Modeling of Intra-Channel Belt Depositional Architecture in Fluvial Reservoir Analogs from the Lourinha Formation, Portugal*

Anneli Ekeland[1], Nina Pedersen[1], John Howell[1], Wojtek Nemec[2], Kevin Keogh[3] and Ingunn Viste[1]

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Abstract

Fluvial channel and channel belt deposits are commonly represented in subsurface reservoir models using an object-based approach that stochastically places a channel facies in a background of overbank deposits. The internal heterogeneity within the channel is usually represented by adding intra-body trends to the petrophysics. The aim of this study has been to study high-quality outcrop analogs, to collect data, and to build small-scale, geocellular models that capture the macro-form scale detail of the intra-channel architecture.

The Jurassic Lourinha Formation crops out in high-quality coastal outcrops in the Lusitanian Basin of Portugal. The studied interval is a mixed net:gross fluvial succession that is considered to be an analog for the Triassic and Lower Jurassic, Statfjord and Lunde reservoirs of the North Sea. Five separate, well exposed channel bodies were selected for study covering a range of stratigraphic settings and fluvial styles. Detailed, logging, photomontaging and bedform architecture studies were supplemented by laser scanning and the building of virtual outcrops. Bar and macro-form bounding surfaces were recorded and reconstructed using the outcrop data and a conceptual understanding of bedform architecture.

The reconstructed bedform bounding surfaces and logs were imported into a geocellular modeling package and models capturing the geometry of the surfaces and the detail of the facies between them were built. Each model is at a comparable scale to a single grid cell in a typical simulation model (c.100 x 100 x 5 m) and can be used to investigate the dynamic influence of the main intra-body heterogeneities through upscaling and reservoir flow-simulation studies. Models have also been built using a process-oriented stratigraphic modeling tool to compare and contrast results.

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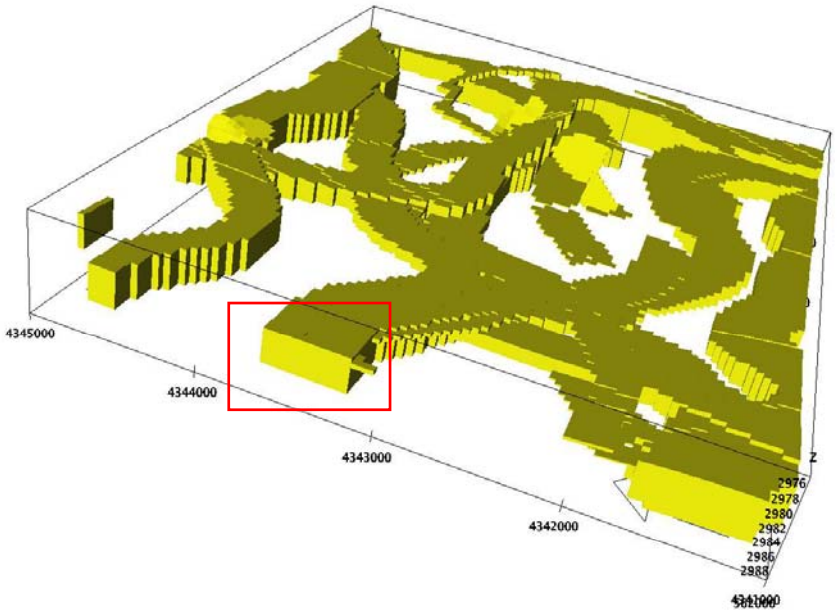
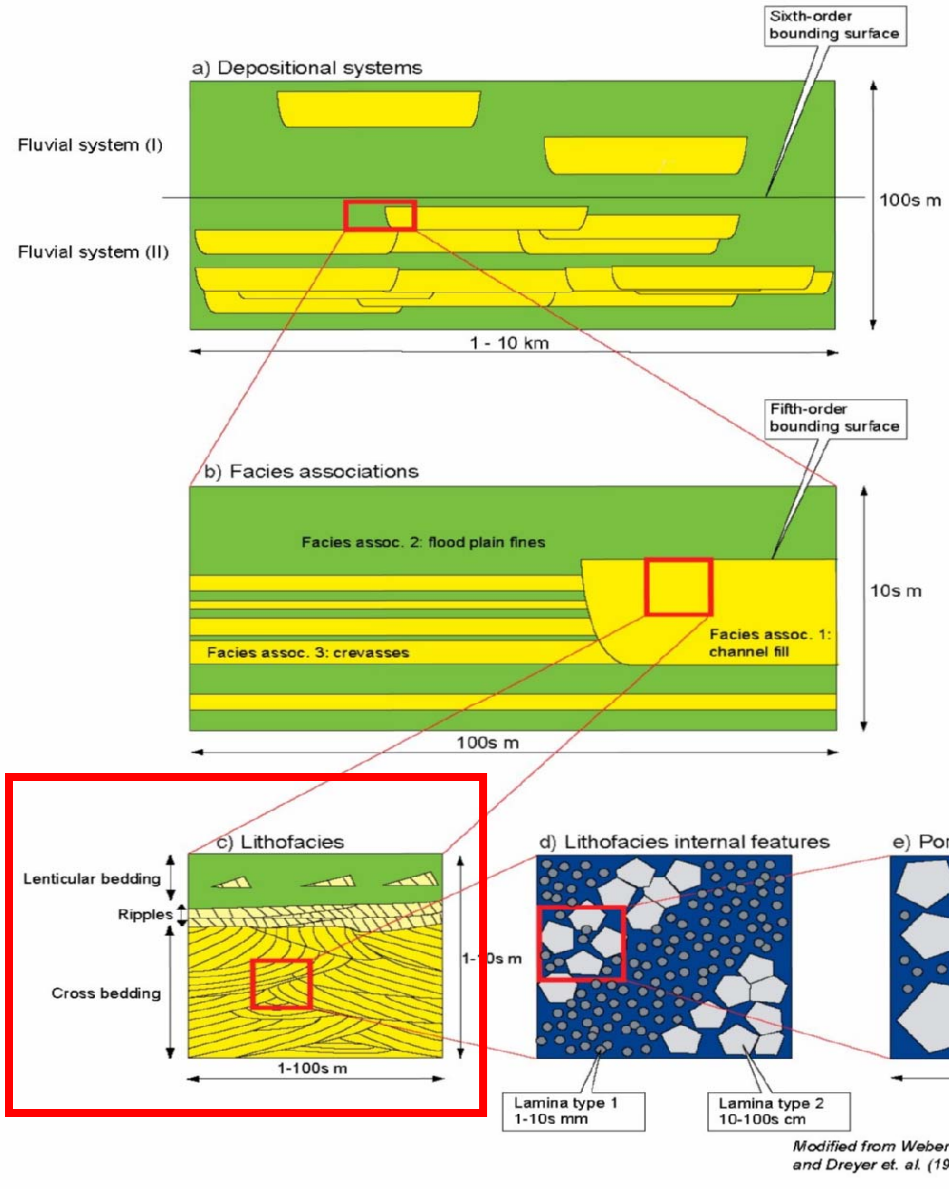
Reservoir modeling of channels



• Fluvial channel belts are typically represented as objects in reservoir models

• However they may contain significant heterogeneity that is not captured

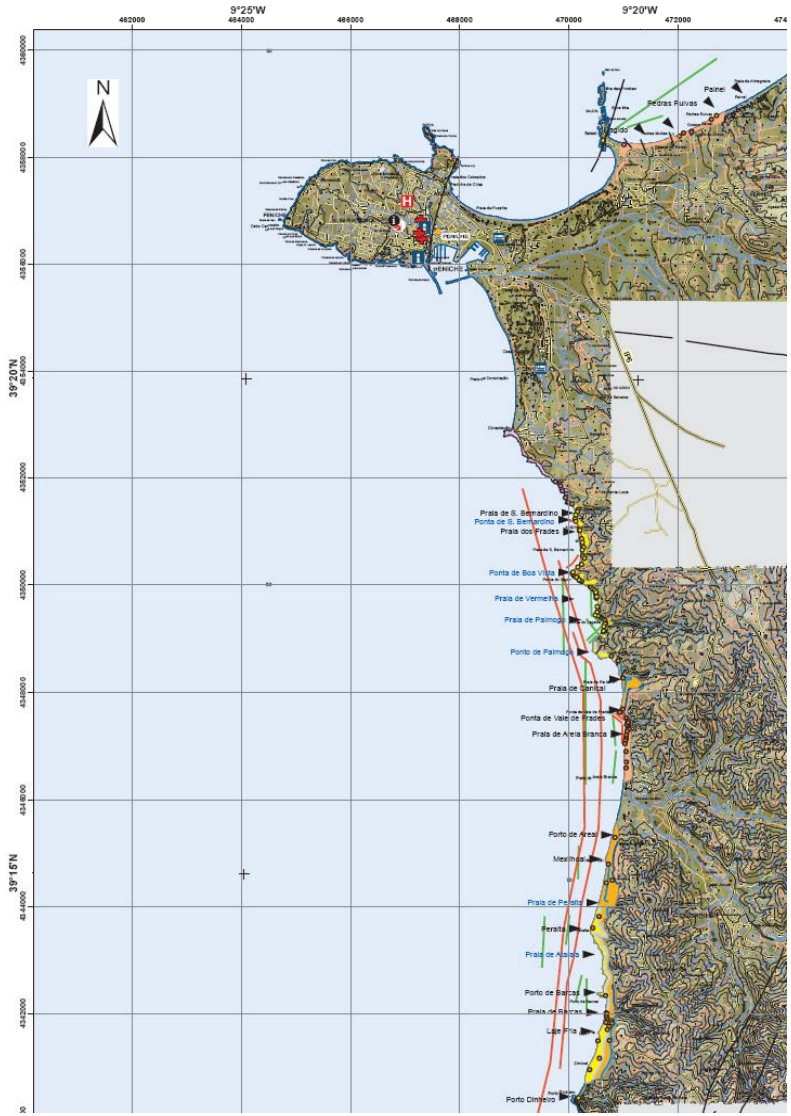


Heterogeneity exists at a range of different scale

This study concentrates on the facies association and facies scale

(Modified from Keogh *et. al,* 2007)

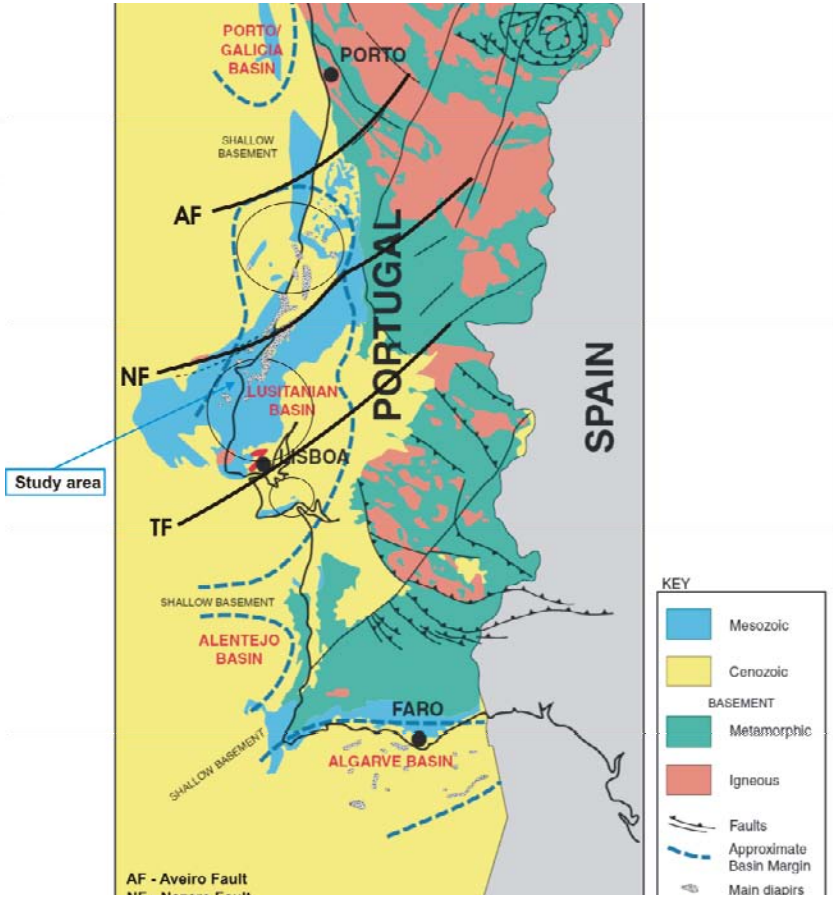
Study area



- West coast of Portugal
- 20+ km of high quality coastal exposure
- Exposure is largely 2D, but a series of bays and headlands gives an excellent 3D component, especially at the smaller scale

Study area

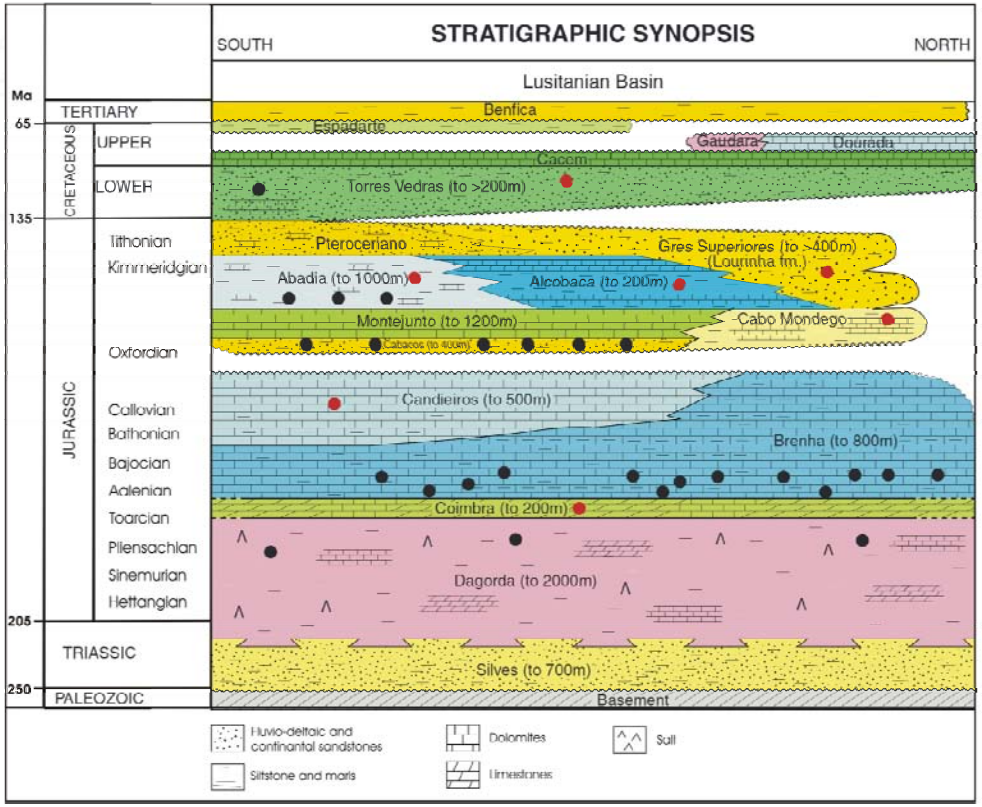
Geological setting

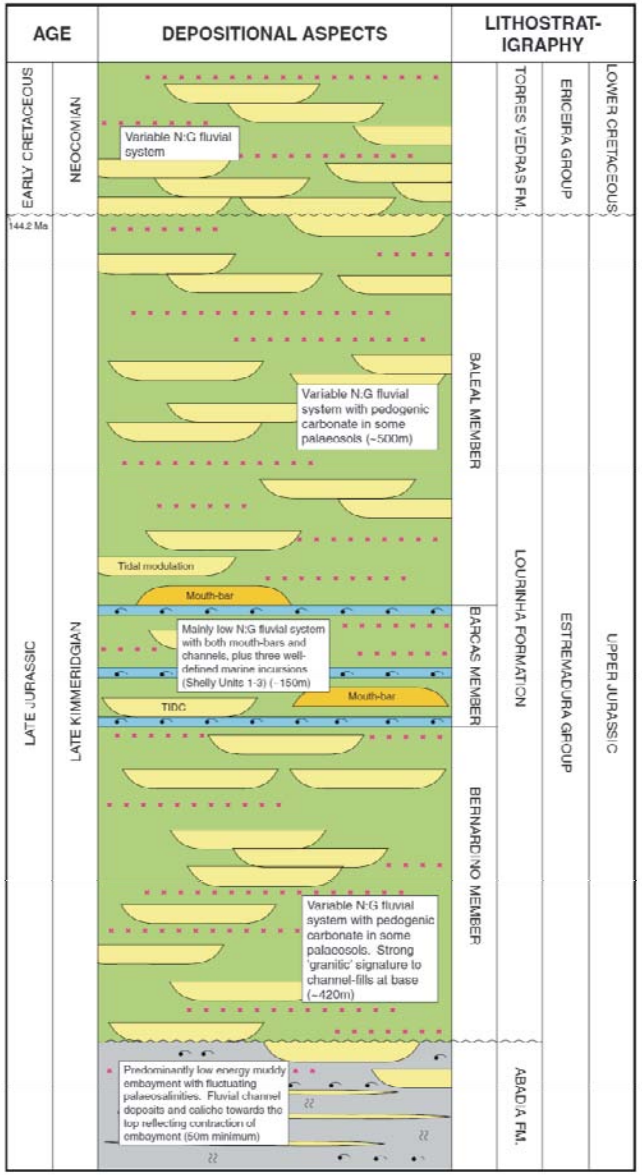


(Courtesy of Ichron)

- Central Lusitanian Basin
- Tectonically active rift basin
- Opening of North Atlantic Ocean
- Faults and halokinesis
- Sub-basins
- Consolaçao Sub-Basin
- Graben structure, elongated N-S
- Drainage towards SW

Geological setting

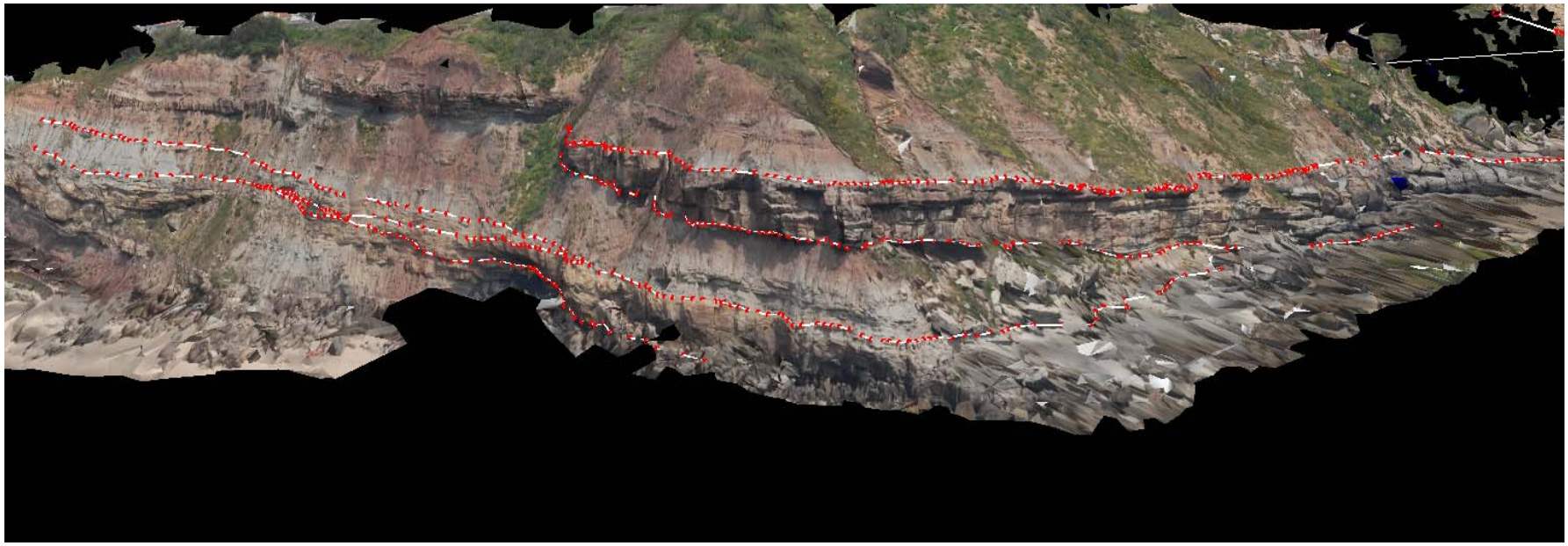




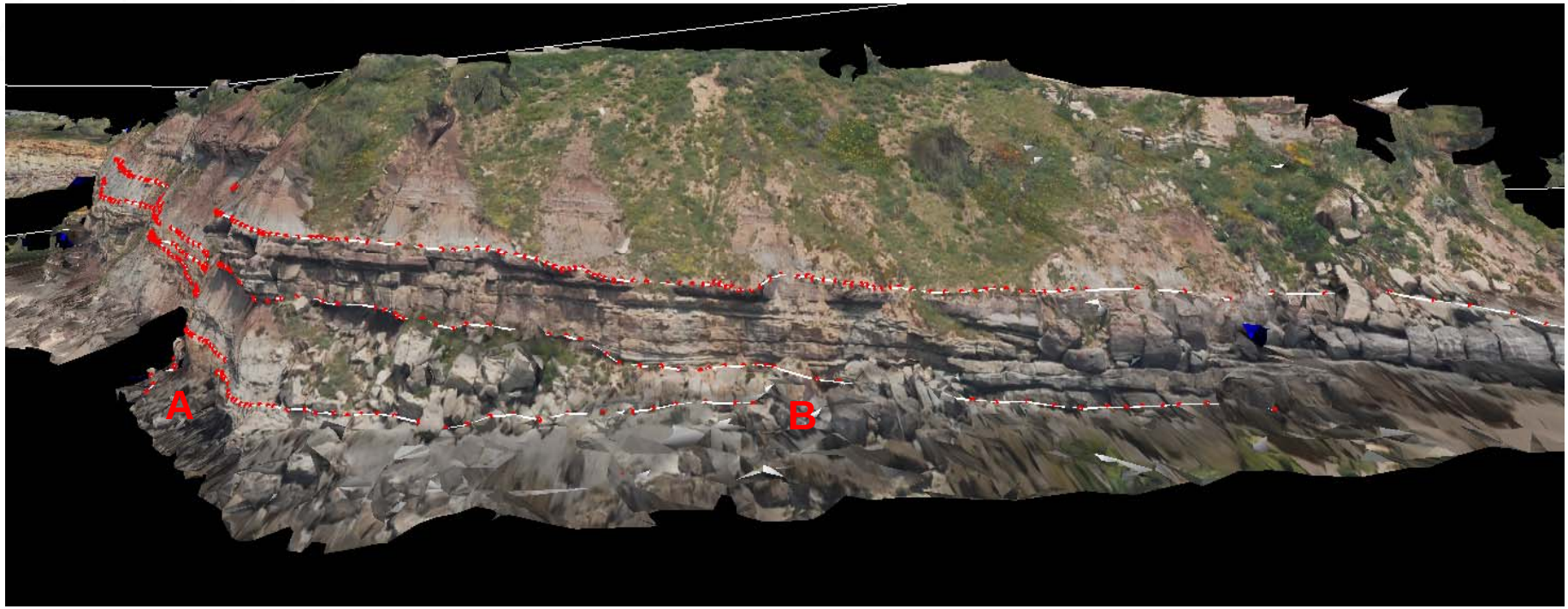
Stratigraphic framework from extensive ongoing study by StatoilHydro and Ichron

Data Collection

Data were collected over 5 field seasons
Data collection included the recording of closely spaced (5 -10 m), detailed sedimentary logs
Paleocurrent and structural measurements
Photo montaging and architectural element analysis
Lidar scanning and the generation of Virtual Outcrops



Towards northeast

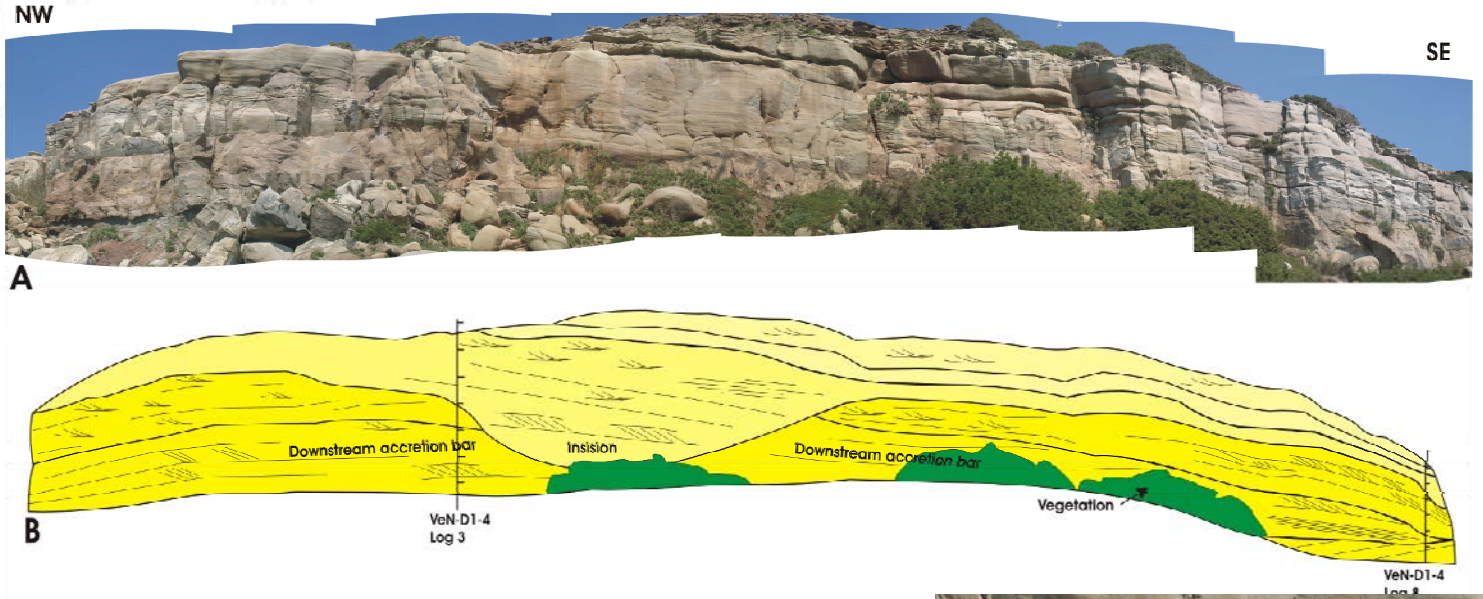


Facies and Facies associations

Sedimentary facies			Structures	Interpretation
F1	PS	Sand-dominated paleosol	May display faint ripples or other primary lamination. Commonly rooted.	Suspension deposits. Slowly moving or static flood waters. Calcified roots developed by replacement of organic material, due to precipitation in ground water.
	PM	Silt-dominated paleosol	May display faint ripples or other primary lamination. Commonly rooted	
	PC	Clay-dominated paleosol	May display silt-stripes and/or other primary lamination. Commonly rooted.	
F2	X	Massive calcretes and silicified layers	Interbebbed with clay- and mudstone	Precipitation in ground water, due to fluctuations in base level.
F3	SGp	Granule-bearing or conglomeratic, poorly sorted sandstone	Unspecified parallel stratification	Bed-load deposits. Deposited during floods, when the river had high flow velocity and capacity.
	SGx	Granule-bearing or conglomeratic, poorly sorted sandstone	Cross bedding	
	SGm	Granule-bearing or conglomeratic, poorly sorted sandstone	Apparently massive	
F4	SCp	Coarse- to very coarse-grained, clean sandstone	Unspecified parallel stratification	Bed-load deposits. Upper and/or lower flow regime.
	SCx	Coarse- to very coarse-grained, clean sandstone	Cross bedding	
	SCm	Coarse- to very coarse-grained, clean sandstone	Appatently massive	
F5	SMdp	Dominantly medium-grained sandstone	Unspecified parallel stratification	Bed-load deposits. Upper and/or lower flow regime.
	SMdr	Dominantly medium-grained sandstone	Ripples	
	SMdx	Dominantly medium-grained sandstone	Cross bedding	
	SMdm	Dominantly medium-grained sandstone	Apparently massive	
F6	SFp	Dominantly fine- to very fine-grained sandstone	Unspecified parallel stratification	Bed-load and suspention deposits. Lower flow regime. Traction currents.
	SFr	Dominantly fine- to very fine-grained sandstone	Ripples	
	SFx	Dominantly fine- to very fine-grained sandstone	Cross bedding	
	SFm	Dominantly fine- to very fine-grained sandstone	Apparently massive	
F7	SM	Sand-dominated heterolith	Laminated and/or lenticular- to flacer bedded	Suspension deposits.
	MS	Mud-dominated heterolith	Laminated and/or lenticular- to flacer bedded	
	M m	Mudstone	Massive looking or very faintly silt/sand-striped, may be sandy in places	

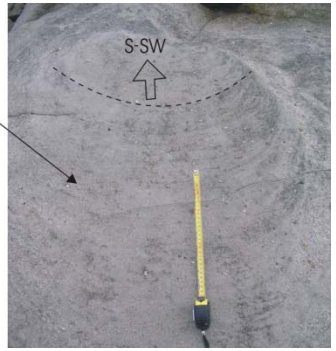
Facies associations		Sub-facies associations		Component facies
FA 1	Channel infill	FA1a	Downstream accretion bar	F3, F4, F5, F6, F7
		FA1b	Point bar	F3, F4, F5, F6, F7
		FA1c	Chute channel	F5, F6, F7
FA 2	Channel Abandonment			F2, F4, F6, F7
FA 3	Floodplain			F2, F3, F4, F6, F7
FA 4	Paleosol			F1

FA1 – Channel fill

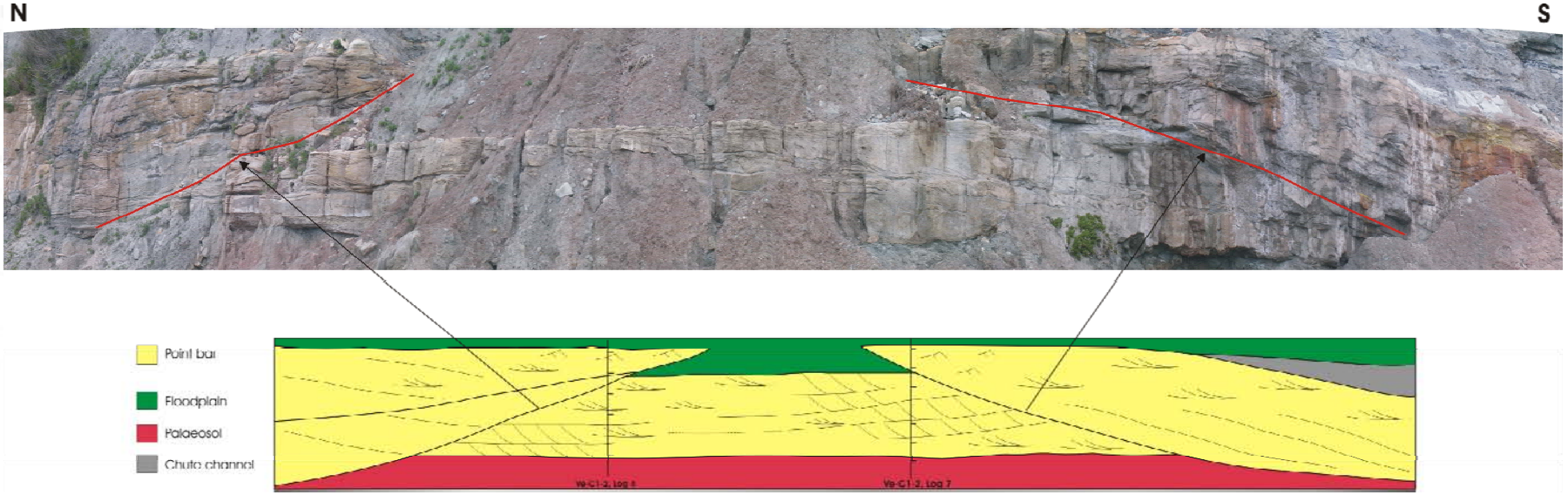


FA1a - Downstream accretion bar

- Extensive
- Convex upward shape
- Erosive base
- Poorly sorted, granule rich, coarse to very coarse grained sandstones
- Trough- and planar cross-stratification
- Main transport direction towards S-SE

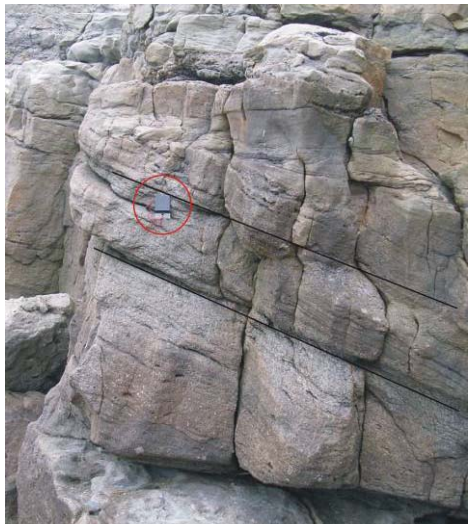


FA1 – Channel fill

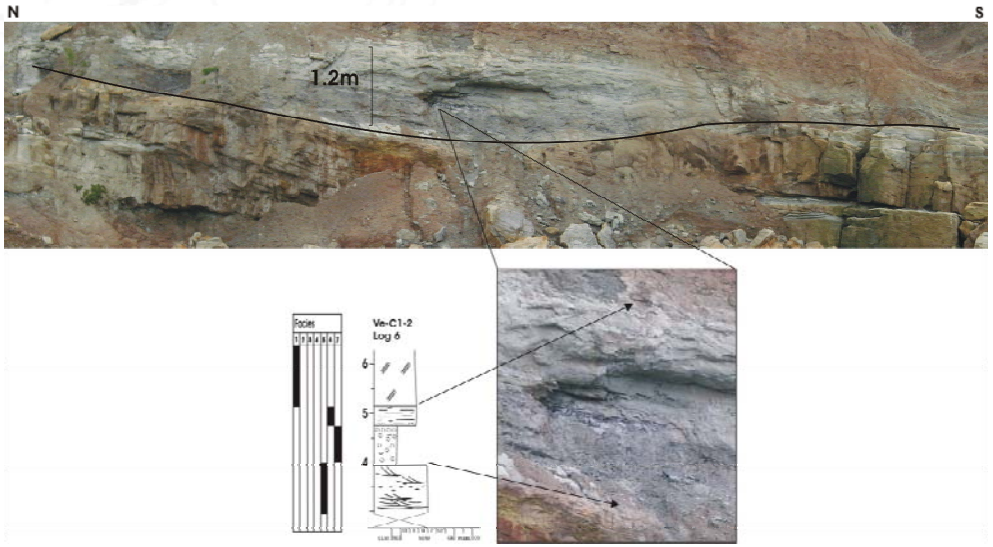


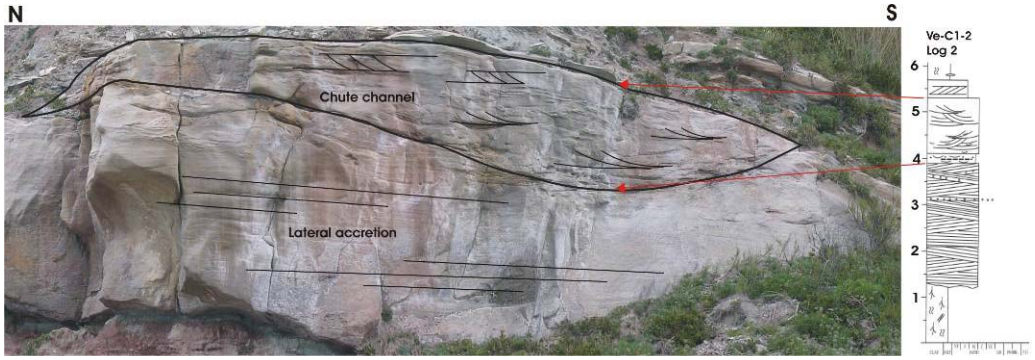
FA1b - Point bar

- Lateral accretion surfaces
- Dominantly medium and fine grained sandstones
- Moderate to poorly sorted
- Planar- and trough cross-stratification
- Occasional ripple cross-lam. on top
- Transport directions varies between SE and SW



FA1 – Channel fill

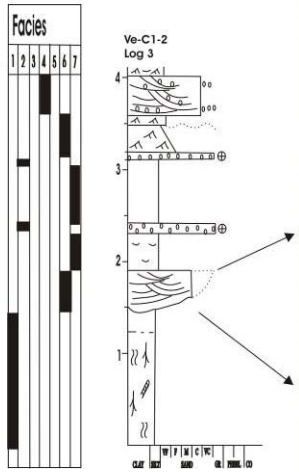




FA1c - Chute channel

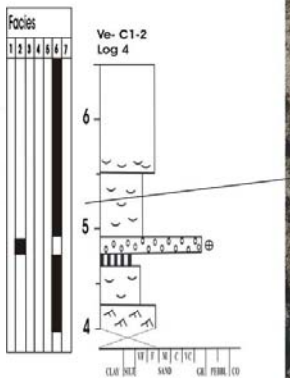
- Lens shaped
- 1-2m thick
- Traced for approximately 10m
- Erode into underlying point bars
- Both mudstone- and sandstone filled

FA2 – Channel Abandonment

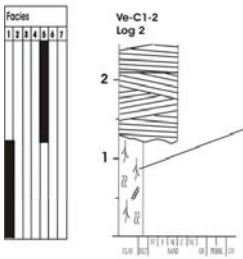


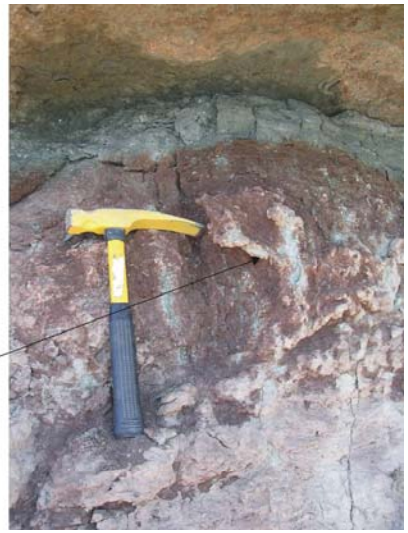
- In between channel bodies
- Muddy siltstone
- Dark grey colour
- Variable extension and thickness
- Usually eroded by overlying deposits

FA3 – Floodplain and FA4 - Palaeosol

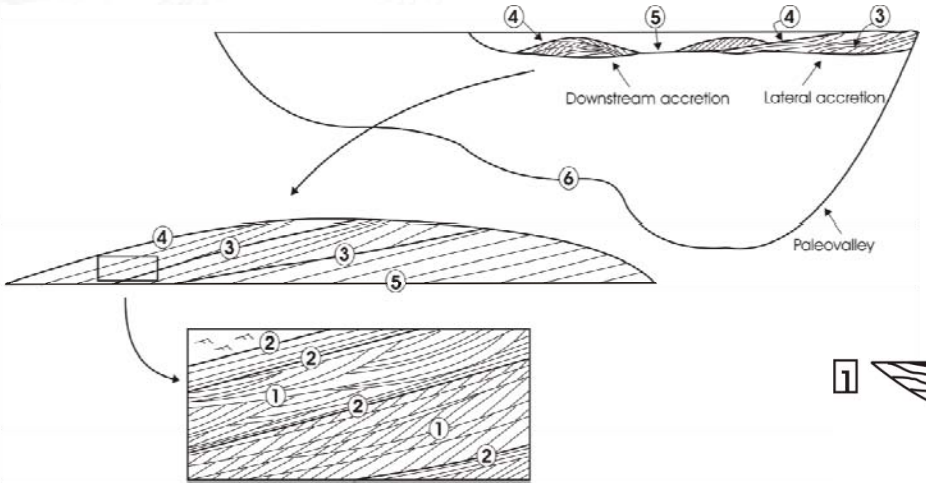


- Occurs above and below channel complex
- Mudstone/siltstone and very fine grained sandstone
- Mottled variegated colour
- Carbonaceous debris and pedogenic structures

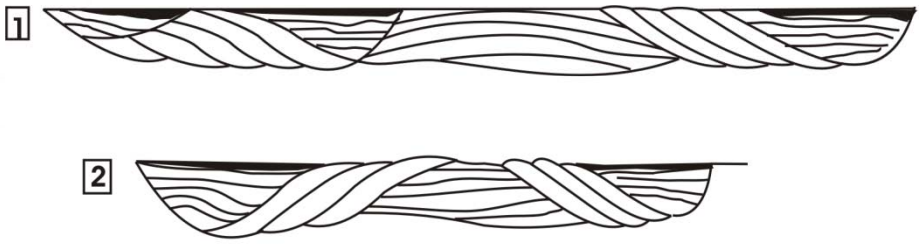


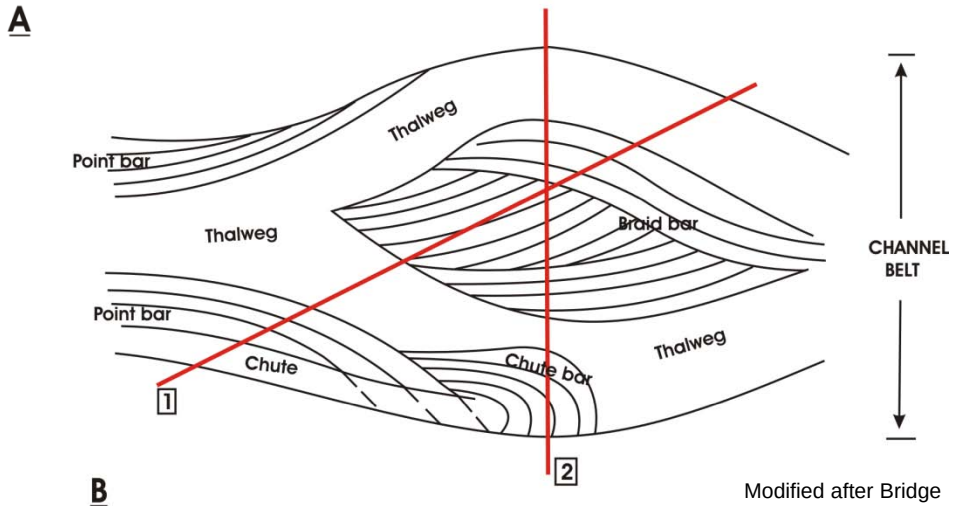


Bedform reconstruction



Modified from Miall (1988a)





Modified after Bridge

Bedform reconstruction

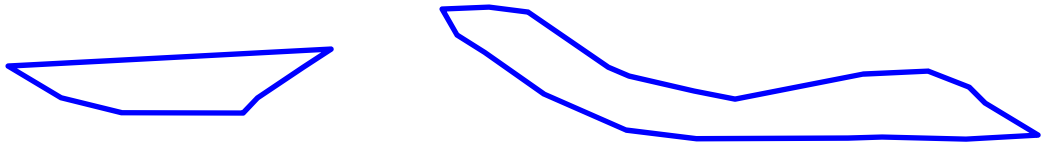
Channel complex Ve-C1-2

- Multi-storey channel complex
- 2 stacked channels
- 3 main depositional episodes

Channel 1

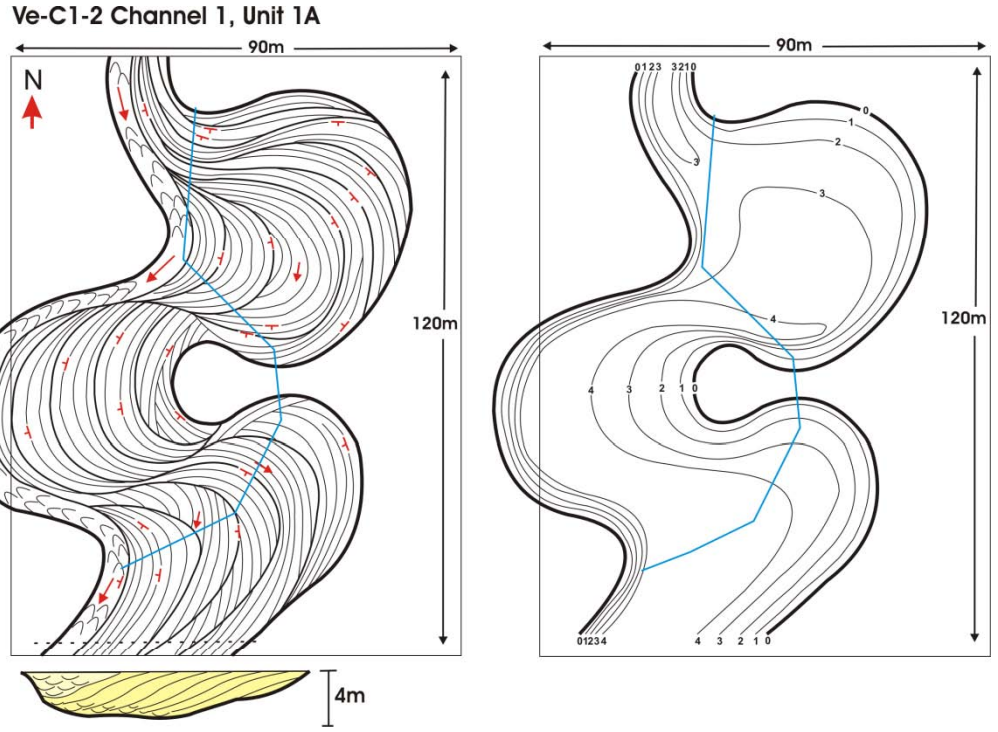
- Unit 1A, 1B and 1C
- Meandering character
- FA1b: Point bar
- FA1c: Chute channel
- FA2: Channel Abandonment

Bedform reconstruction – Channel 1



Unit 1A

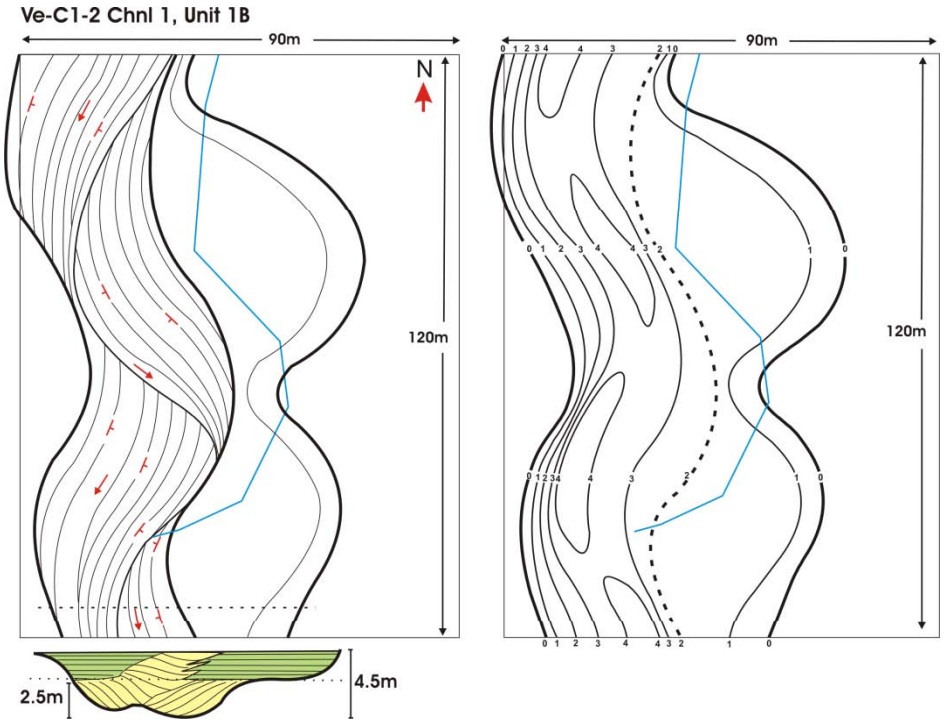
- Base of Channel 1
- 90x120m
- Structural data extrapolated from outcrop (blue line)
- Point bars (FA1b)
- Migration towards west by both expansion and translation
- Topography – max. 4m



Bedform reconstruction – Channel 1

Unit 1B

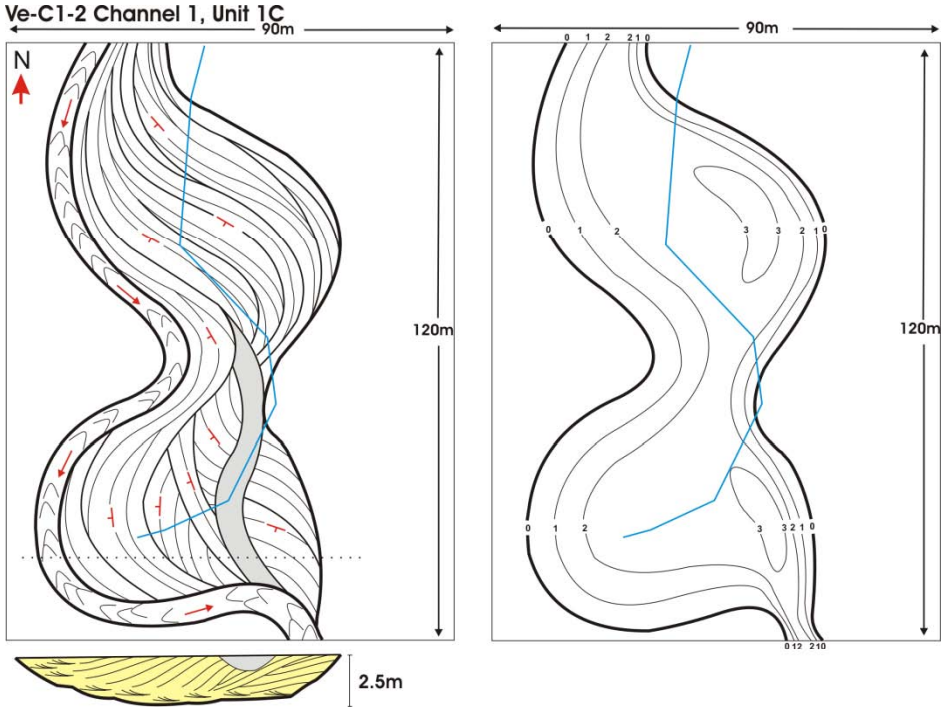
- 90x120m
- Only preserved in the south
- Erosive event (east→west), sediment bypass
- Incision
- Point bars (FA1b) overlapping in a downstream direction
- Mainly migration by translation
- Topography max. 4.5m (only 2.5m preserved in the outcrop)



Bedform reconstruction – Channel 1

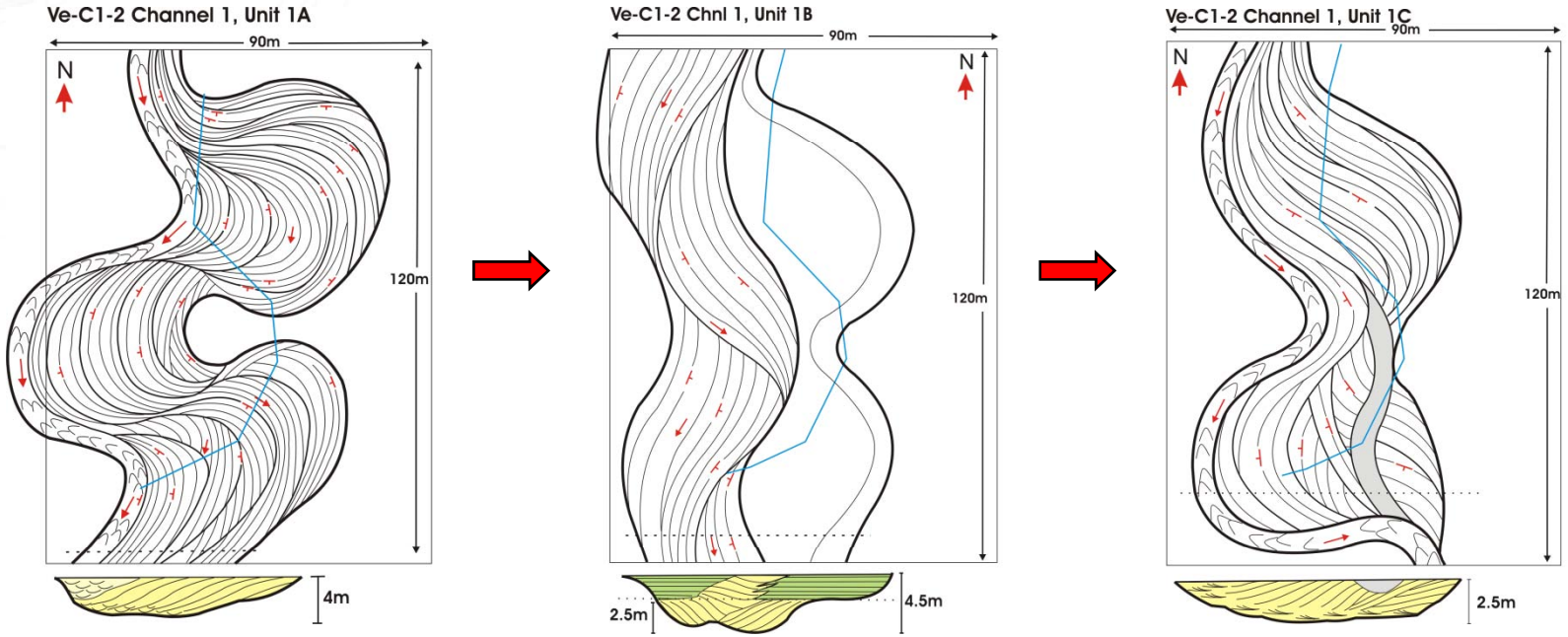
Unit 1C

- 90x120m frame
- Upper part of Channel 1
- Point bars (FA1b) and Chute channel (FA1c)
- Migration towards west by translation and expansion (sinuosity increase)
- Topography max. 2.5m



Bedform reconstruction – Channel 1

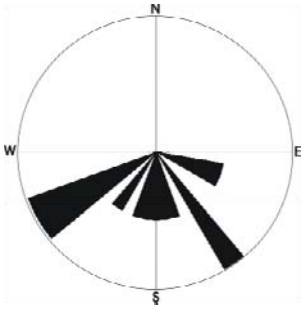
Summary of Channel 1



- deposition
- migration tow. west

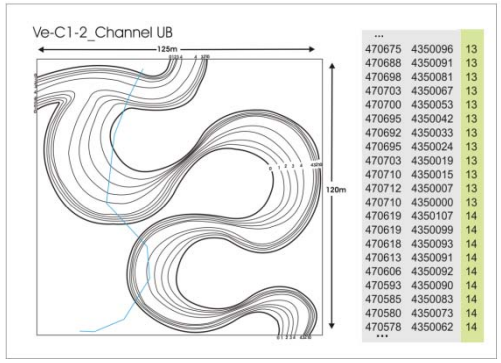
- erosion/sed.bypass
- incision
- deposition

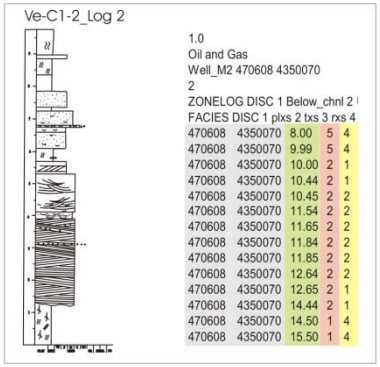
- erosion
- deposition
- migration toward west

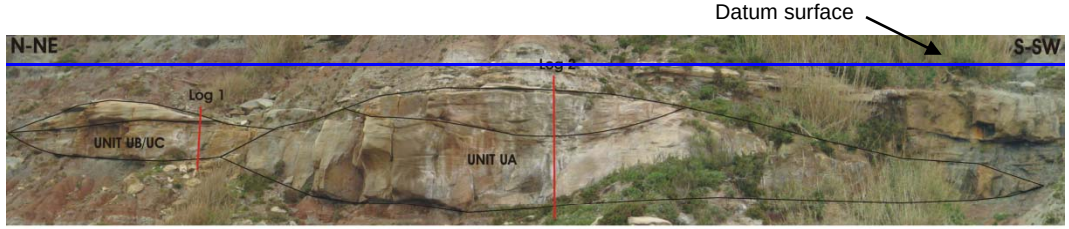


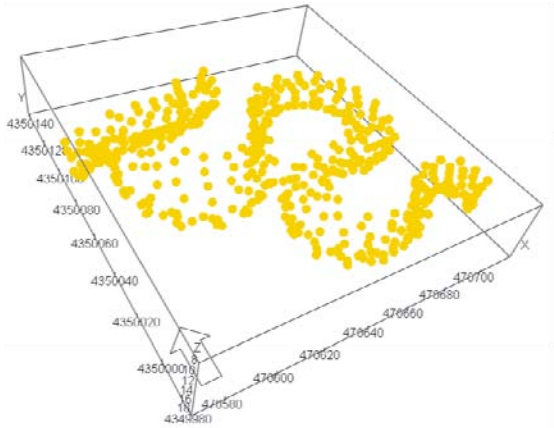
- General trend; migration towards west

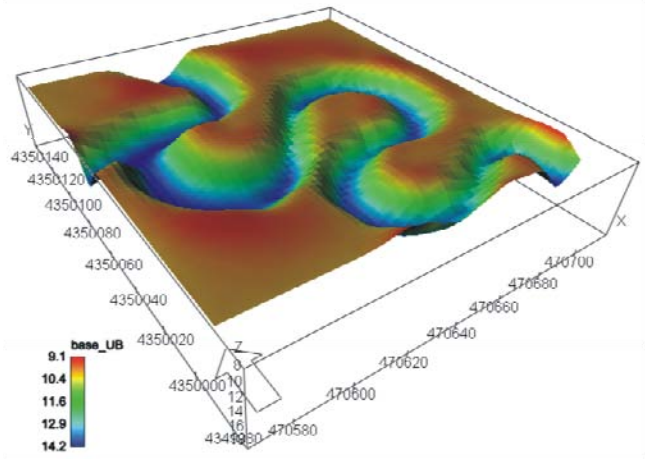
Geological modelling







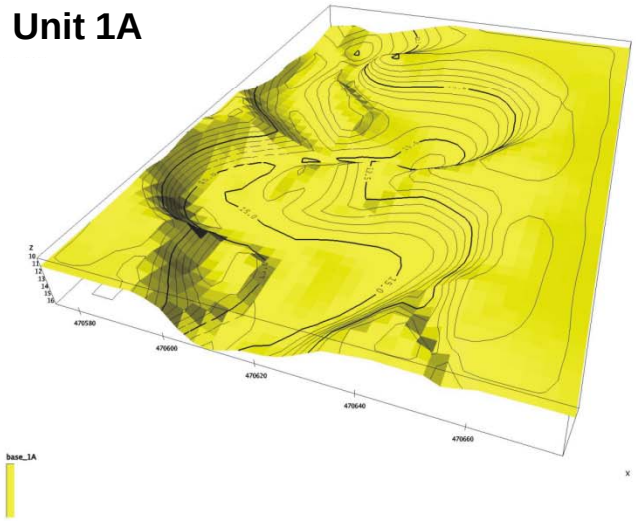




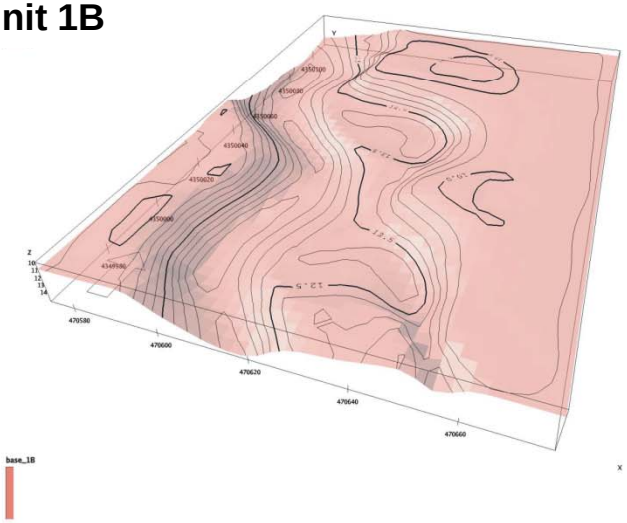
Geological modelling

Surfaces Ve-C1-2_Channel 1

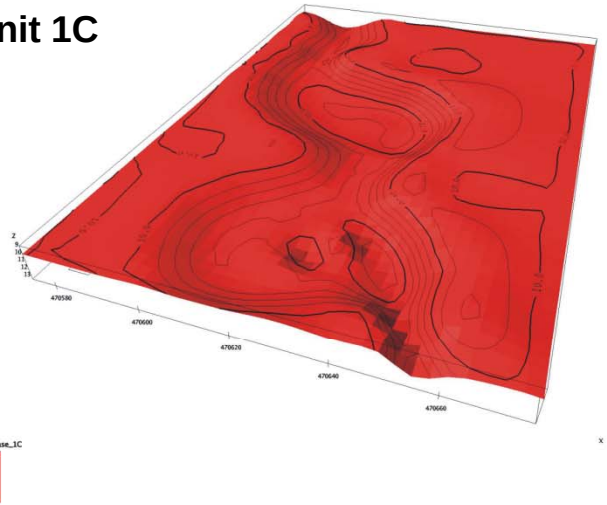
Unit 1A



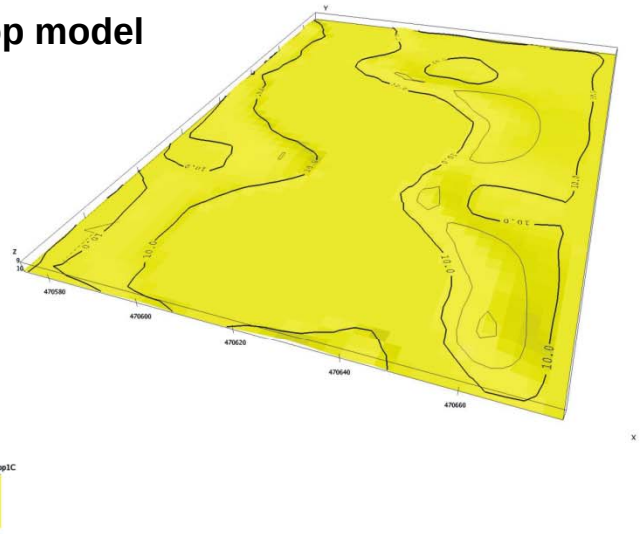
Unit 1B



Unit 1C

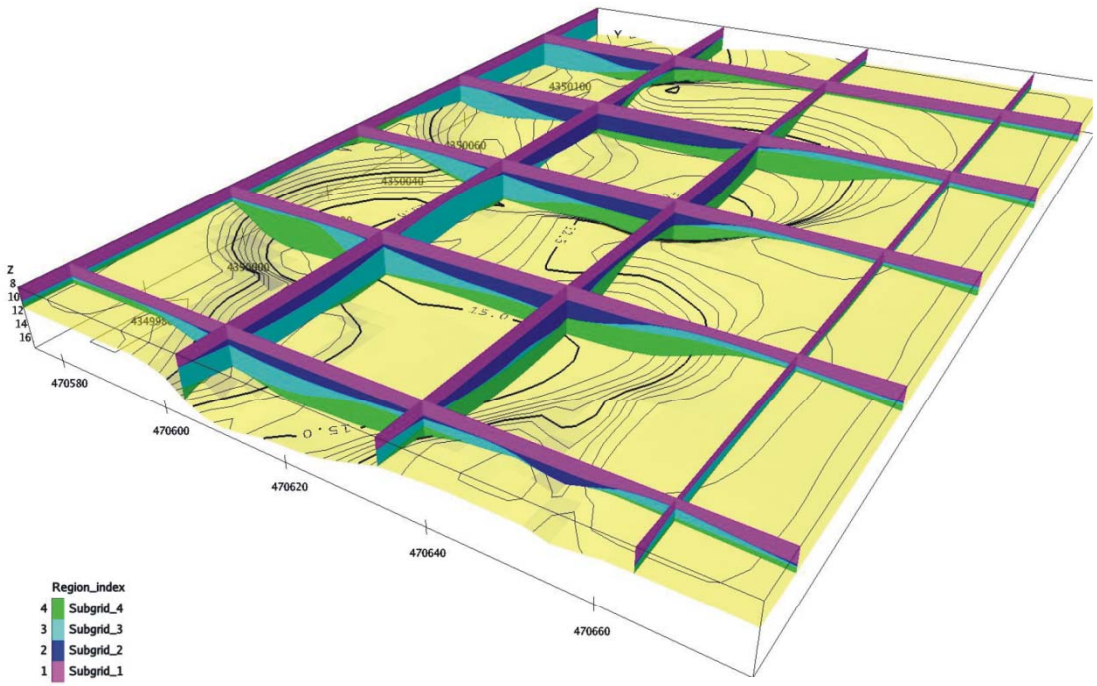


Top model



Geological modelling

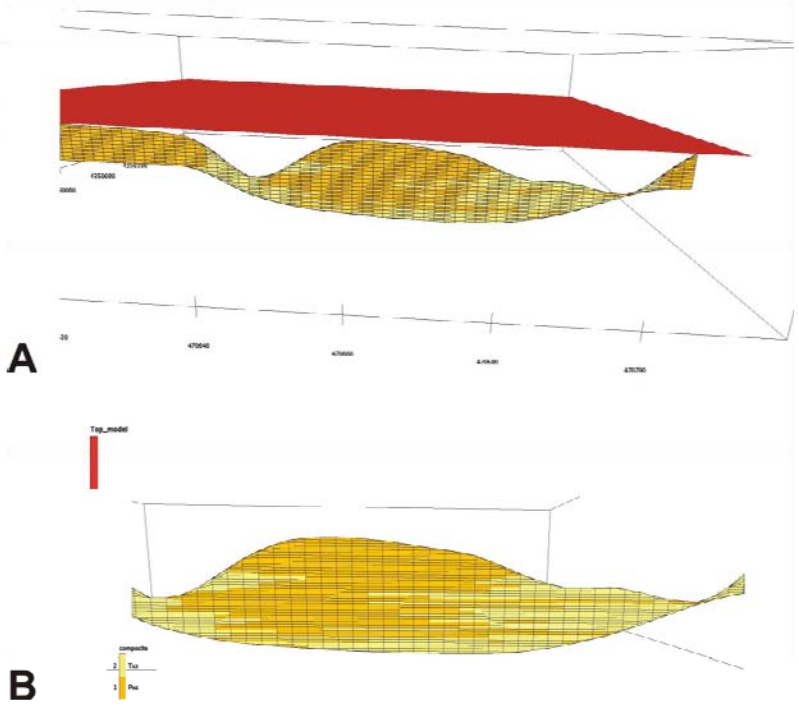
Zones Ve-C1-2_Channel 1



- Represent the volume between two surfaces
- Each zone comprises part of the channel fill
- 4 zones
- Base of each zone represent the base of a unit
- Green = Unit 1A, light blue = Unit 1B, dark blue = Unit 1C and purple = Top model.

Geological modelling

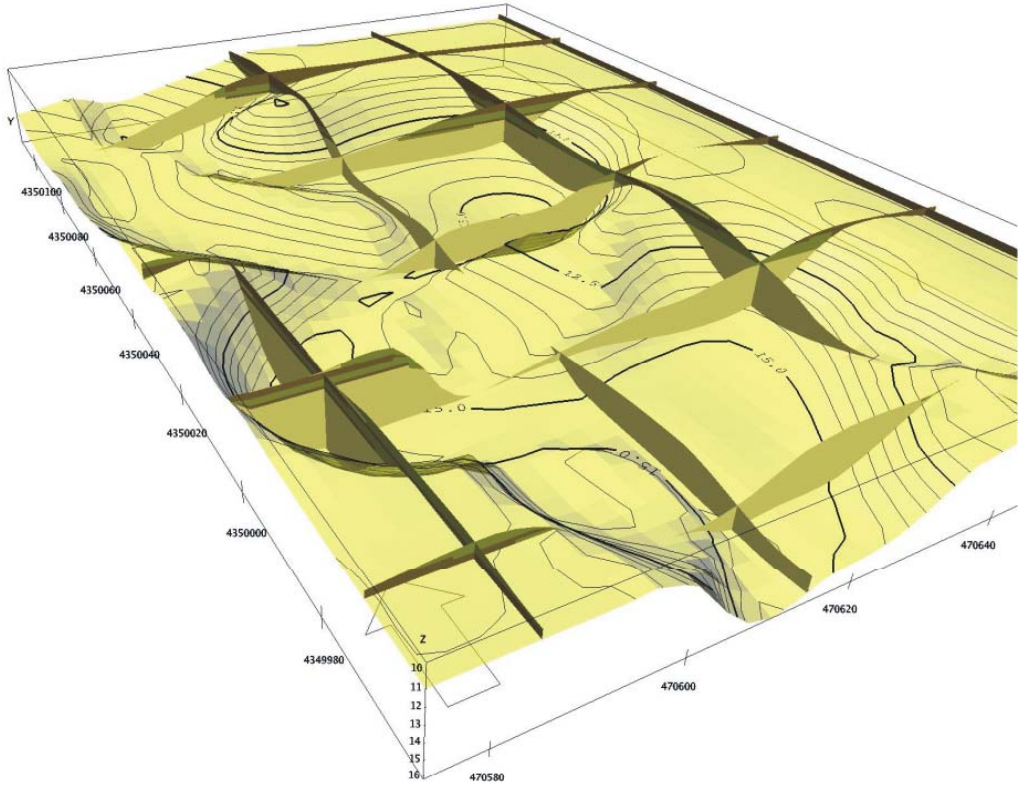
Grid design



- Grid resolution → 2x2x0.2m (XYZ)
- Regular grid
- Follows guide surface which is parallel to palaeo-horizontal
- Capture both the onlapping geometries and the eroded geometries at the top of the model
- Same gridding strategy for all zones

Geological modelling - results

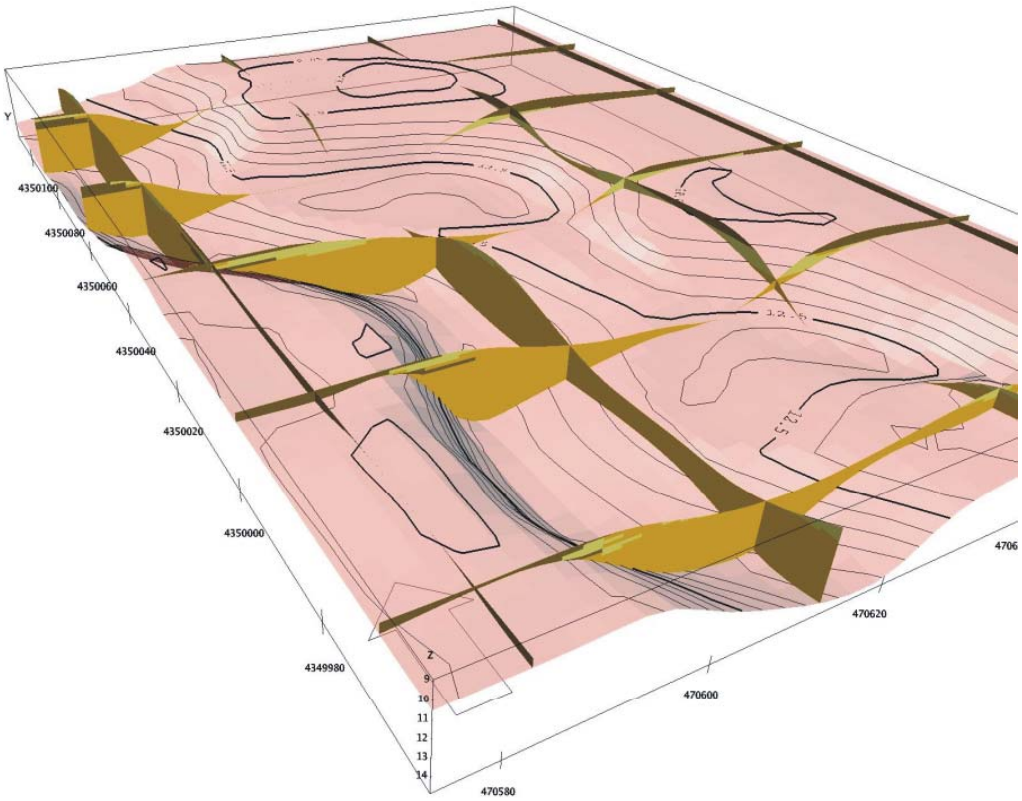
Unit 1A



- Grids populated with facies
- Variety of methods
- Facies:composite
- Object based approach
- Ellipses, 10-20m long 0.2-0.5m thick
- Manual editing to fit the conceptual model

Geological modelling - results

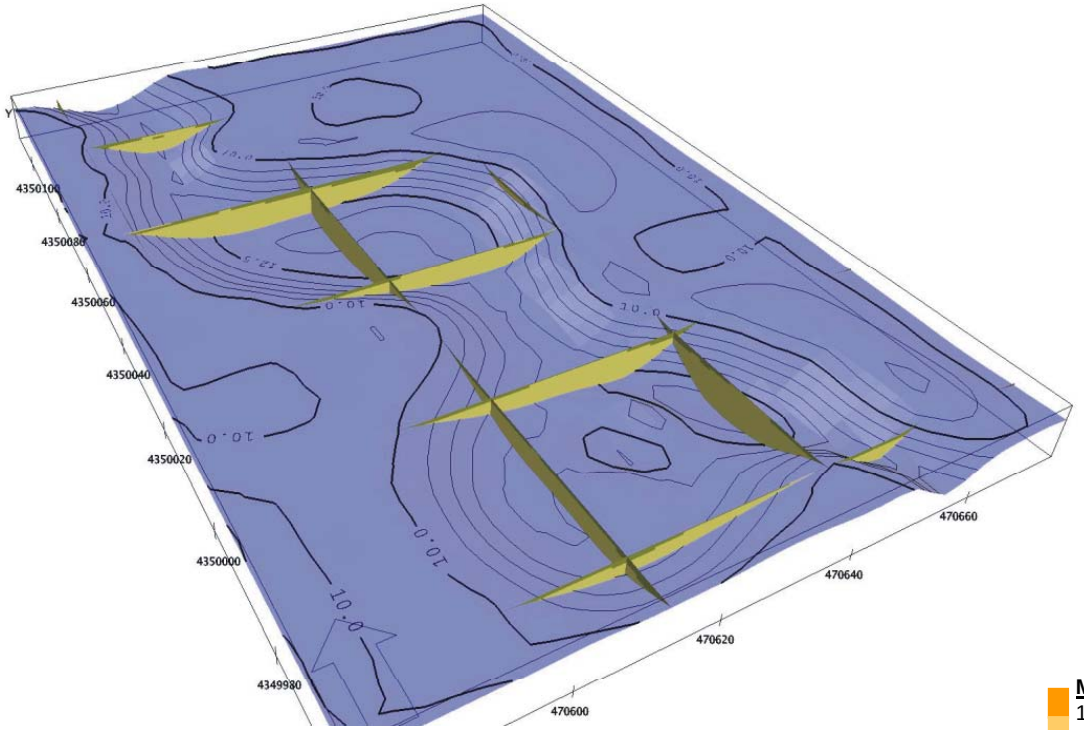
Unit 1B



Modelling facies
1. Planar cross-strat. sst
2. Trough cross-strat. sst
3. Ripple cross-lam. sst
4. Silt

Geological modelling - results

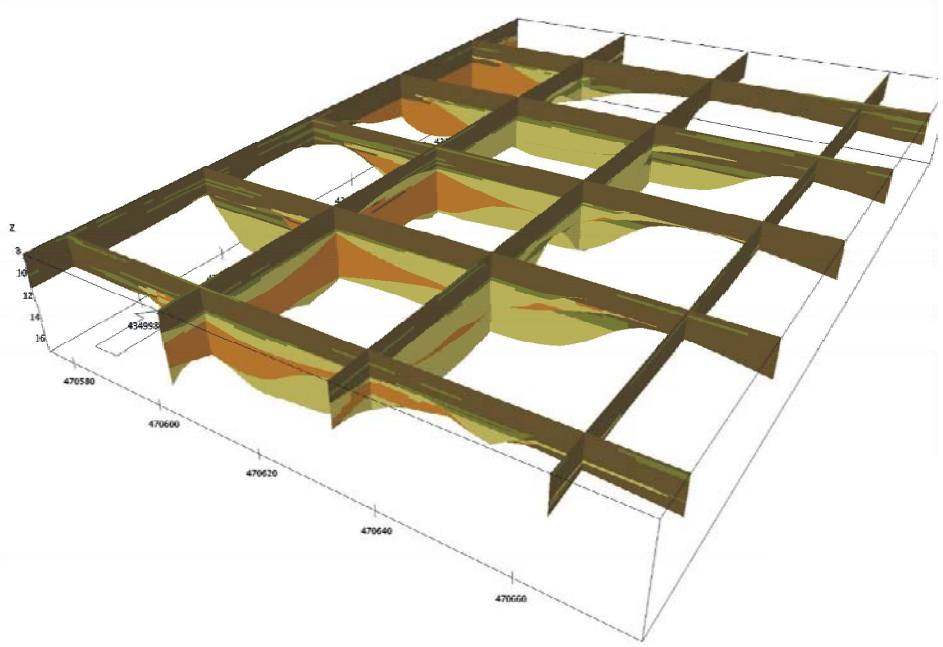
Unit 1C



Modelling facies
1. Planar cross-strat. sst
2. Trough cross-strat. sst
3. Ripple cross-lam. sst
4. Silt

Geological modelling - results

All units



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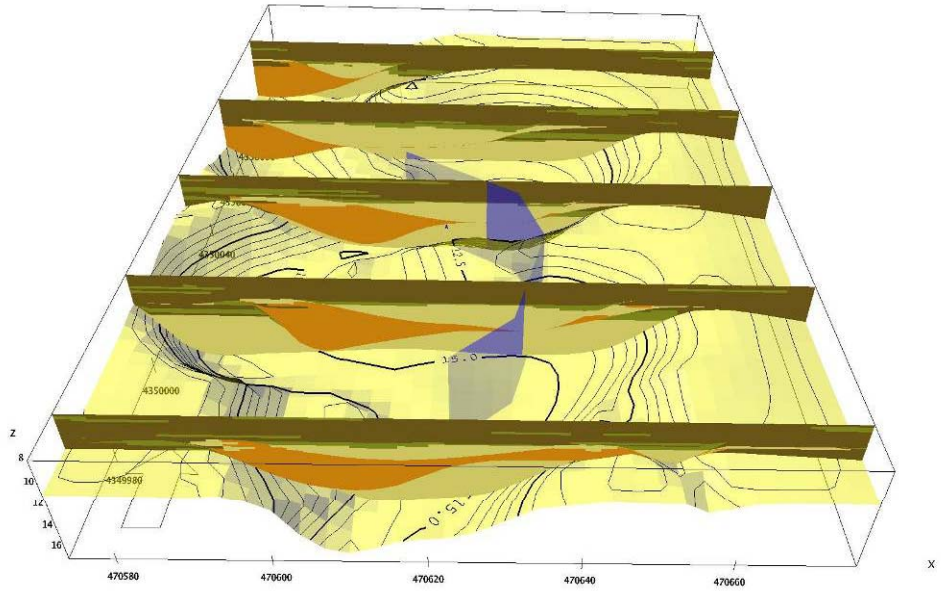
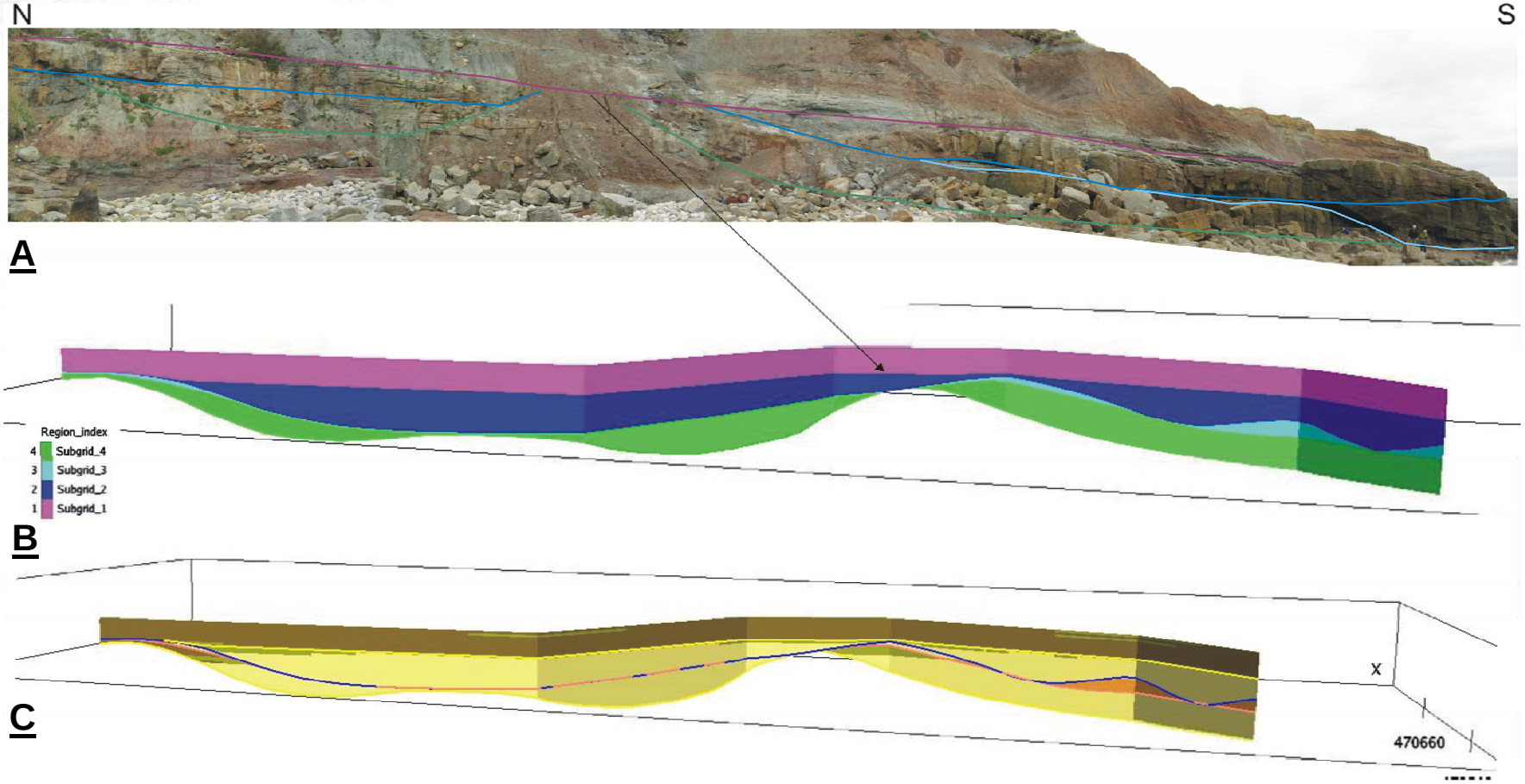


Geological modelling - results



Comparision between outcrop and geo-model

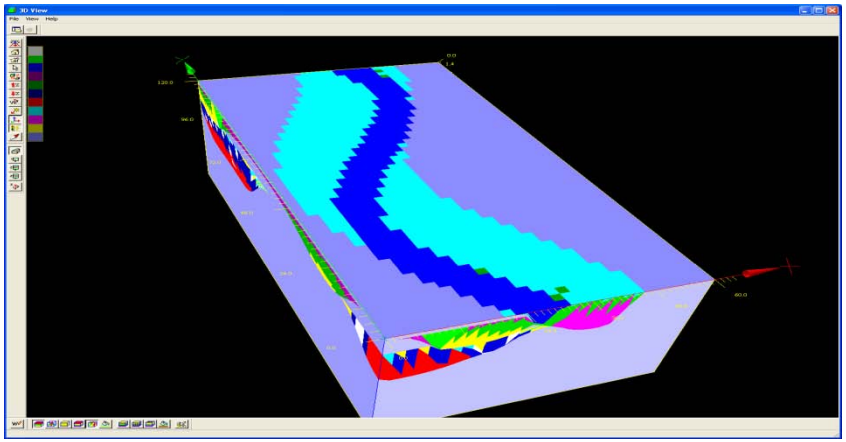
A. Outcrop
B. Zones
C. Facies model

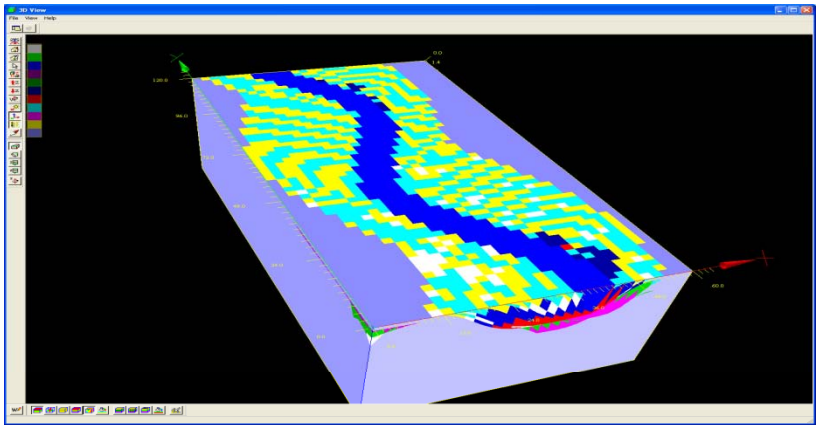
Applications of the models

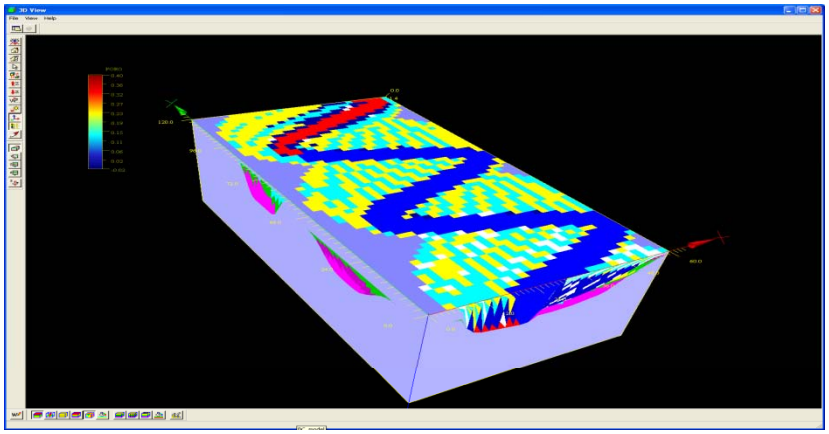
- Capture of small scale facies architecture in larger scale flow simulation models
  - Oil field specific petrophysical and PVT properties can be placed within the small scale facies models and used for upscaling in order to derive appropriate values for larger scale models
- Testing of sensitivites to facies architecture
- Understanding of 3D connectivity
- Training of geologist (and engineers)
- Populating process based models for upscaling

SBed Modelling

SBEd and SBEd studio
SBed studio is a process based geometrical modelling designed for recreating accurate facies models
Data from the field and from the models above are being used to condition a series of models
Models are used to test facies architecture sensitivities to parameters such as net:gross, sinuosity etc
Work is ongoing

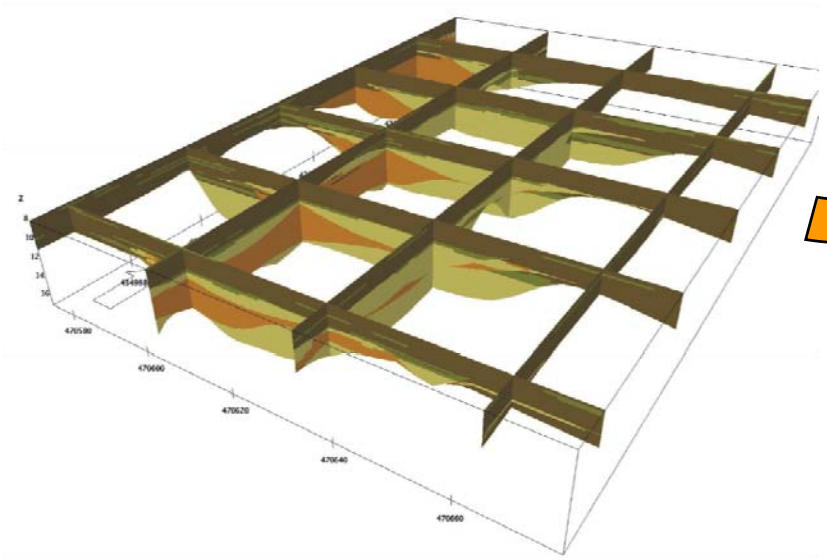


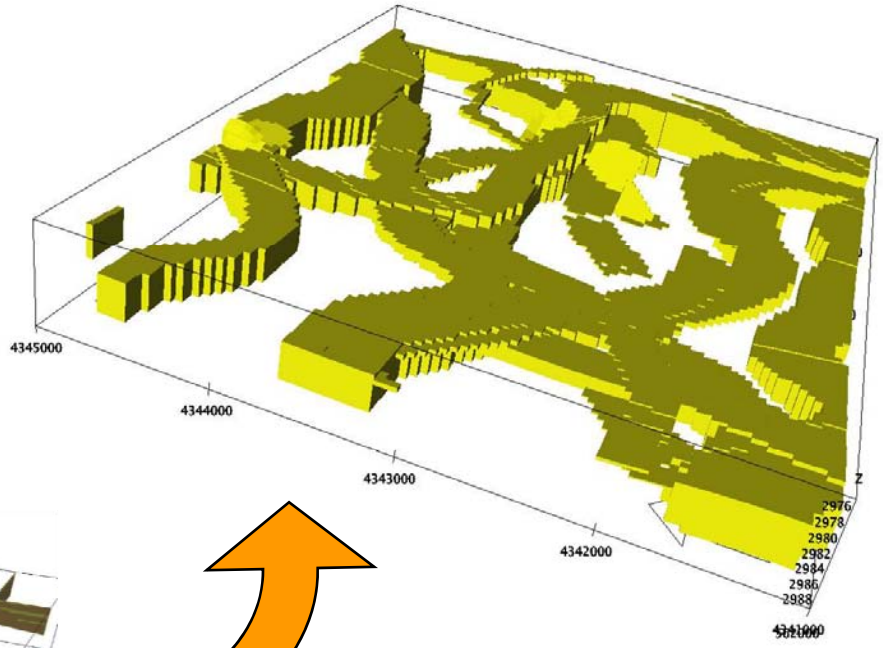




Conclusions

- Channel scale heterogeneities can be captured in small scale 3D models
- Bedform bounding surfaces can be reconstructed from 2D outcrops
- These surfaces can be imported into reservoir modelling software and used as a basis for models
- Logs and outcrop information provide input for facies distribution
- Small scale reservoir models are an integral part of upscaling and reservoir modelling

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Acknowledgments

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Geomodelling for SBed and SBed studio software

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