PS Fourier Analysis of the Laminated Facies of the Middle Bakken Member, Sanish-Parshall Field, Mountrail County, North Dakota*

Virginia A. Gent[1] and Stephen A. Sonnenberg[2]

Search and Discovery Article #50996 (2014)**
Posted August 11, 2014

*Adapted from poster presentation given at AAPG Rocky Mountain Section Meeting, Denver, CO, July 20-22, 2014
**AAPG©2014 Serial rights given by author. For all other rights contact author directly.

[1]EOG Resources, Inc., Denver, CO (ginny_gent@eogresources.com)
[2]Colorado School of Mines, Golden, CO

Abstract

The Bakken Formation is a significant hydrocarbon source and reservoir within the Williston Basin. The Middle Bakken, which is the main horizontal target zone, is subdivided into several facies, including a laminated facies consisting predominately of 1 mm to 5 mm thick lamina pairs of very fine-grained light gray sandstone and very fine-grained dark gray siltstone. Additionally, each well in the eight well data set contained several laminations up to 1.2 cm thick. This study examines the origin of the laminated facies focusing on the origin of the parallel lamination. Recent hypotheses for the origin of the laminated facies include tidal, algal and hyperpycnal gravity flows. The resulting sedimentary structures are similar but are deposited in different shoreline configurations and water depths, which may result in different reservoir characteristics including lateral continuity. The primary analysis method utilizes Fast Fourier Transform (FFT) and periodograms of lamina sets to determine if an underlying tidal signature is present. Results of the spectral analysis show the parallel laminations were deposited in a lower intertidal environment with tidal periodicity ranging from a semi-diurnal to mixed tidal system and synodically driven tidal forces. A number of thick laminations indicated non-tidal influence in laminations such as storm events. Non-sinusoidal lamination pattern resulted from a low sediment influx and probably was the result of eolian transport. Low sediment influx and low tidal range resulted in thin lamination with lack of preservation with the tidal cycles.

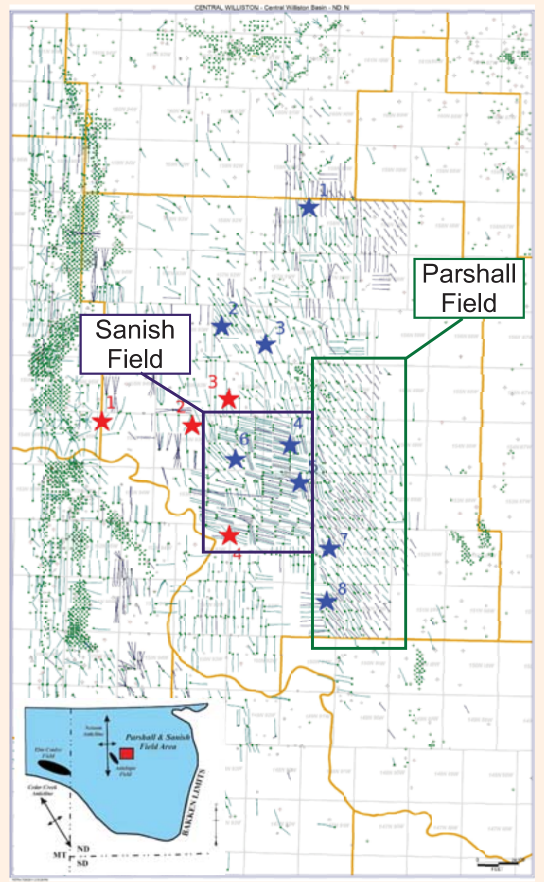
FOURIER ANALYSIS OF THE LAMINATED FACIES OF THE MIDDLE BAKKEN

ABSTRACT

Virginia A. Gent - EOG Resources,
Stephen A. Sonnenberg - Colorado School of Mines

The Bakken Formation is a significant hydrocarbon source and reservoir within the Williston Basin. The Middle Bakken, which is the main horizontal target zone, is subdivided into several facies, including a laminated facies consisting predominately of 1 mm to 5 mm thick lamina pairs of very fine grained light gray sandstone and very fine grained dark gray siltstone. Additionally, each well in the eight well data set contained several laminations up to 1.2 cm thick. This study examines the origin of the laminated facies focusing on the origin of the parallel lamination. Recent hypotheses for the origin of the laminated facies include tidal, algal and hyperpycnal gravity flows. The resulting sedimentary structures are similar but are deposited in different shoreline configurations and water depths, which may result in different reservoir characteristics including lateral continuity. The primary analysis method utilizes Fast Fourier Transform (FFT) and periodograms of lamina sets to determine if an underlying tidal signature is present.
Results of the spectral analysis show the parallel laminations were deposited in a lower intertidal environment with tidal periodicity ranging from a semidiurnal to mixed tidal system and synodically driven tidal forces. A number of thick laminations indicated non-tidal influence in laminations such as storm events. Non-sinusoidal lamination pattern resulted from a low sediment influx and probably was the result of eolian transport. Low sediment influx and low tidal range resulted in thin lamination with lack of preservation with the tidal cycles.

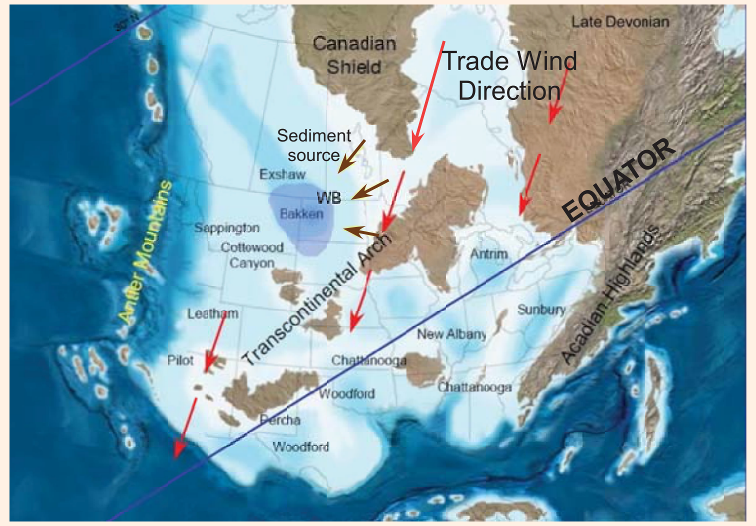
STUDY WELLS LOCATION



NDIC Core Photos and Core data
1) Sidonia 1-6H
2) Ross 7-17H
3) Nelson Farms 1-26H
4) Braaflat 11-11H
5) Sikes State 44-16H,
6) Deadwood Canyon Ranch 43-28H,
7) Van Hook 1-13H,
8) Liberty 2-11H.

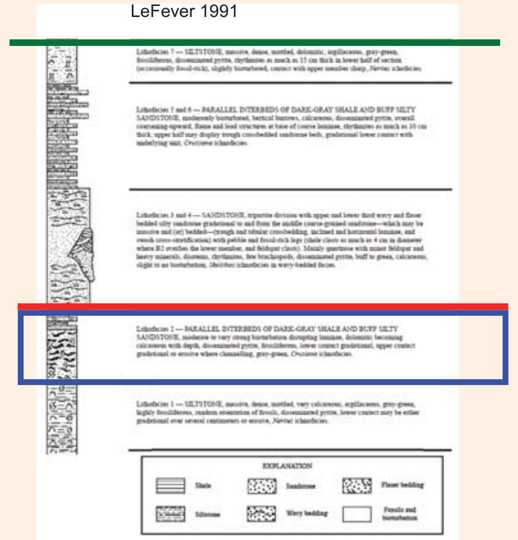
NDIC Core photos only
1) Sara Barstad 64-4H
2) Horst J 1-11H
3) Anderson 28-1H
4)Bartleson 44-1H.

Equator location and trade winds direction late Devonian - early Mississippian



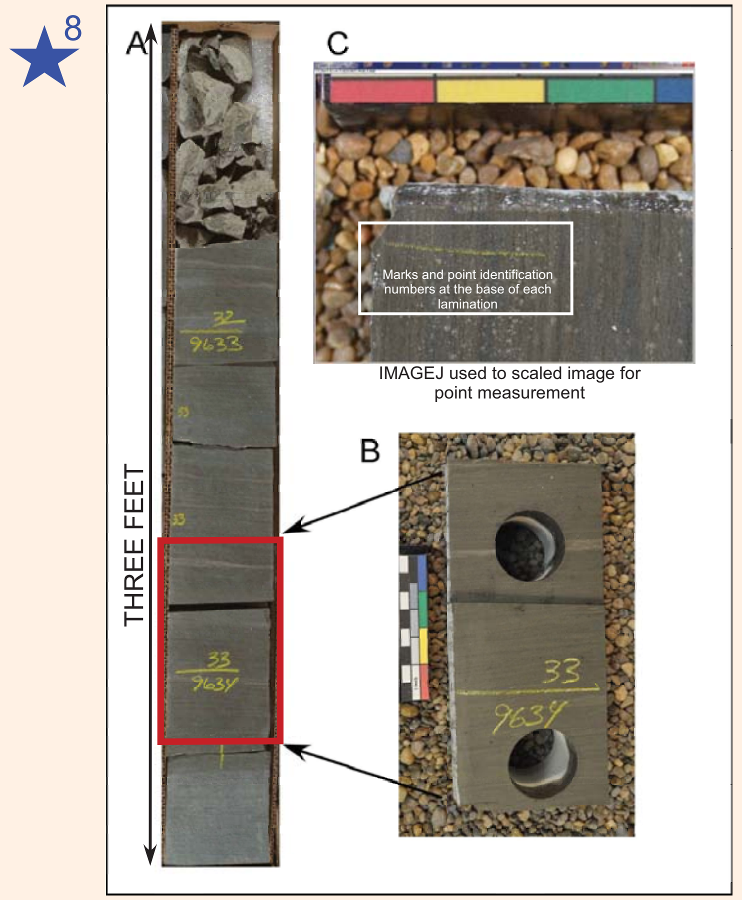
Sediment source for the study area is from the north and east based on proximity to the basin margin and paleotrade wind direction. The Williston Basin was located north of the equator and the paleotrade direction was from the northeast to the southwest. Evidence of a fluvial system is absent in the rock record due to erosion. Climatic condition were very arid with little sediment formation during Bakken deposition. Fine grained, well sorted quartz grains with a rounded texture indicates some sediment was sourced by eolian transport. (modified from Blakey, 2005, and Sonnenberg, 2010)

MIDDLE BAKKEN FACIES DESCRIPTION



Middle Bakken lithofacies descriptions. Facies C is highlighted with a blue box. A sequence boundary (red line) separates faces C and faces D. A maximum flooding surface (green line) is identified at the top of the Middle Bakken. (from LaFever et al., 1991 and Sonnenberg, 2010)

LAMINATED FACIES - LITHOFACIES C

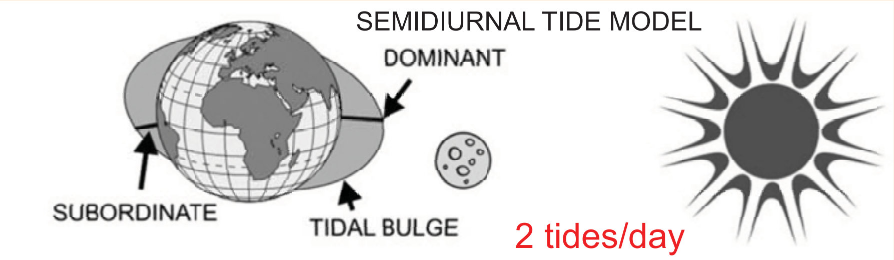


Core section (A) shows location of core photo (B) of facies C from Liberty 2-11H – laminated, argillaceous, calcareous siltstone/sandstone.

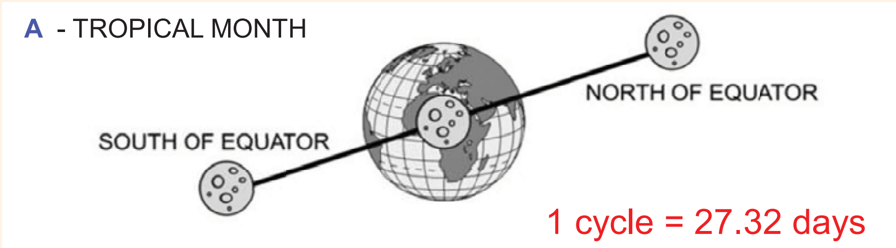
IMAGEJ (NIH public domain Java-based image processing software) scaled photograph (C) shows the multi-point identification used to indicate the base of each lamination. IMAGEJ creates an Excel spreadsheet with scaled x - y coordinates for each point. Lamination thickness is calculated by a simple subtraction of the appropriate coordinates.

SEMIDIURNAL TIDAL LUNAR MODEL

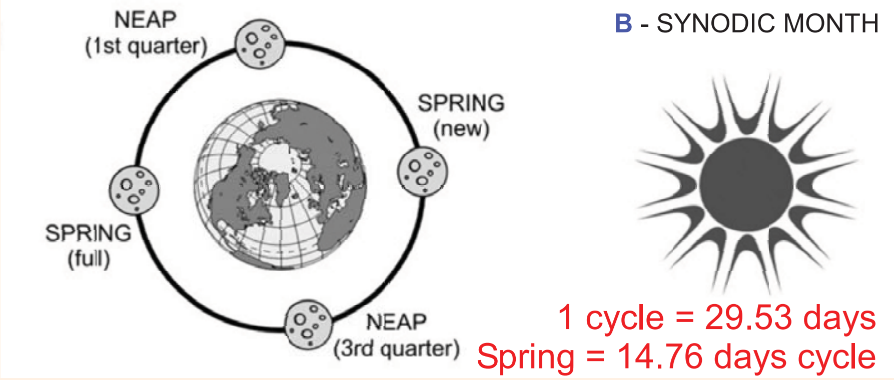
Gravitation fields from the Moon and Sun and variations in their position relative to the Earth causes oceanic bulges. The Earth's rotation through the bulges during a day produces two tides (**semidiurnal**). **Diurnal tides**, one tidal cycle per day, are rare but do occur in several locations world wide. All intermediate tidal systems are classified as **mixed tidal systems** with between one and two tides per day. (Mazumder and Arima, 2005; Archer, 1995; Kvale et al., 1998)



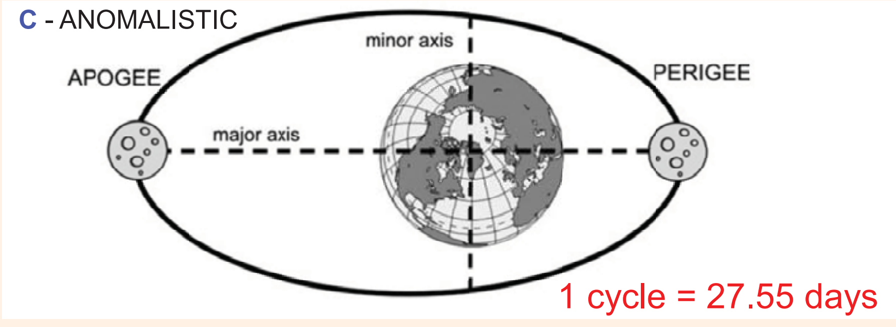
Idealized tidal model illustrating semidiurnal tides. Tidal cycles are the periodic rise and fall of the sea level in response to gravitational forces exerted on the Earth by the Sun and Moon



Tropical month: Tidal cycle related to the declination of the moon relative to the equator. The Moon's orbit is inclined to the equatorial plane. The tidal force is greatest when the Moon is at its maximum declination and least when the Moon's declination is zero. The period of a full tropical tidal cycle is 27.32 days



Synodic month: Tidal cycle related to the phase of the moon. A synodic month is the period of time from new moon to new moon and is 29.53 days long. Spring tides have a 14.76 day cycle. Spring tides are higher than neap tides due to the increase in gravitational pull associated with the Moon, Sun, and Earth alignment

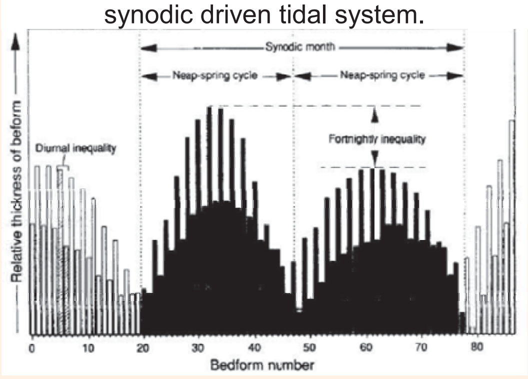


Anomalistic month: Tidal cycle related to the lunar distance from the earth. The Moon has an elliptical orbit and alternates between perigee and apogee. The elliptical orbit affects the magnitude of the two spring tides within a lunar month. The length of time required for the Moon to travel from perigee to perigee is 27.55 days

TIDAL RHYTHMITES

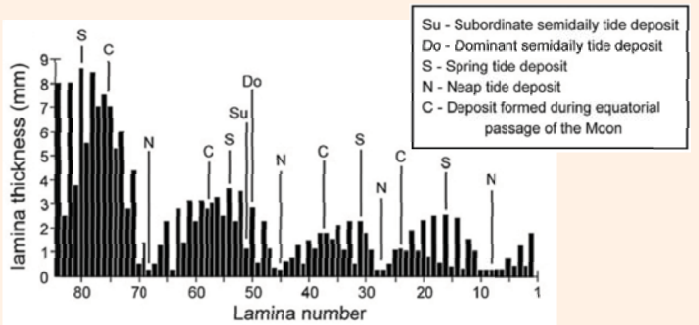
Tidal signatures are preserved in the rock record as vertically accreting parallel laminations or laterally accreting foresets. Tidal rhythmites are millimeter-scale laminations which exhibit rhythmic variation in lamina thickness and grain size. Mudstone drapes between sandstones lamination are indicative of slack periods in the tidal cycle.

Simulated cyclical tidal rhythmites in a synodic driven tidal system.

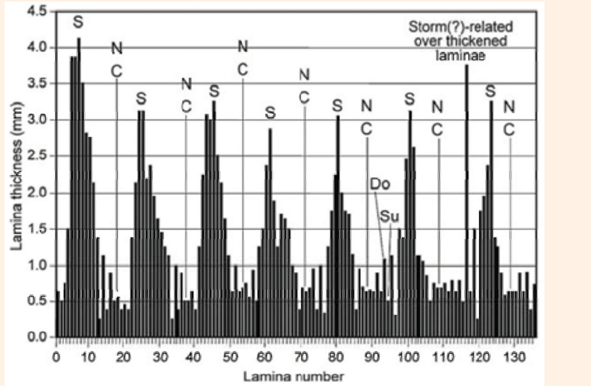


Diurnal inequality - The **lunar declination** (**B**) create high tide height differences during a 24 hour period.
Fortnightly inequality - related to variations in the **lunar distance** (**C**) during a complete lunar orbit
(from Archer, 1996).

CROSSOVER - Tidal laminations deposited when the Moon crosses over the Earth's equator. Identifiable by the dominate and subordinate tidal laminae in a semidiurnal cycle become equal in thickness (diurnal inequality is minimized) (from Kvale, 2006).



Synodic Crossover migration - The letter C identifies the laminations deposited as the moon passes over the equator (**B**). The diurnal inequality "moves" through the spring neap cycle.



Tropical Crossover - laminations are in phase with the neap tides. The diurnal inequality does not move through the tidal cycle.

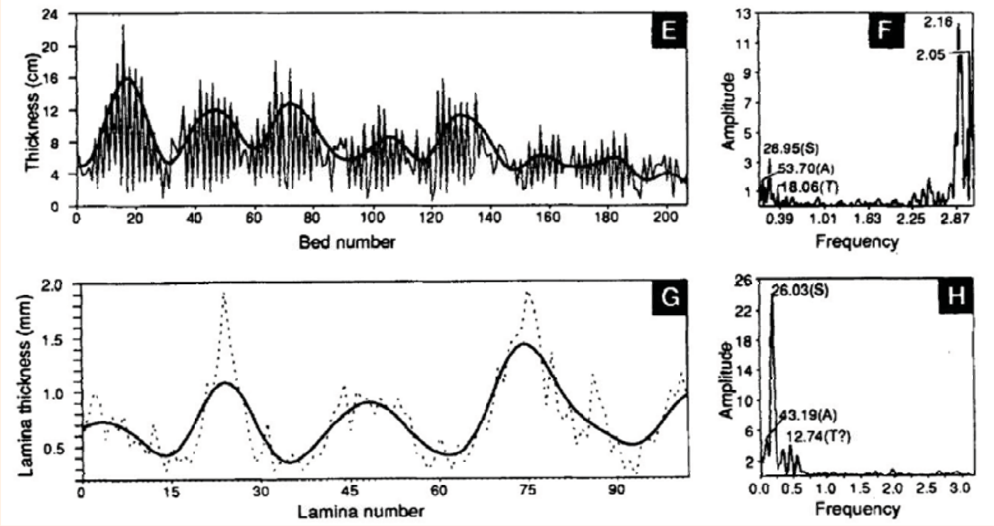
MEMBER, SANISH-PARSHALL FIELD, MONTRAIL COUNTY, NORTH DAKOTA

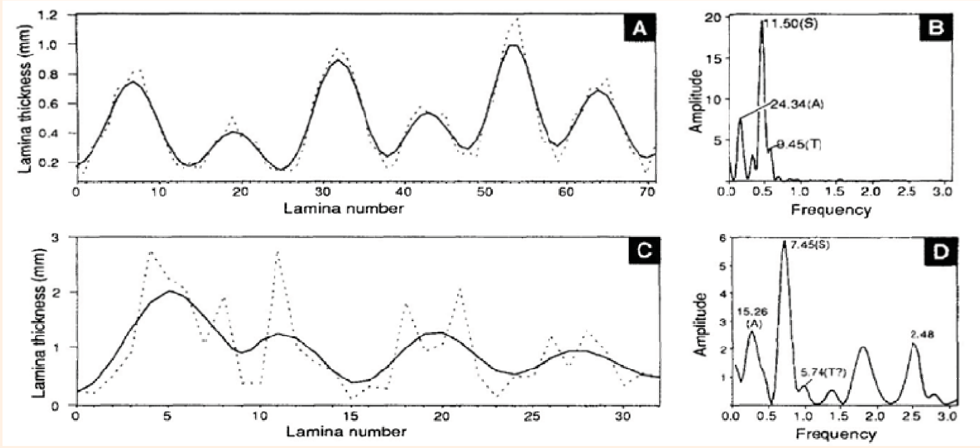
HARMONIC ANALYSIS FREQUENCY MODELING

Fundamental paleotidal periods can be determined from lamination thickness data using Fast Fourier Transform (FFT) algorithm and the output plotted in periodograms (Horne and Baliunas, 1986). Harmonic analysis using FFT resolves a sinusoidal time sequence function into the harmonic components of frequency and amplitude.

The FFT algorithm utilizes the Discrete Fourier Transform (DFT) to detect any underlying sinusoidal signal within a noisy data set. DFT is a computational method used to determine if spectral peaks are present within the data and their frequency (Burden et al., 1981).

The periodogram is a graphical representation of the spectral peaks and the related frequency



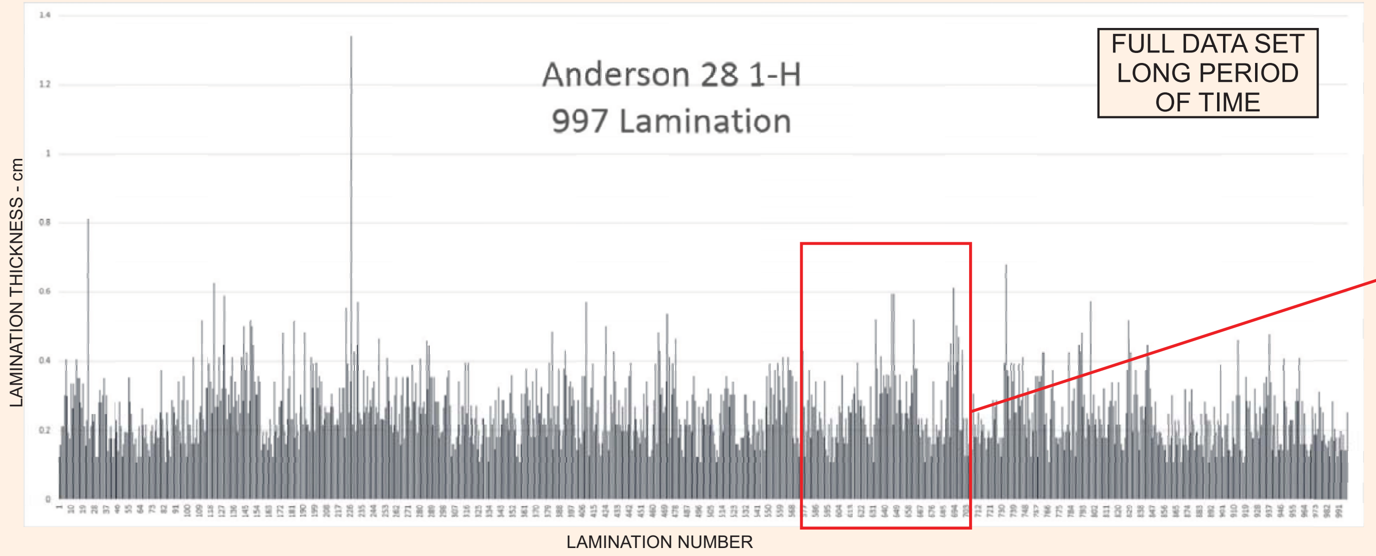


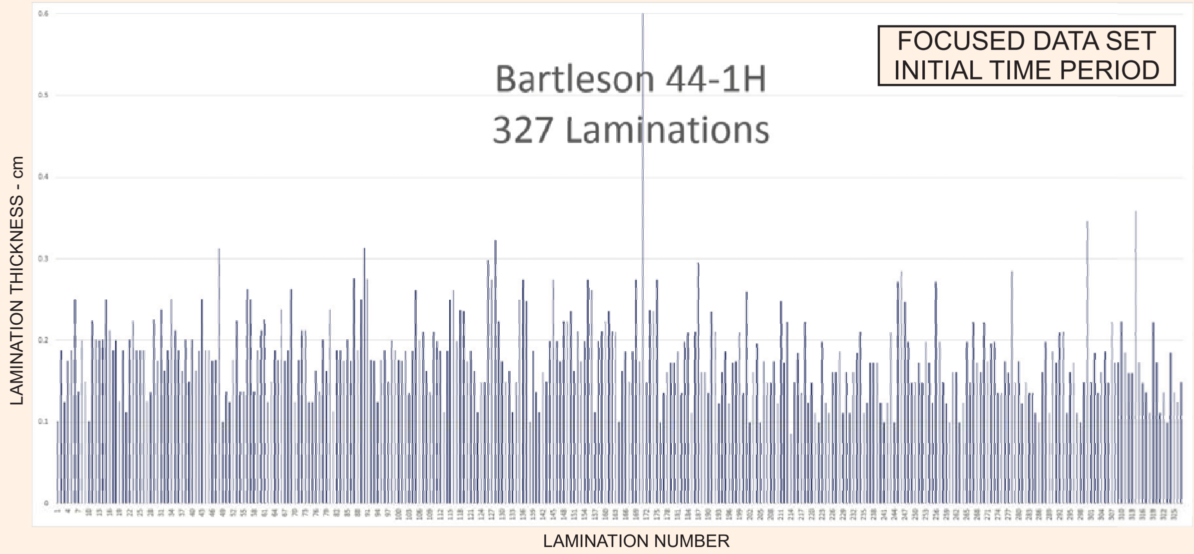
Examples of lamina bar chart and periodogram for a diurnal synodic driven tidal system. The lamina bar chart is a simple graph of lamina sample number vs. lamina thickness. The periodogram x-axis is frequency from the FFT output and ranges from 0 to pi (3.145). The y-axis is the amplitude from the FFT and significant amplitudes are labeled in bundles/cycle. (from Archer, 1996)

Frequency units: the number of cycles per unit time or tidal cycle length per lamination.

Period: the frequency divided into 2*pi. **The period will have the units laminations per tidal cycle**

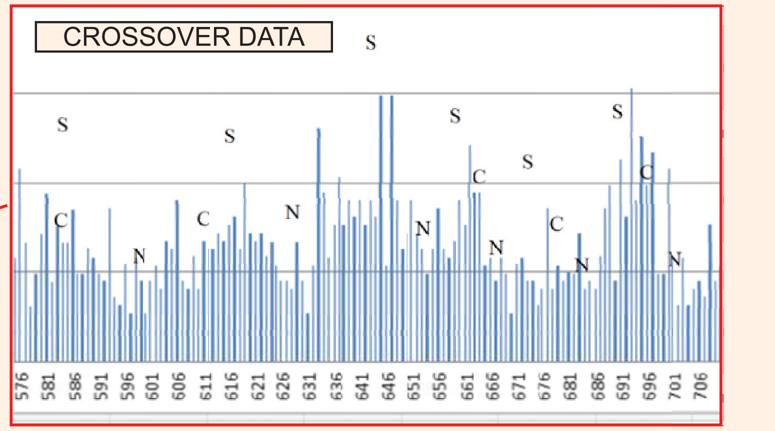
LAMINATION DATA SETS



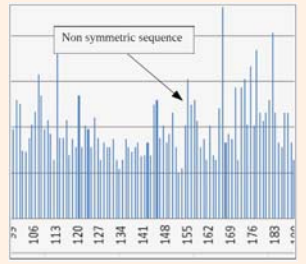


Lamination thicknesses ranged from less than 0.1 centimeters to greater than 1.2 centimeters. The laminations are thin compared to most other tidal data sets but are similar in thickness to the Elatina Formation of Australia, very fine-grained, glacial-sourced siltstone (Periodogram A to left) (Archer, 1996).

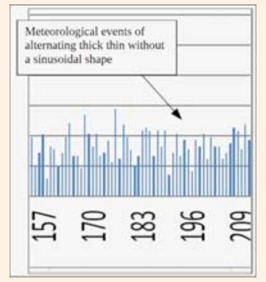
TIDAL OBSERVATIONS



The crossovers "moved" through the sequences, moving from the neap-spring side to the spring-neap side of the sequences. This moving of the crossovers indicates the tidal sequences are controlled by synodic rather than tropical driven tidal forces.



Non-symmetric sequence indicates non preservation



Non-sinusoidal sequence indicates meteorological deposition

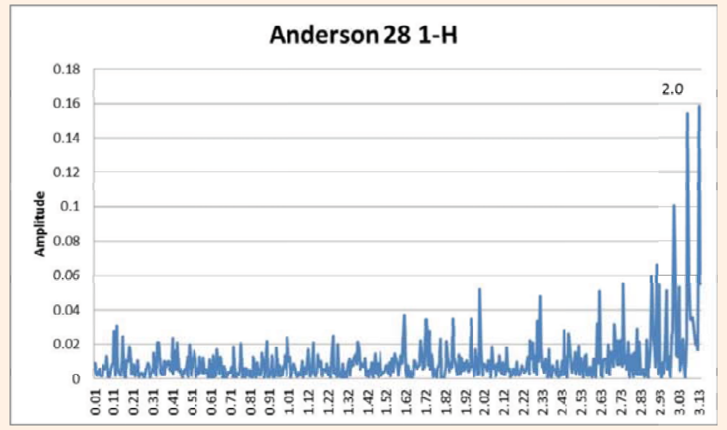
CONCLUSIONS

There is a tidal signature in the laminations and is interpreted as semidiurnal to mixed tides in a synodic tidal system.

Fewer laminations per cycle then expected indicates non preservation and suggest the sediment was deposited in a lower intertidal environment

PERIODOGRAMS

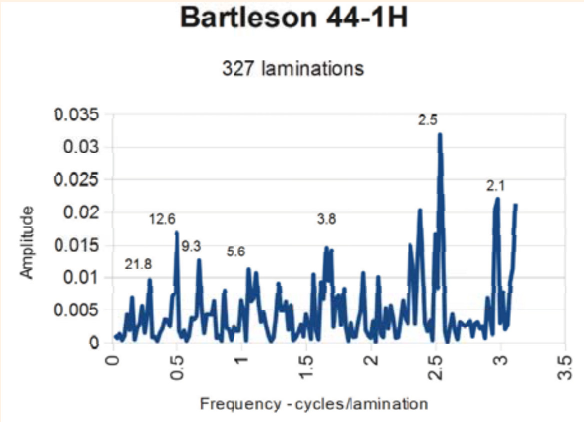
Two sets of periodograms were generated for each data set. The first set included all the lamination data representing a long period of time and provides an overall spectral peak characteristic for the data. The second set focused on a smaller set of 100 to 200 laminations in the lower section of facies C. The lower laminations provide the best tidal signature indication because potential lamination preservation decreased as the accommodation space is filled (Archer et al., 1991). The smaller data sets provide a more accurate picture of the tidal signature in the section with the best potential lamination preservation.



Anderson 28 1-H periodogram for 997 laminations.

Strong spectral peak is noted at a frequency of 3.13 or a period of 2.0 indicating a semidiurnal pattern.

Thick-thin lamination alternations in bar chart corroborates presence of a semidiurnal to mixed tidal system.



Bartleson 44-1H periodogram - first 327 laminations

Strong peaks from 4 to 7 correspond to the minimum number of laminations per cycle observed in the bar charts. These peaks most likely are the result of storm or other non-meteorological events.

The peaks in the 10 to 12 lamination per cycle and the 15 to 21 laminations per cycle are similar to the averages observed in the bar charts

LAMINATION COUNT BASED ON NEAP TO NEAP CYCLES

Number of laminations per cycle range from 25 to 29.

The two or three non-sinusoidal lam/cycle and anomalously thick laminations may represent additional laminations deposited during non-tidal events such as storm events or eolian sediment transport.

.

Low sedimentation rates and low energy periods results in thin laminations and can reduce the number of laminations within a tidal cycle.

Most lamination sequences within the study area contain fewer laminations than expected for a tidal sequence. This indicates the laminations were deposited in a lower intertidal environment.

Well Name	Average lams per cycle	Standard dev.	Min. lams per cycle	Max. lams per cycle	Num of cycles	Total lams measured
Anderson 28 1-H	18.1	6.3	4	31	58	997
Sara Barstad 6-44H	16.3	5.1	5	28	66	1129
Bartleson 44-1H	15.2	7.4	5	31	96	1524
Braaflat 11-11H	12	5.3	4	26	91	1119
Deadwood Canyon Ranch 43-28H	12.7	5.1	5	32	82	1055
Horst J 1-11H	11.5	4.3	5	25	40	466
Liberty 2-11H	11.6	5.6	5	26	43	505
Ross 7-17H	14	5.3	5	29	87	1264
Sikes State 44-16H	13.6	5.7	6	29	89	1294
Van Hook 1-13H	13	3.9	4	20	36	480

SMALL DATA SET PERIODOGRAM SPECTRAL PEAK OCCURRENCES

Well Name	Semi-Diurnal		Meteorological		TIDAL		Climatic
Sara Barstad 6-44H	2	2.5	4	6.6		15 to 21 w	56
Bartleson 44-1H	2	2.6	3 to 4	7	12.6	22 w	
Deadwood Canyon Ranch 43-28H	2.2	2.8	3 to 4	7.5	10 to 11	16	
Horst J 1-11H	2	2.5	3.2	6.6		18	
Ross 7-17H	2	2.5	3.7	5.9	10 to 11	19 to 21 w	41

Archer, A.W., E.P. Kvale, and H.R. Johnson, 1991, Analysis of modern equatorial tidal periodicities as a test of information encoded in ancient tidal rhythmites. In Smith, D.G., G.E. Reinson, B.A. Zaitlin, and R.A. Rahmani (Eds.), , Canadian Society of Petroleum Geologists, Memoir 16, pp. 189196

Archer, A.W., 1995, Modeling of cyclic tidal rhythmites based on a range of diurnal to semidiurnal tidal-station data. Marine Geology, v.123. pp. 110

Archer, A.W., 1996, Reliability of lunar orbital periods extracted from ancient cyclic tidal rhythmites. Earth and Planetary Science Letters, v.141. pp. 110

Blakey, R., 2005, North American paleogeographic maps, early Mississippian (345MA). Web July 12, 2011. http://jan.ucc.nau.edu/rcb7/namD360.jpg.

Kvale, K.P., 2006, The origin of neapspring tidal cycles. Marine Geology, v.235. pp. 518

LeFever, J.A., C.A. Martiniuk, E.F.R. Dancsok, and P.A. Mahnic, 1991, Petroleum Potential of the Middle Member, Bakken Formation, Williston Basin. In Christopher, J.E., and Haidl F (Eds.), Sixth International Williston Basin Symposium: Saskatchewan Geological Society, , pp. 7494

Mazumder, R., and M. Arima, 2005, Tidal rhythmites and their implications. Earth ScienceReviews, v.69. pp. 7995

Sonnenberg, S.A., 2010, The Petroleum System of the Williston Basin. Questar E&P Presentation Powerpoint, .

Semi-diurnal tidal signature: 2-3 laminations/cycle. The smaller data set periodograms all show strong spectral peak. This corroborates both the larger periodogram data sets and the bar chart observations.

Storm or other non-meteorological event: Strong peaks from 4 to 7 correspond to the minimum number of laminations per cycle observed in the bar charts.

Synodic tidal signature: The peaks in the 10 to 12 lamination per cycle and the 15 to 21 laminations per cycle are similar to the averages observed in the bar charts. Slight differences are expected because the bar chart is a numerical average over the entire section.

Anomalistic or seasonal influences: The peak of 56 in the Sara Barstad 6-44H and 41 in the Ross 7-17H. Preservation of this signal may depend on location within the basin.

Diminished amplitude signal is expected with a lack of preserved laminations based on the loss of smaller high-tide (Kvale et al. 1995).