Low frequency seismic
A new tool for exploration and development

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One of the most exciting developments in recent times for hydrocarbon exploration is the advances in Low Frequency Seismic as a tool for hydrocarbon detection. Spectraseis, in collaboration with the Swiss Federal Institute of Technology (ETH Zurich), is leading the industry's biggest research program focused on the theory, methods and applications of low frequency spectral analysis

One of the most exciting developments in recent times for hydrocarbon exploration is the advances in Low Frequency (LF) Seismic as a tool for hydrocarbon detection.

This technology involves the spectral analysis of the ambient seismic wavefield between 0.1 and 6 Hz to extract hydrocarbon reservoir related anomalies. The method uses highly sensitive broadband seismometers – of the type used for earthquake monitoring – to directly record the earth's ambient wavefield down to below 0.1 Hz. The sensors are chosen for their frequency range, low noise floor, and sensitivity. Each recording station consists of a three component broadband seismometer, battery pack, a GPS unit and hand-held controller.

The recorded LF data is analyzed to study amplitude variations or anomalies in the low frequency band range (<10 Hz). Low Frequency hydrocarbon-related spectral anomalies are an observed phenomenon and reported in the literature by Spectraseis and others. Empirical observations suggest that multiphase fluids in hydrocarbon reservoirs redirect energy from the earth's ambient wavefield to cause small energy anomalies as recorded at the surface.

Current hypotheses state that these anomalies may be directly related to the fluids inside the reservoir structure. A preliminary model has been hypothesized to explain the potential source mechanism of the microtremors generating the spectral anomalies. Poroelastic effects, due to wave induced fluid flow and oscillations of different fluid phases, are significant processes in the low frequency range that can modify earth's seismic background wavefield. The assumption here is that hydrocarbon reservoirs are partially saturated while the surrounding rocks are fully saturated (Saenger, 2009).

The Benefits of LF Seismic

A growing number of surveys over different oil and gas ûelds in different parts of the world have established the presence of spectral anomalies in the earth's ambient seismic waveûeld - microtremors - with a high degree of correlation to the location of hydrocarbon reservoirs. A comparison of the different measurements taken around the world show consistency in their presence, though there is variability in detail.

If these microtremors originate from the reservoirs, then the analysis of the anomalies can be used together with other available geophysical data for optimizing well locations during exploration, appraisal, or field extensions, effectively using it for prospect ranking and derisking. The anomaly maps may also be used in frontier exploration settings to detect and rank high hydrocarbon bearing zones, allowing more targeted use of conventional seismic methods.

The use of the earth's ambient wavefield to extract the hydrocarbon related anomalies also carries a low HSE risk. There is no need for external sources, such as explosives or vibrators, nor large infrastructure, such as cables and transportation. Due to larger spacing between sensors and the compact equipment, smaller crews can be used to rapidly survey potential leads within a large concession. Such light equipment and low manpower requirements can be equally valuable in remote and environmentally sensitive areas, where costs and safety risks escalate rapidly. In addition, the lower cost and logistical ease in acquiring LF seismic versus traditional seismic, can be particularly valuable for operators who are focusing on fields that are close to populated areas. Protected areas such as national forests and desert parks which are off-limits to conventional seismic can now be explored with LF seismic as there is virtually no environmental footprint.

By integrating LF seismic results with other available subsurface data, companies can potentially better develop plays hampered by poor seismic imaging, and target stratigraphic traps that can be difficult to map with traditional seismic alone.

Low Frequency Attributes

The Low Frequency data recorded is however complex and often contaminated by anthropogenic noise. Other low frequency features can complicate the analysis.

To counteract this, Spectraseis uses several sophisticated in-house developed tools for noise removal or attenuation. These include the application of statistical spectral analysis to the data to determine the location of spectral anomalies and noise patterns in the low frequency band. Spectraseis has developed several spectral attributes to characterize the data. These attributes are computed once the noise removal process is completed.

The most commonly used spectral attributes are the PSD-IZ and the V/H attributes – both illustrated in figures 1 and 2 respectively. Since all components are recorded, polarization calculations for measured waves are also done. Several attributes may be calculated using the polarization analysis of the low frequency data.

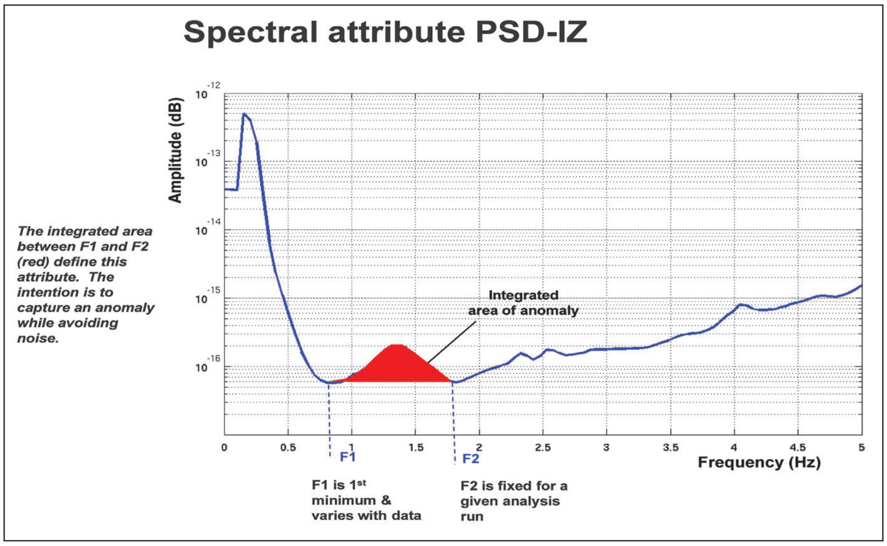

Figure 1

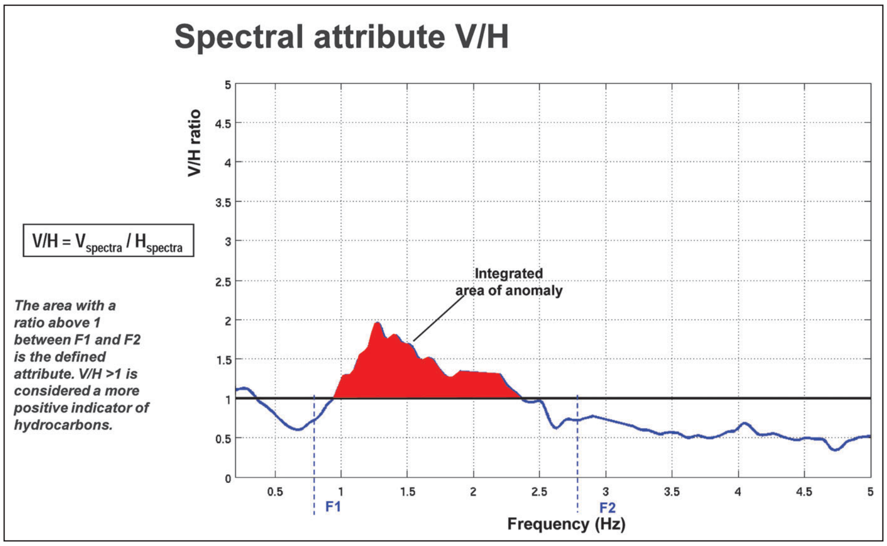

Figure 2

Processing Challenges

One of the primary challenges in analyzing low frequency seismic data is the separation of wavefield components that contain information about the subsurface, from surface-generated noise travelling predominantly as surface waves. Most of the seismic energy that is measured at the surface propagates in the form of surface waves.

The detrimental role of surface-generated noise in passive seismic surveys has been described recently (Hanssen, P., and S. Bussat, 2008, Pitfalls in the analysis of low frequency passive seismic data: First Break, 26, 111–119; Nguyen, Lambert et al EAGE 2009) and highlights the need for advanced acquisition and processing methods for low frequency seismic data.

These processing challenges are best described by a recent case of an onshore project in Europe. This project demonstrates how these advanced acquisition and processing methods can be successfully applied with little impact on local residents. The survey took place around a small city. The layout of the survey consisted of two lines (a southern and northern line) with 25 stations, spaced 300 meters apart, and a maximum line length of 7.5 kilometers. Each station was equipped for continuous passive seismic recording with a buried three-component broadband seismometer, a digitizer, and a GPS unit. An oil reservoir was located approximately in the middle of both lines near the city center.

The LF survey was recorded over a two day period over a known oil field in the region as a test of

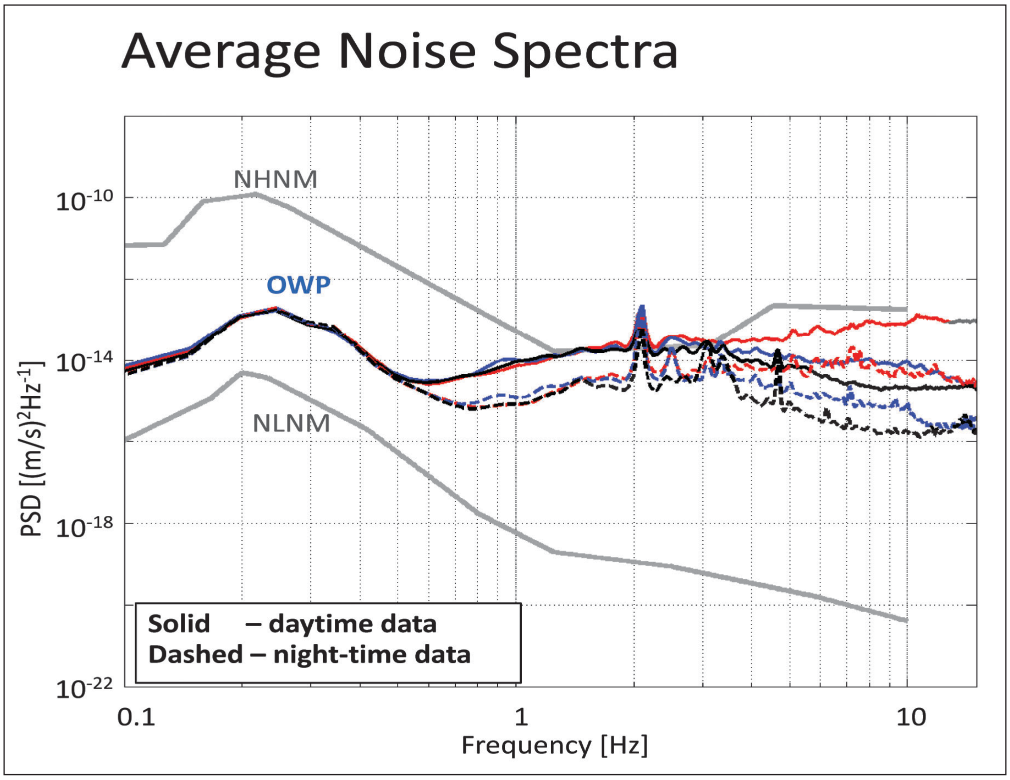

Figure 3

analysis, anthropogenic noise can generally be categorized as two source types: (i) broadband transient signals, created by traffic, fauna, explosions, or falling objects, and (ii) stationary sources of narrow bandwidth, created by machinery, running water, or the structural resonances of buildings or bridges. Spectraseis calculated spectrograms using 40 second time windows with a 20 second overlap. For each spectrum representing a 40 second period, the average power spectral density (PSD) was calculated over a specified frequency band.

For each frequency band, the power spectral densities of all periods were arranged in the histogram. Figure 4 (left) is a histogram of average spectral levels between 0.1 and 10 Hz showing a bimodal distribution caused by transient noise contamination with the higher mode attributed to time periods of transient noise contamination, and the

concept for expanded exploration and development use.

The survey included significant amounts of anthropogenic noise contamination. There was a highway with high traffic volumes, which the southern line ran across, and an industrial quarter, which the northern line ran though.

Figure 3 shows the: average daytime and nighttime noise spectra in the survey area in comparison to the New Global Noise Model. Machinery noise is noticeable at 2.083 Hz.

Intensive data analysis was required to identify and separate various types of anthropogenic noise from the records, in order to isolate the signals due to the uncontaminated seismic background wave field. For LF seismic signal

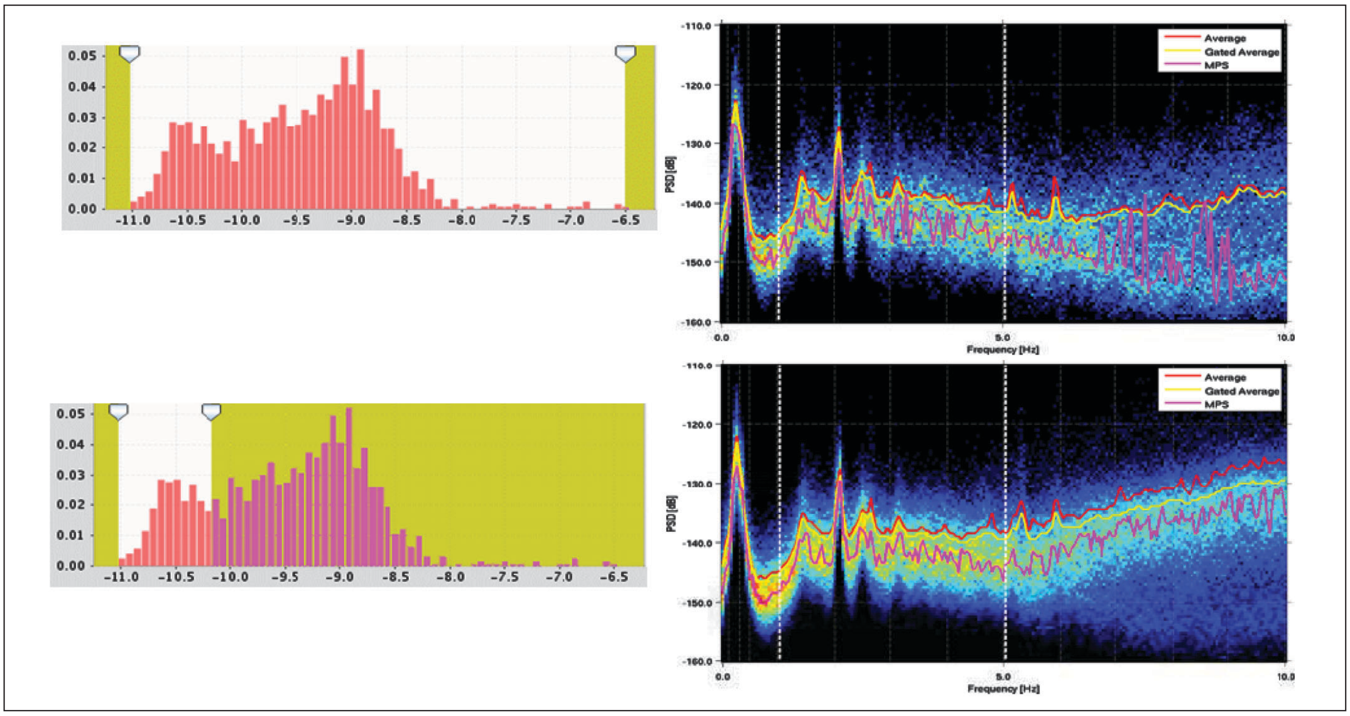

Figure 4

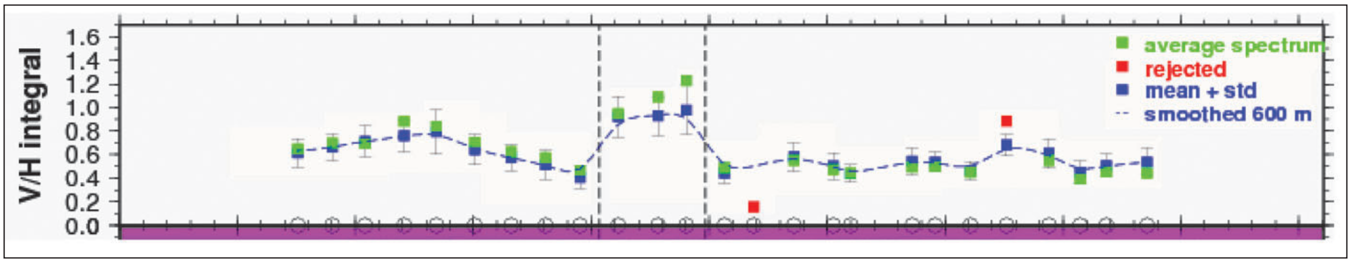

Figure 5

lower mode representing the desired, uncontaminated background.

After data conditioning (bottom right), the variance is reduced and the stationary background noise emerges as the lower end member of the spectral variance. Colors denote frequency of occurrence of the respective PSD level.

For quality control, the spectral variance was examined over a selected time period. An overall reduction in spectral variance was observed and convergence was obtained for the average to the lower level in the histogram, which represented the natural background level, plus stationary noise. In addition, stationary noise manifesting as narrow band peaks were removed with a frequency-domain despiking algorithm.

Two attributes were calculated from the clean, despiked data with transients removed. These attributes were used for the quantification of: (i) integration of the Power Spectral Density (PSD) spectrum of the vertical component, over a data driven frequency band, and (ii) integration of the spectral ratio of the vertical and horizontal components (called V/H). The V/H attribute is more robust with respect to transient noise contamination and was the attribute of choice for this survey due to the urban setting.

The Processing results

A statistically significant increase in the spectral ratio of V/H was observed between 1.5 and 3.5 Hz, over the reservoir. Because the lateral variation of attribute values in the anomalous region is larger than the standard deviation, it can be concluded that the observed anomaly is statistically significant. Furthermore, a check of the near surface statics revealed that the observed, anomalous V/H ratio could not be attributed to site effects or noise in the shallow subsurface.

Through a closer relationship with international operators through the Low Frequency Seismic Partnership, new innovations such as the noise removal techniques, developments in time reverse modeling (TRM) for depth imaging, and the capability to carry out surveys in environmentally sensitive locations, Low Frequency Passive Seismic has become and will continue to be a powerful and cost-effective, de-risking tool.

We therefore concluded that we were observing the surface expression of the modified background seismic wave field related to the target structure.

Ongoing Research

Spectraseis, in collaboration with the Swiss Federal Institute of Technology (ETH Zurich), is leading the industry's biggest research program focused on the theory, methods and applications of low frequency spectral analysis. In October this year, Spectraseis launched a Joint Industry Program for research in Low Frequency Seismic. The partners for this Low Frequency Seismic Partnership are Chevron, Cairn, ExxonMobil, GDF Suez and Pemex.

The program will cover key application elements of low frequency seismic technology, such as data acquisition and processing, as well as fundamental theoretical studies. Participants will be at the leading edge of the latest research on low frequency seismic applications and will learn how to extract the maximum value from this technology for their companies.

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ABOUT THE AUTHOR

Vinay Vaidya is Business Development Director for Spectraseis covering the MiddleEast and Asia region from Abu Dhabi. He has over 25 years experience providing Geophysical Services to the Oil and Gas Industry. He has worked in progressively senior roles in Australia, India, US, and South East Asia. His previous assignments included Integrated Services Director for Paradigm Asia Pacific and Asia-Pacific Manager for Rock Solid Images. He joined Spectraseis in June 2008. He has M.Eng.Sc (Petroleum Engineering) from University of New South Wales and MBA from Deakin University in Australia."