Project Title	**Economic Modeling & Unconventional Gas Resource Appraisal**
Program Line	Tough Gas
Start- and end dates	2012-2016
Business Impact	- Obtain better estimates of economically recoverable unconventional gas resources. - Lower cash flow risk and reduce resource volatility for new entrant operators. .
Author	Dr. Ruud Weijermars (TU Delft & Alboran Partners) R.Weijermars@tudelft.nl
Description	This research project bundles global knowledge of unconventional gas economics (BEG, CSM, industry partners) and reserve maturation (SPE PRMS; SEC guidelines where appropriate), and applies this in a focused assessment of the economic potential of Dutch unconventional gas resources. The development of transparent templates of economic assessments for real Dutch field case studies will help companies in entering the new (Dutch) unconventional plays. One of the principal reasons why development of unconventional fields remains economically risky is that the estimated ultimate recovery (EUR) remains poorly constrained, due to uncertainty in OGIP estimates and recovery factors. Economic modeling will lower the cash flow risk and reduce resource volatility. Such models therefore help to take out some of the risk in developing unconventional gas resources and thereby lower the threshold for companies that want to enter in (Dutch) unconventional plays. These appraisals will also help the Dutch government to obtain better estimates of recoverable unconventional gas resources, toward unconventional resource de-risking. Cash flow models provide support to assess the economic viability of new tough gas plays (tight gas, shale gas, CBM).
Project description - objectives	Identify the critical path for the maturation process of Dutch unconventional resources based on economic threshold and technology cost control. Estimate and optimize economic and technically recoverable resources and ultimately, estimate proved reserves. Models use a mix of deterministic and stochastics assessments models. The input parameters are based on reliable estimates of real costs for technology, services, license fees, royalties and other costs in order to reduce cash flow risk. Benchmarking of reserve maturation cost and well productivity performance, using US analogs, helps to gain a better grip on cash flow projections for unconventional play openers in the Netherlands. Focus is on one hand on the well productivity uncertainty mitigation and on the other hand on cost reduction, using realistic European cost estimates.
Deliverables	An integrated model for economic reserve maturation and a reserve volatility calculator are developed, with specific application to the Dutch subsurface play opener prospects. The models account for forward, regional volatility in oil & gas prices. Generic guidelines are formulated to improve unconventional gas field development strategies. • Well productivity is modeled by coupling with dual porosity reservoir models, using Dutch case studies • Well productivity uncertainty is benchmarked by comprehensive history matching with decline curve analysis – mostly using US analogs. • Conceptual principles are illustrated using the US shale gas plays as case templates. • Discounted cash flow models are applied to determine the economic parts of the Dutch tough gas play. • Peer reviewed publications • Client Reports • Patents

Project Title	**Borehole Stress Modeling & Smart Frac Technology Solutions**
Program Line	Tough Gas
Start- and end dates	2012-2016
Business Impact	- The dimensionless Frac number is a new concept, which can be used as a monitoring tool and should be embedded in driller's software packages. - For Fracking applications, the Frac number creates new possibilities for optimum wellbore orientation, completion and fracking pressure control. - Working with the natural stress state using this approach may reduce drilling and fracking cost, while enhancing well productivity.
Author	Dr. Ruud Weijermars (TU Delft) R.Weijermars@tudelft.nl
Description	This research improves predictions of catastrophic failure of well bores using nomograms and various algorithms and is very valuable for upgrading drilling software. Recently recognized concepts, ''Fracture lens" and ''Fracture Cage", will be translated into practical technology solutions for improved drilling and hydraulic Fracture Engineering. The invention has enormous practical application potential: to improve borehole integrity, safety and drilling efficiency. With more than 150,000 oil and gas wells drilled worldwide each year, the commercial value of the new Frac number related insights could be very substantial.
Project description - objectives	The newly recognized ''fracture caging effect" is a potential drilling hazard which has been completely overlooked by the drilling industry – it is a powerful new insight. The Frac number, a new dimensionless number, which can be used to characterize and monitors stress trajectory patterns around boreholes. That stress pattern is important for knowing more precisely how the rock around boreholes will break in tension and shear. The Frac number approach creates new possibilities to manipulate the net pressure in the nominator of the Frac number such that one creates fracture patterns almost like in ice-skating. Today that subtleness is not there: drillers create fractures like speed skaters that only use brute power, but no ''souplesse" of going with the natural stress directions - they just are just blasting through – which is expensive and risky. Basin scale stress conditions are coupled to local stress states around wellbores to predict the stress trajectories in the reservoir and around wellbores. This research is expanded to include the interaction between wellbore orientation and tectonic background stress to establish the best well architecture for optimum well productivity. Unconventional well productivity will benefit by utilizing natural stress and fracture systems to optimize frac design. Higher well productivity may result when taking advantage of geological structures and natural stress patterns.
Deliverables	- The calculation of the Frac number is a ratio of a net pressure and a far field tectonic stress. These are well defined in the theory but not always well understood by non-theoreticians. Solid instructions and protocol on how to feed-in these parameters to get the best estimates for the Frac number at each depth should be part of the Frac number monitoring software. - Case studies will be developed (Gulf of Mexico, Dutch Graben systems). - Accurate Frac number monitoring is not only relevant for fracking. Even ordinary deep boreholes run tremendous risk if the Frac number is not monitored without a keen eye for the avoidance of the Fracture Caging Effect. It is in fact a runaway effect that may be hard to stop. Setting alarm bells more precise than today is an added safety layer. - For Fracking applications, the insight of the number creates new insight for optimum wellbore orientation, completion and fracking pressure control. - There is also an immediate possibility for cheaper drilling, by utilizing the fracture caging effect to make a bigger hole but using smaller bits. • Peer reviewed publications • Client Report • Patents

Project Title	**Impact Assessment Tools for Unconventional Gas Operations**
Program Line	Tough Gas
Start- and end dates	2012-2016
Business Impact	- Benchmarking of real and perceived risks attributed to and associated with shale gas operations - Improving tools and methods for quantifying surface impact, groundwater risk and seismic impacts
Author	Dr. Ruud Weijermars (TU Delft & Alboran Partners) R.Weijermars@tudelft.nl
Description	There is an important gap between the quantifiable risks of shale gas development as assessed by experts and the perceived risk of the general public. Widening of this gap could lead to decisions based on irrational and emotional processes rather than rational analysis of strategic options available to nations and companies for shale gas development. This study applies and develops objective tools, criteria and concepts for the quantification of risks and impact assessment of shale gas operations. This study involves: - Tools and methods for quantifying surface impact and measures of ecological recovery rates for a range of typical landscapes and regions. - Improves methods for preparing groundwater risk maps for shale gas operations, and illustrative case studies. - Improves methods for seismic risk assessment, modeling natural background stress and potential impact of fracking induced stresses
Project description - objectives	Shale gas development decisions are marred by legitimate public mistrust. Generally, two camps can be distinguished. On one hand there are uncommitted stakeholders (general public, politicians) concerned about environmental impact, groundwater contamination and seismic risk. On the other hand there are committed experts who provide assessments and prospective assessments for new shale gas provinces. They must proof best practice and viability of shale development within the accepted bounds of operational regulations, human safety and environmental impact. In order to overcome public concern and win support of both the people and their chosen political representatives, it is important to develop better methods for visualizing and documenting shale gas development integrity and compliance with existing regulations.
Deliverables	- Improved tools and methods for quantifying and assessing the impact of shale gas operations in exploration wells and new field development projects. - Case studies of Dutch key development regions to help ensure due diligence is followed in the decision making process. - Strong emphasis on presentation methods in format and terms understandable and accessible for the general public. - Emphasis on practical usefulness for policy-makers in assessing strategic options for further development. - Peer reviewed publications - Client Reports

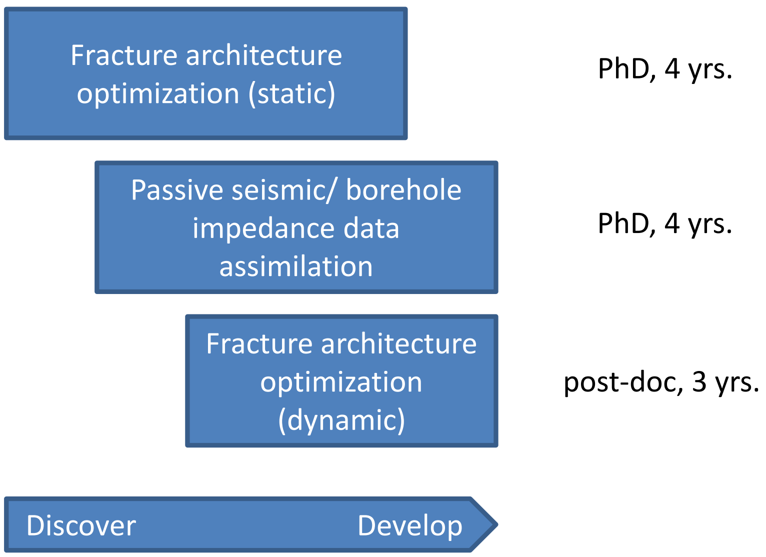
Project Title	**High-Resolution Petrophysical Engineering for Unconventional Recovery**
Program Line	Tough Gas
Start/end dates	2012-2016
Business Impact	- Quantifying and monitoring, physical and chemical rock characteristics at high resolution (sub-meter to micrometer scale). - Monitoring and steering of petrophysical properties for the improvement of production- and injection.
Author	Dr. Karl-Heinz Wolf (TU Delft) k.h.a.a.wolf@tudelft.nl
Description	Petrophysical Engineering: Advanced petrophysical characterization, screening and modification are useful for identifying EGR options for promising production zones and improvement of the reservoir quality. • What types of pores are present and how are total and effective porosity defined for coal, shale and tight sandstones? • How are permeability, sorption and diffusion depending on mineral associated pore types? • Can the physical and chemical behavior of minerals, and by that porosity and flow, be altered by physical and/or chemical and/or mechanical manipulation?
Project description - objectives	In *unconventional*, low-permeability gas reservoirs, like coal seams (CBM), gas-shales and very tight classic reservoirs, physio-chemical effects like diffusion, preferential sorption and dielectrical properties play a major role. We concentrate on: • The visualization and quantification of tight reservoir rock textures, structures and pore-content at sub-meter scale to provide physical data on the bulk rock properties for sweet spot detection and reservoir characterization. • The definition of specific minerals and organic constituents that may interact with fluids, gases and physical/mechanical interference in such a way that transport is influenced to improve (near well) productivity and sweep efficiency. Options for characterization are: • Static properties like petrography, porosity, permeability and gas/fluid composition with i.e.; thin sections/slabs image analysis, micro/macro- CT-scanner, XRD, XRF, Pycnometer, Ruska porosity/permeability, GC, AAS, AES, etc. • Dynamic properties can be obtained with plug sorption-, diffusion- and flow-experiments under standard conditions. In addition, duplicate experiments under higher P,T-conditions, meeting in-situ conditions. -Chemical drying by flue gas injection (N_2, etc.). - Thermal treatment by wellbore heating to increase permeability and porosity of the reservoir rock. In-situ combustion (600 to 1200 ^oC) etc • Dielectric measurements to determine how gas is interacting with the tight shale/coal reservoir matrix. It is expected thar E.M.-charging may change wettability or induce reduced osmosis, especially in tight gas reservoirs, with large fluid-solid matrix interfacial area. Theory must account for these "enhanced" situations and rock flow models again are adapted.
Deliverables	Input parameters for reservoir/production-engineering and injection techniques, i.e.: • Determination of reservoir composition, structures and. • Physio-chemical preference to improve maximum (enhanced) production and/or injection. In an interactive way the petrophysical results are to be implemented into geophysical- geological- and reservoir models to improve reconnaissance and production.

Project Title	3D fracture network formation in tough gas reservoirs
Program Line	Tough Gas
Start- and end dates	2012-2016
Author	Dr. Auke Barnhoorn (TU Delft) auke.barnhoorn@tudelft.nl
Description	In tough gas reservoirs (e.g. tight carbonates, shales) the presence of fractures, either naturally formed or hydraulically induced, are almost always a prerequisite for hydrocarbon productivity of that reservoir to be economically viable. This project studies the formation of fractures in tough gas reservoir rocks (3D fracture geometry and connectivity) and the processes occurring along fracture planes during continuous fluid flow by use of laboratory fracturing experiments combined with 3D visualization of fracture planes and particle distribution along such planes using high-resolution X-ray tomography techniques. The results will provide us with recipes to better predict the potential of tough gas reservoirs, and to optimize hydrocarbon productivity in tough gas reservoirs.
Project description - objectives	This proposal aims to quantify the 3D growth of fracture networks and the fluid flow behaviour with time along fracture networks by an extensive experimental fracturing and visualisation campaign using unique and state-of-the art facilities housed at TU Delft. **Fracturing experiments will determine the:** - Effect of hydraulic fracturing fluids (aqueous and non-aqueous fraccing fluids) on fracture formation, propagation and connectivity in tough gas reservoirs. - Time-lapse experiments monitoring permeability changes in fractured and propped tough gas reservoir rocks during continuous flow of aqueous and non-aqueous fraccing fluids (proppant distribution, fines migration). - Effect of near-borehole and far-field stress fields on fracture formation and propagation during hydraulic fracturing. - Effect of rock anisotropy (e.g. layering) on fracture propagation in tough gas reservoir rocks. Does the overall stress field or the rock anisotropy (e.g. layer parallel fracturing) dominate the orientation of fractures? - Characteristics and statistics of 3D fracture networks during stress-driven fracturing experiments on tough gas reservoir rocks (no borehole fluids). Stress-driven fracturing simulates the natural fracturing process in tough gas rock types. - Geomechanical parameters that govern fracture formation for input into hydraulic fracturing models. **Visualisation and quantification of fracture networks:** The experimental fracturing campaign is accompanied by extensive visualisation of the 3D fracture networks (orientation, connectivity, aperture), proppant distribution and migration of fines using high-resolution 3D X-ray tomography imaging techniques (micrometer scale resolution). This will include the changes of those properties with time during continuous flow through experiments. The outcomes on fracture properties will be up-scaled to reservoir scales and characteristic fracture models will be generated. A collaboration with Prof Drury (UU) is envisaged for certain aspects of the research where even higher resolutions are required. The Focused Ion Beam technique on a Scanning Electron Microscope at UU will provide 3D microstructural information on a nanometer-scale resolution. The experimental fracturing campaign is complemented with studies on fracture characteristics in naturally fractured tough gas analogues (e.g. shales, carbonates), production histories from tough gas reservoirs and geomechanical numerical modelling studies on fracture formation and propagation.
Deliverables	- Predictive models for 3D fracture geometries in tough gas reservoir rocks (e.g. dominant fracture orientations due to heterogeneous stress fields, effect of rock anisotropy). - Effect of fraccing fluids on hydraulic fracturing including the

	preservation/destruction of high-permeability pathways for fluid flow (proppant distribution, fines migration). - Fracture statistics in tough gas reservoir rocks for upscaling to fractured reservoir scales. Yearly reports and scientific publications with descriptions of experimental results, fracture statistics, tools for improved predictions of fraccing efficiency and production performance in tough gas reservoirs, as well as workflows to optimize the development of tough gas reservoirs using hydraulic fracturing stimulation techniques.
Relevance	The invention has enormous application potential for improved prediction of hydrocarbon productivity in fractured tough gas reservoirs. Improving our knowledge of the performance of tough reservoirs is vital for meeting our continuing energy demand in the coming decades.

Project Title	**Fracking Fluid Engineering**
Program Line	Tough Gas
Start- and end dates	2012-2016
Business Impact	Improving the environmental reputation of fracking is essential in order to obtain a license to operate. This project targets the source of potential environmental damage and aims to reduce the environmental threat by changing the polluting properties of the fracking fluid and adding novel “self healing” capacity to remediate any potential damage.
Author	Dr. ir. Timo Heimovaara (TU Delft) T.J.Heimovaara@tudelft.nl
Description	Application of hydraulic fracking a technology for tight gas formations is currently under severe scrutiny because of a negative environmental image. This currently leads to severe opposition by the general public against shale gas projects. This project aims to improve the environmental performance of hydraulic fracking by developing environment compatible fracking fluids (biodegradable and preferably non-toxic).
Project description - objectives	The aim is to develop a novel formulation of fracking fluid which reduces the environmental impact and at the same time provides a strong tracer signal for early detection of possible emission to the environment. Compounds that make the final treatment very complicated and therefore expensive, should be not be used in preparing the fracking fluid. The approach is to develop a fundamental understanding of technology used to improve the gas extraction but at the same time may lead to formation damage such as clogging by biofilm development in the system. For example, fracking fluids generally contain large concentrations of readily biodegradable compounds which lead to a strong initial growth of biofilm, using less biodegradable compounds reduces the growth rate of biofilms. Another approach that will be investigated is to tailor the formulation in such a way that biological processes leading to preferential clogging of flow paths (Biosealing) can be used as a self-healing mechanism aimed toward preventing emissions to the environment. Biosealing is a process has proven to be applicable in closing of water leaks in building pits (http://www.deltares.nl/en/product/340636/biosealing). Important research lines will be the reactive flow and transport modelling in order to quantitatively analyse the behavior of fracking fluid. Special attention is given to the biogeochemical modelling of fracking fluid behavior.
Deliverables	Peer reviewed publications
Illustration Roadmap	year 1: Analysis of functional properties of fracking fluids, identification of environmental threats, microbiological behaviour in proppant filled fractures. Set-up of modelling approaches. year 2: Laboratory experiments, under ambient conditions, analysis of results using models; year 3: Laboratory testing under realistic conditions (bore-hole simulator) year 4: Final tests and presentation of results (papers, conferences)

Project Title	**Geophysical Monitoring of Unconventional Gas Migration**
Program Line	Tough Gas
Start- and end dates	2012-2016
Business Impact	For production of "tough gas", many boreholes need to be drilled. However, once a few boreholes have been drilled and produced, detailed borehole information (1D) calibrates the 3D geophysical information. The latter can then play an important role in the optimization of where to drill the next borehole such that optimal production results can be expected.
Author	Dr. ir. Guy Drijkoningen (TU Delft) G.G.Drijkoningen@tudelft.nl
Description	The combination of seismic and electromagnetic techniques will be investigated in how it can help the production of unconventional gas. It will include the possibility of using the new technique of interferometry that does not require velocity-model information.
Project description - objectives	In this proposal we request funding to develop interferometric methods for monitoring gas presence and migration, combining the use of seismic and EM data. The result of combining seismic and electromagnetic interferometry is 4 x 4-component seismic and 4 x 4-component EM data with sources and receivers relatively close to the gas reservoir. Although the spatial resolution of EM data is much lower than that of seismic data, the main advantage of EM is its power to detect a gas accumulation in a reservoir due to its high resistivity contrast. We will investigate the advantage of combining the retrieved multi-component seismic and EM data for reservoir monitoring. Initial investigations in the Applied Geophysics have shown that, group for shallow subsurface applications, the combination of seismic and electromagnetic data significantly improves the discrimination between porosity and saturation. We expect to obtain a similar improvement in resolving power for reservoir monitoring, using the seismic and electromagnetic data obtained by multi-component interferometry.
Deliverables	Peer reviewed publications Software that: - Forward-modelling code that generates the combined seismic and electromagnetic response of unconventionals - Interferometric code that determines the image from data

Project Title	**Closed-Loop Tight Gas Production Optimization**
Program Line	Tough Gas
Start- and end dates	2012-2016
Business Impact	Control and optimization of the subsurface stresses and flow is essential to optimize economic performance (optimal design, operation and well intervention) and to guarantee operational safety en environmental fidelity (fracture containment through active model-based data-constrained control).
Author	Prof. dr. ir. Jan Dirk Jansen (TU Delft) J.D.Jansen@tudelft.nl
Description	This project will deliver computational techniques, workflows and prototype software to optimize well and fracture locations and dimensions for tight gas production, both in the design stage (field development planning) and in the operational phase (surveillance-, production-, and workover optimization). The optimization will be based on coupled reservoir flow and geo-mechanical models in combination with data from geophysical sources (e.g. passive seismics, wellbore impedance). We will build on our extensive experience in well location optimization, recovery optimization and computer-assisted history matching, as developed for oil production during secondary and tertiary recovery operations.
Project description - objectives	• To develop the concept of closed-loop production optimization (CLPO), also known as closed-loop reservoir management, for tight gas production. • To develop computational techniques and prototype software for CLPO in a combined geomechanical/reservoir flow simulation domain. • To develop data assimilation techniques to update computational models based on geophysical measurements of induced fractures. • Optimization of economic performance , and safeguarding of operational and environmental integrity
Deliverables	Peer reviewed publications, reports, prototype software
Illustration Roadmap	

Project Title	**Multi-scale modelling of fractures and stresses: from basin to well**
Program Line	Tough Gas
Start- & end dates	2012-2016
Business Impact	Mitigating the risks from critical stressed faults while using the potential of pre-existing faults when enhancing reservoir performance by induced fracturing.
Author	Prof. Giovanni Bertotti and Dr. Nico Hardebol (TU Delft) G.Bertotti@tudelft.nl
Description	Hydraulic fracturing should account for regional stress-field and pre-existing fracture-fault systems in order to: (1) mitigate risks of reactivating faults that are under critical stress which induce seismicity (2) enhance fracture permeability by utilizing the regional stress-field and natural fractures. This project develops geomechanical models at multiple length-scales to enable the determination of optimal borehole orientation and with the focus on the Dutch 'shale basins' (Variscan foreland, London-Brabant Massif).
Project description - objectives	**Mechanical models, using fractures and avoiding critical faults:** - We apply finite element numerical models to resolve stress deviations around first-order fault systems and to arrive at predictions on fracturing potential at the local (borehole) scale. The models will quantify the stresses and strain around natural fracture-fault systems to determine their potential for induced fracturing. - The numerical models enable us to combine our detailed knowledge of the Dutch subsurface fault systems, mechanical layering and compilations of regional stress trajectories (world stress map) and to arrive at local predictions of stresses in the affinity of boreholes. - Geomechanical studies have not before bridged between regional-scale (100 km) stress trajectories around major faults to sub-km scale of fracture networks and down to the meter scale around boreholes. We aim at the design of multi-scale models with increasing higher resolution. - The building of fault geometries at multiple scales is based on a novel work-flow that we currently test for multi-scale reservoir flow simulations. Similar multi-scale geometry models can also be used for geomechanical experiments that test the potential of pre-existing fractures. **Quantifying fracturing potential by honouring heterogeneity:** - Explicit geometry models of the fracture-fault networks will be built. Precise descriptions of first-order fault systems from seismics will be included. The design of geometries of sub-seismic faults and fractures is based on our tested work-flow that starts from constraints on orientation, shape and distribution functions (from outcrop analogues and wells) and arrives at stochastic simulations of 3D fracture networks. - Knowledge on the first-order mechanical heterogeneity will come from strength-map models (in collab. with Fred Beekman, UU.). Refinement will be made from current European lithosphere scale down to a regional upper-crustal scale. - Mechanical stratification at the local scale around a borehole will be considered through combined work with analogue model studies (Auke Barnhoorn, TU-Delft) and field analogues that describe relationship between mechanical and lithological stratification.
Deliverables	The models will determine: *) the critically stressed fault systems under natural stress conditions *) the role of reducing locally the effective stress by the injection of high pressure fluids on the stress field at the scale of 10^1–10^3 m. *) risks of activating fault systems *) the potential of using pre-existing fractures to enhance the effectiveness of induced fracturing over wider area.

Project Title	**Tough gas targeting through high-resolution geological characterization of fine-grained sedimentary rock**
Program Line	Tough Gas
Start- and end date	2012-2016
Business Impact	The results of this study will yield guidelines for the smart targeting of potential tough gas reservoirs at reduced uncertainty, hence, reduced environmental footprint.
Authors	Dr. Rick Donselaar & Dr. Gert-Jan Weltje (TU Delft) M.E.Donselaar@tudelft.nl
Description	High resolution geological reservoir models of fine-grained sediments and inherent permeability characteristics will be developed to reduce uncertainty in targeting potential tough gas reservoirs.
Project description - objectives	The subsurface of the Netherlands features thick piles of fine-grained sedimentary rock in - among others - Carboniferous, U. Permian and Triassic continental (fluvial) successions. In the search for conventional hydrocarbon plays the fine-grained sediments are invariably considered as non-permeable facies and hence discarded as 'waste zone'. However, ongoing geological research into the reservoir potential of fine-grained fluvial rock [1] indicates that the depositional process favors the occurrence of thin but laterally very extensive permeable sediment bodies in this waste zone which potentially can store large quantities of tough gas. The aims of the present project proposal are to: (1) Identify the geological boundary conditions for the occurrence of permeable fine-grained intervals with tough gas potential, and (2) Develop predictive tools for quantitative sediment characterization and subsurface mapping. We consider the interplay between depositional setting, mineralogy and diagenetic processes as prime boundary conditions to determine the geological reservoir architecture for tough gas storage. Integration of multivariate statistical modeling techniques, process-based models of sediment properties, outcrop analogue studies and automatic geological core description using non-destructive XRF-based geochemical analysis and high-resolution images will yield high-resolution prediction of the spatial distribution of porosity and permeability in fine-grained fluvial floodplain settings. [1] Donselaar, M.E., Overeem, I., Reichwein, J.H.C. and Visser, C.A. (2011) Mapping of fluvial fairways in the Ten Boer Member, southern Permian Basin. In: Grotsch, J. and Gaupp, R. (eds.) The Permian Rotliegend in the Netherlands. SEPM Spec. Publ., 98, 105-118. ISBN 978-1-56576-300-5
Deliverables	The study will yield high-resolution static and dynamic reservoir architecture models for fine-grained fluvial facies of targeted stratigraphic intervals in the Carboniferous, U. Permian and Triassic of the subsurface of the Netherlands. The models are based on comprehensive quantitative databases we will establish from integrated outcrop and subsurface data acquisition and analysis of size, shape, spatial distribution and internal porosity and permeability characteristics of the potential tough gas targets in fine-grained fluvial sediments. The predictive tools for quantitative sediment characterization and subsurface mapping we will develop are an essential component to quantify prediction errors in the reservoir architecture models, and will yield guidelines for future data acquisition.

Project Title	**Efficient hydraulic fracking simulator including field heterogeneity**
Program Line	Tough Gas
Start- and end dates	2012-2016
Business Impact	Cost reduction of hydraulic fracking operations by reducing risk of induced seismicity
Author	Dr. D.E.A. Van Odyck (TU Delft) D.E.A.vanOdyck@tudelft.nl
Description	Development of a simulation tool that can model hydraulic fracking and induced seismicity including field heterogeneity and stress wave interaction with existing fracture systems with the help of multicore systems to significantly reduce computing time
Project description - objectives	One of the important questions in hydraulic fracking is whether the injection of a fracking fluid into the reservoir not only generates a fractured porous media ready for production but also induces seismic activity. From an operational point of few it is of utmost importance to have a fracking strategy that maximizes subsurface fracture spreading to the lowest cost but does not induce seismicity. This means that before starting operations a computational fast simulation tool is needed to run different fracking scenario's. The injection of fracking fluids initiates stress and pressure waves/shocks in the fluid-rock system. To give precise predictions in order to minimize fracking related risks it is needed to include a geomechanical model that contains the following properties: fluid flow, heterogeneity of the rock, layering of different geological formations, existing fault system and correct wave/shock propagation. We propose a continuum multiphase model that can handle the above described criteria. To minimize the computational effort and to ensure that it is a tool that can be used in the field it is proposed to use well established techniques from the Computational Fluid Dynamics (CFD) community. The combination of fluid flow through a porous medium and the propagation of shock waves in the porous skeleton at the same time is a challenging combination for existing geomechanical codes. They are often based on finite difference(FD)/element(FE) methods and have difficulties in representing moving sharp interfaces, like stress waves/shocks, correctly. Especially higher order methods pose convergence problems in case of FD/FE methods. In order to handle moving sharp interfaces, with the minimum of numerical diffusion it is proposed to use high resolution shock capturing schemes (HRSC) in combination with adaptive mesh refinement (AMR). HRSC scheme's are based on the finite volume approach and guarantee physical correct wave/shock propagation at a minimum of computational cost. The AMR makes sure that the grid is dynamically regridded in neighborhoods of sharp interfaces, like cracks. The use of multicore systems, as encountered in graphic cards (GPU), in everyday PC's enables the use of high performance computing at low cost. It is proposed to use advanced parallel coding techniques to make use of these multicore systems. The combination of above mentioned techniques results in a simulation tool that can be used in the field, given geophysical data, to model real-time the fracture propagation and induced seismicity for a given hydraulic fracking scenario.
Deliverables	Software package and insight in what the induced seismicity is of different hydraulic fracking scenario's in real field situations

Project Title	**Geostatistical extrapolation of basin facies and burial history for reservoir model input and well productivity estimates**
Program Line	Tough Gas
Start- and end dates	2012-2016
Business Impact	- Improve geological input for unconventional reservoir models, to reduce subsurface uncertainty in unconventional appraisals. - Apply geo-statistical extrapolation to reservoir parameters from borehole logs, outcrop analogs and geological facies models
Author	Dr. Gert Jan Weltje and Dr. Ruud Weijermars (TU Delft) G.J.Weltje@tudelft.nl
Description	A strong geo-statistical foundation is needed to improve unconventional reservoir models, as uncertainties propagate throughout the entire workflow. In this setup, geological characterization is intimately linked to petrophysics and reservoir-engineering. The added value to industry consists of the development of advanced geological characterization methods for unconventional basins, in which all available geological knowledge will be integrated to achieve the best possible predictions of reservoir quality and performance.
Project description - objectives	The basin burial history and any tectonic deformation affect the diagenesis and petrophysics in prospective reservoirs. The basin subsidence and tectonics also determine the temperature profile and fluid pressures that control hydrocarbon generation, maturation and migration. Permeability, tortuosity and natural fracture fairways in diffuse and disperse porous media of the reservoir affect the gas migration path and flow rates.
Deliverables	In order to better characterize tight-gas reservoirs, application of outcrop analogs and/or modern analogs should be incorporated to understand better the variability that will be encountered once drilling and completion operations begin. Similar problems are encountered in characterization of the geological structure of shale-gas reservoirs, which are often regarded as being essentially homogeneous in terms of their initial (pre-fraccing) reservoir properties. Reservoir characterization will be carried out using analogs and through the application of ongoing research into high-resolution rock-property modeling based on multivariate analysis of XRF core-scanning data obtained from cores. The use of modern analogs also opens the way to application of powerful methods of process-based simulation, which have been identified as the way forward in reservoir-quality prediction. 1. High-resolution characterization using advanced XRF-core-logging methods allow lithology (lithofacies), porosity, and permeability to be mapped on a cm-scale from cores (Weltje & Tjallingii, 2008), and may be used in conjunction with newly developed multivariate methods of chemostratigraphic correlation to highlight the fine-scale structure in apparently homogeneous shale-rich reservoirs. 2. Diagenetic models based on detailed petrography, reconstructed burial histories and geochemical analyses, can be improved and applied to predict the spatial distribution of reservoir quality (poro, perm) resulting from dissolution and precipitation trends in the subsurface (Ajdukiewicz & Lander, 2010). 3. Process-based modeling of basin filling to predict lithological trends, especially in data-poor environments, will allow us to better predict sediment composition and texture. This part of the work is already well-developed at our department, and currently moves towards integration of basin- and reservoir-scale architecture modeling.