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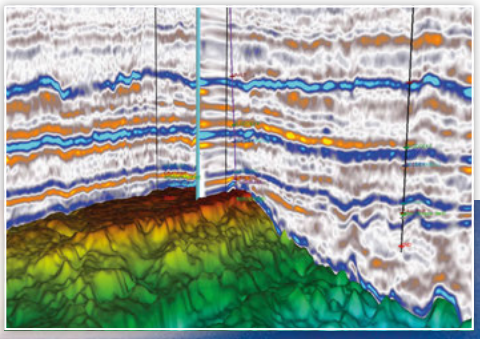

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INDUSTRY ISSUES

No Longer a Dream

Making Waves with Big Seismic Computing

BILL SHEA, Sharp Reflections

In 2006, a 'moonshot' R&D project was launched: to develop interactive software to visualize and process pre-stack seismic data.

To reach this impressive goal, researchers from Equinor (then Statoil) and Germany's Fraunhofer Institute embraced new 'Big Data' compute technologies first developed for manufacturing. Pre-stack specialist company Sharp Reflections successfully commercialized the disruptive technology, and today is again working closely with Equinor to automate analysis of time-lapse seismic to monitor production in maturing fields.

Fostering Innovation

Research and development are crucial to the survival of the oil and gas sector. According to Norsk Petroleum, competitiveness mixed with innovation has driven the Norwegian oil and gas sector forward since its inception. Never has this been more important than now, as the world questions the role of oil and gas in the energy transition.

The support provided by the Norwegian authorities for R&D has also gone a long way towards fostering the innovative atmosphere that exists in Norway's oil and gas sector today. Joint Industry Projects (JIPs) have played a key role in fostering long-term collaboration between oil and technology companies alike, allowing oil companies to pool support for projects with ambitious goals. The sense of 'inventiveness' that is fostered also provides room for pivoting or changing the scope as results and testing take place. Should projects find new, more innovative solutions than were originally intended, this can be encouraged, funded and commercialized.

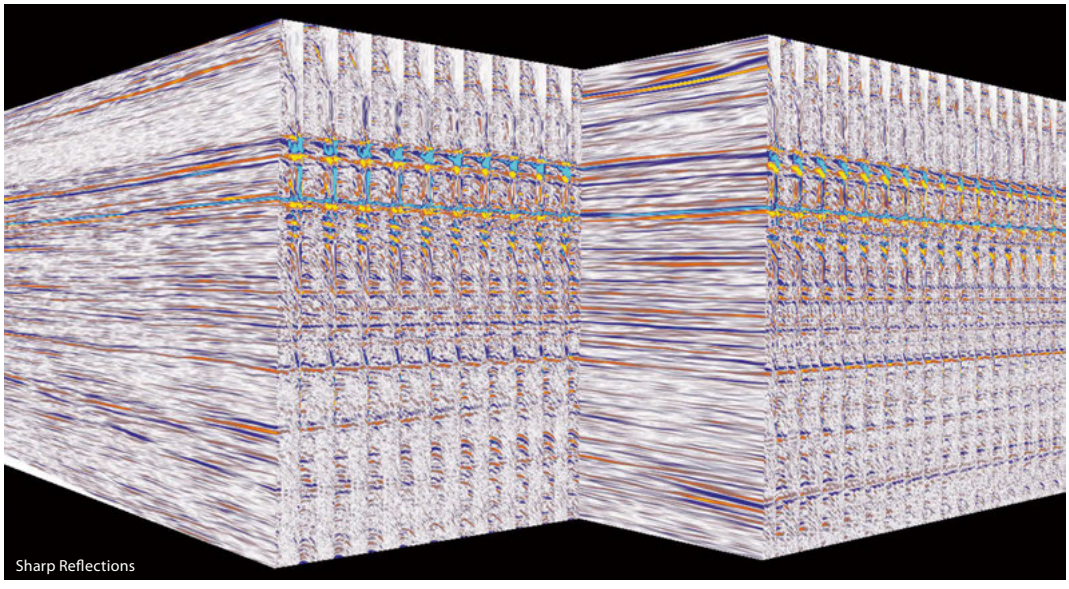
Crowd-Sourced R&D

The development of Sharp Reflection's commercial software *Pre-Stack Pro* provides a window through which it is possible to analyze how the innovative spirit of Norwegian oil and technology companies can be fostered to cultivate truly groundbreaking results. It was born out of an idea to explore potential oil and gas applications using the Fraunhofer Institute's High-Performance Computing (HPC) visualization technology. The adoption of new 3D seismic visualization technology powered by Silicon Graphics supercomputers was proven in the 90s, with entire 3D volumes being loaded directly to computer memory for interactive analysis. The new HPC technology had the potential to visualize much larger 3D datasets, using low-cost commodity computer servers.

Pre-stack gathers, which capture a complete high-fidelity image of the seismic amplitudes recorded by all geophones, looked like an obvious application for Big Data visualization. Depending on acquisition geometry, they are 10s to 100s of times larger than the equivalent full-stack volume: far too big to manipulate efficiently with standard desktop computers. As a result, pre-stack data were typically treated as an intermediate-stage processing byproduct, only rarely making it to the interpreter.

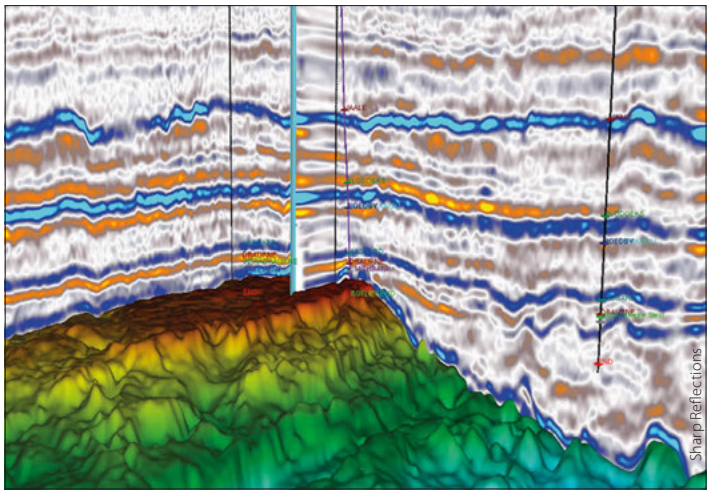
Seeing the potential of the project, the initial seed funds were provided by Statoil. In just a few months the team at the Fraunhofer Institute could import and load 1 TB of pre-stack gathers into memory and interactively roam through the entire data volume. Users could inspect the final processed gathers at any location in the entire survey and quickly assess data reliability. After just a few test projects, it was clear that the toolkit would benefit greatly by adding a small suite of high-value processing tools to improve data

3D pre-stack visualization of migrated seismic. Data can be viewed as angle or offset 'slices' or as traditional gathers, and are typically 10-100 times larger than a single stack volume.



quality. Seeing the long-term value of the research, Statoil launched a three-year strategic project to develop these tools.

Under the original scope, the R&D team delivered an advanced prototype with clear performance advantages. Stakeholders recognized that more effort and funding was required to develop a complete product and Sharp Reflections was launched. A JIP was formed to broaden the sponsor base, with Rock Solid Images (RSI) brought onboard as a development partner. RSI contributed a library of advanced geophysical algorithms that were adapted to the new compute engine, greatly accelerating the launch of the JIP's new commercial software, Pre-Stack Pro. This crowdfunding model established product-market fit and created a small core of early adopters committed to using the software on real datasets.



Today's 3D visualization canvas in Pre-Stack Pro. A nearly-unlimited number of 3D stack and attribute volumes can be loaded to memory on HPC clusters, and browsed interactively. Pre-stack gathers can also be accessed and displayed at specific locations. Data courtesy of Equinor.

True Interpretive Processing

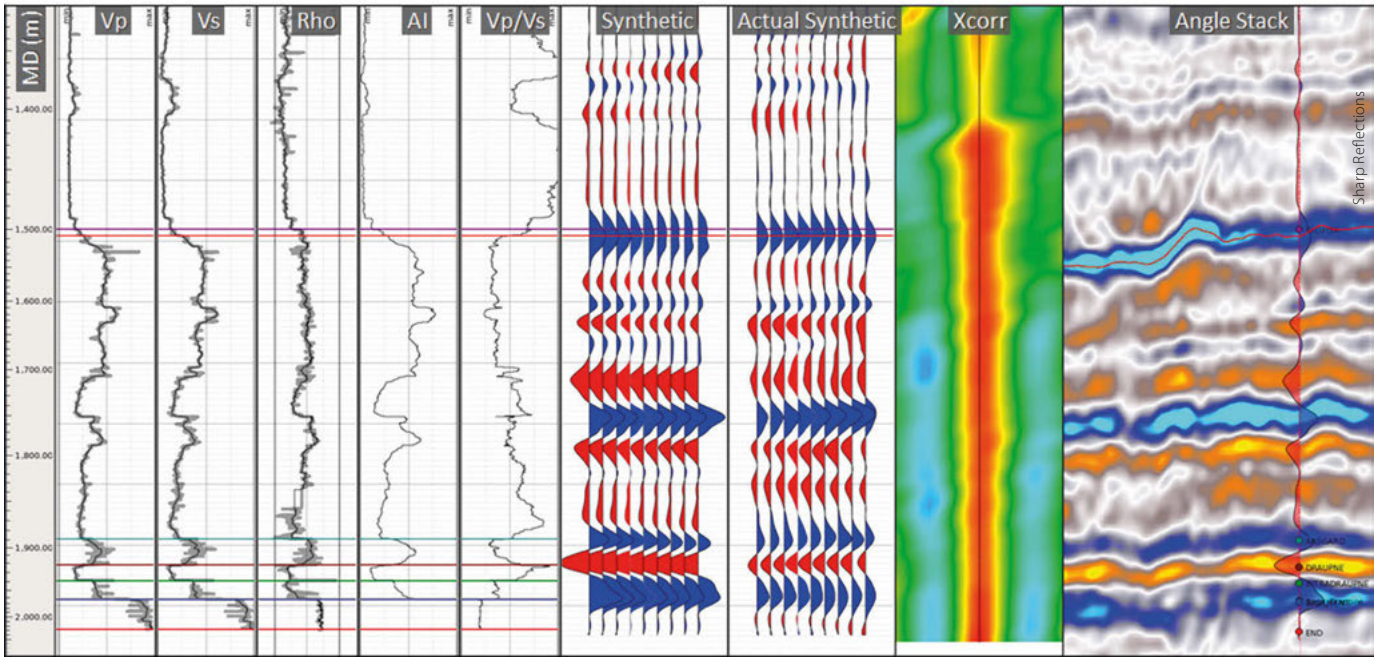
The technology quickly captured a small niche market among hard-core geophysicists seeking a 'light' seismic processing tool that could be used on multiclient 3D exploration surveys. Multiclient data typically require gather post-processing for AVO or pre-stack inversion studies, and Pre-Stack Pro provided a real-time, DIY solution. Many users had hands-on seismic processing experience, with the skills needed to tune processing workflows and optimize data quality for specific reservoir objectives. Through a series of funded foundation projects, these early oil company customers sponsored development of amplitude mapping, well calibration, and pre-stack seismic inversion tools to help de-risk prospects without switching applications. These developments began to blur the traditional boundaries between seismic processing and interpretation software, with a foot in both worlds.

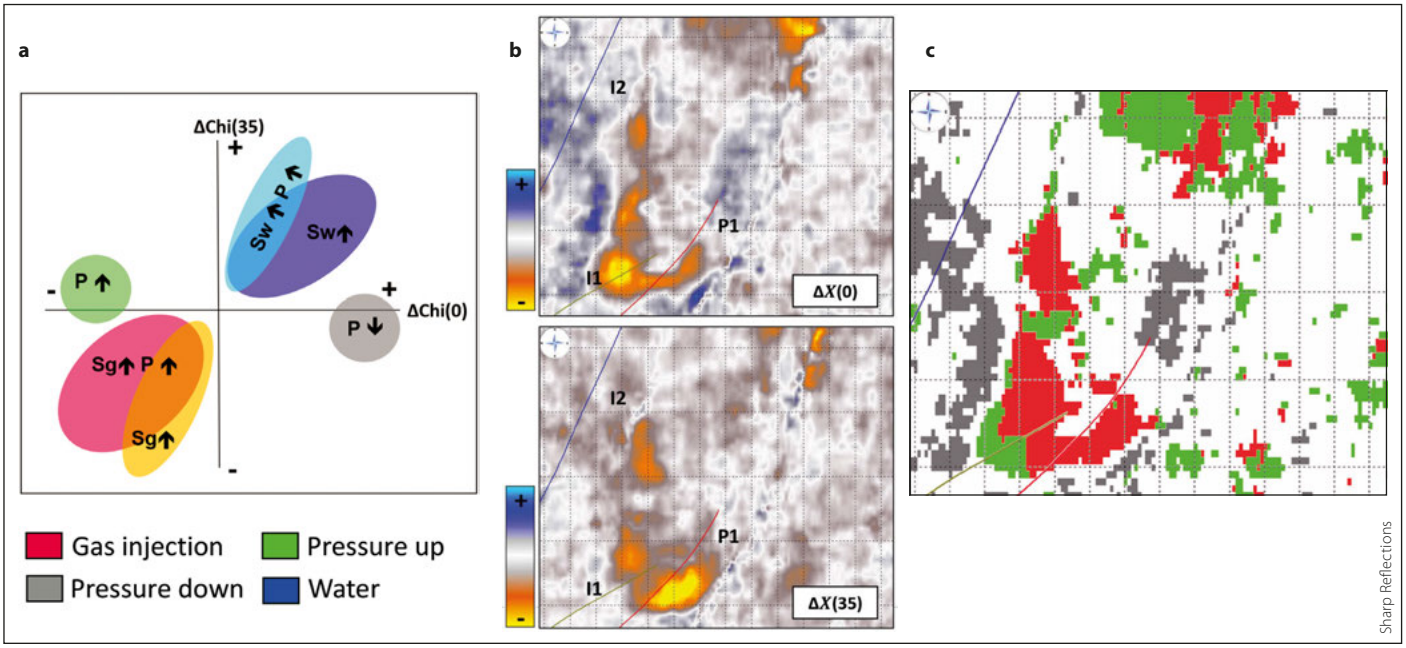
Recognizing the potential of the software beyond marine streamer acquisition, the pre-stack scope was extended. The Fraunhofer research team worked with Sharp Reflections to extend their pre-stack seismic data model, adding a second gather dimension to handle azimuthally-varying seismic data collected on land or with Ocean Bottom Node technology. This resulted in the development of new tools to automatically extract amplitude information from any angle of incidence and any azimuth direction and collect the results in a single five-dimensional seismic volume.

Best Practice Workflows, Brought to Life

Key advisors in Statoil's Production Subsurface Technology organization recognized that Pre-Stack Pro was increasingly

The new pre-stack well tie module. Actual and synthetic pre-stack traces are cross-correlated, providing quick visual feedback about the match quality. The tool eliminates the need to tie synthetics to each individual partial angle stack and simplifies calibration of seismic amplitudes in producing fields.





Quantitative analysis of pre-stack 4D amplitudes improve understanding of dynamic changes in producing reservoirs. (a) individual and combined pressure and saturation changes for water and gas each show a distinct 4D amplitude fingerprint on synthetic EEI models; (b) actual EEI differences for specific reservoir zones are calculated from pre-stack seismic; (c) EEI cross-plots are used to classify the changes according to the expected dynamic response. Data courtesy of Equinor.

used for routine seismic reservoir characterization tasks in producing fields. Nonetheless, critical 'feature gaps' remained. The companies signed a new exclusive R&D deal to plug these gaps and develop an efficient geophysical interpretation workflow stretching from seismic QC and data cleanup to full pre-stack inversion.

Major developments in the 'Efficient QI' (EQI) project included design of a new pre-stack well tie module and implementation of proprietary seismic inversion codes developed by Statoil and the Norwegian Computing Center (Norsk Regnesentral). This new solution had all the functionality required to design, build, run and calibrate the inversion, and to interrogate and extract maps from the 3D results. Statoil also facilitated IP transfer and encouraged the companies to establish a commercial partnership, which then secured Statoil's investment in advanced geophysical technology and a sustainable framework for future innovations.

Sonja Maultzsch, leading advisor for quantitative seismic analysis at Equinor, has already seen the R&D investment bear fruit. "The tools developed through the EQI project empower geophysicists throughout the organization to understand the quality of their pre-stack data and the associated AVO information, with the possibility of interactively evaluating quantitative interpretation products all the way through to pre-stack seismic inversion. This leads to a much more informed understanding of how quantitative interpretation can contribute to well planning or geomodeling projects for a given field and dataset. The threshold for working with quantitative analysis as part of interpretation workflows both in development projects and producing fields has been considerably lowered through the project."

Multidimensional Interpretation

Equinor users soon recognized that the new technology offers even greater benefits when applied to seismic reservoir monitoring, prompting the team to look again at the scope of the research. According to Sissel Grude Haug, R&D project manager for this project, which is still ongoing, small enhancements can make a big impact. "We see that minor improvements to the software can play an important role in analysis of time-lapse seismic data, both pre- and post-stack. By funding the development of these improvements, we ensure that our production geophysicists have the best tools at hand to properly understand and get the most out of their data."

Time-lapse 4D projects consist of a baseline survey and one or more monitoring surveys, generating multiple vintages of data that must be painstakingly acquired and processed to maximize repeatability, resulting in a veritable explosion in total data volumes. Full-angle and multiple partial angle stacks are produced for each vintage, and difference volumes are generated between each time-step and all previous vintages. Three monitoring surveys can create as many as 50 individual and difference volumes, which must be analyzed to yield a comprehensive picture of production-induced changes. Attributes and inversion results add further to the number of derived volumes.

Equinor researchers and 4D specialists now organize these time-lapse volumes into a 'pseudo' pre-stack data structure to create logical collections of volumes for each vintage. By exploiting the 5D data structure developed for multi-azimuth seismic, partial angle stacks for all seismic vintages can be grouped in a single, multidimensional volume. This greatly simplifies the organization

of the seismic database and opens the door to more digital automation. Routine tasks, such as computing maps showing all 4D differences on a specific reservoir horizon, can now be automated with just a few mouse clicks, and quickly compared to production data.

This multidimensional seismic framework also leverages all of the existing pre-stack tools to automate the processing, analysis and interpretation of multiple vintages of 4D data. Automation has also facilitated strategies to boost 4D signal by more aggressively attacking random and coherent noise on each vintage, using exactly the same processing parameters on each survey. This 'parallel stream' reprocessing has proven to boost signal in unswept or partially swept areas of fields.

Today, Equinor is using the new toolkit to quantitatively prize out dynamic changes such as pressure and saturation variations in the reservoir. One technique is 4D Extended Elastic Impedance (4D EEI), which mines and condenses the pre-stack data into weighted stacks that show varying contributions from pore pressure and hydrocarbon saturation effects.

As part of the Snorre field project, 4D EEI was used to optimally separate mixed pressure-saturation (gas and water injection) effects from pure pressure changes in the time-lapse data. This provided valuable understanding on how the Water-alternating-Gas (WAG) injectors are behaving and whether nearby wells are receiving enough pressure support. Improved understanding of dynamic changes allows engineers to optimize placement of producer wells in unswept areas and to optimizing injection rates and fluids of current injectors. According to Ming Yi Wong, a senior reservoir geophysicist at Equinor, "this saves me a lot of time and speeds up the 4D interpretation process, giving me more time to tackle essential technical issues."

To the Cloud – and Beyond!

Bringing the software into the public cloud was the logical next step for realizing the platform's important role in the digital transformation. Pre-Stack Pro has been successfully deployed in two large public computing clouds (Amazon and Microsoft Azure), so clients can carry out pre-stack analysis on some of the largest multiclient 3D datasets in the world without investing in their own HPC hardware.

Looking to the future of the sector, a new multidimensional seismic data structure is also likely to be adopted as a new standard by the Open Subsurface Data Universe, a major industry initiative to develop a standard data platform. High-dimensional seismic data is also expected to play an increasingly important role in seismic artificial intelligence.

Without early stage research and development support, small startups like Sharp Reflections have no hope of undertaking 'moonshot' projects. Crowdfunding and R&D tax incentives can play a vital role in allowing researchers to launch a project, transition from interesting idea to commercial product, and execute fast pivots to discover new applications of the core technology. ■