Geological Modeling:
Deterministic and Stochastic Models

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Community Surface Dynamics Modeling System
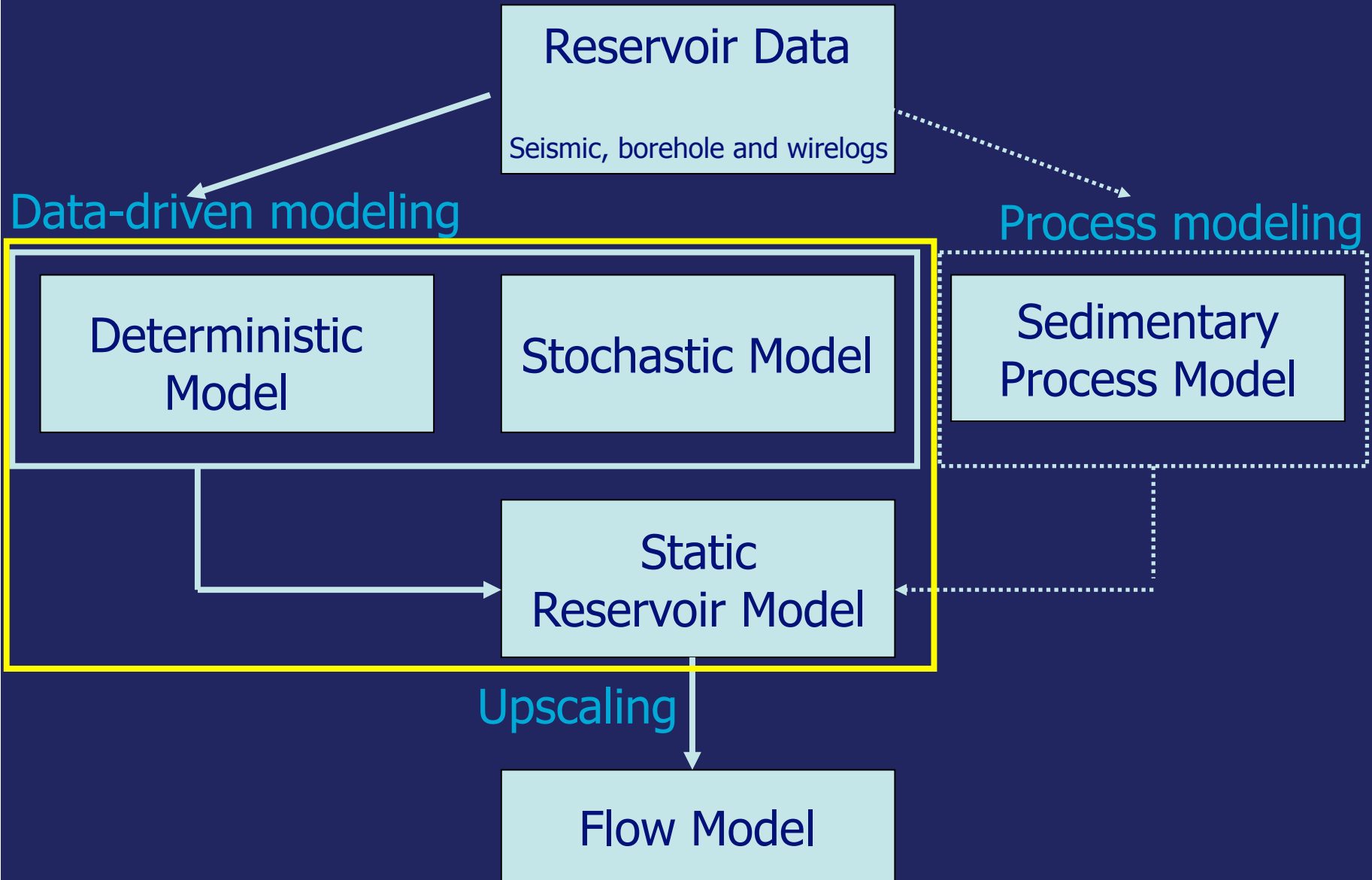
University of Colorado at Boulder

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Course outline 1

- **Lectures by Irina Overeem:**

    - **Introduction and overview**
    - **Deterministic and geometric models**
    - **Sedimentary process models I**
    - **Sedimentary process models II**
    - **Uncertainty in modeling**

- **Lecture by Overeem & Teyukhina :**
    - **Synthetic migrated data**

Geological Modeling: different tracks

Reservoir Data

Seismic, borehole and wirelogs

Data-driven modeling

Process modeling

Deterministic Model

Stochastic Model

Sedimentary Process Model

Static Reservoir Model

Upscaling

Flow Model

Deterministic and Stochastic Models

- **Deterministic model** - A mathematical model which contains no random components; consequently, each component and input is determined exactly.

- **Stochastic model -** A mathematical model that includes some sort of random forcing.

- In many cases, stochastic models are used to simulate deterministic systems that include smaller- scale phenomena that cannot be accurately observed or modeled. A good stochastic model manages to represent the average effect of unresolved phenomena on larger-scale phenomena in terms of a random forcing.

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Deterministic geometric models

- Two classes:
  - Faults (planes)
  - Sediment bodies (volumes)

- Geometric models conditioned to seismic
- QC from geological knowledge

Direct mapping of faults and sedimentary units from seismic data

- Good quality 3D seismic data allows recognition of subtle faults and sedimentary structures directly.
- Even more so, if (post-migration) specific seismic volume attributes are calculated.

- Geophysics Group at DUT worked on methodology to extract 3-D geometrical signal characteristics directly from the data.

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L08 Block, Southern North Sea
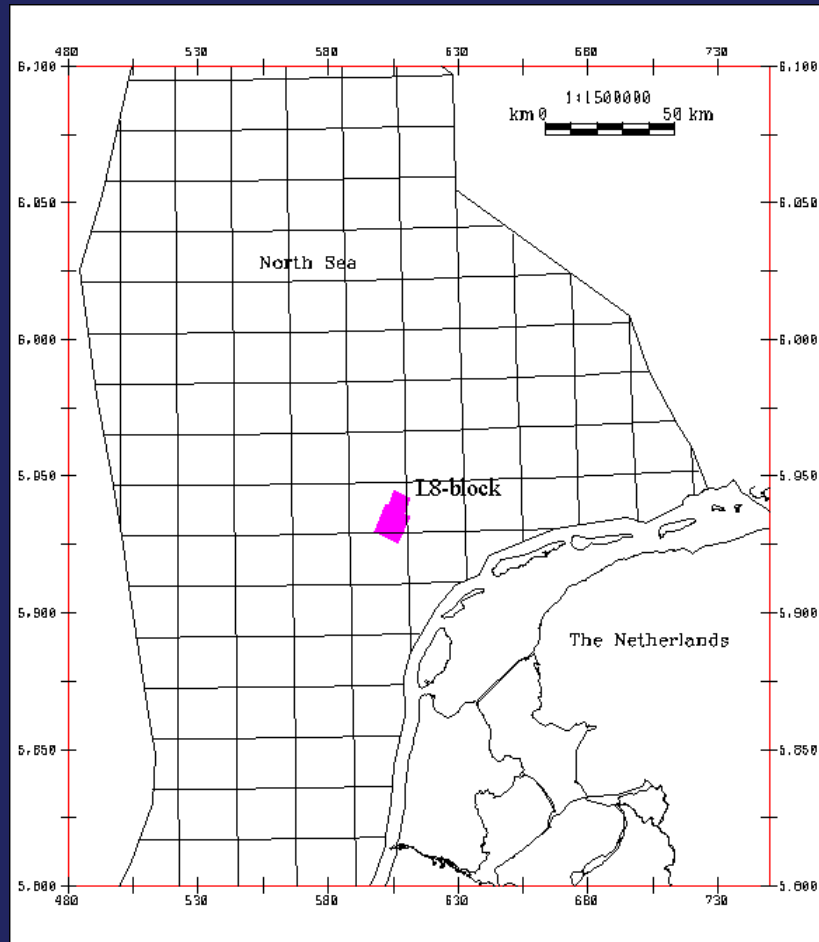
Cenozoic succession in the Southern North Sea consists of shallow marine, delta and fluvial deposits.

Target for gas exploration?

Seismic volume attribute analysis of the Cenozoic succession in the L08 block, Southern North Sea. Steeghs, Overeem, Tigrek, 2000. Global and Planetary Change, 27, 245–262.
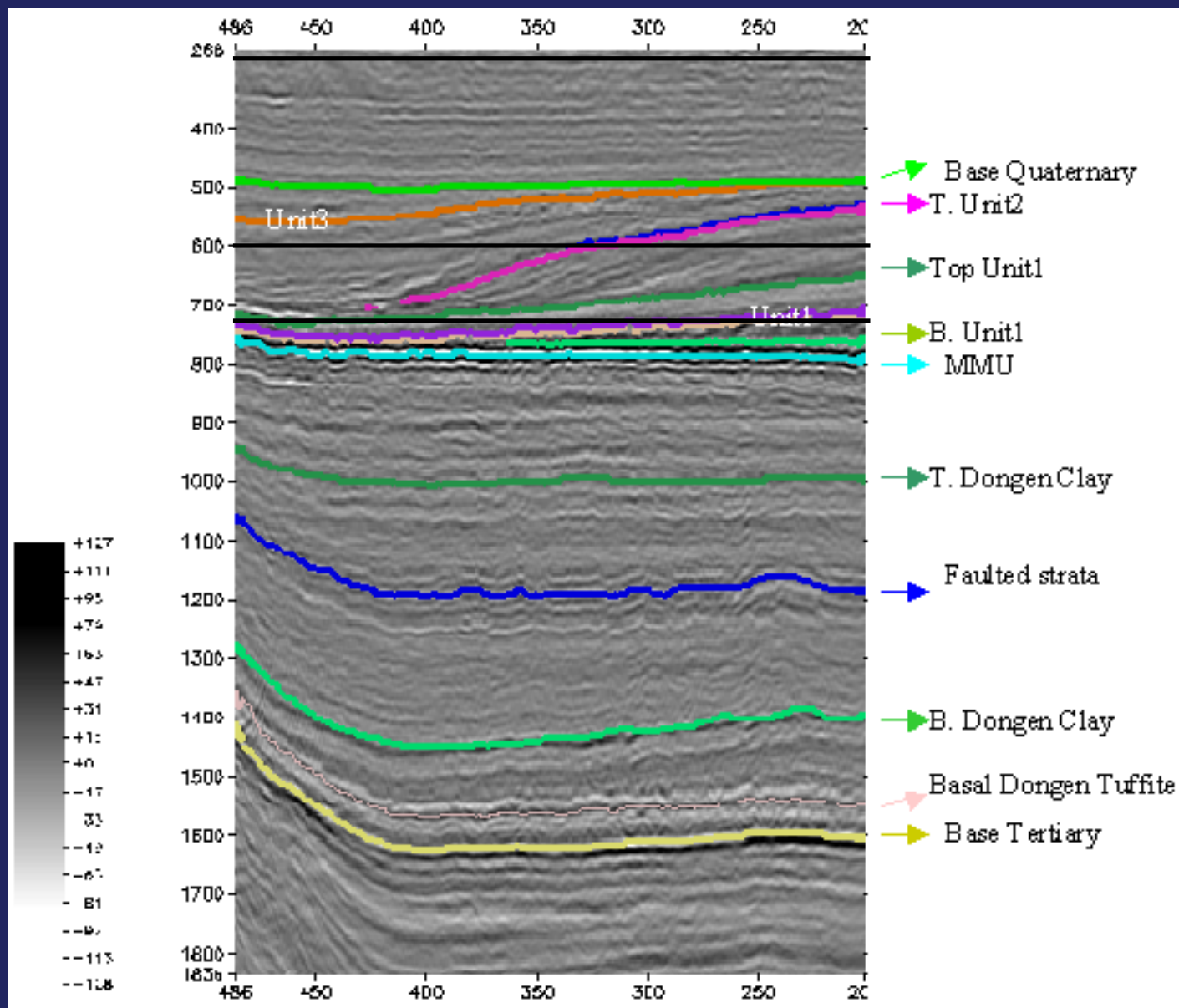
Cross-line through 3D seismic amplitude data,
with horizon interpretations (Data courtesy Steeghs et al, 2000)

The numerous faults have been interpreted as synsedimentary deformation, resulting from the load of the overlying sediments. Pressure release contributed to fault initiation and subsequent fluid escape caused the polygonal fault pattern.
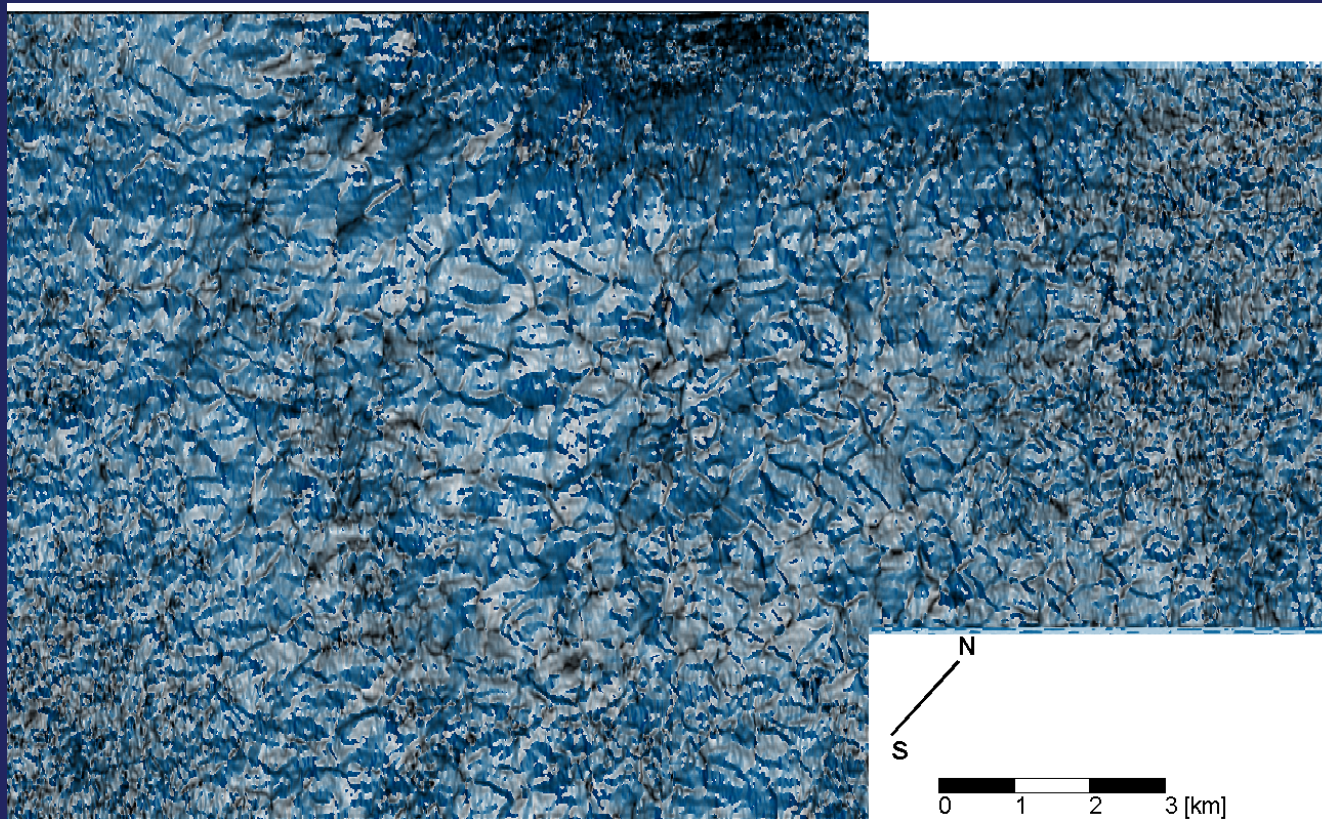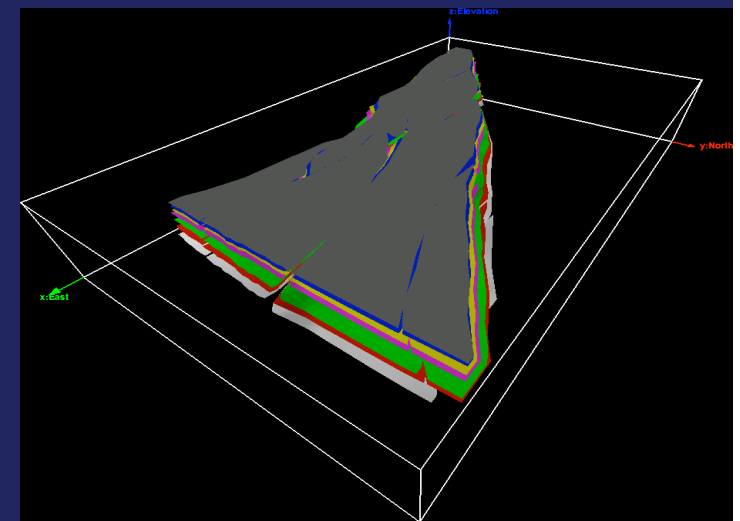

Combined volume dip/azimuth display at T = 1188 ms.
Volume dip is represented by shades of grey. Shades of blue indicate the azimuth (the direction of dip with respect to the cross-line direction).
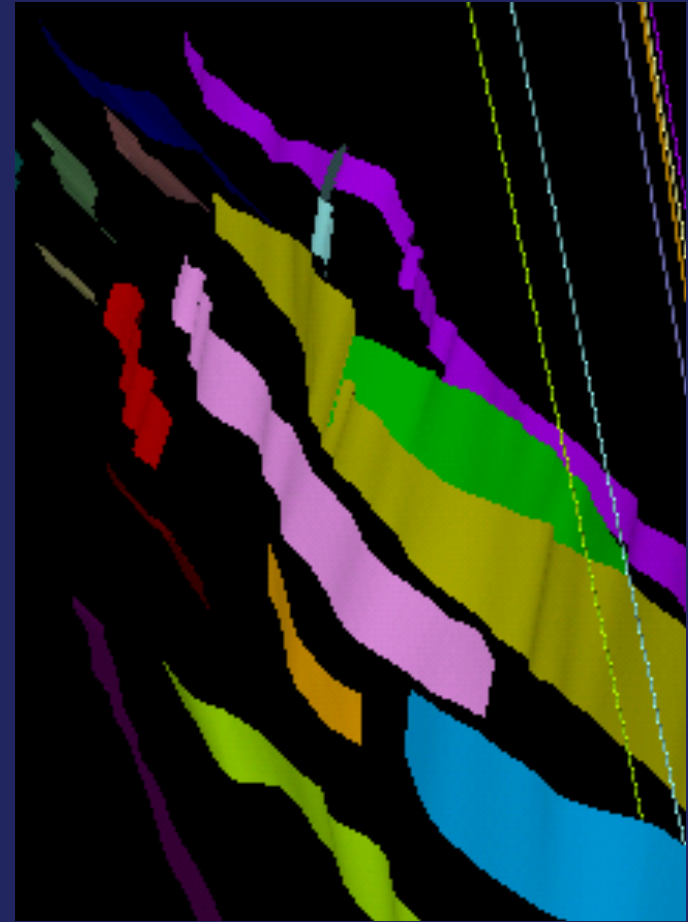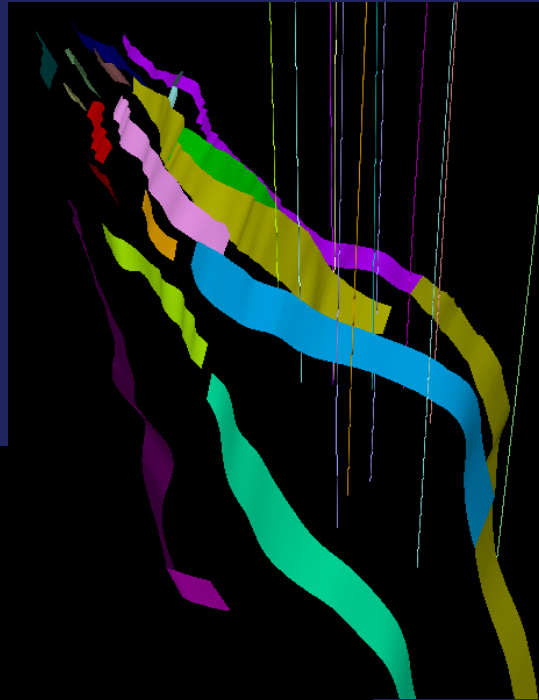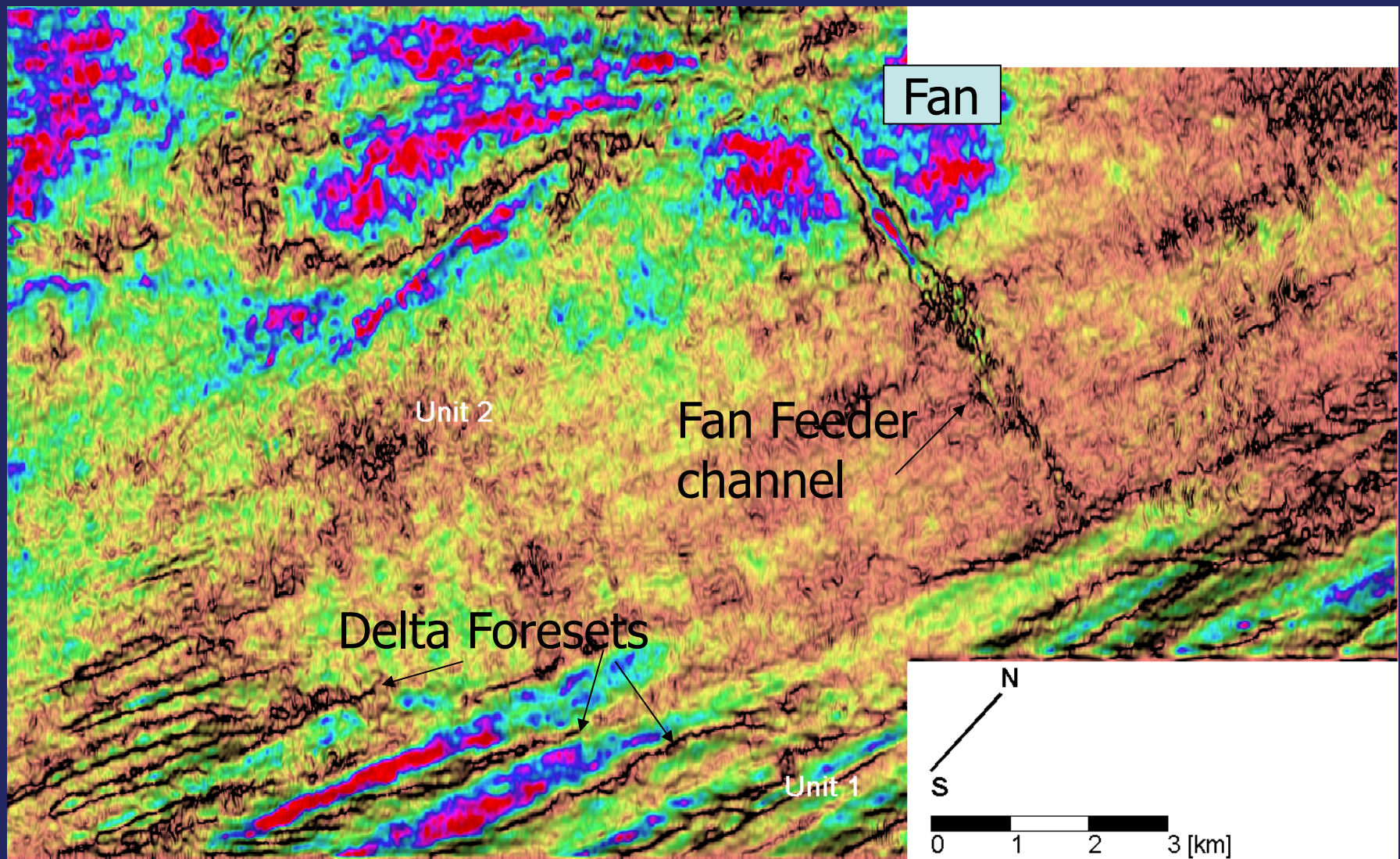
Fault modelling
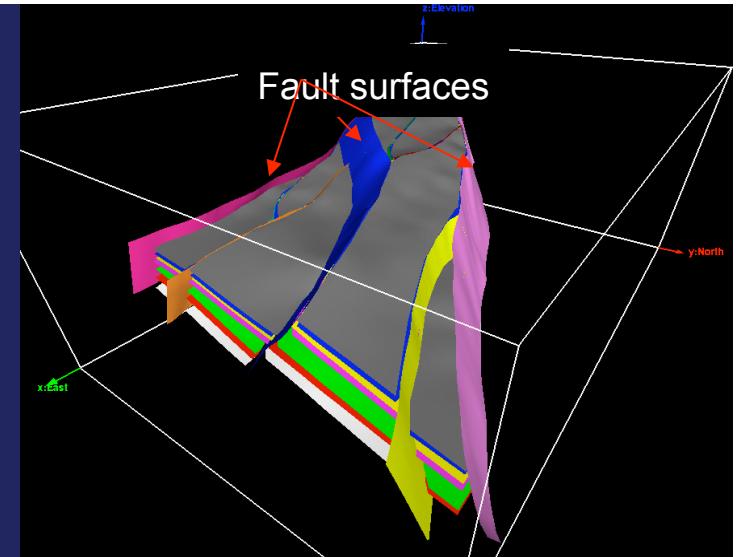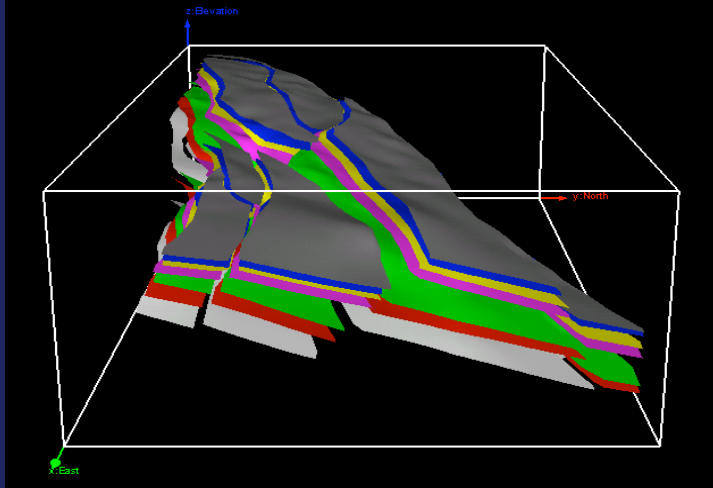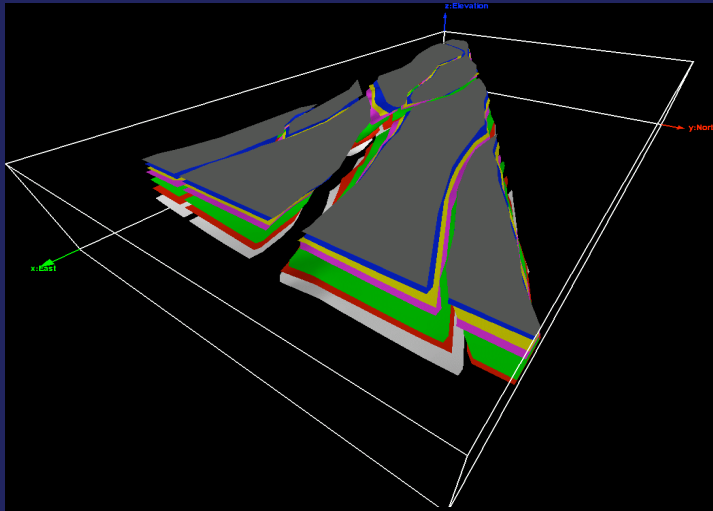
Fault surfaces

- from retrodeformation (geometries of restored depositional surfaces)

Example from PETREL COURSE NOTES

More fault modelling in Petrel

- Check plausibility of implied stress and strain fields
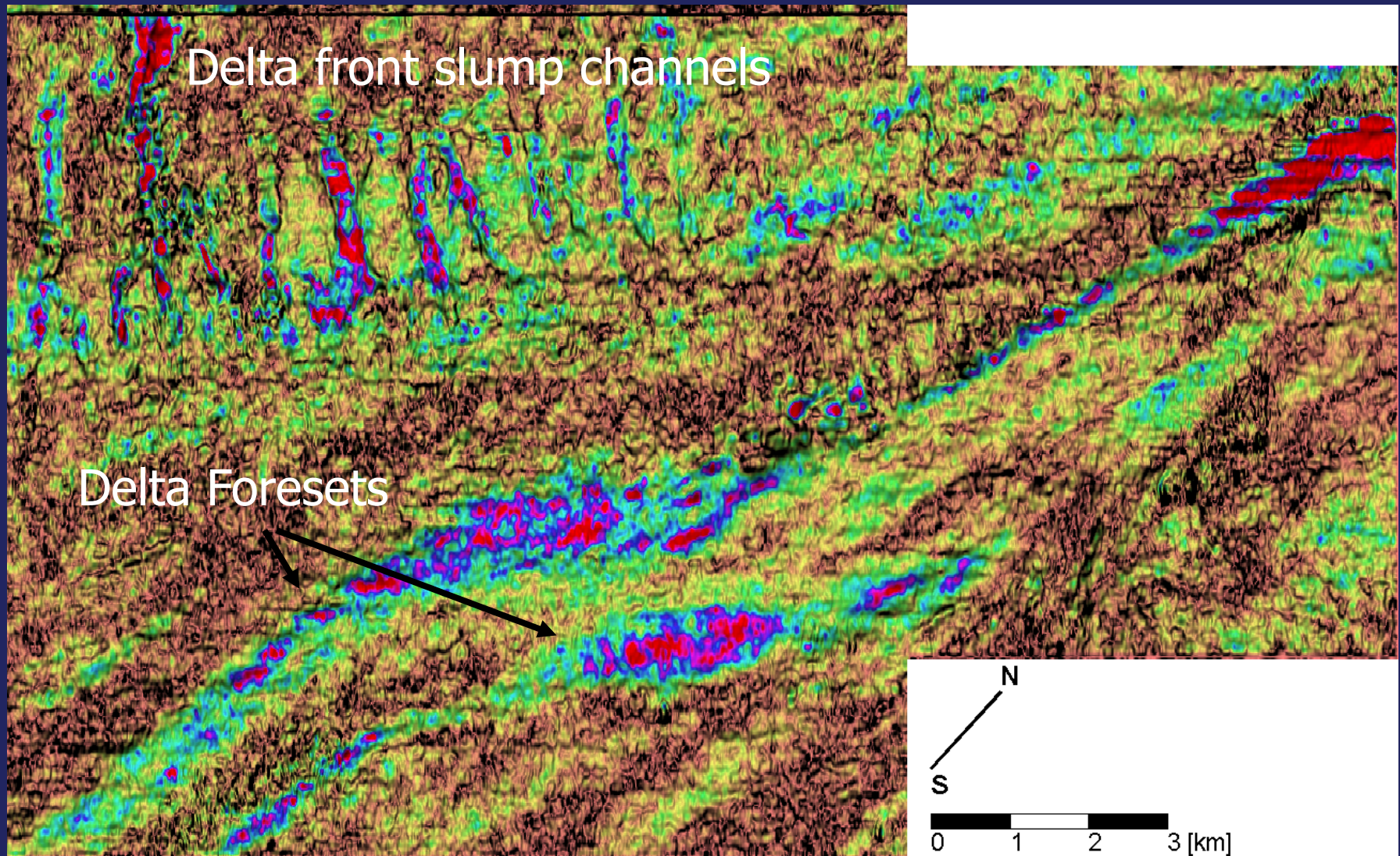
Example from PETREL COURSE NOTES

Fan

Unit 2

Fan Feeder
channel

Delta Foresets

Unit 1

N

S

0   1   2   3 [km]

Combined volume dip / reflection strength slice at T=724 ms

Delta front slump channels

Delta Foresets

N

S

0   1   2   3 [km]

Combined volume dip / reflection strength slice at T= 600 ms

Gas-filled meandering channel
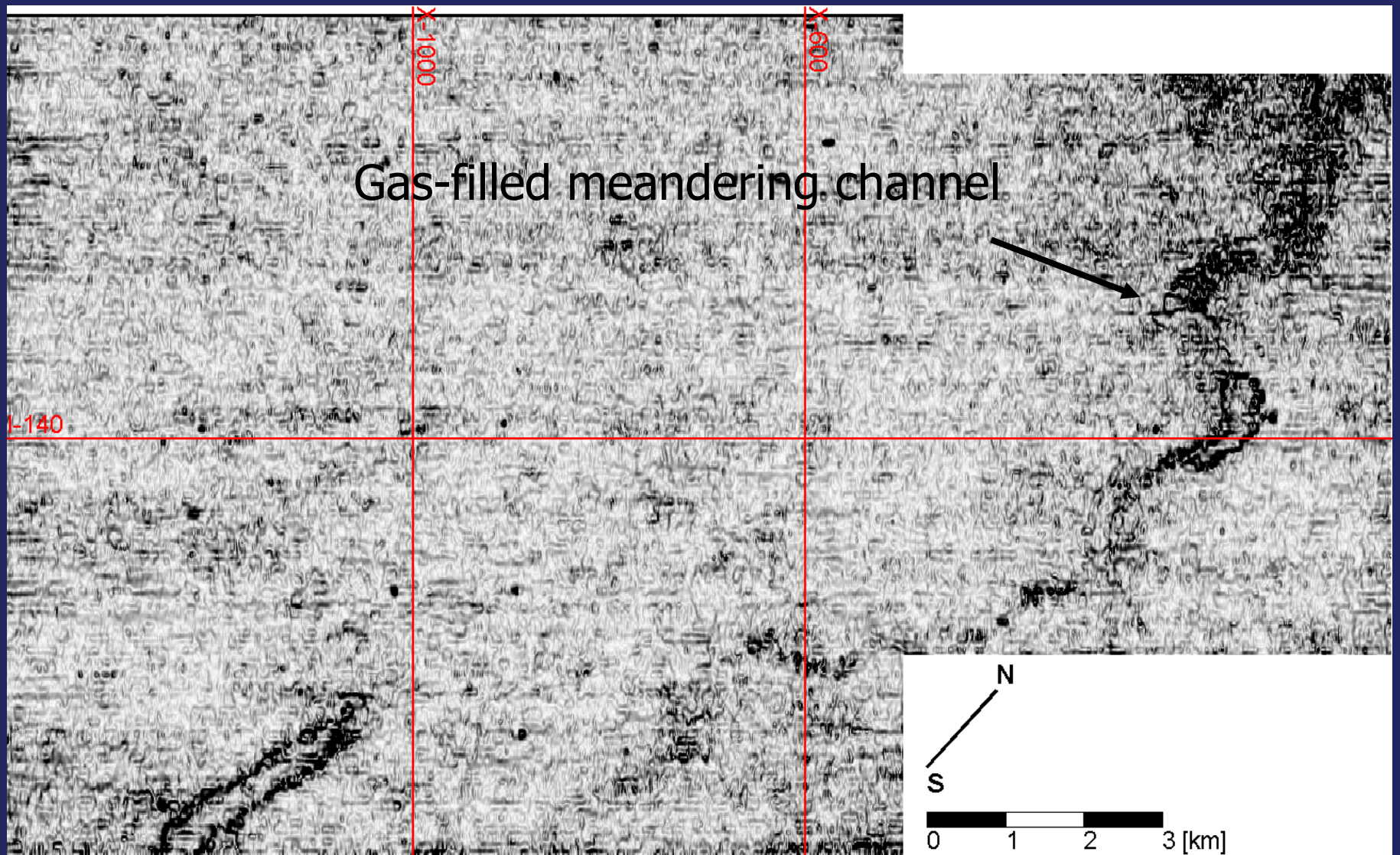
Combined volume dip / reflection strength slice at T= 92 ms

# Deterministic sedimentary model from seismic attributes
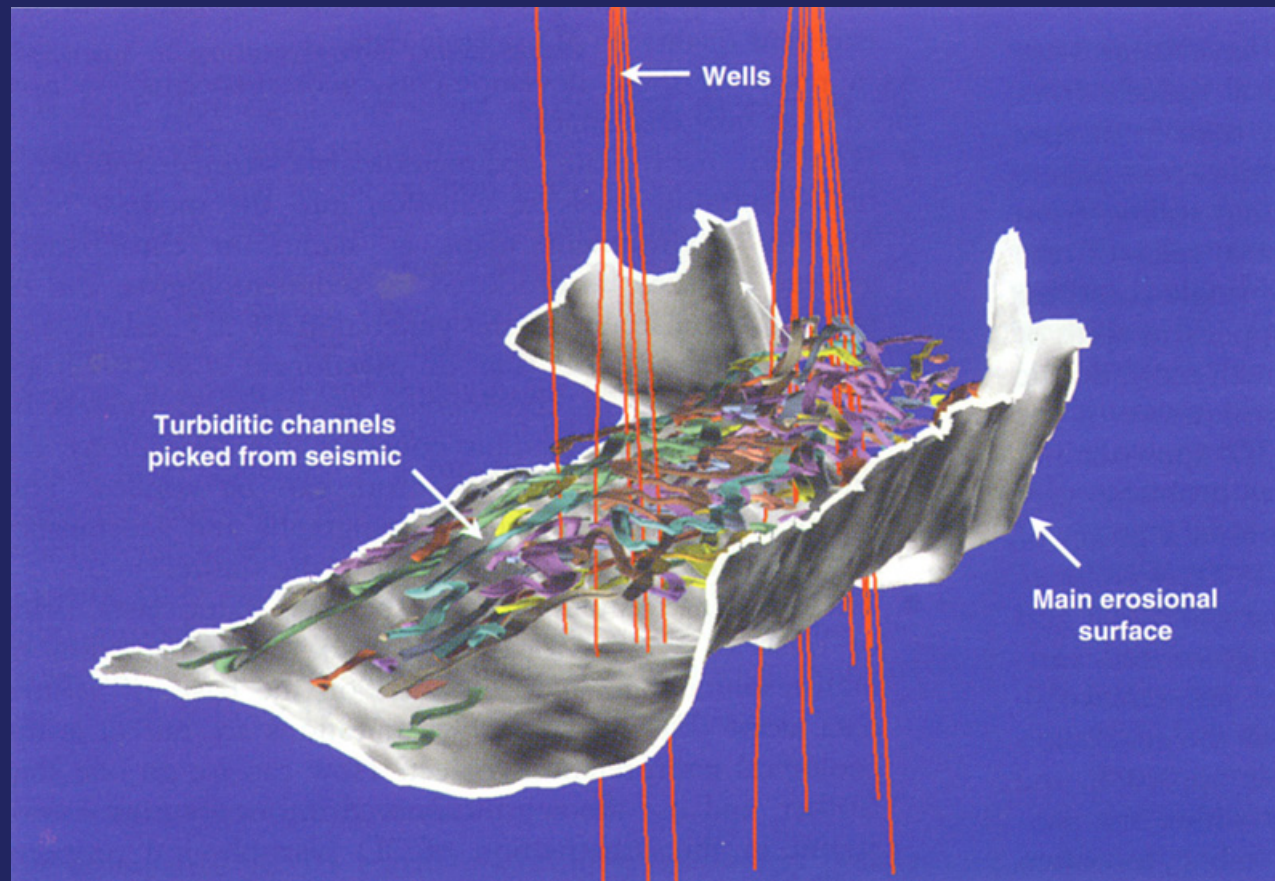
Object-based Stochastic Models

- Point process: spatial distribution of points (object centroids) in space according to some probability law

- Marked point process: a point process attached to (marked with) random processes defining type, shape, and size of objects

- Marked point processes are used to supply inter-well object distributions in sedimentary environments with clearly defined objects:
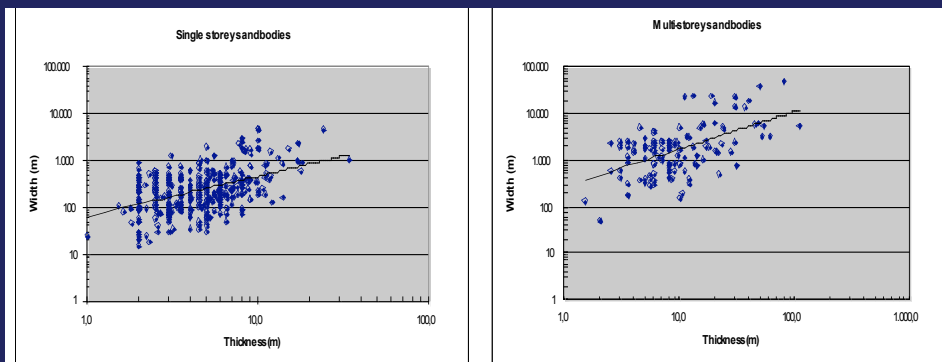 - sand bodies encased in mud
  - shales encased in sand

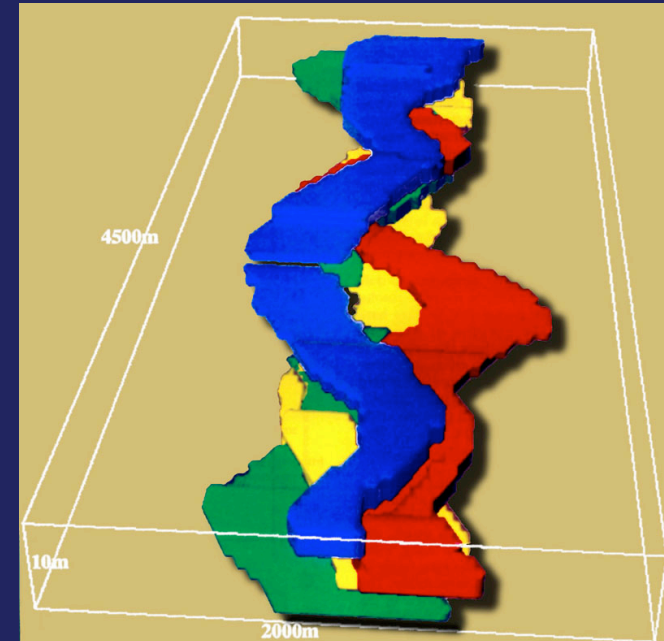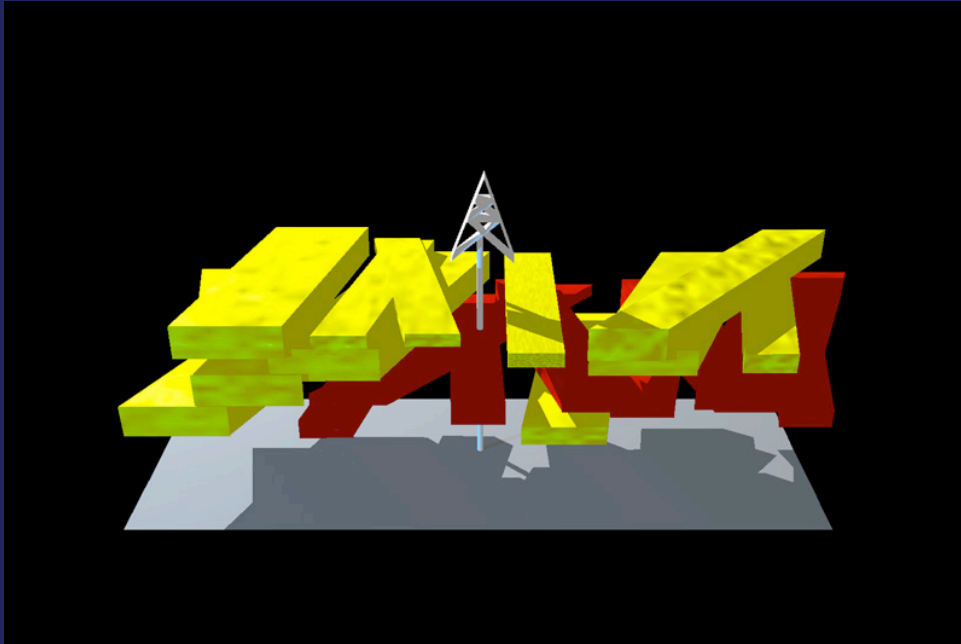# Ingredients of marked point process
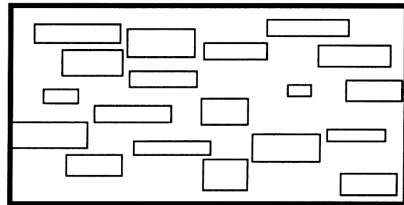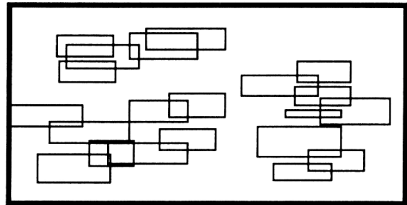
- Spatial distribution (degree of clustering, trends)
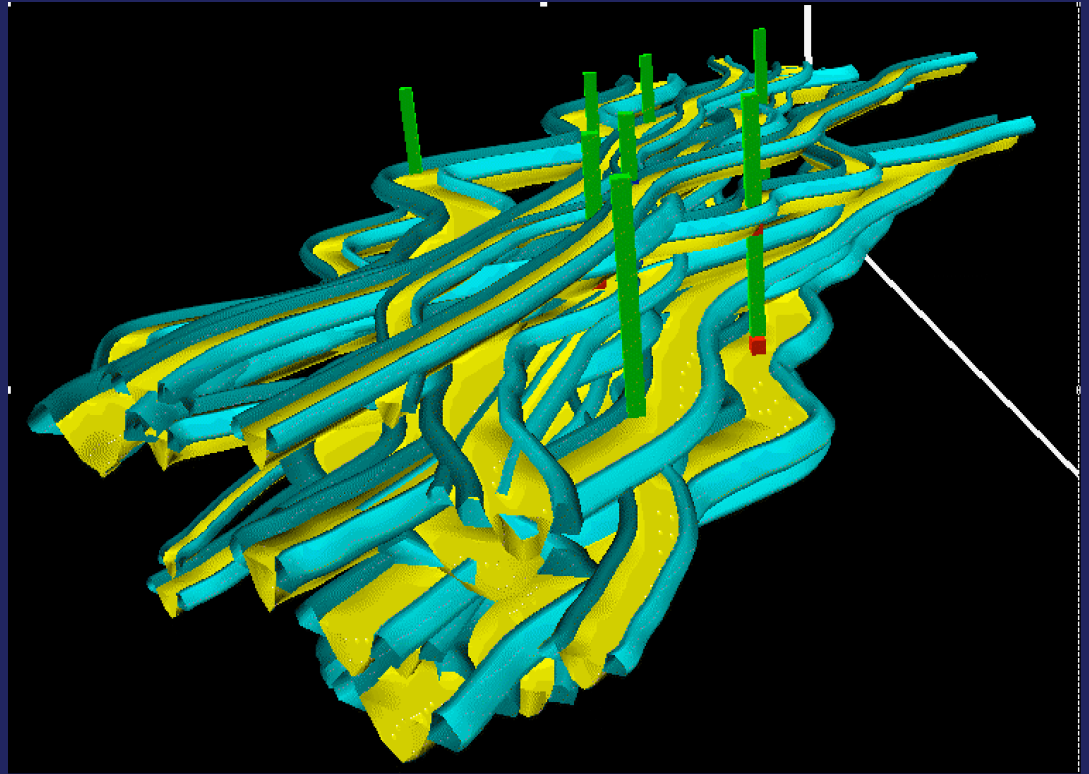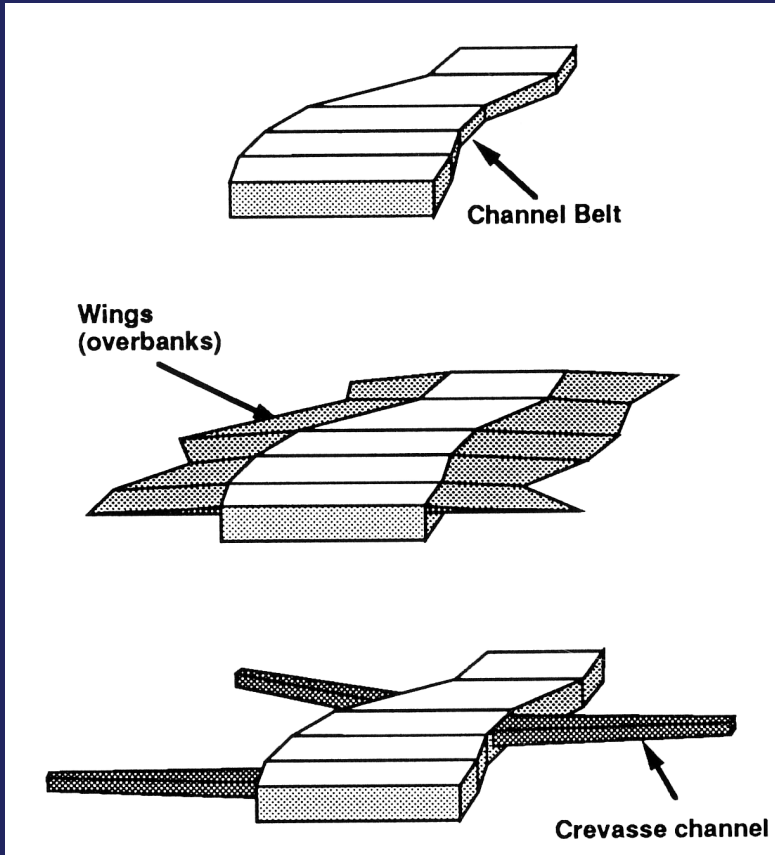- Object properties (size, shape, orientation)
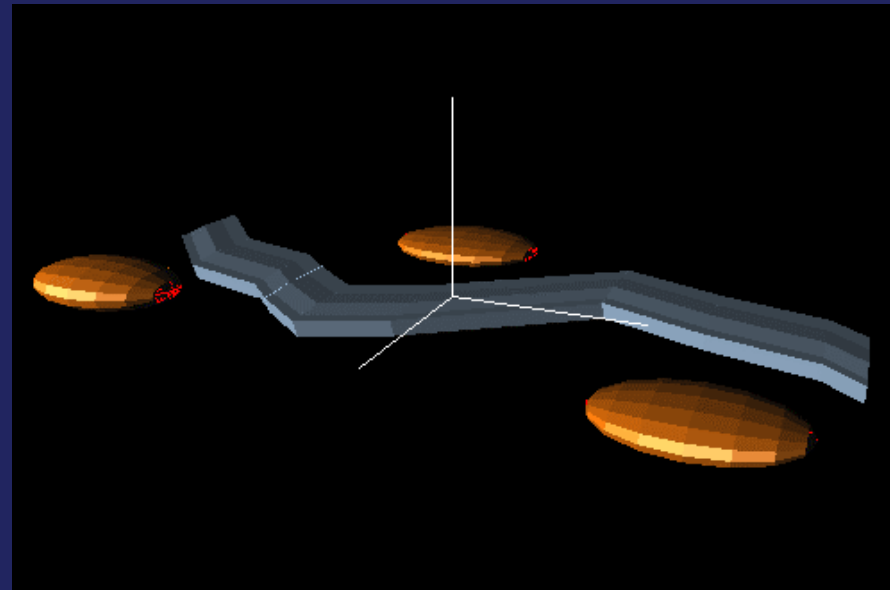
- Object-based stochastic geological model conditioned to wells, based on outcrop analogues

An example: fluvial channel-fill sands

- Geometries have become more sophisticated, but conceptual basis has not changed: attempt to capture geological knowledge of spatial lithology distribution by probability laws
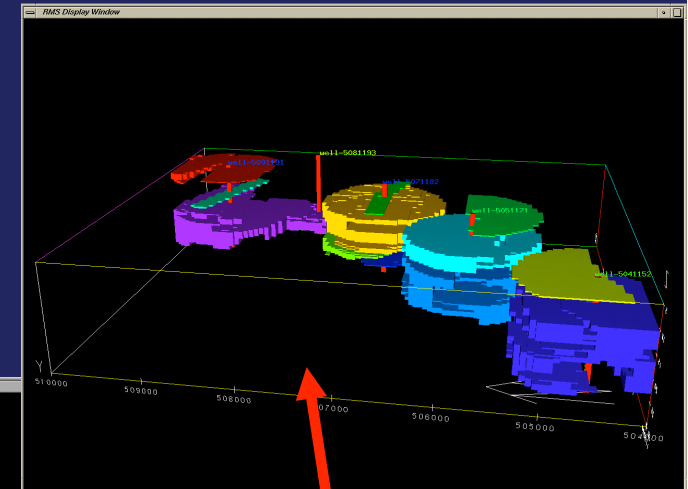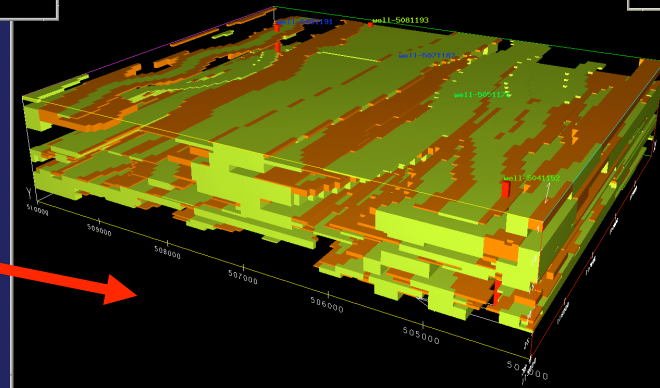
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Channel Belt

Wings (overbanks)

Crevasse channel

- Examples of shape characterisation:
  - Channel dimensions (L, W) and orientation
  - Overbank deposits
  - Crevasse channels
  - Levees

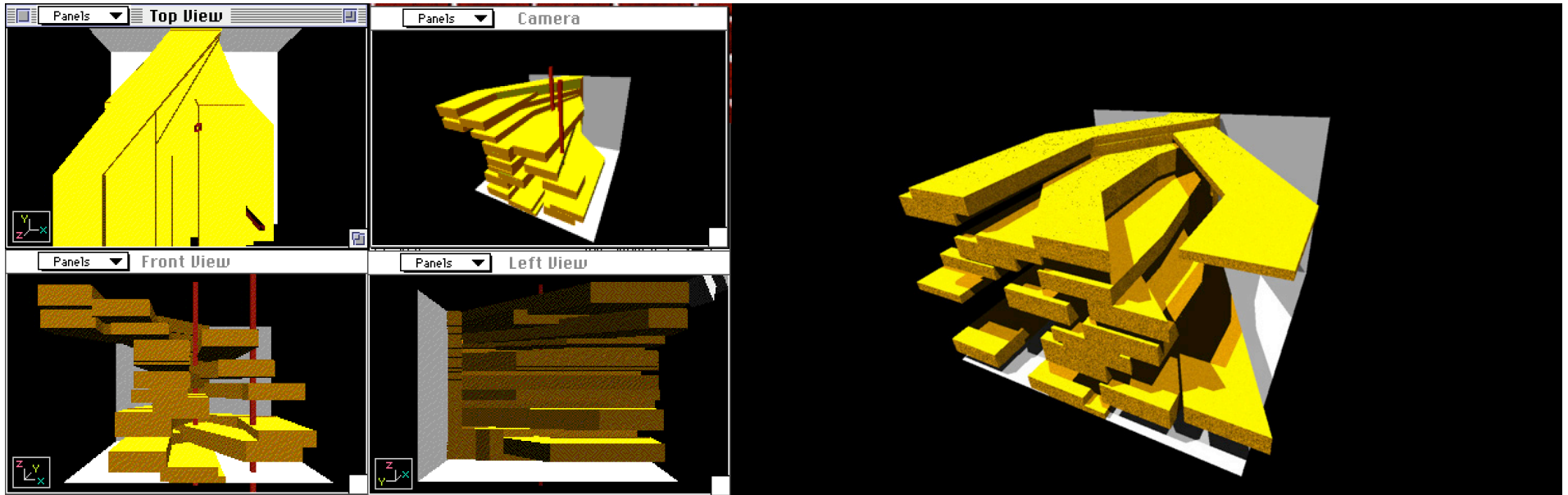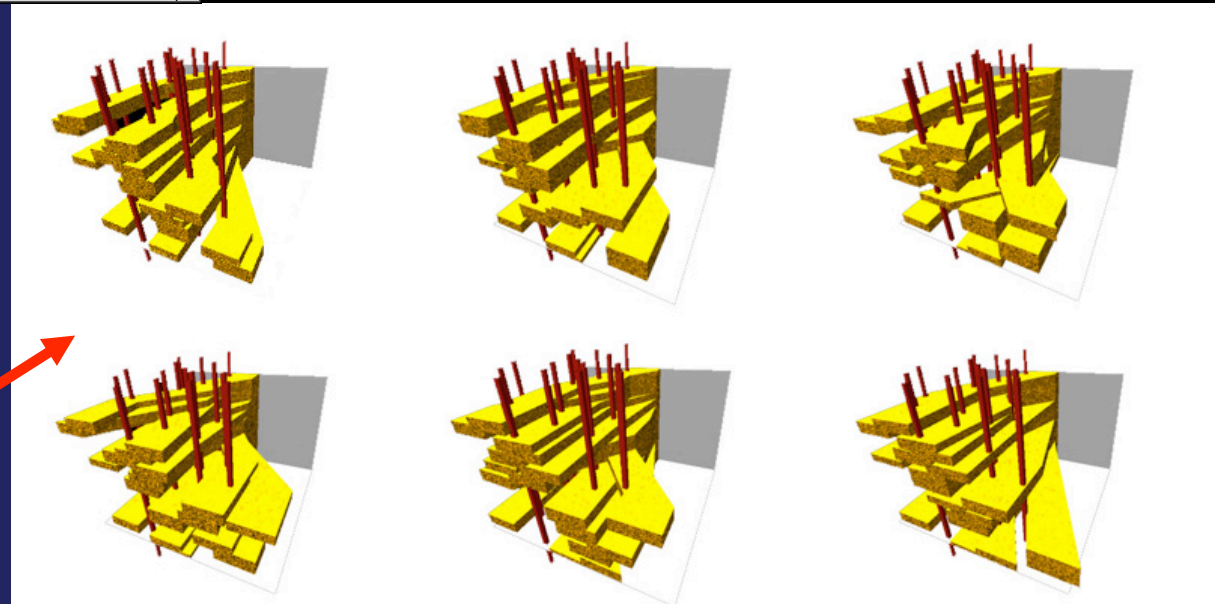# Exploring uncertainty of object properties (channel width)
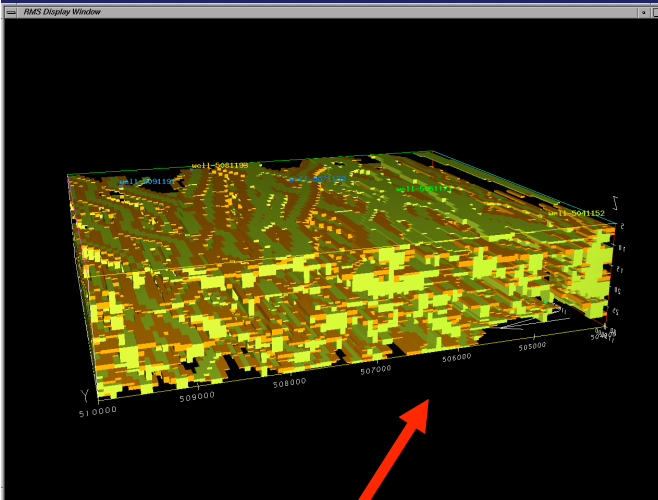
- W = 100 m
- W = 800 m

- W = 800 m
- R = 800 m

How can one quantify the differences between different realizations?

- Major step forward: object-based model of channel belt generated by random avulsion at fixed point

- Series of realisations conditioned to wells (equiprobable)

Stochastic Model constrained by multiple analogue data

- Extract as much information as possible from logs and cores (Tilje Fm. Haltenbanken area, offshore Norway).

- Use outcrop or modern analogue data sets for facies comparison and definition of geometries

- Only then 'Stochastic modeling' will begin

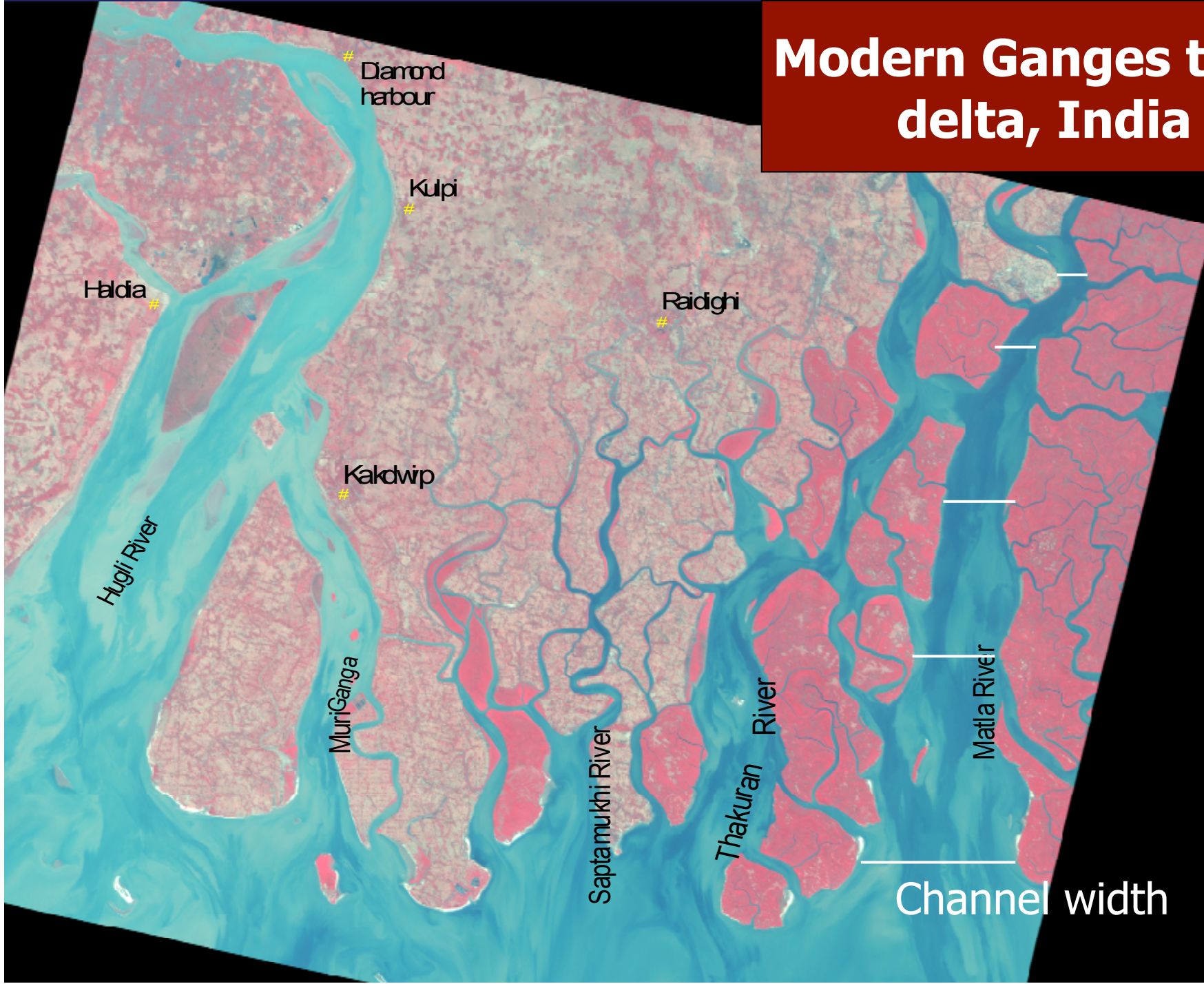**Lithofacies types from core**
Example: Holocene Holland Tidal Basin
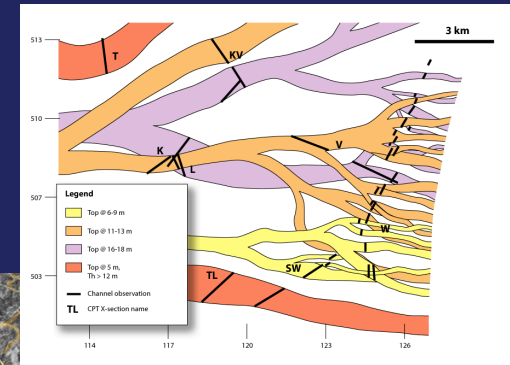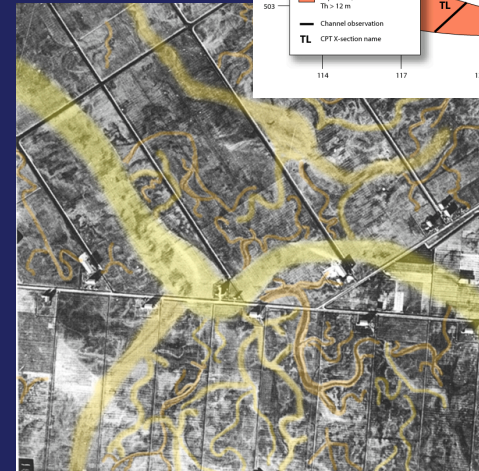
Tidal Channel   **Tidal Flat**   **Interchannel**

Modern Ganges tidal delta, India

distance 50 km

Diamond harbour

Kulpi

Haldia

Raidighi

Kakdwip

Hugli River

MuriGanga

Saptamukhi River

Thakuran River

Matla River

Channel width

Tidal channels

Interchannel heterolithics

Branching main tidal channels

Tidal flats
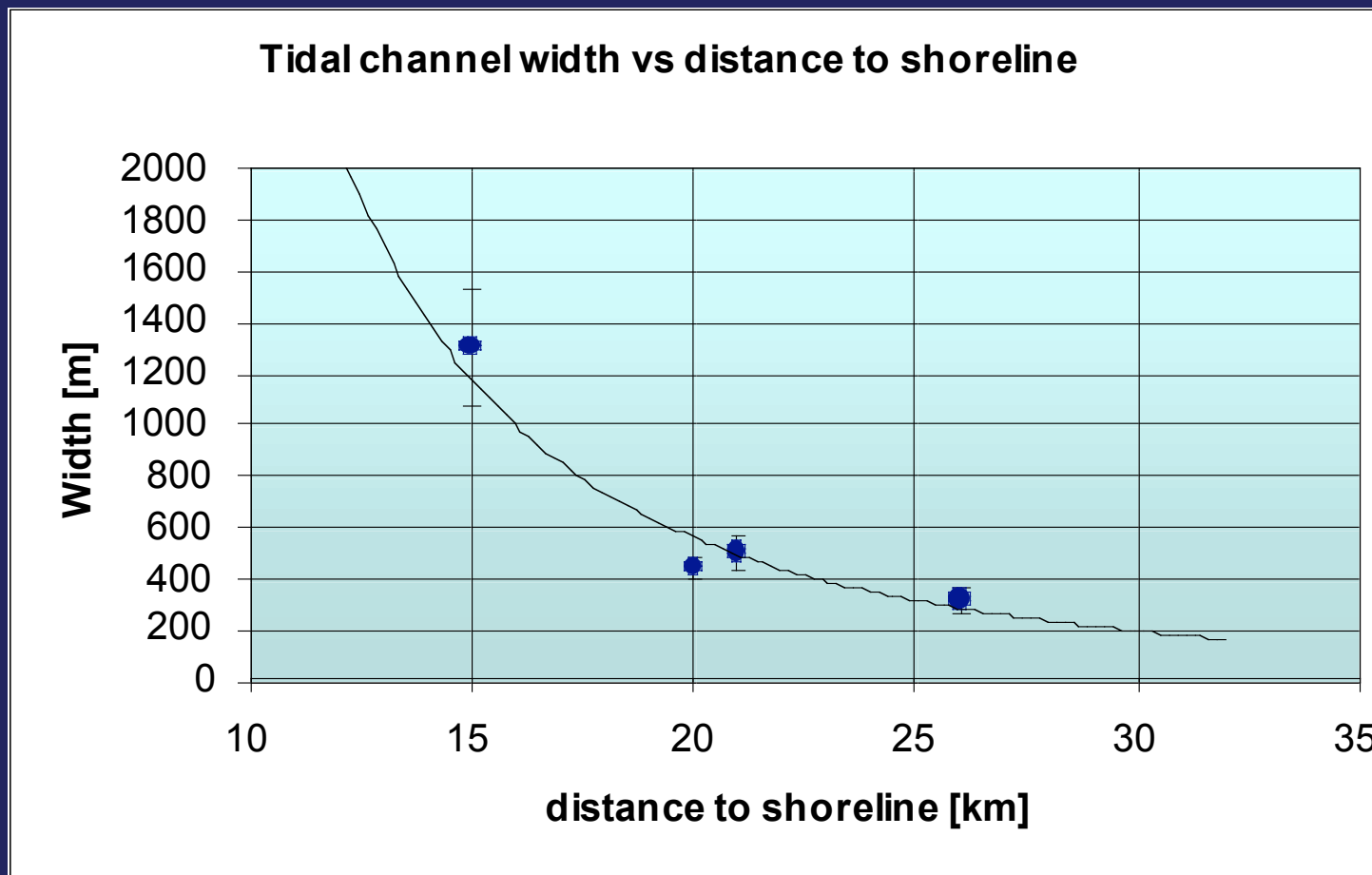
Fractal pattern of tidal creeks
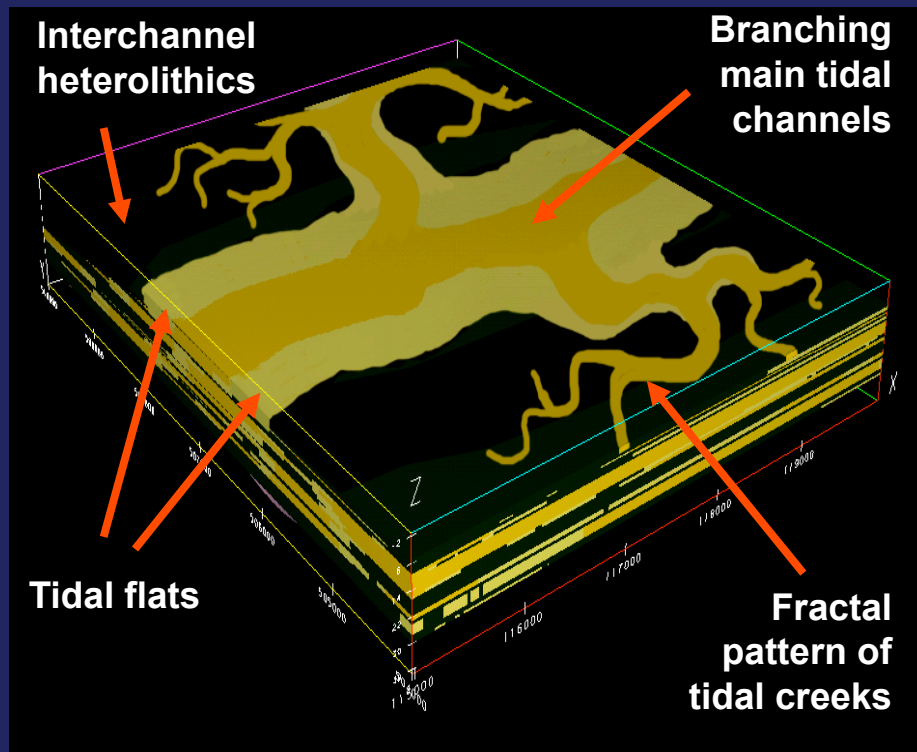
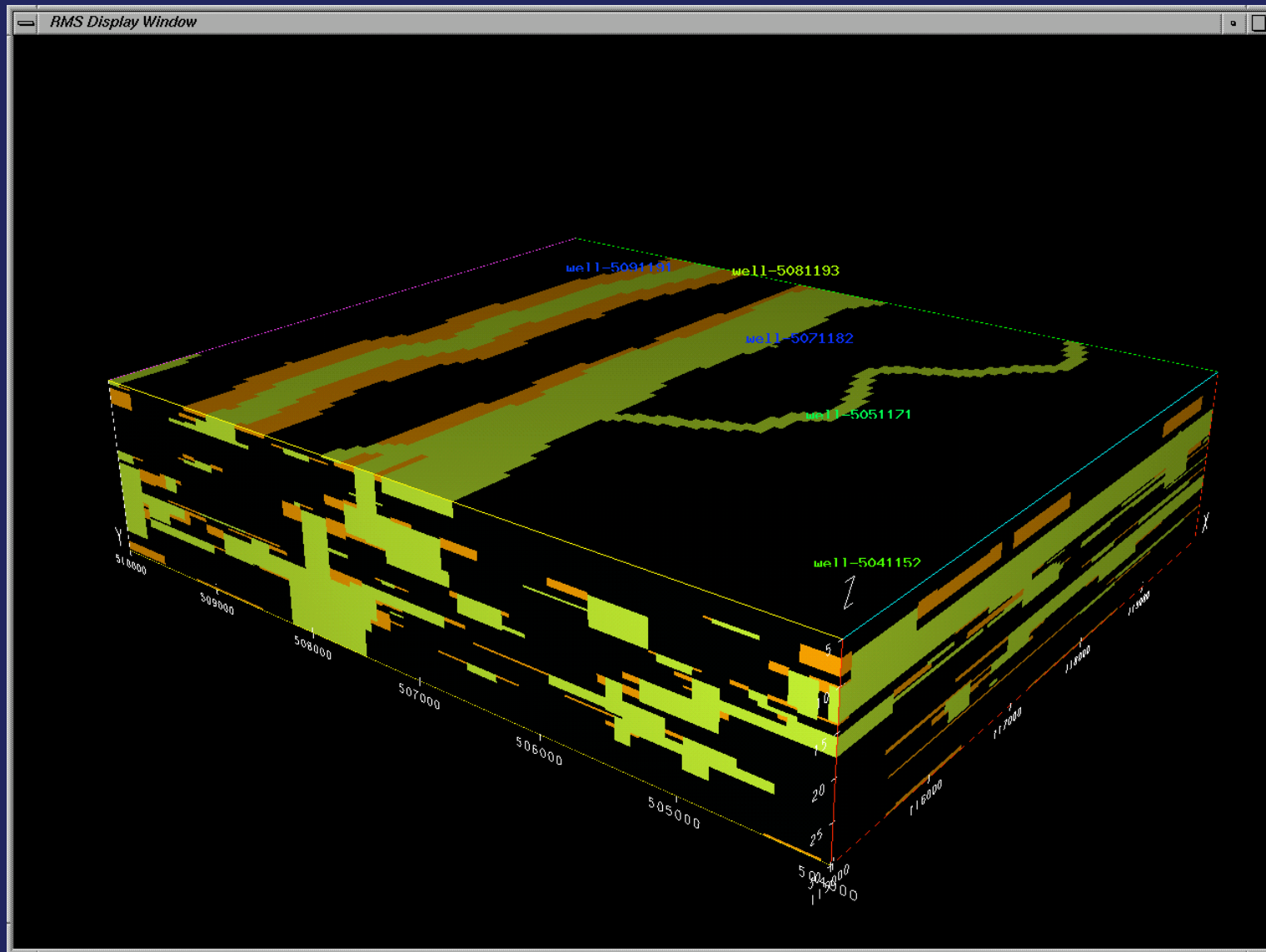Conceptual model of tidal basin (aerial photos, detailed maps)

Growth of fractal channels is governed by a branching rule

Quantify the analogue data into relevant properties for reservoir model

- Channel width vs distance to shoreline

Tidal channel width vs distance to shoreline

The resulting stochastical model......

Some final remarks on stochastic/ deterministic models

- Stochastic Modeling should be data-driven modeling
- Both outcrop and modern systems play an important role in aiding this kind of modeling.

- Deterministic models are driven by seismic data.
- The better the seismic data acquisition techniques become, the more accurate the resulting model.

References

- Steeghs, P., Overeem, I., Tigrek, S., 2000. Seismic Volume Attribute Analysis of the Cenozoic Succession in the L08 Block (Southern North Sea). Global and Planetary Change 27, 245-262.

- C.R. Geel, M.E. Donselaar. 2007. Reservoir modelling of heterolithic tidal deposits: sensitivity analysis of an object-based stochastic model, Netherlands Journal of Geosciences, 86,4.