PRM system monitoring of injection and production processes for safe operation

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Abstract

The challenges of safe oil recovery and injection projects in areas with a challenged overburden, requires increased field- and well surveillance in order to avoid leak to surface events, as previously observed at e.g. the Tordis and the Frade field. Monitoring with Permanent Reservoir Monitoring (PRM) systems through installation of seismic ocean bottom nodes offers a strong monitoring solution, which can contribute with useful information contributing to the understanding of the structural integrity of the caprock; injection well integrity; drilling hazards; as well as fluid movement and stress changes build ups, all needed in order to avoid unwanted events as surface leaks. A PRM system further offers solutions for the collection of data from active seismic surveys and the collection of ambient seismic noise data, which can be used obtaining a better understanding of the shallow structures of the overburden. For surveillance of microseismic events, induced through either production or injection processes, a real-time alarm system is required, in order for the appropriate actions to be made when the induced microseismic events propagates towards the surface before reaching the seabed. Such a system is foreseen to utilize down well pressure data, microseismic data and possible other data available.

Introduction

When performing oil recovery in areas with a challenged cap rock or injection of e.g. cuttings, produced water, CO_2, etc. monitoring of the processes in the subsurface is essential. Permanent reservoir monitoring (PRM) offers a customized solution for this. Installation of PRM systems allows for frequent active seismic surveys, insuring better monitoring of the production. Repeated surveys contribute to more information, allowing better-founded management decisions. By utilizing the PRM system for passive listening between active surveys, detection of microseismic events related to the field and/or well activities is possible. Furthermore, the ambient seismic noise data collected in passive mode opens up for passive microseismic methods used to characterize the shallow overburden and changes therein (e.g. Bussat, 2015; Mordet et at., 2014; and references therein). Data collected in passive mode, can thus provide key information for the operational team, and serve as an important input, to reduce the operational risks.

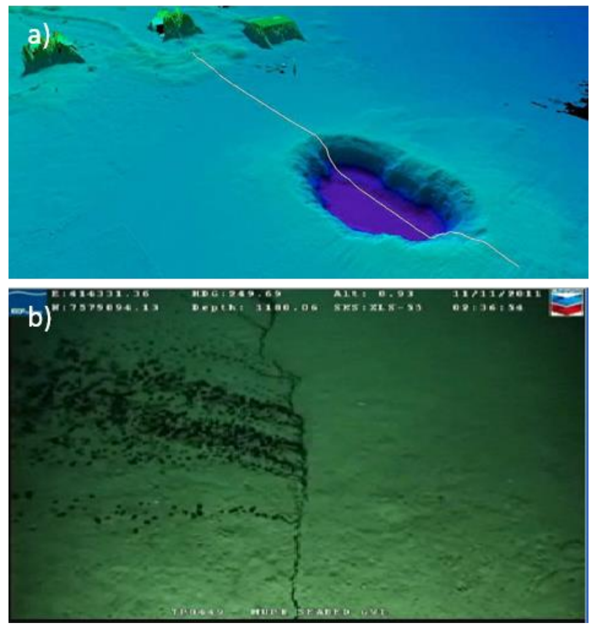

Figure 1. *Examples of incidenced where leak to surface has occured. (a) Tordis field, where a crater occurred after a water injection (from NPD). (b) Frade field, where leaks of crude oil to seabed occurred after a well blowout (from Chevron).*

Several examples exist where incidents with leak to surface have occurred. In Figure 1 we show examples from the Tordis field in the North Sea (a) and the Frade field, Brasil (b). In case of the Tordis field, an oil leak occurred after a water injection. A following study of the seabed identified a large crater of approximately 40 by 70 m and about 7 m deep. Furthermore, the crater is located very close to the underwater installations, indicating that this leak to surface could have had much larger consequences. At the Frade field, a drilling incident in 2009, causing crude oil to seep up of several cracks to the seabed, indicates a challenged cap rock, which requires extra attention and monitoring needs to follow processes in both the reservoir and cap rock. Permanent reservoir monitoring (PRM) offers a strong solution for real-time or near-real time monitoring of both reservoir processes and cap rock integrity. Installation of PRM systems allows for frequent active seismic surveys, insuring better monitoring of the production, as well as passive listening for microseismic events between surveys. All in all, a PRM system can contribute to collection of more data and information, allowing for better-founded management decisions.

Method

Installing a PRM system allows for more frequent and faster organized active seismic survey, hence, increased information on reservoir, production and/or injection is obtained. Furthermore, a PRM system allows for passive listening. That is, passive monitoring in real-time, of e.g. an injection process. In case of microseismic events, these will be detected, and steps in order to minimize the risk for cap rock failure or blowouts can be taken. Furthermore, the ambient seismic noise data collected in passive mode opens up for passive microseismic methods used to surveillance fluid movement, cap rock failures, fracture zones and changes in the overburden (e.g. Bussat, 2015; Mordet et at., 2014; and references therein). The data collected in passive mode, can thus provide key information for the asset team in order to reduce the operational risks.

Figure 2 shows a sketch of concept of the PRM system, in this case for injection well monitoring. The system is installed on the seabed, and records continuously. Data is, via an umbilical collected at the platform, before transferring the data to land in real-time. During campaigns of active seismic surveys the system is set in "active mode" and is used for data collection. The system is autonomous, and can be controlled from shore, hence personnel for recording system maintenance is not needed either on the surveying boat, or on the platform. During injection campaigns, or production, the PRM system can be used for passive listening, used to characterize, and follow, the reservoir processes in real-time. In case of fracturing of the overburden, identified by the occurrence of microseismic events, the propagation of these can be followed from reservoir level and as they propagate upwards. Early detection of cracks propagating towards the seabed is important to adjust the injection strategy, and in this way avoid surface leaks.

The PRM system, offered by Octio AS, is designed with an open architecture, allowing for easy expansion from a small dedicated cap rock system monitoring an injection well to full field systems for increased oil recovery. Furthermore, the system allows for easy connection of third party sensors, through Ethernet on the Seabed. By connecting third party sensors, the collected data can be transferred to the platform through the cable. Sensors as e.g. biological and chemical sensors can monitor the changes in the chemical composition of the water column, in case of a leak to surface event. Combination of many different measurements increase the knowledge of the overburden, the water column and essentially the reservoir, all needed for conducting safe and environmental friendly operations.

Examples

In July 2013 Octio AS installed a PRM system for monitoring of a waste injection well in the North Sea. The design of the seismic array is optimized to accommodate both active surveys, for imaging of the injection reservoir, as well as passive microseismic monitoring (Lindgård and Matveeva, 2013; Løvheim, 2013). The system has been providing continuous data since system start-up in 2013.

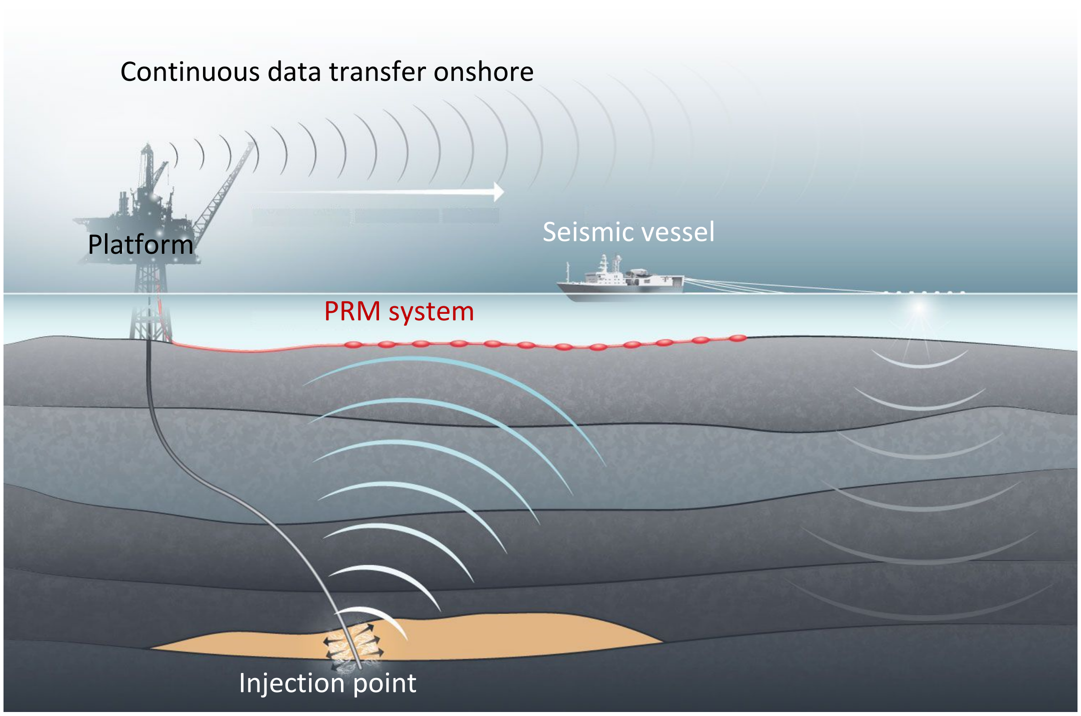

Figure 2. *Sketch of the PRM concept. The system connects to the platform through a fiber umbilical, and from here, the data is continosly transferred onshore in real time. The system records seismic energy in a very wide frequency band from sub-hertz and up to Nyquist, allowing for both active seismic campaigns, as well as passive listening for microseismic events. Furthermore, the design of the system makes it easily expandable, meaning that it is possible initially to install a very small array, for then later to expand it, if needed. (From Fayemendy, 2015).*

The data collected during the last 1.5 year serves as a solid foundation for proof of concept. We have collected many different seismic signals, and have characterized different passive energy sources from sub-hertz up to Nyquist frequency. The system is proven to perform well in the entire frequency domain, and we have observed a good response across the entire array below 0.1 Hz. During the summer 2014, data from an active seismic survey was collected, serving as the 4D baseline for the injection reservoir monitoring. The data holds excellent quality, and the survey was conducted with no equipment downtime.

In passive monitoring mode we have recorded several local and regional earthquakes (Bjerrum et al., 2015b). We have characterized the different noise sources recorded on the seismic array due to rig noise, both propagating along the seabed as Scholte waves and in the water column as water barren noise, as well as seismic interference and ocean loading, from ocean wave oscillation (Bjerrum et al., 2014). Furthermore, we have recorded several perforation shots, which were fired in the waste injection well, as well as in other wells in the field, although both depth and horizontal distance have exceeded the dimensions the system has been designed for. Furthermore, following an injection test, an induced microseismic event was detected at injection level (Bjerrum et al., 2015b; Lindgård et al., 2015; Matveeva et al., 2015).

Given the busy location in the North Sea, we have since start of data collection worked with removal of seismic noise in the data for signal enhancement. The noise sources in the area are varying with season, with summertime being very busy with seismic surveys on close lying fields, while wintertime is affected by the rougher weather, and larger ocean loading. Furthermore, the rig, being only 150 m away from the installed PRM system, poses a significant noise source, with water barren linear noise being the most significant noise signature in the collected data.

We have tested different filtering methods for removal of the seismic interference and successfully enhanced the signal to noise ratio, allowing for event detection (Bjerrum et al., 2015b; Lindgård et al., 2015; Matveeva et al., 2015).

Discussion

For real time monitoring of cap rock integrity and reservoir processes, it is essential with a good system for event detection and predefined alarm values. We have developed a detection algorithm for real-time scanning of the passive seismic data, such that actions with regard to production or injection strategy can be taken when fracking of the cap rock is observed. Such a system is dependent on a good signal to noise ratio, and automatic noise removal is required before the data is scanned for microseismic events.

In Figure 3 we have sketched how such a real-time alarm concept is thought. With the baseline survey as input, together with well pressure data and the passive microseismic data, the monitoring of microseismic events and their correlation with well activities is possible. Injection processes is expected to induce microseismic events, due to the stress changes in the subsurface. As occurrence of these events propagates away from the well and towards the surface, different alarm levels are reached. If a critical level, as e.g. the shallowest barrier is reached the appropriate actions are initiated, such that surface leaks are avoided.

Collecting several types of data, and co-visualize these allows for co-interpretation of the different information (**Feil! Fant ikke referansekilden.**). The visualization, integration and co-interpretation of data from different sets of seismic and non-seismic measurements, possibly connected to the PRM system through third party sensors, is important in order to obtain a better understanding of the sub-surface processes. It is crucial

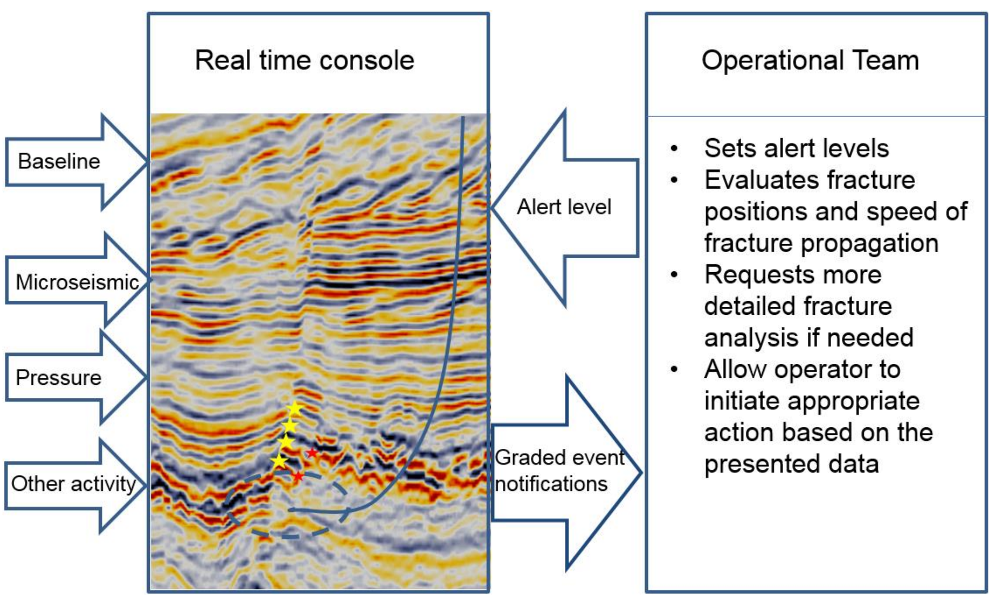

Figure 3. *Sketch of real-time alarm concept. By monitoring and comparing well pressure data, microseismic data, the detection of events can be correlated with well and/or reservoir activities. As the induced microseismic events propagates towards surface, different alarm levels are reached, and when critical levels are reached, the appropriate actions are initiated, in order to avoid surface leakages.*

that the data types can be visually integrated and analyzed in a way that provides both time-critical high level decision support (e.g. early-warning alarms), as well as detailed data drill-down for scientific analysis.

Conclusions

- Installation of PRM systems offers increased surveillance and safety through both active and passive monitoring. Further, by utilizing the ambient seismic noise recorded on such a system for characterizing the shallow overburden and changes herein, offers the field asset team new and more complete information, needed to insure better-founded management decisions and reduce the operational risks.
- Using induced microseismic events to follow the injection and/or production, offers a solution with timely reaction time to change the field operation strategy.
- A flexible PRM system should offer easy system expansion as well as connection of multiple sensor types, as e.g. biological and chemical sensors, measuring the change in the chemical composition of the water column, through the incorporated Ethernet on the seabed.

Acknowledgments

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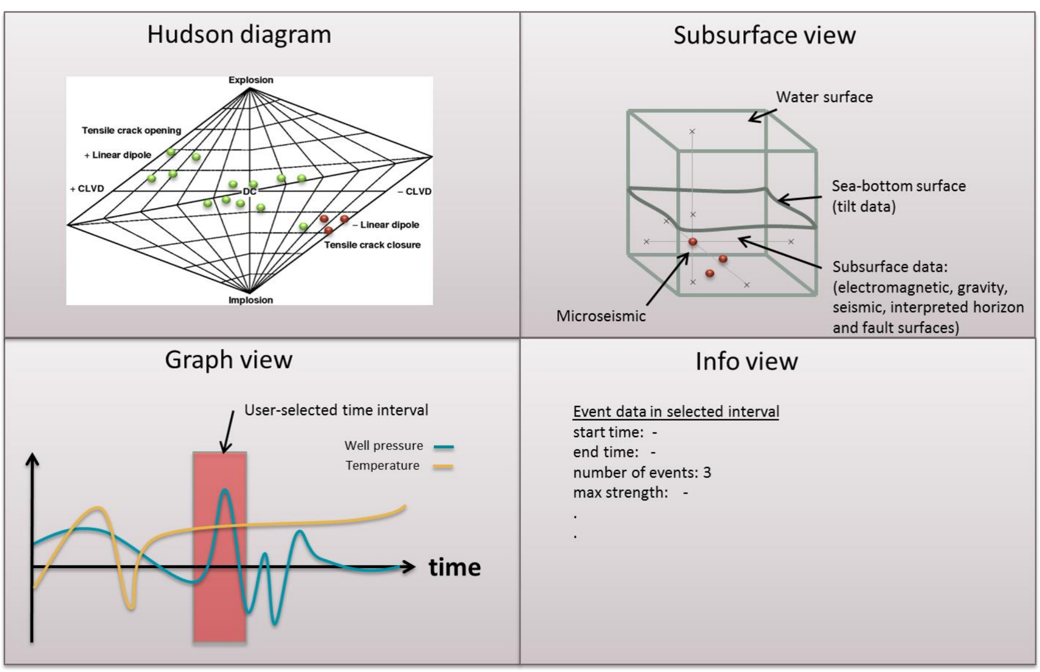

Figure 4. *Sketch of software concept for data co-visualization and interpretation. The four data windows are synchronized. Events inside time window are displayed in red both on the Hudson diagram and in the subsurface view. Any window can be maximized for more in depth analysis (from CMR).*

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