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SPE-193222-MS
The Value of Integrated Borehole Image Analysis to Refine Geological Models: An Example from the Greater Burgan Field, Kuwait

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Next year's dates announced: 11 – 14 November 2019

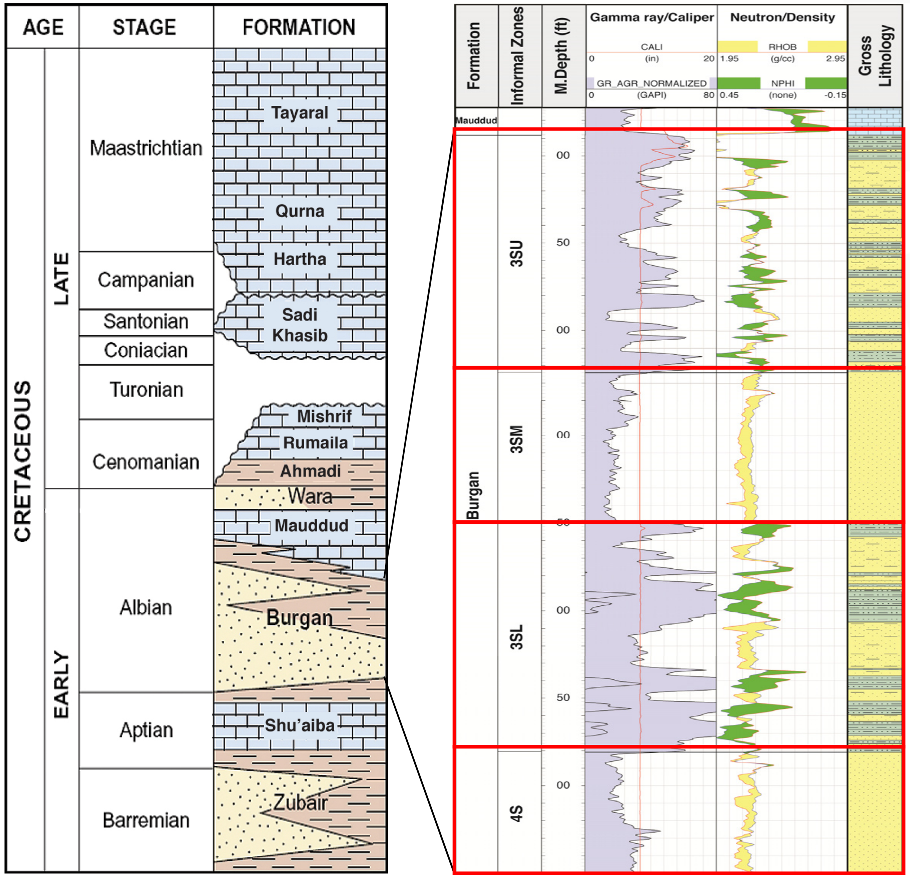
Introduction and aims

- Using examples from the Cretaceous Burgan and Wara Formations in Kuwait, the aim of this presentation is to show the value of integrated core and image analysis for refined geological modelling

- The depositional understanding of the Burgan and Wara Formations is based on
  - core sedimentology
  - biostratigraphy
  - chemostratigraphy
  - conventional wireline logs

- In addition, 3 wells have been selected for a pilot borehole image study to
  - assess the resolution of the image logs relative to core data and wireline logs
  - provide key information on directional data (palaeoflow)
  - refine depositional models

Burgan Stratigraphy



Informally, the Burgan Formation is subdivided into 4 reservoir zones:

- 4S - fluvial channel sandstones
- 3SL - wave/tide-influenced delta heterolithics
- 3SM - tide-influenced channel sandstones
- 3SU - wave-influenced delta, shoreface sandstones and mudrocks

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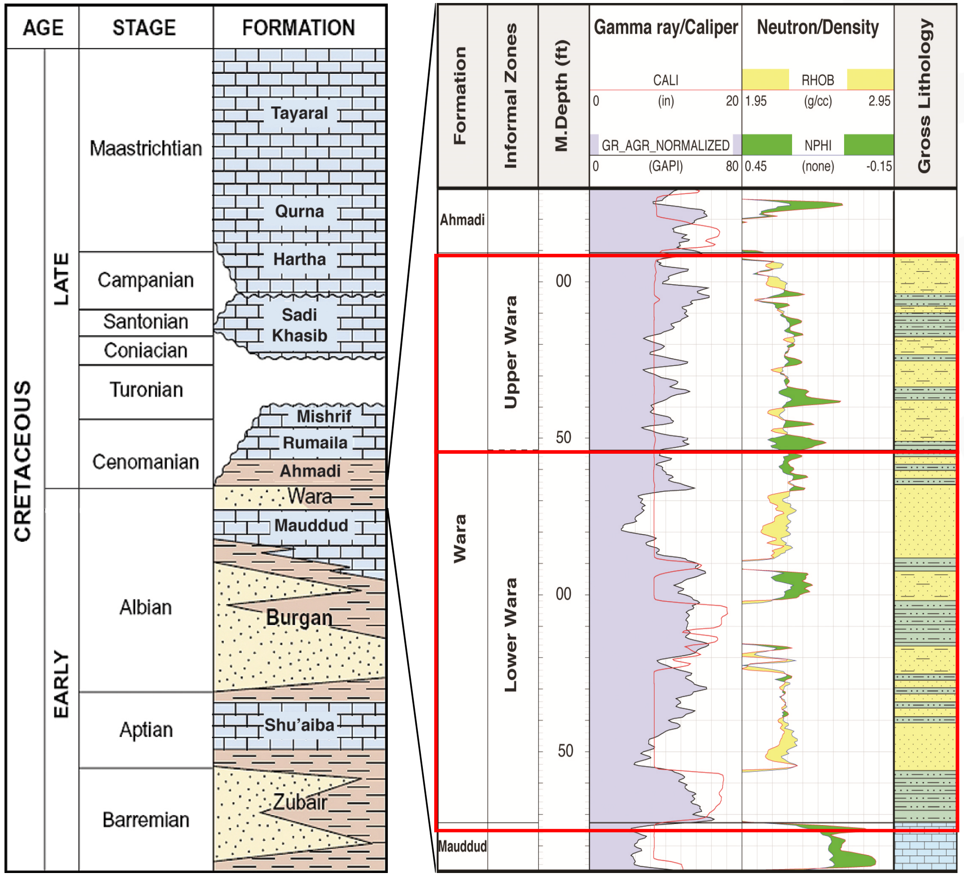
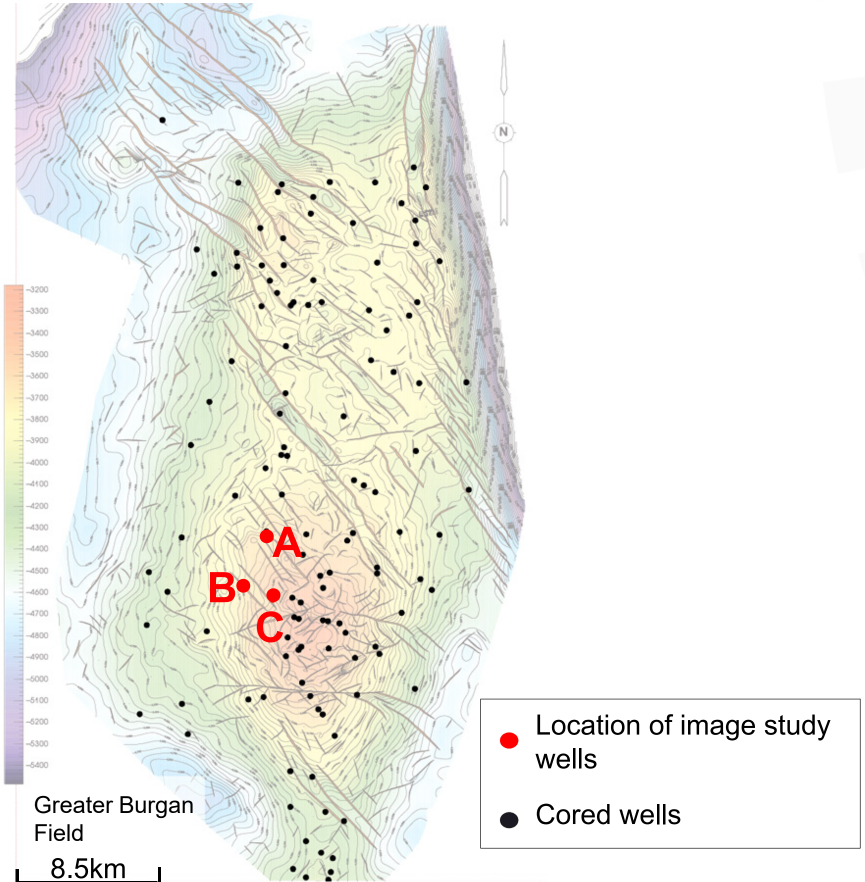
Introduction - Wara stratigraphy



The Wara Formation comprises marine to brackish bay mudrocks and sandstones, incised by valley fill sandstones

- The background **Lower Wara** comprises predominantly offshore to lower shoreface deposits showing a broad upward-shallowing trend
- The **Upper Wara** shows a nearshore bay setting punctuated by common sand/mud flats
- Incised valleys observed throughout the succession depict major falls in sea level with infill concurrent with gradual transgression

Dataset



- Total of >35,000ft of core from 123 wells
- 3 imaged wells - full FMI coverage
  - Well A: 238ft of core (Upper Burgan)
  - Well B: no core
  - Well C: 184ft of core (Wara)
- Good quality core (>4" slabbed core width)
- Image quality reduced over mud-prone intervals as a result of borehole damage
  - Generally allows for confident, high-resolution image assessment

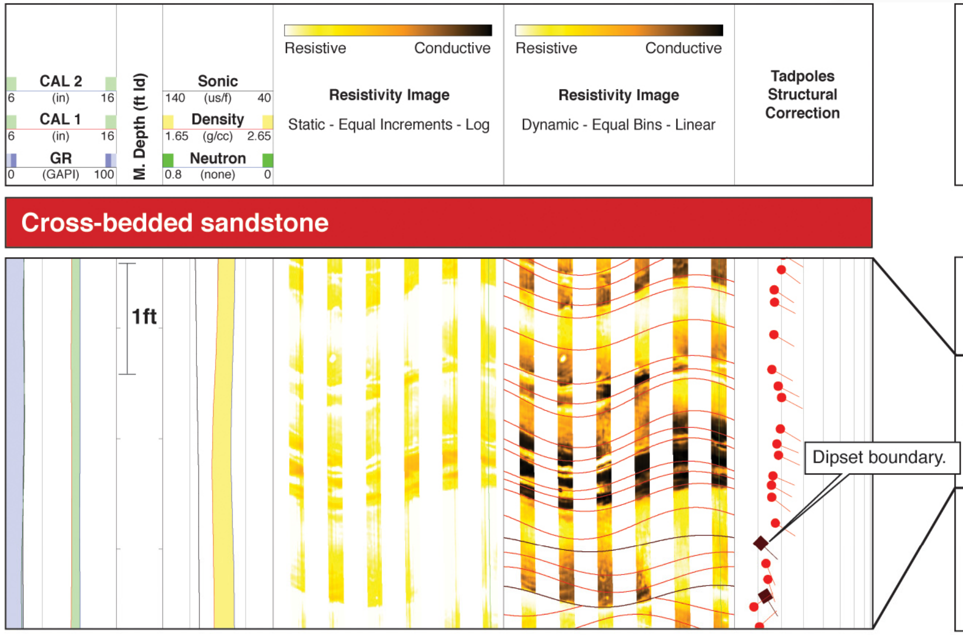
Image Workflow

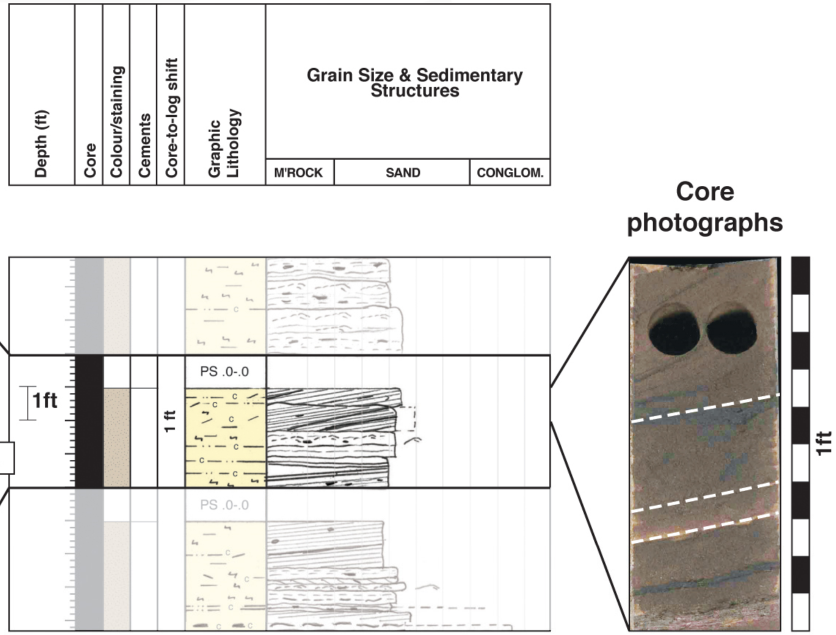
1. Data review
- Data review and loading
- Image processing

2. Data analysis and interpretation
- Image-to-core calibration
- Manual dip picking
- Structural dip evaluation and correction
- Classification of image facies
- Palaeoflow assessment
- Sedimentological and stratigraphic interpretation

Image Facies

Bed to sub-bed scale characterisation of image logs, calibrated against core and wireline logs





BHI Character: Regularly laminated sandstones with persistently high-angle dip magnitudes (typically >10°) and locally upward-steepening trends. Within individual bedsets azimuths are consistent.

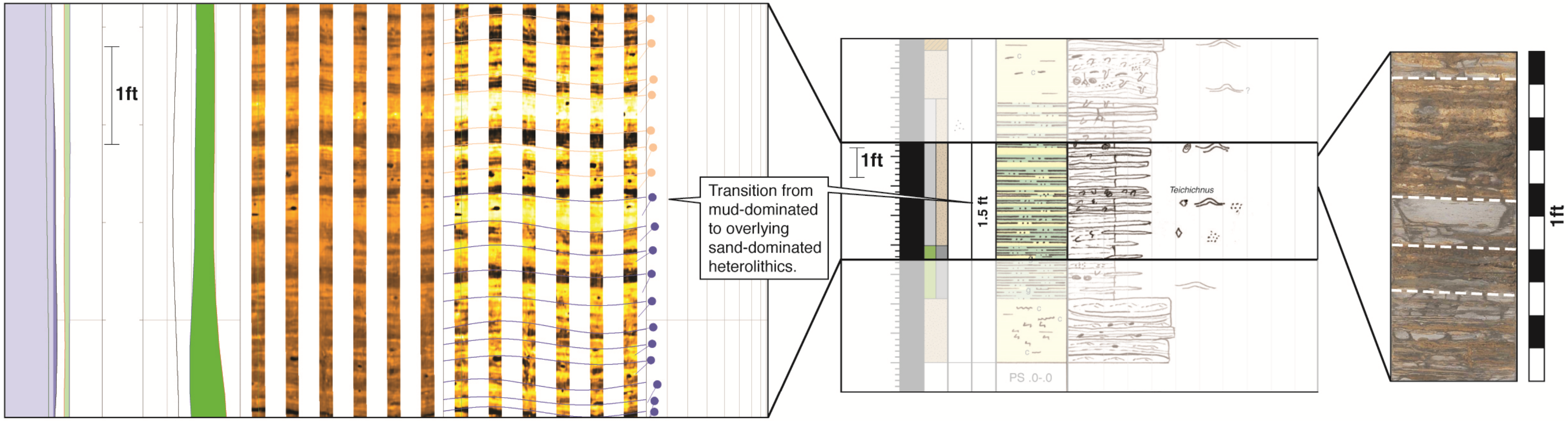
Log Character: Low to moderate GR response with moderate to wide sand-type neutron/density separation.

Core Lithotypes: Analogous to high-angle cross-stratified sandstones, although these may not always be accurately recorded in core due to core slabbing not carried out parallel to maximum dip. As a result this may also encompass laminated and massive sandstones.

Image Facies

Selected heterolithic example - note different resolution of heterolithics in image (cm to dm-scale) and core (mm to cm-scale)

Sand-dominated/mud-dominated heterolithics



BHI Character: Dm-scale alternations of sandstones and mudrocks appearing as contrasting conductive and resistive laminae. Typically characterised by low-angle dips (<10°), rare moderate dip magnitudes (*c.*10-25°) after structural correction.

Log Character: Moderate to high GR response with moderate to wide mud-type neutron/density separation. Mud-dominated heterolithics display slightly higher GR and wider mud-type neutron/density values than sand-dominated heterolithics.

Core Lithotypes: These are represented in core by laminated sand and mud-dominated heterolithics, but may also include dm-thick interbeds of laminated or even massive sandstones. Laminations observed in core are typically mm to cm-scale, while they appear thicker (generally cm to dm-scale) in the image due to the lower resolution of the resistivity tool.

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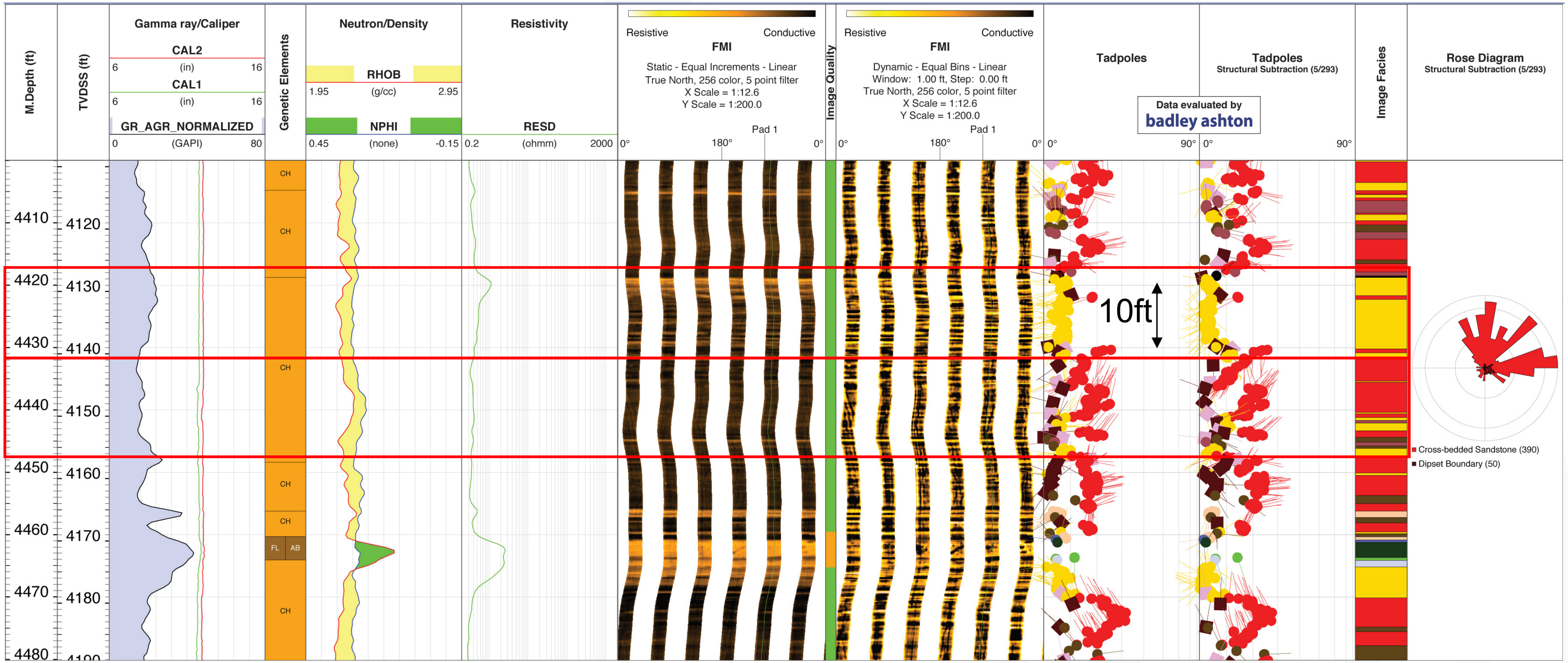
Detail offered from BHI



Superior detail and information relative to well logs

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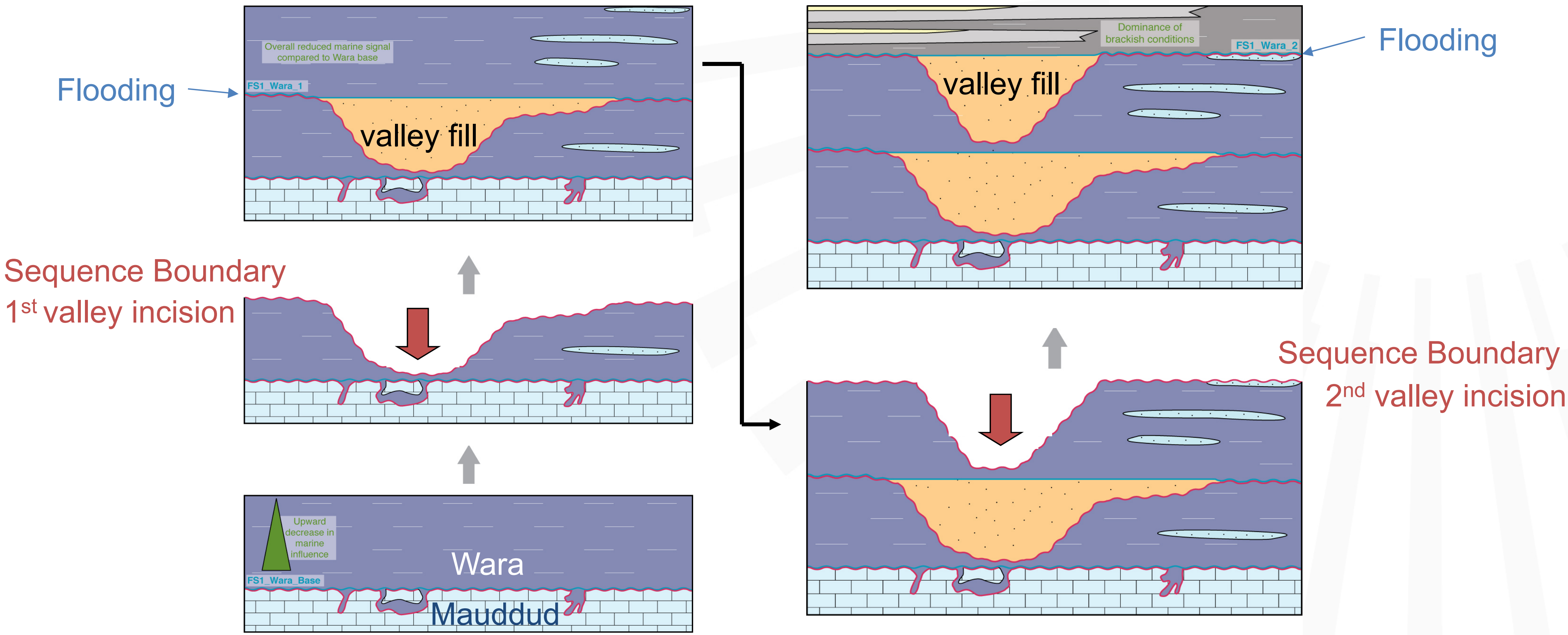
CASE STUDY 1

Identification of sequence boundaries/base of valley-fill reservoirs in the Wara Formation

Lower Wara depositional evolution



Value of image data for refined depositional interpretations

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ADIPEC

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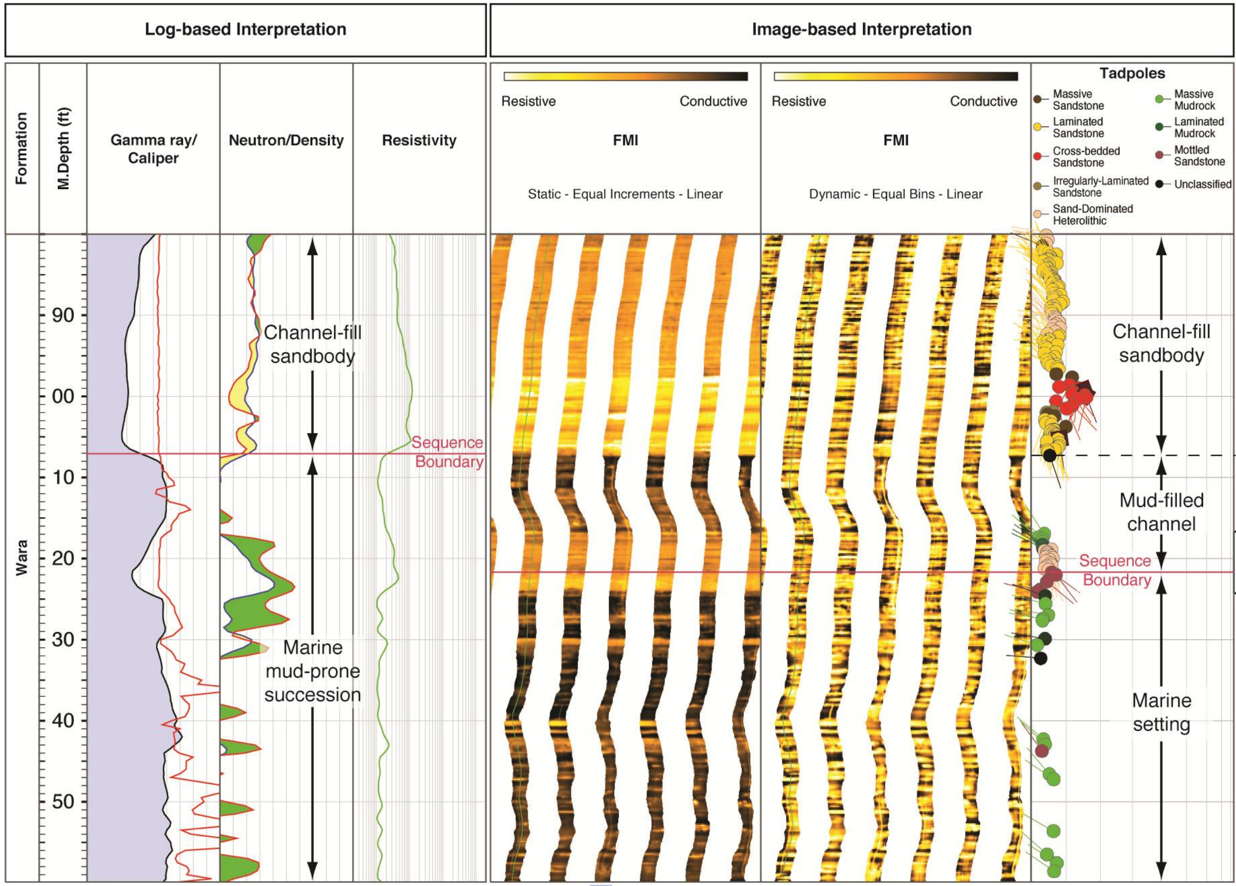

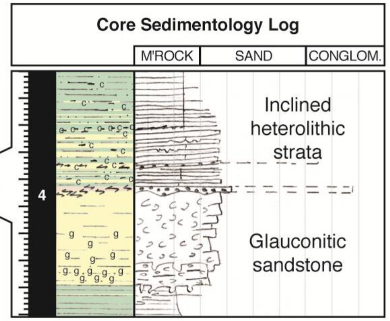

Image interpretation supported by core sedimentology

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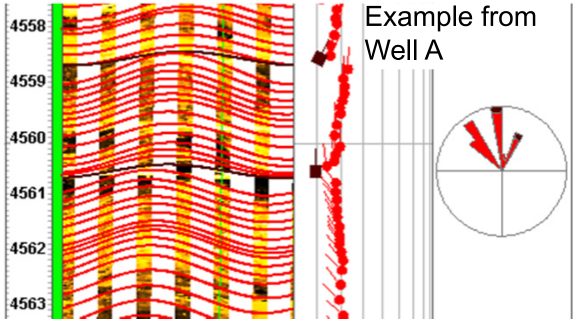
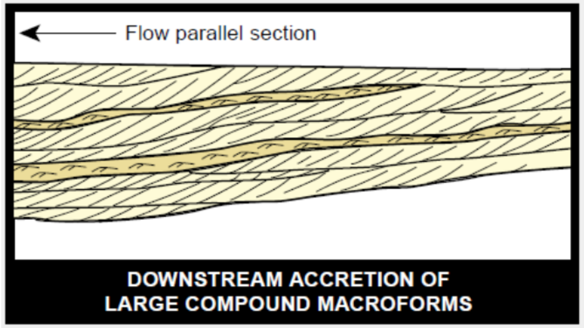
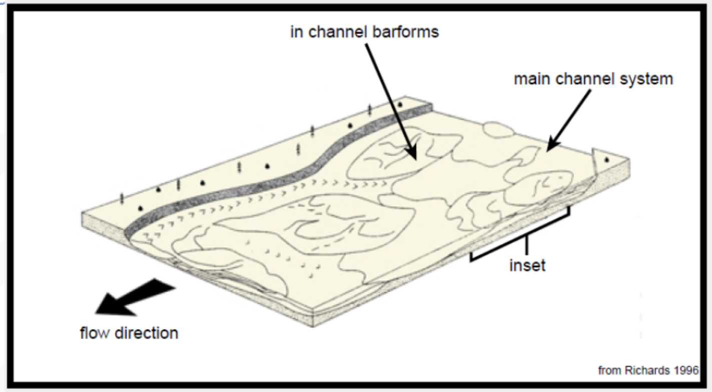
CASE STUDY 2

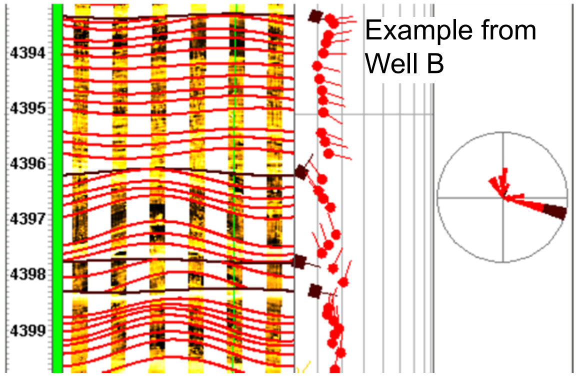
Channel sinuosity in the Burgan Formation

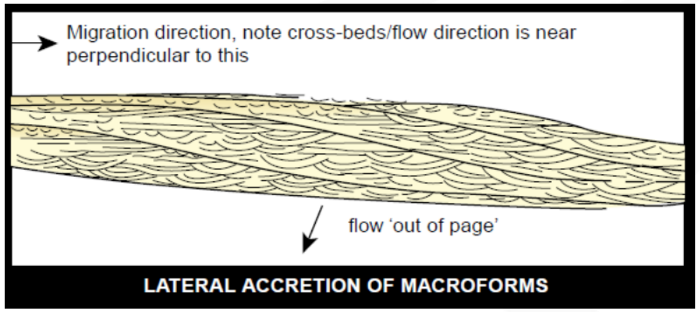
Establishing channel sinuosity from dip data

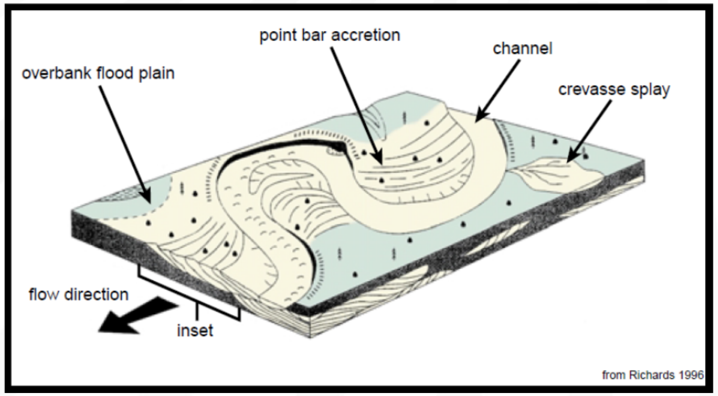






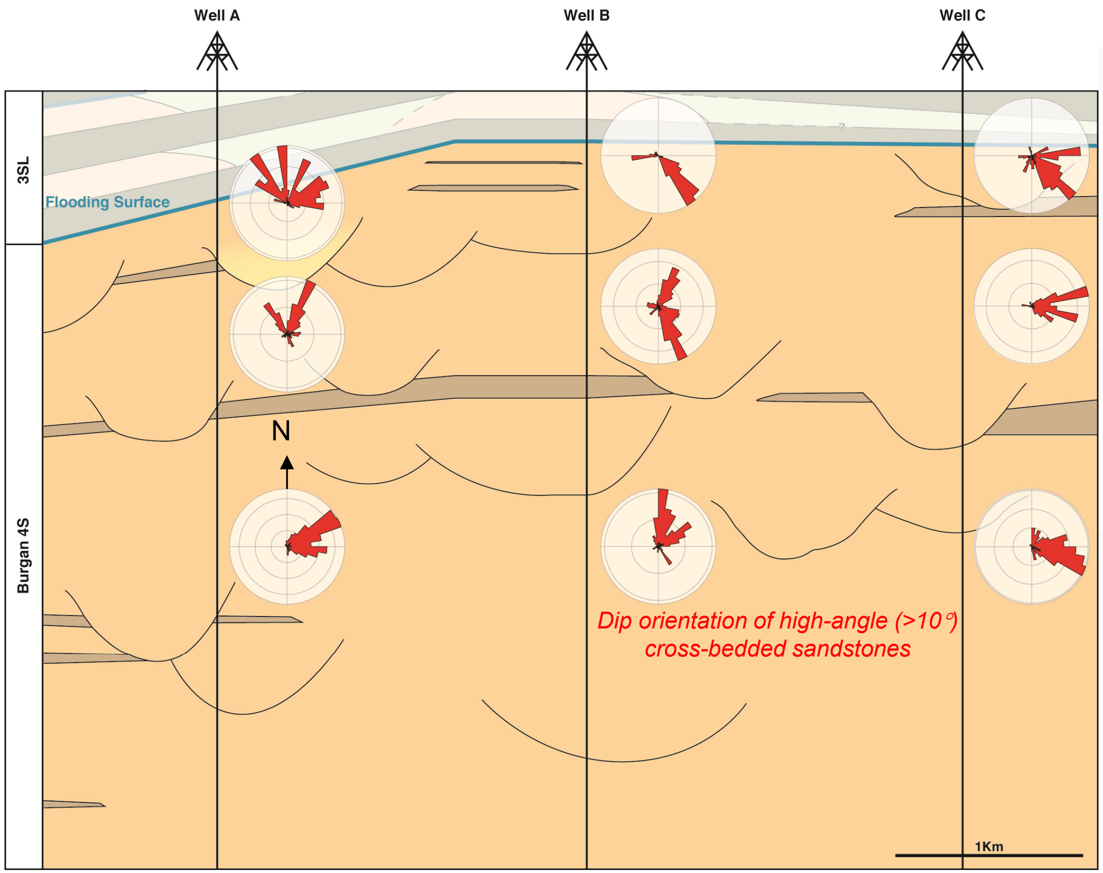






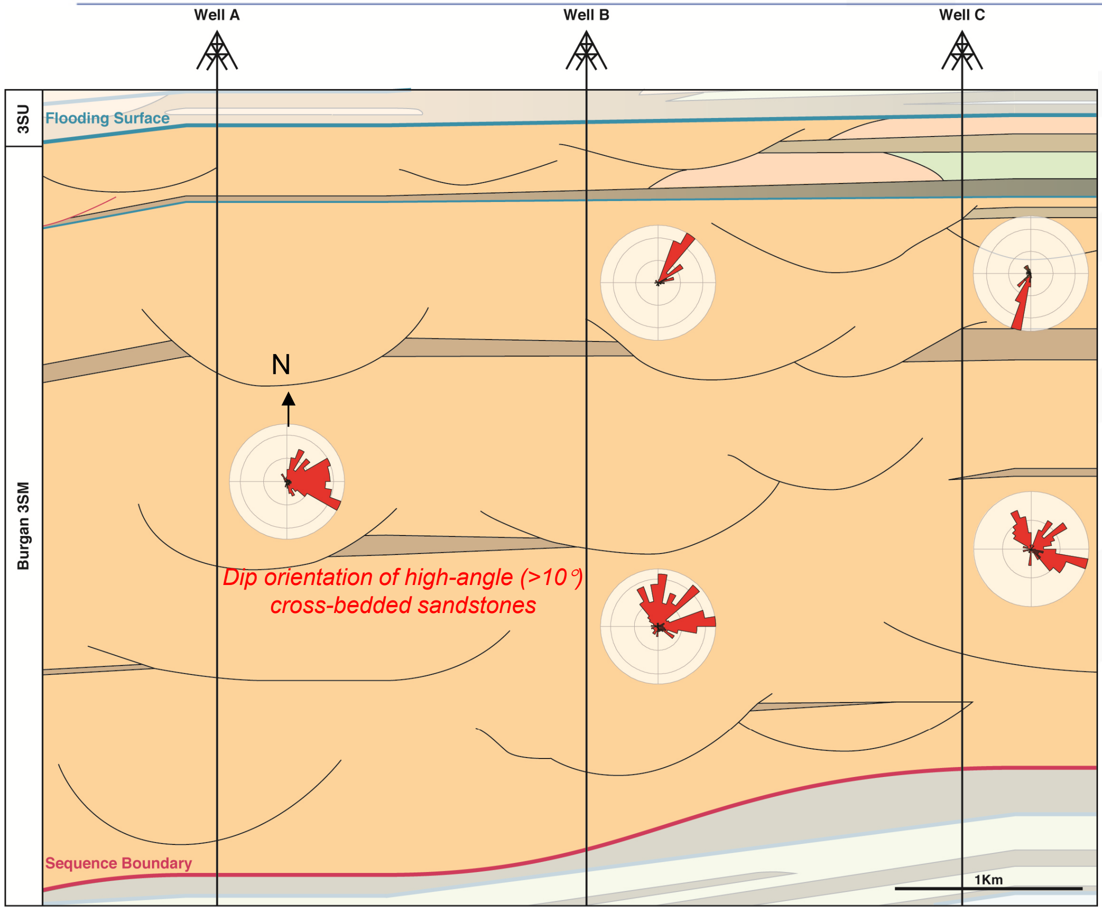
- Presence of lateral accretionary bedforms (point bars) implied from dip relationships
- Implications for channel sinuosity and ultimately reservoir architecture and fluid flow pathways

Palaeoflow data and its value to assess channel sinuosity



- **Burgan 4S**: dominance of high-angle cross-bedded sandstones stacked within fluvial channels
- Dip magnitudes vary between 10-25°
- Majority of dip azimuths towards NE/E
- Stronger easterly direction in Well C
- Bedset boundaries generally aligned with sandstone dips
- SE/E direction towards 4S top in all three wells - *gross directional change of the 4S channel system prior to its abandonment?*
- Dominance of downstream migrating bedforms within low-sinuosity channels likely

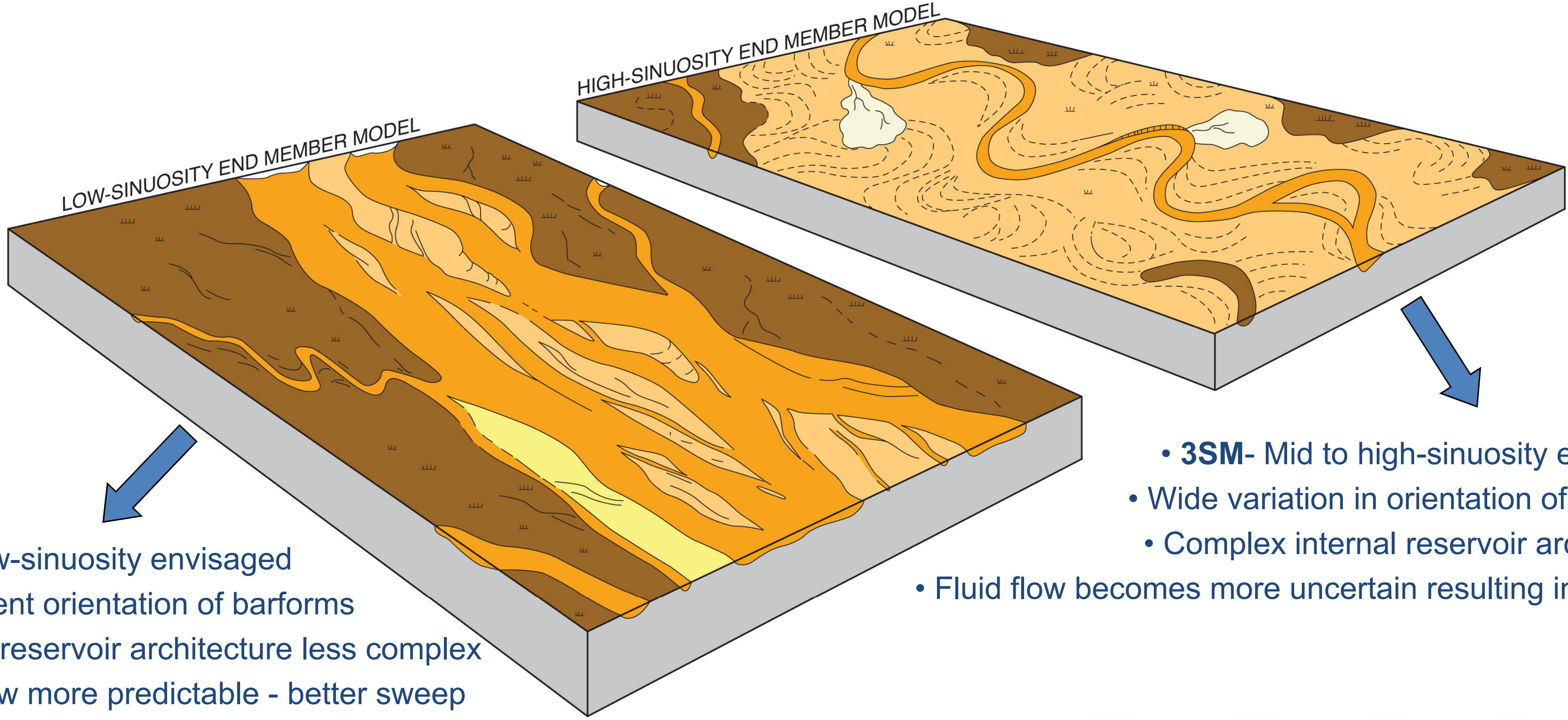
Palaeoflow data and its value to assess channel sinuosity



- **Burgan 3SM**: high-angle cross-bedded sandstones stacked within tidally-influenced channels
- Dip magnitudes vary between 10-25°
- Directional spread in the order of 60-90°, dominant N to E orientation
- Dipset boundaries locally oriented oblique to surrounding sandstone packages - *lateral accretion surfaces?*

- Some lateral/point bar development and higher channel sinuosity?

Depositional model end members



- **3SM**- Mid to high-sinuosity envisaged
- Wide variation in orientation of barforms
- Complex internal reservoir architecture
- Fluid flow becomes more uncertain resulting in reduced recovery.

- **4S** - Low-sinuosity envisaged
- Consistent orientation of barforms
- Internal reservoir architecture less complex
- Fluid flow more predictable - better sweep

Conclusions

- Resistivity image logs provide a detailed and cost-effective tool for sedimentological and structural evaluations, in particular, when calibrated against core
  - Recognising the limit of image resolution
  - Systematically classifying meaningful image facies
  - Improving the understanding of depositional and structural reservoir heterogeneity
- The geological understanding of the origin of sandstone dips is crucial for the reliable assessment of sandbody orientations, channel sinuosity and ultimately fluid flow behaviour
  - Greater variability of bar types in the middle Burgan (3SM) channel sandbodies compared to the lower Burgan (4S)
  - Potentially implies presence of higher sinuosity channels and a more complex reservoir architecture and fluid flow pathways in the 3SM reservoir
  - Requires confirmation from larger image well dataset

Acknowledgements / Thank You / Questions

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