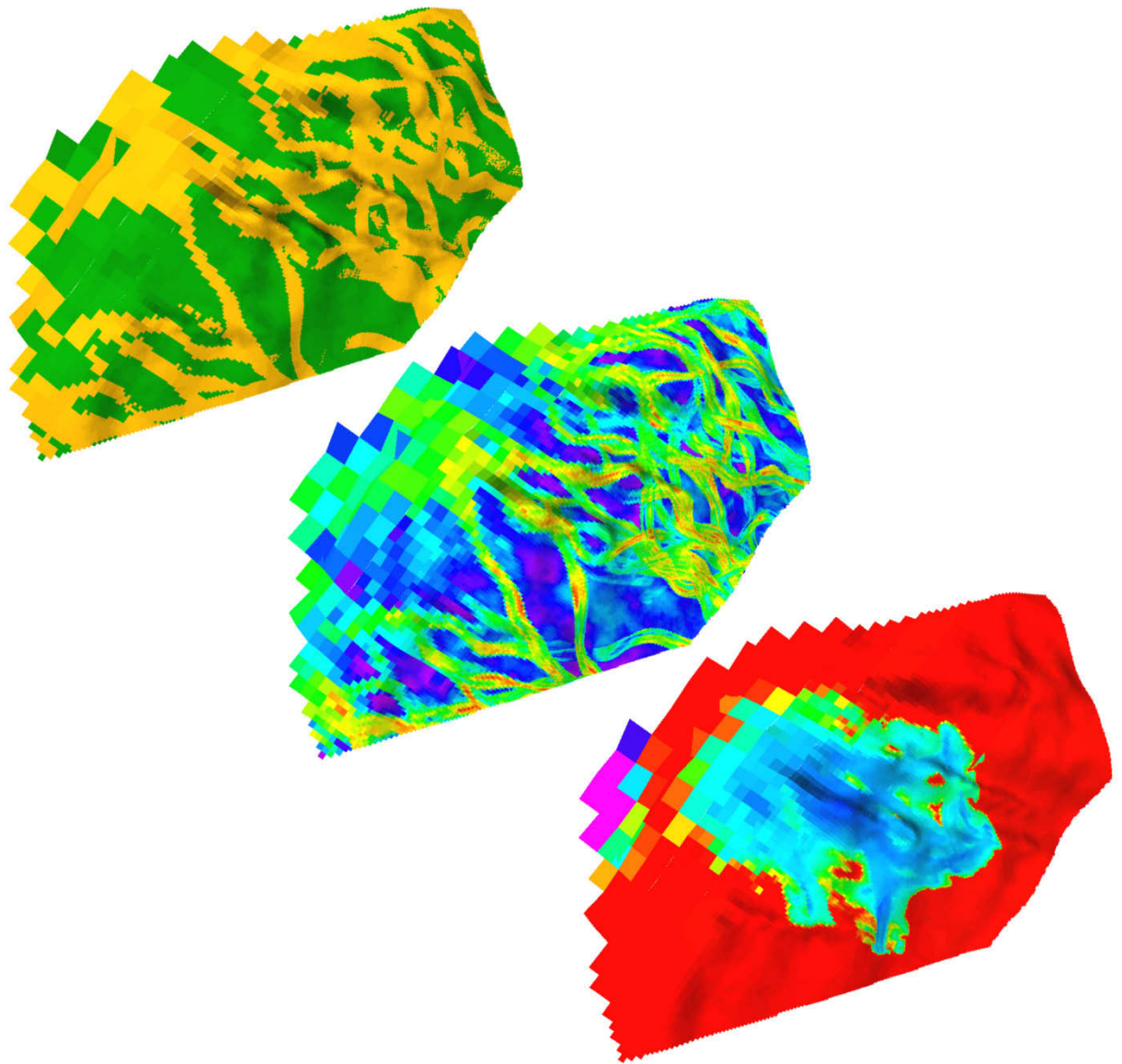


# Managing the Interdisciplinary Requirements of 3D Geological Models

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## **7 FROM GEOLOGICAL INTERPRETATION TO DYNAMIC**

### **MODEL**

This chapter brings together the conclusions from the case study, upscaling, static modelling and dynamic modelling chapters in order to assess whether the geological interpretation and design of the static models can be used to predict the changes to dynamic models as grids are upscaled. The limitations of this study are discussed, as are its application to current and potential future modelling practices.

### **7.1 Incorporating Analogues into the Model Design**

#### **Process**

The results from this study have shown that the dimensions of cells in models are an important factor for the reliability of results achieved in reservoir simulation. The issue of sandbody dimensions, cell size, and the number of cells in a model needs to be addressed in the planning stages of model building so that the models can be designed to minimize the design related uncertainties in reservoir simulation results. In order to assist the decision making process two charts have been developed. These charts allow the user to study the interaction between sandbody dimensions, cell size, model size and %change prior to the building any models.

The impact on model size (i.e. the total number of cells) of different cell sizes can be assessed using CHART A (Figure 7.1). This allows the interpretation of depositional environments to be incorporated into early model discussions via the use of analogues to predict geologically appropriate cell sizes in an upscaled model (Riordan et al., 2008). For accurate modelling in a dynamic reservoir model, the upscaled cell size should be at most a third of the length and width of the smallest significant sandbody type. CHART B (Figure 7.2) indicates the potential difference in ultimate production between an upscaled model with cell sizes chosen using CHART A and a much finer base grid. This process will also aid

geologists in deciding the amount of detail required. If a particular facies type, such as narrow channels, cannot be captured reliably in the upscaled model due to model size constraints, time and resources may not be expended modelling them.

The upper Volador barrier-island system is presented as an example of how to use the charts. The depositional facies most likely to limit the size of cells in the model is the tidal channels. The average width of individual tidal channels is interpreted to be 600 m (Figure 7.3). The facies model could be upscaled to 300 x 200 m without losing the morphology of the channels. This would result in a grid containing approximately 150,000 cells. For this cell size, the *CSWR* relative to the tidal channels is 0.5. CHART B indicates that for a *CSWR* of 0.5 the maximum %change that could be expected is 14%. If the grid cells were reduced in size to 200 x 130 m so that the *CSWR* is 0.33 (the minimum required for achieving a strong correlation coefficient), the number of cells in the model would be approximately 300,000 cells.

For a depositional environment that has a very large sandbody size—such as a shoreface (with no fluvial channels), the limiting factor in deciding upon upscaled grid sizes may be something other than sandbody dimensions. Factors that may influence the choice of cell sizes are well spacing, proximity to fluid contacts and the upscaling limits of seismic-attribute-derived reservoir properties. The results from this study support the reservoir modelling “rules of thumb” that there should be at least three cells between producing and injecting pairs (Weber and van Guens, 1990; Ertekin et al., 2001). Weber and van Guens (1990) also state that there should be at least three cells between wells and original oil-water contacts, and possibly more for gas-water contacts. Staggs and Herbeck (1971) concluded that at least three layers are required for each continuous sandbody in which vertical flow may occur.

## **7.2 Static Parameters, Upscaling and Simulation**

In *Chapter 4* the following parameters were established to be the primary controls on the behaviour of static parameters with upscaling:

- Upscaling beyond half the width of the channel (or other facies) will result in change of sandbody morphology and a loss of channel connectivity,
- Upscaling beyond the width of the dominant facies will result in a change to the distribution of porosity within the model,
- The distribution of pore volume by facies will change once grids are upscaled to a point at which facies distribution changes,
- Shape and orientation of cells should reflect the orientation of the major sandbodies. Square cells are the best way to minimize morphology problems that can result from upscaling,
- Upscaling has the potential to change flow paths. Upscaling beyond the width and/or thickness of thin features (porosity/permeability zones or barriers) will result in their loss—which may introduce, remove or smooth flow paths.

One of the aims of the dynamic modelling process was to establish if these criteria for upscaling static parameters have any influence on the results of dynamic models.

### **7.2.1 Upscaling beyond half the width of the channel (or other facies) will result in loss of morphology**

The loss of channel morphology can be clearly seen in the pattern of waterflood in the reservoir simulation. As cells become larger, the channel margins blur and disappear and the pockets of unrecovered oil in low permeability zones are lost (Figure 7.4). The *r* vs. *CSWR* charts indicate that the relationship between the base grids and the upscaled grids begins to change from 'strong' to 'moderate' when the cell width is a third of the channel width. It is also at this point that the relationship starts to shift away from 1:1, resulting in frequent overestimation of ultimate production.

In the coast scenarios the average field production is relatively stable as the grids are upscaled. However, the detail of oil saturation changes as the grids are upscaled. When the porosity detail is no longer identifiable, there will be a corresponding loss of detail in the water saturation (Figure 7.5). In the coast scenario both channel morphology and porosity

morphology are lost at about the same point—a point at which the production profiles become unstable.

### **7.2.2 Upscaling beyond the width of the dominant facies body type will result in a change to the distribution of porosity within the model**

The points at which changes to porosity distribution from the original distribution to a normal distribution occur are summarized in Table 7.1.

The change in porosity distribution is most noticeable in wells that penetrate poor quality reservoir (for example Realization 2, SQ100-25 Figure 7.6). As the grids are upscaled and the end member low porosity values are lost, injection or production becomes possible in previously tight wells. In the SQ100-25 scenario this occurs at the 50 x 40 grid. Similarly for other channel widths it occurs in the grid at which the porosity distribution becomes normal (Table 7.1). Establishing how influential the changing of porosity distribution is on wells that penetrate channels, and in the 280 m channel models is challenging. In the SDA280-25 scenario the wells either penetrate channels or overbank, and the resulting production profiles are very stable until the channel width is exceeded (Figure 6.41 and Figure 6.61). Unfortunately this point coincides with the point at which there are three cells or fewer between Well A and the other wells. This is shown to produce changes in results (Figure 6.12). However, the fact that the wells that have high recovery show very little change across this boundary, while the poor performing wells change significantly suggests that the results are at least partially reliable.

### **7.2.3 The distribution of pore volume by facies will change once grids are upscaled to a point at which facies distribution changes**

The relationship between pore volume and facies distribution is not a good indicator of potential production behaviour. Due to the different methods of upscaling used for the facies and porosity grids, channel quality porosity will be retained as grids are upscaled but get redistributed into the overbank facies (Figure 6.3). This project was designed so that

reservoir properties at the wellbore are not fixed, but change with each realization. This results in a high level of variation in well productivity between realizations. This variability is not reflected in the pore volumes associated with each facies—this remains relatively constant for all realizations (Figure 5.33). For both channel widths there is approximately 10–20% change in pore volume of the channel facies before the cell size exceeds the channel width (Figure 7.7 and Figure 7.8). Once the channel width is exceeded, the pore volume associated with the fluvial facies decreases rapidly, while the total pore volume of the model remains virtually unchanged. The change in pore volume associated with the fluvial facies prior to the cell width exceeding the channel width does not appear to be reflected in the average field production or the *%change* of production relative to the base model (Figure 7.9 and Figure 7.10). Although the average production changes at the point at which the cell size exceeds the channel width, in most cases there is not much variation in results prior to the channel width being exceeded. The magnitude of the change in pore volume associated with the channel facies once the cell width exceeds the channel width is not usually reflected in the average field production, or *%change* in field production. The pore volume associated with the fluvial facies in the 25% sand scenarios changes far more than that of the 50% sand scenarios. The average *%change* as the grids are upscaled is similar for both sand volumes in most cases (Figure 7.8).

Similarly, the direction of change in average production trends is not always reflected in the changing pore volumes associated with each facies. The pore volume associated with the fluvial facies always decreases as the grids are upscaled, but the average production shows a variety of trend directions. It is noted however, that the amount of variability may be the result of having insufficient realizations to produce a statistically significant distribution—the results can be skewed by one or two anomalous wells. This study indicates that the change in facies pore volume are not directly indicative of the behaviour of upscaled grids, but provides an indication of where changes in behaviour are most likely to happen.

#### **7.2.4 Shape and orientation of cells should reflect the orientation of the major sandbodies. Square cells are the best way to minimize morphology problems that can result from upscaling**

The changes in production as the homogeneous models are upscaled indicate that as the grid cells get larger the performance of the models differs (Figure 6.12). The square grid design has less variation as the grids are upscaled than the SSA and SDA grids. In the channel and coast scenarios this study has not identified an underlying influence of the grid design separate from the interaction of the grid and the geology. All grid designs produce a similar range of ultimate recovery values for each scenario. There are differences in the trends identified in the average field production between the grid designs, but there are insufficient data points to be certain that these differences in trend are statistically significant, and not unduly influenced by one or two realizations. Realizations where wells are located near channel edges produce changes to production between upscaling steps, and realizations where wells do not penetrate channels produce very large increases in production as the grids are upscaled. These two behaviours can dominate the average field production of a scenario, making any underlying trends associated with the interaction of sandbody shape and size with grid orientation impossible to identify.

#### **7.2.5 Upscaling has the potential to change flow paths. Upscaling beyond the width and/or thickness of thin features (porosity/permeability zones or barriers) will result in their loss—which may introduce, remove or smooth flow paths**

The potential of upscaling to alter flow paths is seen in the following ways in the scenarios examined:

- Wells that penetrate low porosity and permeability cells and do not flow (or inject) in the base grid will begin to flow/inject when the grids are upscaled to the point that the porosity distribution is altered (Figure 7.6).

- Wells that are adjacent to channel margins behave differently as the margins shift due to upscaling.
- The simulation parameters are not optimized for studying this issue as injected water moves into the overbank facies. If this was specifically excluded the smoothing out of flow paths may be easier to see—especially in the 100 m channels.

### **7.3 Scope for Further Work**

1. The upper Roundhead Member was not modelled as it was expected that its high net:gross ratio would limit the amount of variability seen during upscaling that could be attributed to the channel dimensions. The results of the comparison of CSWR against correlation coefficient for the shoreface model suggest that this assumption is probably correct. The majority of the correlation coefficient values for the high net:gross shoreface and lower Roundhead scenarios fall between 0.8 and 1—indicating a strong relationship between the base and upscaled grids. There is up to 5% variation in production between upscaling steps for both the beach and coast scenarios. However, the fact that the channels do appear to be influencing the results (the beach scenario has higher, less varied, correlation coefficient values) suggests that the influence of channel width when upscaling a high net:gross reservoir should be investigated.
2. The difference in the spread of correlation coefficients between the beach scenario and the coast scenario is attributed to the presence of the fluvial channels in the coast scenario. However, an alternative cause may be the fact that only three realizations of the beach scenario were modelled for two of the grid designs. Further work on the beach scenario is required to clarify this result.
3. The channel models built for this project include an overbank facies, that has some porosity and permeability, which was included in the upscaling process.



Examples of channel models in the literature do not always model an overbank facies, instead restricting flow to the channel facies (for example: Larue and Hovadik, 2006; Larue and Hovadik, 2008). The influence of channel width on upscaling this style of model should also be investigated.

4. The conclusions of this project are based on multiple facies models of different designs, but which all had the same rock and fluid properties in the reservoir simulation. Changing these properties will change the results produced for each realization. It is unknown whether the trends established in this study would also be different if input parameters had been changed. In particular, the trends plotted on the correlation coefficient ( $r$ ) vs. *%change* and *CSWR* charts apply specifically to this dataset. Further work needs to be carried out to see how applicable the curve on the *%change* vs. *CSWR* chart (Figure 7.2) is in a wider context.
5. The study of the behaviour of grids with very large cell sizes was limited by the size of the field and the spacing of the wells. Although the  $r$  vs. *CSWR* chart indicates that once the *CSWR* exceeds 1 the relationship between the base grid and the upscaled grids is poor, this is an area that should be further examined. There are situations where models with kilometer scale cells are required. An extension of the work carried out in this project would help to establish how well these models are likely to be capturing the actual behaviour of the reservoir.
6. The permeability grids in this study were upscaled using one of five methods available within RMS (diagonal tensor). Prior to the application of the diagonal tensor method no work was carried out to establish the precise nature of the forces controlling the fluid flow through the model—gravity or capillary. Once again, it is unknown if changing the method of permeability upscaling would affect the trends in upscaling results produced by this project.

## **7.4 The Way Forward – How Do the Results Apply to Future Modelling**

### **7.4.1 Current Trends in Modelling**

The scientific literature contains abundant examples of current research into methods of upscaling fine-scale, heterogeneous 3D models to maximize the retention of heterogeneity. Papers such as Stern and Dawson (1999), Durlofsky et al. (1996), Chawathé and Taggart (2004), King et al. (2006) and Talbert et al. (2008) focus on varying the amount of upscaling that grids undergo (non-uniform coarsening) by identifying layers or areas with similar properties—similar to the flow zones described by authors such as Hearn et al. (1984) and Ebanks (1987). The conclusion of this study that cells should not be more than a third of the sandbody width is applicable to this style of upscaling as it provides a guide as to how many cells are needed in the reservoir facies.

Another approach is to build extremely fine models of bedding structures which get incorporated into coarser models via the use of pseudo functions. Bedding structures have been found to influence the way fluid flows through sandstone, and this may be sufficient to change the performance of reservoir simulations in some circumstances (Lasseter et al., 1986; Ringrose et al., 1993; Pickup et al., 1994b). This has led to the generation of pseudo functions, which are derived from mathematical equations designed to capture the influence of small scale relative permeability (Jacks et al., 1973; Cao and Aziz, 1999). There are a variety of methods used to calculate pseudo functions, and they are sensitive to the forces that are influencing flow in a given reservoir (such as capillary pressure or gravity) (Cao and Aziz, 1999; Darman et al., 2001; Stephen et al., 2008). Examples of recent studies incorporating pseudo functions include Stephen et al (2008), Rustad et al. (2008), Lerdahl et al. (2005), Pickup et al. (1994a), Mikes et al. (2001). Both Rustad et al. (2008) and Stephen et al. (2008) found that the permeability variation at the pore scale (bedding lamina) is a critical influence on the results of field scale simulation.

These papers do not discuss the size of the upscaled cells used when studying the effectiveness of pseudo functions, and nor do they investigate the differences in predicted production that can result from different realizations. Rustad et al. (2008) and Stephen et al. (2008) do not discuss whether or not the use of pseudo functions reduces the amount of uncertainty associated with the results of field scale reservoir simulation. Models incorporating pseudo functions are based on assumptions about the style of bedforms associated with a given facies. As was discussed in *Chapter 3* (depositional analogues), interpretation of the style of channel deposition from core and wireline data alone is unreliable unless distinct bedding planes can be identified in core (Bridge, 2006). Given the wide variety of bedding structures that can occur in channels (Davies et al., 1993; Bridge, 2006) directly modelling such features in a field scale study must add significantly to the uncertainty associated with the reliability of the outcomes of modelling. For example, the upper Roundhead Member lowstand fluvial channels have been interpreted as being low sinuosity channels rather than meandering channels in a low accommodation setting. For a conventional model of a high net:gross reservoir the distinction is largely academic (Larue and Hovadik, 2008), but for building a very fine model that tries to incorporate bedding structures the difference is significant (Davies et al., 1993; Bridge, 2006).

Similarly in a shoreface environment, each part of the shoreface is associated with different bedforms and levels of bedding disruption as a result of biologic activity. The inclusion of bedform related pseudo functions in the modelling process places a great importance on the detailed interpretation of depositional facies and their distribution. In such a situation it may not be sufficient to model a single shoreface facies as was done in this project.

The difference to the outcome of models with different interpretations of bedding style is unknown. Given that most authors tend to only publish examples of identifiable success stories, the real value of incorporating this level of detail into models on a regular basis appears to be largely untested. In attempting to build a better model, another layer of uncertainty is added to the overall process. Extremely fine models do not provide any greater understanding of what is between wellbores.

### **7.4.2 The Future of Models – More Models or More Cells?**

Gorell and Bassett (2001) note that the amount of cells handled easily by reservoir simulators is historically an order of magnitude less than the number of cells in geological models. Although advent of multi-core processors and distributed processing has the potential to close this gap, another use for increased computing power could be the simulation of multiple grid sizes for grid sensitivity analysis and the simulation of many upscaled realizations and scenarios, instead of the simulation of a few detailed models. The results of this study show that (depending on channel width) when internal structures are not specifically modelled, there is statistically little difference in average field production between a grid with 20 m cells and one with 50 m cells, but potentially a very large difference in the number of cells in a model (Figure 7.1). In a commercial environment, the imperative to achieve the fastest simulation run-times possible is likely to remain in many situations. This study has shown that 10 realizations are not enough to produce statistically reliable indicators of average field performance. The design of the study is such that there is potential for a wide variety of results from one scenario—and one realization can dominate statistical estimates.

By running a small series of simulations on grids upscaled vertically it was established that for the channel design used in this project a 3-layer grid was likely to produce very similar simulation results to a 24-layer grid. By concentrating on 3-layer grids for the remaining seven realizations an enormous amount of time was saved in the simulation process.

Another advantage of running simulations on a series of grid sizes is that problems with grid design or simulation inputs can be identified. During the course of this work, on several occasions sets of models were simulated with an incorrect parameter. These mistakes were identified because the results of the simulation, when viewed as part of a series, contained anomalies. When the mistakes were corrected the results produced a consistent, explainable pattern. The anomalous (incorrect) results would not have been recognised as such if only one grid size had been modelled.



## **7.5 Figures & Tables– Geological Interpretation to Dynamic Models**



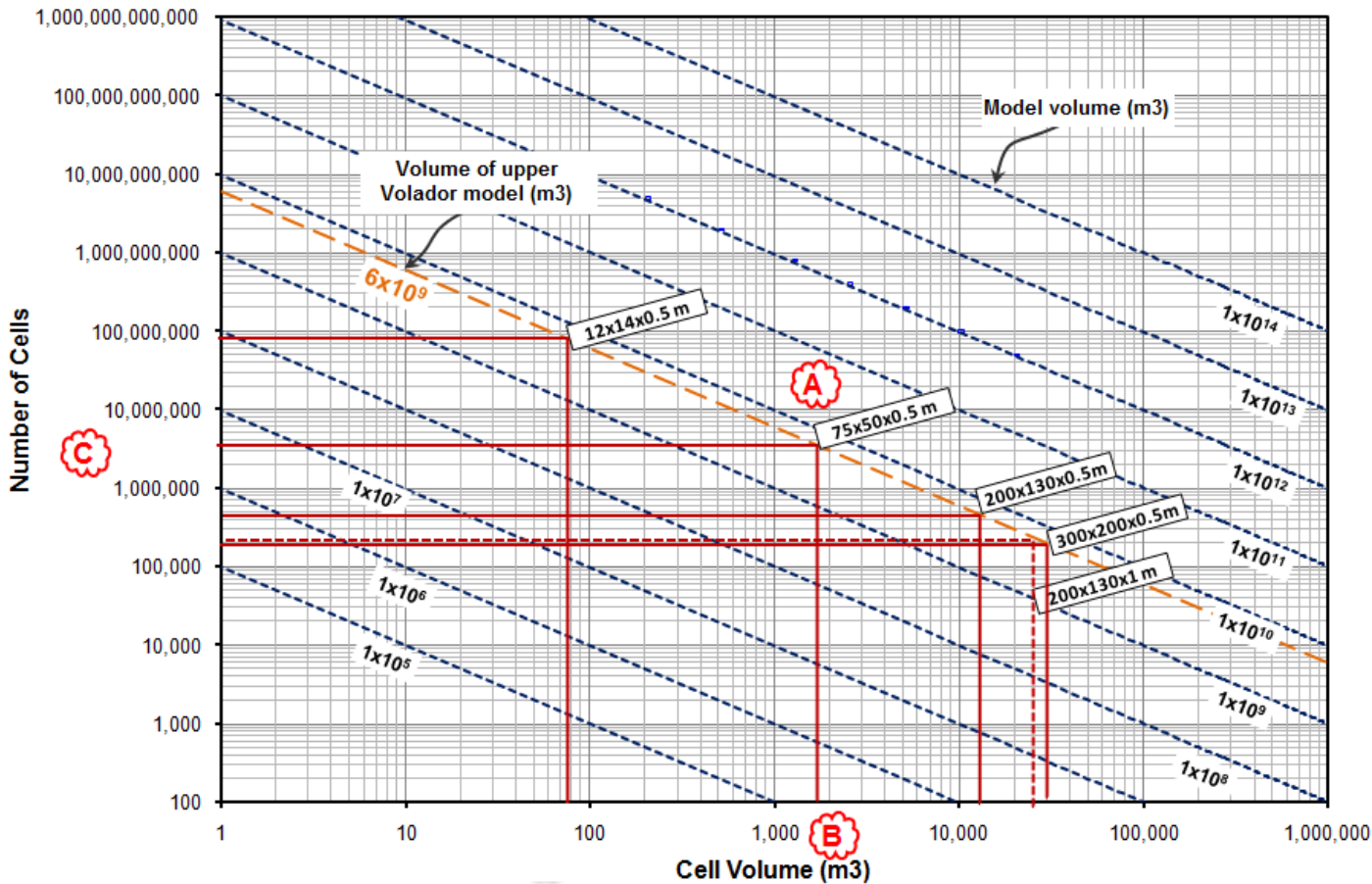
<b>GRID DESIGN</b>	<b>CHANNEL WIDTH</b> (m)	<b>GRID</b> (No CELLS)	<b>GRID DIMENSIONS</b> (X & Y m)	<b>CSWR</b>
<b>SQUARE</b>	100	50x40*	280 x 240	2.8
<b>SQUARE</b>	280	25 x 20	560 x 480	2.0
<b>SHOREFACE DIP ALIGNED</b>	100	60 x 20*	235 x 490	3.25
<b>SHOREFACE DIP ALIGNED</b>	280	30 x 10*	470 x 980	1.68
<b>SHOREFACE STRIKE ALIGNED</b>	100	60 x 80	235 x 120	2.35
<b>SHOREFACE STRIKE ALIGNED</b>	280	30 x 40	470 x 245	1.68

\* previous grid altered but still bimodal or lognormal

**Table 7.1. The point at which porosity distribution becomes normal for each channel width and grid design.**







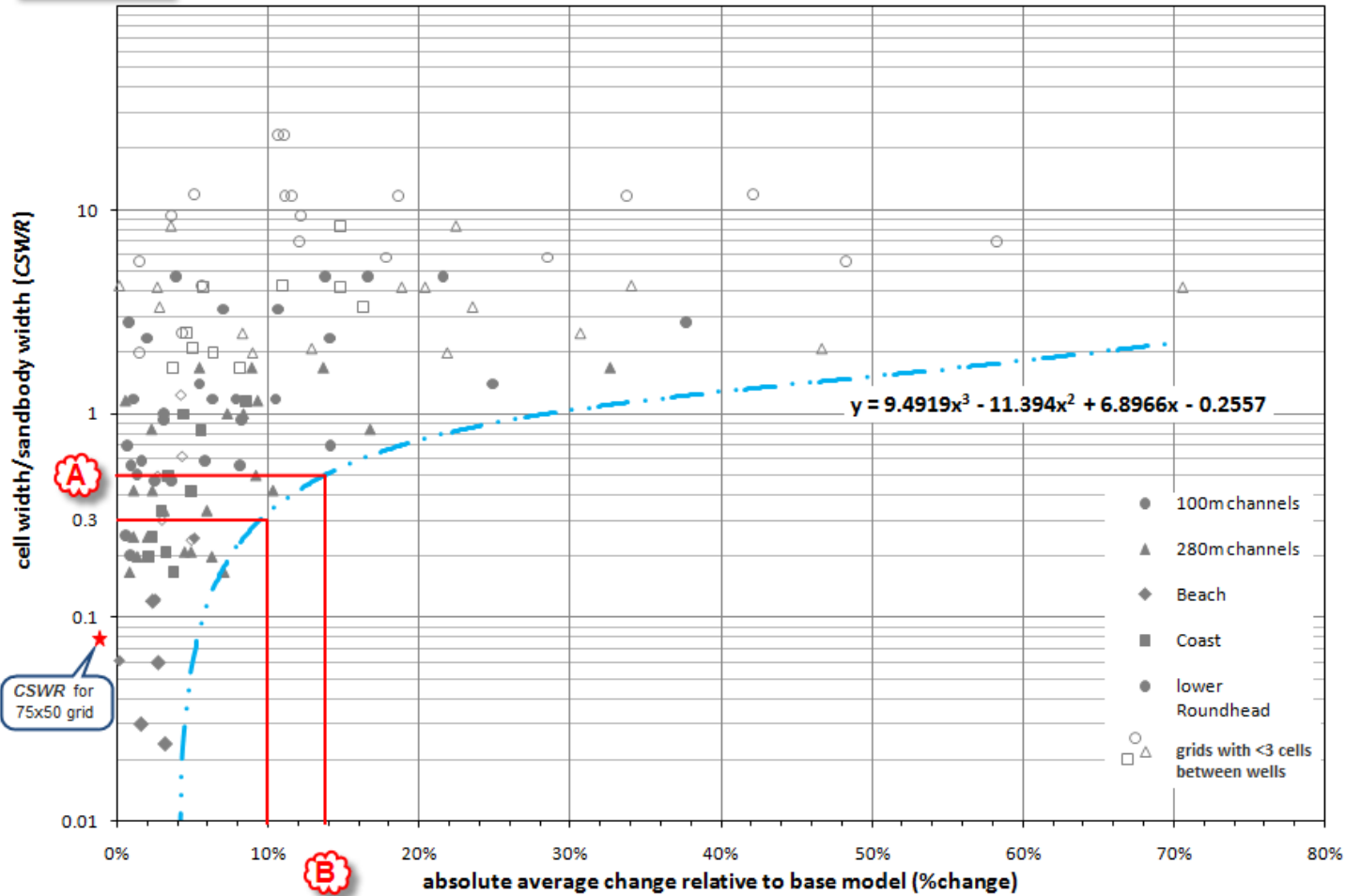
**CHART A**

- A: Calculate the model volume (area x reservoir thickness) in metres.
- B: Calculate the volume of proposed cell sizes (e.g. 75x50x0.5 = 1,875m<sup>3</sup>)
- C: Look up the approximate number of cells in the model.
- D: Got to **CHART B** to estimate potential change in ultimate production from upscaled grid with cells of size chosen.

**Figure 7.1. Nomogram for estimating the potential number of cells in a 3D model.** The red lines indicate the approximate number of cells in a model of the upper Volador Formation (see Figure 7.3). The nomogram indicates that if the model cells were to be 12x14x0.5 m (the base grid dimensions for the square models), there would be approximately 90 million cells in the grid. In order to achieve a smaller number of cells for the geological model the cells need to be much larger. In Figure 7.3 the base grid is 75 x 50 x 0.5 m—which results in a grid of approximately 3.5 million cells. The maximum recommended upscaled grid size is 220 x 150 x 0.5 m—which would result in a grid containing approximately 250,000 cells. If the grid were also upscaled vertically to 220 x 150 x 1 m cells, the number of cells in the grid would be reduced to approximately 150,000.

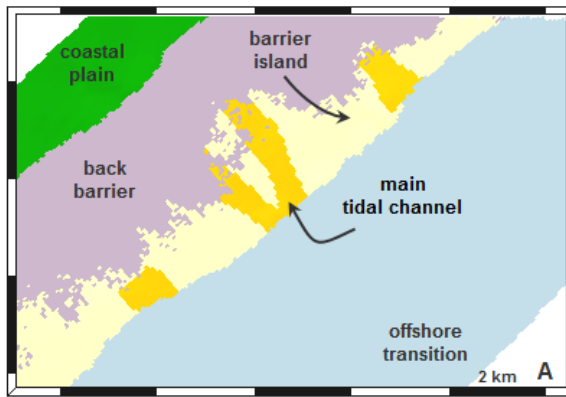
CHART B

Change in Production vs CSWR



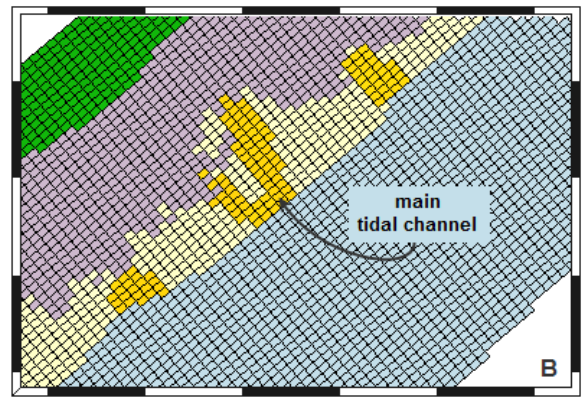
- A: Calculate potential CSWR from interpreted facies dimensions.
- B: Estimate average change in ultimate production compared to a very fine model.
- C: If the potential %change is too large, determine maximum acceptable amount of change and calculate the necessary CSWR. Return to **Chart A** to calculate the number of cells in the grid.

Figure 7.2. Chart for estimating the %change in ultimate production of an upscaled grid. After a suitable grid cell size for simulation has been established in CHART A (Figure 7.1), the resultant CSWR can be plotted on CHART B to determine the maximum expected %Change. In the upper Volador barrier-island example, if a grid cell size of 300 x 200 m was proposed (CSWR = 0.5) this chart indicates that the potential %change is 14%. The recommended grid cell size of 220 x 150 m has a potential %change of 10%. If less %change is desired then the necessary CSWR can be calculated, and the potential number of cells recalculated on CHART A. Note: how applicable this curve is to other datasets is uncertain: it may require adaptation before use on other datasets.



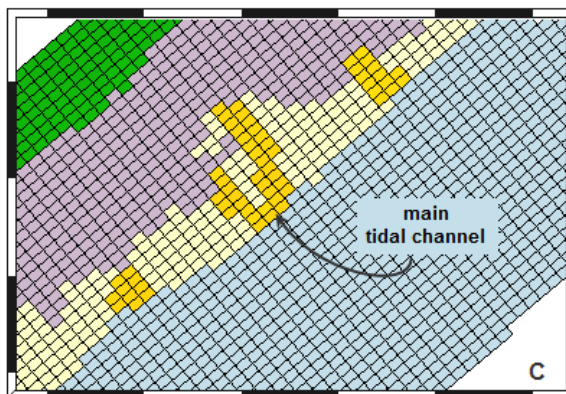
Geological Grid. grid cells 75 x 50m.  
Width of tidal barrier is on average 600 m.  
Barrier is between 570 m and 2300 m wide.

CSWR of tidal channels: 0.125  
CSWR of barrier: 0.08



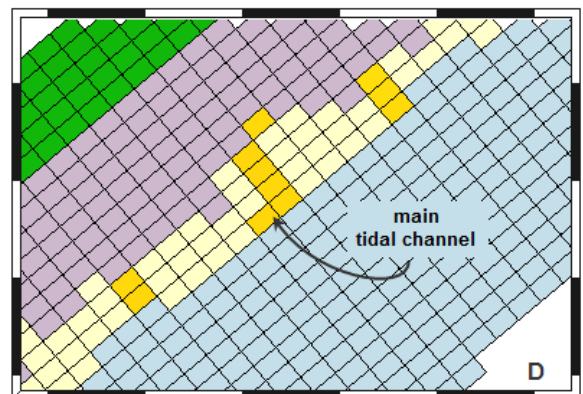
Grid cells 200x130m.  
Width of main tidal channel is 600m (3 cells).  
Barrier is between 600 m and 2400m wide (at least 4 cells).

CSWR of tidal channels: 0.33  
CSWR of barrier: 0.23 (minimum barrier width).



Grid cells 300 x 200m.  
Width of main tidal channel is 600m (2 cells).  
Barrier is between 600 m and 2400m wide (at least 3 cells).

CSWR of tidal channels: 0.5  
CSWR of barrier: 0.33 (minimum barrier width).



Grid cells 600 x 400m (the average width of the channels in the original model).  
The width of main tidal channel is 600m-1200m (1-2 cells) and the barrier is now 800-1600 m wide.

CSWR of tidal channels: 1.0  
CSWR of barrier: 0.66 (minimum original barrier width).

**Figure 7.3. Model of the upper Volador Formation barrier-island system.** The four figures show the effect that upscaling will have on the facies model. If the model is upscaled to 300 x 200 m cells (C) the morphology of the tidal channels and barrier are both preserved—however the results of the dynamic modelling indicate that the cells should be no more than a third of the width of the tidal channel (B). If the model is upscaled to 600 x 400 m cells the width of both the barrier and the tidal channel are both altered and simulation results could vary significantly from that which would be achieved with the base grid (A).



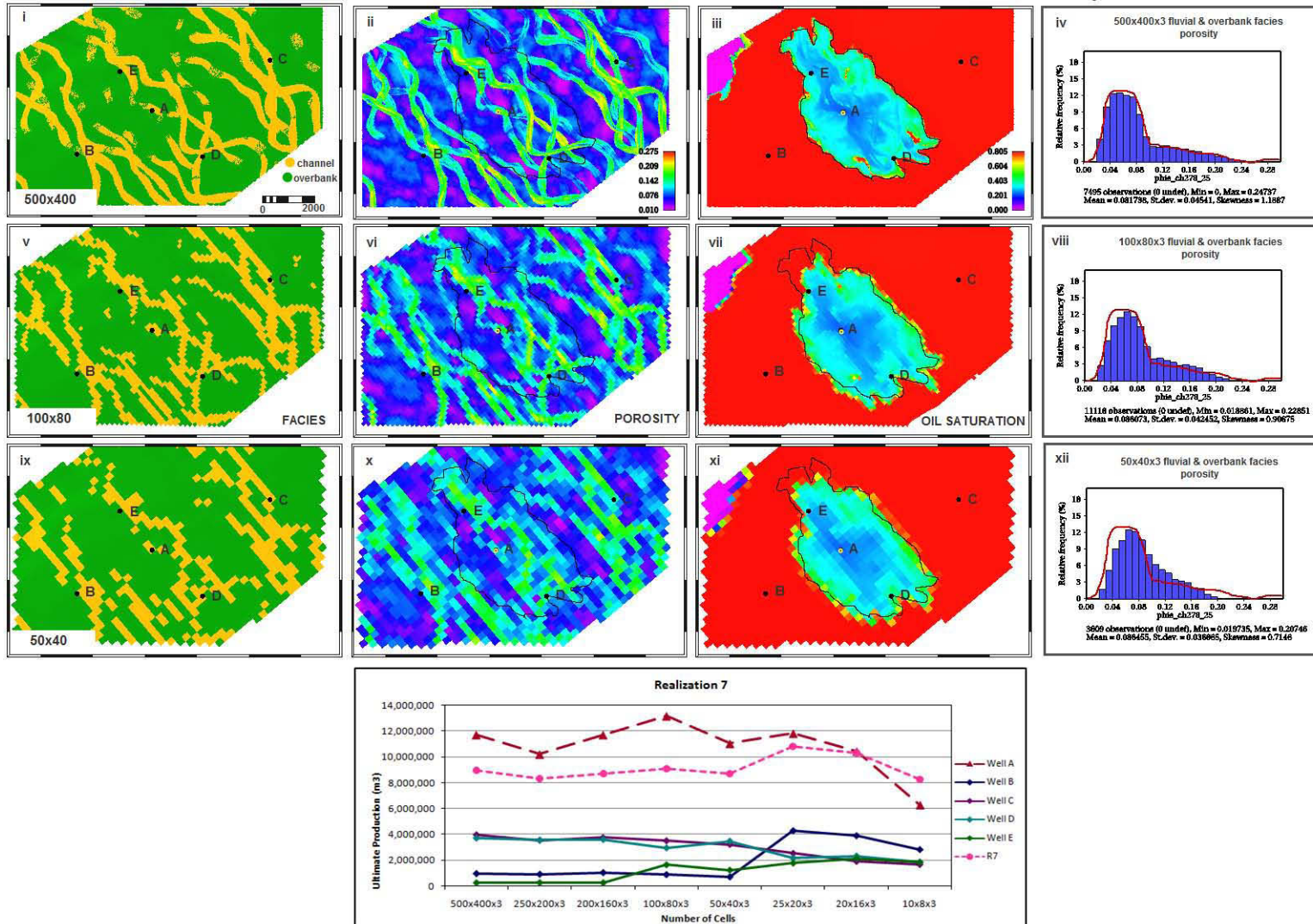
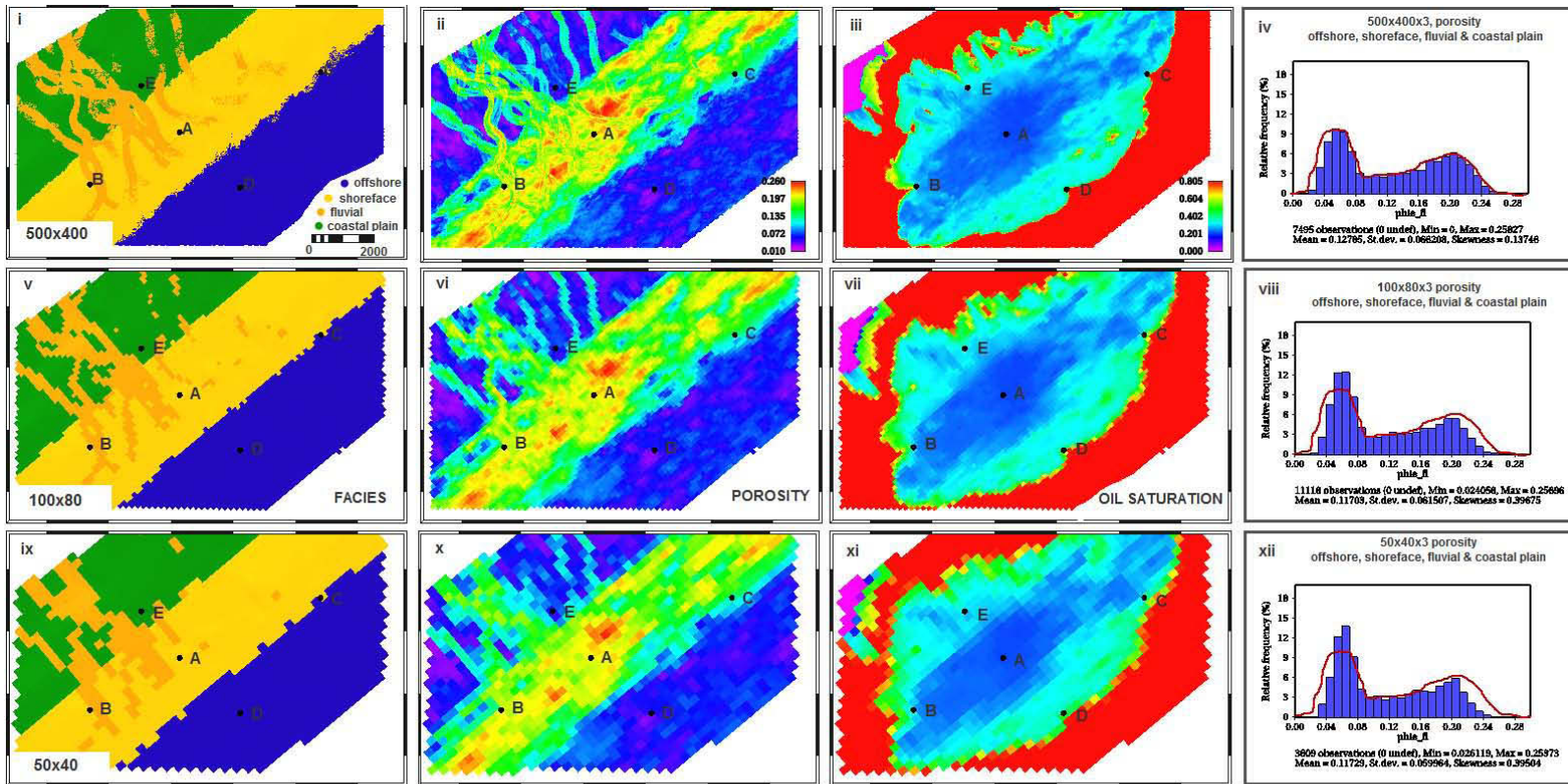
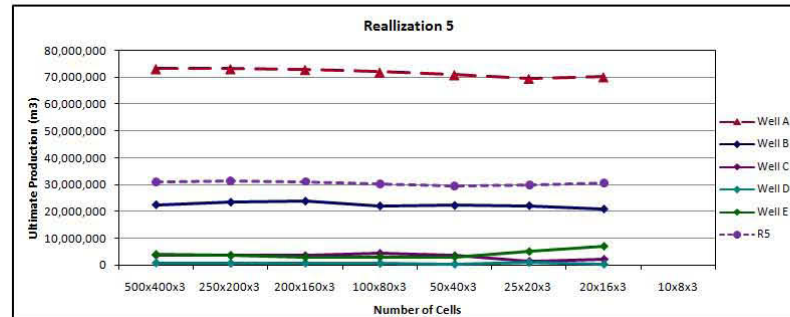
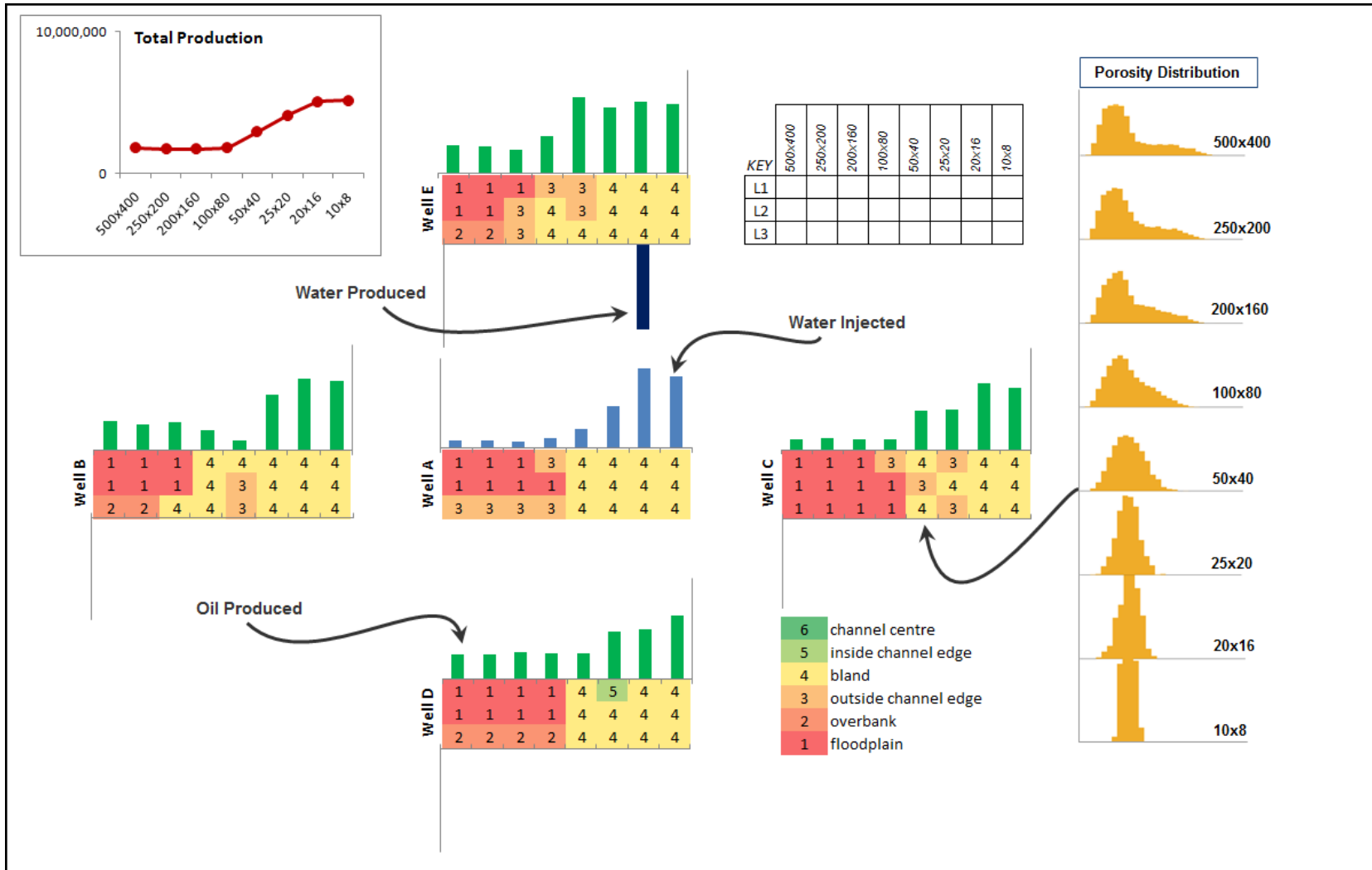


Figure 7.4. Oil Saturation at the end of 20 years production. SQ280-25, R7, layer 3. The three grids shown all have cells widths that are less than or equal to the channel width. This plot highlights the changes to water influx that occur as grids are upscaled. The detail of the water saturation influx along the channels is blurred when the cells are half the channel width (100 x 80 grids) and lost when the cell width equals the channel width. Despite the differences in water influx (see black outline) the total field production is relatively constant between these three grids. As the grids are upscaled there is a subtle shift in the porosity distribution. Wells B and E are located on the outside edges of channels in the 500 x 400 grid (i and ii) and the porosity at the wellbores improves as the grids are upscaled (ix and x). This is reflected in their ultimate recovery. Wells D and C are located in the centre of channels and are relatively unaffected by upscaling.



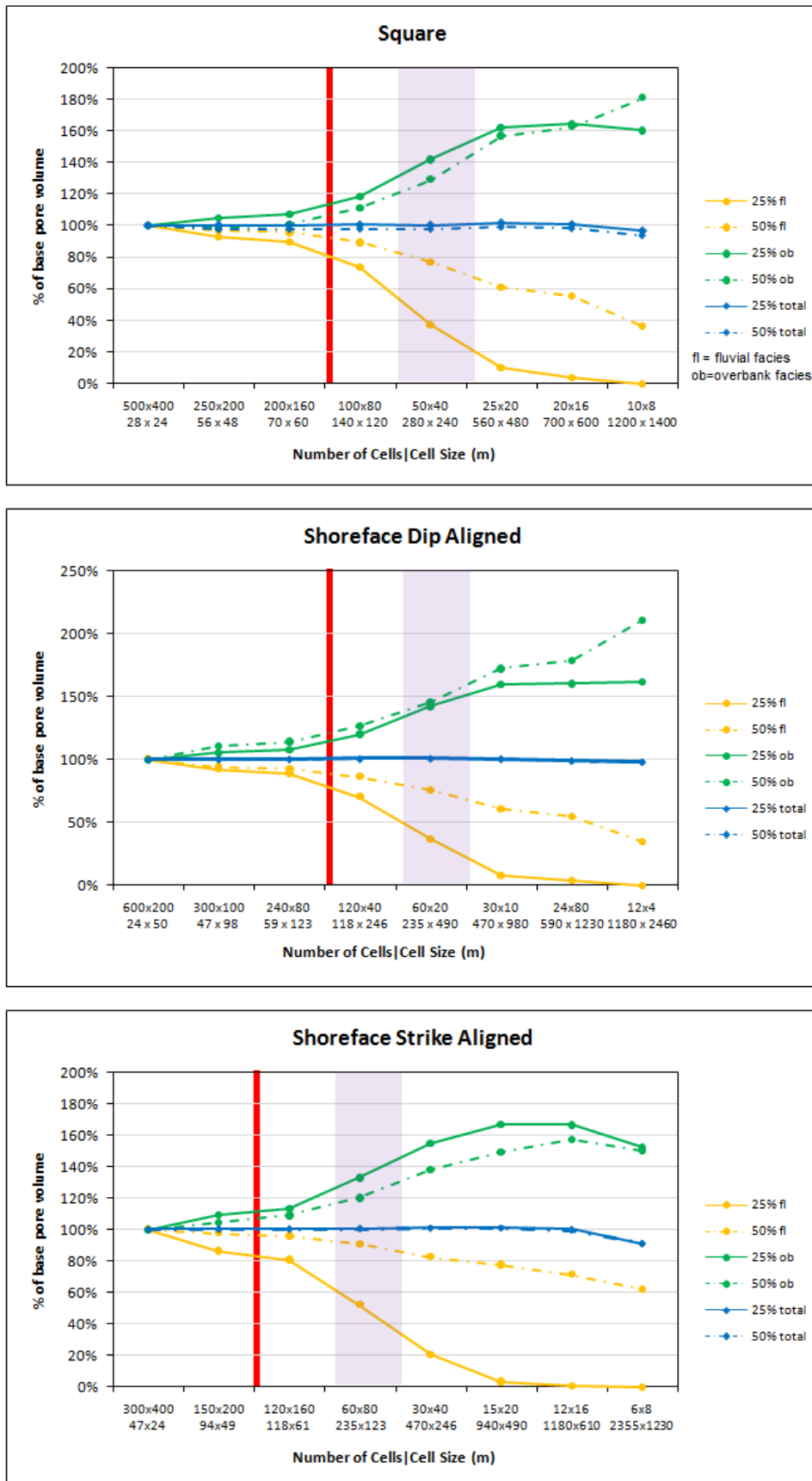
**Figure 7.5. Coast scenario, Square mode, R5 layer 3.** This figure highlights the visual differences in the 500 x 400, 100 x 80 and 50 x 40 grids. Despite the visual differences, the ultimate recovery for the wells and the field is constant between the three grids. The cells in the 50 x 40 grid are the same width as the channels on the coastal plain. The 50 x 40 grid is the last grid to retain detail of the porosity within the shoreface.





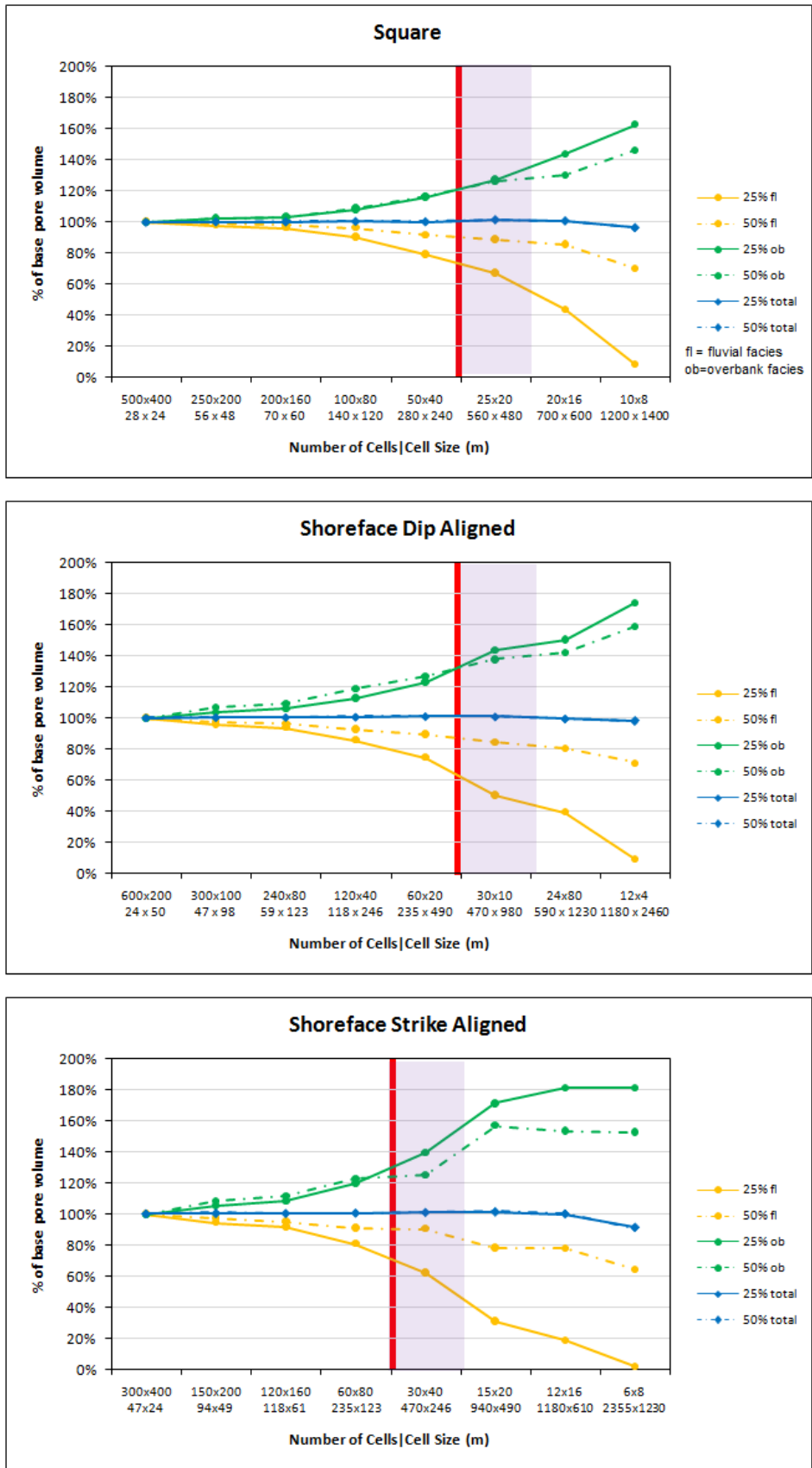
**Figure 7.6. Channel proximity to wells and porosity distribution. SQ 100-25, Realization 2.** This realization shows how non-reservoir intervals can become producing intervals if upscaled enough. The point at which the porosity grid becomes 'bland' (yellow) often corresponds to the point at which the porosity distribution becomes 'normal': the 50 x 40 grid.



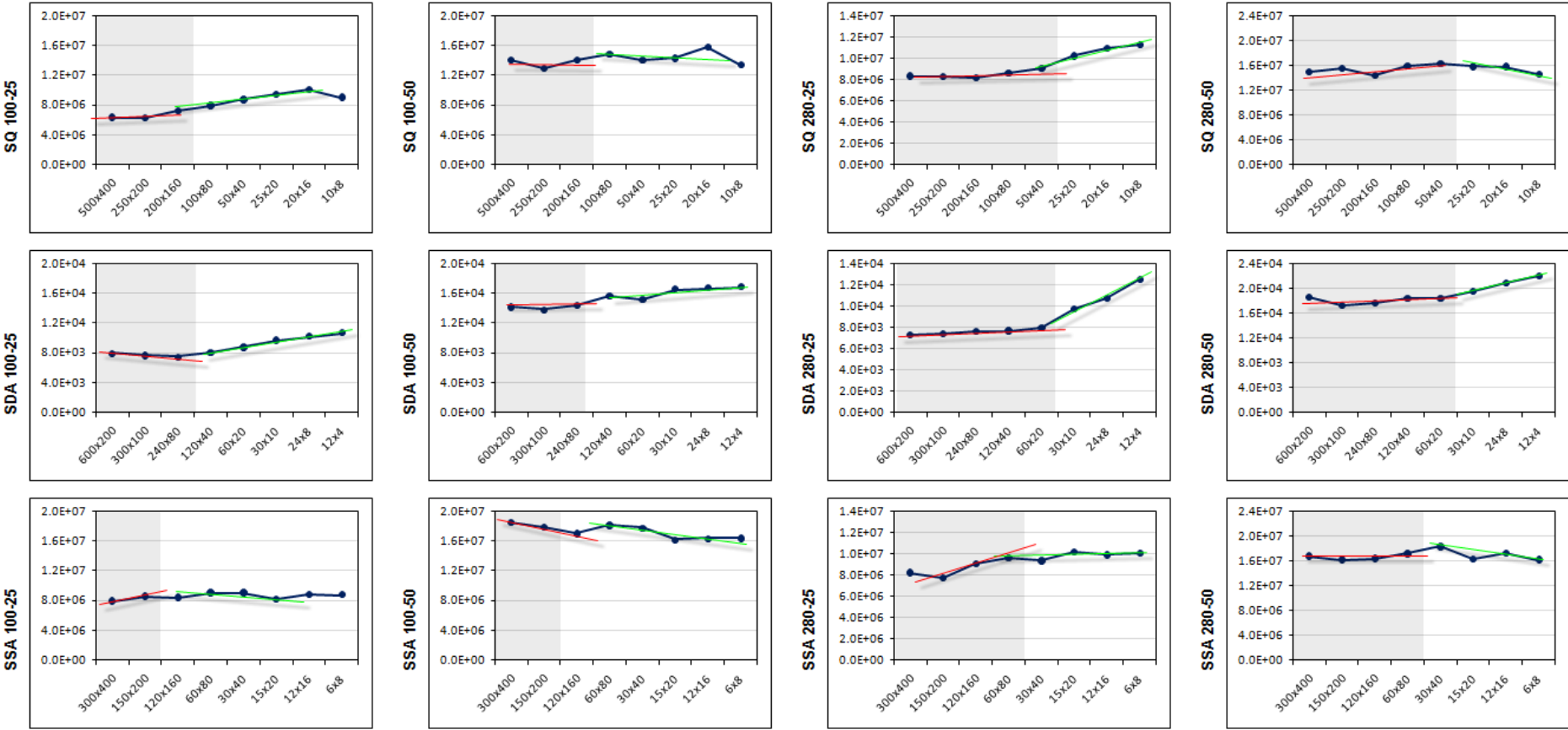


**Figure 7.7. Change in average pore volume by facies distribution compared to channel width and porosity distribution. 100 m channel scenarios.** The red lines highlight the point at which the cell width becomes greater than the channel width (100 m). The purple shading highlights the grid where the total porosity distribution becomes normal. In all grid designs the fluvial facies has shrunk by approximately 10–20% by the time the channel width is exceeded.

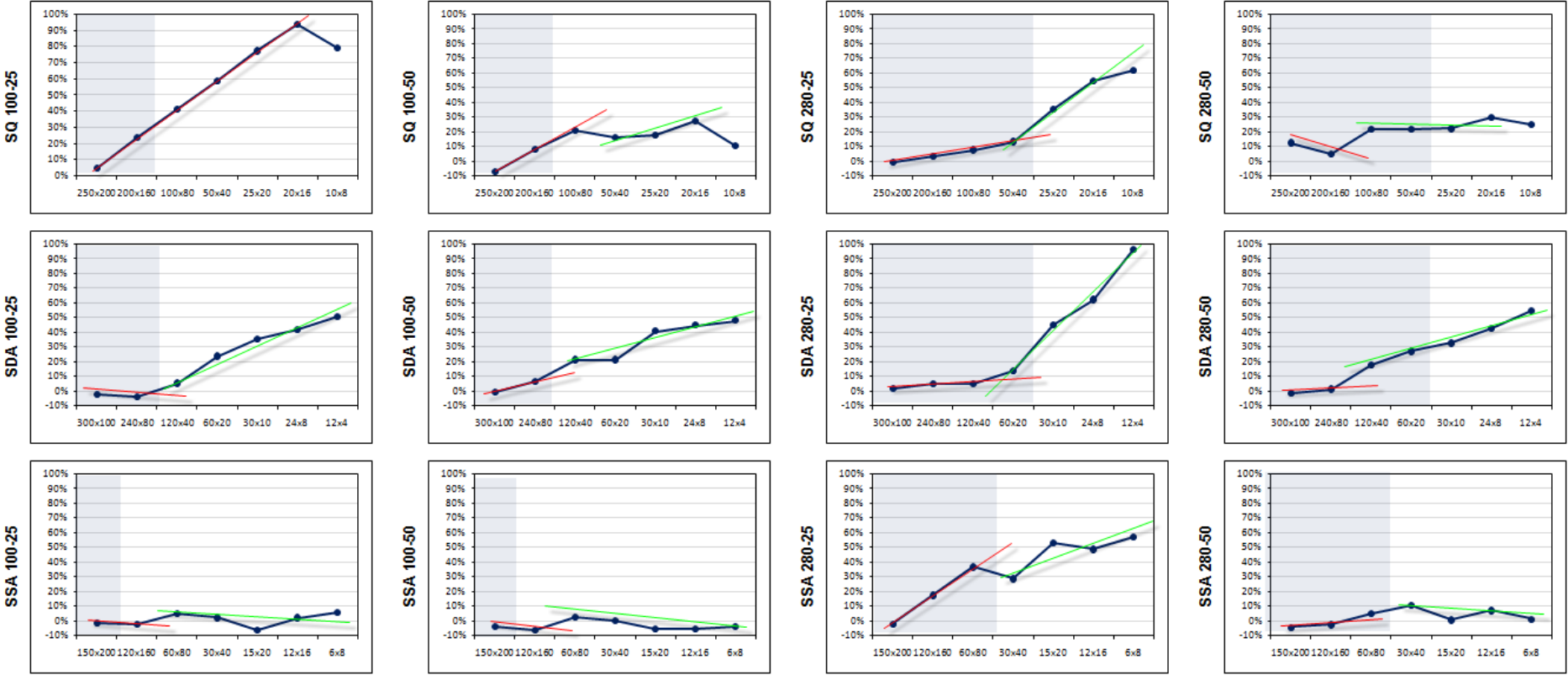




**Figure 7.8. Change in average pore volume by facies distribution compared to channel width and porosity distribution. 280 m channel scenarios.** The red lines highlight the point at which the cell width becomes greater than the channel width (280 m). The purple shading highlights the grid where the total porosity distribution becomes normal. The pore volume is redistributed amongst the facies before the channel width is exceeded by the cell width, and in all grid designs the fluvial facies has shrunk by approximately 20% by the time the channel width is exceeded.



**Figure 7.9. Average field production—all channel scenarios.** The pale blue-grey shading highlights the cells that are narrower than the channel width. The red and green lines highlight the trends in average recovery as the grids are upscaled. They indicate that in most cases there is a change in trend as the grids are upscaled beyond the channel width. In the square grids, the change in trend seems to occur when the cells are approximately half the channel width (250 x 200). If this pattern is applicable to the other grid designs, it may provide an explanation as to why the trends are weak in the SSA 100m scenarios. In the SSA 100-25 and 100-50 models only the 300 x 400 grid has cells that are half (or less) than the channel width. The 150 x 200 grid has cells approximately 100 m wide.



**Figure 7.10. Average %change in field production relative to base grid between upscaled grids and the base grid for all channel scenarios.** The blue-grey shading indicates the grids where the cell width is less than the channel width. The red and green lines highlight the trends in average recovery as the grids are upscaled. The trend in the SQ 100-25 scenario is the result of changes in three realizations. These plots indicate that in general, the average amount of change is similar for the 25% gross sand and 50% gross sand scenarios for each channel width. This is in contrast to the amount of change that is seen in the pore volumes, where the fluvial facies in the 25% gross sand scenario has a much larger amount of pore volume change than the 50% gross sand scenario (Figure 7.8).

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## **8 CONCLUSIONS**

The aim of this project was to determine if the interpretation of depositional environments could be used to determine the appropriate size of grid cells in a dynamic model prior to the construction of a model?

### **8.1 Flounder Field Study**

The study of the Flounder Field produced a more detailed stratigraphic interpretation of the upper Volador Formation and Roundhead Member than has previously been published. The portion of the Volador Formation immediately below the Roundhead Member has been subdivided into five units and renamed the upper Volador Formation (Riordan et al., 2004). The main reservoir interval (known as the T.1.1 reservoir (Sloan, 1987) or the Roundhead Member (Bernecker and Partridge, 2001) has been divided into two units—the upper and lower Roundhead Member—that are separated by a sequence boundary. A series of palaeogeographic maps has been drawn for the 18 units interpreted. These show a coastline dominated by overall marine transgression, but interrupted by periods of relative sea level fall, with associated erosion and lowstand deposits. Three depositional systems were interpreted. The upper Volador Formation was deposited in a transgressive barrier-island system. The lower Roundhead Member was deposited on a transgressive strandplain with narrow fluvial channels. The upper Roundhead Member consists of lowstand fluvial deposits partially filling an incised valley, overlain by transgressive estuarine deposits and marine sediments.

### **8.2 Analogue Data**

The Flounder Field case study highlights the variability in depositional environments that can occur within one reservoir interval. The three environments interpreted have different depositional styles and sizes of sandbodies (Figure 3.35). The conceptual models highlight

the difference that sandbody dimensions can make to predicted production results when grids are upscaled. As much information as possible needs to be extracted from core, wireline and production data to define the environment of deposition and the associated sandbody dimensions. Modern and ancient analogues are an excellent source of additional information about the potential sizes of sandbodies. Care needs to be taken when acquiring sandbody dimensions of modern depositional environments from satellite imagery. The best looking, easiest to measure analogues are usually large, and may provide a skewed understanding of the possible dimensions of ancient systems.

## **8.3 3D Modelling**

### **8.3.1 Static Models**

The spatial and statistical distribution of static parameters such as facies, porosity and permeability is altered by the upscaling process. Upscaling static models to the point that the grid cells are larger than the facies bodies will result in a change in the distribution of facies, porosity and permeability. As grids are upscaled the high and low value end-members are lost and the statistical distribution of porosity and permeability tends towards a normal distribution; regardless of the original distribution of the data. This will alter the pore volume associated with each facies in the model. The connectivity of facies bodies breaks down once the grid cells are more than half the size of the facies objects. However, the porosity and permeability associated with the facies bodies may persist until the porosity distribution begins to be altered once the cell size exceeds the size of the sand bodies.

A comparison of the upscaled facies models and upscaled porosity models shows that the porosity associated with the channel facies is present in the model in grids where the channel facies has been 'averaged out' of the facies model. This is related to the different methods often used for upscaling facies models and porosity models. Care needs to be taken when assessing the connectivity of channels within upscaled models—it should not be judged only on the facies model, but on a combination of both facies and porosity.

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A very simple rule of thumb for upscaling is that if the detail in the base porosity grid is not identifiable in the upscaled grid, the ultimate production from the upscaled grid is likely to be very different from what would be calculated for the base grid.

### 8.3.2 Dynamic Models – Average Production

A factor known as *CSWR* (the ratio of cell width to sandbody width) has been developed for this study. *CSWR* enables the comparison of results from models with varying cell dimensions and depositional environments. The correlation coefficient between the total field production of the upscaled grids and the total field production of the base grid decreases as grids are upscaled. The relationship goes from a strong correlation (0.8–1) when the *CSWR* is less than 0.3, to moderate (0.5–0.8) when the *CSWR* is between 0.3 and 0.75, and is poor once the *CSWR* exceeds 0.75. This lowering of the correlation coefficient translates into a maximum difference in ultimate production between the base grid and upscaled grid of less than 10% when the *CSWR* is less than 0.3, to greater than 20% difference when the *CSWR* is greater than 0.75.

Once grids are upscaled beyond the width of the facies bodies ( $CSWR > 1.0$ ), the porosity and permeability distribution will be altered to a normal distribution. The result of this amount of upscaling is that individual sandbodies are no longer identifiable and the grids appear 'bland'. The average ultimate recovery of multiple realizations from these grids will differ from that of the base model by at least 30%.

### 8.3.3 Dynamic Models – Individual Realizations

The response of individual realizations to upscaling is related to the position of the wells relative to the reservoir sand bodies. Wells that are located in the centre of reservoir quality bodies will show less variation as a result of upscaling than ones located either close to the boundary between reservoir and non-reservoir quality rock, or those located well away from reservoir quality rock. Where wells are located close to the boundary of a reservoir quality rock, there may be significant changes to the performance of the well at any upscaling step.

Grid induced changes to ultimate production can only be identified by visually comparing the base grid and upscaled grid around every well bore on every layer (which is not always practical) or by running reservoir simulation on several different grid sizes and comparing results. Although this study does not fix the properties at the wellbore—allowing for a wide array of production results, these conclusions are applicable to situations where the geology at the wellbore is known. In that situation, the issue of proximity of the wellbore to the edge of the reservoir quality sandbodies is still an issue. When facies models are built, the modelling process can control what facies the well penetrates but do not generally dictate the position of the well within the sandbody.

The interpretation of depositional environments should be incorporated into the design of grids that will be upscaled for reservoir simulation in the design stage of the model building process. Simple charts have been developed in this study that can be used to estimate the number of cells in a potential model and study how the *CSWR* may influence the uncertainty associated with the results of reservoir simulation of multiple realizations compared to models with grid cells less than one-third the size of the reservoir sandbodies.

*In conclusion, this study has shown that the interpretation of depositional environments have a significant influence on the design of grids for static and dynamic models. The distribution of sandbodies within a model relative to wellbores will influence how predicted production changes as grids are upscaled. Multiple realizations of dynamic models are essential to capture the variability that results from uncertainties in sandbody distribution. Porosity distributions within static models provide an indicator of when grids have been upscaled to the point that the results of dynamic modelling will not reflect that of a finer scale grid.*

*This study has shown that the interpreted dimensions of sandbodies within a depositional environment can be used to predict the optimal and maximum size of grid cells in an upscaled grid. The size of grid cells should be no more than one-third the size of reservoir sandbodies if the ultimate production is to be kept within 10% of a fine-scale model that captures key geological geometries that influence fluid flow.*





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