

THE NEXT ERA IN SEISMIC TECHNOLOGY

Foundation technologies of full-wave imaging, including wide azimuth designs and single point sensors enhances final images

Seismic surveys are now faced with various limitations on conventional 3D P-wave seismic imaging.

According to Joe Jacquot, Director, Strategic Product Marketing, Input/Output (i/o), these limitations are specifically seen on deployment of geophone receiver arrays in the field, rather than deployment of high fidelity single-point digital multicomponent receivers; narrow azimuth survey designs rather than wide azimuth survey designs; short offsets rather than long offsets; and recording p-wave data only rather than P-wave data, S-wave data and source-generated noise (ground roll).

Jacquot explains to Pipeline how these limitations result in poorer quality seismic images, poor measurements of avo and anisotropy and no s-wave information; while taking a focus in the Middle East.

What are the main challenges that you meet in the Middle East? Does the region require any specific need?

We see source-generated and side-scattered noise, near-surface velocity variations and vertical resolution as the main challenges. One specific need of the Middle East is higher resolution seismic images with a reduced cycle time.

How do you address these issues?

Input/Output offers Full-wave seismic imaging on land and on the seabed.

Full-wave imaging allows the use of vector-filtering techniques to attenuate the source-generated and side-scattered noise, point-receivers eliminate intra-array static and together with full-wave imaging, allow improved near-surface velocity solutions and the broad bandwidth images achieved with full-wave imaging enables interpreters to see thinner reservoirs in greater detail.

What are its key differentiators compared with other seismic solutions?

Compared to conventional seismic acquisition and other seismic acquisition techniques, full-wave imaging delivers

- Broader bandwidth, higher resolution seismic images

- Improved P-wave images, cost-effective S-wave images
- More accurate anisotropy and AVO measurements
- Seismic frequencies down to 1 - 2 Hz, more closely matching well log information and critical for robust seismic inversions

How is Full-wave seismic imaging able to produce these differentiators?

Broader bandwidth, higher resolution images are achieved by using single-point receivers that eliminate intra-array statics that plague geophones arrays. Geophone arrays act as filters that eliminate the highest returning seismic energy frequencies. Broader bandwidth, higher resolution images are also achieved by using micro-electro-mechanical systems (MEMS) based accelerometers inside the single-point receivers to measure ground motion, rather than the moving coil / spring combinations used in geophones. Most geophones have a resonant frequency of 10 Hz, below which it is problematic to accurately record ground motion. Accelerometers can measure ground motion frequencies down to 1- 2 Hz.

What circumstances triggered you to come up with this solution?

Since the earliest use of seismic data in hydrocarbon exploration, geophysicists have primarily concerned themselves with the apparent direction and speed with which seismic waves travelled through the earth. They have focused on compressional waves (P-waves) and treated shear waves (C-waves and S-waves) and near-surface waves (source-generated noise) as noise that need to be removed. Conventional 3-D P-wave seismic makes basic assumptions about the nature of the recorded wave-field that limit our ability to sufficiently image reservoirs and their associated fluids for maximum economic impact.

Because of these assumptions, we are faced with the fact that 3-D, as the technology is currently implemented, is beyond its first-generation success and is diminishing in its ability to add economic value. The diminishing usefulness of conventional 3-D technology directly affects our ability to find and develop

new economic reserves with acceptable risk. Perhaps more significantly, plans to extract additional hydrocarbons from existing fields suffer from the diminishing economic impact of current 3-D technology.

How does this work?

Unlike conventional 3D P-wave imaging, full-wave seismic imaging on land and on the seabed, involves (repeated and expanded from above):

- Faithfully recording the complete 3D ground motion from all seismic signals - P-wave energy, S-wave energy as well as source-generated noise (Conventional P-wave imaging measures only the vertical component of ground motion because it uses geophones, not multicomponent sensors)
 - Accurately measuring anisotropy for P-wave and S-wave energy, both for velocity and for amplitude (Conventional P-wave imaging makes limited measurements of anisotropy because typically far (enough) offsets are not recorded in the field and cross line offsets are much less than in line offsets (narrow azimuth surveys vs. wide azimuth surveys).)
 - Obtaining an unaliased sampling of the subsurface imaging objectives (Wide azimuth, long offset, multicomponent surveys that have sufficient receiver spatial densities to avoid aliasing the subsurface imaging objectives generate large mounts of raw seismic data. The field recording system must be able to handle the data generated by these surveys.)
 - Recording the full bandwidth of frequencies that the earth will return (Typically geophones are limited by their resonant frequency from recording frequencies lower than 10 Hz whereas accelerometers in digital sensors (such as VectorSeis receivers) can acquire frequencies down to 1 – 2 Hz. Likewise, geophones are typically deployed in field arrays which suffer from intra-array statics. These field arrays act as high-cut filters that effectively discard or filter out the highest seismic frequencies that are returning from the subsurface.)
- Of prime importance in full-wave acquisition is the field recording equipment. The technology foundations required for land full-wave imaging are high vector fidelity, three-component, single-point receivers such as VectorSeis® sensors, and high capacity land acquisition systems, such



as Input/Output's System Four™, capable of supporting the high spatial receiver densities and large channel count operations required by wide-azimuth and long- offset multicomponent recording. A significant corollary to the high-channel count and the sensor technology is the additional benefit of significantly improved operational efficiencies due to the incorporation of next-generation technologies in recording systems and single-point receivers. This corollary mitigates the cost impact and potential safety issues of high-channel-count operations. Full-wave seismic imaging has at least six general requirements:

1. High-vector fidelity, multicomponent (generally three-component), single-point receivers that preserve the relative amplitudes between components thus allowing successful vector-oriented processing
2. A wide-azimuth active 3-D field receiver patch to faithfully sample and record the azimuthally-oriented component of amplitude and velocity anisotropy
3. Field seismic survey offsets sufficiently long allowing at least 45 degrees of reflection angle. This angle is beyond the point where the assumption of a two-term velocity is necessarily valid and where the vertically oriented symmetry of anisotropy can become significant.
4. A sufficiently high channel-count acquisition system that can accommodate #2 and #3 above as well as allowing receiver spacing in the active field 3D receiver patch that avoids spatially aliasing the subsurface imaging objectives in either the P-wave or S-wave domains. This requirement does not require source-generated noise to be acquired in a spatially unaliased form, or to have the subsurface imaging objectives vastly over-sampled to address source-generated noise elimination.
5. Point-source and point-receiver acquisition to preserve as faithfully as possible velocity and amplitude anisotropy, especially given the acquisition of the long offsets at widely varying azimuths. Point sources and receivers also address requirements #6 below.
6. Faithfully recording and preserving the maximum seismic frequency bandwidth that the earth returns, with special considerations given to low frequencies. Because of the very deep targets now being explored where P-wave bandwidth is normally limited and because converted-wave data is already band-limited

and considering that high-resolution reservoir analysis using acoustic and elastic inversion normally requires high frequencies for resolution and low frequencies for compaction information and for a stable inversion

Three-component, high vector-fidelity, single-point receivers provide four significant benefits over conventional geophone receiver arrays:

- Extremely accurate measurements of all ground motion - both seismic signal and noise
- No directional bias, making them ideal for recording azimuthal variations in seismic velocities and amplitudes (anisotropy)
- Freedom from intra-array statics, providing higher bandwidth, higher resolution seismic signals
- Easily deployed, better coupled, with lower weight and bulk for improved field operational efficiency

High vector-fidelity receivers are required for the complete and accurate measurement of ground motion. By measuring this motion on three orthogonal axes, these receivers provide information that describes the apparent ground motion at the instant each sample was recorded. New generation MEMS digital receivers (P. Maxwell et al. 2001) such as VectorSeis fulfil these requirements. These sensors exhibit broad bandwidth, low distortion and tight sensitivity calibration, thereby contributing to the overarching term vector fidelity.

VectorSeis sensors are deployed as point receivers. The main reason for this is that single-point receivers lack directional bias; therefore

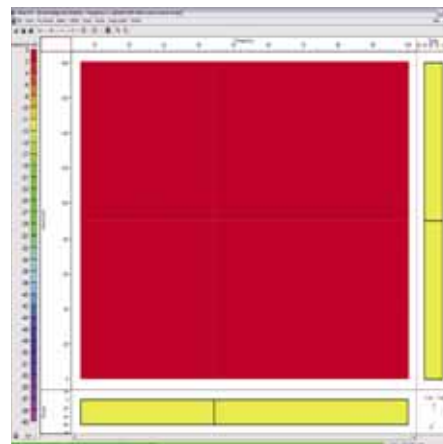


Fig 2a

they are uniquely suited for measuring the anisotropy of seismic signals both azimuthally and transversely. Figure 2a is a plot of recorded signal frequency (X axis), receiver array azimuth (Y axis), and attenuation (color scale), showing the complete lack of directional frequency attenuation for point receivers when using point sources. Figure 2b shows significant frequency and azimuth-dependent attenuation effects for a 12-sensor array and point source, assuming the seismic signal emergent angle is non-vertical. Higher frequencies experience greater attenuation effects, thereby reducing the reliability of anisotropy measurements. These signal frequency components are not recoverable; they are lost forever, thus reducing the bandwidth and resolution of the seismic images and impairing the accuracy of anisotropy measurements.

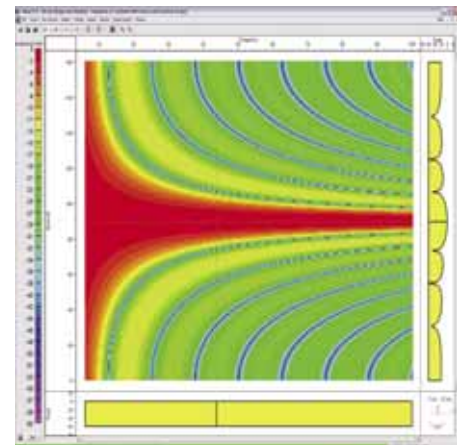


Fig 2b

What are your recent activities in the Middle East?

I/O is involved in projects in countries such as Oman, Kuwait, Saudi Arabia as well as the North African Arab counties such as Egypt and Algeria.

We conducted our first ME Seismic Technical Forum in February. It brought together nearly 50 executives and technical representatives from leading oil & gas companies, seismic acquisition contractors and research institutes to share knowledge on current industry trends and to discuss developments in next-generation seismic technologies, including digital full-wave imaging. We are already planning our second forum next year. ■