Characterization of Fractured Reservoirs

Reliable, predictive models to optimize carbonate reservoir performance
Integrated approach: Improved performance.

Fossil fuels will account for 80 percent of the world’s primary energy mix in 2030—slightly less than today’s figures. With global energy demand and consumption forecast to grow rapidly during the next 20 years—and since the industry cannot guarantee new discoveries—a more realistic solution lies in sustaining production from existing fields. The vast majority of these reserves are trapped in fractured carbonate reservoirs. Therefore, it will be necessary to understand the fluid flow mechanisms of reservoir systems more fully to achieve optimum recovery.

Because carbonate reservoirs typically have a lower recovery factor than sandstone reservoirs, they offer great potential to increase production.

CARBONATES MATTER
A significant percentage of oil and gas reserves are trapped in fractured carbonate reservoirs—more than 60 percent of the world’s proven oil reserves and 40 percent of the world’s gas reserves. While increasing oil and gas production from carbonate reservoirs may not be the only solution to meeting forecast energy demand, it is clear that these reservoirs will play an increasingly important role in the future of our industry.

Carbonate reservoirs are considered to be extremely challenging in terms of accurate recovery prediction because of their complexity and heterogeneity. Most carbonate reservoirs are naturally fractured and contain fractures that can range from isolated microscopic fissures to kilometer-wide collections called “fracture swarms” or “corridors.” These fractures create complex paths for fluid movement which impact reservoir characterization, and ultimately, production performance and total recovery.
**OBTAINING FRACTURE ATTRIBUTES FROM SEISMIC DATA**

Q-Technology* single-sensor seismic hardware and software provides high-quality 3D seismic data for detecting and evaluating fracture properties between wells.

The effective density and orientation of diffuse subseismic fractures between wells can be interpreted from high-quality measurements and analyses of azimuthal seismic anisotropy—the variations in both the velocity and amplitude of seismic waves traveling in different directions.

Seismic attribute processing reveals subtle structural details in the reservoir on the order of a seismic wavelength. Curvature attributes are used to infer stress regimes which correspond to fracture density.

The FCM* fracture cluster mapping workflow employs discontinuity extraction procedures, such as “ant tracking” algorithms. When used in borehole-driven workflows these procedures automatically extract both fault patches—having scales on the order of kilometers, and fracture corridors having spatial extents of several hundred meters.

Calibrating the fractures—inferred from seismic features—to hard data derived from the borehole provides a measure of confidence to the geologist or reservoir engineer in building these features into a fracture model.

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**DFN MODELING—EXPLOITING FRACTURE CONNECTIVITY**

Seismic processing cannot provide information about the geomechanical and hydraulic properties of a fracture network. Therefore, it is not enough to simply map the statistics of the natural fracture system of a reservoir. It is the dynamic behavior of the fracture network that is critical to determine reservoir performance.

Petrel* seismic-to-simulation software combines information from multiple domains into a unified representation of the reservoir. The discrete fracture network (DFN) workflow is used to realistically model the dynamic behavior of the fractures that give rise to reservoir-scale and well-scale noncontinuous flow behavior. In the DFN workflow, each fracture is characterized by its physical properties such as surface area and shape, and each has specific fluid flow properties—of permeability, compressibility, and aperture.

A DFN model typically combines deterministic and stochastic discrete fractures. Deterministic fractures are observed using FMI* fullbore formation microimager borehole image logs and fracture corridors that are directly imaged through high-resolution seismic data using Q-Technology services.

Other, usually smaller-scale fractures that form diffuse fracture networks are generated stochastically to match their collective properties (density and orientation) observed through seismic data.

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*Images: In the section view above, the FCM workflow reveals many fracture clusters. The insert around the well shows good agreement between fracture intensity interpreted from an FMI log and that interpreted from 3D seismic data.*

*Streamlines in an ECLIPSE FrontSim reservoir simulation model containing two fracture corridors with an injector in the center and producers in each corner. Water saturation is displayed along the streamlines. The streamlines mostly follow the corridors while some move out of the corridor reflecting the matrix/fracture exchange for this model.*
INTEGRATED OPERATIONS

One of the many advantages of the DFN approach, using Petrel software, is that it integrates information from a wide range of sources including 2D and 3D seismic data, maps, outcrops, reservoir geomechanics, well logs, well tests, and flow logs, as well as structural or depositional conceptual models. A DFN model can contain millions of fractures at different scales.

ECLIPSE FrontSim software uses streamline simulation technology, allowing engineers and geologists to screen fluid flow in multiple fine-scale models, and validate upscaling to coarser-scale simulation models. The 3D simulation grid contains the fracture porosity, permeability, and sigma factor required for a dual porosity or dual permeability simulation. The upscaled models can be fed into ECLIPSE finite difference software to provide a rigorous full-reservoir simulation.

A SYSTEMATIC APPROACH

We generate high-quality inputs to the DFN model through our proprietary seismic data acquisition and data analysis services (Q-Technology services); our formation testing tools (MDT* modular formation dynamics tester tool); as well as our borehole image logs (FMI tool, OBMI* oil-base microimager tool, UBI* ultrasonic borehole imager tool, and Sonic Scanner* acoustic scanning platform).

The key to modeling fractured reservoirs is integrating a unique combination of data. Petrel software integrates multiple measurements of varying scale. It also supports an iterative workflow which allows the static description of the fractures to be coupled with the ECLIPSE* reservoir simulation software. This results in more reliable reservoir management decisions.

The quality of the model relies not only on the most accurate inputs, but also on the best interpretation—one that is tailored to your specific needs. Schlumberger Data & Consulting Services (DCS) applies extensive experience in modeling naturally fractured reservoirs around the world to every project using a systematic approach and a system of internal reviews that ensure the quality of our service.

DCS provides centers of excellence staffed with experts in the fields of geology, geomechanics, and reservoir engineering—all essential skill sets for accurate fracture modeling. In addition, the VISAGE* stress analysis simulator relates rock stress to reservoir properties for better prediction capability.

Our systems and technologies provide reliable, predictive models of notoriously complex reservoir systems. Because every naturally fractured reservoir is unique, the combination of our experience, systematic approach, and focused engineering efforts means we deploy optimal fracture models. Through this approach we are improving fracture characterization across all scales of operation, enhancing competency and performance in many areas including well planning, and drilling and production optimization.
FRACTURES IN FOCUS
There are several significant factors to note when considering fractures in carbonate reservoirs:

- They typically strike and dip in the same direction.
- Their productivity is related to their density, aperture, and connectivity.
- They vary in size, both horizontally and vertically.

Fracture corridors can be distinguished from diffuse fractures. The density and orientation of fractures in diffuse fracture systems can be measured with high-definition seismic surveys that uniformly sample the offset-azimuth continuum. These provide collective information that is used to construct a stochastic model which describes the geometry and properties of the fracture network.

In contrast with diffuse fractures, fracture corridors consist of thousands of parallel fractures densely packed together to form a volume that is typically a few meters wide, a few tens of meters high, and several hundred meters long. Fracture corridors act as highways for fluids in the reservoir and knowledge of their exact position enables dynamic reservoir simulation to give reliable results.

THE SOLUTION: AN INTEGRATED APPROACH
Production rates and volumes are also influenced by fracture network flow characteristics between producing wells. However, analytical tools originally designed and developed for clastic reservoirs measure fracture properties only in the vicinity of the well(s) and attempt to predict the distribution of fractures based on indirect observations or assumptions. In naturally fractured carbonate reservoirs, these methods will not provide sufficient data to define the entire reservoir framework.

The development of these reservoirs requires an approach that can directly sample the entire reservoir to obtain the best possible understanding of the fracture corridor network and its impact on the fluid flow within the reservoir. This includes how the dynamic stress regime (geostress) within the reservoir affects permeability. This can be achieved using an integrated approach of advanced seismic processing and DFN modeling—a workflow that considers discrete fracture networks—to provide a complete seismic-to-simulation workflow.
Characterization of Fractured Reservoirs

Naturally fractured reservoirs present many challenges. The uncertainties relating to the size of the physical structure and the fluid content of the reservoir make understanding fluid flow unpredictable.

Schlumberger uses a unique combination of modeling and visualization techniques to simulate fracture properties providing a more complete understanding of the reservoir and its fluid flow mechanisms.