# SHALE GAS EXPLORATION AND PRODUCTION

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## Background

With a view to energy security of the world ,unconventional energy resources - coalbed methane (CBM) , Methane Gas Hydrate,shale gas, basin centred gas ,tight gas,oil shale and heavy oil- exploration and exploitation is pertinent task before geoscientist . Shale gas is natural gas from shale formations which acts as both the source and the reservoir for the natural gas. Each Shale gas reservoir has unique characteristics. Shale has low matrix permeability, so gas production in commercial quantities requires fractures to provide permeability . For a given matrix permeability and pressure, gas production are determined by the number and complexity of fractures created, their effective conductivity, and the ability to effectively reduce the pressure throughout the fracture network to initiate gas production. Understanding the relationship between fracture complexity, fracture conductivity, matrix permeability, and gas recovery is a fundamental challenge of shale-gas development. Shale gas reservoirs almost always have two different storage volumes(dual porosity) for hydrocarbons, the rock matrix and the natural fractures .Because of the plastic nature of shale formations, these natural fractures are generally closed due to the pressure of the overburden rock. Consequently, their very low, matrix permeability, usually on the order of hundreds of nanoDarcies (nD), makes unstimulated, conventional production impossible. Almost every well in a shale gas reservoir must be hydraulically stimulated (fractured) to achieve economical production. These hydraulic fracture treatments are believed to reactivate and reconnect the natural fracture matrix .

## Aims

Shales and silts are the most abundant sedimentary rocks in the earth's crust. In petroleum geology, organic shales are source rocks as well as seal rocks that trap oil and gas. In reservoir engineering, shales are flow barriers. In drilling, the bit often encounters greater shale volumes than reservoir sands. In seismic exploration, shales interfacing with other rocks often form good seismic reflectors. As a result, seismic and petrophysical properties of shales and the relationships among these properties are important for both exploration and reservoir management. Another key difference between conventional gas reservoirs and shale gas reservoirs is adsorbed gas. Adsorbed gas is gas molecules that are attached to the surface of the rock grains . The nature of the solid sorbent, temperature, and the rate of gas diffusion all affect the adsorption . Presently , the only method for accurately determining the adsorbed gas in a formation is through core sampling and analysis. Understanding the effects of adsorption on production data analysis increase the effectiveness of reservoir management in these challenging environments. They contain natural gas in both the pore spaces of the reservoir rock and on the surface of the rock grains themselves that is referred to as adsorbed gas .This is a complicated problem in that desorption time, desorption pressure, and volume of the adsorbed gas all play a role in how this gas affects the production of the total system. Adsorption can allow for significantly larger quantities of gas to be produced. Shale gas reservoirs present a unique problem for production data analysis.

The effects of the adsorbed gas are not clearly understood except that it tends to increase production and ultimate recovery. The phenomena of gas storage and flow in shale gas sediments are a combination of different controlling processes.

Gas flows through a network of pores with different diameters ranging from nanometres (nm = $10^{-9}$m) to micrometres (μm = $10^{-6}$m). In shale gas systems, nanopores play two important roles. Petrophysical imaging employs first,second & third generation wavelet to delve deep into complex shale gas reservoir. Nanoscale gas flow in Shale gas sediments has scope to cope with research on dry nanotechnology(smartfluid/nanofluid).Anisotropy in sediments may develop during deposition or post deposition. In clastic sediments, anisotropy can arise both during and after deposition. In carbonates, anisotropy is controlled mostly by fractures and diagenetic processes, and so tends to arise after deposition. For anisotropy to develop during deposition of clastics, there needs to be an ordering of sediments-in essence, some degree of homogeneity, or uniformity from point to point. If a rock were heterogeneous in the five fundamental properties of its grains- composition, size, shape, orientation and packing-anisotropy cannot develop because there would be no directionality intrinsic to the material. Anisotropy at the bedding scale that arises during deposition therefore may have two causes. One is a periodic layering, usually attributed to changes in sediment type, typically producing beds of varying material or grain size. Another results from the ordering of grains induced by the directionality of the transporting medium. Anisotropy is therefore governed not only by variation in the type of material but also by variation in its arrangement and grain size.

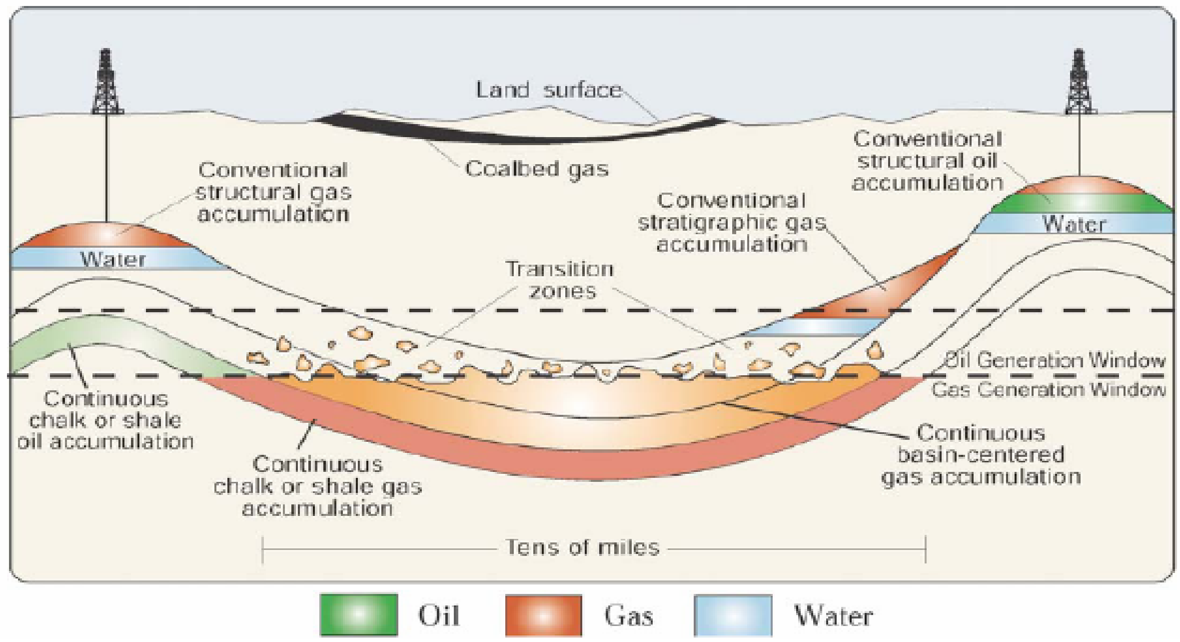


**Fig1:** Diagram Showing the Area of Occurrence of Shale Gas

Shale, with its inherent heterogeneity and anisotropy, has always been problematic in many operations ranging from seismic exploration, well-log data interpretation, well drilling and well-bore stability problems, to production. Research work focus at bridging the gap between invariant characteristics at nano scale of sedimentary rocks and their macroscopic properties. 3D seismic is becoming successful because of the ability to identify fracutre and fault trends. Surface geochem cannot identify in the subsurface where the frac or fault systems will be intersected by the drill bit. This is why 3D is now being used aggressively and successfully.

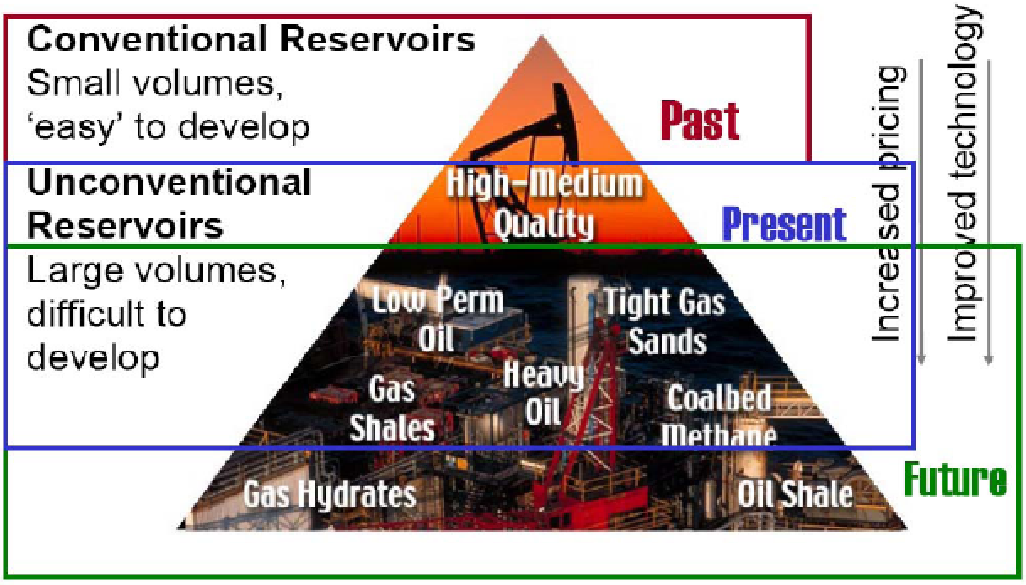


**Fig2:** The resource triangle unconventional resources

**Methods**

Geologically complex and low permeability reservoirs,from which hydrocarbons may be sourced ,which require special evaluation and technology ,and some form of stimulation for economical production , in particular Tight sand ," shale" and coal. Unconventional reservoirs require some form of stimulation to obtain commercial production. Shale gas reservoirs require fracture stimulation to unlock gas from extremely low-permeability formations. As fracture stimulation is an important aspect of well completions, production companies need to know basic information about fractures such as whether they will open (and stay open), direction of fracture propagation, dimensions and type of fracture, and whether they will stay in zone. Increasingly, seismic is utilized to provide such information and guide drilling and completions. Three types of information extracted from seismic are useful in optimizing drilling locations: fracture characterization, geomechanical properties, and principal stress measurements (vertical maximum and minimum horizontal stresses). Given the target depth of formations in shale gas basins that are being exploited today, the maximum principal stress is vertical, giving rise to HTI (horizontal transverse isotropy). This means that the fracture system is comprised of vertical fractures which cause anisotropic effects on seismic waves as they pass through. These anisotropic effects are observed on 3D seismic data as changes in amplitude and travel time with azimuth. In multicomponent data shear wave splitting can be observed. The relationship between changes in P-wave amplitude with azimuth in anisotropic media to invert the observed seismic response and predict fracture orientation and intensity. This information is of great value to production companies because it indicates the optimum horizontal drilling azimuth and offers the prospect of subsequent fracture stimulation as a solution to tap into existing natural fracture systems.A clear understanding of the geomechanical properties and their distribution explains the reservoir heterogeneity and thus the variation in economic ultimate recovery (EUR) between wells.
Geophysicist derives a host of geomechanical properties from migrated CDP gathers, including Young's Modulus, Poisson's Ratio, and shear modulus, by first inverting the data

for P- and S-wave velocities and density. With this information, fracture dimensions can be predicted and wells drilled in the most brittle rock.Linear Slip Theory for geomechanical properties is used to calculate stress values.

**Nonlinear Seismic Imaging**

In a nonlinear elastic system, the principle of superposition does not hold and the frequency mixing, harmonic generation, and spectral broadening takes place. These changes that add new frequencies to the frequency spectrum provide us with a means of measuring the elastic nonlinearity parameter of the reservoir rocks. This elastic nonlinearity parameter is unique, and can be effectively used as a seismic attribute to map the rock properties of the reservoirs for improving the results of the exploration and exploitation efforts. The sensitivity of the nonlinear response to the porosity, fracturing, and pore fluids of the reservoir rocks is relatively larger than the linear measurements being used today. Industry needs to take advantage of this additional seismic attribute to reduce the ambiguity of the seismic-based geologic interpretation.Nonlinear seismic imaging enables the end-user to retain the conventional linear seismic images and provides additional nonlinear seismic images that identify the porous and fractured reservoir rocks. In areas where the current seismic fails to map the stratigraphic or fractured hydrocarbon traps, nonlinear seismic technology can provide the useful reservoir information. Unconventional reservoirs require some form of stimulation to obtain commercial production. Shale gas reservoirs require fracture stimulation to unlock gas from extremely low-permeability formations.As fracture stimulation is an important aspect of well completions, production companies need to know basic information about fractures.Three types of information extracted from seismic are useful in optimizing drilling locations: fracture characterization, geomechanical properties, and principal stress measurements (vertical maximum and minimum horizontal stresses).Anisotropic effects are observed on 3D seismic data as changes in amplitude and travel time with azimuth. In multicomponent data shear wave splitting can be observed.

When geophysics met geomechanics : Imaging of geomechanical properties and processes using elastic waves. The focus is primarily on geophysical imaging using elastic waves, whose propagation is controlled by a material's elastic properties and density. The former can be thought of as the summation of contributions over a range of length scales: grains, discontinuities (including cemented or uncemented grain contacts), inter- or intra-granular cracks, fractures and layers, which can all be anisotropic or can produce an anisotropic aggregate material. Geophysicist derives a host of geomechanical properties from migrated CDP gathers, including Young's Modulus, Poisson's Ratio, and shear modulus, by first inverting the data for P- and S-wave velocities and density. With this information, fracture dimensions can be predicted and wells drilled in the most brittle rock.

**Azimuthal Anisotropic Seismic Signal processing:**

LinearSlip Theory for geomechanical properties is used to calculate stress values. Generally, the stress state is anisotropic leading to the estimation of both the minimum and maximum horizontal stress. As the seismic data measure dynamic stress, results are then calibrated to the static stress that is effectively borne by the reservoirs at depth, making it possible to predict the hoop stress and the closure stress as key elements defining the type and motion of fractures. At locations where the differential horizontal stress ratio (DHSR – the ratio of the difference between the maximum and minimum horizontal stresses to the maximum horizontal stress) is low, tensile fractures will form in any direction, creating a fracture swarm. If the maximum horizontal stress is much greater than the minimum, then fractures will form parallel to the direction of maximum horizontal stress.

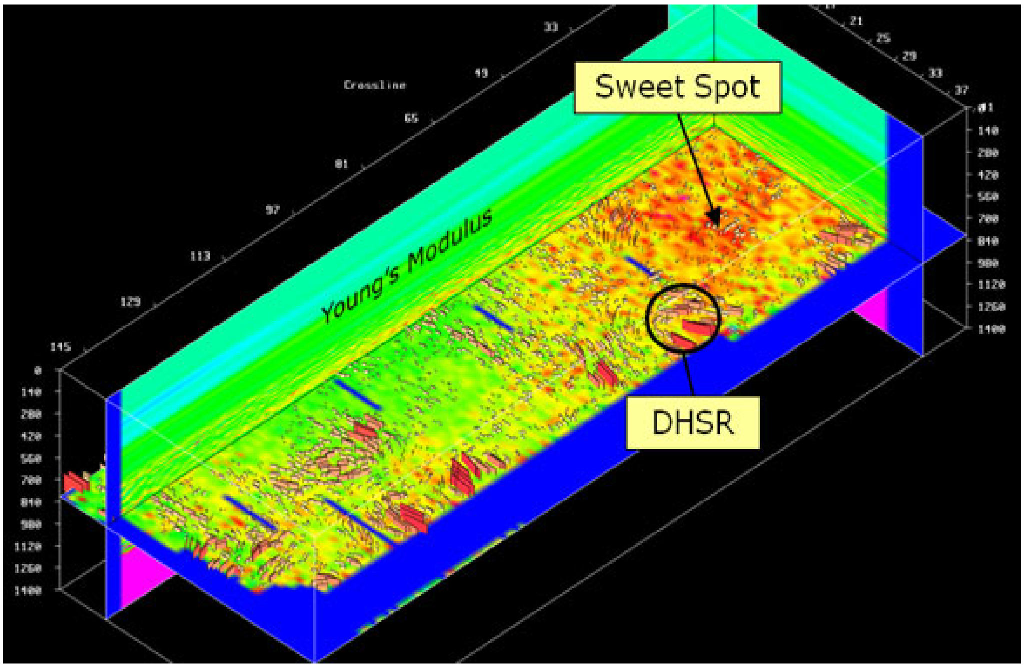


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**Fig.3:**colour represents estimates of Young's Modulus, while the small vertical plates show HSR. Large plates correspond to large values of DHSR. The prospect locations are where Young's Modulus values are high (rock is most brittle) and DHSR plates are small (fracture swarms will form). (Image courtesy of CGGVeritas)

**Results**

Hydraulic fracturing is a process that results in the creation of fractures in rocks, the goal of which is to increase the output of a well. The hydraulic fracturing is used to increase or restore the rate of fluid flow within the shale reservoir and horizontal drilling creates maximum borehole surface area in contact with the shale.Hydraulic fracture complexity is the key to unlocking the potential of shale plays. Microseismic monitoring suggests that complex fracture network can be developed in some shale plays. Microseismic monitoring is a proven technology and has been widely used to monitor and evaluate the effectiveness of hydraulic fracture treatments in various formations, including shale. Theoretically, in shale plays, a complex fracture should produce better compared to bi-wing planer fractures as a result of increased fracture surface area. The value of the microseismic data is that it provides operators with 3D visualization of where the hydraulic fracture process is impacting the rock in the reservoir. When real-time monitoring is used, the micro-seismic information can be used to prevent fracture growth out of zone. Micro-seismic hydraulic fracture monitoring is another of these new technologies. One of the principal costs in extracting natural gas is the hydraulic fracture process. The rock must undergo extensive fracturing to create the permeability required to allow gas to flow into the wellbore. "Micro-seismic methodologies arguably offer industry the best method to determine the efficiency of the fracture stimulation process, as it applies to making contact with the gas resource locked in the rock.

Water lifecycle of Hydraulic Fracturing in Shale Gas Reservoirs: In addition to water and proppant ,nano enhanced proppant(OxBall and OxFrac light, high-strength ceramic proppants) other additives are essential to successful fracture stimulation. Hydraulic fractures are formed in the direction perpendicular to the least stress. The water lifecycle for hydraulic fracturing consists of water acquisition, chemical mixing, well injection, flowback and produced water (hydraulic fracturing wastewater), and wastewater treatment and waste disposal.Implications of Hydraulic fracturing water lifecycle and the potential impacts are analysed of large volume water withdrawals from ground and surface waters on drinking water resources; chemical mixing- surface spills on or near well pads of hydraulic fracturing fluids on drinking water resources; well injection- the injection and fracturing process on drinking water resources; flowback and produced water- surface spills on or near well pads of flowback and produced water on drinking water resources ; wastewater treatment and waste disposal- inadequate treatment of hydraulic fracturing waste waters on drinking water resources.Laboratory studies provide a better understanding of hydraulic fracturing fluid and shale rock interactions, the treatability of hydraulic fracturing wastewaters, and the toxicological characteristics of high-priority constituents of concern in hydraulic fracturing fluids and wastewater

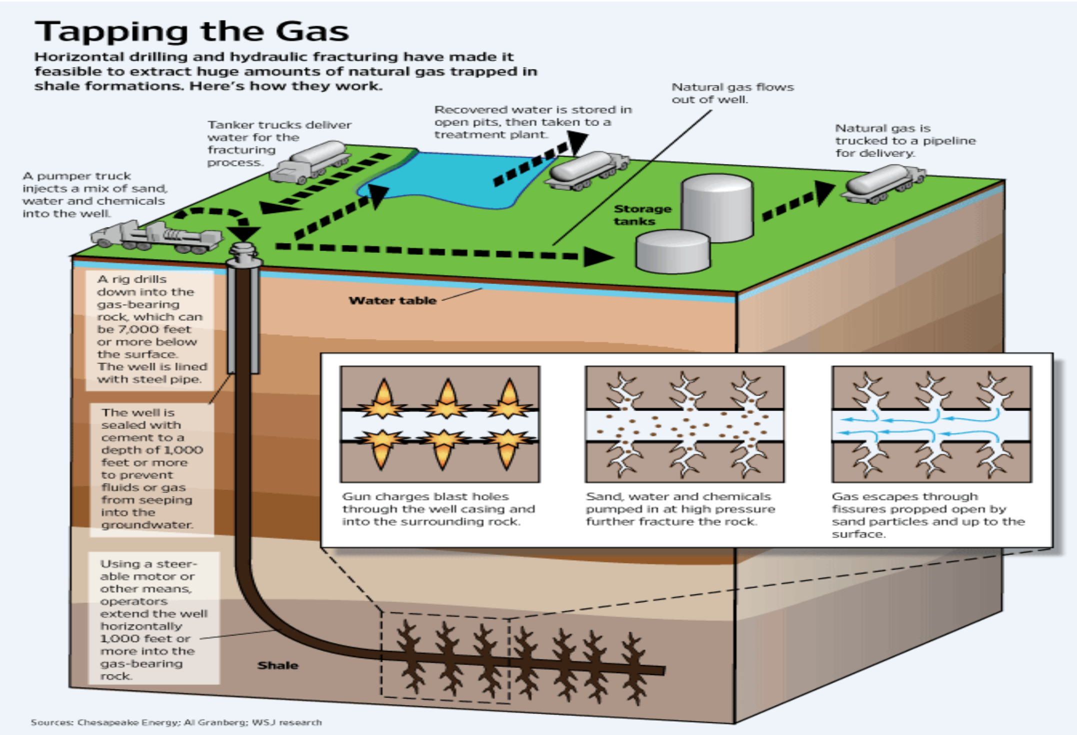


**Fig.4:** Introduction of horizontal drilling & Hydrofracturing in Shale

Darcy and diffusive flows in the matrix and stress-dependent permeability in the fractures:

Permeability measures the ability of fluids to flow through rock (or other porous media). The darcy is defined using **Darcy's law,** which can be written as:

where: $v = \frac{\kappa \Delta P}{\mu \Delta x}$ *v* is the superficial (or bulk) fluid flow rate through the medium

κ is the permeability of a medium ,µ is the dynamic viscosity of the fluid

Δ*P* is the applied pressure difference ,Δ*x* is the thickness of the medium

**Navier–Stokes equation Incompressible flow** $\rho\left(\frac{\partial v}{\partial t} + v \cdot \nabla v\right) = -\nabla p + \mu \nabla^2 v + f$

**Navier–Stokes equation , Compressible flow**

$$\rho\left(\frac{\partial v}{\partial t} + v \cdot \nabla v\right) = -\nabla p + \mu \nabla^2 v + \left(\frac{1}{3}\mu + \mu^v\right)\nabla(\nabla \cdot v) + f$$

**Fick's first law** $J = -Dgrad\Phi$ **, Fick's Second Law** $\frac{\partial \varphi}{\partial t} = D\nabla^2 \varphi$

Tthe description of matrix flow by considering diffusive (Knudsen) flow in nanopores. when Darcy flow becomes insignificant due to nanodarcy matrix permeability, Knudsen flow takes over and contributes, substantially, to the transfer of fluids from matrix to fracture network. **Knudsen flow** describes the movement of fluids with a high Knudsen number, that is, where the characteristic dimension of the flow space is of the same or smaller order of magnitude as the mean free path.The Knudsen number is a dimensionless number defined as: $\frac{\partial \varphi}{\partial t} = D\nabla^2 \varphi$ , $K_n = \frac{k_B T}{\sqrt{2}\pi \sigma^2 p L}$ ,

for an ideal gas.

For particle dynamics in the atmosphere, and assuming standard temperature and pressure, i.e. 25 °C and 1 atm, we have $\lambda \approx 8 \times 10^{-8}$ m, or approximately $2.6 \times 10^{-9}$ ft.

**Conclusions**

According to geologists, there are more than 688 shales worldwide in 142 basins. Shale Gas exploitation is no longer an uneconomic venture with availability of improved technology as the demand and preference for this clean form of hydrocarbon have made Shale Gas, an energy in demand. The reserve accretion, production & development of shale gas from one basin to another around the world are rapidly increasing. Seismic anisotropic data processing provide information of fractures in shale. Real-time monitoring of micro-seismic events indicates fracking experts to immediately optimize the hydraulic stimulation process by modifying the fracture stage design while pumping into the formation. The real-time data is employed for experiment with how different perforation patterns impacted fracture propagation and make real-time changes in the fracture technologies As a result, fracking experts can optimize future well placement and completion designs, for cost-effective drainage of unconventional reservoirs. Shale gas performance is analysed by using wavelet transform.Geomechanical (break outs) information is obtained by wavelet analysis of petrophysical log data. NMR(Nuclear Magnetic Resonance) Logging is very efficient for characterization of reservoir,petrophysical imaging and Gas Dynamics in Gas Shale

Nanopores.Water management and environmental impacts of hydraulic fracturing should be analysed to cope with our earth system.

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