Steam injection monitoring with high resolution time lapse seismic

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Abstract

The challenge to produce parafinic oil from shallow sandstone reservoir in the Fazenda Alvorada onshore field, located Northeast of Reconcavo Basin, led to the option of using steam injection as a secondary recovery process. In 1994, a project was designed to introduce the 4D seismic technology in Petrobras and at the same time to evaluate the efficiency of that recovery process. Petrobras opted by monitor the injection using for the first time high resolution time lapse seismic. Geophones with 60 Hz resonance were used instead of conventional 10 Hz in the sucessive acquisitions. Circumstantial reasons led to almost 5 years interval between the successive surveys what increased the difficulties to the project. This work will focus on some aspects related with acquisition, processing and interpretation of that 4D project.

Introduction

The Field of Fazenda Alvorada was discovered in 1984, located in the Northeast compartment of the Reconcavo Basin, inserted in the high block of the Pedras fault. It is formed by 3 main blocks with accentuated inclination (25 degrees) to Southeast and separated by normal flaws on SE/NW direction. Each block has independent accumulations and its own oil/water contac (Figures 1 and 2). t. The stratigraphic sequence crossed by the wells is constituted by sediments of the Barreiras, Candeias, Agua Grande, Itaparica, Sergi and Aliança formations. The main oil reservoirs producing are constituted of sandstones belonging to the Agua Grande, Itaparica and Sergi formations. It was first chosen as a pilot project to introduce seismic time lapse technology in Petrobras. All the feasibility analysis done by CENPES, Petrobras research center group, showed that we could expect impedance variation at around 13%. Due to the thin reservoir (Agua Grande sandstone around 25 m thick) it was decided to experiment geophones with high resonance frequency (60 Hz). The first acquisition was performed in September 1995, two months before the date scheduled to start the steam injection process. Due to the production strategy of the Asset Team responsible for the field was decided to postpone the start of the steam injection and all the injection equipment and facilities were transferred to be used in another field of Reconcavo basin.

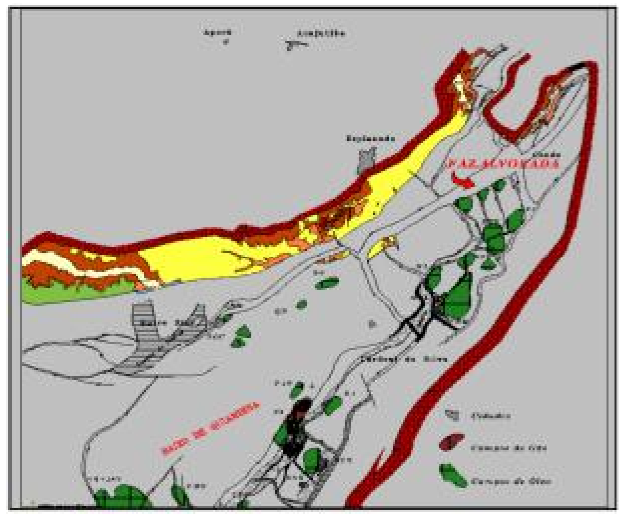


Figure 1 - Localization of Fazenda Alvorada field on Northeast portion of Reconcavo basin.

So, the injection process on Fazenda Alvorada started only in December 1999, what made it possible to acquire the second seismic survey by December 2000. With such large time interval between the sucessive acquisitions many were the challenges related with processing strategies. At the same time the injection had some operational problems that led to additional difficulties to the monitoration of the steam flow.

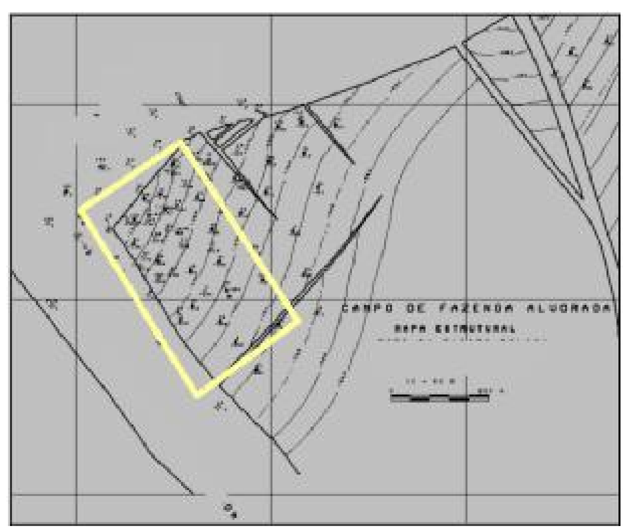


Figure 2 - Structural map of top of Agua grande Fm and the 4D area (in yellow).

Feasibility Analysys

The first feasibility analysis was performed in 1995 based on laboratory evaluations and indicated that temperatures above 120^{0}C would be enough to make the injection seismically visible, leading to velocity variations between 9 and 13 %. At that time it was not common the use of methodologies as the one introduced by Lumley and others, in which they take into account other variables as signal/noise ratio, fluids compressibility and others. The project, using that classification system, reached 31 points in 50 maximum possible. More recently, based on the information derived from the STARS simulator (CMG), a modeling using Biot-Gassman was done to the period of the legacy and monitor acquisitions. The petrophysical parameters of well FAV-X were used to calibrate the model. The result, shown in Figure 3, represents the velocity difference map. Blue areas are related with wavefront propagation, while red colors highlight an effect that can be related with the presence of propagation barriers.

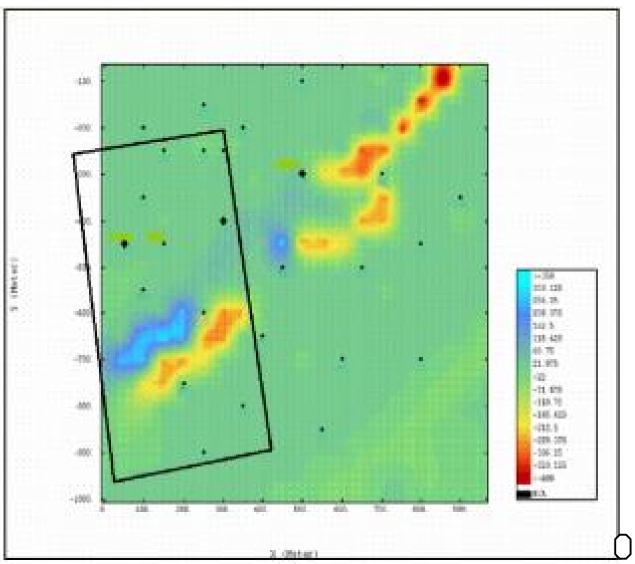


Figure 3 - Velocity difference map. Blue areas are related with wavefront propagation, while red colors highlight an effect that can be related with the presence of propagation barriers.

Acquisition

The surveys (September 1995 and December 2000) were acquired by Petrobras seismic crew using the parameters bellow:

line interval - 10m	shot interval (cross line) - 5m
shot interval(in line)-20 m	cell 2.5 X 2.5 m
spread - 0-7.5 -397.5 m	fold - 10
sample interval - 1ms	record length - 2 sec.
Low cut - 36Hz/36 db/oct	High cut 500 Hz/ 72 db/oct
source - explosive 150 g	Source - 6 m deep
Geophone depth - 6 m	

The large time difference between the surveys took to large differences in the seismic responses. Some, we believe can be related with variations on surface conditions and operational procedures like the interruption of noisy production activities and others could be explained by the stress of the 60 Hz Geophones that remained without using since the first acquisition. The Figure 4 shows two groups of records from the different surveys acquired at the same position, close to the injector well FAV-A.

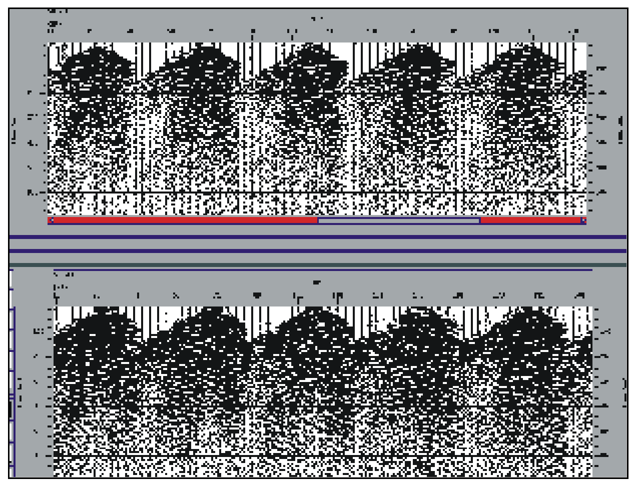


Figure 4 - Group of records from the base (above) and monitor (below) surveys. Notice the difference in the signal-to-noise ratio, ground roll and energy.

Cross Equalization and Interpretation

The simultaneous processing was conducted by the Regional seismic processing group of Petrobras in Bahia using PROMAX software. Many different procedures were tried and the final option was to produce two images with as many common parameters as possible, as static corrections or velocity fields, and to regularize the coverage, mute, missed traces and other differences that were minimized during the processing.

The interpretation was performed using the software PRO4D(tm) that has the advantage of making possible, in the interpretation environment, to evaluate the impact of fluids substitution, cross equalizations of the different surveys and the generation of various difference maps choosing from many attributes and exploring their correlation, in terms of material balance, with the fluids movement. During the workflow we perceived how sensitive were the results to the chosen crossequalization strategy. So, much effort was spent in the

experimentation of different alternatives (like the width and position of crossequalization windows or operator length to apply global phase match filters - Figure 5).

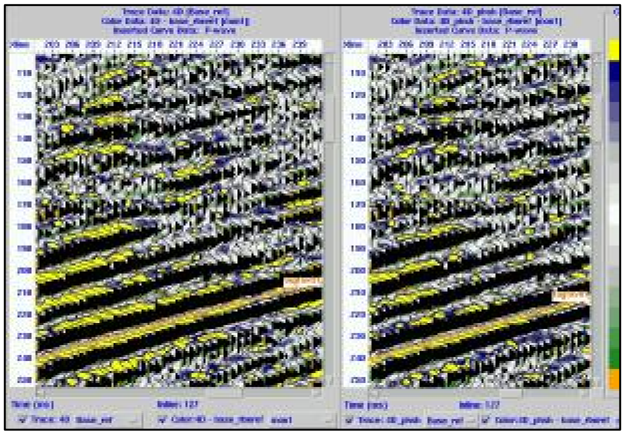
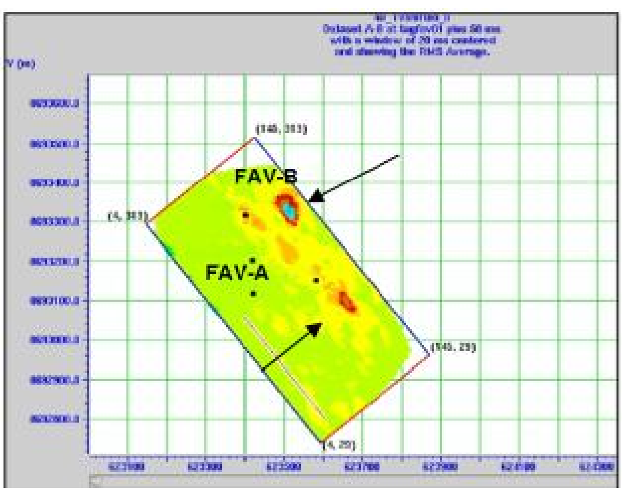


Figure 5 - Difference of monitor and legacy data (color variable density) superimposed on the legacy data, before (left panel) and after (right panel) use of global match filter.

Other important question was to consider that we should expect other differences than just those related with oil remobilization at reservoir level. The 5 year difference between surveys certainly could result in variations on near surface conditions that could introduce some difference beyond those at reservoir interval and bring some difficulty to the cross equalization process.

Figure 6 - Difference map in a window centered in the reservoir. There are two clear zones of differences (arrows), One related with the injectors and the other related with the water flow (below).



The difference in the signal/noise ratio observed on some areas of the 3Ds can explain why the differences around the well FAV-B are more perceptible than those under well FAV-A (Figures 6 and 7). The interruption of the injection process in some moments in the 11 months period is another important cause for a so different behaviour of the two wells (Figure 8).

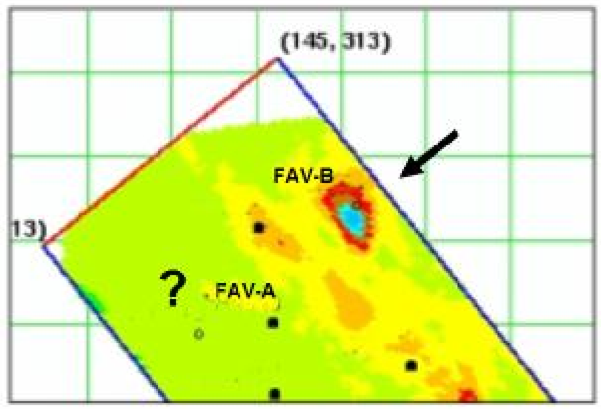


Figure 7 - Zoom from figure 6. Note the absence of response on the area around FAV-A injector.

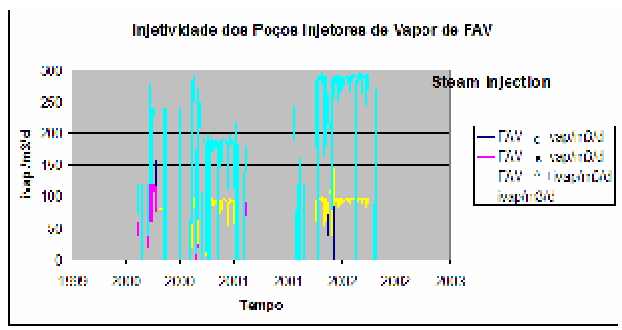


Figure 8 - This graph shows that the steam injection was not continuous during the monitored time.

A method to evaluate how much confidence one can reliable have in the difference maps is to generate the same map in different windows above and bellow the target reservoir interval. Once the overburden had no production effect the difference maps generated after cross equalization should show no differences. At the same time we can expect the difference maps to continue reproducing the same results when generated at window intervals bellow the target level (Figure 9).

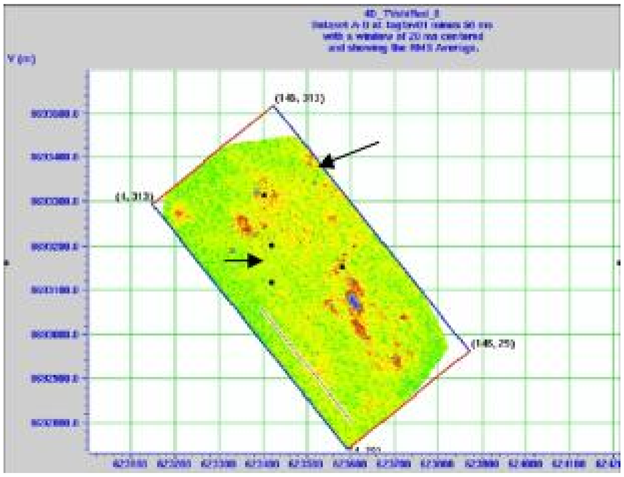


Figure 9 - Difference map in a window above the reservoir interval. Compare with figure 6 especially in the injectors interval (arrow).

Conclusions

Many were the factors that made difficult to evaluate the steam injection efficiency by the seismic monitoring. The problems that caused some interruption of the injection and the large time difference between legacy and monitor seismic are among the main problems. With such large time interval we could expect some variation on the overburden response due to superficial variation. Notwithstanding these difficulties the monitoring succeeded in being able to detect differences related with fluids movement. The difference map, although did not show differences around one of the injectors (FAV-A) led to what can be understood as a previsible result considering the high variation of signal/noise ratio between legacy and monitor surveys. The petrophysical model confirms this result (Figure 3), and showed, with the historical data of the simulator, that this well was not so efficient in the injection process.

The difference pattern observed around well FAV-B indicate that despite the low variation in petrophysical reservoir conditions in the area there is some preferential fluid flow that can be related with the depositional system of the reservoir. So, expecting some anisotropy in fluid flow we can use that to optimize the future injection pattern.

The use of 60 Hz geophones also make it possible to avoid the tuning interference that could had made impossible to have confidence on amplitudes variations due to 4D tuning. As an additional investigation at the time the monitor data was acquired it was used together (side by side with 60 Hz arrays) 10 Hz geophones to evaluate the difference in response compared with the high resolution geophones and to determine if the next surveys could be acquired with conventional geophones.

Another important conclusion was that of the possibility of performing the cross equalization in the interpreters enviroment what can be considered as a fundamental approach, because the subtle differences in time lapse seismic are quite dependent of the strategy used for processing the data. At the same time the interpreter has the capability of recognizing what and where are the acceptable differences.

Acknowledgments

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References

Resultados do monitoramento das frentes de vapor através da modelagem petrofísica aplicada nos campos de Fazenda Alvorada e Fazenda Belem. *Odilon Keller Filho & Marco Cesar Schinelli, II Encontro sobre Injeção de Vapor - Petrobras, 2003.;*

Avaliação em Laboratório da sensibilidade do Método sísmico no monitoramento de processo térmico de recuperação secundária no campo de Fazenda Alvorada. Lucia Duarte Dillon & Guilherme Fernandes Vasquez - Boletim de Geociências da Petrobras, Dez/1993.;

Levantamento 4D de Alta resolução para monitoramento de reservatório. Campo de Fazenda Alvorada - Segunda fase. Marco Cesar Schinelli & Raimundo Conceição Pereira, Relatório interno - Petrobras, Set/2000.