LOWER CAMBRIAN GAMMA LOG DATA FROM WELLS IN WESTERN VERMONT AND NORTHEASTERN NEW YORK

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Abstract:

This report is broken into two parts corresponding with plate 1 and plate 2. Plate 1 outlines the acquisition and processing of well data from two wells in western Vermont. Included in this are the tools used and methods for reducing noise in the data. Additionally, examples of specific lithologies seen in borehole camera imagery are outlined. Plate 2 compares cyclicity seen in the processed Vermont gamma-ray well data to gamma-ray well data in correlative stratigraphy of New York (Altona Formation of the Potsdam Group).

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Plate 1: Data Acquisition & Processing of Two Subsurface Wells through the Monkton Formation in Burlington, VT

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Plate 1: Abstract

This study presents gamma emission data for the Lower Cambrian Monkton Formation. The raw data was aquired from two wells in Burlington, VT. This work describes the tools and methods of aquisition for this data from two open hole wells. Additionally, a borehole camera was used in one of the wells to help identify specific lithologies within the Monkton Formation. Examples of this are outlined in this work. Further details about the borehole imagery and how it is used in interpreting the Monkton Formation can be found in Maguire (2018).

The intensity of gamma emissions is controlled by the abundance of radioactivity-emitting minerals present in different lithologies, however gamma log data is subject to random noise due to the counting statistics other sources of error and because radioactive processes are inherently subject to statistical variation (Czubek, 1986). This work describes the series of data filtering steps to remove unusable data, adjust for water within the wells and to reduce noise.

Methods

Both the Fleming and the previously logged Champlain College wells are located within the city limits of Burlington, VT. The Fleming well is a former teaching well located on the University of Vermont campus (Figure 1) that was drilled in 1996. The total depth of the well is ~ 91 meters with the first 41 meters in casing. Gamma data was collected using a Mount Sopris Instruments 2PGA-1000 POLY- GAMMA PROBE taking readings in 5 cm increments. A caliper tool was also used to log the diameter of the entire well to be used in open water filled holes corrections. Water is located within the well at ~68 meters in depth. Additionally, a downhole camera was used to get imagery of the stratigraphy through the uncased portion of the well. The previously logged Champlain College data was acquired from Jon Kim of the VT State Geology Survey. This well was logged by Jon Kim and Edwin Romanowicz (S.U.N.Y Plattsburgh) in 2012 using the same Mount Sopris Instruments 2PGA-1000 POLY-GAMMA PROBE taking reading in 3 cm increments.

A series of data filtering steps were taken to remove unusable data, adjust for water within the wells and to reduce noise. The same filtering procedures were done on both wells. All data from in well casings was deemed unusable and omitted from discussions. Though attenuation from well casing can be adjusted for, a lack of driller notes from both wells made it impossible to identify where overburden transitioned into bedrock. This lead to all data from stratigraphy within the well casing to be omitted from this study. Both the Champlain College and Fleming wells contained water below ~56 and ~68 meters, respectively. An industry standard correction factor for all points, within open water filled holes, based on hole diameter was applied to these portions of the wells. (Mont Sopris Instruments, 2008).

Smoothing of the raw gamma emission data was completed to suppress statistical noise and account for variation in vertical resolution inherit to gamma logging tools. Two assumptions about borehole gamma logging were used in setting the parameters for filtering. First, the vertical resolution of a gamma probe is between 30-60 cm which means that any gamma data point could be measuring emissions over this interval of well stratigraphy. Second, across this vertical resolution readings are being picked up in a normal distribution relative to the center of the sensor (Cannon, 2015; Gadeken et al., 1997; Theys, 1999). To account for these two factors a moving average was taken vertically over ~40cm of data points in the well log and weighted over a normal distribution. The normal distribution curve used was a Hanning Curve, such that values in the center of the data points being averaged were weighted more in the moving average than those at the top and bottom or, in other words, the gamma probe, over the vertical resolution, was less influenced by rocks further away from it than by the rocks directly adjacent to it.

Figure 2: Champlain Well Gamma Data

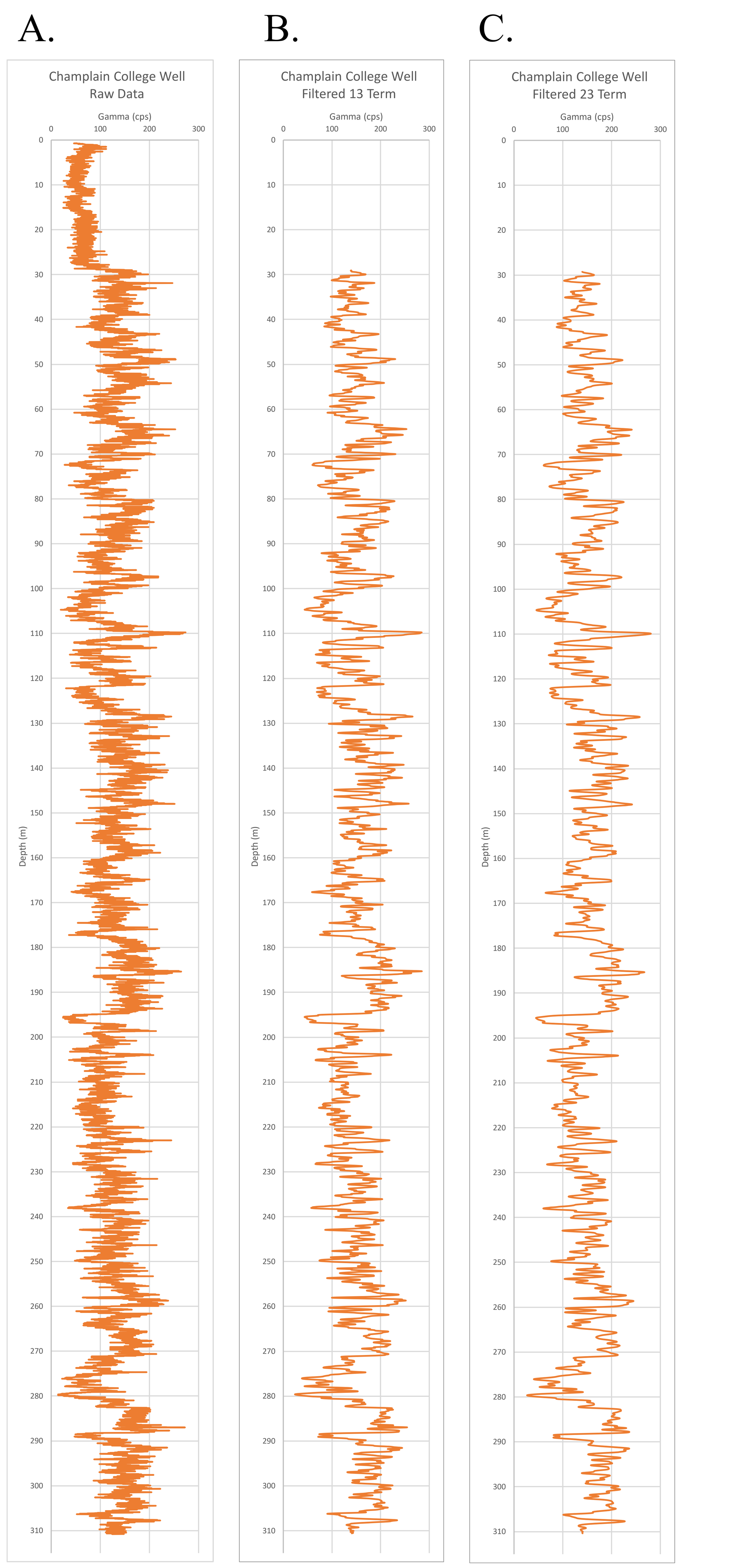

Figure 2: Gamma well log data from the Champlain College Well. The Y axis represents the depth in (m) within the well, while the X axis represents the gamma value in counts per second (cps). (A) is the raw gamma data with no filtering. Not knowing the accuracy of the drillers notes both (B) & (C) have had the data from within the well casing removed when doing subsurface interpretations. Additionally, both (B) & (C) have been adjusted for open hole well with water per the Mount Sopris Instruments 2PGA-1000 POLY- GAMMA PROBE manual. (B) has been smoothed using a 13 term weighted moving average over a normally distributed Hanning curve, representative of a vertical resolution of ~30 cm. (C) has been smoothed using a 23 term weighted moving average over a normally distributed Hanning curve, representative of a vertical resolution of ~60 cm.

Figure 3: Fleming Well Gamma Data

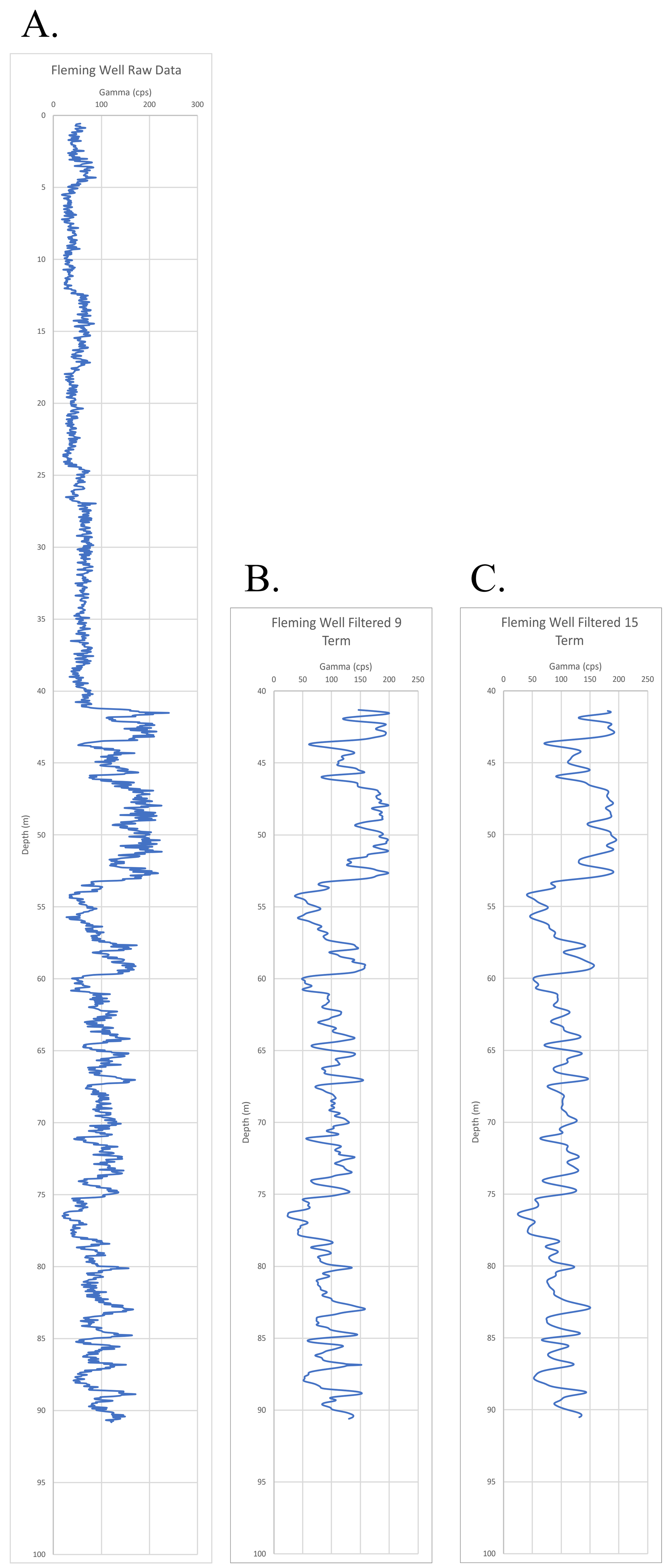

Figure 3: Gamma well log data from the Fleming Well. The Y axis represents the depth in (m) within the well, while the X axis represents the gamma value in counts per second (cps). (A) is the raw gamma data with no filtering. Not knowing the accuracy of the drillers notes both (B) & (C) have had the data from within the well casing removed when doing subsurface interpretations. Additionally, both (B) & (C) have been adjusted for open hole well with water per the Mount Sopris Instruments 2PGA-1000 POLY- GAMMA PROBE manual. (B) has been smoothed using a 9 term weighted moving average over a normally distributed Hanning curve, representative of a vertical resolution of ~30 cm. (C) has been smoothed using a 15 term weighted moving average over a normally distributed Hanning curve, representative of a vertical resolution of ~60 cm.

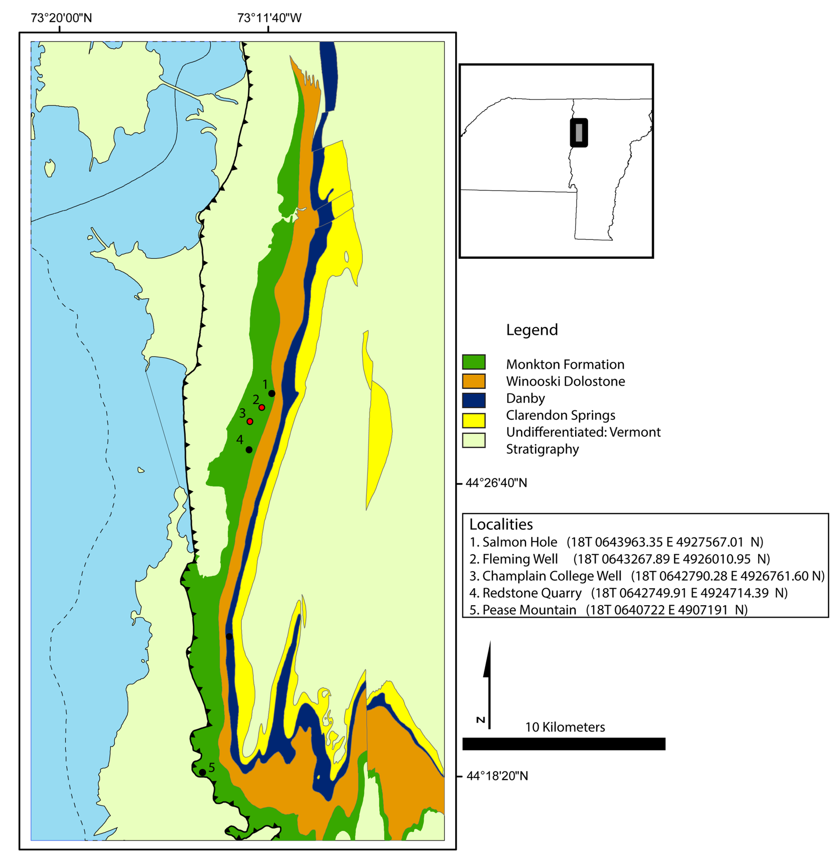

Figure 1: Locality Map

Figure 1: Simplified bedrock geologic map of Vermont showing localities for wells and outcrop studies within the Monkton Formation. Base map is the bedrock geologic map of Vermont Ratcliffe et al. (2011).

Figure 4. Fleming Well Borehole Image Examples

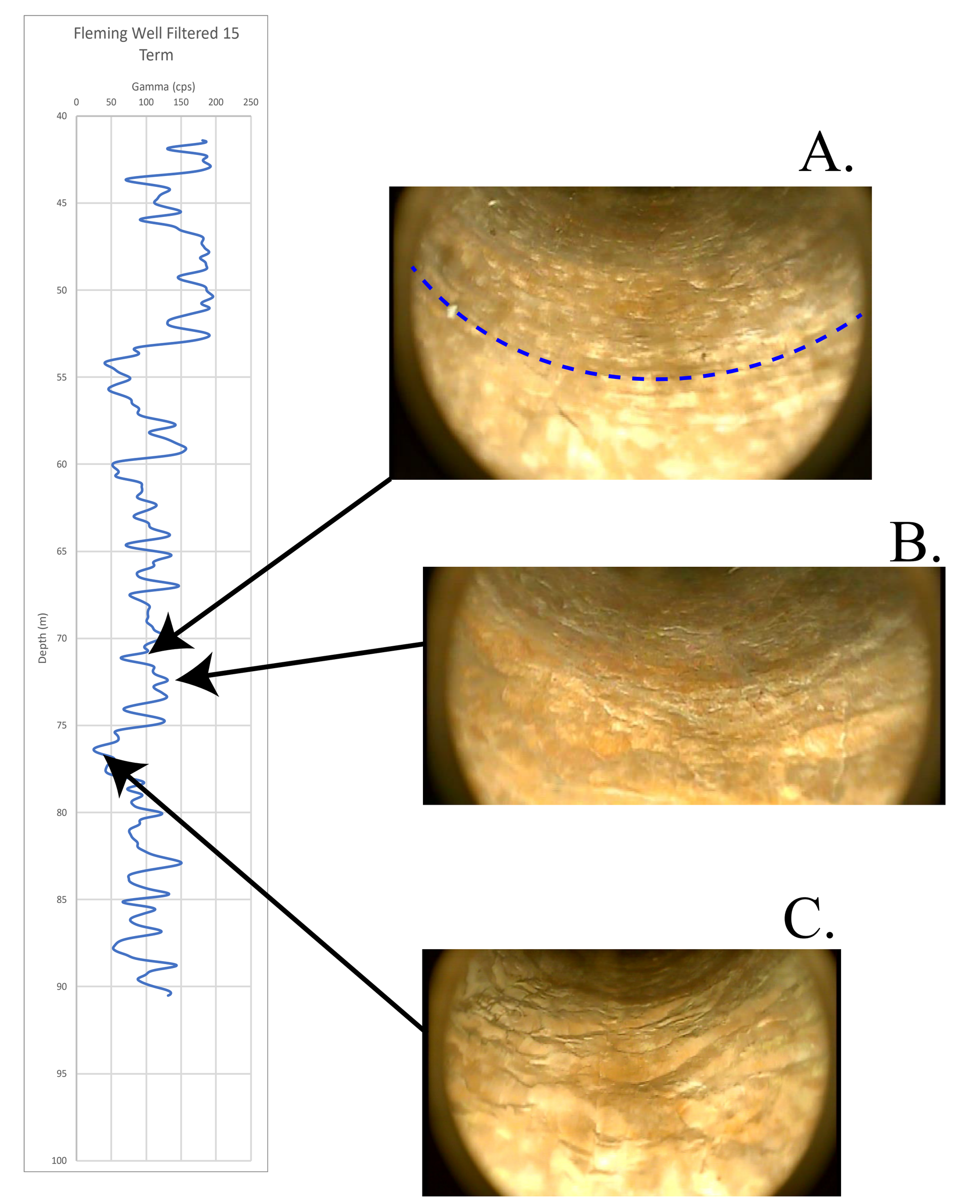

Figure 4: Fleming Well gamma log data smoothed with a 15-term moving average and associated borehole images of Monkton Formation lithologies. (A) shows an example of the supratidal/high intertidal cryptalgalaminate dolostone and a low gamma value (50-100 cps). The blue dashed line represents a flooding surface and transition back into an intertidal environment seen by the increase in darker terrigenous materials. (B) highlights intertidal sand, silts and dolostones representative of the tidal flat. The sawtooth shape seen on the gamma represents the interbedding of these rock types that have contrasting gamma values. Though dolostones are present, the overall high gamma values (100-150 cps) are seen because of the higher amounts of finer grained terrigenous silts. (C) has the lowest gamma values of any lithology (<50 cps) and the borehole image shows the light colored structureless dolostone being identified as a platform carbonate.

Plate 2: Comparison of cyclicity in late Lower Cambrian gamma ray data from wells in VT and NY

Plate 2: Abstract

Gamma ray emission data from wells through the Altona Formation in northern NY and the Monkton Formation in western Vermont reveal cycles in lithology that are related to sea level and sediment supply. The Monkton has more well developed meter-scale cyclicity than the Altona. Trends in accommodation space recorded in the stratigraphy of both units indicate that the Monkton and lower Altona record deposition under conditions of decreasing accommodation space. Biostratigraphic data that indicates that the two units are partially correlative in age are compared to sea level trends interpreted from gamma data. A thick carbonate-dominated sequence in the middle of the Altona is interpreted to record rapid sea level rise which was followed by sediment supply equilibration in the upper part of the unit. These two stages would be represented in Vermont by deposition of the Winooski Formation.

WAVELET METHODS:

A Continuous Wavelet Transform (CWT) is a mathematical transform to deconstruct a signal into a load of wavelets being added together, similar to a Fourier Transform (FT), which deconstructs a signal from the time domain to the frequency domain in terms of sine and cosine terms. The benefit of the CWT over the FT is that it is deconstructing the signal with finite wavelets at a range of periods, while maintaining the position within the signal where that comparison in occurring. In the case of well logs the time domain is synonymous for the depth domain, or position in the well. The CWT can be used for detection of superimposed periodic cycles (Prokoph and Barthelmes 1996). The CWT with a Morlet function was used because the similarity to a periodic sinusoidal function would be best to pick up cyclic variation on the gamma log between cycles of clastic and carbonate lithologies.

Raw data was smoothed to reduce statistical noise inherent in radioactive decay systems and well logging acquisition. Smoothing was done using a weighted moving average detail of which can be seen in the methods section of plate 1. The continuous wavelet transform was completed using the biwavelet package for for R-Studio developed by Tarik C. Gouhier, Aslak Grinsted and Viliam Simko (2018).

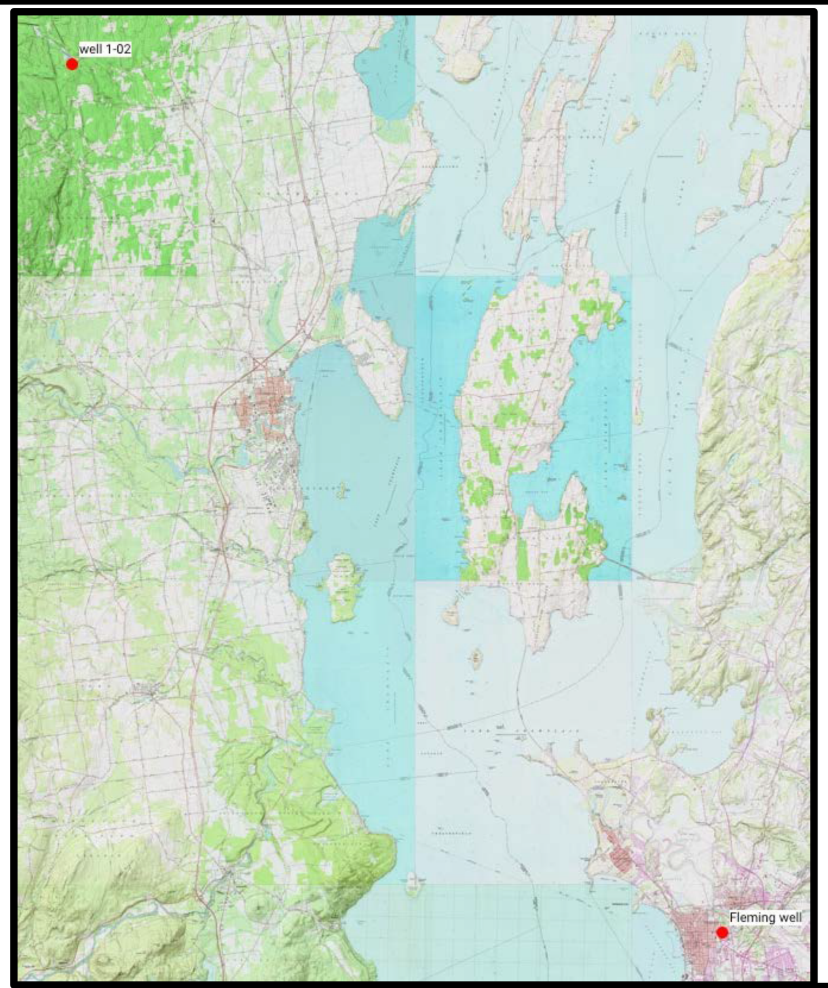

Figure 1: Locality map for wells:
Altona 1-02: 18T612713E, 4965704N;
Champlain College: 18T0642790.28E, 4926761.60N;

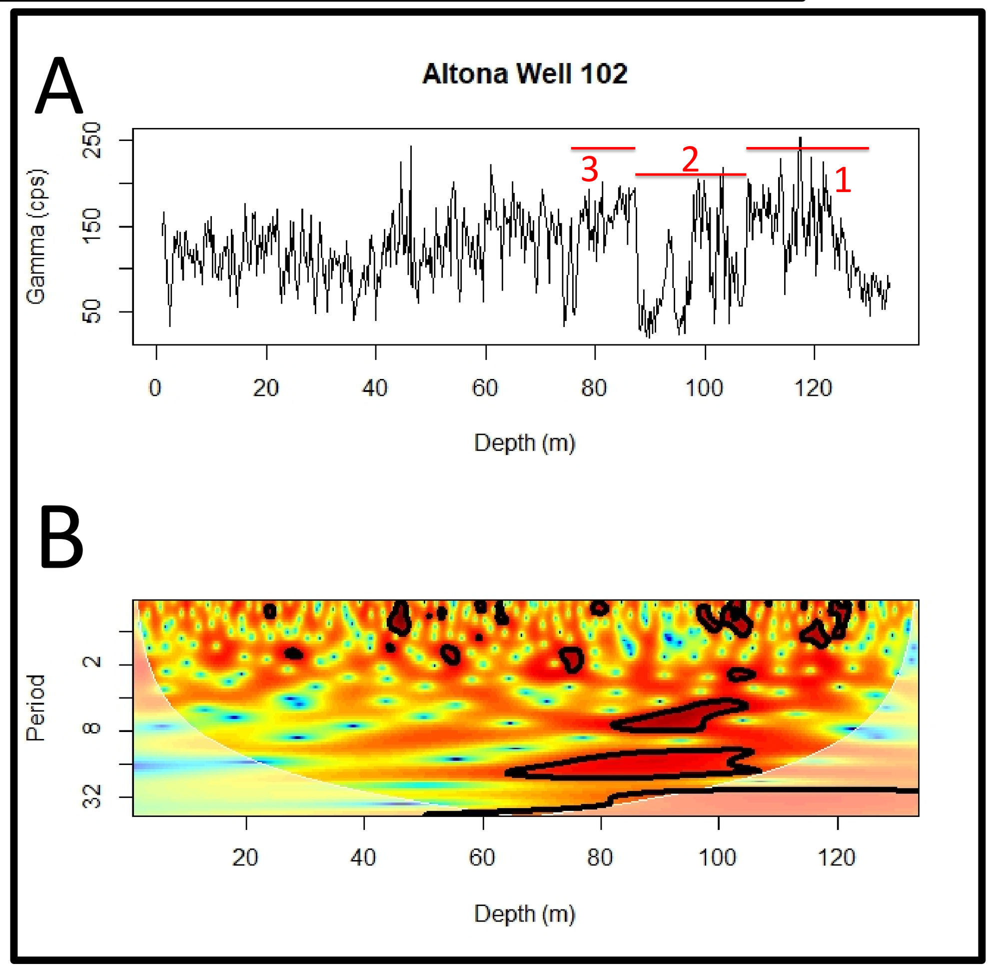

Figure 4: A: Horizontal red lines represent 3 intervals in the Altona with different characteristic gamma patterns. **B.** Condensed gamma log and wavelet analysis, Altona Fm. The dark red colors represent statistically significant cyclicity at the period represented by the Y axis of the graph. The data shows that meter-scale cycles are present in the stratigraphy best below 95 meters in the well; meter-scale cycles are less well developed in the upper 60 meters of the well. Longer period cycles (>10's meters) are present in the lower half of the unit.

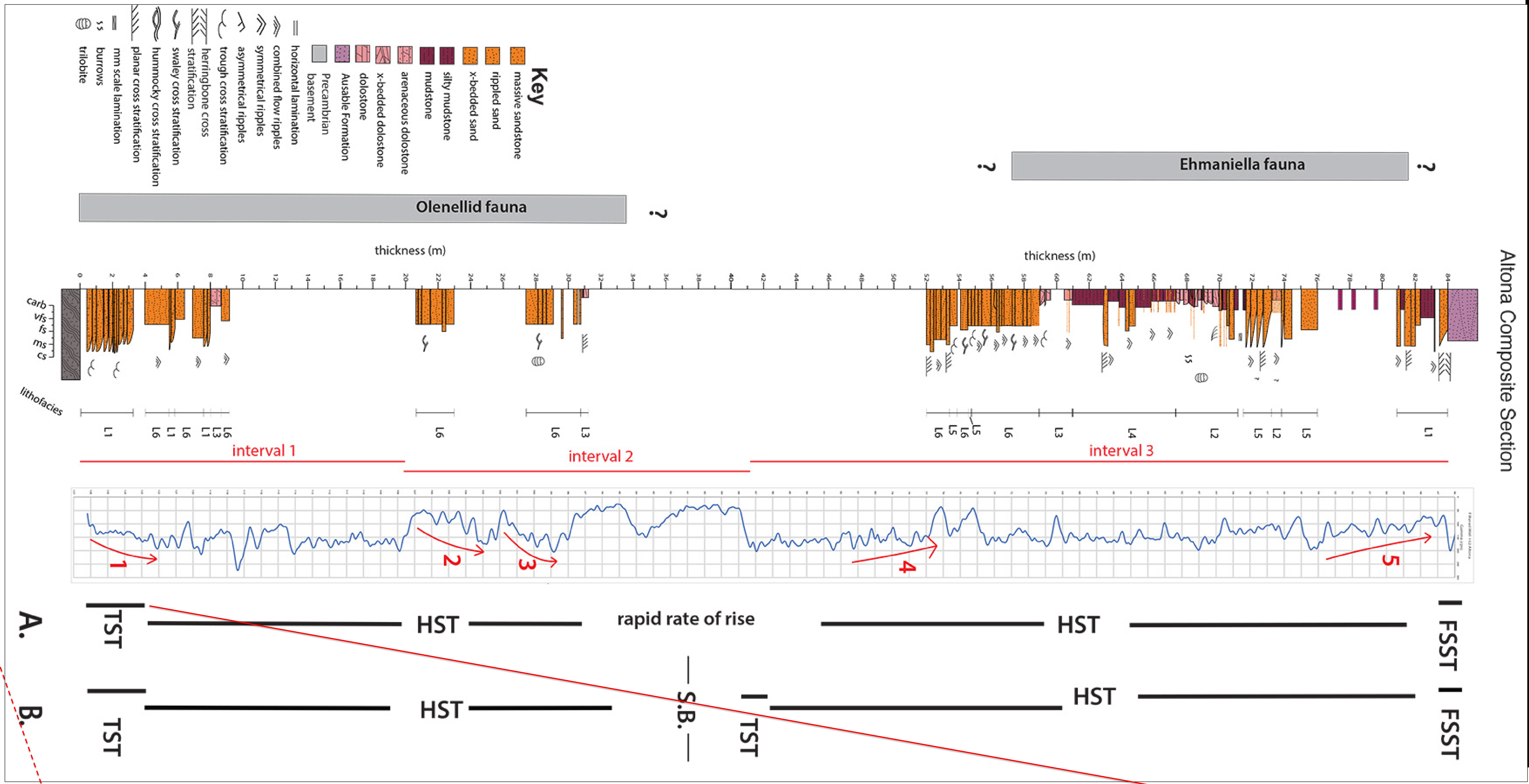

Figure 2: Altona Formation stratigraphic column constructed from field data plotted against a reduced gamma log profile from Well 1-02.
The interpretation of cycles 1-5 as well as the system tracts represented by the stratigraphy is contained in Brink, et al. (2018). Red lines between the Altona and Monkton Formation stratigraphic columns represent the portions of these units that record deposition in the same systems tracts and are thought to be correlative. The Altona TST is thin due to the later onlap in NY. The bulk of the Altona is deposited in HST. Maguire, et al (2018) describe the changes in accommodation space in the Monkton and the implications of this to the rate of sea level change. These interpretations suggest that the Winooski Formation in VT might be correlative with the upper 40 meters of the Altona.

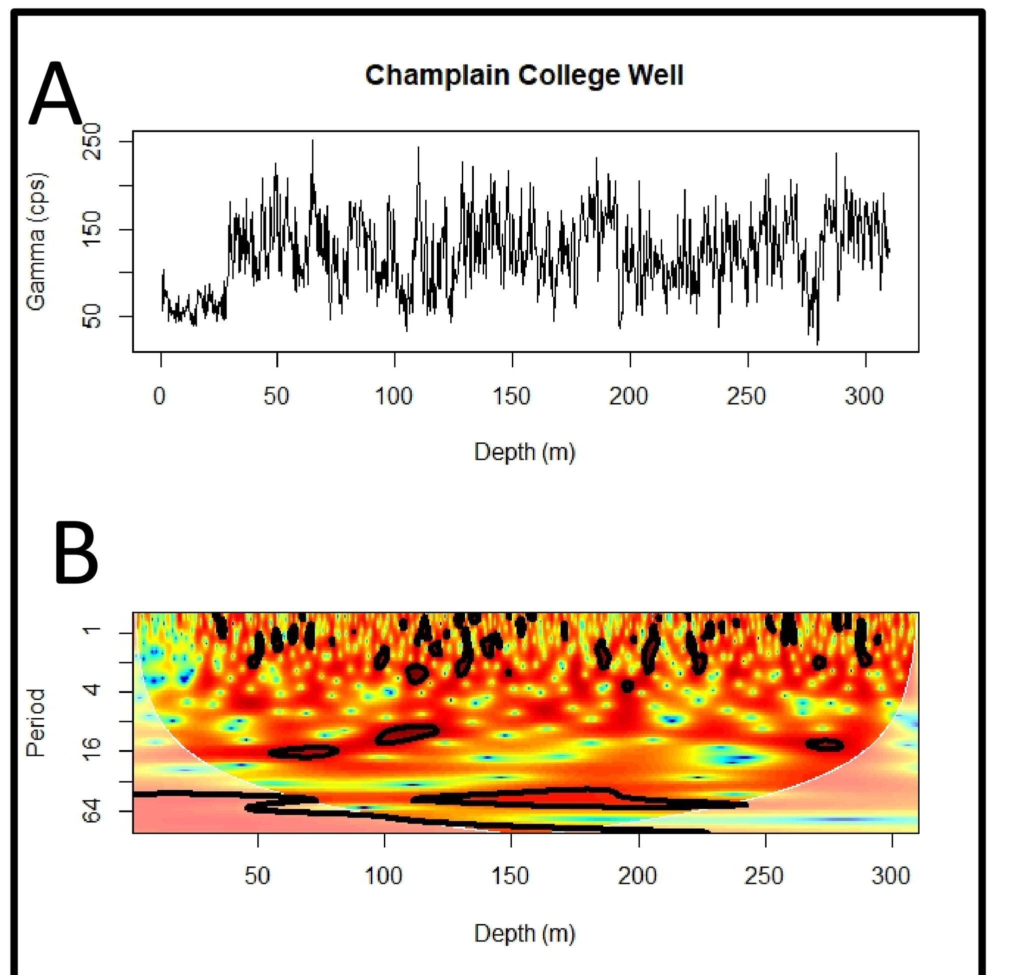

Figure 5 A and B: Condensed gamma log and wavelet analysis, Monkton Fm. Meter-scale cycles are well developed through the entire stratigraphy

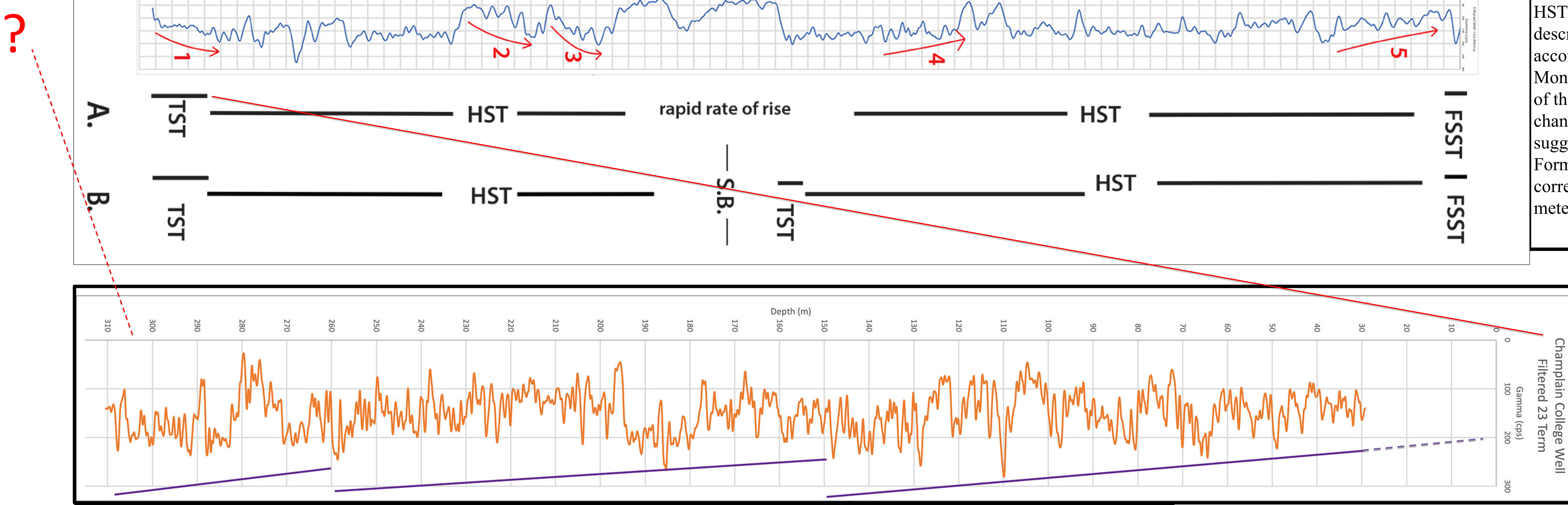

Figure 3: Gamma log profile from the Monkton Fm., Champlain College well. Purple lines indicate the three intervals in the Monkton stratigraphy that Maguire, et al. (2018) recognize as recording different characteristic parasequence architectures.

Conclusions:

When comparing at the Monkton and the Altona wavelet analysis there are some similarities and differences. Both sections have thicker (> 6 meter) portions of the stratigraphy that indicate larger scale sedimentary cycles. These large scale periodic cycles may indicate overall change from more proximal clastic dominated deposition to more distal carbonate dominated deposition in the formations. However, the Monkton Formation has many statistically significant smaller scale (< 4 meter) cycles. These smaller scale cycles may be representative of the clastic/carbonate parasequences seen in the Monkton tidally-dominated stratigraphy. Smaller scale sedimentary cycles may not be as prevalent in the Altona because of the lack of contrast between carbonate and clastic lithologies at that scale. In other words, the gamma signature in a purely clastic cycle may not have enough contrast to be easily identified within the CWT method. However, it is also likely that the storm-dominated deposition of the Altona does not lend itself to well developed cycles. A wave dominated environment, like the Altona, may not produce the consistent, repeating small scale lithologic patterns that one would expect in a tidally dominated environment.