A low frequency, passive seismic experiment over a carbonate reservoir in Abu Dhabi

Mohammed Y. Ali,[1]* Karl A. Berteussen,[1] James Small,[1] and Braham Barkat[1]

A low frequency passive seismic experiment was conducted over an onshore carbonate oilfield in Abu Dhabi in an effort to confirm and understand the origins of a low frequency signal that has been observed above several hydrocarbon reservoirs in the area. While the analyses of the data are still on-going the preliminary results of the experiment have confirmed the existence of a narrow band of low frequency (2.5-2.8 Hz) signals over the oil reservoir zone; however, this analysis has found that these signals are also detected over the water saturated zone. More studies will need to be conducted to fully investigate the particle motion of these waves, their apparent velocities, and the azimuth of their wave fronts.

Background

For the past several years a narrow band of low frequency (1.5 – 4 Hz) signals have been observed and reported over a number of hydrocarbon reservoirs mainly in the Middle East including some oilfields in Abu Dhabi (Dangel et al., 2003; Holzner et al., 2005). The observations suggest that the low frequency signature diminishes towards the rim of the reservoir and is absent above non-reservoir locations. It has been suggested that these signals are caused by non-linear behaviour of the interaction between liquid hydrocarbons, water, and the pore-rock materials in the reservoirs which distort the normal signature of the Earth's natural ambient vibration spectra.

The analyses of such low frequency data have previously been used as a direct hydrocarbon indicator for the optimization of well placement during exploration, appraisal, and production. However, the possible causes of this low frequency energy are not well understood and it has yet to be demonstrated what types of waves are being observed as well as the physical behaviour of the multiphase fluid system in the reservoir. Furthermore, to date most of these observations have only been based on the vertical component of the signal motion. As a result, this experiment aims to better understand the wave systems causing these observations by systematically mapping the temporal and spatial variations of the low frequency waves recorded. The results of this passive seismic experiment will help to determine the source of such low frequency energy and its possible application in the detection and monitoring of hydrocarbons in carbonate reservoirs.

The processing and modelling of the data from the experiment are still on-going; hence, the aim of this short paper is to present the preliminary results of the experiment.

Data acquisition

Survey area

The field is a NE-SW elongated, moderate relief anticlinal structure located onshore in the Abu Dhabi Emirate. The producing zones are all within the Lower Cretaceous Thamama Group which is characterised by trangressive and regressive carbonate cycles reflected by different depositional facies. This oilfield was selected as a suitable site for the experiment because it has a clear and well-defined oil-water contact (OWC) according to geoscientists currently working on the field.

Acquisition procedures

The experiment was carried out in May and June of 2007 and included the acquisition of 480 measurements of typically 24 hour length covering an area of approximately 33 km^2. The signals were recorded using 6 ultra sensitive three-component seismometers (Guralp CMG-6TD) with frequency response of 0.03 Hz to 50 Hz, and sensitivity of 2000 V/m/s.

The survey consisted of a 2D profile running from Well 'W1' (near location A) to location B, and also included detailed studies around both locations (Figure 1). Location A is situated over the maximum oil column (>120ft) of the reservoir, whereas location B was positioned over an area that presumably contained no oil. The OWC is located 2000 m from W1 along the profile and has been mapped using both 3D seismic and well data. The investigations conducted at locations W1 and B were designed to measure the apparent velocity, azimuth, and particle motion of the waves. The 2D seismic array was intended to connect the two sites in addition to revealing the particle motion of the waves.

One of the seismometers was placed in the immediate vicinity of well W1 where it was left to continually record throughout the entire survey. All others seismometers were left collecting data at each location for a minimum of 24 hours. Stations were individually located using a combi-

[1] *The Petroleum Institute, P.O. Box 2533, Abu Dhabi, UAE.*
* *Corresponding author, email: mali@pi.ac.ae.*

nation of both handheld GPS, and compass and measuring wheel. The seismometers were placed on concrete slabs for firm ground contact in pits of approximately 1 m diameter and 50 cm depth and then covered and buried to reduce ambient noise from surface sources.

Recordings of arrivals from two significant earthquake events in China and Guatemala during the survey confirmed the accuracy of timing, alignment, and phase of each of the instruments and their individual sensors.

The preliminary results being analyzed and presented here are from seismometers that were recording at location A (over the oil reservoir) and location B (assumed to be over the water column) for 60 minute periods from midday (12:00) and midnight (24:00) local time.

Data processing

Various signal analysis techniques were applied to the data in order to investigate the nature of the low frequency signal. These techniques included time series, power spectral density, and time frequency analyses.

Figures 2 and 3 show the power spectral density of the sensors located at A and B from all three wave field components; vertical (v), north-south (n), and east-west (e). The power density spectrum has been calculated over 60 minutes of continuous recording data. These analyses permitted the discrimination of the low frequency signal from low amplitude artificial noise sources. The Time frequency displays were generated and used to detect the presence, or absence, of the narrowband low frequency signal.

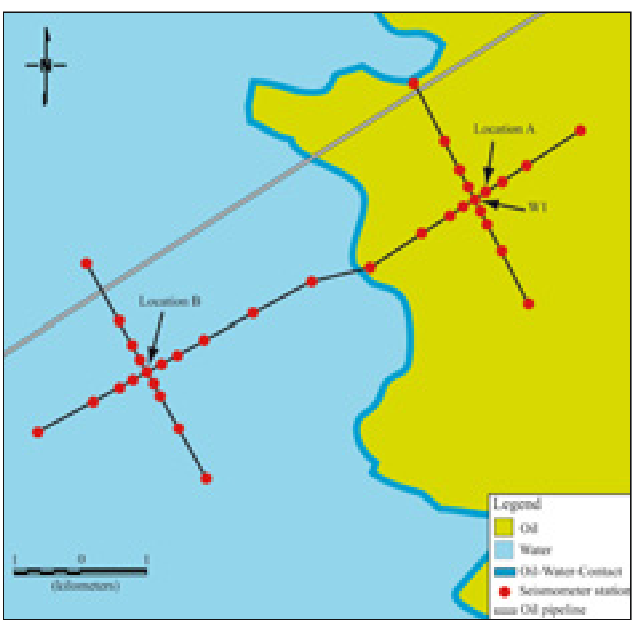

Figure 1 *Location map of the oilfield showing oil saturated reservoir, water saturated area, oil-water contact, locations of the seismometers, and an oil pipeline that runs to the north of the field. W1 indicates the position of a suspended well, and locations A and B are the sites of the seismometers discussed in the text.*

Preliminary data interpretation

Observations from the analyses of the seismometer data obtained at locations A and B (Figures 2 and 3) reveal the following:

- A narrow band of low frequency (2.5 – 2.8 Hz) signals were observed over both the oil reservoir (location A) and the water saturated zone (location B). The low frequency signal observed above the water saturated zone is interpreted as being due either to deeper reservoirs (e.g., from the Arab

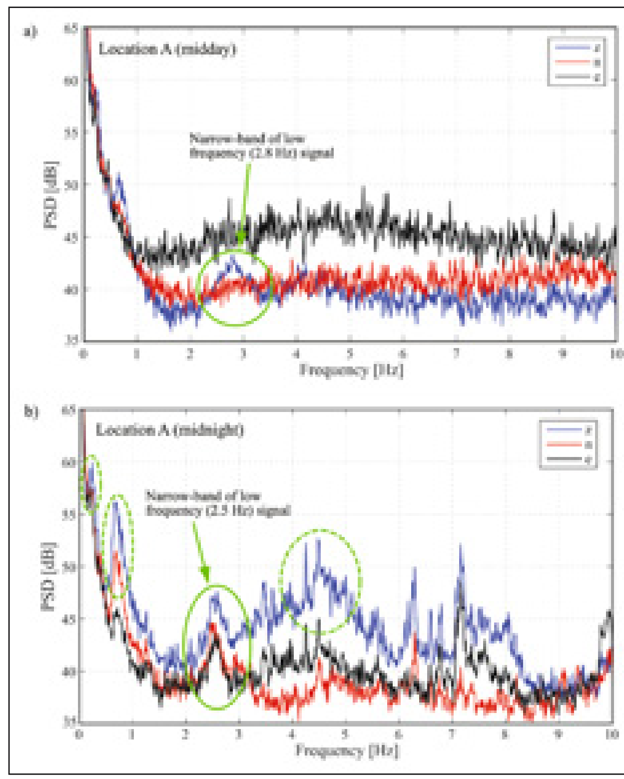

Figure 2 *a) A comparison of power spectral density (PSD) data recorded from individual sensor components over a 60 minute interval at midday from location A. The sampling rate is 200 Hz. The data recorded from individual sensors are displayed in different colours. (b) A comparison of power spectral density (PSD) data recorded from individual sensor components over a 60 minute interval at midnight from location A. A narrow band of low frequency (2.5-2.8 Hz) signals is observed. The vertical component has higher PSD during the night compared with that observed at midday. During the night the low frequency signals are observed in all components (vertical, north-south and east-west), whereas during the day time recording period only the vertical sensor shows the low frequency signal. Solid ellipses indicate the narrowband low frequencies observed. The dashed ellipses indicate other anomalous signals observed.*

formations) which may possibly occur below the water saturated zones, or, if the emitted signal itself were not actually a pure P-wave but rather a combination of P-, S-, and surface waves.

- During the midday period it appeared that only the vertical sensor (z) had recorded the low frequency signal, whereas all three sensors (vertical, north-south, and east-west) had detected it over night. The causes for this variation in signal character between midday and midnight at the same location are still unclear and will require further study. One explanation could be that the low frequency signal includes S-wave and/or surface wave components resulting in the observed responses from the non-vertical sensors. Also, higher noise during the midday recording period, particularly in the east-west (e) wave field component could be masking the signal.
- The dominant peak of the low frequency signal recorded during the midday period was ~2.8 Hz, whereas 12 hours later the peak had shifted to a slightly lower frequency of ~2.5 Hz.
- There is a considerable increase of spectral power density of the data from the vertical sensor collected during the midnight period compared with that recorded at midday suggesting that there was more activity during the night. We suspect that this may be due to noise from the nearby oil pipeline.
- The signature of the signals from the vertical sensor collected during midday at locations A and B are exactly the same for frequencies below 6 Hz, suggesting that they originate from the same source. However, this is not the case in the vertical component spectra collected at midnight which shows a considerable variation in character between the sites. In addition, several other signals with both low and high frequency content are observed over night.
- Strong low frequency narrow bands (~0.2 Hz and ~0.7 Hz) are observed in all sensors at both locations. This effect could possibly be caused by noise radiating from ocean waves which emit their maximal energy around 0.2 Hz (Aki and Richards, 1980). The frequencies of approximately 0.7 Hz are possibly due to waves emitted along coastal areas due to the interaction between sea waves and the coast or variations in meteorological conditions such as wind speed (Cara et al., 2003).

Conclusions

The experiment has provided key information that is needed to better understand the low frequency signal that has been reportedly observed over several hydrocarbon reservoirs in the area.

Preliminary results indicate that a narrow-band of low frequency signal is present above the hydrocarbon reservoir as previously claimed, but that this signal is also observed over nearby non-reservoir locations. Variations in the character of the signals recorded 12 hours apart during midday and midnight periods were observed but not fully understood. More analyses are underway to better understand the wave system causing these observed effects by mapping the temporal and spatial variations of all wavefield components. In addition, further experiments are planned.

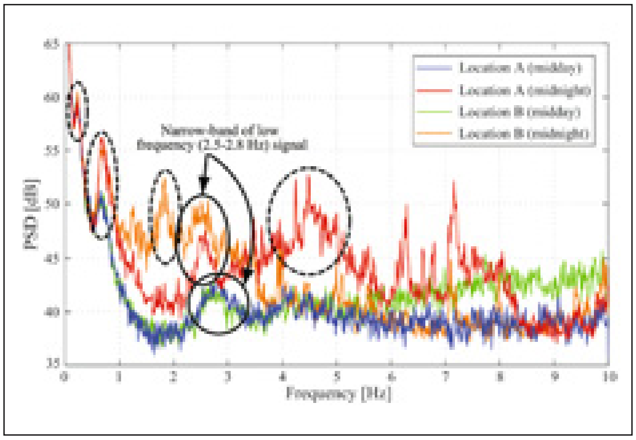

Figure 3 *Comparison of the spectral signature of the vertical sensors for 60 minute recording intervals measured at location A (above oil reservoir) and location B (outside the reservoir) during midday and midnight periods. Solid ellipses indicate the narrow low frequencies observed at locations A and B although the maximum peak of the signal slightly varies between the midday and midnight periods. The dashed ellipses indicate other anomalous signals observed.*

Acknowledgements

We are grateful to the Oil-Subcommittee of the Abu Dhabi National Oil Company (ADNOC) and its operating companies (OpCos) for sponsoring this project. We thank Mr. Marwan Haggag for his logistical support of the fieldwork and in coordinating the project. Seismometers were hired from SEIS-UK.

References

Aki, K., Richards, P.G. [1980] Quantitative seismology: Theory and methods. Freeman.

Cara, F., Giulio, G.D. and Rovelli, A. [2003] A study on seismic noise variation at Colfiorito, Central Italy: Implications for the use of H/V spectral ratios. *Geophysical Research Letters*, **30** (18), 10.1029/2003GL017807.

Dangel, S., Schaepman, M.E., Stoll, E.P., Carniel, R., Barzandji, O., Rode, E.D. and Singer, J.M. [2003] Phenomenology of tremor-like signals observed over hydrocarbon reservoirs. *Journal of Volcanology and Geothermal Research*, **128**, 135-158.

Holzner, R., Eschle, P., Zurcher, H., Lambert, M., Graf, R., Dangel, S., and Meier, P.F. [2005] Applying microtremor analysis to identify hydrocarbon reservoirs. *First Break*, **23**, 41-46.