Objects vs. Layers: the Diagnostic 3D Seismic Process - a new method for imaging, measuring, and evaluating subterranean "common-impedance objects" (e.g., petroleum reservoirs)

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Summary

Quantum Mechanics tells us that both light and matter have a subtle but useful wave-particle duality. For example, it is difficult to devise an experiment that reveals either the wave nature of particles (matter), or the particle nature of waves (e.g., light, or electromagnetic radiation). I contend that the earth's seismic subsurface is characterized by an analogous, if less profound, object-layer duality. Tools and methods we use to look for one characteristic of the subsurface (traps in dipping strata or layers) often obscure the evidence for the equally useful effects on the other side of the duality: localized (reservoir) objects. In analogy to medical imaging methods (**Figure 1**), I have used examples from South Timbalier Blocks 23/26 (**Figure 2**), and Eugene Island Blocks 27/46 (**Figure 3**), to illustrate a novel process that recognizes all the historically useful, layer-based assumptions made in acquisition, processing and interpretation; and ignores and re-sequences processing steps to accentuate the (3D volumetric) object nature of petroleum reservoirs. Although it is done now almost universally, it is time-consuming and expensive to convert object-filled seismic data to layered-earth-model images, and not only on the young, clastic sediments of the Gulf of Mexico. The relatively low density and velocity (acoustic impedance) of porous rock and petroleum fluids make carbonate and igneous rocks, equally fair game for the use of the D3DSP. Some "Frequently Asked Questions" about the history and methods of the D3DSP are also included.

Introduction

I offer both a technical and seismic case history paper. In the technical portion, I discuss differences in methodologies for conventional layer/trap/amplitude (and AVO) mapping, versus the D3DSP, which works with the 3D shape and volumetric characteristics of Common-Impedance Objects (CIOs), using volume visualization software, such as VoxelGeo (**Figure 1**). I also summarize some of the acquisition-preference and processing differences between the D3DSP and conventional methods, and present some useful guidelines for a post-stack-migration D3D-processing sequence example, used in the U.S. Gulf of Mexico. A much fuller description is given in my U.S. Patent write-up, available at www.vtvinc.com.

Case Histories

The abbreviated case histories will cover two areas along the Gulf of Mexico shallow-water shelf. ST-23/26, immediately south of the giant, salt-cored Bay Marchand field, was the first offshore data set ever attempted for the D3DSP, and its 1996 speculative Ocean Bottom Cable (OBC, 82 x 82 feet x 4 ms, dual-sensor) 3D data turned out to be well-suited to the assumptions of the D3DSP. And it led to some interesting comparisons (**Figure 4**) between conventional section-view images and the CIO-volumetric views (map, section, and a 3D spinning-CIO animation, on the VTV website). But in this giant, mature GOM field, the drilling of subtly trapped prospective leads has been difficult to justify, based on the D3DSP analyses, alone.

EI-27/46 is the more spectacular technical (and economic) story, in that it, too, was OBC speculative data, shot in 1995, but acquired at a 3 ms sample interval and D3D-reprocessed to a 2 ms interval (**Figure 5**). Its trace spacing of 55 x 55 feet, also gave a much higher resolution volumetric result, which definitely supported the (no partner) exploratory test. It resulted in a high-rate (up to 30 million cubic feet of gas per day), subtly trapped accumulation that is well on its way toward a much higher Estimated Ultimate Recovery (EUR) than conventional "Amplitude-Anomaly-Area multiplied by Estimated-Sand-Thickness" analysis. The gas in this CIB CARST sand was, indeed, subtly trapped. The drilled location was chosen from conventional amplitude data (but strongly D3D-supported, prior to spud), just down-time-dip from an 8.2 billion cubic feet of gas (bcfg), watered-out, thin sand well, with no observable stratigraphic or fault separation. Potential partners, reviewing only the well logs (with questionable Kelly Bushing elevations), production history, and conventional 3D seismic data, evidently thought it to be a high-risk prospect, and that the modest amplitude anomaly (upon which the EI-27 lease was acquired) might well be a "footprint" of the depleted (8.2-bcfg-produced and water-swept) reservoir, over 10,400-feet deep.

But the presence of over 27 bcfg cumulative production well, drilled in EI-46 the year after the survey was shot (so the 1995 seismic saw the 29 bcfg that was discovered in 1996), and its exceptional match to the D3D images and volumetrics, provided more than enough confidence to recommend its drilling, strongly. The conventional amplitude anomaly (**Figure 3**, left side) was inconsistent with the extremely thin (12 feet of gas on water) CIB CARST sand, perforated in the Norcen #2 well. The D3DSP used VoxelGeo-seed-planted volumetric analyses, and arrived at a final size and shape that was the largest possible CIO (approximately 29.2 bcfg, using an engineer-supplied recovery factor), before a more relaxed cutoff grew a much-too-large CIO (jumping across known faults and probable formation layer boundaries), that was judged to be geologically unrealistic. The final EI-46 CIO (**Figure 3, lower right**) explained the presence of thin sand found in the Norcen #2 well. **Figure 3,** lower right D3D-CIO shows it on an internal edge of the "anomaly", whereas the left-hand conventional amplitude map shows it in the midst of the "bright spot". And it fit the Norcen #2 EUR, nicely. By September, 2002, when the D3D-reprocessing and -analyses were being performed, the Norcen well had cum'ed 27 bcfg, was still flowing 13 mmcfgpd, but the water-cut was increasing strongly. The EUR was thought to be approximately 29 bcfg.

At EI-27, the final D3D-impedance-cutoff was determined by both the shape of the D3D-impedance-CIO, with its flat (GWC?) base seen in **Figure 4**, and the same cutoff value required to grow the VoxelGeo-calculated 29.2 BCF (nice match to the EUR) CIO, at EI-46. The reprocessed seismic data were high resolution, relative (logarithm of) acoustic-impedance seismic trace VOXELs, tied to known well control. Simple fluid-substitution modeling predicted that a water-swept reservoir would not have the anomalously low D3D-impedance signature that was observed at EI-27. Residual "fizz-water" would, indeed, produce a very slow reservoir sand velocity, but not a particularly low density, and the acoustic impedance is the product of these two rock properties. The wavelet-interference tuning effects of conventionally processed (layered-assumptions) seismic could and did produce the conventional amplitude anomalies seen on the left side of **Figure 3**, and the EI-27 D3D-CIO (upper right corner) had too large a VOXEL-calculated volume to be an 8.2 bcfg footprint. The D3DSP gave the total area AND the laterally varying thickness of the CIO, requiring only a reservoir sand velocity from the Norcen well transit-time log. And it supported drilling this conventionally risky (but D3D-solid) test, without partners.

Finally, two animations are included, viewable either here or at the VTV's technology website (www.vtvinc.com). The first movie shows the CIB CARST sand reservoirs, at EI-27 and EI-46, opaque and spinning, surrounded by transparent non-reservoir rocks. The other movie shows the "evolution" of the EI-27 CIB CARST gas sand reservoir, as it starts with its highest D3D-impedance detection threshold ("cutoff" = -58), forming the largest, least compact CIO, in which the low-D3D-impedance of the EI-27 reservoir has joined up with the EI-46 reservoir, possibly through a common, somewhat low-impedance aquifer. In the animation, it then shrinks (as the cutoff value is lowered, incrementally) to a minimum-sized CIO, with this lowest D3D-impedance-cutoff, sweet-spot surrounding the exploratory drill site. Note that this is the opposite of the 36 frames displayed in **Figure 6,** where frame #1 is in the upper-right corner (these 36 frames are analogous to a surveyed Jeffersonian Township, where Section Number 1 is in the NE, upper-right, corner).

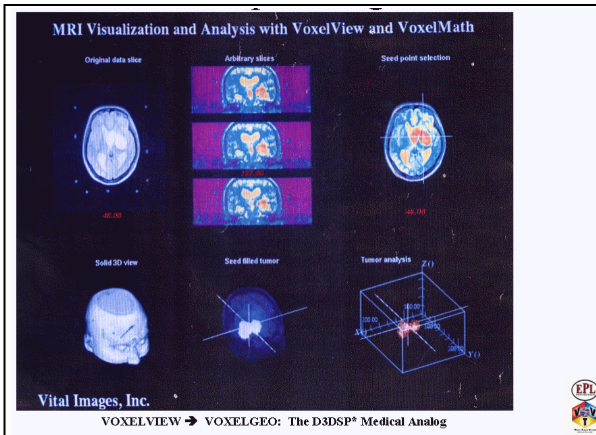

Figure 1: D3DSP's Medical analogy is MRI in VoxelView

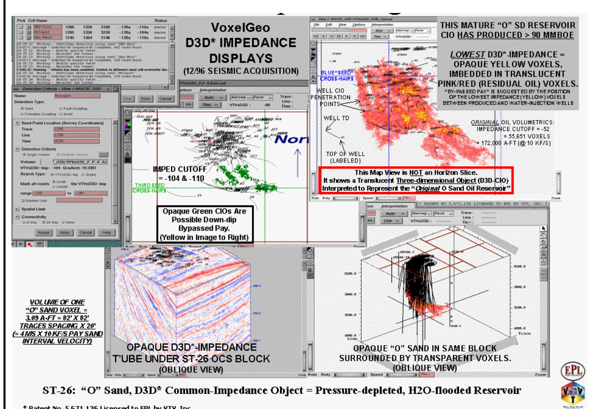

Figure 2: "O" sand reservoir CIO at ST-26.
Produced reservoir residual oil interpreted to be red.
Remaining (1996) pay is yellow.
Possible by-passed compartments are green.

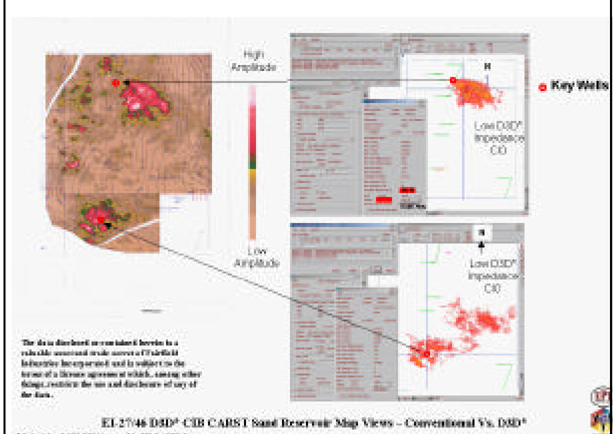

Figure 3: Conventional (left) and D3D-impedance (right).
CIB CARST sand conventional amplitude map (left).
Map-views of CC sand CIOs (right),
EI-27 (top) and EI-46 (bottom).

Objects Vs. Layers: The Diagnostic 3D Seismic Process (D3DSP)

Theory and/or Method

At ST-26 and South Pass Block 24 and Block 27 fields, I made a scoreboard for the success of D3D-impedance by comparing reservoir level D3D signatures to 18 and 52 logged and producing zones at ST-26 and South Pass Block 24 and 27 fields, respectively. Although I will show only a very few examples of this work here, I found D3D images predicted the pay zones by a score of 26-0, when unequivocal seismic and log data were used, and 50-20 when I used results from questionable (edge of survey or uncertain time-depth conversion) seismic or well log data. When a good low-D3D-impedance anomaly corresponded to a good active, or subsequently discovered, producing reservoir, I counted it as a "point" for D3D. Likewise, a poor D3D anomaly coincident with a reservoir we wished we had not spent money to drill, log, and complete, was a point for the D3DSP. Poor D3D combined with good production, and a good D3D anomaly combined with a poor reservoir, were counted as points against the D3DSP (but not necessarily in favor of conventional methods). This, and Deepwater Analog field study work on pay sand reflectivity in Gulf of Mexico fields, showed that (good) reservoirs produce low-relative acoustic impedance anomalies. It took almost a year to collect these scoreboard-recorded images (not shown here), because this research had to be carried out in my "spare-time".

<u>GOM (Post-stack-migration) D3D-reprocessing example</u>

1. INITIAL PRE-PROCESSING
2. COMPENSATION FOR INSTRUMENT IMPULSE RESPONSE & GEOMETRIC SPREADING
3. 1st PASS TIME VARYING (Time-Domain) SPECTRAL BALANCING (TVSB)
4. TOMOGRAPHIC / REFRACTION STATICS
5. SURFACE-CONSISTENT SPIKING-DECONVOLUTION
6. AMPLITUDE ANOMALY PROCESSING
7. SURFACE-CONSISTENT AMPLITUDE COMPENSATION
8. RESIDUAL AMPLITUDE COMPENSATION (Offset Only)
9. AMPLITUDE ANOMALY PROCESSING (CMP Only)
10. PRELIMINARY VELOCITY ANALYSIS
11. 1st PASS RESIDUAL REFLECTION STATICS
12. RESIDUAL REFLECTION STATICS VELOCITY ANALYSIS
13. 2nd PASS REFLECTION STATICS
14. MUTE SELECTION (to insure "OVA")
15. COMMON MIDPOINT FINAL STACK
16. "SMART" TRACE & SAMPLE INTERPOLATION
17. POST-STK TIME MIGRATION (E.G., Ext. Stolt?)
18. 2nd PASS TVSB ON D3D-REFLECTIVITY VOLUME
19. PHASE ROTATION (if needed)

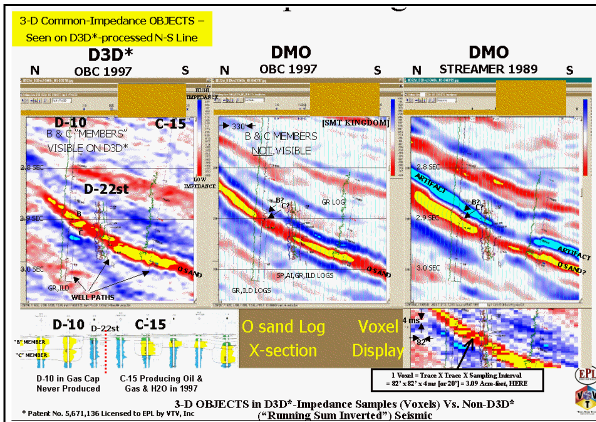

Figure 4: (Left) 1996-acquired D3D-impedance twin line.
(Center) 1996 Orig. conventional (RUNSUM-impedance).
(Right) 1987 Streamer-cable DMO convent'l processing.

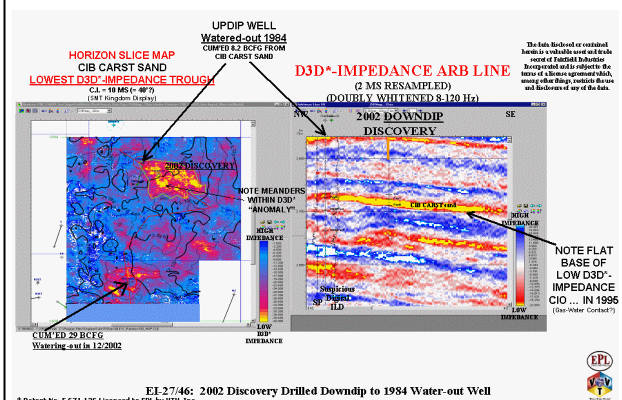

Figure 5: D3D-impedance "CC" sand reservoirs at EI-27/46.
Note: Up-time-dip watered-out well prod. 8.2 BCFG.
Arb line (right) shows flat based low-CIO (yellow).
EPL#1 well hit low-CIO. EI-46 29B's perfed edge.

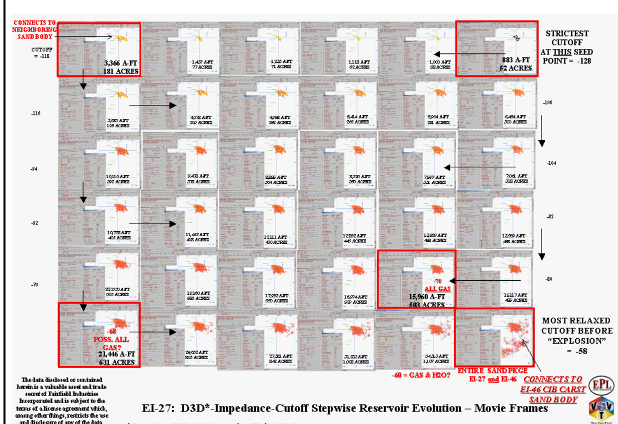

Figure 6: EI27 CIB CARST sand D3D-impedance evolution.
Upper-right: lowest D3D-impedance "cutoff".
Lower right: largest CIO connects pays thru aquifers.
Selected "All Gas" cutoff = -68.

Objects Vs. Layers: The Diagnostic 3D Seismic Process (D3DSP)

20. D3D-IMPEDANCE VOLUME (Running-Sum-Integration "Inversion")
21. FINAL FILTER SELECTION (Low-cut Only?)
22. DELIVERABLES (Inline & Crossline Numbering Consistent with Original-processed Data)

Figures shown:

Figure 1 shows the medical analogy, which triggered this novel line of applied geophysical research. Physicians use MRI scans to locate and quantify (and treat) many types of pathologies, today. Using a volume visualization and analysis program called VoxelView, a predecessor to VoxelGeo, a tumor is shown within the normally opaque head of a patient. **Figure 2** shows the "O" sand reservoir CIO at ST-26, with its many development wells, and in many views and states of voxel-transparency. **Figure 3** compares the CIB CARST gas sand reservoirs at EI-27 and 46, with a conventional amplitude map. The conventional amplitudes could not provide a consistent story behind the 29 bcfg produced at EI-46 (from such a "ratty" logged pay) or behind the appearance of a low-impedance "foot-print" down-time-dip from an 8.2 bcfg watered-out gas well. My D3DSP work told both stories to me. **Figure 4** compares an arbitrary line through three active, unproduced or undrilled logged "O" sand reservoirs at ST-26. The horizontal and vertical resolution of the internally complex (lower-left cross-section) "O" sand are more obvious on the D3D-impedance line (left) than on either the unreprocessed DMO line (center) or the 1987-shot streamer cable line (right). **Figure 5** displays a conventional-interpretation horizon-slice and vertical section over the EPL #1 CIB CARST gas sand discovery well. The CIO's flat base and possible communication (confirmed by the discovery well's slightly drawn-down pressures) with the 8.2 bcfg cum well, up-time-dip, are clearly shown**.** **Figure 6** shows all 36 frames of the CIB CARST sand evolution movie that is viewable, in motion at **www.vtvinc.com**. Starting from the upper right corner, it shows the effect of gradually relaxing the D3D-impedance detection threshold (or impedance cutoff) value. The starting voxel ("seed") point was always in the EPL #1 CIB CARST gas sand (10,000 f/s), and the smallest sweet spot connected to reservoir perforations is "grown" by using the lowest possible cutoff. The largest CIO grown, before the detection had to be manually stopped (it was running away into wet sands and shales), is shown in the lower right frame, where it was able to jump through a possible common-aquifer zone, into the Norcen #2 gas sand producer in EI-46, to the south.

In this talk, I discuss some fundamental differences in the conventional and D3D seismic processing:

Layers:

- ✍The search for TRAPS forms the foundation for our acquisition, processing, and interpretation methods
- ✍Samples, traces, dip, Fresnel zones, wavelets, horizons, faults, continuity, stack and migration velocities, amplitudes, AVO (amplitude variations with offset), DMO, stacking, reflectivity.
- ✍Objects:
- ✍Exploding "reflector" (diffractor) model of the earth, with diffracted energy generated by every acoustic impedance (AI) discontinuity.
- ✍Relative (near vertical-incidence scalar, non-elastic) AI, subsurface 3D distributions.
- ✍Time Cubes (T'ubes), Estimated Depth T'ube, OVA (offset variations absent).
- ✍Voxels (volume pixels = samples), Common-Impedance Objects (CIO's = detected sub-volumes or geobodies), Volume Visualization software.
- ✍Voxel dimensions not limited to field-acquired trace and time sample intervals. Lowest D3DSP resolution limits not firmly established.
- ✍Valuable CIO properties are: TWT, depth, shape, volume, average and maximum thickness, average and maximum D3D-impedance value along a vertical stack of voxels (a trace).
- ✍Along the Gulf Coast, anomalously low impedance ✍ possible petroleum reservoir.
- ✍Warning: "Pressure-depleted" reservoirs can result in low-impedance pitfalls. Walk carefully!
- ✍Water depletion drive raises the reservoir's relative impedance (density), so the D3DSP is not as easily deceived as "Bright Spots" and "AVO".
- ✍Flat CIO base ✍ possible fluid contact.
- ✍Lower-D3D-impedance in updip portion of CIO ✍ possible gas gap.
- ✍TRAPS are not always apparent. Look for low-impedance, petroleum-filled porosity signatures.

Frequently Asked Questions (addressed orally)

1. How did the Diagnostic 3D Seismic Process concept arise?
2. How are D3D seismic volumes different from more conventional 3D volumes?
3. How is the D3DSP different from working with conventionally "inverted" seismic volumes?
4. Is a special type of acquisition technique required for the D3DSP, or can any 3-D seismic volume be re-processed to create a D3D-impedance T'ube?
5. How is D3D processing different from 3D processing?
6. Does AVO play a role in the D3DSP?

7. What use are synthetic seismograms and wavelet analyses to the D3DSP?
8. Are the high D3D frequencies really "signal", or just processing artifacts?
9. What is the resolution limit of a D3D-impedance volume?
10. What is most difficult about locating valuable subsurface objects using the D3DSP?
11. Is a volume visualization workstation (e.g., VoxelGeo, GeoViz, Magic Earth, etc.) required forinterpretation, using the D3DSP?
12. What roles can (or should) a D3D-trained Geophysicist, Geologist, and Engineer, play in the application of the D3DSP?

Conclusion

Good low-D3D-impedance anomalies seem to match quite well with good production, even if the reservoir trap is poorly understood. So, do not let the processor be so quick to judge signal (nice continuous layers) versus noise (possibly random objects). Many real geological sections (e.g., road-cuts, canyon walls) are quite "noisy", but contain potentially valuable, recoverable resources. Think about what these real cross-sections might look like, if our eyes could "see" acoustic impedance, rather than colors and textures. D3D-impedance volumes are faster and cheaper to produce than conventional 3D volumes, and allow quicker, more accurate volumetric (and high-resolution 3D shape) analyses than layered-earth-model 3D data methods. Stay in the time domain as long as necessary, to identify and measure your targeted CIO's, before depth converting for drilling prognoses and field development. The velocity distribution of the earth's subsurface is highly variable and often unpredictable. The influence of the layered-earth model is incredibly difficult to avoid in acquisition, processing, interpretation and even in marketing prospects. It is easy to see why engineers find it difficult to talk about their reservoir models with geoscientists. Objects versus layers. And consider the modern appliances and tools that have become available once the wave-particle duality of Quantum Mechanics, became accepted and came into wide use and application: computers, televisions, cell phones, MRI's … and nuclear bombs. The earth's seismic object-layer duality will be valuable for a variety of subsurface imaging applications, not just oil and gas. Ask near-surface geophysical (seismic, GPR) investigators if objects or layers are more important to them.

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