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Mapping fluid distribution in a pinch-out reservoir model: A physical modeling study

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ABSTRACT

This work shows the results obtained from seismic physical modeling experiments that image the non-homogeneous, two-phase distribution of immiscible fluids inside a cavity in a pinch-out model. The main goal of this study was to verify how the seismic sections can be used to observe the fluid distribution in this type of reservoir. A high-resolution deconvolution method was applied to improve the image resolution and depth migration correctly positioned the events. Instantaneous attributes were used to assist data interpretation. The results provided an image of the oil–water interface and revealed a complex fluid compartmentalization pattern that was confirmed by numerical modeling simulations. The results of this study should improve the understanding of mapping fluid distributions from seismic sections in pinch-out reservoirs.

1. Introduction

The production of hydrocarbons results in variations in fluid distribution within petroleum reservoirs. Those variations are mainly related to formation waters or even injected waters occupying the porous space that was previously occupied by hydrocarbons. Seismic technology has been applied in hydrocarbon exploration for more than half a century. In the beginning, only 2D data were acquired, but in the 1970s, 3D data started to be used not only for exploration but also for reservoir characterization (Grochau, 2009; Sheriff and Geldart, 1995). Once seismic signals are sensitive to the variations in fluid distributions inside a reservoir, they can be used for reservoir monitoring to assist in managing well locations and Enhanced Oil Recovery (EOR) operations. The key factor in seismic reservoir monitoring is the contrast of the physical properties of the reservoir fluids. If the properties have low contrast, the oil–water contact (OWC) will be practically indistinguishable in the seismic images. Even if the contrast is enough to provide a seismic signature of the OWC, it can be masked in some situations by noise, diffractions, multiples or other effects, such as seismic tuning.

Physical modeling can be used as a source of experimental data in the study of the seismic method. In this type of modeling a geological model is constructed at the laboratory scale, which normally consists of metal, plastic, acrylic and natural or synthetic rocks (Ebrom and McDonald, 1994). A source, commonly a piezoelectric transducer, is used to emit seismic energy, and the reflected energy is recorded, producing a seismogram (Cooper et al., 2010). Prior knowledge of the model that generated the experimental seismic data may support data interpretation and assist in understanding how the model characteristics influence the seismic signals. In this manner, seismic physical modeling data can be used to test new processing algorithms and acquisition techniques or to study the seismic response of a specific geological model.

The delineation of the interface between different fluids in seismic images has been the subject of several papers reported in the literature; many of them present results from physical modeling experiments. Soucémarianadin et al. (1989) used a tomography technique (direct method) to map the fluid distribution pattern in boxes filled with quartz grains and glass beads that were submitted to flows of miscible and immiscible fluids. Sherlock et al. (2000) and Marschall and Sherlock (2002) simulated time-lapse seismic acquisition by injecting immiscible fluids (kerosene, air and water) in a sandbox model. The seismic sections showed that the changes within the model were related to the fluid saturation changes. They also performed an experiment using a model saturated with gas and water and mapped the fluid contact using the instantaneous phase seismic attribute. The seismic attributes can occasionally clarify the visualization of features, relationships and patterns in the seismograms (Sheriff, 2005).

Mu and Cao (2004) studied the seismic response of a sand reservoir model saturated with different fluids (CH_4, CO_2, oil and water), while Wang et al. (2009) observed the patterns displayed in the seismograms of a sandbox model saturated with gas, oil and water. Cooper et al. (2010), however, performed seismic physical modeling of a wedge model, observing diffractions, multiples and wave mode conversion in the seismic sections.

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In this work, we carried out scaled ultrasonic seismic measurements on a model composed of a Plexiglas block with an empty wedge that could be filled with different fluids. Such a wedge cavity can be interpreted geologically as a pinch-out reservoir or a trap. Some examples of pinch-out reservoirs are Gulfaks (Norway), Marlim and Peregrino (Brazil). Brine and engine oil were used to simulate the formation water and petroleum, respectively. The main purpose of the experiment was to verify the effects of the wedge model geometry on the seismic response and to map the fluid distribution inside the model. A basic processing flow was applied to enhance the signal-to-noise ratio, and instantaneous seismic attributes were used to assist the data interpretation.

2. Experimental set-up

This work was composed of three major steps: acquisition, processing and interpretation of the experimental data. The model was constructed with Plexiglas, resulting in a block with dimensions of 300 mm × 100 mm × 180 mm. Subsequently, a cavity with a width of 100 mm was drilled to represent an approximate wedge. Fig. 1 shows a model illustration; the cavity width is in the direction perpendicular to the plane of the figure.

The scaling factor used was 1:10,000 for time and distance, leaving velocity unscaled. Velocity measurements in the non-cavity part of the block were performed using the direct transmission method and resulted in a P-wave velocity of 2777 m/s in the Plexiglas. In the experiments, only fluids (brine and engine oil) were used to fill the cavity. Table 1 lists the physical properties of these fluids. Initially, the model was positioned in such a way that the cavity could be accessed from the top to fill it. The same volume (70 ml) of brine (lower half) and engine oil (upper half) was used to fully fill the cavity. We used a C clamp compressing a rubber strip and an aluminum plate to seal the cavity. Silicon was applied to the bottom edges of the rubber strip to prevent leaks. When the model was rotated back to the original position (Fig. 1), the fluids assumed a heterogeneous distribution, as shown in Fig. 2, due to the differences in fluid viscosities and densities. The blue, orange and yellow rectangles in Fig. 2 indicate regions of different fluid contents, which can be directly observed in the model as follows: I — only brine, II — only oil and III — brine and oil. The model was placed inside a water tank for the ultrasonic measurements, and the distance from the water surface to the model top was kept at 100 mm.

3. Data acquisition

The measurements were carried out using the ultrasonic physical modeling facilities of Petroleum Exploration and Engineering Lab (LENEP) at the North Fluminense State University (UENF) in Brazil, as shown in Fig. 3. The single-channel apparatus includes timing (triggering) and a wave generator, digitizer boards, low-noise amplifiers and contact transducers with central frequencies of 1 MHz. The system has two piezoelectric transducers, one source and one receiver. The transducers are displaced by stepper motors controlled by a computer. The data acquisition consisted of 60 lines of 300 mm each along the pinch-out model, with a common-offset of 28 mm between transducers, which is the smallest physically possible due to the system arrangement. The transmitted signal was a tone burst waveform windowed by a Bartlett function, Fig. 4. The central frequency was set to 500 KHz to correspond to 50 Hz, which is typically found in real seismic data. The spatial step between traces and lines was set to 2 mm. Table 2 lists other parameters used for these measurements, and the survey area can be observed in Fig. 2.

Table 1
Physical properties of the fluids used to fill the cavity.

Property\fluid	Brine	Engine oil
Density (g/cm^3)	1.023	0.864
P-wave velocity (m/s)	1544	1384
Concentration	40 g/L	–
Viscosity (cP)	0.987	232.800

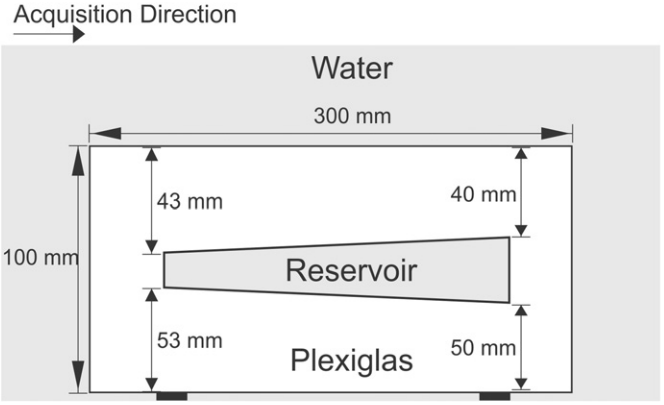

Fig. 1. Pinch-out reservoir model illustration.

4. Data processing

The data processing tasks were applied in the following sequence (Fig. 5): static correction, band-pass filtering, resampling, geometrical spreading correction, deconvolution and depth migration.

The static correction was applied to correct time shifts between the lines, most likely caused by a slant in the water tank support table. The static correction algorithm works as follows: (1) a time window is defined around the flat portion of the model (model top) reflections where correlations will be done in the steps (2) and (3), (2) a reference trace is chosen and its autocorrelation is calculated, (3) each trace is cross-correlated with the reference trace and (4) each trace's time shift is obtained from the time difference between the maxima on the correlations of steps (2) and (3). More details about static correction methods can be found in Marsden (1993). Band-pass filtering prepared the data to be resampled and removed the low-frequency coherent noise that most likely originated from air-conditioners and from the

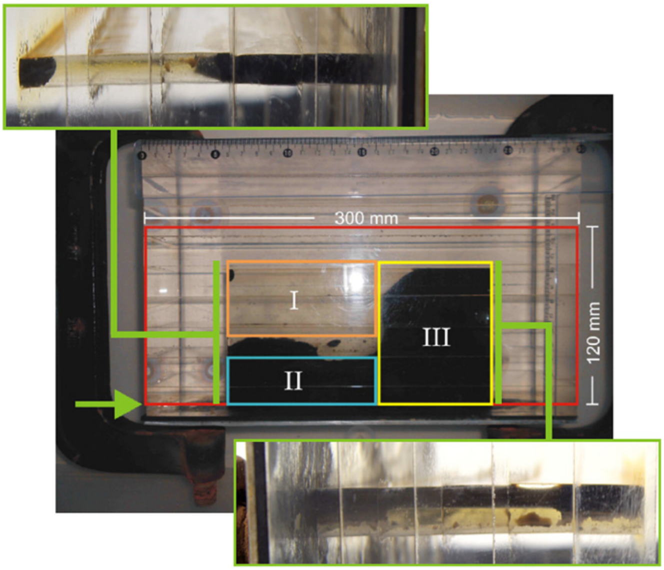

Fig. 2. Photograph of the pinch-out model top. Green rectangles show photographs taken in cross-sections at right and left sides. The red rectangle indicates the survey area. The green arrow indicates the survey direction and the beginning of the first line. Blue, orange and yellow rectangles indicate regions of different fluid contents.