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Holistic reservoir characterization

This approach starts with raw digital data, data conditioning, and data fusion to create realistic 3-D reservoir models.

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Holistic reservoir characterization uses all available information to describe the reservoir properties, understand its ability to store hydrocarbons, and ultimately maximize the production. First, a clear goal of what to achieve must be established. For example, is the objective to learn about specific properties such as reservoir extent, architecture, porosity, permeability, and other parameters? Or do you want to plan infill and injection wells? Or do you want to monitor fluid flow?

The next step is to gather necessary geological, geophysical, and reservoir data and apply appropriate technologies to extract the reservoir properties. The final stage is to integrate and fuse individual data into a reservoir model for simulation, risk control, and production purposes.

One key element of holistic reservoir characterization is data quality.

Another key element is 3-D seismic data.

The last key element discussed here for holistic reservoir characterization is workflow. Good theories and algorithms are part of any successful project. An effective workflow is a must to conduct a project, meet the deadlines and ensure the quality.

Data quality and integrated database

Naturally, the first step in a reservoir characterization project is to gather all necessary data, preferably in digital format in a fully integrated database. Since geoscientists deal with different data types from geological, geophysical, reservoir, and engineering data, it is crucial to make the data available 24/7 and make sure the data quality is good before analyzing.

Many technical papers have been published to address the data quality issues for core, log, and seismic data. Geotrace has two systems: Diamond for seismic processing and imaging, and Tigress for database and interpretation. The latter is known for well and production data quality control and data conditioning before advanced processing.

For example, logs are corrected for borehole condition and environmental invasion before petrophysical analysis, while seismic data are conditioned for static and noises before processing and imaging.

To take full advantage of digital data, a seamless digital database with a user-friendly graphic interface and multidisciplined integration toolkit is very valuable — not only for holistic reservoir characterization, but also for any type of E&P project. Tigress has been used in many mission-critical projects by oil companies. The fully integrated database not only meets the requirements for storing all E&P data but also handles the data exchange with other systems.

Reservoir and fluid properties from inversion

To find and produce hydrocarbons in today's competitive E&P environment, the conventional reflectivity seismic data for mapping structure and identifying traps is no longer sufficient. It is vital to know much more about the rock formation and fluid type before

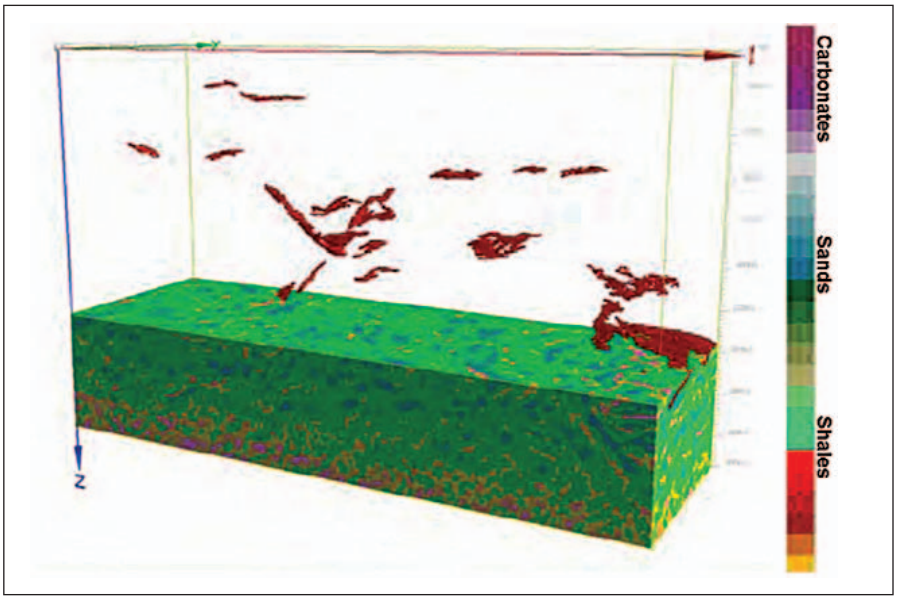

***Figure 1.** Reservoir characterization using lithology and fluid prediction from prestack seismic inversion calibrated with well, geological, and production data for lithology cube and pay 3-D geobodies with a minimum connectivity cutoff. (Images courtesy of Geotrace)*

drilling. Advanced technologies including Geotrace's RockRes apply prestack seismic inversion to predict the lithology and fluid types for better prospect evaluation and ultimately better production.

Prestack seismic inversion employs amplitude versus offset (AVO) theory to predict lithology and fluids. The earlier application of the two-term approximation of Zoeppritz equations, which use plane waves to describe the amplitude responses across the offset, is limited to shorter seismic offset or small incident angle. For modern seismic acquisition with long offset and large incident angle, it is more accurate to apply three-term approximation. Besides better approximation, it is essential that the input seismic data is high resolution (HR) to have good inversion. Geotrace has developed a technology called Bandwidth Extension (BE), which applies the theories of continuous wavelet transform and harmonics to achieve resolution that is beyond the conventional methods. By taking advantage of HR-enhanced data and carefully calibrating the prestack inversion with well data, geological data, and interpreted horizons, it is able to produce 3-D volumes of detailed P-wave velocity, S-wave velocity, and density that are respectively the proxy of sonic, dipole sonic, and bulk density logs. Moreover, other petroelastic parameters such as Bulk modulus, Shear Modulus, Young's Modulus, and Poisson's Ratio can also be derived for further rock lithology and fluid type identification.

One recent reservoir characterization project was performed in the Nile Delta, Northern Egypt, where proven gas reserves are estimated at 42 Tcf. The main reservoirs are deepwater plays of young Tertiary slope-channel complex. The reservoir distributionis mainly controlled by the hinge line created during the Cretaceous age through vertical aggradations of the shelf-edge along the steep fault-bounded shelf-slope break. The holistic reservoir characterization offers the client the needed information of lithology and fluid, not only for the reservoirs but also for the overburden and underburden formations. Figure 1 demonstrates the result of 3-D lithology and pay volumes from the project. The lithology volume is color-coded for sand, shale, and carbonates classification as well as for sand reservoir quality. The pay volumes of 3-D geobodies in red are extracted using proper cut-off ranges of density and Poisson's Ratio from the petrophysical evaluation of calibration wells. The 3-D geobodies with various rock and fluid properties can then be integrated to build the 3-D subsurface earth model for geological characterization and a reservoir model for reservoir characterization and simulation.

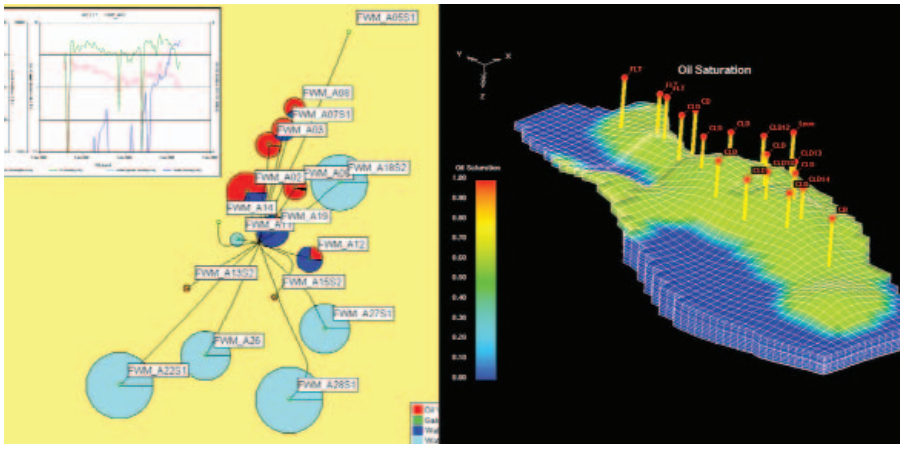

Figure 2. Production history per fluid type per well, production bubble map per field, and reservoir simulation per reservoir for history match.

Production workflow

Once all the original digital data are properly quality-controlled, conditioned, and integrated after processing and imaging, 3-D rock and fluid properties can be reliably predicted from inversion. The next step in the workflow for holistic reservoir characterization is to build the reservoir model using those 3-D volumes of predicted rock and fluid parameters that reflect realistic spatial distribution and heterogeneity. Thanks to the leading-edge technology of calibrated prestack inversion and statistical approach, which generates a range of properties, reservoir simulation can be tested with different scenarios from a statistical solution for better history matching with production data.

Furthermore, for better holistic reservoir characterization, 4-D seismic can be acquired to monitor the production and fluid front movement, further refining the reservoir model for production and cash flow management as illustrated in Figure 2.

Conclusions

There are many tools and technologies to help reservoir characterization. The holistic approach starts with raw digital data, quality control, and rigorous data conditioning to ensure data integrity before any processing and analysis. Next is the application of digital data fusion, such as calibrated prestack seismic inversion with well, geological, and production controls to accurately characterize the rock and fluid properties that truly represent the spatial distribution and the heterogeneity of a formation — 3-D subsurface models for reservoirs and surrounding rock formations to understand the geological setting. A detailed, realistic 3-D reservoir model can then be constructed for simulation and history matching to minimize the risk and maximize the production. Finally, the holistic reservoir characterization can employ 4-D seismic to monitor production and fluid flows, plan injection and infill wells, and detect any subsidence for well stability and damage control. This holistic reservoir characterization can be an invaluable methodology for E&P. E&P