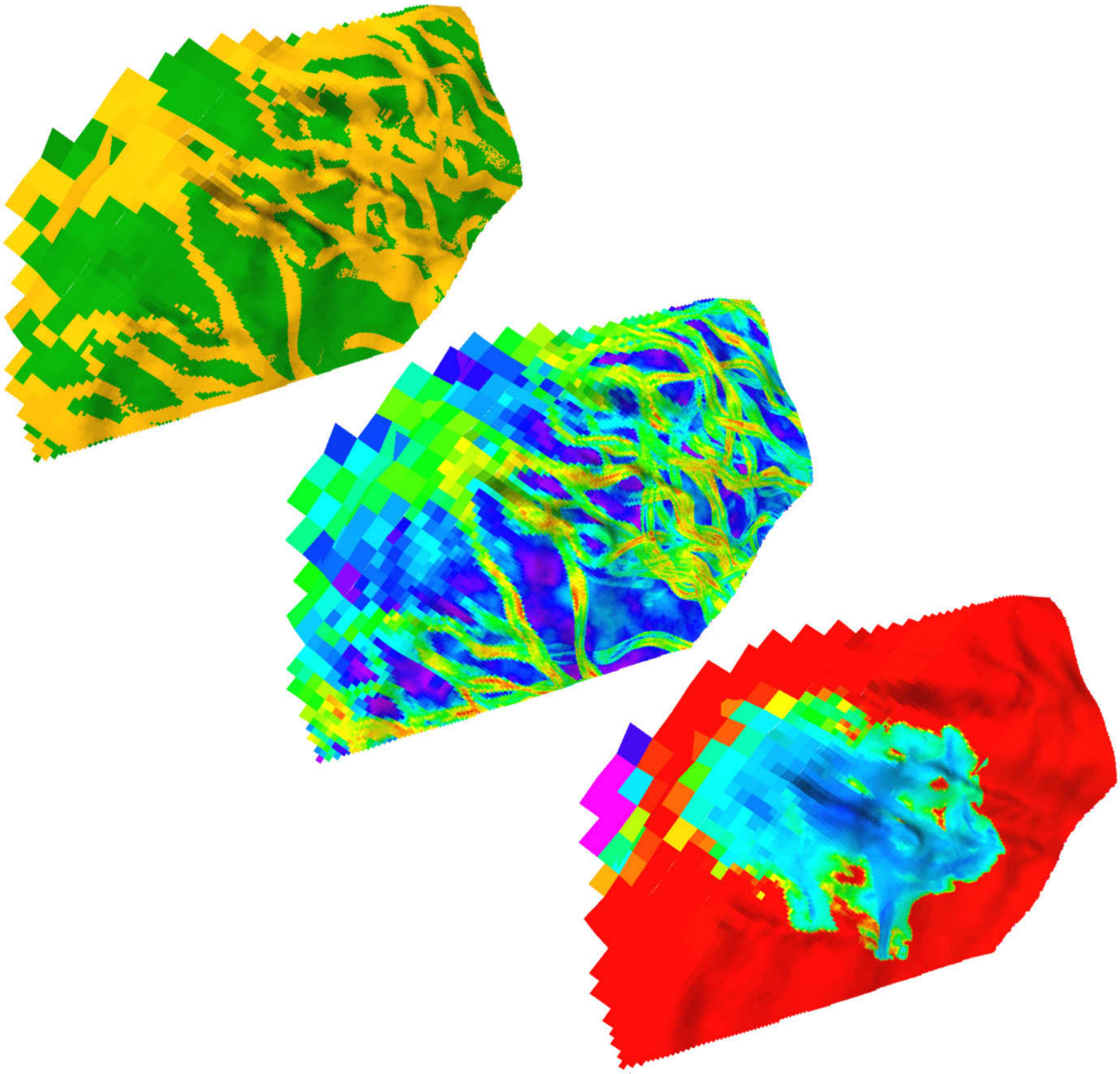
Managing the Interdisciplinary Requirements of 3D Geological Models



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1 INTRODUCTION

1.1 Study Rationale

3D reservoir models (also known as geological models, static models, geo-cellular models) are 3D virtual representations of a stratigraphic succession created from interpreted subsurface data, typically over the area of an oil or gas field, and comprised of 6-sided polyhedron (cells).

Computers have been used by engineers and geologists to model reservoirs in three dimensions since the 1960's, and since that time there have been many discussions as to how detailed 3D models need to be for reservoir simulation (for example: Coats, 1969; Staggs and Herbeck, 1971; Baker and Moore, 1996; Saleri, 1998; Castellini et al., 2003; Durlofsky, 2003). As computer power has improved, the models being built by geologists are becoming increasingly complex. However, at the present time the number of grid cells that reservoir simulators can handle remains an order of magnitude less than what geologists can build (Gorell and Bassett, 2001; Chawathé and Taggart, 2004). In order to run reservoir simulation (dynamic models) on geological models (static models) it has been standard practice for models to be upscaled. Upscaling is the process of reducing the number of grid cells while retaining, as much as possible, the fluid flow and volumetric characteristics. The number and size of cells in an upscaled model has until recently been influenced more by what computers could handle—rather than what was geologically appropriate. Possibly because of this, it is surprisingly hard to find literature examples of studies of models that have been upscaled to a variety of cell dimensions and simulated, with the results related back to the underlying geology of the model. Although the increasing use of multi-core processors and parallel processing has the potential to close the gap between geological and engineering computational requirements for 3D models, it is anticipated that in many commercial environments upscaling will continue into the foreseeable future due to the time benefits it provides.

The ever increasing amount of processor power available to geologists and engineers could be utilized in several ways:

- To build extremely detailed geological models that attempt to emulate features such as bedding structures, sub-seismic faults or small sandbodies—potentially improving the modelling of water-floods and oil recovery and bypassed oil (Keogh et al., 2007). In many cases these models may still need to be upscaled.
- To run (potentially slow) reservoir simulation on a few fine[*] models (1–10's of metre cells).
- To increase the speed of simulation runs on coarse models (10's–100's of metre cells), thus improving the turn-around time on modelling projects.
- To perform reservoir simulation on many medium (10's of metre cells) 3D models with different sandbody connectivity and/or permeability distributions and profiles—potentially improving the understanding of the uncertainties associated with the reservoir models and the predicted outcomes (Gorell and Bassett, 2001; Hovadik and Larue, 2007; Larue and Hovadik, 2008).

This list highlights the fact that geological input into dynamic models remains at the heart of the future of 3D modelling. An enormous amount of information is available about the depositional environments and sedimentology of petroleum reservoir rocks. The challenge for geologists building 3D reservoir models is how much detail needs to be captured in the geological model and how well is it retained in the upscaling process. Jian et al. (2002) and Larue and Hovadik (2008) both found that models that have the same net:gross but look very different can produce similar results. The studies carried out by Jian et al. (2002) and Larue and Hovadik (2008) were designed such that no upscaling was required. This project looks at whether results change, as models are upscaled, in a manner that can be related to the depositional facies interpretation that is the first step in building a geological model.

[*] *What constitutes a 'fine', 'medium' or 'coarse' model is dependent upon the size of the area being modelled. The cell sizes quoted herein would be applicable to the Flounder Field which covers an area approximately 12x6 km.*

The aim of this study is to examine how geology influences the results of reservoir simulation as grids are upscaled. The key question that this project addresses is:

Can the interpretation of depositional environments be used to determine the appropriate size of grid cells in a dynamic model prior to the construction of a model?

1.2 Study Workflow

This project had two main components—an oil field study and a 3D modelling study (Figure 1.1). The field study consisted of core interpretation, structural interpretation, wireline log interpretation, and the development of a series of depositional facies maps. The Late Cretaceous intra-Latrobe reservoir in the Flounder Field in the Gippsland Basin was chosen for the field study component of this project. At the time the project commenced in 2001 there were 42 wells drilled in the Flounder Field, with a well spacing of 200–1500 metres. Approximately 230 m of core had been cut over the reservoir interval. ExxonMobil provided wireline logs for all the wells, core analysis data, petrophysical logs and 3D seismic data as part of its contribution to the APCRC[1] Reservoir Characterization and Improved Oil Recovery Program which concluded in 2004. A sequence stratigraphic framework was used for the interpretation of the wireline logs. Placing the interpretation into a sequence stratigraphic context can assist in the recognition of potential flow units and aid in the prediction of sandbody dimensions in a paralic depositional environment (Reynolds, 1999).

Modern and ancient analogues of the depositional environments interpreted (barrier island, strandplain and fluvial-filled incised valley) were studied in order to understand their potential dimensions, and which aspects of these environments need to be modelled and retained in the upscaling process.

The 3D model building component consisted of two stages—static models and dynamic models. The 3D models are bounded by the structure of the Flounder Field and the intervals

[1] *Australian Petroleum Cooperative Research Centre*

modelled were defined by flooding surfaces, sequence boundaries and parasequence boundaries interpreted in the field study. By defining the architecture of the reservoir model with flow unit boundaries, geological information is incorporated into reservoir simulations (dynamic models) (Ebanks, 1987). Two generations of static models were built. The first generation of models honoured the well data of the intervals modelled. Building these models provided the opportunity to finesse the interpretation of sandbody distribution and dimensions in a three dimensional context. Issues such as angles of shoreface progradation can only be fully understood by building 3D models that honour the well data. The second generation models were conceptual models that used the same structure and petrophysical distributions as the first generation models, but did not honour the data at the well locations. These models provided the flexibility to study how changing sandbody dimensions and sand content interacted with upscaling and influenced reservoir simulation results. Three grid designs were built, each with different cell dimensions (Figure 1.2). The three grid designs are defined by the orientation of the longest axis of the cells relative to the palaeoshoreline being modelled (square, shoreface dip aligned and shoreface strike aligned). For each grid design, six facies models (scenarios) were created, and ten realizations were generated for each facies model. These models were then upscaled vertically from 24 layers to 12, 6 and 3 layers and horizontally by factors of 2, 4, 5 10, 20, 40, 50 and 100.

The dynamic modelling stage of the project focused on the conceptual models. At the beginning of the dynamic modelling process, a homogeneous model was simulated for each grid design. The homogeneous model had constant porosity and permeability. This simulation was carried out in order to assess the influence of the grid design on the simulation results as the grids were upscaled. Three realizations of each scenario were then simulated for the horizontally and vertically upscaled grids (Figure 1.2). The results from these simulations indicated that the difference in results between the 24-layer grids and the 3-layer grids were small, and that the response of the 3-layer grids to upscaling was comparable to that of grids with more layers. Once this was established, the 3-layer grids became the focus of all the dynamic modelling work. A further seven realizations of all horizontally upscaled grids (with 3 layers) were simulated. Five vertical wells were created for the dynamic modelling, which were spaced so that in all grids there were never two wells in one cell. A five-spot injection pattern was simulated, using the same injection and production properties for all dynamic models. The final stage in the dynamic modelling process was to simulate one of the first generation models (using the 5-spot injection pattern) that honoured the well data so that the results from a real data set could be compared to those of an equivalent conceptual model.

The results from all the static and dynamic models were analyzed—focusing on how static properties and total field production change as grids are upscaled. The ratio of cell width to sandbody width (*CSWR*) is used to compare the influence of sandbody size on ultimate recovery for all facies models and grid cell dimensions.

1.3 Thesis Layout

The case study of the Flounder is discussed in *Chapter 2.* *Chapter 3* examines modern and ancient analogues of the depositional environments that are identified in *Chapter 2*, and the modelling implications of interpreting such environments. *Chapter 4* details the building and analysis of the static models. In *Chapter 5* the influence of upscaling on static parameters such as facies models and porosity distribution is examined. *Chapter 6* details the dynamic modelling component of the project. This chapter examines the results of the simulations and discusses the similarities and differences between upscaled grids, and between different realizations and facies models. *Chapter 7* compares the results of the dynamic modelling to those of the static models, and examines how they can be applied to the design of future static models that will be upscaled for reservoir simulation. It is not recommended that *Chapter 7* be read without first reading *chapters 4, 5* and *6*, as there are analytical methods discussed in this chapter which are introduced and explained in the prior chapters. The overall project conclusions are presented in *Chapter 8*. Note that all figures are located at the end of the chapters.

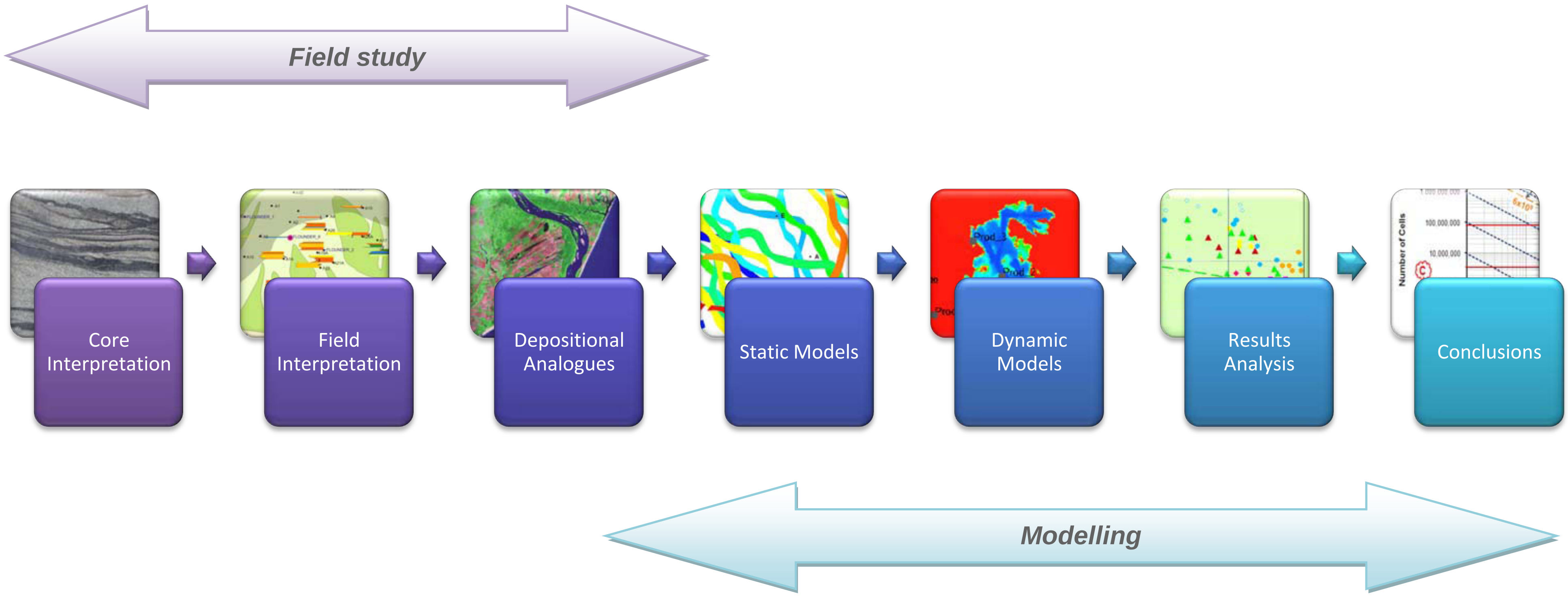

Figure 1.1. Workflow followed in this thesis.

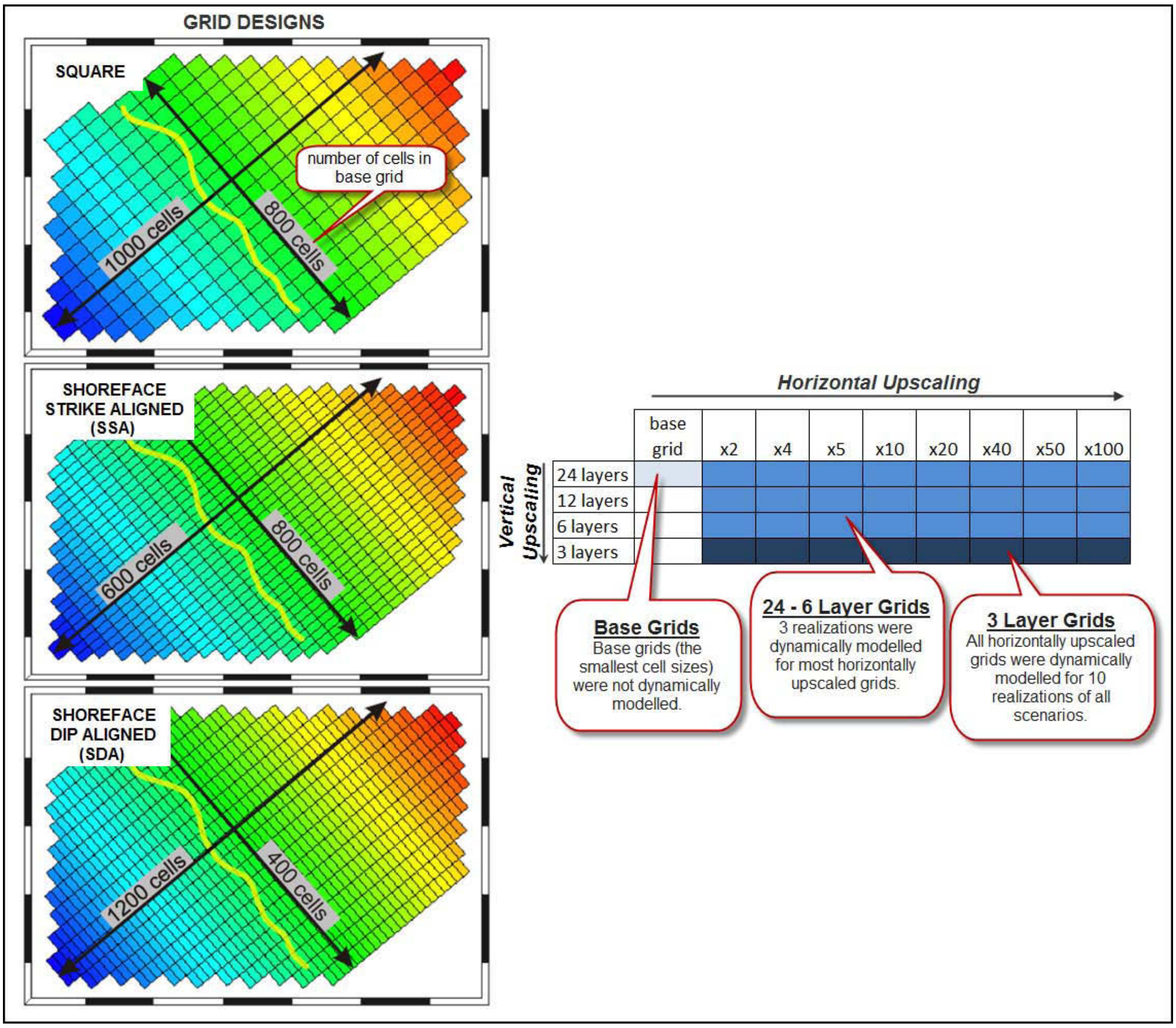

Figure 1.2. Grid design and upscaling. The three grid designs all underwent the same pattern of vertical and horizontal upscaling. The base grids (smallest cell sizes for each grid design) were not simulated as they contain too many cells for the available computers to be able to process. The yellow lines on the grids indicate the orientation of the channel facies in all scenarios.