[PS]Automated Cyclostratigraphic Analysis in Carbonate Mudrocks Using Borehole Images*

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Abstract

Stacking analysis provides a useful method for correlation and sequence stratigraphic analysis. Deep-marine mudrocks have fine scale vertical heterogeneity that is commonly ignored in conventional core descriptions. With the move to exploit resources plays, quantifying this heterogeneity is essential. Borehole images are the most suitable dataset to use because of their high resolution (up to 0.2 inch vertical resolution). However, manual processing of data at this level of detail is time consuming and can be subjective. In addition, correlations between two adjacent wells can be difficult based solely on facies, due to the large number of cycles observed.

In this study, we present a workflow for automated stacking analysis using the Modified Fischer Plot (MFP) algorithm from borehole images. The MFP measures the departure from mean cycle thickness. Hundreds of feet can be analyzed in tens of seconds to minutes in an objective manner. Because of their relatively planer lamination, deep-marine sediments lend themselves to automation. Automated picking of intervals in borehole images is based on contrast detection in resistivity values. After a quick quality inspection, suitable pad images are cross-correlated and aligned. They are summed together to increase signal to noise ratio, then smoothing is used to remove irregularities. Vertical difference in the resultant data is calculated, and a contrast limit is used to define surfaces. Obtained intervals are then used to calculate a MFP.

We apply the workflow on a deepwater carbonate mudrock succession. A geologic model is used to define cycles in borehole images. The cycles can be procedurally implemented in the workflow using a set of rules such as interval thickness, minimum resistivity contrast, and average interval resistivity. Core description and photos are used to ground truth borehole images of facies. A sequence stratigraphic interpretation is also made for the studied interval. Spectral analysis shows that picked intervals are ordered. The identified sequence stratigraphic surfaces have a signature on the MFP which can be used as an aid for sequence stratigraphic analysis. In general, automated MFP is suitable for rapid stacking pattern analysis when coupled with a geological understanding of the area.

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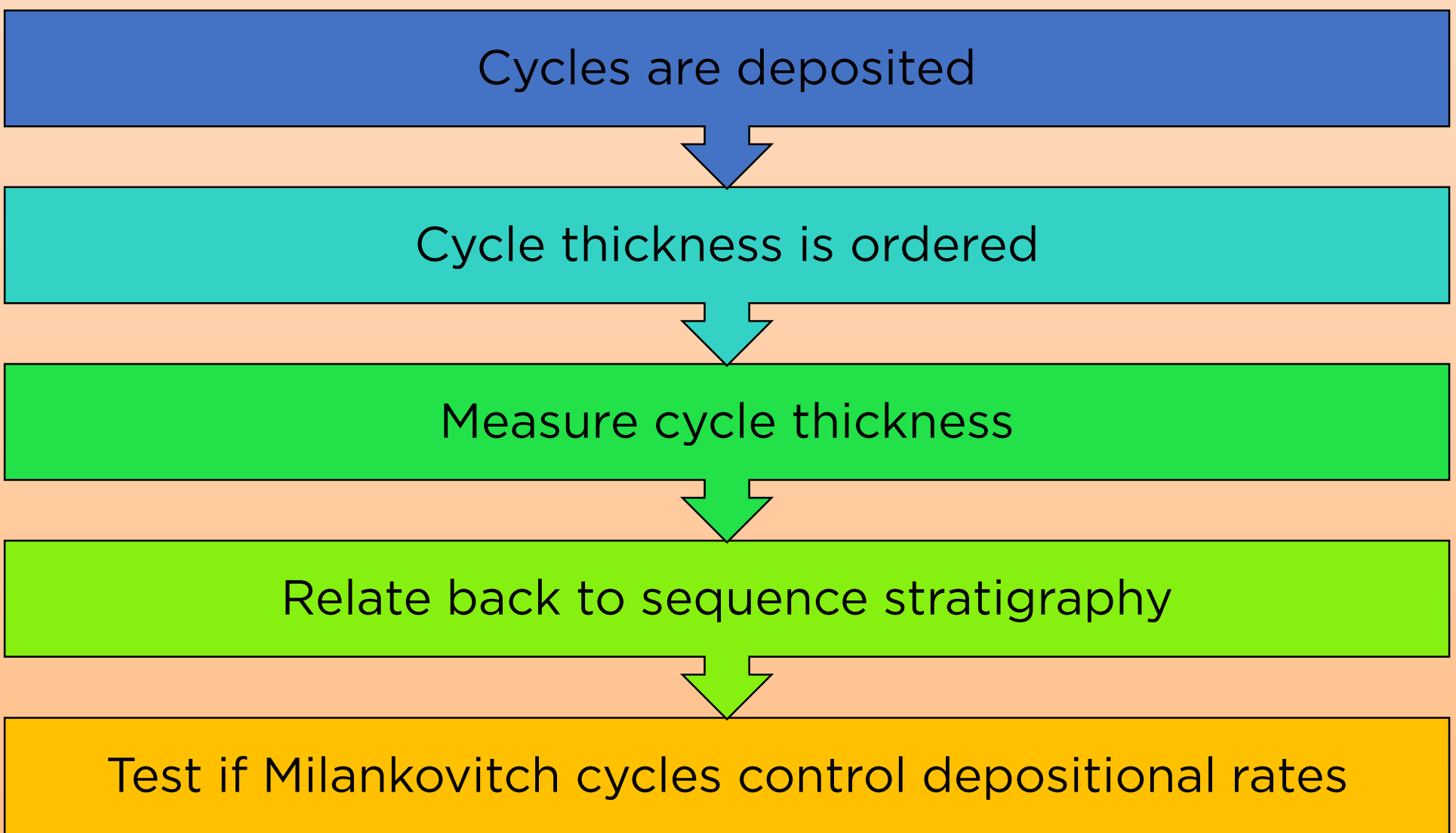2. Chevron Technology Company

1. ABSTRACT

Stacking analysis provides a useful method for correlation and sequence stratigraphic analysis. Deep-marine mudrocks have fine scale vertical heterogeneity that is commonly ignored in conventional core descriptions. With the move to exploit resources plays, quantifying this heterogeneity is essential. Borehole images are the most suitable dataset to use because of their high resolution (up to 0.2 inch vertical resolution). However, manual processing of data at this level of detail is time consuming and can be subjective. In addition, correlations between two adjacent wells can be difficult based solely on facies, due to the large number of cycles observed. In this study, we present a workflow for automated stacking analysis using the Modified Fischer Plot (MFP) algorithm from borehole images. MFP measures the departure from mean cycle thickness. Hundreds of feet can be analyzed in tens of seconds to minutes in an objective manner. Because of their relatively planer lamination, deep-marine sediments lend themselves to automation. Automated picking of intervals in borehole images is based on contrast detection in resistivity values. After a quick quality inspection, suitable pad images are cross-correlated and aligned. They are summed together to increase signal to noise ratio. Smoothing is used to remove irregularities. Vertical difference in the resultant data is calculated. A contrast limit is used to define surfaces. Obtained intervals are then used to calculate a MFP. We apply the workflow on a deep-water carbonate mudrock succession. A geologic model is used to define cycles in borehole images. The cycles can be procedurally implemented in the workflow using a set of rules such as interval thickness, minimum resistivity contrast, and average interval resistivity. Core description and photos are used to ground truth borehole images of facies. A sequence stratigraphic interpretation is also made for the studied interval. Spectral analysis shows that picked intervals are ordered. The identified sequence stratigraphic surfaces have a signature on the MFP. The MFP can be used as an aid for sequence stratigraphic analysis. In general, automated MFP is suitable for rapid stacking pattern analysis when coupled with a geological understanding of the area.
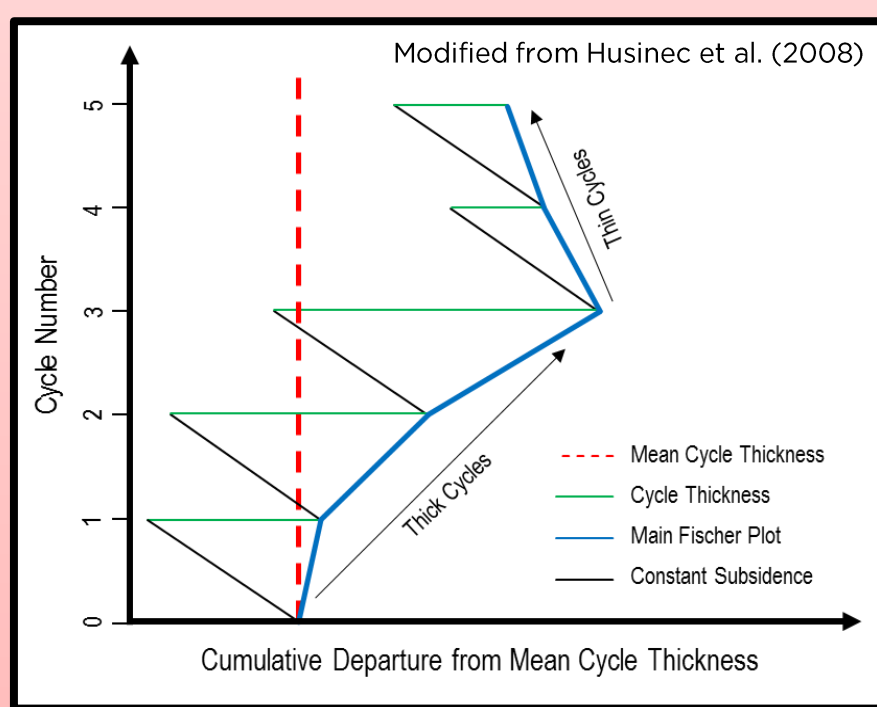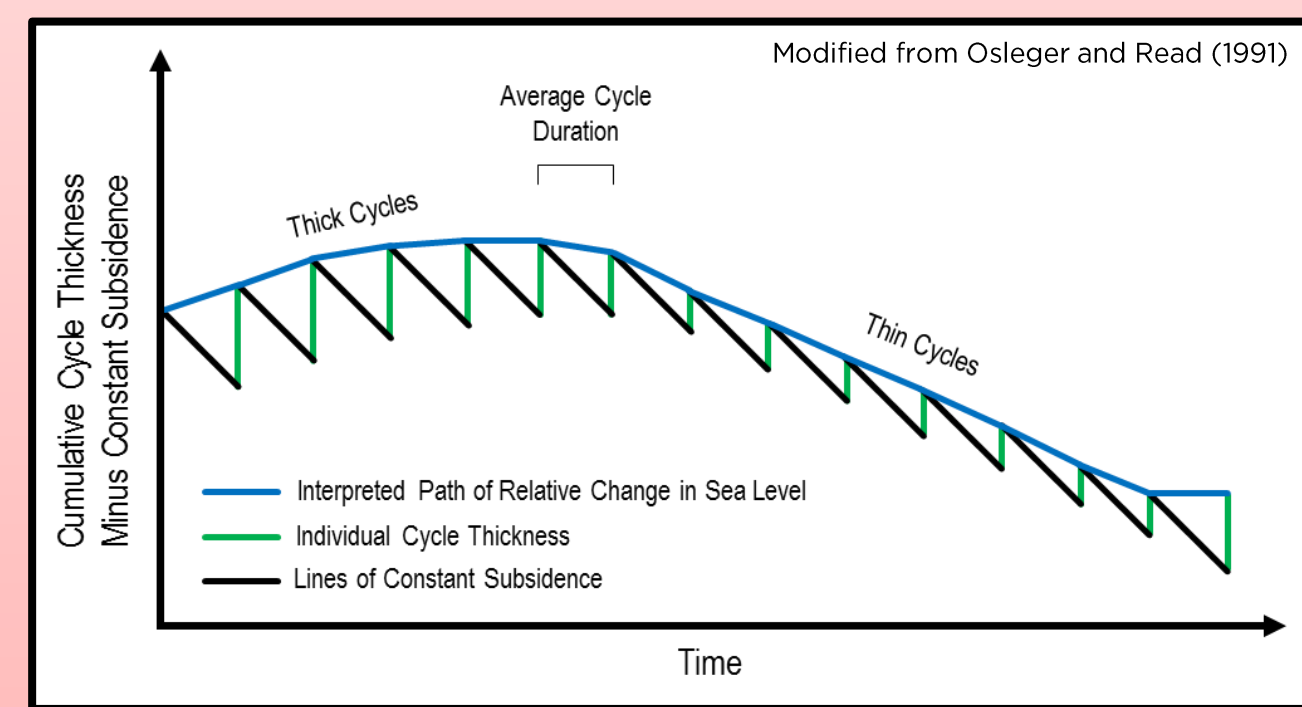
2. STUDY OBJECTIVES

To develop a fast and efficient workflow using borehole images that can aid geologists in developing a sequence stratigraphic interpretation of mudrocks.

This is done by quantifying cycle thickness change throughout the studied interval.

- Cycles are deposited
- Cycle thickness is ordered
- Measure cycle thickness
- Relate back to sequence stratigraphy
- Test if Milankovitch cycles control depositional rates

3. BACKGROUND INFORMATION

The Fischer plot is a graphical method to analyze stacking patterns in parasequences by plotting cumulative cycle thickness against time.

Modified from Osleger and Read (1991)

Modified from Husinec et al. (2008)

Fischer Plots Assumptions (Fitchen, 1997)

- Parasequences completely fill the accommodation space
- Compaction is neglected
- Parasequences deposition time is relatively constant.
- Subsidence rate is relatively constant.

In Fischer plots, cycles are plotted as vertical lines separated by a constant time equal to the average cycle deposition time. A path of relative change in sea level can be interpreted from the graph.

Modified Fischer plots (MFPs) are plotted as cumulative departure from mean-cycle thickness versus cycle number or depth.

Milankovitch cycles occur due to systematic changes in Earth's precession, obliquity and eccentricity. Their effect have been the recognized in the geologic record.

Spectral analysis can be used to extract cyclicity from data.

Cycle	Periods (Thousands of Years)
Eccentricity	95, 100, 120, and 410
Obliquity	41, 29, and 54
Precession	19, 23, 14, and 28
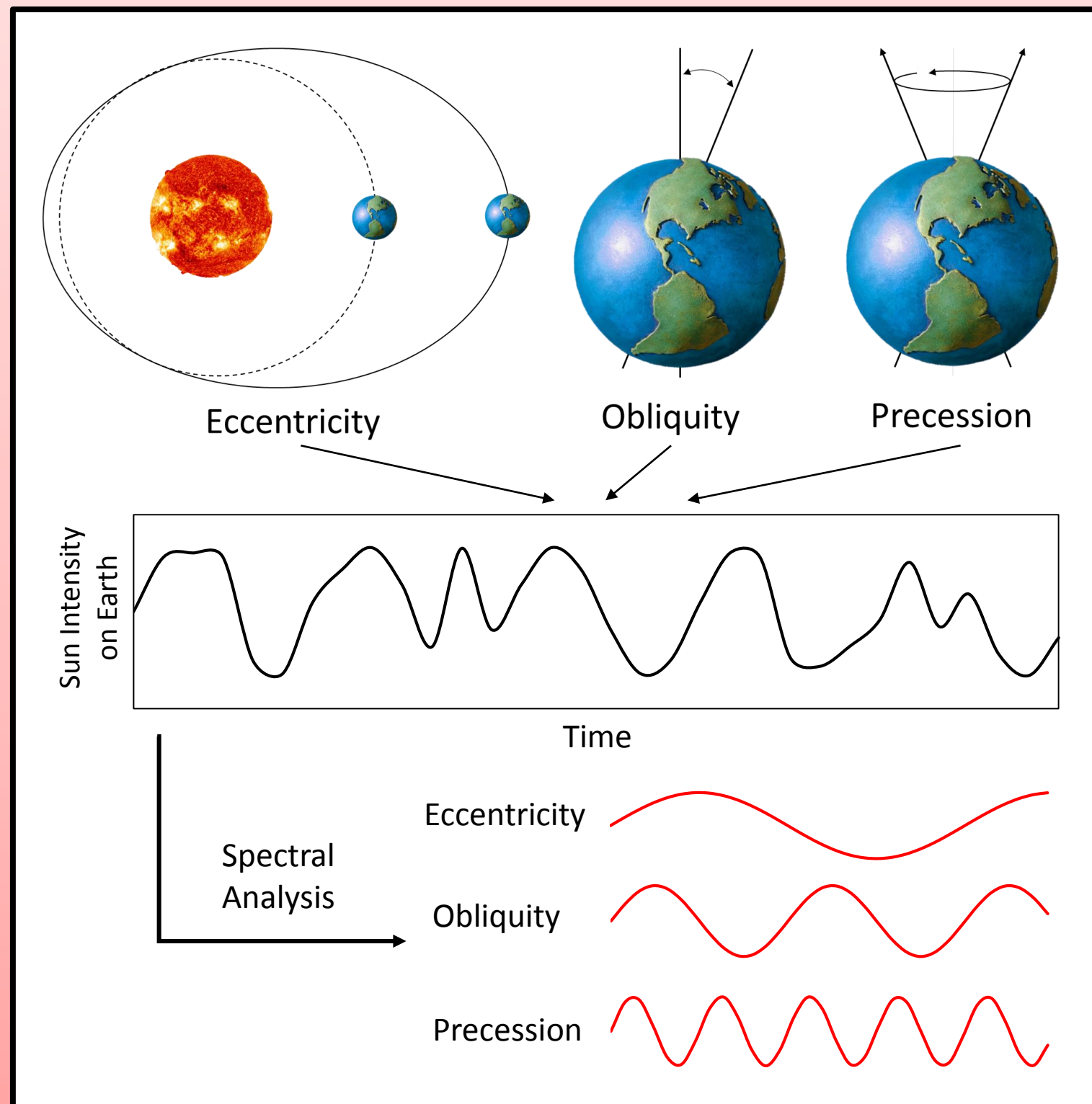
4. GEOLOGIC SETTING AND DESCRIPTION

The Callovian Tuwaiq Mountain and the Oxfordian Hanifa Formations are deposited in a marine carbonate shelf.

These formations are considered the main source for the Mesozoic petroleum hydrocarbon system in Arabia.

The studied interval (red circle) is located in one of the deepest intra-shelf basin in the area.

Modified from Cantrell et al. (1991)

Modified from Ziegler (2001)
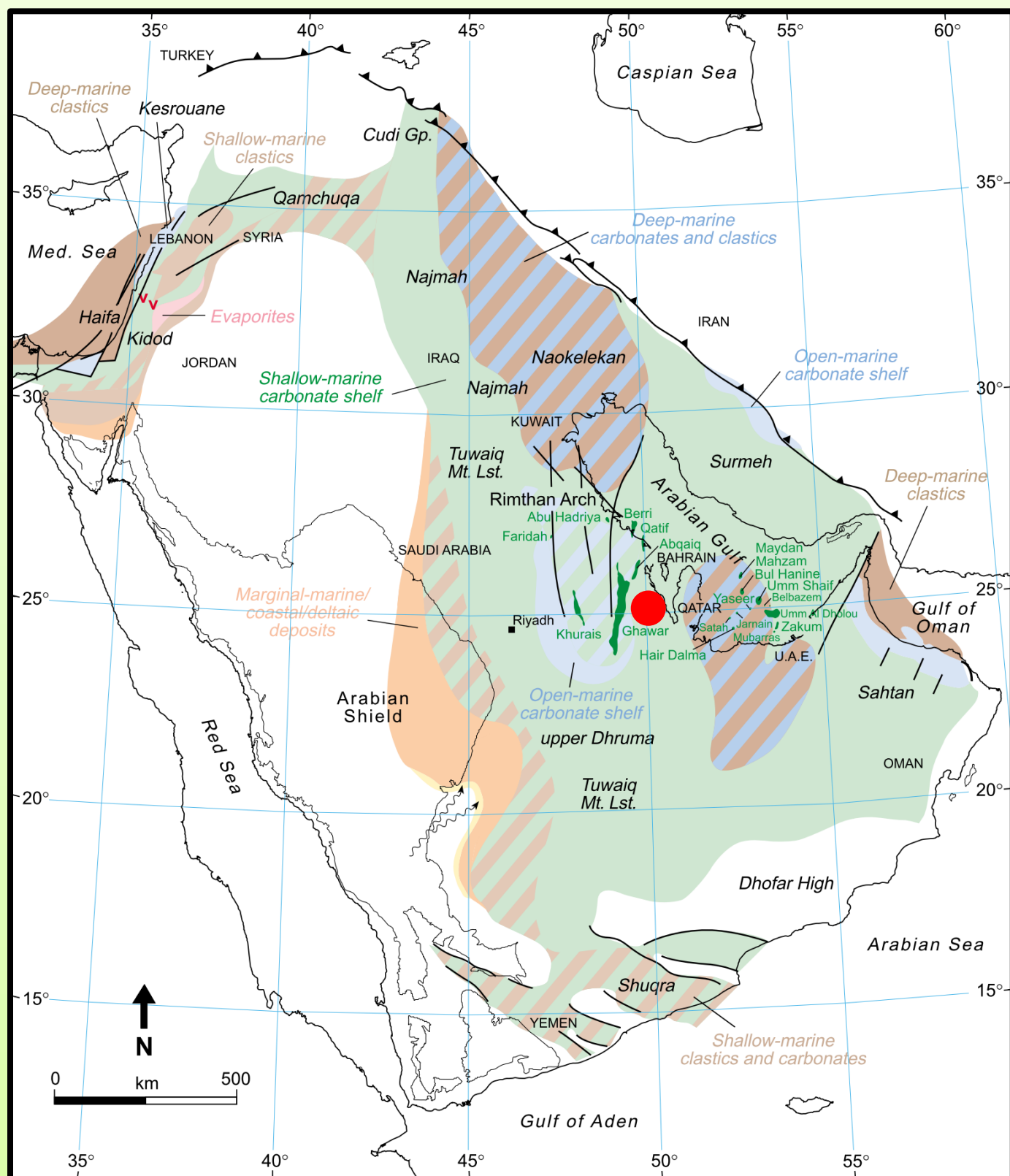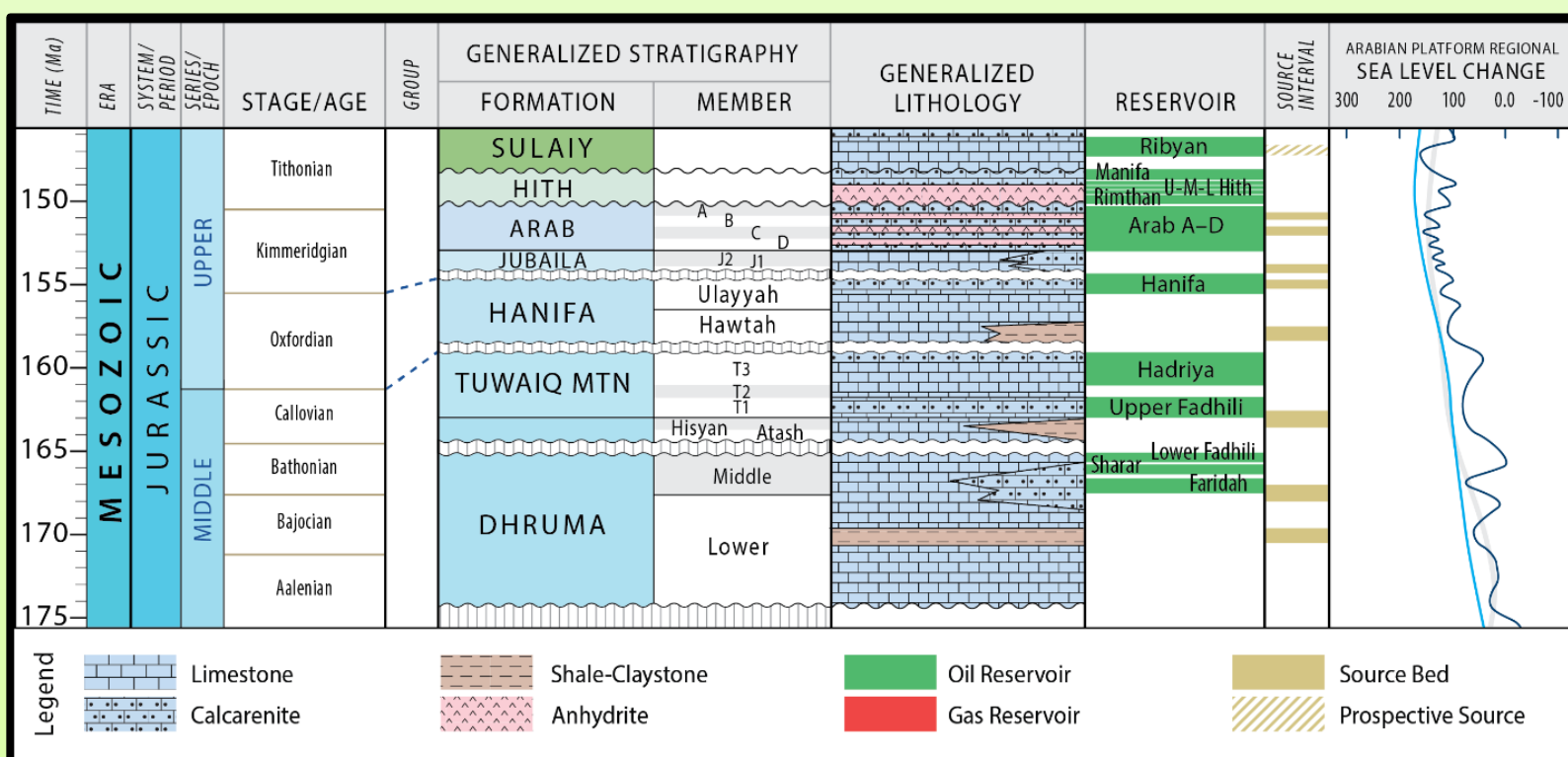
Five general facies have been identified in the interval (see Section 5). The interval in the study area are interpreted to be deposited in a relatively deep environment in an intra-shelf basin.

A sequence stratigraphic framework was defined for the Hanifa Formation based on core and thin section descriptions, well logs, and geochemical data.

Tuwaiq Mountain Fm. Hanifa Fm.
Modified from Lindsay et al (2006)

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5. FACIES ANALYSIS

PALMATE ANHYDRITE

White to light gray anhydrite. Palmate structures with varying length are clearly present. Anhydrite intervals and crystals are separated by carbonate.

3 cm

BIOTURBATED PACK- TO WACKESTONES

Gray to brown grainy, faintly laminated packstone to wackestone. Moderate to high bioturbation is present.

3 cm

LAMINATED DARK AND LIGHT MUDSTONE

Laminated rhythmic dark brown, dark gray and light brown mudstones and wackestones (to muddy packstones). Lighter intervals have more sparry calcite and darker intervals have more organic matter and muds. Clasts include forams, thin shelled bivalves and peloids. Fractures are calcite healed.

3 cm

CEMENTED PACKSTONES AND GRAINSTONES

Gray to light gray cemented fine to coarse packstones and grainstones. Grains are composed of forams, bivalve shells, and other unidentified clasts. Bioturbation is more abundant in the muddier sections. Visible porosity in some intervals is generally moldic and inter-granular. Wispy organic lamination, grading to stylolites, are present.
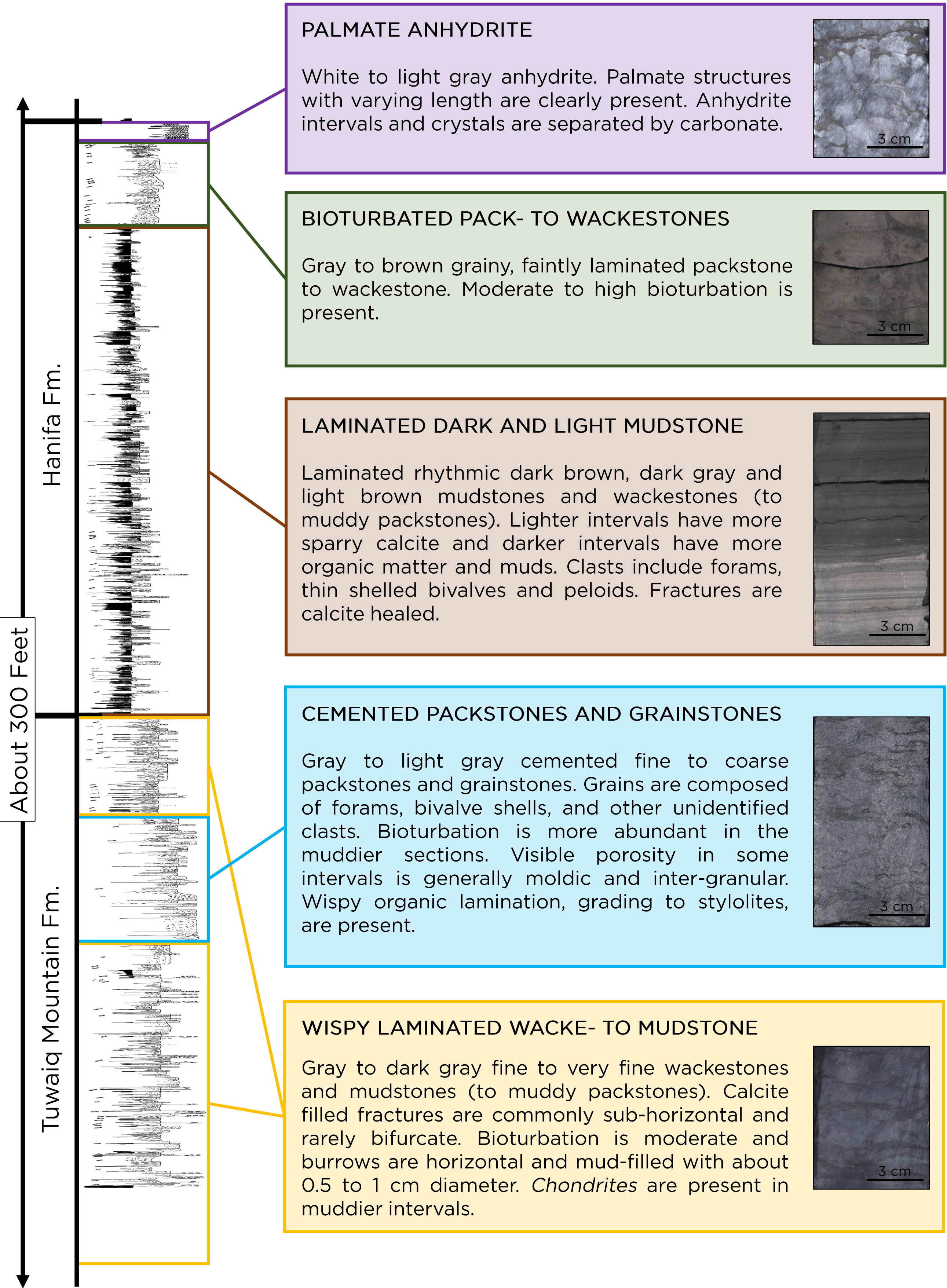
3 cm

WISPY LAMINATED WACKE- TO MUDSTONE

Gray to dark gray fine to very fine wackestones and mudstones (to muddy packstones). Calcite filled fractures are commonly sub-horizontal and rarely bifurcate. Bioturbation is moderate and burrows are horizontal and mud-filled with about 0.5 to 1 cm diameter. *Chondrites* are present in muddier intervals.

3 cm

Hanifa Fm.

About 300 Feet

Tuwaiq Mountain Fm.

6. CYCLOSTRATIGRAPHIC ANALYSIS METHODOLOGY

Pre-processing

Quick quality check of the borehole image pads is done manually.

Included   Excluded

Smoothing can be applied and inaccurate data points can be removed automatically by assigning a set range from the mean.

n.STD   Mean   n.STD

Frequency

Very High Values due to inaccurate measurements. Move to Maximum of Data

Resistivity Measurement

Mean pad is calculated by aligning and averaging pads to remove dip effects. Cross correlation is used to align pads.

f
g
(f * g)
Cross Correlation

Pad 1   Pad 2   Pad 3   Pad 4   Mean Pad
High
Low
Resistivity
Align Pads and Average

Surface Picking

An Intensity log is calculated. Difference log is calculated to measure the vertical contrast.

Image Log   Intensity Log   Difference Log
Sum Horizontally   Subtract Vertically

Surfaces are picked based on contrast in the difference log. They can be based on different parameters (which can be based on geologic models):

(1) Minimum cycle thickness
(2) Resistivity value threshold
(3) Cycle contrast threshold

Resistivity (Image Log Intensity)

(3) Peak Height Difference

Depth

(2) Peak Height

(1) Peak Separation

Cyclicity Analysis

Modified Fischer plots (MFP) is used for cyclicity analysis. It is defined by Sadler (1993).

Calculate cycle thickness from surfaces picked

Calculate mean cycle thickness

Calculate departure from mean interval Thickness by subtracting each individual interval thickness by mean cycle thickness

Normalize departure From Mean Interval Thickness by dividing each value by mean cycle thickness

Calculate the cumulative dimensionless departure from mean cycle thickness

Plot Modified Fischer Plots (cumulative departure versus cycle number or cycle depth)

Compare to Geologic Analysis

Interpreted thickening and thinning cycles in the MFP are compared to the facies observed or expected.

Zero Line
Depth
Same as average
Much thinner than average
Thinner than average
Much thicker than average
Thicker than average
Cumulative dimensionless departure from mean cycle thickness

The slope of the MFP is related to the amount of deviation from the average cycle thickness.

MFP is correlated with the sequence stratigraphic surfaces and modified as necessary. Geological understanding is a must as the relationship between the MFP signature and the system tracts is not unique.

Heterogeneous Thinner than average
Homogenous Thicker than average

Spectral Analysis

Dominant frequencies are extracted by spectral analysis.

Signal
Frequency Domain Plot
Amplitude
Frequency
Plot Frequency versus amplitude for each decomposed sine signal

Depositional controls is examined using the analysis.

Extract dominant frequencies by spectral analysis

Convert frequencies to wavelength and time periods using average depositional rates

Compare results to Milankovitch cycles and to nearby wells

Make inference about depositional controls

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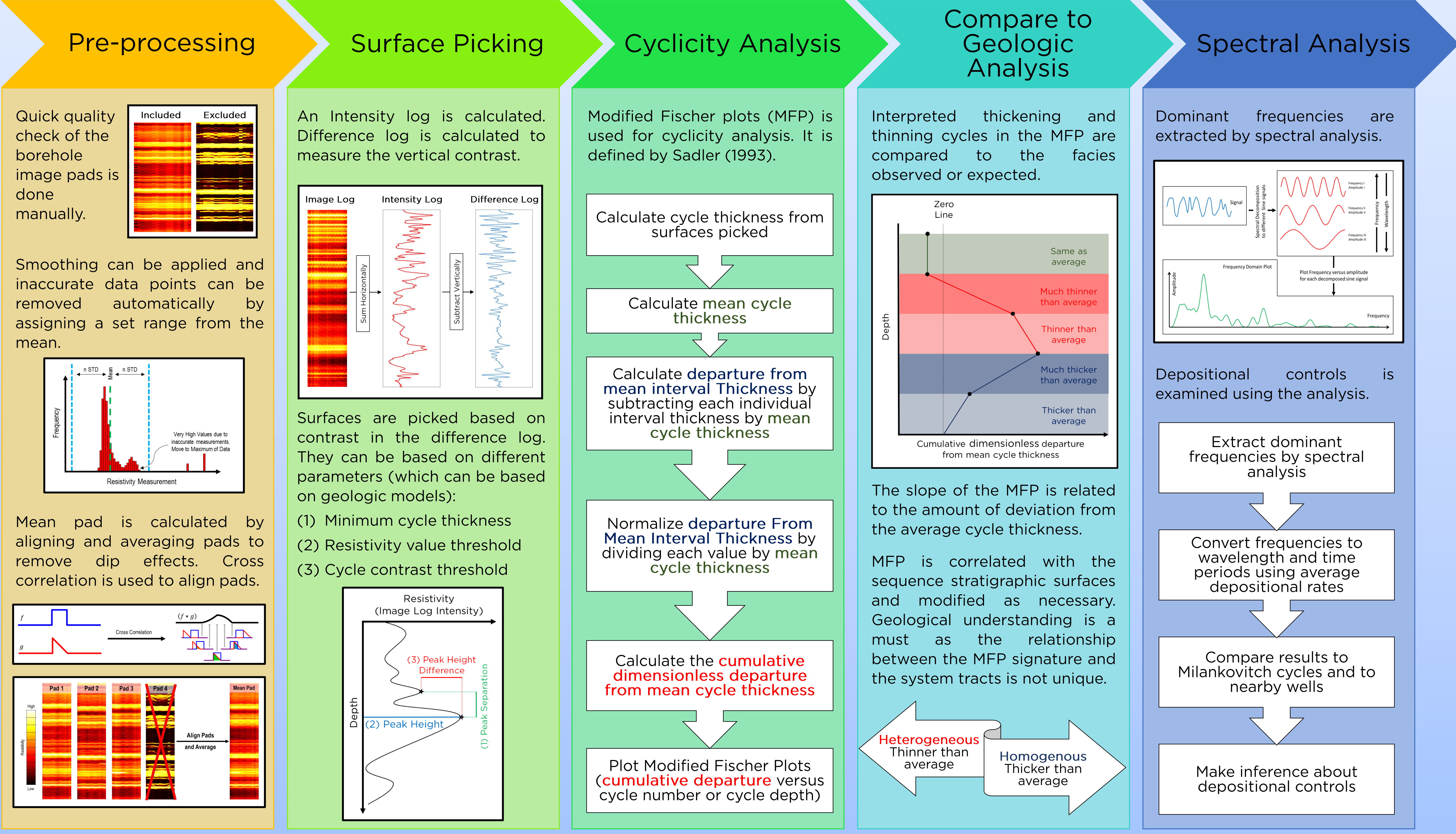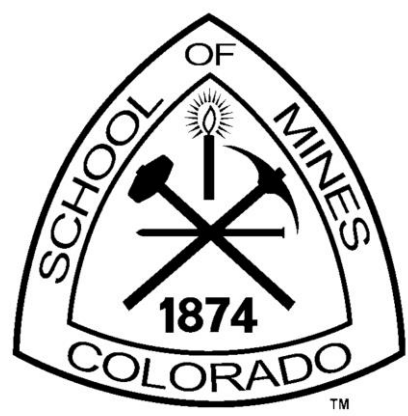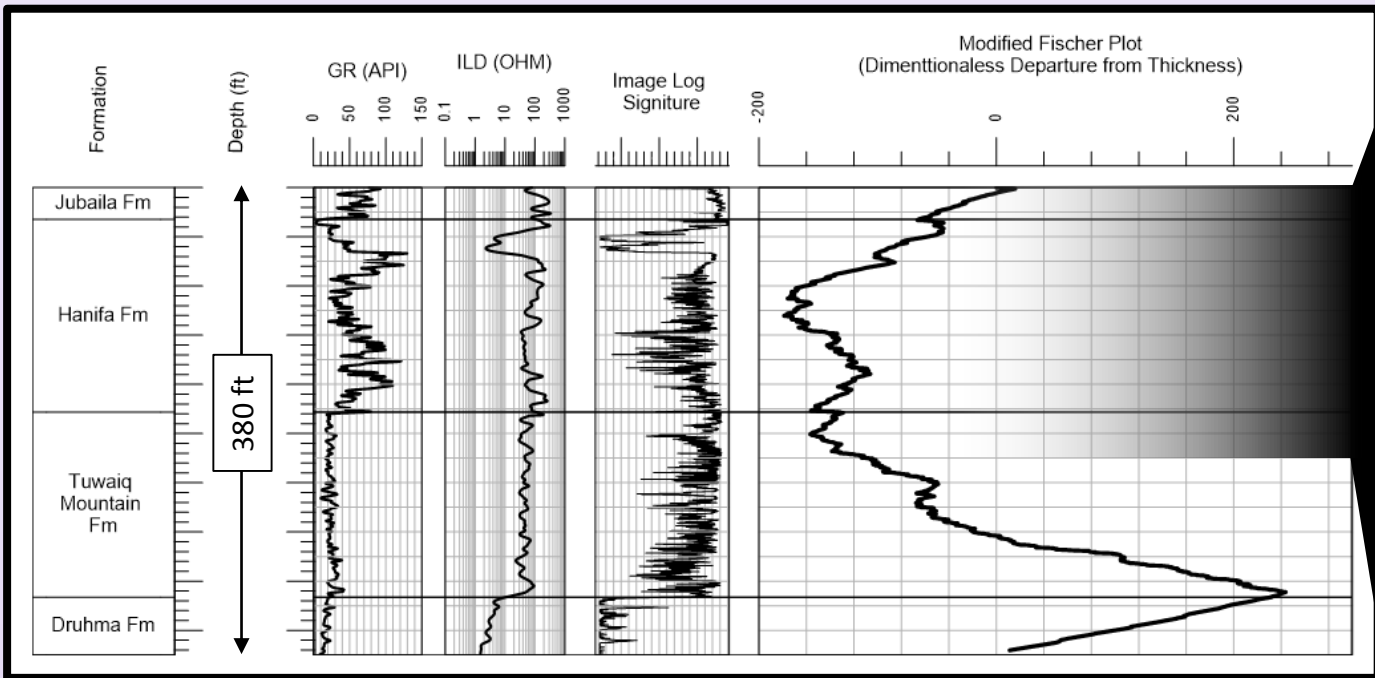Mustafa A. Al Ibrahim[1], Neil F. Hurley[2], and Rick Sarg[1]

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2. Chevron Technology Company

7. CASE STUDY RESULTS

The Modified Fischer plot (MFP) shows signatures of formation tops. Tops are related to depositional processes.

MFP in the Hanifa Fm. shows a good correlation with the independently defined sequence stratigraphic framework for the interval. An extra surface was identified using the MFP plot and confirmed by revisiting the core.

Facies in the system tracts in the study area show a predictable response:

System Tract	Rock Composition	Geologic Interpretation	Cycle Thickness	Graphical MFP Representation
Transgressive System Tract (TST)	Dark organic rich carbonate mudrocks	Basin deposits	Thicker than average	Shift to the right
Highstand System Tract (HST)	Interlayered light gray and dark gray carbonate mudrock	Inter-layerd influx of platform material and basin deposits	Thinner than average	Shift to the left
Lowstand System Tract (LST)	Fine grained light gray to brown carbonate rocks	Large influx of platform material	Much thicker than average	Shift to the right

Spectral analysis shows Milankovitch cycles signature. Is this evidence that factors that controls cyclicity on the platform operate in the basin too? More analysis is needed to confirm the hypothesis.
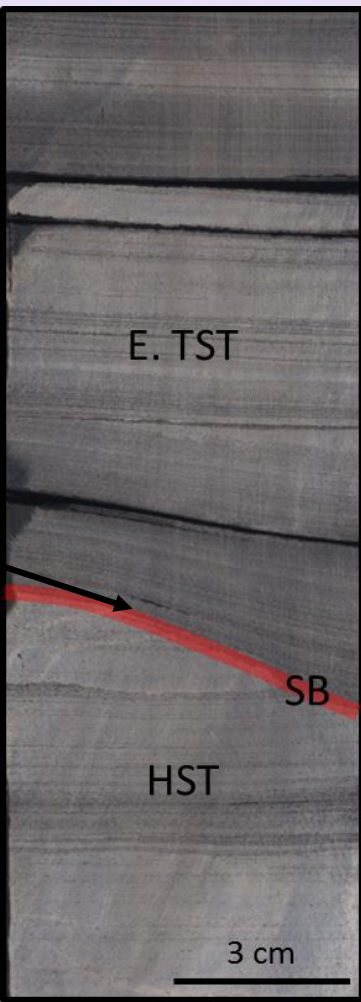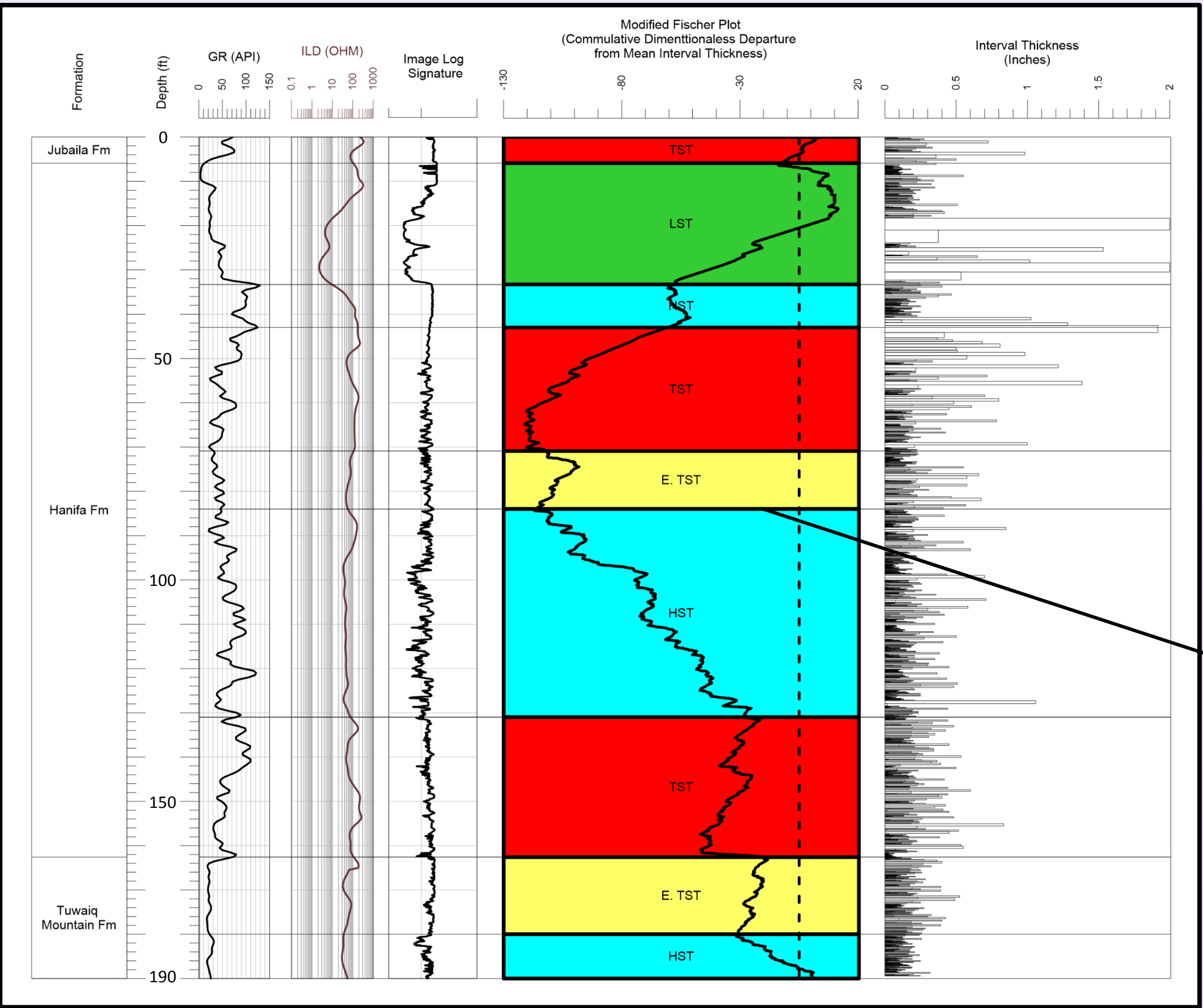
8. DISCUSSION

General trends are stable with varying parameters. Different geologic models can be used for the analysis.
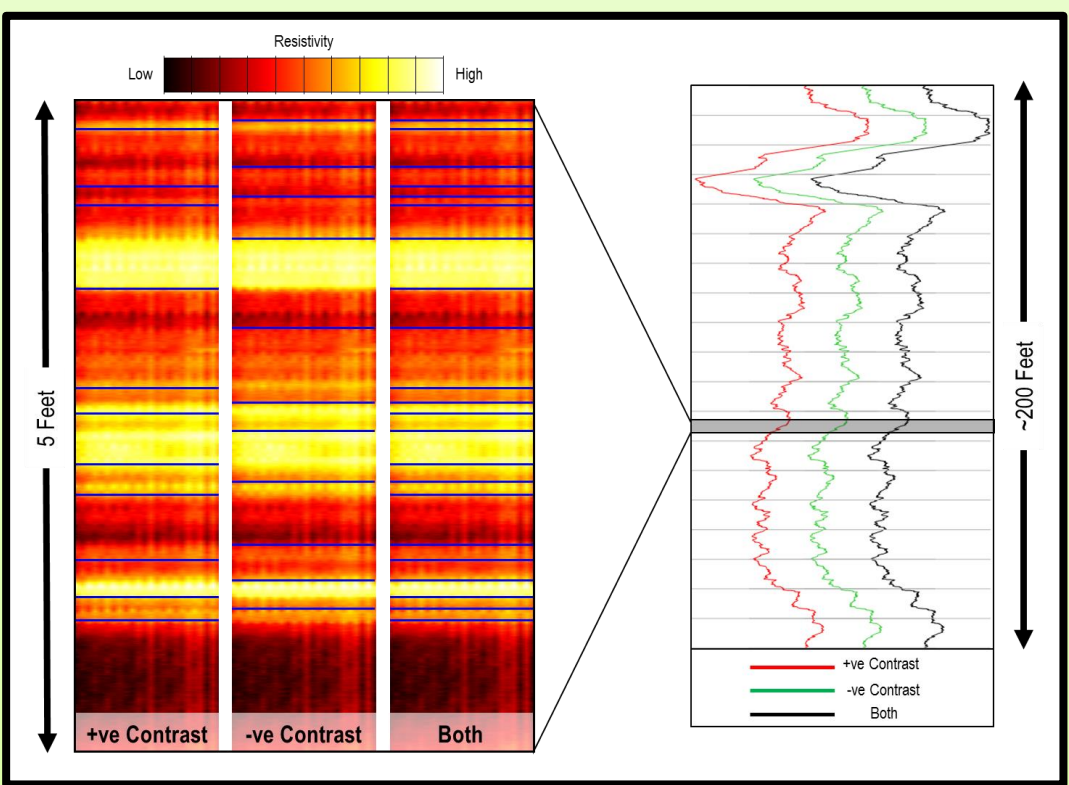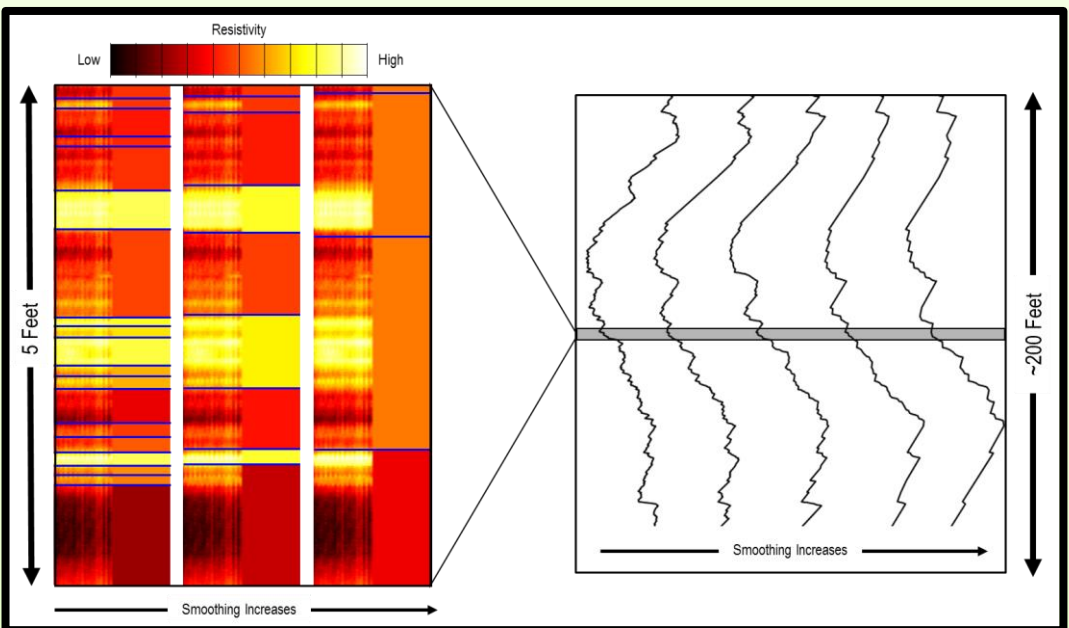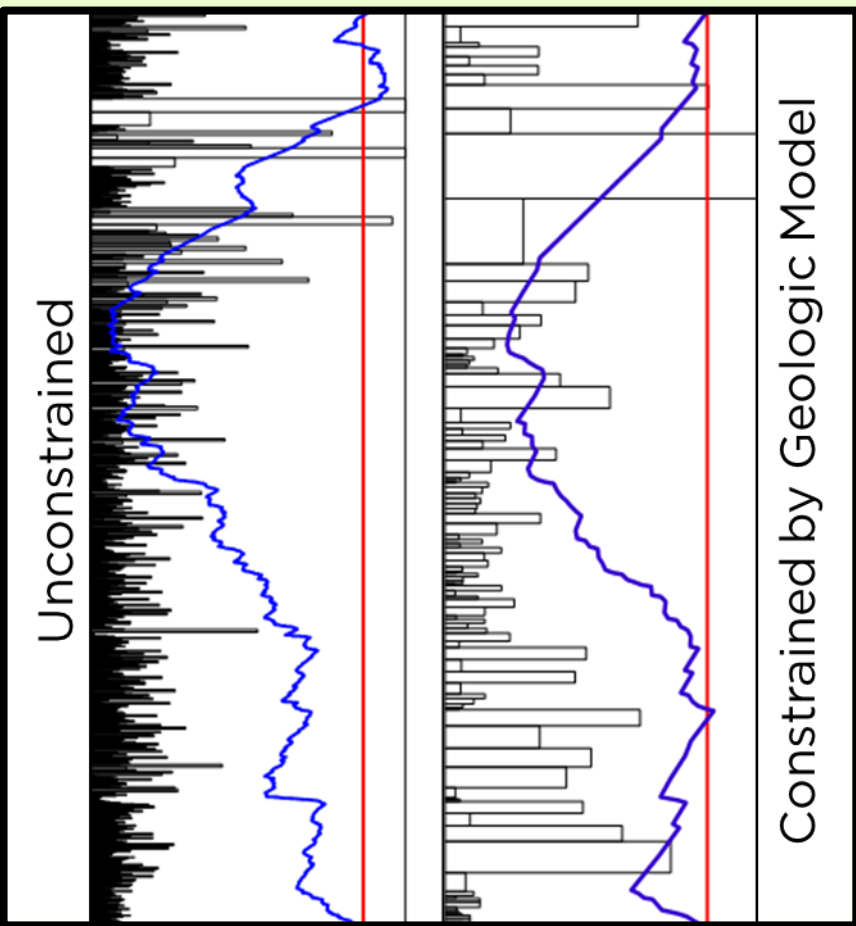
9. FUTURE WORK

❖ Test the possibility of using the workflow for intra-basinal well correlation

❖ Study the relationship between basinal and platform carbonates. Can they be correlated using this analysis? Is cyclicity in controlled by the same processes?

❖ Caliber logs can be incorporated into the automated workflow to produce a confidence factor.

❖ Core photos can be used in the analysis in the absence of image logs. Virtually any data can be used, however, higher resolution is preferred to capture the vertical heterogeneity.

WHITEBOARD
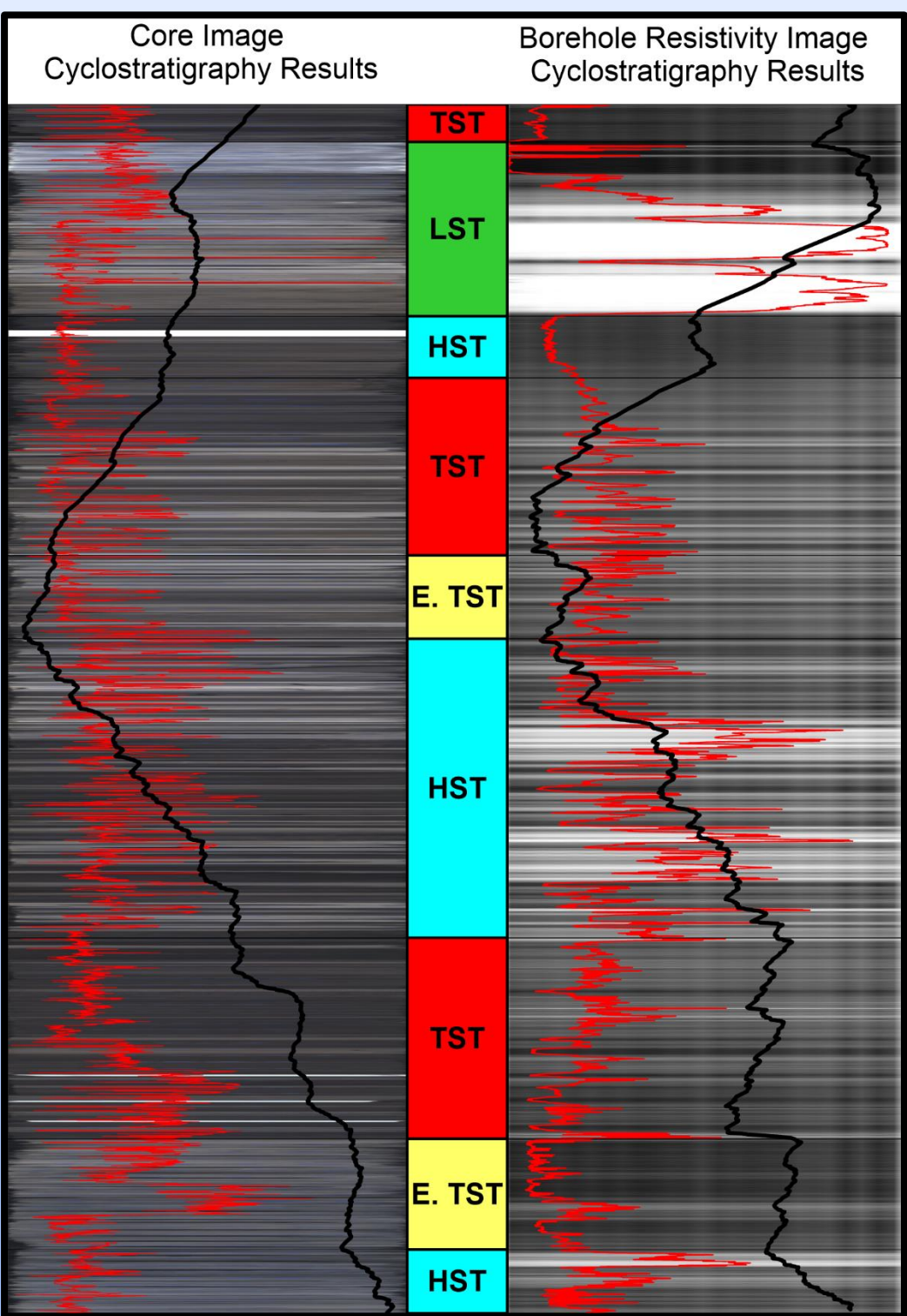
10. CONCLUSIONS AND FINAL REMARKS

❖ Automation of Fischer plot algorithm on borehole images allows for an objective and fast examination of cyclicity in basinal carbonates.

❖ The modified Fischer plot workflow can be used to define sequence stratigraphic surfaces, and study small and large scale vertical heterogeneity.

❖ The vertical heterogeneity at the lamination scale can be related back to climatic and tectonic changes (sequence stratigraphy).

❖ The basinward deposits are controlled, at least partially, by such factors. The modified Fischer plots correlated well with the geologic interpretation and sequence stratigraphic analysis. Spectral analysis showed that Milankovitch cycles are present.

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12. ACKNOWLEDGMENTS

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