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The development of Analog Reservoir Modelling for seismic and reservoir engineering research

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Abstract

This paper describes a research program at the Australian Resources Research Centre (ARRC) to establish and use an analog model of a turbidite channel reservoir to gain insight into issues of uncertainty in reservoir simulations of channelised fields and their seismic expression. The project is unique in that it integrates seismic and reservoir engineering research in a controlled laboratory environment. The research is based around a cementation technique that allows synthetic sandstones to be fabricated with pre-determined physical properties such as porosity, permeability and impedance. These laboratory models provide real data that do not rely on assumptions, and are therefore useful to compare with numerical simulations of both the seismic and fluid-flow response.

The 1:1000 scale model comprises two intersecting sandstone channels within an impermeable acrylic matrix. Fluid communication between the channels exists in two separate intersecting areas with contrasting flow connectivity. Production from the initially oil-saturated model was performed via water-flood, and the injected water was dyed blue to allow the displacement process to be recorded on video. Production rates and data such as time to water breakthrough, produced water/oil ratio and cumulative recovery was recorded and used to history match reservoir simulations of the production response.

Scaled time-lapse 3D data were acquired before and after production at frequencies of 50 kHz and 1 MHz. The 1 MHz data provides high-resolution images and accurate monitoring of the oil and water distribution. The 50 kHz data honours the correct scaling of the relative seismic wavelength-to-channel size, where the individual channels are within tuning thickness, and provide data for valid comparisons with seismic attributes in field data from similar reservoirs. An analysis of velocity dispersion indicates that the measured acoustic response to changes in saturation at 50 kHz is representative of the expected lower frequency seismic response.

Keywords: 4D seismic; Attributes; Turbidites; Physical modelling

1. Introduction

Increased costs associated with the push towards deep-water reservoir production means that risks in exploration and development remain significant, despite continual technological advances. The understanding of risk and uncertainty in these frontier environments presents a major challenge to the industry. The connectivity of the reservoir is a key factor influencing the dynamic performance. Permeability architecture is difficult to determine precisely, and this uncertainty

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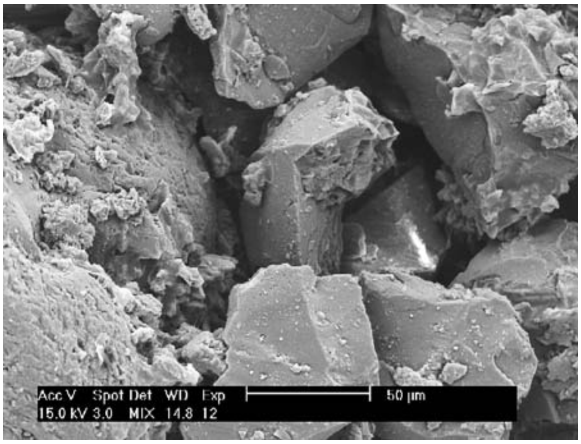

Fig. 1. Scattered electron micrograph image of a CIPS sandstone. This example comprises pure quartz sand with bi-modal grain-size distribution. The calcite cement precipitates onto the grain surfaces at the contacts, giving the synthetic sandstones acoustic, fluid-flow and mechanical properties that are representative of natural sandstones.

leads to differences in estimates of cumulative recovery, which has an important bearing on how best to design production facilities (Larue and Friedmann, 2001). This is particularly important in deep-water reservoirs where our understanding of complex geological systems is restricted by the limited resolution of seismic data and fewer well penetrations due to the high costs of drilling.

Knowledge of the spatial distribution of reservoir and fluid properties and their evolution during production is crucial for defining an optimal production strategy. Determination of these parameters is based on the use of computerised reservoir simulation algorithms, constrained by information from wells and by seismic data recorded over time. The success of this technology depends on the validity of the models that represent the reservoir architecture and the models that relate the seismic response to the *in situ* reservoir conditions.

A unique experimental program between CSIRO Petroleum and Curtin University of Technology has been devised to investigate issues relating to uncertainty in reservoir simulations of channelised fields and their seismic expression. The program, known as Analog Reservoir Modelling (ARM), integrates aspects of seismic and reservoir engineering research and allows realistic field-scale phenomena to be simulated in a controlled laboratory environment.

2. Analog Reservoir Modelling (ARM)

ARM is based around a synthetic cementation technique that allows scaled analogue representations of reservoir systems to be constructed in a laboratory. The project is unique in that it is the first of its kind to integrate seismic and reservoir engineering research in a controlled laboratory environment. These models provide real data that do not rely on assumptions, and are therefore useful to compare with numerical simulations of both the seismic and fluid-flow response. The cementation technique, known as Calcite In-situ Precipitation System (CIPS), allows sandstones to be fabricated with pre-determined physical properties, such as porosity, permeability and impedance (Sherlock and Siggins, 2004). Fig. 1 shows a scattered electron micrograph image of a pure quartz sand cemented using the CIPS method. Calcite cement is precipitated at the grain contacts in a similar manner to natural calcite cementation. Laboratory tests have shown that CIPS sandstones closely reproduce the acoustic and mechanical properties of natural sandstones (Kucharski et al., 1996).

2.1. Turbidite channel model design

A two-channel model is presented here as a 'proof of concept'. The 1:1000 scale model is 1 m × 1 m × 0.11 m, and consists of two intersecting sandstone channels within an impermeable and transparent acrylic matrix. A 3D geological model of the channels was initially designed using Roxar's RMS and Nextwell software. The design was then drafted into a CAD model for computerised machining of the channels into the acrylic background that represents surrounding low-permeability shales or mudstones (Fig. 2). This ensured exact correspondence between the numerical and physical model architecture to allow valid comparisons between the observed and simulated production response.

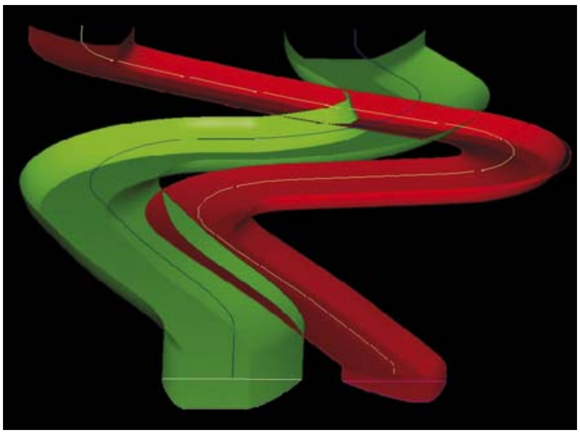

Fig. 2. CAD drawing of two-channel model used for computerised machining of channel architecture from an acrylic slab. The model area is 1 m^2, and the thickness of the upper and lower channels is 20 mm and 30 mm, respectively.