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Monitoring Microseismicity in Oil Boreholes

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ABSTRACT
Micro seismic events or ultra-micro earthquakes (M -3 to 1.0) are generated from normal production and also by injection activities for early oil recovery (EOR) in oil boreholes. The recorded micro seismicity is associated with the stress and pore pressure changes in and around the reservoir and can be used to continuously monitor the reservoir stress field and related fluid flow dynamics in real time. These ultra-micro earthquakes, when detected with proper instrumentation, allow us to measure fluid movement away from the well locations. Field wide monitoring between the wells is important for optimum reservoir management, and it is achieved by mapping the hydrocarbon fluid pathways in a producing reservoir. Recording and analyzing the passive micro seismic events have the potential for defining the fluid flow patterns and or the reservoir flood fronts. Maps of fluid pathways aid in reservoir management by optimizing development plans and improving the ultimate oil recovery.

INTRODUCTION

Optimization of reservoir management requires the monitoring of fluid dynamics or drainage patterns of reservoir production and injection processes. Modelling studies in a large oil field of Saudi Arabia suggest that conventional monitoring technology like time lapse or 4D seismic technique may not be applicable every where. This is because the sensitivity of change in acoustic impedance or seismic signature in carbonate reservoirs is extremely low, below the delectability of 4D seismic measurements (Dasgupta, 2005). Passive monitoring of micro seismic tremors, has the potential for defining the fluid drainage patterns or the reservoir flood fronts that are invisible to active seismic techniques.

Reservoir rocks react to changes in stress and strain associated with pressure changes in the reservoir and generate microtemors (M -3 to 1.0). These tiny tremors or ultra-micro earthquakes are caused by slippage or tensile deformation on pre-existing fractures/faults. The ambient stress field is perturbed by fluid or CO_2 injection and oil extraction. The stress change induces shear slippage along the zones of weakness like fractures and faults. This shear slippage generates micro seismic events. Several successful experiments are made towards monitoring micro seismicity in geothermal boreholes (e.g. Dorbath et al., 2009), and also for EOR in oil boreholes (e.g. Dsagupta and Jervis, 2008; Rutledge et al., 2008); some results are presented here.

FIELD EXPERIMENTS

A network of sensors is made spatially on the surface and at different levels in the oil borehole. The sensors record the arrival times for compressional waves (P-waves) and shear waves (S-waves) of the micro seismic events (Fig.1). These data may be used to determine the hypocenter parameters by multiple regression analysis (Kayal, 2008), and the epicentral and 3D hypocentral maps could be produced to understand the fluid flow at depth.

The experiment provides an opportunity for a field wide continuous monitoring in real-time as the fluids are produced or extracted from, and injected into the reservoir. Anisotropic fluid flow or directionally uneven flow rates are sometimes associated with reservoir production and injection operations. This information could also be applied in inferring the distribution of reservoir properties such as permeability related to fractures and faults and reservoir connectivity for numerical modelling.

FIELD EXAMPLES

Examples of an epicentral map and a 3D hypocentral map are illustrated here to understand the efficacy of the microearthquake technique in oil producing boreholes.

Rutledge et al., (2008) reported a successful experiment of micro seismicity monitoring in boreholes due to CO_2 enhanced oil recovery in the Utah oil field (Fig 2). The seismicity revealed two NE-SW striking fracture zones. No seismically active structure was found by the surface 3D seismic survey. Some 3800 micro earthquakes with moment magnitude Mw –1.2 to 0.8 were recorded within ~ 2 km of the treatment well during the first year of the monitoring; the seismicity was induced during the continuous CO_2 injection. Focal mechanism solutions of the events indicated strike slip faulting that indicates shear failure on micro fractures due to fluid flow dynamics. The frequency magnitude relation showed the b-value of the order of 2.0, which is almost twice the normal value in a tectonically active zone. This higher b-value is characteristic of induced seismicity due to injection. There was no main shock to associate this large sequence of micro earthquakes as aftershocks. The micro seismicity

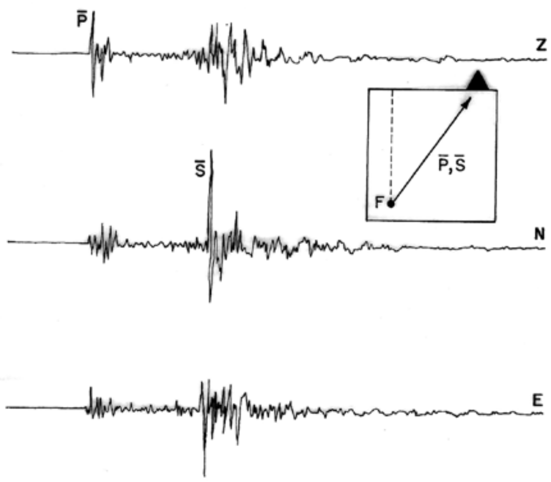

Figure 1. A record (seismogram) of a micro seismic event; Z represents the vertical component, N and E are the two horizontal components. Arrival of P wave is well identified in Z component, and the S-wave in horizontal components (after Kayal, 2008).

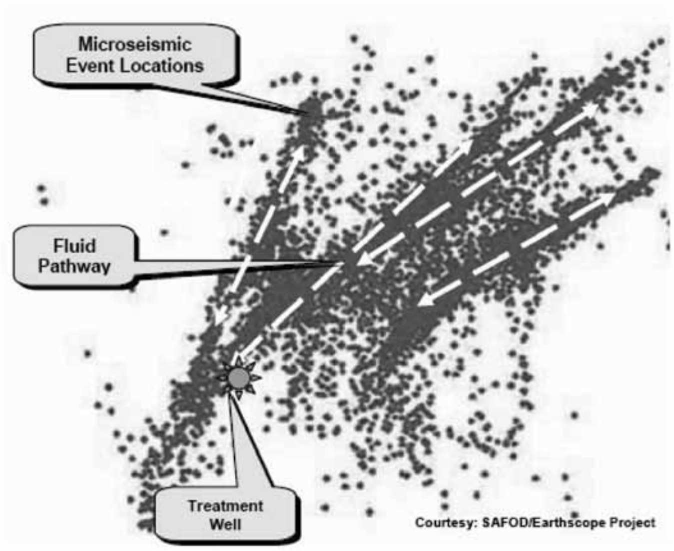

Figure 2. Epicentral map of ultra-microearthquakes (M -1 to 0) in an experiment of CO_2 injection in Utah oil well that were recorded within about 2 km (after Rutledge et al., 2008, AGU meeting).

trends indicate the fluid flow dynamics in real time. The increase in pore pressure causes micro fractures to generate the micro seismic events.

Dorbath et al., (2009), on the other hand, examined cumulative seismic moment with fluid injection in geothermal boreholes. The temporal evolution of the cumulative seismic moment showed that once the faults/fractures are activated, the seismicity becomes largely independent of the injection parameters. This means that, once a large fault is activated, their behaviour becomes independent of the injection. Their identification and mapping may be challenging for future prospecting.

Dasgupta and Jervis (2008) reported microearthquake monitoring in a Saudi Arabian oil field (Arab-D) for mapping reservoir drainage pattern. The experiment was unique because of the large array of permanent multi-component seismic sensors that were deployed at various levels in the borehole and over a surface area surrounding the borehole. The microearthquakes down to moment magnitude Mw -3.0 were recorded simultaneously by the surface and borehole sensors. The microearthquake data could provide the location, relative fracture density and reservoir-flow for optimizing reservoir production and ultimate recovery. A 3D view of the microearthquake activity in an oil reservoir in Arab-D is illustrated in Fig.3.

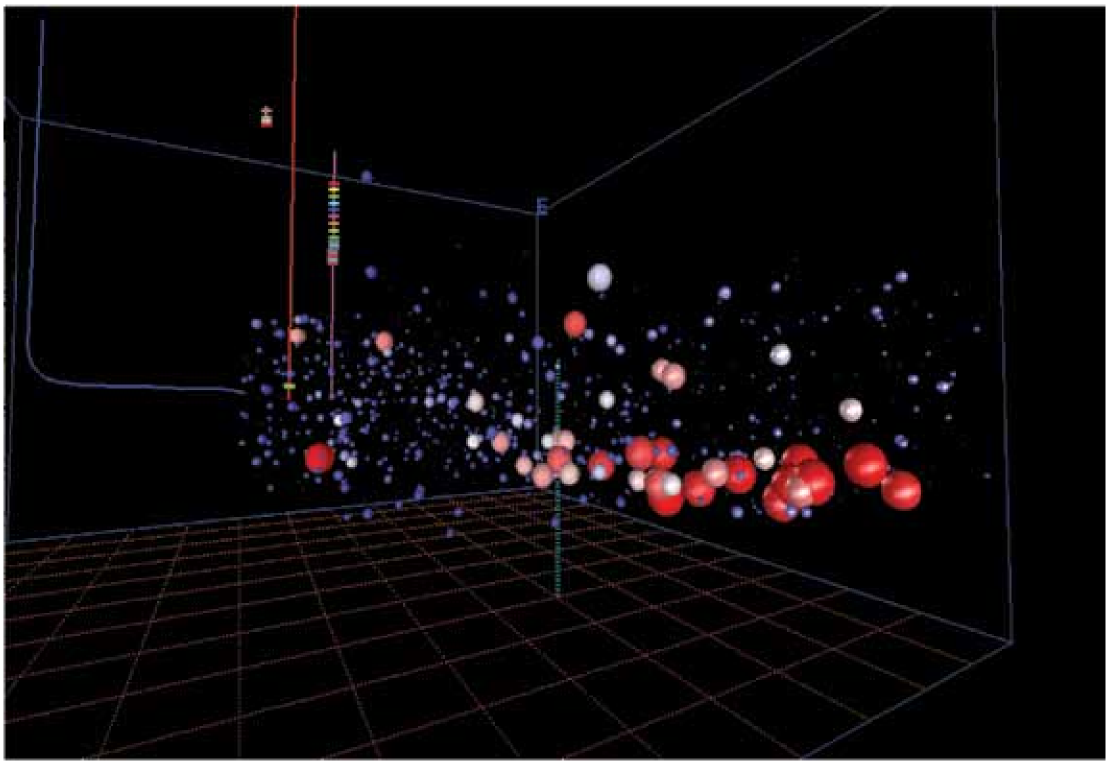

Figure 3. A 3D view of microearthquake hypocenters following liquid injection at the Arab-D reservoir level, the magnitudes (Mw -3.0 to 1.0) of the events are indicated by size of the balls (after Dasgupta and Jervis, 2008).

CONCLUSIONS

Micro earthquake monitoring techniques provide a method for continuously detecting micro seismic events for monitoring fluid pathways in a hydrocarbon reservoir. By combining surface and down hole sensors the mapping of fluid flow over a reservoir volume between the wells is possible. This information may be applied in inferring the distribution of reservoir properties such as permeability related to fractures and faults and reservoir connectivity for numerical simulation of fluid flow. The results increase the precision in reservoir model descriptions and potentially improved recovery.

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