Practical volume visualization methods for imaging complex structures, North Eastern Venezuela

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Abstract

Practical 3D Volume Visualization methods were developed at PDVSA to address complex structural interpretation problems in the Eastern Venezuela Fold and Thrust Belt. Typically, the data quality are poor, deep duplex structures and imbricate over thrusts are common. New and efficient Volume Imaging and Interpretation methods were needed, developed and used successfully to meet business needs.

Practical, implies simplicity and efficiency, while preserving a sufficient amount of detail to properly address the seismic interpretation problem. The visualization solution presented here, called OVSS or "Optical Voxel Super Stack" is a three dimensional imaging process that relies on both conventional and unconventional use of simple visualization technologies. It is specifically designed for poor quality 3D seismic data. Three brief case histories from the Eastern Venezuela Fold and Thrust Belt are presented to illustrate the results of using OVSS to image and map complex structural architectures. Results include improved three dimensional structural models, improved understanding, new prospective structures and sufficient lead time for additional structural analysis and integration with other technologies and data. Drilling results of wells that have reached their objectives have encountered significant hydrocarbon reserves.

Introduction

Structures within the Eastern Venezuela Fold and Thrust Belt are often difficult to image and interpret, therefore, are higher risk business ventures. An enhanced 3D Volume Visualization method, called Optical Voxel Super Stack (OVSS) was developed at PDVSA to improve the imaging of complex structures in North Eastern Venezuela. (OVSS method is a variation of the basic OVS procedure which is applying transparency to a consecutive stack of 3D lines to visually enhance common reflectors by constructive interference). Results clearly revealed imbricate over thrusts and duplex structural architectures, allowing for faster mapping, model building, lead identification, and integration into the regional structural and stratigraphic frameworks. Results were achieved early in the interpretation process utilizing PDVSA´s Visualization Facilities. (CAVY -Centro Avanzado de Visualizacion de Yacimientos and INTEX – Interpretación de Exploracion). Results also verified and improved previously mapped objectives, located new opportunities, and helped expedite management approval for drill.

Regional Geology

The Eastern Venezuela Basin (Figure 1) is associated with the eastward migration of the Caribbean plate along the El Pilar strike slip fault zone and other unnamed offshore faults (Pindell, 1990). To the south, the Serranía del Interior, a Cretaceous to Paleogene passive margin sequence, was folded as a result of Neogene transpression resulting in a N70°E striking fold and thrust trend (Chevalier, 1993). These trends continue to the south into the Monagas foothills with their large structural oil traps (Carnevali, 1989; Aymard, 1990) which also include the prospective structures mentioned in this paper. A 6-8 km thick Neogene foreland basin overlies a northward-dipping Cretaceous to Paleogene sedimentary rocks and Precambrian crystalline basement of the Guyana shield to the south (Hung, 1997).

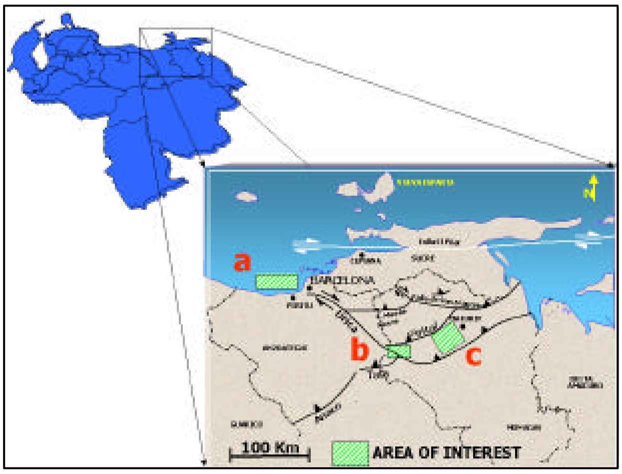

Figure 1. Index map of the Eastern Venezuela Basin showing major structural elements and areas of interest.

Visualization

Distinctions need to made between the two general types of visualization; surface and volume. Surface Visualization is the utilization of surfaces, or surface based objects in three dimensional space. Surface visualization can also be defined by the absence of the use of transparency on a volume of seismic data. Volume Visualization is a process of applying opacity (transparency) to an isolated subset of 3D seismic to reveal its internal features. The interpretation of these results are called Volume Interpretation. Therefore, Volume Visualization is the specific process of revealing what is in the data and Volume Interpretation is its interpretation. The conventional Optical Voxel Stacking (OVS) and new Optical Voxel Super Stack (OVSS) are both Volume Visualization processes, Figure 2.

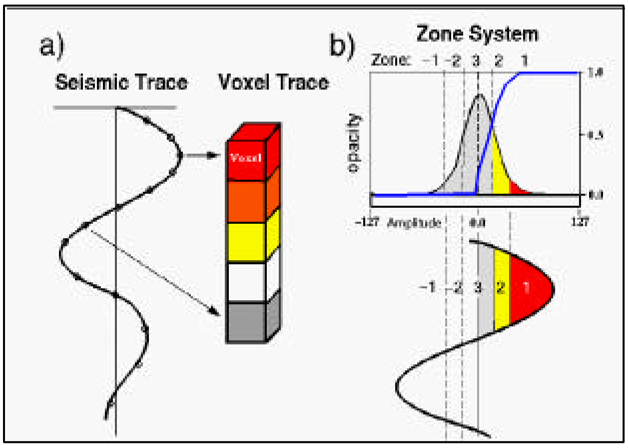

Figure 2. Volume based Visualization Technology showing (a) seismic to Voxel* conversion and (b) opacity function with respect to seismic wiggle trace.

Optical Voxel Stack (OVS)
Optical Voxel Stacking was originally designed in the mid 1990´s to enhance subtle seismic fluid contacts Figure 3.
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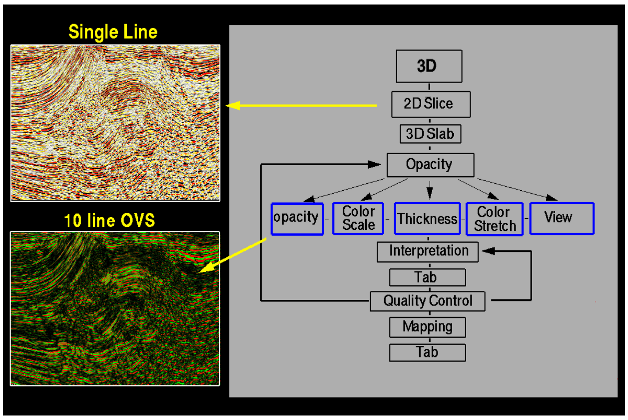

Figure 3. Optical Voxel Stack (OVS) workflow.

The process is based on the constructive visual alignment of weak and sparse voxels* from a stack of lines, consisting of series of consecutive semi-transparent 3D slices (inlines, crosslines or time slices). OVS is dependent upon the geologic consistency of seismic events and the random nature of non geologic reflections or noise. Artifacts can be enhanced. The visual alignment of individual semi-transparent voxels creates an apparent enhancement by slight brightening, thus, making the subtle event, more visible, Figure 4. From this we can differentiate the enhancement by this dynamic visual alignment with the rigid mathematical summation (fixed orthogonal stacking) of data.

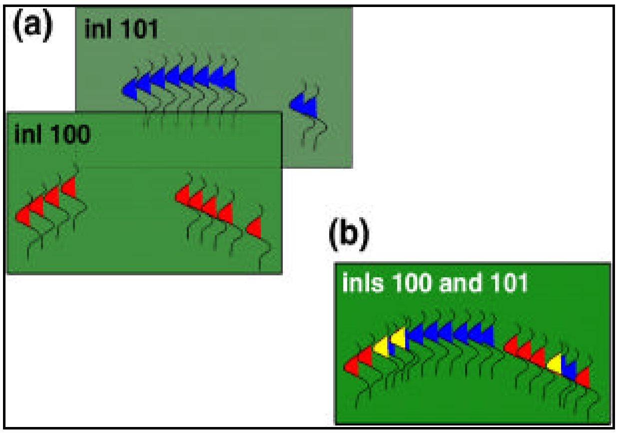

Figure 4. Schematic representation of the basic Optical Voxel Stack Technology. (a) Two consecutive semi-transparent lines imaging different reflections (red and blue) from the same strata and (b) the results of visual overlay and alignment showing reflection composite and apparent brightening (yellow).

Since the strike and dip of geologic reflectors are variable, fixed orthogonal stacking often results in image smearing, therefore, the OVS may require rotation along the horizontal and vertical axis for optimal reflector alignment. Thus, optimal reflector and fault plane alignment are often independent procedures. This is an important benefit of the technology, which allows the interpreter to customize OVS/OVSS operations for specific objectives.

Features that are commonly enhanced are, structural dip, fault planes, stratigraphic facies changes, high amplitude packages, and flat events. The amount of stack depends on the objective and data. Stacks of three (approximately 50m) to fifty lines (approximately 1200m at 25m line spacing) are commonly used. Figure 5 illustrates the before and after results of a 20 line conventional OVS.

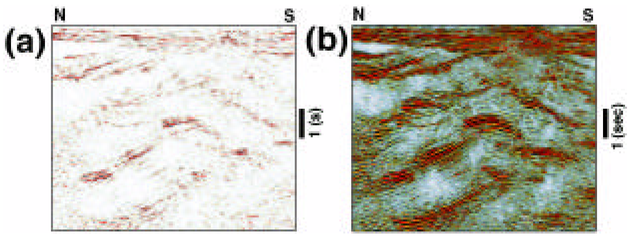

Figure 5. Example of the conventional Optical Voxel Stack. (a) a single semi-transparent line. (b) results of stacking 20 consecutive semi-transparent lines showing improved structural imaging.

Optical Voxel Super Stack (OVSS)
Optical Voxel Super Stack is an enhancement on the original OVS concept. The method is the same as

conventional OVS except for the addition of a “wild seed”, or spilling Sub Volume Detection (SVD) step, Figure 6.

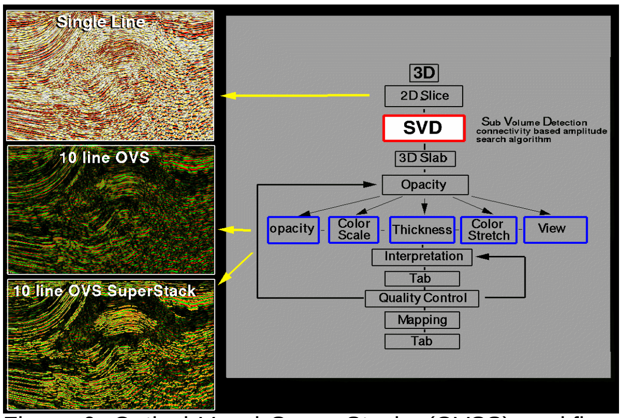

Figure 6. Optical Voxel Super Stack (OVSS) workflow, highlighting the Sub Volume Detection step.

A detection is allowed to generously “spill” or run unconventionally beyond the normal horizon or amplitude SVD limit. The idea is to allow the “wild” detection to spill into other high amplitude and semi-continuous reflectors which are then highlighted with opacity with respect to the undetected data in the stack. In this way, high amplitude packages are further highlighted by its contrast against unhighlighted low amplitude areas. The highlighted, high and moderate amplitude packages generally take the form of the overall structure, thus, allowing the general structural architecture to be seen. The combination of applying opacity (Volume Visualization) independently to both the high to moderate amplitude enhancements (the detection) and the subtle background events, results in a OVSS.

A more aggressive detection, which spills throughout the entire 3D volume, can also produce a rough pseudo-structural framework. Its interpretation is best performed within isolated subvolumes in 3D space. New OVSS detections can then be run within that subvolume for improved clarity and detail.

Method

The Optical Voxel Super Stack (OVSS) method integrates volume visualization, volume interpretation and digital interpretation workflows, Figure 6.

The method begins by searching through the focus area using 3D slices for evidence of reliable structural dip. Once a line has been identified, it is used as the “center” line for the initial OVS. Typically, I usually add five lines on either side of this “center” line making the initial slab 11 lines thick. Opacity is applied to both trough and peak amplitudes and visualization optimized and ballanced.

Depending on the geology and seismic data, additional lines may be added or removed from the stack to optimize results. This entire process is peformed in 3D space.

Initial OVS results are used as the starting point for the selection of the amplitude to be detected for the OVSS procedure. In poor data quality areas, small energy bursts or patches of higher amplitude reflections may be the only visible evidence of structural continuity, such amplitudes serve well as a starting point for the OVSS seed detection process.

Once an amplitude has been selected, a “Seed” point is registered (an amplitude is selected) on that amplitude and detection allowed to spill generously. Initially the detection may be limited to a local group of reflections. In that case, the detection range should be increased and allowed to spill further laterally and vertically. The idea is to allow the detection to spill (run wild) throughout much of the focus area and 3D survey, in effect tracking and connecting the structural framework throughout the 3D. Once a suitable runaway or wild detection is complete, a time structure map on the “top” may be generated. This may require removing or hiding overlying detections that may obscure the view to the area of interest. Although very crude, rough structure maps can be made quickly in poor data areas. In one 3D survey, several large “missed” prospects have been identified using this method and with further mapping, the leads were put on the drilling schedule at PDVSA. The primary benefits are, very little time and effort were needed to reveal complex structural geology and prospects were quickly identified in poor data areas.

Once the leads were identified, or the focus area determined, vertical OVSS 3D sections are used to aid in structural interpretation. Both OVS and OVSS are heavily dependent on the opacity filter for optimizing the visualization. The process of creating optimal visualizations is a “technical art”, therefore, care must be taken when adjusting the volume visualization parameters.

In general, seismic data can be very sensitive to minor opacity adjustments, therefore, careful considerations need to be made during its use. Since the brightness of aligned semi-transparent voxels can be slightly cumulative, high opacity settings can mask data behind it. Therefore, maximum opacity settings should be avoided by setting the opacity value to approximately 80-90%. This prevents the higher opacity voxels nearest to the viewer from obscuring voxels behind, which would nullify the OVS effect. The idea is to balance the visualization by reducing the opacity of amplitudes to an appropriate level, according to the amplitude strength such that the voxels become transparent enough to constructively add across the entire dynamic range of the data and thickness of the stack. This is the balance needed for an “optimal” OVS visualization. Optimal OVSS requires independent opacity balancing for both the detection and background (undetected) data, then blended together using transparency with careful color and opacity adjustments.

Once the OVS/OVSS is optimized, the stack is locked as a unit and moved or tabbed through the volume. Fault and horizon interpretation are manually digitized at this time. Automatic horizon trackers do not operate well in poor data areas, therefore, manual digitization is necessary. Normally, the initial thickness of the stack and initial visualization parameters are kept constant, however, as the geology, seismic and objectives change, minor visualization adjustments are usually necessary to preserve optimal results. Through this workflow (Figure 6) structural frameworks in poor data areas can be made.

Case 1
Offshore 3D

In the North Western portion of the Eastern Venezuela Basin (Figure 1a), offshore 3D seismic shows a major Lower Miocene Unconformity separating prospective shallower Neogene section from the underlying Cretaceous to Paleogene strata Figure 7.

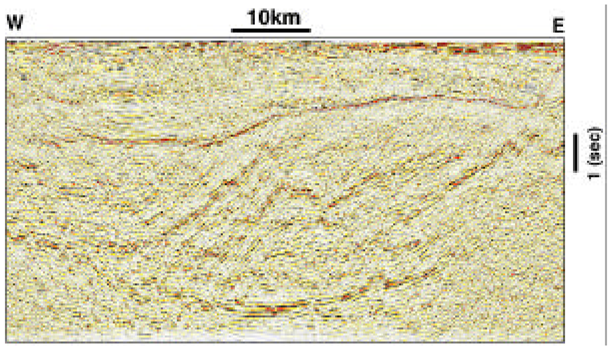

Figure 7. Offshore Venezuela 3D. Original inline showing Neogene and sub-unconformity Cretaceous section.

The Cretaceous through Paleogene strata are assumed to be the northern extension of the Eastern Venezuela Fold and Thrust Belt, a proven profitable oil system onshore.

The seismic data quality below the Miocene Unconformity are generally fair to poor. However, OVSS was applied to the deep seismic data and complex Miocene imbricate over thrusts of Cretaceous rocks were revealed, Figure 8.

Time structure maps were created from the OVSS, and leads were identified and integrated into the regional framework. Multiple OVSS steps were required to evaluate the approximately 1000sq km of area. OVS was heavily utilized in the younger section, identifying and ranking many prospects that were classified within shelf, slope and deep water environments. Key benefits are the early understanding of the complex structure which contributed to early identification of deep leads, its integration into the regional structural framework and the generation of the lead inventory.

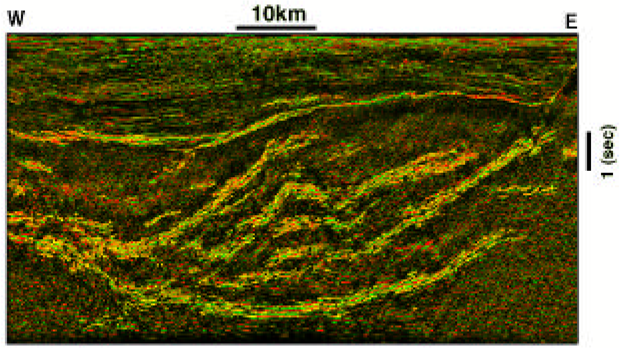

Figure 8. Results of applying a 11 line OVSS on inline shown in Figure 7. Cretaceous imbricate thrust blocks are revealed.

Case 2
Tacat 3D

The Tacat 3D is located in the Western portion of the North of Monagas area (Figure 1b). The data was re-processed several times to improve structural imaging but interpretation remains difficult. Possible Miocene and Oligocene leads within a duplex structure are nested between and below three major thrust blocks, from the North, the North dipping Tala and Pirital Thrusts and from the South the south dipping Tacat back thrust, Figure 9.

The general prospect area was previously defined by the exploration project, however, better structural definition and stratigraphic models were needed. Nearby key wells, the TAG-11E (TD 17,217ft) and TAG-16 (TD 16,700 ft) encountered repeated section and numerous sands but only the TAG-16 was productive. Approximately 10 kilometers to the East, two other key wells, the PIC-2E (TD 22,500ft) and the PIC-5E (TD 20,200ft) were basically void of sand. Both TAG and PIC wells needed to be integrated into a coherent structural stratigraphic model since the leads are located between the sand rich and sand poor wells.

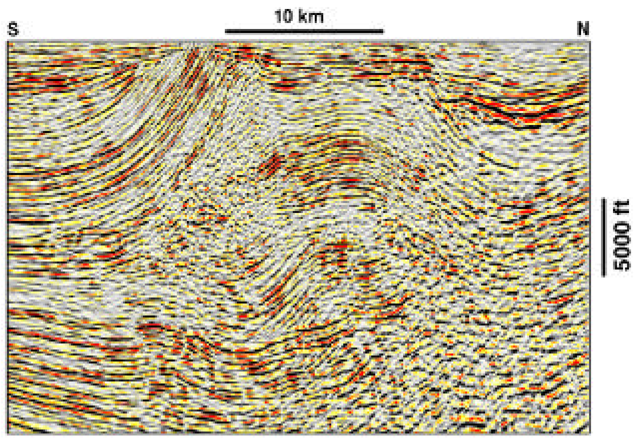

Figure 9. Tacat Merge Depth 3D. Single line conventional seismic display.

Custom OVSS procedures were performed allowing for improved horizon and fault interpretation. An example of OVSS results are shown in Figures 10 and 11.

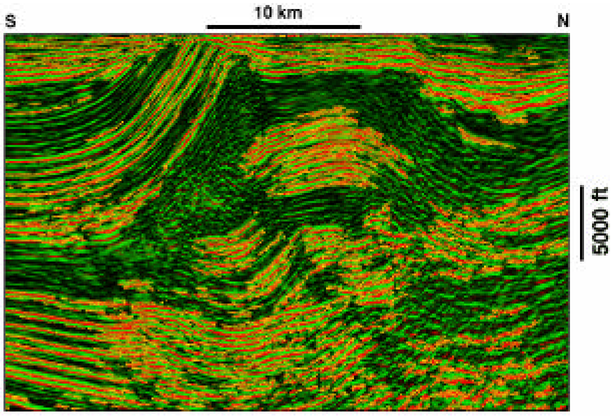

Figure 10. Tacat Merge Depth 3D. OVSS results of 26 inline stack using line shown in Figure 9 as the center. Major structural elements revealed.

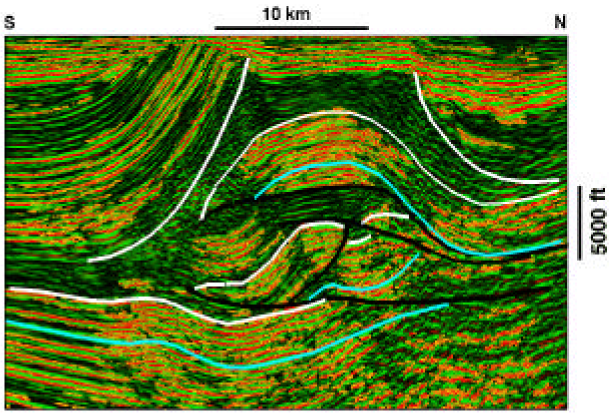

Figure 11. Tacat Merge Depth 3D. OVSS of 26 inline Stack with showing interpretation of Figure 10.

Cross sections were forwarded to structural geologists for line balancing and determination of fault offset distances of each thrust block for paleographic reconstructions. An improved structural model was made. At the time of writing this paper, the prospect was being drilled and encountered significant hydrocarbons reserves.

Case 3
Cotoperi 3D
The area of interest is in the Northern most petroleum providence known as the North of Monagas, near the city of Maturin (Figure 1c). The prospect lies along a North East to South West trending complex of overthrusts. The Northern mega-structure contains the Campos Cotoperi (Total Fina Elf), Orocual and Tropical (Repsol-YPF) and the fields El Furrial, Corozo, and San Vicente constituting the most prolific Petroleum zone-trend within the East Venezuela Basin.

The primary objectives of the Cotoperi Norte Prospect are the Oligocene Naricual Sands. The prospect is partially overlain by the Pirital Thrust Fault Block which includes higher velocity Cretaceous strata. The prospect is also overlain by additional thrust fault blocks of Oligocene and Eocene strata. Seismic data quality is fair to poor. Because of poor quality seismic data at the drilling locations, the structural risk was high. Volume Visualizations utilizing OVS and OVSS were used to improve the imaging , and lowering the risk of structure thus supporting the original interpretation and expediting managements decision to drill.

Customized OVSS sections were systematically made in the inline and crossline directions over the prospective area and continued throughout the entire 3D survey for 100 percent coverage. This helps preserve interpretation continuity across the 3D area. The asset teams original Top and Base Naricual interpretation was displayed within each OVSS section and checked for quality. The work was performed in PDVSA´s “CAVY” , Centro Avanzado de Visualizacion de Yacimientos, a Visionarium Environment, where modifications were made by a collaborative team effort. Overall the Visualization confirmed the overall prospect concept with an improved interpretation and model, Figure 12.

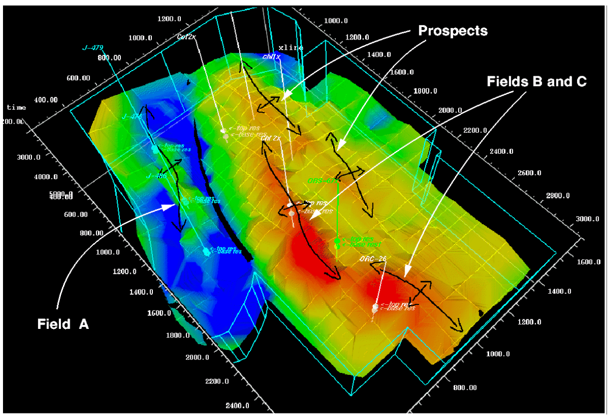

Figure 12. Cotoperi 3D. Structure Map generated from OVSS Volume Interpretation Process.

3D animations were made to clarify the communication of the complex structure and drilling target to management. At the time of this writing two wells were in operation, the first DST on one well tested significant amounts of oil and the other had not reached the objective. Published preliminary reserve estimates range from 350-460MMBO of light oil and 0.87 to 1.6 BCF gas.

Conclusions

The Volume Visualization method, Optical Voxel Super Stack has provided PDVSA's 3D seismic data interpreters with new valuable methods to quickly image and interpret complex structural geology. It has also significantly reduced the interpretation cycle time of an offshore frontier area by quickly providing the exploration team with a 3D structural framework and lead inventory. Results have also verified and improved previously mapped prospects, which reduce structural risk and helped expedite managements decision to drill. These simple methods are time and cost effective and easy to use. We have successfully utilized OVS and OVSS procedures on many projects and it has become a standard interpretation procedure at PDVSA.

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Foot notes

* Voxel is an acronym for ¨Volume Pixel Element¨,a three dimensional equivalent of a seismic sample.