Palynology of the Upper Cretaceous Ferron-Notom Sandstone, Utah

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PALYNOLOGY OF THE UPPER CRETAEOUS FERRON-NOTOM SANDSTONE, UTAH

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science in

The Department of Geology and Geophysics

by

Isil Akyuz
B.S., Ankara University, 2009
December 2014
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ABSTRACT

The Late Cretaceous Ferron-Notom Sandstone Member of the Mancos Shale Formation plays a dominant role in oil production in Utah. Although numerous sedimentological and sequence stratigraphic studies have been conducted in recent years on this sequence, palynological analyses had not yet been undertaken. Here we present palynological data from one hundred twenty eight samples collected in the Ferron-Noton Sandstone Member outcropping in south-central Utah. The purpose of this study is to refine our understanding of climatic and depositional environments and to build a biostratigraphic palynological framework. The dominance of terrestrial palynomorphs, especially the high yield in moisture-loving cryptogam spores recovered, indicates a depositional environment characteristic of hydromorphic floodplain paleosols in subtropical to tropical climates. Although dinoflagellates are rare, four intervals with occurrences in marine phytoplankton cysts likely indicate brief periods of increased marine/tidal influence and/or maximum flooding surfaces. The continuous presence of pollen grains *Nyssapollenites albertensis* place the interval studied within the *Nyssapollenites albertensis* Interval Zone (Nichols 1994), constraining the age of the Ferron-Notom Sandstone between the latter part of the Cenomanian and the early Coniacian, in agreement with the bentonite and ammonite-derived Turonian ages proposed in previous studies.
1. INTRODUCTION

The Ferron-Notom Sandstone Member of the Mancos Shale Formation is a highly productive Upper Cretaceous oil and gas reservoir. This Member is also an important outcrop analogue for fluvial-deltaic petroleum systems (Bhattacharya and Tye 2004). Studying these past systems and comparing them to modern depositional complexes can help understand how, and under which environmental conditions these reservoirs are built. The reservoir associated with the Ferron-Notom Sandstone Member was deposited along the Cretaceous Western Interior Seaway (CWIS) during the Turonian (Peterson and Ryder 1975; Cobban et al. 2007), a time interval known to be the warmest period of the Cretaceous, as evidenced by composite oxygen isotopic records (e.g. MacLeod et al. 2013; Huber, Norris, and MacLeod 2002). During that interval, sea level was at its highest of the Mesozoic and Cenozoic, and what is now the state of Utah, which today is mainly desert, was characterized on its central and eastern border as a coastal environment. The Ferron-Notom Sandstone Member thus provides an ideal sequence to understand coastal/deltaic deposition under an extreme greenhouse climate. During the Turonian Stage, three major clastic wedges, the Vernal, Last Chance, and Notom delta complexes, were built as a consequence of northeast progradation of fluvial-deltaic deposition (Ryer and Anderson 2004; Gardner 1995) (Fig. 1). Other penecontemporaneous depositional sequences of the CWIS include the Cardium Formation in Alberta, Canada, the Frontier Formation in Wyoming, and the Gallop Sandstone Formation in New Mexico (Li and Zhu 2014; Gardner 1995).

The studied section, the Ferron-Notom Sandstone Member, was deposited above the Tununk Shale, a Late Cenomanian to Lower Turonian formation. Based on ammonites, the Ferron-Notom Sandstone was estimated to be Middle to Upper Turonian in age (Cobban et al. 2007; Peterson and Ryder 1975). This Member is disconformably overlain by the Santonian Blue Gate Shale (Fielding 2010; Peterson and Ryder 1975) (Fig. 2). These three formations together comprise the Turonian–Santonian Mancos Shale.

The Ferron-Notom outcrop sampled for this study is exposed in the Henry Mountains in south central Utah (Fig. 3). On the basis of lithological characteristics, the Ferron-Notom
Sandstone was previously divided into two units, the Lower and Upper Ferron-Notom (Peterson and Ryder 1975). While shelf sandstone and marine shale beds can be found in the Lower Ferron-Notom member, fluvio-deltaic deposits, including channel sandstones, floodplain deposits, and coals, can be seen in the Upper Ferron-Notom (Ryer and Anderson 2004; Peterson and Ryder 1975; Li, Bhattacharya, and Campbell 2010). The present study focuses on the Lower to Upper Ferron-Notom transition and on Upper Ferron-Notom deposits.

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 Country, Utah. Gray, Patalski, and Schapiro

Figure 1: Paleolocation map illustrating the Ferron-Notom-Vernal Frontier Delta along the Western Interior Seaway during the Turonian (base map provided by ©Ron Blakey, Colorado Plateau Geosystems, Inc.).
focused on the coal intervals and correlated coal zones by using pollen and spore assemblages from Ferron Sandstones. Lohrengel (1969) and Nichols (1995) described some palynomorphs from the Kaiparowits Plateaus, central southern Utah. Several additional studies have been conducted to interpret the Upper Cretaceous terrestrial floras of North America. For example, Jameossanaie (1987) reported on the palynology of South Hospah coal-bearing deposits, McKinley County, New Mexico, and described some important Upper Cretaceous palynoflora.

The new detailed palynological study discussed herein aims to refine the understanding of the climatic and depositional settings during the middle to upper Turonian of Utah. Dinoflagellate cysts should provide evidence for marine incursions, if these occurred, while spores and pollen would provide information about the type of plants that grew during this greenhouse-climate time interval. Any drastic changes in plant composition observed would indicate that climatic changes occurred during the time of deposition. The second focus of this study is to develop a high-definition biostratigraphic framework to assist in biosteering wells in regional sequences contemporaneous to the Ferron-Notom Sandstone deposits.

Figure 2: Stratigraphic column showing the Upper Cretaceous succession of the Henry Mountains (Modified from Fielding (2010).
Figure 3: Maps illustrating the Ferron Notom Outcrop Belt and the location of the study area (Modified from Li et al. (2012)).
2. MATERIAL AND METHOD

One hundred twenty eight palynological samples were taken from Sweetwater Creek, between the Henry Mountains and Utah Highway 24. This location was selected because it is well exposed, and both channel and floodplain deposits outcrop extensively (Fig. 3). Where possible, samples were collected at approximately 10 cm intervals from floodplain mudstone and coal intervals in the 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 sediments. After the residues were rinsed to neutrality, a heavy liquid (ZnBr$_2$) was used to separate the organic from the fine mineral fractions. When possible, up to 300 palynomorphs were counted per sample. Identification and description of the palynomorphs was conducted using an Olympus BX 41 transmitted-light microscope housed in the Center for Excellence in Palynology (CENEX), Louisiana State University. All palynomorphs recovered were tabulated. StrataBugs biostratigraphic data management software was used to create distribution and range charts.
3. RESULTS

3.1. Overall palynomorphs recovery

A total of 5,789 palynomorphs were counted from the 128 collected samples. Palynomorph recovery varied from fair 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 oxidized and destroyed, especially in the lower part of the section. Morphotypes recovered include 82 species of pollen and spores, 6 species of dinoflagellate cysts and other algae, and two palynomorphs of unknown affinity. Average relative abundance of Ferron-Notom palynomorphs consists of 61.7% of cryptogam spores, 9.9% of gymnosperm pollen, 9.2% of angiosperm pollen, and 19.2% of 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 summarized in Figure 4. These data are presented in relation to changes in lithology and outcrop measurements. Generalized quantitative distribution and range charts of the Ferron-Notom palynomorphs can be found in Appendixes A and B. 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 and are based on the distribution of species recovered and the changes in abundance of seven main palynomorph groups (Fig. 4). The four zones are described below.

Zone 1, the lower part of the Ferron-Notom outcrop studied, spans between 6.0 to 7.70 m from the base of the outcrop. It is characterized by the most continuous presence in dinoflagellate cysts, and the first occurrence of *Nyssapollenites albertensis* and *Cyathidites concavus*. The
Figure 4: Stratigraphic distribution chart displaying lithostratigraphy, the relative abundance of the seven palynological assemblages, and key palynostratigraphic events identified in the Ferron-Notom Sandstone Member studied.
common occurrence of *Schizoporis* sp., *Schizophacu*s sp., and *Taxodiaceaepollenites* sp., also mark this zone.

Zone 2 ranges from 7.70 to 13.00 m and its base is characterized by an acme in *Cyathidites* spp.

Zone 3 ranges from 12.20 to 20.50 m and is characterized by the first occurrence of *Appendicisporites unicus*, *Triporoletes radiatus*, *Enzonalasporites bojatus*, and *Tetrangulidinium* sp., and the last occurrence of *Cyathidites concavus*. In addition to these events, the common occurrences of *Zlivisporis cenomanianus*, *Araucariacites* sp., and *Todisporites* spp., are identified in this zone. Zone 3’s base is also marked by an increase in dinoflagellate cysts.

Finally, Zone 4 is characterized by the first occurrence of *Cicatricosisporites crassiterminatus*, and the last occurrence of *Appendicisporites unicus* and *Appendicisporites auritus*. Additionally, the common occurrence of *Laevigatosporites* sp., *Zlivisporis reticulatus*, *Cicatricosisporites crassiterminatus*, *Foraminisporis simiscalaris* are also noted in the Zone 4.

### 3.3. Palynomorphs recovered from the Ferron-Notom Sandstone Formation and their environmental significance

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

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 and Koppelhus 2005). Relative abundances of *Zlivisporis* average approximately 12.7% of the total
specimens counted. Two acmes of *Zlivisporis cenomanianus* have been identified at 19.10 and 19.20 m. The abundance and variety of *Zlivisporis cenomanianus*, recovered along the CWIS in other studies, have varied from rare to dominant. For example, Ravn and Witzke (1994) reported that *Zlivisporis cenomanianus* was recovered in almost every sample throughout the Dakota Formation; however, in other formations, they were very rare. The reason for this variability may be local paleoecological effects such as changes in moisture availability. Liverworts and hornworts favor 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 reproduction of these bryophytes.

Other cryptogram spore groups recovered include spores of fern genera *Cyathidites*, *Gleicheniidites*, *Laevigatosporites*, and *Todisporites*; and spores of bryophyte *Aequitriradites*. 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 very 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 (Braman and Koppelhus 2005; Lawrence 1951). *Aequitriradites* is believed to be the spore of some unknown liverwort. Archangelsky and Archangelsky (2005) compared *Aequitriradites* they recovered from Cretaceous sections in Patagonia to the spores of the aquatic genus *Riella*. They noted that the genus was characteristic of temperate to warm and humid environmental conditions.

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

Pollen grains from gymnosperms and angiosperms are less abundant than the spores recovered; however, the diversity of these forms is interesting. Gymnosperm assemblages average 9.9% in relative abundance. Among the gymnosperms recovered, bisaccate grains are prevalent, with 4% 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. Of interest, species resembling the Southern genus *Phyllocladidites*, could be related to living *Lagarostrobos franklinii* (Vajda, Raine, and Hollis 2001), would indicate a preferred habitat on river banks or in proximity to a river. Other gymnosperm pollen, including *Araucariacites*, *Cycadopites* sp. *Taxodiaceaepollenites*, *Ephedripites*, *Zonalopollenites*, and *Classopollis* made up an average of 5.9% of the total yield. The association of *Taxodiaceae*, *Araucariaceae*, and *Pinaceae* has been reported for moist upland areas near water, and in temperate to subtropical environments (Orlansky 1971). *Taxodiaceaepollenites* 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 9.2% of the total yield. The assemblage of angiosperm pollen includes the following species: *Aquilapollenites psilatus*, *Cupanoidites* spp., *Cupuliferoidaepollenites* spp., *Foveotricolporites* spp., *Liliacidites* spp., *Margocolporites* spp., *Monosulcites spinosus*, *Nyssapollenites* spp., *Nyssapollenites albertensis*, *Retitricolpites* spp., *Tricolpites* spp, *Rousea* sp. and *Stellatopollis* spp. *Cupanoidites* spp is related to some of the *Cupanieae* from America, Madagascar, and Australia. These species occur in a wide range of humid, tropical to subtropical environments (Coetzee and Muller 1984). The gymnosperm *Cycadopites* and angiosperm *Monosulcites* are palm-like pollen found subtropical and tropical lowland swamp areas (Mann 2007; Braman and Koppelhus 2005). The most predominant genus of angiosperm is *Tricolpites*, representing 5.1% of the total specimen counted. Other angiosperm genera are rare or only occur intermittently.

Two other plant species, *Enzonalasporites bojatus* and *Aquilapollenites psilatus*, were recovered in the upper section of the Ferron-Notom Sandstone Member. *Aquilapollenites psilatus* has been reported in several studies, including from the Campanian-Maastrichtian Edmond Group of Alberta, Canada (Srivastava and Braman 2013). These authors suggested that this species was actually a trilete spore in equatorial view and proposed it be included in schizaeceans, *Cyathidites*
or *Deltoidospora*. Here we keep with the traditional view that this is actually a pollen (not a spore) that displays a very unique triprojectate morphology. Although they are not abundant, the occurrence of these species is noteworthy because these species are the only triprojectate pollen recovered along the section. *Enzonalasporites bojatus*, which has an uncertain affinity (Currie and 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 19.2% of the total specimens tabulated. Fungal spores are the most prominent, with 9.6% of the total. They are present throughout the section. This is interesting because most modern studies, done in hospitals on air sample quality, show that peaks in fungal spores often occur during hot, humid, rainy weather and during harvest seasons. 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 fresh water algal spores were also recovered, accounting for up to 6.5% of the total assemblage. Spores of fresh water algae include *Schizophacus parvus*, *Schizophacus* sp., *Schizosporis* sp., *Tetranguladinium* sp., *Chomotriletes minor*, and spores of *Zygnemaceae*. The green algae family *Zygnemataceae* is known as a paleoclimatological and paleoenvironmental indicator (Lindsröm 2013; van Geel et al. 1989; Yi 1997; Warny et al. 2009). For instance, *Tetranguladinium* have been reported in sediments of humid warm temperate to subtropical-tropical regions that have a dry season (Davis 1992; Lindström 2013; van Geel, Coope, and van der Hammen 1989; Yi 1997). *Tetrangulidinium* has also been reported from Upper Cretaceous non-marine sediments along the CWIS (Bercovici et al. 2009; Braman 2001; Lucas, Braman, and Spielmann 2003). *Tetranguladinium* was regarded as a dinoflagellate cyst or acritarch in previous studies (Batten and Lister 1988; Fensome et al. 1990); however, according to more recent studies, it has been reported as a zygospores of cyanobacteria or *Zygnemaceae* (Fensome and Williams 2004; Yi 1997). The spores of *Zygnemaceae* are excellent indicators of the fresh-water realm and their presence has been reported as an indicator of fresh water ponds in Antarctica during the Mid-Miocene Climatic Optimum (Warny et al. 2009).
Similar fresh-water algal taxa, to those recovered from the Ferron-Notom Sandstone, have also been reported in several formations throughout the CWIS (Nichols 1997; Braman and Sweet 2012; Orlansky 1971; Jameossanaie 1987).

Dinoflagellate cysts, although very rare in the section, were recovered in four main intervals of the Ferron-Notom Sandstone studied. The overall lack of dinoflagellate cysts might be indicative of floodplain deposition under low salinity sea-surface conditions. A similar lack of dinoflagellate cysts is observed today in sediments taken in various areas in the Mississippi Delta, in the Gulf of Mexico, where salinity ranges from 0 to 20 psu. The presence of diverse freshwater algae recovered from the Ferron-Notom Sandstone Member supports this hypothesis. Although they are rare, four occurrences are important to note, because they might indicate brief episodes of increased marine influence, or flooding surfaces with associated increases in salinity. From the bottom of the section, up to 7.70 m, is the only interval with an almost continuous presence of dinoflagellate cysts. These probably represent the time in the section with the most marine influence. Following this period, dinoflagellates appeared mostly at three levels; at 11.40 (5%), at 12.30 (3%) and at 17.35 m (4%).

Most of the spore and pollen species recovered are indicative of warm-loving, moist to marine environments, indicating that deposition occurred under the influence of a tropical climate in the floodplain. Therefore, mangrove pollen was expected to be found in these sequences, but this was not the case. The lack of mangrove pollen in the section is remarkable, and the reason for this absence is unknown. Traverse (2007) observed a similar lack of mangrove in other Cretaceous sections, and proposed a possible explanation in that Classopollis-producing plants may have occupied and dominated the mangrove habitat. Srivastava (1976) indicated that plants producing Classopollis have affinity with araucarian and/or gnetalean conifers. They occupied environments such as the well-drained soils of lowland coastal areas, preferring the warm climate of transgressive seas. Other studies (Heimhofer et al. 2008; Orlansky 1971) suggest that Classopollis indicates warm semi-arid to arid coastal palaeoenvironments, with pollen thought to be produced by Cheirolepidiaceae, an extinct group of thermophilous conifers. Heimhofer 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 reinforces our environmental interpretation.
4. DISCUSSION

4.1. Age of the Ferron-Notom Sandstone Member

Previous ammonite and inoceramid biostratigraphic studies constrain a Middle Turonian age for the Ferron-Notom sequence (e.g. Cobban et al. 2007; Peterson and Ryder 1975). Because of an erosional unconformity between the Ferron-Notom Sandstone Member and the Blue Gate Shale Member above, several ammonite zones representing Upper Turonian to Upper Coniacian time are missing. Additional work performed by Zhu et al. (2012) on bentonite beds refined the age of the Ferron-Notom Sandstone Member deposition to between 91.25 and 90.63 Ma, confirming the existence of an important unconformity between the Ferron-Notom Sandstone Member and the Blue Gate Shale Member.

Several palynostratigraphic events (acme, LOOPS, and HOOPs) are noted in Figure 4. 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 gymnosperm and spore taxa, such as Cicatricosisporites, Deltoidospora, and Appendicisporites recovered, have little biostratigraphic significance due to their long ranges. The best palynostratigraphic marker in the Ferron-Notom Sandstone is the tricolporate angiosperm species Nyssapollenites albertensis. This pollen taxon defines the Nyssapollenites albertensis Interval Zone (Nichols 1994, 1997). The presence of Nyssapollenites albertensis throughout 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., Classipollenites sp., Taxodiaceaeapollenites hiatus, Deltoidospora minor; Echinatisporis sp., Foramirusports simiscalaris, Cupuliferoidaepollenites sp., Gleicheniidites senonicus, and Laevigatosporites sp. The absence of the trporate angiosperm pollen Proteacidites is another indication of the Nyssapollenites albertensis Interval Zone (Nichols 1994; Braman and 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 (Nichols 1994; Dyman, Perry Jr, and Nichols 1988). The palynostratigraphy thus supports the bentonite age but does not improve the resolution.

4.2. Summary of the environmental significance of the assemblage recovered

The dominance in spores of ferns, hornworts and liverworts characterized all the depositional environments studied. Cryptogams require soil with high-moisture content to produce gametophytes. Hence the high abundance of spores suggests a deposition in a wetlands or other hydromorphic floodplain paleosol. The occurrence of fresh-water algal spores, including *Schizophacus parvus*, *Schizophacus* sp., *Schizosporis* sp., *Tetranguladinium* sp., *Chomotriletes minor* and *Zygnemaceae*, were identified in this section and indicates fresh-water input into the depositional environment, most likely from a fluvial source to the bay-head delta and/or floodplain. The abundance of fungal spores also supports a continuously wet tropical climate, especially in time of peaks in fungal spores. Gymnosperms such as Taxodiaceae (including the swamp cypress) and swamp palms, found throughout the Ferron-Notom section, are indicative of swamp environments, similar to those found today in South Louisiana.

Gymnosperm pollen such as Araucariaceae, Podocarpaceae, and Pinaceae, that might have inhabited upland areas (Orlansky 1971; Nichols and Brown 1992), were probably transported by wind or and water to the floodplain. The two types of vegetation recovered were most likely supported by the local topography, with gymnosperms (other than Taxodiaceae) being abundant in moist upland areas, while spore and angiosperm producing plants were growing in relatively low-lying or swampy areas.

In four stratigraphic levels, occurrences in dinoflagellate cysts indicate increased marine influence and higher sea-surface salinity, most likely during a transgressive phase, a time of maximum flooding, or in times of enhanced tidal influence.
5. CONCLUSION

A detailed palynological analysis of the Upper Cretaceous Ferron-Notom 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 age reported by Zhu et al. (2012). Based on the palynomorphs recovered, precise information concerning the depositional environments and the vegetation that covered the Notom delta area during the middle Turonian were acquired. Vegetation was dominated by ferns, hornworts and liverworts that shared the swamp/floodplain with swamp cypress and palm-like trees that produced Monocolpites and Cycadopites. Abundant fresh water algae and river-bank indicative species confirmed the deposition in hydromorphic floodplain paleoenvironments. Mangrove were absent from the assemblage, but their ecological niche was most likely occupied by an extinct species, Classopollis, known to favor lowland coastal areas, and the warm climate of transgressive seas. This interpretation is reinforced by the abundance of fungal spores, whose high abundance in modern air is often associated with warm humid climate. This climatic trend, a continuously wet tropical to subtropical climate, characterizes the entire interval studied. If an important Late Turonian cooling event [as suggested from oxygen-isotopic records; e.g. Voigt and Wiese (2000)] impacted the region, it occurred after the deposition of the interval studied. This time interval might best be characterized by a zone of non deposition during a regressive event, possibly time-equivalent to the disconformity identified between the two upper members of the Mancos Shale. Four episodes of dinoflagellate cyst occurrences indicate the presence of a maximum flooding surface and/or increased marine influence.
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## APPENDIX A: QUANTITATIVE DISTRIBUTION OF PALYNOMORPHS RECOVERED IN FERRON-NOTOM SECTION EXPRESSED IN ABSOLUTE ABUNDANCES

### Quantitative Distribution of Palynomorphs Recovered in Ferron-Notom Section

<table>
<thead>
<tr>
<th>Palynomorph</th>
<th>Absolute Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Araucariacites spp.</td>
<td>6.07 S-2</td>
</tr>
<tr>
<td>SP</td>
<td>6.30 S-4</td>
</tr>
<tr>
<td>5</td>
<td>7.90 S-20</td>
</tr>
<tr>
<td>2</td>
<td>8.80 S-29</td>
</tr>
<tr>
<td>3</td>
<td>9.20 S-34</td>
</tr>
<tr>
<td>10</td>
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**Notes:**
- Absolute abundances are expressed in S-notation, where S represents the taxonomic level.
- Samples are indicated by specific codes
- Total abundance values are also provided for reference.
### Range Chart of Palynomorphs recovered in the Ferron-Notom Section

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### Taxa Listed

- **Alisporites spp.**
- **Angiosperm undiff.**
- **Appendicisporites spp.**
- **Cicatricosisporites crassiterminatus**
- **Deltoidospora spp.**
- **SP**
- **Gleicheniella tenacissima**
- **Micropalaeocolpites injurionis**
- **Microreticulatisporites spp.**
- **Nyssapollenites spp.**
- **AL**
- **Schizophacus spp.**
- **Trilete undiff.**
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- **Foveotricolporites spp.**
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- **Cupuliferoidaepollenites spp.**
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- **Dinocysts indeterminate**
- **Cupulafacies concavus**
- **Aquilapollenites psilatus**
- **SP**
- **Monolites sp.**
- **SP**
- **Taxodiaceaepollenites hiatus**

### Additional Notes

- **Appendicisporites cristatus**
- **Appendicisporites major**
- **Appendicisporites insignis**
- **Cyathidites spp.**
- **FU**
- **Gleicheniella tenacissima**
- **Micropalaeocolpites injurionis**
- **Schizophacus spp.**
- **Trilete undiff.**
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- **Aquilapollenites psilatus**
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- **Monolites sp.**
- **SP**
- **Taxodiaceaepollenites hiatus**
APPENDIX C: ILLUSTRATIONS OF SELECTED TAXA IDENTIFIED IN FERRON-NOTOM SECTION

Plate 1

Light photomicrographs of species of terrestrial palynomorphs recovered in the studied section. All specimens are at the same magnification.

1. *Cicatricosisporites crassiterminatus*, Sample S-119 23.00 m.
2. *Deltoidospora* sp., Sample S-102 21.58 m.
5. *Appendicisporites unicus*, Sample S-111 22.35 m.
7. *Aequitriradites* sp., Sample S-11 7.00 m.
11. Pinaceae, Sample S-104 21.75 m.
12. *Classopolis* sp. Sample S-20 7.90 m.
**Plate 2**

Light photomicrographs of species of terrestrial palynomorphs recovered in the studied section. All specimens are at the same magnification.

1. *Cycadopites* sp., Sample S-90 16.10 m.


4-5. *Monosulcites* sp., Sample S-117 22.85 m, S-97E 20.55 m.

6. *Margocolporites* sp., Sample 119 23.00 m.


8. *Tetranguladinium* sp. Sample S-72 16.50 m.
VITA
Isil Akyuz was born in Ankara, Turkey. She obtained her bachelor’s degree in Geology from Ankara University in 2009. She was awarded a full scholarship by the Turkish Petroleum Corporation for M.S. degree in palynology at Louisiana State University in 2010. After the completion of her master’s degree, she will join to the Turkish Petroleum Corporation Research Centre as a palynologist/biostratigrapher.