Time-Lapse Seismic Investigation of CO_2 Injection at Delhi Field, Northeastern Louisiana

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Abstract

Delhi is an onshore oil field in the Northeast of Louisiana, USA. The reservoir is constituted by siliciclastic sandstones that present a high degree of heterogeneity. Currently the field is undergoing CO_2 injection as a tertiary recovery program.

In this work we present the use of time-lapse seismic to identify permeability barriers and the subsurface behaviour of the CO_2 injected in Delhi field.

Introduction

Delhi Field was discovered in 1944. In the sixties, water injection began and took place for more than 4 decades. Nowadays, the field is undergoing CO_2 injection as a tertiary recovery program.

According to Powell, 1968, the reservoir is constituted by siliciclastic sandstones with an average porosity of 30% and permeability ranging from 500 md to 5000 md. The reservoir rocks have a high degree of heterogeneity and are buried at an average depth of 1000 meters.

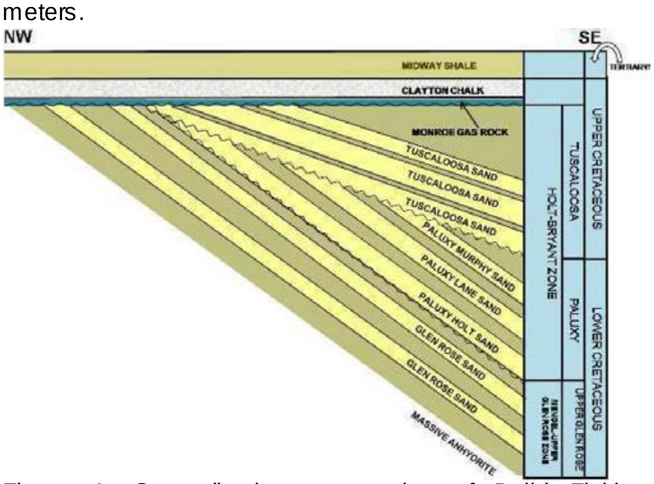
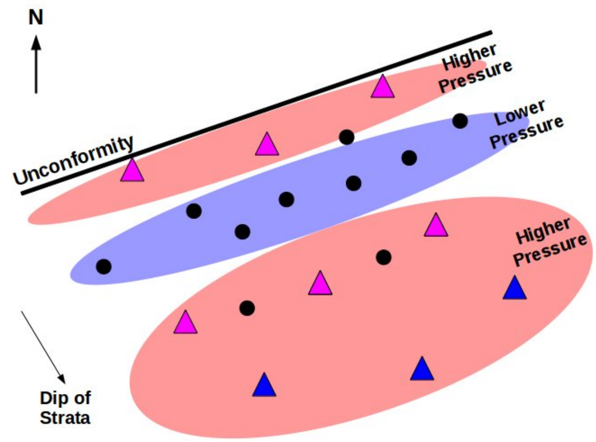


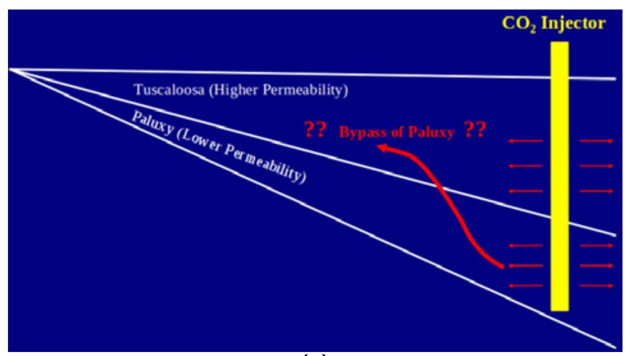
Figure 1: Generalized cross section of Delhi Field (Denbury Resources, RCP Meeting, 2009).

As described in Silvis, 2011, fluids in Delhi Field consist of brine (90%) and hydrocarbons (10%), with API gravity of 41º and 0.77 cp viscosity. The reservoir rocks are sandstones of the Tuscaloosa and Paluxy formations (figure 1). They were deposited during Cretaceous. The reservoir layers dip southeastwards with a slope that ranges from 3 to 5 degrees. On the top, the reservoir rocks terminate against a horizontal shale layer, the Midway Shale.

The injection of CO_2 is being performed according to the strategy shown in figures 2a and 2b. This way, a gradient pushes fluids towards the production wells.



(a)



(a)

Figure 2: CO_2 injection and fluids production strategy. Figure 2a is a map representing a 4 square miles. Wells are represented in the following way: pink triangles stand for Tuscaloosa injectors, blue triangles stand for Paluxy-Tuscaloosa injectors, and black dots stand for producers. The pink ellipses are high pressure zones (due to CO_2 injection) and the blue ellipse is a low pressure zone (due to fluids production). Figure 2b shows a vertical cross section containing an injector. It illustrates the possible bypass of Paluxy sandstones by the CO_2.

Although the reservoir sandstones present relatively homogeneous porosity (averaging 30%), their permeability is highly heterogeneous (ranging from 500 md to 1000 md).

Essentialy, there are two main problems proposed by this work. The first is to identify the permeability barriers and preferred directions of fluid flow. The second is to check if Paluxy sandstones are being swept by the CO2. As the Paluxy sandstones have lower permeability and are on the bottom of the reservoir, the CO2 might be flowing directly to the Tuscaloosa sandstones.

Time-lapse seismic

The injection of CO2 started in November of 2009, the baseline seismic survey was acquired in January of 2008, and the monitor survey in June of 2010.

Figure 3 shows a section with the difference between baseline and monitor. On the bottom of the reservoir there is a strong amplitude difference between monitor and base, which is caused by a decrease in P-impedance. This decrease in P-impedance is a consequence of the substitution of water by CO2. The position of this anomaly coincides with the location of a injector well.

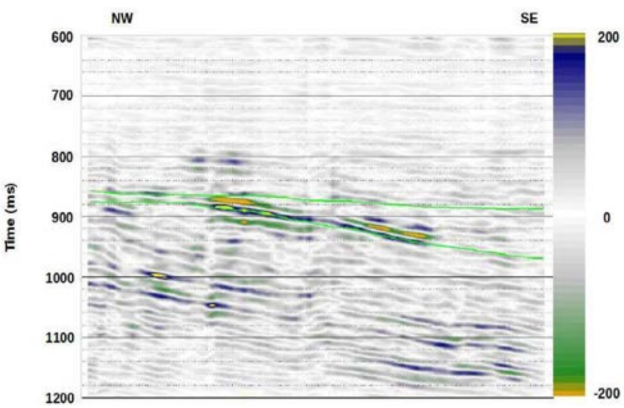


Figure 3: Vertical section of the differece between monitor and baseline data. The green lines represent the reservoir boundaries.

The RMS average of the difference between monitor and baseline is shown on the maps of figures 4a and 4b. The maps were extracted from the lower reservoir intervals. Also in the maps, one can see a strong correlation between the spatial distribution of the anomalies and the location of the injector wells.

From the anomalies found on the maps, one can see that the fluids are migrating updip from the southern wells towards the Northwest. In between wells 160-1 and 164-3 there is a zone which is not reached by the CO2. This zone is indicated by the black circle (figure 5a). The red lines highlight other permeability barriers that have been interpreted. Also, it is clear that the CO2 injected by the wells 146-1, 158-4, and 164-3 do not migrate to the Northwest, which is in agreement with the reservoir boundary imposed by the presence of the unconformity. To the East, in between wells 146-1 and 123-1, there is an anomaly that shows an unrestrained flow of CO2.

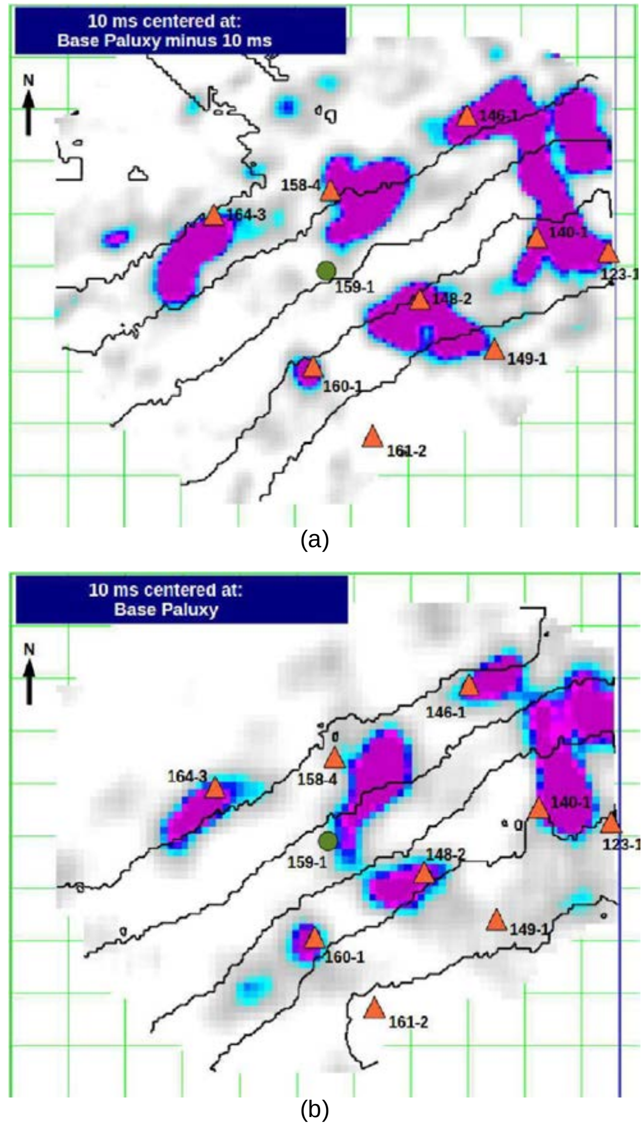


Figure 4: Maps showing RMS average of the difference between monitor and baseline. The map in 4a was extracted along the middle of the reservoir, and the map in 4b was extracted along the bottom of the reservoir. Orange triangles represent the location of injectors, and black contours are constant depth lines.

Another important fact is that these anomalies are present on the bottom of the reservoir. This fact makes it clear that the Paluxy sandstones are being swept by the CO2.

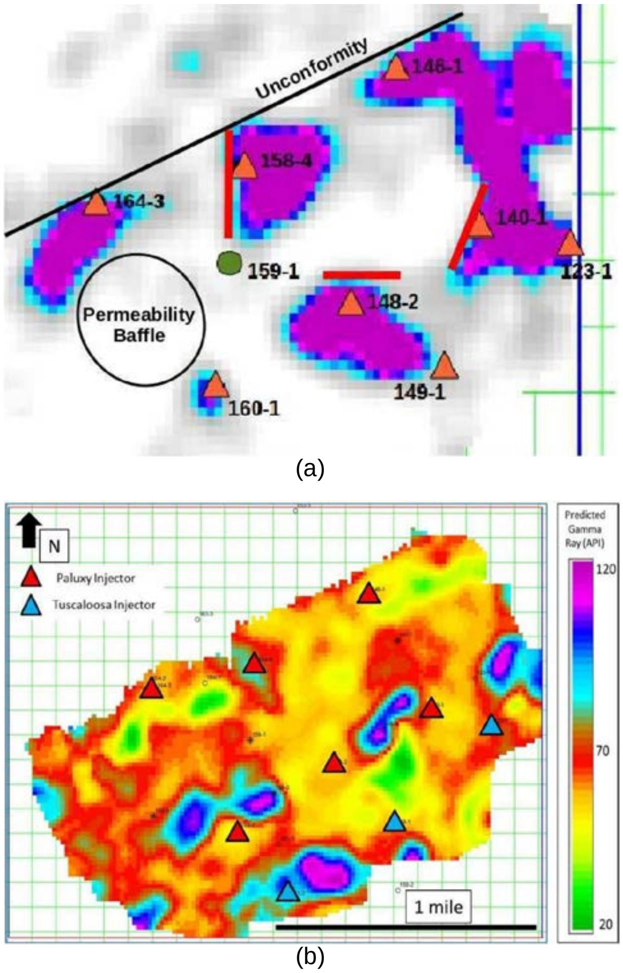


Figure 5: Map in 5a shows an interpretation of permeability barriers. Map in 5b shows predicted values of gamma ray along Paluxy Formation, from the work of Ramdani, 2012.

Correlation of time-lapse seismic and other data

The interpretation above can be strengthened by the results obtained by Ramdani, 2012. Ih his work, Ramdani correlated AVO attributes with gamma ray values from well logs at the same location. From this correlation, he was able to predict gamma ray values at other locations. Using this methodology, he created a gamma ray map at Paluxy level (figure 5b) from which one can infer lithology. High gamma ray values are related to shaly rocks (lower permeability), while low gamma ray values are related to sandy rocks (higher permeability).

There exists a strong correlation between Ramdani's shaly bodies and the permeability barriers interpreted in figure 5a. This result enhances the likelihood that the interpreted permeability barriers are real.

Another result from Alharty, 2011, shows a fluid flow chart obtained from a simulation using the current reservoir model. Figures 6a and 6b show the streamlines resulting from this simulation. The streamlines highlighted by black arrows in figure 6a can be correlated with amplitude anomaly located in between wells 146-1, 140-1, and 123-1 (figure 4a). In the same way, streamlines highlighted on figure 6b, can be correlated with anomalies between wells 158-4, 159-1, and 148-2 (figure 4b). Hence, the results from time-lapse seismic corroborate the results from fluid flow simulation and vice-versa.

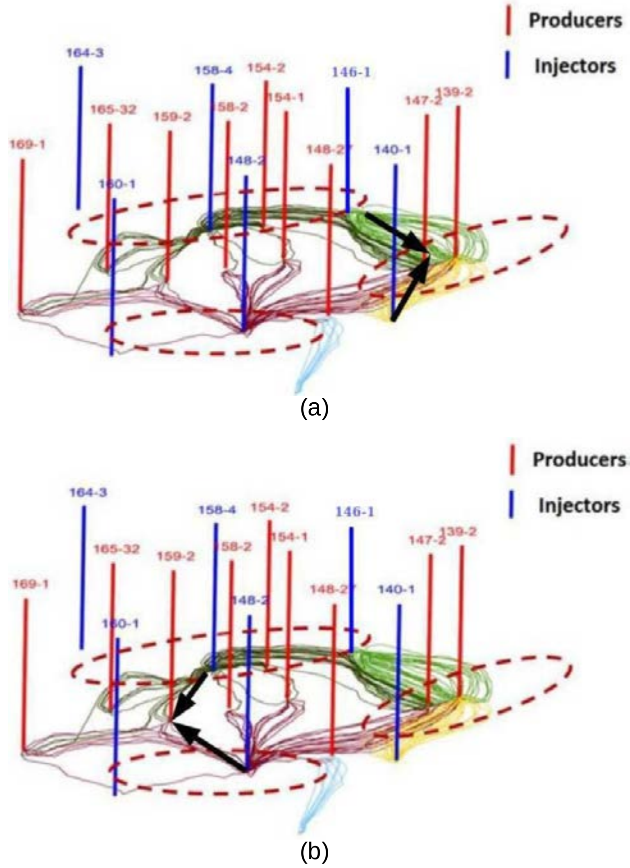


Figure 6: Streamlines of injected CO2, according to the work of Alharty, 2011.

Nevertheless, streamlines between wells 169-1 and 159-2 (figure 6a) do not agree with the time-lapse seismic maps (figures 4a and 4b). In the maps, no anomaly is present in this area, thus it is likely that CO2 is in fact not reaching this zone. Indeed, from Ramdani's work one can also conclude that this is a low permeability zone. Hence, it turns out that the reservoir model must be updated, including the time-lapse seismic information.

Conclusions

This work showed the usefulness of time-lapse seismic data as a source of information to understand how fluids behave in a producing reservoir. Particularly, reservoirs analogous to Delhi are prone to present a good response to time-lapse seismic.

In this work, permeability barriers have been unveiled, which can be used as a valuable input to an update of the current reservoir model.

This work dropped the question mark on the sweep efficiency of Paluxy. It was concluded that the CO2 is not bypassing Paluxy sandstones.

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