

<div><div>5</div><div>10.811</div><div>E</div><div>EVALUATION</div></div>	<div><div>23</div><div>50.942</div><div>X</div><div>X-RADIATION</div></div>		
<div><div>16</div><div>32.065</div><div>P</div><div>POSITION</div></div>	<div><div>5</div><div>10.811</div><div>E</div><div>EDUCATION</div></div>	<div><div>18</div><div>39.948</div><div>R</div><div>REALISATION</div></div>	<div><div>20</div><div>40.078</div><div>T</div><div>TRANSFORMATION</div></div>
	<div><div>9</div><div>18.998</div><div>I</div><div>INNOVATION</div></div>	<div><div>19</div><div>39.098</div><div>S</div><div>SOLUTION</div></div>	<div><div>5</div><div>10.811</div><div>E</div><div>EXPLORATION</div></div>

# UNLOCKING UNCONVENTIONALS

SUPPORTING THE GLOBAL ENERGY REVOLUTION

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# UNLOCKING UNCONVENTIONALS

## SUPPORTING THE GLOBAL ENERGY REVOLUTION

The global energy demand reached an all-time high in 2014 and will continue to increase in the decades to come. At the same time production from conventional reservoirs has reached a historical maximum and is steadily declining. Accordingly, the oil and gas industry is turning its attention more and more towards exploration and production of unconventional reservoirs. And with success!

Production from unconventional reservoirs used to be non-commercial due to their complexity and ultra-low permeabilities. Advances in drilling and completion technologies, however, have turned them into economically viable resources. Consequently, in the past decade oil and gas production from shale plays has revolutionized the US energy market. This economic success has triggered global interest in unconventional resources, leading to the discovery of vast reservoirs on every continent. But how do we define unconventional?

### CONVENTIONAL OR UNCONVENTIONAL?

Originally, the difference between conventional and unconventional reservoirs was an economic distinction, i.e. economic versus uneconomic. In conventional reservoirs, hydrocarbons are generated from organic-rich source rocks and migrate to porous reservoir rocks with relatively high permeability, where they are trapped below a sealing caprock. This high permeability makes the hydrocarbons easy to extract.

Unconventional reservoirs, on the other hand, comprise a broad group of reservoirs characterized by low permeability and low porosity, including source rocks with such low permeability that the hydrocarbons are trapped inside the source rocks. Because of these characteristics, unconventional reservoirs require stimulation to recover commercial oil and gas volumes. Consequently, production from unconventional needs extensive reservoir characterization and modeling and more engineering manpower.

### TERMINOLOGY

The terminology describing unconventional reservoirs used to depend on the author or company or geographical area of the resource, causing some confusion. SGS uses the following terminology:

**Shale gas and shale oil** – Hydrocarbons that are generated from mature, organic-rich source rocks and have been retained within the source rocks.

**Tight gas and tight oil** – Hydrocarbons that have migrated from their source rocks and are trapped in reservoirs with low porosity and very low permeability.

**Coal bed methane** – Gas that is naturally present in coal layers, adsorbed in the coal matrix. Decreasing the water pressure allows the methane to desorb from the coal, after which it can be extracted from the reservoir.

**Bituminous sands** – Also known as oil sands or tar sands, they consist of loose sands or partially consolidated sandstones saturated with a dense and viscous form of petroleum called bitumen.

**Oil shale** – Consists of immature, organic-rich rock containing kerogen. Converting the kerogen into oil requires pyrolysis.

**Gas hydrates** – Clathrate compounds in which the host molecule is water and the guest molecule is a gas. They occur naturally in large quantities in the deep ocean floor and permafrost.

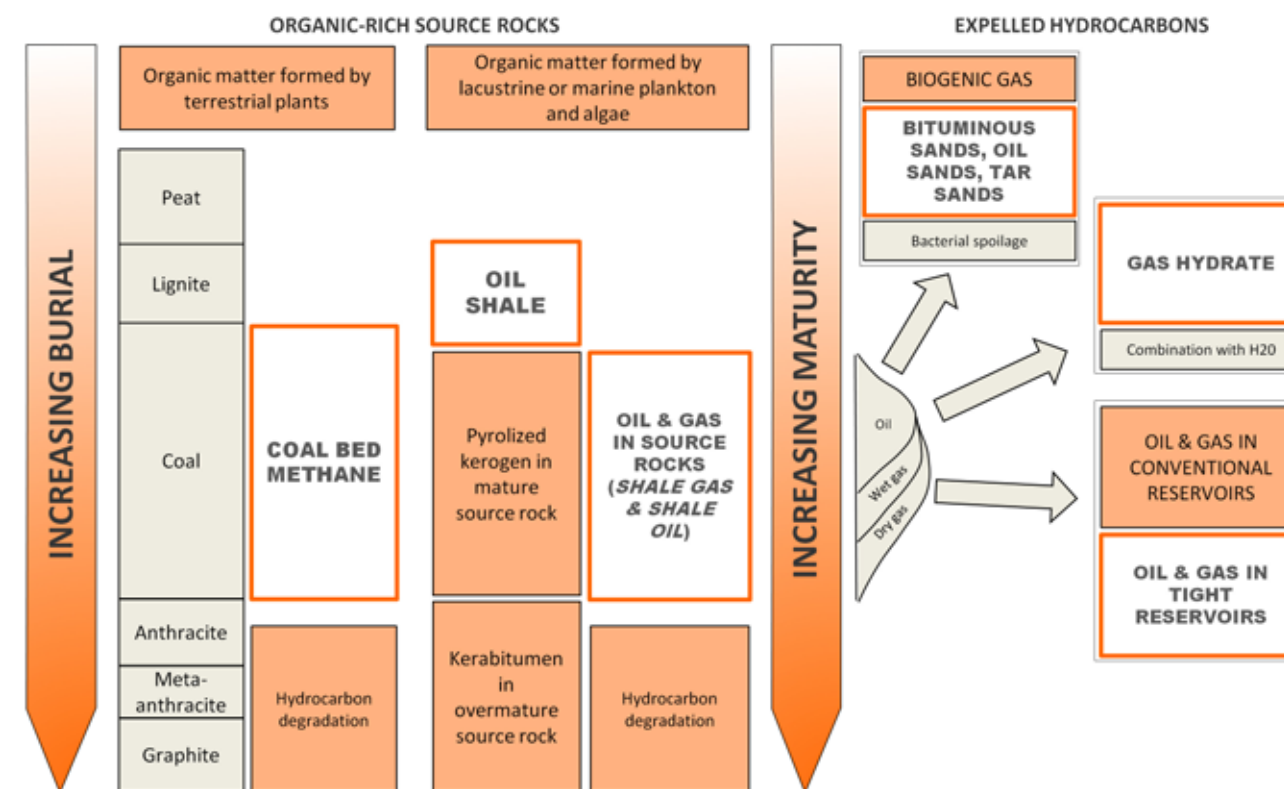
### SGS SERVICES

With the recent commercial success of oil and gas production from shales and the discovery of vast unconventional reservoirs, we have come to realize that the potential of unconventional is tremendous. The challenge the industry now faces is to optimize the methods for exploration and development of these unconventional resources, to unlock their potential and meet the energy demand of the future in a responsible and efficient way.

SGS is the world's leading inspection, verification, testing and certification company. Recognised as the global benchmark for quality and integrity, we employ over 80,000 people and operate a network of more than 1,650 offices and laboratories around the world. SGS is providing services and solutions for every part of the oil and gas industry and offers independent services from the upstream to the downstream sector.

**SGS HORIZON** – Founded in 2001, SGS Horizon became part of the SGS Group in April 2008, giving us more than a decade of knowledge and experience in a wide range of oil and gas regions, settings, and environments. SGS Horizon provides integrated subsurface studies covering every phase of the lifecycle of oil and gas fields, from early exploration to development planning and production. In these studies expertise in a variety of disciplines is combined, including seismic processing and interpretation, geology, petrophysics, and reservoir and well engineering.

In light of the developments in the energy market in the past decade, SGS Horizon utilized the vast resources and expertise across the SGS group to develop innovative analysis methods and workflows specifically to meet the challenges encountered in unconventional reservoirs. With customized solutions adding valuable information for optimized field exploration and development, SGS Horizon is determined to continue to service the oil and gas industry as it moves into the new world of unconventional.



# MULTI-SCALE SHALE CHARACTERIZATION

## UTILIZING THE FULL POTENTIAL OF EXISTING DATA

Shale reservoirs are among the most prospective unconventional resources globally, holding vast amounts of oil and gas. Production from shale, however, is challenging due to low permeability in combination with its heterogeneous and anisotropic nature. The currently applied methods for evaluation and characterization of shale reservoirs are based around modern and comprehensive data sets, including dual sonic logs and core data. In practice, these data are often not available for shale zones.

To provide evaluation and characterization of shale plays in the absence of modern data sets, SGS Horizon, in collaboration with SGS ARQS and SGS INTRON, has developed the Multi-scale Shale Characterization service. In this customizable workflow, innovative analytical methods performed on drill cuttings are used to obtain direct measurements of key reservoir properties. The results are integrated with logging data and seismic for upscaling and multidimensional reservoir mapping and modeling. By utilizing the full potential of old, existing data sets, the Multi-scale Shale Characterization service provides the means to assess the hydrocarbon potential and delineate sweet spots of unconventional shale plays in the absence of modern logging data and cores.

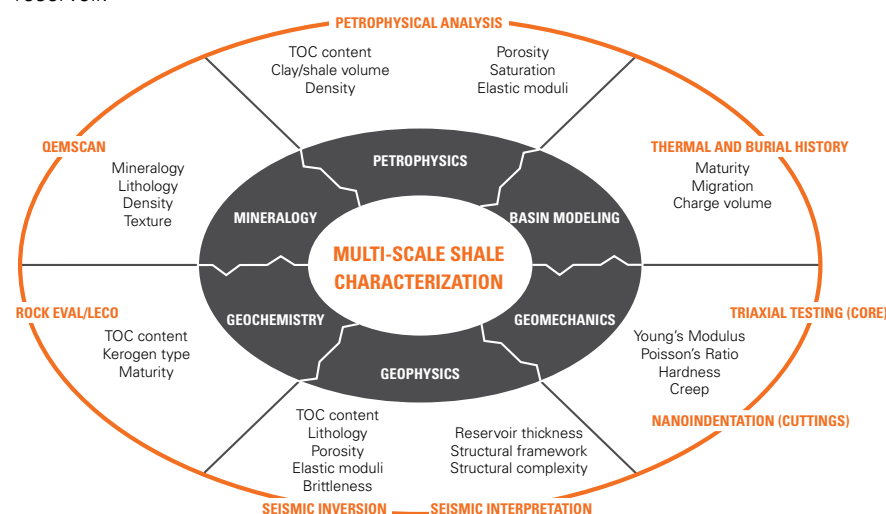
### FROM DRILL CUTTINGS TO RESERVOIR MODEL

The quality of a reservoir model is directly correlatable to the quality of the input data. To ensure high-quality input data, the Multi-scale Shale Characterization workflow combines different cutting-edge analytical methods on drill cuttings to provide direct measurements of rock properties. LECO carbon analysis and Rock Eval are used to analyze the organic geochemistry, including the TOC content, maturity, and kerogen type. QEMSCAN provides quantitative mineralogical analysis of drill cuttings, and is combined with nanoindentation to determine the mechanical properties of the shales. Natural fracture networks are identified and mapped using high resolution CT-scanning, and the porosity and permeability are measured using the latest laboratory techniques. Combining the different rock properties allows for a comprehensive characterization of the shale reservoir.

The analytical results obtained from drill cuttings are integrated with logging data and seismic. The logging data are analyzed using petrophysical evaluation techniques, adjusted for shales and supported by drill cutting data, providing upscaling and characterization on well scale. Seismic interpretation is used to determine the geometry of the reservoir and provides additional information on the distribution of key reservoir properties in 2D and 3D. All these data serve as input for a multidimensional reservoir model dedicated to assessing the hydrocarbon potential of shale plays and delineating the vertical and lateral continuity of sweet spots in the reservoir.

### IMPROVING FIELD EXPLORATION AND DEVELOPMENT

The Multi-scale Shale Characterization service is applicable to both single well and multi-well studies, as well as studies at reservoir scale. Due to its customizable workflow, the service can be used for different applications. As the workflow is based around existing data sets, it is the ideal tool for re-evaluation of existing well data prior to the planning of expensive data acquisition programs and provides support for investment decisions. The service helps to guide field exploration and development planning through the identification of



sweet spots and problematic zones in the reservoir. Combining the workflow with production data allows for well and field production analysis and helps explaining unexpected production issues.

By using innovative methods for analyzing existing well data, the Multi-scale Shale Characterization service reduces the need for modern logging data and cores, offering a cost-efficient solution for comprehensive characterization and evaluation of unconventional shale plays.

### TRACK RECORD

The Multi-scale Shale Characterization workflow has been developed and tested over the course of several studies in different areas, including Europe and Northern Africa. The results of these studies confirmed that reliable values for the rock properties can be obtained using analytical methods on drill cuttings and can be integrated with logging data and seismic for a reliable evaluation of shale plays.

SGS performed two asset evaluation studies for shale sections in Northern Spain, comprising structural evaluation, geochemical and mineralogical characterization, basin modeling, and sweet spot delineation. The project deliverables included a 3D model for distribution of the reservoir properties, a resource statement, the geological risk assessment, and the probability of success.

A multi-well study was performed for the Silurian Hot Shales of Algeria. In this study, drill cuttings from 5 wells were used to determine the geochemical parameters, mineralogy, texture, and mechanical properties. The results were integrated with logging data and used for well correlation. Based on this the shale gas opportunity was confirmed, stratigraphic subdivisions were made, and sweet spots within the reservoir were identified.

A single well evaluation was performed for the Toarcian Shales of the Paris Basin, France. Core samples from different depth intervals were subjected to different analytical methods to determine the rock properties of the shales. The core data were upscaled through integration with logging data. The results were used for a comprehensive characterization and analysis of the vertical heterogeneity.



**INTEGRATION OF INNOVATIVE ANALYTICAL METHODS ON DRILL CUTTINGS WITH LOGGING DATA AND SEISMIC OFFERS UNIQUE INSIGHTS INTO THE COMPLEX CHARACTER AND RESERVOIR PROPERTIES OF UNCONVENTIONAL SHALE PLAYS, ADDING VALUABLE INFORMATION THAT REDUCES UNCERTAINTIES AND SUPPORT THE OPTIMIZATION OF FIELD EXPLORATION AND DEVELOPMENT.**





# GEOCHEMICAL SERVICES

## LABORATORY ANALYSIS AND CONSULTING

Petroleum Geochemistry is a relatively young science with rapidly developing technologies and applications. SGS Horizon works at the forefront of geochemical technology and offers a full range of geochemical services. SGS applies geochemistry on a regional, field and well scale and is experienced in the integration of geochemical data with the results from geological and mineralogical and petrophysical studies.

Regional scale geochemical studies include source rock evaluations, oil-to-source rock correlations and hydrocarbon habitat studies. On a field scale, our geochemists address reservoir architecture and reservoir continuity issues and gather information on fluid contacts and fluid properties. SGS also applies geochemical technology for single well evaluations: not only for conventional exploration and appraisal well evaluations but also for identification of pay-zones in unconventional reservoirs.

### PETROLEUM SYSTEM ANALYSIS

A petroleum system analysis consists of three main elements: (1) a source rock evaluation, (2) an oil-to-source rock correlation study and (3) a reconstruction of the burial history.

SGS geochemists have integrated the three elements of a petroleum system analysis in different geological settings and bring a global perspective to every regional study. Petroleum system analysis starts with source rock screening, a deceptively simple but often challenging task, particularly at high maturity levels. In addition to routine TOC screening and pyrolysis (Rock Eval) based analyses, SGS geochemists use a wide range of analytical tools, including biomarker analysis, compound specific isotope analysis and visual kerogen analysis to characterize source rocks in terms of type and maturity. By

integrating the results from bulk and molecular parameters, the geochemists are able to distinguish source effects from maturity effects and reconstruct the original source potential of the source rock. Source rock kinetic parameters are acquired to understand source rock conversion as a function of temperature, and to define the oil and gas windows in depth.

Until recently, the main application of source rock studies was to quantify the charge risk of undrilled exploration prospects. But as a result of the rapid increase in shale gas output in the US and Canada, source rocks all over the world are now being reassessed for their potential as oil and gas prospects. At the advanced levels of maturity that are required for shale gas generation, only a limited number of geochemical parameters are effective and SGS makes use of diamondoid distributions and where possible, regional maturity data to supplement the pyrolysis based measurements.

### GEOCHEMICAL FINGERPRINTING FOR FIELD SCALE STUDIES

Geochemical fingerprinting is routinely applied for production allocation and for assessing reservoir continuity. Hydrocarbons in separate reservoir units within a single accumulation often show small differences in molecular and isotopic composition.

The compositional differences of oils can be quantified with High Resolution Gas Chromatography (HRGC) and visualized in so-called oil fingerprints. For quantification of differences between gas reservoirs, SGS makes use of Gas Chromatography Isotope Ratio Mass Spectrometry (GCIRMS). Geochemical production allocation has been proven to provide accurate results, also where 'conventional' metering becomes difficult, for instance in cases of high water production or with very 'uneven' production splits. Even well integrity issues, such as the identification of annulus gas, can be effectively solved with geochemical fingerprinting based on carbon isotope analysis.

### SINGLE WELL EVALUATIONS

The identification of pay intervals and fluid contacts is a first priority in all exploration well evaluations. SGS uses a number of specialized geochemical analyses for well evaluations, ranging from advanced mud logging to fluid inclusion screening and solvent extract analysis. Early estimates of fluid properties like gas oil ratio and API gravity are made based on hydrocarbon show detection and help select intervals for down-hole fluid sampling and well testing. Geochemical technology also plays an important role in evaluating appraisal wells: questions about reservoir connectivity are addressed by geochemical fingerprinting, which can even be carried out on cuttings samples.

Extrapolation of common fluid contacts across the field is achieved by integration of pressure data with geochemical fingerprinting.

In tight and in shale gas reservoirs, the successful identification of pay zones relies to a large degree on the results from advanced geochemical mud gas logging. Wells that test unconventional hydrocarbon plays are generally drilled outside a structural closure and the well evaluations depend on the identification of (minor) hydrocarbon shows. The evaluation of unconventional wells requires the integration of (compositional and isotopic) data from PVT samples, with the continuous data streams from the well site gas chromatograph or mass spectrometer. As a result, unconventional well evaluations have become geochemical data intensive and the interpretation has become the responsibility of trained specialists using dedicated interpretation software.

### LABORATORY SERVICES

SGS and partners are running worldwide numerous stationary and mobile laboratory units, serving the Oil & Gas Upstream and Downstream sector as well as the environmental industry. Our core competences are the PVT laboratory analyses and crude oil essays. SGS laboratories also perform on a routine basis geochemical laboratory analyses (e.g. TOC, Rock Eval, GCMS) as well as high resolution isotope analysis.

SGS laboratories offer production chemistry services such as fluid compatibility analyses, core flood system analyses, rheology and emulsion studies to support Enhanced Oil Recovery (EOR) and chemical EOR (cEOR) studies. SGS offers integrated chemical and geochemistry services comprising of high quality standard and ISO compliant laboratory analyses, certification and comprehensive interpretations and study reports.

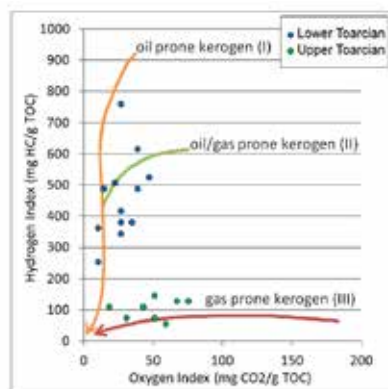
### TRACK RECORD

SGS Horizon performed an advanced fluid characterization and geochemical review of geochemical fluid and rock analysis studies, on 4 wells in offshore Sabah, Malaysia. In the course of the study the fluid compositions, whole oil gas chromatography & biomarker mass spectrometry and Multi-Dimensional-Gas-Chromatography (MDGC) data were analyzed and interpreted. The purpose of the study was the detection of vertical and lateral fluid composition variations and the correlation to source rocks.

SGS Horizon performed an evaluation of the exploration potential of a large block area offshore Oman. The study included the seismic processing and interpretation and the detailed subsurface evaluation, as well as the development of hydrocarbon play concepts, and prospect identification. During the course of the study the analysis of the basin subsidence history, the identification of hydrocarbon source rocks and the modeling of their maturation history was performed.

In the course of two asset evaluation studies of the shale gas potential for several shale sections in the Basque-Cantabrian Basin, Northern Spain, SGS Horizon performed the structural evaluation and the geochemical and mineralogical characterization of the source rocks and shales. In order to identify the shale gas "sweet spots" the maturation history of the shales were evaluated and modeled. Based on the results, a quantitative resources evaluation and the evaluation of economical exploitation of the under-explored organic rich formations of the Basque-Cantabrian Basin were conducted.

SGS Horizon performed a joint research project with the scope to establish a laboratory analysis and 2D/3D modeling workflow, in order to establish and distribute a shale facies model for Silurian shales in SW Algeria. All laboratory analyses such as mineralogy (QEMSCAN), SEM, TOC, Rock Eval and high resolution CT scans (Computer Tomography) were performed on a large number of cutting samples from five wells. The analysis data were correlated with wireline logs, and lateral distribution trends of the shale characteristics were established and provided sufficient information for a reliable prediction and delineation of gas shales.





# MINERALOGY AND TEXTURE

## SGS ADVANCED RESERVOIR QUALITY SERVICES

The SGS ARQS group provides applied mineralogy services that are optimized for the oil and gas industry. Using a host of techniques, it specializes in mineralogical, textural and geochemical analyses. Having worked in basins all over the world, our dedicated mineralogists are able to assist in virtually any form of reservoir whether it be characterization of stacked sand bodies in SAGD operations for oil sands operators, identifying and delineating zones within a seemingly homogenous unconventional shale gas reservoir, identifying a scale build up on a down-hole pump, defining macro porosity values in a conventional carbonate play, or calibrating geophysical log responses in an illitic clay rich tight sand reservoir.

ARQS does this through the use of a combination of industry-leading analytical tools, leveraging the strengths of each technique. These include:

- automated mineralogical modal x-ray dispersive based tools such as QEMSCAN
- clay speciation determinations using fractionated samples in XRD
- high resolution scanning electron imaging and analysis by SEM
- large scale mineralogical characterization of cores using hyperspectral imaging
- high volume bulk elemental analysis using XRF and ICP-AES
- trace elemental investigations using ICP-MS

- niche and routine analytical methods are available

Using specialist preparation techniques, almost any form of medium can be analysed including core plug offcuts, archived drill cuttings, sediment impregnated water filtration pads, to production tubing that has become clogged by scale and sediment.

It is important to fully understand the strengths and limitations of each technique that is being employed. Our team of experienced geologists and mineralogists are proficient in explaining the strong points of each technique and can assist in designing an analytical program optimized to the project requirements and required deliverables. Additionally the ARQS group prides itself on client contact during the analysis and once a report is submitted. An option exists with each report to integrate existing or multiple data from various aspects of the project so as to ensure the most is being extracted from performed analysis.

### TEXTURAL MINERALOGICAL ANALYSIS

Understanding the rock matrix is a core value in petrophysical or wireline interpretation studies. Minerals intrinsically control fundamental petrophysical parameters such as grain density and directly or indirectly influence many of the wireline responses e.g. density, resistivity, spontaneous potential, gamma ray etc. In addition, mineralogical controls on rock and engineering properties are of mounting

importance as the dependence on tight and / or unconventional resources such as oil and gas shale and oil sands increases. Therefore, accurate and reproducible determination and quantification of the mineral assemblage is of critical importance in reservoir characterization, well evaluation for completion optimization, and ultimately, the selection of a drilling location.

- Techniques used by ARQS are quantifiable, accurate and repeatable
- Quantitative mineralogy and lithology for calibration against multi-mineral models from petrophysical analysis
- Visualisation of the rock fabric which allows for determination of authigenic and detrital mineral phases, their distribution and their influence on reservoir quality.
- Clay and carbonate speciation, occurrence, origin and swelling index which are important factors in the performance of stimulation techniques.
- Textural information. This is integral to the delineation of units within complex heterogeneous reservoirs
- Identification of mineralogically and lithologically distinct zones for well-to-well correlation
- Matrix density values calculated from actual mineralogy for log calibration and more accurate porosity calculation
- Textural data for vertical and lateral depositional trends, sedimentary processes and environment of deposition

### INTEGRATED RESERVOIR CHARACTERIZATION

All analyses provided by SGS ARQS are offered as standalone services, however, in most cases a combination of different techniques is required to achieve the certainty demanded by our clients. In a similar fashion, ARQS can incorporate knowledge already garnered from prior learnings into the analysis. The integration of datasets can, in some cases, serve a cost saving measure, but mostly it is performed to increase the confidence in the analysis being undertaken or alternatively, highlight areas where different techniques are

not in agreement. Integrated reservoir characterization may also be required where limited datasets are available, such as the evaluation of an uphole completion zone which was not encompassed in the original wireline logging program.

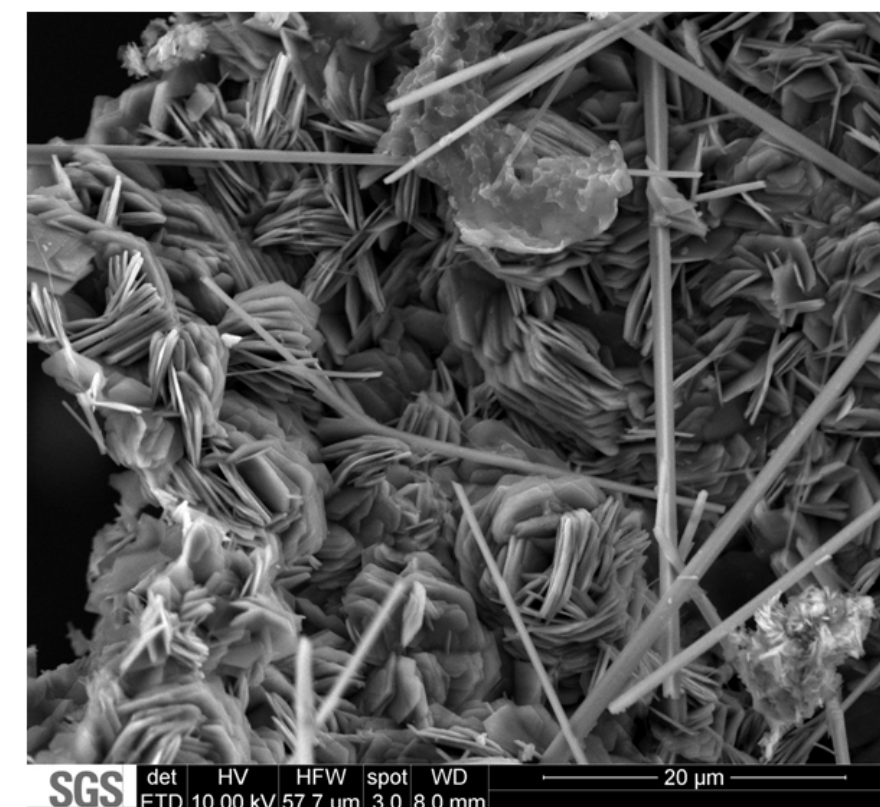
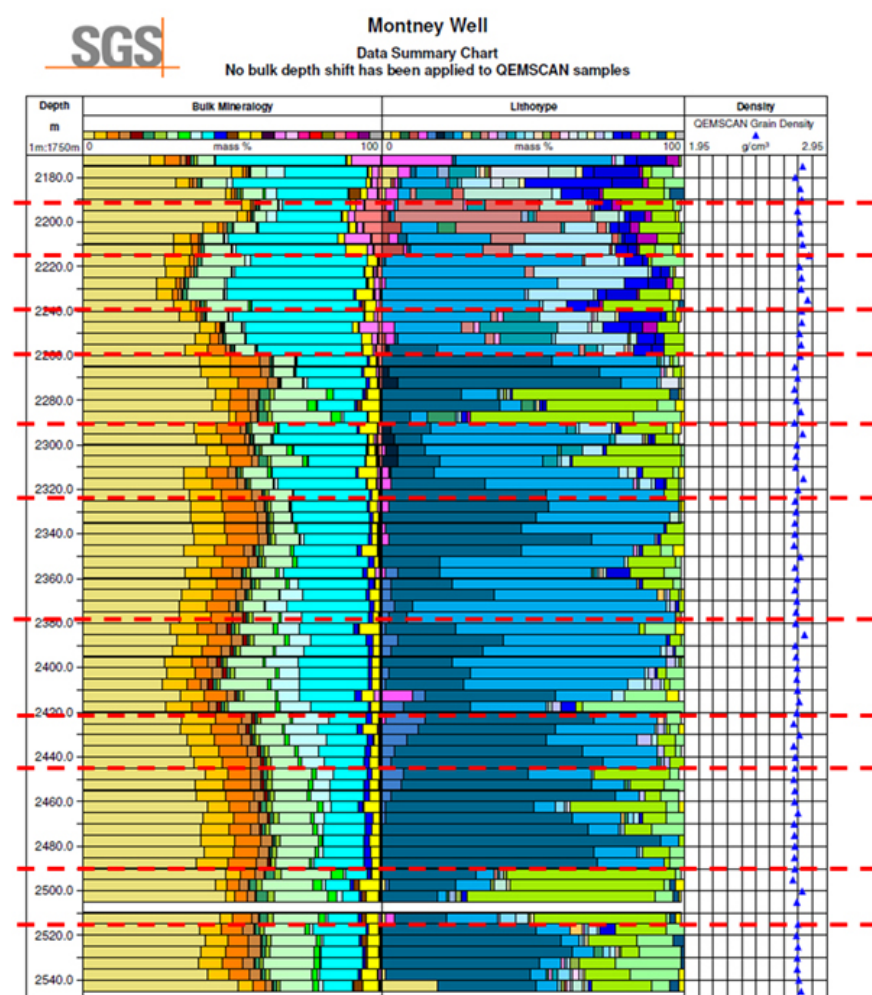
### OPTIMIZING UNCONVENTIONAL ANALYSIS

A key challenge in exploration and production from unconventional is dealing with the compositional and textural complexity and the associated variation in rock properties. Comprehensive characterization of the mineralogy and lithology is therefore essential. Since running complex wireline logs and cutting core in the horizontal legs is operationally difficult or in some cases cost-prohibitive, there is often limited geological data available to support well evaluation and reservoir characterization. Using high resolution techniques much of the same information generally gathered from conventional core studies can now be extracted from drill cuttings.

QEMSCAN also plays an important role in our unconventional service, and is an integral part of the SGS Multi-scale Shale Characterization Service, developed to provide characterization and evaluation of unconventional plays. In this workflow, QEMSCAN is used to determine the mineralogy and texture of shale reservoir rocks through the analysis of drill cuttings, which, when combined with other techniques, forms the basis of a comprehensive characterization of the reservoir.

### TRACK RECORD

SGS's team has an extensive track record with more than a decade of experience in providing applied mineralogical analytical services dedicated to the oil and gas industry. Clients include national oil companies, independent oil and gas operators, university departments and research institutions from the world over. ARQS has successfully performed applied mineralogy in exploration, evaluation and trouble shooting studies in conventional, oil sands, carbonate, unconventional and oil and gas resources globally.





# MICRO ROCK MECHANICS

## THE QEMSCAN-NANOINDENTATION APPROACH

Production from shale reservoirs relies on hydraulic stimulation, and consequently mechanical analysis of the reservoir rocks is a key part of exploration. Its importance is emphasized by the fact that after more than a decade, 25 % of all hydraulic stimulation operations are ineffective, mainly due to an incomplete understanding of the subsurface<sup>1</sup>.

Due to their heterogeneous and anisotropic nature, the mechanical behavior of shales is different to that of conventional reservoir rocks. Understanding the mechanical behavior of shales therefore requires a comprehensive evaluation of the mechanical properties and deformation processes. The methods currently used in the evaluation of a reservoir's mechanical properties are limited by the availability of high quality data such as tri-axial core analysis and dipole sonic logs. To optimize field development and production, new methods and technologies are required to accurately predict the mechanical behavior of shale reservoirs during hydraulic stimulation based on existing well data.

Building on the expertise of SGS Horizon, SGS ARQS, and SGS INTRON, SGS has developed a unique approach for the mechanical analysis of shale, by combining QEMSCAN with nanoindentation for the analysis of drill cuttings. This integration of the mechanical properties with the mineralogy and texture, offering new

insights into the mutual relations between these properties, and is essential for understanding and accurately predicting the mechanical behavior of the heterogeneous and anisotropic shales.

### PIONEERING THE USE OF INNOVATIVE TECHNOLOGY

Nanoindentation is the most promising technology in the field of innovative mechanical analysis methods for unconventional. Developed in the material sciences, it is used to determine the mechanical properties of small samples, making it perfectly suited for analysis of drill cuttings. During nanoindentation measurements, a hard tip with known mechanical properties is pressed into the sample. By simultaneously measuring the load applied on the indenter and the displacement of the indenter into the surface, the mechanical properties are determined and the deformation processes are analyzed. Nanoindentation thus provides direct measurements of

the mechanical properties, overcoming the lack of high quality core samples and modern logging data sets.

SGS has pioneered the use of nanoindentation in shale reservoir studies, developing a unique approach for interpreting nanoindentation data. This approach stands out in its ability to integrate all parameters obtained from nanoindentation measurements, providing the most detailed mechanical analysis currently available in the oil and gas industry. In this approach, the data obtained from nanoindentation measurements are plotted in load-displacement plots. From the elastic response of the sample, the Young's Modulus and the hardness are determined, after which the work-of-indentation approach is employed to determine the plastic and elastic work areas, giving information on the active modes of deformation. Finally, the amount of creep (i.e. deformation under constant pressure) is measured, providing a direct indication of the brittleness. All these parameters are combined in a comprehensive

study of the mechanical behavior and used to estimate the hydraulic stimulation potential, which is key in the identification of sweet spots within the reservoir.

### INTEGRATED RESERVOIR CHARACTERIZATION

Our nanoindentation services are incorporated in the SGS Multi-Scale Shale Characterization workflow, developed specifically for the evaluation of shale reservoirs based on the analysis of drill cuttings. In this workflow, nanoindentation is combined with QEMSCAN analysis, which allows for a detailed integration of the mineralogy and texture with the mechanical behavior. This integration enables us to distinguish between the different constituents of the heterogeneous shales and adjust the mechanical analysis accordingly by handpicking the most representative drill cuttings for the nanoindentation measurements. Our expertise in utilizing QEMSCAN-supported nanoindentation ensures high-level analysis of the mechanical behavior and more accurate assessment of the hydraulic stimulation potential.

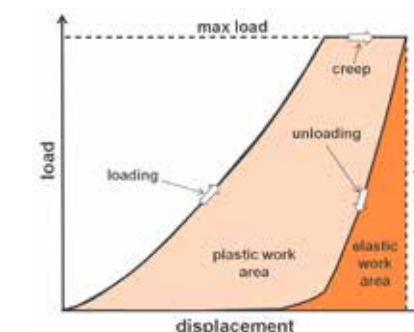
The results of the QEMSCAN analysis and nanoindentation measurements are combined with results of geochemical and structural analyses on drill cuttings to give a comprehensive characterization of the reservoir. The cuttings data are upscaled through integration with log data and seismic for assessment of the hydrocarbon potential and identification of sweet spots in the reservoir.

### TRACK RECORD

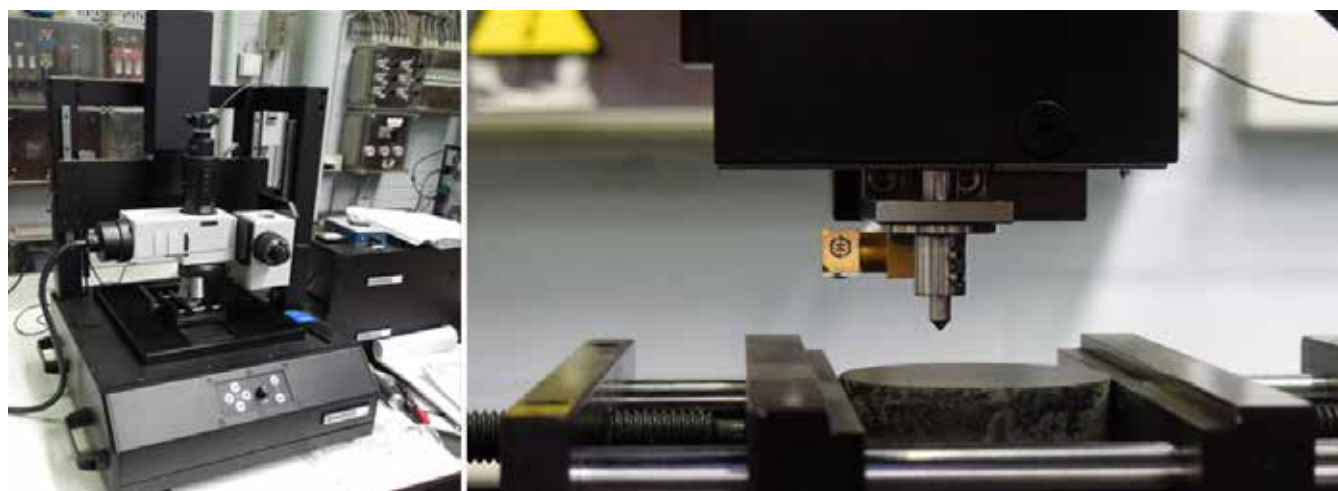
SGS has pioneered the use of nanoindentation on shales, perfecting the technique over the course of several studies.

In one of our most recent studies, the QEMSCAN-nanoindentation approach was used on drill cuttings samples from the Silurian Hot Shales of Algeria. With the results we were able to determine the effect of a varying mineralogy on nanoindentation measurements and to distinguish between different lithotypes based on nanoindentation data.

For a single well evaluation of the Toarcian shales of the Paris Basin, France, the QEMSCAN-nanoindentation approach was used to determine the mechanical properties of both core samples and fragmented core samples and compared with triaxial test data. The results allowed us to determine the effect of mineralogical heterogeneity and shale anisotropy on nanoindentation measurements. The close match between the nanoindentation data and the triaxial test data validated the use of nanoindentation on drill cuttings.



**NANOINDENTATION, COMPLEMENTED BY QEMSCAN, PROVIDES UNIQUE INSIGHTS INTO THE MECHANICAL BEHAVIOR OF SHALES, ENHANCES OUR UNDERSTANDING OF THE SUBSURFACE AND REDUCES THE UNCERTAINTIES IN THE SHALE PLAYS AND SUPPORT FIELD DEVELOPMENT, STIMULATION AND PRODUCTION**



<sup>1</sup> Welling & Company (2012) - Hydraulic Fracturing Report



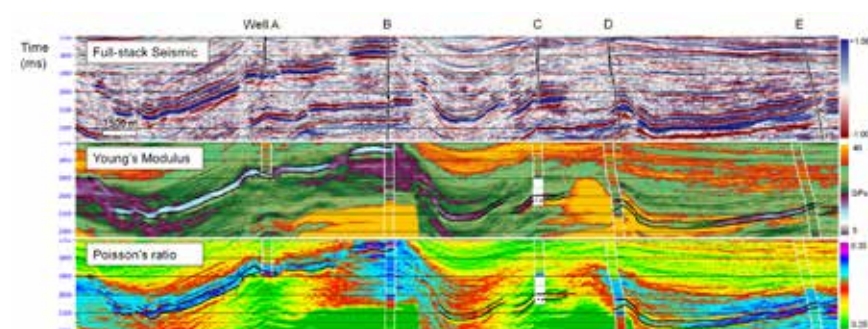


# QUANTITATIVE SEISMIC INTERPRETATION

## SEISMIC INVERSION FOR UNCONVENTIONALS

Advances in seismic interpretation techniques have opened up a whole new world of possibilities for interpreting seismic data. In addition to conventional interpretation for mapping geological structures, developments in quantitative interpretation have enabled the derivation of rock and fluid properties from seismic. In the context of unconventional, these techniques can be applied to derive key reservoir properties, such as TOC content and the elastic moduli, and help guide the 2D and 3D delineation of zones in the reservoir with favorable characteristics for production.

Building on a team of experienced professionals, SGS Horizon offers services covering the entire workflow, from seismic processing to (quantitative) interpretation and inversion, both as standalone services and as part of our integrated subsurface studies.



### SEISMIC INVERSION

Quantitative seismic interpretation includes AVO (or AVA) analysis and seismic inversion. AVO analysis uses the variation in seismic reflection amplitude with offsets, providing basic information on the lithology and pore fluids and can be used to detect hydrocarbons in the subsurface. Seismic inversion is the process by which seismic reflection data are converted into rock properties, adding a wealth of information on key reservoir properties.

Pre-stack simultaneous inversion is a version of inversion which uses CDP gathers and log data as input. This result in three volumes of absolute rock properties tightly calibrated to the well data: P-impedance, S-impedance, and density. From these three volumes the Vp/Vs ratio can be determined, as well as the elastic rock properties, including Young's Modulus and Poisson's Ratio. For unconventional, these elastic moduli are especially important as they are used to identify zones within the

reservoir which are most susceptible to hydraulic stimulation. Additionally, the Vp/Vs ratio has been demonstrated of being capable to identify reservoirs which are "invisible" to conventional seismic amplitudes and acoustic impedance displays, greatly enhancing our understanding of the subsurface.

### INTEGRATED RESERVOIR CHARACTERIZATION

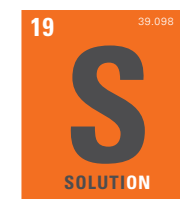
Successful reservoir characterization requires the close integration of geophysics with petrophysics, geology, and engineering. At SGS, all these disciplines are combined in integrated studies. Consequently, in addition to offering our seismic processing and seismic interpretation services as standalone services for both conventional as unconventional reservoirs, we have developed the Multi-scale Shale Characterization workflow. In this workflow, seismic interpretation is combined with drill cutting measurements and logging data to provide a comprehensive characterization

and evaluation of unconventional shale plays. This integration of data allows for calibration of the seismic interpretation using the drill cuttings measurements together with logging data, ensuring accurate inversion results. These results can then be used to distribute the key reservoir properties in 2D and 3D and identify sweet spots within the reservoir.

### TRACK RECORD

SGS Horizon has successfully carried out seismic processing and seismic interpretation in many projects, ranging from exploration studies to asset evaluations and from re-determinations to integrated field development planning, covering different regions worldwide, including Europe, Africa, the Middle East, Asia-Pacific, the former Soviet-Union, and South America.

In many of our recent studies, seismic inversion proved to be a valuable additional tool to map the reservoir properties on top of the conventional seismic interpretation. In a case study of the Posidonia Shale in the West Netherlands Basin, seismic inversion was successfully used to determine the elastic rock properties and map the zones with the highest potential for hydraulic stimulation.

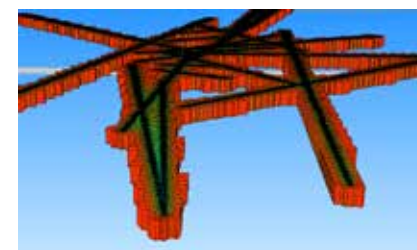


# SHALE GAS PRODUCTION FORECAST

## THE DYNAMIC CHALLENGE

With the rise of unconventional, more and more companies are investing in shale plays, evaluating their hydrocarbon potential and booking reserves. In this, the analysis of dynamic data is critical, as errors in production forecasts can lead to incorrect evaluation of reserves. The results of dynamic data analysis have a significant impact on investment decisions.

SGS Horizon has an experienced team of professionals, offering services that cover the entire dynamic simulation workflow, from inventorizing dynamic data (including PVT, SCAL, DST, PT, RFT/MDT, production, pressures) through data interpretation (including definition of PVT models, pressure transient analysis, production analysis, and volumes) to history matching and forecasting. The dynamic simulations are not limited to 3D modeling but are complemented by 2D models and analytical methods to provide model input data and to quality check model results.



### DYNAMIC SIMULATION OF UNCONVENTIONALS

Because of their ultralow permeability, production from shales relies on a large interface area between the reservoir and the wells, which is created by hydraulic stimulation of the reservoir. To correctly simulate production, the main mechanisms affecting flow need to be quantified. Already challenging in conventional reservoirs, understanding and quantifying these flow mechanisms in shale reservoirs is even more complicated.

Due to the ultralow permeability the part of the reservoir that is most likely to produce is the volume that is effectively stimulated, which is known as the stimulated reservoir volume (SRV). The reliable estimate of the SRV can therefore significantly improve the forecast of the production performance of a shale gas well. Additionally, secondary networks of fractures can improve production outside of the SRV.

Other parameters affecting gas flow include the stress dependent permeability, diffusion, and desorption. On top of that, large pressure gradients cause PVT properties such

as compressibility and viscosity to radically change throughout the reservoir, resulting in non-linear behavior which is difficult to capture in models.

In addition to the nonlinear PVT behavior, additional parameters affecting gas flow, and challenges in SRV estimation, shale gas reservoirs are characterized by complex well and frac geometries. Due to these challenges associated with shale gas, conventional decline techniques are not suitable for long term production forecast of shale reservoirs. Deviation from conventional methods can therefore lead to dramatic errors in production forecasts.

### SGS DEVELOPMENTS

SGS Horizon is constantly developing and testing methods and workflows for the dynamic simulation of shale gas reservoirs, ensuring that our methods are in line with the latest technologies. Our participation in the KAPPA Unconventional Resources Consortium (KURC) is an example of this. KURC was founded to bring together expertise and data from across the industry, with the objective of developing analysis tools applicable to shale reservoirs as an alternative to conventional decline techniques. As a partner, SGS Horizon has access to the numerical and analytical software tools developed by KURC and is applying these tools in evaluation studies.

In our workflows, input parameters (including TOC content, pressure,

temperature, Ro) are combined with essential modeling parameters, including the free gas versus adsorbed gas ratio and Langmuir isotherms. These parameters are determined based on measurements or are derived from carefully selected producing analogues, allowing us to determine the volumes and generate production forecast profiles, based on low-, mid-, and high-case scenarios, employing deterministic or probabilistic approaches.

### TRACK RECORD

The reservoir engineering department of SGS Horizon has extensive experience with dynamic simulation projects, both as single disciplinary exercises and as part of integrated multi-disciplinary subsurface studies. Over the years, we have been participating in hundreds of dynamic simulation projects worldwide, ranging from field (re)development studies to large equity redetermination projects with reservoirs ranging from tight fractured oil reservoirs to giant gas fields.

SGS Horizon performed an evaluation of a shale gas reservoir in Northern Spain. In this study, production profiles were generated and the volumes, including the estimated ultimate recovery (EUR), were estimated. Furthermore, KURC software was applied to multiple data sets from various regions. The software was used to analyze, simulate, and forecast the production from shale reservoirs based on dynamic data.



## COALBED METHANE (CBM) EVALUATION SERVICES

Coalbed methane (CBM) and coal mine methane (CMM) is trapped underground, and is generally not released into the atmosphere until coal-mining activities unleash it. Historically, CBM has been considered a nuisance in the coal mining industry and methane that accumulated in a coal mine was purposely vented to the atmosphere. However, with the ever-increasing demand for energy, CBM is now a popular form of unconventional natural gas.

CBM is an unconventional resource that requires the amalgamation of vital information in regards to the origin of the gas, reservoir continuity, compartmentalization and migration. In order to be able to offer a total service package for any CBM or CMM project, SGS and Raven Ridge Resource (RRR) have a close cooperation and supply integrated CBM and CMM services capability globally. The SGS/RRR team has the experience and capability to:

- Fully measure and define methane production potential contained in coal beds and surrounding strata.
- Delineate, map and quantify the gas resources and reserves associated with coal.
- Assess and forecast the CBM and CMM production potential, and economic viability of recovery and utilization options.
- Recommend best practices for CMM drainage in underground coal mines to promote safe and healthy working conditions.
- Design CMM projects and assist in establishing greenhouse gas accounting measures to qualify for emission credits created from methane recovered, used/destroyed and hence not liberated during the coal mining life cycle.

### OUR STRENGTH

SGS Minerals Service team is globally recognized in the coal industry for providing the full range of coal sampling and analytical services. SGS runs a global network of 90 coal laboratories, which offer a complete line of coal laboratory analyses and testing services required for the characterization of

coals, CBM and CMM resources. The laboratory services comprise all type of geochemical analyses (e.g. TOC, ash content, GCMS, isotopes etc.) and include Vitrinite reflectance measurements and degassing experiments (Langmuir Isotherms).

Raven Ridge Resources is the global leader in CBM and CMM technology and provide technical expertise and project management services to the oil, gas, and public sector entities worldwide.

RRR specializes in assessment of energy resources, particularly coalbed and coal mine methane.

SGS Horizon provides integrated solutions throughout the field life cycle, covering all subsurface, well and engineering aspects from exploration through development and production to abandonment for conventional oil and gas reservoirs and “unconventionals” such as shale gas, shale oil and CBM. SGS’s core strength is the integration of geology, geophysics, geochemistry, petrophysics, reservoir and petroleum engineering and drilling and well technologies.

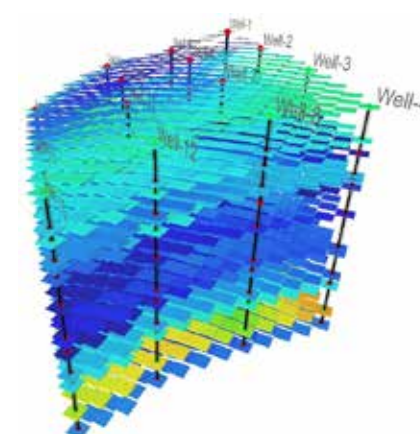
SGS Horizon developed specific workflows for the assessment of the unconventional reservoirs and is utilizing a full suite of modeling software such as CGM Star, Fekete and Kappa’s analytical and numerical modeling software modules (KURC) developed for the analysis of unconventional reservoirs. This enables SGS Horizon to provide reliable production forecasts and CBM reserve assessments.

The integration of RRR’s expertise, SGS’s laboratory capabilities and SGS Horizon’s state-of-the-art subsurface modeling know-how provide a comprehensive service package to the oil & gas industry as well as to the mining industry and support the commercial exploitation of CBM and CMM plays.

### INNOVATIVE WORKFLOW

Three elements define whether a CBM play is potentially successful:

- Coal quantity and quality
- Gas quantity and quality
- Productivity



The quality of the coal is determined by laboratory measurements. The key geochemical parameters are the coal rank (Ro) and its gas and water content. The gas productivity of a coal layer is controlled by the structural setting i.e. bed thickness and continuity, brittleness and cleats (fracturing) and the over – and under-burden lithology.

The integration of geological, geochemical and geomechanical parameters allow the construction of 3D coal reservoir models in the static and dynamic realm. CBM geomodels incorporate the continuity, thickness and maturity of the coal beds and simulate the interaction with the surrounding lithologies. These are of interest when modeling the permeability or hydraulic stimulation.

SGS Horizon has the profound experience from more than 350 simulation studies of conventional and unconventional reservoirs, performed since 2001. In the course of the CBM reservoir modeling process we integrate seismic, petrophysical and geochemical data, geomechanical properties as well as dynamic well data such as pressures, DFIT data and gas production data.

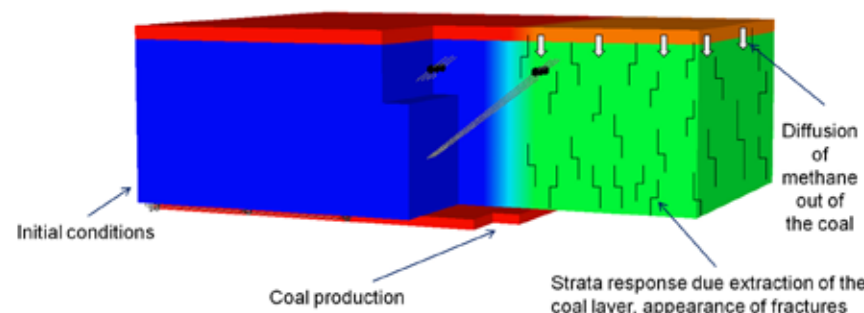
The results of the static modeling provide a reliable gas in place (GIIP) while the dynamic modeling allow the production forecast of CBM wells and the assessment of the commercial value of the asset. Furthermore the models assist to optimize the well completions and well spacing. SGS Horizon applies all state-of-the-art modeling software packages such as Petrel, Eclipse, CMG Star, Fekete and Ecrin Suite, whatever is most appropriate for your study’s objective.

Numerous SGS laboratories worldwide provide analytical services such as vitrinite reflectance and coalification grade, coal typing, gas content and composition analyses.

### TRACK RECORD

RRR and SGS Horizon jointly conducted a study of an underground coal mining complex in Vietnam. The purpose of the study was to determine the technical and economic feasibility of employing state-of-the art gas turbines fueled by low concentration CMM and Ventilation Air Methane (VAM) to supplement power required for the mining and coal processing operations. The study comprised detailed analysis of the underground coal mining complex’s future plans for two active mines and two mines under construction. Historical coal production and correlated methane emissions data were used to forecast the complex’s VAM emissions. Reservoir simulation software was used to forecast CMM that will be produced using the technological approach employed by the mining company to drain gas from gassy coal seams.

SGS Horizon and RRR reviewed and assessed the technical viability of a large scale CBM development project in SE Asia and provided technical expertise and advise for future development activities. In the course of the study the productivity of numerous coal seams were evaluated and modeled, and the completion and stimulation efficiency of several pilot wells were assessed.





# TIGHT GAS SERVICES

## INTEGRATED SOLUTIONS FOR TIGHT RESERVOIRS

SGS Horizon has a unique capability for modeling the effects of hydraulic fractures on well productivity and recovery efficiency and as such is well positioned to support tight gas development projects. Combining the above with an integrated approach, through the presence of strong experienced multi-disciplinary teams, SGS has added significant value to a number of tight gas (TG) projects around the globe.

### SCOPE

TG development has made significant progress over the years, mainly through advanced technology and strong commodity prices. As interest in TG development moves to new and often deeper hydrocarbon basins with their own unique set of challenges, significant issues remain to be resolved. These relate to an improved understanding of the reservoir, more advanced perforating and testing techniques, or multi-stage stimulation processes. The key to TG development is the integration of multiple technologies and disciplines.

For TG developments to be successful, recognition of the productivity sweet spots, definition of representative pilot project locations and appropriate technologies are essential.

Detailed understanding of the depositional environment and its diagenetic overprint can be combined with the fracture model to evaluate various scenarios of reservoir behavior. Various well types, varying from vertical to horizontal, hydraulically fractured, or drilled in underbalanced conditions, can then be tested in a reservoir simulator to define the most cost effective development methodology.

### TRACK RECORD

SGS carried out an integrated study for a customer in Pakistan with the objective to define development strategies for two tight gas fields, onshore Pakistan. The project scope amounted to 50 man-months and comprised:

- Re-interpretation of the petrophysical data

- Creation of static and dynamic models
- Field development study
- Well engineering study addressing:
  - Well design concepts and costs
  - Hydraulic fracture modeling for existing wells
  - Hydraulic fracture design for future wells
  - Underbalanced drilling and managed pressure drilling
  - Borehole stability
  - Multilateral systems
- Definition of a pilot project

One of the study requirements was to create full field forecasts based on a development consisting of more than 50 hydraulically fractured wells. Under these conditions dynamic models tend to become difficult to manage and to suffer from convergence problems. A special technique was developed in-house to circumvent these problems, while yielding accurate results. After the project the customer has been following up on the project recommendations and investigated the option of carrying out a pilot in one or both fields.

For a customer in the Netherlands a development plan was constructed for a complex Rotliegend reservoir located in the North Sea. This field is strongly heterogeneous and poorly developed with the majority of permeabilities well below 1mD. Consequently, the transition zone extends almost over the entire gas column to the top of the reservoir. A detailed field development study was completed in three months.

The study comprised interpretation of production tests, seismic interpretation, 3D geological modeling and reservoir simulation to evaluate the gas benefits for various well designs. Using reservoir models, the benefits of underbalanced drilling (UBD) vs. reservoir hydraulic fracturing were evaluated. In addition, concepts around improved mobility of gas in a large transition zone were incorporated.

In a sweet gas development project in Germany, production comes from a number of stacked reservoirs. These reservoirs have been on production since the early 1980s. Hydraulically multi-fractured horizontal wells were used for development of the super tight (micro Darcy) reservoir. Wells are typically based on a design of 5 to 7 propped fractures with a spacing of a few hundred meters. The study involved developing a workflow to represent accurately the complex hydraulically fractured wells in Eclipse using an effective connection approach calibrated to fine scale simulation and analytical models. The model was calibrated to pressure and production data, but also to well test data acquired during fracing. Using this abundant and high quality data considerably enhanced the characterization of the reservoir. The study formed the basis for further well proposals and enabled the customer to successfully optimize the design of the complex and costly wells.



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WHEN YOU NEED TO BE SURE

