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monitoring of induced microseismicity in an onshore oilfield from Abu Dhabi, United Arab Emirates: Implications for carbonate reservoir monitoring

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ABSTRACT

We present the first pilot study of a microseismic monitoring survey using a single vertical downhole array in an onshore oilfield in Abu Dhabi, the United Arab Emirates. The microseismic data are acquired continuously for 27 days in conjunction with gas and water injection in the Lower Cretaceous Thamama and Shuaiba reservoirs. The aim of this pilot study is to verify the ability of microseismic monitoring to reveal information about fracture system and fluid flows within the carbonate reservoirs in response to fluid injection. For the majority of the data, the signal to noise ratio is less than 1 dB, which makes it very challenging to find well-defined P and S waves simultaneously. However, a total of ninety microseismic events are detected using the combination of amplitude ratio, hodogram and apparent velocity analysis. The occurrence of detected events shows a strong relationship with the injection rates. Subsequently, the probabilistic global grid-search strategy is employed to obtain locations of these events. The spatial distribution of the events detected in the Thamama II reservoir correlate well with NW-SE oriented pre-existing fault and fracture systems in the oilfield. By contrast, the events detected in the Shuaiba reservoirs are scattered without a major trend and depth constraint probably due to various azimuths of injectors. The high *b* values retrieved from Gutenberg-Richter formula suggest that the reservoirs are stiff. Moreover, the different behaviors of the released seismicity and *b* values for lower (Thamama II reservoir) and upper (from Shuaiba I to Shuaiba IV reservoirs) group of events indicate that microseismicity is induced more easily in Thamama II reservoir than Shuaiba reservoirs. It is reasonable because the injection in Thamama II reservoir just started a year ago while that in Shuaiba reservoir has been going on for the past 20 years. Therefore, it is more likely for Thamama II to induce more microseismicity than Shuaiba reservoirs. Overall, this study demonstrates that the microseismic technique can be considered as a potentially important monitoring tool to reveal information about fracture systems in the carbonate reservoirs of Abu Dhabi oilfields.

1. Introduction

The application of induced microseismicity has attracted considerable interest as a tool for reservoir monitoring (Rutledge et al., 1998; Maver et al., 2010) since its first case study in a waste water injection well in Denver, USA (Healy et al., 1968). The monitoring of microseismic events in hydrocarbon reservoirs has the potential to reveal the geometry of small fractures, which can be hardly observed in surface seismic surveys (Albright and Pearson, 1982; Oye and Roth, 2003). This information can provide invaluable knowledge of fluid flow path, stress changes and geomechanical deformation caused by fluid injection or depletion within hydrocarbon reservoirs (Miyazawa et al., 2008; Maxwell et al., 2010). Furthermore, microseismic monitoring has been proven useful in enhanced oil recovery, planning of new production and injection wells, adjusting of stimulation design, waste injection monitoring, risk assessment and overburden characterization (McGarr and Simpson, 1997).

Although microseismic monitoring has not been widely applied in the United Arab Emirates (UAE), several important case studies in surrounding regions have demonstrated the potential of this technique in carbonate reservoirs. For example, Gaucher et al. (2008) reported a microseismic monitoring pilot study in Minagish field, western Kuwait, to assess the occurrence of induced microseismic events by the production operations. The monitoring zone was the Minagish Oolite,

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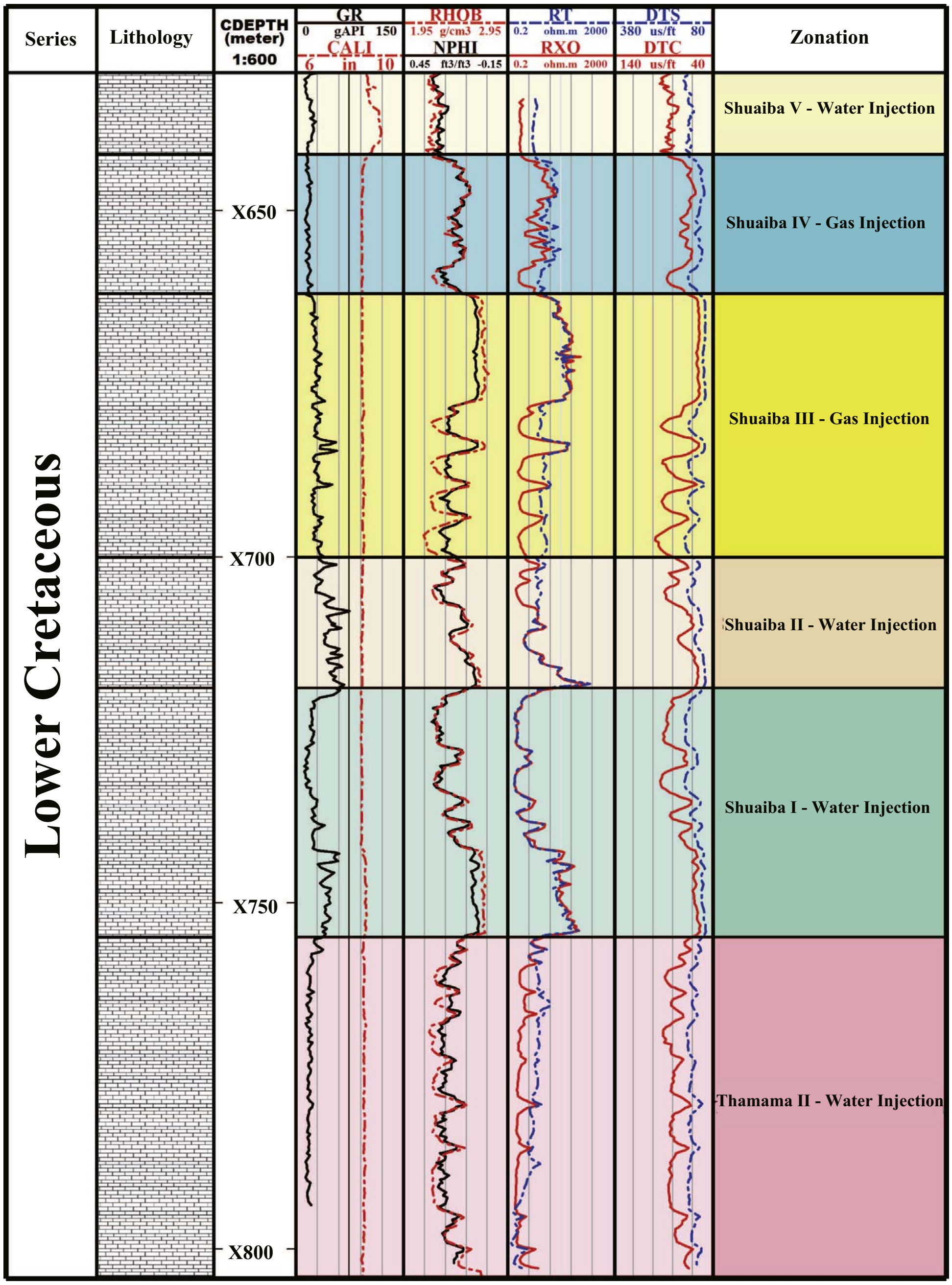

Fig. 1. Lithology, log character and reservoir zonation of study oilfield in Abu Dhabi, United Arab Emirates. GR, CALI, RHOB, NPHI, RT, RXO, DTS and DTC represent gamma ray, caliper, density, neutron porosity, resistivity of the uninvaded zone, resistivity of flushed zone, slowness of shear wave and slowness of compressional wave, respectively. In addition, different colors stand for various reservoir formations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

a microporous carbonate reservoir of about 350 ft thick and around 9600 ft deep. Four 3C-geophones were deployed for 50 days in an abandoned well on the eastern flank of the field. About 600 microseismic events with magnitudes of −2.0 to 0.3 were located (Gaucher et al., 2008). Most of the events were located on the western side of a NNE-trending line between the injectors and the producers, which is consistent with the structure of the field (Gaucher et al., 2008).

In the Gawar field of Saudi Arabia, microseismic monitoring experiment was conducted to map possible fracture zones and investigate water flooding in the Arab-D reservoir, a limestone with some dolostone horizons (Jervis and Dasgupta, 2009; Vernier et al., 2009). The microseismic network comprised a large surface and downhole arrays. The experiment recorded more than 9000 microseismic events with magnitude of −2.2 to 1.1 in 28 days of continuous monitoring (Jervis and Dasgupta, 2009; Vernier et al., 2009). These microseismic events were possibly generated by stress gradients induced by production and injection activities in the Arab-D reservoir (Jervis and Dasgupta, 2009). Therefore, the experiment demonstrated strong correlation between injection rate and detected microseismic events, which may suggest the microseismicity is controlled by localized fractures zones (Jervis and Dasgupta, 2009).

In Oman, the induced microseismic events detected in the Yibal field were found to be at shallow depths, mostly induced by production of Natih gas reservoir (Jones et al., 2004; Sarkar, 2008; Sarkar et al., 2008). Majority of these events occur along pre-existing NE-SW faults paralleling to the maximum regional horizontal stress direction, which indicates the reactivation of existing faults in this region (Li et al., 2011a, 2011b). In addition, Al-Anboori and Kendall (2008) reported a microseismic monitoring study of two carbonate reservoirs (Natih A and Shuaiba Formations). In this study passive seismic data were