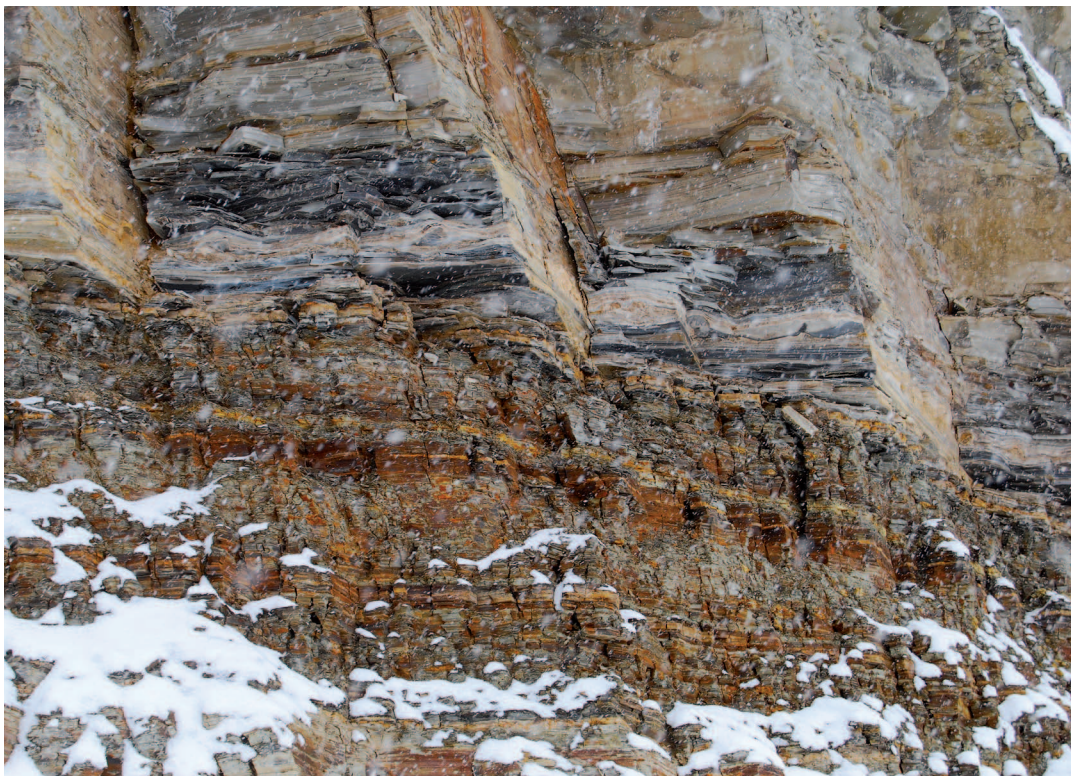
THE POTENTIAL OF UNCONVENTIONAL RESOURCES



TNO innovation for life

A revolution is taking place on the worldwide gas market due to the increase in domestic natural gas production in the USA, primarily from shale gas plays. Whereas shale gas is mainstream production in the USA, its exploration and production is still considered 'unconventional' elsewhere; the deposits are generally lower in resource concentration and more dispersed, and require well stimulation or other extraction/ conversion technology. Oil and gas regimes in other parts of the world are distinctively different compared to the USA, in terms of geology, regulations, and surface conditions.

Environmental concerns will likely impose more strict regulations in the near future for shale gas exploration and production to ensure safe and responsible exploitation. Developing shale gas plays outside the USA therefore remains challenging and will depend on tomorrow's innovations.

Worldwide shale gas resources are estimated at more than 450 Tm^3. However, most of these can only be accessed if technology becomes available that has less surface impact, produces less waste and ensures long-term safety for the environment. At present worldwide implementation of shale gas production technologies are mostly pending.

TNO is building on more than 60 years of oil and gas experience in developing innovative solutions for sustainable, efficient and secure energy supply. This folder presents TNO's main research focus areas applicable for shale gas and other unconventional resources. Technologies are evaluated for individual stages of development (exploration, drilling, stimulation and completion, production and downstream activities), but TNO is also able to integrate these stages for full chain analysis by a multidisciplinary approach.

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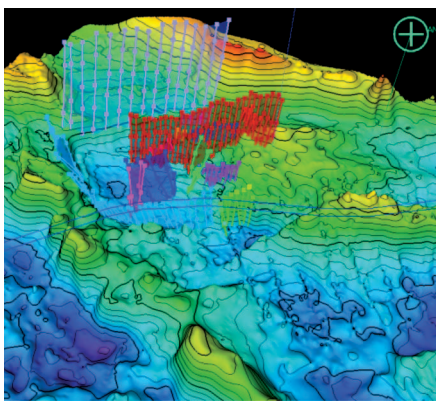
EXPLORATION

Organic rich shales act both as a source, reservoir and seal. Exploring for shale gas therefore differs from conventional exploration. Petroleum system analysis, sweet spot analysis and the evaluation of natural fracture- and fault networks are essential for proper exploration for shale gas and to decrease the number of wells required for development.

PETROLEUM SYSTEM ANALYSIS

- Regional mapping of the area by means of well log and seismic interpretation, uncertainty assessment, fault modeling and reservoir identification.
- Basin modeling, including temperature evolution, maturity, source rock potential, fluid flow and corresponding pressures, porosity and permeability.
- Pressure and fluid system analysis using pressure and effective stress distribution, hydraulic reservoir continuity, leakage zones interpretation and petroleum system dynamics.



SWEET SPOT ANALYSIS

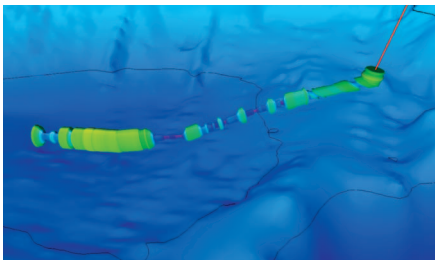
- Evaluation of vintage data for new ventures using all data available, including digitising paper or scanned logs.
- Detailed mapping of shale horizons and faults using seismic data for reservoir geometry and volumetrics. Seismic attribute evaluation supports the reservoir characterisation.
- Evaluation of petrophysical and geomechanical reservoir parameters by means of well log interpretation and well test analysis.
- Cross-calibration of reservoir zonations and depositional regime with palynological analyses.
- Porosity, permeability can be estimated based on geological history reconstruction through basin modeling.
- Laboratory measurements of critical parameters, such as vitrinite reflectance, Rock-Eval, Carbon and Sulfur (LECO) and geomechanical parameters, either in-house or with preferred partners.

EVALUATION OF NATURAL FRACTURE AND FAULT NETWORKS

- Stress field analysis, including determination of stress orientations through image log evaluation.
- Fault seal and cap rock evaluation using regional stress data, fault juxtaposition and shale gauge information.

DRILLING

Drilling for shale gas exploration or production purposes causes surface impact. Multiple horizontal wells drilled from a single surface location can minimise this.



ADVANCED DRILLING SUPPORT

- Target member/zone selection, based on intraformational zoning.
- Application of measurements while drilling (i.e. biosteering) to maintain the position within the chosen member/zone and optimise well contact with the formation.

3D SPATIAL PLANNING

- Evaluation of coinciding subsurface activities, like groundwater extraction, geothermal energy, etc.
- Optimal well (site) planning to minimise surface impact of shale gas development.
- Evaluation of well interference to optimise production when drilling multiple wells from a single surface location.

RISK ASSESSMENT

- Risk assessment from drilling to stimulation & completion to production.

STIMULATION & COMPLETION

Gas within a shale layer is adsorbed to clay particles, dissolved in kerogen or bitumen, or present in pores or fractures. Because shales in general hold little free gas the rock formation needs to be stimulated or fractured in order to release more gas. This methodology has an important impact on well functionality.

HYDRAULIC FRACTURING

- Modeling and prediction of fracture propagation and fluid flow using geomechanical and fluid flow simulators.
- Monitoring the behavior of hydraulic fractures based on (micro)seismics and well test analysis.
- Improving the biocide effectiveness in fracturing fluids.
- Application of smart (nano-)tracer technology based on responsive tracer particles.
- Application of switchable viscosity fluids for conformance treatment and hydraulic fracturing.

MITIGATING WELL INSTABILITIES

- Development of techniques to mitigate liquid loading, such as innovative coatings.
- Modeling gas lift and liquid slugging in horizontal wells to optimise production.
- Improving completion strategy, e.g. positioning of tubing compared to perforations and fractures.

FLOW-BACK WATER TREATMENT (LARGE VOLUME, SHORT PRODUCTION TIME)

- Separation of oil from water with ceramic membranes or pertraction.
- Scaling prevention on membranes or within pipes (for example due to sulfates).
- Technologies for water reuse, re-injection and zero liquid discharge.
- Desalination technology for water treatment.

WELL TEST ANALYSIS;

- Pressure transient analysis to estimate reservoir parameters and dimensions to further improve the reservoir model.
- Evaluate hydraulically fractured wells using time-lapse well test analyses.

MINIMISING SURFACE IMPACT

- Optimal well-site placement and planning.
- Monitoring induced seismicity.

RISK ASSESSMENT

- Risk assessment from drilling to stimulation & completion to production.

PRODUCTION

Producing shale gas is challenging. Monitoring and simulation can optimise production from shale gas reservoirs.

PRODUCTION OPTIMISATION

- Optimising production strategies using first principle models of top side equipment, well and reservoir to minimise the effect of water influx, such as slugging or liquid loading.
- Simulating the propagation of pressure waves and corresponding pressure pulses in liquid systems to optimise hydraulic fracturing.
- Modeling liquid slugging in horizontal wells.
- Setting up a dynamic monitoring system for production forecasting and monitoring well integrity.
- Evaluation of production strategies using first principle models of top side equipment, well and reservoir.

DOWNSTREAM

The quality of gas from shale gas reservoirs can differ from conventional reservoirs. Gas separation technologies or integrated local systems can be a solution for gas utilisation.

MINIMISING SURFACE IMPACT

- Development of predictions and understanding of ground movement associated with the production of shale gas.
- Forward and inverse modeling of ground movement using both analytical and numerical models.
- Calibration of ground movement simulations using surface and InSAR satellite data.
- Decoupling deep and shallow causes for ground movement.

PRODUCTION WATER TREATMENT;

- Water treatment on the produced water of fractured gas, combined with reinjection.
- Evaluation of potential for zero-liquid discharge.

PRODUCTION PERFORMANCE;

- Coupled well-(near)well simulations to predict liquid flow distributions.
- Evaluation of computational fluid dynamic models for the simulation of the near-wellbore region
- History matching of production data for shale plays.

RISK ASSESSMENT;

- Risk assessment from drilling to stimulation & completion to production.

GAS QUALITY

- Investigate the quality of the produced shale gas, and if off-spec, use separation technologies for utilisation or define possibilities for direct use.

INTEGRATED LOCAL SYSTEMS

- Perform responsible waste management.
- Optimise use of produced heat.
- Define local options for direct use of the produced gas.

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