[PS]Quantifying Uncertainties around Net Rock Volume: Application of Analogue Informed Facies Models*

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Search and Discovery Article #70311 (2017)**
Posted December 26, 2017

*Adapted from poster presentation give at AAPG International Conference and Exhibition, London, England, October 15-18, 2017

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Abstract

A key challenge for geomodellers is the identification and quantification of uncertainties, which become particularly difficult to handle when combining multiple geological concepts, data sources and modelling methods. In reservoirs with limited well control, it is important to incorporate appropriate analogue data to populate the inter-well volume. A novel approach is proposed here that allows for unbiased, analogue-informed modelling to directly control uncertainties in facies-modelling parameters, and to assess their impact on Net Rock Volume (NRV). A case study of a 'braided' fluvial reservoir succession, offshore NW Australia, penetrated by five wells, is used to demonstrate this novel approach. Data contained within the Fluvial Architectural Knowledge Transfer System (FAKTS) database, which stores data on fluvial sedimentary units from multiple analogues, is used to generate several scenarios that represent end-member depositional concepts. Raw data were converted from FAKTS into input parameters for direct application in facies modelling algorithms. The uncertainty range of each parameter was captured as part of the conversion, before being applied to uncertainty workflows. The relative impact of all parameters is shown through tornado plots. The impact when utilizing object- vs. pixel-based methods, including their influence on ranges of NRV, was also explored. Traditional random seed modelling on its own predicts little to no difference in NRV since the percentage of sand (Net-to-Gross) was fixed. Changing the size of the geobodies had similar results, as the desired sand percentage could be attained by altering the number of channel bodies. However, object dimensions do affect the reservoir architecture and therefore the potential connected hydrocarbon volume. By comparing the connected sand volume per well, the impact of the dimensional uncertainty on recovery was determined. To assess the impact of different depositional environments, different ranges of sand percentage were considered. To assess the impact of different algorithms, the percentage of sand was altered systematically for each algorithm. This allowed determination of noise level and quantification of the effect of algorithm choice. By combining different concepts and approaches, and linking them to analogue data, the full uncertainty space associated with facies modelling of the chosen field was assessed. The demonstrated methodology is repeatable in application to other reservoirs.

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Quantifying uncertainties around Net Rock Volume: application of analogue-informed facies models

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Introduction

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In reservoirs with limited well control, it is important to incorporate appropriate analogue data to populate the inter-well volume. A novel approach is proposed here that allows for unbiased, analogue-informed modelling to directly control uncertainties in facies-modelling parameters, and to assess their impact on Net Rock Volume (NRV).

A case study of a fluvial reservoir succession, offshore NW Australia, penetrated by 5 wells, is used to demonstrate this novel approach. Data contained within the Fluvial Architectural Knowledge Transfer System (FAKTS) database, which stores data on fluvial sedimentary units from multiple analogues, is used to generate several scenarios that represent end-member depositional concepts. Raw data were converted from FAKTS into input parameters for direct application in facies modelling algorithms. The uncertainty range of each parameter was captured as part of the conversion, before being applied to uncertainty workflows. The relative impact of all parameters is shown through tornado plots. The impact when utilizing object- vs. pixel- based methods, including their influence on ranges of NRV, was also explored.

1. The Database

Fluvial Architecture Knowledge Transfer System

FAKTS is a research-led flagship initiative of the Fluvial Research Group (FRG) at the University of Leeds. It is a relational database storing hard and soft data about fluvial sedimentary architecture, populated with data derived from both original FRG fieldwork studies and peer-reviewed literature syntheses. The database integrates information from both modern rivers and ancient outcrop examples; selected because they represent potential analogues to hydrocarbon reservoirs hosted in fluvial rocks.

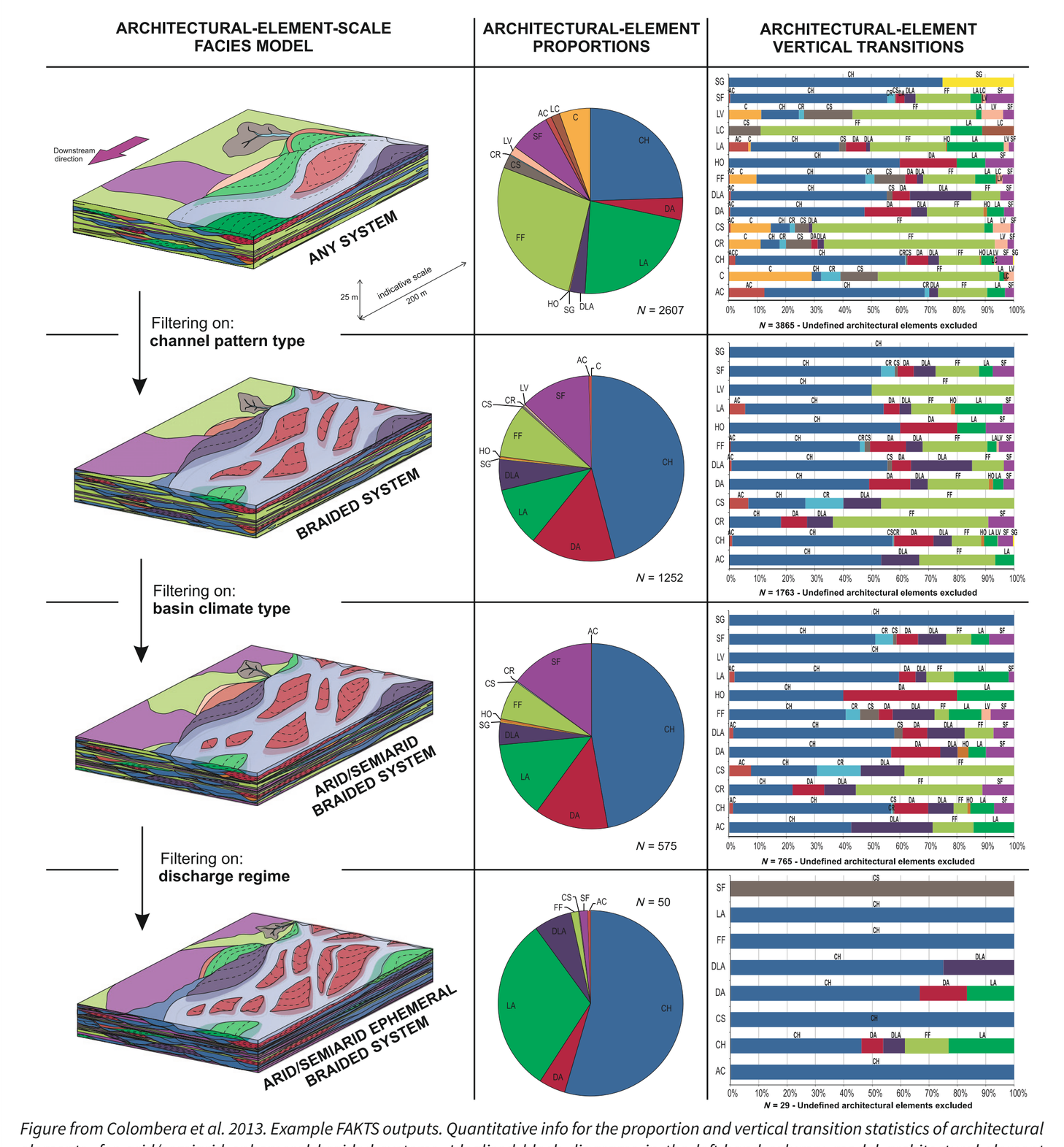
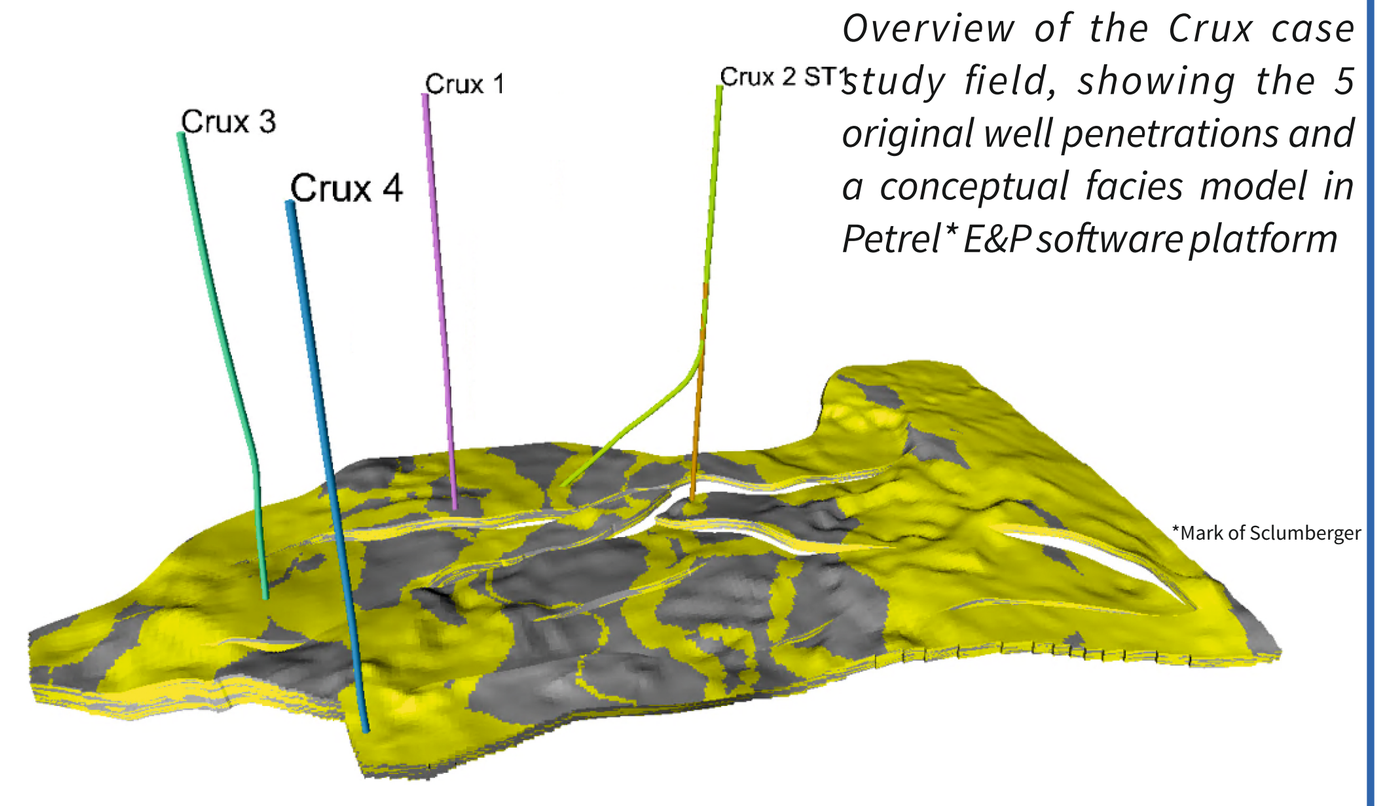


Figure from Colombera et al. 2013. Example FAKTS outputs. Quantitative info for the proportion and vertical transition statistics of architectural elements, for arid/semiarid ephemeral braided systems. Idealised block diagrams in the left-hand column; model architectural-element proportions, presented as pie-charts in the central column, vertical transition statistics are presented in the righthand column as bar charts quantifying the percentage of types of 'upper' elements (colour-coded and labelled in the bars) stacked on top of a given type of 'lower' element (labels on the vertical axis).

2. Parameterising of Depositional Concepts

Converting raw analogue data straight into modelling parameters

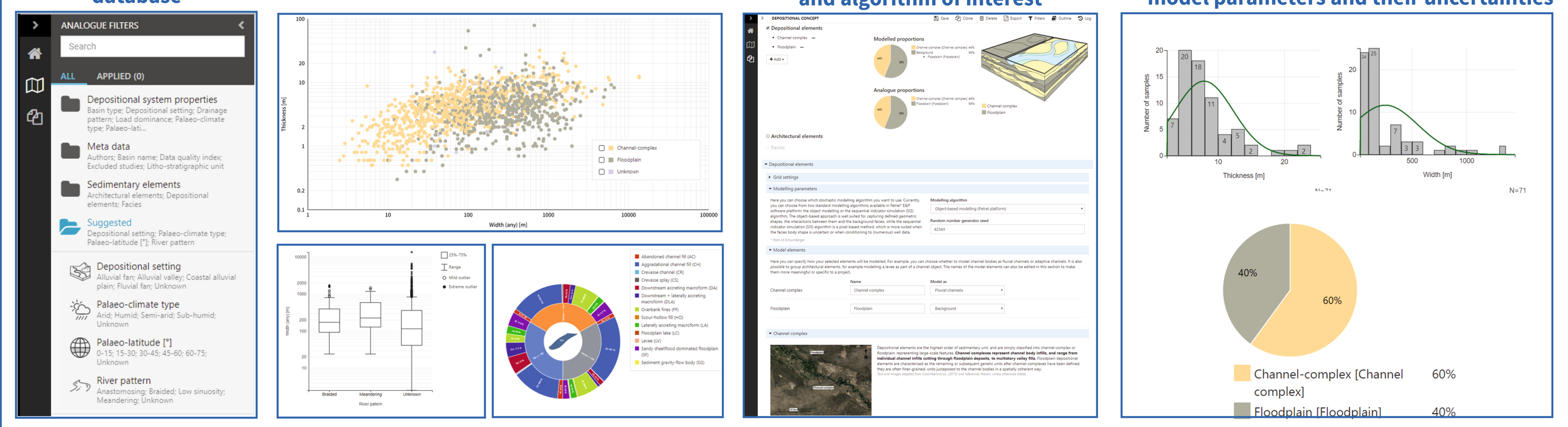
We have used Ava Clastics [reservoir modelling software that uses automated parameterisation of modern and ancient analogues to directly inform facies modelling algorithms] to explore the FAKTS database and to find filters that would represent the depositional concepts in mind for the Nome A Sandstone of the Crux field, NW Australia. Within the tool is an automatic conversion mechanism called GeoCypher™. This tool takes a filtered subset of the analogues and transforms that into parameters for a selected facies modelling algorithm. This gave us to possibility to quickly inform both geobody dimensions for object based models and generating variograms for sequential indicator simulation in a systematic way.



Overview of the Crux case study field, showing the 5 original well penetrations and a conceptual facies model in Petrel E&P software platform*

*Mark of Schlumberger

The Workflow:



The generic workflow steps going through the Ava Clastics tool to go from exploring analogue data to assessing model input parameters and their uncertainties.

3. Case Study: Crux Field

Rather than creating a purely synthetic model grid and testing the algorithm behaviour there, we have opted for increased realism by employing a case study. This also allowed for a more realistic workflow for finding and applying suitable analogue data, which typically is a pain point for many geomodellers.

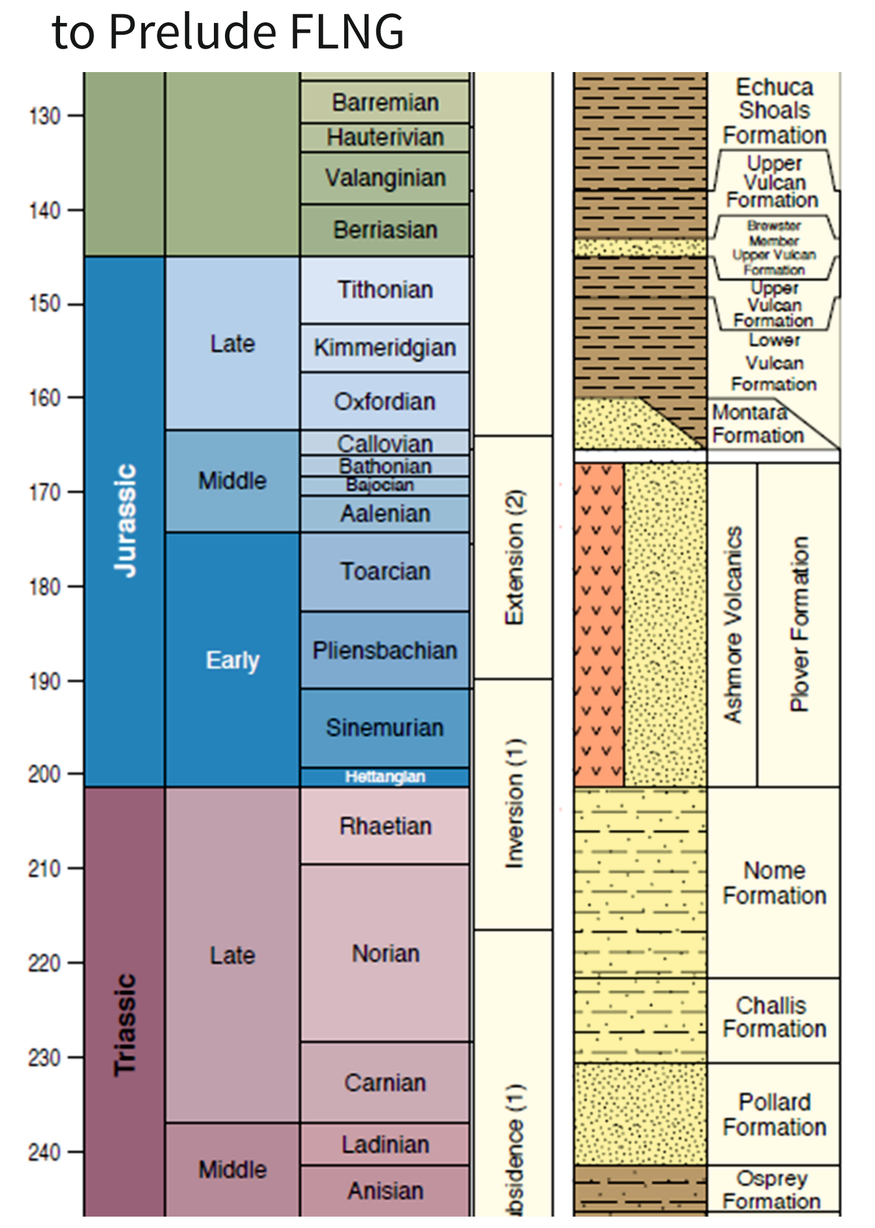
Our case study focuses on one particular reservoir section called the Nome A Sandstone of the Crux field, NW Australia.

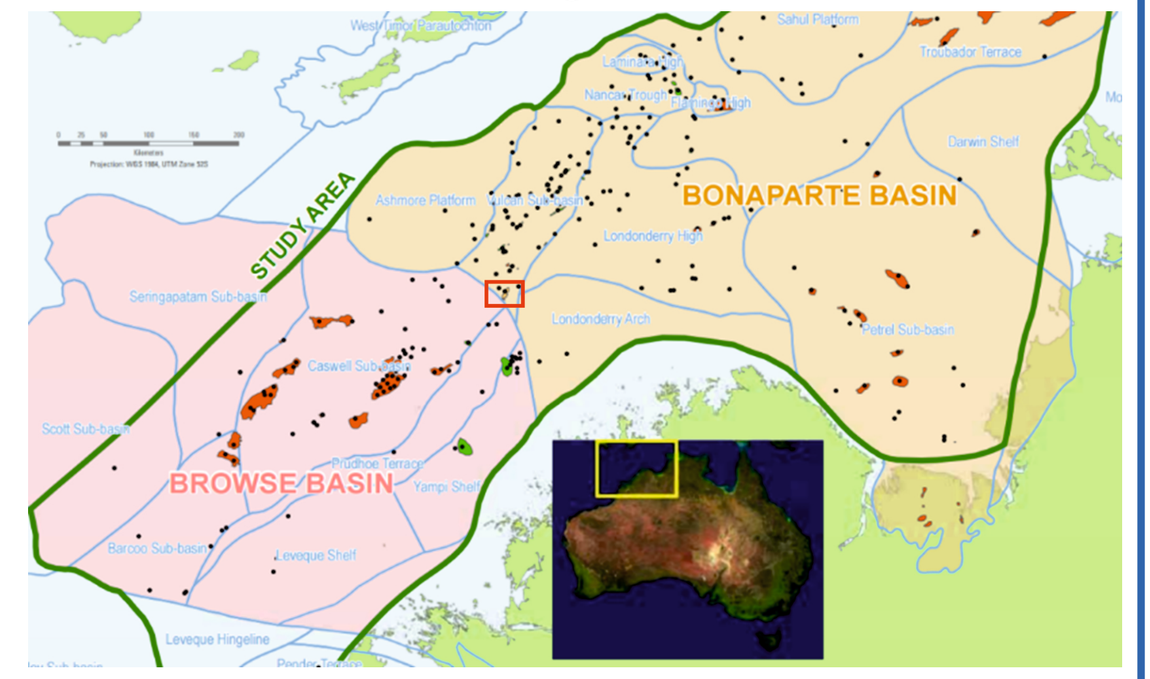
A short summary of the field

- The Crux field is located on the edge of the Browse Basin (Heywood Graben), offshore Northern Australia
- Paleozoic to Cenozoic depocentre in excess of 15.000m of sediments (Struckmeyer et al., 1998)
- First wildcat (Crux1) drilled in 2004 by Nexus energy encountered a 244m gas column
- Following the discovery, Nexus energy continued the appraisal of the Crux gas field (2006-2008) with shooting of 3D seismic and drilling of Crux2, Crux2-ST1, Crux3 and Crux4 wells
- The Crux Field contains ~2.2 TCF but is not yet in production
- Several development concepts are under consideration; including standalone FLNG facility or backfill to Prelude FLNG

History of the Browse Basin

- Basin was initiated as a series of extensional half-grabens established during the Permian (break-up of Pangea)
- Late Triassic to Early Jurassic compressional reactivation resulted in partial inversion of half-graben geometries and the formation of large scale anticlinal and synclinal features
- An Early to Middle Jurassic extensional phase resulted in faulting overprint and collapse of Triassic anticlines (origin of Heywood graben)
- From the Late Jurassic to the Cenozoic, accommodation space was controlled by the interplay of thermal subsidence, minor reactivation events and eustasy.
- Reservoir facies are best developed within the fluvio-deltaic Jurassic Plover Formation
- Upper Jurassic – Lower Cretaceous (Vulcan fm.) and Lower Cretaceous (Echuca Shoals) claystones provide regional seals throughout basin
- The Nome Formation of the Triassic is the main reservoir rock in the region



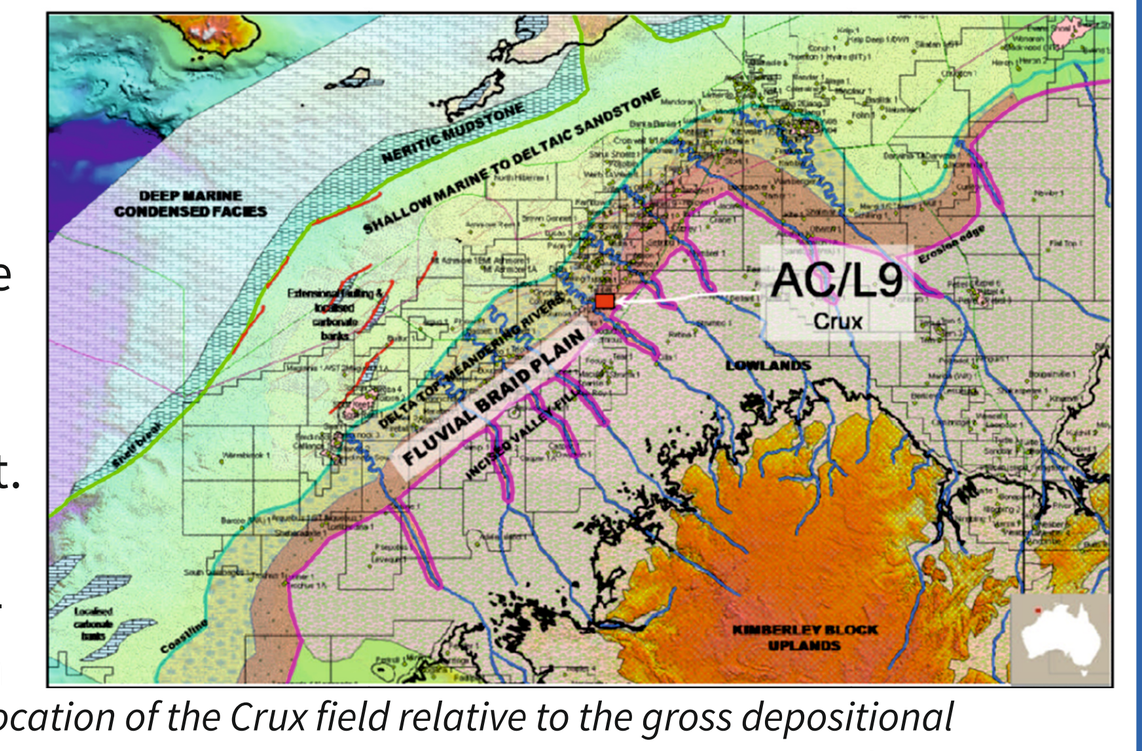


ABOVE: Overview of the Browse and Bonaparte basins and their sub-basins. The Crux field is located in the Heywood Graben on the edge of the Browse basin, offshore NW Australia. (TGS 2016 Australian Acreage Release)

LEFT: Tectonostratigraphic Chart (Modified after Kelman et al. 2014) of the Browse Basin

Nome A Sandstone depositional model

- The Triassic Nome Formation exhibits very high NTG; in some instances >80%. The sands are interpreted as being deposited in a high energy braided fluvial environment.
- A palaeogeographic reconstruction has implied that the sediment provenance (Kimberley Block Uplands) was situated to the SE of the field and the coastline at time of deposition of the reservoir rock was approximately 50km to the northwest.
- The consistency between reservoir properties of the Crux-2ST1 and Crux-3 wells suggests little lateral variation in reservoir quality of the Nome Sands.



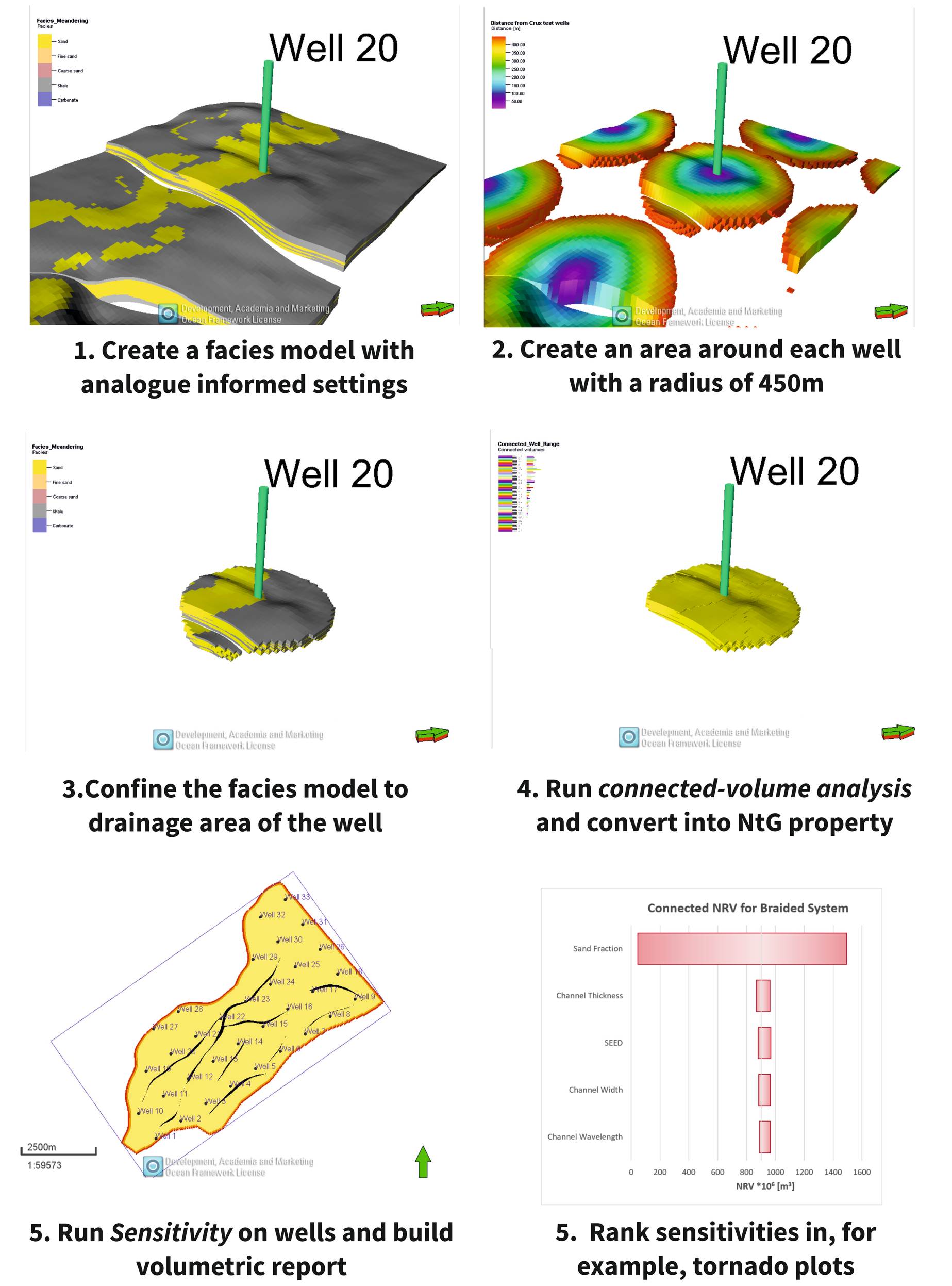
Location of the Crux field relative to the gross depositional environments, which places the crux area on a belt of braided plains. (Nexus Energy Crux-4 well completion report)

4. Methods for Connected NRV

Total Net Rock Volume (NRV) is very useful in field assessments, but does not always give a realistic pre-cursor to the real recovery from flow simulation. Here we hope to get at least some handle on how different geological scenarios and different facies modelling algorithms behave when focusing on the volume of connected sand rather than the total (potentially partly-connected) sand.

- In order to rule out the effect of a single well location, we have created 33 'dummy' wells, equally spaced throughout the model at 1000x1000m.
- Well influence radius (used as analogue for drainage area) is set to 450m to prevent the 'double-counting' of volume by overlapping areas.
- We have assumed the faults to be sealing – to allow for an additional look into areas where well placement does play a role.
- We used the Petrel E&P software platform* to perform the facies model runs and Ava Clastics was used as the source for the analogue data and the generation of facies modelling input parameters.

Calculating the connected Net Rock Volume in each sensitivity run



Graphic representation of the workflow used to calculate and report on the connected Net Rock Volume.

Calculation of 'Kept sand %'

To compare the modelling scenarios and investigate the influence of Sand fraction, we wanted to see how much of the targeted NtG for each run was preserved as connected sand in range of the wells. For this we created the 'Kept sand %' which effectively is the amount of connected sand as a fraction of the targeted sand fraction.

Example:

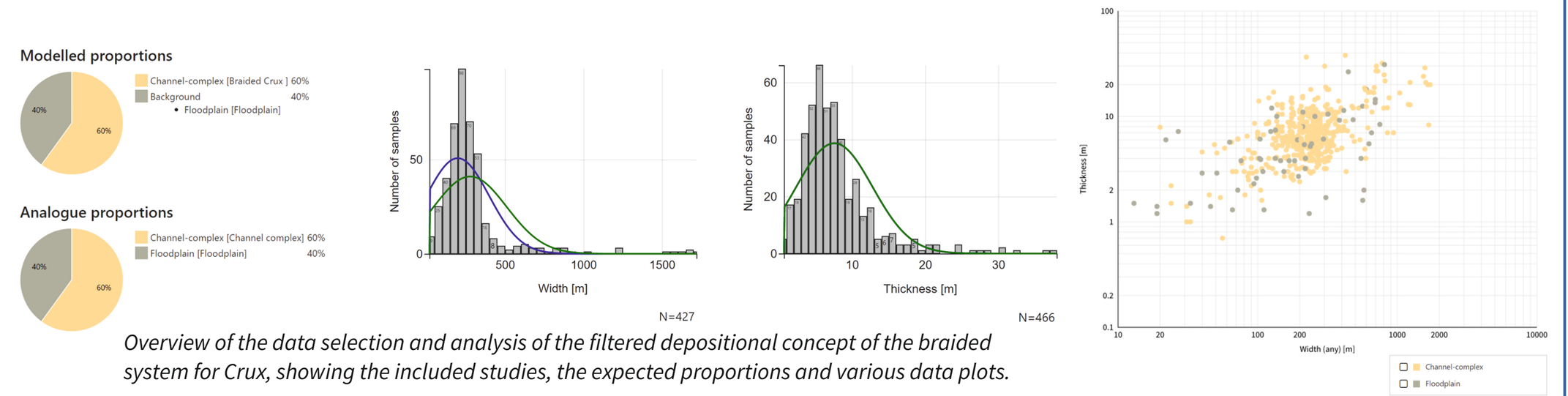
- Facies modelling run with Channel Fraction = 20%
- Bulk volume around the well: 100*106 m3
- Reported Connected Sand: 10*106 m3
- Modeled Sand fraction is 10%, half of the targeted sand fraction was either not modeled or not connected with the well. Resulting in a 'Kept sand %' of 50%

*Mark of Sclumberger

5a. Object Based: Braided System

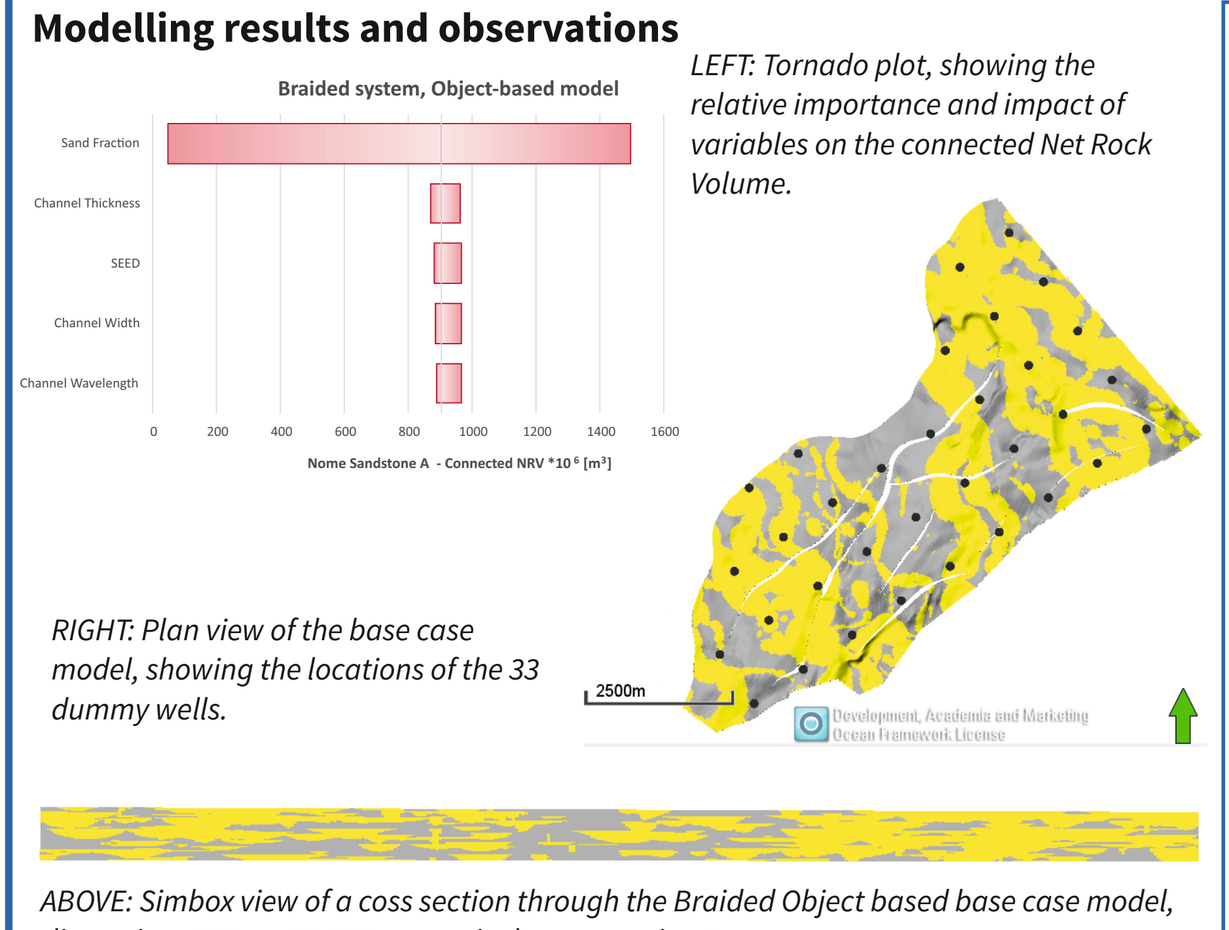
By only using literature data specifically for Crux, we would not have had enough data to inform all the input parameters needed for an Object Based model run. Therefore, we took suggestions from literature to filter the FAKTS database using Ava Clastics. Filters applied are set to rule out (Semi-) Humid Environments, but to include studies with a palaeo-latitude of 30-35° and identified as braided river systems.

Obtained analogue data and some of the resulting input parameter distributions



Overview of the data selection and analysis of the filtered depositional concept of the braided system for Crux, showing the included studies, the expected proportions and various data plots.

Modelling results and observations



LEFT: Tornado plot, showing the relative importance and impact of variables on the connected Net Rock Volume.

RIGHT: Plan view of the base case model, showing the locations of the 33 dummy wells.

ABOVE: Simbox view of a coss section through the Braided Object based base case model, dimensions 100m x 10.000m – vertical exaggeration 2x.

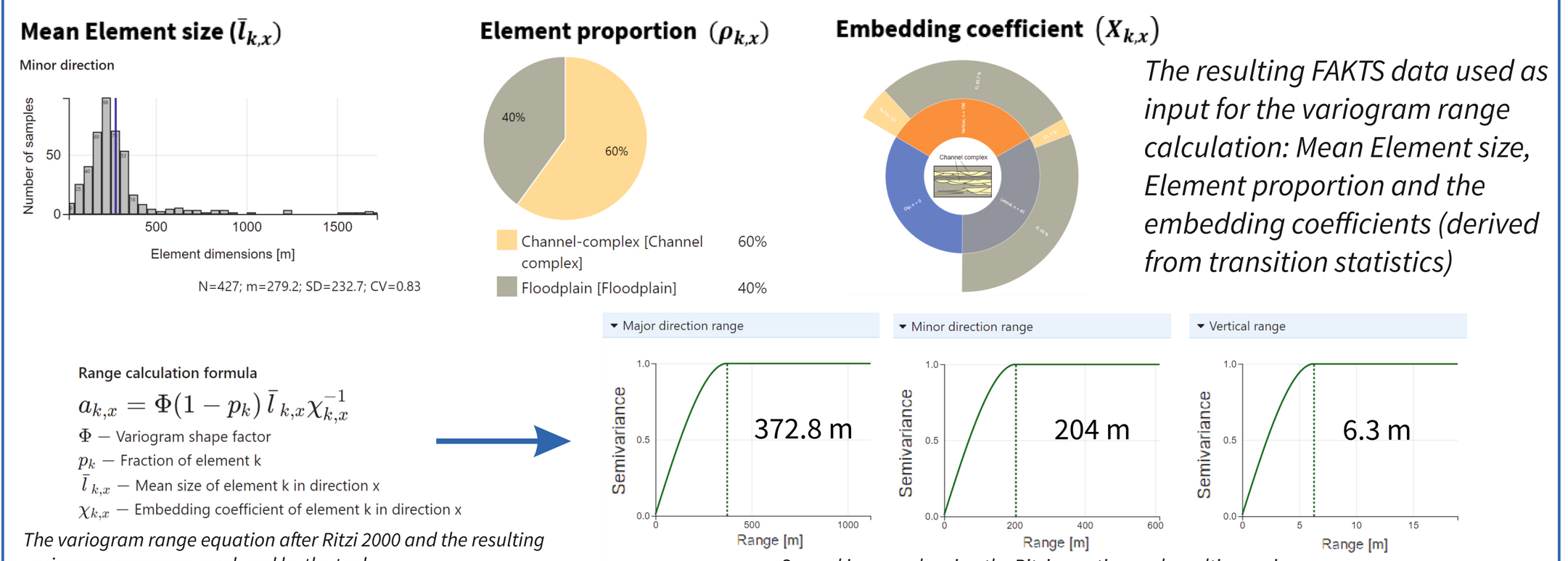
Observations

- All geo-statistical analysis of the data distributions coming from the filtered data.
- The impact of varying Sand Fraction on NtG is as expected.
- Channel thickness is controlling the vertical connectivity. Plan view sections suggested more disconnected sand patches, but this is counteracted by the channels linking up in the 3rd dimension.
- Within braided models, the wavelength is of lesser importance. Channels will be less tortuous resulting in fewer lateral connections.
- All parameters (other than Fraction) have a more positive effect on uncertainty of the connected NRV in the wells, this indicates that our base case was relatively poorly connected.
- Range of uncertainties for the 4 lesser variables certainty ranges were suggested by standard is around 10% with a base case sand fraction of 60%.

5b. Pixel Based: Braided System

In order to investigate the use of the same depositional concept, we used the same data from FAKTS, but now have selected a different modelling method in Petrel: Sequential Indicator Simulation. The key issue with using a pixel-based method is finding suitable ranges for variograms. For this method we have used the approach published by Ritzi (2000) that relates variogram range to data variability, element size, facies proportions and their respective embedding coefficients. The analogue database (FAKTS) will inform these parameters.

Using the same analogue data as for the OBM Braided models, but informing a different algorithm.

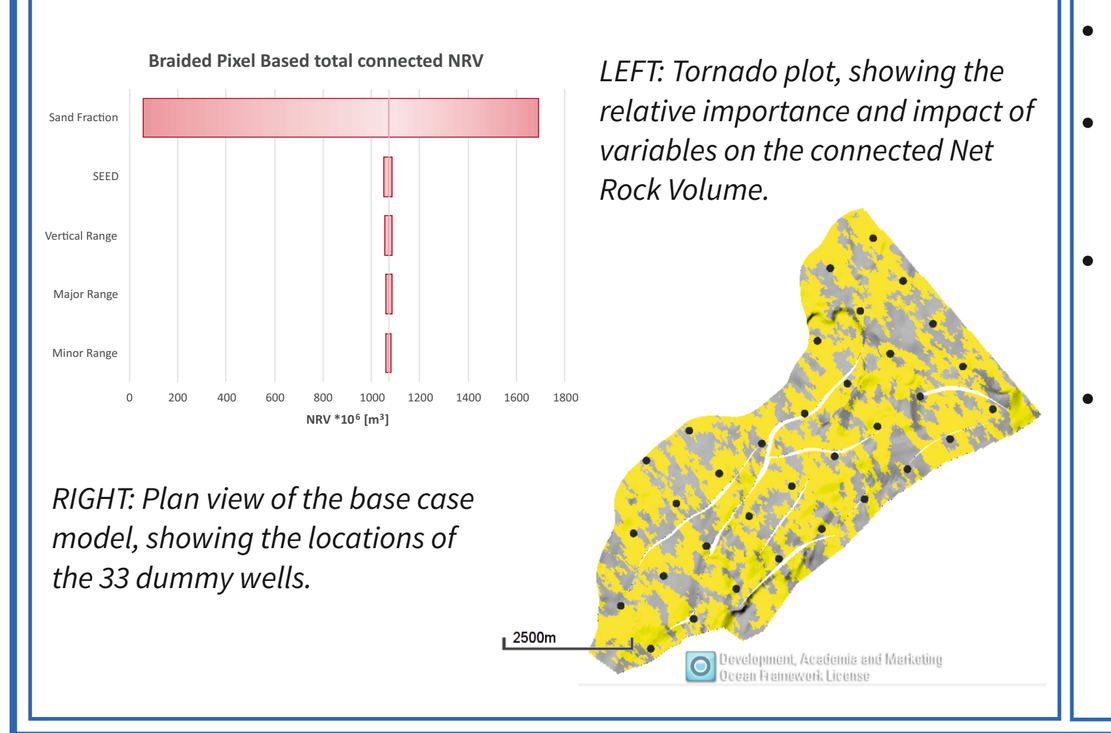


The resulting FAKTS data used as input for the variogram range calculation: Mean Element size, Element proportion and the embedding coefficients (derived from transition statistics)

The variogram range equation after Ritzi 2000 and the resulting variogram ranges as produced by the tool.

Several images showing the Ritzi equation and resulting variogram ranges

Modelling results and observations



LEFT: Tornado plot, showing the relative importance and impact of variables on the connected Net Rock Volume.

RIGHT: Plan view of the base case model, showing the locations of the 33 dummy wells.

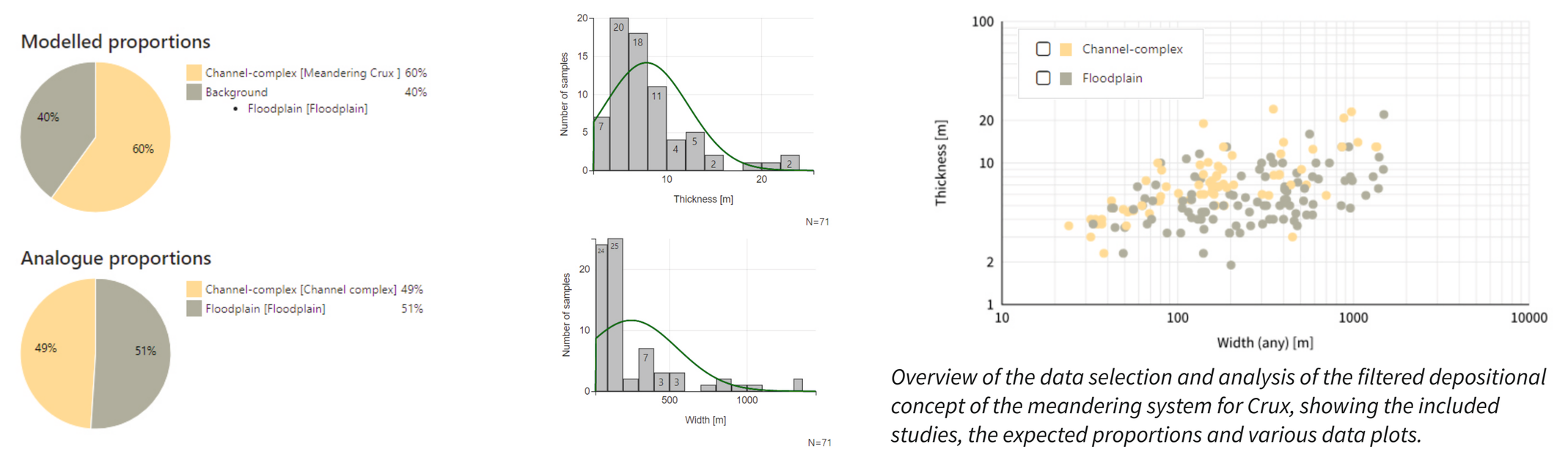
Observations

- Sand Fraction is the major control on the amount of connected sand in the model.
- Closer study of the fraction (see 6. kept sand analysis) shows that the base case fraction of 60%, already has > 97% of kept sand, meaning that the base case is almost fully connected.
- We expected a larger influence of vertical and minor ranges on connected net volume, but these are only apparent for lower sand fractions.
- Range of uncertainties for the 4 lesser variables is around 3%, which is much lower than expected.
  - This can only be partly attributed to the algorithm's response to the 60% sand fraction in the base case.
  - The consequence of using a variogram-range equation is that the distributions in thickness and width only affect one of the 4 factors in the equation, limiting their impact on the overall variogram-range, resulting in a smaller spread in the connected NRV as expected.

5c. Object Based: Meandering System

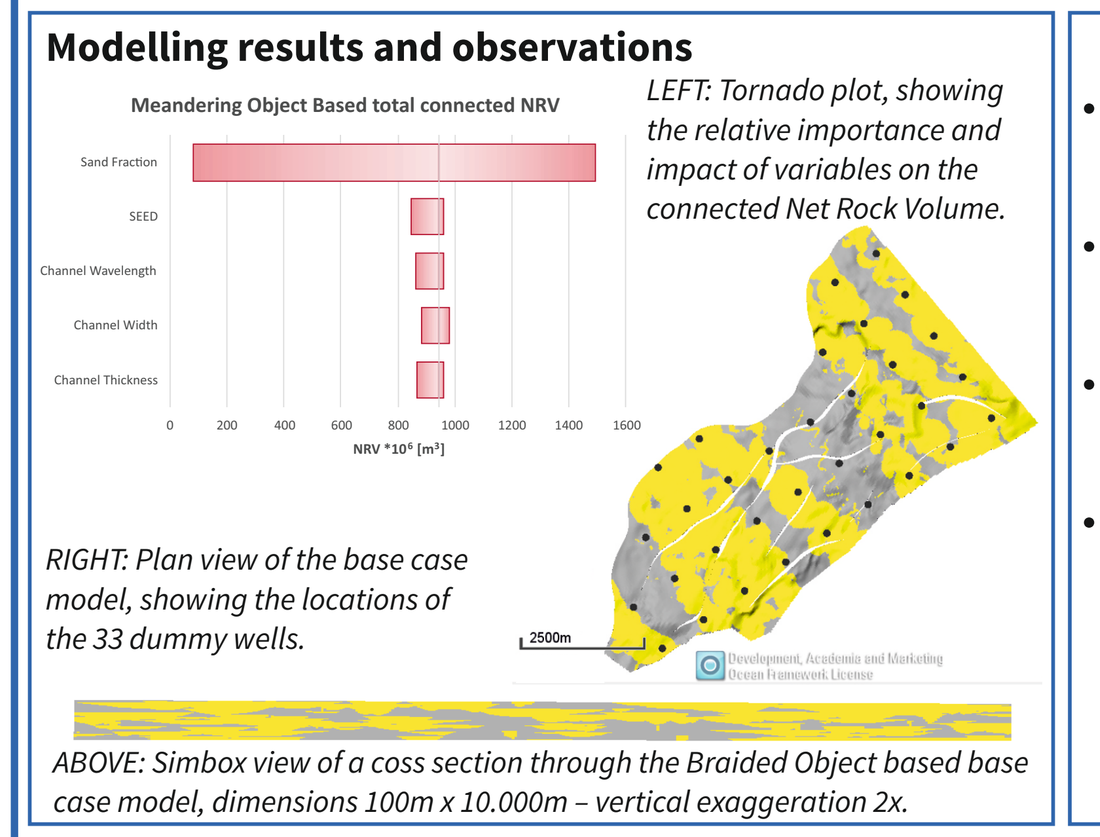
In standard modelling workflows, finding applicable analogue data can be very time-consuming, limiting the time left to explore different depositional scenarios. Making a conscious decision between systems like braided and meandering rivers is arbitrary and often these fluvial systems sit between their end members. To test the consequences of a different depositional concept we have performed the same analyses as for the braided system, only this time we have filtered the data to include only meandering systems.

Same approach as 5a, but now with a Meandering depositional environment



Overview of the data selection and analysis of the filtered depositional concept of the meandering system for Crux, showing the included studies, the expected proportions and various data plots.

Modelling results and observations



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RIGHT: Plan view of the base case model, showing the locations of the 33 dummy wells.

ABOVE: Simbox view of a coss section through the Braided Object based base case model, dimensions 100m x 10.000m – vertical exaggeration 2x.

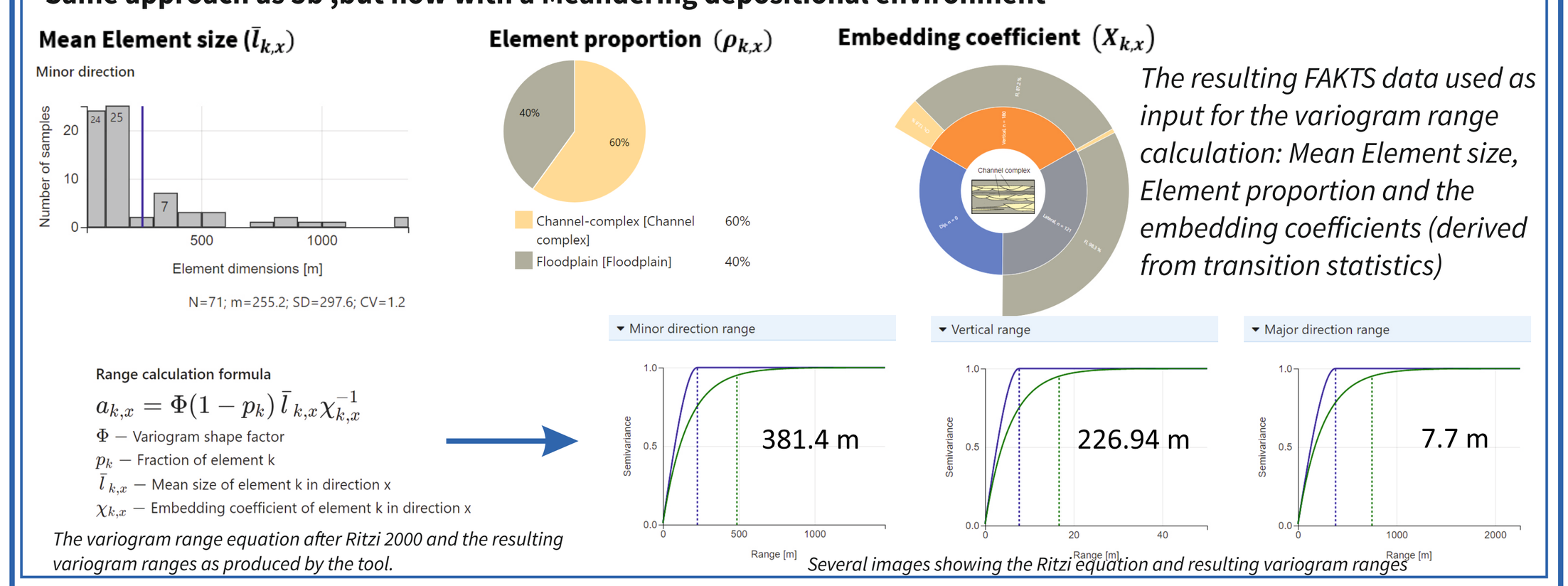
Observations

- Uncertainty ranges were chosen to reflect the ranges suggested by the database. Except for the sand fraction, which was uniformly varied between 5 – 95%.
- Although the database suggested a sand fraction of 49% we changed this to 60% to allow for a better comparison between the four different scenarios.
- As initially expected, channel wavelength for meandering systems shows a more significant influence on the connected net volume than in the braided case.
- Although the sensitivities are quite similar, we were surprised with the low impact of the channel thickness
  - Due to the high sinuosity, individual channels fuse into wider bodies, increasing the lateral connectivity superseding the impact for channel thickness on the Net connected volume.
  - In the braided case the straighter channels tend to stack, meaning their thickness is important in vertical connectivity.

5d. Pixel Based: Meandering System

In our final scenario, we reused the analogue data from the previous Object-based run, but performed the sensitivity tests on the Sequential Indicator Simulation (SIS) algorithm in Petrel. We have followed the same method as for the braided pixel based approach, which allows us to compare the sensitivities between both two geological and the two modelling scenarios.

Same approach as 5b ,but now with a Meandering depositional environment

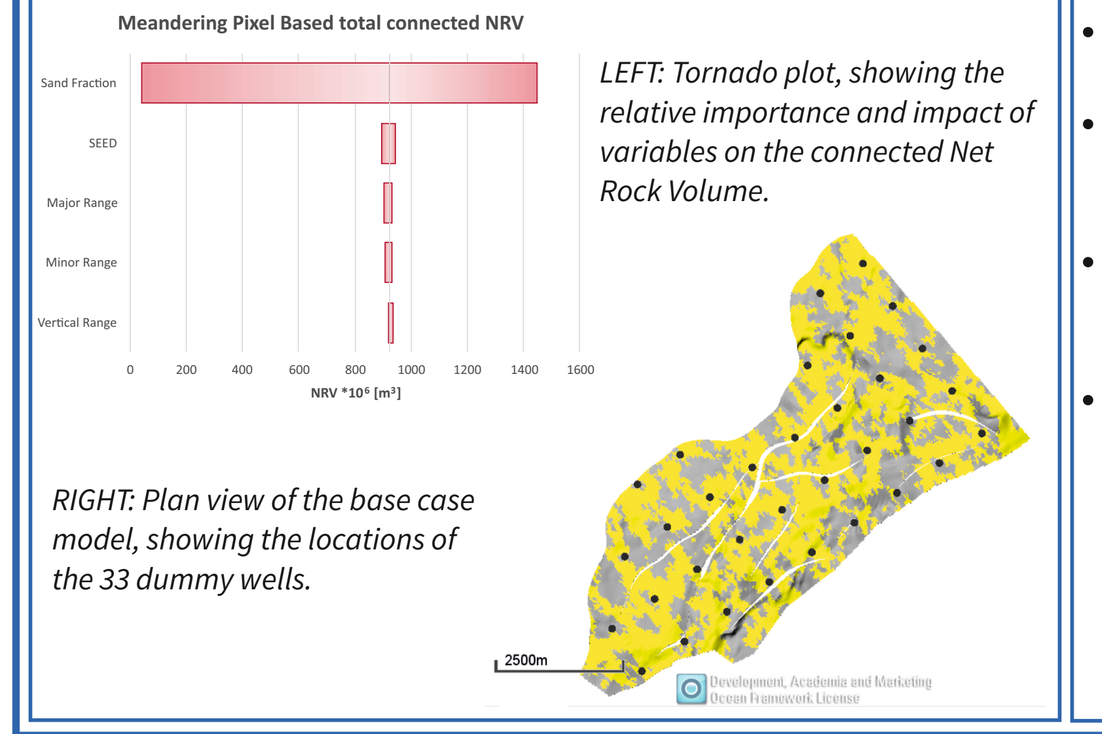


The resulting FAKTS data used as input for the variogram range calculation: Mean Element size, Element proportion and the embedding coefficients (derived from transition statistics)

The variogram range equation after Ritzi 2000 and the resulting variogram ranges as produced by the tool.

Several images showing the Ritzi equation and resulting variogram ranges

Modelling results and observations



LEFT: Tornado plot, showing the relative importance and impact of variables on the connected Net Rock Volume.

RIGHT: Plan view of the base case model, showing the locations of the 33 dummy wells.

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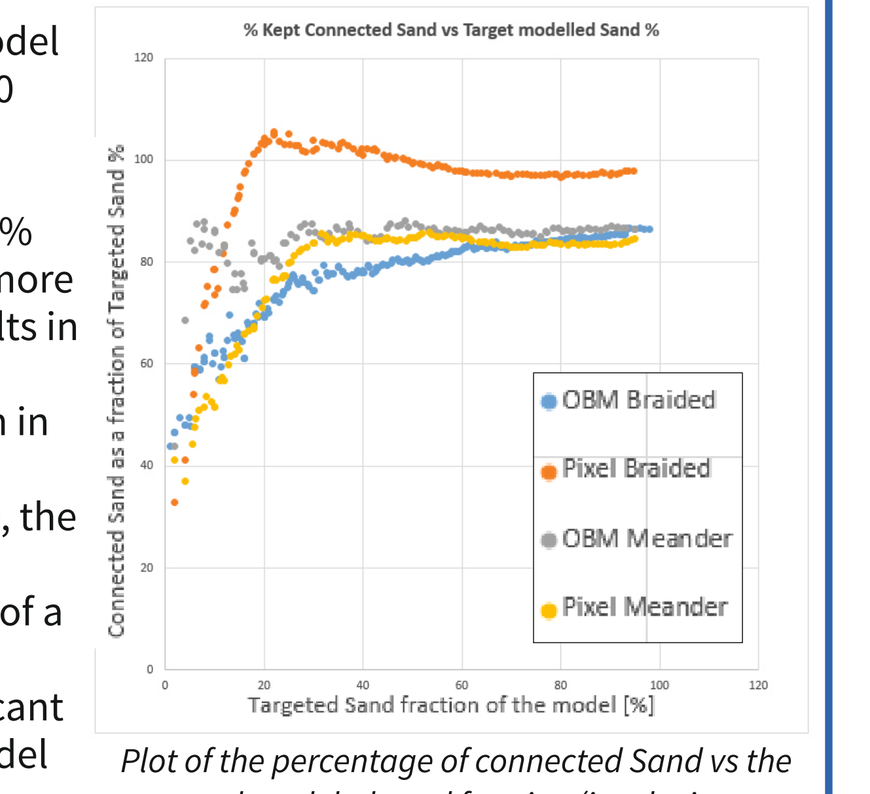
  - The consequence of using a variogram-range equation is that the distributions in thickness and width only affect one of the 4 factors in the equation, limiting their impact on the overall variogram-range, resulting in a smaller spread in the connected NRV as expected.

6. Kept Sand Analysis

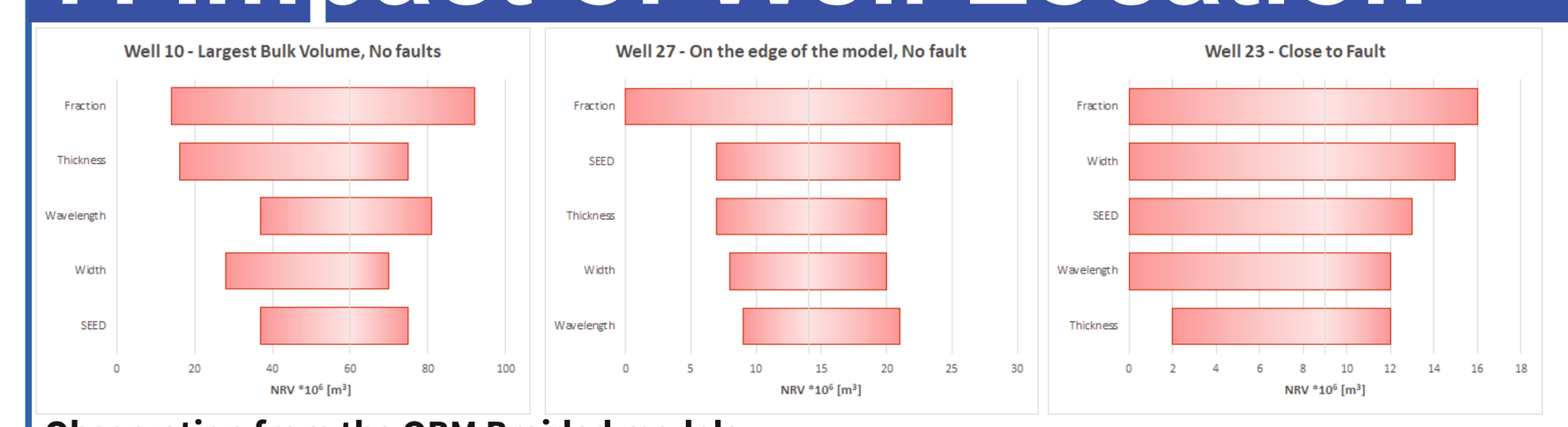
We have investigated how different scenarios and different modelling methods would influence the connected sand % when varying the net to gross of these systems. To this end, we have set-up separate sensitivity runs for each scenario, where we vary the only the input sand %. By plotting the input sand fraction against the calculated Kept Sand % we were able to observe some interesting phenomena.

- Use of a case study opposed to conceptual model may account for the model not reproducing the behaviour described in percolation theory (King, 1990 and Hovadik & Larue 2010) where the NtG threshold for fully connecting systems in 3D lies at 30% (rule of thumb).
- It is striking that the connected sand > 100 % between the range of 20 - 40% target modelled sand. This is caused by the algorithm modelling slightly more sand than specified. At 20% targeted fraction, a modeled NtG of 21% results in a 105% connected sand fraction.
- At the low sand fraction the % connected sand is much higher than shown in previous percolation studies (Hovadik & Larue 2010).
- Perhaps this can be explained by a combination of (vertical) grid cells size, the number and spacing of wells. The 1000m well spacing results in the wells sampling 70% of the total volume of the model, meaning that the chance of a well encountering sand in a low NtG run is high.
- The choice of depositional concept is quite important as there are significant differences in the displayed model connectivity between the different model concepts (braided vs. meandering).
- The differences between the two concepts will likely impact development strategies and ultimate recovery.



Plot of the percentage of connected Sand vs the targeted modeled sand fraction (i.e. the input sand fraction) for each of the 4 concepts.

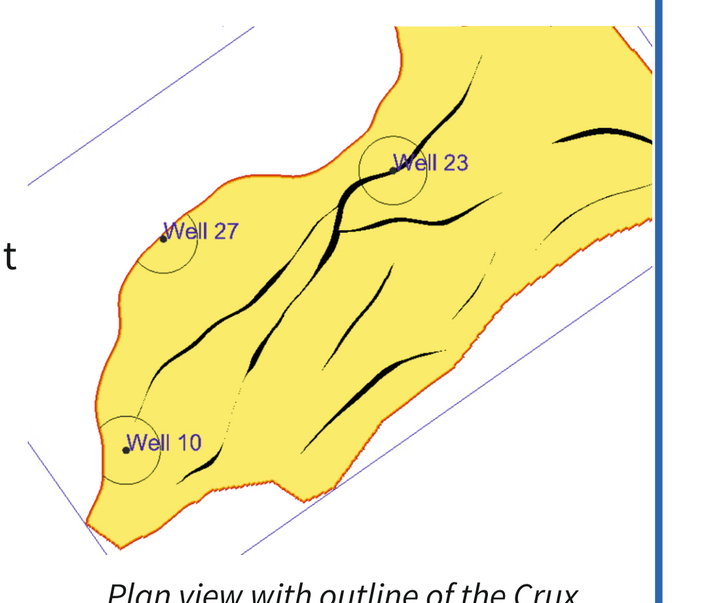
7. Impact of Well Location



Individual tornado charts of the ranked sensitivities for three typical well locations: a) area with large bulk volume – Well 10 b) Near the edge of the model – Well 27 c) Close to faults – Well 23.

Observation from the OBM Braided models

- In the central regions of the model (e.g. away from faults and model boundary) the potential connected volume is not restricted, so the tornado charts show very similar trends.
- This is because they have the biggest effect on the total connected NRV - example is Well 10.
- Around the edges of the model, the tornado charts concur with the overall trend, but have less NRV due to their reduced GRV.
- Close to faults we see the most dramatic changes in tornado chart - our method holds the faults to be sealing.
- This results in normal GRV's but significantly lower NRV as sand cannot connect through the sealing fault.
- Also, in the case of Well 23 - There were quite a few occasions where the well rendered zero Net Rock Volume even with a targeted sand fraction of 60%.
- Possibly due to the well being cut by a fault and missing some stratigraphic section.
- We observe large differences in individual well connectivity and sensitivities compared to the overall behaviour of the field. For future work we propose to look whether inconsistent well connectivity in models is more dependent on the type of algorithm rather than the conceptual model.



Plan view with outline of the Crux field, showing the location of the three typical wells: 10 – 27 – 23.

8. Summary and References

1. In a high NtG system the OBM and Pixel based algorithms are good at generating the expected connected volumes; the algorithms can reproduce percolation theory.

2. In lower NtG systems, the Pixel and OBM algorithms have a tendency to be more connected than anticipated.

- This is thought to be due to the density of wells in the model.

3. There are small differences in the variogram range between the braided and meandering cases; a method was found to include the channel sinuosity, but was not used as part of this study (future work).

4. The choice of depositional environment is important; irrespective of modelling algorithm, variations in connectivity are observed between the 2 environments:

- Braided environments tend to connect vertically due to the low sinuosity of the systems with the channels tending to stack.
- In the meandering environment the channels connect more laterally than they do vertically.

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