STRATIGRAPHIC FORWARD MODELLING - A METHODOLOGY COME OF AGE ?

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Summary

Although the forward stratigraphic modelling of basin fill has been of interest to small groups of mathematical geologists since the 1940's it has not really become accessible to applied geologists until the 1990's. There are several reasons for this. Perhaps the prime reason is improved access to powerful computational facilities, and graphics engines that enable results to be visualised, and therefore communicated, in seconds rather than minutes or hours. Forward modelling can be subdivided into a number of categories: 1D, 2D, 3D, 4D, geometric, diffusion, process, stochastic, etc.. The different approaches reflect differing needs and problems. The following paper discusses the current state of modelling in three spatial dimensions over geological time periods and points to some future directions.

Introduction

By stratigraphic forward modelling we mean the development and use of numerical computer models that attempt to simulate or emulate the processes that result in the deposition and preservation of sediment in basins at scales from metres to hundreds of kilometres.

Stratigraphic forward modelling (SFM) offers challenges to model developers, explorers, and basin analysts at all levels. SFM rises to the challenge of quantifying and applying what is known of the physical and chemical processes underlying basin fill and preservation over geological time periods. At the same time, predictions based on SFM are capable of reducing risk in economic exploration within some types of basin. The models do not pretend to be perfect. They will probably always be in a state of development. Like weather forecasts there will be always something that could be improved. Nevertheless they have reached a state of utility and reproducibility that was unthinkable ten years ago. The recognition, led by sequence stratigraphic models, that three-dimensional stratal geometries are driven by two very simple processes in complex interplay has also lent credence to three-dimensional SFM predictions. The interplay between the rate of creation and destruction of accommodation and the changing rate of sediment supply at all spatial and temporal scales creates the complete complexity of initial basin fill.

Typical Problems

What sort of problems has SFM been applied to in recent years? On the NW Shelf of Australia it has been used to predict sand location and quality in passive margin settings. It has been used to predict sediment distribution on Base Cretaceous surfaces over areas up to 60000 km^2 (Browse and Yampi Shelves) (Griffiths and Paraschivoiu 1998). It has predicted sand distribution in hanging wall fans and basin-floor fans (Kendrew Trough). It has been used to examine gold distribution in buried river channels (West Australia). It has been used to predict toe-ramp sand bodies in the Neocomian Barrow Delta over a modelled area of over 130000 km^2.

Procedure

The numerical techniques vary from model to model but have been developed around our understanding of the basic processes involved in basin fill. If a basin is to exist a crustal depression is formed for some reason (compression, extension, thermal processes etc.), the depression creates an opportunity for water-, or wind-, borne sediment to accumulate together with the *in situ* formation of carbonates and organic matter. The stratal architecture within the basin is dependent on the fine balance between the rate of creation or destruction of accommodation and the rate of sediment supply. Modern SFM tools allow these processes to be modelled in three spatial dimensions at scales of metres to hundreds of kilometres over geological time periods. The half-dozen or so 3D models available all use different assumptions and numerical schemes, but the method of operation is the same. All available knowledge of the basin is examined. For a frontier basin this may not be very much, but the geographical limits, location of major sediment supply external to the basin, the stratigraphic timing of the major events, any information about the basin fill, any biostratigraphic data, any seismic lines that may exist, can all be incorporated in the model. The modelling team works closely with geophysicists, sedimentologists, biostratigraphers, petrophysicists to build a composite model of how the basin filled over the time interval of interest. There will be a huge number of unknowns, but these are unknown to everyone, which is why it is a frontier basin. The difference is that by using SFM the consequences of a variety of possible scenarios can be quantitatively tested. Tectonic influence on sediment distribution can be modelled using many different rates. The effects of sediment supply character and volume can be investigated as well as timing in relation to tectonic movement. Usually a major reason for the basin still being relatively underexplored is the lack of major structural closures visible on early seismic. Thus exploration in frontier basins is often also associated with the 'deliberate search for the subtle trap', and it is the, often seismically transparent, stratigraphic relationship between reservoir and seal lithologies that have potential in such basins. SFM has been used to predict the possibility of such stratigraphic traps on the NW Shelf. The procedure used to build 2D (sectional) stratigraphic forward models has been described in detail in Griffiths and Hadler-Jacobsen (1991) and Griffiths and Paraschivoiu (1998). The three-dimensional case is a straightforward extension of this, and if 3D-Chronostrat (Nordlund and Griffiths 1993) is used to generate the volumetrics all the three-dimensional information is already available.

How do we know if SFM gives believable results ? First and foremost we use the relationship proposed by the Exxon team in the 1970's, that seismic reflections are time boundaries. This has been supported by most studies that have critically examined the hypothesis. The fundamental Exxon hypothesis was that a seismic reflection, in a non-inverted basin, separates younger strata above from older strata below. SFM starts at a lower reflector, treated as a depositional surface, and MUST duplicate not only the three-dimensional internal geometry of reflectors to the upper-most reflector of the simulation, but also the thickness relationships of the entire package. In complex areas deriving the initial depositional surface can be difficult, but again this is no different to the requirements of any thorough exploration effort, or seismic interpretation, apart from the fact that SFM demands defendable numbers. The grain-size and biostratigraphic information from wells in the modelled area of the basin must also be reconciled with the simulation results. A useful approach is to deliberately withhold information from one or more wells while building the model input files. If the SFM manages to duplicate the hidden data then the predictions away from well data may be more credible. At the end of the day the only proof of a prediction is to drill, but in a frontier basin probably more than any other, a relatively inexpensive approach such as Stratigraphic Forward Modelling is a useful and proven frontier idea to apply to test an exploration concept pre-drill, make quantitative predictions concerning the probable location and quality of reservoir and seal, identify sites that would repay further geophysical investigation, and rank potential drill sites. Examples of SFM application with differing amounts and quality of input data are shown.

Future prospects

There are several developments on the immediate horizon. Process related models based on solving the Navier-Stokes equations in a Lagrangian framework (eg. Sedsim) will be supplemented by, and integrated with, heuristic models such as Fuzzim for non-clastic sediments. Diffusion-based models such as Dionisus and combined diffusion/stochastic models such as that produced in Manchester may develop some hydraulic components to cope with multiple grain-sizes. There will be a convergence of technologies over the next decade driven by the increasing ease of use and recognised value of the predictions made by these models.

References.

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