Introducing geological processes in reservoir models

Reservoir modelling and reservoir simulation are based on data collected at multiple scales with resolution ranging from sub-millimetre to tens of metres. New software using knowledge of the geological processes forming the reservoir rock now makes it possible to generate more accurate reservoir models, thereby improving prediction of both production profiles and reservoir volumes.

Cross bedding in the Mayaro Formation, Mayaro Beach, Trinidad.

Janice Liwanag

Improved oil and gas recovery is in the mind of almost everyone these days, and in order to get more hydrocarbons out of the reservoir it is of utmost importance to have realistic reservoir models. Following several years of industry sponsored research; a new reservoir modelling software is now bridging the gap between fine-scale and large-scale data.

Geomodeling, a Canadian company, has developed software with a focus on integrating multi-scale data into reservoir models. They do this by modelling the effects of fine-scale sedimentary bedding on large-scale reservoir permeability. The software, which has been named SBED, has contributed to improved prediction of both production profiles and reserve volumes in several fields in the North Sea as well as in the Norwegian Sea.

Backed by funding from major international petroleum companies, SBED is now making its way to the desktops of geoscientists interested in reducing the uncertainties in reservoir characterization.

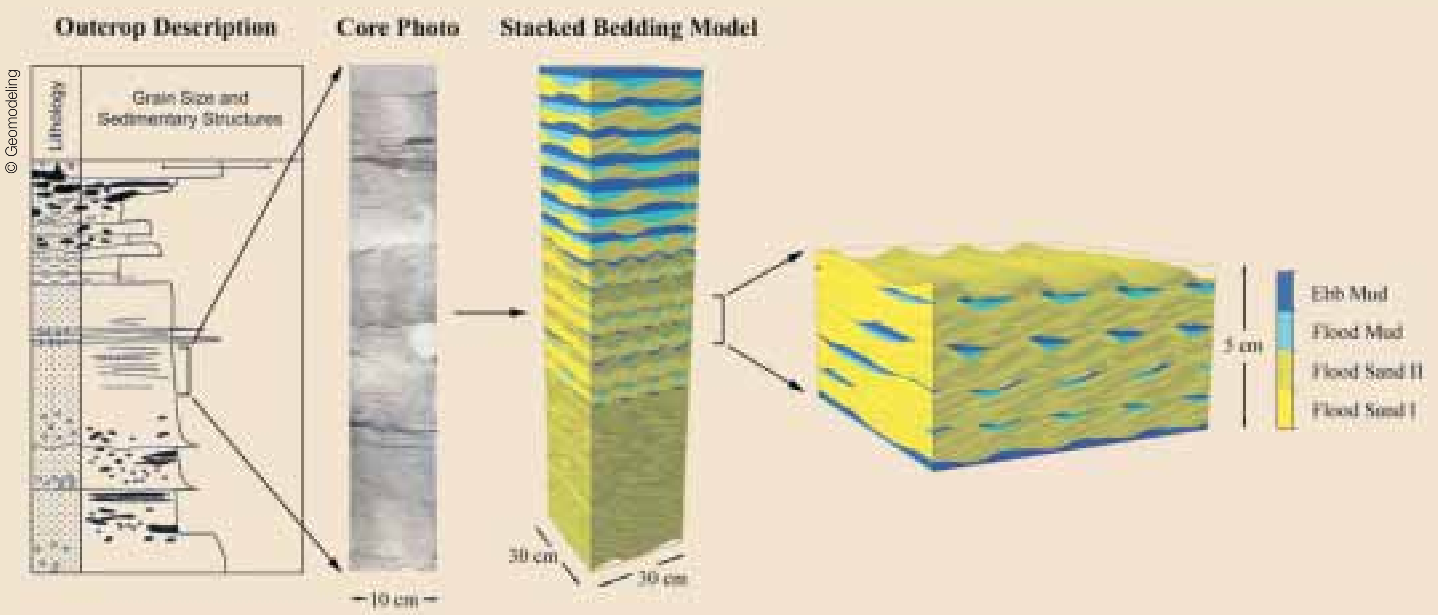
Missing scales

SBED addresses an ongoing challenge that reservoir asset teams face throughout the petroleum industry: Creating large-scale sub-surface models that honour input data describing reservoir properties at different spatial scales. These data include thin section data, core-plug measurements, well log results, seismic data and outcrop observations.

"Fluid flow is controlled by heterogeneity occurring at multiple scales - from sub-millimetre-scale pore spaces to metre-scale shale beds to sand bodies up to dozens of metres in size. All these elements can act as baffles or barriers to moving fluids," explains Renjun Wen, SBED's inventor and Geomodeling's founder and CEO. "This is why it is important to integrate multi-scale data," he adds.

"The more heterogeneous the field, the more complicated it is to calculate flow parameters such as vertical and horizontal permeability," he says. "To obtain more accurate permeability estimates and recovery factors, petroleum geoscientists need to consider the impact of multi-scale heterogeneity on fluid behaviour, even at the smallest scales."

Renjun Wen views reservoir data in terms of the scale at which it is collected: "Data from thin sections and core plugs are direct measurements of reservoir rocks and are the most quantitative information about reservoir. The resolution of these data is sub-millimetre to a few centimetres. Well log data reflect reservoir properties near the well bore and are important for deriving

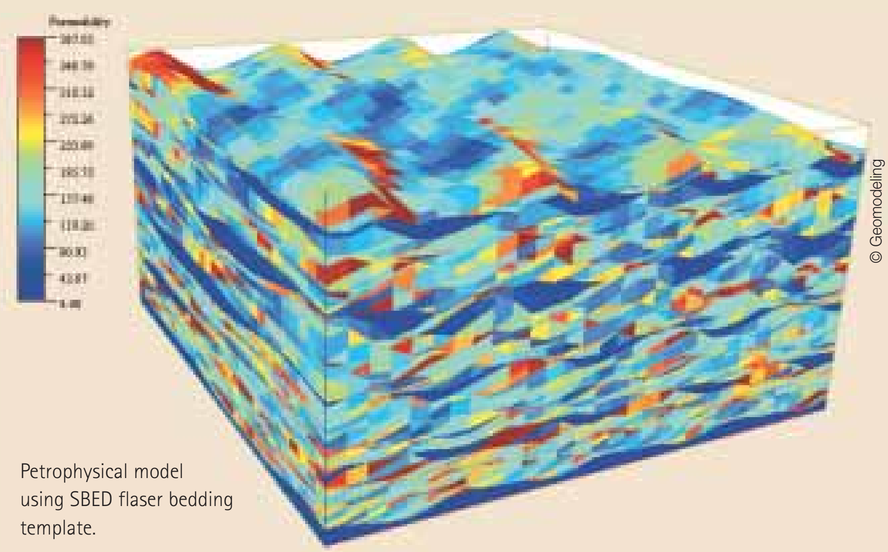


The SBED modelling method is based on core and outcrop data and generates 3D stacked bedding models. The block diagram shows a detail of tidal sediments with flaser bedding.

porosity and oil saturation. The resolution here is from decimetres to a few metres."

"Between core and well log data there is a 'missing scale', ranging from a few centimetres to one metre, at which we do not have rock measurements. Reservoir properties at this scale are mainly controlled by sedimentary bedding structures, even for rocks that have undergone diagenesis. Between well log and seismic data, there is another missing scale in measurement - from one to ten metres. Reservoir properties at this scale are largely controlled by internal stratification, such as cross bedding in fluvial reservoirs and thin-bed shales in deep water reservoirs."

"Reservoir models are largely conditioned by seismic data with resolution of about 15 to 30 metres," Wen says. "They don't include the bedding structures and internal stratification observed below seismic resolution."



Petrophysical model using SBED flaser bedding template.

Complementing existing tools

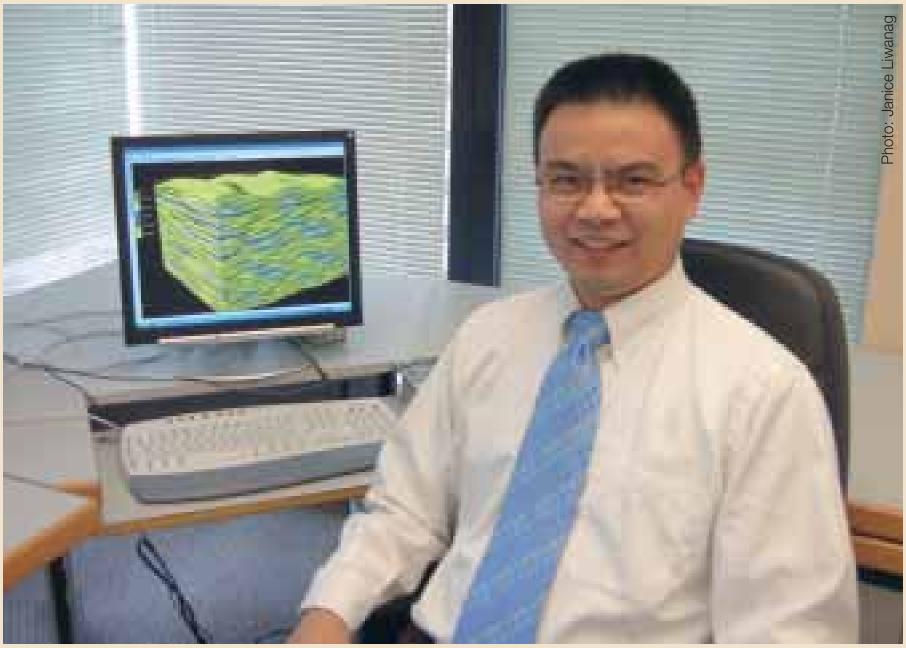
Upscaling is the process of mathematically extrapolating fine-scale reservoir data to coarser scales in order to populate reservoir grids cells up to dozens of metres in size. Conventional upscaling methods such as *arithmetic, geometric or harmonic averaging* do not consider the fact that the data is biased to a specific grid scale or to a sampling location. When the upscaled data is input to petrophysical simulations, the results incorporate the errors introduced by data bias and increase the uncertainties in reservoir predictions.

Wen summarises the advantage of the SBED modelling and upscaling method: "SBED generates geological models representing the scale at which the data was collected. The user populates these models with the corresponding data and then upscales the model - not just the data. The results reflect the reservoir properties at the corresponding scale and can be used to predict properties at scales for which we have no direct measurements."

Indeed, the SBED modelling and upscaling approach represents a paradigm shift in reservoir modelling. But as Wen points out: "SBED is not meant to *replace* existing reservoir modelling tools. It actually complements existing tools by providing detailed heterogeneity models, which can improve reservoir property modelling. In this way, it acts more as a plug-in tool for reducing reservoir uncertainty."

The SBED modelling method

The SBED modelling workflow starts with a conceptual interpretation of reservoir geology, based on core and outcrop observations. Equipped with a library of over 100 built-in geological templates, the user builds a 3D near-well-bore model. Depositional environments such as fluvial, shoreface or deep-water facies can be reproduced by



Renjun Wen, SBED's inventor and Geomodeling's founder and CEO.

stacking the bedding templates. The geometry of bedding, facies and boundary layers can be edited to match the observed geology.

Once the geological framework is established, the user populates the model with porosity and permeability measurements derived from core plugs and then conditions the model to well data. SBED petrophysical models are *upscaled* by numerical simulation methods. The upscaled models can then be exported to third party reservoir simulators. Based on multiple geological scenario simulations, asset teams can evaluate the range of oil and gas in place and quantify the associated uncertainties.

In addition to geological and petrophysical grids, SBED generates upscaled parameters, such oil saturation, porosity and relative permeability, for calculating recovery factors, sweep efficiency and reserves. The software also delivers template curves of facies-dependant kv/kh. This ratio of vertical to horizontal permeability is an important parameter for evaluating fluid flow, and is difficult to measure in thin-bed sediments.

The beginning

In 1987, Wen moved to Norway from his native China to pursue research interests in geostatistics and petroleum geology. As part of a post-doctorate project at the Norwegian University of Science and Technology in the early 1990's, Wen developed the core technology of SBED.

Wen explains how the SBED modelling method differs from traditional methods: "Using conventional object- or pixel-based modelling methods, one models geological bodies and layers by assigning objects or pixels with certain dimensions and petrophysical parameters. This is adequate for modelling large-scale, massive structures, but not for representing millimetre- to metre-scale heterogeneity."

"The algorithms used to generate SBED models don't just mimic bedding structures and internal stratification. They mimic the physical processes that created the bedding structures, such as bedform migration, erosion and deposition. We refer to this modelling approach as being 'process-oriented', because it captures the sedimentary processes - not just the preserved sediments. This is why the resulting models are geologically realistic."

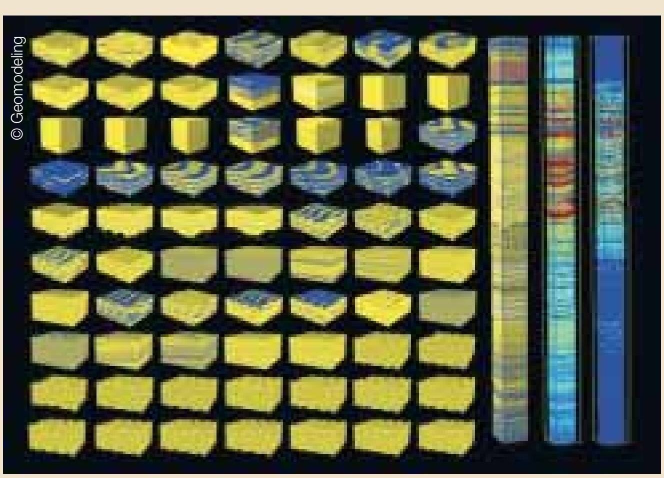
Based on his research, Wen was contracted by the Statoil Research Centre in Trondheim in 1996 to participate in an integrated reservoir characterisation study called the Remaining Reserves project. The aim was to explore solutions for improving oil recovery in the Norwegian sector of the North Sea fields, where shallow marine and fluvio-deltaic sandstone reservoirs hosted proven oil volumes. The reservoir asset teams knew that part of the solution was to include the effects of small-scale heterogeneity in full-field-scale reservoir models. However, available reservoir modelling technologies were unable to model the complex inter-layering in the sandstone fields.

In two months, Wen developed software that could realistically model the cross bedding and parallel bedding structures observed in the deposits. These detailed models were subsequently used to calculate kv/kh for the reservoir units and helped to define strategies for optimal recovery.

New opportunities

After completing his contract in the Remaining Reserves project, Wen immigrated to Canada with his wife and two children. They settled in the booming oil and gas industry hub of Calgary, Alberta, where Wen saw great opportunities for taking his research to the business units of major petroleum companies. With savings earned from consulting projects in Norway, Wen registered Geomodeling and started his software development business from the basement of his home in late 1996.

In the summer of 1997, Wen was again contracted by Statoil, this time to participate in the 'Advanced Modelling of Heterogeneous Tidal Reservoirs' (AMHTR) project.



In a SBED digital rock library more than 100 bedding templates can be stacked to create near-well-bore geological models.

The project area was the oil and gas-condensate fields of the Halten Terrace, offshore Norway, where the reservoir intervals were tidal deposits of complexly interlayered mud and sand. Here, the recovery factors were typically below 30%, much lower than the over 60% recovery achieved in the fluvial and shallow-marine oil reservoirs in the North Sea. The difference was attributed to the complex fluid behaviour caused by fine-scale tidal bedding in the Halten Terrace.

The goals of the AMHTR project were 1) to develop models that realistically represented the tidally influenced deposits, and 2) to develop a method for accurately estimating porosity and effective permeability (k) of thin mud layers, especially kv/kh, for input to flow simulations. From his basement office, Wen designed tidal bedding models that mimicked sedimentary structures such as flaser and lenticular bedding.

Statoil successfully used these models to characterise the Halten Terrace fields and to estimate the effective properties of highly heterogeneous units. Based on detailed studies that included the use of kv/kh ratios calculated from SBED models, Statoil engineers re-designed water treatment facilities in the Tyrihans field, where production of light oil is planned to start in 2009. In the Heidrun field, reservoir optimisation studies showed that the estimated recovery potential achieved with small-scale modelling corresponds to millions of barrels of oil.

Innovation through partnerships

Following Wen's work in the AMHTR project, SBED technology was still largely considered as a research tool. Geomodeling's founder took SBED a step closer to commercialisation by following a simple philosophy: "The point of research and development is to find real-world solutions that can be used by your peers," says Wen, "And the best way to find the solutions is to build on the knowledge of your peers."

In 2000, Geomodeling established an SBED research and development consortium with industry partners BG International, ExxonMobil, Fortum (now ENI), Norsk Hydro, Shell, Statoil and Total. The aim of the project was to develop SBED as a commercial heterogeneity modelling and upscaling tool for sedimentary bedding structures. With the financial support and technical input of consortium members, SBED version 1 was delivered in 2002. It included modules for simulating parallel bedding, cross bedding, flaser/wavy/lenticular bedding, massive bedding, hummocky cross stratification, bioturbation and point bars.

Software development in SBED Phase II (2002-2004) focused on metre-scale heterogeneity modelling of internal stratification and bounding surfaces in the genetic units. The delivered product was SBEDStudio, which included three deep-water modules: channel-infill, channel-levee architecture and depositional lobes. These modules were developed in the context of full-field modelling, where seismic-derived horizon and attribute surfaces were used as conditional data.

Currently, the SBED JIP is in Phase III and now has eight industry partners: BHP Billiton, ConocoPhillips, ENI, ExxonMobil, Norsk Hydro, Shell, Statoil and Total. Phase III development focuses on three main areas: 1) integrating Phase I (SBED) and Phase II (SBEDStudio) products with other reservoir modelling software, 2) researching methods for conditioning data to bedding structure and infill architecture modules, and 3) developing more upscaling functions. Recent advancements in Phase III include the addition of multi-phase upscaling, which will be the first of its kind in the industry.

Plans for Phase IV include developing a multi-step upscaling workflow and creating more SBED templates (such as carbonates and delta environments). Geomodeling also plans to integrate SBED with third party reservoir interpretation software, such as Petrel, RMS, and GOCAD and to build links to other modelling tools, such as resistivity forward modelling and well test simulation technologies.

The next step

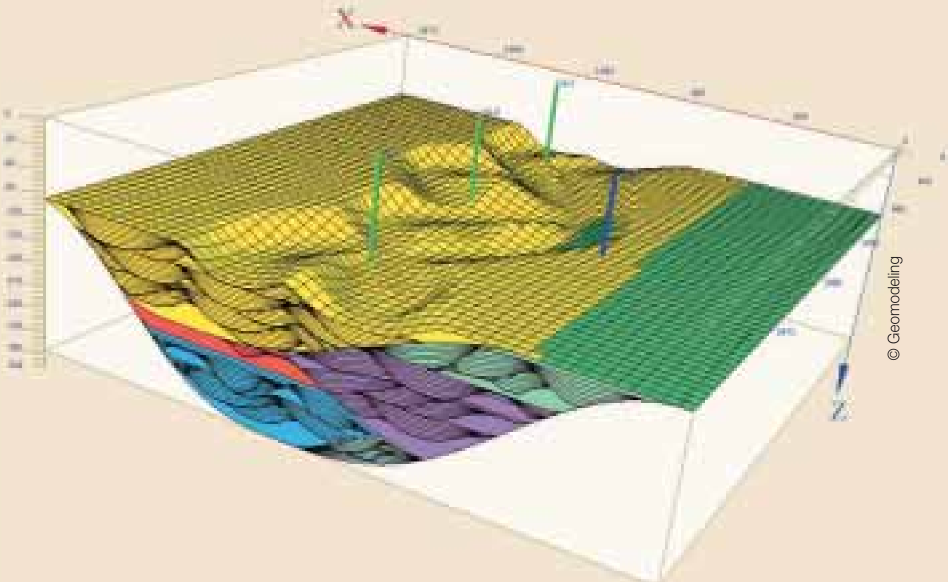
Geomodeling has evolved from a one-man operation into a corporation with over 60 employees in Canada, China, Mexico, Norway, United Kingdom and USA. In 2005 alone, the number of staff has increased by 30%. And the company continues to grow.

"The biggest challenge in managing a growing company is to keep innovating while we grow," Renjun smiles, knowing all too well about growing pains. "Many companies stop innovating or reach a plateau in product development when they decide to expand their markets. We aim to set the industrial standard and then continuously move that standard to the next level."

And Geomodeling is equipped for the challenge. A venture capital from Norwegian investor Offtech Invest AS will help to bring Geomodeling to the next level of innovation. The funds are being channelled to software development and international commercialisation of SBED.

"The quality of technology and talent offered by Geomodeling makes this investment attractive," said Trygve Lægreid, spokesperson for Offtech Invest AS. "The impact that multi-scale modelling in general, and Geomodeling's portfolio of products in particular, will make on the industry is going to be very significant."

While other software companies may have achieved success by thinking "large-scale", it is clear that Geomodeling has filled an industry niche by considering the fine details in between.



© Geomodeling

Reservoir heterogeneity model generated in SBEDStudio, showing internal stratification in a multi-channel depositional system.