AVOIDING ROUTINE CORE ANALYSIS PLUG DAMAGE BY PROPER EVALUATION OF CORE GAMMA-RAY, CORE DESCRIPTION AND WELLSITE CORE SAMPLING

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ABSTRACT

Great effort and care is exercised to select proper cleaning methods for Special Core Analysis (SCAL) plugs. In contrast selecting the proper cleaning methods in Routine Core Analysis (RCA), which deliver majority of information for the static reservoir model and whose plugs act as backup samples for SCAL, is often neglected.

Mild and more expensive cleaning methods are often avoided in RCA as the large sample number would lead to a considerable cost increase. In this paper, two case studies from oilfields in Germany are presented where massive plug damage while cleaning took place while RCA, leading to a biased distribution of petrophysical data in the cored reservoir and a lack of back-up plugs for SCAL. This plug damage would have been avoided by a proper evaluation of existing data such as total core gamma-ray, geological core description, Dean Stark fluid extraction and results from “Hot Shot” as well as Tracer plugs taken at the wellsite. So called “Hot Shot” plugs are sampled to receive porosity and permeability data within 2 weeks by limiting the cleaning time to a few days. Integration of the information from these sources can be used to identify core sections where cleaning should be avoided or short list plug samples requiring a more selective and milder cleaning method compared to conventional approaches. Considering a closer look at available data offers a proactive means of avoiding damaged plugs during Routine Core Analysis and the loss of valuable data for the reservoir model.

INTRODUCTION

In 2013 and 2015 two German oil wells were drilled and cored. Core recovery from well M was 32m using 4 inch core diameter. The formation cored was Dogger beta sandstone (Jurassic Age) between 3249 and 3282 m depth. The degree of consolidation in this formation can vary and weakly consolidated core sections were expected.

Well S was cored in three sections using 3 ½ inch diameter. Cores 1 and 2 had a recovery of 28 m (1673-1705 m depth) of carbonate rock (Malm, Gigas-Layers). Core 3 was drilled in Dogger epsilon sandstone (Jurassic Age, 27 m core recovery, 2005-2032 m depth). Wellsite plugs were drilled in both cases and wax preserved for Hot Shot, Dean

Stark and Tracer/Water salinity (R_w) analysis allowing a quick data return time. Lubricants for drilling the wellsite plugs differed in both cases (Table 1).

At wellsite M a deuterium tracer was used. Focus was on good quality Dean Stark plugs and Water salinity (Rw) determination. Therefore, air was used for plug drilling. At wellsite S focus was on iodine tracer detection (Mud contamination) and Hot Shot Plugs. To prevent clay damage saturated KCl brine was used as lubricant. Reservoir brines of the two oilfields also show different salinities. The reservoir brine of field M has a TDS of 110 to 170 g/L and brine of field S vary between 216 to 235 g/L.

After wellsite plugs and 1m core sections were received in the laboratory, gamma-ray core logging and overview CT scans were run. On cores from well S a quick look core description was carried out prior to drilling RCA Plugs. Table 1 gives an overview of wellsite plugs, brine salinities, drilling lubricants and routine core analysis measures after samples were received in the laboratory.

CLEANING METHODS

Routine measurements as porosity and absolute gas permeability require clean and dry samples. Oil residuals, water, as well as evaporated salts, mud filtrate and other contaminants have to be removed for comparable data. The success of a cleaning method is related to sample permeability, crude oil composition, type of drilling mud and applied temperature. Three methods are commonly applied in RCA:

a) Hot Soxhlet Extraction,
b) Cool Sohlet Extraction, and
c) Total Immersion Cleaning.

Hot Soxhlet extraction is regarded a harsh cleaning method where plugs undergo cycles of drying and being immersed in the solvent. The boiling point of the solvent, e.g. toluene T=112°C, defines the cleaning temperature. Temperature reduction is achieved while Cool Soxhlet cleaning by extending the time till the condensed solvent gets in contact with the sample. Total Immersion Cleaning prevents drying cycles of the rock sample. A batch of samples is permanently immersed in a flask at constant temperature. The solvent is circulated in a Soxhlet cell connected to the sample chamber. Lower temperatures lead to longer cleaning times and might be inefficient removing contaminants. On the other hand large temperature variations are avoided regarded to be more suitable for delicate, e.g. clay rich, samples. Details on cleaning methods can be found in API RP 40; 1998; Cuic, 1975; Anderson, 1986, McPhee at al., 2015.

ROUTINE PLUG PREPARATION

Plug diameter for RCA is 1.5 inch. Drilling lubricants in the laboratory were white mineral oil (Blandol®) for oilfield M and kerosene for oilfield S.

Mild immersion cleaning was applied on plugs from well M using chloroform/methanol azeotrope (max. T~ 60 °C). Soxhlet cleaning on samples from well S was done in two steps. Hot Soxhlet cleaning with methanol (max. T~60°C) was followed by Hot Soxhlet cleaning with toluene (max. T~110°C). Humidity oven drying (T=60°C, 40% relH) followed cleaning in both studies.

Available Pre-Cleaning Informations		
	Well M	**Well S**
Dean Stark/Rw Plugs	x	x
Hot Shot Plugs	-	x
Core CT Scans	x	-
Core gamma	x	x
Quick Core description	-	x
Soxhlet Cleaning (1st methanol, 2nd toluene)	-	x (1^{st})
Mild Immersion cleaning (chloroform/methanol azeotrope)	x	x (2^{nd})
Humidity oven drying (60°C/40% rH)	x	x
Drilling Lubricant wellsite plugs	Air	KCl brine
Routine Plug drilling lubricant	White mineral oil	Kerosene
Reservoir Brine Salinity (g/mL)	110-170	216 -235

Table 1: Overview on plug preparation at wellsite and laboratory as well as available pre-cleaning information. After observing damage on well S plugs, cleaning method was changed to mild immersion cleaning.

DAMAGED PLUGS

After plug preparation was finished 43 out of 88 plugs were reported fractured/damaged for well M and only 84 out of 212 plugs from well S could be used for permeability measurement. This means that 49% of all RCA plugs from well M and 60 % of all RCA plugs from well S were damaged/fractured. Examples of damaged plugs are given in Figures 1 and 2. Additional plugs from well S core were drilled to increase sample numbers. Immersion cleaning was carried out on these plugs leading to no damage.

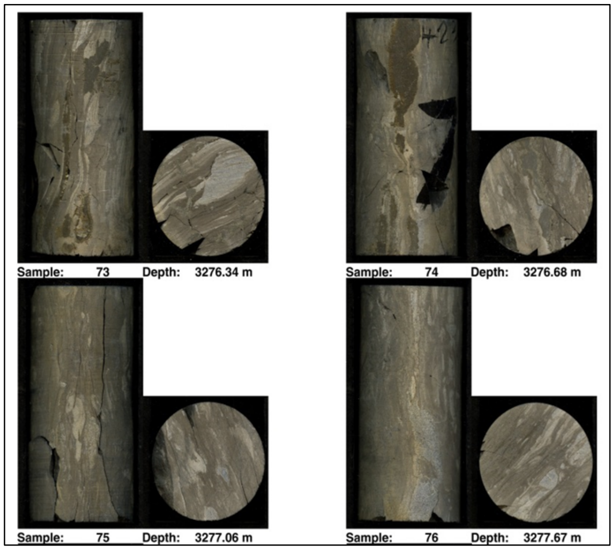

Figure 1: Damaged RCA plugs from oilfield M after cleaning and drying. Sample diameter is 1.5" inch.

Figure 2: Damaged RCA plugs from oilfield S after cleaning and drying. Sample diameter is 1.5" inch.

To find the reason for the vast number of damaged plugs a study followed looking for early indications of fragile reservoir zones. As wax-preserved plugs were taken at the wellsite and core logging data were available prior to cleaning, the question arose whether information from these sources could have prevented the plug damage.

EARLY INDICATIONS FROM WELLSITE PLUGS

Dean Stark plugs (McPhee et al., 2015; API RP 40) provide information of in-situ oil and water saturations of the cored reservoir zone. Dean Stark extraction is done in two steps. First water and hydrocarbons are extracted using toluene. The volume of evaporated water is collected and measured in a condenser. The loss of hydrocarbons is determined by mass balance. In a second step precipitated salt is removed by methanol extraction, which is commonly done in a Soxhlet apparatus.

Hot Shot plugs are taken to gather early information on basic reservoir properties such as gas permeability, porosity and grain density. In order to achieve a quick turnaround, cleaning time in the laboratory is reduced enabling results within a month. After being measured a second cleaning procedure follows to make Hot Shot results comparable to RCA data. A change towards higher permeabilites and porosities commonly accompanies this second cleaning cycle. Reviewing photographs of Dean Stark and Hot Shot plugs damages are visible on samples from well S (Fig. 3).

Figure 3: Oilfield S. Damaged Dean Stark plug (left) and damaged Hot Shot Plug (right). after cleaning and drying. Sample diameter is 1.5" inch.

In comparison Dean Stark plugs from field M showed no signs of cleaning damage. Plugs sampled for water salinity/Rw study also showed no signs of damage in fresh state. Plugs broke after centrifuge extraction of the reservoir fluids and thus no cleaning procedure followed.

CORRELATION BETWEEN DAMAGED PLUG LOCATION AND AVAILABLE CORE DATA

As a next step results from core gamma-ray log and quick look core description were compared with the location of damaged plugs along the cores. Figure 4 compiles the information on plug locations (Dean Stark, Tracer/Rw, Plugs involved in RCA, damaged) and total core gamma-ray response for core 2 from oilfield M. Zones of API values above 120 can be correlated with damaged plug locations. The graph shows that only one Dean Stark plug (8 DS@3255.04 m) was sampled where plug damage occurred. Information coming from DS plugs has therefore been considered biased due to sample location.

Figure 5 compiles this information for core 1, well S. Hot Shot and Dean Stark Plugs in this case are sampled below a core depth of 1685 m. A reservoir zone where massive plug damage occurred. Dean Stark plug 9 (core depth 1690.14m) is shown in Figure 3. All DS plugs in that zone show fractures. Hot Shot plug 10 in contrast shows no sign of plug damage as do three further RCA plugs. Strong variations of the gamma-ray response below 1685m coincides with this observation. A minimum of 40 API and a maximum of 100 API is measured (Figure 5). Similar graphs as seen in Figures 3 and 5 can be generated for all other sections of the cored wells. In general, total gamma ray response in cores from oilfield M is 80 – 170 API. Dogger epsilon Sandstone formation in core 3, well S varies between 40 -170 API. Gamma-ray response for the Malm carbonate formation in cores 1 and 2 from well S is between 40 and 130 API. The quick look core description available for cores from well S allow a correlation between gamma-ray response, damaged plug location and rock facies. Figure 6 includes the lithology after quick look core description.

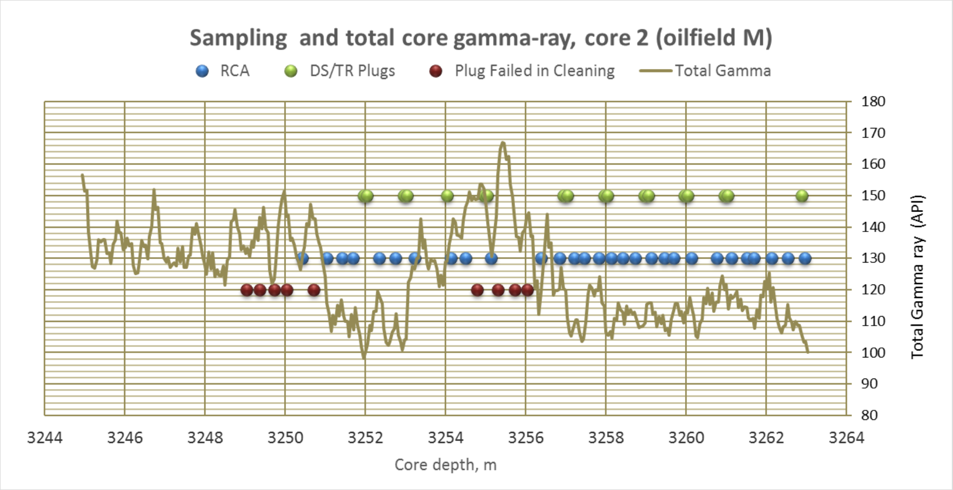

Figure 4: Graph combining plug locations and total gamma-ray response of core 2 (Sandstone formation, oilfield M).

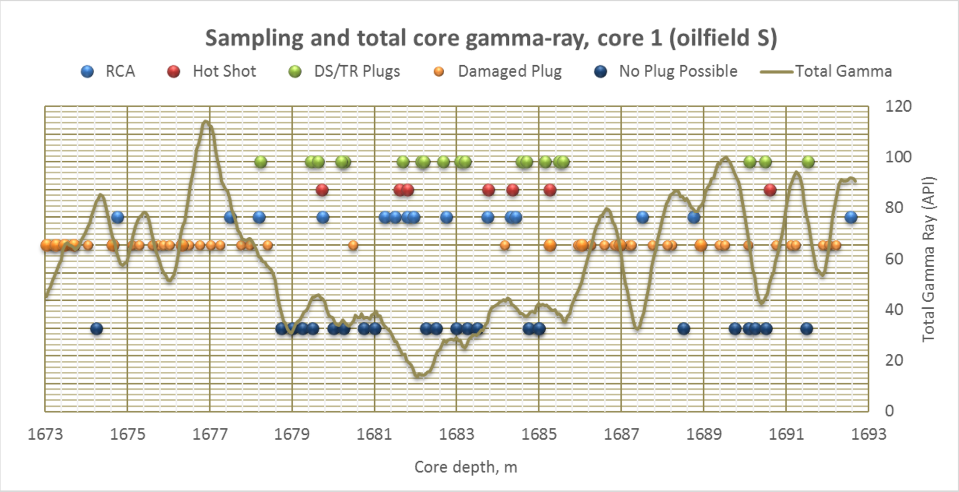

Figure 5: Graph combining plug locations and total gamma-ray response of core 1 (Carbonate rock formation, oilfield S).

Below the core depth of 1700m an increase of the total gamma-ray response as well as a series of damaged plugs correlates with mudstone facies. Other damaged plugs below this depth are located in the limestone facies. Figure 7 shows the slabbed core sections of two damaged plugs within the Malm limestone (Plug 80@ 996.52m, Plug 84@1997.5m).
Plugs 80 and 84 are described as wackestone with gradational grain contacts. Plugs 85 and 86 are did not fail while cleaning. These plugs are described as packstone.
Damaged plugs of the Dogger epsilon sandstone (core 3, field S, cores 2-4, field M) are mainly coming from depositional environments described as argillaceous (muddy) sandstone, (marine) mudstone, distal mouth bar and pro delta. In core 3, well S a core

section of 2 m described as sandstone showed a high gamma-ray response and three plugs drilled in that zone failed while cleaning. A more detailed look at core description mentions characteristics as gravelly and mudclasts (Fig. 8).

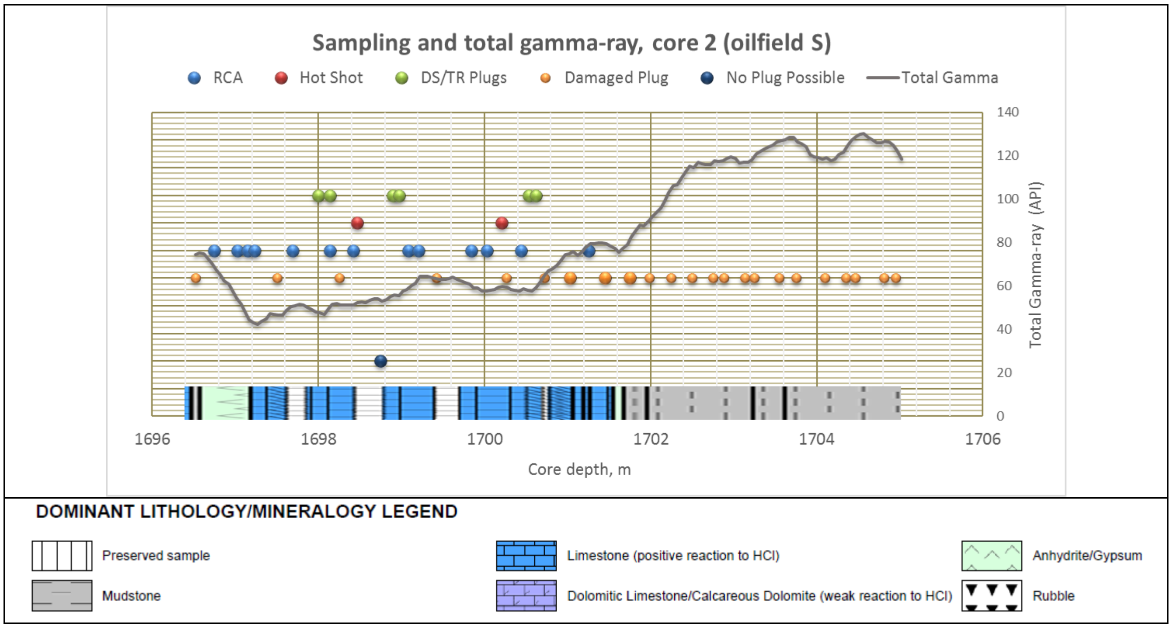

Figure 6: Graph combining lithology, plug locations and total gamma-ray response of core 2 (Malm Carbonate, oilfield S).

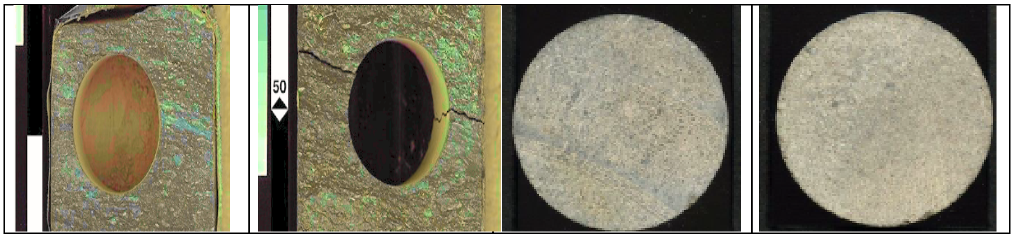

Figure 7: Image of slabbed core 2 of well S and clean plugs. Left to right: Plug 80 (damaged), 1996.52m, Plug 84 (damaged), 1997.5m, Plug 85, 1697.69m, Plug 86, 1998.14m. Plug diameter is 1.5" inch.

The impact of oil saturation on plug damage can hardly be evaluated. Only three Dean Stark Analysis data are available from core sections where plug damage occurred.
In well M only Dean Stark plugs 8S lies in a zone where plug damage appeared. Oil saturation measured was 36.3% PV. Dean Stark plugs 9 and 10 from core 2, well S showed oil saturations of 30.5 and 22.1% PV. A better correlation between oil saturation and plug failure might be achieved using log interpretation.

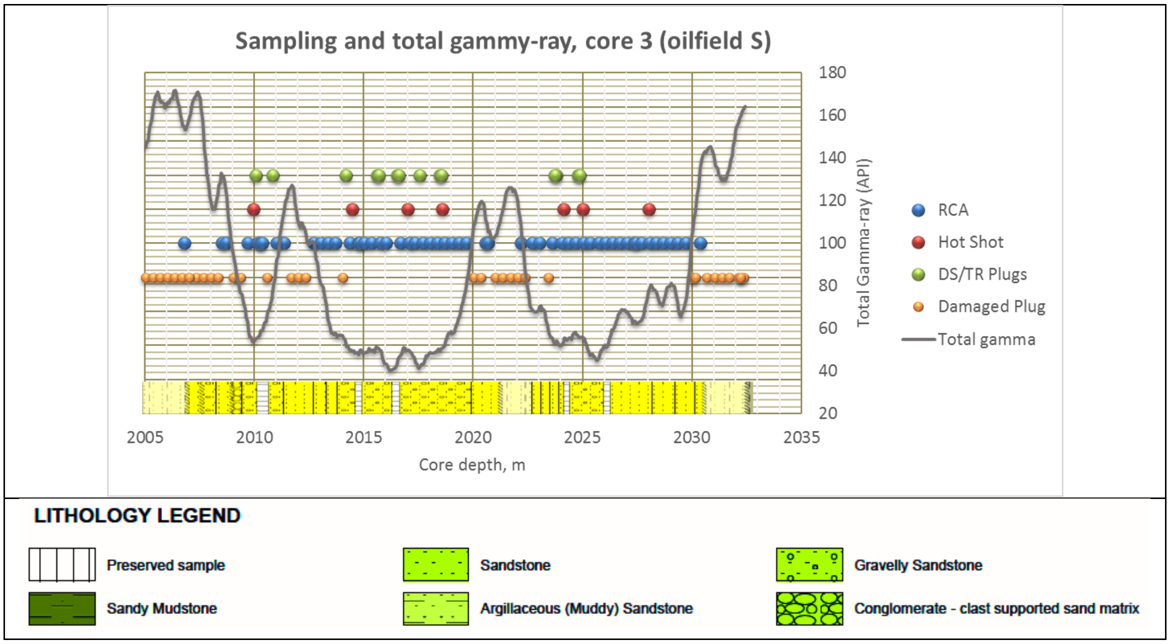

Figure 8: Graph combining lithology, plug locations and total gamma-ray response of core 3 (Dogger-epsilon sandstone, oilfield S).

CONCLUSIONS

Two case studies are presented where massive plug damage (40 and 60% of RCA plugs) occurred while RCA cleaning. Examples of Dogger sandstone as well as Malm carbonate rock are presented. Two different cleaning routines were run. Stepwise Soxhlet cleaning on oilfield well S and immersion cleaning on oilfield well M samples were performed. In the case of well S the combination of high temperature (max. T~110°C) and aggressive solvent toluene most probably lead to the damage of the muddy and mudstone dominated core sections. Although in the case of field M lower temperatures (max. T~60°C) were applied the azeotrope of chloroform/methanol lead to plug failures. In the case of well M depositional facies classified as marine mudstone, distal mouth bar and pro-delta dominated the damaged plugs. Reviewing available information coming from wellsite plugs, gamma-ray core logging and quick look core description lead to the conclusion that selective and milder cleaning of plugs from these damaged sections would have been sufficient. It is known from literature that the difference of thermal expansion coefficients of fluids and minerals together with temperature variations, e.g. Soxhlet cleaning, leads to mechanical stress, e.g. clay laminated core sections (Towhata & Kuntiwattanakul, 1994; Hueckel &Pellegrini, 1992; Baldi et al., 1988; McKinstry, 1965; Rosenbrand et al., 2014; Kutasov, 1999). Salinity gradients between clay bound water and the free fluid surface can lead to the same effect (Farrokhrouz and Asef, 2013).

A stepwise approach might be thought of, where wellsite plugs, gamma-ray core logging and quick look core description allows to identify oil free and fragile core sections.

Plugs from these zones might only need mild immersion/cold Soxhlet cleaning avoiding aggressive solvents. Aggressive solvents as toluene or chloroform can solve embedded bitumen acting as cement. A mild first cleaning allows the measurement of routine parameters delivering early first data similar to Hot Shot plugs. Hydrocarbon bearing plugs might be cleaned in a two-step approach using toluene or chloroform/methanol azeotrope in a second run. The presented case studies have shown that plug damage hardly occurs in the oil saturated reservoir zone where Dean Stark plugs are sampled.

This more selective plug preparation would reduce costs and help to avoid damaged plugs leading to a biased sampling of the core material. The quality of rock data for static model can also be significantly improved with unbiased RCA data and back-up plugs for Special Core Analysis and rock mechanical studies would be available.

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REFERENCES

1. Anderson, W. (1986): Wettability Literature Survey – Part 1: Rock/Oil/Brine Interactions and the effect of core handling on wettability. SPE 13932.
2. API, "Recommended Practices for Core Analysis". API RP40, (Feb. 1998).
3. Baldi, G. et al. (1988): Thermal volume change of the mineral-water system in low porosity clay. Can. Geot. J., Vol. 25, pp. 807-825.
4. Cuic, L. E. (1975): Restoration of natural state of core samples. SPE 5634.
5. Farrokhrouz, M and Asef, M. R. (2013): Shale Engineering - Mechanics and Mechanisms. CRC Press. 288 pages.
6. Hueckel, T. and Pellegrini, R. (1992): Effective stress and water pressure in saturated clays during heating-cooling cycles. Can. Geotech. J., Vol. 29, 1095-1102.
7. Kutasov, I.M. (1999). Applied Geothermics for Petroleum Engineers. Developments in petroleum Science, Vol. 48, 347 p., Elsevier.
8. McByrne, M. and Patex, I. (2004): Core sample preparation – An insight into new procedures. SCA2004-50.
9. McKinstry, H. (1965): Thermal expansion of clay minerals. The American Mineralogist, Vol. 50, pp. 212-222.
10. McPhee et al. (2015): Core Analysis. A Best Practice Guide. Developments in petroleum Science, Vol. 64, 852 p., Elsevier.
11. Rosenbrand, E., Fabricius, I. L., & Kjøller, C. (2014): Effect of temperature on sandstone permeability: Mineral fluid interaction. Technical University of Denmark, Department of Civil Engineering.
12. Sonneborn Refined Products B.V. (2016): Material Safety Data Sheet (MSDS) White Mineral Oil BLANDOL®.
13. Towhata, I. and Kuntiwattanakul, P. (1994): Behavior of clays undergoing elevated temperature. XIII ICSMFE, New Delhi, India.