Fundamentals of 3D Seismic Volume Imaging*

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Abstract

Seismic interpreters continue to be challenged by the growing numbers of 3D seismic and attribute volumes available for subsurface evaluations. Volumes including geometric, trace, inversion and, AVO attributes continue to grow while interpreters struggle to work basic volumes. The solution is to use techniques that accelerate and simplify common seismic interpretation procedures while increasing productivity by documenting details and observations. These techniques are integrated in volume imaging, an interactive process, using several key methods designed in concert to address common structural, stratigraphic and depositional problems. The process is driven by a single key visualization technology, Opacity Editing. Using the opacity editor successfully requires understanding a methodology based on particular technologies, specifically data scaling, volume trimming, color displays, and knowledge of how these interact with opacity. This paper discusses the technologies and work flows that are necessary for performing interactive volume imaging.

Seismic Amplitude Scale and Histogram

As a first step, data is loaded into memory as eight bit, with a dynamic range of 256 bins. The maximum negative amplitude is the zero bin, and the maximum positive amplitude is the 256th bin, with one amplitude unit per bin. The eight-bit integer data may be renumbered, for example to -128 to +127 or +/- 10,000 with 40 amplitude units per bin. The data can then be displayed a histogram. The data's histogram is an important tool that displays a “blueprint” of the volume, a bell shaped curve that includes important information such as scaling, amplitude distribution, clipping, null values and phase shifts, which are discussed in the following paragraphs.

Initially data is loaded decimated to quickly quality check the histogram’s shape for excessive lateral compression about the zero crossing “witch hat”, which may cause imaging problems. A decimation of one reduces the volume by 75%. The objective section should be measured for amplitude strength and checked for existing clipping. Quality volume imaging requires data be at least 50-60% of the bin range. If however the objective is low amplitude, the high amplitudes may be clipped which will expand the lower amplitude range, and increases your ability to image and extract geobodies. On the other hand, clipping may already exist and is identified by the presence of spikes in the maximum positive and maximum negative bins. Clipping does not remove data values; it simply moves them into the maximum value bins. Phase shifts are checked by observing if the data is symmetrical about the zero crossing and is easily edited upon loading. Null values infill voids between the 3D survey boundary and its oriented rectangular box that defines its coordinate space. Null values are placed in the zero crossing bin, often making a spike that may distort the histogram shape by vertical compression. The spike may be truncated to reveal the true shape of the histogram. With calibrated data, clipping may be performed using specific ranges. Simply turning the respective bins on and off helps understanding where your data resides and how it is distributed over the amplitude spectrum. This is especially useful when identifying data distributions for imaging attributes.

Color and Opacity

Each original color in volume imaging has 255 opacity related hues that is determined by the background color. For example, the color red is red at opacity of 1.0; as the opacity level lowers, red become more transparent, slowly taking on more of the background color until it becomes that color at opacity of 0.0. The color red changes based on its opacity level and background color. This occurs with all colors, and this is why high contrasts become critical at low opacity values on low amplitude data. The colors that show the highest contrast at the lowest opacity values (0.0-0.3) against a black background are white, yellow and green and, therefore are selected for low amplitude Zone 3 (Z3) imaging. Red is considered a low contrast color at low opacity values, so it is only used for high impedance Z1 imaging with high opacity settings of (0.7-1.0). Positive amplitudes on the opacity editor are divided into three amplitude Zones. Zones 1, 2 and 3 are colored red, yellow and white respectively, which correspond to high, moderate and low amplitude data and are assigned to the primary visualization objective. The opposite polarity is colored green to white; although not fully discussed in this paper, these amplitudes would be imaged in a similar way. Four original colors are used (red, yellow, white and green) for entire visualizations, with original non-transparent red and green and semi-transparent yellow and white. Colors are kept intentionally simple and one uses their hues for additional detail. Selection of colors for visualization needs to be done with understanding of knowing how color contrasts change with respect to opacity levels.

Volume Imaging – Amplitude Bands

This section discusses the use of amplitude bands in volume imaging. The seismic color, is scaled (stretched) to the dynamic range of the data, within the limits of the bin range, and displayed in the opacity editor, Figure 1a. In this procedure, the data range is less than the bin range, but the maximum colors, by default, are extended to the maximum bins. Limiting the maximum data values short of the maximum bin range ensures the maximum bin containing clipped data is separate from useful amplitudes. A positive wavelet is positioned below the histogram, Figure 1b, where color is used to correlate between the histogram and seismic data zones. To the right, a single voxel trace (volume pixel element) with colors bands projected in from the wavelet is part of a 2D section, Figure 1c. Notice the correlation of color bands in the histogram, wavelet and the 2D section. The 2D section shows a high Z1 amplitude termination, leaving Z2 and Z3 amplitudes, and farther out, the Z2 amplitudes terminate with Z3 amplitudes throughout, Figure 1d. Symmetry is used to create a complete cross section, which is extended back into 3D space, creating a 3D geobody. Note that the geobody has a Z1 red core, which is surrounded by two other lower amplitude bands. Bands and zones are synonymous. Amplitudes in 3D space consist of concentric amplitude bands with the highest amplitudes in its center, Figure 1e. An actual seismic rendering of a channel, a pixilated 2D section and a full visualization of a geobody, are shown in Figure 1 f-h. To reveal the extent and internal variations of all three bands, opacity edits are carefully made on each zone

In the geobody shown in Figure 1e , the thickness of Z3 amplitudes over the central Z1 area are thin (thickness “a”, Ta) compared to the thickness at the ends of the channel (thickness “b”, Tb). In general, Z3 amplitudes are rendered with low opacity levels targeting structural and stratigraphic details in the thicker area, not the thin Z3 amplitudes overlying the Z1 core. In doing so, the Z3 amplitudes over the Z1 core are so low they become transparent to the eye. Careful independent editing on each amplitude band creates optimal visualizations.

Zone System

The Zone System was designed to assist interpreters to make precise opacity edits on specific seismic amplitudes using a color-coded system. It directly relates specific opacity curve edits to specific seismic amplitudes. The interpreter identifies the color of the amplitude of interest, determines what that amplitudes needs (a little more or less opacity), and applies an appropriate opacity edit only in that zone. The Zone System directs interpreters to exactly where to make the opacity edit. The zone number determines how the edit should be made. A high amplitude Z1 edit applies to approximately 5% of the volume, which is the inner band, while low amplitude Z3 edits apply to approximately 60% of the volume, which is the outer band. Z3 edits effect the entire volume and while Z1 edits only affect a small part. Zone 3 contains the largest proportion of data and it is the most edited zone. Very small edits should be made so incremental changes can be observed. Zone 1 high amplitudes usually represent the core of channels and fans or any high impedance event. The Z3 amplitudes, comprise low amplitude strata, and contain 50-70% of the stratigraphic and structural information, e.g. distal facies, subtle amplitude terminations, faults and fluid contacts.

Volume Trimming

Volume trimming is the most efficient method for isolating objectives for volume imaging because it does not require surfaces. The volume is loaded and it is applied immediately. The two main optical voxel stack (OVS) procedures are: 1) a vertical slab for stratigraphic/structural imaging and 2) a horizontal slab for geomorphologic imaging. From a volume-imaging standpoint, imaging horizon-keyed slabs is done the same as horizontal slabs.

Structural/Stratigraphic Imaging

A vertical slice is positioned on a target and approximately four to six slices are added to each side creating a slab. It is better to begin with a narrow slab, so that the target is easily tracked during visualization. In deep parts of a section, 51 slices have been successfully used for imaging large structures; therefore, thickness depends on objective and data quality. Important geologic detail such as pinch outs, on laps, faults, structural profiles, stratigraphic packages and dipping strata are imaged by bringing specific features into visual alignment by tilting and rotating the slab. Since stacking events by visual alignment results in brightening, visual alignment equates to enhancement. Random noise does not brighten since its amplitudes do not stack. Since dip can vary throughout the section, various viewing directions are needed for enhancing various targets. Faults are generally low amplitude and enhanced by the alignment of bed terminations. In vertical sections both trough and peak amplitudes are imaged at the same time. Lighting from above or below may be applied to further enhance results.

Geomorphologic Imaging

Horizontal slabs are initially about 40 milliseconds thick (approximately 80-100m) and are interpreted in a similar way as geologic surface maps. Slab thickness depends on average frequency, objective dip, amplitude strength and data quality. Slabs are imaged by working the high and moderate amplitudes first and infilling with Z3 amplitudes. This completes the imaging on the positive side followed by careful blending in the negative green zones. Integrated pattern recognition is highly recommended, because it delays first impressions until more data are viewed. If the thickness of the objective is less than the slab thickness, the entire objective will be visible. However, in most cases only a portion of an objective or event will be revealed. Interpreters need to be skilled in recognizing events that are parts of larger geologic features. Partial channels will appear as small semi-linear segments, and fans as high amplitude strips long a reflector. Although incompletely imaged, recognizing partial channels in a slab is more reliable than recognizing channels on a slice. Slowly rendering the data from the bottom up is very advantageous. Anticlines will close and synclines will open. In addition, fault lineaments, amplitude extents and distributions and depositional features automatically integrate, building up a 3D paleo-landscape. The ultimate goal is to image Z3 and Z2 data and then infill with low amplitude Z3 data, followed by imaging the opposite polarity into the view.

Summary

Volume imaging is an art, requiring technical balance between functionalities and objectives that help interpreters efficiently see seismic details in 3D space. Understanding how the system operates greatly helps interpreters produce quality results. Benefits are derived from multitasking on structural, stratigraphic and depositional problems in 3D space. Once an interpreter becomes grounded in the fundamentals, the technology is much easier to apply to volumes such as geometric, trace, inversion and AVO attributes and will help safeguard against pitfalls.

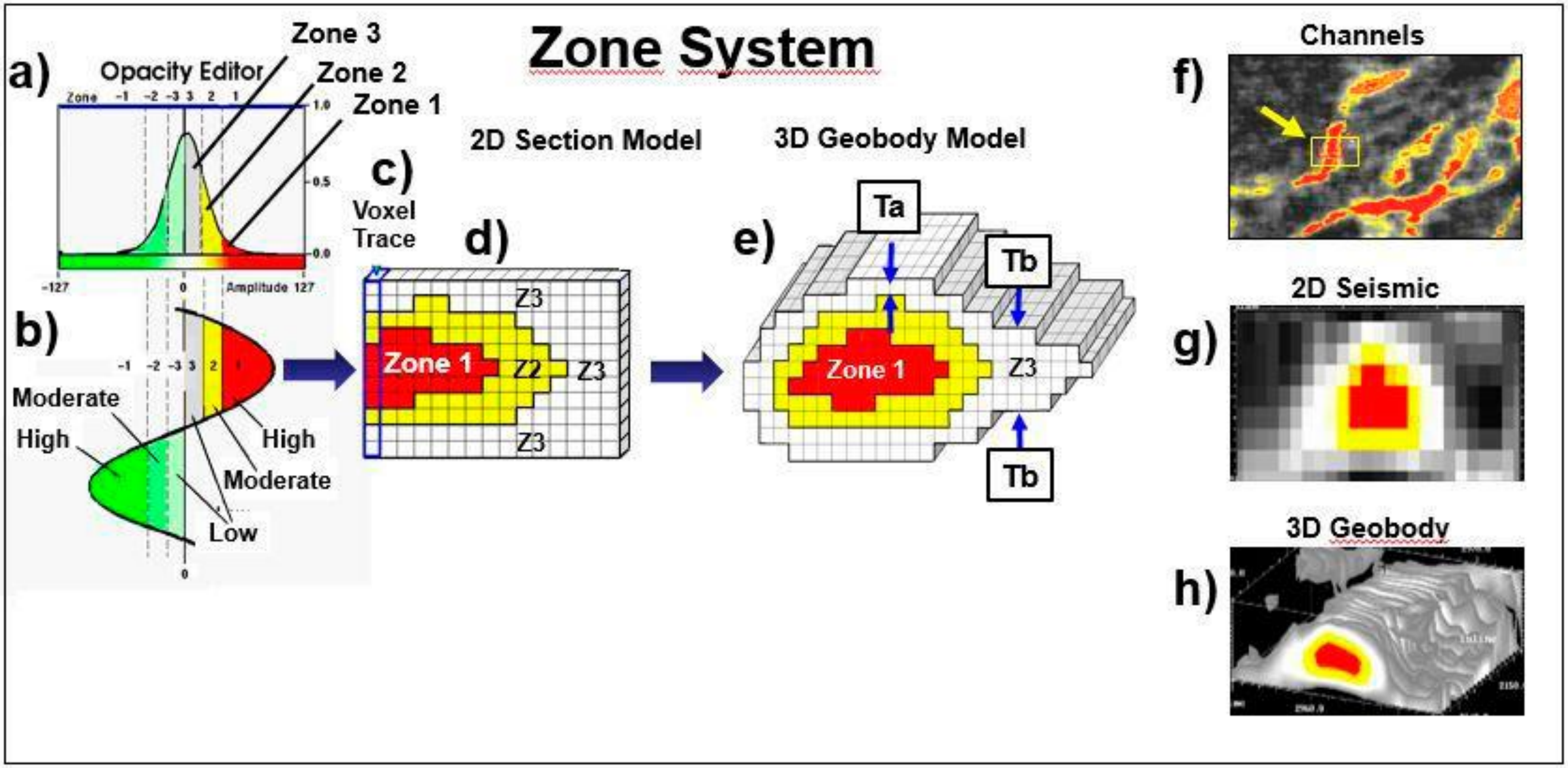

Figure 1. Zone System. a) Scaled histogram, b) positive wavelet, c) voxel trace, d) model 2D section, e) model 3D geobody, f) imaged seismic channels, g) 2D seismic section pixilated, and h) 3D channel geobody.