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Side View Seismic Locator (SVSL) - Micro Seismic Technology

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Summary

Side view Seismic locator (SVSL) is a micro-seismic technology based on the processing of SCATTERED (as opposed to the reflected) waves to determine zones of open fracturing in reservoirs and achieve the highest production rates and also to avoid drilling complications.

Keywords: SVSL - Side View Seismic Locator

Introduction

Micro-seismic technology designed to determine zones of abnormal or open fracturing. Its distinction is in the processing of scattered waves, as opposed to reflected seismic waves, traditionally processed by the industry. SVSL has an excellent track record predicting drilling locations with highest production rates as well as assisting in well design and avoiding drilling complications. It can work as a seismic reprocessing/interpretation technique or as a field seismic acquisition method.

Theory and/or Method

Essentially new to western companies, SVSL is a method of seismic exploration which is designed to study fracturing and, in particular, open fracturing (instances where spaces in the fractured rock are not filled with rock material). The developers of SVSL observed over many studies that open fracturing is generally associated with better hc production. Moreover, it has been found that the greater the degree of open fracturing, the higher the hc production. By identifying zones of abnormal open fracturing, SVSL determines and ranks those drilling locations with the highest potential production rates.

Conventional seismic exploration methods rely primarily on the use of typical reflected waves. In contrast, SVSL uses the analysis of scattered waves, reflected waves which are

characterized by much shorter wavelengths and much lower energy. Reflected waves can be segregated into several types.

Depending on the relation between the length of the elastic wave λ and the size of the rock heterogeneity L , one of the three types of seismic waves is generated in the course of reflection:

1. At $\lambda \ll L$ mirror-reflected waves (seismic waves);
2. At $\lambda \approx L$ scattered waves of the resonance type (diffracted waves);
3. At $\lambda \gg L$ scattered waves of Rayley type (scattered seismic waves).

In geological formations, various seismic waves are generated by the predominating heterogeneities in the target area:

- a. Reflected waves are formed due to the boundaries of lithofacies;
- b. Diffracted waves are formed due to extended dislocations of bedding;
- c. Scattered waves are formed due to ensembles of open fractures.

Each of these waves has specific dynamic and kinematic parameters which are considered during observation and processing. Using this information, Terra in turn can efficiently identify these waves in the observed seismic wave field. Scattered seismic waves are different from



reflected waves in two primary ways:

- The dynamic attribute – their amplitude is 10-100 times less as compared to reflected waves;
- The kinematic attribute – the wave front (travel time curve) relates to the type of the point source.

The acoustic impedance of an open fracture is of an order higher than that of other subsurface geological features. Therefore, scattered waves provide specific information pertaining to open fracturing.

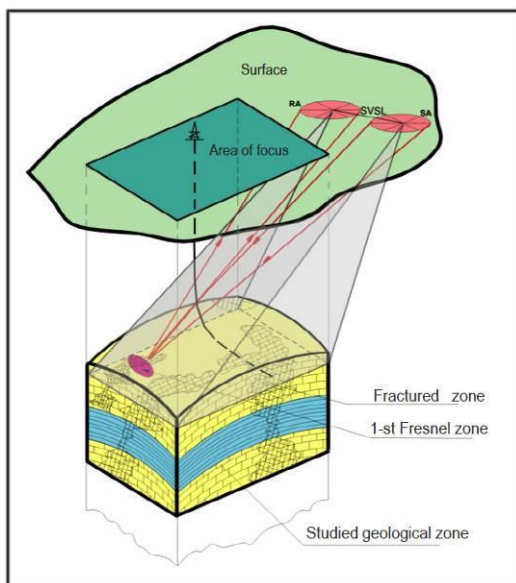


Figure 1: Schematic of the SVSL schematic layout. RA – receiver aperture, SA – source aperture, source of energy

SVSL's identification of scattered seismic waves is based on the principle of the Side-View Seismic Locator which is widely used in radar systems (aircrafts and satellites), sonar systems (vessels and submarines), and experimental physics to identify particles whose size is much less than the wavelength of irradiating field.

The intensity of open fracturing is an integrated (combined) parameter characterizing the quantity (density), length, and width of fractures. The geological interpretation of SVSL results is based on the tectono-physical models describing the regularities of fracturing distribution in geological formations depending on its stress-deformed state. Basic tectono-physical models used by SVSL are as follows:

Model 1. The fracturing field varies depending on the magnitude and orientation of the normal stress vectors.

Model 2. The fracturing field appears in an anticlinal fold formed by vertical tectonic stress acting from beneath (the uplifting of an underlying block).

Model 3. The fracturing field appears in an anticlinal fold formed by a horizontal stress (side thrust fold).

Tectono-physical Model 1 (Figure 2): The distribution and orientation of fracturing (lines and dotted lines in squares) that is created by the different types and combinations of dynamic forces (arrows) is shown.

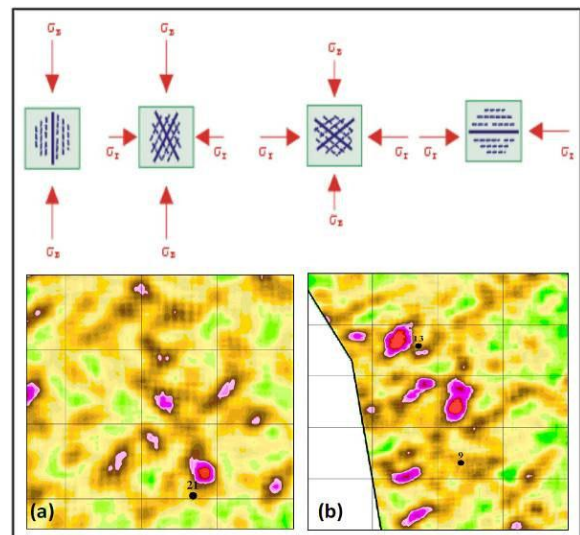


Figure 2: Tectono-physical model 1: an example that illustrates the similarity of tectono-physical Model 1 that is evidenced by the SVSL fracturing distribution on the horizontal SVSL sections. Middle Makarikha O&G field, Komi Republic of Russia: (a) orthogonal fracturing system; (b) unidirectional fracturing system

Tectono-physical Model 2 (Figure 3): Concentric type of the fracturing distribution caused by tectonic uplift.

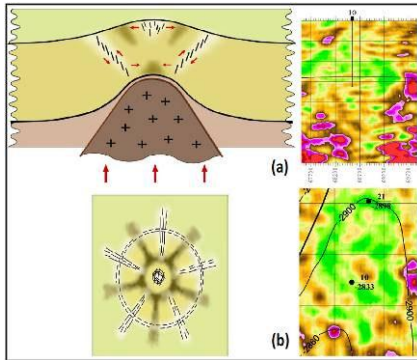


Figure 3: Tectono-physical model 2; field example: (a) horizontal section; (b) vertical section

Tectono-physical Model 3: the distribution of fracturing in the anticlinal side thrust fold and a field example illustrating same are shown below in figure 4.

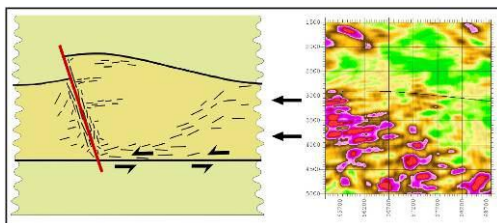


Figure 4: Tectono-physical Model 3. An example illustrating the similarity of Model 3 and SVSL fracturing distribution.

Another demonstration of the results produced by SVSL data is provided below (Figure 5). Studying field data and open fracturing, SVSL identified the correlation between the azimuthal orientation of open fractures and Formation Micro Scanner (FMS) well logging data (Orenburg oil and gas field).

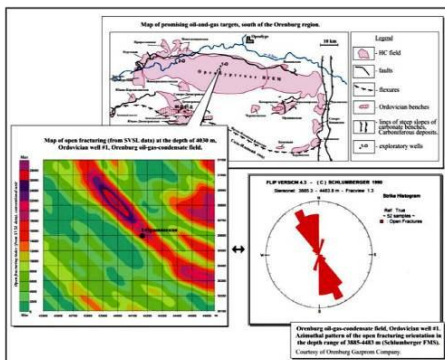


Figure 5: Correlation between the azimuthal orientation of open fractures and Formation Micro Scanner (FMS) well logging data

Exploring with SVSL

When incorporating SVSL in an exploration project, Terra can either reprocess existing seismic data or acquire seismic directly in the field. The following will describe the general method, process and results of the respective data sources.

Reprocessing of Existing Seismic Data

In the case of reprocessing existing seismic data, SVSL supplements the conventional analysis/interpretation of subsurface structures with a map showing zones of abnormal open fracturing.

The SVSL reprocessing technique superimposes conventionally acquired and processed structure data (deformation) over the target's distribution of open fracturing. Hence, a more informative subsurface rendering is produced that uses both common reflected and scattered waves (Figure 5, Figure 6, and Figure 7). Typical time required for the reprocessing of 2D/3D seismic data is 45-60 days from the date of seismic data delivery to the Terra SVSL processing center.

Data requirements:

1. 2D seismic data is to be in format SEG-Y;
2. The velocity prepared for pre-stack migration depth model and based on the results of 2D processing (seismic isolines and vertical seismic section), which are necessary for the combination of the presentations of SVSL and CMP cross sections;
3. More detailed requirements are provided at the time of engagement.

Results/Output of Seismic Data Reprocessing

Typical results of existing seismic data reprocessing via SVSL include:

- Vertical section(s) of the distribution of open fracturing of rocks along existing lines;
- Combined cross sections depicting common reflected and scattered seismic wave analysis;
- Geological interpretation(s), where applicable, recommendations, and final report;



- Conclusions often identify key drilling locations indicating the highest potential production based on the inferred higher permeability associated with zones of open fracturing.

A few examples of the 2D seismic data reprocessing results combined with existed seismic data are shown below (Figure 6 and Figure 7).

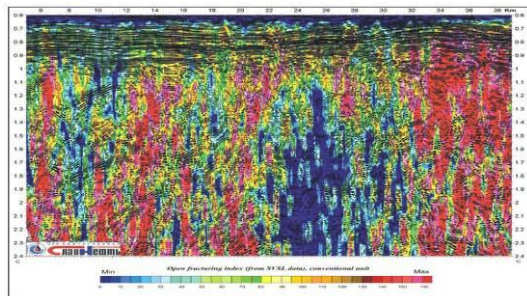


Figure 6: Combined representation of 2D CMP seismic data (reflected waves) and distribution of the energy of scattered waves by SVSL

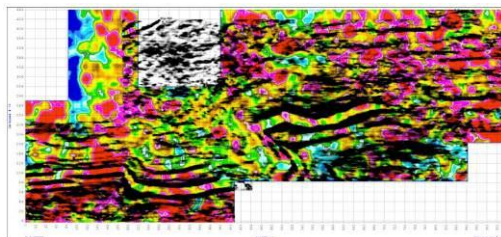


Figure 7: Combined representation of 3D seismic – amplitudes of reflected waves and distribution of the energy of scattered waves by SVSL

Real Time SVSL Field Seismic Data Acquisition Description

In cases where seismic data is not available, a similar map of zones of abnormal, open fracturing can be produced by directly acquiring seismic data in the field. Real time SVSL data acquisition and processing utilizes the same physical principals of the SVSL technology, as described above, except data is obtained via conventional seismic data acquisition with an energy source (standard seismic equipment and units are applied in the SVSL field observations).

SVSL technology has the following distinctions (original features) as compared to other seismic methods:

- Applying areal observation systems (source and receiver apertures) in the field survey;
- Original algorithms for identifying scattered waves (Focusing Transformation and Side-View Location) in data processing;
- Synchronous stacking of signals of scattered waves with the stacking fold of 104, suppression of reflected waves via special observation geometry called the Side-View Seismic Locator;
- Applying a new class of models (Tectono-physical models) in the geological interpretation;
- Observations are performed with the use of a specific pattern in the positioning of the source (SA) and receiver (RA) apertures, implementing the schematics of a “2-position SVSL locator”;
- To implement the side-view location method, the SAs and receiver RAs are positioned outside the target area;
- Sites of SA and RA installation are selected based on specific SVSL requirements and proprietary calculations. Terra is also mindful of minimizing ecological and agriculture impact, and considers the presence of restricted and inaccessible zones, amongst other factors. ;
- Distinct specifications of the apertures:
 - o number of source/receiver stations in each aperture is about 100;
 - o diameter of apertures ranges from 1.0 to 2.0 km.

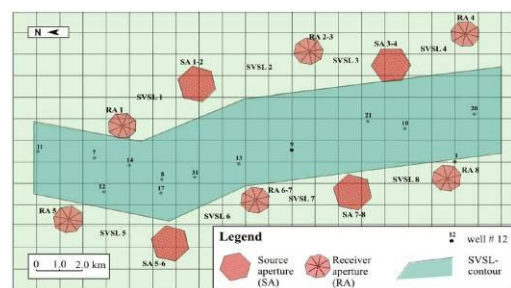


Figure 8: Typical layout of SVSL equipment for field data acquisition.

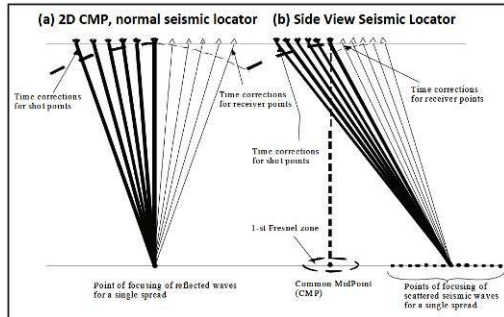


Figure 9: Fracturing study of geological formations in Middle Makarikha oil and gas field: (a) an example of the installation of SVSL source and receiver apertures; (b) comparison of CMP (reflected waves) and SVSL (scattered waves) observation schemes

The entire data acquisition process for SVSL typically takes only a few days (3 to 8 hours of active recording for the area of ~15 sq km), not including the mobilization and demobilization of the equipment, and geophysical human resources. The definitive size of a target exploration area and the target depth intervals are determined in face-to-face discussions with a respective operator's exploration manager.

Processing of SVSL Field Data

The following briefly describes the processing stage of SVSL technology, after the acquisition of scattered seismic wave data has been completed in the field.

- Hardware: Multiprocessor UNIX-servers and parallel data-processing PC-clusters.
- Software: Standard data processing procedures (filtration, introduction of corrections, etc.) are implemented with the use of workstation software such as Focus (Paradigm Geophysical), Geovector+ (CGG), etc.
- A series of correction coefficients is applied to consider the refraction of seismic waves in a layered medium.
- Scattered waves are identified in the seismic wave field using a proprietary 3D software module implementing the "Dual Conjugated Focusing of Emitted and Scattered Waves in the SA and RA."
- To better identify and determine the energy coefficient of scattered waves, the in-phase stacking of signals is performed with the stacking fold of

more than 104 in each point of a studied zone.

- Results of SVSL data processing are yield a 3D cube of the energy of scattered waves displayed as a series of vertical and horizontal sections of open fracturing intensity.

To identify scattered waves in the seismic wave field, innovative and proprietary data processing software is applied. This software is based on the "Dual conjugated focusing of emitted and scattered waves" both for source and receiver apertures (Figure 10).

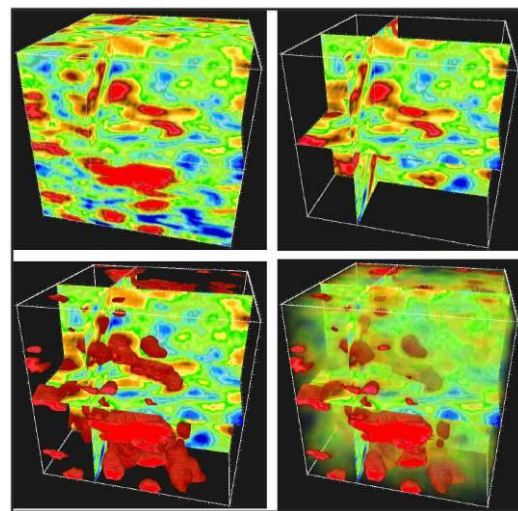


Figure 10: Example of SVSL 3D processing result. Cube of geo-medium shows zones of abnormal fracturing in red.

SVSL Results/output

The processing results and examples of the practical implementation of SVSL technology are demonstrated below.

As is typical in the development of any technology, SVSL passed through various stages of "tuning", design-shaping and testing in the course of many pilot and commercial projects. In many such cases, existing data related to open fracturing was already available and served as an important comparable during development. The types of previously existing field results include:

- Intervals, where drilling complications have occurred owing to an intense fracturing (mud loss, sticking of a drilling tool, etc.);



- Fractured intervals identified from well logging;
- Respective wells in producing oil fields, where the daily and cumulative oil production data was available.

Moreover, a number of studies were performed in order to experimentally check and verify the relationship between the energy of scattered seismic waves and the intensity of open fracturing in the respective subsurface zone. Over many years and after many field surveys, it was proved that the maximum production rate was generally achieved in zones with abnormally high fracturing. Moreover, production rates and longevity were even more impressive in those cases characterized by open fracturing with sub-vertical orientation and deep-seated “roots”. Such correlations were found in several locations including Western and Eastern Siberia, the Republic of Tatarstan, the Timan-Pechora province of Russia, North Caucasus, and Iran, to name a few. In those zones characterized by minimal fracturing in carbonate oil fields, most wells turn out to be “dry” (for instance, Caspian edge zone).

One of the examples of such pilot projects was a comparison of SVSL data and drilling data for a super deep well #20000 “Minnibaevskaya” in Romashkin oil field, Republic of Tatarstan (Russia), shown in Figure 11.

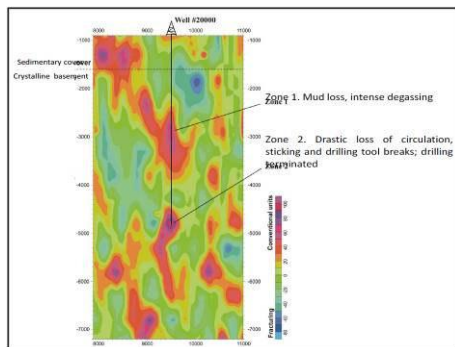


Figure 11: SVSL data on open fracturing perfectly matched drilling results in well #20000

Another typical result of the cube of 3D open fracturing distribution for the target area at a certain depth interval is shown below on Figure 12.

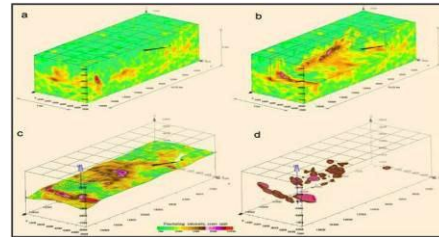


Figure 12: Example of SVSL output visualization of open fracturing distribution(a) open fracturing cube; (b) open fracturing cube and inside sections showing internal distribution of fracturing; (c) distribution of open fracturing for the target horizon; (d) distribution of abnormally high fractured zones

In addition, SVSL analysis reports often show a horizontal fracturing cross section within a pay horizon as well as vertical cross sections through a projected borehole. In addition, a diagram is supplied showing the variation of fracturing along the planned wellbore, which allows for selection of an optimal drilling plan and prediction of possible drilling complications (Figure 13).

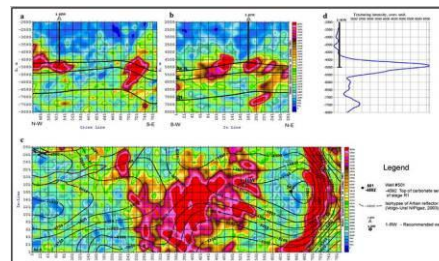


Figure 13: Recommendations for well 1-RW: (a, b) SVSL cross sections; (c) SVSL horizontal section; (d) diagram of open fracturing variation with depth along the axis of the wellbore.

SVSL technology is extremely efficient in identifying abnormally fractured zones as well as those drilling locations with the highest hc-flow-rate production potential, both in existing fields and areas under the initial exploration. Several typical results are shown below in Figure 14 through Figure 17.

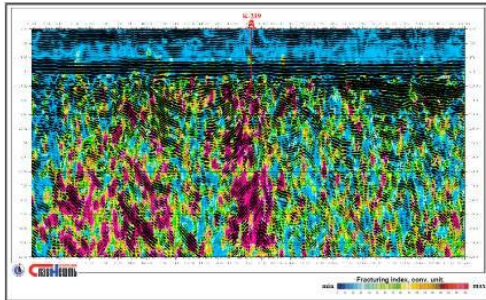


Figure 14: Example of the mapping of fractured zones using the reprocessing of 2D CDP seismic data. Well #219 was drilled into a center of a subvertical zone of intense fracturing. The well test produced significantly above average oil inflow from the Riphean deposits for the region.

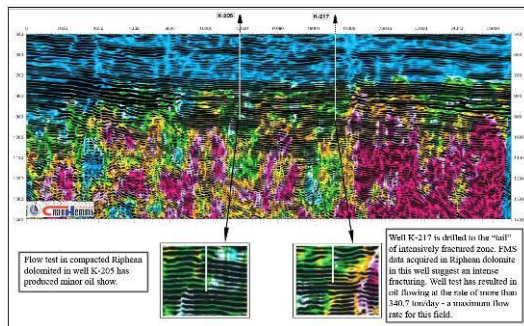


Figure 15: Seismic line # 406198 (Courtesy of Slavneft), Kuyumba oil field, East Siberia, Krasnoyarsky region

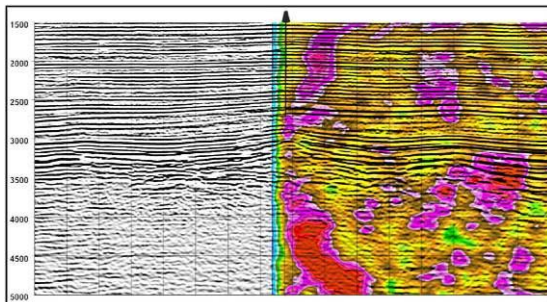


Figure 16: Purposeful drilling of a production well into the fractured sub-vertical zone. Combined presentation of CDP-2D seismic section (black and white) and SVSL section of open fracturing distribution (colored). North Dem'yanovsk oil field (West Siberia). Result: Test of well #30 produced a flow rate of-300 tons/day from Bazhenian deposits – a maximum for the North Dem'yanovsk field and the whole oil region.

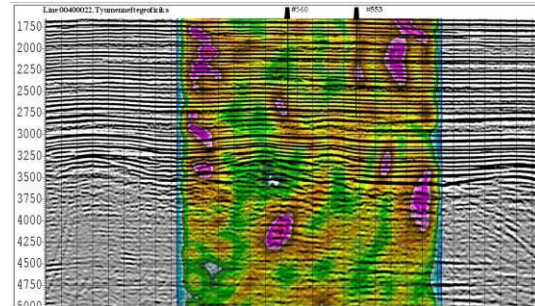


Figure 17: Purposeful implementation of hydraulic fracturing in well #560 based on recommendations derived from SVSL analysis (North Dem'yanovsk oil field). After SVSL analysis and recommendations, the hydrofrac was performed in well #560 (where the initial oil inflow rate was as low as of 6 ton/day). Post- hydrofrac, this well connected with a highly-fractured zone. As a result, a high oil inflow rate of about 80 ton/day was produced.

By using SVSL data to predict drilling complications, exploration companies may take measures to avoid and prevent such complications. To predict drilling complications, SVSL draws a depth diagram of fracturing variation along the planned borehole. This data is then used as geological and technological information. Based on the SVSL data, it is also possible to distinguish other drilling complications such as possible mud loss or blowout (following the tectono-physical interpretation of the geodynamic situation in the area under study).

SVSL technology was first developed in 1990-1991 and successfully tested in Tatneft and Orenburg- Gazprom in 1992-1993. Since 1990, it has been commercially applied in the major oil and gas regions of Russia: West and East Siberia, Ural-Volga, Timano-Pechora regions, North Caucasus, Sakhalin, and abroad. SVSL studies have been performed in over 100 oil and gas exploration areas and projects ranging in size from 4 to 500 sq km.

SVSL is clearly a unique seismic technology that is designed to study the 3D distribution of open fractures in geological formations. After years of field study, the correlation between zones of abnormal, open fracturing and higher hc production has been definitively established. Providing great cost savings, SVSL is applied without the need to drill. There are no other seismic exploration analogues for SVSL throughout the world in terms of its accuracy or efficiency in the study of fracturing. In 2010, a group of SVSL and SLEC technologies developers received the highest scientific and engineering recognition



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in Russia – a State Award. The process for registering both technologies has commenced under the Russian System of National Standards as standard industry exploration tools. This gives further credibility to SVSL and SLEC, and establishes these technologies as important exploration tools that need to be considered by the industry, much in the same way that other geophysical methods have their place in exploration (aeromagnetic and gravimetric surveys, seismic, etc.).

Conclusions

Focusing transformation of the seismic wave field allows identify reflected and scattered seismic waves and draw the images of geological structure and distribution of open fracturing of studied formations simultaneously. SVSL results are presented as a 3D cube of the energy of scattered seismic waves which is interpreted as the spatial distribution of open fracturing. It is visualized using multimedia tools capable of animated dynamic imaging. For the purpose of convenient analysis and interpretation of the resulting 3D distribution of fracturing, the results are presented in the form of a cube with semitransparent faces and sections.

Finally it a powerful tool in seismic technology to identify detailed subsurface features at a micro level.