DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2013/8

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Including down hole logs obtained in the well

Niels H. Schovsbo

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

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1. Introduction

The Sommerodde-1 (DGU# 248.62) well was drilled in November 2012 as part of the GeoCentre financed project 'Silurian stratigraphy and basin development' awarded to Niels Schovsbo and Arne Thorshøj Nielsen (Figure 1). The aim of the well was to core the stratigraphically most complete sequence through the Cambro-Silurian shales onshore Bornholm. To achieve this goal the well was spudded near the south-eastern coast of Bornholm where the youngest Silurian shale outcrop (Bjerreskov & Jørgensen 1983).

The well was logged by Rambøl and GEUS in January 2013 and the combined results of the logging campaigns makes the Sommerodde-1 one of the most extensively logged scientific boreholes in Denmark.

The purpose of this report is to present the logs recorded in the well and to outline a preliminary log stratigraphy based mainly on the GR log response. The report is written prior to analysis and inspection of the cores and the stratigraphical analysis is thus likely to be modified once the full data has been evaluated.

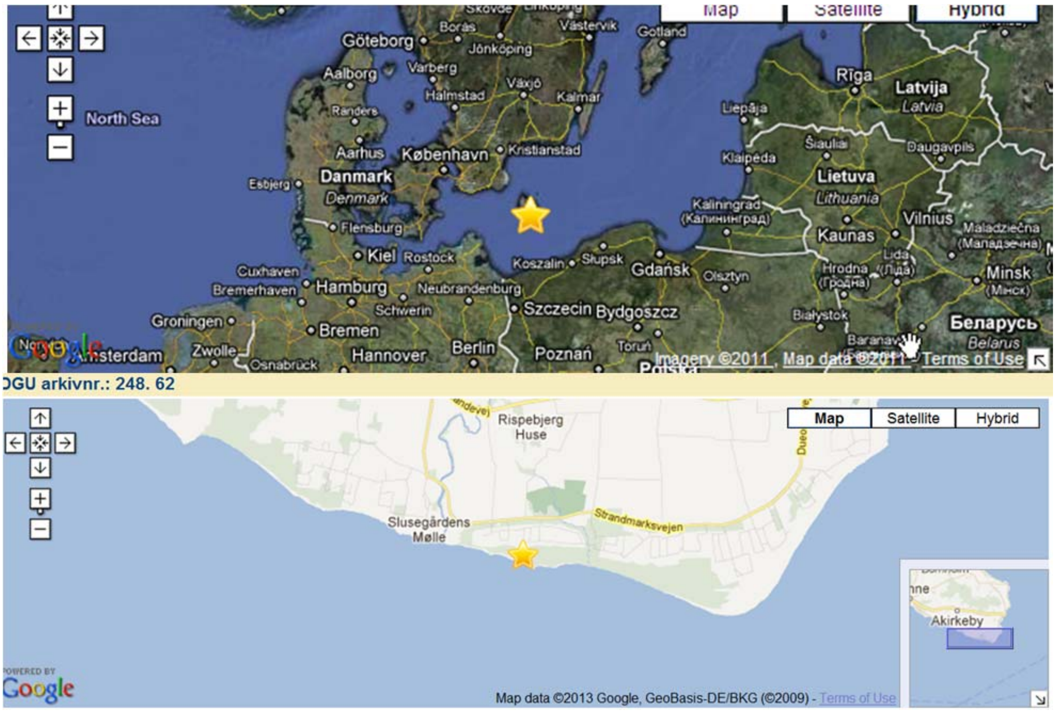

Figure 1. Map showing the location of the Sommerodde-1 (248.62) well on southern Bornholm, Denmark. Direct hyperlink to well information hosted at GEUS: http://data.geus.dk/JupiterWWW/borerapport.jsp?dgunr=248.62.

2. Well data summary sheet Sommerodde-1

DGU unique well id:	248.62
Common well name:	Sommerodde-1
Location, address:	Mølle Odde 15, 3720 Nexø, Bornholm
UTM zone	33
Drill Position, UTM:	501197, 6094480
Terrain elevation, m:	7.64 DNN
TD:	250.3 m depth below terrain
Formation at TD:	Læså Fm, Norretorp Mbr
Drilling type:	Diamond coring
Core diameter:	5.5 cm
Hole Diameter:	7.7 cm
Core barrel length:	3 m
Recovery:	From below 6.5 m: 100%
Drilling fluids:	Fresh water with no additives
Casing:	From 0-10 m
Drilling company:	Fakse Kalk A/S, Hovedgade 13, 4654 Fakse Ladeplads.
Drilling date:	4th November 2012 – 3rd December 2012
Logging:	8-9 January 2013 by Rambøll and 14 January by GEUS
Purpose:	Scientific, stratigraphical evaluation
Location of cores:	GEUS core store, Valhøjs Alle 179, 2620 Rødovre
Summary:	The Sommerodde-1 well cored Silurian shales between 6.5-174.9 m, Ordovician shales above the Alum Shale between 174.9-218.3 m, Ordovician-Cambrian Alum Shale between 218.3-246.3 m and Lower Cambrian sandstone between 246.3-250.3 m. A total of 168.4 m Silurian shales was cored. The Lower Silurian Rastrites shale was completely cored and estimated to be 92.4 m thick in the well. The Alum Shale Formation is 27.7 m thick and include the Middle Cambrian Andrarum and Exsulans limestone beds. The well was terminated at 250.3 m in the Norretorp Member of the Læså Fm after penetrating the Rispebjerg Mbr (3.5 m thick).

Log stratigraphy of the Palaeozoic interval in the Sommerodde-1 well

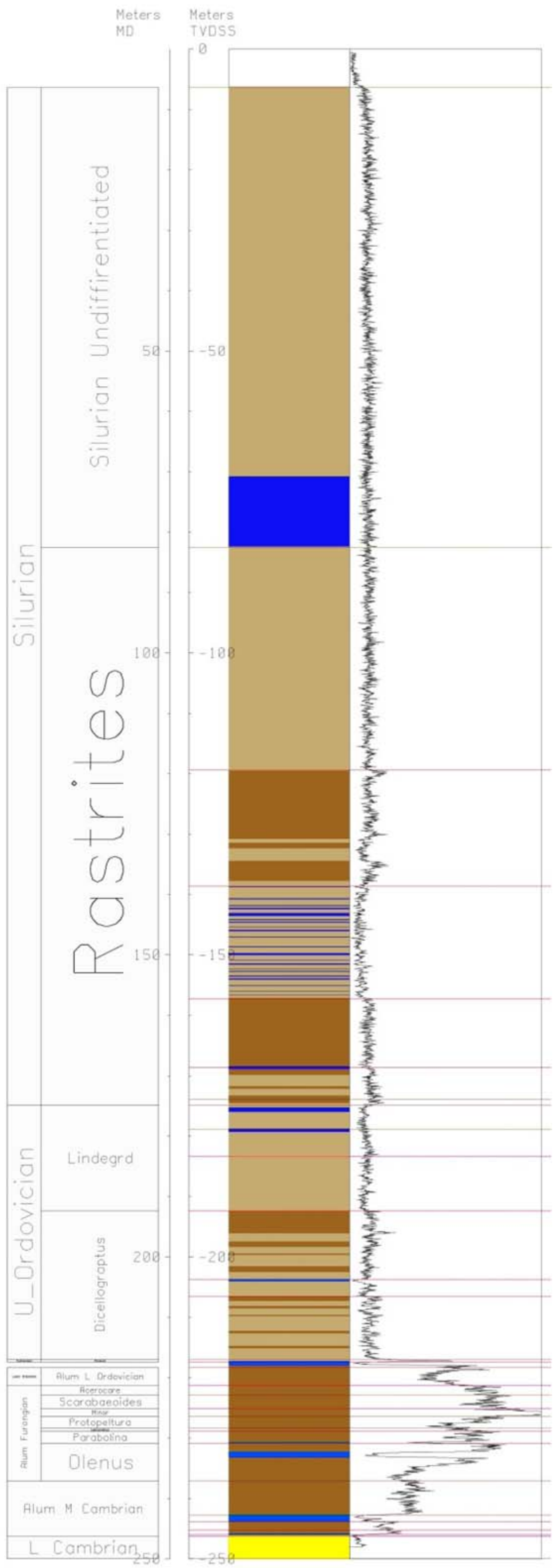

Figure 2. Overview of the Sommerodde-1 well. Legend: yellow, sandstone; dark brown, dark shale; light brown, light grey-brown shale; light blue, carbonate/limestone; dark blue, carbonate cemented shale. Log curve: gamma ray curve obtained by GEUS. Log picks are presented in Table 2.

3. Well logs in Sommerodde-1

The Sommerodde-1 well was logged by Rambøll on the 8th-9th January 2013 and by GEUS on the 14th January 2013. The purpose of the Rambøll log acquisition was to characterise the formation whereas the purpose of the GEUS acquisition was to characterise the water, to establish the water flow zones and to take water samples in the well during test pumping.

The technical part of the data acquisition by Rambøll is described in the data report prepared by Rambøll and included in this report in Appendix A. The digital version of the report and the well logs obtained in the bore hole is available on the DVD attached to this report.

Table 1. Overview of down-hole logs obtained in the Sommerodde-1 well by Rambøll and GEUS. Well logs obtained by Rambøll in the bore hole are further detailed in Appendix A.

Name	unit	Description
By Rambøll		
Gamma ray	API	Formation gamma ray response
Spectral gamma	API, %, ppm	Formation content of U, K and Th
Density (CDL)	ccm/g	Bulk density
Porosity	%	Neutron porosity
Sonic, Vp, Vs	Km/s	Sonic velocity
Resistivity	Ohm-m	Formation resistivity
Calliper	mm	Borehole diameter
Susceptibility	CGS E5	Magnetic susceptibility of formation
Acoustic televiewer		Acoustic amplitude picture
Optic televiewer		RGB picture
By GEUS		
Gamma ray	API	Formation gamma ray response
Fluid temperature	degree C	Fluid temperature. No pumping
Fluid property	µS/cm	Fluid conductivity. No pumping
Flow rate	rpm	Flow log. No pumping
Flow rate	%	Scaled flow log

3.1. Summary of logs obtained by Rambøll

A selection of the logs obtained in the Sommerodde-1 is shown in Figure 3 and 4. No problems were encountered during the log acquisition by Rambøll and the planned log program could be carried out in the full length of the borehole. The first run in the hole was made with the optic televiewer. The water in the well was clear and only the lower 30 cm of the well was filled with dark muddy water and consequently an excellent optic televiewer log was obtained in the bore hole.

A full description of the acquisition program is presented in Appendix A.

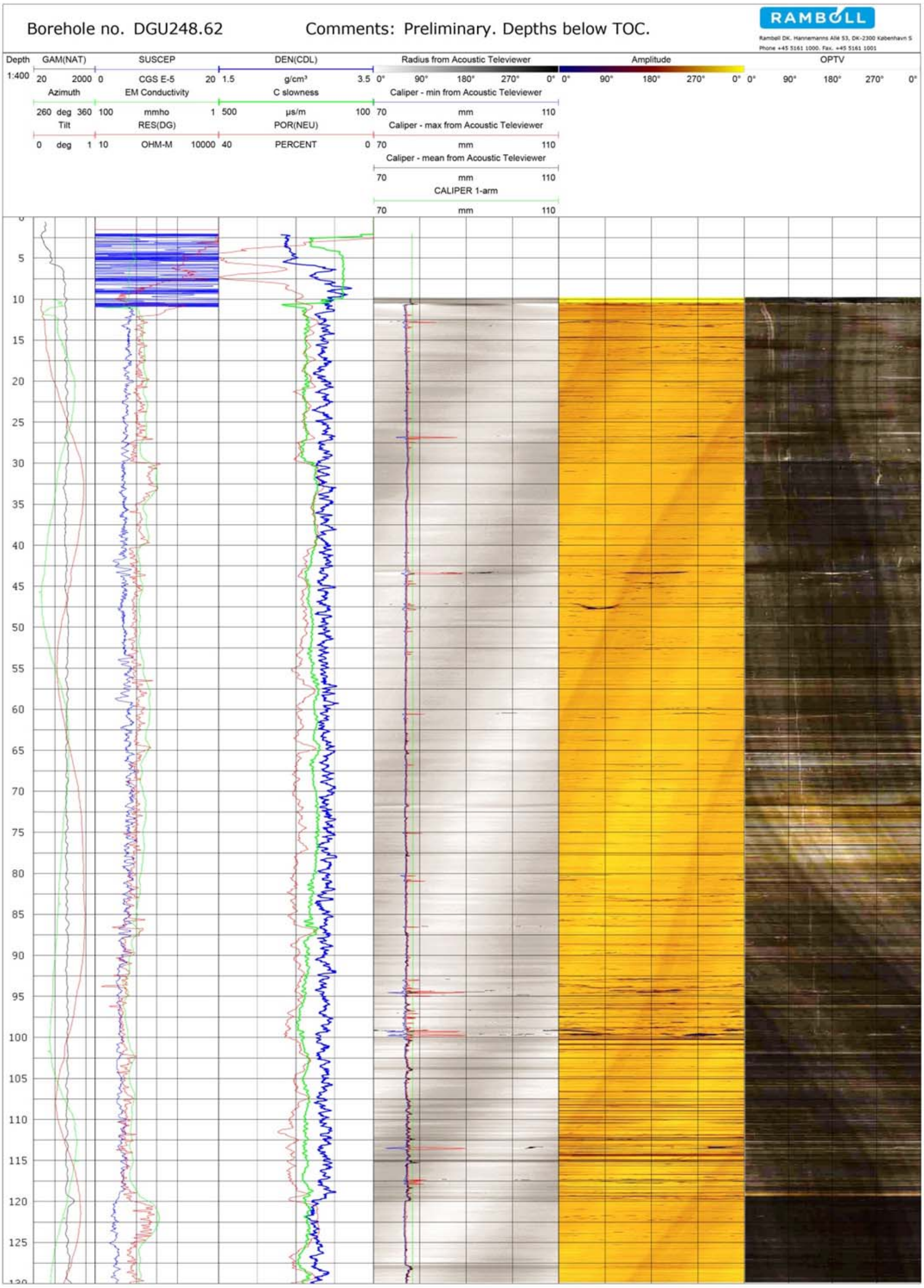

Figure 3. Presentation of selected logs measured in the Sommerodde-1 well by Rambøll in the interval 0-130.0 m.

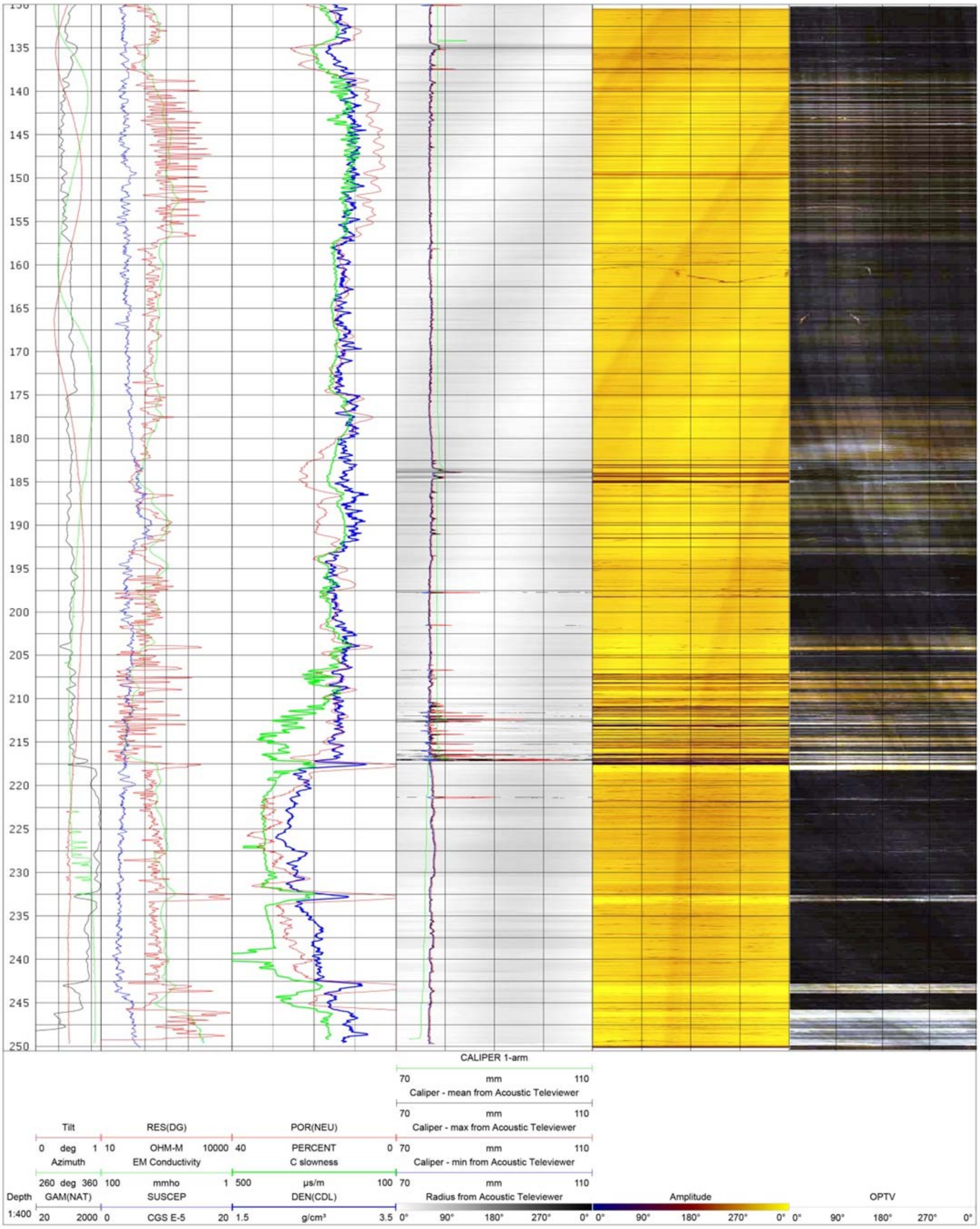

Figure 4. Presentation of selected logs measured in the Sommerodde-1 well by Rambøll in the interval 130.0-250.3 m.

3.2. Summary of logs obtained by GEUS

The log types acquired by GEUS are presented in Table 1 and in Figure 5. The focus of the logging was on water properties and fracture flow properties of the shales. No problems were encountered during the acquisition and the planned analytical program was carried out.

The temperature log show a steady increase from 8°C in the topmost part increasing to 14°C in the basal part of the well. The resulting apparent geothermal gradient is thus 24°C pr. Km. The water conductivity is low in the upper 40-50 m and high stable values occur from below 130 m. An apparent maximum in conductivity is seen about 210 m which suggests that a small influx of low conductive water occur in the basal part of the well.

The water flow log show highest inflow rates within the upper 40 m of the well. At depth the in-flow rates decreases rapidly and the interval from 80 m and below only contributes with 20% of the total flow in the well. The low flow rate suggests that only few fractures are open in the shales and that these tend to occur in the upper part. This mode of occurrence is in good agreement with information from the optic and acoustic televiewer logs where only few open factures was observed.

Water samples were collected after the flow zones were established. The water samples were picked as cumulated water samples at 10 m (water representing the complete well), at 235 m (water from levels in the Alum Shale) and at 245 m (water from the Lower Cambrian Sandstone) depth.

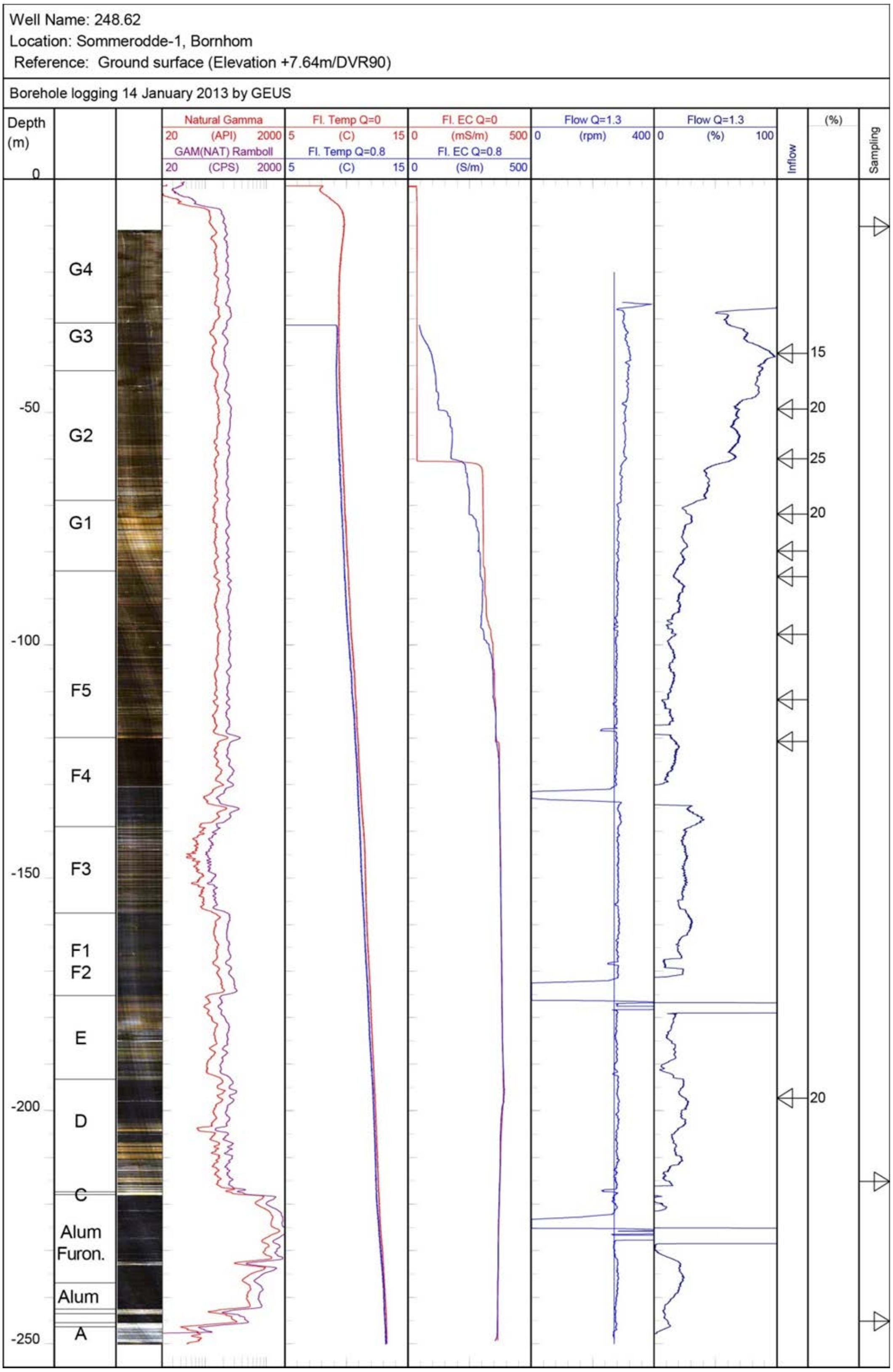

Figure 5. Presentation of logs measured in the Sommerodde-1 well by GEUS. Arrows pointing to the left indicate significant water inflow zones. Number indicate the percentage contribution to the total flow for each inflow zone. Arrows pointing to the right indicate position of water samples. The optic televiewer shown on the left is acquired by Rambøll.

4. Stratigraphy

4.1. Litho- and biostratigraphical frame for the Lower Palaeozoic on Bornholm

The Lower Palaeozoic litho- and biostratigraphical frame is presented in Figures 6, 7, 8 and 9.

The Cambrian sand- and siltstones in Denmark and in southern Sweden (Scania) comprise the Nexø, Hardeberga, Læså and Gislöv Formations (Figure 6). For a recent review of these formations see Nielsen & Schovsbo (2006) and Nielsen & Schovsbo (2011).

The Nexø Fm comprises a reddish coloured somewhat arkosic sandstone.

The Hardeberga Fm comprises well-sorted strongly cemented quartzite sandstone. The formation includes subordinate silt- and mudstone beds.

The Læså Fm is dominated by greenish grey siltstone with variable glauconite content. Phosphorite nodules occur at several levels and sandstone layer are common especially in the upper part of the formation. The top member, the Rispebjerg Member, is a regionally distributed sandstone bed that records a major regressive event (Figure 6).

The Alum Shale Fm consists of dark organic rich mudstone with abundant disseminated pyrite deposited in the Middle Cambrian to Lower Ordovician (Tremadoc). In Denmark and Scania the formation has a low proportion of diagenetic carbonate beds (Figure 7). This lithology has been termed the ‘outer shelf type’ by Schovsbo (2002). Alum Shale with higher proportions of non-shale beds including primary carbonates, conglomerates and diagenetic carbonate concretions are present in the south-central parts of Sweden and on Öland (Figure 7). This lithology has been termed ‘inner shelf’ type by Schovsbo (2002). The Exsulans and Andrarum limestones (both <1 m thick) occur in the lower part of the formation (Figure 7). These marker beds are primary bioclastic limestones. These beds represent periods with elevated oxygen at the sea-floor that allowed for colonisation of diverse benthic faunas (Schovsbo 2001 and Nielsen & Schovsbo 2006) and they represent important stratigraphical horizons that are particular easy to recognise on gamma ray logs due to their low GR response.

Ordovician shales and limestone formations above the Alum Shale (Figure 8) comprises the Bjørkåsholmen Fm, Tøyen Shale, Komstad Limestone, Almelund Shale, Dicellograptus Shale (here used for the Sularp, Skagen, Mossen, Fjäcka shales of Scania) and the Lindegård Fm (previous the Jerrestad and Tommarp mudstones) (Figure 8).

The Bjørkåsholmen Fm is a thin (<2 m) cold water bioclastic carbonate unit that contains variable amounts of clay, phosphorite and glauconite. Do not occur on Bornholm.

The Tøyen Shale in southern Sweden is a greenish-grey mudstone with occasional siltstone beds. Dark organic rich intervals occur in the upper part of the shale in the Olso area. A 10 cm thick development of this shale has recently been drilled in the Billegrav-2 well apart for this the unit has not been identified in Bornholm.

The Komstad Limestone is a thin-bedded cold water bioclastic carbonate. The unit contains variable amounts of clay, phosphorite and glauconite. It is known from Bornholm and southern Sweden (Scania), but peters out westwards and is likely not present subsurface of Denmark.

The Almelund Shale (previous upper Didymograptus and lower Dicellograptus shale) is a black to dark-grey shale with rare carbonate interbeds. The shale occur not Bornholm and was not included in the log stratigraphy by Pedersen & Klitten (1990) for Bornholm (Figure 10).

The Dicellograptus Shale is a grey to dark mudstone. The term Dicellograptus Shale is used here for the Sularp, Skagen, Mossen and Fjäcka shales of south central Sweden (see Bergström et al. 2002). The lower part contains numerous bentonite beds including the up to one meter thick 'Kinnekulle' Bentonite (included in the Sularp Shale on southern Sweden) which represents the most significant volcanic eruption in the entire early Palaeozoic (Bergström et al. 2002).

The Lindegård Fm is a bioturbated green-grey mud- to siltstone. Thin sandstone beds with conglomeratic horizons may occur.

The Silurian is represented by the Rastrites and Cyrtograptus shales on Bornholm. Upper Silurian shales - the Nøvling and Rønde Fms - are present in the Nøvling and Rønde wells (Michelsen & Nielsen 1991).

Silurian formations in Scania, comprises the Rastrites, Cyrtograptus and the Colonus shales and the Öved-Ramsåsa Group (Figure 9).

The Rastrites Shale (Figure 9) comprises a black to dark-grey silty mudstones. Current generated sedimentary structures and calcite cemented sandy beds occur in some intervals. TOC rick intervals occur notably in the base of the Formation and in the *convolute* graptolite Zone (Schovsbo 2003).

The Cyrtograptus Shale (Figure 9) comprises a shale unit dominated by grey silty mudstone (Bjerreskov 1975, Pedersen & Klitten 1990).

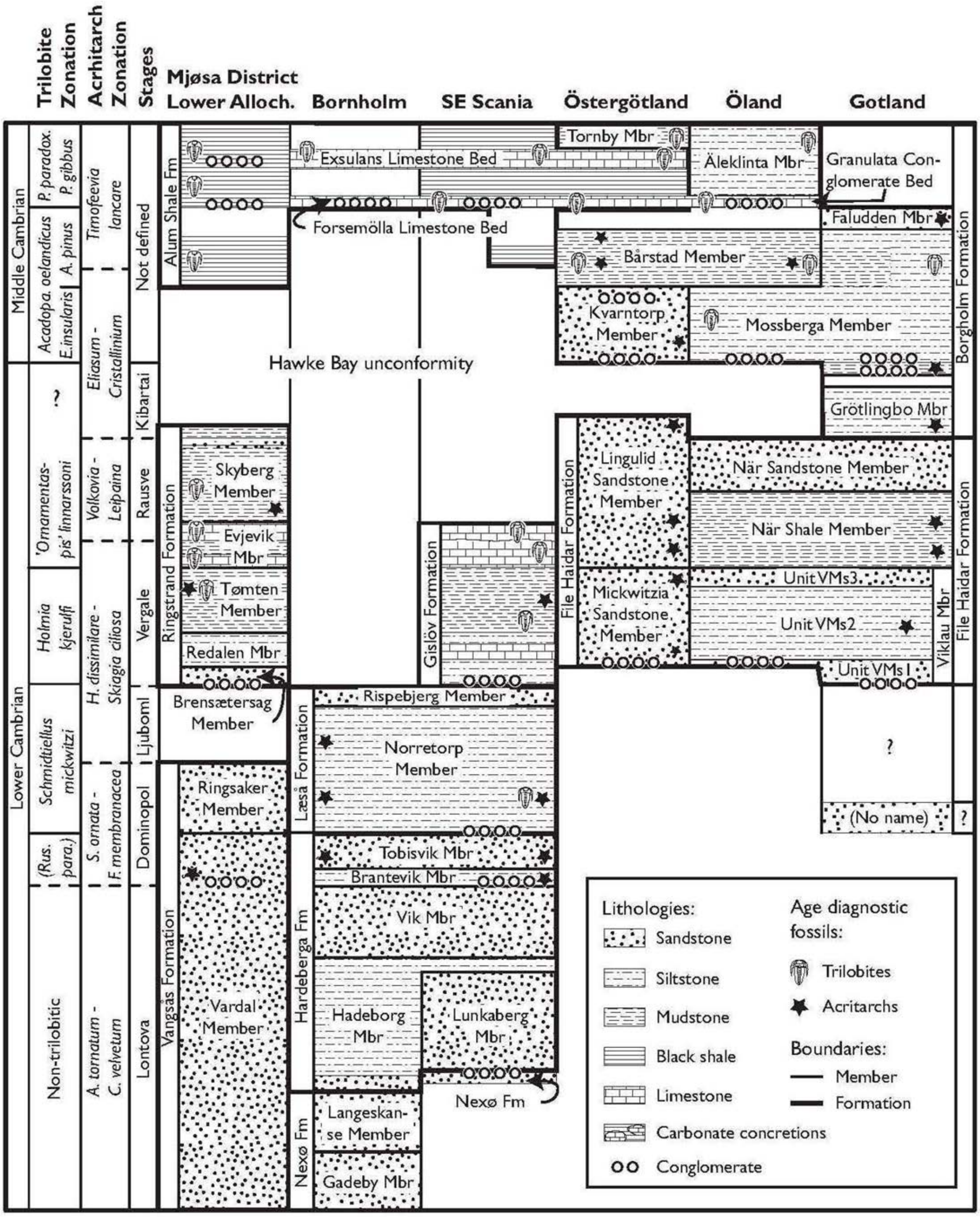

Figure 6. Lithostratigraphic scheme for the Lower and lower Middle Cambrian of southern Scandinavia. From Nielsen & Schovsbo (2006).

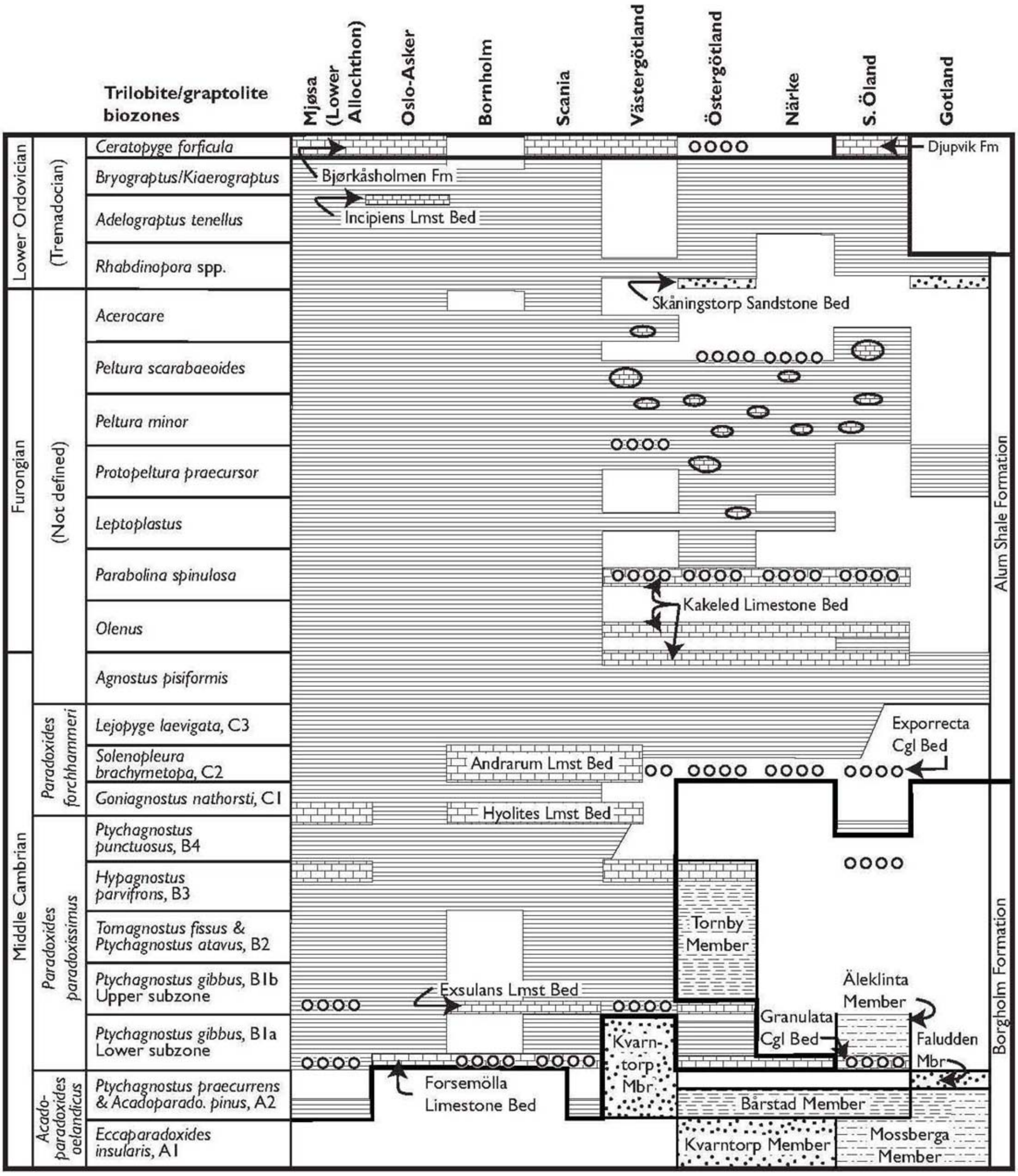

Figure 7. Lithostratigraphic scheme for the Middle Cambrian, Furongian and Lower Ordovician (Tremadocian) of southern Scandinavia. Avery sophisticated biostratigraphy has been established for the Middle Cambrian and Furongian based on agnostid and olenid trilobites. From Nielsen & Schovsbo (2006).

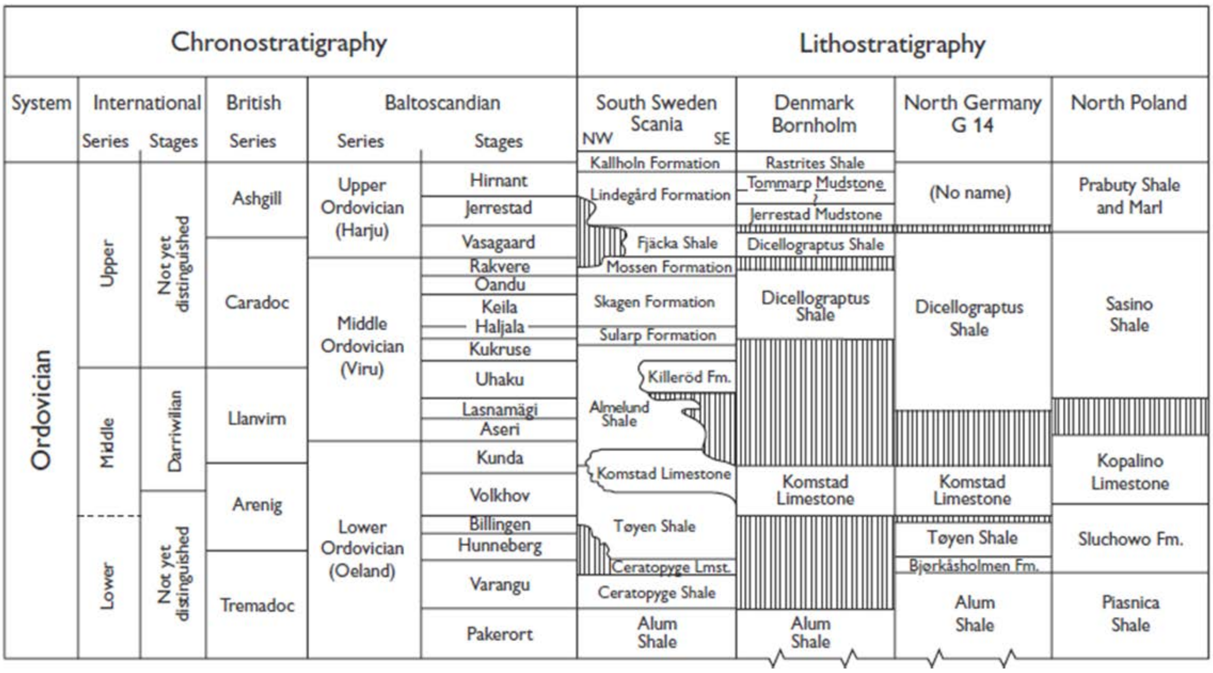

Figure 8. Stratigraphy of Scania, Bornholm, northern Germany (G14) and northern Poland with indications of main lithologies. From Stouge & Nielsen (2003).

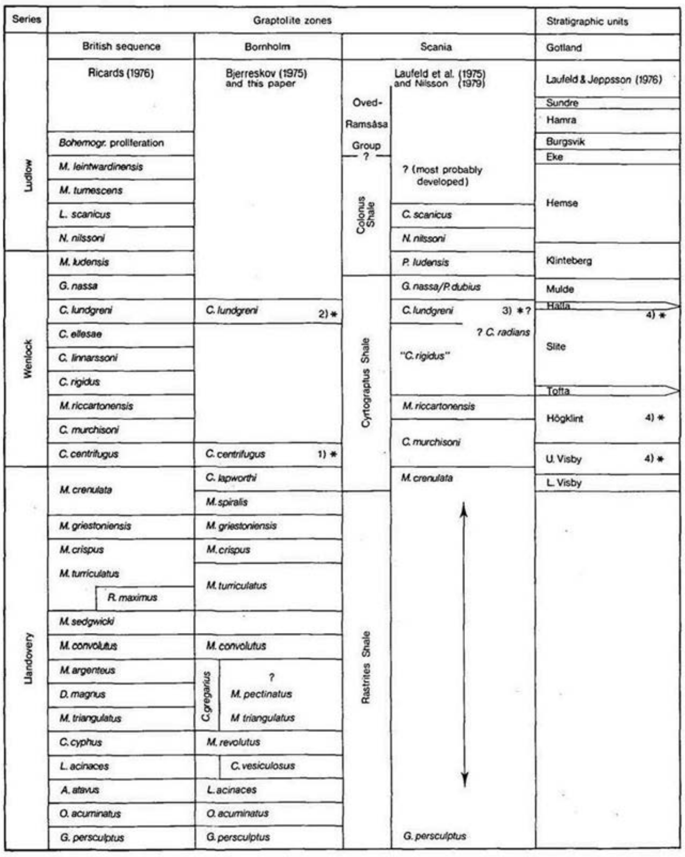

Figure 9. Silurian stratigraphy of Bornholm and Scania (Bjerreskov 1975, Bjerreskov & Jørgensen 1983).

4.2. Logstratigraphical units on Bornholm

Pedersen & Klitten (1990) discerned 7 units (A-G) and 16 subunits based on the GR log pattern in water and scientific wells on Bornholm and they demonstrated its local consistency by preforming detailed log based correlations (Figure 10). In the Billegrav-2 well the log signature of the log based units were expanded to also include the formation resistivity and sonic velocity (Schovsbo et al. 2011).

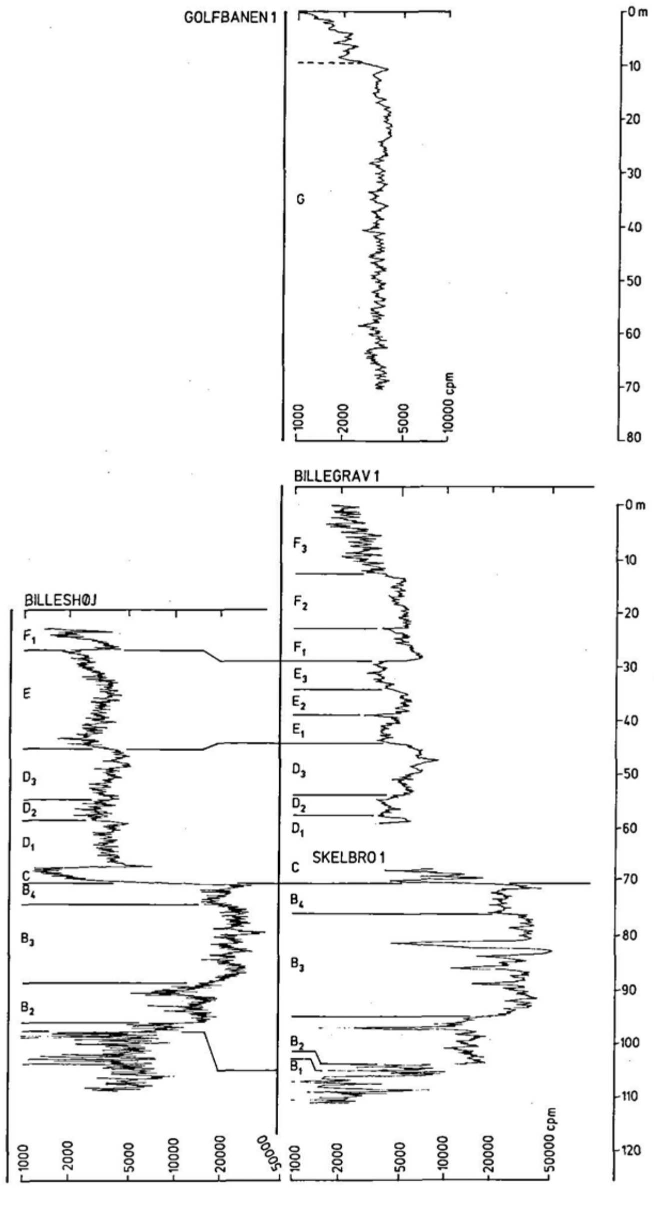

Figure 10. Example of correlation between the Billegrav-1, Billeshøj, Skelbro-1 and Golfbanen-1 wells on southern Bornholm. The A-G refers to the log units. From Pedersen & Klitten (1990).

Below follows a brief description of the log based units, based on Pedersen (1989), Pedersen & Klitten (1990) Nielsen & Schovsbo (2006) and Schovsbo et al. (2011). The biostratigraphy is inferred from Bjerreskov (1975), Koren & Bjerreskov (1997), Stouge & Nielsen (2003) and Nielsen & Schovsbo (2006).

Typical thicknesses and TOC content are cited for each unit based on the Skelbro and Billegrav wells.

Unit A: Rispebjerg Member and top of Norretorp Member, Læså Fm
Rispebjerg Member (3.7 m in Skelbro-1): Light grey medium to coarse grained quartz sandstone. The top part is impregnated with phosphorite.
The Norretorp Member is c. 100 m thick (Nielsen & Schovsbo 2006) and only the very top of the unit is penetrated by Skelbro-1 and Billegrav-2 wells. The upper part of the member is composed of fine silty sandstone partly heterolitic. The unit is extensively bioturbated.
TOC: No sample (0% TOC assumed).
Age: Early Cambrian. *Schmidtiellus mickwitzi* trilobite Zone.

Unit B: Alum Shale Formation (33 m in Skelbro-1)
The unit is characterized by very high gamma- readings. The Alum Shale consists of black organic rich mudstone with beds and nodules of limestone. Barite and pyrite minerals occur both as disseminated crystals and as nodules.

<u>Unit B1: Exsulans Limestone and lower Middle Cambrian Alum Shale (0.8 m in Skelbro-1)</u>
The unit top is marked by low gamma values indicative of the base of the Andrarum Limestone. The B1 unit represent the Exsulans Limestone (0.2 m) and Alum Shale (0.6 m). The Exsulans Limestone is a primary bio-clastic carbonate bed.
TOC: 4% (one sample)
Age: Mid Cambrian (*P. paradoxissimus* to *P. forchhammeri* superzones).

<u>Unit B2: Andrarum Limestone and upper Middle Cambrian to basal Furongian Alum Shale (9.4 m in Skelbro-1)</u>
The log unit is bounded upwards by a sharp increase in gamma ray readings and the unit represents an interval in the Alum Shale characterised by intermediate gamma values. The unit contains in the Skelbro-1 well a diagenetic carbonate concretion (with low gamma readings) located about 3 m from the top of the unit. The concretion contains abundant olenid trilobites and represents the basal part of the Furongian. Concretions of similar age are also known from Scania (southern Sweden) and the concretion is informally termed the ‘Olenus stinkstone’.
TOC: 5–8% (12 samples)
Age: Mid Cambrian (*P. forchhammeri*) to the lowermost Furongian (lower *Olenus* Zone).

<u>Unit B3: Furongian Alum Shale (18 m in Skelbro-1)</u>
An interval characterised by very high gamma values. Top of the interval is placed at the start of a stepwise decrease in GR values. The high fluctuation in GR values in some intervals in the unit reflects the presence of diagenetic carbonate nodules and beds. A very distinct spike in the gamma values occurs in the middle of the unit. A similar spike can be observed in numerous logged water wells on Bornholm and in logged wells in Scania. The high GR readings occur in a shale level that represents the Furongian *Peltura* Zones.
TOC: 8–14% (19 samples)
Age: Furongian (upper *Olenus* Zone – *Acerocare* Zone)

Unit B4: Ordovician Alum Shale (5 m in Skelbro-1)
An interval characterised by intermediate GR values. The interval is bound upwards by a very sharp drop in GR values reflecting the Komstad Limestone.
TOC: 4–9% (5 samples)
Age: Furongian (*Acerocare*) – Early Ordovician (Tremadocian)

Unit C: Early Mid Ordovician Komstad Limestone (0–3.9 m)
An interval characterised by very low GR readings reflecting the Komstad Limestone: The unit is a cold water carbonate that contains variable amounts of clay, phosphorite and glauconite.
TOC: 0% (no samples - TOC assumed)
Age: Mid Ordovician (Dapingian)

Unit D: Dicellograptus Shale (> 7 m in Billegrav-1)
The unit is represented by grey to dark grey mudstone. It contains numerous bentonite beds in its lower part. The unit was not penetrated by Billegrav-1.

Unit D1: "Lower" Dicellograptus Shale (> 2 m in Billegrav-1)
The unit is characterized by high GR readings. The unit is composed by grey mudstone with abundant bentonite beds. The bentonites are easily recognized due to their high GR readings. The unit is bounded upwards by a local minimum in the GR values.
TOC: 0.5% (one sample)
Age: Late Ordovician (Caradoc), roughly corresponding to the *Dicellograptus foliaceus* Zone

Unit D2: "Middle" Dicellograptus Shale (5 m in the Billegrav-1 well)
The unit is characterized by high GR readings, and is composed of grey mudstone with few bentonite beds. The trace fossil *Chondrites* occurs frequently. The unit is bounded upward by a marked increase in GR values.
TOC: 0.1–1% (7 samples)
Age: Late Ordovician (Caradoc), roughly corresponding to the lower part of the *Dicranograptus clingani* Zone

Unit D3: "Upper Dicellograptus Shale" (9 m in the Billegrav-1 well)
The unit is characterized by high GR readings and is upward bound by an interval with very low GR values. The unit is composed by dark graptolitic mudstone with a few bentonite beds.
TOC: 0.1–5% (8 samples)
Age: Late Ordovician (Caradoc-Ashgill) roughly corresponding to the upper part of the *Dicranograptus clingani* Zone and the *Pleurograptus linearis* Zone.

Unit E: Lindegård Formation (25 m in the Billegrav-1 well)
The unit is characterized by moderate high GR readings, and is composed by green-grey mud and siltstones that usually are bioturbated. Sandstone beds and thin conglomeratic horizons occur.

E1: "Lower" Lindegård Fm (6 m in the Billegrav-1 well)
The unit is characterized by low GR reading. The top is marked by an interval of distinctive low GR values. The unit comprise grey mudstone intensely bioturbated in its top and base.
TOC: 0.1–0.4% (7 samples)
Age: Late Ordovician (Ashgill), *Tretaspis granulata* Zone

<u>E2: ”Middle” Lindegård Fm (5 m in the Billegrav-1 well)</u>
The unit is characterized by higher GR reading that the units above and below. The upper boundary is located at a low GR interval. The unit are composed of grey green siltstone.
TOC: 0.1–0.2% (5 samples)
Age: Late Ordovician (Ashgill), likely roughly corresponding to the *Staurocephalus clavifrons* Zone

<u>E3: “Upper” Lindegård Fm (5 m in the Billegrav-1 well)</u>
The unit is characterized by very low GR readings. It is composed by silty mudstone with occasional sandstones, partially conglomeratic. The sandstone beds are carbonate cemented with up to 25% carbonate.
TOC: 0.1–0.2% (4 samples)
Age: Late Ordovician (Hirnantian), likely roughly corresponding to the *Dalmanitina mucronata* Zone

Unit F: Rastrites Shale (> 27 m in the Billegrav-1 well)
The formation is characterized by low to medium high GR readings. The total thickness of the Rastrites Shale is estimated at 80 m in the Øleå area (Bjerreskov 1975). Only the lower 29 m were penetrated by the Billegrav-1 well. The unit is composed by silty mudstones, occasionally with current generated sedimentary structures, and grey siltstone which contains calcite cemented sandy beds in some intervals. Dark grey to black intervals occur.

<u>F1: Rastrites Shale (23–29.2 m)</u>
The base of the unit is characterized by a very marked increase in GR reading. This base consists of approximately 1.5 m thick dark graptolitic mudstone with some silt beds. From here the GR values decreases and the top of the unit is placed at a local minimum in GR values.
TOC: 0.4–3% (7 samples)
Age: Late Ordovician (Hirnantian) to Early Silurian (Llandovery). *G. persculptus* to *A. ascensus graptolite* Zones.

<u>F2: Rastrites Shale (11 m in Billegrav-1)</u>
The unit is characterized by intermediate high GR values. The top of the unit is defined at a plateau in GR values just below a low GR interval. The unit is characterized by grey siltstone with silty mudstone beds.
TOC: 0.5–1% (12 samples)
Age: Early Silurian (*M. acuminatus – vesiculosus* graptolite Zones).

<u>F3: Rastrites Shale (10 m in Billegrav-1)</u>
The unit is characterized by low and variable GR values. The top of the unit is defined at a GR minimum just prior to a low GR interval. The unit consist of grey siltstone with abundant calcite cemented sandy beds. The interval has a cyclic appearance on the log that is caused by alternating cemented sandy beds (low GR values) with silty mudstone (high GR values).
TOC: 0.5–0.8% (10 samples)
Age: Early Silurian (*vesiculosus* graptolite Zone).

<u>F4: Rastrites Shale (10 m in Billegrav-2)</u>
The unit is characterised by general high but variable GR values. The top is marked by marked decrease in GR values. This definition is a slight modification of Pedersen & Klitten (1990) that placed the top of the unit a few m above the marked decrease in GR values.

However, moving the boundary slight down gives a much better definition of the top but also limits the rock type in the unit to black shale. The unit consist of black organic rich mudstone.
TOC: 1.4–3.9% (10 samples)
Age: Early Silurian (*convolutes* graptolite Zone).

F5: Rastrites Shale (8 m thick, not drilled from the top in the Billegrav-2 well)
The unit is characterised by rather low GR values. The unit consist of grey siltstone.
TOC: 0.1-1.0 (8 samples only lower 7 m characterised in Billegrav-2)
Age: Llandovery, Early Silurian (*M. turriculatus – ? M. spiralis* graptolite Zone).

Unit G: Cyrtograptus shale (64 m drilled by the Golfbanen-1 well)
The unit was defined based on the GR signature in the un-cored water well 'Golfbanen-1 (248.54)' that drilled a shale section between 7 and 79 m (Pedersen & Klitten 1990). The GR signature of the unit appears to be very uncharacteristic and no prominent changes in lithology appears to occur (Figure 10). The top of the G unit was picked at a marked decrease in GR response just above a sharp increase in GR reading at a depth of 8 m (Figure 10). Re-inspection of the well data (Pedersen & Klitten 1990) suggests, however, that the decrease in GR response rather reflect a combination of damping of the GR signal in the steel casing and that the top 7 m of well in not shale but instead less radiogenic quaternary deposits. In summary the proposed log signature of the top of the G unit indicated by Pedersen & Klitten (1990) is not viewed as depositional. No units within the G unit were established by Pedersen & Klitten (1990).
TOC: No samples analysed. Assumed less than 1% based on visual examination of cutting samples from the Golfbanen-1.
Age: Late Llandovery to Wenlock, Early Silurian (C. *lundgreni – C. lapworthi* graptolite Zone).

5. Logstratigraphy of the Sommerodde-1 well

A log stratigraphical breakdown based primarily on the GR and the optic televiewer logs of the Sommerodde-1 well is presented in Figure 11 and in Table 2 and a log based correlation between the Sommerodde-1 and the Billegrav-2 well is presented in Figure 13.

The Silurian section:

Unit F

The log stratigraphical units F1, F2, F3 and F4 are readily identified on GR log and from the optic televiewer signal (Figure 11). The F unit is 92.4 m thick in total.

Unit F1. A 6.2 m thick dark green grey shale. The base on eth unit is characterised by elevated GR log response.

Unit F2. A 11.4 m thick dark green grey shale. The base on eth unit is characterised by elevated GR log response.

Unit F3. A 18.7 m thick light grey green to light pale grey shale. The unit is slightly thicker than in the Billegrav-2 well (Figure 13). In the Billegrav-2 part several fault zones occurred in this part of the bore hole and it was suspected that parts of the section were faulted out. In the Sommerodde-1 no fault zones has been identified and it is believed that the thickness reflect true depositional thicknesses.

The optic televiewer proved particular suited to resolve the lithological variations in the F3 unit that are composed of rhythmically bedded shale and carbonate cemented shale. The pattern is not interpreted to reflect a primary Milankovitch forced variation but is rather viewed as a diagenetic induced pattering (Figure 12).

Unit F4. A 19.2 thick dark black to dark green shales. The unit is characterised by elevated GR log response. The mid part of the unit is characterised by somewhat lower GR values.

Unit F5. A 36.9 m thick dark grey to green shale. The upper boundary of the F5 unit has not previously been defined. It is here used as a synonym with the top of the Rastrites Shale and should according to the traditional definition correspond to the top of the *M. spiralis* graptolite zone (Figure 9). The unit above F5 is thus the Cyrtograptus Shale or the G unit of Pedersen & Klitten (1990).

In the Sommerodde-1 the top of the F5 unit is placed at a lithological transition from predominantly dark grey shale to lighter shale. The transition is gradual, but is placed at 82.5 m in the Sommerodde-1 well.

Unit G

The G unit has not previously been subdivided. Based primarily on the optic televiewer log the G unit is here subdivided into 4 units each defined by a characteristic lithology and GR-resistivity log pattern (Figure 11).

Unit G1. A 12.5 m thick light green shale. The light colouring increases gradually towards base and top. The unit is identified primarily from the optic televiewer log since it has an indistinct GR log response.

Unit G2. A 30 m thick light grey to dark green shale. The top of the unit is placed where the an increase in the resistivity log occur reflecting a change to more darker lithologies occur.

Unit G3. A 10 m thick dark coloured shale unit. The unit is clearly identified on the optic televiewer log and by a slightly lower GR log response and distinctly higher formation resistivity readings compared to the units above and below. The top of the unit is placed at a point of decrease in the resistivity log.

Unit G4. A 25 m thick light grey to green shale characterised by low and stable GR values. The unit include numerous silty to sandy beds similar to those exposed on the beach just south of the well location (Bjerreskov & Jørgensen 1983). The base of the unit is placed at a point of increasing resistivity values corresponding to a change to dark lithologies seen in the optic televiewer log.

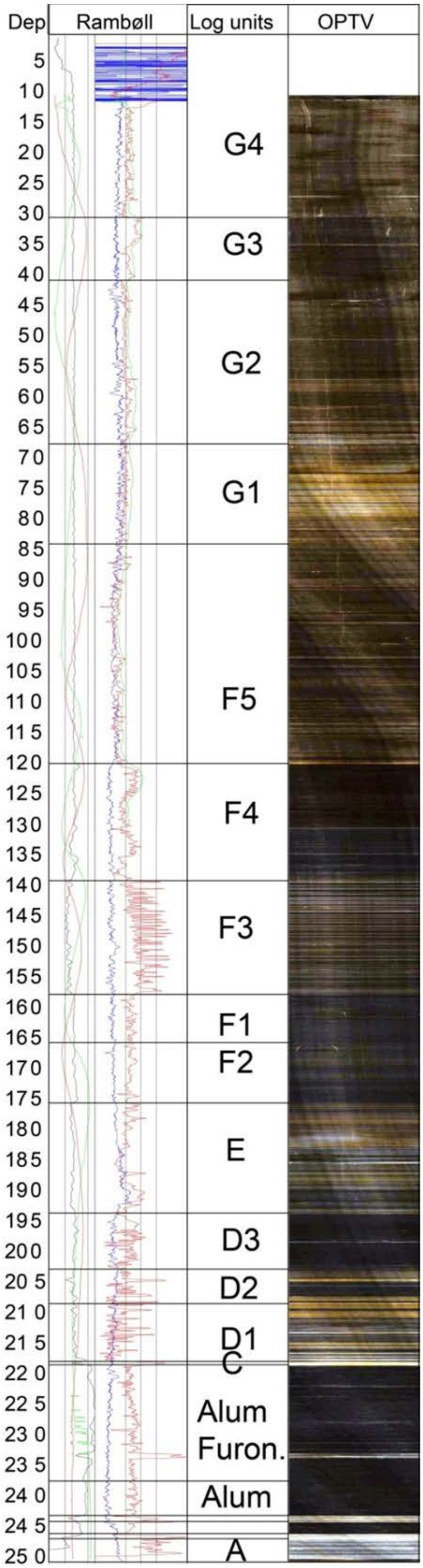

Figure 11. Logstratigraphical analysis of the Sommerodde well. The logs are obtained by Rambøll (see Figure 3 and 4).

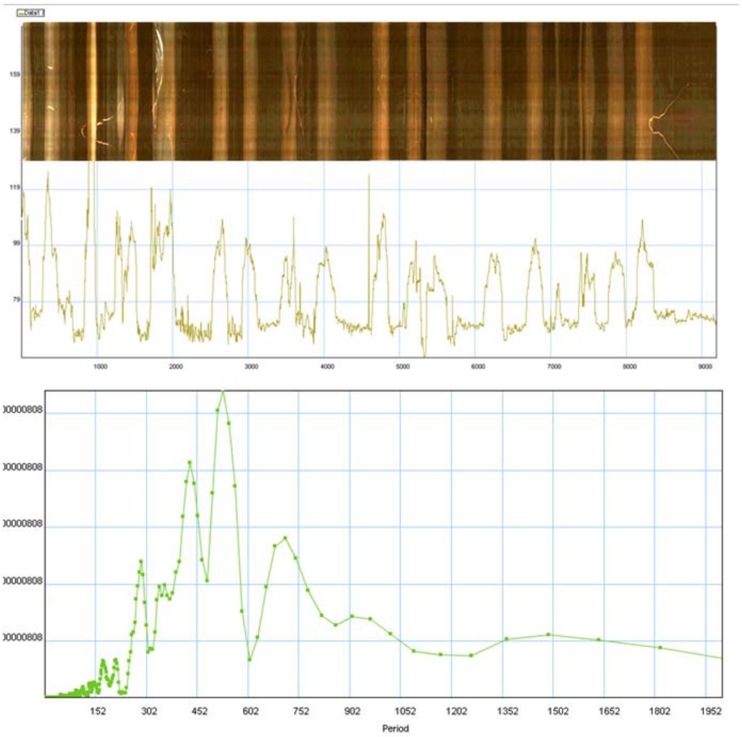

Figure 12. Example of an analysis of the cyclicity in the F3 unit. The top illustration shows a 7.8 m long section from the optic televiewer log and the corresponding grey tone variation within the interval. The illustration below shows a spectral density analysis of the grey tone variation. The periods are in pixels (9187 along the 7.8 m section) and the analysis indicates that there are multiple frequencies present notably at 24, 37 and 42 cm.

The Ordovician section above Alum Shale

Unit C

The Komstad limestone is 0.6 m thick and identified by its low GR and high resistivity response (Figure 11). The base of the limestone is developed as a conglomerate characterised by relative high GR response possibly due to the enrichment of uranium in the phosphatised pebbles.

Unit D

The tri-parting of the D unit is clearly expressed in the optic televiewer log wherefrom the occurrence of black shales and light bentonite beds are very easily seen (Figure 11).

The D1 unit is 11.5 m thick and consist of interbedded bentonite and shale. The unit has a characteristic appearance on the resistivity log reflecting soft and less resistive bentonite alternating with hard resistive shale. The top of the D1 unit is placed at a point of low GR response.

The D2 unit is 3 m thick and consist of light to dark shale with few bentonite beds. The base is placed at an increase in GR values reflecting a darkening of the shale. The top is placed at a low GR response.

The D3 unit is 10.1 m thick and characterised by dark shale. The log pattern is similar to that of a high GR unit. The top of the unit is placed at a point of decreasing GR values.

Unit E

The E unit is 18 m thick and characterised by light green shale that is in part carbonate cemented. Sandstone beds also occur. The GR log response is lower compared to the above and below lying F and D units.

The Alum Shale section

Unit B
The Alum shale is 28 m thick and characterised by dark black shale with subordinate limestone beds and concretions. The formation are characterised by very high GR values that exhibit a very characteristic stepwise increase in GR value rising to peak values in the mid part of the formation from where the GR values decreases in a stepwise manner again (Figure 11).

Pedersen & Klitten (1990) defined 4 log units for the Alum Shale on Bornholm (Figure 10). As an alternative to these units Schovsbo& Nielsen (2012) defined a subdivision of the shale with a much higher stratigraphical resolution by introducing log picks that are closely related to the biostratigraphic zonal boundaries (Table 2).

The Middle Cambrian part of the Alum Shale in the Sommerodde-1 well is 9 m thick. The unit includes the Andrarum and Exsulans Limestones that are easily identifiable based on low GR response and high resistivity response. The shale above the Andrarum Limestone is characterised by rather stable high GR values and the top of the Middle Cambrian is placed just below a slight decrease to lower GR values.

The Furongian part of the Alum Shale Formation is 17 m thick and characterised by very high GR values. The base of the Furongian is placed at a local minimum just before the GR values increases to levels that is typical twice as high as in the Middle Cambrian. Within the Furongian high GR values occur within the upper *Olenus* trilobite Zone, the uppermost part of the *Parabolina* trilobite Zone and in the *Peltura minor* trilobite Zone. The later maximum is the highest in the formation.

The Ordovician part of the Alum Shale is 2 m thick and characterised by lower GR values than the Furongian.

Lower Cambrian Sandstones
Unit A is 4 m thick in the Sommerodde-1 well. The unit is characterised by very low GR values compared to the Alum Shale.

Table 2. Pick depth for the Sommerodde-1. Picks for other wells are from Schovsbo & Nielsen (2012).

Pick_name	TERNE-1	Sommerodde-1	BILLEGRAV-2	SKELBRO-2	SLAGELSE-1
T_Prezechstein	2312.7	6.4	4.5	2.7	2625.8
G4_base		30.3			
G3_base		39.8			
G2_base		70.0			
G1_base	2755.7	82.5			
F5_base	2812.6	119.4	10.4		
F4_base	2857.6	138.6	31.7		
F3_base	2938.0	157.3	45.7		2903.0
F2_base	2958.2	168.7	55.7		
Base_Silurian	2977.4	173.9	60.2		
F1_base	2981.9	174.9	61.1		
E3_base	2991.8	178.9	63.9		
E2_base	3000.7	183.4	68.7		2919.6
E1_base	3024.3	192.4	73.8		2919.7
D3_base		203.8	84.5		
D2_base		206.5	87.6		
D1_base		217.0	95.4		
U_Ordovician	3088.1	217.0	95.3		
top_komstad	3122.0	217.4	95.4	2.7	2919.8
top_toeyen	3122.0	218.0	95.8	8.5	
top_bjoerkaasholmen	3173.2	218.0			
top_alum	3173.5	218.0	95.8	8.5	2919.9
top_D2	3186.6	218.3	95.9		
top_D1	3203.2	218.3	96.0		
top_furongian	3207.6	220.4	98.5	11.6	2919.7
top_scarabaeoides	3220.2	222.9	101.2	14.5	2919.9
top_minor	3234.8	225.2	103.7	18.9	2922.3
top_protopeltura	3240.2	226.4	105.1	23.6	2929.2
top_leptoplastus	3244.6	228.4	107.0	25.9	2931.1
top_parabolina	3246.7	228.9	107.4	26.2	2931.6
top_olenus	3256.8	230.9	109.2	26.6	2932.0
top_m_cambrian	3272.1	237.1	115.8	34.2	2939.1
top_lejopyge	3277.7	240.1	118.9	37.2	2943.6
top_andrarum	3294.8	242.8	120.8	40.2	2947.0
base_Andrarum	3300.5	243.9	121.7	41.0	2948.1
top_B2	3320.4				
top_exsulans	3327.5	245.3	123.0	41.6	
base_Exsulans	3334.1	246.0	122.4	42.0	
base_forsamolla	3341.8	246.0			
top_gislov	3351.7	246.3	122.8		2949.0
top_laesaa	3351.7	246.3	122.8		2957.7
top_Hardeberga	3351.8				2969.8

Log stratigraphy of the Palaeozoic interval in the Sommerodde-1 well

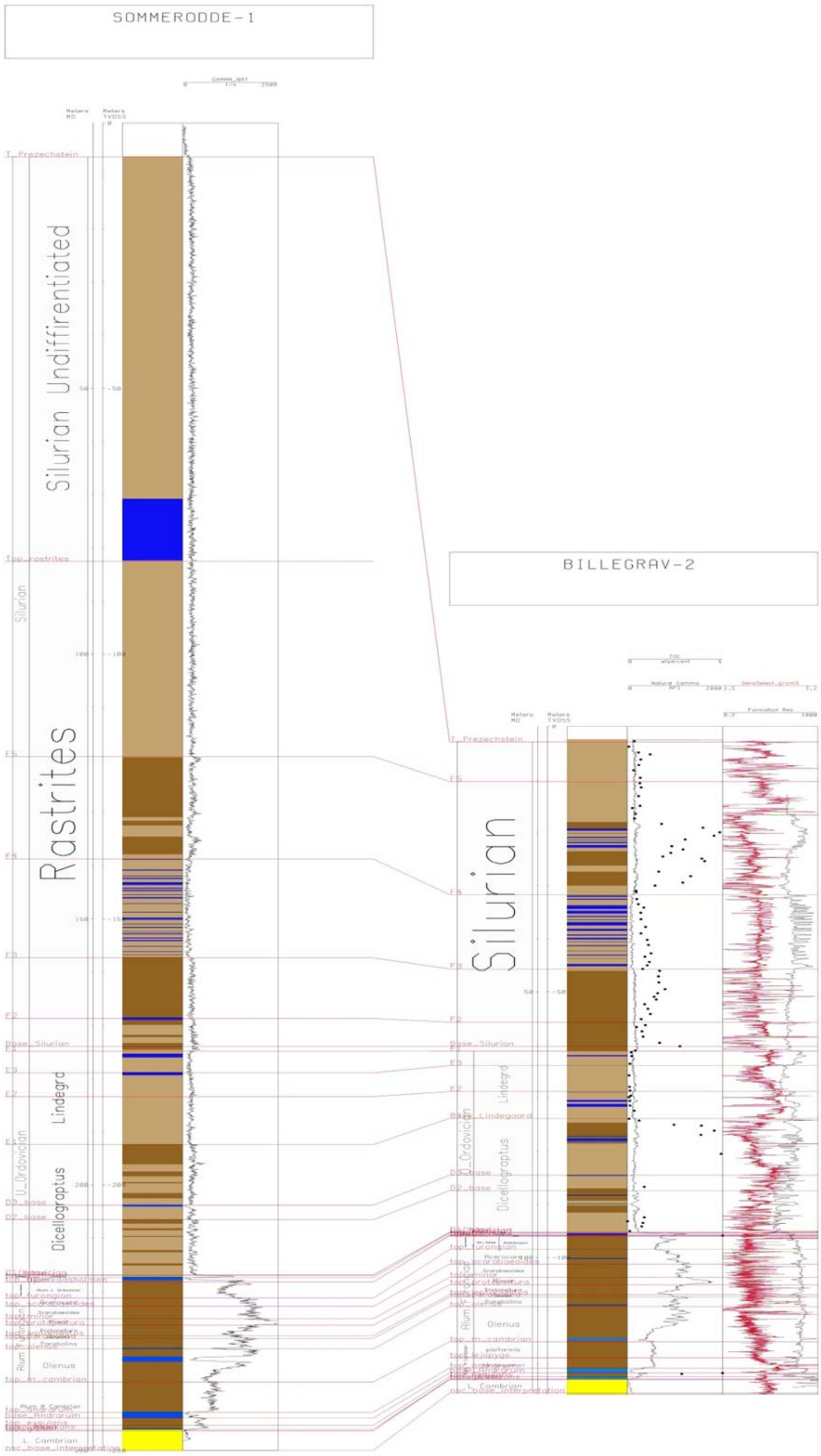

Figure 13. Correlation between the Sommerodde-1 and Billegrav-2 wells.

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7. Files included on DVD

Attached to this report is two DVDs that contains the following:

DVD1: Text and appendix

1. In folder A*ppendix_A_B:* well log data obtained by Rambøll incl reporting by Rambøll
2. In folder *table:* Excel files with the data presented in the tables 1 and 2.
3. A pdf version of this report *Log stratigraphy Sommerodde 1 (DGU 248.62)*.pdf

DVD2: Log data obtained by Rambøll in las, lIs & dlis log data format

Appendix A: Geophysical borehole logging by Rambøll

Intended for
Total

Document type
Report

Date
February 2013

BORNHOLM - DENMARK

GEOPHYSICAL BOREHOLE LOGGING IN

BOREHOLE 248.62 (SOMMERODDE-1)

RAMBOLL

BORNHOLM - DENMARK
GEOPHYSICAL BOREHOLE LOGGING IN BOREHOLE 248.62 (SOMMERODDE-1)

Revision	**0**
Date	**07/02/2013**
Made by	**UTN**
Checked by	**JRI**
Approved by	**UTN**
Description	**Geophysical borehole logging in borehole 248.62 (Sommerodde-1)**

Ref	1100003693

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CONTENTS

APPENDICES

1. SUMMARY

Ramboll has performed geophysical borehole logging in a new cored borehole Sommerodde-1 (248.62) situated on Bornholm, Denmark.

The objective of the survey is to determine the physical properties of the rock mass around the borehole, e.g. to determine rock types and fracture. Geophysical borehole logging was used to measure changes in physical properties in the borehole and the bedrock surrounding the boreholes.

The borehole was recorded from Top Of Casing (TOC) to the bottom of the borehole. The borehole was approximately 250 m long.

The present report comprises a description of the applied equipment and the performed logging program, the fieldwork, data delivery and a presentation and discussion of the results.

Composite sheet of all the processed logs is included in Appendix 1.1 and 1.2. Sheet of each log run are included in Appendix 2.1 – 2.7.

The results from the geophysical borehole logging are presented graphically as a function of depth in the drawings.

2. INTRODUCTION

This document reports the results gained by the geophysical borehole logging in borehole 248.62 (Sommerodde-1).

All measurements were conducted by RAMBØLL January 8 and 9, 2013. The borehole was recorded from Top Of Casing (TOC) to the bottom of the borehole. The technical data from the borehole is shown in Table 1-1. The location of the borehole is shown in Figure 1-1.

Table 1-1. Technical data for borehole 248.62.

Borehole	248.62
Synonym	Sommerodde-1
Depth, meter	250.3
Datum	EUREF89
Co-ordinates (UTM33)	501197, 6094480
Elevation (DVR90)	7.64
Casing length [m]	10.6
Borehole diameter [mm]	77 mm

Figure 1-1. Overview over boring 248.62 on Bornholm.

3. EQUIPMENT

The geophysical borehole logging was performed with 8 tools or stacks, resulted in the suite of log properties listed in Table 4-1. The tools and recorded logs are listed in Table 3-1.

Table 3.1. Logging tools and logs recorded.

Tool	Recorded logs	Dimension	Source Detector Spacing	Source type
NGAM GeoVista Natural Gamma	Natural gamma	70 x 3.8 cm		
SGAM GeoVista Spectral Gamma	Potassium (K) Percent 40, Uranium (U), Thorium (T)	90 x 7.3 cm	51mm x 153mm	NaI Scintillator
FDSB GeoVista Sidewall Compensated Density	Density, 1-arm caliper	189 x 6.6 cm	16 cm	100 mCu Cs137
9072 Century Compensated neutron 3 m focused guard	Natural gamma, 3 m focused guard log resistivity Compensated Neutron Porosity	310 x 6.4 cm		200 GBq Am-241/Be
9310 Century Sonic	Full wave form traveltime providing P & S-wave velocity picking, compensated P-wave traveltime, cement bond location, natural gamma	300 x 6.1 cm	Near 91.4 cm, far 121.9 cm	
FWS Robertson Triple Sonic	Full wave form data, compensated formation transit time and natural gamma	245 x 4.5 cm	Near 60 cm, Mid 80 cm, Far 100 cm	
8622 Century Magnetic susceptibility	Magnetic susceptibility, natural gamma	203 x 4.1 cm		
DILS GeoVista EM Dual Induction	Medium and a Deep Induction conductivity	170 x 4,5 cm		
BHTV Electromind Acoustic televiewer (Ultrasonic borehole imager)	Full waveform acoustic amplitude and traveltime, 360° orientated acoustic image, 360° very high resolution caliper, Borehole azimuth and dip and natural gamma	210 x 4.2 cm		
OPTV Electromind Optical televiewer (Optical borehole imager)	360° RGB digital orientated optical image, Borehole azimuth and dip and natural gamma	260 x 5.8 cm		

4. EXECUTION

4.1 In general

In general the measurement procedures follow the internal Ramboll procedures and the tool manufactures procedures for geophysical borehole logging. The logging program was executed January 8 and 9, 2013. All relevant logging events are described in the daily report sheets.

The applied logging equipment was calibrated and cleaned before arrival to site.

All log types was recorded running the tool upwards from bottom to top. The only exception to this was the running of the optical televiewer which was run in the downward direction as the first log.

For control, each log run was normally recorded both in a downward and in an upward direction using the down run as a repeat section. For the density tool recording a repeat section in upward direction controls the data. The depth of the probe in the borehole and the tension on the cable is shown on the recording computer during logging.

The Optical televiewer was recorded with 0.5 mm sample interval and the acoustic televiewer was recorded with 1.5 mm sample interval. All other logs were recorded with 1 cm sample intervals and a max. logging speed of 6 m/min, except sonic logs, which were recorded with 2 cm sample interval.

4.2 Nonconformities

Due to very low recorded values in some part of the formation it was not possible to get a perfect match of the down- and up-run log from the magnetic susceptibility tool.

The sonic results had been recorded by the Century 9310 sonic tool, the results from the Robertson sonic tool FWS, has not been used.

It was on possible to pick the S-wave arrival in some parts of the borehole.

All other logging has been performed in accordance with the activity plan.

5. RESULTS

5.1 Presentation

All relevant logging events were described in the daily report sheets.

Logs presented in drawing no. 1.1 and 2.1 to 2.8 respectively are presented in Table 5-1.

Table 5-1. Logs presented in drawings no. 1.1 and 2.1 to 2.8

Log	Log name short	Unit	Tool
Natural gamma	GAM(NAT)	API	All tools or stacks
Potassium (K)	Potassium	%	SGAM
Uran (U)	Uranium	ppm	SGAM
Thorium (Th)	Thorium	ppm	SGAM
Focused guard log resistivity, 300 cm	RES(DG)	ohm-m	9072
Porosity	POR(NEU)	PERCENT	9072
Induction conductivity - Deep	ILD	mmho (mS/m)	DILS
Induction conductivity - Shallow	ILS	mmho (mS/m)	DILS
P-wave (compress wave)	C slowness	µs/ft	9310
S-wave (shear wave)	S slowness	µs/ft	9310
Full wave form, near receiver	AMP(N)	µs	9310
Full wave form, far receiver	AMP(F)	µs	9310
Picked Transit time, near, C-wave	TIME(N) - C	µs	9310
Picked Transit time, far, C-wave	TIME(F) - C	µs	9310
P-wave velocity (compress wave)	C-VEL	m/s	9310
S-wave velocity	S-VEL	m/s	9310
High resolution 1D Caliper	CALIPER MEAN	mm	BHTV
360° Radius image	Radius	-	BHTV
360° Amplitude image	Amplitude	-	BHTV
Borehole azimuth magnetic north	AZIMUTH MN	deg	BHTV
Borehole inclination from horizontal	DIP	deg	BHTV
360° Optical image	OPTV	-	OPTV
Raw 3C magnetometer data	HX, HY, HZ	-	OPTV, BHTV
Raw 3C accelerometer data	GX, GY, GZ	-	OPTV, BHTV
Gamma-gamma density	DEN(CDL)	g/cm^3	FDSB
Caliper, 1-arm	CAL1	mm	FDSB
Density from short spacing sensor	SSD	g/cm^3	FDSB
Density from long spacing sensor	LSD	g/cm^3	FDSB
Compensation	DRHOB	g/cm^3	FDSB
Magnetic susceptibility	SUSCEP	CGS E-5	8622
Magnetic susceptibility	MAGSUSCEP	$SI*10^{-5}$	8622

5.2 Orientation, depth reference and removing of data

Orientation of images

The orientation of the results from the Optical and Acoustic televiewer tools, are processed to magnetic north in the borehole.

Length calibration of data

Using the natural gamma in the different tools as a reference log, a longitudinal calibration between consecutive log runs is made.

Removing of data

The processing of the data includes removal of spikes, negative and unrealistic values and data collected in the casing.

5.3 Calculated log curves

The different logs are calculated as described in Table 5-2.

Table 5-2. Calculated log curves

Log	Description of log calculation
BRHOB	The compensation is calculated as (LSD-SSD)/3
Density	The compensated Density is calculated as LSD + DRHOB
Natural gamma	The natural gamma log was converted from CPS to API by multiplying the constant 0.47 on the natural gamma recorded by the 9072 tool and the constant 0.172 on the Spectral Gamma SGAM tool. This constant was computed from the logs previously performed by Century in the API borehole in USA.
TIME(N) – C and TIME(F) - C	The first arrivals are picked automatically and manually adjusted.
C-VEL	The C-VEL velocity is calculated using the difference in distance between the far and near receiver divided by the time difference between the first arrival from the far and near signal. (121.9 cm– 91.4 cm)/(TIME(F) – TIME(N)ime(far) – Time(near)).
S-VEL	The S-VEL is picked on a Semblance Velocity Analysis made on the full waveform sonic logs.
Full wave form, far receiver C slowness and S slowness	Slowness curves are calculated as reciprocal values of the respective velocity curves times the length of one feet.
Magnetic susceptibility	The magnetic susceptibility was converted for CGS units to SI units by multiplying the CGS value by 4π.
Caliper, high resolution. 360°. CALIPER 3D	The caliper 3D is calculated using the acoustic travel time and the velocity in the borehole fluid. The velocity in the is estimated to 1510 m/s.
High resolution 1D Caliper CALIPER MEAN	The caliper mean is calculated using the mean travel time from the acoustic televiewer, , fluid velocity and the internal travel time in the acoustic televiewer
Radius	The Radius Imange is calculated using the mean travel time from the acoustic televiewer, , fluid velocity and the internal travel time in the acoustic televiewer-

6. DATA DELIVERY

The raw data is included on the digital media with background data in Century, GeoVista and Electromind format. The reported data is delivered in PDF, WellCAD (WCL), LAS, LIS or DLIS. Filenames are listed in Table 6-1.

Table 6-1. Reported data and log run in PDF. WCL, LAS, LIS and DLIS File format.

Log Run	Probe/Stack	Log direction	Filename / log run	Format
Combined	-	-	DGU248.62 Presentation 1 to 500 and 1 to 10	PDF, WCL
Run1	OPTV	Down	DGU24862_OPTV_540_None_20130108_0824_dn_alignedMN_RUN1	PDF,WCL, LAS, LIS, DLIS
Run2	BHTV	Down	DGU24862_BHTV_180_None_20130108_1120_dn__alignedMN_RUN2	PDF,WCL, LAS, LIS, DLIS
Run3	9072	Up	DGU24862_01-08-13_15-10_9072C_.01_0.58_250.50_ORIG_RUN3	PDF, WCL,LAS
Run4	8622	Up	DGU24862_01-08-13_16-21_8622C_.01_0.53_250.12_ORIG_RUN4	PDF, WCL,LAS
Run5	9310	Up	DGU24862_01-08-13_17-16_9310C2_.02_0.24_249.23_ORIG_RUN5	PDF,WCL, LAS, LIS, DLIS
Run6	NGRS_FDSB	Up	DGU24862_NGRS_FDSB-4139_20130100_0902_up_RUN6	PDF, WCL,LAS
Run7	SGAM_DILS	Up	DGU24862_SGAM-4334_DILS-4207_20130100_1052_up_RUN7	PDF, WCL,LAS

Appendix B: well logs by Rambøll

Appendix 2.7

RAMBØLL

CO TOTAL
WELL 248.62
FLD NEKSØ
CTY DENMARK
STE BORNHOLM
FILING No

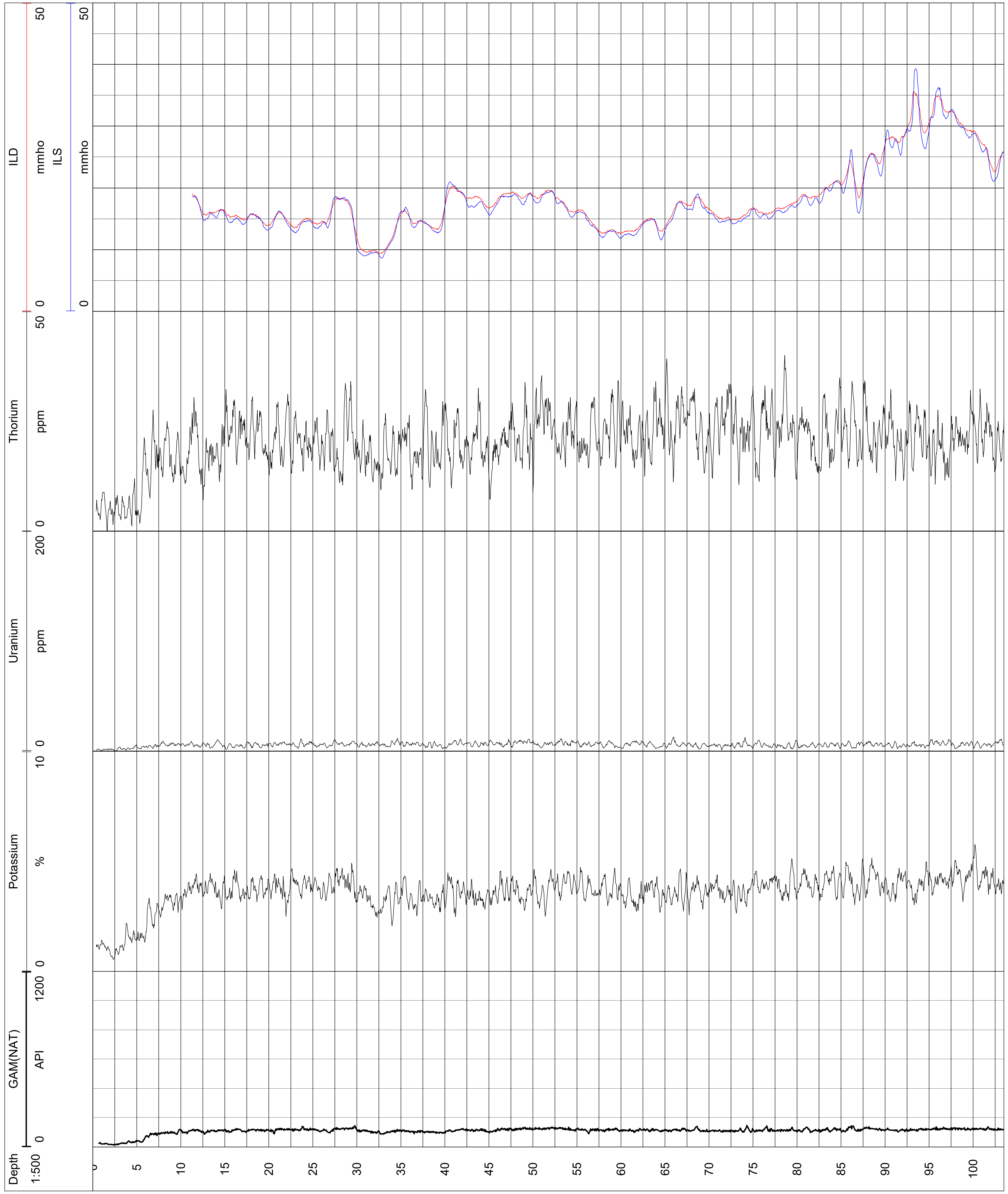
COMPANY	TOTAL		
WELL ID	248.62		
FIELD	NEKSØ		
COUNTRY	DENMARK	STATE	BORNHOLM

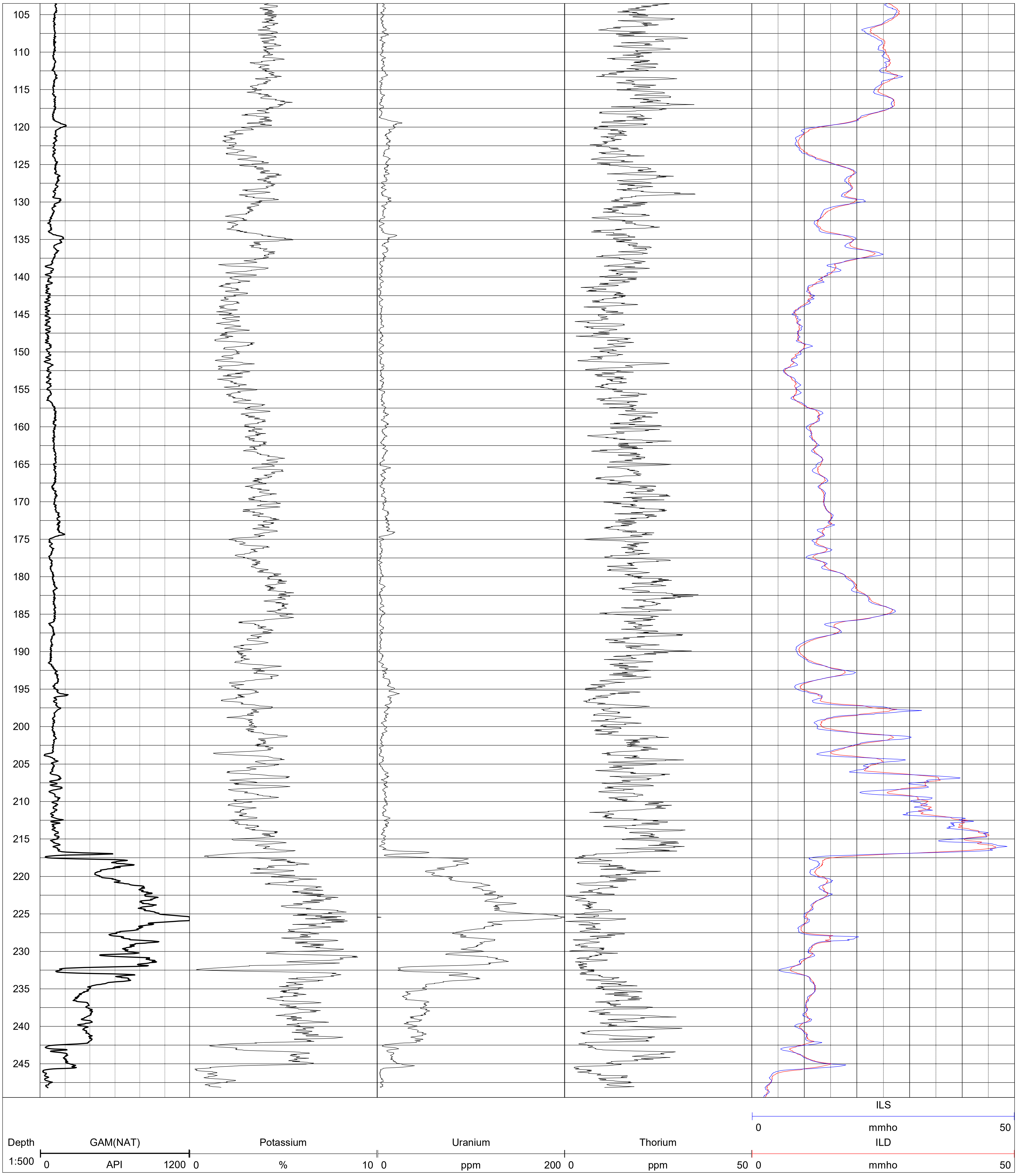
LOCATION MØLLE ODDE 15 3730 NEKSØ SEC TWP RGE	OTHER SERVICES

PERMANENT DATUM		ELEVATION	7.64 m, DVR90	K.B.
LOG MEAS. FROM	Ground	ABOVE PERM. DATUM		D.F.
DRILLING MEAS. FROM	Ground			G.L.

DATE	09/01/2013	TYPE FLUID IN HOLE	Water
RUN No	7	RESISTIVITY	2.6 - 29.5 ohm-m
TYPE LOG	SGAM + Dual Induction	DENSITY	1 g/cc
DEPTH-DRILLER	250.3 m	LEVEL	0.5 m
DEPTH-LOGGER	250.3 m	MAX. REC. TEMP.	13.3 °C
BTM LOGGED INTERVAL	249.6 m		
TOP LOGGED INTERVAL	0.7 m		
SCALE	1:500		
RECORDED BY	Jørgen Ringgaard, Uffe Nielsen		
WITNESSED BY	Niels Schovsbo		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
	3"	0 m	250.3 m	3"		0 m	10.4 m





Depth
1:500
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
GAM(NAT)
0 API 1200
Potassium
0 % 10
Uranium
0 ppm 200
Thorium
0 ppm 50
ILS
0 mmho 50
ILD
0 mmho 50

Appendix 2.6

RAMBOLL

CO TOTAL
WELL 248.62
FLD NEKSØ
CTY DENMARK
STE BORNHOLM
FILING No

COMPANY	TOTAL		
WELL ID	248.62		
FIELD	NEKSØ		
COUNTRY	DENMARK	STATE	BORNHOLM

LOCATION
MØLLE ODDE 15
3730 NEKSØ

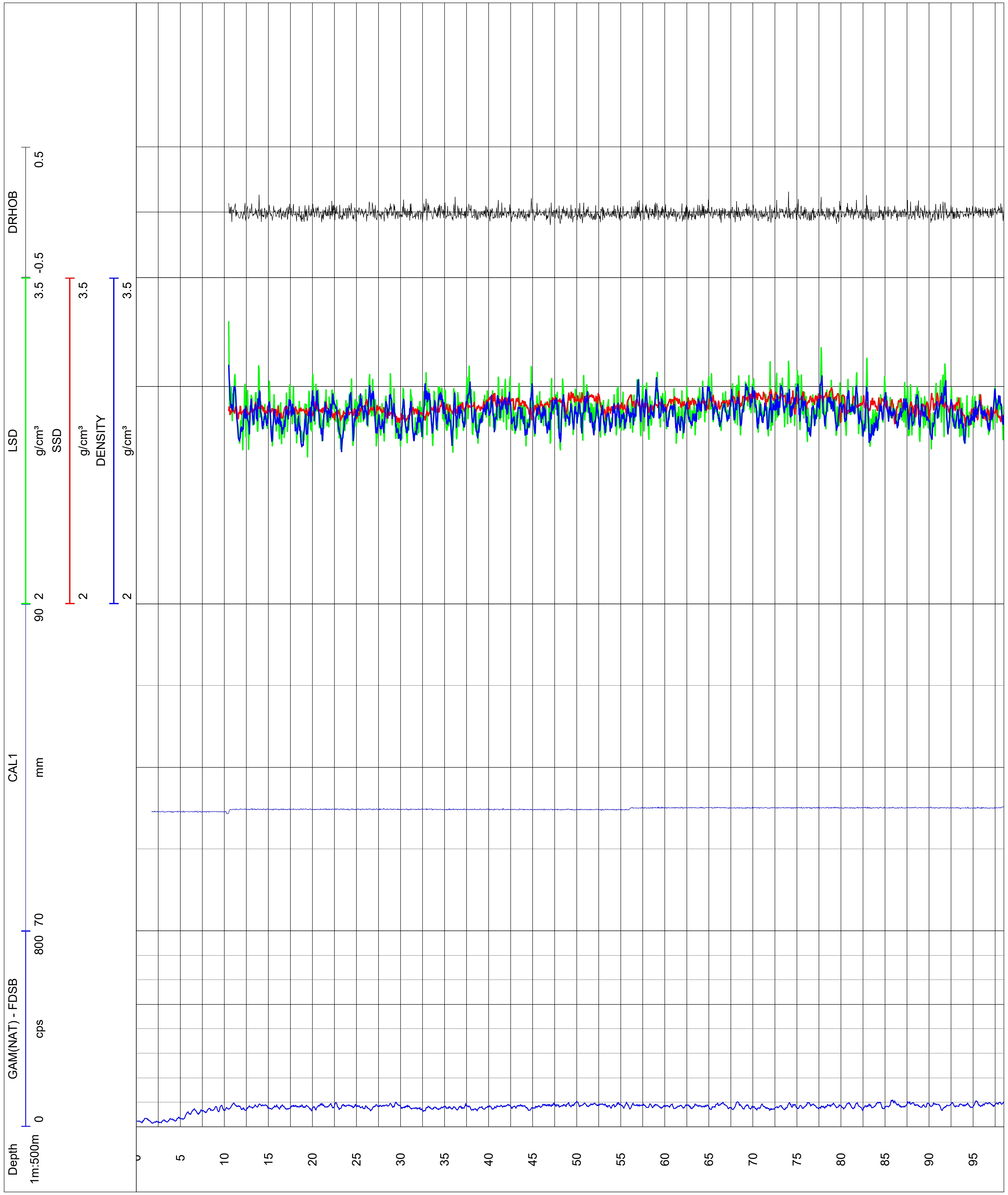
OTHER SERVICES

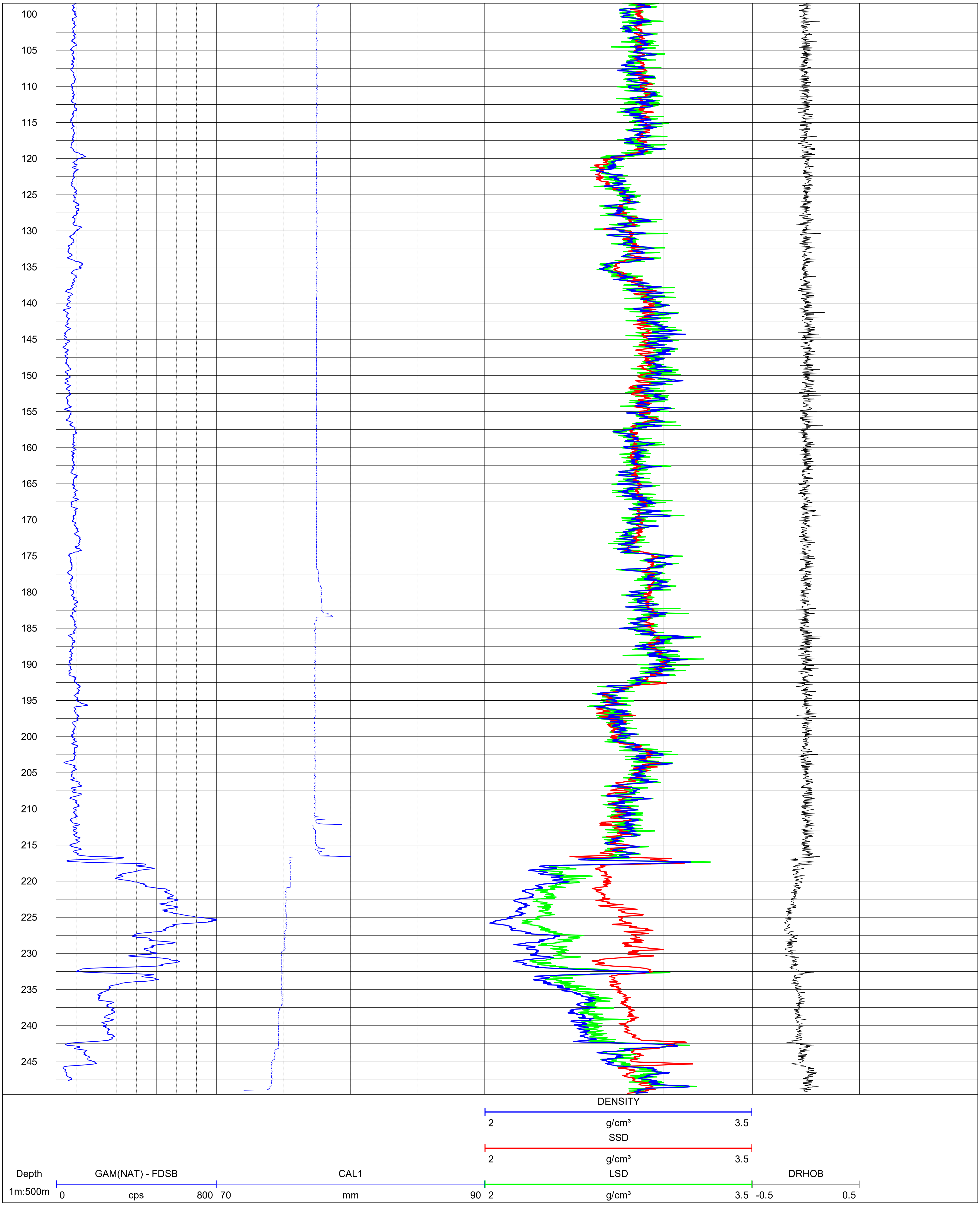
SEC TWP RGE

PERMANENT DATUM		ELEVATION	7.64 m, DVR90	K.B.
LOG MEAS. FROM	Ground	ABOVE PERM. DATUM		D.F.
DRILLING MEAS. FROM	Ground			G.L.

DATE	01/09/2013	TYPE FLUID IN HOLE	Water
RUN No	6	RESISTIVITY	2.6 - 29.5 ohm-m
TYPE LOG	Density + 1-arm Caliper	DENSITY	1 g/cc
DEPTH-DRILLER	250.3 m	LEVEL	0.5 m
DEPTH-LOGGER	250.3 m	MAX. REC. TEMP.	13.3 °C
BTM LOGGED INTERVAL	249.2 m		
TOP LOGGED INTERVAL	0.3 m		
SCALE	1:500		
RECORDED BY	Jørgen Ringgaard, Uffe Nielsen		
WITNESSED BY	Niels Schovsbo		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
	3"	0 m	250.3 m	3"		0 m	10.4 m




100
105
110
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135
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145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
DENSITY
2
g/cm³
3.5
SSD
2
g/cm³
3.5
Depth
1m:500m
GAM(NAT) - FDSB
0
cps
800
CAL1
70
mm
90
LSD
2
g/cm³
3.5
DRHOB
-0.5
0.5

Appendix 2.5

CO TOTAL
WELL 248.62
FLD NEKSØ
CTY DENMARK
STE BORNHOLM
FILING No

COMPANY	TOTAL
WELL ID	248.62
FIELD	NEKSØ
COUNTRY	DENMARK
STATE	BORNHOLM

LOCATION
MØLLE ODDE 15
3730 NEKSØ

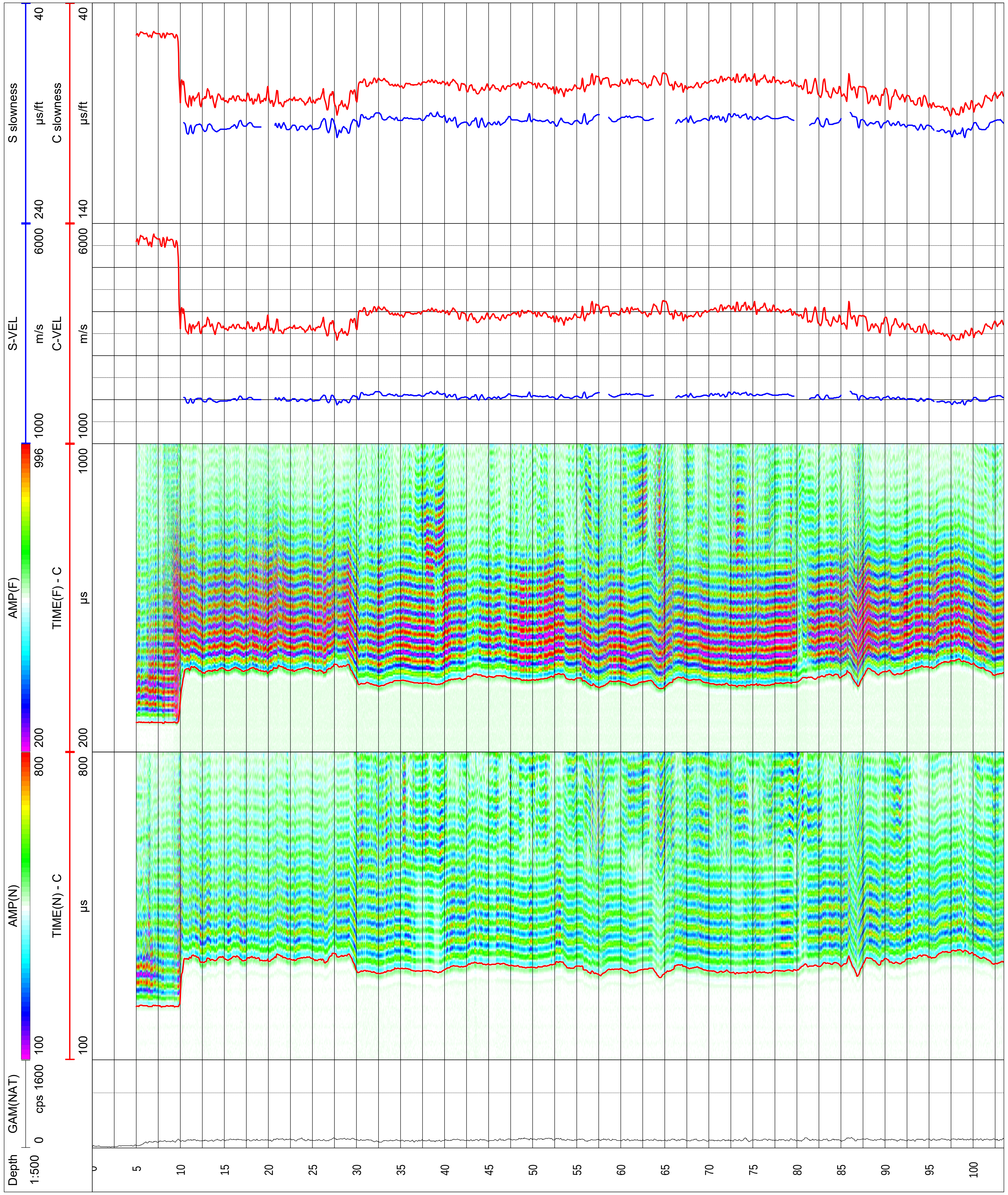
SEC TWP RGE

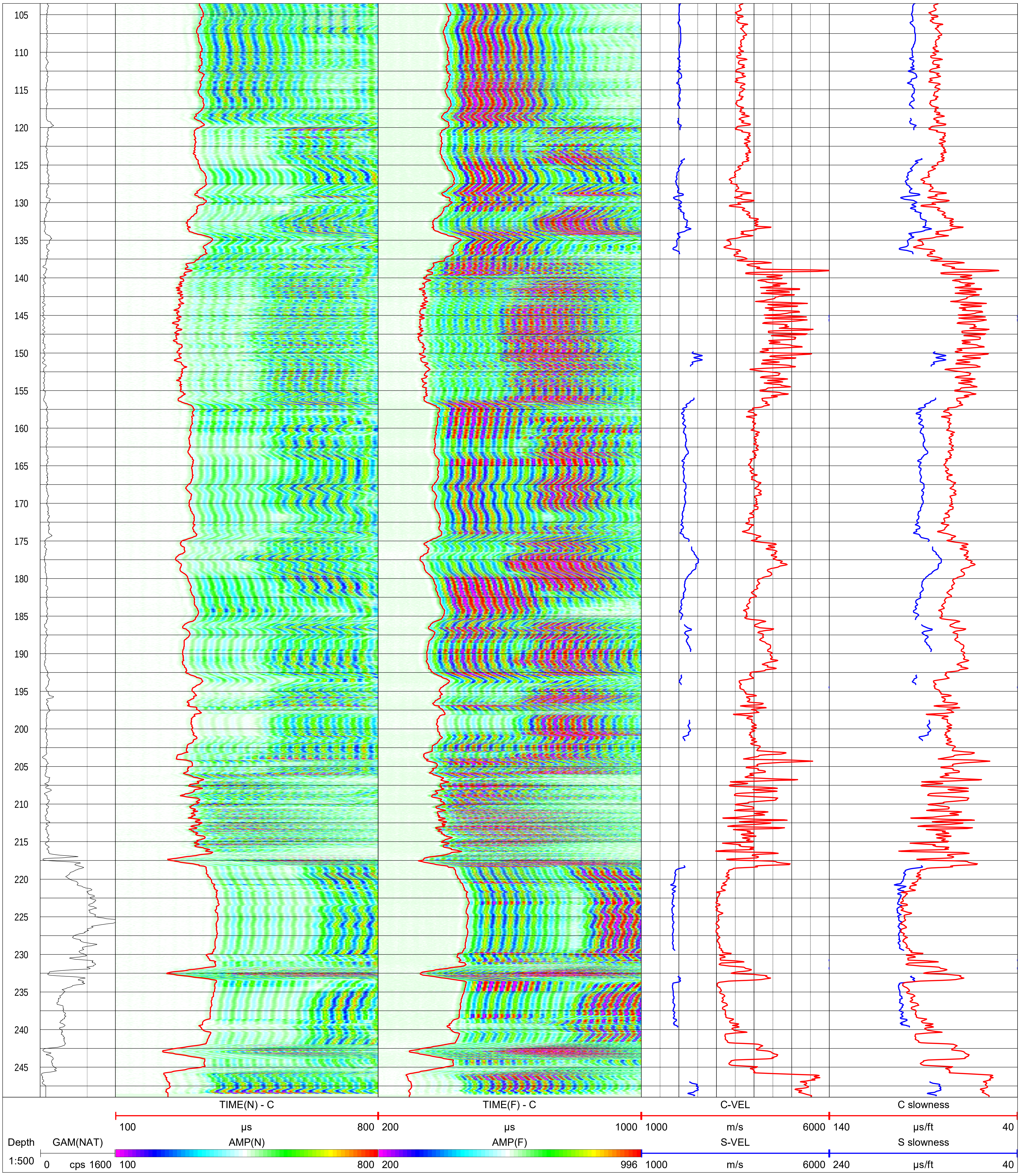
OTHER SERVICES

PERMANENT DATUM		ELEVATION	7.64 m, DVR90	K.B.
LOG MEAS. FROM	Ground	ABOVE PERM. DATUM		D.F.
DRILLING MEAS. FROM	Ground			G.L.

DATE	01/08/2013	TYPE FLUID IN HOLE	Water
RUN No	5	RESISTIVITY	2.6 - 29.5 ohm-m
TYPE LOG	9310 - SONIC	DENSITY	1 g/cc
DEPTH-DRILLER	250.3 m	LEVEL	0.5 m
DEPTH-LOGGER	250.3 m	MAX. REC. TEMP.	13.3 °C
BTM LOGGED INTERVAL	0.1 m		
TOP LOGGED INTERVAL	249.0 m		
SCALE	1:500		
RECORDED BY	Jørgen Ringgaard, Uffe Nielsen		
WITNESSED BY	Niels Schovsbo		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
	3"	0 m	250.3 m	3"		0 m	10.4 m

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115
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125
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135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
TIME(N) - C
100 µs 800
TIME(F) - C
200 µs 1000
C-VEL
1000 m/s 6000
C slowness
140 µs/ft 40
Depth
1:500
GAM(NAT)
0 cps 1600
AMP(N)
100 800
AMP(F)
200 996
S-VEL
1000 m/s 6000
S slowness
240 µs/ft 40

Appendix 2.4

RAMBØLL

CO TOTAL
WELL 248.62
FLD NEKSØ
CTY DENMARK
STE BORNHOLM
FILING No

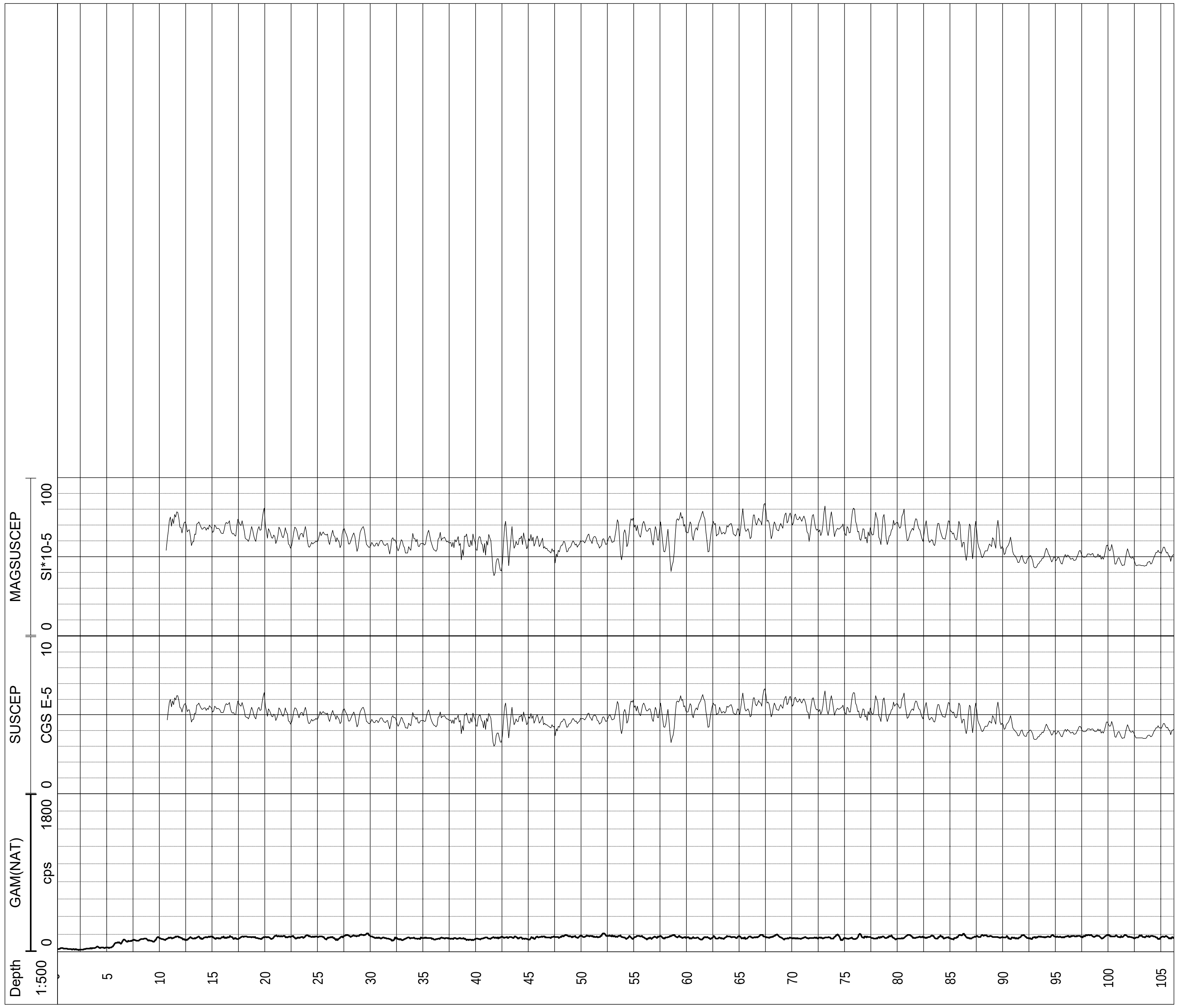
COMPANY	TOTAL		
WELL ID	248.62		
FIELD	NEKSØ		
COUNTRY	DENMARK	STATE	BORNHOLM

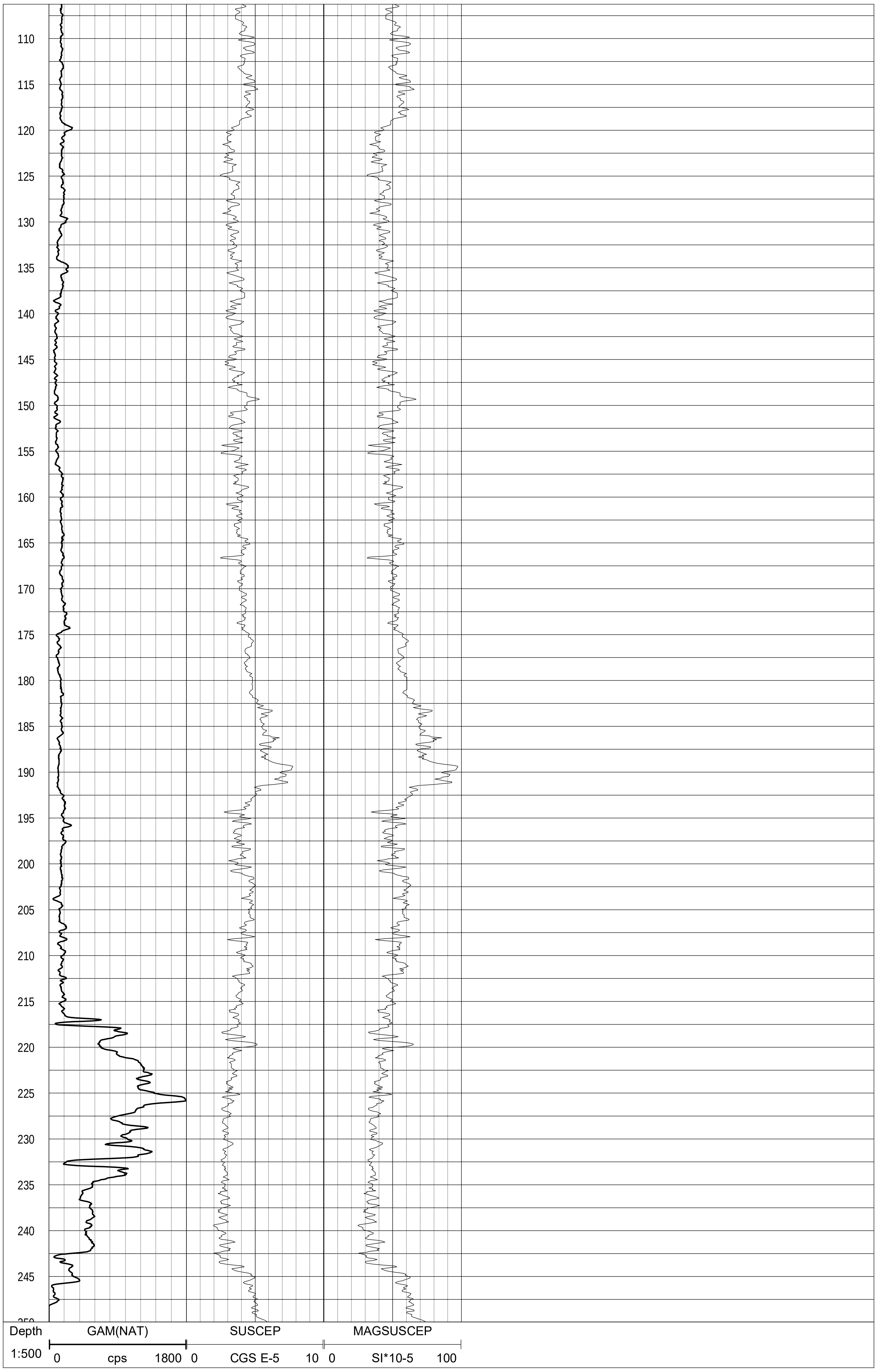
LOCATION MØLLE ODDE 15 3730 NEKSØ SEC TWP RGE	OTHER SERVICES

PERMANENT DATUM		ELEVATION	7.64 m, DVR90	K.B.
LOG MEAS. FROM	Ground	ABOVE PERM. DATUM		D.F.
DRILLING MEAS. FROM	Ground			G.L.

DATE	01/08/2013	TYPE FLUID IN HOLE	Water
RUN No	4	RESISTIVITY	2.6 - 29.5 ohm-m
TYPE LOG	MAGSUSCEP	DENSITY	1 g/cc
DEPTH-DRILLER	250.3 m	LEVEL	0.5 m
DEPTH-LOGGER	250.3 m	MAX. REC. TEMP.	13.3 °C
BTM LOGGED INTERVAL	249.9 m		
TOP LOGGED INTERVAL	0.3 m		
SCALE	1:500		
RECORDED BY	Jørgen Ringgaard, Uffe Nielsen		
WITNESSED BY	Niels Schovsbo		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
	3"	0 m	250.3 m	3"		0 m	10.4 m





110
115
120
125
130
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140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
Depth
1:500
GAM(NAT)
0 cps 1800
SUSCEP
0 CGS E-5 10
MAGSUSCEP
0 SI*10-5 100

Appendix 2.3

RAMBOLL

CO TOTAL
WELL 248.62
FLD NEKSØ
CTY DENMARK
STE BORNHOLM
FILING No

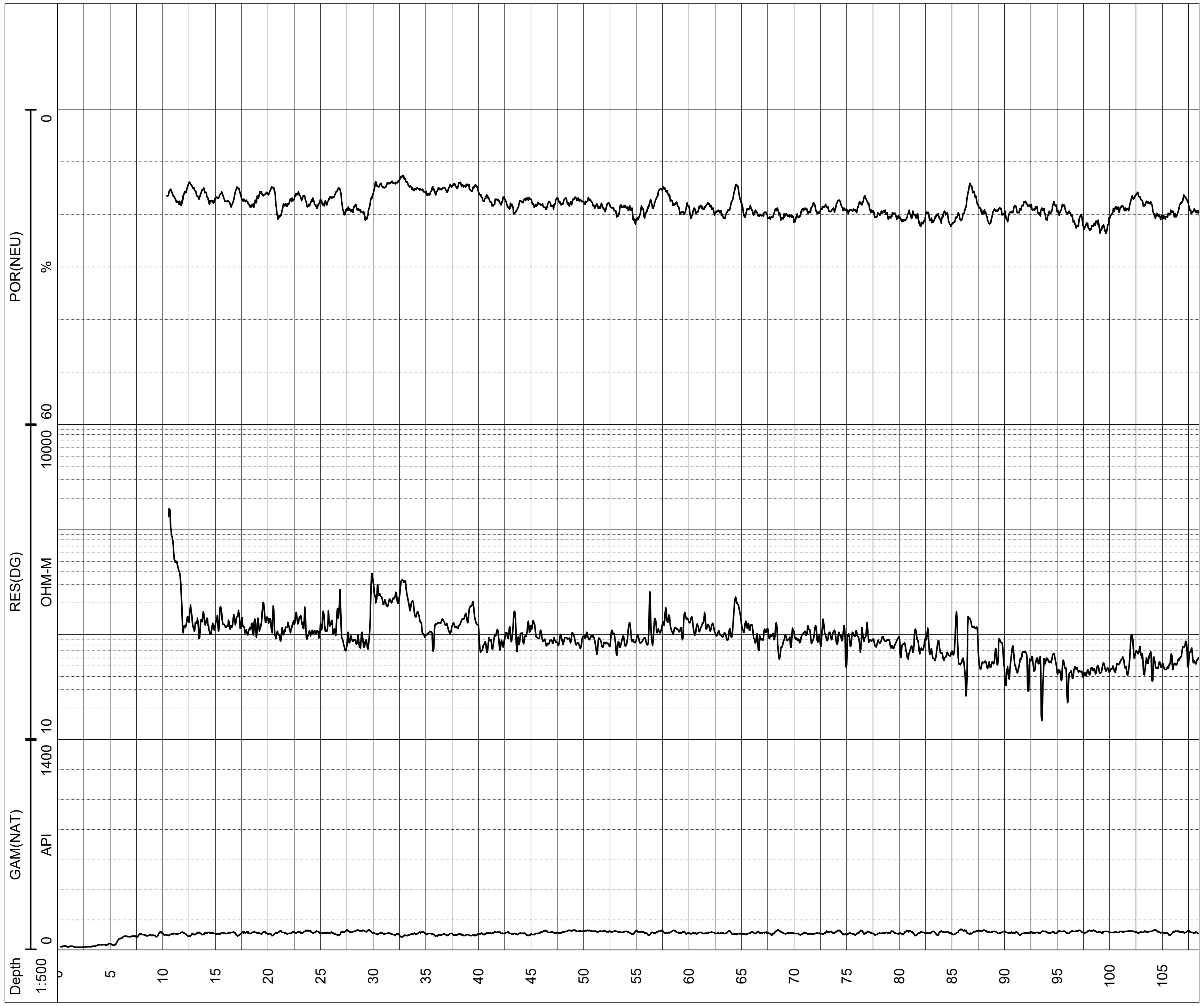
COMPANY	TOTAL		
WELL ID	248.62		
FIELD	NEKSØ		
COUNTRY	DENMARK	STATE	BORNHOLM

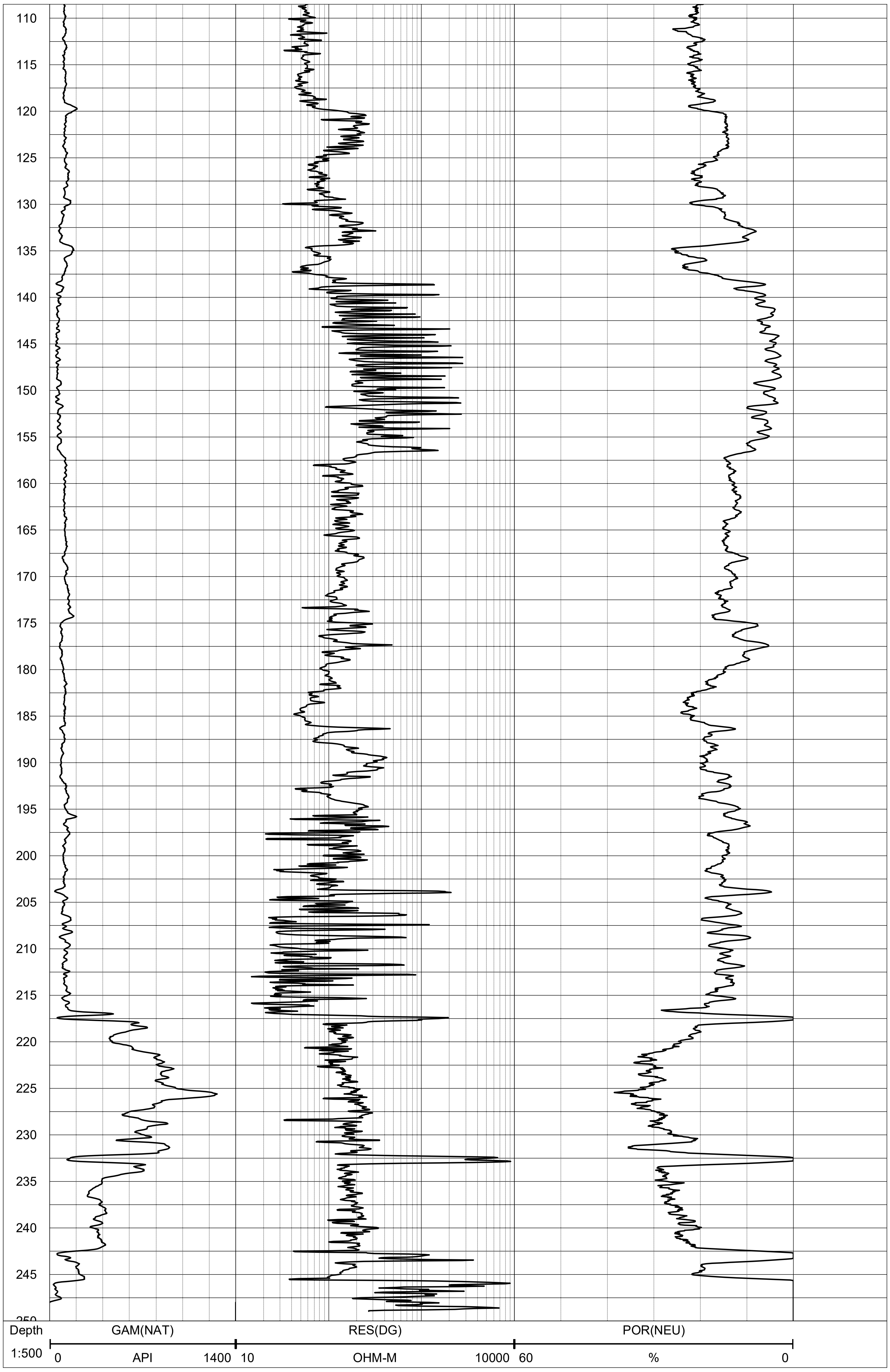
LOCATION MØLLE ODDE 15 3730 NEKSØ SEC TWP RGE	OTHER SERVICES

PERMANENT DATUM		ELEVATION	7.64 m, DVR90	K.B.
LOG MEAS. FROM	Ground	ABOVE PERM. DATUM		D.F.
DRILLING MEAS. FROM	Ground			G.L.

DATE	01/08/13	TYPE FLUID IN HOLE	Water
RUN No	3	RESISTIVITY	2.6 - 29.5 ohm-m
TYPE LOG	9072 Neutron Porosity, GuardLog	DENSITY	1 g/cc
DEPTH-DRILLER	250.3 m	LEVEL	0.5 m
DEPTH-LOGGER	250.3 m	MAX. REC. TEMP.	13.3 °C
BTM LOGGED INTERVAL	250.0 m		
TOP LOGGED INTERVAL	0.4 m		
SCALE	1:500		
RECORDED BY	Jørgen Ringgaard, Uffe Nielsen		
WITNESSED BY	Niels Schovsbo		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
	3"	0 m	250.3 m	3"		0 m	10.4 m

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145
150
155
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165
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175
180
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195
200
205
210
215
220
225
230
235
240
245
Depth
1:500
GAM(NAT)
0
API
1400
RES(DG)
10
OHM-M
10000
POR(NEU)
60
%
0

Appendix 2.2

RAMBØLL

CO TOTAL
WELL 248.62
FLD NEKSØ
CTY DENMARK
STE BORNHOLM
FILING No

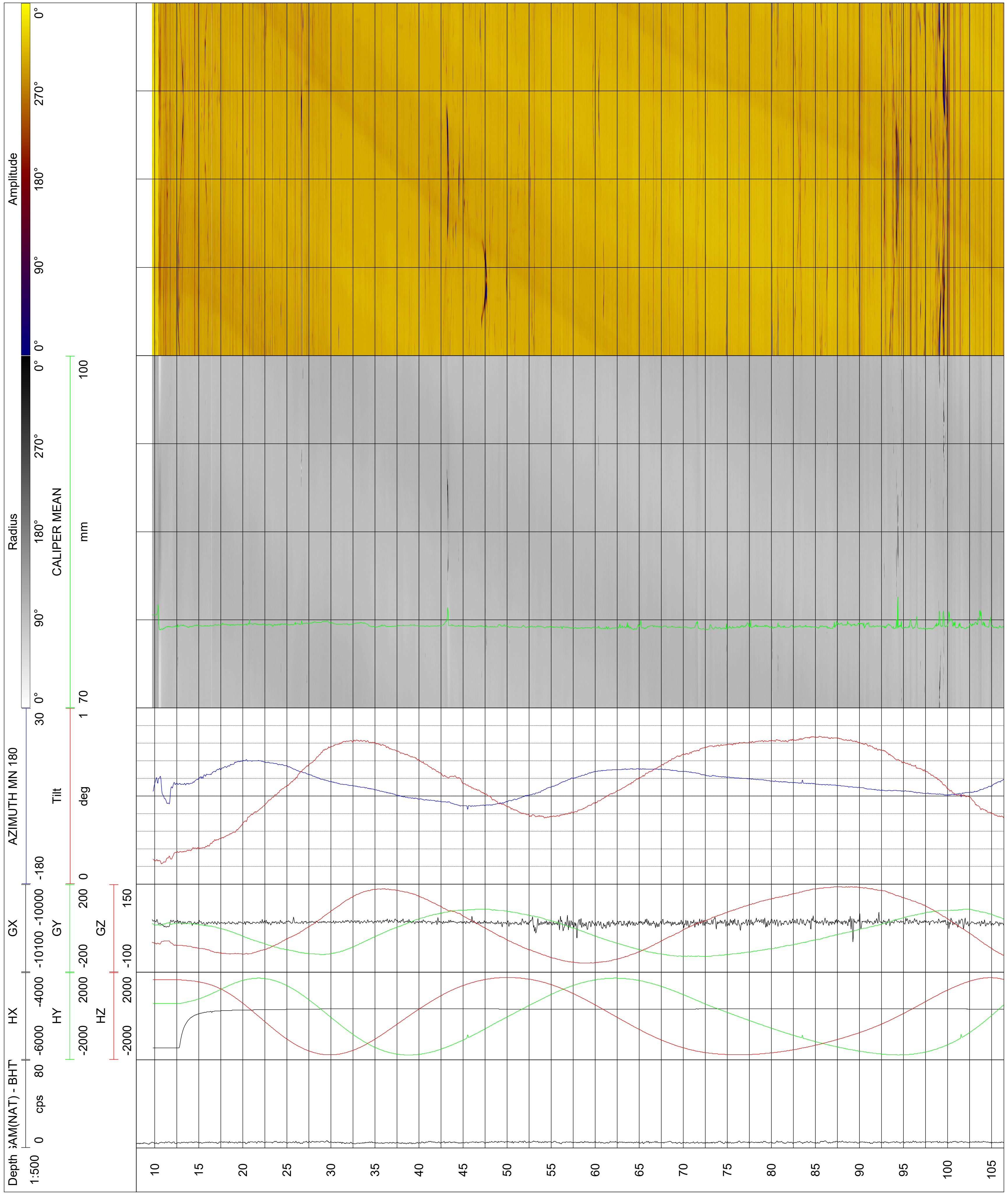
COMPANY	TOTAL		
WELL ID	248.62		
FIELD	NEKSØ		
COUNTRY	DENMARK	STATE	BORNHOLM

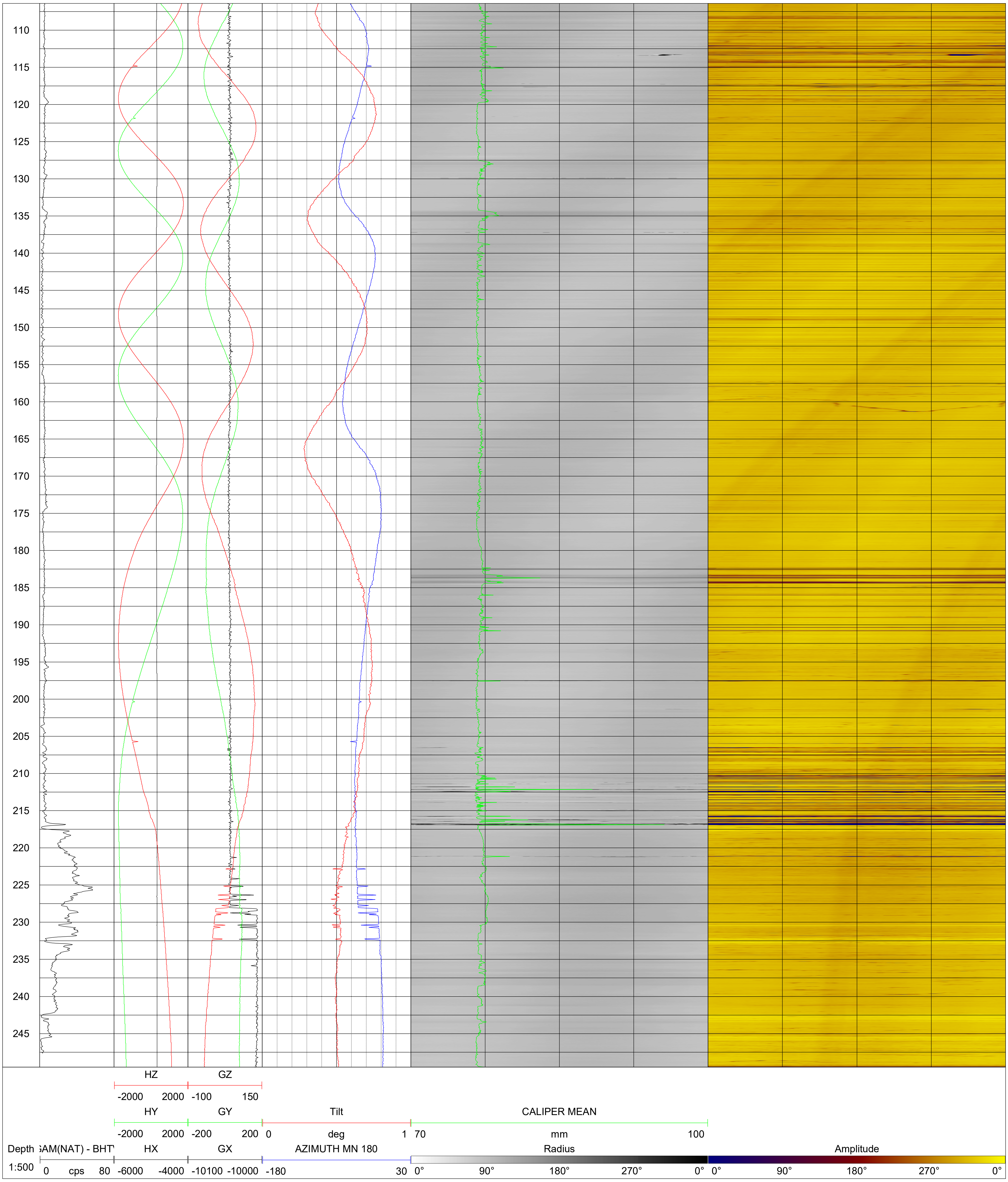
LOCATION MØLLE ODDE 15 3730 NEKSØ SEC TWP RGE	OTHER SERVICES

PERMANENT DATUM		ELEVATION	7.64 m, DVR90	K.B.
LOG MEAS. FROM	Ground	ABOVE PERM. DATUM		D.F.
DRILLING MEAS. FROM	Ground			G.L.

DATE	01/08/13	TYPE FLUID IN HOLE	Water
RUN No	2	RESISTIVITY	2.6 - 29.5 ohm-m
TYPE LOG	BHTV	DENSITY	1 g/cc
DEPTH-DRILLER	250.3 m	LEVEL	0.5 m
DEPTH-LOGGER	250.3 m	MAX. REC. TEMP.	13.3 °C
BTM LOGGED INTERVAL	249.5 m		
TOP LOGGED INTERVAL	9.71 m		
SCALE	1:500		
RECORDED BY	Jørgen Ringgaard, Uffe Nielsen		
WITNESSED BY	Niels Schovsbo		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
	3"	0 m	250.3 m	3"		0 m	10.4 m





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210
215
220
225
230
235
240
245
HZ
GZ
-2000 2000 -100 150
HY
GY
Tilt
CALIPER MEAN
-2000 2000 -200 200 0
deg
1 70
mm
100
Depth
ɜAM(NAT) - BHT
HX
GX
AZIMUTH MN 180
Radius
Amplitude
1:500
0 cps 80 -6000 -4000 -10100 -10000 -180 30 0° 90° 180° 270° 0° 0° 90° 180° 270° 0°

Appendix 2.1

RAMBØLL

CO TOTAL
WELL 248.62
FLD NEKSØ
CTY DENMARK
STE BORNHOLM
FILING No

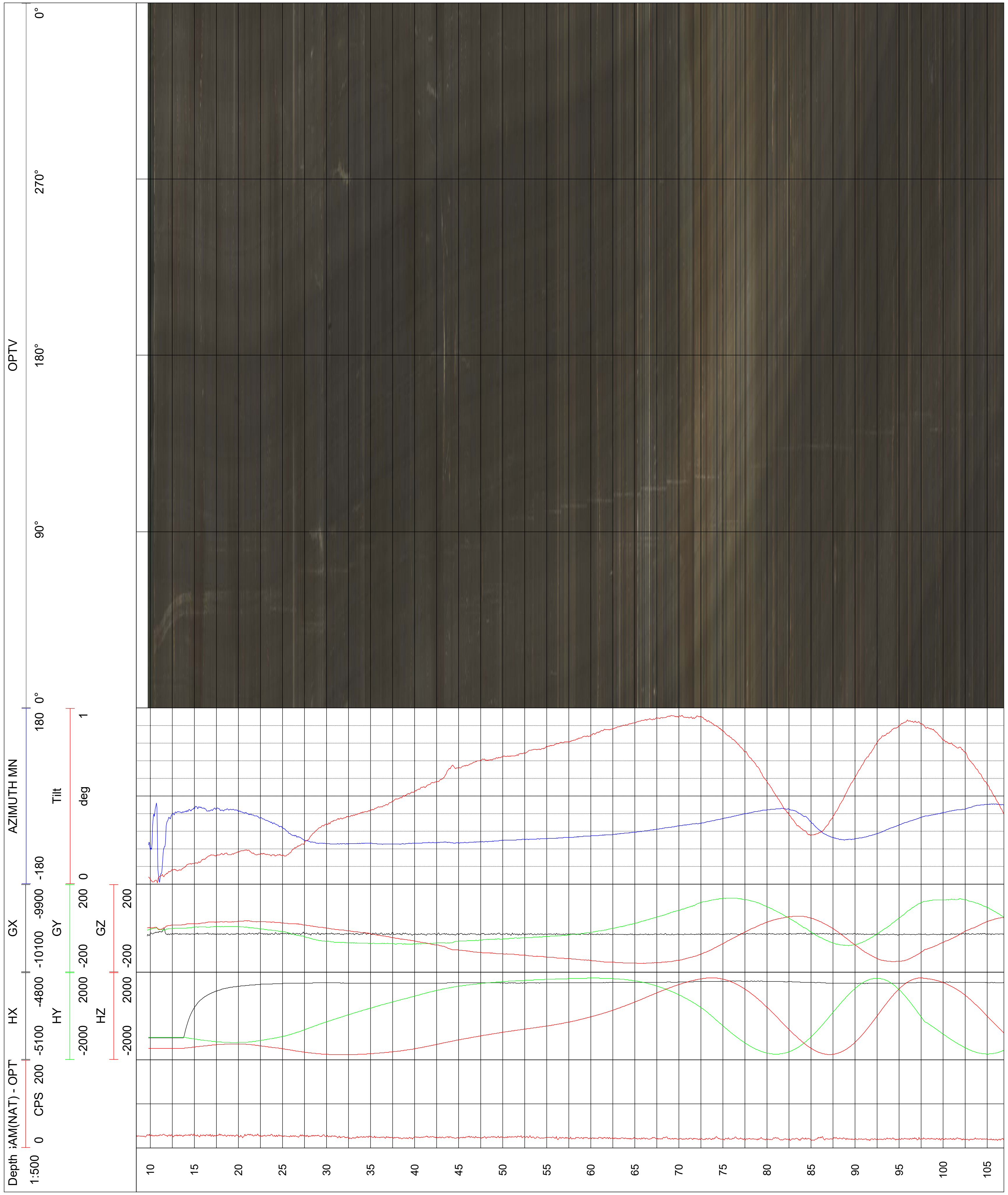
COMPANY	TOTAL		
WELL ID	248.62		
FIELD	NEKSØ		
COUNTRY	DENMARK	STATE	BORNHOLM

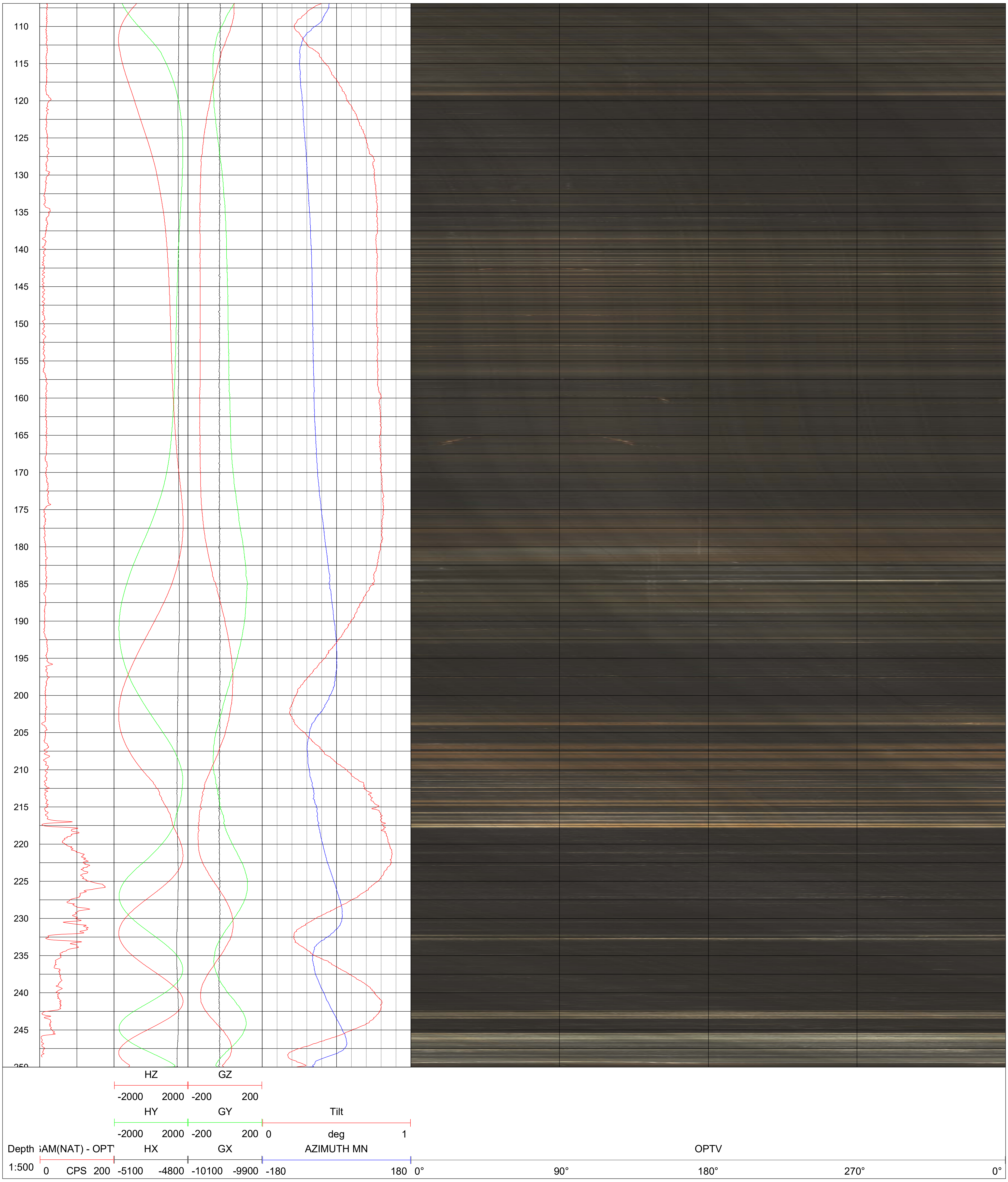
LOCATION MØLLE ODDE 15 3730 NEKSØ SEC TWP RGE	OTHER SERVICES

PERMANENT DATUM		ELEVATION	7.64 m, DVR90	K.B.
LOG MEAS. FROM	Ground	ABOVE PERM. DATUM		D.F.
DRILLING MEAS. FROM	Ground			G.L.

DATE	08/01/2013	TYPE FLUID IN HOLE	Water
RUN No	1	RESISTIVITY	2.6 - 29.5 ohm-m
TYPE LOG	OPTV	DENSITY	1 g/cc
DEPTH-DRILLER	250.3 m	LEVEL	0.5 m
DEPTH-LOGGER	250.3 m	MAX. REC. TEMP.	13.3 °C
BTM LOGGED INTERVAL	250.01 m		
TOP LOGGED INTERVAL	9.68 m		
SCALE	1:500		
RECORDED BY	Jørgen Ringgaard, Uffe Nielsen		
WITNESSED BY	Niels Schovsbo		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
	3"	0 m	250.3 m	3"		0 m	10.4 m





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185
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215
220
225
230
235
240
245
HZ
GZ
-2000 2000 -200 200
HY
GY
Tilt
-2000 2000 -200 200 0 deg 1
Depth
GAM(NAT) - OPT
HX
GX
AZIMUTH MN
OPTV
1:500
0 CPS 200 -5100 -4800 -10100 -9900 -180 180 0° 90° 180° 270° 0°

Appendix 1.1

CO TOTAL
WELL 248.62
FLD NEKSØ
CTY DENMARK
STE BORNHOLM
FILING No

COMPANY	TOTAL		
WELL ID	248.62		
FIELD	NEKSØ		
COUNTRY	DENMARK	STATE	BORNHOLM

LOCATION
MØLLE ODDE 15
3730 NEKSØ

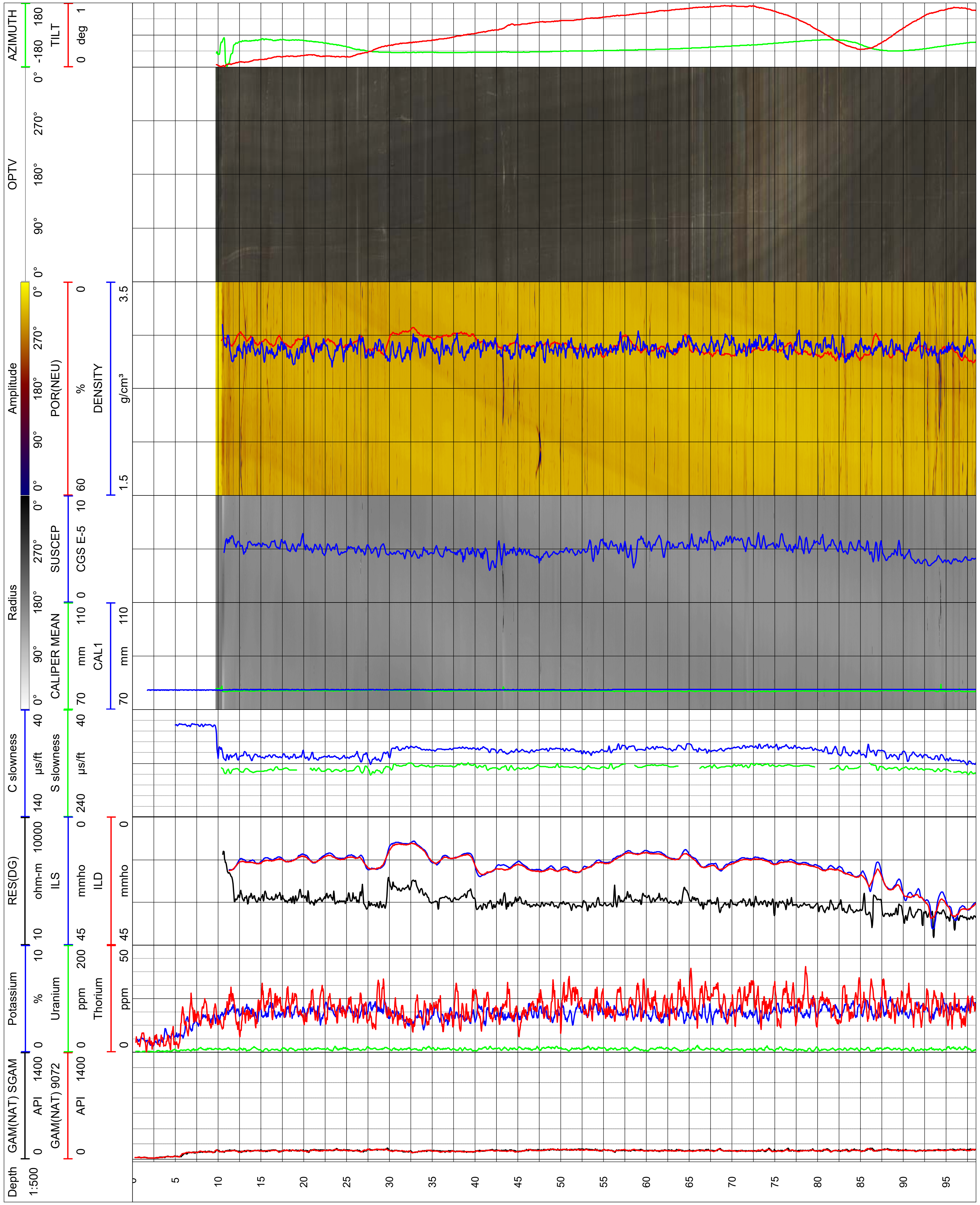
OTHER SERVICES

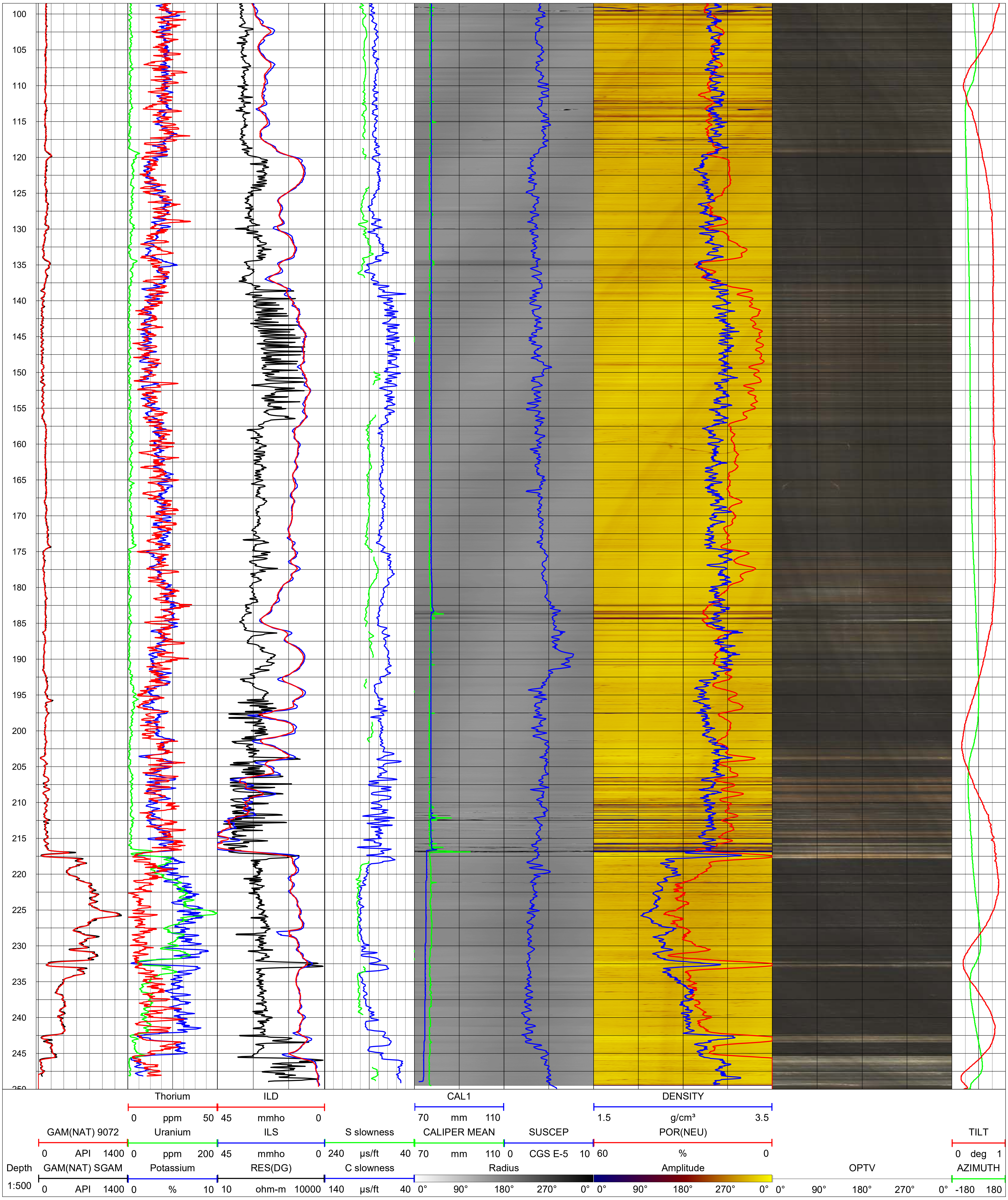
SEC TWP RGE

PERMANENT DATUM		ELEVATION	7.64 m, DVR90	K.B.
LOG MEAS. FROM	Ground	ABOVE PERM. DATUM		D.F.
DRILLING MEAS. FROM	Ground			G.L.

DATE	08/01/2013	TYPE FLUID IN HOLE	Water
RUN No	1-7	RESISTIVITY	2.6 - 29.5 ohm-m
TYPE LOG	Presentation panel	DENSITY	1 g/cc
DEPTH-DRILLER	250.3 m	LEVEL	0.5 m
DEPTH-LOGGER	250.3 m	MAX. REC. TEMP.	13.3 °C
BTM LOGGED INTERVAL	250.01 m		
TOP LOGGED INTERVAL	9.68 m		
SCALE	1:500		
RECORDED BY	Jørgen Ringgaard, Uffe Nielsen		
WITNESSED BY	Niels Schovsbo		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
	3"	0 m	250.3 m	3"		0 m	10.4 m

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110
115
120
125
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135
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145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
GAM(NAT) 9072
0 API 1400
GAM(NAT) SGAM
0 API 1400
Thorium
0 ppm 50
Uranium
0 ppm 200
Potassium
0 % 10
ILD
45 mmho 0
ILS
45 mmho 0
RES(DG)
10 ohm-m 10000
S slowness
240 μs/ft 40
C slowness
140 μs/ft 40
CAL1
70 mm 110
CALIPER MEAN
70 mm 110
SUSCEP
0 CGS E-5 10
Radius
0° 90° 180° 270° 0°
DENSITY
1.5 g/cm³ 3.5
POR(NEU)
60 % 0
Amplitude
0° 90° 180° 270° 0°
OPTV
0° 90° 180° 270° 0°
TILT
0 deg 1
AZIMUTH
-180 180