# Identification of Sand Dunes in the Early Jurassic Nugget Formation in the Moxa Arch of Wyoming Using Seismic Attributes, Petrophysical Modeling, and Seismic Data Conditioning*

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Abstract

The Moxa Arch has been an important geologic structure for hydrocarbon exploration since the mid-1940s in the Green River Basin. It is also recognized by the US Department of Energy as one of two carbon sequestration sites within Wyoming. The Early Jurassic Nugget Formation within the Moxa Arch is a possible reservoir for carbon sequestration, however past drilling may have compromised it as such. The Nugget Formation is an eolian sandstone that was deposited as part of the Early Jurassic sand sea that covered Arizona, Utah, and southwestern Wyoming. Seismic attribute analysis shows the presence of northwest-southeast trending linear geologic features believed to be eolian dunes and inter-dunal deposits. Previous works, using outcrop study, on the Nugget Formation and Navajo Sandstone (equivalent of Nugget) have measured a northeast-southwest general paleo-wind direction during the time of deposition.

The Petrophysical analysis of three surrounding wells also shows that the eolian sands have high porosity resulting in low impedance, while the inter-dunal deposits, composed of evaporites and carbonates, are impermeable barriers and have high impedance. Analysis of co-rendered coherence, curvature and P-impedance clearly displays the extent and nature of the eolian dunes within the 3D volume. The seismic facies attribute calculated by using the Self Organizing Maps (SOMs) algorithm also confirms the presence of more sand facies on top and more evaporite/carbonate facies at the bottom of the Nugget Sandstone Formation. The paleo-wind direction was calculated based on these NW-SE trending lineaments delineated from the seismic attributes and found to be going from NE to SW, matching the outcrop studies being done earlier for the same formation.

References Cited

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http://intheplaygroundofgiants.com/geology-basics-2/an-introduction-to-physical-geology/

Chan, M.A., and A.W. Archer, 2000, Cyclic eolian stratification on the Jurassic Navajo sandstone, Zion National Park: Periodicities and implications for paleoclimate, *in* D.A. Sprinkel, T.C. Chidsey Jr., and P.B. Anderson, eds., Geology of Utah's Parks and Monuments: Utah Geological Association Publication, v. 28, p. 607-617.

Parrish, J.T., and F. Peterson, 1988, Wind directions predicted from global circulation models and wind directions determined from eolian sandstones of the western United States - a comparison: Sedimentary Geology, v. 56, p. 261-282.

Verma, S., E. Campbell-Stone, H. Sharma, S. Mallick, and D. Grana, 2016, Seismic attribute illumination of the Moxa Arch: A probable site for carbon sequestration: SEG 86th Annual International Meeting, Expanded Abstracts, p. 1874-1878.

Vermaa, Sumit, Shuvajit Bhattacharyab, Brady Lujana, Dhruv Agrawala, and Subhashis Mallick, 2018, Delineation of early Jurassic aged sand dunes and paleo-wind direction in southwestern Wyoming using seismic attributes, inversion, and petrophysical modeling: Journal of Natural Gas Science and Engineering, v. 60, p. 1-10.

Identification of Sand Dunes in the Early Jurassic Nugget Sandstone in the Moxa Arch of Wyoming using Seismic Attributes, Petrophysical Modeling and Seismic Data Conditioning

Dhruv Agrawal
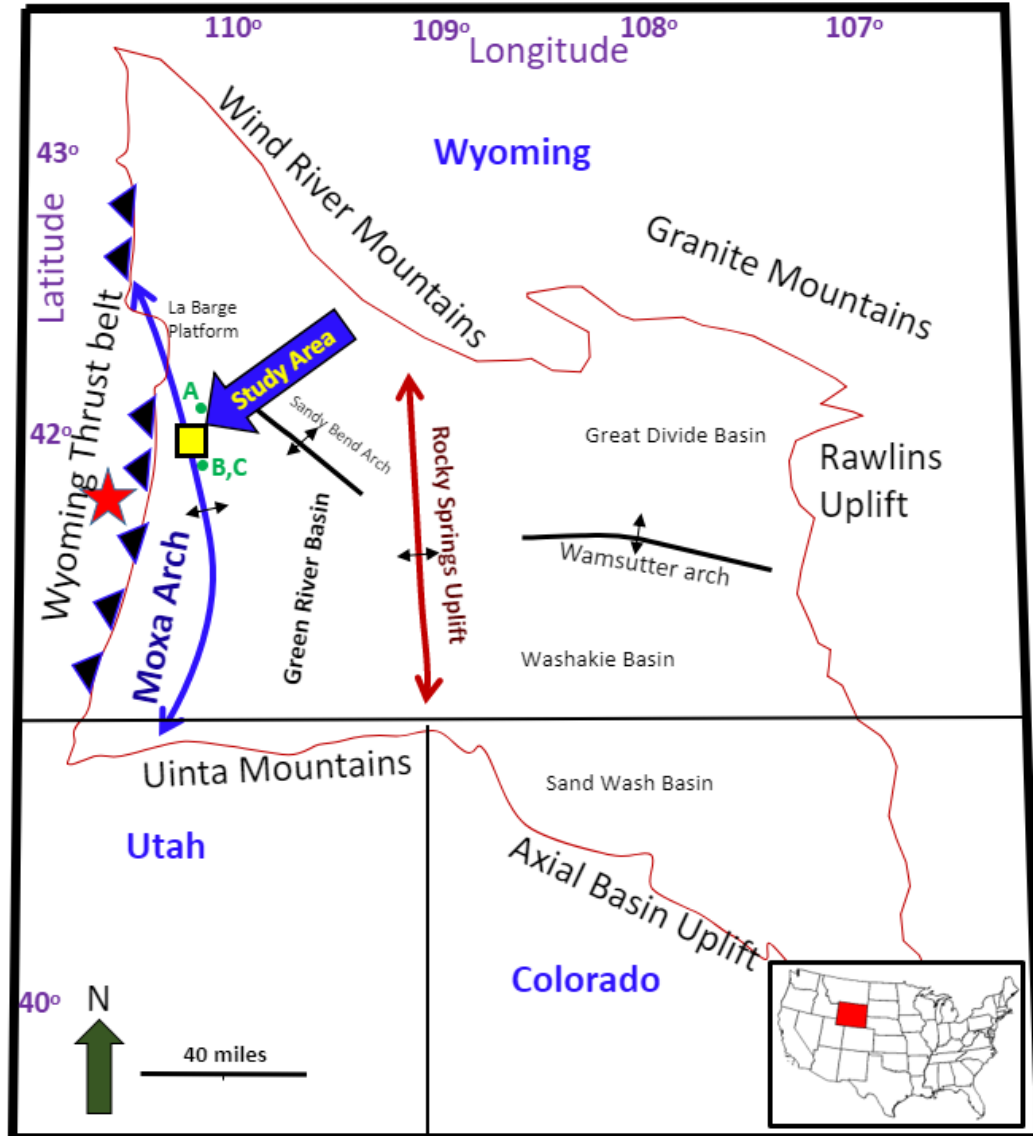May 22nd, 2019

Contents
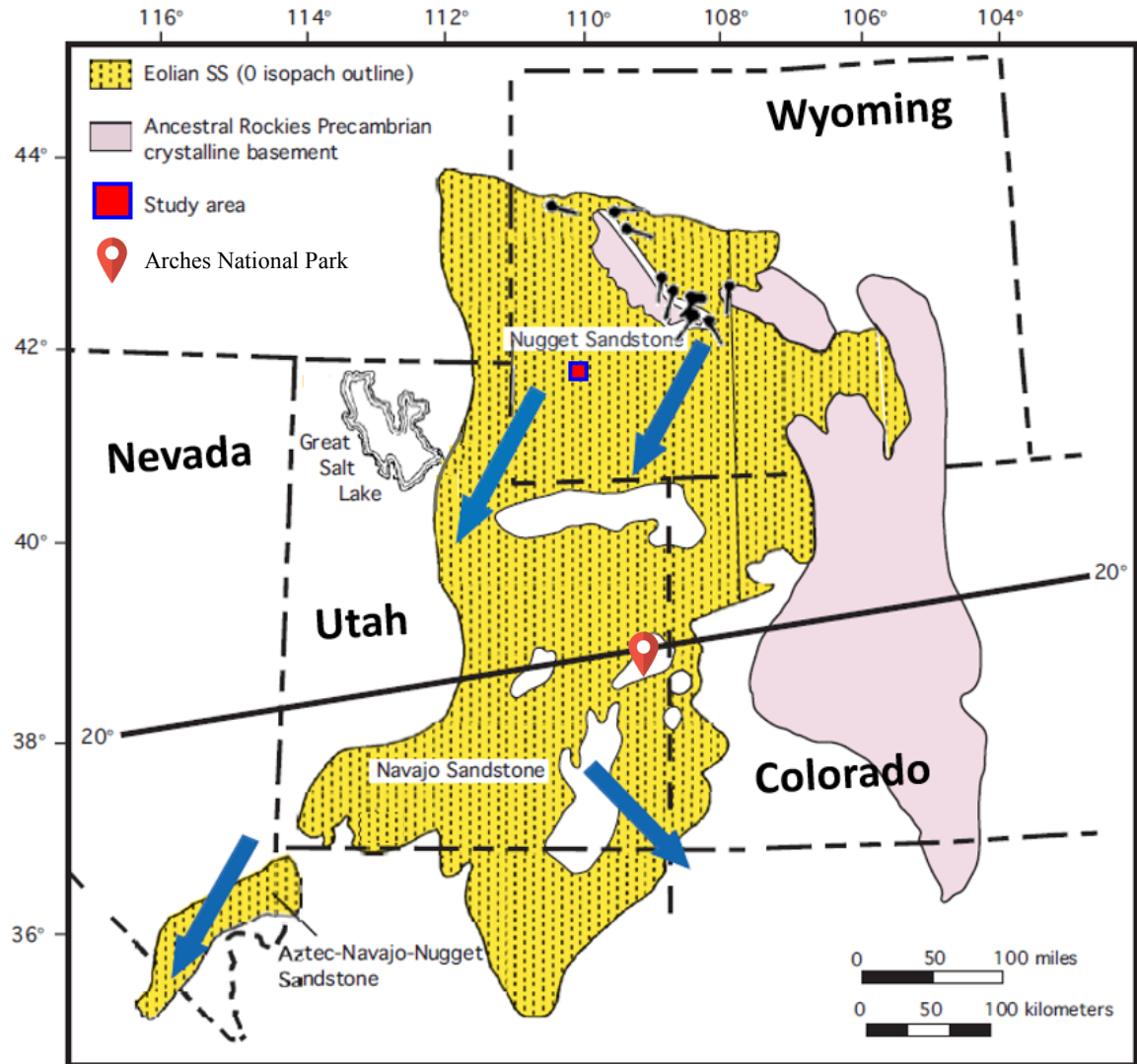
Paleo wind direction of Nugget and Navajo Sandstone through outcrops (after Parrish and Peterson, 1988; Chan and Archer, 2000)

Contents

- Introduction
- Geology of the study area
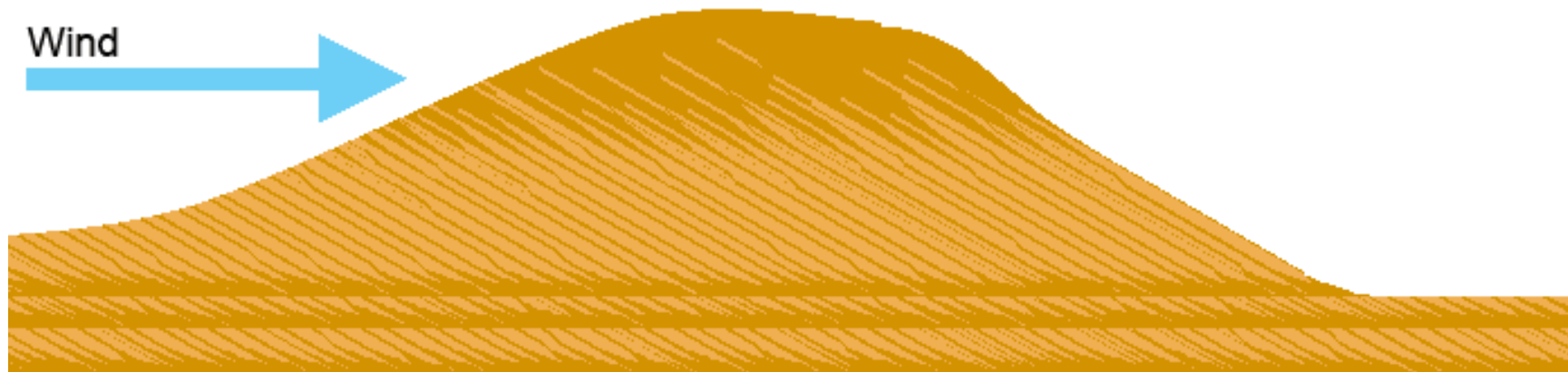- Formation, characteristics and types of sand dunes
- Seismic and well log data analysis
- Seismic conditioning
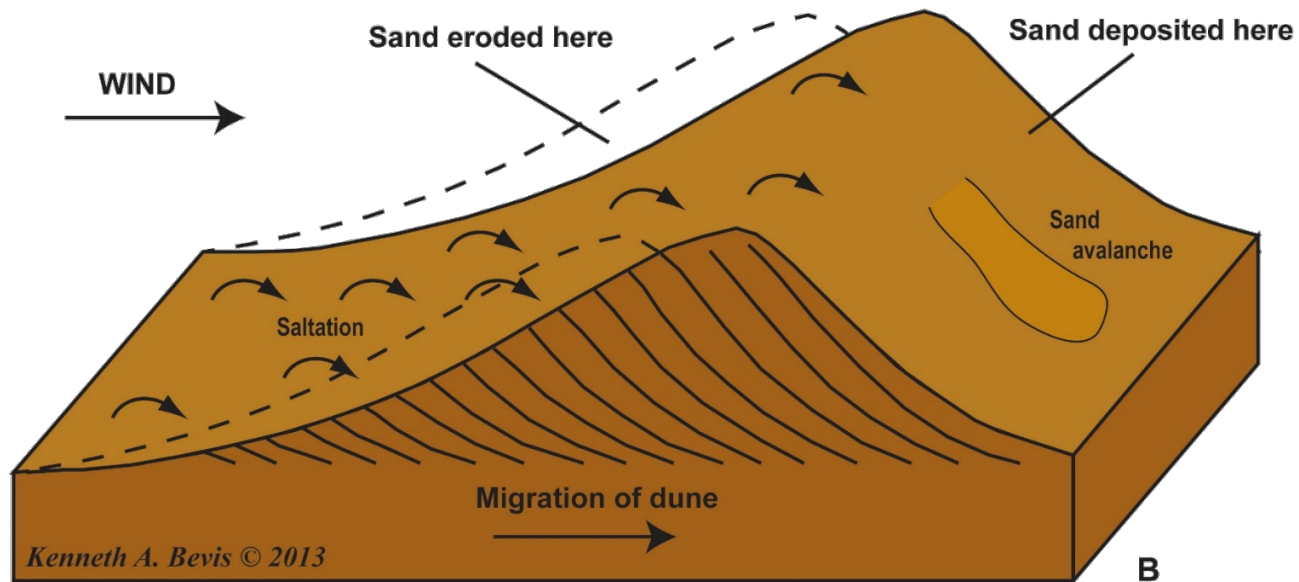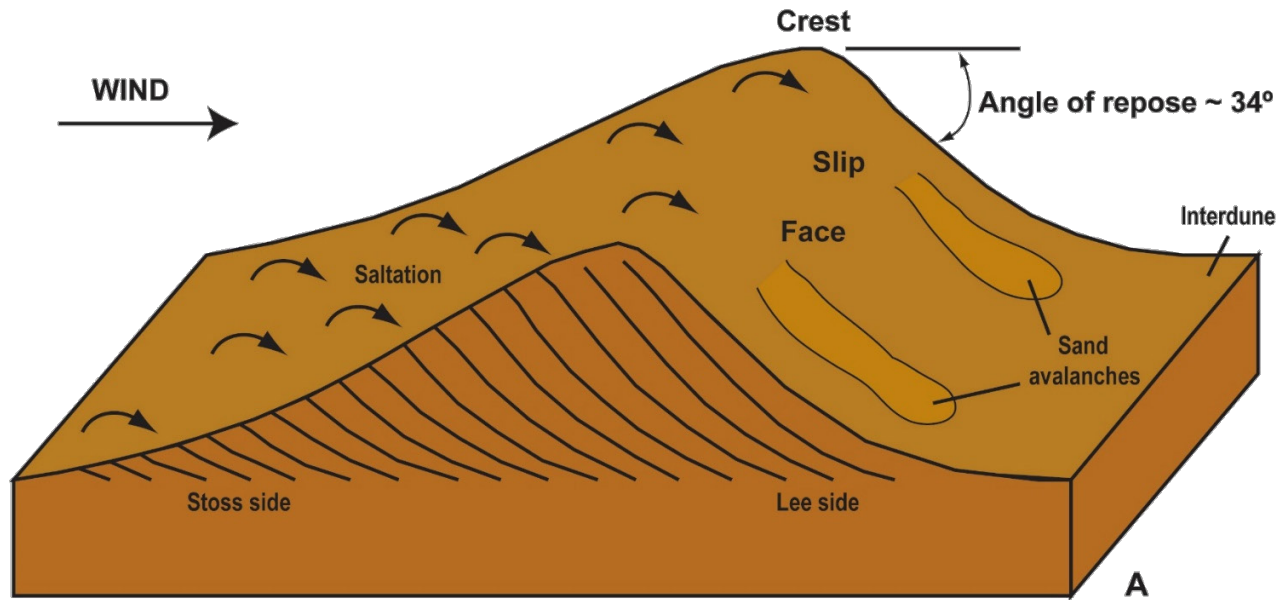- Conclusions and Acknowledgements

- Location map of the Moxa Arch and Rocky Springs Uplift
- Yellow square is the seismic survey and A,B and C are the wells used
- Red star is coal based Naughton Power Plant producing CO_2 (after Verma et al., 2016)
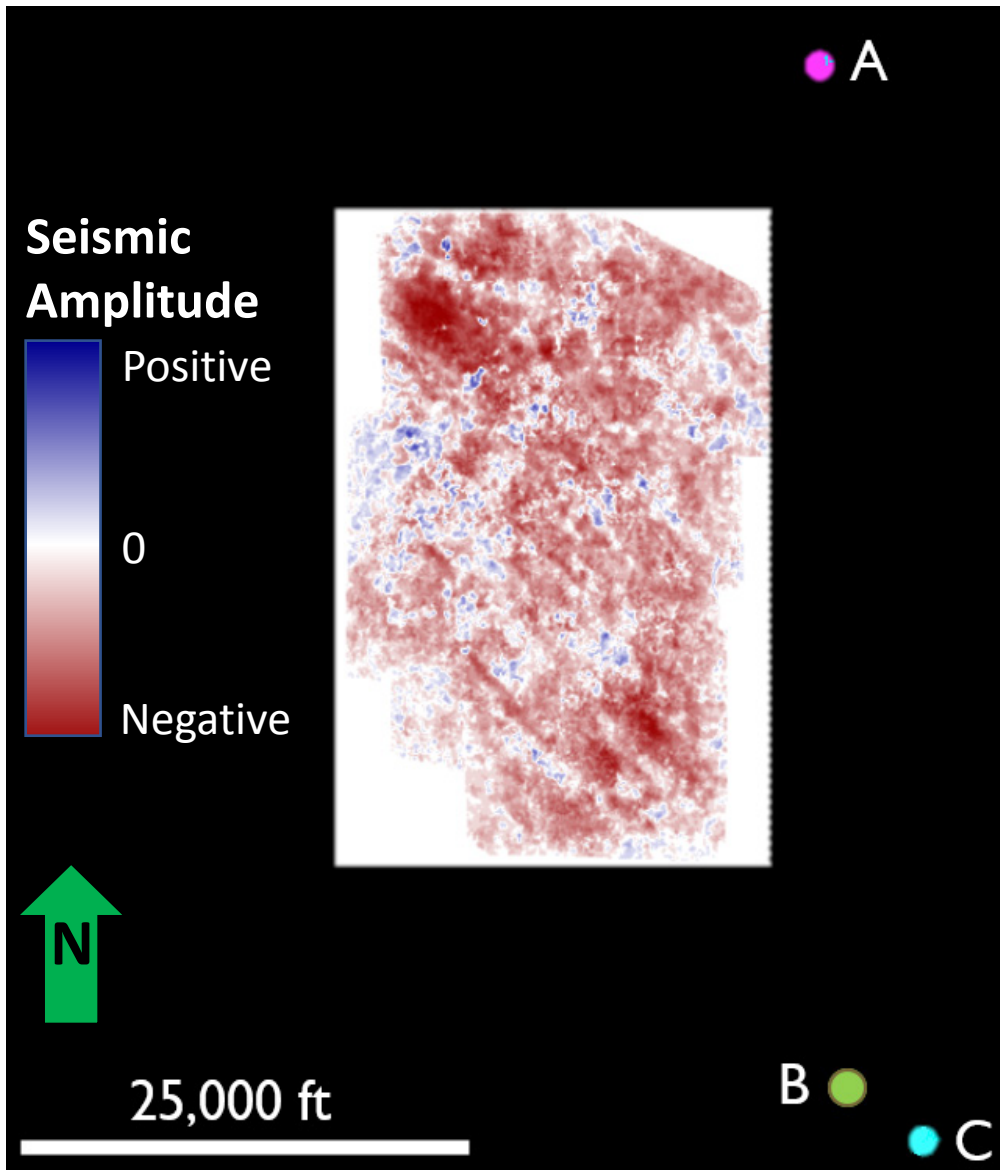
Locations of wells A, B and C relative to the seismic survey area

Seismic amplitude time slice at 1 sec
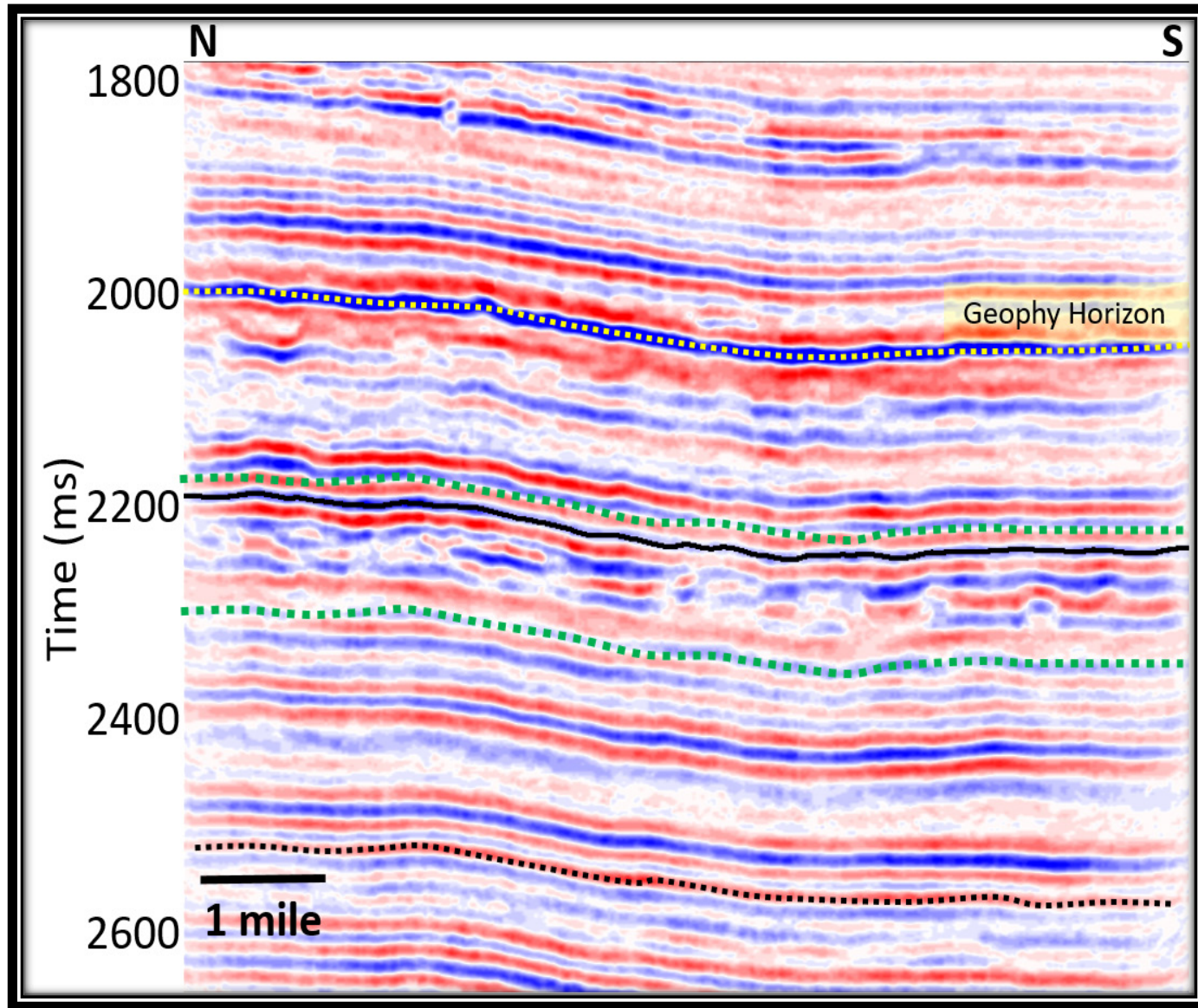
Seismic amplitude vertical section

Peculiar features or funny looking things (FLTs)

seen in seismic
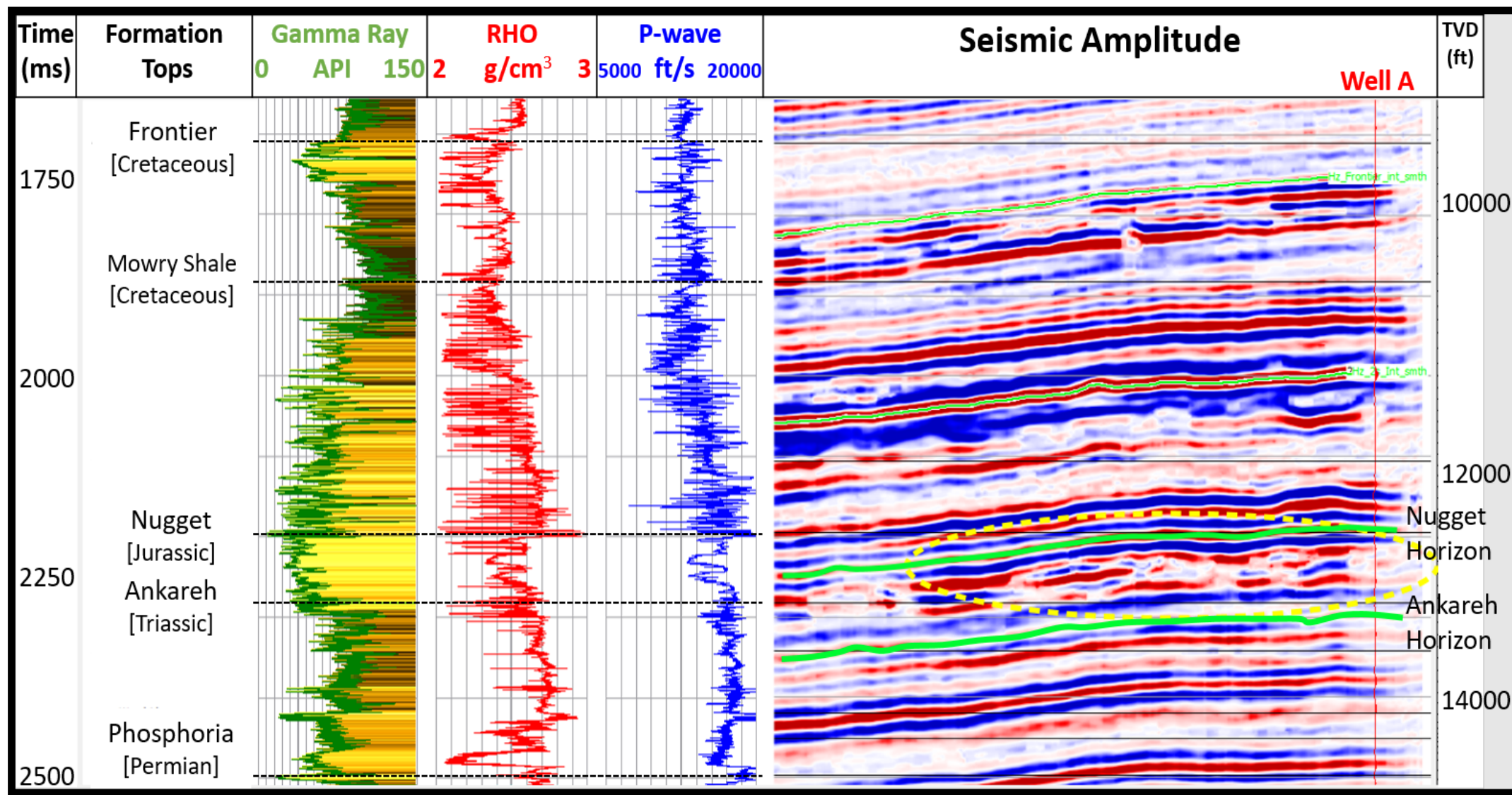
Well to seismic tie – well A (highlighted as red vertical line).
Yellow ellipse exhibits the interesting structures

North American continent during early Jurassic

(after National Park Services, 2018)
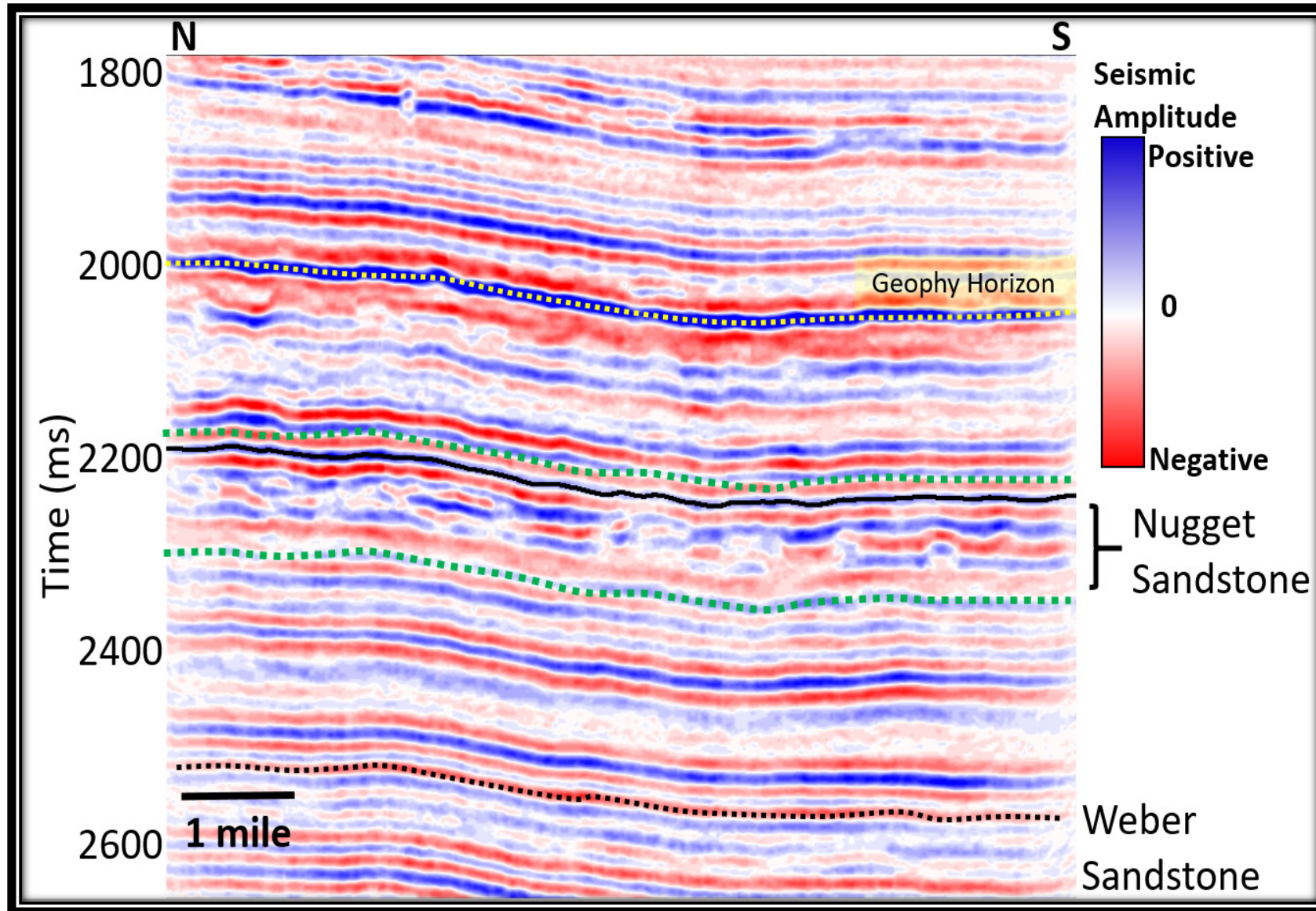
Seismic amplitude vertical section
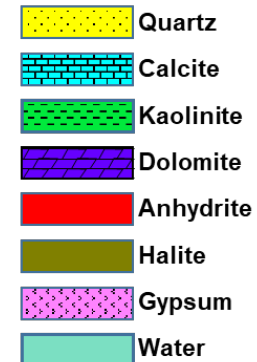Nugget Sandstone is about 75 ms thick (Verma et al., 2018)

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- Seismic and well log data analysis
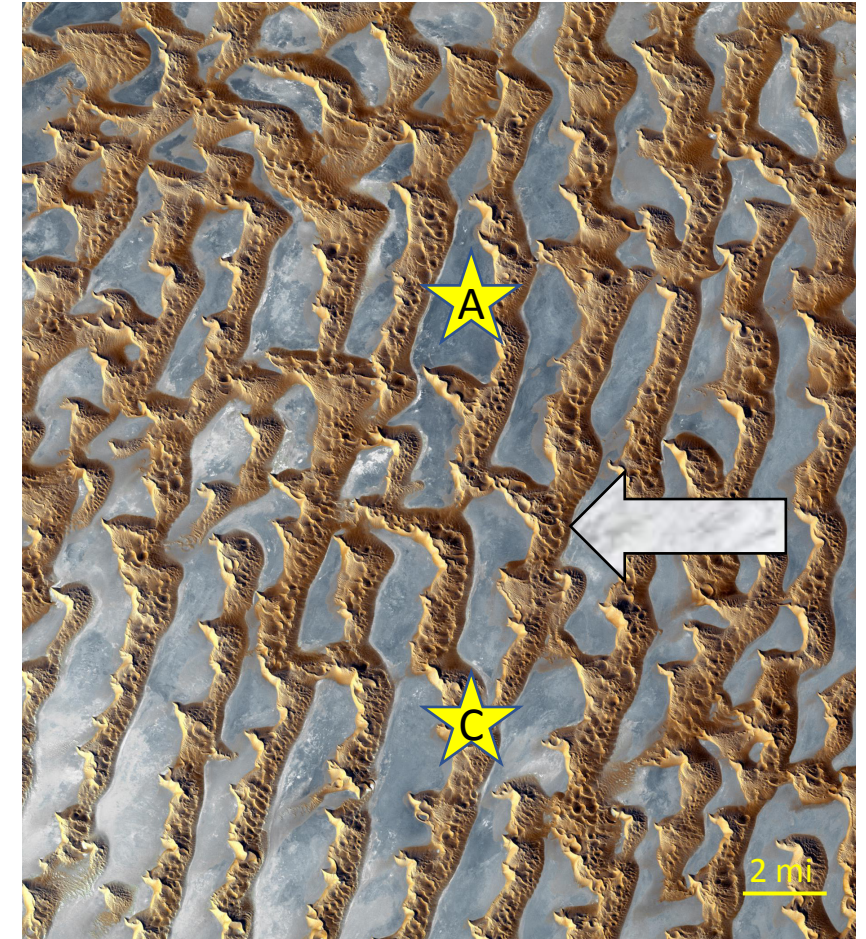- Seismic conditioning
- Conclusions and Acknowledgements

Sand Dune
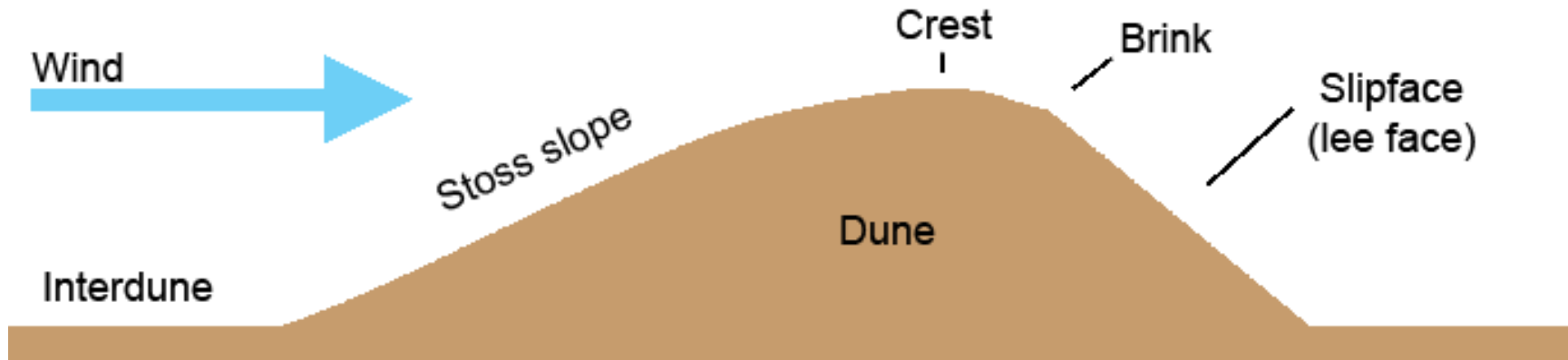
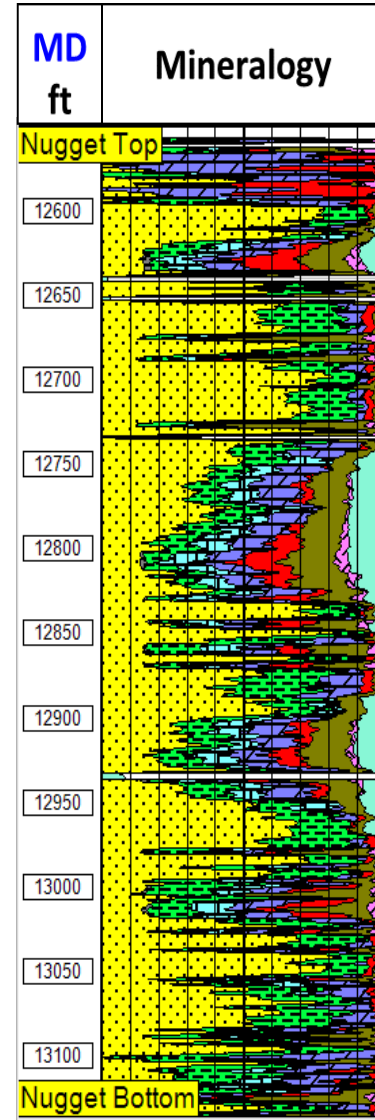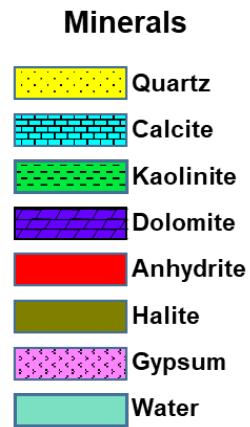Stoss and lee faces of a sand dune with respect to the paleocurrent direction

http://smallpond.ca/jim/sand/overview/

Sand Dune

Formation and propagation of a sand dune (Bevis, 2013)

Sand Dune

Barchan Dunes

Linear Dunes

Transverse Dunes

Parabolic Dunes

Barchan Dunes becoming Transverse Dunes

Star Dunes
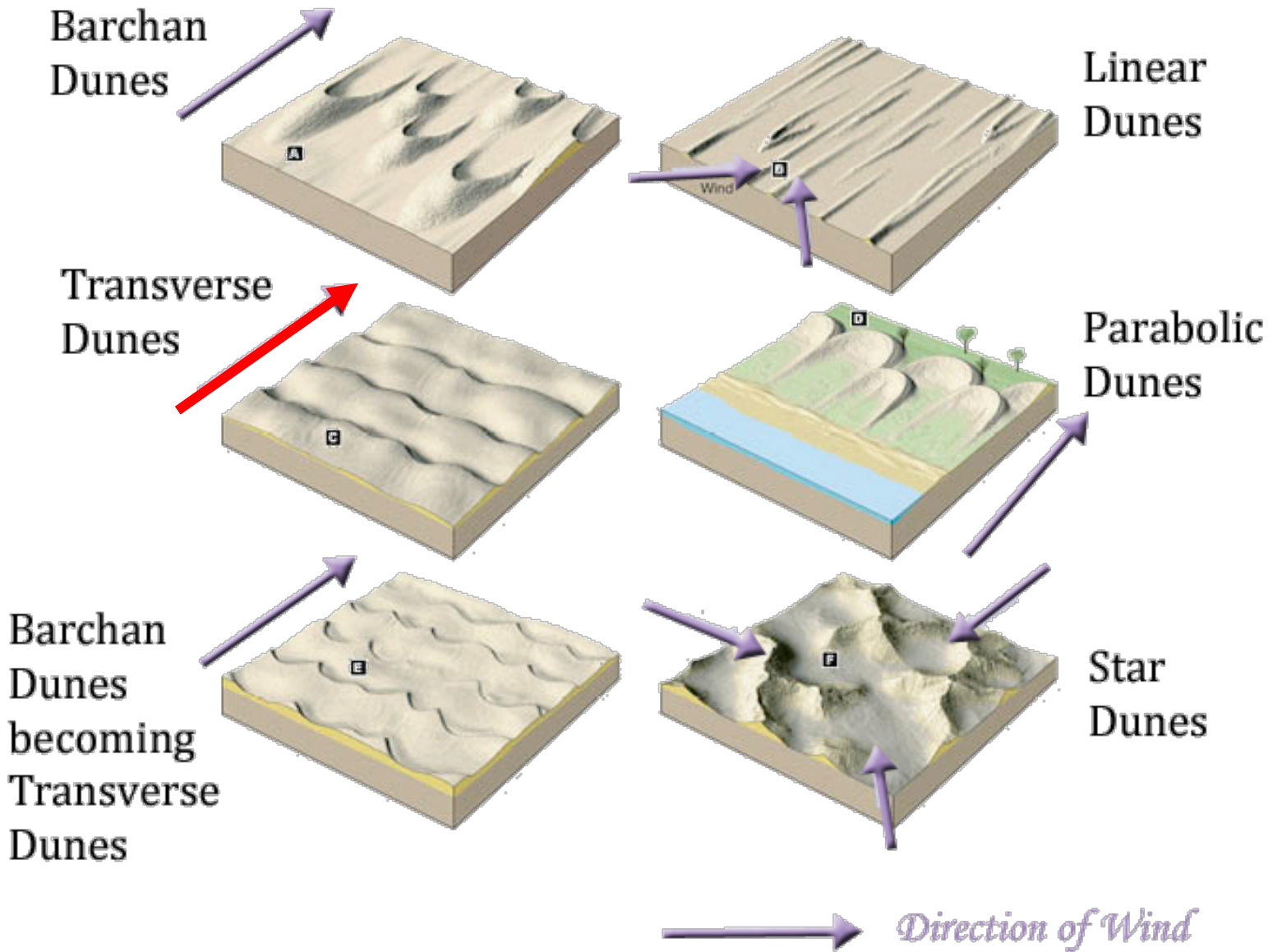
Major types of sand dunes

Direction of Wind

Sand Dune

Outcrop from the Navajo Sandstone in the Arches National Park

SE

NW

Cross Beddings

Transverse Dunes

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- Introduction
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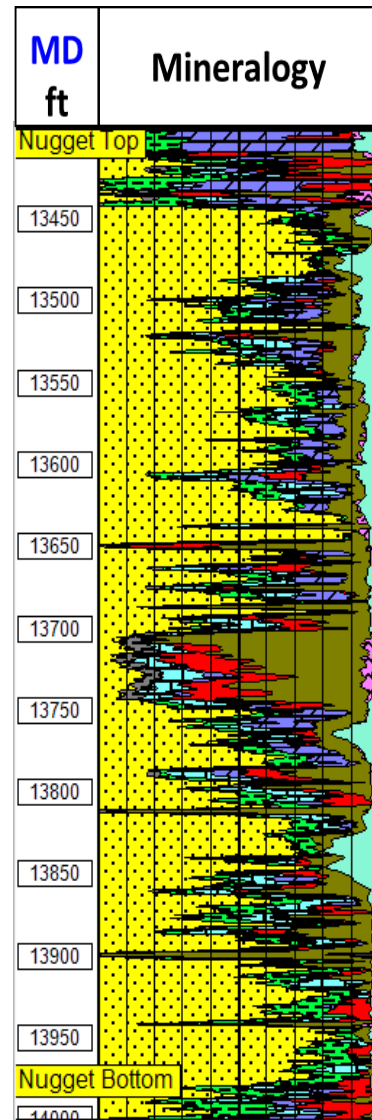- Conclusions and Acknowledgements

Petrophysical analysis
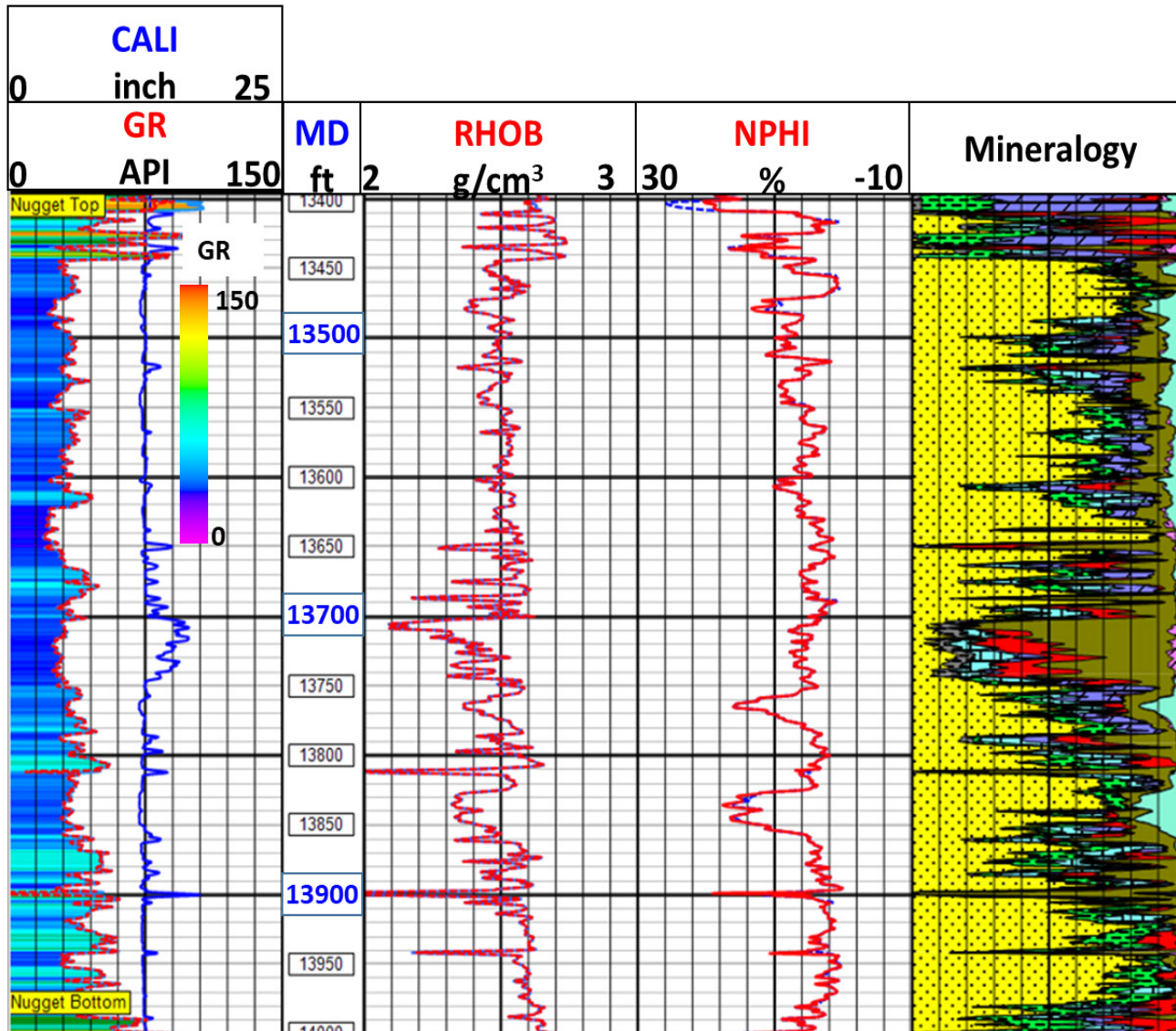
Stochastic mineral solution from well C. The mineralogy determines the primary mineral composition to be quartz (sands).

Petrophysical analysis

Well C

Well A

Minerals legend:
- Quartz
- Calcite
- Kaolinite
- Dolomite
- Anhydrite
- Halite
- Gypsum
- Water

Modern Day Analog – Rub al' Khali, Arabia

Statistical multi-mineralogical solutions for wells C and A.
Note the lithological heterogeneity between both wells (Verma et al., 2018)

Coherence

Outcrop from the Navajo Sandstone in the Arches National Park

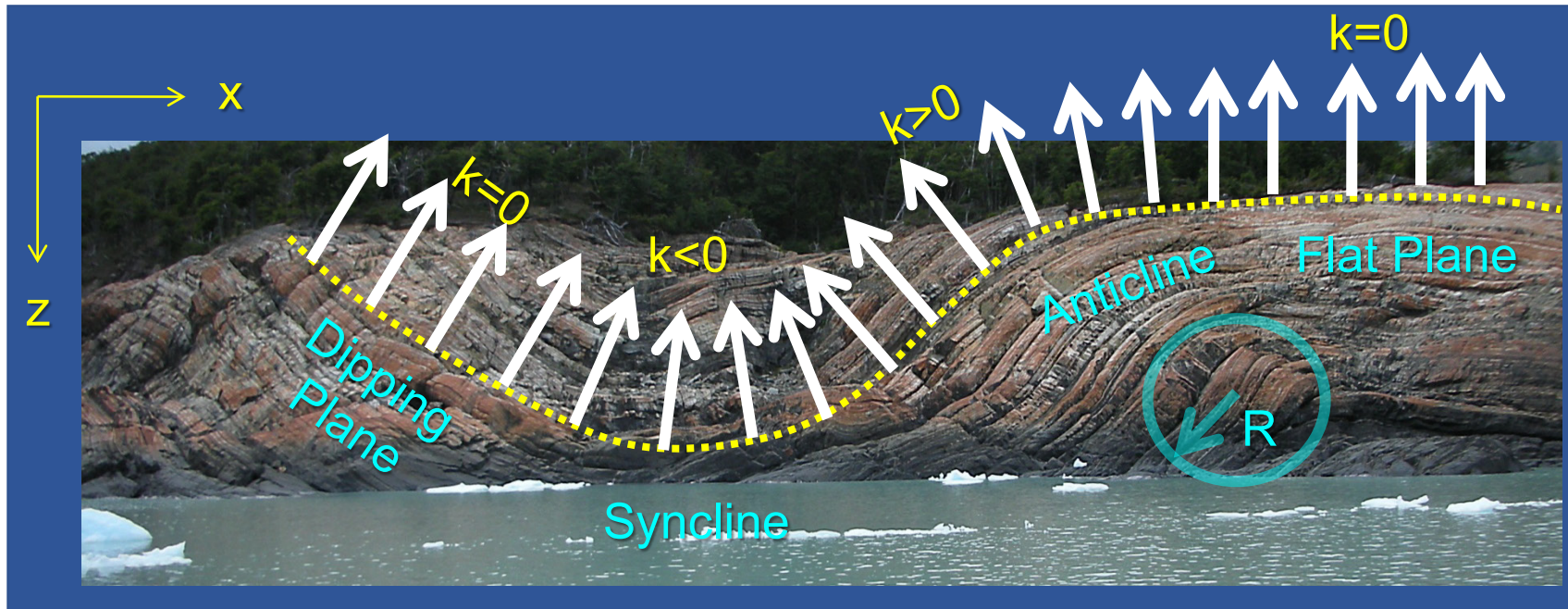# Coherence

(a) 64 ms below Nugget
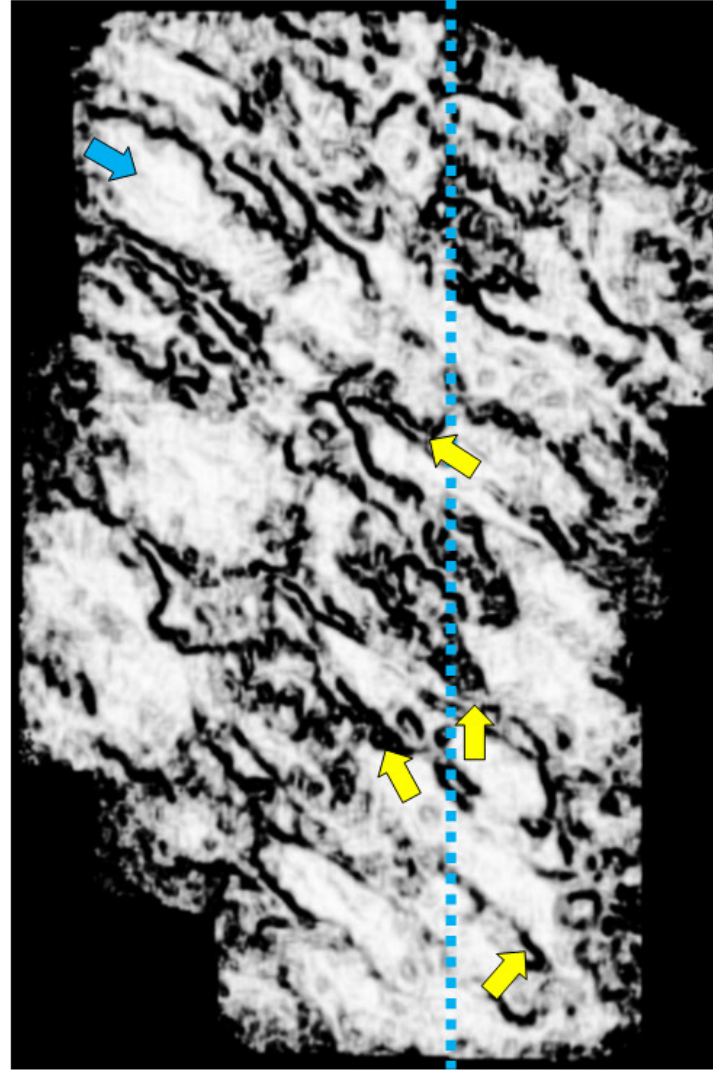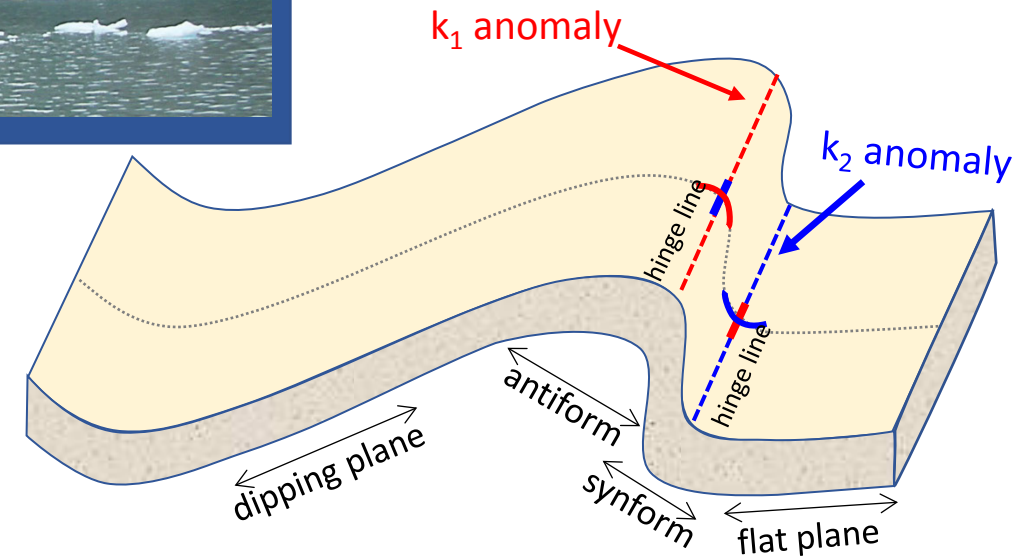
(b) 44 ms below Nugget

(c) 24 ms below Nugget
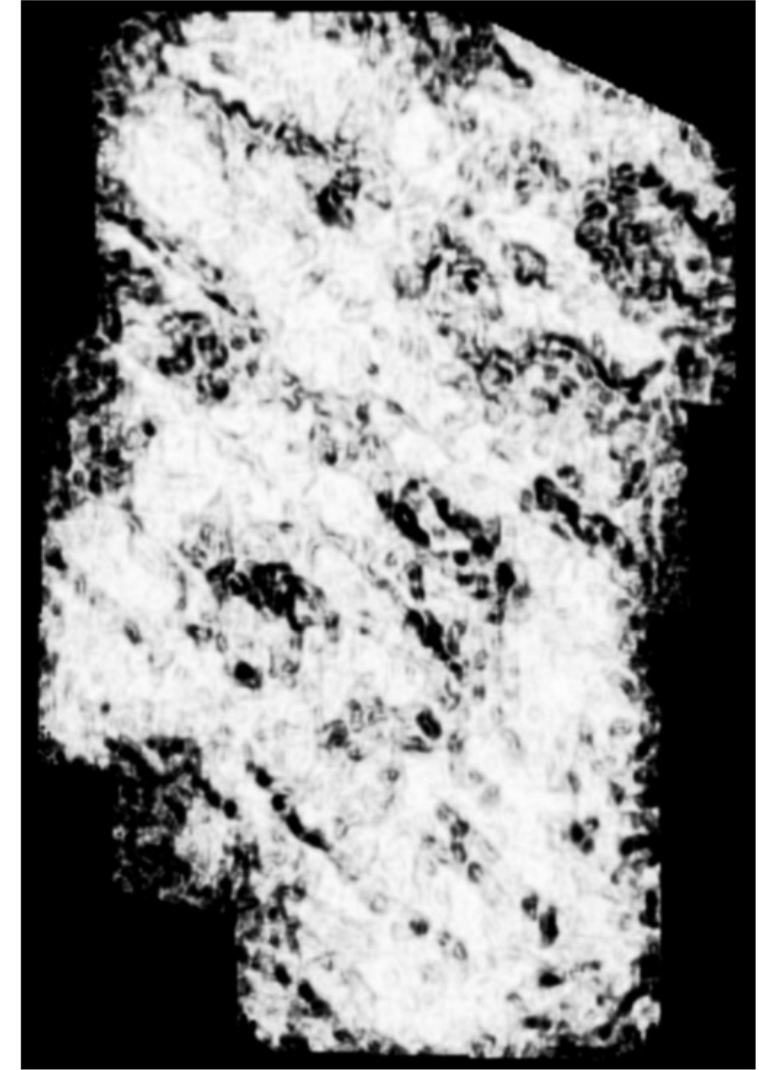
Stratal slices of the coherence attribute, 1 represents maximum similarity 0 represents maximum dissimilarity.
Blue arrow indicates interdunal and yellow arrow indicated dunal environment.

Structural Curvature

$$k = \frac{1}{R} = \frac{\dfrac{d^2 z}{dx^2}}{\left[1 + \left(\dfrac{dz}{dx}\right)^2\right]^{3/2}}$$
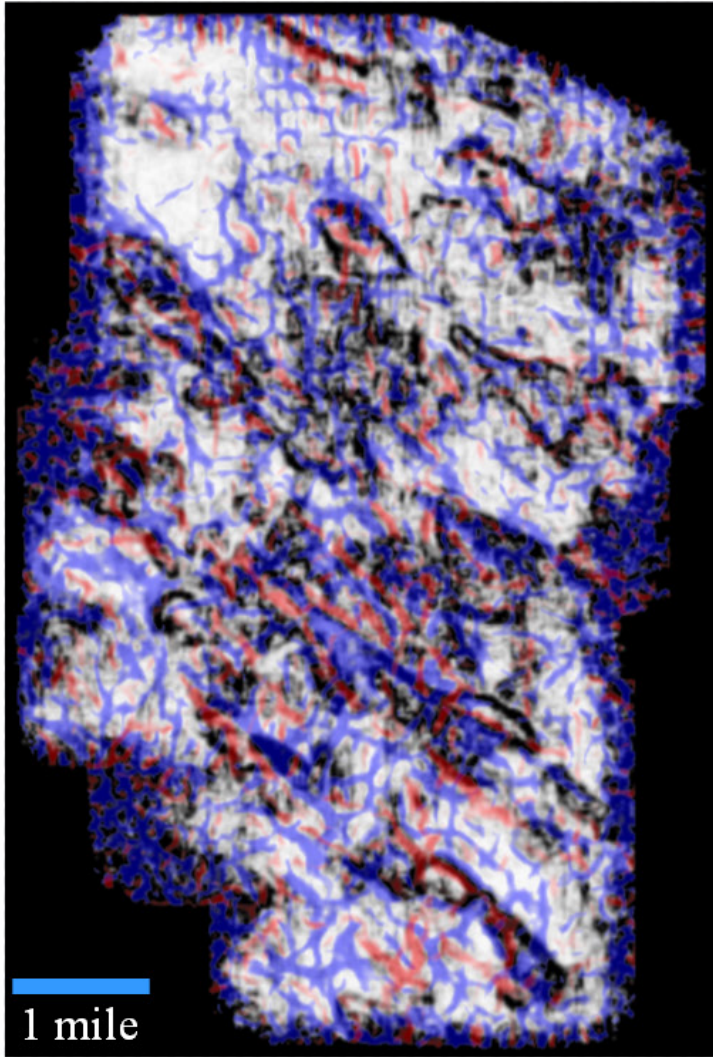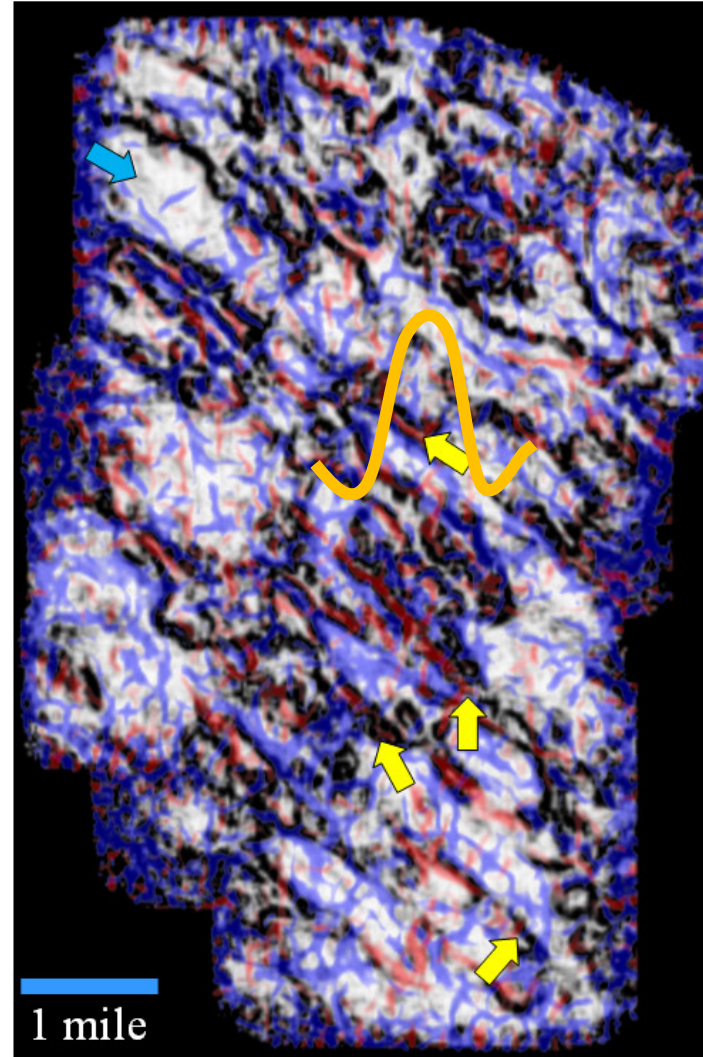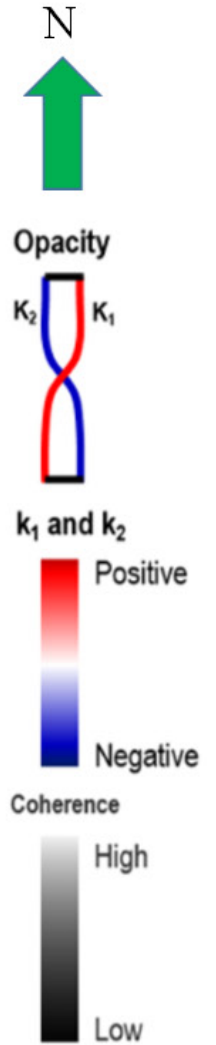
Antiform: k > 0
Plane: k = 0
Synform: k < 0

Curvature has 2 main components k_1 (most positive curvature) and k_2 (most negative curvature)

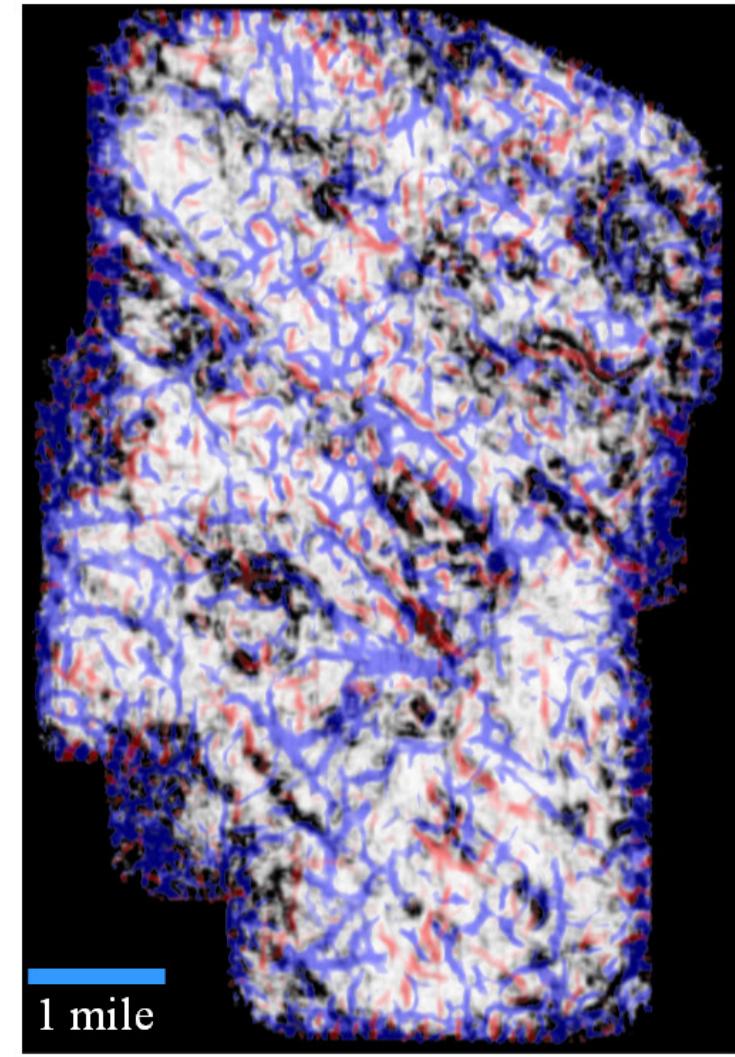(Slide courtesy: Dr. Marfurt)

Structural Curvature

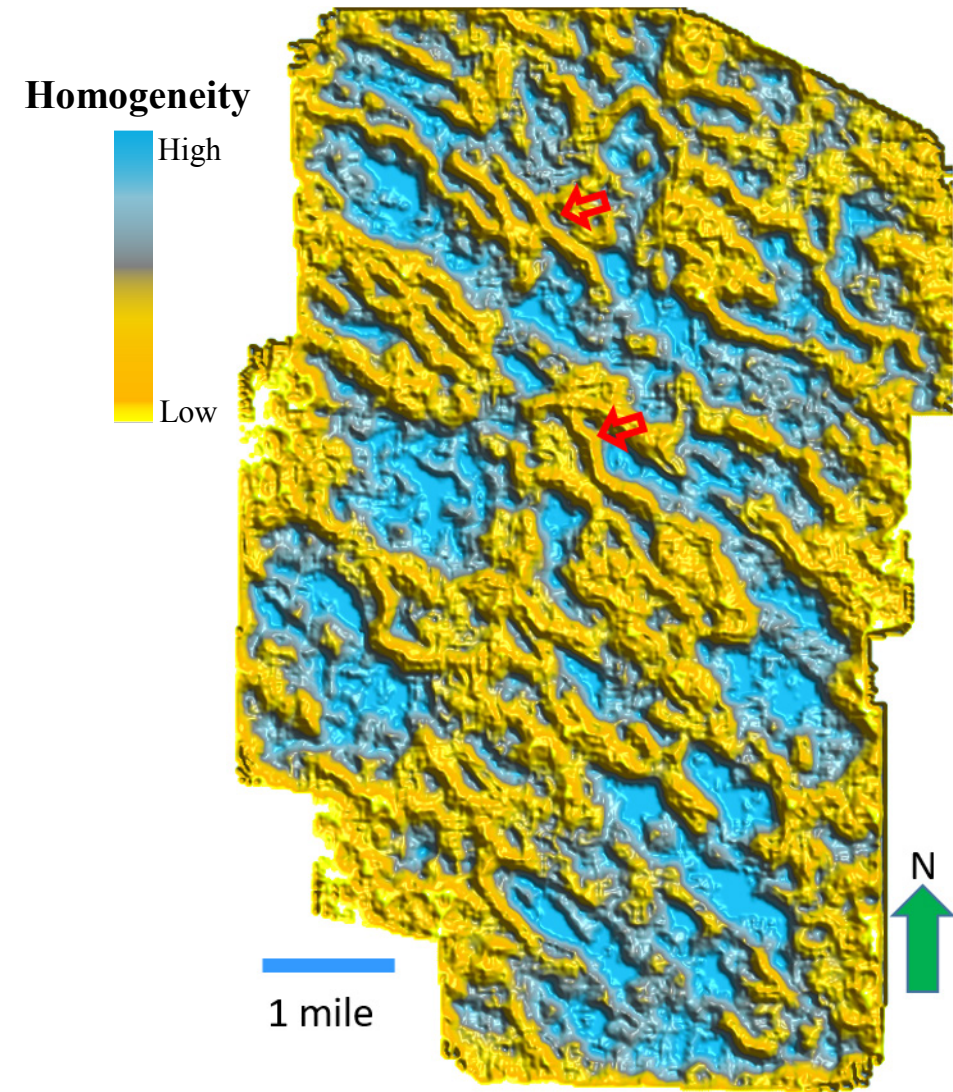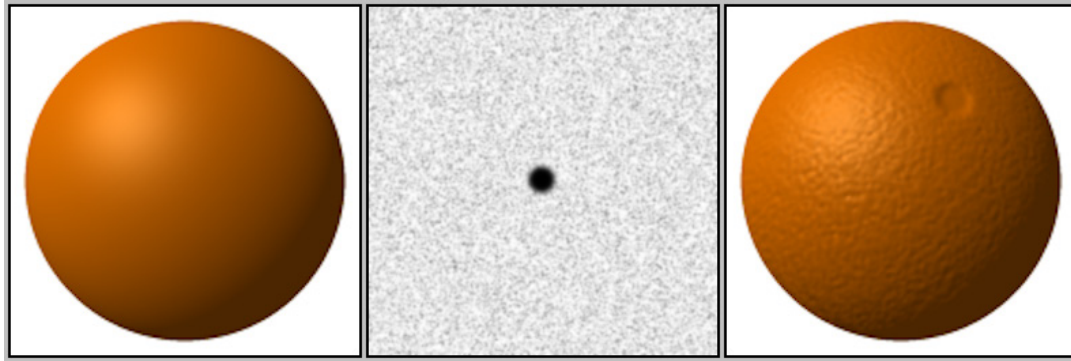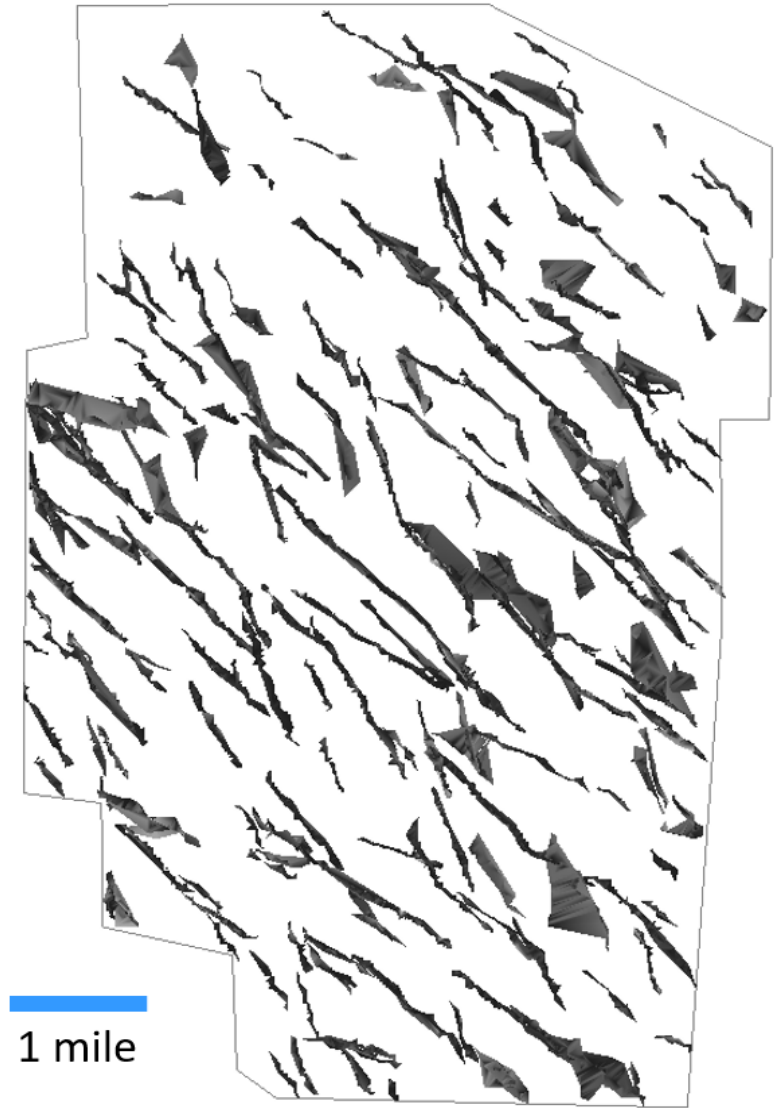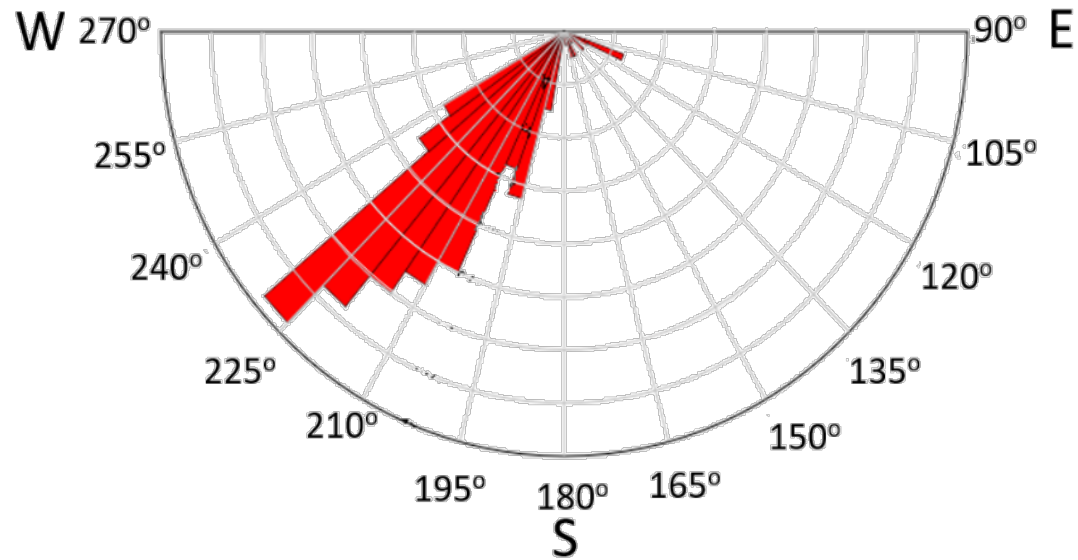(a) 64 ms below Nugget   (b) 44 ms below Nugget   (c) 24 ms below Nugget

Stratal slices of the curvature attributes (k_1 and k_2) co-rendered with coherence.
Blue arrow indicates interdunal and yellow arrow indicated dunal environment.

Bump Mapping

Left – sphere without bump mapping, Middle – bump map to be applied, Right – sphere with bump mapping
GLCM Homogeneity applied with a bump map, red arrows illuminate the stoss side with gradual dip (Verma et al., 2018)
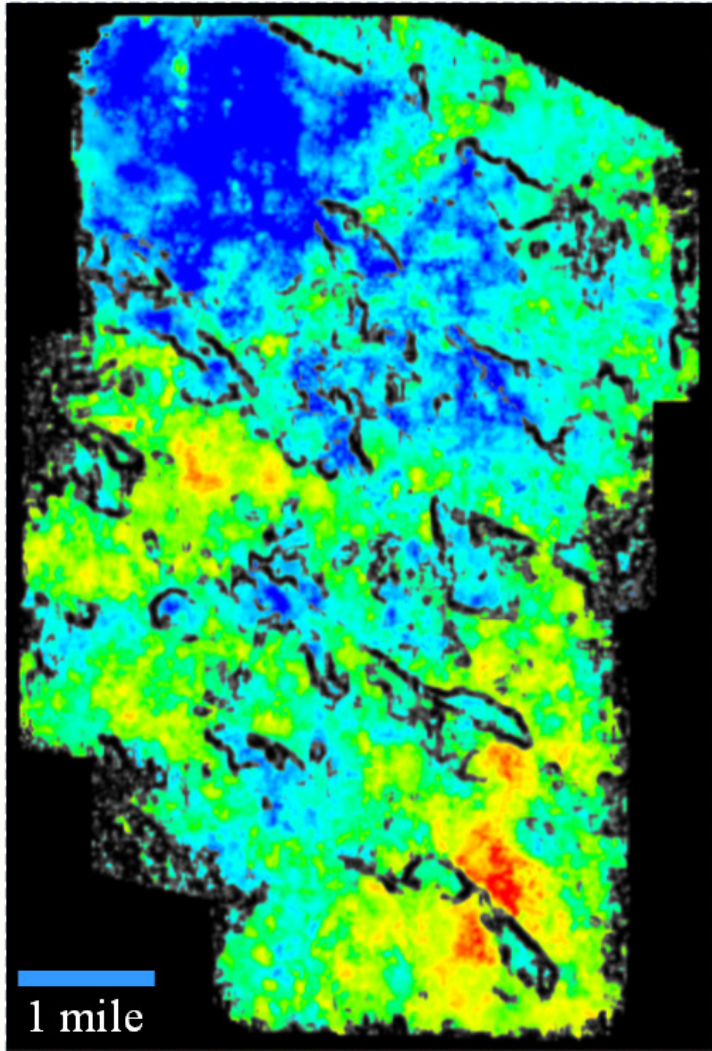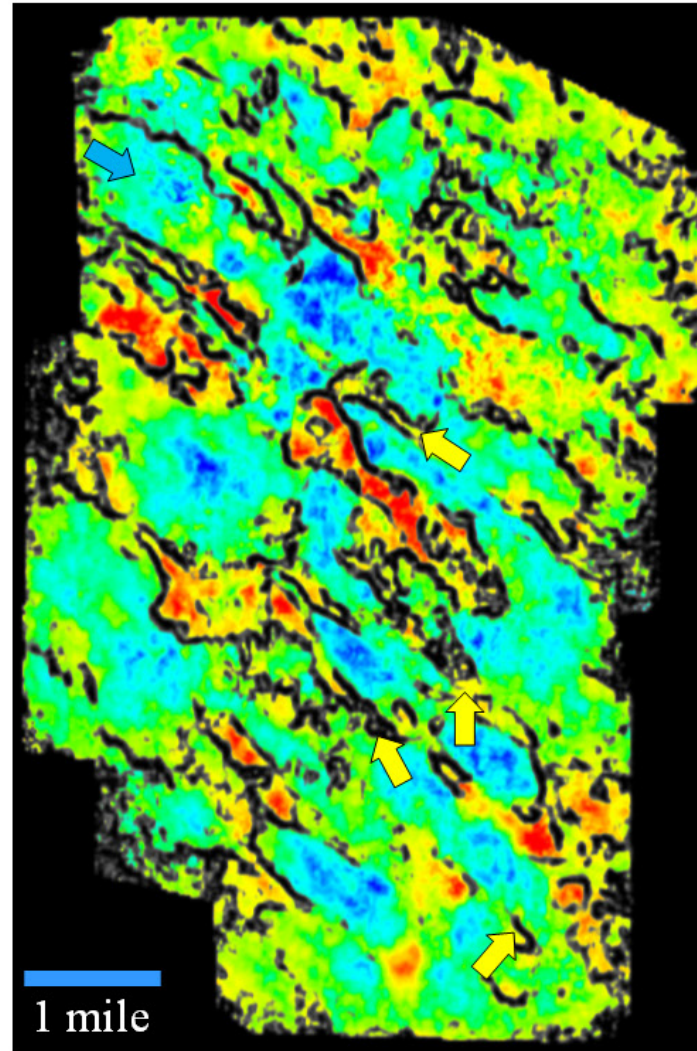
Paleo-wind direction

Left: Rose Diagram showing average wind direction, Right: Ant Track workflow showing directions of the lineaments
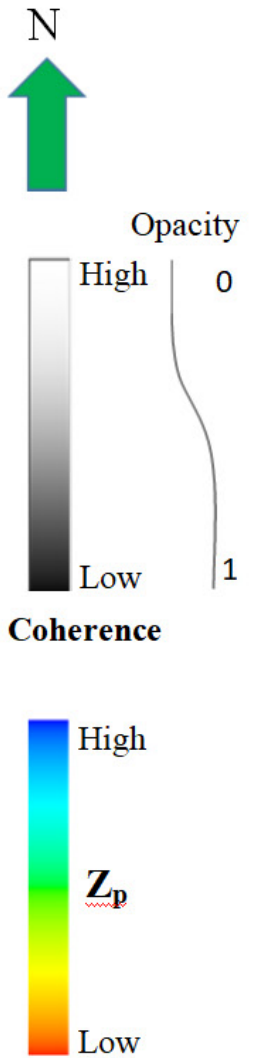
P-impedance

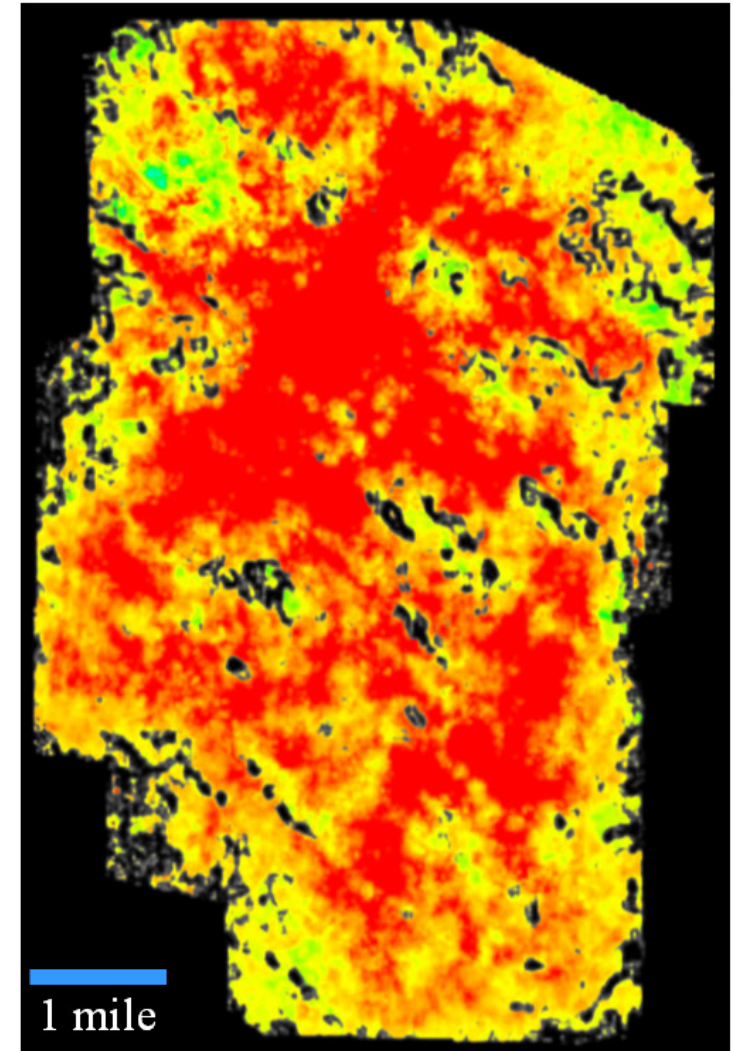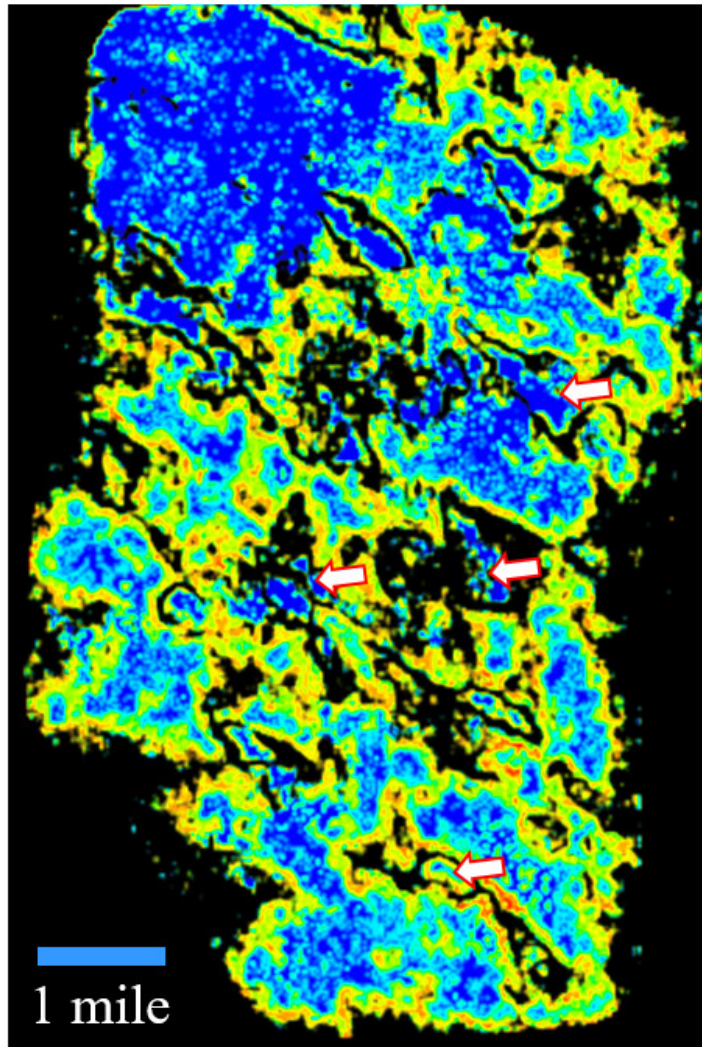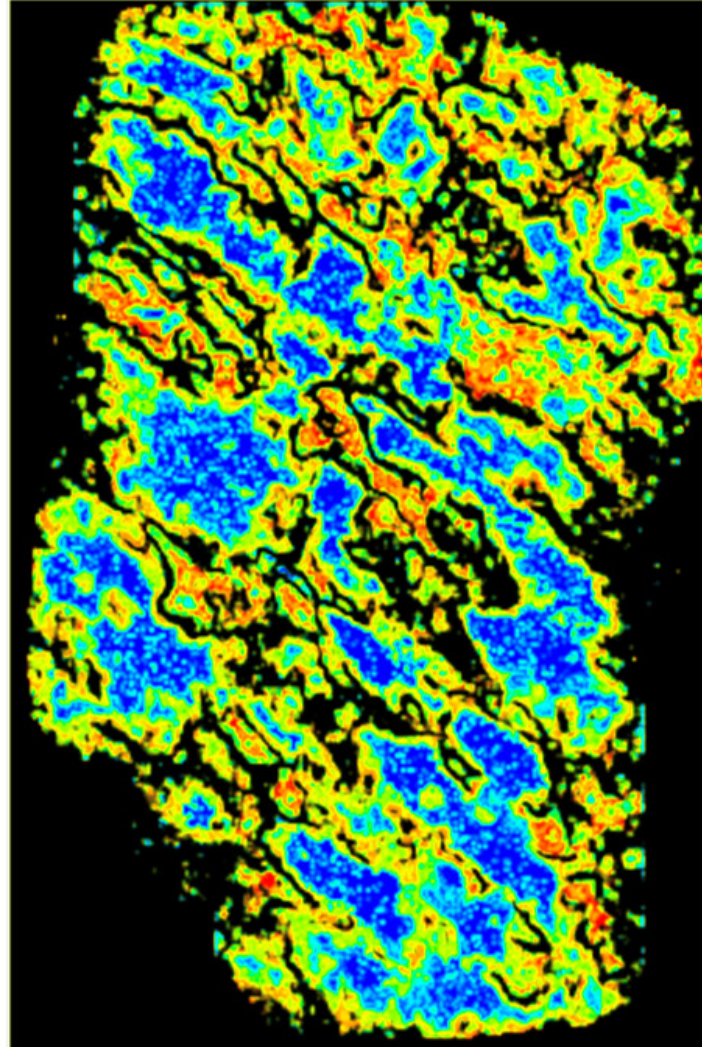(a) 64 ms below Nugget   (b) 44 ms below Nugget   (c) 24 ms below Nugget

Stratal slices of P-impedance (Zp) co-rendered with coherence.
Blue arrow indicates interdunal and yellow arrow indicated dunal environment.
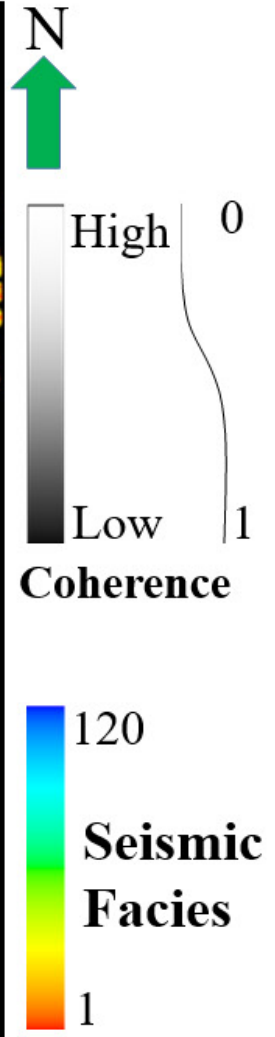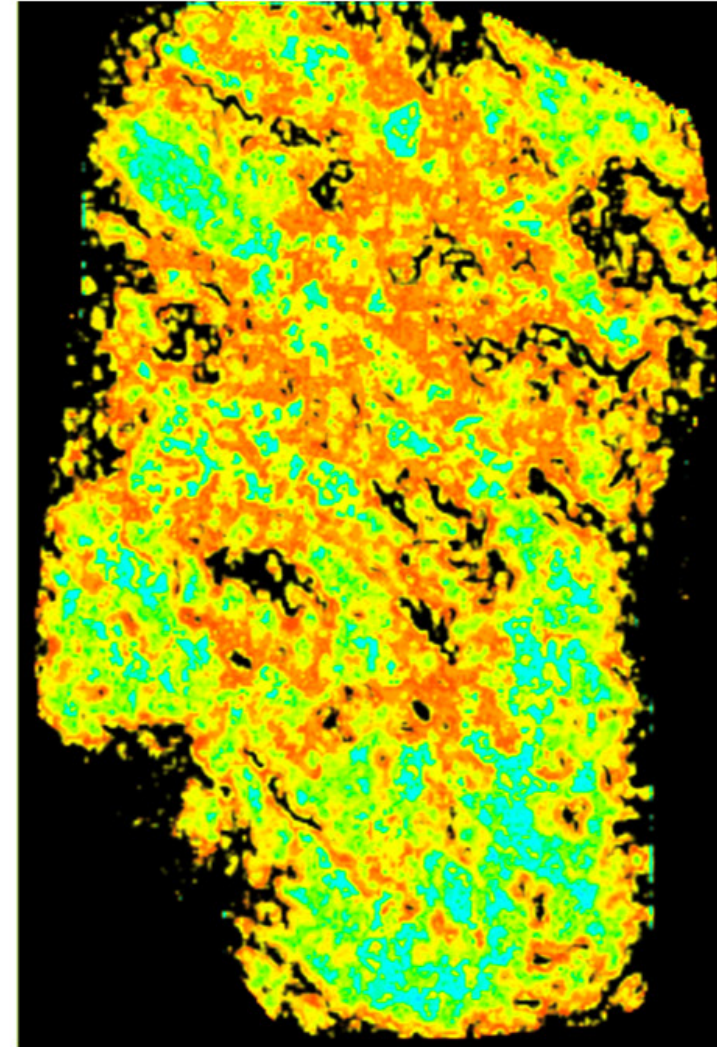
Seismic Facies

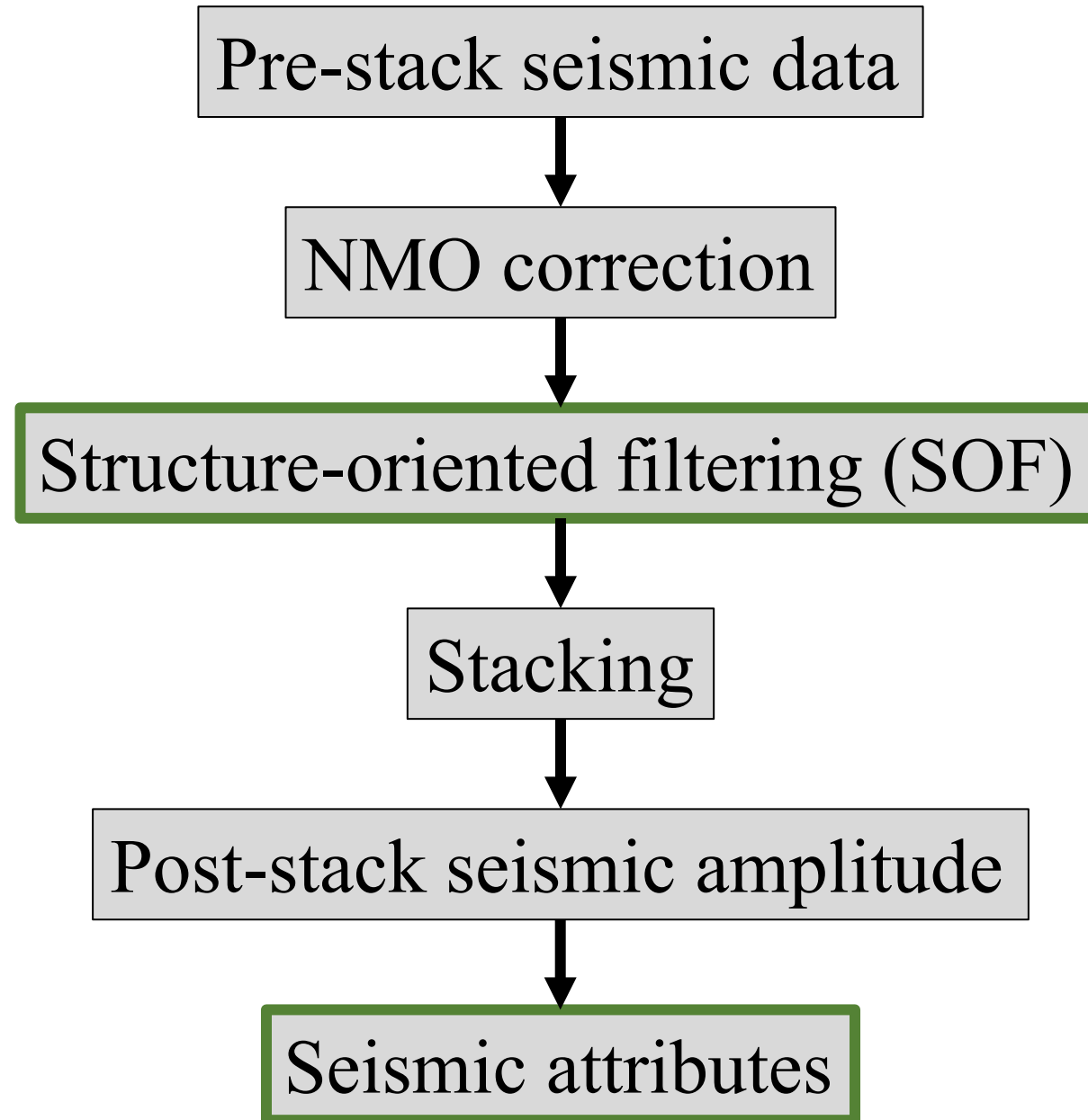## (a) 66 ms below Nugget (a) 42 ms below Nugget (a) 26 ms below Nugget

Stratal slices of the seismic facies co-rendered with coherence. Generated with self-organizing map (SOM) algorithm Correlation with P-impedance indicate blue colored facies are interdunal deposits while yellow are dunal (Verma et al., 2018)
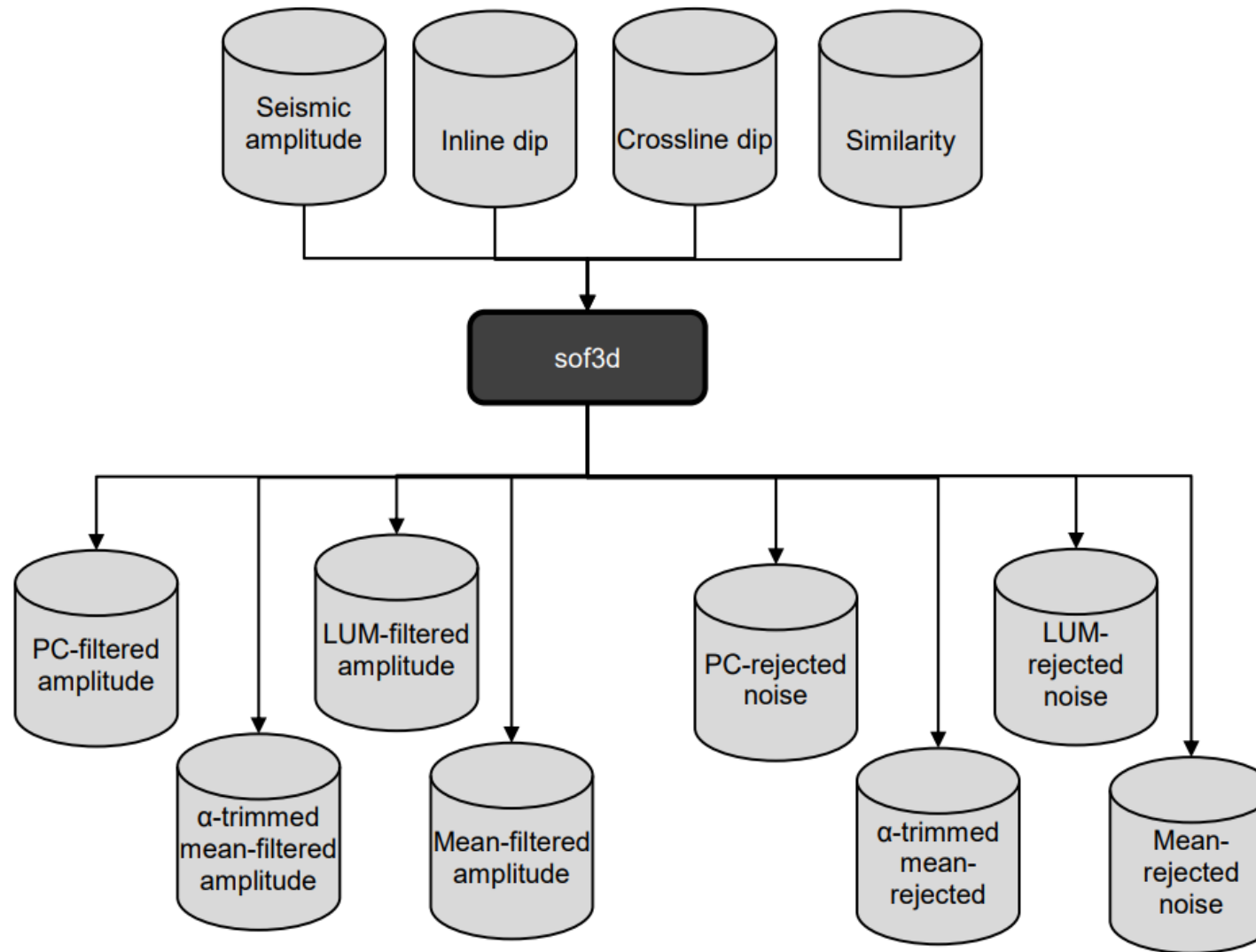
Contents

Seismic Processing and Conditioning workflow

```
┌─────────────────────────────┐
│   Pre-stack seismic data    │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│       NMO correction        │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────────────┐
│  Structure-oriented filtering (SOF)  │
└─────────────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│          Stacking           │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────────┐
│   Post-stack seismic amplitude   │
└─────────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│      Seismic attributes      │
└─────────────────────────────┘
```
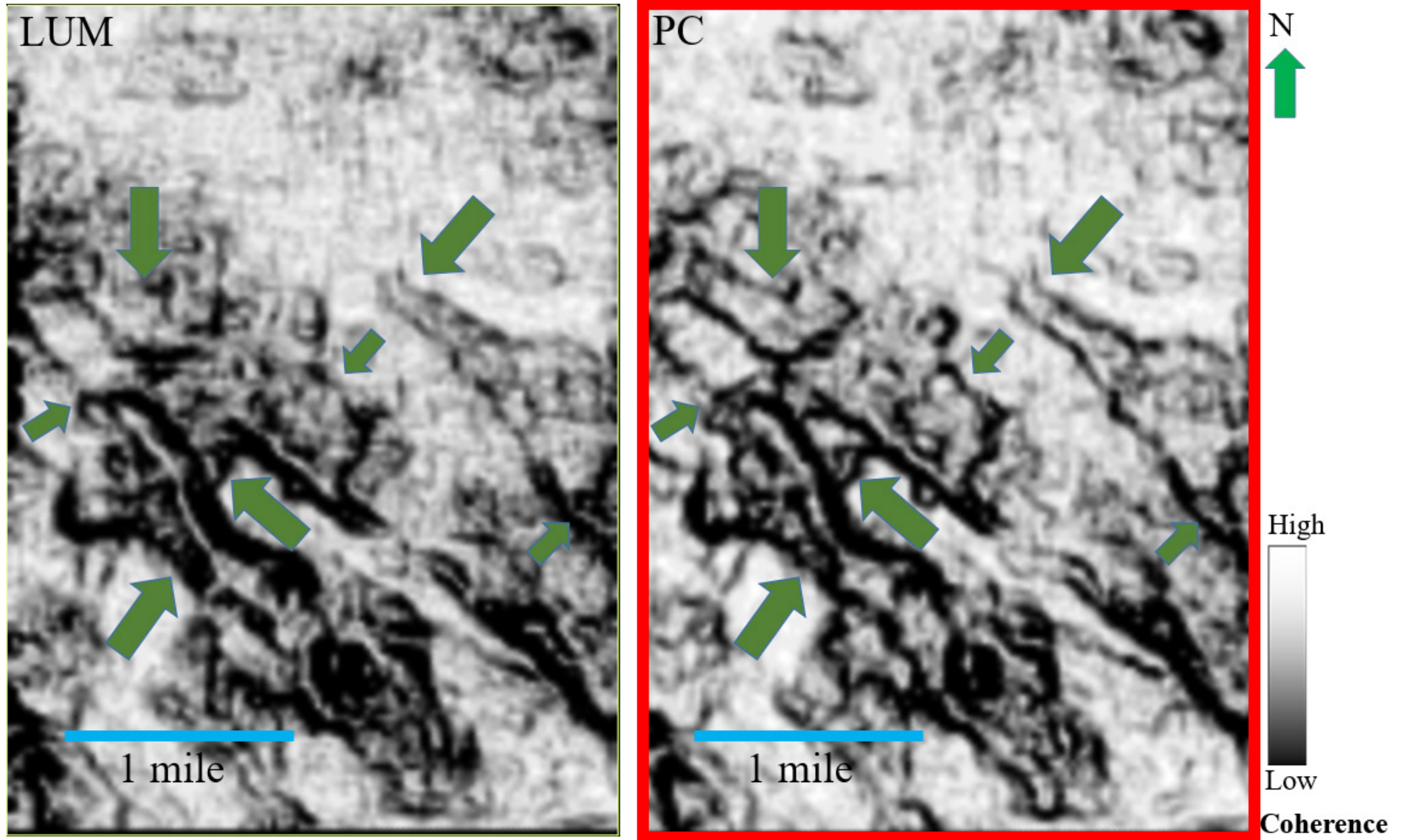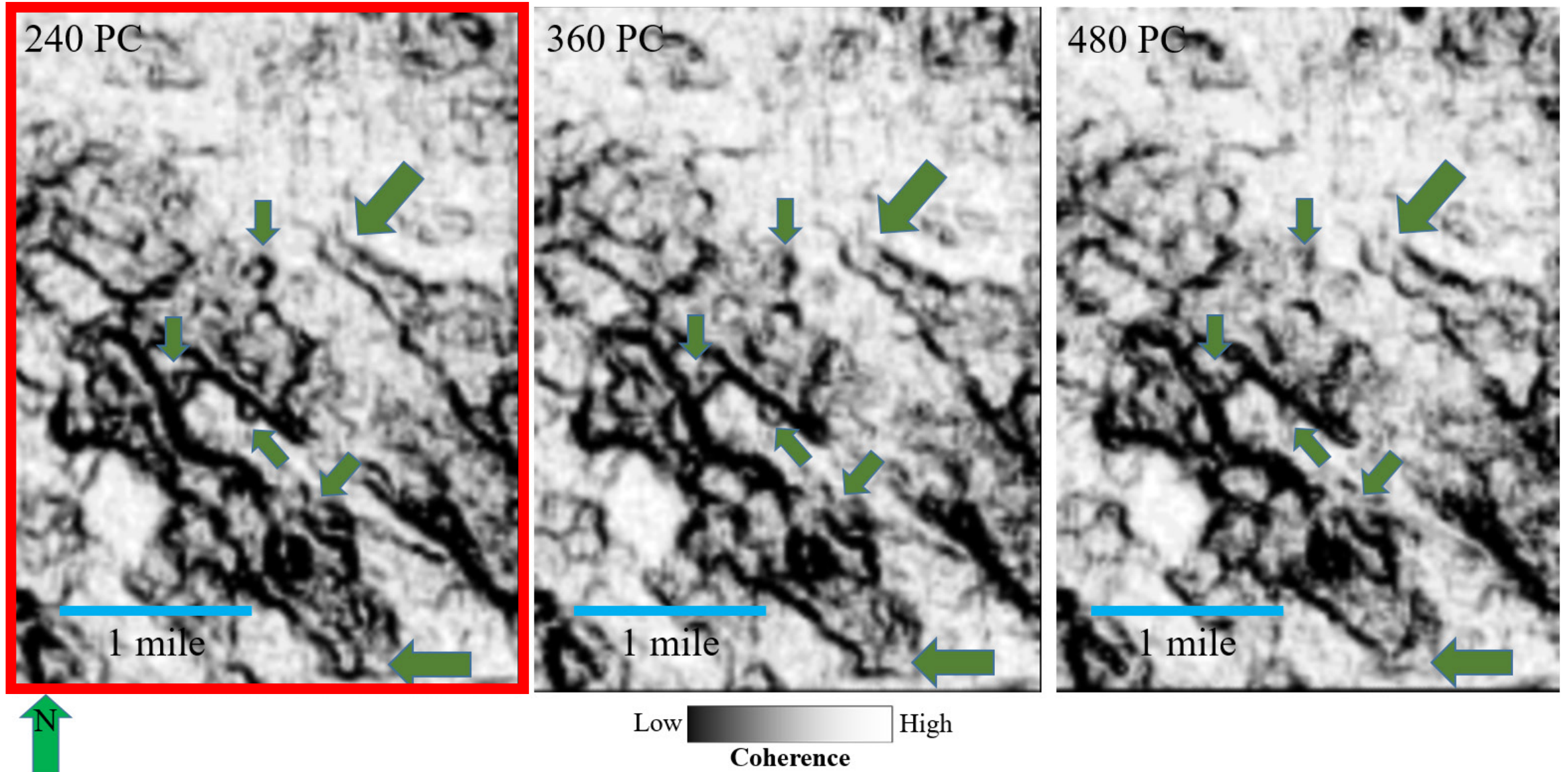
Structure-oriented filtering

Flowchart of SOF exhibiting inputs and outputs (AASPI, 2019)
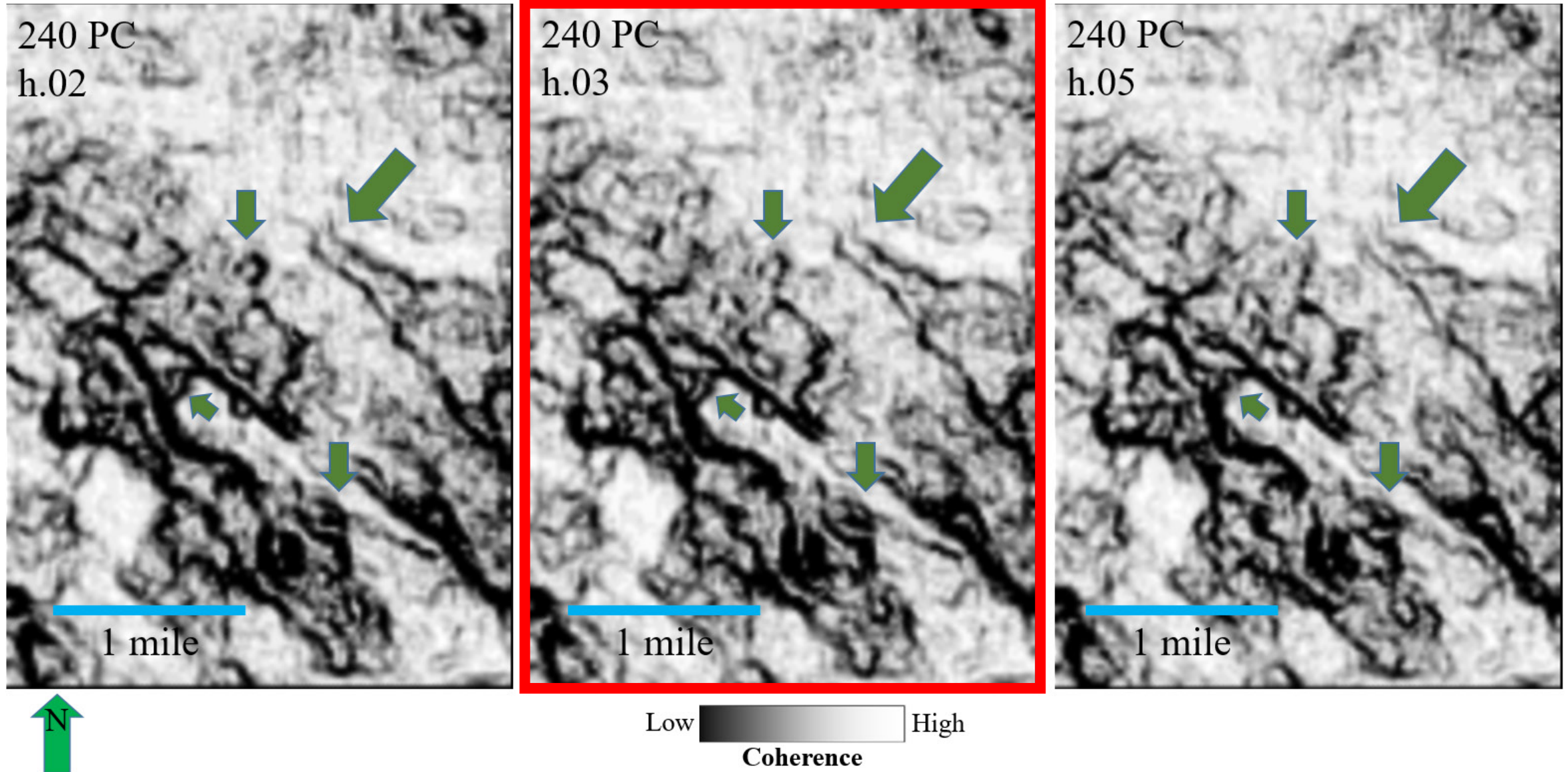
Structure-oriented filtering

Coherence slices for LUM and PC filters applied on the cropped dataset.
Green arrows show features resolved better in PC than LUM filter
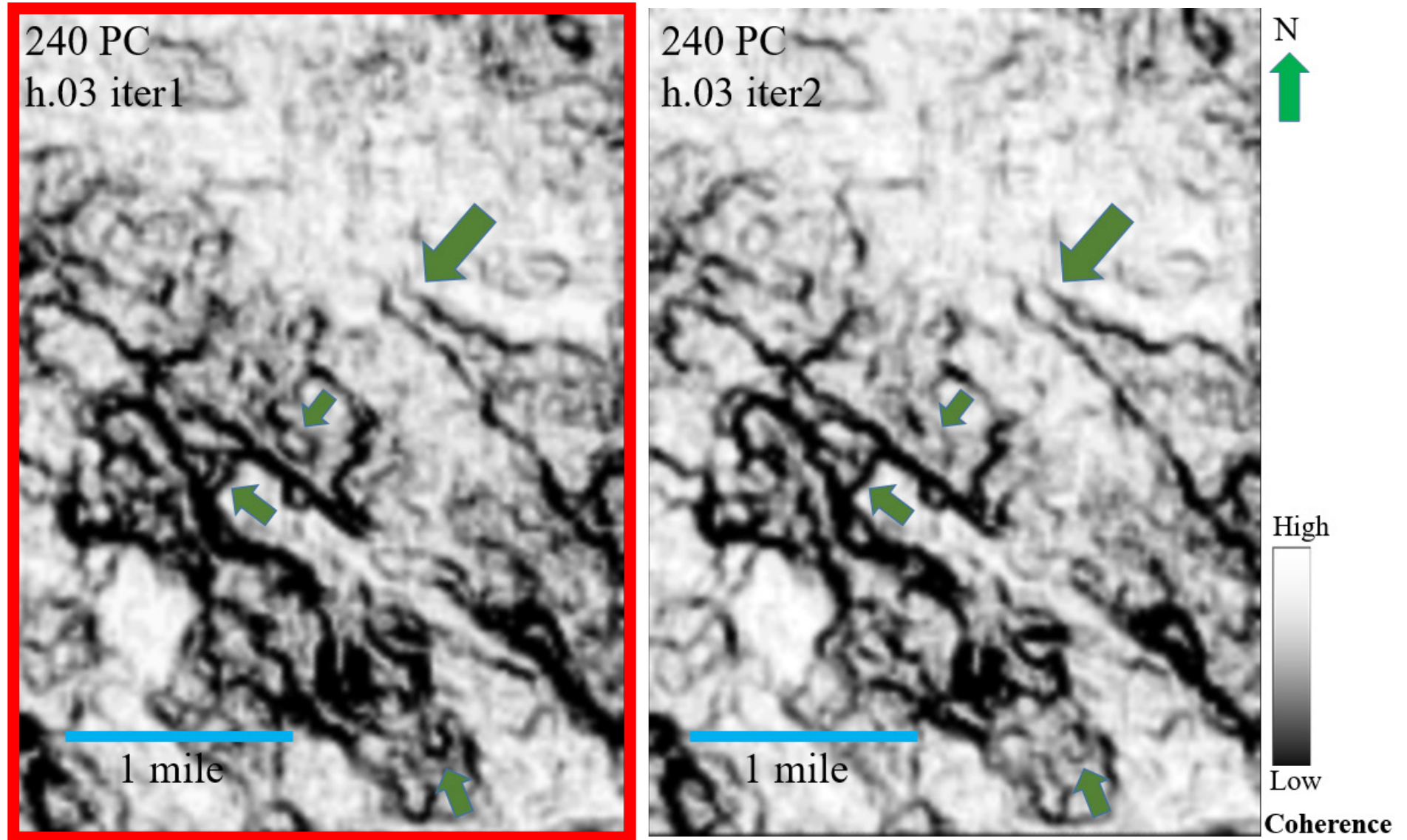
Structure-oriented filtering

Coherence slices for different inline and crossline window radii (ft) for cropped dataset.
240 ft window shows the best resolution
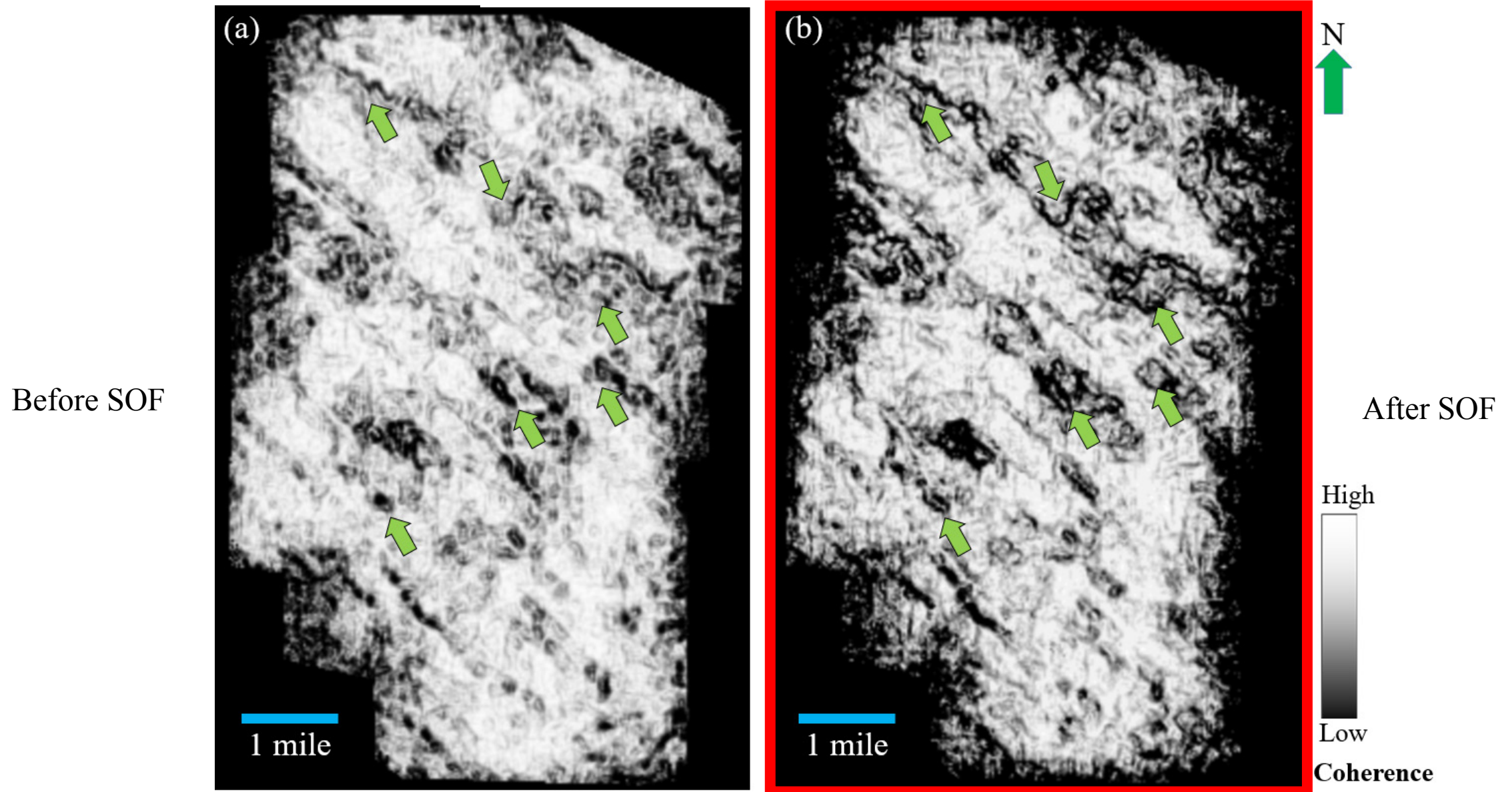
Structure-oriented filtering

Coherence slices for different window height (s) for cropped dataset.
0.03 s window height shows the best resolution

Structure-oriented filtering

Coherence slices for multiple SOF iterations applied on the cropped dataset.
1st iteration shows sharper structures and better resolution

Structure-oriented filtering

Stratal slices of the coherence before and after the seismic data conditioning, both are 24 ms below Nugget. The green arrows indicate features being better resolved after SOF

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Modern-day Analog

- Well to seismic tie – Nugget Sandstone

- Seismic attributes delineate sand dunes

- Bump mapping highlighted stoss and less sides

- P-Impedance and SOMs distinguish facies

- SOF enhances discontinuities

- Carbon sequestration reservoir

Homogeneity

High

Low

2 mi

1 mile

N

Acknowledgements
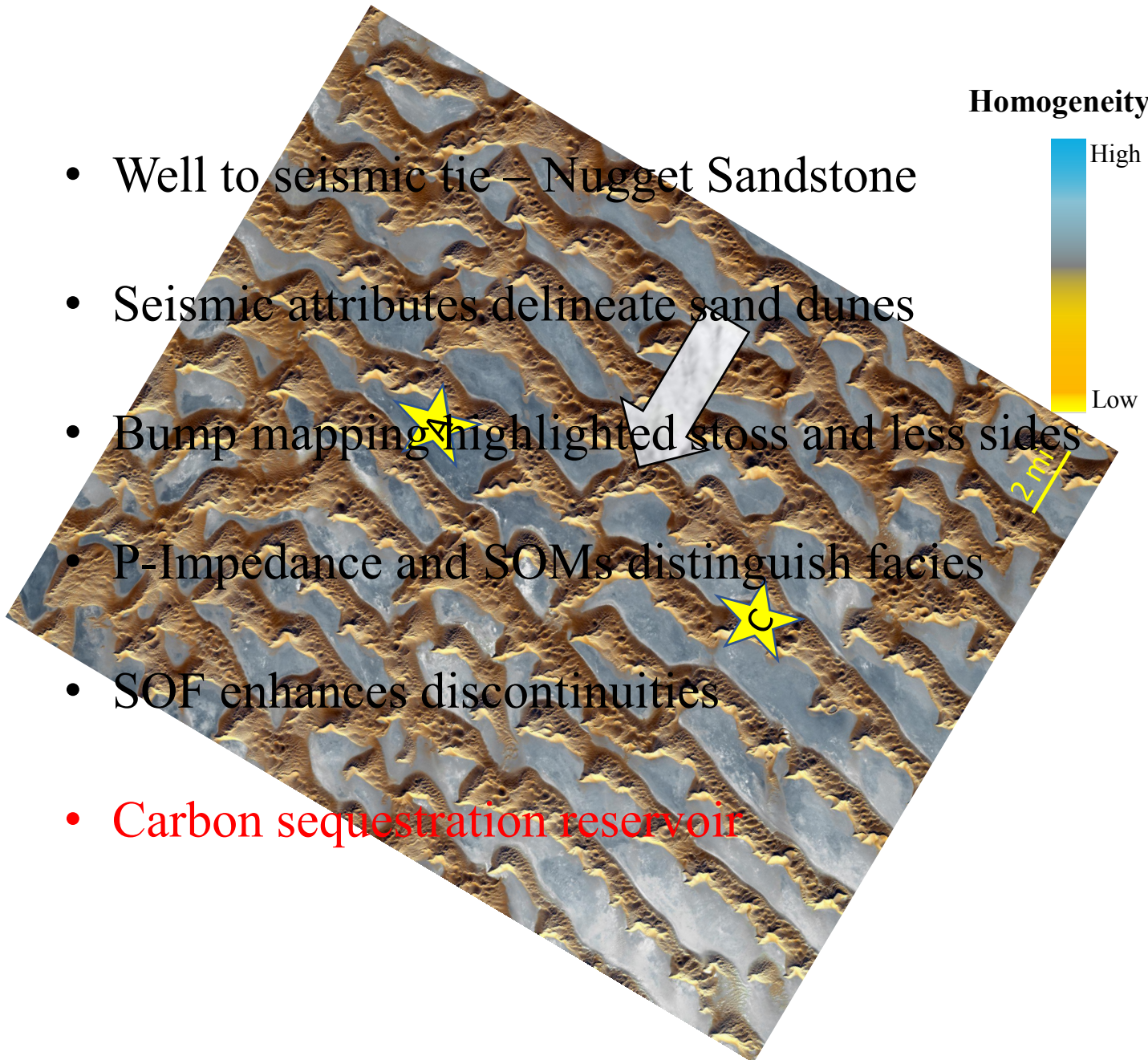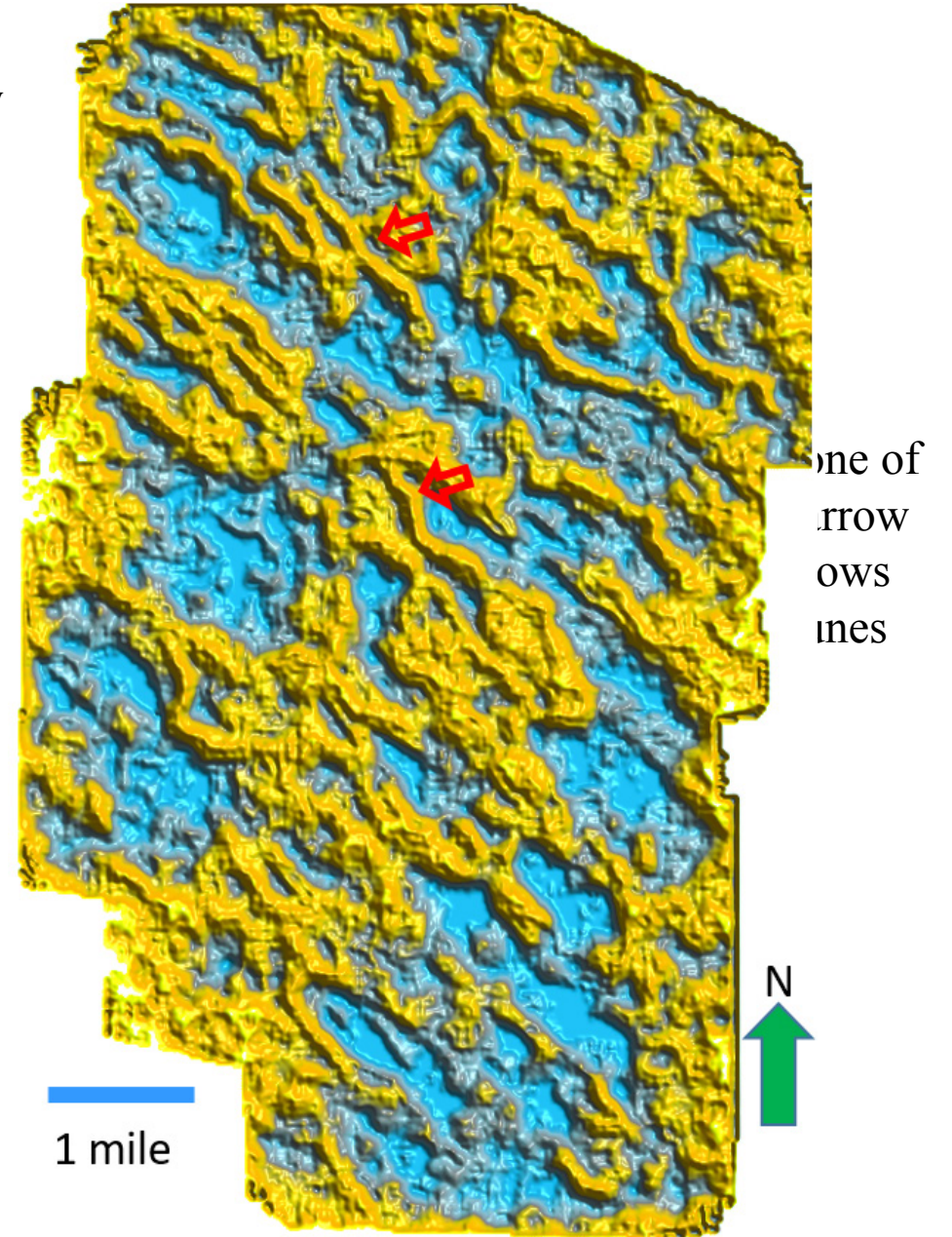
- Dr. Sumit Verma, Dr. Miles Henderson, Brady Lujan, Matt Scipione

- AASPI for seismic attributes and seismic conditioning

- Schlumberger's Petrel for interpretation

- CGG Geosoftware for HampsonRussell for well to seismic tie

- US Department of Energy

- University of Wyoming