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TNO report

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Final Report – A framework for the assessment of ductile shales for wellbore sealing and abandonment

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1 Project information

Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

Subsidy reference: TKI2018-08-GE

Topsector Energy, TKI Nieuw Gas:

Program line Geo Energy, research theme Decommissioning and Abandonment

Project duration:

May 1st, 2018 – April 30th, 2019

Project partners:

TNO (coordinator), EBN, Total, Shell, Oranje Nassau Energy, Neptune

2 Technical reporting

2.1 Management Summary

The use of natural ductile shales for sealing boreholes of oil and gas wells has recently received an increasing interest. From wellbore events it is known that shales have the capability to close wellbores in short time frames and cause drilling issues and non-productive time. Recent studies have investigated the potential to use natural, ductile formations for well sealing and abandonment with quite promising results. This study investigated potentially ductile clay formations in the Netherlands and explores options and procedures to identify them.

Generally, it is known that the ductile behaviour of natural clays and shales may vary depending on various factors such as (clay) mineralogy, petrophysical and mechanical parameters. When limited geomechanical information is available, parallels may be found between geomechanical properties and other properties such as mineralogy and geohydrology to assess the ductility of the formation.

In this study several potential proxies for ductile behaviour have been investigated. Additionally, a methodology has been developed to assess the ductility of shales and has been applied in case studies to subsurface formation and selected wells in the Netherlands. The developed procedure and a database of proxies and information on ductile shales in NL has been provided to the partners.

The knowledge gained and the procedure developed will support setting up a pilot test to investigate the potential of ductile shales in the field to work towards an implementation of this technology in the Netherlands.

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2.2 Introduction, motivation and scope

Many oil and gas wells in the Netherlands and elsewhere will be taken out of production in the next years. The wells should be safely abandoned so that no leakage to the environment should occur in the long-term. Oil and gas wells are traditionally abandoned using cement plugs. Cement will deteriorate under certain downhole conditions or due to improper placement in the course of tens to hundreds of years which raises questions with respect to the long-term integrity of abandoned wells. Instead of using cement, there is increasing interest to use ductile, natural materials as bentonite for well sealing and even further to use the sealing potential of ductile rock layers (caprocks) located above an oil or gas reservoir. In particular rocksalt and shale show plastic, ductile behavior downhole. The major advantage of such materials is that they can remain stable for millions of years. The use of shale and rocksalt as seals may not only be more safe environmentally, the concept may also be financially more attractive (Fischer et al., 2016a,b).

It is known that the ductile behaviour of shales depends on (clay) mineralogy, petrophysical and mechanical properties (Josh et al., 2012; Koenen et al., 2014). Shales represent the most abundant sedimentary rock and their ductility depends on numerous properties (compared to evaporites). This study focused on the potential of clayey formation for natural wellbore sealing with focus on the Netherlands.

Although variable information is available about the geomechanical properties of buried shales the relationship between ductility and petrophysical or mineralogical parameters is not well understood, except the role of smectite content which can be used as an indicator for ductility. However, in order to identify potential natural sealing formation for wellbore closure in the subsurface it is crucial to increase the understanding of shale ductile behaviour.

When limited geomechanical information is available, parallels may be found between geomechanical properties and other properties on mineralogy, geohydrology, etc. Such properties refer to e.g. clay type, permeability, burial depth, diagenetic features. Insight is thus needed to couple the ductile properties to better known properties such as hydraulic conductivity, mineral composition or porosity, as this relation has not been investigated intensively up to now, to provide a methodology to identify ductile shales in the subsurface (of NL).

The objectives of this project were:

1. Which shales show ductile behaviour and which do not?
2. Which parallels exist for ductile shales between geomechanical properties and other petrophysical or mineralogical properties?
3. Can we establish an inventory of shales in NL and their properties with respect to ductility/usage for wellbore sealing?

The study provides an assessment procedure for the identification of shale rocks that are supposed to show ductile behavior in order to identify locations and wells in which ductile shales could be tested or used for well sealing and abandonment.

2.3 Project structure and execution

The aim of this project was to investigate several potential proxies for ductile behaviour. Additionally, a methodology has been developed to assess the ductility of shales and was applied to the subsurface of the Netherlands. A case study has been conducted to test and evaluate the selection procedure on selected wells in NL.

The project result was a report and a shale database in which the following is addressed:

1. Identification of the geomechanical properties of shales that lead to ductile behaviour as opposite to stiff or brittle behaviour

2. Identification of correlations between geomechanical parameters and other geo-scientific parameters of shales with a focus on ductile shales
3. Selection criteria for the identification of ductile shales useful for natural sealing of wellbores

The following activities were performed to achieve the results:

- Data collection for intensively studied shales
- Data scanning for less intensively studied ones
- Data extraction for geomechanical and other properties, incl. set-up of first database
- Data analysis on geomechanical behaviour of shales in relation to its properties
- Data analysis on proxies from mineralogy, etc. for geomechanical properties of shales

During the project no major organizational or technical problems occur, However the original project duration had to be extended for two months to include another case study for testing the developed evaluation procedure on two more example sets. The project budget or scope was not affected. Deliverables have been submitted on time at the agreed dates.

2.4 Results and conclusions

In this study we have developed a methodology to classify ductile shales in the subsurface and assess the potential of clayey formation for natural wellbore sealing with focus on the Netherlands. We have found and tested several proxies and tools for assessing the ductile behaviour of clay formations. The main conclusions are:

- The ductile behaviour of clay formations can be divided in plastic/creep behaviour and physico-chemical swelling behaviour of clay minerals. Under water-saturated conditions the latter is dominated by osmotic-swelling which is largely induced by changes in salt concentrations in the pore water.
- Smectite clay minerals are most sensitive to this type of swelling, but mixed-layer illite-smectites and illites can also swell by this process.
- Dongen Formation (i.a. Ieper Clay), and the Landen Formation contain mostly smectite and are most prone to swelling. Shale from the Vlieland Formation contains more mixed-layer illite-smectites which can still swell but to a lower extend, and shales from the Aalburg Formation predominantly contain illite and kaolinite which will be least prone to swelling. Siltier intervals and higher carbonate content, e.g. in the top part of the Ieper, result in lower swelling capacities.
- Porewater in Dutch clay formations is likely brackish/saline to hypersaline. Input of fresh water would therefore induce swelling.
- Mineralogical data is scarce and does not predict creep behaviour. We have therefore also tested the use of well logs to predict the ductile behaviour of clay formations.
- Two wells were chosen to test the methodology. Both wells had been reported in EBN's geo-drilling event database to have had borehole stability problems in the Ieper Clay and Vlieland Claystone. Various geomechanical properties were determined from wireline logs from offset wells, such as Young's Modulus, Shear Modulus, and Uniaxial Compression Strength. All logs were able to pinpoint the ductile shale intervals that caused hole pack-offs.

- A procedure has been developed to help assessing potential ductile clay formations with available data.

2.5 Contribution to the TKI Nieuw Gas, program line Geo Energy roadmap objectives, the TKI subsidy regulation and knowledge development

The project provided knowledge supports the use of natural materials as the sealing material for permanent well sealing by developing a screening procedure to identify potential ductile formation in the Netherlands that could be used for natural formation wellbore sealing. The impact of this contribution in terms of energy saving and / or CO₂ emissions, the major goal of the TKI subsidy regulation, is significant, however difficult to quantify. Rock salt and ductile shales represent a high percentage (> 50%) of caprocks of (small) gas fields on-and offshore in NL. Leakage of methane has a large greenhouse effect (>20x CO₂ effect) and CH₄ emissions from abandoned boreholes have been proven to present a significant but underestimated source of greenhouse gas emissions (Kang et al., 2014). Effective borehole sealing significantly contributes to reducing greenhouse gas emissions and protecting the environment.

Natural sealing of new and existing wells is considered to be effective, cheaper, to require substantial less energy and is in principle much more sustainable than engineered solutions. It can help to reduce both the cost of decommissioning and associated CO₂ emissions without impairing long-term containment of the wells (Hopmans and Wollenweber., 2018). Thus the project helped to achieve specific objectives of the TKI program line Geo Energy research theme Decommissioning and Abandonment, which are in particular:

- Minimize negative effects of small-scale gas extraction on the environment and economics
- Re-use of existing infrastructure and integration with other energy activities in the North Sea.
- Development of sustainable and cost-efficient methods and techniques relating to integrity and state monitoring (pipelines, wells, installations); closure of wells, platforms and finding useful use (decommissioning);
- Safety, reliability and integrity (offshore installations and pipelines).

The developed knowledge and procedure for identifying potential natural well sealing formations will support the fast implementation of this technology by enabling the selection of potential well and field trials.

Overall, the method could be a game-changing approach with respect to long term zonal isolation performance and economic abandonment procedures at the same time.

2.6 Follow-up activities, spin-offs and exploitation

The results of this project have not been disseminated to public but are exploited by being used for searching for suited pilot wells to test ductile shale formations for wellbore sealing and abandonment in field tests. The developed screening procedure is available to all operators and partners of the TKI program line Geo Energy research theme Decommissioning and Abandonment.

The results feed into follow-up projects of the TKI program line Geo Energy research theme Decommissioning and Abandonment such as:

TKI 2019: Natural seals research and test well, and

TKI 2020: Natural Sealing Large-scale implementation

For further information on this project please contact the secretary of TNO's Applied Geoscience Group at secretariaat-aarde@tno.nl.

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