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Porosity of the Bunter Sandstone in the Southern North Sea Basin based on selected Borehole Neutron Logs

SRE Programme

Internal Report IR/05/074

BRITISH GEOLOGICAL SURVEY

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Contributor

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Foreword

This report is the published product of a study by the British Geological Survey (BGS). The potential of the Bunter Sandstone as a reservoir rock for the storage of carbon dioxide depends on many factors including porosity, geological seal and injectivity. This report presents the porosity of the Bunter Sandstone across the Southern North Sea Basin as calculated from neutron logs, NPHI, SNP and NEUT.

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Summary

This report presents the results of a porosity study of the Bunter Sandstone (BNS) in the Southern North Sea Basin based primarily on the analysis of neutron logs.

The Bunter Sandstone is a Triassic fluvial sandstone (Cameron et al 1992). It contains layers or lenses of varying thickness of shale and/or siltstone. The Prizm module from the GeoGraphix interpretation software suite (v. 2004.1), was used to display the borehole logs. Neutron logs were plotted alongside gamma, sonic and density logs. The gamma log was used to identify shales in the Bunter Sandstone to assist in averaging the neutron porosity over the sandy intervals only. Most porosities in the BNS had values in the interval of 10-22% but some extremes as low as 1% and as high as 27% were identified. Gas effect and salt cementation were also noted in some boreholes. Maps of the neutron and core porosities, depth to, and thickness of the sandstone, were produced in GeoAtlas, also from the GeoGraphix Interpretation suite 2004.1.

In general the lowest porosities not linked with salt cementation coincided with the Sole Pit Trough, a major depocentre for the BNS.

1 Introduction

The Bunter Sandstone (BNS) was deposited during the Triassic as fluvial channel sandstones in an arid environment (Cameron et al 1992). It contains layers or lenses of varying thickness of shale and/or siltstone.

Neutron logs (NPHI, SNP and NEUT) from boreholes in the Southern North Sea (SNS) were used to calculate the average porosity of the sandstone in the BNS (table 1). NPHI and SNP give a direct reading of percentage porosity. NEUT log readings were converted from API units to give an average porosity in percent using Schlumberger Log Interpretation charts based on mud type, hole diameter and temperature (Schlumberger 1969a). For this study, only the net sandstone thickness and porosity components of the BNS formation were considered. That is, high shale content sections of the BNS were ignored.

To generate a neutron log, high energy neutrons are continuously emitted from a radioactive source. Collisions with hydrogen nuclei cause the greatest loss of energy and slow the neutrons considerably. After several collisions, the neutrons diffuse into the formation where they are captured by the nuclei of atoms such as hydrogen or silicon. Therefore, in formations where the hydrogen content is high, most of the neutrons are slowed down and captured by nuclei in the formation a short distance from the source, decreasing the count rate at the detector. Hydrogen is present in pore water (and liquid hydrocarbons), thus a low count rate implies a high formation porosity. The neutron log is affected by both free and bound water and so gives inaccurate porosity readings in shales and is affected by some evaporites such as gypsum. The neutron log is also affected by the presence of organic matter, such as in coals or organic shales.

Density and neutron logs can generally be used to determine porosity in clean sandstones accurately. However, in the Southern North Sea, natural gas, halite cement and shale are present in some wells which affects the accuracy of the porosity as calculated from the neutron and/or density logs. Where thick shale layer(s) occurred in the BNS, or the gas effect was observed, the neutron porosity was calculated only in the sandstone units.

The porosity was also calculated using the density log (PHID) for comparison with the neutron porosity as a quality check. Where PHID was significantly different from the neutron porosity, the log was re-examined to check for shale, gas, halite cement, or a combination of these factors. Porosities calculated from the neutron logs are in limestone units, correcting the results to sandstone porosity tended to give a too high result compared to the porosity as calculated from the density log or core samples, probably because a correction for shale present in the sandstone is required, thus it was decided to use limestone porosity units for the final porosity maps.

The neutron porosity should give a correct porosity reading when halite cement is present because NaCl contains no hydrogen ions in its matrix and therefore the clogged pore spaces will be shown as low porosity. Natural halite contains small inclusions of preserved water which are too small to noticeably affect the neutron log. Density logs however, measure the bulk density of the rock and pore-fluids combined and therefore overestimate the porosity when the pore spaces a filled with halite. Both the neutron and density log are affected by the presence of natural gas. Natural gas trapped in the pore spaces has a much lower hydrogen concentration (Schlumberger 1969b) than water, resulting in a higher neutron count and falsely low porosity. PHID gives a high porosity reading since the fluid density drops in the presence of gaseous hydrocarbons. As a result, a wide separation is observed between the neutron log and formation density log when plotted on the same track, this is known as the gas effect and is observed in some wells studied here.

2 Neutron porosity of the Bunter Sandstone

2.1 NEUTRON AND DENSITY LOGS

Neutron logs are usually calibrated in limestone porosity units. To generate a neutron log, high energy neutrons are continuously emitted from a radioactive source. Collisions with heavy nuclei do not slow the particles down much, but a collision with a hydrogen nucleus of near equal mass causes the greatest loss of energy and slows the neutrons considerably. After several collisions, the neutrons diffuse into the formation where they are captured by the nuclei of atoms such as hydrogen or silicon. Therefore, in formations where the hydrogen content is high, most the neutrons are slowed down and captured by nuclei in the formation a short distance from the source, decreasing the count rate at the detector. Conversely, for a formation with low hydrogen content, most of the neutrons travel further from the source before being captured, increasing the count rate at the detector. Hydrogen is present in pore water and hydrocarbons. A high count rate therefore implies a low formation porosity.

The neutron tool consists of a fast neutron source and a detector, or for more recent tools, two detectors (near and far). The source emits particles such as 3He (Rider 1996). Neutrons that reach the detectors from the source react with the detector material to produce energetic charged particles which are detected through their ionizing ability. The efficiency of the counter at the detector varies inversely with the square root of the neutron energy. They therefore respond mainly to thermal (lower energy) neutrons. Epithermal (higher energy) neutrons can be detected if the detector is covered by a cadmium sheath to absorb the thermal neutrons.

The depth of investigation of the neutron tool is usually of the order of 15-25cm. Maximum investigation is in low porosity materials. The neutron tool has good bed resolution, usually around 60cm for the logs used here. The neutron log is not suitable for use in shaly lithologies: The neutron log is sensitive to hydrogen in free and bound water and thus gives erroneously high porosities of 40-50% in shales (Rider 1996).

The NEUT log is the count rate in API units. It requires manual correction for borehole temperature, mud salinity and borehole diameter.

The Sidewall neutron log (SNP) counts the faster, higher energy epithermal neutrons, thus the perturbing effects of strong thermal neutron absorbers (such as chlorine and boron) in the formation waters are minimized. The SNP tends to be pressed against the side of the borehole with sufficient force that much of the softer mud is scraped away, improving accuracy compared to non-directional tools (Schlumberger 1969b). However, a mud cake correction may still be required.

The CNL log is an improvement on the SNP log because two detectors are used, minimising the borehole effect (caused by mud column, mud cake, rugosity and casing). NPHI is the corrected neutron log (CNL) in a cased borehole. NPHI is a ‘thermal porosity’ log (i.e. the detectors count lower energy thermal neutrons) calculated from the near and far count rates using a cased hole ratio-to-porosity transform (Schlumberger 1989).

The neutron porosity was also compared to PHID (density porosity) as a quality check. PHID is calculated from the density log using;

$$PHID = \frac{RhoM - Rhob}{RhoM - RhoF}$$

Where Rhob is the bulk density as measured by the density logging tool, RhoF is the fluid density and RhoM is the matrix density. The fluid density is generally assumed to be 1.0g/cm^3 for freshwater and 1.1g/cm^3 for saline water. The matrix density is generally assumed to be 2.68g/cm^3 compared to 2.65g/cm^3 for sandstone (0% porosity), 2.71g/cm^3 for limestone (0%

porosity) and 2-2.8g/cm^3 (depending on compaction) for shale (Rider 1996). If constant matrix density figures are applied to a formation and the matrix porosity is not constant, the density porosity calculated will be inaccurate. It was assumed that the neutron porosity would be more suitable for this study than PHID due to the density assumptions made for calculating PHID and the sensitivity of the neutron logs to porewater in sandstones.

2.2 POROSITY

The borehole logs were displayed using the Prizm module from the GeoGraphix interpretation software suite (v. 2004.1), was used to display the borehole logs. Gamma (GR), sonic (DT or SONL), neutron (NPHI, SNP or NEUT), bulk density (RHOB), bulk density correction (DRHO) and formation porosity calculated from bulk density (PHID) were plotted. A maximum value of 60API for GR was used to define the boundary between sandstone and shale and this was used to limit the section of log used to calculate thickness and average porosity of the Bunter Sandstone in the boreholes. The average porosity calculated from the neutron log was compared to the PHID averaged over the same interval as a quality check (see table 1). The neutron logs were calibrated in the standard unit of limestone porosity units, however, applying the correction to convert to sandstone porosity tended to give a too high porosity compared to PHID and values obtained from core analysis, probably because a further correction for shale content was required (which would have reduced the calculated porosity). After comparison with PHID, it was decided to use limestone porosity units read directly from the NPHI and SNP logs or calculated from the NEUT logs.

The results of these porosity calculations were plotted on a map using GeoAtlas, another part of the GeoGraphix software package (figure 1). The coastline and limits of the Bunter were provided by M. S. Bentham and K. L. Shaw. The contours are spaced at 1% porosity variation. Core porosities where available from well completion reports are also plotted in figure 1. Some high porosities which were considered to be erroneous have been omitted (see table 1). Figure 2 shows the depth to the top of the sandstone in the BNS formation as measured in these boreholes and figure 3 shows the sandstone thickness.

2.3 DISCUSSION

Comparing Figure 1 to the known geological features of the SNS reveals that the low in the centre of the plot coincides with the northern end of the Sole Pit Trough, and some of the greatest thicknesses of BNS observed in the studied boreholes. The low in the north of the plot maps over an area where the BNS thins close to its northern margin on the southern flank of the mid North Sea high. There is evidence for salt cementation in some of the boreholes in this area. The high porosity to the south of the plot is close to the southern margin of the SNS basin where the BNS begins to thin towards the London-Brabant massif. The high porosity readings to the east of the BNS are on the edge of the Cleaver Bank high (Cameron et al 1992). Thus the primary control on the Bunter Sandstone in the Southern North Sea Basin appears to relate to its original depositional setting; porosity is lowest in the BNS depocentre and highest on the surrounding highs. It is unclear however if this is a result of primary depositional features, early diagenesis or compaction and cementation during burial. This should be clarified by petrological studies of core samples currently in progress.

Some of the borehole logs, such as OS 52/5-3 show a clear 'gas effect' (figure 4; Tullow, released). Water and liquid hydrocarbons have roughly the same amount of hydrogen, but gas usually has a considerably lower hydrogen concentration (Schlumberger 1969b). The lower hydrogen content results in a higher neutron count and underestimates the porosity. Also, PHID gives a high reading since the fluid density drops greatly in the presence of gaseous hydrocarbons. As a result, a wide separation is observed between the neutron log and formation density log when plotted on the same track. A clean, water saturated sandstone would be expected to have a GR of 80-90API, a sonic log of around 80μ/ft, a density of around 2.32g/cm^3 and a neutron log reading of around 16% (Rider 1996). The gas effect in a pure sandstone should have a sonic log reading of 85μ/ft, density 2.3g/cm^3 (slightly less than for a clean sandstone) and a neutron reading of around 6% (lower than for a clean sandstone) (Rider 1996).

Salt cementation also causes a falsely high density porosity reading and is accompanied by a low on the sonic log. Pure salt should be identifiable on the borehole log suite by GR 15-20API, sonic 66.7μ/ft, density 2.03g/cm^3 and neutron 0 to –3% (Rider 1996). In the north of the study area an extremely low neutron porosity was calculated for 42/10A-1 which is likely a result of salt cementation. Low neutron porosities accompanied by lower sonic and GR readings suggest that salt cementation also affected wells such as 49/16-7Z (figure 5; ConocoPhillips, released) around this region. The BNS is thin in these boreholes in the north of the study area.

Overall, porosity ranges between 1 and 27% in the Bunter Sandstone for the boreholes studied. The majority of boreholes show a BNS neutron porosity of 10-22%. The thickness of the sandy BNS ranges from zero to few metres to a maximum of 345m in the Sole Pit Trough.

Table 1: Neutron and core porosity of the Bunter Sandstone in selected wells in the Southern North Sea.
Values plotted in figures 1-3 highlighted in red.

Well	Comments	Top of Sst	Bottom	Thickness	NPHI Por	SNP Por	NEUT Por	PHID Por	Core Por	Field
41/20-1		430.4	618.7	188.3					16.7	
42/10A-1	very shaly, 20m BNS. Tried NPHI for top half, NPHI>PHID.	1251.8	1262.4	10.6	0.3			14.77	2.4	
42/15b-1		1024.9	1088.1	63.2					11.8	
42/25-1	At least 80m sst.	1114		80					22.0	
42/26-1	no BNS									
43/12-1	mf-no gas. BNS sandy	1382.7	1485.1	102.4	19.86					
43/13A-1	mf-sandy, few silty layers. Base taken as where NPHI changes to more shaly?	1403.6	1481.4	77.8	16.63			26.9		Esmond gas field
43/13A-3	thick shale nr top, smaller shales nr bottom of BNS. Can't see BTSH.	2226.5	2451.6	225.1	17.51			21.69		Esmond gas field
43/15-1		1637.1	1767.8	130.7					15.0	Gordon gas field
43/15A-2	mf-suspended gas well. Sandy, clayst nr top. & at bottom. Some calc cements.	2779.3	3024.5	245.2	20			24.36		
43/16-1		931.2	1082	150.8					16.9	
43/3-1	very little sst. Mf - NEUT scaled 350-850, digital log in prizm too high? Very silty.	1676.4	1693.3	16.9			10			
43/8A-3	mf-shaly at top BNS and interbedded shale near bottom. NPHI has many 'lows'	1758.6	1803.8	45.2	10.6			14.7		
44/22-1	no BNS									
44/23-3	no mf but looks like salt/shales top of BNS	1404.2	1498.1	93.9	20.03			24.62	19.4	
44/7-1	GR fairly shaly, cutoff here above shaly spike near bottom	1514	1553.6	39.6		27.42		16.25		
47/03-C2	don't have logs at top of BNS. Sst starts 1743.2. Plus logs shaly layer in middle	1840.3	1929.7	186.5	26.04			27.41		
47/14A-07	mf-sst occ. Anyhdrite and clayst. Clayst at bottom of BNS. Por 22%, Sw=100%	1982.3	2205.6	223.3	21.48			19.61		
47/14A-5	mf-sandy, occ thin clayst layers. BUT gr-looks shaly.	1621.7	1770.4	148.7	21.37			16.43		
47/25-2	GR-bottom half shaly.	1327.3	1388.2	60.9		19.36				
47/9B-4	mf-sst with some dolo and siltst.	2063.5	2261.4	197.9	14.37			15.15		
47/9B-5A	mf-clayst layers. most GR almost at 60 - most BNS shaly.	1864.6	1940	75.4	15.09			15.49		
47/9B-6	mf-some siltst layers. Gen. low NPHI	2028.2	2224.3	196.1	16.52			12.7		
48/03-2	mf-TD in BNS. Sst poorly sorted+coarsening. Interbd mud/siltst. Gr-shaly patches	1766.9	2028.8	261.9	11.83			19.21		
48/06-23	no logs in BNS									
48/06-28	mf-abandoned gas well. Mudst and dolo layers. Logs-sandy, thin shales.	1387.2	1732.2	345	no NPHI			16.68		
48/07-2	mf-poorly sorted. Thin silts. Poor visible porosity. Logs - bottom looks shaly	998	1251.5	253.5	12.81			18.95		
48/11-1	GR low. NEUT v high top half, then low bottom half	1972.5	2159.7	187.2			13	11.78		
48/12-1	GR-thin shaly layer at top. Mf por ~ 14%clean sst, 10%Limest por.	1489.1	1783.2	294.1		12.43		14.81		
48/13B-03	mf-v fine grained coarsening downwards, mod. Cemented. Siltst interbeds.	1685.3	1916	230.7	14.13			16.58		
48/2-1	mf-sst, some siltst. Poor visible porosity	2439.7	2772.8	333.1	10.9			11.23		
48/21-1	GR-shaly top	1531.5	1570.7	39.2			16	7.44		

52/5-2	mf-subangular	956.8	1073.4	116.6		22.07		21.63		Hewitt gas field
52/5-3	mf-sst interbed with shale fair porosity. Log-gas effect at top?(911-941)	941	1123.9	182.9	21.71			21.12		Hewitt gas field
52/5-3	mf-sst interbed with shale fair porosity. Log-gas effect at top?(911-941)	911.9	1123.9	212	20.45			22.62		Hewitt gas field
53/1-1	logs small part of BNS only plus strange low at top. BNS sandy 1008-1365	1008	1083.9	75.9		21.33		26.89		
53/12-1		1016.5	1267.6	251.1			23	24.59		
53/16-1	small BNS. Mf-shaly layers, poor-fair porosity.	640.5	693.6	53.1		33.86		29.24		
53/7-2	GR-shaly patch in middle. Mf-30-40%por at top, 10-25 lower in BNS	1150.5	1229	78.5		23.82		22.48		
53/7-2	GR-shaly patch in middle. Mf-30-40%por at top, 10-25 lower in BNS	908	1100	192		25.46		24.53		
54/1-1	GR-top half shaly. Mf-many shale and clay layers	1671.7	1855.4	183.7		16.22		16.96		

48/21-2	GR-shaly bottom. Top neut, rhob, phid high - ignored.	1530.4	1570.8	40.4			17	7.27		
48/23-2	mf-sst, little siltst.	1343.3	1476.4	133.1	22.37			19.22		
48/29-A2	no Fm, no mf.									
48/30-1	gas effect at top, so use logs underneath. BNS 1077.9-1278.5	1163	1278.5	200.6		22.32		21.57		
48/30-8	no porosity logs in BNS									
48/30-9	mf-sandy, minor clayst&anhydrite.	1057.7	1273.6	215.9	18.76			18.55		
48/6-10	GR-shaly patch in middle	1936.2	2010	73.8			17			
48/6-10	GR-shaly patch in middle	2028	2258.1	230.1			17			
48/9-1	mf-sst, evaporite nr top. Many silt/claystlayers. Poor-mod por. Lst bottom of BNS	2482.4	2716.1	233.7	10.7			12.33		
49/11A-1	thick 'shale' layer in middle of sst	1753.1	1980.6	227.5	16.93			15.06		
49/11A-1	thick 'shale' layer in middle of sst	1700.7	1980.6	279.9	15.56			14.13		
49/11A-2	no BNS									
49/13-1	no BNS. Mf-shaly, some siltstone to v fine sst beds. No BNS marked.									
49/16-7Z	mf + logs -many silt/clayst layers: not good reservoir.	1627.3	1815.9	188.6	13.45			11.8		
49/16-8	mf-BNS faulted against ZG and BTSH, many silt/clay layers. No NPHI for BNS									
49/17-1	mf-bunter v shaly and poorly sorted. Logs-top of BNS shaly so used	1420.8	1608.4	187.6			20.5	20.01		
49/2-1	no mf. GR-shaly top and bottom of BNS so used	499.7	630.5	130.8		26.38		29.09		
49/2-1	BNS 1787.65-1794.36 only									
49/21-4	mf-clayst at top.NPHI+RHOB logs stop~1492 (BNS1346-1682) thick shale in middle.	1458.7	1492.5	33.8	14.64			15.96		
49/21-4	mf-clayst at top.NPHI+RHOB logs stop~1492 (BNS1346-1682) thick shale in middle.	1354.4	1492.5	138.1	15.83			14.96		
49/21-5	clay interbeds, no porosity log. GR has many 'shaly' patches.									
49/25A-5	only have mf for -R05; ZG only, prizm interp on logs questionable									
49/27-H1	mf-loose sand, shale/siltst interbeds. Logs-shaly bottom.	1125.1	1372.7	247.6	21.02			19.52		
49/28-4	mf-shale interbeds, fair visible porosity. Log BNS shaly esp at top. BNS on u. evap.	1777.8	1875.4	97.6	18.99			15.79		
49/28-5	mf-sst, some clay nr top. Poor visible porosity. Logs- GR 'shaly' at top	1456.1	1560	103.9	20.38			18.48		
49/28-6	mf-poor-fair visible por. Clay interbeds. Log - shaly patches at top.	1528.9	1702.5	173.6	19.29			18.41		
49/28-7	mf-sst with poor-fair por. Fault in lwr part of BNS. Odd porosity peaks in logs.	1734.2	1773.8	39.6	20.46			16.89		
49/28-8Z	mf-beds of silt/mudst. Logs-top looks shaly	1529.9	1707.4	177.5	21.4			22.52		
49/28-9Z	mf-no shows, sst grading to siltst. Log - v.low NPHI in BNS	1459.9	1644.3	184.4	6.14			30.05		
49/30-1	GR-quite shaly. Only PHID logs in BNS.	1451.1	1646.1	195				19.88		
49/6-1	log only small part of BNS, sand 1200-1348.4, but log only	1250.4	1323	72.6			39	18.96		
49/9-1	no BNS									
50/26a-2		1550.8	1725.5	174.7					19.8	Orwell field
50/26a-3		1610.9	1680.4	69.5					20.5	Orwell field
50/26a-4		1585.9	1732.8	146.9					21.0	Orwell field
52/5-11	high DT, SNP, PHID at top but low GR-salt cemented? Mf silty at bottom. F-m grain	1090.1	1222.2	132.1		22.65		22.46		

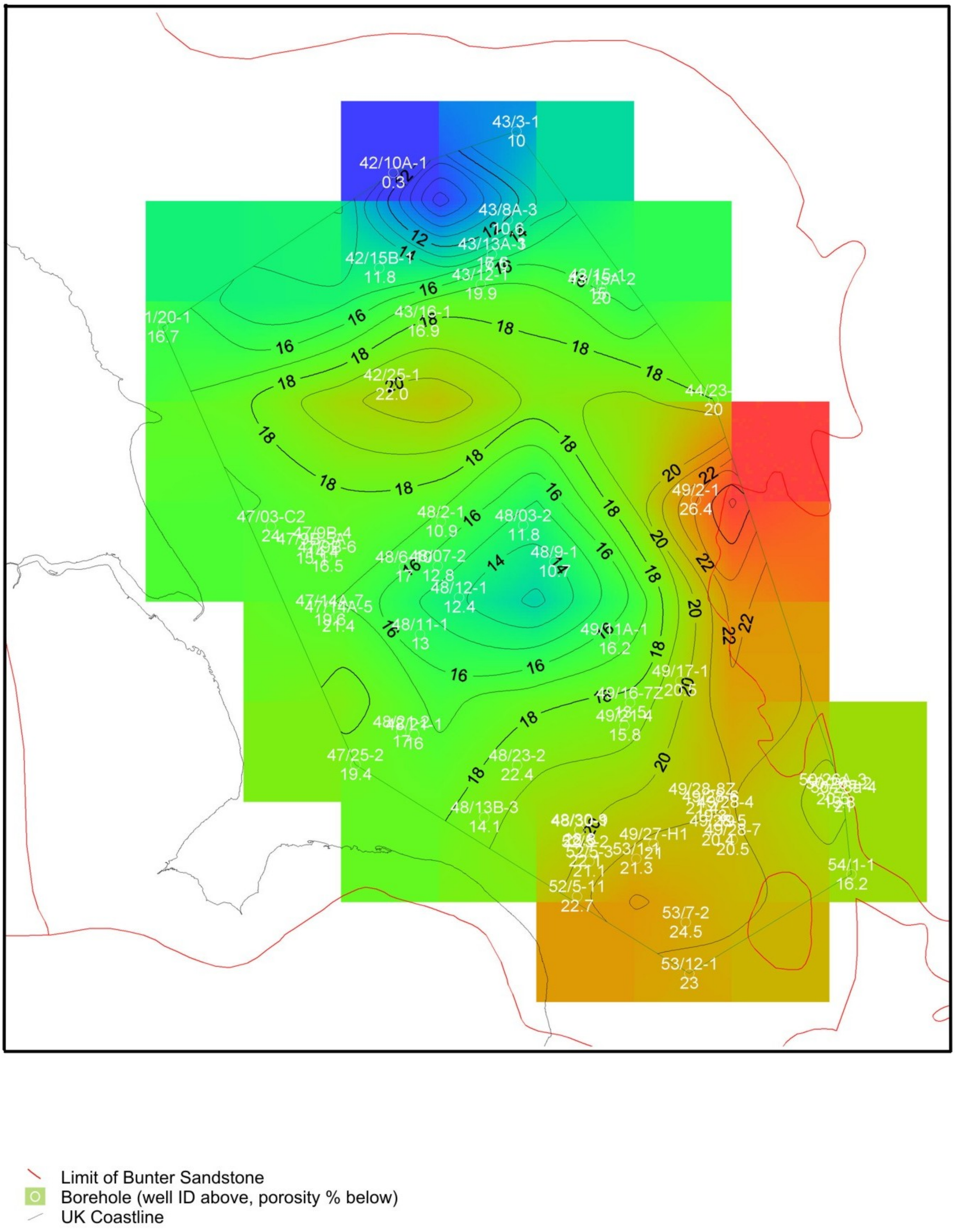
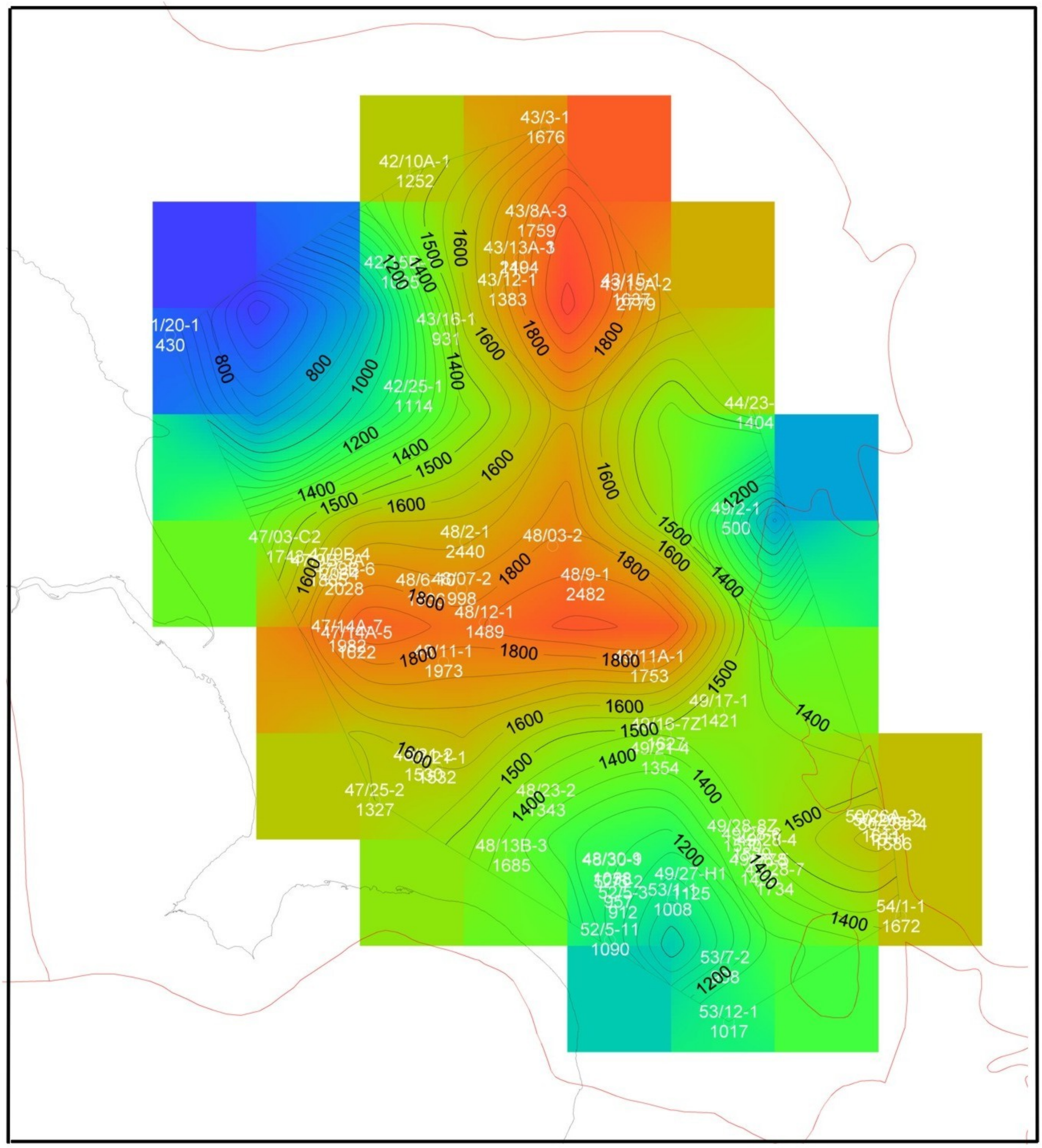
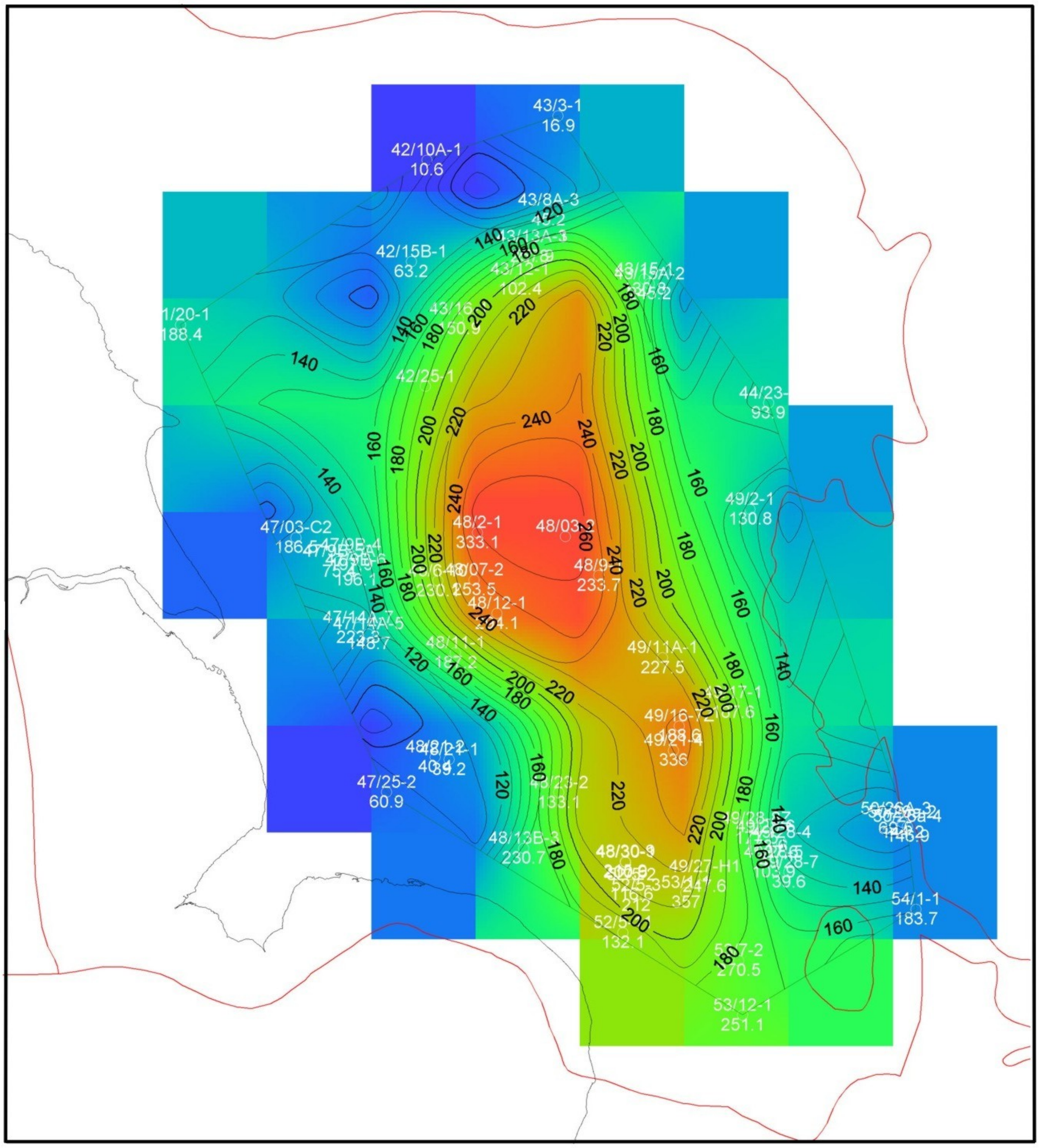


Figure 1: Porosity (%) of the Bunter Sandstone in the Southern North Sea.
Porosity contours every 1%.
Orange indicates high porosity, blue indicates low porosity



Limit of Bunter Sandstone
Borehole (well ID above, porosity % below)
UK Coastline

Figure 2: Depth to sandstone in the bunter Sandstone in the Southern North Sea.
Contours every 50m.
Orange indicates deeper sandstone, blue indicates shallower sandstone.



Limit of Bunter Sandstone
Borehole (well ID above, porosity % below)
UK Coastline

Figure 3: Thickness of the Bunter Sandstone in the Southern North Sea.
Contours every 10m.
Blue indicates thinner sandstone, orange indicates thicker sandstone

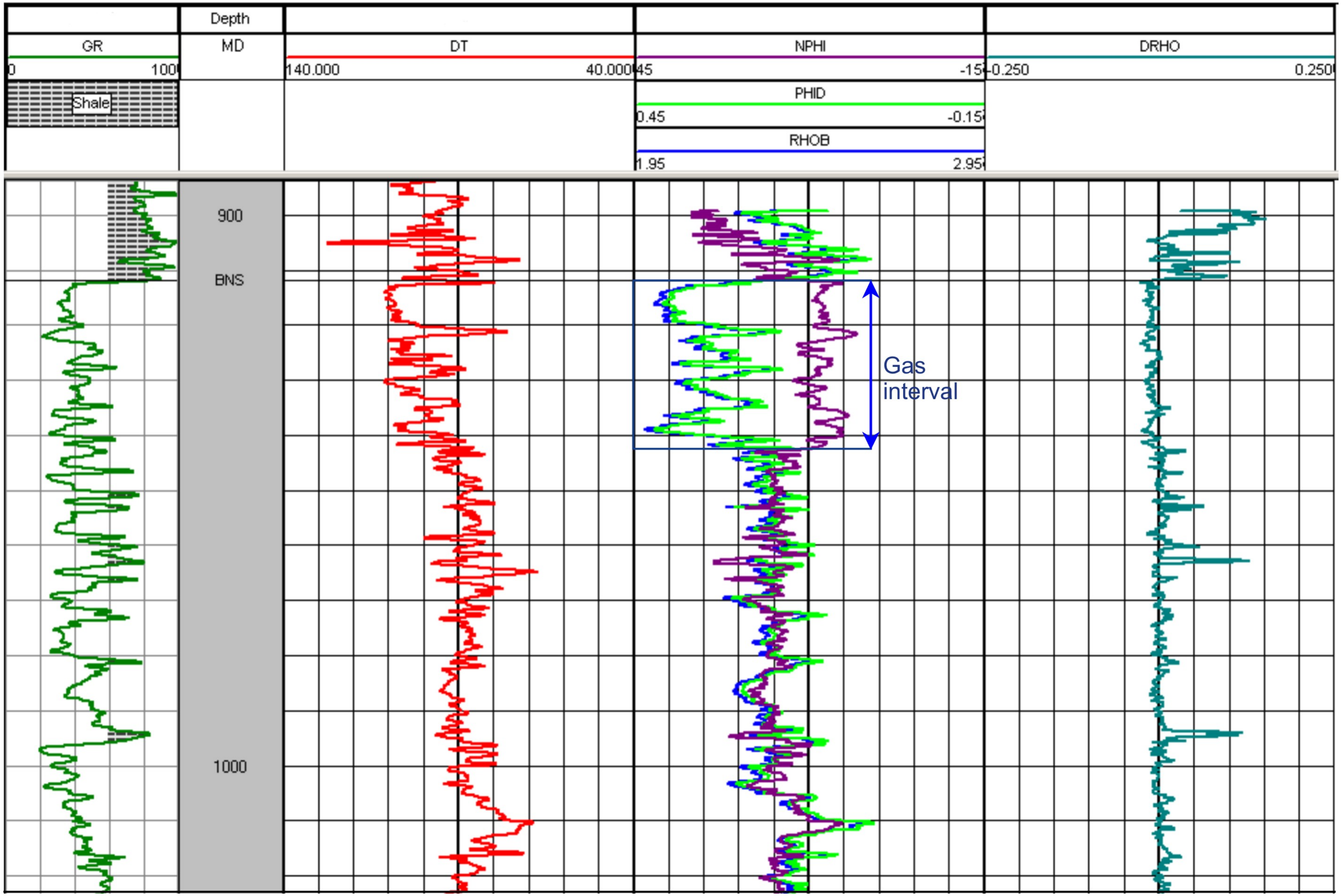


Figure 4: Gas effect at the top of the BNS in well 52/5-3.

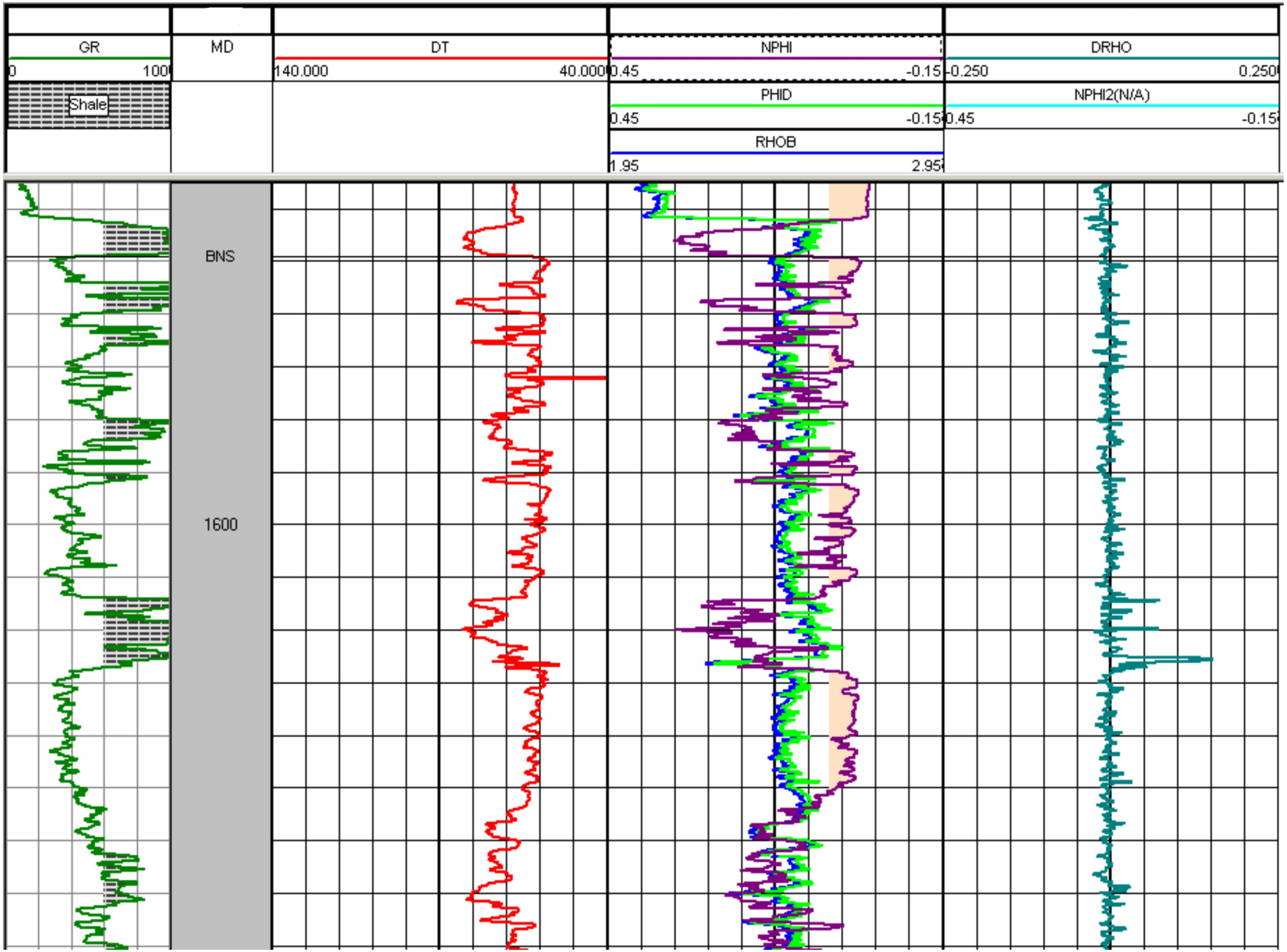


Figure 5: Salt cementation in the BNS (shaded orange on the NPHI log) in well 49/16-7Z

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

CAMERON T. D. J., CROSBY, A., BALSON, P. S., JEFFREY, D. H., LOTT, G. S., BULAT, J., and HARRISON, D. J. 1992 *The Geology of the Southern North Sea. British Geological Survey United Kingdom Offshore Regional Report.* (London: HMSO). ISBN 0 11 884492 X

RIDER, M. H. 1996. *The Geological Interpretation of Well Logs.* Second edition. (Caithness: Whittles Publishing). ISBN 1 870325 36 2

SCHLUMBERGER 1969a. Log Interpretation Charts 1969. (England: Schlumberger Limited)

SCHLUMBERGER 1969b. Log Interpretation principles 1969. (England: Schlumberger Limited)

SCHLUMBERGER 1989. Log Interpretation Charts 1989. (USA: Schlumberger Limited)