Core and Image Log Analysis of Permian Paleowind Directions in the Unayzah-A Reservoir, Subsurface Eastern Central Saudi Arabia*

Mohammed Al-Masrahy[1,2], John Melvin[2], Osman Abdulatif[3], and M. H. Makkawi[3]

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Abstract

The Lower Permian Unayzah A reservoir unit in the subsurface of central and eastern Saudi Arabia displays widespread evidence of deposition under arid to semiarid conditions, very commonly in a wind-dominated, eolian setting. In the area studied, a number of distinctive eolian depositional facies are recognized from core and image logs, including: dunes, interdunes, sand sheet and playa lakes. These facies occur with a high degree of vertical and areal repeatability throughout the Unayzah A. The study further investigated the distribution of azimuthal variability in Permian paleowind data across the Kingdom. These data were derived from image log patterns throughout the eolian dune facies identified in the Unayzah A reservoir unit from within four fields selected for this study. The study involved sedimentological description of 1160 feet of core from six wells, and analysis of 4000 feet of image log data from twenty one wells, spanning an area from central to eastern Saudi Arabia. A hierarchical approach was employed to investigate the paleowind directions. The paleowind azimuth data were i) recorded appropriately for each identifiable bed, ii) averaged over each bed-set within each well, iii) averaged over each well, iv) averaged over each field and, v) averaged over the four studied fields. This rigorous approach resulted in the identification of a dominant paleowind direction toward the east-northeast (present day), ranging between 40 and 100 degrees with a mean vector of 72 degrees. Identifying the dominant paleowind direction provides an understanding of dune distribution and shape throughout the reservoir. It also facilitates the optimum exploitation of porosity and permeability distributions during field development.

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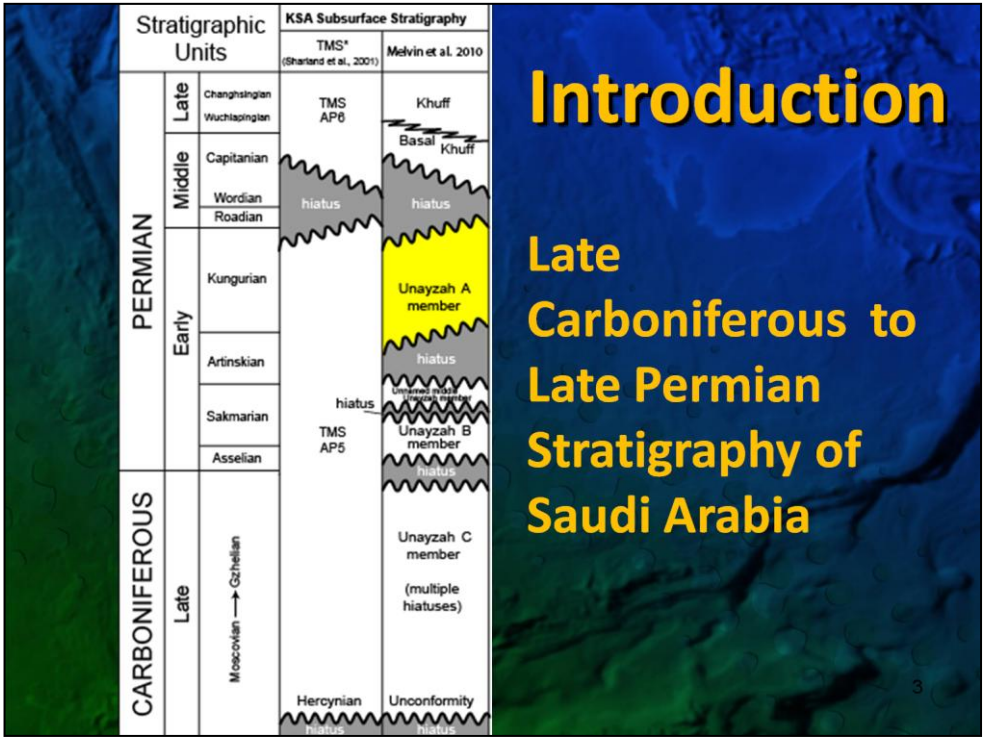
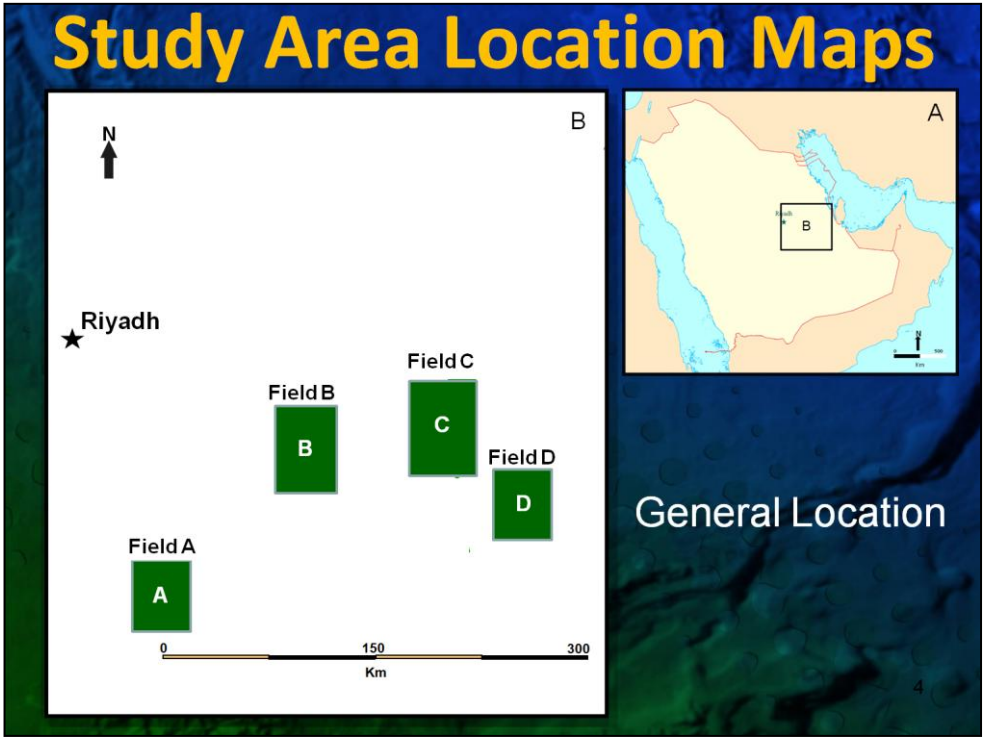
Outline

- Introduction
- Core Study
- Image Log Study
- Results
- Conclusion



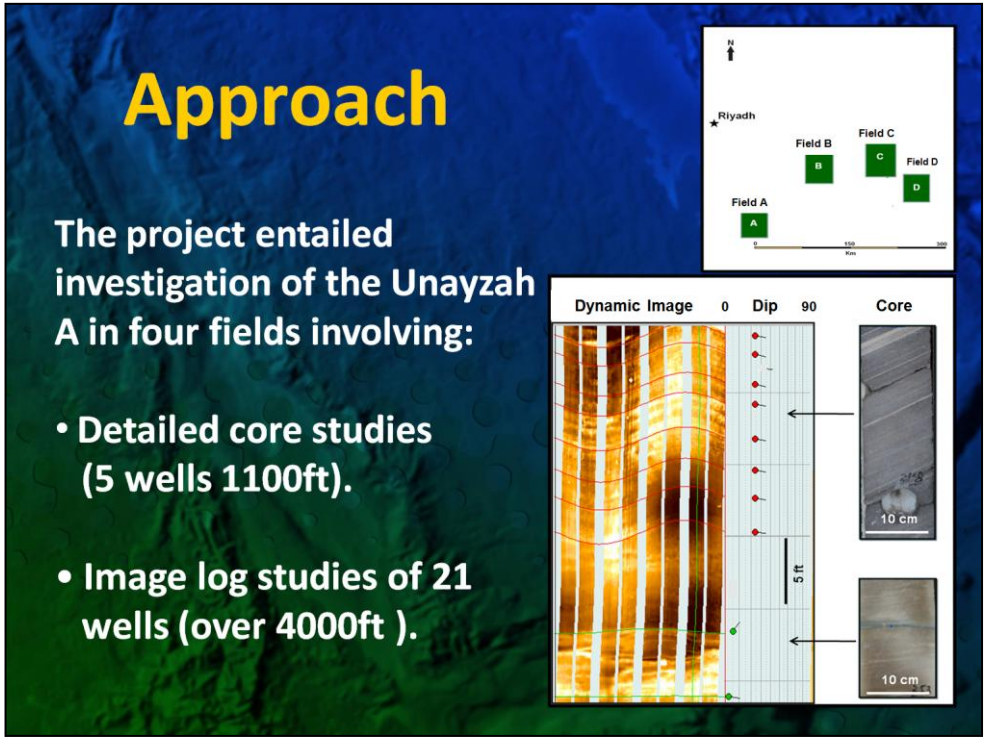
Presenter's notes: Diagram illustrating the Late Carboniferous to Late Permian stratigraphy of Saudi Arabia. The Unayzah-A Member (the subject of this study) is highlighted in yellow.



Presenter's notes: Location maps. A. Map of the Arabian Peninsula showing the general location of the study area. B. Map highlights positions in eastern-central Saudi Arabia of the studied fields (A, B, C, and D).

Objectives

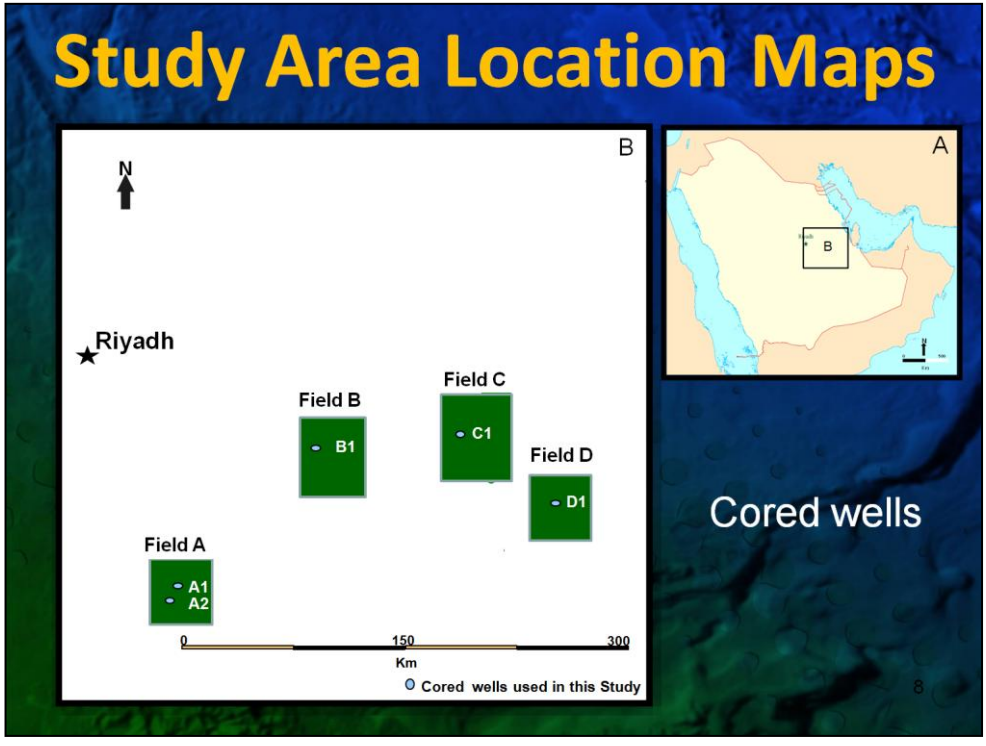
- To determine from core, the depositional setting of the Unayzah A in the study area.
- To determine, from electrical image logs, the paleowind direction and dune type in the Unayzah A in the study area.



Presenter's notes: Example of dynamic image log data and core photos illustrating the high-angle lamination from eolian dune facies and low-angle lamination from interdune facies. Note: (1) The sine-wave amplitude in the dynamic image log data represent a high-angle lamination of eolian dune facies, the dip data to the right of the image showing the dip and azimuth of the imaged dipping planes. (2) The upper core photo showing distinctive high-angle grain-size segregation lamination of eolian dune facies which are represented in the image log data by the high-amplitude sine-waves. (3) The lower core photo showing the interdune flat laminations; note the flat gray siltstone bed in the middle of the photo, which is represented in the image log data by the flat green sine-wave.

Core Study

- Facies description
- Facies associations
- Depositional environment



Presenter's notes: The maps show the locations of the cored wells used in this study.

Facies Description

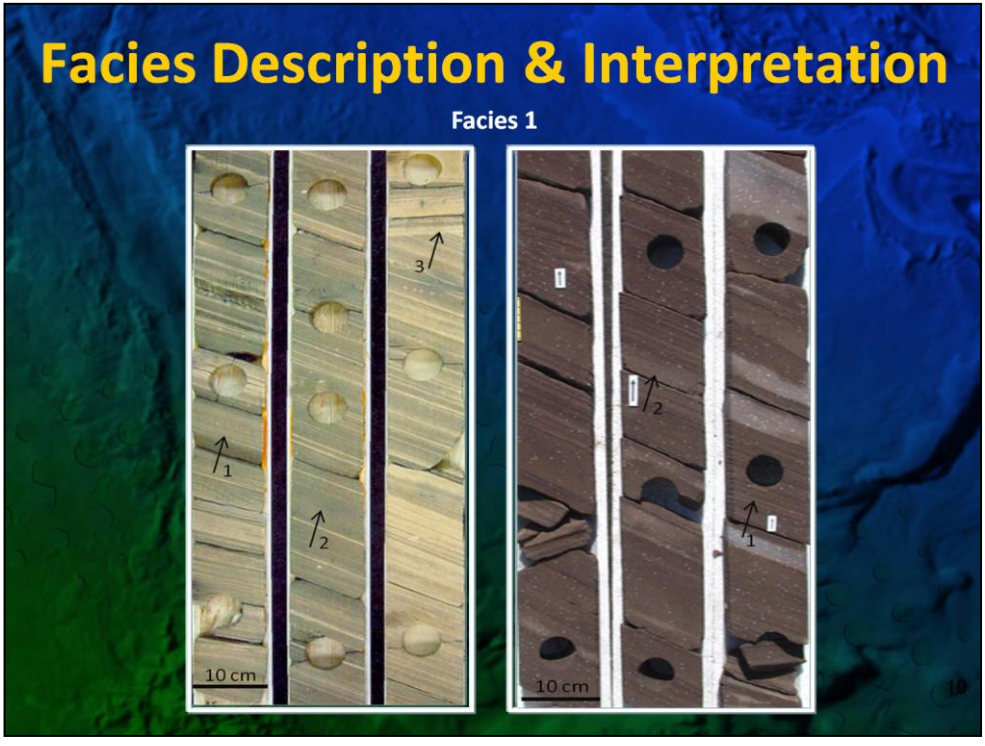
Facies 1: High-angle cross-bedded sandstones

Facies 2: Low-angle to flat-laminated sandstones

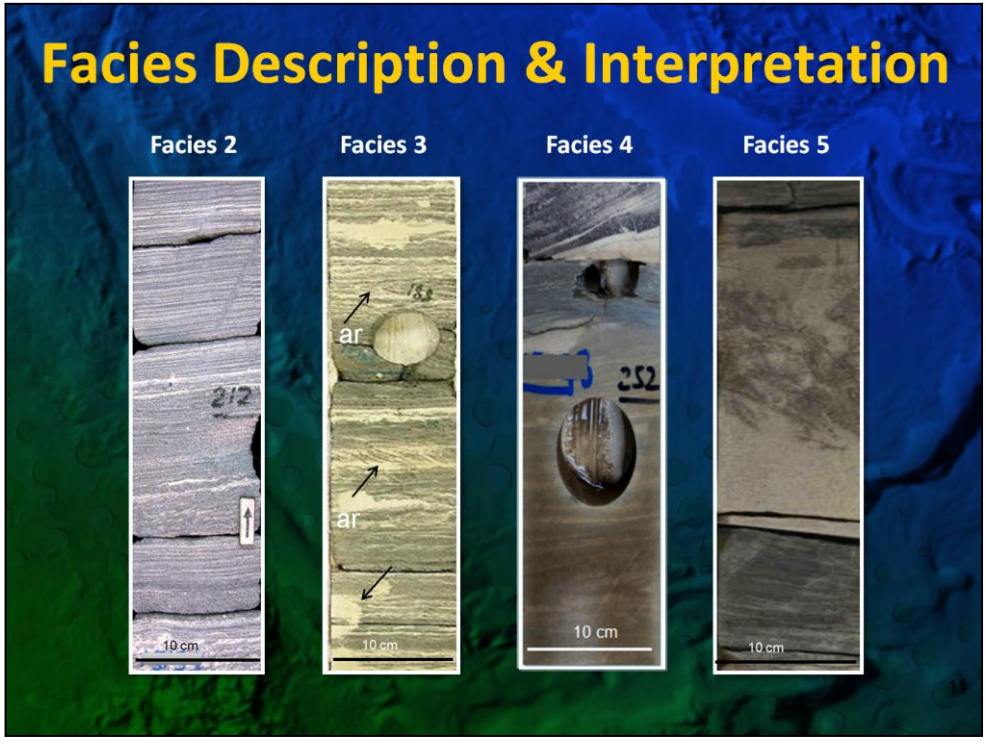
Facies 3- Irregularly laminated sandstones

Facies 4: Irregularly laminated, silty sandstones

Facies 5: Poorly sorted, carbonate-cemented sandstones



Presenter's notes: Core photographs illustrating eolian sand deposits encountered within the Unayzah-A Member in the study areas. They show high-angle cross-bedded, fine- to medium-grained sandstone.

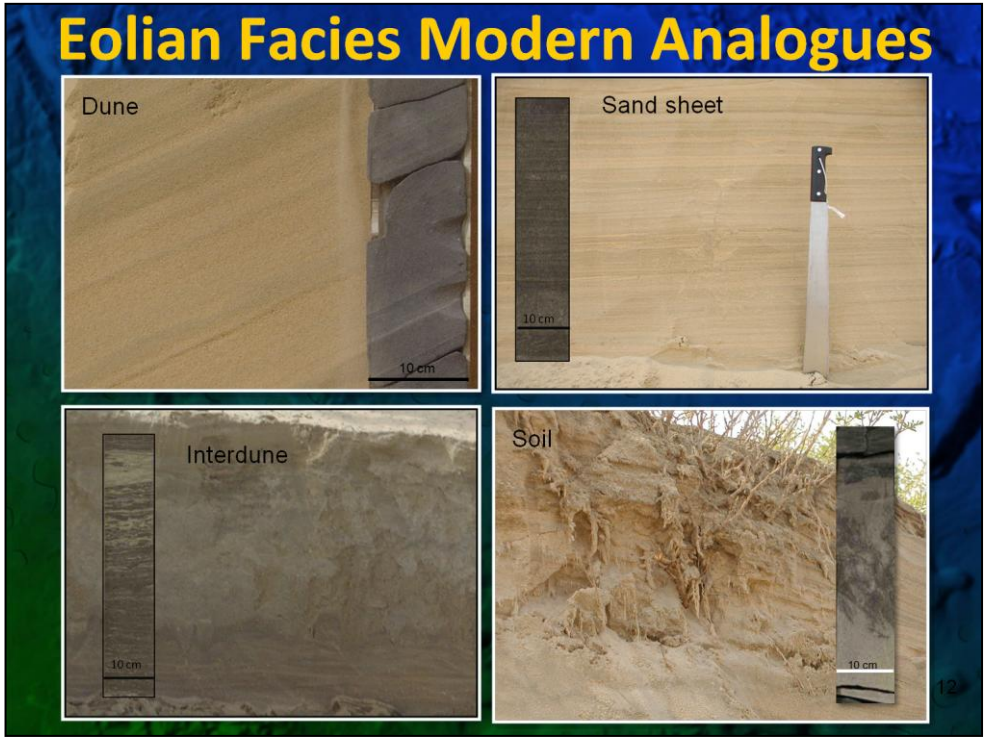


Presenter's notes: Facies 2- Core photographs illustrating eolian sand sheet deposits encountered within the Unayzah-A Member in the study areas. They show fine-to medium-grained sandstone with flat to low-angle lamination (and rare crinkly-laminated interbeds). Note: (1) the grain-size segregation lamination varies in thickness in this well; (2) in some cases very low-angle truncation of the laminae-sets is also recognized; and (3) the clear flat to very low-angle "pin-striped" grain-size segregation lamination.

Facies 3-Core photographs illustrating representative features of the damp interdune environment encountered throughout the studied wells. Representative cores are all fine- to medium-grained, moderately sorted sandstones dominated by irregular crinkly laminae that are associated with a damp interdune setting. The well developed adhesion ripples are indication of a sabkah environment. Note the white patches of anhydrite cement (arrowed) that also are usually related to sabkah-type environments.

Facies 4- Core photographs from the study area illustrating the Unayzah-A playa lake deposits or wet interdune. Note that the core is dominated by the very fine-grained, silty sandstone and siltstone units. Also note (1) the irregular to crinkly lamination, (2) the fining-upward of very fine-gained sandstone into siltstone, indicative of deposition under subaqueous conditions, such as shallow ephemeral lake environment, and (3) overlying high-angle lamination eolian dune facies.

Facies 5-Core photographs illustrating example of the paleosol deposits recognized in the Unayzah-A Member in the study area. In general, this facies is recognized by the pronounced poorly sorted and heavily disrupted sandstones. Note the mottling, which indicates plant rooting and a shallow water table.

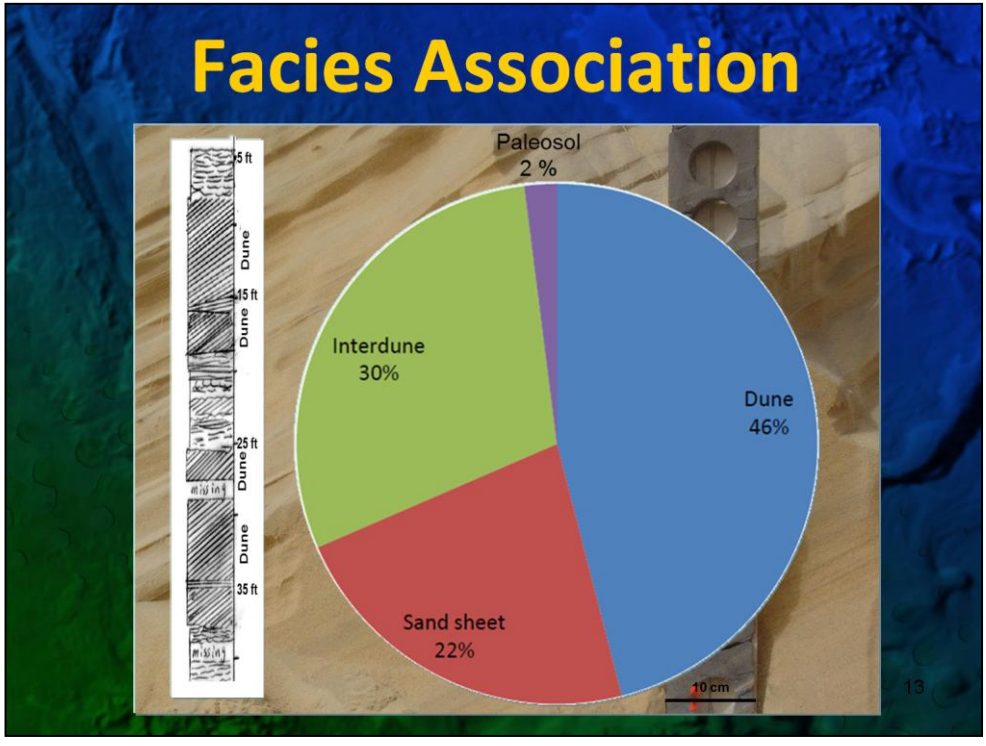


Presenter's notes: 1-Trenched section through a modern sand dune, showing a comparison between ancient eolian deposits (core sample- well D1) and modern eolian deposits. Similarity of high-angle cross-bedding and grain-size segregation lamination.

2-Trenched section through modern sand-sheet deposits, showing a comparison between modern eolian sand-sheet deposits and ancient sand-sheet deposits from core (well C1). Note the low-angle lamination compared to eolian dune deposits (modern: Half-moon Bay Dhahran, Saudi Arabia).

3-Trenched section through a modern interdune facies and a 4-in. subsurface core, showing comparison between modern and ancient interdune deposits from core (well B1). Note the horizontal lamination and the adhesion ripples and aqueous deposits (modern: Half-moon Bay Dhahran, Saudi Arabia).

4-Photographs showing a comparison between modern soil deposits and ancient soil deposits (paleosols). Modern trenched section through an arid eolian deposit (Half-moon Bay, Dhahran), showing very disrupted sediment caused by heavy plant rooting through the original sand-sheet deposits. Core photograph from well B1 showing poorly sorted sandstone with distinctive cement color mottling that is due to plant rooting.



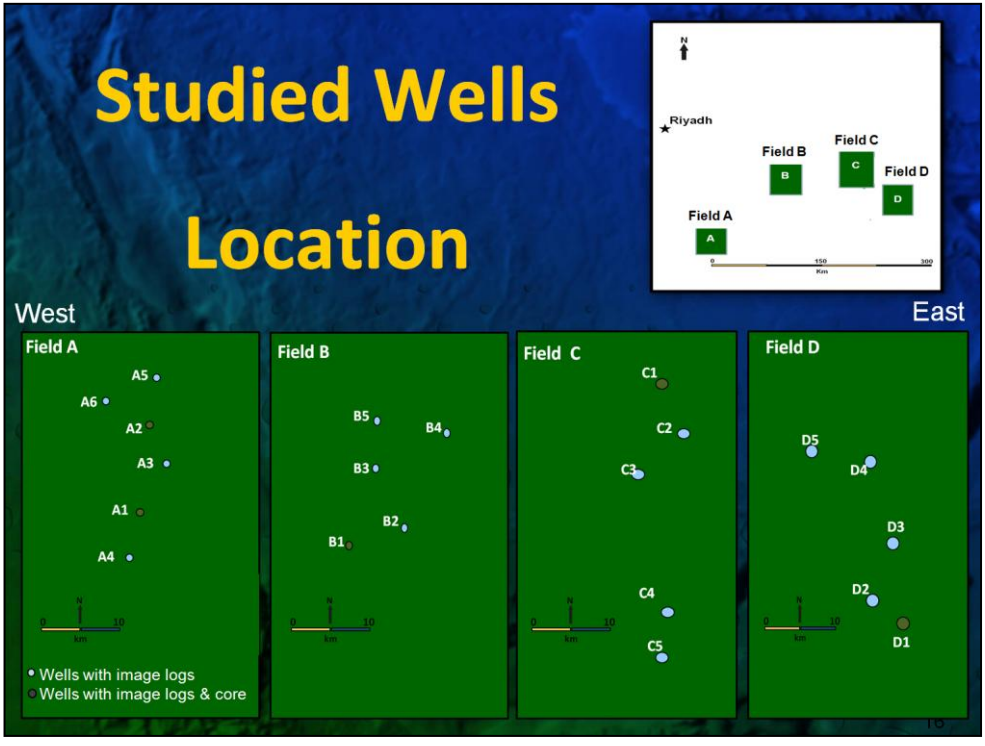
Presenter's notes: The background picture emphasizes the similarity between modern and ancient eolian deposits. The Graph shows the average Unayzah-A eolian facies distribution in the cored wells. Note that the eolian dune and the interdune (wet and damp interdune facies combined) facies are the dominant facies, suggesting an arid to semiarid depositional environment.

Image Log Study

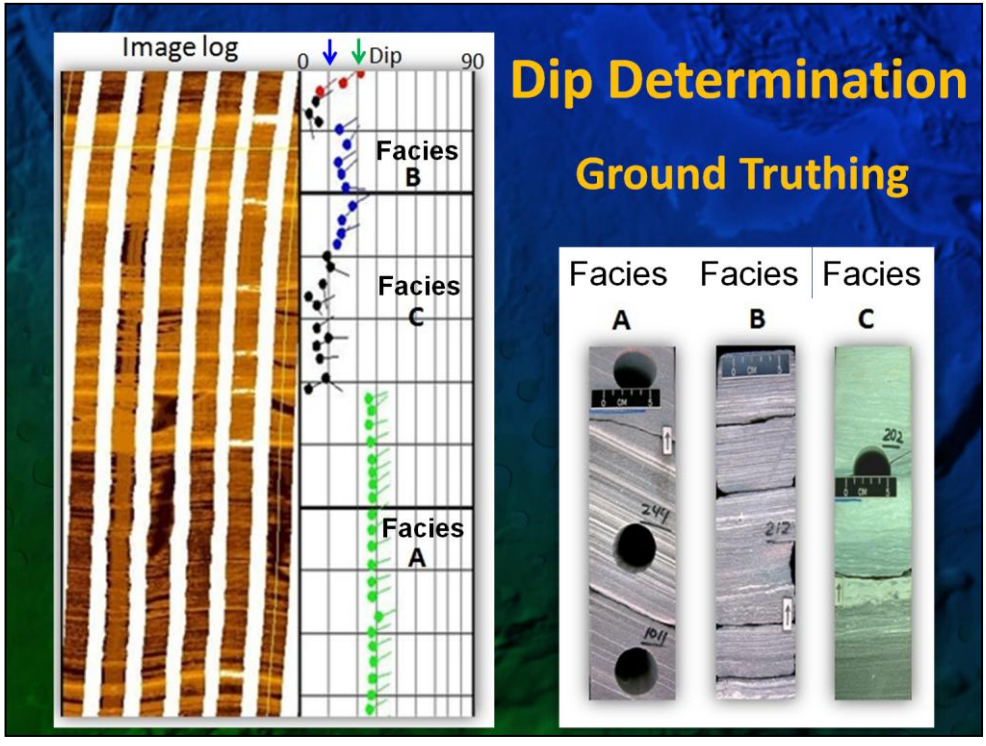
- Methodology
- Dip determination
- Facies determination and data "ground truthing"
- Paleowind investigation
- Dune type

Methodology

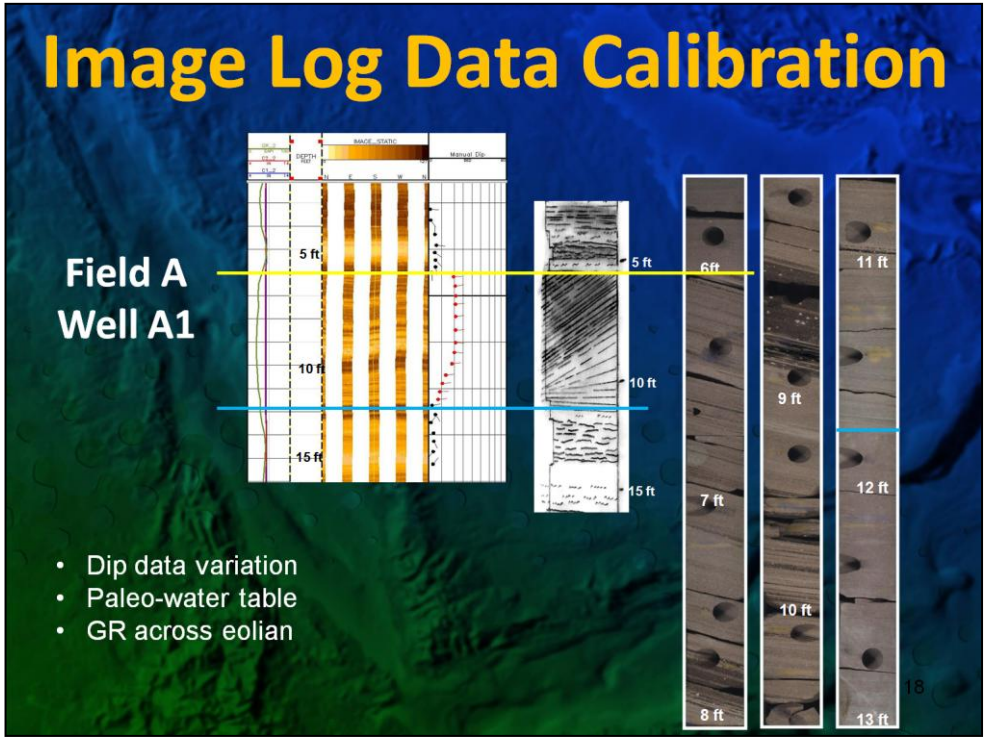
- Importance of Image logs in interpreting eolianites
- Borehole images data from 21 wells (over 4000 ft of section)
- Dip log analysis (angle and direction)
- Electrofacies analysis, integrated with core data
- Evaluation of paleowind directions throughout the study area.



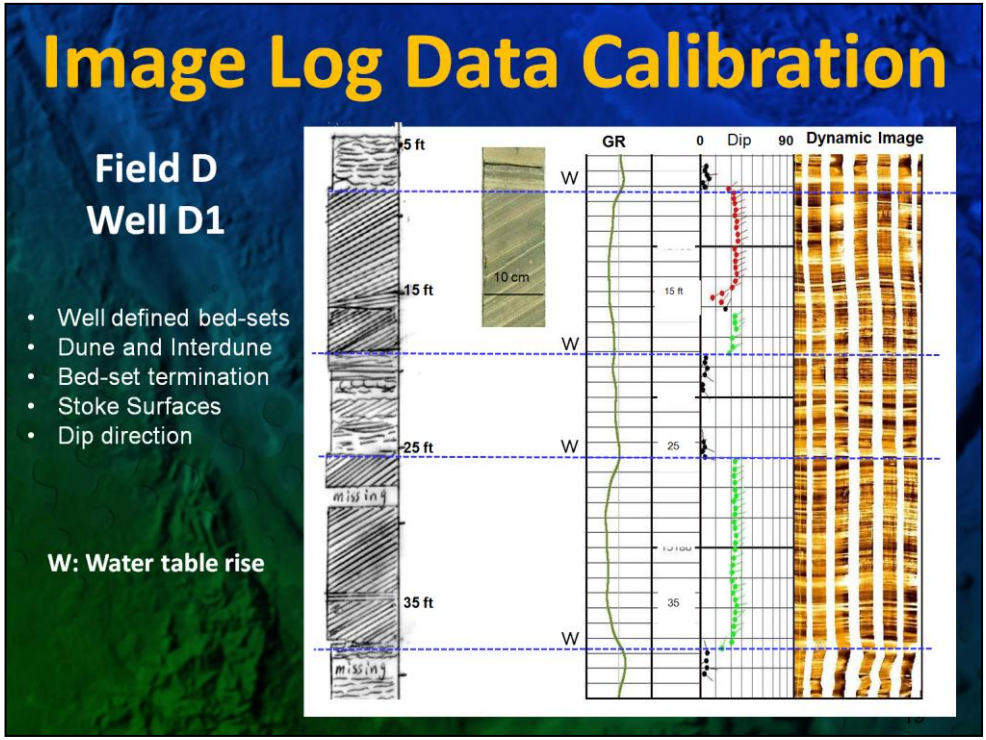
Presenter's notes: Location maps: The top map of east-central Saudi Arabia (note Riyadh's location) shows the general location of the studied fields (A, B, C and D). Lower detailed maps showing the selected fields and the locations of the studied wells in each field.



Presenter's notes: Image log and core photos from the studied cores, showing correlation between image log and core data. The core photos illustrate the different facies encountered in the Unayzah-A Member. Facies A represents the eolian sand dunes deposits; facies B represents the sand-sheet deposits; and facies C represents the interdunes deposits. The image log data shows the equivalent dip data for these facies. The dip data above 20° (green tadpoles) represents the eolian dune facies, the dip data between 10°-20º (blue tadpoles) represents the sand-sheet deposits and the dip data between 0°-10° (black tadpoles) represents the interdune facies. Note the dip direction of eolian dune facies is to the east-northeast.



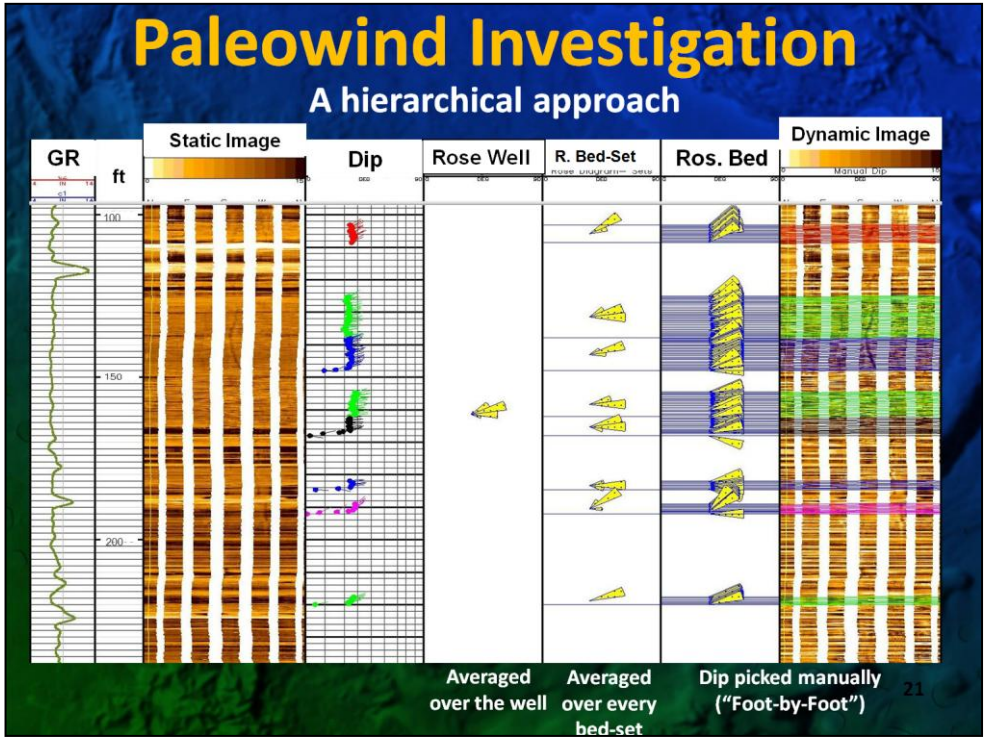
Presenter's notes: Calibration example of an image log and the corresponding core across a 13-ft interval from well A1. This shows the correlation between core and image log data for the eolian dune deposits, high-angle cross-stratification and the interdune flat-irregular lamination. Note: (1) The high-angle dip data and low-angle dip data, which reflect the dune and interdune facies, respectively. (2) The different orientation of the interdune dip data and the dominant east direction of the dune deposits. (3) The clear abrupt truncation of the dune facies seen on both the core and image log (Yellow line) represents the paleo-water table. (4) The GR (green curve on the left of the image log) response to the eolian and interdune facies: high across interdune deposits (due to the high content of argillaceous material) and low in the clean sands of the dune deposits.



Presenter's notes: Image log-core correlation in Well D1, showing well defined bed-sets of sandstone displaying high-angle cross-lamination (dune facies) between 7-15 ft and low-angle lamination (interdune facies) between 5-7 ft. Cross-laminated bed-sets are terminated upward abruptly and horizontally by "Stoke Surfaces" (blue dashed line), indicating a rising water table. Note the dominant unimodal eolian dune dip direction of east-northeast on the image log data.

Paleowind Investigation

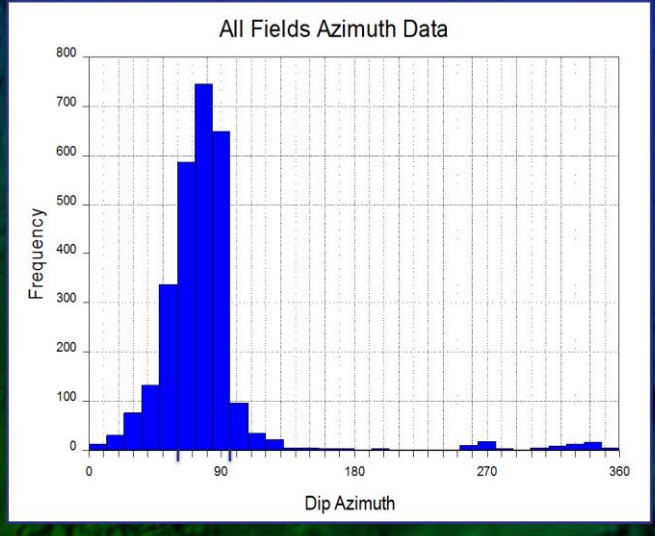
- Manually picked dip data on a foot-by- foot scale across all the dune facies in all the studied wells (over 4000 feet of image log data)
- Employed a hierarchical approach in the analysis
- Determined the dune type and paleowind direction



Presenter's notes: Interpreted high-resolution borehole image log data, illustrating the hierarchical approach used to investigate the paleowind direction across the Unayzah-A Member, utilizing the azimuth data of eolian-dune-facies bedding. Note the well-averaged data displayed on rose azimuth plots showing east-northeast paleowind direction (present-day orientation).

Results

Paleowind Investigation Azimuth Data

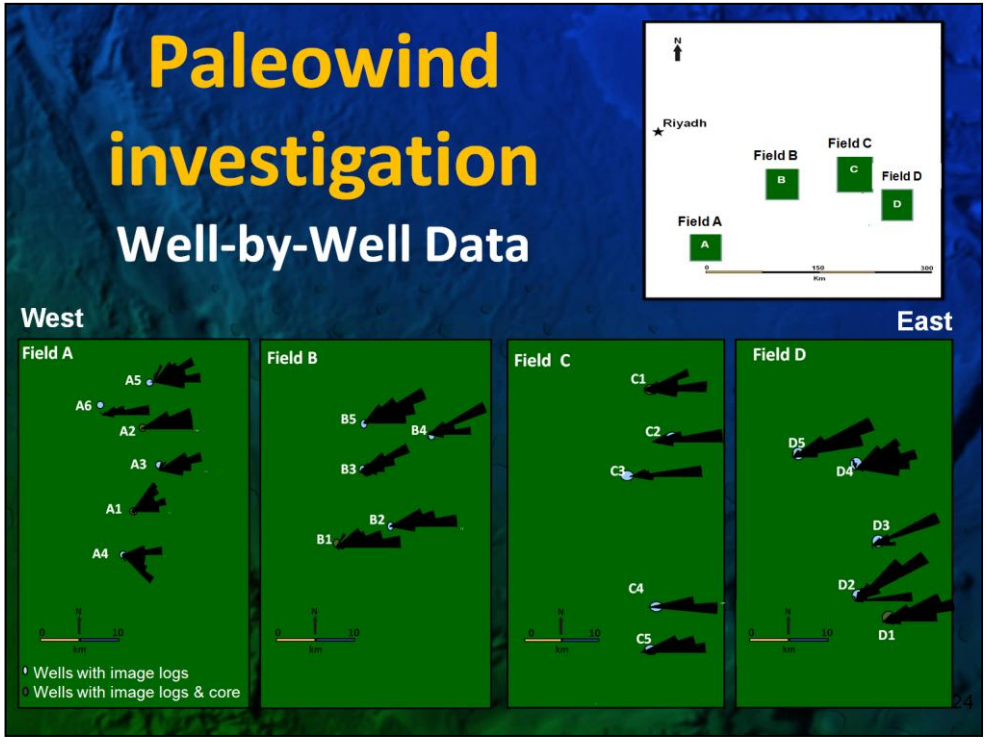


21 Wells

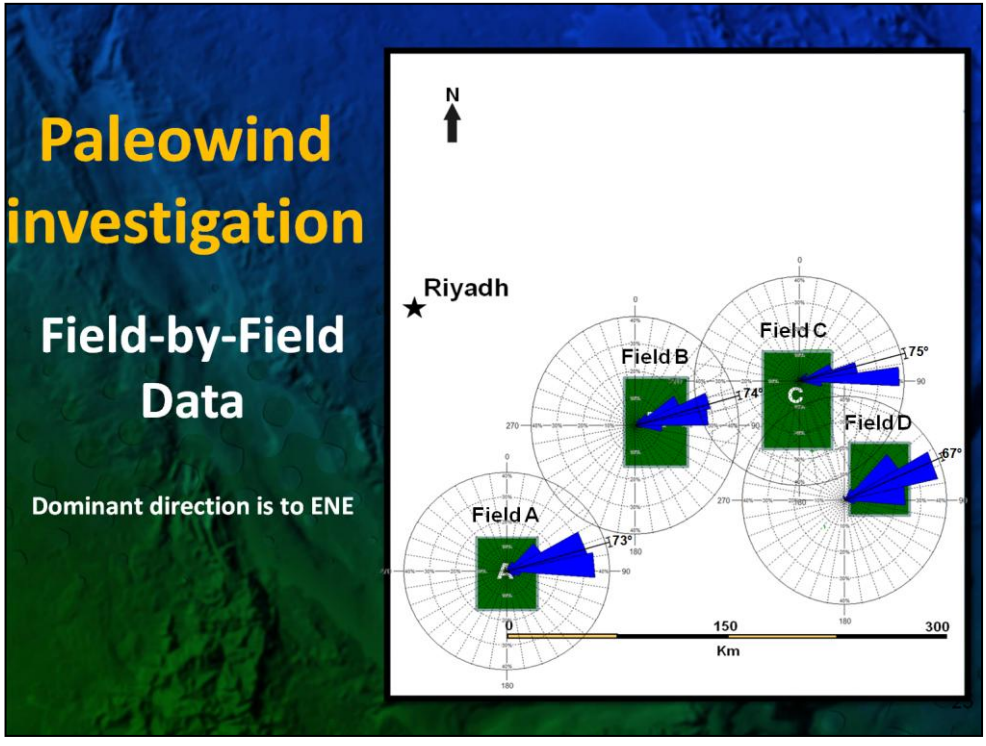
Over 4000 ft of section

2800 data points collected

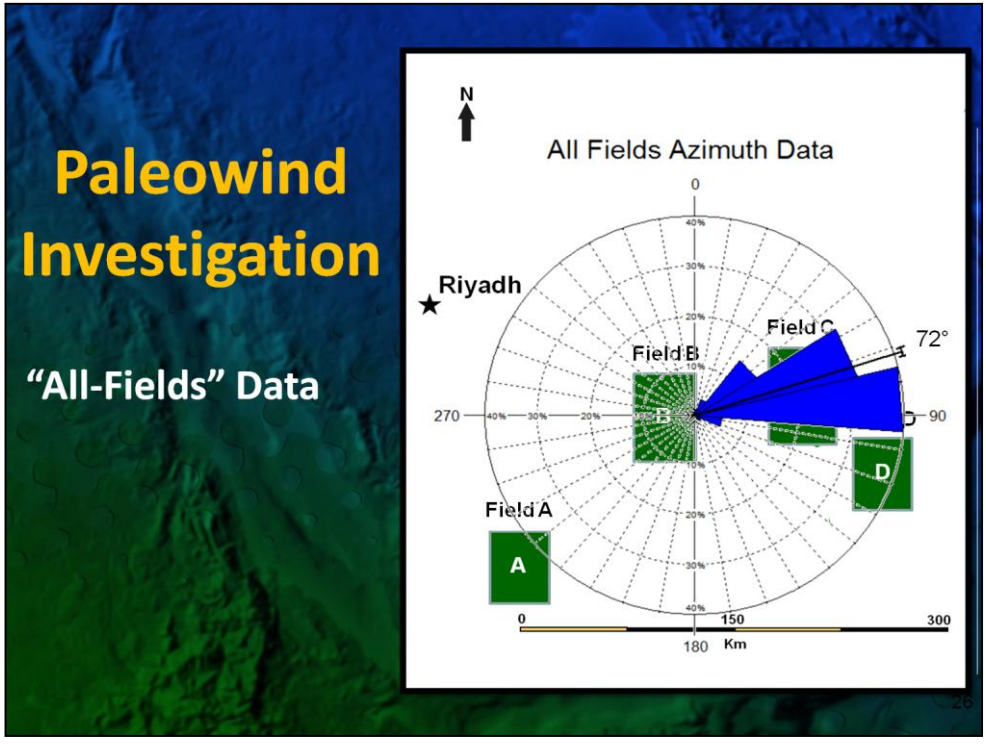
Presenter's notes: Histogram showing the total number of the data points (frequency) used in this investigation and the frequency of each azimuth. The X axis represents the dip direction (azimuth) of each image log data point collected from the studied wells. The Y axis represents the number (frequency) of points for each azimuth. Note that 88% of the data is between 45-98º with highest concentration of the dip azimuth data between 60º-98º reflecting a dominant direction toward east-northeast.



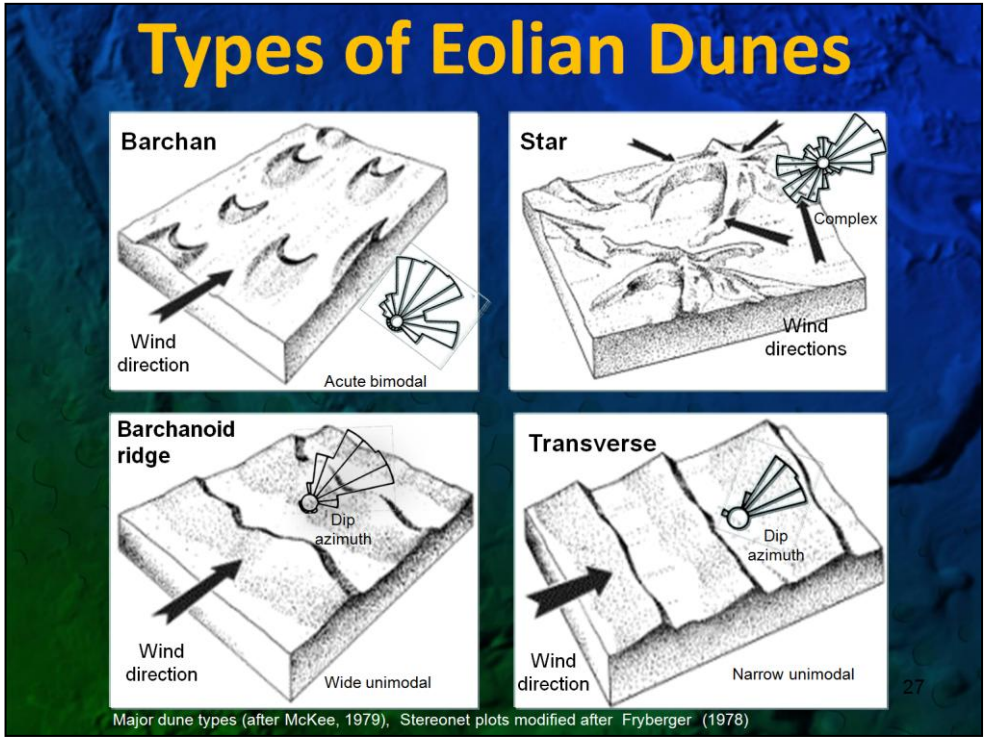
Presenter's notes: Location maps: Top map showing the field locations (A, B, C and D) (note the location of Riyadh); bottom maps showing a close-up of the selected fields and the wells used in this study. Rose diagrams are used to graphically summarise the directional data. The azimuth data rose diagrams are posted at the well locations. Note the generally narrow and unimodal shape of the azimuth data and the dominant orientation to the east-northeast (present day) in all the studied wells from Field A in central Saudi Arabia to Field D in eastern Saudi Arabia.



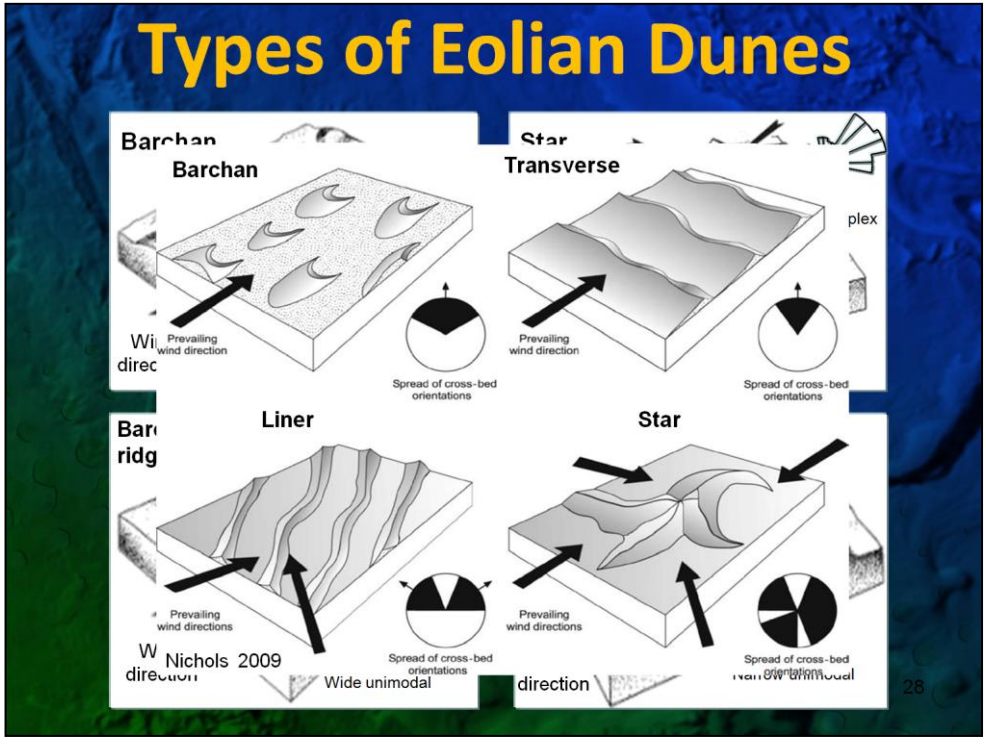
Presenter's notes: Paleowind directions in the study area, inferred from the dip azimuth data; rose diagrams are used to graphically summarise the directional (azimuth)data. Rose diagrams (using Oriana software) show the dip azimuth data for each field; this indicates the paleowind direction for each field. The data shows a unimodal and narrow orientation strongly concentrated between (60-98º). This indicates a dominant paleowind direction toward east-northeast (present day); the azimuthal mean values range between North 67-75 degrees East.



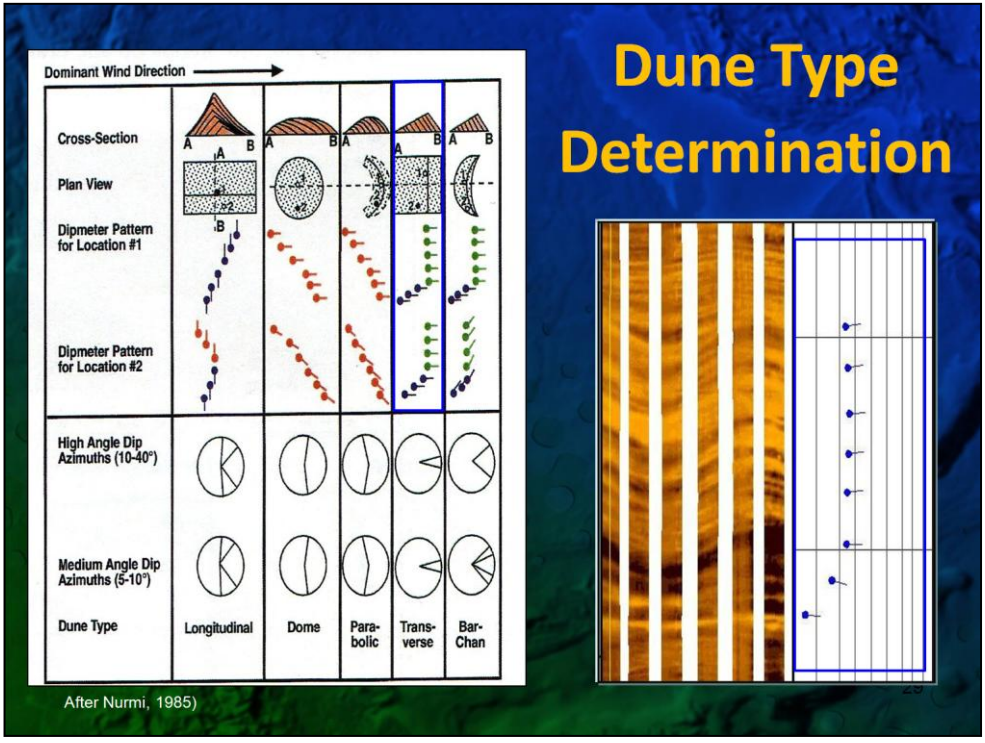
Presenter's notes: Paleowind directions inferred from all the dip azimuth data: the rose diagram is used to graphically summarise the directional (azimuth) data. It shows the dominant paleowind direction for the whole study area (four fields). The data indicates a wind direction toward east-northeast (present day) with range between (40º-110º); 88% of the data falls between 45-98; the strong concentration (70%) is between (60º-90º), and 26% of the data points falls between (80º-90º), with mean of 72º.



Presenter's notes: Dune schematics, illustrating eolian dune forms from the classification of McKee (1979). These include barchan, barchanoid, transverse and star dunes. Rose diagrams from Fryberger (1978) are posted on the dunes showing the relationship of dune forms and wind regimes. As wind regime becomes complex (multidirectional), dune forms evolve into more complex forms with greater internal complexity, as expressed in the rose diagrams. Note the unidirectional orientation and the narrow window of the azimuth data that belongs to the transverse dune type. The forms of these main eolian dune types are determined by the direction of the prevailing wind(s) and the availability of sand. The rose diagrams show the likely distribution of paleowind indicators (high-angle cross-bedding).

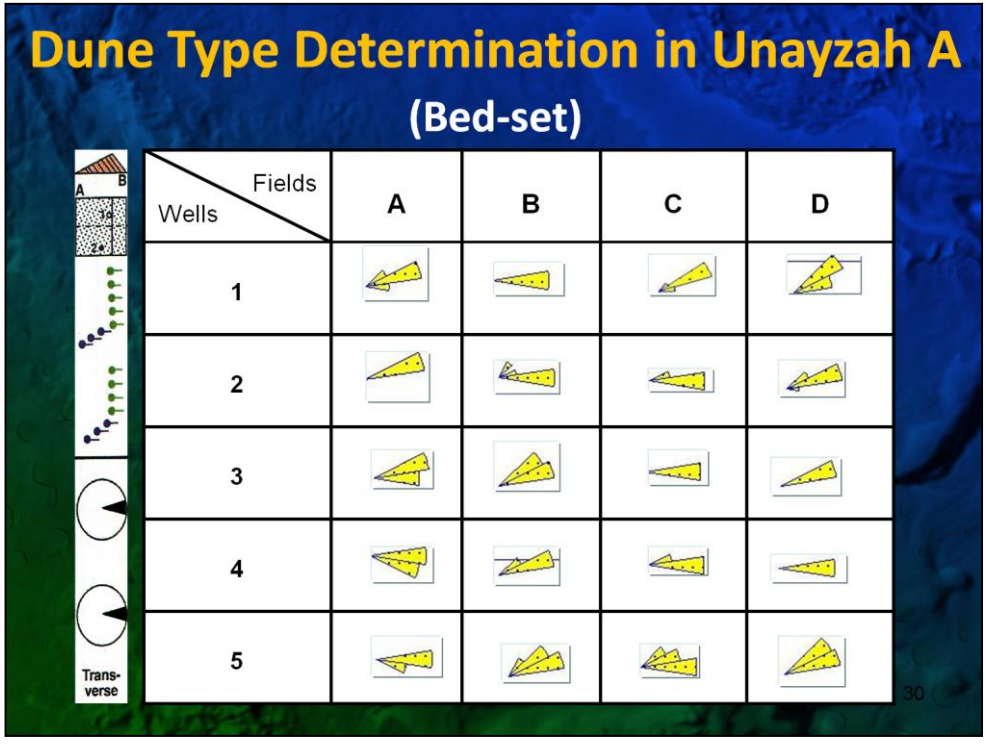


Presenter's notes: Dune schematics, illustrating eolian dune forms and wind directions, from Nichols (2009). Rose diagrams show cross-bedding dip directions.



Presenter' notes: Dip characteristics of the basic dune types, illustrating internal structure of the dune forms and the corresponding dipmeter patterns in the dunes at two locations and the corresponding rose diagrams (the wind is blowing to the east). Note the decrease downward in dip and the corresponding narrow unimodal azimuth data throughout the transverse dune type (after Nurmi, 1985). The dip pattern correlates well with the dipmeter data collected across the proposed transverse dune system in this study.

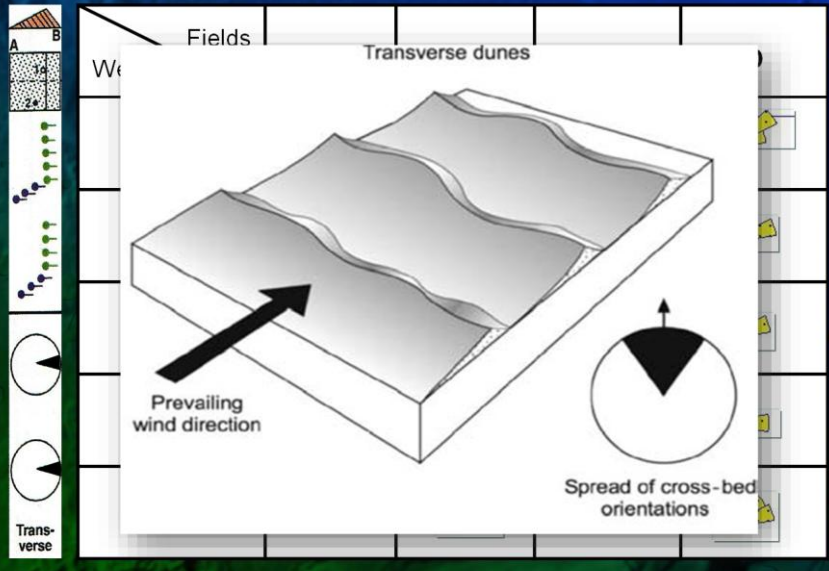
Image log and dip data across eolian dune facies observed in well D1. This example is similar to the transverse dipmeter patterns observed by Nurmi (1985).



Presenter's notes: Rose diagrams from representative bed-set data from the 20 studied wells. This illustrates the narrow unimodal orientation of the analyzed azimuth data, with good comparison to the azimuth data in transverse dune internal structure, as determined by Nurmi (1985) (column to the left of the table). This suggests strongly that the transverse type is the dominant dune type in the Unayzah-A Member.

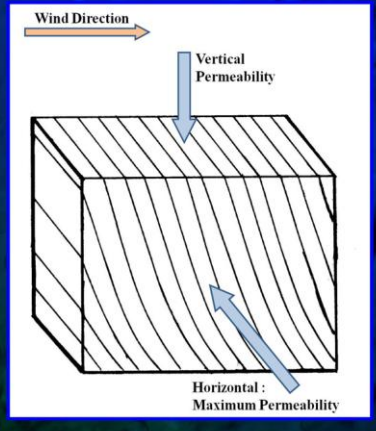
Dune Type Determination in Unayzah A

(Bedset)



Reservoir Implications

- Optimum permeability trends are typically perpendicular to paleowind transport (assuming transverse dunes).
- Interdune facies provide reservoir vertical barriers/baffles.
- Lateral permeability anisotropy in eolian sediments resulting from more continuous laminae perpendicular to the wind direction.



Presenter's notes: Three-dimensional schematic illustration of the lateral (horizontal) permeability anisotropy in eolian sediments resulting from more continuous laminae perpendicular to the wind direction. In this diagram the wind is blowing from west to the east. The optimum permeability is perpendicular to the wind direction (north-south).

Conclusion

- **Core Study:** (dune, sand sheet, damp and wet interdune, and paleosol)
- The dune sands comprise the major portion (46%) of the reservoir
- **Image log study:** The dominant wind direction is east- northeast (72°)
- The dune type is a N-S trending transverse dune system
- Integration of core and image log data
- Economic implication.

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- AAPG for giving me the opportunity to present our work

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