the Lower Ferron–Notom unit, and fluvial–deltaic deposits, including channel sandstones, floodplain deposits and coals predominate in the Upper Ferron unit (Peterson & Ryder 1975, Ryer & Anderson 2004, Li et al. 2010). Zhu et al. (2012) subdivided the Notom into six sequences, 18 parasequence sets and 43 parasequences. The uppermost, and youngest, sequence 1 comprises a 5–25-m-thick compound incised valley system overlain by about 23 m of interbedded channel belt sandstones and muddy floodplain deposits, including crevasse splay deposits, coals, floodplain pond mudstones and palaeosols (Famubode 2014, and Figure 4). These 23 m are the focus of this study. The sampled section has been subdivided into nine fluvial aggradational cycle sets, based on analysis of pedostratigraphical cycles and river channel deposits, and these have in turn been grouped into three higher-frequency sequences (Famubode 2014). These are designated from youngest to oldest as 1A, 1B and 1C (Figure 5). The lowest sequence 1C is the upper tidally influenced part of a 5-m-thick sandy valley-margin fill. Several horizons have also been identified as candidate flooding surfaces. Assuming that the entire sequence 1, including the compound incised valley, represents about 100,000 years’ duration, these 23 m likely represent around half that time, or about 50,000–60,000 years.

The present study evaluates palynofacies and palynostratigraphy to search for evidence of marine incursions within floodplain stratigraphic successions that could correlate with high-frequency marine flooding surfaces, and to identify possible Milankovitch-style palaeoclimatic controls on the origin of high-frequency sequences.

Only a few studies have been conducted on the Upper Cretaceous terrestrial floras of Utah and adjacent areas. Orlansky (1971) described and illustrated 124 palynomorph species from 20 samples from the Straight Cliffs Sandstone, Garfield County, Utah. Gray et al. (1966) focused on the coal intervals and correlated coal zones using pollen and spore assemblages from Ferron Sandstones. Lohrenzel (1969) and Nichols (1995) described palynomorphs from the Kaiparowits Plateau, in south-central Utah. Several additional studies have been conducted to interpret the Upper Cretaceous terrestrial floras of North America in adjacent areas. For example, Jameossanaie (1987) reported on the palynology of South Hospah coal-bearing deposits, in McKinley County, New Mexico, and described some important Upper Cretaceous palynomorphs.

![Figure 2. Stratigraphic column showing the Upper Cretaceous succession of the Henry Mountains (modified from Fielding 2010).](image-url)
Figure 3. Maps illustrating the Ferron Sandstone Member outcrop belt and the location of the study area (modified from Famubode 2014).
The new, detailed palynological study presented herein aims to refine the characterisation of the climatic and depositional settings, and evaluate the nature of high-frequency sequences formed during the middle to upper Turonian of Utah. Dinoflagellate cysts should provide evidence for marine incursions, while spores and pollen provide information about the type of plants that grew during this purported greenhouse-climate interval. Any drastic changes in plant composition observed would indicate that climatic changes occurred during the development of the Ferron sequences. The second focus of this study is to develop a high-definition biostratigraphical framework for regional sequences contemporaneous to the Ferron Sandstone Member deposits.

2. Material and methods

One hundred and twenty-eight palynological samples were taken from Sweetwater Creek, between the Henry Mountains and Utah Highway 24. For each sample, one kerogen slide and two > 10-μm fraction slides were studied. This location was selected because it is well exposed, and both channel and floodplain deposits outcrop extensively (Figure 3). Where possible, samples were collected at approximately 10-cm intervals from the floodplain mudstones and coal intervals in the 23-m-thick section. Chemical processing was performed on all samples and proceeded according to techniques described in Brown (2008). Hydrochloric and hydrofluoric acids were used to digest the...
Figure 5. Stratigraphical distribution chart displaying the lithostratigraphy, the relative abundance of palynomorphs recovered in Ferron-Notom Section and the key palynological events identified in the Ferron Sandstone Member studied. These are graphed against the sequence stratigraphical interpretation proposed by Famubode (2014). Notes: FAD stands for First Appearance Datum and LAD stands for Last Appearance Datum.
3. Ferron Sandstone Member palynological results

3.1. Overall palynomorph recovery

A total of 5789 palynomorphs were counted from the 128 samples collected. Palynomorph recovery varied from very poor to good with several samples essentially barren. For each of these samples, several slides had to be scanned to increase the number of palynomorphs observed. Regarding the barren samples, palynomorphs may have been oxidised by natural processes and destroyed, especially in the lower part of the section. The difficulty of working with such a poor yield might explain why very few palynological analyses have been performed on this important sequence. Despite these time-consuming, low-yield analyses, important palaeoenvironmental information was gathered from this study. The morphotypes recovered include 82 species of pollen and spores, six species of dinoflagellate cysts and other algae, and two palynomorphs of unknown affinity. The average relative abundance of Ferron palynomorphs consists of 61.7% fungal spores, 9.5% gymnosperm pollen, 9.0% angiosperm pollen and 19.8% other palynomorphs, including mostly fungal spores, algae and palynomorphs of unknown affinity. Clearly, the depositional environment is dominated by ferns and bryophytes, such as mosses, liverworts and hornworts, all indicative of very moist environments.

Relative abundances of significant palynomorph groups, biozones and events are summarised in Figure 5. These data are presented in relation to changes in lithology and other outcrop measurements. Some of the most abundant taxa recovered are illustrated in Plates 1 and 2.

3.2. Palynostratigraphy

Four palynological assemblage zones were defined for this data set. These are based on the distribution of species recovered and the changes in abundance of seven main palynomorph groups (Figure 5). The four zones are described below.

Zone 1 spans between 6.0 and 7.70 m from the base of the section. It is characterised by the most continuous presence of dinoflagellate cysts, and the first occurrences of Nyssapollenites albertensis and Cyathidites concavus. The common occurrence of Schizoporis sp., Schizophacus sp. and Taxodiaceapollenites sp. also marks this zone.

Zone 2 ranges from 7.70 to 13.00 m and its base is characterised by an acme in Cyathidites spp., and abundant fungal spores.

Zone 3 ranges from 13.00 to 20.50 m and is marked by the first occurrence of Appendicisporites unicus, Triporoletes radiatus, Enzonalasporites bojatus and Tetraangularinium sp., and the last occurrence of Cyathidites concavus. In addition to these events, common occurrences of Zlivisporis cenomanianus, Araucariacites sp. and Todisporites spp. are identified.

Finally, the uppermost Zone 4 is characterised by the first occurrence of Cicatricosisporites crassiterminatus, and the last occurrences of Appendicisporites unicus and Appendicisporites auritus. Additionally, the common occurrence of Laevigatosporites sp., Triporoletes reticulatus, Cicatricosisporites crassiterminatus and Foraminisporis simiscalaris is also noted in Zone 4.

3.3. Palynomorphs recovered from the Ferron Sandstone Member and their environmental significance

Among the fern spores, Schizaeaceae species resembling the living Anemia are one of the most prominent forms recovered. The genera Appendicisporites and Cicatricosisporites collectively represent 13% of the total specimens counted. An acme of Cicatricosisporites crassiterminatus occurred from 23.0 to 23.05 m. The abundance and variety of schizaceous spores (schizaeaceans) is similar to those recovered from Upper Cretaceous rocks throughout the KWIS (Agasie 1969, Jameossanaie 1987, Nichols 1995, Ludvigson et al. 2010).

Another abundant spore genus recovered is Zlivisporis, a genus belonging to the Hepaticae or liverworts. Note that in many previous studies, these spores have been assigned to the genera Rouseisporites, Triporoletes or Inaperturopollenites (Braman 2001). These small bryophytes require moist environments and grow in a prostrate manner on stable surfaces Braman & Koppelhus (2005). Relative abundances of Zlivisporis average approximately 12.7% of the total specimens counted. An acme of Zlivisporis cenomanianus has been identified from 19.10 to 19.20 m. The abundance and variety of Zlivisporis cenomanianus recovered along the KWIS in other studies have varied from rare...
to dominant. For example, Ravn & Witzke (1994) reported that *Zelvisporis cenomanianus* was recovered in almost every sample throughout the Dakota Formation; however, in other formations, it was very rare. The reason for this variability may be local palaeoecological effects such as changes in moisture availability. Liverworts and hornworts favour soil with high moisture, and tolerate minor flooding, but these plants would die if fully submerged (Warny et al. 2012). On the other hand, soils that are too dry would prevent the reproduction of these bryophytes.

Other cryptogam spore groups recovered include spores of fern genera *Cyathidites, Gleicheniidites, Lavernigatosporites* and *Todisporites*, and spores of the bryophyte *Aequitirradites*. Collectively, these represent an average of 20.1% of the specimens recovered. *Gleicheniidites* is a terrestrial fern that is mostly found in tropical and temperate environments. *Todisporites* is interesting as it belongs to the family Osmundaceae or Cinnamon ferns, a group that has three living genera including terrestrial and subaquatic ferns. It is mostly found in temperate to tropical swampy regions (Lawrence 1951, Braman & Koppelhus 2005). *Aequitirradites* is believed to be the spore of some unknown liverwort. Archangelsky & Archangelsky (2005) compared *Aequitirradites* they recovered from Cretaceous sections in Patagonia to the spores of the aquatic genus *Karella*. They noted that the genus was characteristic of temperate to warm and humid environmental conditions.

Many other cryptogam spore genera have a relative abundance lower than 1% of the total. The abundance and variety of spore specimens increase progressively from the lower to the upper part of the section.

Pollen grains from gymnosperms and angiosperms are less abundant than the spores recovered; however, the diversity of these forms is interesting. Gymnosperm assemblages average 9.5% in relative abundance. Among the gymnosperms recovered, bisaccate grains are prevalent, with 3.7% of the total palynomorphs recovered. The assemblage of bisaccate pollen includes the following species: *Abiespollenites* sp., *Alisporites* sp., *Parvisaccites* sp., *Piceapollenites* sp., *Pityosporites alatipollenites*, *Pityosporites* sp., *Pristinuspollenites* sp., *Rugubivesculites* sp. and *Vitreisporites* sp. Other gymnosperm pollen, including *Araucariaeites, Taxodiaceae pollenites, Ephedrrites, Zonalapollenites, Cycadopites* spp. and *Classopollis*, made up an average of 5.8% of the total yield. The association of Taxodiaceae, Araucariaceae and Pinaceae has been reported from moist upland areas near water, and in temperate to subtropical environments (Orlansky 1971).

*Taxodiaceae pollenites* pollen was produced by trees that are the principal component of swamp-forest vegetation (Nichols 1995) and are most likely similar to *Taxodium* species such as the swamp cypress found today.

Angiosperm pollen grains represent only 9.0% of the total yield. The assemblage of angiosperm pollen includes the following species: *Aquilapollenites psilatus, Cupaniecites* spp., *Cupuliferidae pollenites* spp., *Foveotricolporites* spp., *Lillicadites* spp., *Margocolpites* spp., *Monosulcites spinosus, Nyssapollenites* spp., *Nyssapollenites albertensis, Retricolpplites* spp., *Tricollites* spp., *Rousea* sp. and *Stellatopollis* spp. *Cupaniecites* spp. is related to some of the Cupanieae from tropical and subtropical regions of America, Madagascar and Australia. These species occur in a wide range of humid tropical to subtropical environments Coetzee & Muller (1984). The gymnosperm *Cycadopites* and angiosperm *Monosulcites* are palm-like pollen found in subtropical and tropical lowland swamp areas (Braman & Koppelhus 2005, Mann 2007). The most predominant genus of angiosperm is *Tricollites*, representing 5.1% of the total specimens counted. Other angiosperm genera are rare or only occur intermittently.

Two other species, *Enzonalasporites bojatus* and *Aquilapollenites psilatus*, were recovered in the upper section of sequence 1. *Aquilapollenites psilatus* has been reported in several studies, including from the Campanian–Maastrichtian Edmond Group of Alberta, Canada Srivastava & Braman (2013). These authors suggested that this species was actually a trilete spore in equatorial view and proposed it be included in the Schizaceae, *Cyathidites* or *Deltidospora*. Here we keep with the traditional view that this is actually a pollen (not a spore) that displays a unique triprojectate morphology. Although it is not abundant, the occurrence of this species is noteworthy because it is the only triprojectate pollen recovered along the section. *Enzonalasporites bojatus*, which has an uncertain affinity Currie & Koppelhus (2005), was recovered previously in the Upper Santonian–Lower Campanian Milk River Formation in southern Alberta, Canada (Braman 2001).
Other palynomorphs recovered include dinoflagellate cysts, other algae and fungal spores, together making an average of 19.8% of the total specimens tabulated. Fungal spores are the most prominent, with 9.5% of the total. They are present throughout the section. This is significant because most modern studies done in hospitals or aerobiology laboratories on air-sample quality show that peaks in some fungal spores often occur during hot, humid, rainy weather and during harvest seasons (Emberlin 2000). As harvest is not a consideration in the Cretaceous, the abundance of fungal spores has significant implications for the climatic conditions during the time of deposition. Several freshwater algal spores were also recovered, accounting for up to 6.5% of the total assemblage. Spores of freshwater algae include *Schizochytrus parvus*, *Schizochytrus* sp., *Schizosporis* sp., *Tetragraduladinium* sp., *Chomotriletes minor* and spores of Zygmemataceae. The green algae family Zygmemataceae is known as a palaeoclimatological and palaeoenvironmental indicator (van Geel et al. 1989, Yi 1997, Warny et al. 2009, Lindström 2013). For instance, *Tetragraduladinium* have been reported in sediments of humid warm temperate to subtropical—tropical regions that have a dry season (van Geel et al. 1989, Davis 1992, Yi 1997, Lindström 2013). *Tetragraduladinium* has also been reported from Upper Cretaceous non-marine sediments along the KWIS (Braman 2001, Lucas et al. 2003, Bercovici et al. 2009). *Tetragraduladinium* was regarded as a dinoflagellate cyst or acritarch in previous studies (Batten & Lister 1988, Fensome & Williams 2004). The spores of Zygmemataceae are an excellent indicator of a freshwater realm, and their presence has been reported as an indicator of freshwater ponds in Antarctica during the Mid-Miocene Climatic Optimum (Warny et al. 2009). Their presence here might be indicative of floodplain ponds or lake-fill deposits. Taxa of freshwater algae, similar to those recovered from the Ferron Sandstone Member, have also been reported in several formations throughout the KWIS (Orlansky 1971, Jameossanaie 1987, Nichols 1997, Braman & Sweet 2012).

Dinoflagellate cysts, although very rare in the section, were recovered in four main intervals of sequence 1 in the Ferron Sandstone Member. The overall lack of dinoflagellate cysts might be indicative of dominant fluvial deposition under low-salinity sea-surface conditions. A similar lack of dinoflagellate cysts is observed today in samples of sediments taken in various areas of the Mississippi Delta, along the Gulf of Mexico, where salinity ranges from 0 to 20 psu. The presence of diverse freshwater algae recovered from sequence 1 of the Ferron Sandstone Member supports this hypothesis. Although they are rare, the four occurrences are potentially quite important because they might indicate brief episodes of increased marine influence or flooding surfaces with associated increase in salinity. The lower part of the section, up to 7.70 m, shows the almost continuous presence of dinoflagellate cysts. These probably represent the time in the section with the most marine influence and correlate with deposition within a brackish and tidally influenced valley fill. Following this period, dinoflagellates appeared mostly at three main levels: at 11.40 m (5%), at 12.30 m (3%) and at 17.35 m (4%). Each of these occurrences correlates with previously defined flooding surfaces that were based on sequence stratigraphic analysis by Famubode (2014). This strongly supports the interpretation of flooding surface-capped fluvial aggradation cycle sets and high-frequency sequences in this largely non-marine succession.

Most of the spore and pollen species recovered are mostly indicative of warm, moist to marine environments, indicating that the deposition occurred under the influence of a tropical climate in a floodplain to paralic setting. Although mangrove pollen was expected to be recovered in these sequences, it was not found. The lack of mangrove pollen in the section is remarkable, and the reason for this absence is unknown. Traverse (2007), who observed a similar lack of mangrove in other Cretaceous sections, and proposed a possible explanation in that *Classopolis*-producing plants may have occupied the mangrove habitat. Srivastava (1976) indicated that plants producing *Classopolis* have an affinity with araucarian and/or gnetalean conifers. They occupied environments such as the well-drained soils of lowland coastal areas, and preferred a warm climate, although some modern Araucarian species extend today to the tree line in modern southern Chile and Argentina (Bowman et al. 2014 and references therein). Other studies (Orlansky 1971, Heimhofer et al. 2008) suggest that *Classopolis* indicates warm, semi-arid to arid coastal palaeoenvironments, with pollen thought to be produced by

Cheirolepidiaceae, an extinct group of thermophilous conifers. Heinhofer et al. (2008) indicated that this species can be found in tidally influenced, shallow-water deposits, and that these plants could thus indicate the vicinity of the palaeo-shoreline. In the section studied herein, the co-occurrence of Classopolis at levels where dinoflagellate cysts are found tends to confirm Traverse’s theory and broadly reinforces our paralic environmental interpretation.

4. Age of the Ferron Sandstone Member

Previous ammonite and inoceramid biostratigraphical studies constrained a middle Turonian age for the Ferron Sandstone Member (e.g. Peterson & Ryder 1975, Cobban et al. 2006). Because of an erosional unconformity between the Ferron Sandstone Member and the Blue Gate Shale Member above, several ammonite zones representing late Turonian to late Coniacian time are missing. Additional work performed by Zhu et al. (2012) on bentonite beds refined the age of the Ferron Sandstone Member deposition to between 91.25 and 90.63 Ma, confirming the existence of an important unconformity between the Ferron Sandstone Member and the Blue Gate Shale members of the Mancos Shale Formation.

Several palynostratigraphical events (acmes, FADs, and LADs) are noted in Figure 5. These might prove useful to correlate this section to cuttings, but no palynological markers allow us to refine the 91.25 to 90.63 Ma bentonite age. The recovered gymnosperm and spore taxa, such as species of Cicatricosisporites, Deltaoidospora and Appendicisporites, have little biostratigraphical significance due to their long age ranges. The best palynostratigraphical marker in the Ferron Sandstone Member is the tricolporate angiosperm species Nyssapollenites albertensis. This pollen taxon defines the Nyssapollenites albertensis Interval Zone (Nichols 1994, Nichols 1997). The presence of Nyssapollenites albertensis in the studied section thus places it within the interval zone indicating a late Cenomanian to early Coniacian age. Other species known to be associated with the Nyssapollenites albertensis Interval Zone were also identified throughout the section, including Cicatricosisporites spp., Classopolis sp., Cupuliferoideaepollenites sp., Deltaoidospora minor, Echinatisporis sp., Foraminisporis simiscalaris, Gleicheniidites senonicus, Laevigatosporites sp., and Taxodiaceaeepollenites hiatus. The absence of the tricorate angiosperm pollen Proteacitides is another indication of the Nyssapollenites albertensis Interval Zone (Nichols 1994, Broman & Sweet 2012), suggesting that the age of the section cannot be younger than Coniacian. This interval zone has been reported in several formations in Utah and adjacent areas, including the Frontier Formation in Montana (Dyman et al. 1988, Nichols 1994). The palynostratigraphy thus supports the bentonite age but does not improve the resolution.

5. Summary of the environmental significance of the assemblage recovered

The dominance of spores of ferns, hornworts and liverworts characterises the entire section studied. Cryptogams require soil with high moisture content to produce gametophytes. Hence, the high abundance of spores suggests deposition in wetlands or hydromorphic floodplain palaeosols, as also suggested by the sedimentological analysis (Famubode 2014). The occurrence of freshwater algal spores, including Schizophaucus parvus, Schizophaucus sp., Schizosporis sp., Tetranugadunium sp., Chomotritites minor and Zygmenataceae, in this section indicates freshwater input into the depositional environment, most likely from a fluvial source. The abundance of fungal spores also supports a continuously wet tropical climate, especially in times of peaks in fungal spores. Gymnosperms such as Taxodiaceae (including the swamp cypress) and swamp palms are found throughout the Ferron Sandstone Member and are indicative of swamp environments, similar to those found today in South Louisiana, USA.

Gymnosperm pollen, such as Araucariaceae and Pinaceae that might have inhabited upland areas (Orlansky 1971, Nichols & Brown 1992), were probably transported by wind or/and water to the floodplain. The two types of vegetation recovered most likely reflect the local floodplain or broader river valley topography, with gymnosperms (other than Taxodiaceae) being abundant in moist upland areas while cryptogams and angiosperms were growing in relatively low-lying or swampy areas.

There are four main stratigraphical levels marked by occurrences of dinoflagellate cysts, indicating increased marine influence and higher sea-surface salinity. These occurrences correspond perfectly to transgressive events defined on the basis of sequence stratigraphic analysis, palaeosol typing (pedostratigraphy) and stacking patterns of fluvial aggradational cycles defined by Famubode (2014). These most likely indicate transgressive phases in times of maximum flooding or enhanced tidal influence.

6. Conclusions

A detailed palynological analysis of the Upper Cretaceous Ferron Sandstone Member of the Mancos Shale Formation in Utah was conducted. Palynostratigraphy places the age of the section within the Nyssapollenites albertensis Interval Zone (Nichols 1994), indicating
that the section is no younger than mid-Coniacian and not older than mid-Cenomanian. This supports the 91.25–90.63 Ma bentonite-derived ages reported by Zhu et al. (2012). Based on the palynomorphs recovered, precise information concerning the depositional environments and the vegetation that covered the deltaic area during the middle Turonian was acquired. Vegetation was dominated by ferns, hornworts and liverworts, which shared the swamp/floodplain with swamp cypress, cycads and other palm-like trees. Abundant freshwater algae and river-bank-indicative species confirmed deposition in hydromorphic floodplain palaeoenvironments. Mangroves were absent from the assemblage, but their ecological niche was most likely occupied by an extinct species producing *Classopollis*, known to favour lowland coastal areas, and the warm climate of transgressive seas. This interpretation is reinforced by the abundance of fungal spores, whose high abundance in the air today is often associated with a warm, humid climate. This climatic trend, a continuously wet tropical to subtropical climate, characterised the entire interval studied. If an important Late Turonian cooling event (as suggested from oxygen-isotopic records; e.g. Voigt & Wiese 2000) impacted the region, it occurred after the deposition of the interval studied. This time interval might be characterised by a zone of non-deposition, possibly time-equivalent to the hiatus identified between the Ferron Sandstone and Blue Gate Members of the Mancos Shale Formation. Four episodes of dinoflagellate cyst occurrences indicate increased marine influence and correlate with previously identified flooding surfaces.

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