‘Scale Is Everything’ -- the Permian Cedar Mesa Outcrop, a ‘Qualitative’ Analog for the Permian Unayzah, ‘Wet’ Eolian Depositional System in Saudi Arabia

By
Christian J. Heine[1] and John Melvin[1]

Search and Discovery Article #50088 (2008)
Posted October 5, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, Texas, April 20-23, 2008

[1]Upstream Ventures (Joint Venture Exploration), Saudi Aramco, Dhahran, Saudi Arabia (christian.heine@aramco.com)

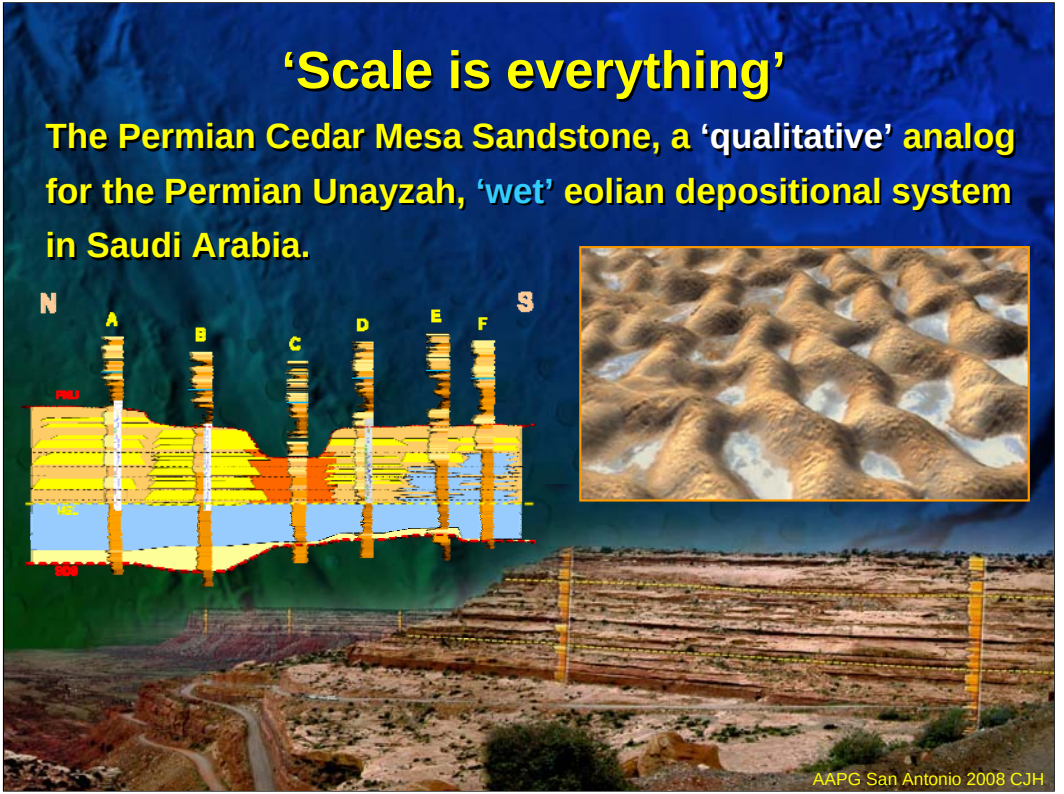
Abstract

One of the most important contributions outcrop analogs can provide to you as a geoscientist is a feeling for scale. Questions like; well spacing, reservoir compartments, model cell size, horizontal vs. vertical wells, and production anisotropies may at least be visualized and possibly understood at outcrop scale.

The Permian Cedar Mesa sandstone, a well documented ‘wet’ eolian deposit in southern Utah, is an outstanding outcrop analog for the Permian Unayzah ‘A’ reservoir. Field observations from Permian Cedar Mesa outcrop along the Moqi Dugway road-cut display the characteristic alternating ‘wet’ and ‘dry’ cycles of a ‘wet’ eolian depositional system. From core, image log studies, and well-log cross sections, the eolian Unayzah reservoir was identified as a ‘wet’ eolian transverse dune depositional system. In well log cross-sections through the Unayzah ‘A’ reservoir, the ‘wet’ and ‘dry’ depositional cycles were recognized and incorporated into the geocellular model layering scheme as time lines.

The borehole image log was a critical tool for facies recognition in the Permian eolian reservoirs of Saudi Arabia. Four distinct depositional facies have been identified on image log and confirmed with detailed core description, namely: dune, sand-sheet, paleosol, and playa. A numerical proportion of each facies was determined from well data for each reservoir sequence and an object-based modeling technique was used to distribute the image log identified facies.

The resulting geocellular model was scaled to match the outcrop and visualized in 3-D. As the outcrop would suggest, the ‘wet’ and ‘dry’ cycles of eolian deposition were modeled as separate packages honoring the well facies proportions. In cross-section the model displayed the characteristic ‘wet’ and ‘dry’ cycles observed in the Cedar Mesa outcrop.



Presenter’s Notes:

Scale is one of the most difficult properties to get a feel for in geocellular modeling. A good outcrop analog can add a tremendous amount of value to the modeling process.

Questions like; well spacing, reservoir compartments, model cell size, horizontal vs. vertical wells, and production anisotropies may at least be visualized and possibly understood at outcrop scale.

Outline

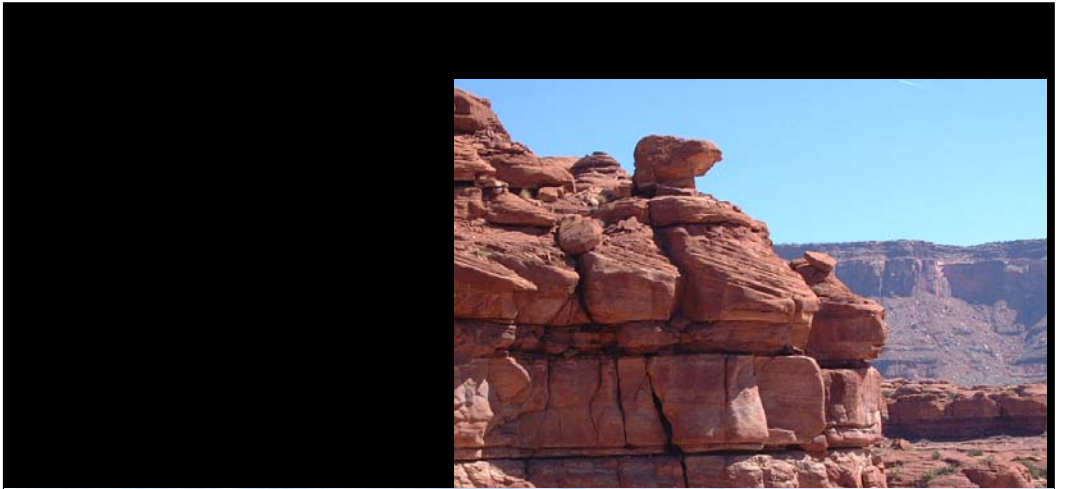
- Characteristics of a ‘wet’ eolian system
- Demonstrate the Unayzah ‘A’ reservoir is a ‘wet’ eolian system
- Identify the outcrop to be used as an analog
- Qualitative application of the outcrop analog in building the stratigraphic framework
- Model reservoir facies and porosity
- Visualize the resulting geocellular model

Short list of authors discussing ‘wet’ eolian processes

Baars, D.L. (1962)
Blakey, R.C., Peterson, F. and Kocurek, G. (1988)
Brookfield, M.E. (1977)
Clemmensen, L.B. 1989
Clemmensen, L.B. and Blakey, R.C. 1989
Havholm, K.G. and Kocurek, G. 1988
Kocurek, G. 1984.
Kocurek, G. 1988.
Kocurek, G. and Ewing, R.C. 2005
Kocurek, G. and Havholm, K.G. (1993)
Kocurek, G., Havholm, K.G., Deynoux, M. & Blakey, R.C. 1991
Rubin, D.M. and Hunter, R.E. 1985
Langford, R.P. and Chan, M.A. (1988)
Langford, R.P. and Chan, M.A. (1989)
Langford, R.P. and Chan, M.A. (1993)
Loope, D.B. (1984)
Loope, D.B. (1985)
McKee, E.D. & Moiola, R.J. 1975
Mountney, N., 2006
Mountney, N. and Howell, A. 2000
Mountney, N.P. and Jagger, A. 2004
Peterson, F. (1988)
Rubin, D.M. and Hunter, R.E. 1984
Rubin, D.M. and Hunter, R.E. 1985

Presenter’s Notes:

This is a very short list of authors who have written about wet eolian deposits and highlighted in orange, are those authors who have directly addressed the Cedar Mesa.



Outline

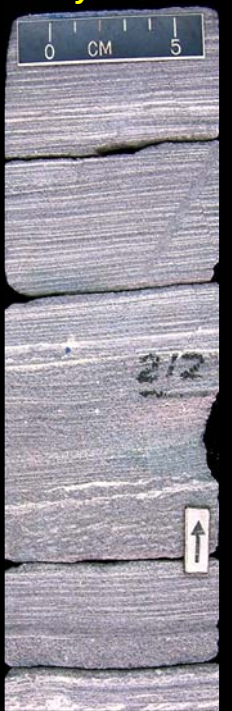
- Characteristics of a 'wet' eolian system
- Demonstrate the Unayzah 'A' reservoir is a 'wet' eolian system
  - Unidirectional wind
  - Dune deflation to the water table
  - Laterally continuous layers and surfaces both wet & dry
  - paleosols

Unayzah core

Dune

slipface deposits grain-flow and wind-ripple laminations

Unayzah core



Sand-Sheet

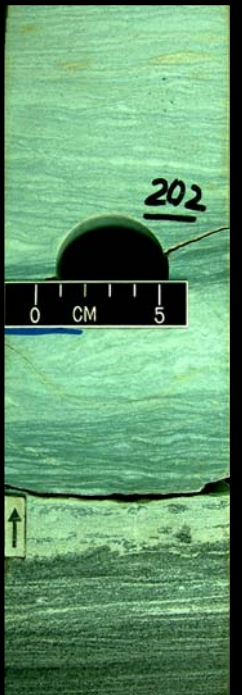
wind-ripple lamination ‘pin-striping’

Unayzah core

Paleosol

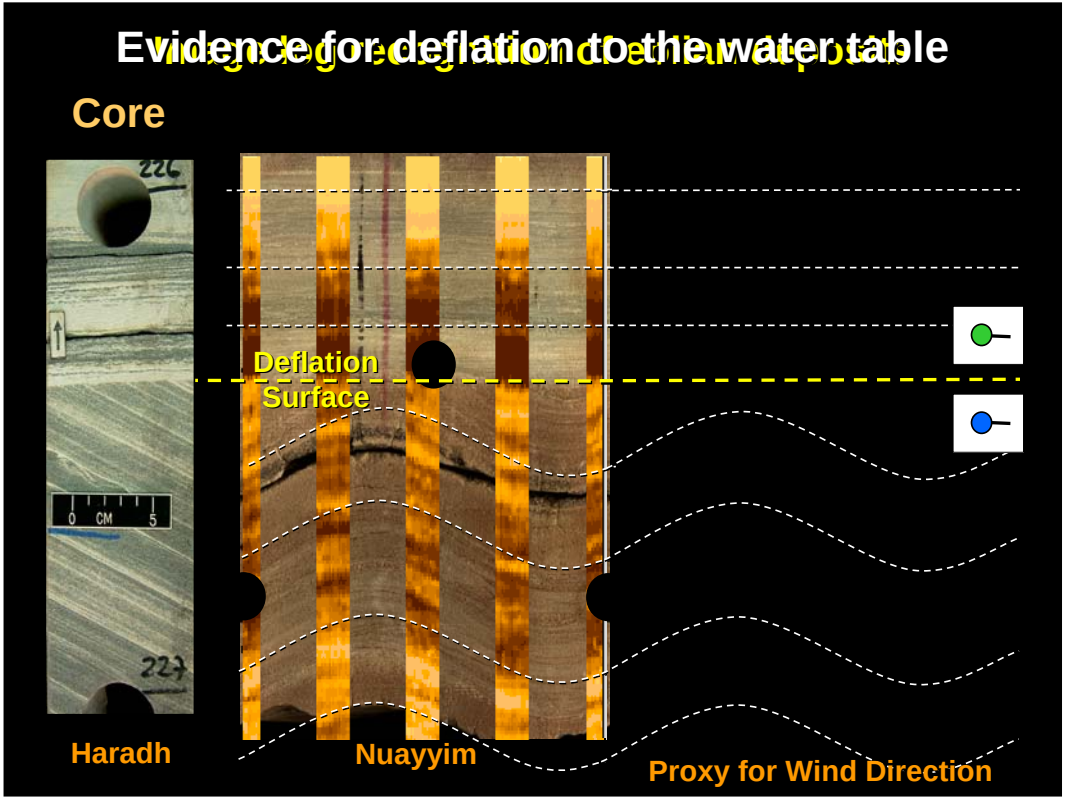
Root scars, calcrete, caleche, mud-cracks

Unayzah core



Playa / Interdune

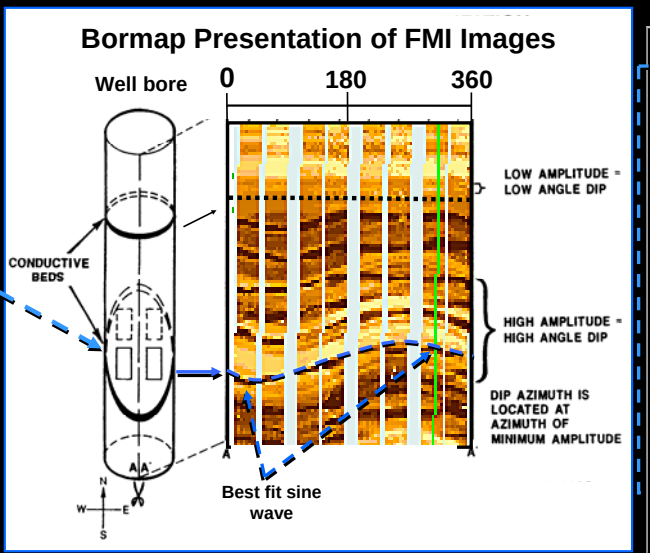
Horizontal laminations, adhesion ripples and water-lain deposits



Presenter's Notes:

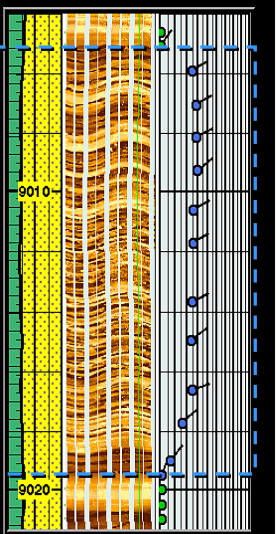
1. Slabbed core with recognizable dune facies and flat-lying playa deposits
2. A 360 scan of the core displays the bedding we recognize with an image log
3. The image -log has the vertical resolution to capture the high-angle bedding.
4. The sine waves and resulting dip pattern confirm the slipface orientation.

Characteristic dip pattern for the dune facies

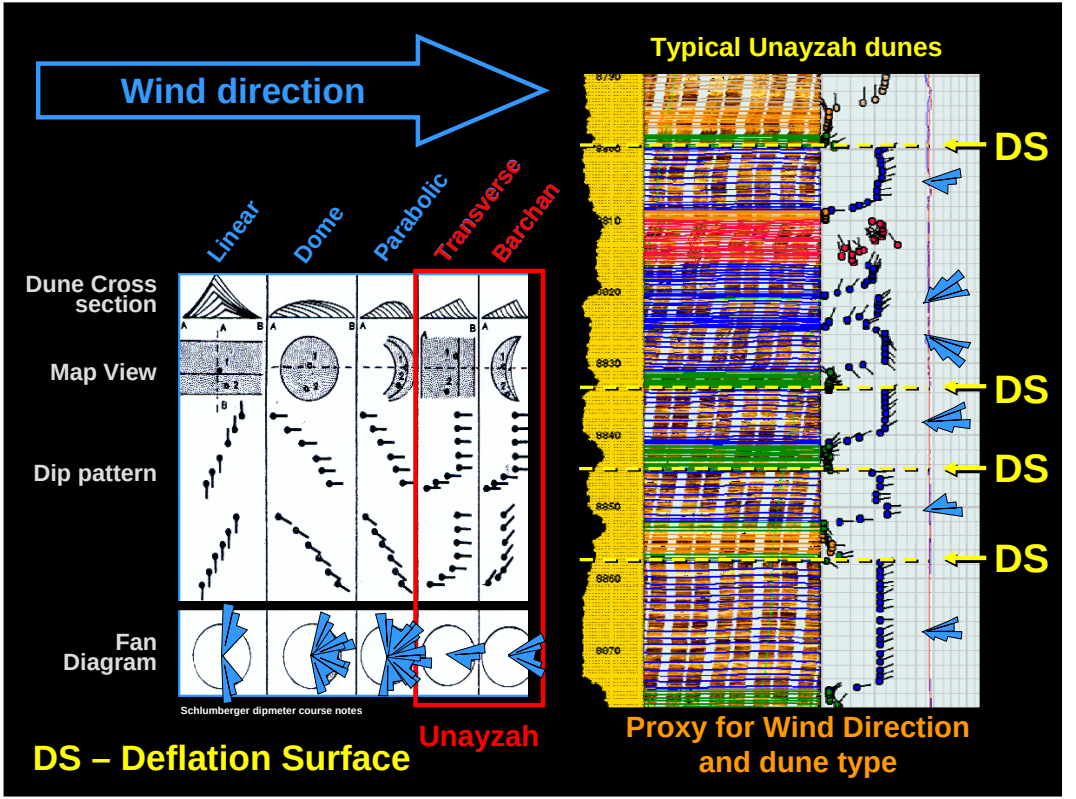


Schlumberger dipmeter course notes

Image log

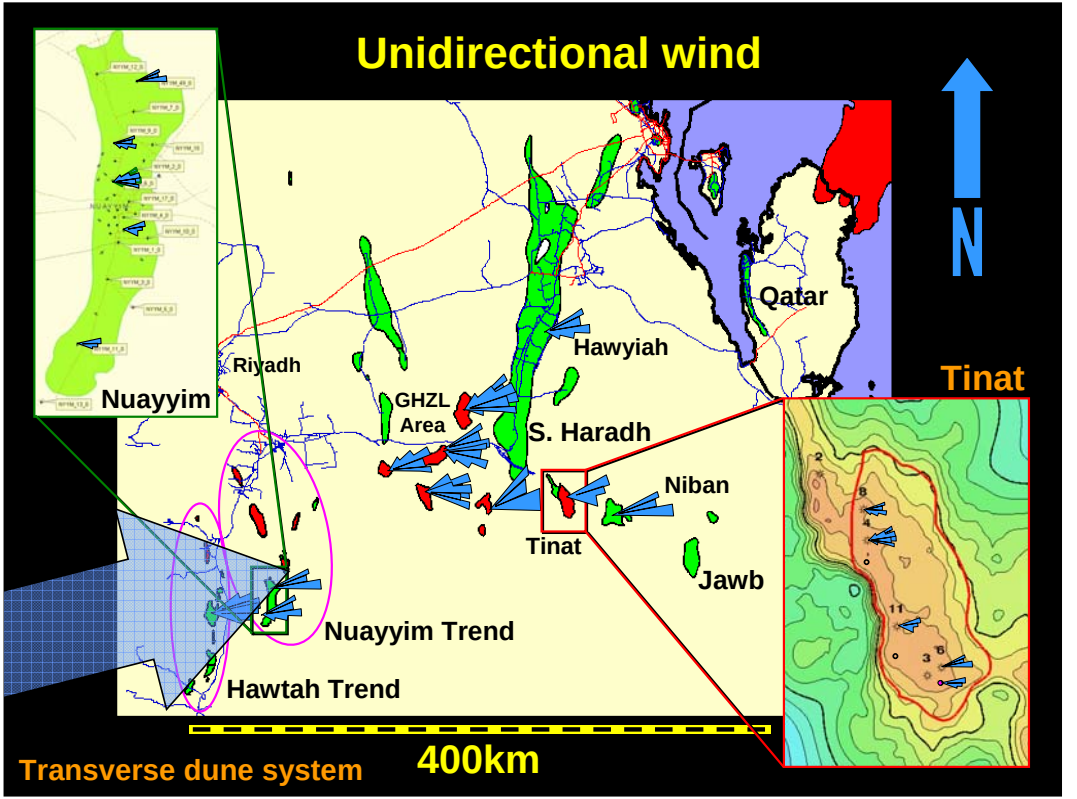


16' dune package



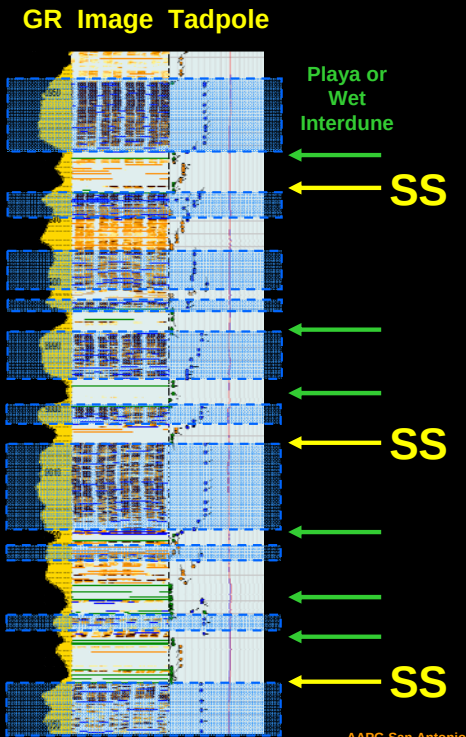
Presenter's Notes:

1. Looking at the image log on the right for example, the dune deposits clearly fall within a narrow unimodal dip direction.
2. From this a dune type (transverse) can be inferred, along with an orientation for the dune crest. An east dipping slipface gives a north-south striking dune body.

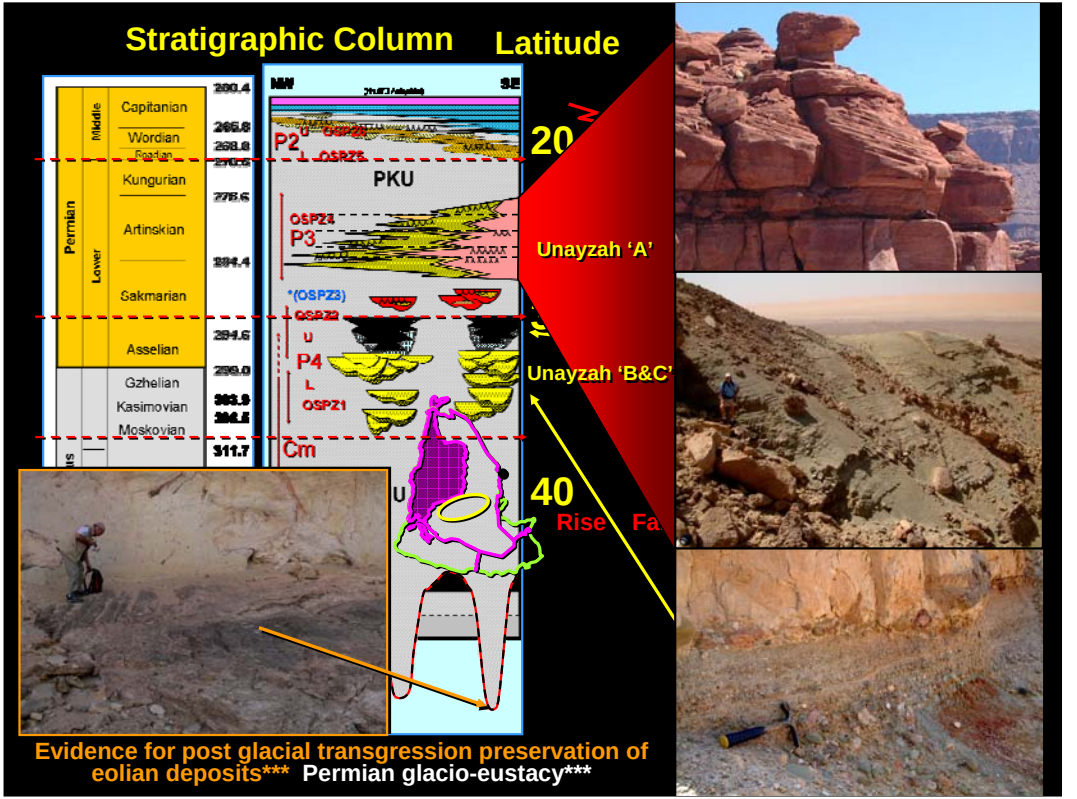

Unidirectional wind
N
Nuayyim
Riyadh
GHZL
Area
Hawyiah
Qatar
S. Haradh
Niban
Tinat
Jawb
Tinat
Nuayyim Trend
Hawtah Trend
Transverse dune system
400km

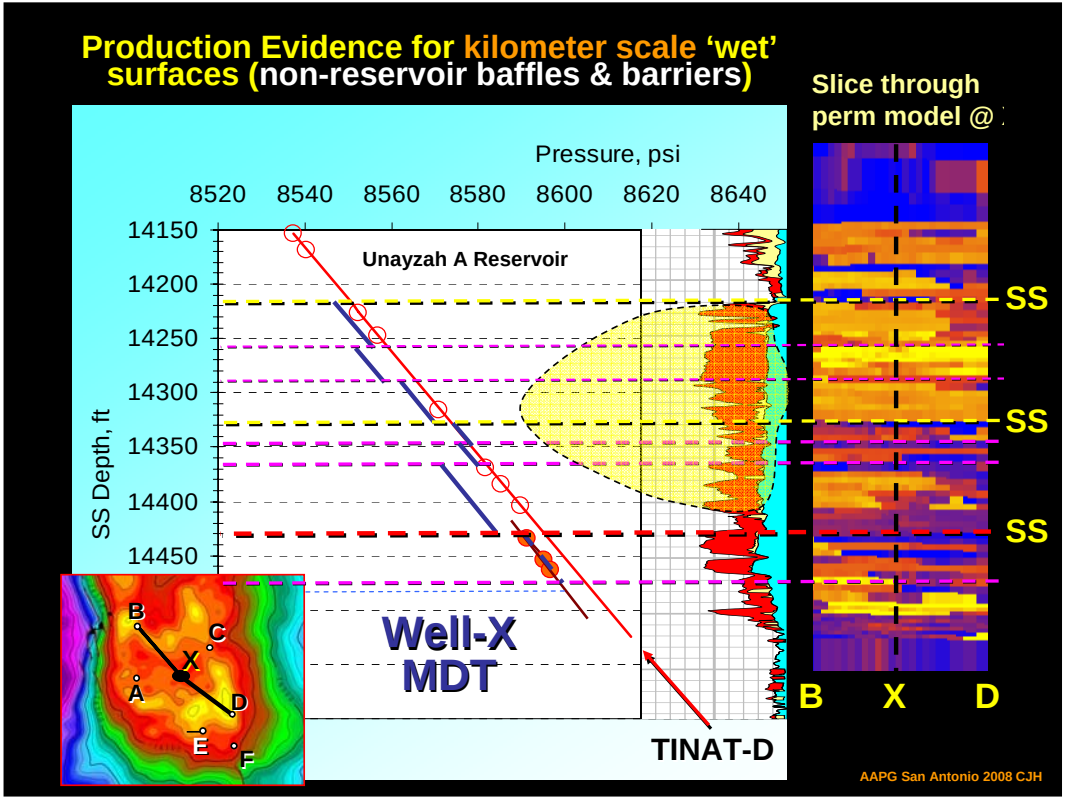
Abundant ‘wet’ interdune deposits

Water table controlled deflation possibly related to Permian glacio-eustacy***



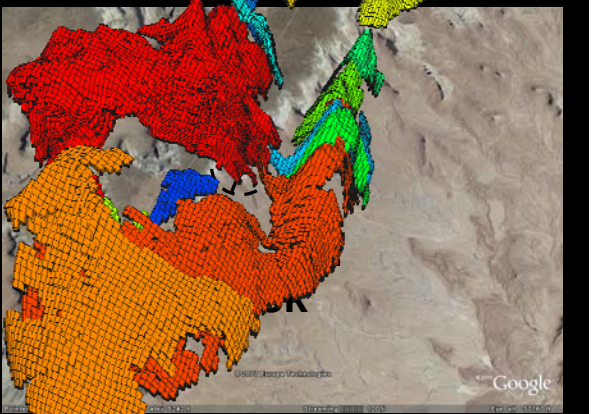
AAPG San Antonio 2008 CJH


Stratigraphic Column
Latitude
Permian
Middle
Lower
Capitanian
Wordian
Roadian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moskovian
260.4
265.8
268.8
276.5
284.4
294.6
299.0
303.9
306.5
311.7
P2
OSPZ5
PKU
OSPZ4
P3
*(OSPZ3)
OSPZ3
U
P4
L
OSPZ1
Cm
20
Unayzah 'A'
Unayzah 'B&C'
40
Rise
Fa
Evidence for post glacial transgression preservation of eolian deposits***
Permian glacio-eustacy***


Production Evidence for kilometer scale 'wet' surfaces (non-reservoir baffles & barriers)
Slice through perm model @
Pressure, psi
8520
8540
8560
8580
8600
8620
8640
SS Depth, ft
14150
14200
14250
14300
14350
14400
14450
Unayzah A Reservoir
Well-X MDT
TINAT-D
SS
SS
SS
B
X
D
A
B
C
D
E
F
X
AAPG San Antonio 2008 CJH

Scale Hawiian model 2005 Kilometers

Cedar M[illegible]a outcrop Southeast Utah



250 x 250 cell size
~1k grid spacing for
oil wells @ 6,000'

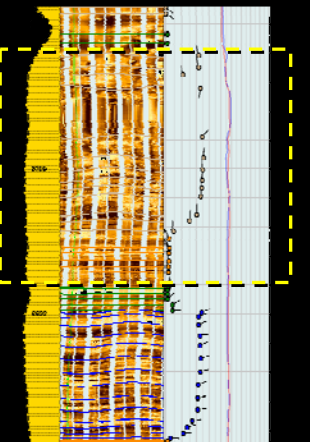
SGI

Well developed Paleosols in Unayzah
Core & image log

Tinat

Nuayyim

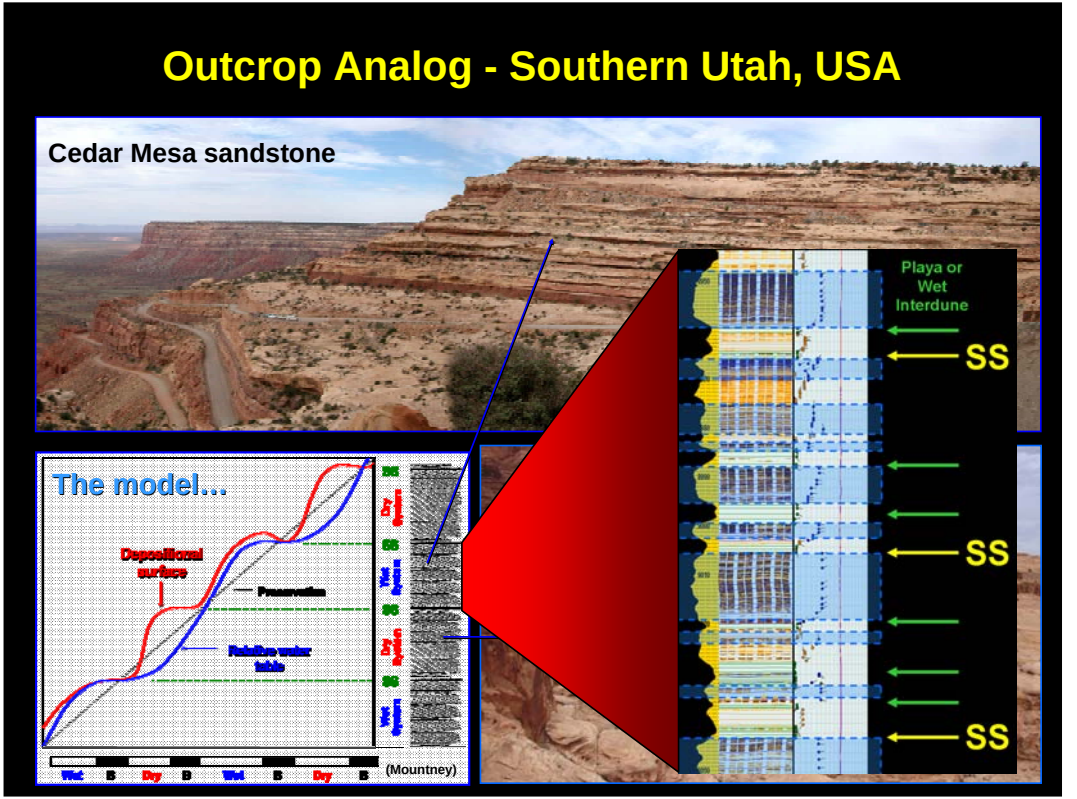
Nuayyim



Characteristics of wet eolian systems from literature	Unayzah Characteristics suggesting a wet eolian system
1.Unidirectional dune migration	1.Regional Unayzah image log studies
2.Laterally extensive layers 1-30m thick	2.Field-wide correlations, production history (Tinat) and Hawtah geobody
3.Layers extending for hundreds of square kilometers	3.Similar layering schemes from field to field 200Km apart
4.Flood surfaces or super surfaces that cover 20 to over 400 km2	4.Production history Tinat, Hawtah geobody & Field correlations
5.Water table controlled deflation possibly related to Permian glacio-eustacy***	5.Abundant deflation surfaces, The Unayzah 'A' often rests on glacial deposits glacio-eustacy***
6.Well developed paleosols	6.Confirmed in core & image-log

Outline

- Characteristics of a ‘wet’ eolian system
- Demonstrate the Unayzah ‘A’ reservoir is a ‘wet’ eolian system
- Identify the outcrop to be used as an analog
- Qualitative application of the outcrop analog in building the stratigraphic framework
- Model reservoir facies and porosity
- Visualize the resulting geocellular model



Presenter's Notes:

The Cedar Mesa outcrop at Moqi Dugway I believe is a great analog for the Unayzah 'A' eolian reservoir. I can relate all the features I see in outcrop to the core taken from the Unayzah eolian reservoir.

•Dunes, Sand Sheets, Paleosols, & playas. Plus, I get a real feel for the lateral continuity of the reservoir sands as well as the non reservoir flooding surfaces.

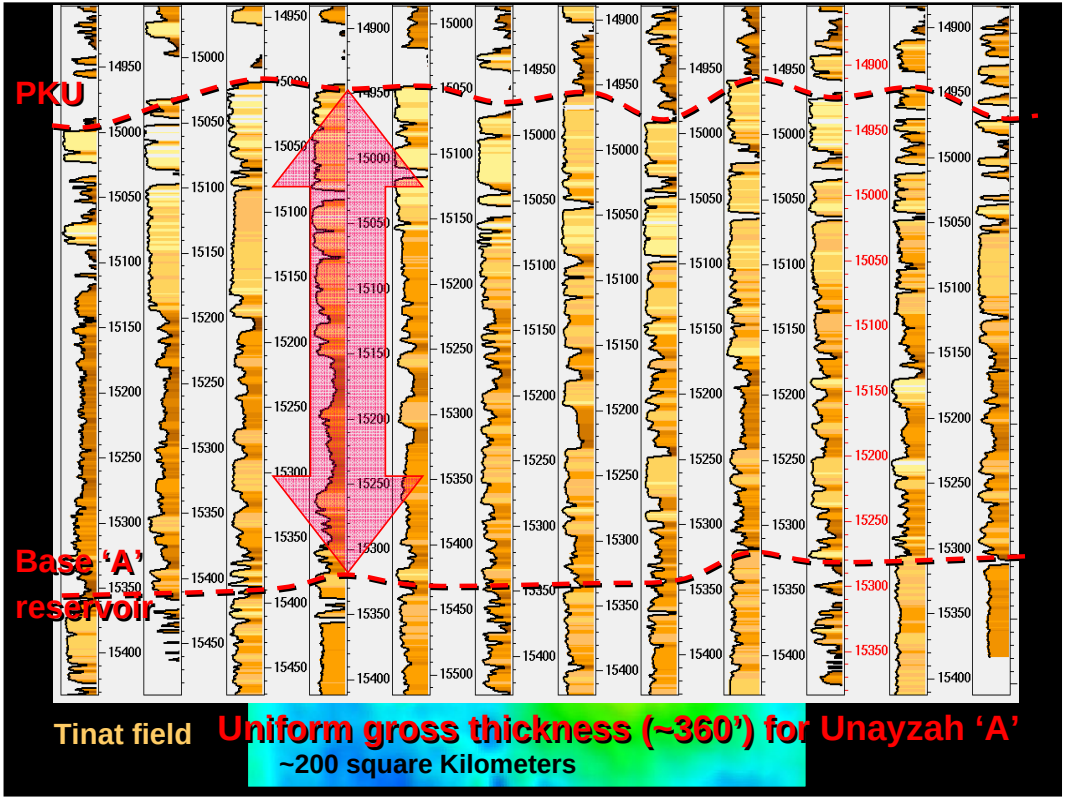
Outline

- Characteristics of a ‘wet’ eolian system
- Demonstrate the Unayzah ‘A’ reservoir is a ‘wet’ eolian system
- Identify the outcrop to be used as an analog
- **Qualitative** application of the outcrop analog in building the stratigraphic framework
- Model reservoir facies and porosity
- Visualize the resulting geocellular model

First things first:

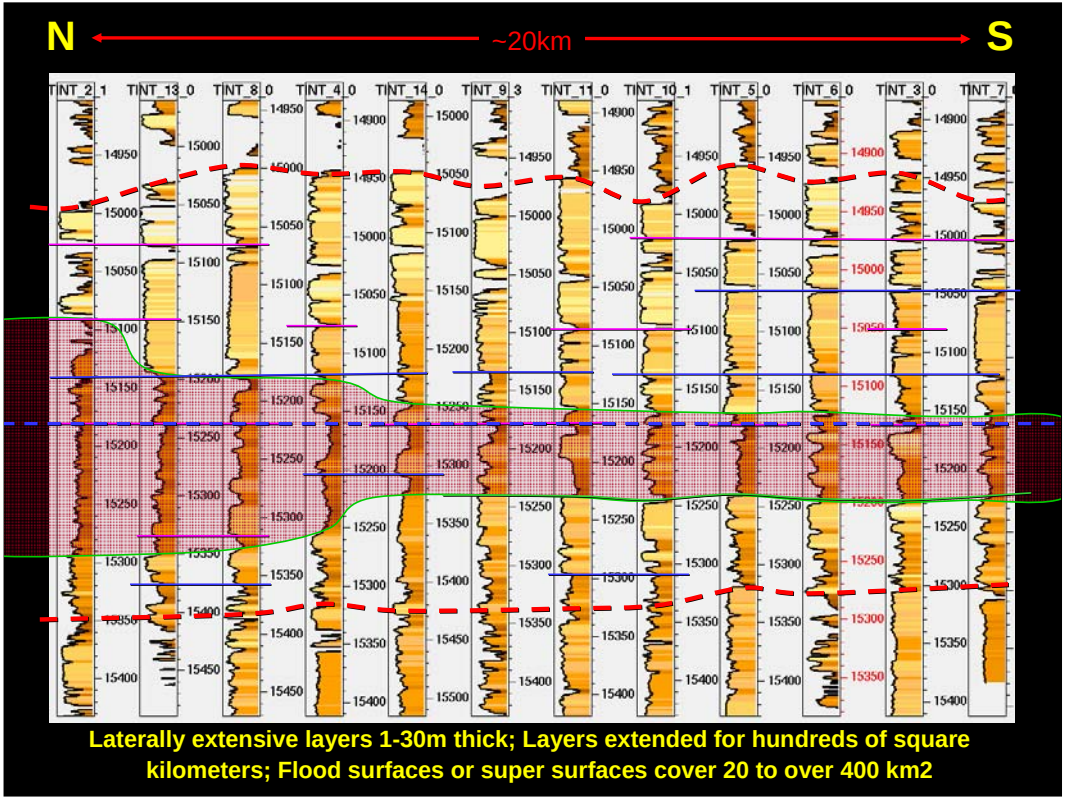
- Divide or layer the reservoir into meaningful geological units or zones.
- Keep ‘WET’ cycles together & ‘Dry’ cycles together.
- Maintain the parallel appearance.
- On logs, phantom through layers where there is no obvious pick.

Application of outcrop observations in constructing the stratigraphic framework



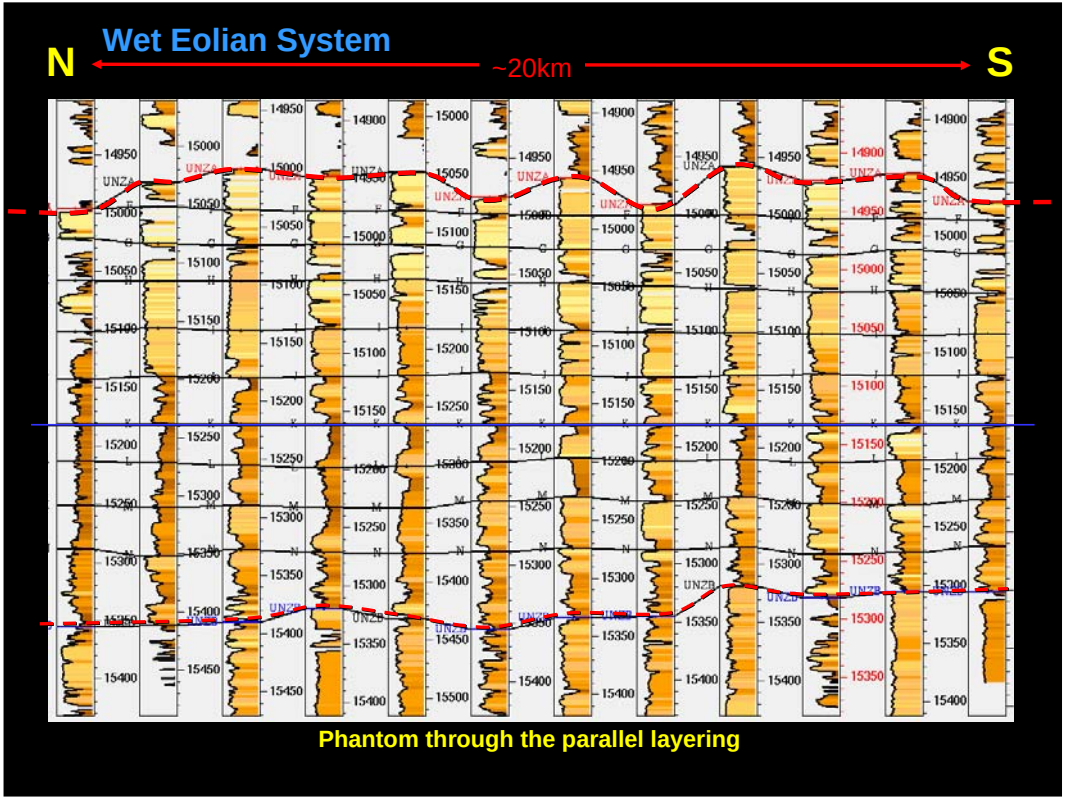
Presenter's Notes:

1. The Tinat structure is about 20 Km. in length
2. The Unayzah 'A' reservoir is a uniform, 360' feet thick accumulation of aeolian and associated arid deposits between two unconformities.



Presenter's Notes:

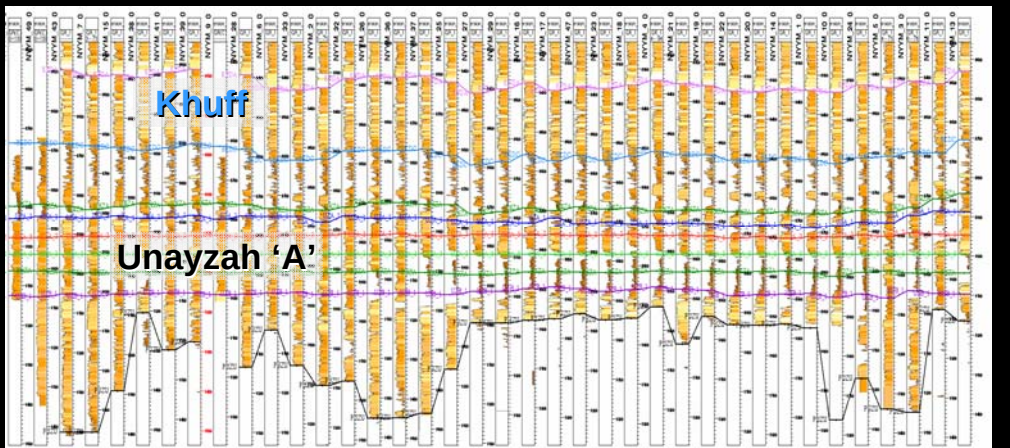
1. Using the wet aeolian Cedar Mesa analog, several 'partial' correlations can be made showing the wet and dry cycles.
2. From north to south, a very distinct wet period can be correlated across the field.
3. This serves as an internal datum for layering the reservoir.



Presenter's Notes:

1. Layers can then be traced across the reservoir as time lines.
2. The Pink box shows where both dry and wet systems can occur at the same time.

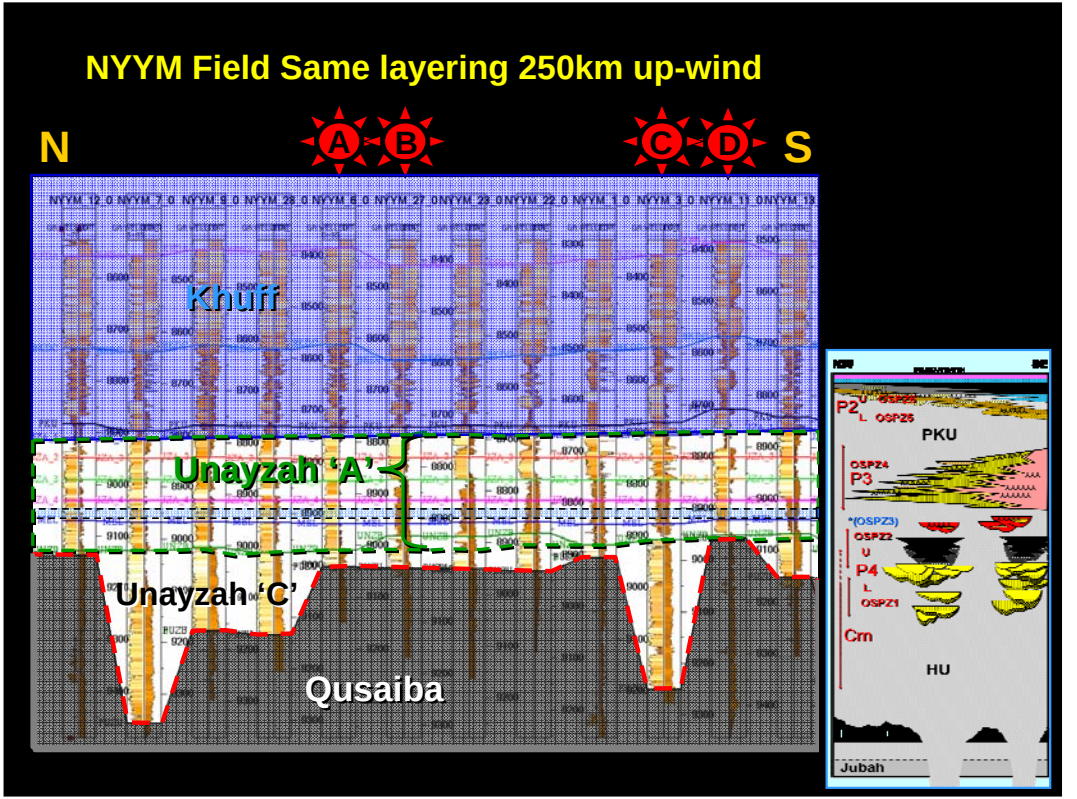
Similar layering scheme, same facies, 250km up-wind from Tinat



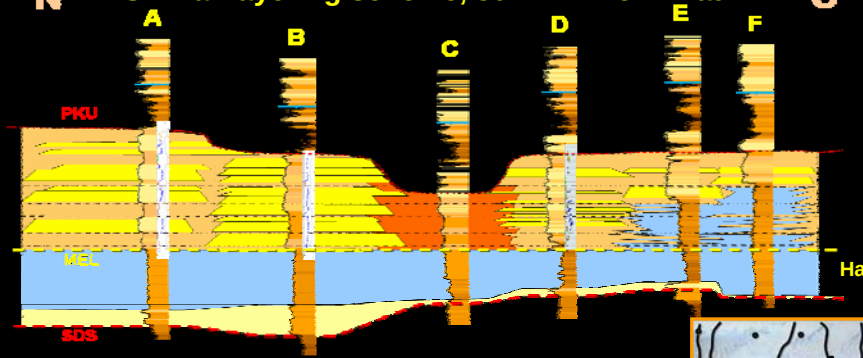
N Nuayyim Field S

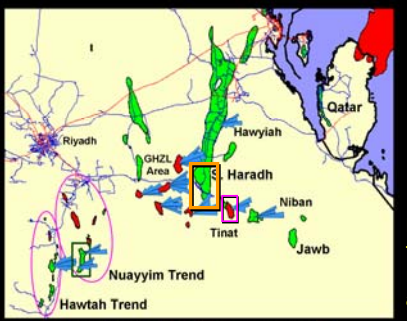
Laterally extensive layers 1-30m thick; Layers extended for hundreds of square kilometers; Flood surfaces or super surfaces that cover 20 to over 400 km2

NYYM Field Same layering 250km up-wind



Similar layering scheme, 30km NW of Tinat





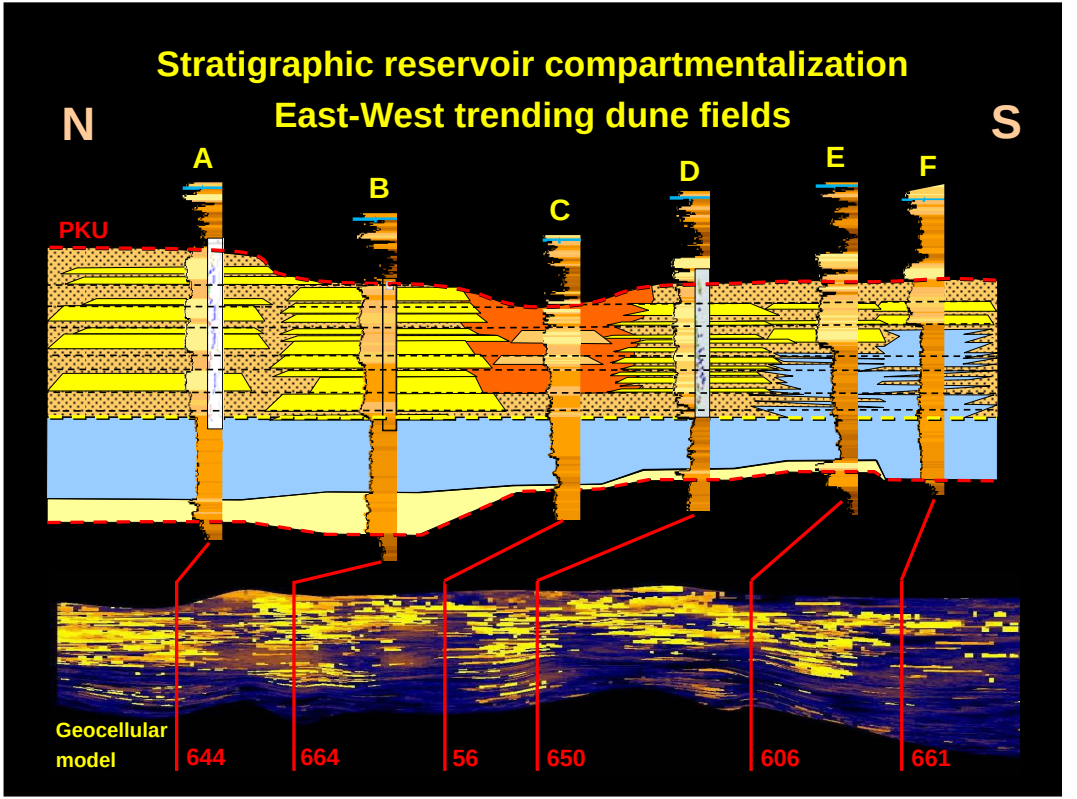
Transverse dune system

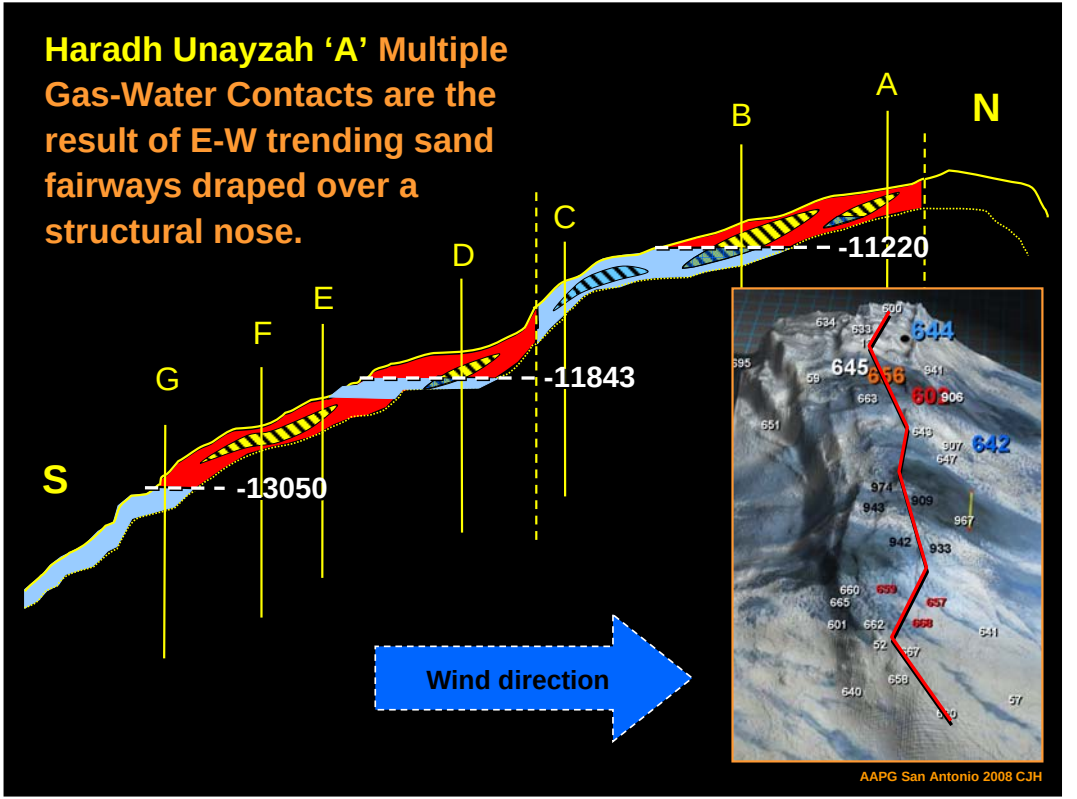
Scaled satellite image of modern dune field with Unayzah structural contours ~ 500 Sq. Kilometers

Wind direction

Regional map for scale to show the spatial relationship of the fields and layering scheme

AAPG San Antonio 2008 CJH

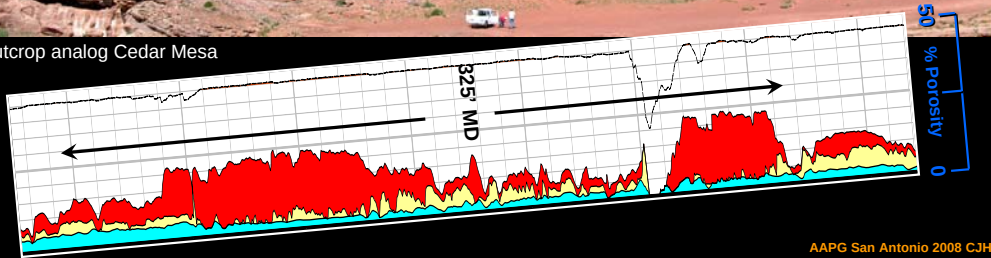

Stratigraphic reservoir compartmentalization
East-West trending dune fields
N
S
A
B
C
D
E
F
PKU
Geocellular
model
644
664
56
650
606
661


Haradh Unayzah ‘A’ Multiple Gas-Water Contacts are the result of E-W trending sand fairways draped over a structural nose.
A
B
C
D
E
F
G
N
S
-11220
-11843
-13050
Wind direction
AAPG San Antonio 2008 CJH

Use the outcrop analog to help explain drilling a Unayzah High Angle Well

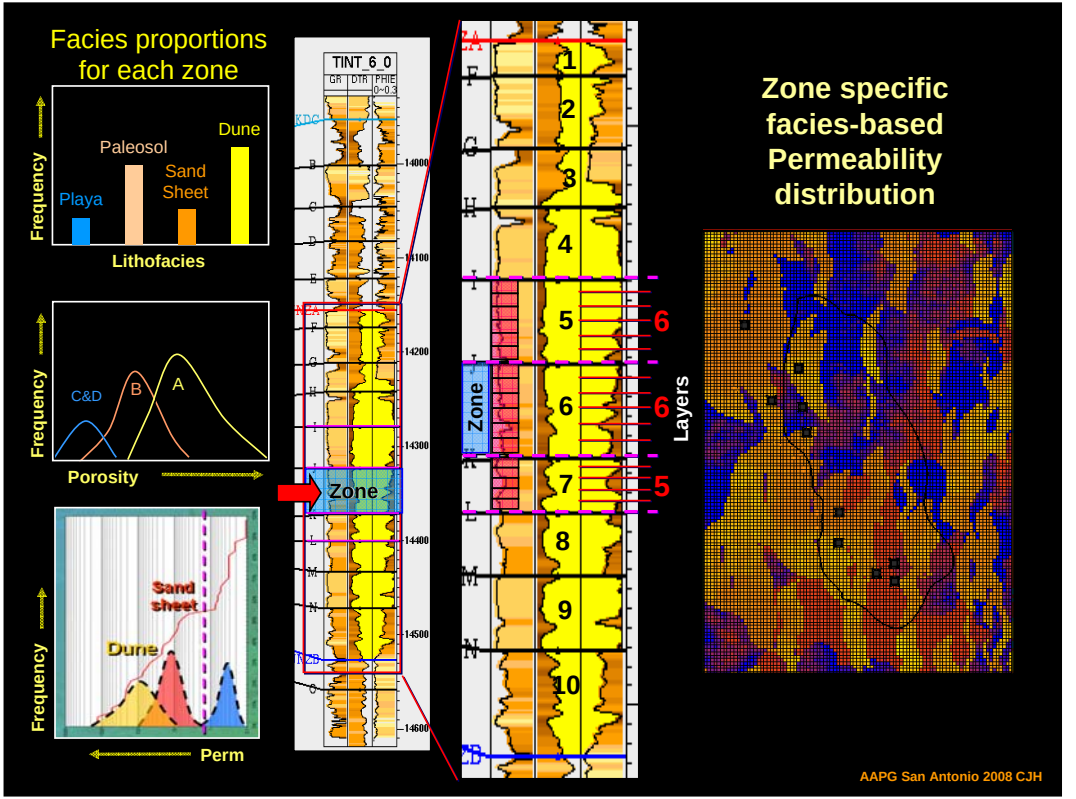
- Conventional screen completion
- Sand free 62 MMSCFD at 5800 psig

Outcrop analog Cedar Mesa



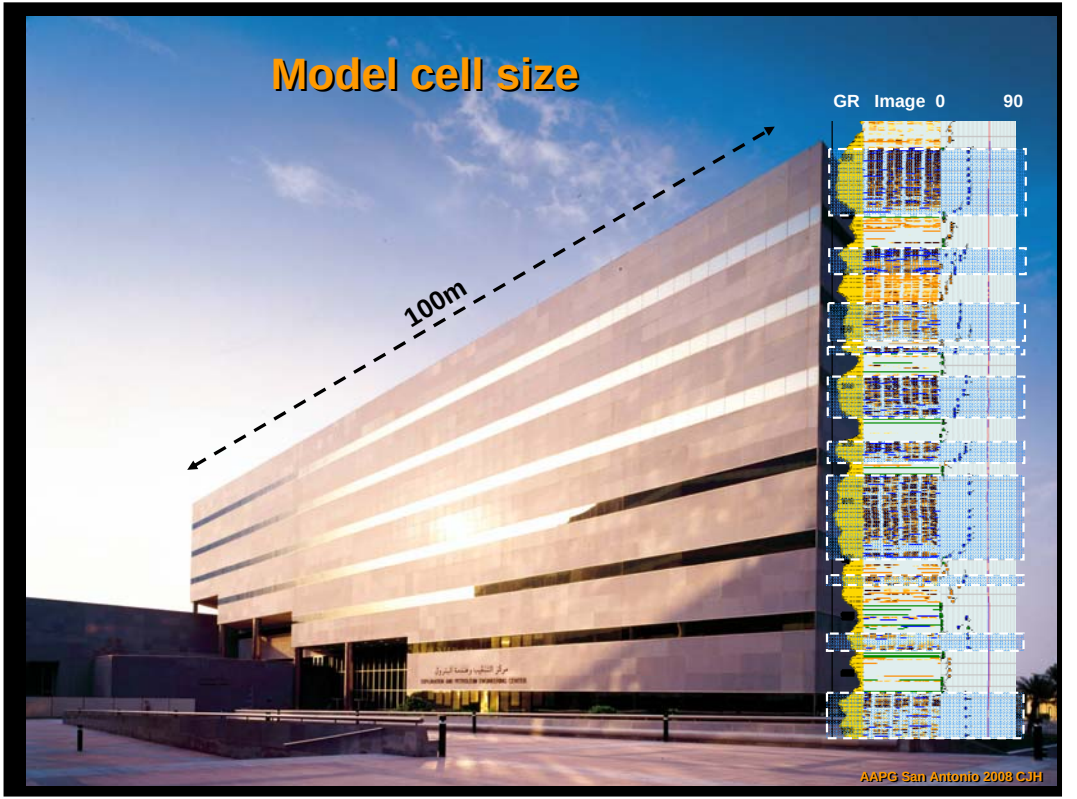
Outline

- Characteristics of a ‘wet’ eolian system
- Demonstrate the Unayzah ‘A’ reservoir is a ‘wet’ eolian system
- Identify the outcrop to be used as an analog
- Qualitative application of the outcrop analog in building the stratigraphic framework
- Model reservoir facies and porosity
- Visualize the resulting geocellular model

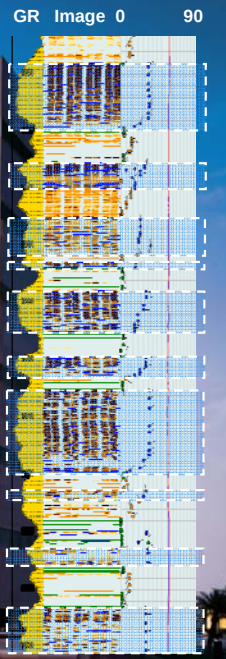


Presenter's Notes:

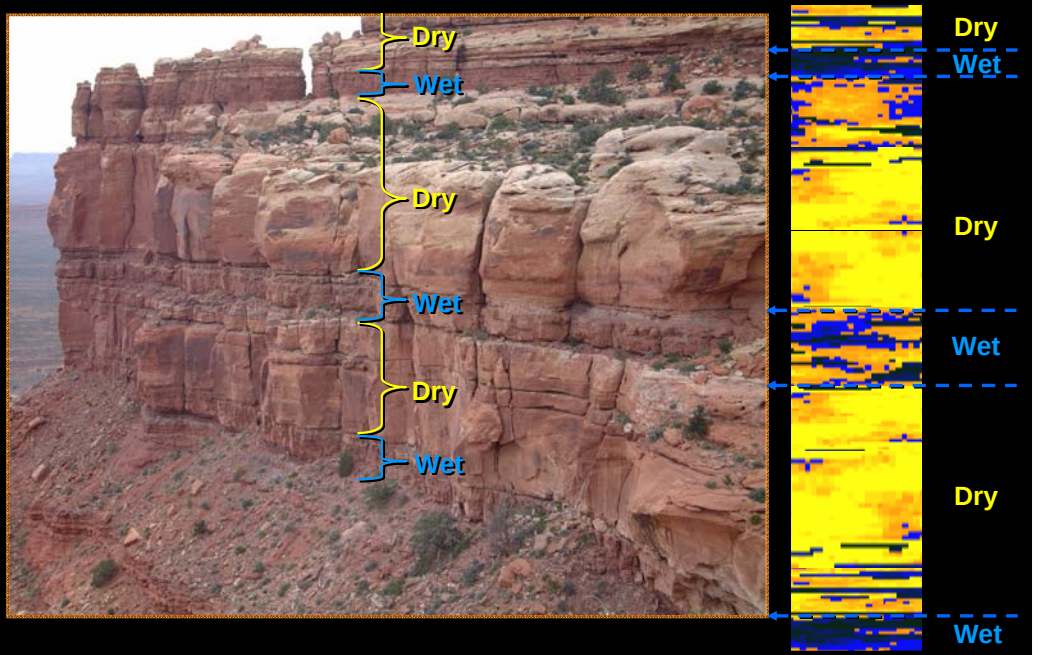
1. Object model the facies preserving the facies proportions.
2. Distribute porosity using the underlying facies model and zone specific porosity histograms.
3. Distribute Permeability using the facies and porosity models and zone specific, facies based permeability transforms.


Model cell size
GR Image 0
90
100m
AAPG San Antonio 2008 CJH

The outcrop can be used to help determine the model cell size



Outcrop Analog & Geocellular Model Visualization



Conclusions

- The eolian Unayzah is a 'wet' eolian dune system.
- Dune preservation was controlled by an overall rapid base level rise probably post-glacial***
- The reservoir can be layered using the Super Surfaces as time lines while maintaining the overall parallel appearance as seen in the outcrop.
- This is a 'Qualitative' use of an outcrop analog.

Presenter's Notes:

The outcrop emphasizes the lateral extent and correlatable nature of the wet and dry cycles.

Visualize the model on the outcrop