REF: Arnold et al, 2011. "Hierarchical benchmark case study for history matching, uncertainty quantification and reservoir characterisation." Computers and Geosciences.

Watt Field Case Study

Introduction

Benchmark problems have been generated to test a number of issues related to predicting reservoir behaviour however they are usually focused on a particular aspect of the reservoir model (e.g. upscaling, property distribution, history matching, uncertainty prediction, etc.) and the other decisions in constructing the model are fixed. This is true for features that require an element of interpretation due to indirect measurements of the reservoir, noisy and incomplete data and judgements based on domain knowledge.

The Watt Field Case Study was developed to consider interpretational uncertainty integrated throughout the reservoir modelling workflow. Like in real life we require the modeller to make interpretational choices as well as to select the techniques for modelling and simulation. The interpretational choices are around the following areas:

(1) Top structure seismic interpretation – seismic interpretation of the top structure defines the enclosure size and can be ambiguous from the data and the depth conversion
(2) Fault network definition – fault location, dimensions and the connectivity of the network defines the partitioning of the reservoir
(3) Grid resolution – pay off between number of iterations and resolution of the model to capture the reservoir features adequately.
(4) Facies modelling approach – choice of algorithm to populate model with properties
(5) Facies interpretations – how the facies are estimated from well logs through cutoffs
(6) Petrophysical property prediction from the available well data – how to predict permeability and porosity across the reservoir
(7) Relative permeability data

The aim of the model is to help develop methods for accounting for features that are not included in traditional history matching approaches such as top structures and faults, while including qualitative uncertainties that are difficult to impossible to parameterise. The hope is that techniques and be developed and tested that account for many possible geological scenarios in history matching and subsequent uncertainty quantification of a producing reservoir.

The Watt Field is a semi-synthetic study is based in part on real field data and in part on synthetic data. We provide, top structures, fault models, grids, seismic sections, wireline and core data to build the geomodel and SCAL, PVT and production data to construct and history match the simulation model. We provide no geomodel, preferring instead to allow the researcher to develop their own models for simulation. An ECLIPSE(TM) simulation model is provided for each of the pre-defined grid resolutions.

To make this problem useable in a manageable time period for researchers/engineers to apply, multiple gridded models, available to download which are hierarchically related to the different interpretational choices. A hierarchical approach would integrate uncertainty from the geological interpretation of the reservoir, the structural interpretation of faults and top structures, interpretational errors from wireline logs and available well data.

Using the data provided the researcher would choose one or several possible scenarios, or sample over the space between the scenarios to predict the uncertainty in the forecasts from simulation models. All the data has been provided herein.

Researchers are not limited to the 81 provided models, rather they are encouraged to think beyond the scenarios provided by us and produce their own models.

Field Overview

The Watt field is a synthetic study based on a mixture of real field and synthetic data to describe a realistic field example. Top structure and wireline data is based on real field data however the fluid properties, relative permeability, and capillary data are synthetic. The field development plan is also synthetic resulting in an artificial production response. The model spans a 12.5km by 2.5 km surface area, elongated in the East/West direction with a total modelled thickness of around 190m, much of which is below the oil water contact. The field is located around 1555m subsurface with an initial reservoir pressure of 2500psi as measured from RFT and well test data. The WOC is identified from wireline and RFT data at a constant 1635m subsurface.

The interpreted depositional environment for the field is a braided river system, where a number of different possible outcrop analogues and modelling techniques could be applied. Common facies types in this kind of environment are fluvial channel sands, overbank fine sands and background shales.

The field was initially appraised through a set of 6 wells, Well A-F then subsequently developed through a set of 16 horizontal production wells located across the central part of the reservoir and 5 horizontal and 2 vertical (one of which is a recompletion of Well B) injection wells around the edges. Horizontal multi-lateral wells were selected in the original development plan to maximise the distance from the WOC due to the low relief of the field and increase oil production rates.

An interpretation of the top structure and major faults was picked from the seismic in the time domain and then depth converted. The seismic data and TWT surface are given below along with a few seismic lines and the well picks for the surface tops. From uncertainties in this process 3 possible tops are provided. In addition 3 possible structural models are provided below and the 9 resulting top surfaces are shown. 3 grid resolutions and 3 electrofacies interpretations are provided making a total of 81 possible simulation grids to choose from.

Porosity and permeability data is provided for Wells A and C as core data and Neutron Density porosity data is provided for all wells A-F. Six rel perms, 3 for the coarse sand facies (code 0) and 3 for the fine sand (code 1) are provided with variability between each curve constituting uncertainty in what is the representative curve to use.

Table 1 gives the list of all choices provided in this benchmark with choices required on the grid resolution, top structure, fault model and facies cutoffs, facies modelling approach and rel perm data. All this data can be found in the folders within this appendix. Grids are produced for every combination of top structure, fault model and grid resolution already, with upscaled facies logs provided for each of the vertical grid resolution options.

We also provide information on the depositional environment and the possible ranges of structures and proportions. 6 rel perm curves (3 for each of the sand facies) are provided and can be used on their own or as part of a prior range. Simulation models for each grid resolution are provided.

We also provide production data from all production wells for a period of 8 years. This is provided with the intention of history matching the reservoir to the data and producing estimates of the reservoir uncertainty.

REF: Arnold et al, 2011. "Hierarchical benchmark case study for history matching, uncertainty quantification and reservoir characterisation." Computers and Geosciences.

Model property	Description	File name	
Grid	100 m by 100 m by 5 m	G-1	Total of 81 different combinations of these properties
	100 m by 100 m by 10 m	G-2	
	200 m by 200 m by 5 m	G-3	
Top Structure	1	TS-1	
	2	TS-2	
	3	TS-3	
Fault Model	1	FM-1	
	2	FM-2	
	3	FM-3	
Facies Model (Cutoffs)	0.6	CO-1	
	0.7	CO-2	
	0.8	CO-3	
Modelling approach	Data is provided for different possible field depositional models based on different outcrop analogues. Data from these sources could be used in the construction of the geological model		
Relative permeability data	Coarse sand relperms	RP_0_1	
		RP_0_2	
		RP_0_3	
	Fine sand relperms	RP_1_1	
		RP_1_2	
		RP_1_3	
Simulation model	100 m by 100 m by 5 m	100 100 5	
	100 m by 100 m by 10 m	100 100 10	
	200 m by 200 m by 5 m	200 200 5	

Table 1: Table of uncertain choices to make in choosing a scenario for this model. The combination of Grid resolution, Top structure, fault model and facies cut-off uncertainty leads to 81 different possible combinations of the options.

1. Top structure choices

Uncertainties in the top structure are accounted for by developing a number of possible tops from the same depth converted horizon, conditioned to 3 different sets of well picks. A total of 3 different well picks were chosen by 3 different interpreters from the same wireline data with a variation in top structure height of between 2 and 20 meters depending on the well. The seismic horizon was tied to each of the well picks using different multivariate conditional smoothing techniques to produce 3 different top structure realisations to be used in constructing the model grid.

Variation in the well picks for each well vary greatly from well to well with significant variation in wells E and F of up to 10 meters while wells A and B are extremely well correlated to the data (a small uncertainty). As the model is conditioned to only the 6 appraisal wells each well has a significant influence on the GRV calculation. The truth case scenario lies somewhere in the well picks range we have defined.

REF: Arnold et al, 2011. "Hierarchical benchmark case study for history matching, uncertainty quantification and reservoir characterisation." Computers and Geosciences.

2. Fault network choices

Several major faults were identified from the seismic data and depth converted along with the top structure. Fault displacements are calculated from the top structure curvature therefore contain an implicit uncertainty in the throw amount along the fault. All the observed faults strike in a general East/West direction and there is no large scale faulting visible in seismic in other orientations. The presence of sub seismic faulting with a North/South strike direction is explored as it would impact on connectivity between the wells. As no significant displacements are observed in the appraisal nor horizontal production wells we assume the displacements on any North/South trending faults is quite small.

We have therefore developed two possible models of the faulting in the reservoir one with only East/West trending faults and one with additional North/South sub seismic faults with displacements less than 10m (therefore not visible in seismic data). The total number of East/West trending faults remains constant in both scenarios with additional North/South faults being added only within the oil saturated region of the reservoir (to reduce the complexity of the model).

Fault seal is also unknown though the juxtaposition of some of the faults effectively partitions the reservoir in places. In each of the models we have made available a simple constant fault transmissibility value is assigned to each fault so these parameters could be used as history matching variables.

3. Grid choices

A set of gridded models is developed for each combination of top structure and fault interpretation for different vertical and lateral grid resolutions using corner point grids. The choice of grid resolution can be complex as we need to balance the accuracy of the model to capture the features of the reservoir that impact flow with a reasonable simulation run time, particularly for history matching. We provide 3 different possible grid resolutions described below in Table 2 though any grid resolution can be chosen for this exercise. The truth case model was carried out on a higher resolution model. The choices are a pay off between vertical and horizontal resolution and total numbers of grid cells (and therefore simulation run times) in the model.

Grid Name	200_200_ 5	100_100_10	100_100_5
Grid cell count	112 * 30 * 40	226 * 59 * 21	226 * 59 * 40
Grid cell dimensions	200m * 200m * 5m	100m * 100m * 10m	100m * 100m * 5m
Total number of cells	134,400	280,014	533,360

Table 2: Model Grid dimension for fine and coarse grid options provided.

REF: Arnold et al, 2011. “Hierarchical benchmark case study for history matching, uncertainty quantification and reservoir characterisation.” Computers and Geosciences.

4. Facies proportions and modelling approach choices

Facies can be identified in the wells in cored sections where available, however away from the wells wireline data is required. There are a number of approaches to identify the facies from wireline response, gamma ray being a common method for differentiating between sands and shales. In this reservoir there is a significant amount of noise in the gamma data that makes it less useful as a facies predictor. As an alternative the facies is predicted from RPD with different cut-offs being applied to identify the coarse sand facies. 3 cutoff values have been developed and the facies logs predicted for all 6 appraisal wells. Facies logs are developed for each cutoff and an upscaled log for each of our grids is provided.

The choice of how to model the facies distributions is left completely open to allow a range of modelling techniques to be applied to the chosen grid for history matching. Traditional Gaussian simulation and Object modelling techniques could be used as well as other techniques such as multipoint statistics (MPS) (Caers, 2001). To help in the calibrating the model to realistic data a number of possible outcrop analogues are provided in as part of the download with measurements of key features such as channel dimensions and shale body lengths. The outcrop analogues supplied indicate the range of possible feature dimensions and do not represent the actual modelled system.

5. Permeability prediction

Permeability data is available from core plug data in Wells A and C. Prediction of permeability in the other wells can done using techniques like sequential cosimulation or a direct prediction from identified poroperm correlations. This can be developed where no core plug data is available using log predictions like neutron density porosity. Figure 1 shows the correlation between neutron density and core plug porosity estimates and the probability histograms for both measurements of porosity. The good correlation and similar probability distributions suggests we can expect good porosity predictions from the neutron density logs in the other wells.

REF: Arnold et al, 2011. "Hierarchical benchmark case study for history matching, uncertainty quantification and reservoir characterisation." Computers and Geosciences.

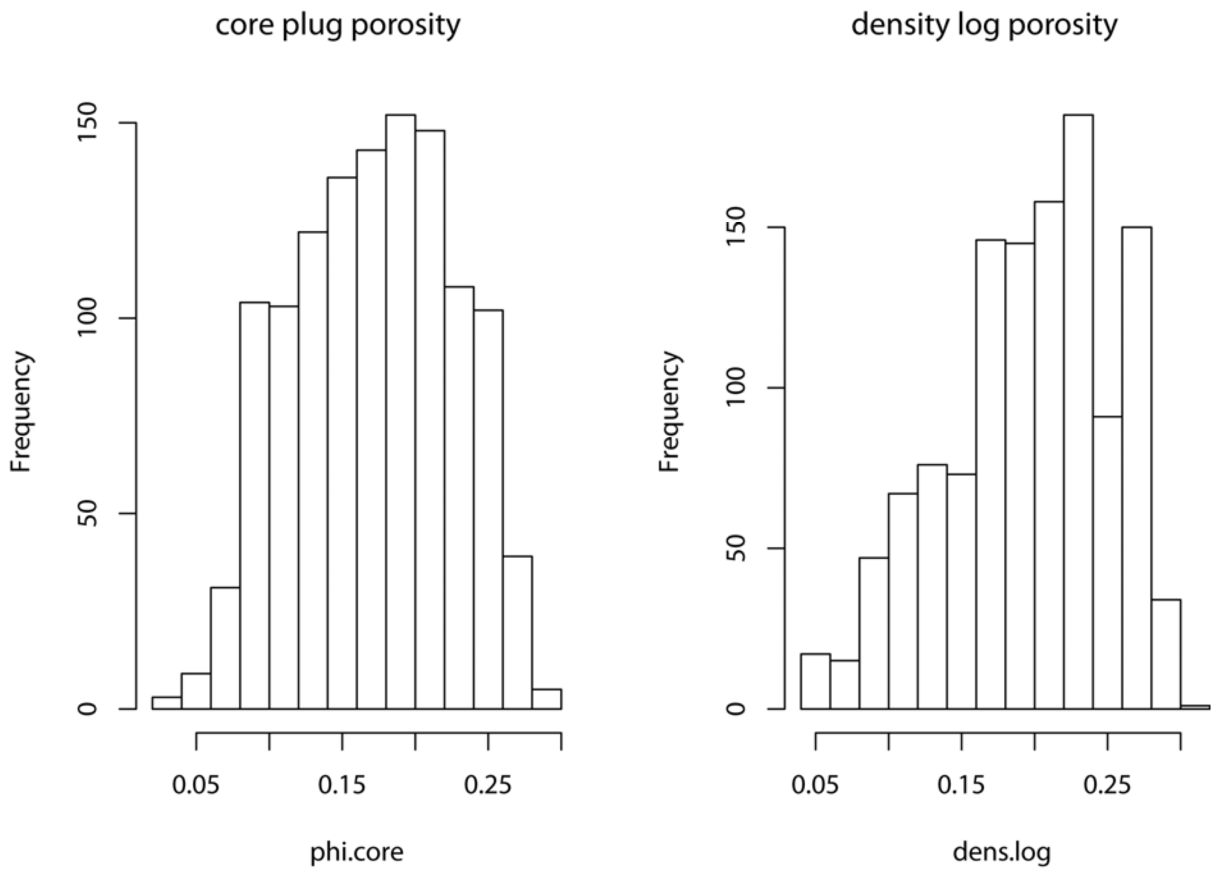


Figure 1: Porosity distributions for well core plug data and neutron density predictions. The two distributions are very similar.

We can account for the uncertainty in the permeability predictions in a number of different ways such as different poroperm correlations are developed from core poroperm data. Examples of this might be based on (1) a simple global linear correlation from all well data and (2) a linear correlation per facies. Many other approaches could be applied to this problem including Global Hydraulic Elements (Amaefule et al, 1993) or a layered zonation model for permeability prediction. These approaches are not necessarily the approach used in creating the truth case model, and they may or may not provide a good estimate of the real permeability field.

A total of 6 Relative permeability data curves were taken from wells A, D and F for both the coarse and fine sands (3 for each facies). There is no significant capillary pressure in this reservoir therefore no data is provided. PVT data is provided for the reservoir and is based on a single sample of the reservoir fluid. It is assumed to be representative of the entire reservoir with little uncertainty.

Production history data was created from a truth case model for a total of 2903 days (8 years). Oil, water and Gas rates and BHP data are provided for each and a Gaussian noise of 15% of the value was added to the data.

Benchmark objectives

The objective of this benchmark is to demonstrate ways of accounting for uncertainty in the qualitative elements of reservoir modelling, where we generally assume such features are fixed deterministic aspects of the model as they are (a) hard to parameterise and (b) hard to estimate the prior uncertainty. The model should be applied to history matching problems to use the production data to estimate the reservoir forecast uncertainty.

Our hope is that new and existing techniques that can handle uncertainties in the top structure, fault model, facies model and appropriate grid resolution can be applied to this study to provide good routes to dealing with these kinds of uncertainties. Also this benchmark is suitable to testing/developing methods for dealing with limitations in the grid resolution, new realisitic facies modelling approaches, gridding methods, history matching approaches for multiple scenarios and extensions to the Bayesian/uncertainty quantification methodology. We hope you find it useful!

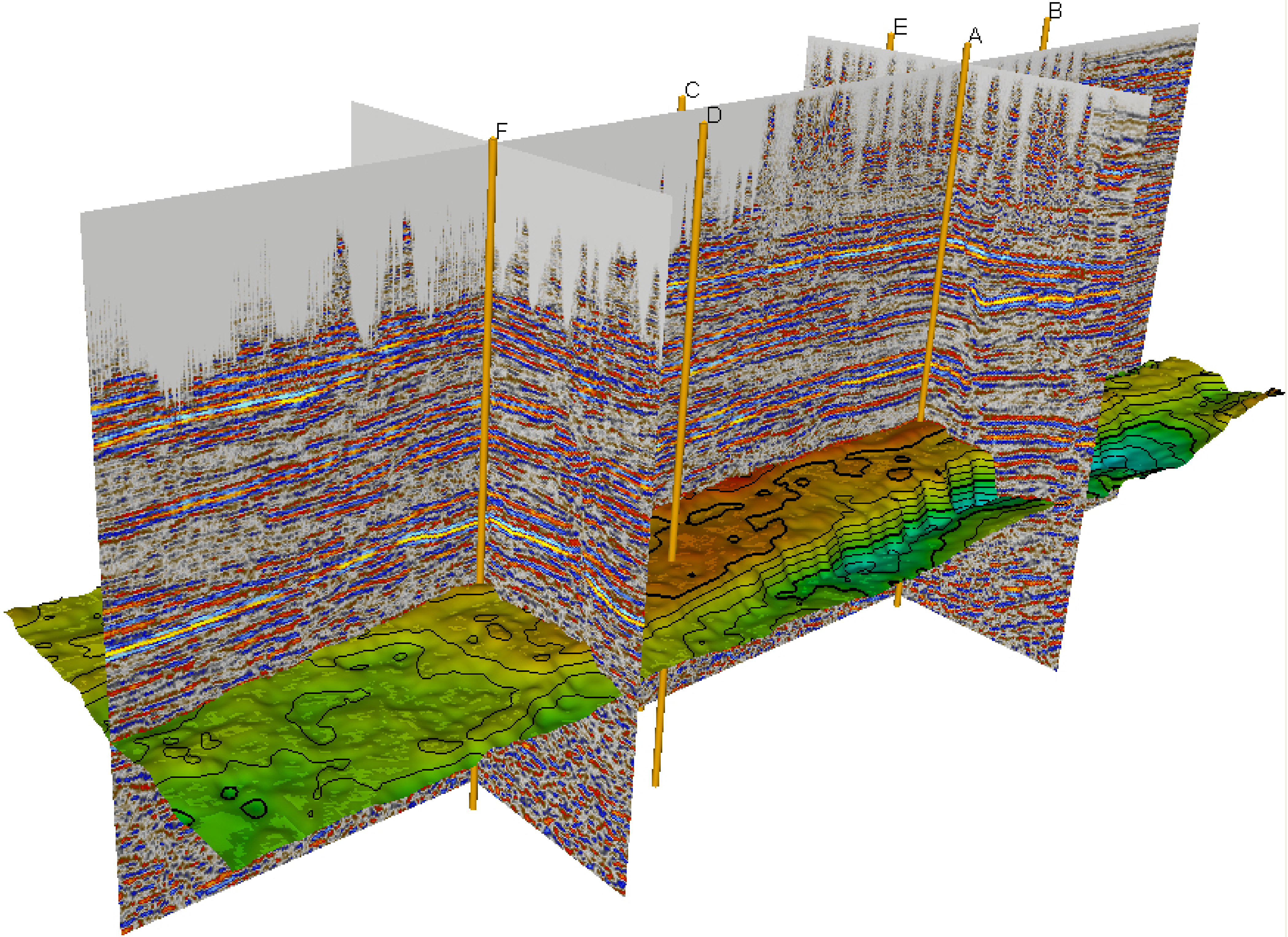
You can contact dan.arnold@pet.hw.ac.uk with any questions or if you would like to share/show us your results.

References

Caers, J. 2001. "Geostatistical reservoir modelling using statistical pattern recognition". Journal of Petroleum Science and Engineering, Volume 29, Issues 3–4, May 2001, Pages 177-188

Amaefule, J. O., Altunbay, M., Tiab, D., Kersey, D. G., and Keelan, D. K., 1993. "Enhanced reservoir description: using core and log data to identify hydraulic (flow) units and predict permeability in uncored intervals / wells." SPE 26436, SPE Annual Technical Conference and Exhibition, 3-6 October 1993, Houston, Texas, 205 – 220.

Top structure seismic interpretation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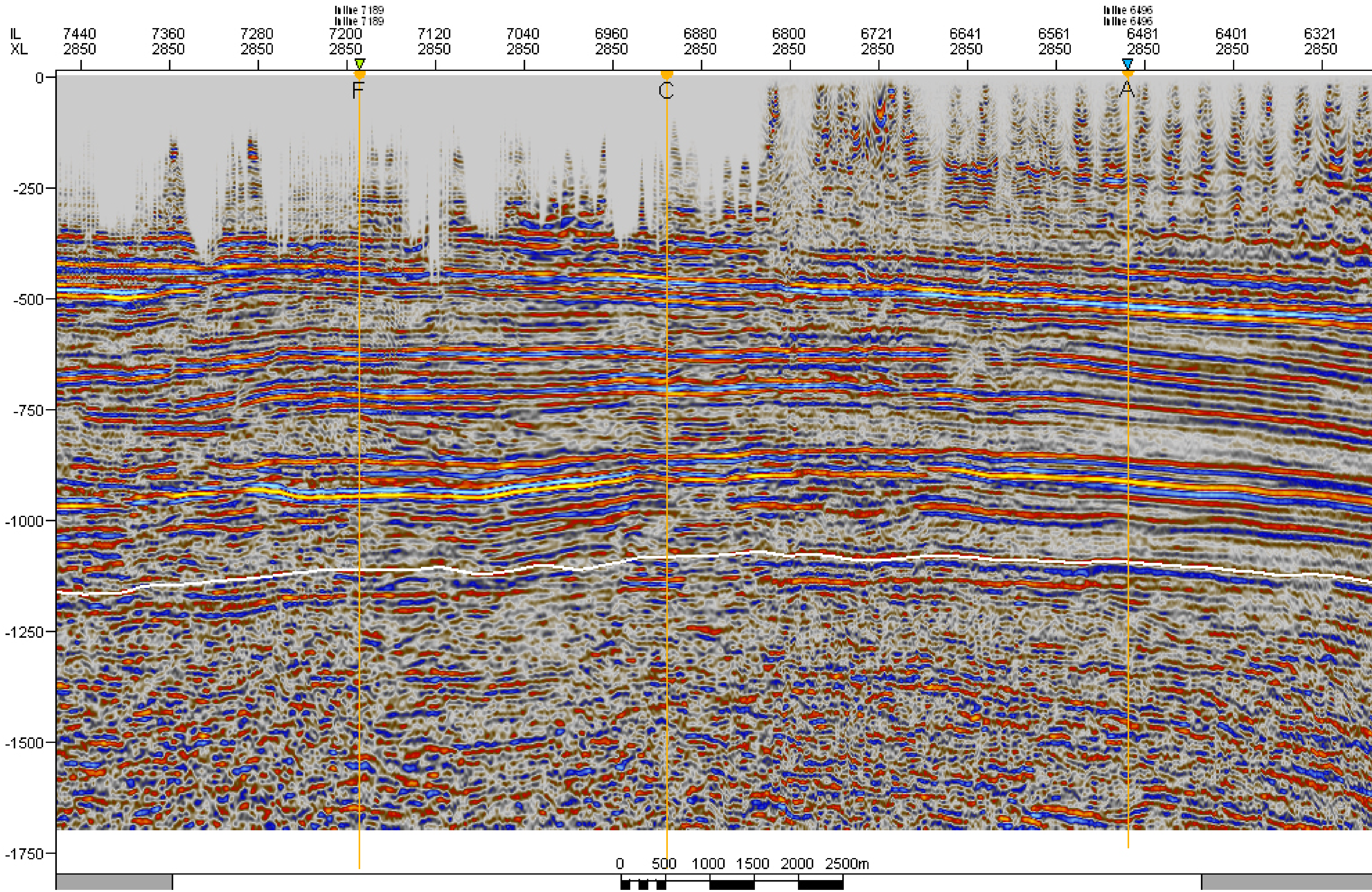

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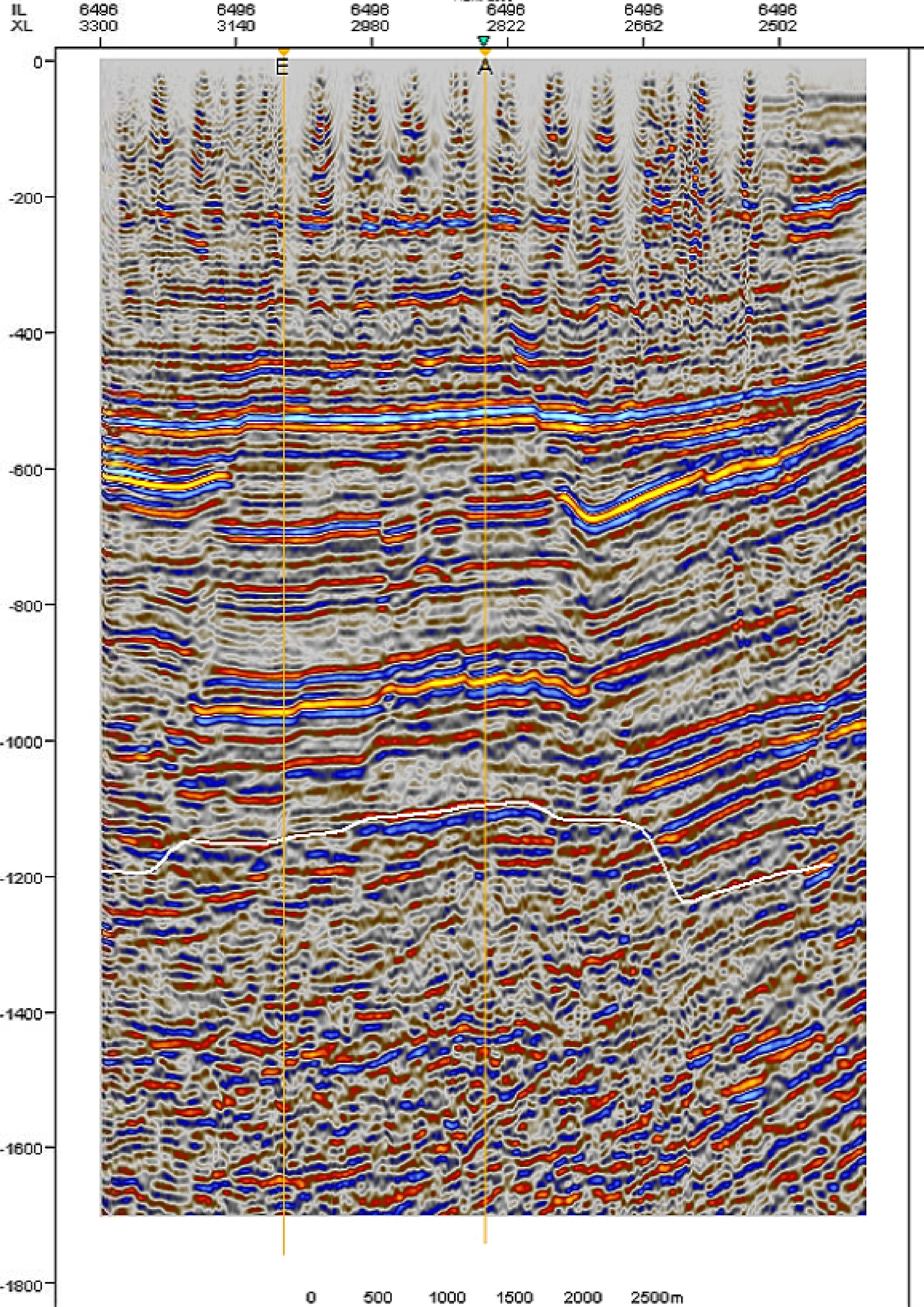

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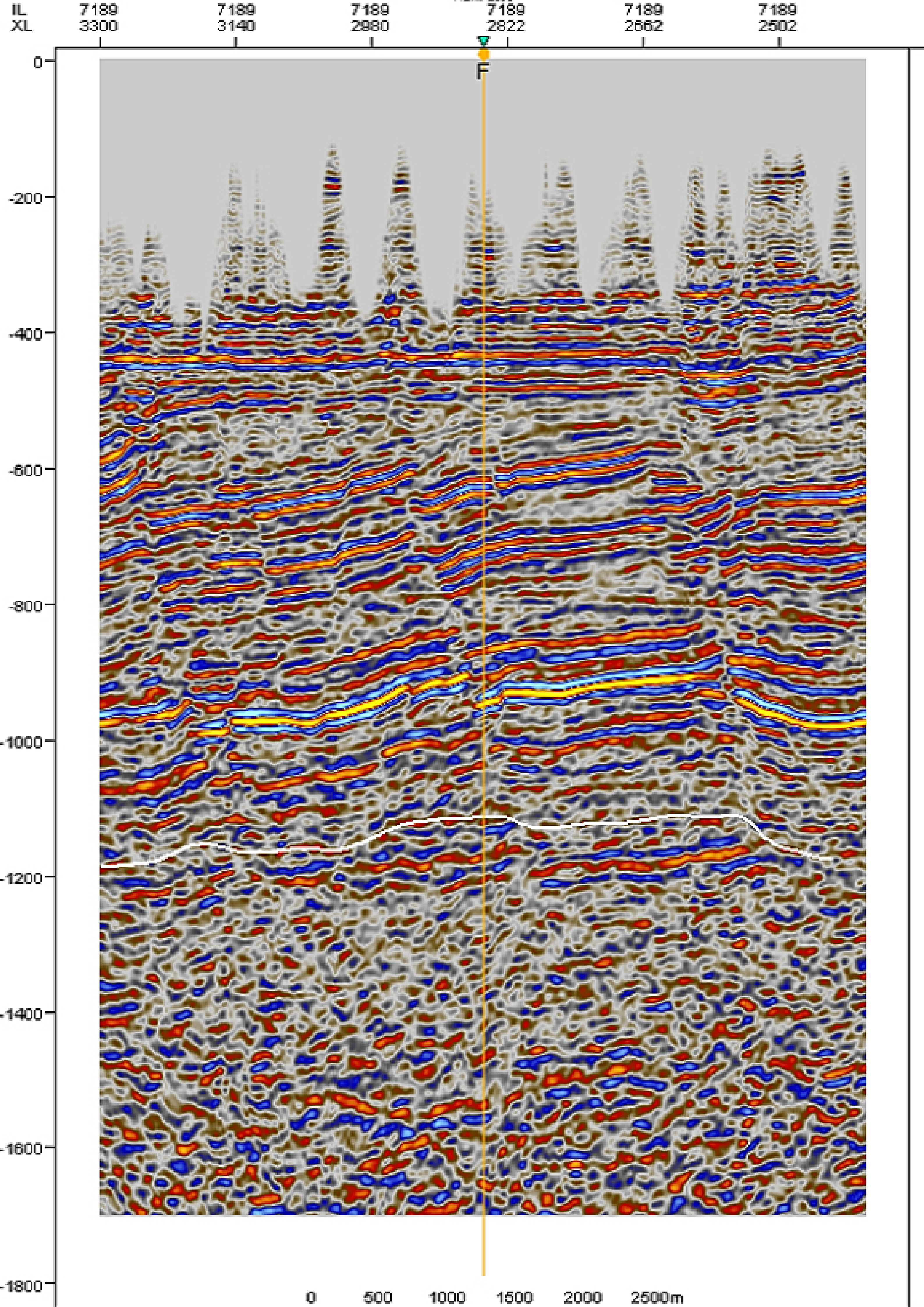
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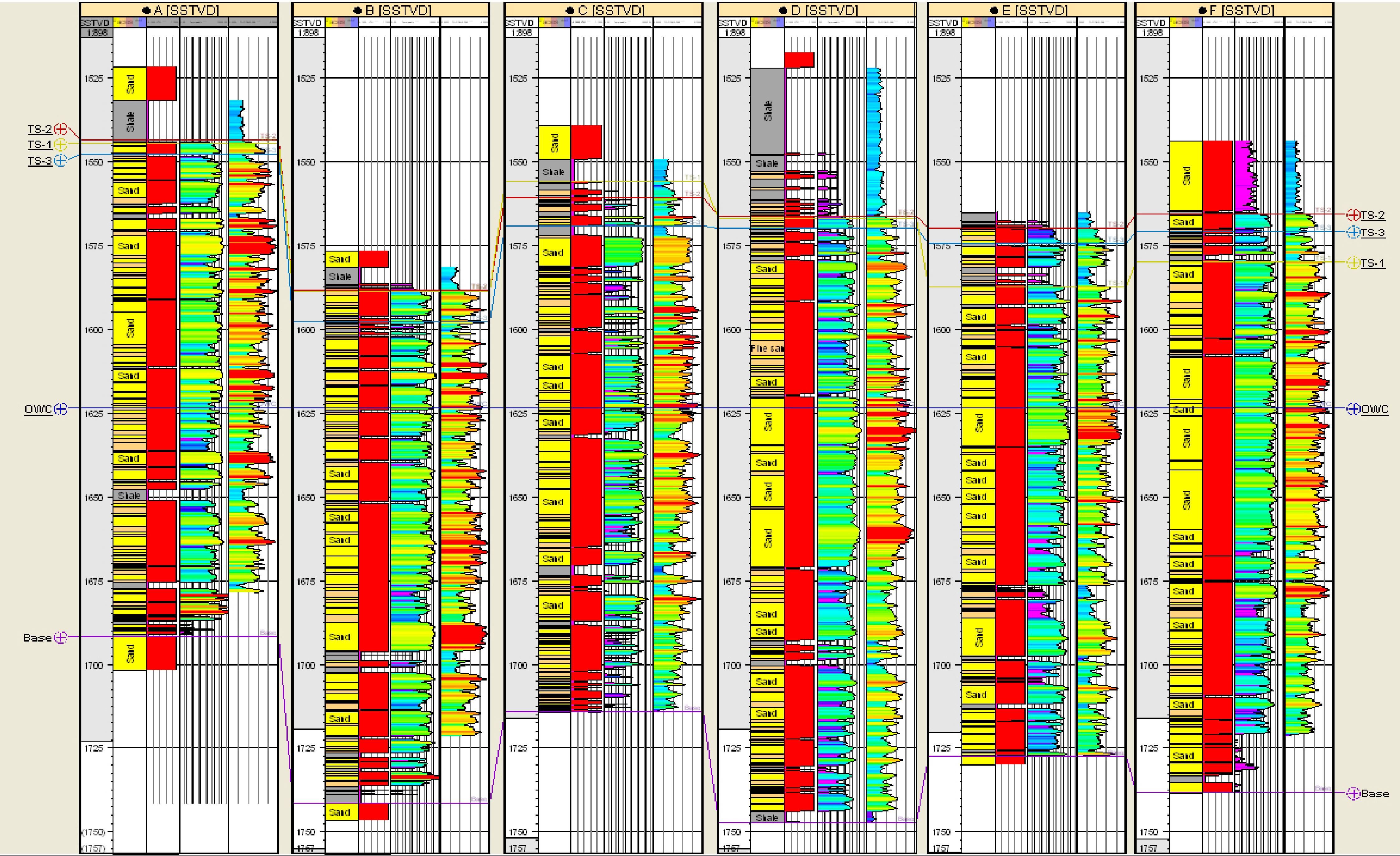
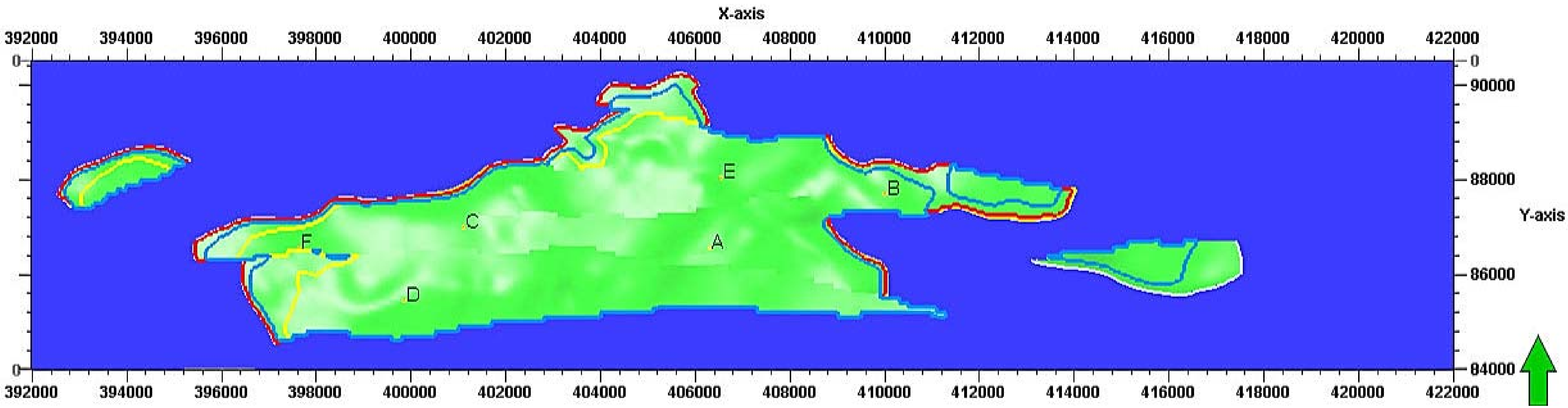
Well correllation panel Wells A-F, showing the top structure well pics for TS-1, TS-2 and TS-3. Facies is based on the 0.7 RPS cutoff

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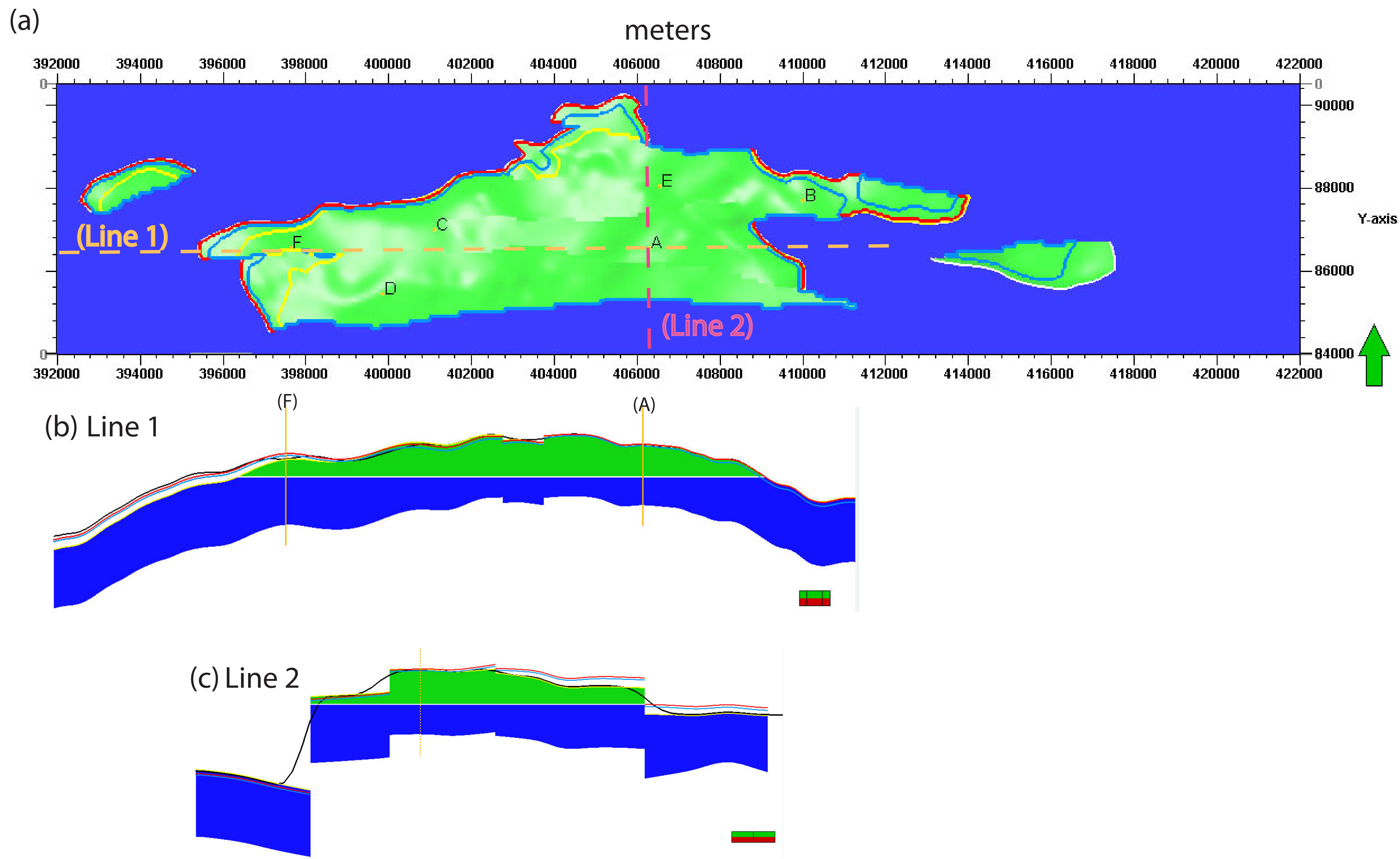
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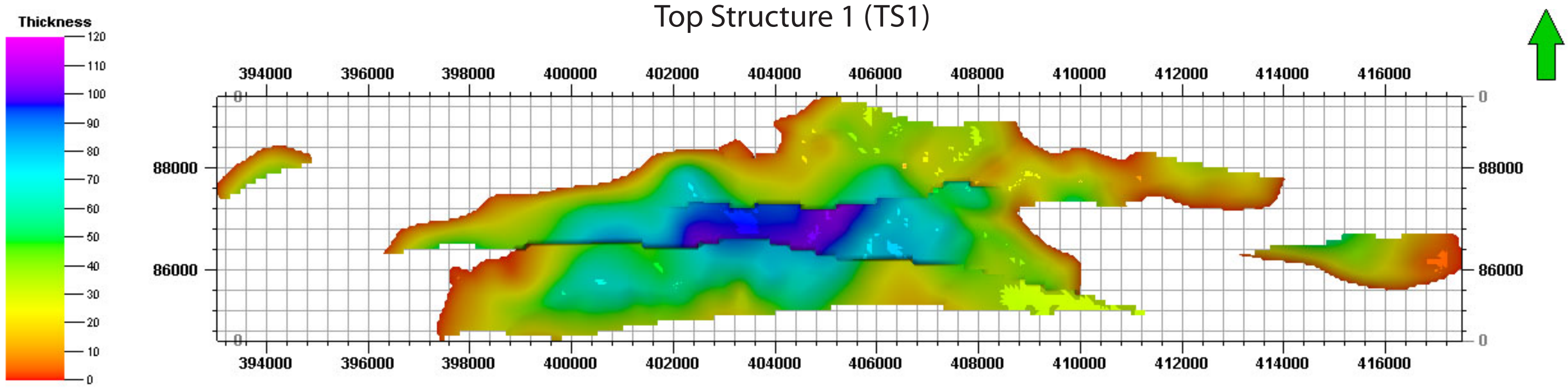
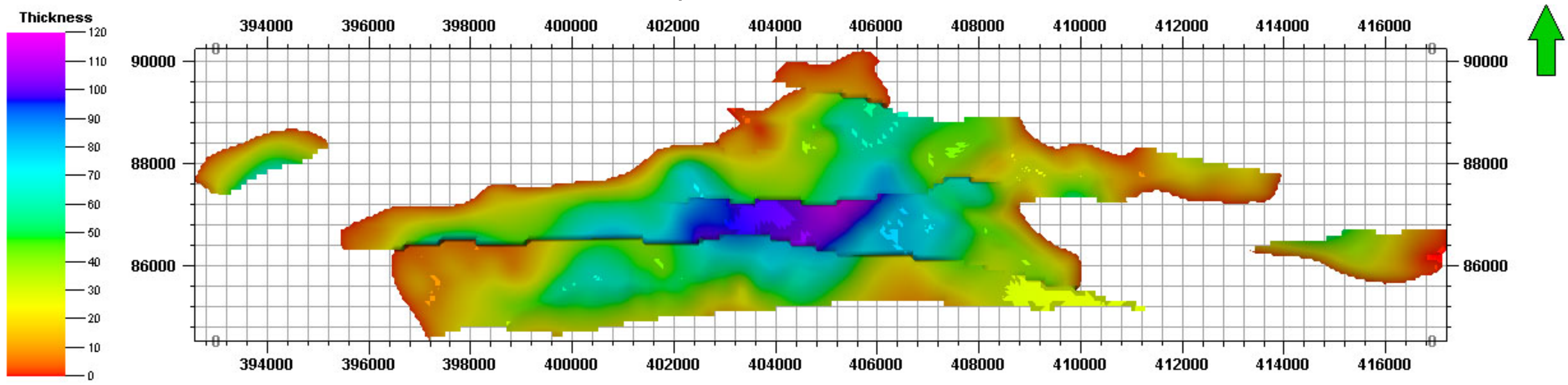
(c) Line 2

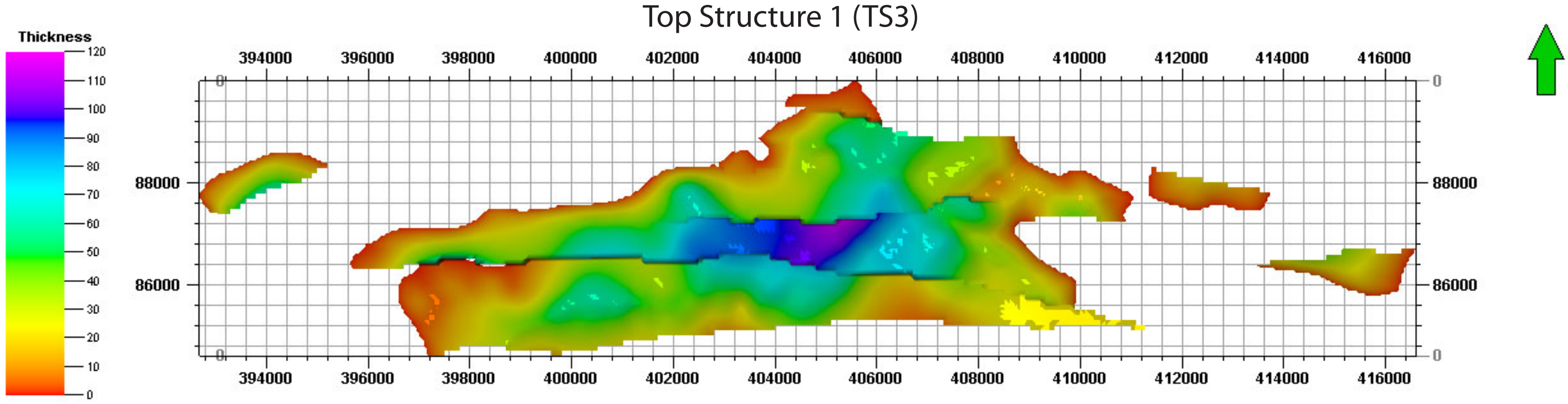
Top Structure 1 (TS1)



Top Structure 1 (TS2)



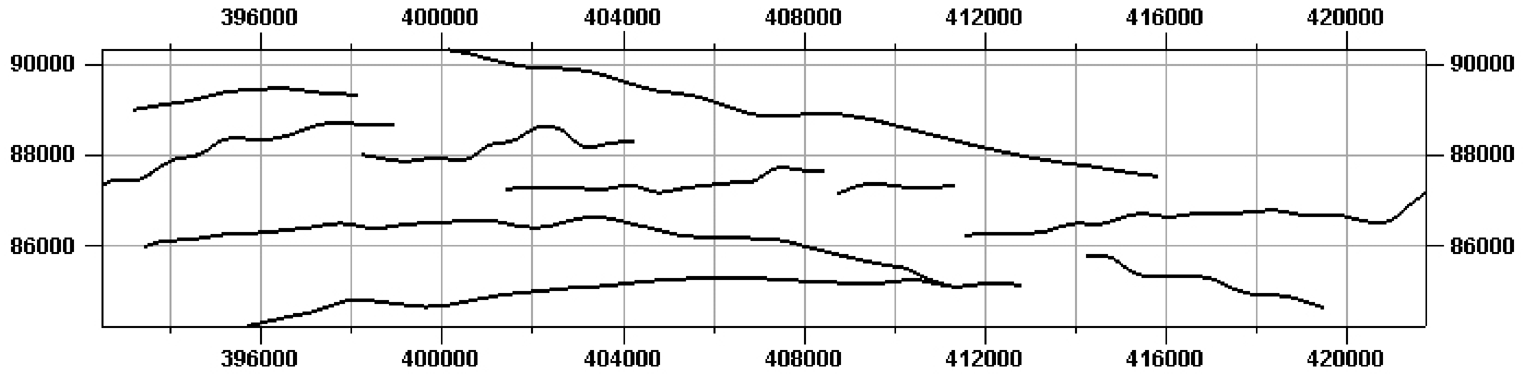
Top Structure 1 (TS3)



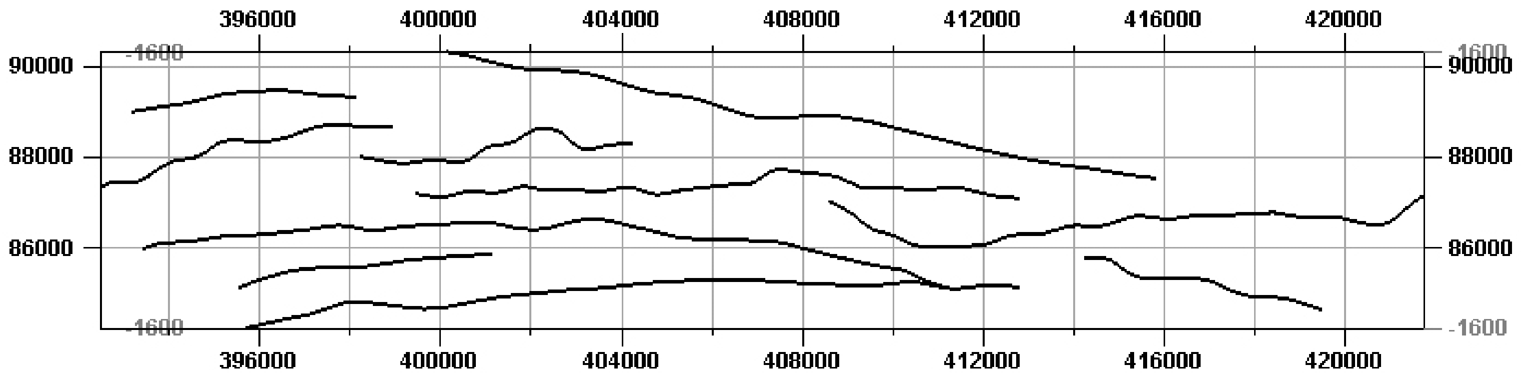
Fault network definition

FAULT MODELS

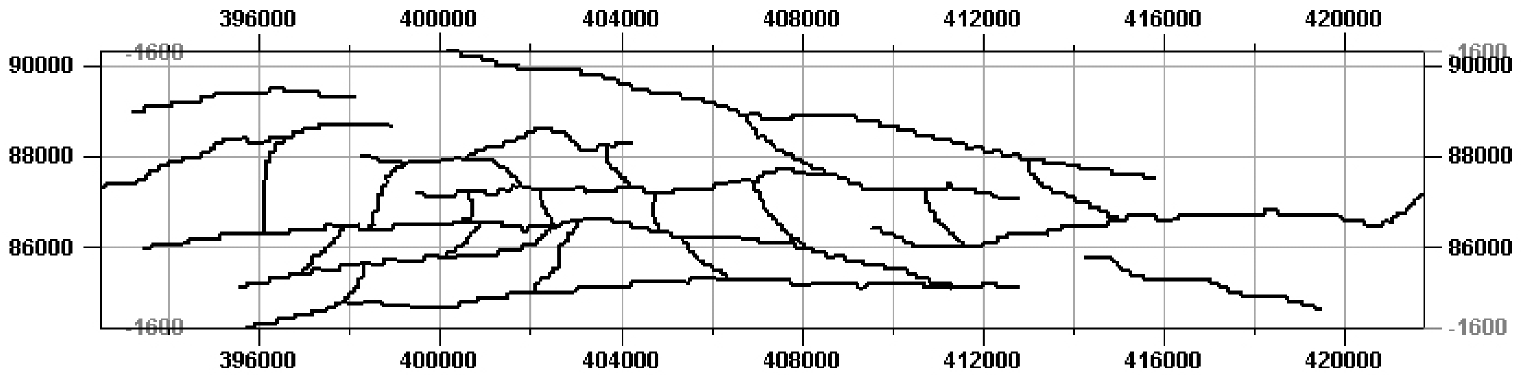
FAULT MODEL 1



FAULT MODEL 2

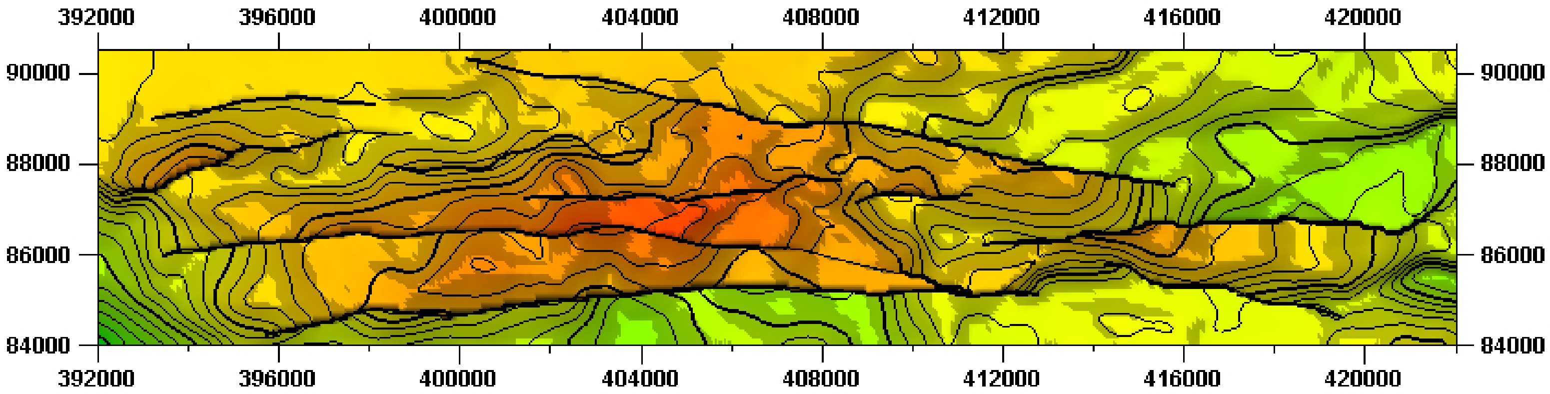


FAULT MODEL 3



TOP STRUCTURE 2

FAULT MODEL 1



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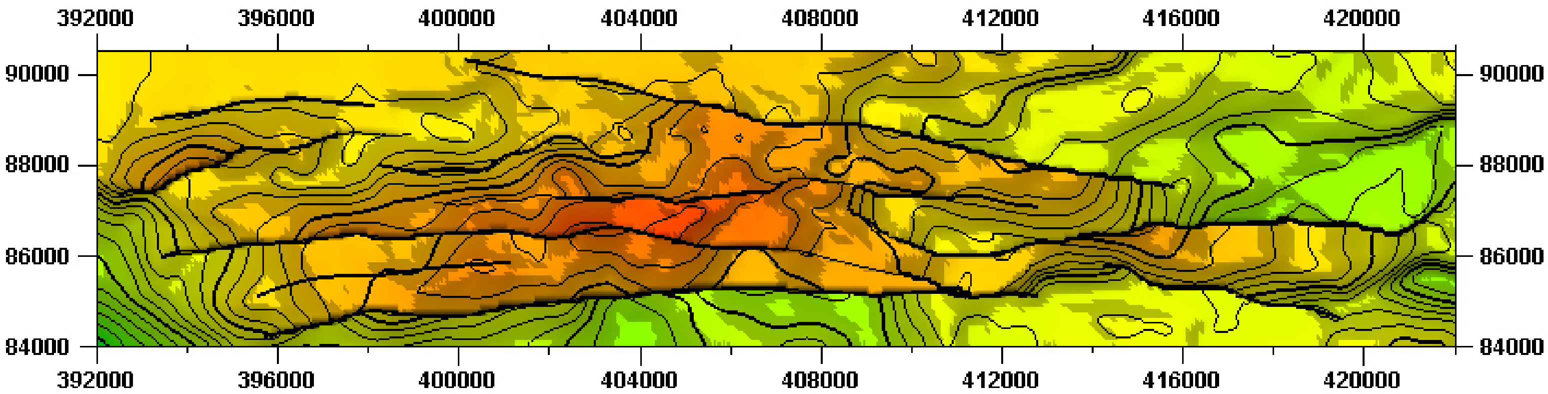

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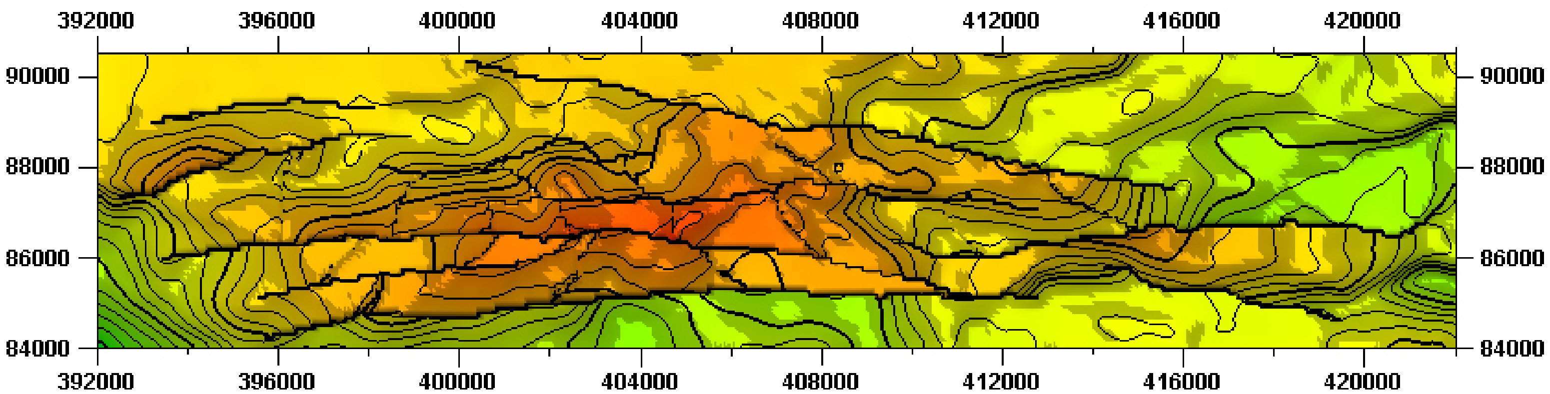
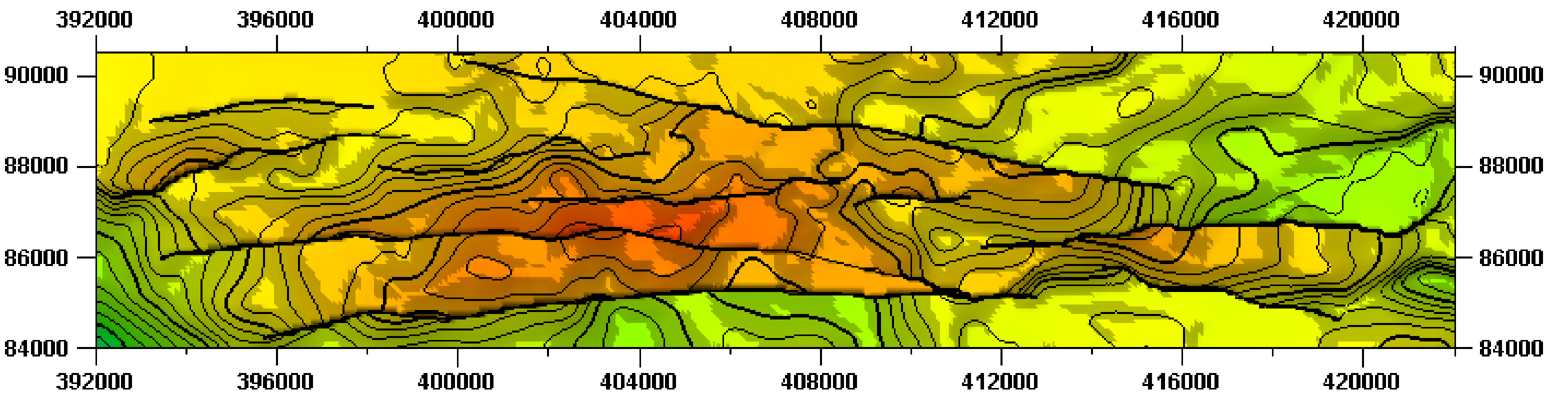


TOP STRUCTURE 1

FAULT MODEL 1



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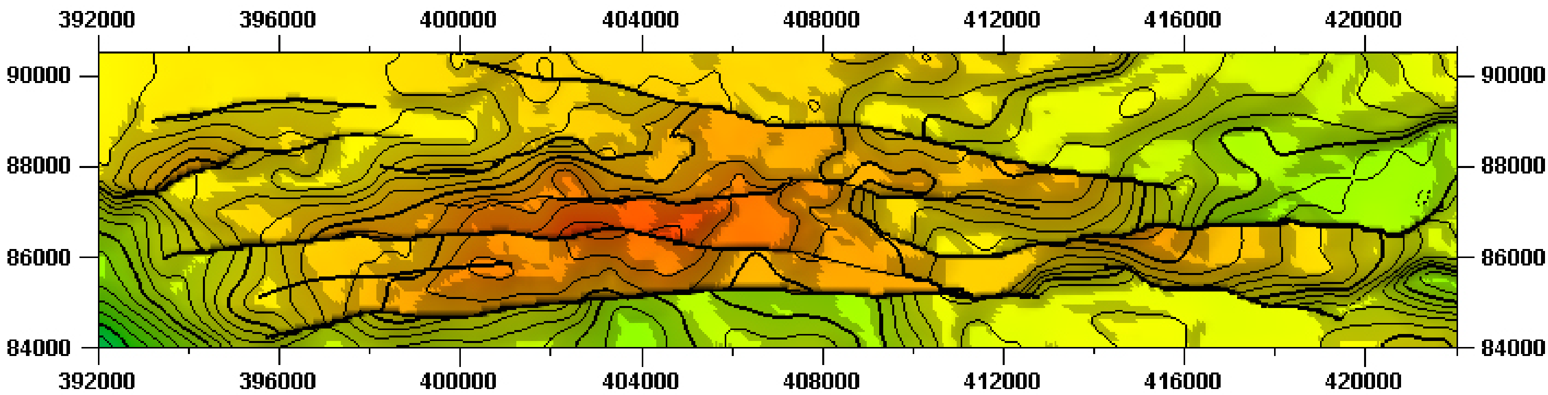

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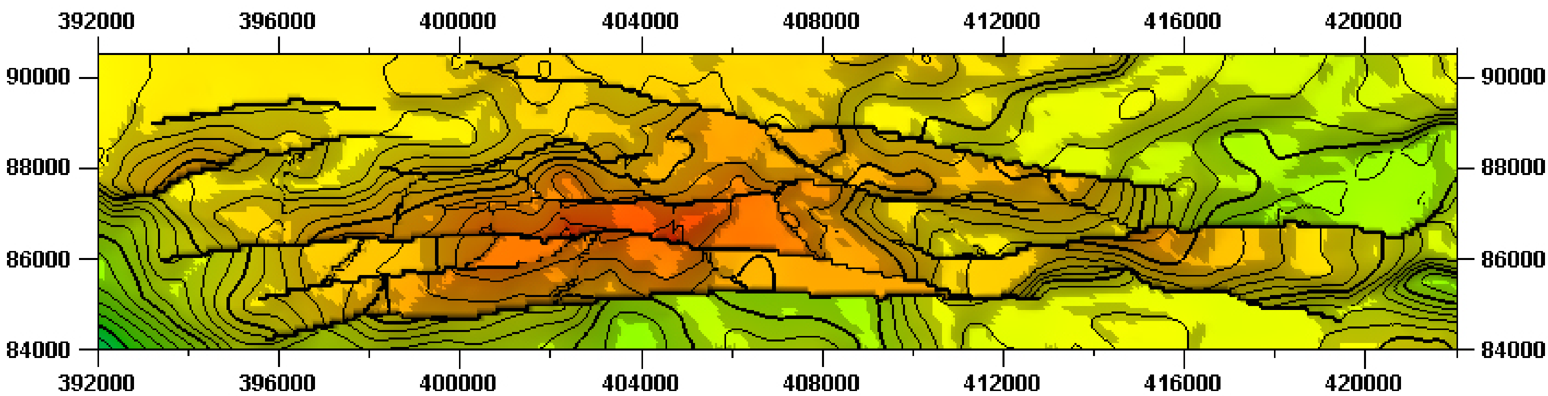
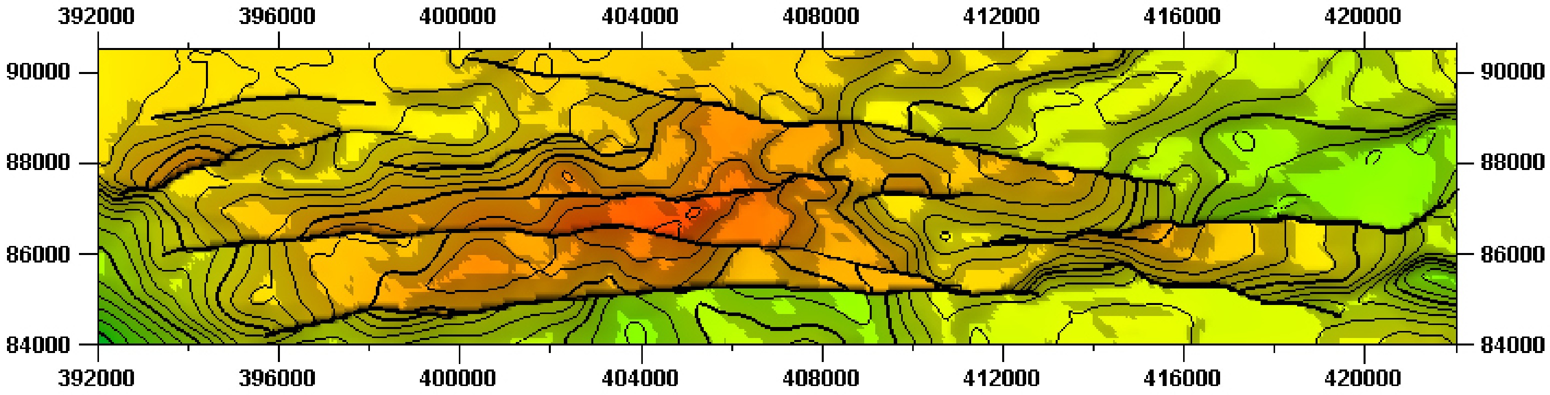


TOP STRUCTURE 3

FAULT MODEL 1



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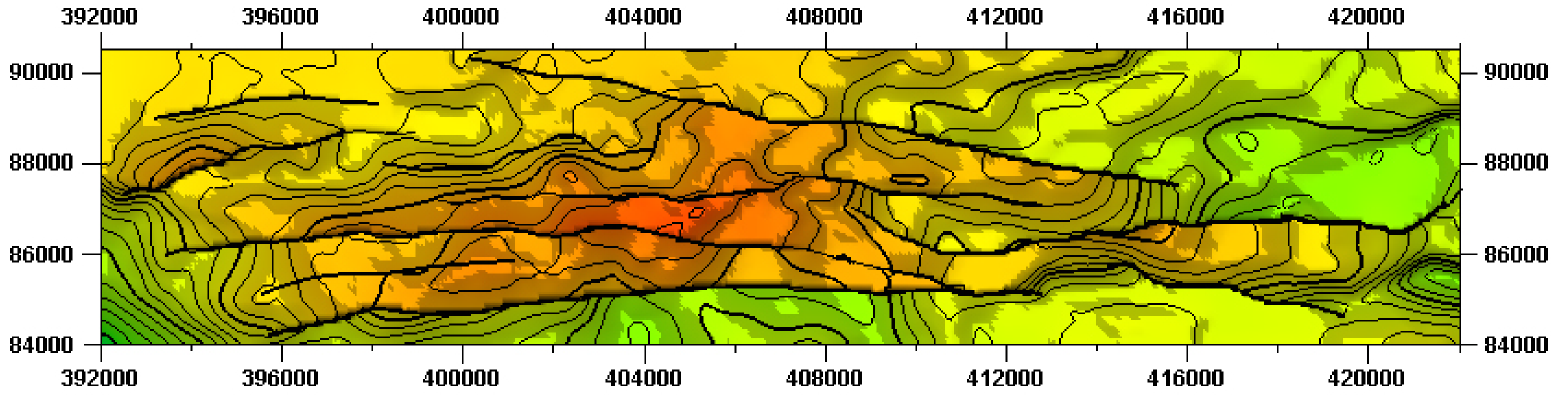
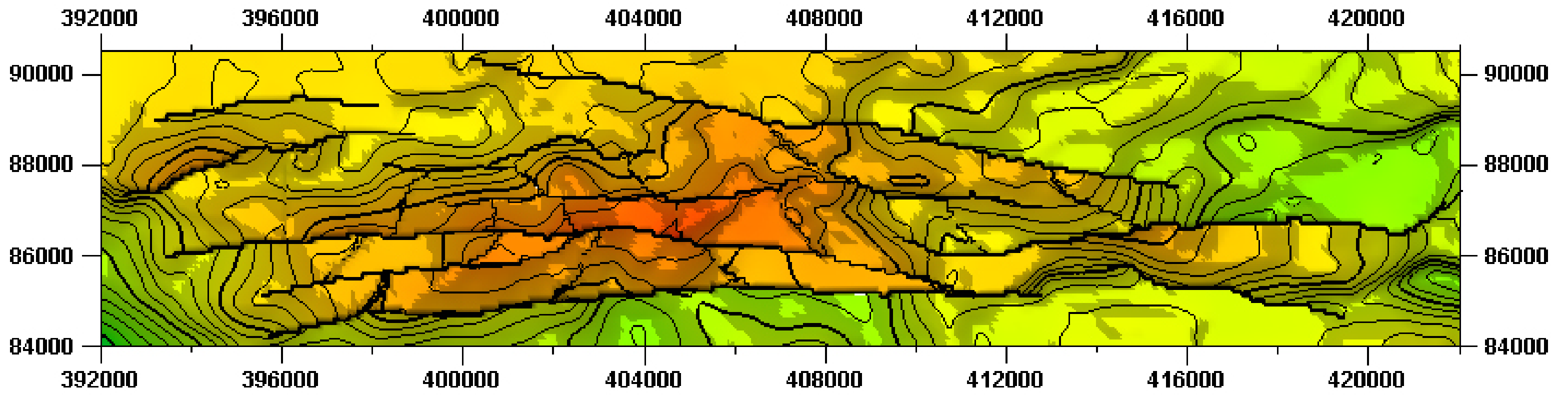


FAULT MODEL 3



Grid resolution

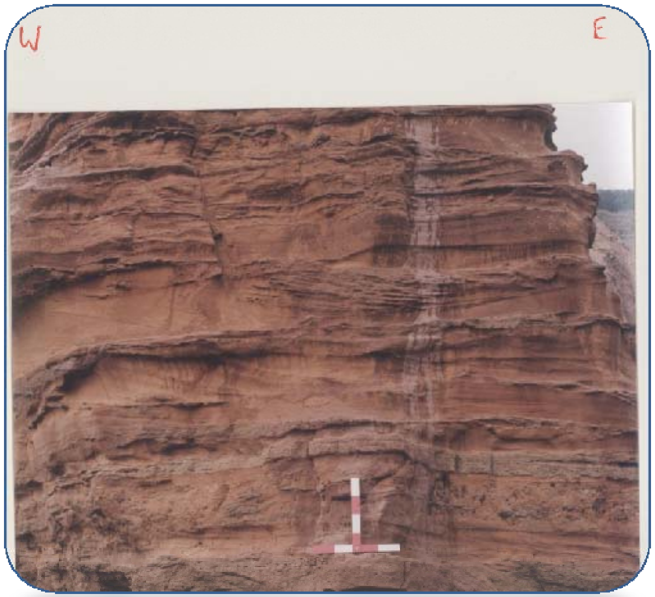
	200 * 200 * 5	100 * 100 * 10	100 * 100 * 5
Grid cell count	112 * 30 * 40	226 * 59 * 21	226 * 59 * 40
Grid cell dimensions	200m * 200m * 5m	100m * 100m * 10m	100m * 100m * 5m
Total number of cells	134,400	280,014	533,360

Figure 1: Model Grid dimension for fine and coarse grid options provided.

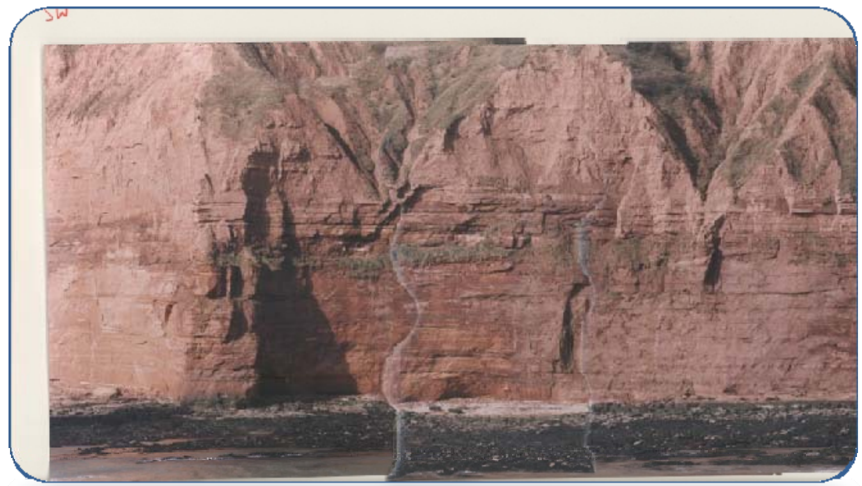
Facies modelling approach

The spatial modelling approach applied to this reservoir is left to the individual researcher. To help we have identified dimensions of common structures in braided systems so you can use the data in an appropriate modelling approach.

Otter Sandstone



- Dune? and Braided Fluvial Origin
- Triassic Otter Sandstone South Devon



- Calcrete Rich
- Primary Structure Dominated by Trough Cross Bedding

Otter Sandstone

Gross	100 m – 180 m
Net:Gross	~80%
Channel Thickness	1-8 m
Width-Thickness Ratio	High (very laterally extensive)
Stacking Patterns	Multi-Storey and Multi-Lateral

- Lateral and vertical amalgamations
- Trough cross bedding indicates braided fluvial system(No clear signs of Lateral accretion units)
- 20-30% Porosity in SST but calcrete plugs reduces to ~10%
- Higher NTG than Well A

Montanana – Castisent Sandstone

- Tremp-Graus Sub-basin
- Southern Pyrenean Basin
- Meandering fluvial system

Montanana – Castisent Sandstone

Gross	Up to 40 m
Net:Gross	40 -45%
Channel Thickness	2-3 m
Width-Thickness Ratio	~12:1
Stacking Patterns	Lateral accretion units, composite multi-storey/multilateral sandstone bodies

- Upward fining sequences
- Net pay in point bar sandbodies

Olson - Escanilla Formation

- Olson Area
- Meandering
- Ainsa Basin

Olson - Escanilla Formation

Gross	80m
Net:Gross	32 %
Channel Thickness	3-6m
Width-Thickness Ratio	10:1 – 50:1
Stacking Patterns	Single storey and multi storey

Villanova de Prades – Montsant system

- Alluvial Fan

- Fan / Distributary system
- Southern Ebro Basin
- Basin margin setting
- Stacked proximal conglomerates, becoming channelised laterally interbedded with mudstones/siltstones

Villanova de Prades – Montsant system

Gross	>100 m succession
Net:Gross	~30%
Channel Thickness	>2 m
Width-Thickness Ratio	High (very laterally extensive)
Stacking Patterns	Layered (interspersed w/ shales)

Huesca - Canal del Cinca

- Meandering
- Ebro Basin

- Distal part of Huesca system
- Isolated, laterally accreted sandbodies

Huesca - Canal del Cinca

Gross	10-15m
Net:Gross	~15%
Channel Thickness	1-1.5m
Width-Thickness Ratio	5:1 – 15:1
Stacking Patterns	Isolated sandbodies

- Laterally accreted sandbodies
- Fine sandstone floodplain deposits
- Low Net:Gross

Huesca - La Serreta

• Braided/Meandering

• Ebro Basin

• Multi-Storey and Multi-Lateral

• Medial to Proximal Position in Huesca Fluvial distributary System

•Amalgamated Channels

Huesca - La Serreta

Gross	20-30m
Net:Gross	50%
Channel Thickness	Mean 4 -5m Maximum 11m
Width-Thickness Ratio	15:1 – 25:1
Stacking Patterns	Multi-Storey and Multi-Lateral

- Intermediate Net:Gross
- 10 – 20% Proportion of Ribbon SST bodies out of total number of channel SST Bodies
- High Percentage of Channel SST 50 – 60%
- ~20% Overbank Sand & Silt
- ~20% Overbank fines

Huesca - Pertusa

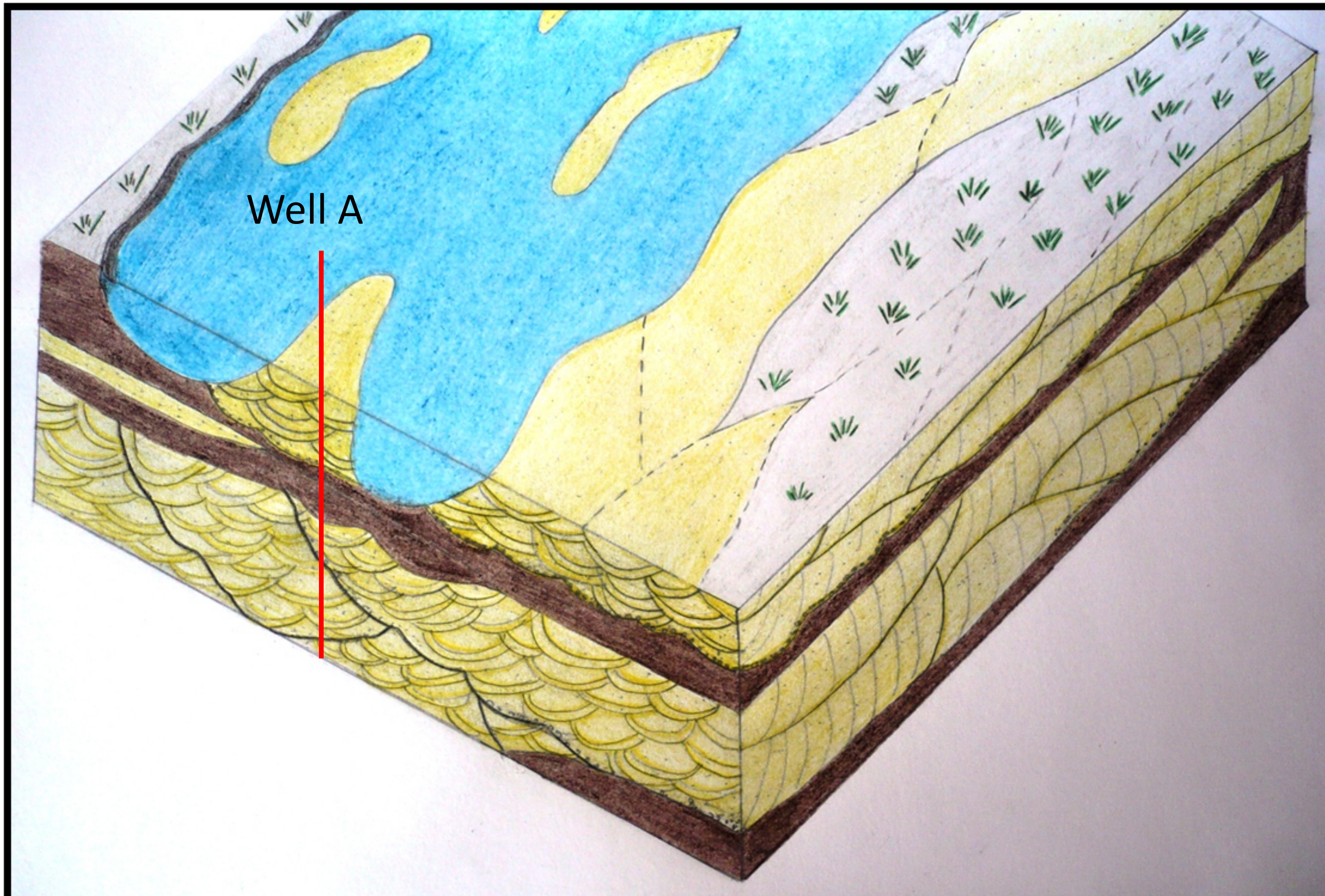
- More Proximal Position in Huesca Fluvial Distributary System
- Braided Fluvial System
- Ebro Basin

Huesca - Pertusa

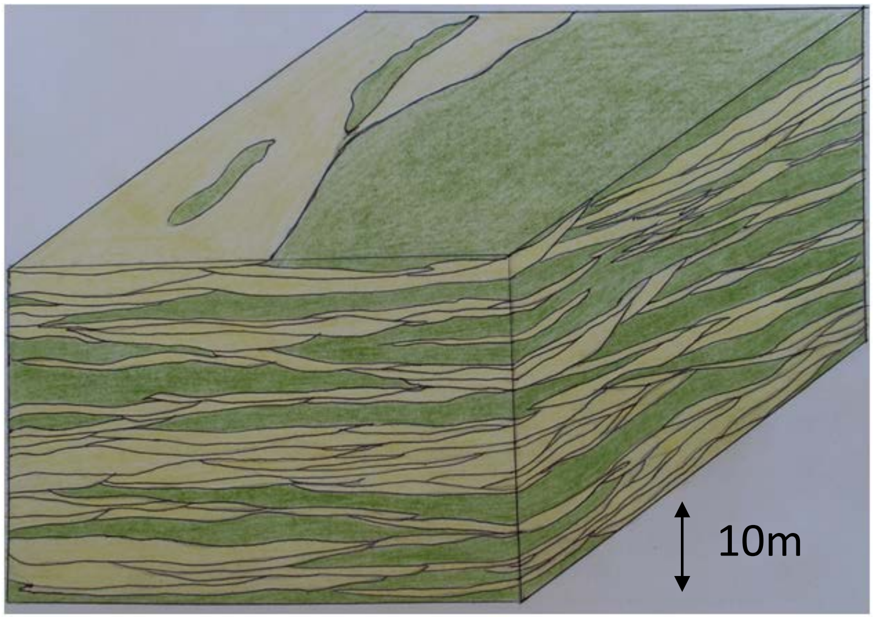
Gross	38 m
Net:Gross	60 % – 70 % (25m)
Channel Thickness	5-10 m
Width-Thickness Ratio	15:1-25:1
Stacking Patterns	Multi-storey/Multilateral

- High Net:Gross successions
- More proximal part of the fluvial distributary system
- Sandstone dominated channels

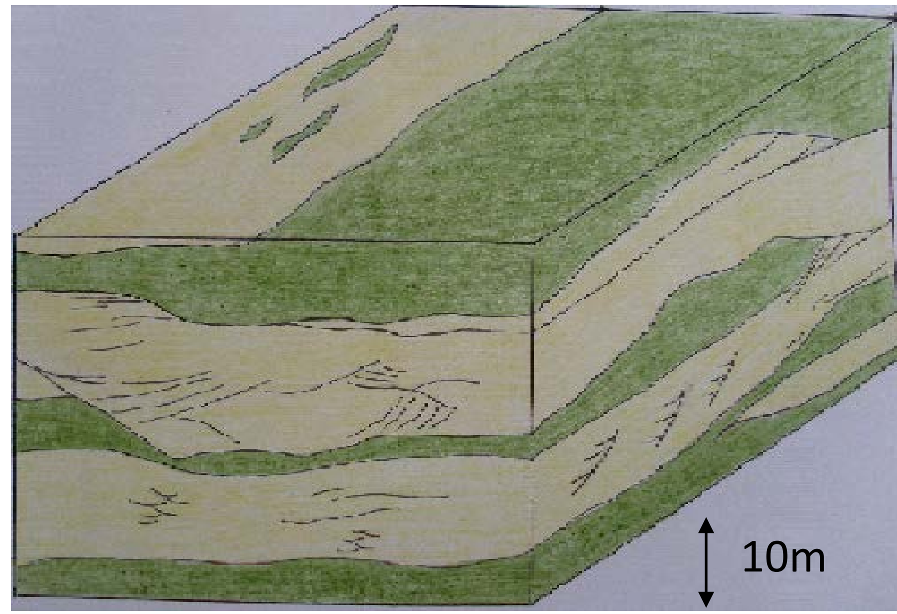
Well A Block Diagram



Geological model



Building block 1



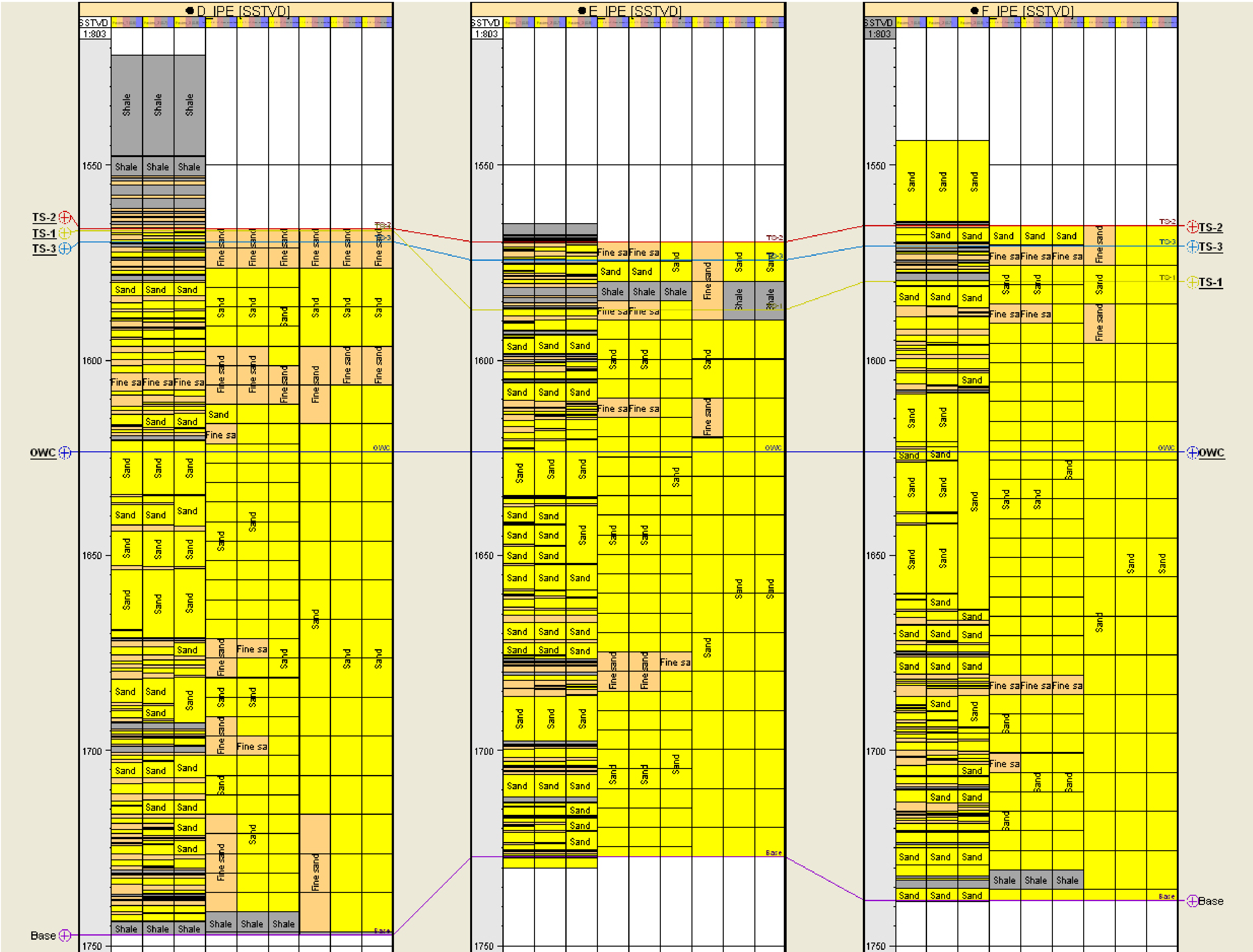
Building block 2

Training Image for Multipoint Statistics

Facies interpretations

Facies logs for wells A-C for RPD cutoffs 0.6, 0.7 and 0.8 for high res log, 5 m vertical grid and 10m vertical grid.

Facies logs for wells D-F for RPD cutoffs 0.6, 0.7 and 0.8 for high res log, 5 m vertical grid and 10m vertical grid.



Petrophysical property prediction

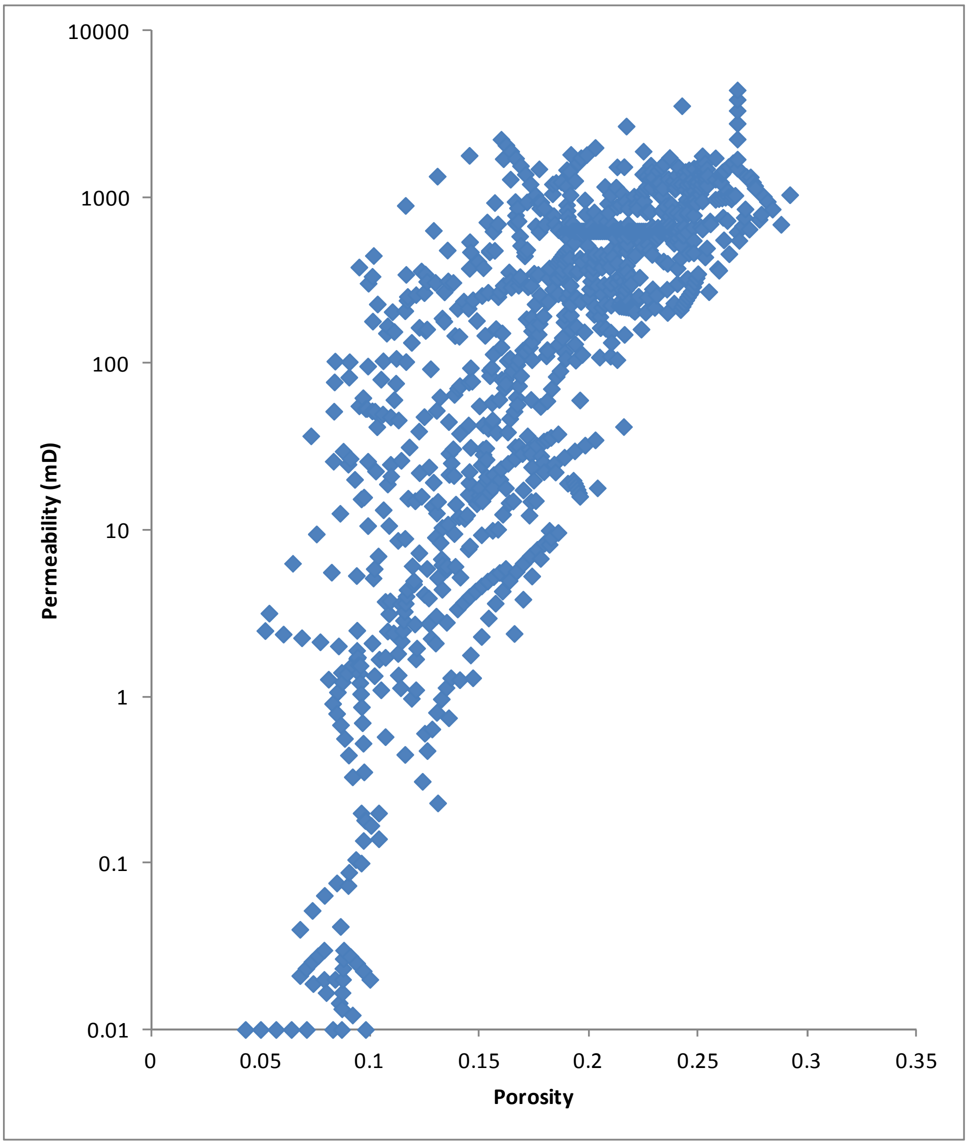


Figure 2: Porosity Permeability plot for Well A

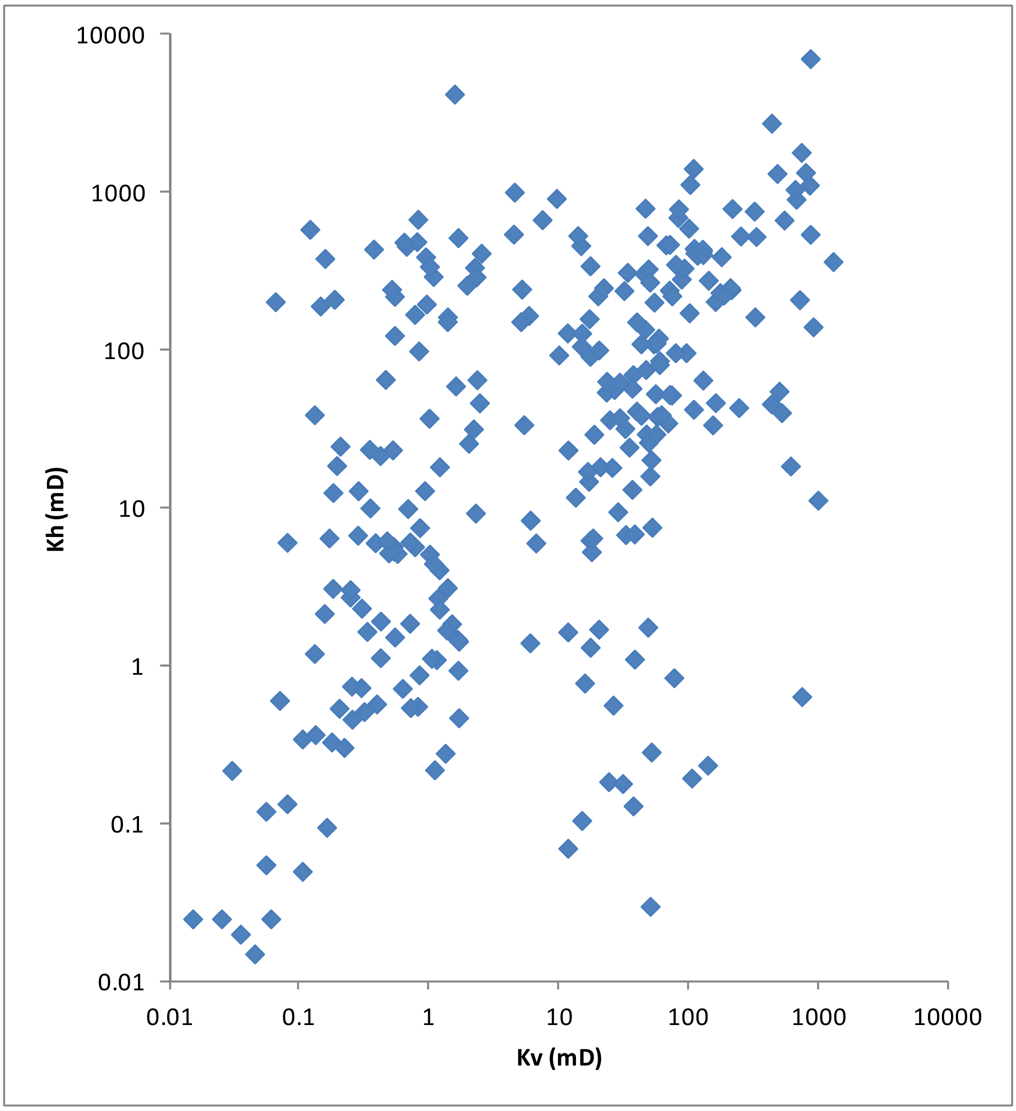


Figure 7: Kv/Kh for Well C

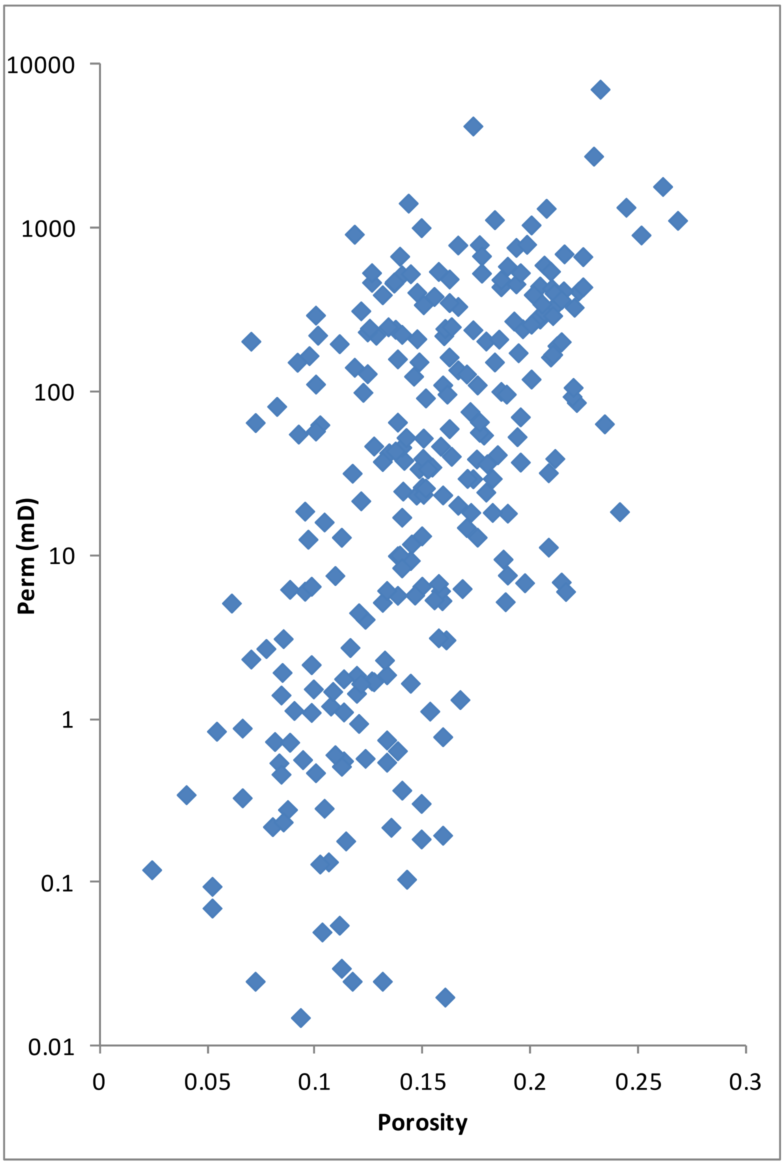


Figure 6: Porosity Permeability plot for Well C

Relative permeability data

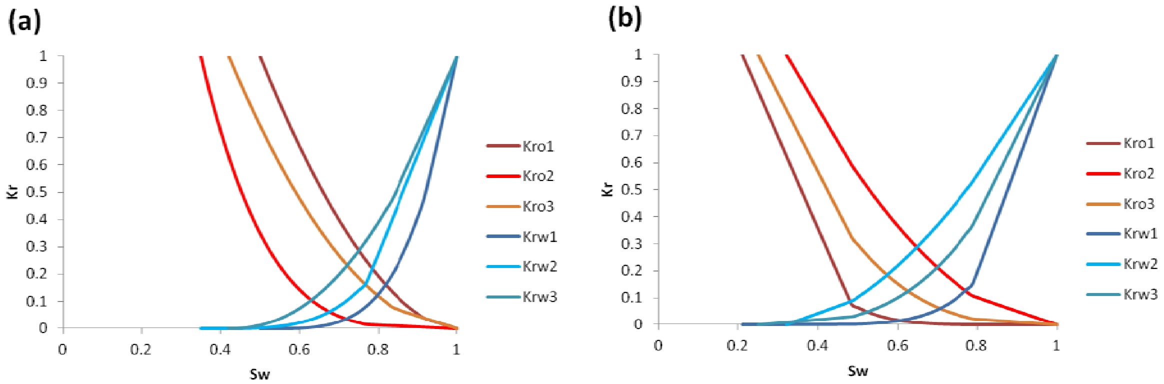


Figure 5: Relative permeability data gathered from wells A and C for (a) Fine sand (facies 1) and (b) Coarse sand (facies 0). A total of 6 samples are provided, 3 for each facies type. No data is provided for the shale facies.