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Passive Broadband Seismometers Sample Natural Seismic Wave Field To Acquire Low-Frequency Data

The benefits of passive low-frequency seismic technology are compelling, with an increased probability of successfully defining hydrocarbon zones prior to embarking on a drilling program and supporting the economic development of reserves that were previously considered uneconomic because of a lack of good seismic data.

By Andrew Poon

SAN ANTONIO–There is no doubt that economically finding, developing and producing oil and gas reservoirs is becoming more challenging. New unconventional reserves in shale, tight sand and heavy oil formations are not following conventional well engineering practices or geoscience models. Drilling and producing sweet spots in the reservoir, which explains why some horizontal wells are successful while others are not, have become critical success factors.

At the same time, with new technologies available, most companies are able to produce conventional oil and gas economically. As a result, more and more companies are faced with the prospect of developing previously "unrecoverable" oil, necessitating investment decisions that assume the size of the prize. At the same time, new reservoir prospects are increasingly complex and inaccessible–ranging from environmentally sensitive areas to urban settings.

There is clearly a need for technologies that can be directly influenced by the reservoir fluids before committing to a full drilling program. With a measurement that is more indicative of the presence of moveable hydrocarbons, companies can improve the economics of their prospects and provide better "business cases" for their investments.

FIGURE 1

Typical Passive LF Sensor Package

One technology that addresses these challenges is passive low-frequency (LF) seismic, which uses broadband seismometers to directly sample the earth's low-frequency (<10 Hertz) natural seismic wave field. Figure 1 shows a typical passive LF sensor package. Cableless sensors record LF data over 24 hours per seismic line with a footprint of one square-foot per sensor without requiring an external source (dynamite or vibroseis).

The acquired data are processed and analyzed to study small lateral variations. Sufficient quantities of multiphase fluids in hydrocarbon reservoirs directly affect these small variations and generate anomalies in the earth's ambient seismic wave field, providing a direct indication of hydrocarbons.

The benefits of this technology to the operator are compelling because they increase the probability of success in defining hydrocarbon zones prior to embarking on a drilling program. LF passive seismic also helps support the economic development and production of reserves that were previously considered uneconomic because of a lack of good seismic data, which results in not being able to justify investing in prospects with poor physical accessibility, unknown field size and geological complexity.

Benefitting Independents

So how can LF seismic technology benefit U.S. independent oil and gas producers in their exploration and development operations? One of the key challenges that U.S. independents face is making potential onshore prospects economically viable.

This has become particularly important since, as the Independent Petroleum Association of America notes, the past few years have seen U.S. independents become increasingly focused on domestic onshore production operations–no surprise considering the growth in unconventional resource plays. According to a survey by IPAA, more than 43 percent of independents now hold federal or Indian lease acreage onshore.

LF passive seismic can be a key enabling technology in opening new prospects and exploration areas, as well as revitalizing mature areas. For example, California is a state where the reserves remaining in many fields are considered too small for economic development by majors. However, if the residual reserves are better defined, they may prove more economic for independents and justify the investments required to re-enter those fields. Some of the fields are unpredictable in terms of production, and many are located close to urban areas and national parks, where traditional cabled seismic techniques with vibration sources are unsuitable, but where LF passive seismic with cableless sensors is a viable option.

There are numerous other "small field" examples, such as fields in eastern Tennessee, where Cheyenne Resources Corp. is making inroads using passive LF seismic, as well as onshore fields in Louisiana, Illinois, Ohio, Texas, Arkansas, Alaska and elsewhere. With small potential finds, managing exploration costs is vital.

In addition, the growth in unconventional resources has brought exploration and development close to urban areas. In the Barnett Shale, for instance, horizontal drilling technology is allowing wells to be drilled under the Dallas-Fort Worth Airport and on the campus of Texas Christian University. Drilling is also taking place in urban areas in the Haynesville Shale play in Louisiana and the Marcellus Shale in Pennsylvania. Even in states such as Ohio, where shale and tight sand plays have not been major drivers in drilling activity, 23 percent of all wells drilled since 2004 have been in urban areas.

Since LF seismic responds to quantities of moveable, multiphase fluids in the reservoir, it can be used as a positive indicator of potential sweet spots or pockets of gas in an otherwise nonporous matrix.

To this end, the relatively low cost and environmentally friendly ease of acquiring LF data can be particularly valuable for operators. With a reduction in manpower, and the ability to better manage risk and improve the value of conventional data, there are potential savings and efficiencies to be had.

In addition, LF passive seismic has a very light environmental footprint with no need for external sources or large infrastructure such as cables and transportation. LF passive seismic can cover 400-500 square kilometers in less than 30 days and provide an analysis of the data for interpretation within 90 days of acquisition. Figure 2 outlines a typical example survey design for a prospect ranking application. In this particular case, the layout covers 310 kilometers with 40 sensors acquiring the data over 8-10 days.

Finally, LF seismic data reduces the direct costs, and health, safety and environmental risks of expensive dry holes. According to IPAA data, out of 5,624 exploratory wells drilled in 2008, 1,786 (32 percent) were dry. LF seismic can help reduce this percentage of unsuccessful wells.

Eliminating Noise

One of the primary challenges for LF

passive seismic–particularly in busy urban settings–is noise. One reason why LF seismic is affected by fluid in the reservoir, as opposed to the reservoir matrix, is because of the relatively low signal from the earth's natural wave field. On the other hand, because the anomalies being detected are low in amplitude, it is critical to eliminate as much contaminating, human-generated noise as possible. This is an area in which technology advances are achieving positive results.

First, software has an important role to play in capturing as much information as possible on the surroundings in a low signal-to-noise environment. Measurement dates and times must all be taken into account, since noise such as traffic and industrial activity can vary during the day and the week.

With this in mind, field crews can be equipped with controllers that have built in GPS receivers (Figure 3). The field data are characterized according to variables such as time, stability, noise and weather influences. Unwanted noise is then removed by "marking" unwanted time windows in the data signals. The data analyst views both the raw signal in the time domain as well as in a spectrogram, where the frequency components of the signal can be viewed in relation to time.

A data analyst then plots multiple spectrograms that represent data recorded during the same time window, and identifies specific measurement windows to analyze over a geographic area. This makes it possible to do further analysis on these synchronous measurements and create 2-D attribute profiles or grid maps of LF attributes.

Urban Survey

A LF passive seismic survey was acquired over an oil field in Germany with results that could be of interest to U.S. companies with operations in urban areas or areas with high rates of background noise. The survey is a good example of how one can acquire exploration data accurately in and around populated areas with little impact on local residents, and where human noise can be mitigated by specialized tools and workflows.

The survey took place around a city with a population of 50,000. 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. The survey's objective was to test LF passive seismic over an oil reservoir located near the city's center.

Being a relatively populated area, there was significant potential for anthropogenic (human-generated) noise contamination. There was a highway with high traffic volumes, which the southern line crossed, and an industrial quarter, which the northern line ran though.

Careful data analysis was required to identify and separate the two types of anthropogenic noise: broadband transient signals created by traffic, for example, and stationary sources of narrow bandwidth created by such sources as machinery or running water. Spikes from machinery were removed along with remaining transient noise using automated and statistically-based algorithms.

Spectrograms using 40-second time windows with a 20-second overlap were

FIGURE 2

Sample Survey Design (Prospect Ranking Application)

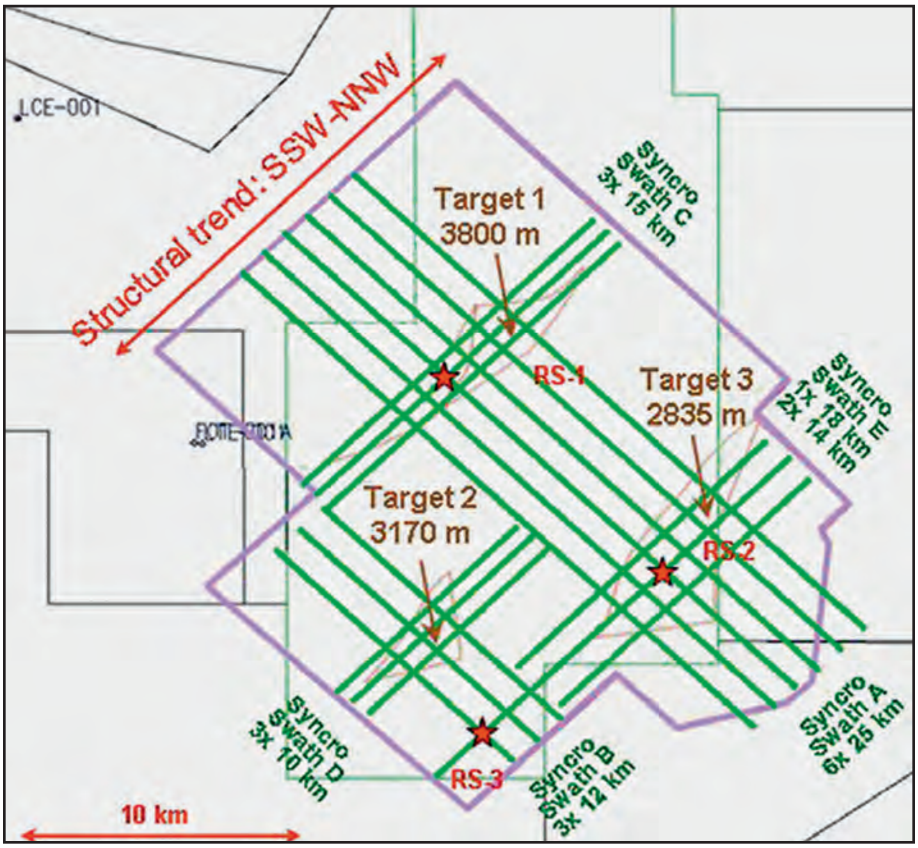
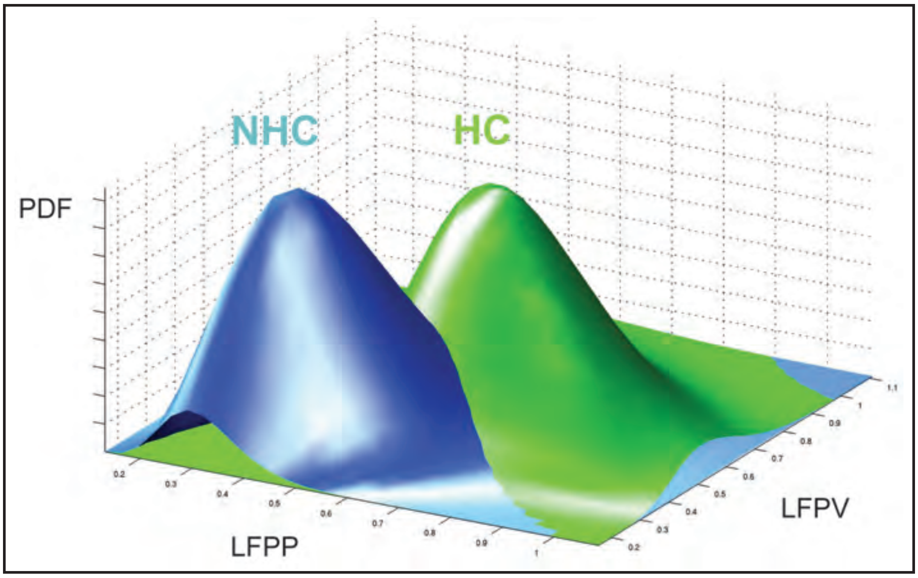


FIGURE 3

Controller with Built-In GPS Receiver

FIGURE 4

Hydrocarbon Likelihood (Texas Field)



acquired. For each spectrum representing a 40-second period, the average power spectral density was calculated over a specified frequency band. Two attributes were calculated from the clean data and used for quantification: an integration of the power spectral density spectrum of the vertical component over a data-driven frequency band, and an integration of the spectral ratio between vertical and horizontal components (V/H). The V/H attribute is more robust with respect to transient noise contamination and was the attribute of choice for this survey because of the urban setting.

A statistically significant increase in the spectral ratio of V/H (between 1.5 and 3.5 Hertz) was observed over the reservoir over a night-time window. 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.

The results confirmed the potential of LF seismic to the client in conventional oil reservoirs, and demonstrated that anthropogenic noise can be identified and filtered out to ensure that accurate exploration data are recorded.

New Statistical Methods

New statistical methods also are being introduced into LF seismic with valuable applications for U.S.-based independents. One such example is the Bayes methodology, a statistical inference in which evidence or observations are used to update or infer the probability that a hypothesis may be true. In LF surveys, Bayesian methodology captures basic empirical relationships between recorded LF data and the subsurface properties, represented as statistical probability distributions, accounting for both uncertainty and variability.

Figure 4 outlines a LF survey conducted over a field in Texas to identify the most hydrocarbon-rich areas. As a first step, two small sets of receivers–representative of hydrocarbon (HC) and nonhydrocarbon (NHC) areas–were selected. The attributes of these sets were used to construct HC and NHC probability density functions (PDFs) over the multivariate attribute space (shown in green and blue, respectively).

The Bayes method then compares new LF seismic observations to the basic statistical relationships and decides what subsurface property best fits the empirical observations. Because of the statistical nature in the empirical models, this decision on what subsurface property is involved comes with a degree of confidence in the form of a probability of hydrocarbon content.

By comparing the survey attributes against these class PDFs, a subsequent HC probability is computed for each receiver. The results are HC probability maps that are easier to interpret and more accurate than previously produced hydrocarbon potential maps based on a single (average) attribute value.

The Bayesian DHI process has been tested based on two attributes (the strength and variability of the empirically observed hydrocarbon tremor) over four fields with known surface projection of the oil/water contact.

The process utilized median and standard deviation of the distribution in time of an LF energy attribute with the distribution median offering a more robust energy measurement compared with previous techniques that estimated energy based on one large time period. In addition, the multiattribute prediction process was shown to be superior to a deterministic predictor based on tremor energy alone. The process provided quantitative HC probability maps that were easy to interpret and could be used for risk analysis.

As experience with passive LF seismic grows, the technology continues to be developed and new advances are taking place in processing and subsurface characterization capabilities. Over the past three years, more than 30 LF surveys have been successfully completed for several companies around the world, demonstrating the applicability of LF in carbonates and sandstones for oil, gas and heavy oil reservoirs.

From frontier exploration to field extensions, and from prospect derisking to reservoir property mapping, there are significant and potentially highly beneficial LF passive seismic applications for U.S. independents. ❐

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