A Pilot Project: Passive Seismic Experiment for Reservoir Monitoring and Characterization at King Fahd University of Petroleum and Minerals*

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Abstract

As part of National Science, Technology, and Innovation Plan of the King Abdulaziz City for Science and Technology (KACST) program, we recently received two-year funding to carry out a small-scale pilot passive seismic (PS) experiment. The experiment involves setting up thirty three-component passive surface stations over an active reservoir. The main scope of the experiment is to better understand the subsurface reservoir using passive seismic data. We believe that our research will be a small step forward in the right direction to develop a new tool to meet the increasing demand for world marketed energy consumption which is projected to increase by 44 percent from 2006 to 2030 (see the international energy outlook 2009 at http://www.eia.doe.gov/oiaf/ieo/index.htm).

Introduction

Passive Seismic (PS) is relatively new technology in the oil and gas industry. However, it has been successfully applied in mining industry where real-time-seismic activities are continuously monitored to decide whether it is safe to send miners into the underground or not (Luo et al., 2010 and Gibowicz, 1995). Moreover, it has also been used in monitoring the performance of geothermal reservoirs and excavation stability in nuclear waste repositories (Asanuma et al., 2004 and Young, 1999). The concept of PS is based on the simple principle that any small movements in the earth can be seismic sources. A PS experiment depends mainly on the microseismic activity in the area. The main advantage is that it does not require application of an active source and thus can be carried out without mobilizing a synthetic source or waiting for earthquake events. That is why there has been an increase in PS research (Deflandre et al., 1995; Maxwell et al., 2000; Papoulia and Makris 2007) and oil and gas industries are steadily progressing toward the PS idea. Deflandre et al. (1995) successfully mapped gas movements using PS experiments in the Paris basin in France. Holzner et al. (2005) made an attempt to apply microtremor analysis to identify hydrocarbon reservoirs. Dangel et al. (2003) observed tremor-like signal observed over hydrocarbon reservoirs. Maxwell et al. (2000) used PS experiments to identify the fault pattern in the Ekofisk Field. They concluded that the advantage of PS is that faults with small throws can be directly detected, whereas these faults are typically indirectly mapped with reflection seismology by offset horizons. Papoulia and Makris (2007) have shown the correlation between recorded microseismicity and the presence of active faults. Rutledge et al. (1998) carried out a PS experiment from 1993 to 1995 in the seventy-six oil field, Clinton County, Kentucky where oil is produced from low-porosity, fractured carbonate rocks at <600 m depth. They discovered previously undetected, low-angle thrust faults above and below the currently drained depth intervals.

Over the last few years, a number of workshops and dedicated technical sessions on PS were held by European Association of Geoscience and Engineers (EAGE), Society of Exploration Geophysicist (SEG), and American Geophysical Union (AGU) (AGU 2009, EAGE 2006, EAGE 2007, EAGE 2009, SEG 2006, 2007, 2008, 2009). At present, the majority of PS applications in the oil industry are focused on imaging hydraulic fracture simulations and mapping (see Maxwell and Shemeta, 2008; Rutledge and Phillips, 2003). However, little attention is being paid especially by the academic institutions towards small-scale investigations to better understand the subsurface with an integrated approach. We believe that PS is likely to become an important new tool for hydrocarbon exploration and development and thus, we at King Fahd University of Petroleum and Minerals (KFUPM) need to play a role in PS research in the Kingdom of Saudi Arabia (KSA).

Objectives

The primary objective is to see the correlation between hypocenters and active faults or fractures as well as the seismicity and the fluid-flow movements within the reservoir over an active reservoir. We will address a number of fundamental questions that are of great importance to the oil and gas industry.

1) Can the PS experiment effectively be used as a practical reconnaissance tool in hydrocarbon exploration?
2) Can we reduce the ambiguity in the interpretation of the seismic images by combining them with the results we obtain from this experiment?

Scope of Work

The scope of our experiment is to better understand the subsurface by using PS results integrated with all other available field data including the well and the VSP (vertical seismic profile) data. Our long-term vision is to develop PS methodology as a reliable additional tool for hydrocarbon exploration in KSA. In general, we will begin the experiment by setting up thirty complete three-component passive surface stations over an active reservoir for twelve months to locate passive events. The exact location of the stations is being evaluated on consultation with Saudi Aramco. We will concentrate mainly on mapping the hypocenters of the recorded events. We expect most passive events to occur on pre-existing weakness zones and the precise localization of the events will improve the understanding of fluid-flow movements under the subsurface. We will analyze passive events to determine the spatiotemporal pattern under an active reservoir.

Procedure

The basic hypothesis to be tested by this pilot project is whether microseismicity pattern can be correlated to local fluid-flow movements or active fault/fractures. Unlike other experiment, the recorded microseismic data cannot be used directly for any correlation. It is necessary to process the data in order to identify, locate, and characterize the microseismic events, which in turn can be interpreted in terms of type, frequency of occurrence, magnitude, locations etc. Recently, Green and Greenhalgh (2009) caution against misinterpreting surface waves as microseismic events. They showed that several of the “allegedly” successful microseismic events have been actually surface waves. Draganov et al. (2009) pay attention to this word of caution and used receiver arrays, FK filters, and seismic interferometry on passive seismic data in order to suppress surface wave energy and enhanced the quality of passive seismic events. They ended up with passive-seismic shot records that comparable to active shot records acquired in the same location. Based on these recent developments in the field of passive seismic, we intend to pay special attention to the surface wave leakage problem and devise suitable field and processing methods for suppressing it and enhancing the microseismic events coming from the reservoir.

As for processing, we will follow the following standard data processing steps:

- PS signals will be analyzed with event detection algorithms to determine when an impulsive energy source has taken placed
- signals will then be retrieved with some pre-trigger time window not to miss the signal prior to the detected signal
- hypocentral location and origin time will then be determined and stored in a database
- database of hypocentral locations will be presented in 3-D
- additional seismic attributes will be determined from the amplitude and frequency content such as the event magnitude, energy release, by assuming some fracturing model the stress release, area, and placement of slip

Conclusion

This proposed research will enable us to conclude upon completion the understanding of how and when to use passive seismic experiments in the context of hydrocarbon exploration in KSA. Further, if the PS experiment is deemed effective then it can be used for large-scale deployments such as the northwestern region where it can add vital unexplored look into the subsurface. We will seek to continue PS experiment for additional 2-year period extending approximately from 2011 to 2013. This long-term seismicity database can then be used to determine whether any significant correlations exist between the fluid movement and distribution of microseismic events or the location of microseismic hypocenters and active faults/fractures.

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