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TerraTek TRA Tight Rock Analysis Services

Characterization and completion design of unconventional reservoirs

APPLICATIONS

- Unconventional, tight (low-porosity and low-permeability) reservoirs
- Evaluation of petrological, petrophysical, geochemical, and mechanical drivers of reservoir production
- Determination of gas in place (free and adsorbed) in core
- Assessment of reservoir quality and production potential
- Evaluation of completion quality, fracturability, and rock-fluid sensitivity
- Discrimination of mudstones by type and degree of reservoir quality
- Analysis of heterogeneous, anisotropic mechanical properties
- Analysis of rock-fluid sensitivity, including loss of fracture conductivity over time
- Core-to-log integration for propagation of core-measured properties across the field using logs
- Basin-scale heterogeneous property models for mapping regions with good reservoir and completion qualities (sweet spots)
- Integration of data obtained at multiple scales (core, sample, log, and field)
- Material property model definition for extrapolation of core-based properties across the field with logs alone

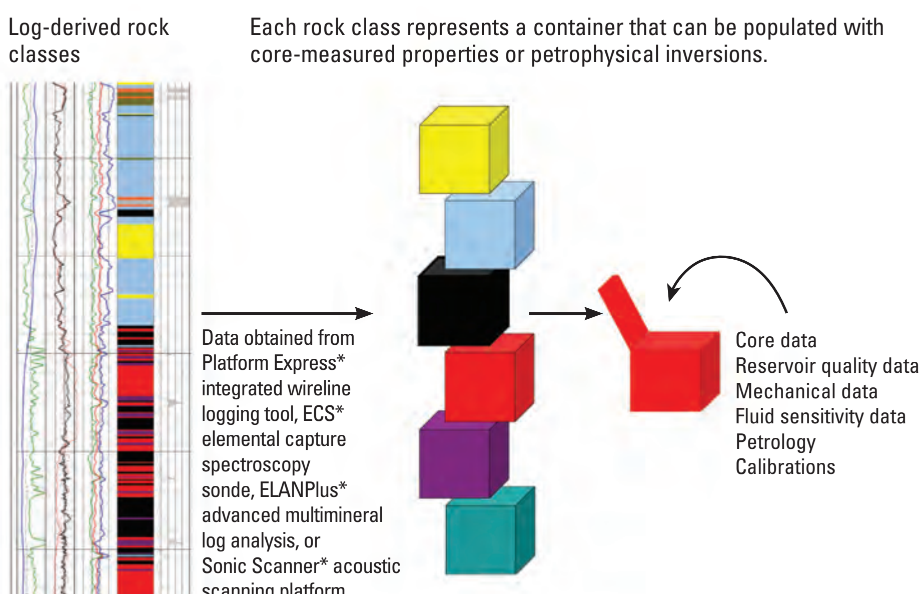
Successful production through reservoir and completion quality

Although unconventional tight reservoirs are geographically extensive (making them easy to find) and have relatively simple structural architecture and stratigraphic continuity, they are composed of a number of lithofacies that change in thickness, regional distribution, and stacking patterns, making them challenging to understand on many levels.

Some of these facies have reservoir potential whereas others do not. The building block lithofacies are primarily variations of argillaceous, siliceous, calcareous, and transitional mixtures of these end-member matrix compositions. However, these facies vary in depositional texture, organic content, and clay and kerogen maturation.

Additional complexity is created by rock fabric at different scales. Microlamination due to sediment deposition gives rise to a high degree of mechanical anisotropy. On a larger scale, the presence and distribution of mineralized natural fractures affect the ability to hydraulically fracture these formations, as well as generate fracture complexity to increase fracture surface area. Successful production in unconventional reservoirs depends on a combination of high reservoir quality and high completion quality.

Unfortunately, some conditions that are conducive to high reservoir quality (e.g., high organic content and high pore pressure) are also responsible for high horizontal stress, making them difficult to fracture. The building block lithofacies may not have stress containment barriers to vertical fracture propagation. In addition, fracture surface area, while easy to produce, is typically hard to retain, resulting in loss of fracture conductivity and hence loss of well production. Thus, the challenge is to understand heterogeneous formations for maximizing production.



Each rock class identified by the logs defines a container that can be populated with multiple, equally well-constrained core-measured properties. When these facies are subsequently recognized through logs alone in uncored wells, their inferred core-equivalent properties can be extracted from associated containers. With this approach, vertical and lateral changes across a field can be delineated properly.

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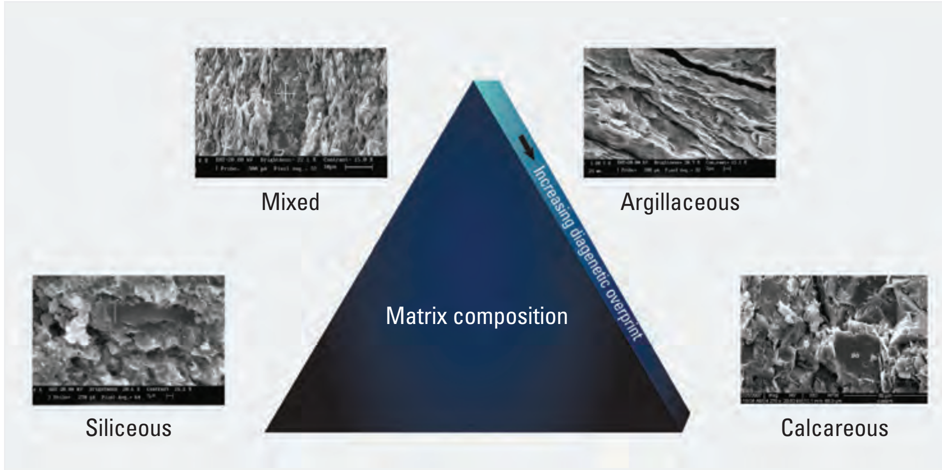
BENEFITS

- Maximized well productivity by understanding vertical and lateral heterogeneity of reservoir quality and completion quality along the well path
- Increased recovery from knowledge of reservoir quality and completion quality
- Enhanced coring efficiency by predefining a sampling strategy for the field based on logs
- Evaluation of reservoir quality based on hydrocarbon-filled porosity, permeability, organic content, maturation, and pore pressure
- Evaluation of completion quality based on fracture containment, fracturability, and rock-fluid sensitivity

FEATURES

- Resolution of nano- to microdarcy permeabilities
- Resolution of pore-fluid saturations and types in low-porosity rocks
- Measurement of effective porosity separate from total porosity
- Integration of core-, log-, and seismic-scale heterogeneities
- Population of measured properties throughout the field using logs and development of a heterogeneous earth model (HEM), a regional-scale representation of heterogeneous rock properties



Rock texture and composition are fundamental properties that affect reservoir and completion quality. Mapping reservoir units with the best combined conditions identifies reservoir and completion quality across the field.

TerraTek TRA* tight rock analysis services integrate comprehensive evaluation of core geology, mineral and organic petrology, geochemistry, reservoir properties, and mechanical properties to determine two fundamental requirements for successful production from unconventional reservoirs: reservoir quality and completion quality. Monitoring well productivity alone without understanding these properties leads to ambiguous interpretations of the data and erroneous conclusions.

Reservoir quality evaluates and ranks the productivity potential of the various lithofacies in the play. Properties defining reservoir quality are measured in the laboratory on core samples, and after core-to-log integration, are propagated across the field based on log (and seismic) measurements. These properties define the reservoir potential and cannot be altered by field operations.

Completion quality reveals the potential for creating and retaining adequate surface area for production. Properties affecting completion quality are more difficult to measure and predict, so evaluations are sometimes of lower confidence than those of reservoir quality. However, completion quality can potentially be modified from bad to good by changing the hydraulic fracturing treatment conditions.

Identification of productive shales, optimal fracture zones, and treatment design

Fundamental properties affecting reservoir quality are rock texture and composition, hydrocarbon in place (interstitial and adsorbed), permeability, organic content and degree of maturation, and pore pressure. Other relevant parameters such as pore fluid saturation, clay type, and clay-bound water are indirectly reflected by the above fundamental properties. Thus, most prolific gas-bearing units are identified based on measurements of

- total gas—canister desorption and a combination of adsorption isotherms and tight rock gas-filled porosity
- petrophysical properties—porosity, permeability, pore fluid saturations (water, gas, and mobile oil), clay-bound water, and bound hydrocarbons
- petrological properties—depositional texture, matrix composition, and organic type, content, and degree of maturation
- geochemical properties—organic content, type, and degree of maturation.

Fundamental properties affecting completion quality are rock texture and composition, mechanical anisotropy, surface hardness, tensile strength, creep, contrast in the horizontal stress regime, contrast in fabric, presence of weak interfaces, and rock-fluid

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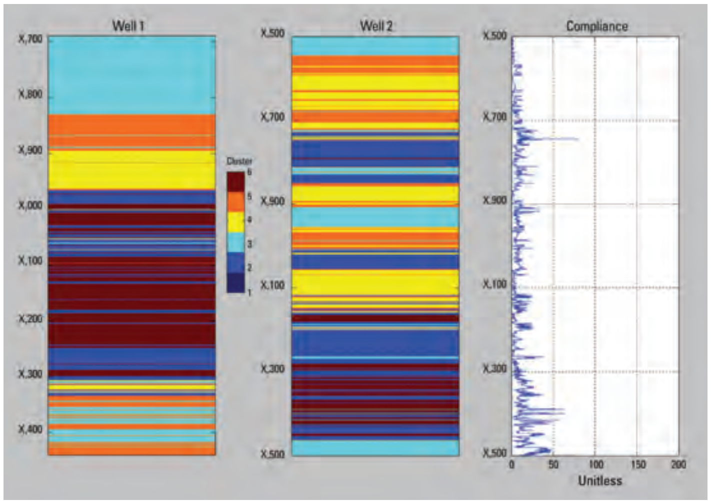

Heterogeneous reservoirs are composed of a number of dominant rock classes that change laterally in thickness and stacking patterns.

sensitivity (e.g., softening). Other relevant properties, such as proppant embedment, fracture conductivity, imbibition, and water trapping, are indirectly reflected. Thus, reservoir classes with high completion quality are identified based on measurements of

- mechanical properties—elastic and acoustic anisotropy, tensile and compressive strength, surface hardness, fracture toughness, and creep
- magnitude and orientation of the horizontal stress and variability between reservoir and nonreservoir units
- presence, orientation, and filling of weak interfaces and bonding units on cores
- optimal orientation between weak interfaces, mineralized fractures, and maximum horizontal stress (for developing fracture complexity and maximizing surface area during hydraulic fracturing)
- conditions of surface area retention after hydraulic fracturing, including rock-fluid sensitivity (e.g., softening), solids production (e.g., tensile spalling), proppant embedment, water retention, and decrease of fracture conductivity as a function of stress
- conditions of fracture-face reduction of permeability (imbibition).

Treatment design is optimized by mapping regions with the best combined conditions of reservoir and completion quality across the field.

Sample-, core-, and log-scale heterogeneities

Unconventional reservoirs are heterogeneous and strongly anisotropic. Thus, analysis of the spatial variability of material properties and core-log relationships is critical. *N*-dimensional TerraTek HRA* heterogeneous rock analysis services for logs and high-resolution, continuous strength profiles along the core length provide the measurements required for evaluating sample-, core-, and log-scale heterogeneities and for developing scaling relationships. The analysis also optimizes core sampling and sample location for adequate cost-effective representation of material properties.

Laboratory testing of cores also provides the calibrations for transferring the knowledge gained from the core-testing program to other wells using logs, seismic data, or both. Predictive models are developed with the laboratory-measured data for subsequent evaluation of lateral heterogeneity and mapping of reservoir and nonreservoir lithologies (rock classes) along the basin. The evaluation is typically conducted based on multiwell log data (through heterogeneous rock analysis) and enables mapping of all properties relevant to reservoir and completion quality along the basin. In addition, when 3D seismic data is available, it is used to better propagate data between wells.

Rotary sidewall plugs (SWPs), whole cores, or rock fragments (cuttings) are required to measure relevant properties and relate them to log responses. Sampling of all relevant nonredundant lithologies (i.e., reservoir and nonreservoir classes) is fundamentally important for subsequent analysis of reservoir productivity, hydraulic fracturing containment, and retention of surface area. TerraTek TRA services for analyzing rock classes provide a mathematically precise method for selecting the extent of the region to be sampled (top and bottom depths for coring), depth location, and number of SWPs. The services also aid in determining the depth location of rock samplings (cuttings) required for laboratory testing. Having the results of multiwell or seismic heterogeneous rock analysis prior to coring helps in selecting the best well locations to core.

Results

- Description of fundamental reservoir properties (geological, petrological, petrophysical, geochemical, mechanical, fluid sensitivity, and in situ stress)
- Continuous estimate of productivity potential along the various reservoir units, differentiating degrees of quality between them
- Continuous estimate of hydraulic fracture containment, indicating whether fracture containment is possible
- Estimate of loss of fracture conductivity and fracture surface area
- Alternative designs (single- or multiple-stage treatments) to mitigate lack of containment
- Continuous evaluation of candidate reservoir sections for refracturing
- Improved geologic reservoir model

Once laboratory data is measured, statistical analysis of relevant reservoir and completion quality is conducted at the rock-class level to develop the reference model. These properties are then used to populate the basin-scale model using well logs, seismic data, or both.

Geological model

Geological and stratigraphic models are difficult to construct in unconventional reservoirs because of the high variability in the basin and the low resolution of the traditional tools used to develop these models. TerraTek HRA services aid in defining stratigraphic boundaries and provide improved definitions of the architectural basin classes.

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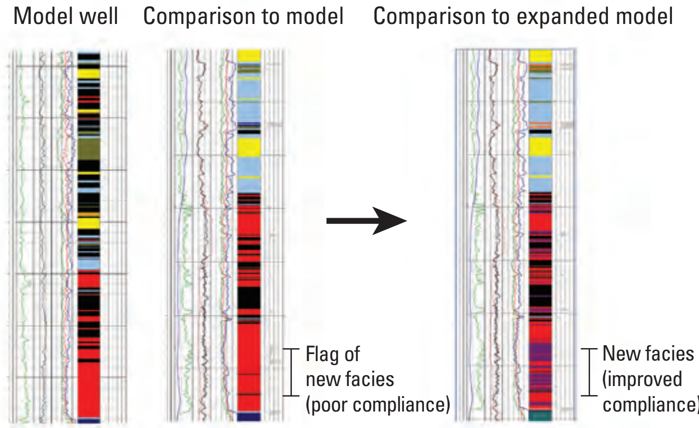
Heterogeneous rock analysis and development of the backbone data model

In a heterogeneous system composed of a number of dominant rock classes with well-defined material properties, the goal is to identify these classes (i.e., the building blocks of the system), sample them, and measure their properties. The initial evaluation program is designed to identify these building block lithofacies. Results help define the sampling strategy.

The second stage of the project consists of laboratory measurements on core and subsequent data analysis. It is designed to comprehensively characterize material properties of both the reservoir and nonreservoir rock classes. Core-to-log integration is the process by which the laboratory- and log-measured values are related to each other to develop a reference heterogeneous rock analysis model for subsequent population of rock classes identified through log analysis alone. Heterogeneous rock analysis is a mathematically precise method for identifying rock classes defined in a reference well (e.g., wells with core) and comparing them with a subsequent well. The analysis also outputs a measure of the degree of similarity (compliance) between bulk-log responses of the two wells.

Analysis of compliance enables recommendations for subsequent coring and is a means for quantifying the overall confidence on the basin-scale model. Typically, the model may start with few wells and have a high degree of confidence limited to the neighborhood of the cored wells. As new samples are obtained and the reference model is updated, the region of confidence increases. Knowing the statistical distribution of all measured properties for each rock unit enables further development of the backbone data model. This heterogeneous earth model (HEM) provides necessary input data for any subsequent analysis or numerical modeling (e.g., production prediction and ultimate recovery in ECLIPSE* reservoir simulation software or mechanical stability evaluations in VISAGE* reservoir geomechanics modeling software).



Identification of new facies not appearing in a model well is done by evaluating the compliance between the model well and any subsequent well. When a new facies is identified, it can be isolated, added to the model, and recognized going forward.

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