Physical Modeling of the Effects of Grain size on Seismic Imaging of a Pinch-out Reservoir

Jhonnes Pin Silva, Marco A. R. Ceia, Roseane M. Misságia, LENEP/UENF

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Abstract

The most common method used worldwide for reservoir characterization is seismic reflection, this method seeks to model the conditions of formation and fluid contained therein. This paper presents a physical modeling of a pinch-out reservoir aiming to study the variation in seismic responses due to the effects of changes in porous media. The experiments were conducted using ultrasonic signals with central frequency of 500KHz to perform seismic surveys on a Plexiglass block with wedge-type cavity to simulate the reservoir. Three grain sizes of glass beads were selected and used to fill cavity, they were: 106 - 53µm, 250 - 150µm and 425 - 212µm. The seismic surveys were performed using a constant spacing between source-receiver that enabled a seismic imaging of the reservoir. The entire process was repeated for each particle size, using the same parameters in order to compare the response. The results showed that the best resolutions are associated to material with the largest grain size.

Introduction

The most common geophysical method used worldwide for reservoir characterization is seismic reflection, that seeks to model the conditions of formation and fluid contained therein. Seismic responses could vary in different porous media This paper aims to study how the grain size could affect the seismic response in analog models of sandstone "pinch-out" reservoirs, using physical modeling techniques with seismic ultrasonic surveys in small-scale reservoir models and analyzing the influence of the parameters of data acquisition in vertical resolution of seismic monitoring, looking up to integrate and correlate their results for the understanding of the seismic response on different grain sizes in the reservoir. The resolution of the seismic signal can be influenced by the geometry of stratigraphic features. This type of stratigraphic feature ("pinch-out") is observed in several producing oil fields. In Brazil, we can cite Marlim and Peregrino fields (Ceia and Misságia, 2011). The variation in seismic responses due to the effects of different particle sizes can be understood as the influence of environment on seismic attenuation, velocities, amplitudes and reflectivities of each interface.

Method

The system is designed to simulate seismic geological models in small scale. It consists of a steel frame, where motorized arms constituted by a set of chains, pulleys and six stepper motors are controlled by a computer and make move two transducers (transmitter and receiver) in all three dimensions (x, y, z). The transmitter emits an ultrasonic signal that travels through the model whille part of its energy is reflected in the interfaces and capted by the receiving transducer. The electrical signal generated in the receiver is amplified, digitized and stored on a computer in SEG-Y format, similar to record seismic scale field.

An ultrasonic transducer converts electrical energy to mechanical energy in the form of sound as the reverse. In general these transducers operate at center frequency in the range of 50 KHz to 10 MHz, and can simulate compressional or shear ultrasonic waves. The transducers can be positioned on the surface of the models, simulating land surveys, or water depth, when models are immersed in a water tank simulating marine surveys.

In order to reach the goals, the following methodology is drawn by dividing the work steps as outlined in figure 1.

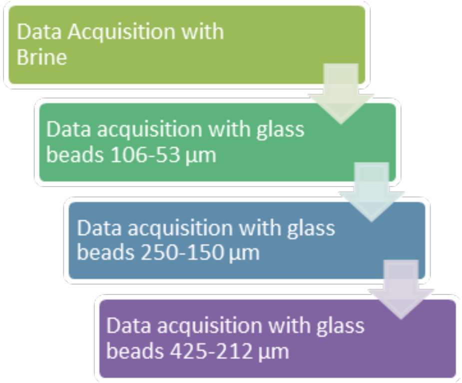

Figure 1: Work step flowchart.

One of the basic concepts for building physical models in reduced scale is that the fidelity to the physical model must reproduce the physical properties of the actual scene, also in reduced scale, the scales must be maintained, as illustrated in Figure 2. Then the model dimensions, the frequency of the transmitted signal, the source-receiver spacing, the spatial sampling and temporal sampling scale should correspond to a field situation. We must pay attention to the scale factors, because they are important parameters in the propagation of seismic waves linear dimensions of the radii of transmission, such as thickness and depth of the layers investigated, the length of the wavelet, the density of the medium, velocities of the waves (O`Brien, et al., 1971). In our experiment the scale factor is 1:10.000. According to Ebron et al. (1994), the ratio between the size of the geological feature and the wavelength shall be the same both in the field as the template.

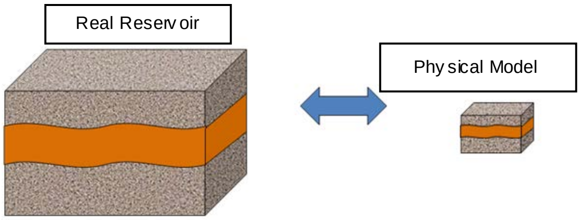

Figure 2: Scale model.

The model consisted of non-porous Plexiglas material and was made by gluing 9 plates with P-wave velocity of 2777 m/s. Later on, a cavity was machined in the resulting block as shown in Figure 3, in order to simulate the edge of a wedge in a pinch-out reservoir which is a thinning of the reservoir layer characterized by the boundary of the reservoir during the process of sediment deposition.

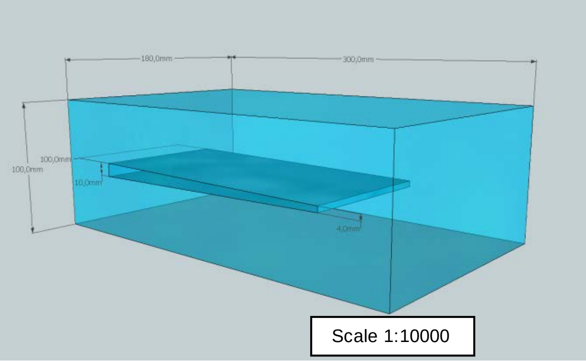

Figure 3: Model schematics.

The experiments were conducted with constant spacing between source and receiver and the model was immersed in a water tank. Recordings were taken from the left edge of the model to right edge crossing the reservoir from thicker part towards the thinner. Each survey comprises 151 seismic traces.

The reservoir was filled with brine with salinity of 40 g/l. After it has been fully filled, the model was sealed with a rubber strip and an aluminum plate, pressed by a C-type clamp and placed inside the tank. Then the first survey was performed, producing a seg-y file. Later, glass beads were introduced to the reservoir, expelling part of the water, and other surveys were performed for each set of glass beads.

The frequency used in the experiment was 500 KHz, and water depth between the top of the model and the transducers were 100 mm. Our experiment was designed assuming a scale of 1:10,000, which corresponds to a water depth of 1000 m in a real marine survey. The same way, the used frequency corresponds to a frequency of 50 Hz in a real survey.

The glass beads used to fill the cavity were selected to have the smallest possible particles in order to preserve the fidelity of the model, and avoid generating points of diffraction, whose spreading signal could degrade the seismic image resolution (Misságia and Ceia, 2011). Thus, we sought materials whose diameter was much smaller than the wavelength of the signal. However, to represent the inter-particle pore space of a real rock in the mentioned scale, this material should have an average diameter in the range of ηm. Once the available glass beads diameters were in the range of tenths to hundreds µm, they can represent very coarse conglomeratic material as cobbles and boulders at 1:10,000 scale.

Three particle sizes were selected and used, they were 106 - 53µm, 250 - 150µm and 425 - 212µm. The entire process was repeated for each particle size, using the same parameters in order to compare the response. A CILAS 1180 particle analyzer was used to determine the particle distribution. That device is based on light diffraction. The samples (water-saturated glass beads) are placed into the equipment, then the measurement is possible due to the existence of particles in the optical path of the laser light. This way, the equipment can provide the particle size distribution.

Table 1: Diameters of glass beads.

Glass Beads	Mean Diameter
106-53 (smallest)	278.26 µm
250-150 (intermediate)	150,84 µm
425-212 (largest)	278.26 µm

The modeling system includes a data acquisition software developed in LabView platform. This software was designed with a series of dashboards that allow the configuration of the parameters needed to run the experiment.

Results

Figure 4 shows the result for the reservoir containing only brine. It's possible observe clearly the top and bottom interfaces once the attenuation throughout the water seems to have little influence in the signal propagation. That situation did not occur when glass beads are introduced into the reservoir as observed in Figure 5 (smallest grain size), Figure 6 (intermediate grain size) and Figure 7 (largest grain size). In fact, the resolution of those interfaces vary inversely to the grain size.

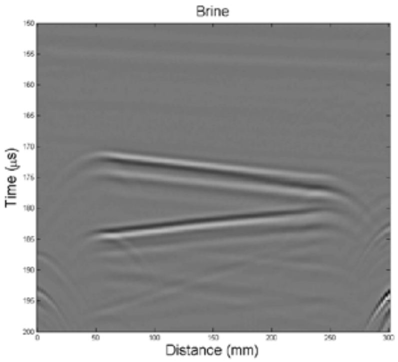

Figure 4: Seismic image of the physical model with the reservoir filled only with brine.

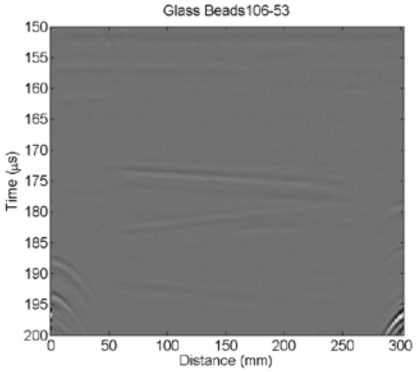

Figure 5: Seismic image of the physical model with the reservoir filled only with brine and glass beads (106-53µm).

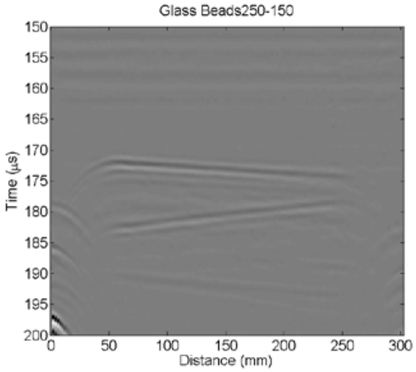

Figure 6: Seismic image of the physical model with the reservoir filled only with brine and glass beads (250-150µm).

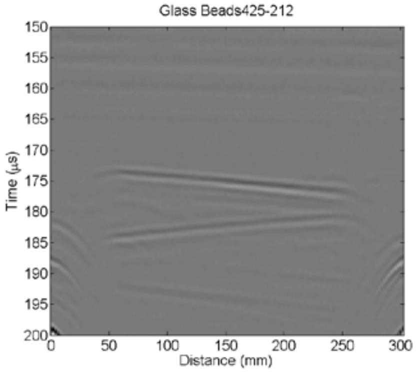

Figure 7: Seismic image of the physical model with the reservoir filled only with brine and glass beads (425-212µm).

Figure 8 shows a single trace obtained at middle of the model (trace 75) which presents all the reflections of the experiments for the four different situations of reservoir filling.

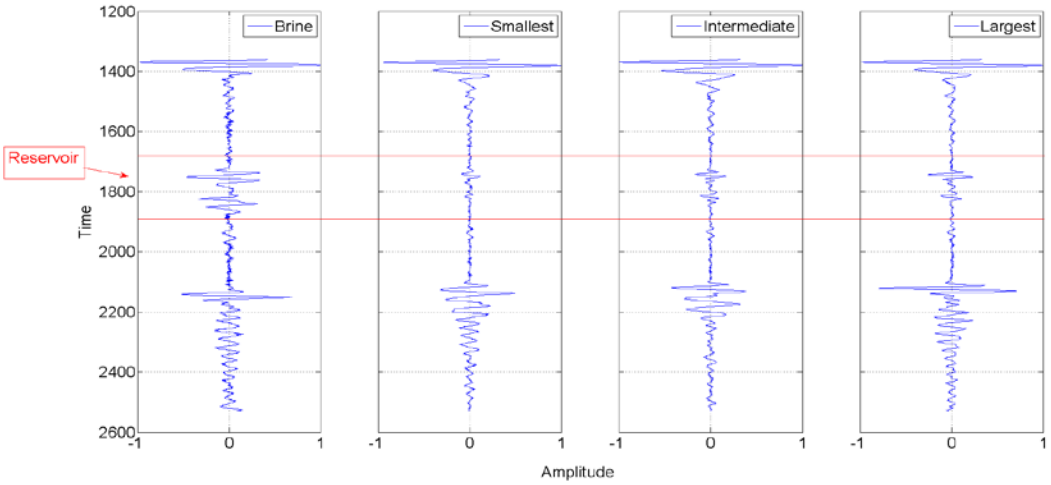

Figure 8: Seismic traces number 75 (middle of the reservoir).

Considering that the wave peak amplitude can be obtained in the time intervals that the wave spent to travel across the layer, one can use equation (1) to correlate time to depth:

$$\text{Velocity} = \text{distance}/\text{time} \qquad (1)$$

Where the distance (or depth) can be obtained from the model and the time is obtained from the previous traces (Figure 8) after associating the peaks to the interfaces that caused the reflections. Table 2 shows the RMS velocities for the reservoir in each of the filling cases.

Table 2: RMS velocity in the reservoir for different filling cases.

Reservoir	Velocity RMS m/s
Brine	1609,195
Smallest Glass Beads	1772,152
Intermediate Glass Beads	1891,892
Largest Glass Beads	2000,000

With the velocity values, a graph of RMS velocity x average particle size was plot as shown in Figure 9, which can denote the increment of RMS velocity as the grain size increases.

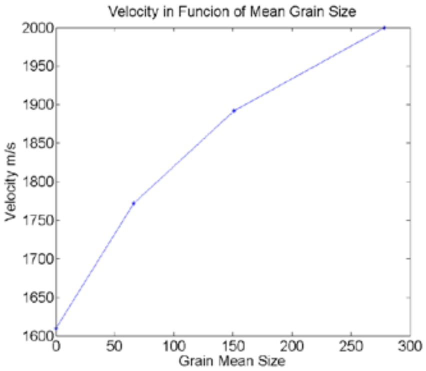

Figure 9: Graph of RMS velocities for different grain sizes.

From the observation of Figure 8, it was also possible to extract and analyze the amplitudes at each reflection. The normalized peak values associated to the interfaces are shown in Table 3. This normalization is related to amplitude maximum of each filling case.

Table 3: normalized peak amplitudes.

Reservoir	normalized in each reflector respectively		
Brine	1	0,4352	0,1658
Smallest Glass Beads	1	0,0764	0,0549
Intermediate Glass Beads	1	0,1326	0,0604
Largest Glass Beads	1	0,2243	0,1970

Using the info reported on Table 3 it is possible to draw a graph of the normalized peak amplitudes versus the mean grain size of the filling cases as shown in Figure 10.

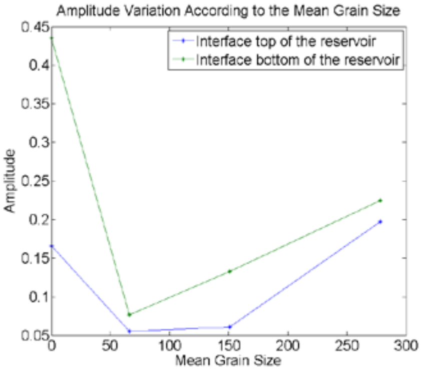

Figure 10: Graph normalized peak amplitudes.

Another possible analysis is related to the reflection coefficient, which can be found from a deconvolution of the data (Yilmaz, 1987) as shown in Figures 11, 12, 13 and 14.

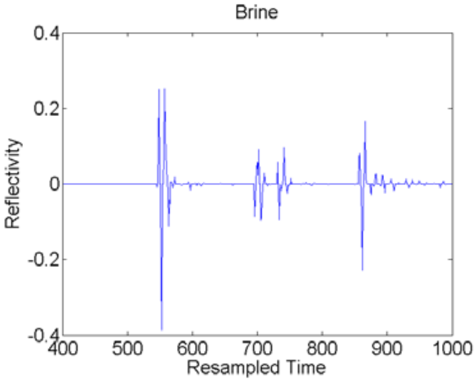

Figure 11: Reflectivities when the reservoir is filled only with brine.

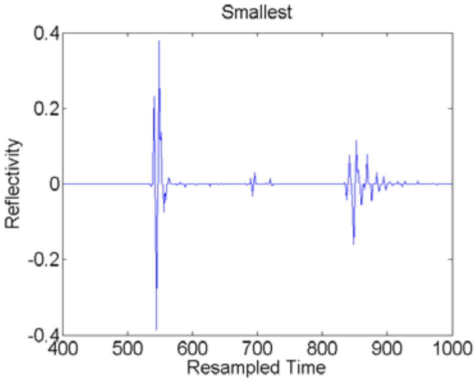

Figure 12: Reflectivities when the reservoir is filled with brine and the smallest glass beads.

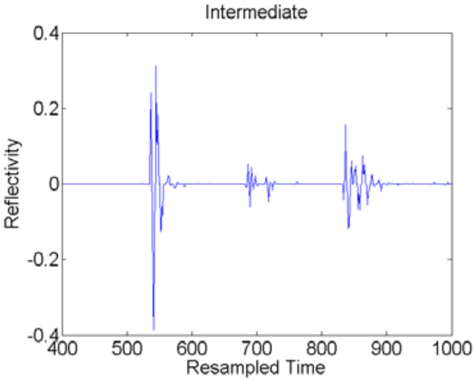

Figure 13: Reflectivities when the reservoir is filled with brine and the intermediate glassbeads.

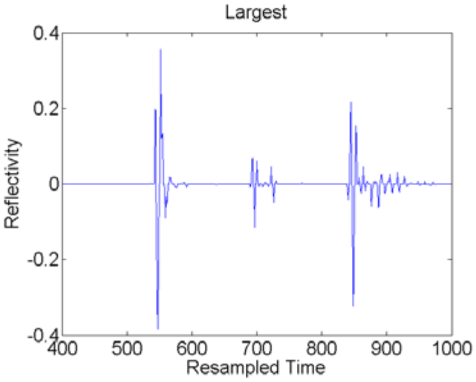

Figure 14: Reflectivities when the reservoir is filled with brine and the largest glass beads.

From the reflectivies, it is possible to summarize the absolute values for each interface in each filling case as described in Table 5 and ploted in Figure 15.

Table 5: Reflectivity of the interfaces: Water-Plexiglass, Top of the reservoir and Bottom of the reservoir.

	Interfaces		
	Top Plexiglass	Top Reservoir	Bottom Reservoir
Brine	0,386	0,098	0,096
Smallest	0,386	0,032	0,014
Intermediate	0,386	0,062	0,045
Largest	0,386	0,116	0,049

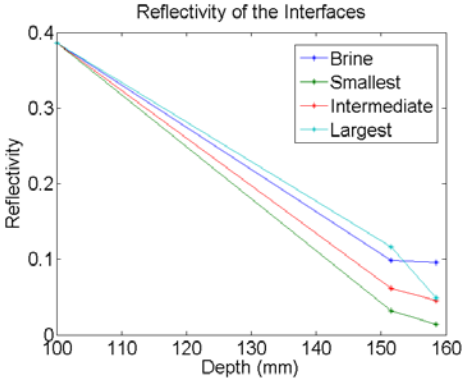

Figure 15: Variation of the reflectivity according to the interfaces.

Conclusions

The best resolution of the seismic image of the pinch-out structure occurs when only the fluid phase is filling the reservoir and is characterized by strong amplitudes and well defined contours associated to the top and bottom interfaces. When solid material (glass beads) is added, the resolution vary inversely to the grain size, once the delienation of the interfaces, especially the bottom one, becomes more difficult to be observed due to small amplitudes of the reflected signal.

The addition of the glass beads made the top interface reflectivity (absolute values) to decrease significantly in comparison to the only-fluid filling results, but the grain size did not affect considerably the observed values. However, the bottom interface reflectivity was severely influenced by the particle size in acordance to Hamilton (1972) and Park et al.(2009). In general, the reflectivity of the bottom interface is higher than the top interface one.

Velocities were also affected by the glass beads and increase as the size of the beads increase and that behaviour can make the top and bottom of the reservoir to get close. Fortunately, both interfaces could be distinguished in all of the seismic images of the experiments.

These experiments were succesful in describe how the grain size of the sediments can influence the resolution of the seismic images and can be useful in the interpretation of analog structures.

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