Preston New Road-1z:
LJ/06-09(z)
HFP Report

Preston New Road-1z HFP Report					
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Version	**Section**	**Revision Information**		**Date**	**Reviser**
Procedures are reviewed as per proposed review date, or sooner if a significant change to the operation has taken place, to ensure relevance to the systems and process that they define.					

Contents

1 OPERATIONS SUMMARY

Preston New Road-1z (PNR-1z, LJ/06-9z) was sidetracked from Preston New Road-1 (PNR-1). The surface location of the well is located within EXL 269, the bottom hole location is within PEDL165. Both licences lie within the Bowland Basin, Lancashire, North West England. The well is located within a 100km^2 3D seismic survey in the same structural fairway as the shale gas discovery well Preese Hall-1. It is located approximately 3.9km south of Preese Hall-1.

The lateral section was completed with a 4.5" liner, tied back to surface with a 4.5" to 5.5" tapered tie back string. 41 mechanically manipulated multi-cycle frac sleeves were placed approximately every 15 – 17m with the liner and cemented in place. During hydraulic fracturing operations the sleeves were shifted open selectively using 2" coiled tubing assembly. A "slickwater" hydraulic fracture design consisting of mains water, recycled flowback water, 100 mesh sand and a friction reducer to reduce pumping pressures was used to stimulate PNR-1z. The over-riding objective was to complete hydraulic fracturing operations in full accordance with planning consent conditions and regulatory requirements, and with zero safety, environmental or community related incidents. Hydraulic fracturing operations took place during the period 15th October – 17th December 2018. All operations were conducted under the seismicity limits of the Traffic Light System (TLS) set out in the Hydraulic Fracture Plan (HFP). This report has been drafted and submitted in accordance with Section F.13 of the Consolidated Onshore Guidance Version 2.2, June 2018. No wireline image logs or coring were undertaken in PNR-1z.

Due to the seismic limitation not all the sleeves were stimulated with the designed frac fluid and proppant of 400m^3 and 50 tonnes. Table 1 shows the total volumes pumped at each sleeve and the sequence in which they were pumped.

Date	Sleeve #	Activity	Volume (m^3)	Proppant (mT)	10% HCl (m^3)	FR (kg)
15-Oct	1	DFIT	1.87	0.0		0.5
16-Oct	1	Mini/Main	162.7	0.0		36.0
17-Oct	2	Mini/Main	318.1	22.4	1.0	82.0
18-Oct	3	Mini/Main	393.8	50.8	1.0	87.0
19-Oct	12	Mini	33.9	0.0	1.0	9.0
20-Oct	12	Main	221.6	6.5	1.0	53.0
22-Oct	13	Mini/Main	384.8	37.1	1.0	92.0
23-Oct	14	Mini/Main	128.9	2.0	0.5	31.0
24-Oct	18	Mini	10.5	0.0	1.0	0.0
25-Oct	22	Mini/Main	350.9	17.0	1.0	84.0
26-Oct	30	Mini/Main	142.2	3.6	1.0	35.0
27-Oct	31	Mini/Main	111.7	2.4	1.0	27.0
29-Oct	32	Mini/Main	119.1	4.8	1.0	28.0

Date	Sleeve #	Activity	Volume (m^3)	Proppant (mT)	10% HCl (m^3)	FR (kg)
30-Oct	39	Mini	15.3	0.0		5.0
30-Oct	41	Mini	15.7	0.0	1.0	5.0
31-Oct	37	Mini	13.3	0.0	1.0	3.6
31-Oct	40	Mini	13.3	0.0		3.4
02-Nov	38	Mini	14.3	0.0		3.9
02-Nov	35	Mini	14.3	0.0	0.8	3.8
08-Dec	37	Main	78.4	3.6	1.0	18.3
10-Dec	37	Main2	99.5	2.8	1.0	24.0
11-Dec	38	Main	268.2	27.9	1.5	64.0
13-Dec	39	Main	261.2	27.2	2.5	63.0
14-Dec	40	Main	248.9	19.7	1.5	59.0
15-Dec	41	Mini2	18.1	0.0	3.0	4.0
17-Dec	41	Main	431.0	50.4	2.0	99.7
		Total	**3871.6**	**278.2**	**25.8**	**921.2**

Table 1 Summary on injected volumes in each sleeve

2 WELL INTEGRITY

A pressure test was carried out after each casing string was installed to ensure the integrity of that barrier. The pressure testing limit was within a safety margin of the maximum burst rating of the casing, which was not exceeded during hydraulic fracturing operations. The annulus outside the main production string was continually monitored to ensure there was no leakage from the inner barrier. Post fracturing the casing was also pressure tested above the frac sleeves on 15th December 2018, to a pressure of 350 bar to ensure the integrity of the production string.

3 PNR-1Z CASING DIAGRAM

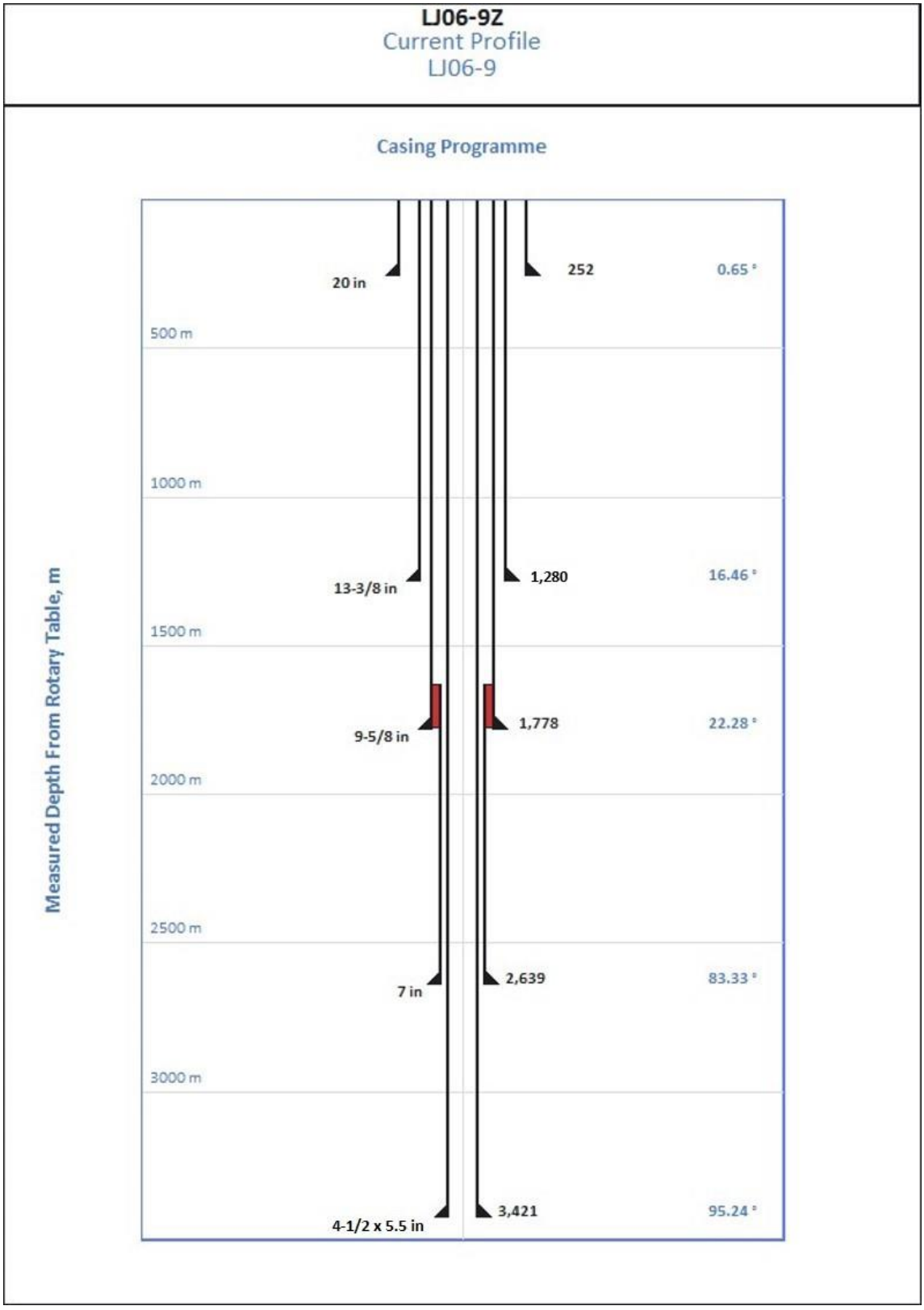

Figure 1 PNR-1z casing diagram

4 WELLBORE DIAGRAM WITH LOCATION OF FRACTURE SLEEVES ON SEISMIC DISPLAY

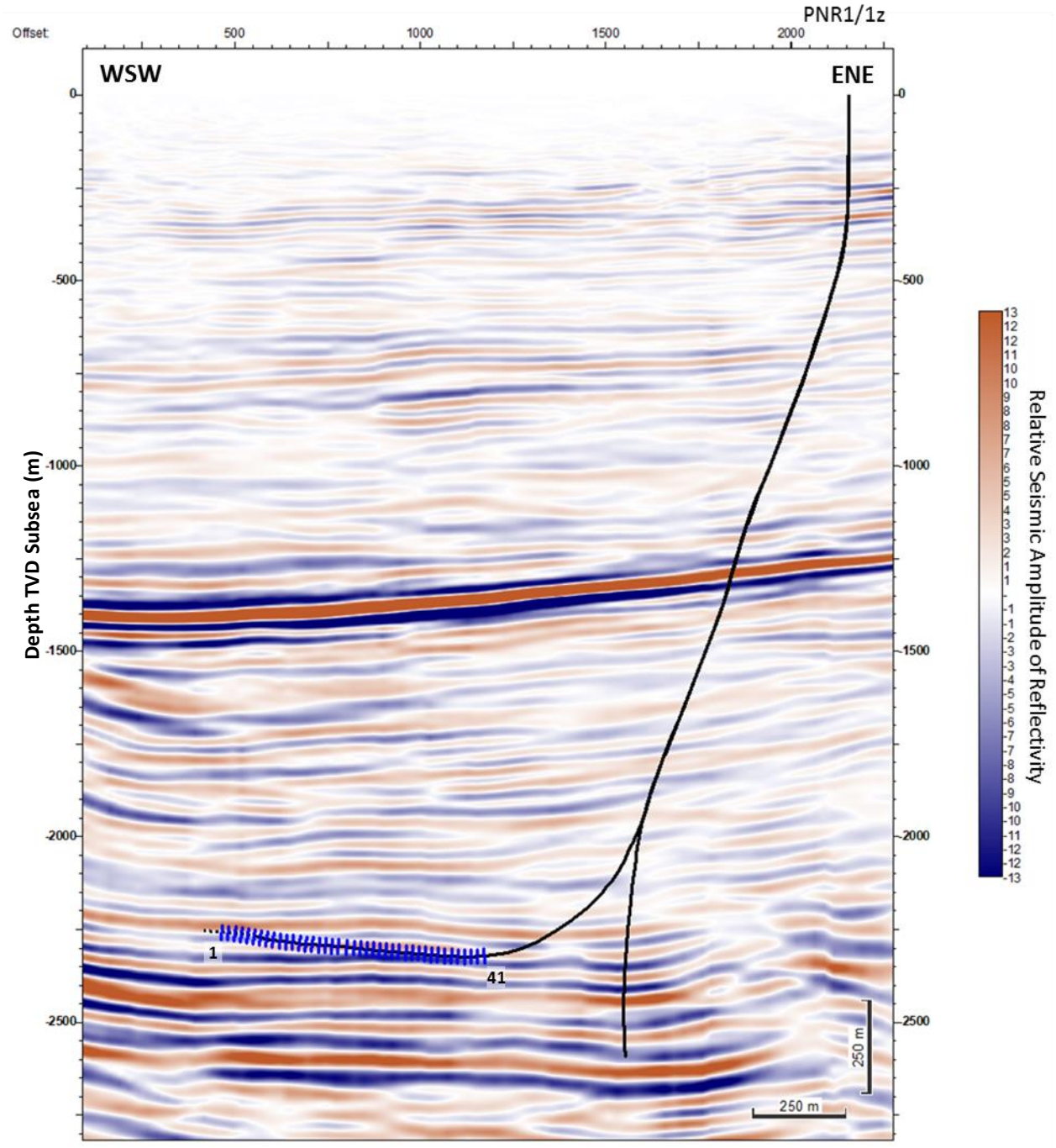

Figure 2 PNR-1z wellbore diagram and fracture zones projected onto 3D seismic inline

5 GEOLOGICAL CROSS SECTION

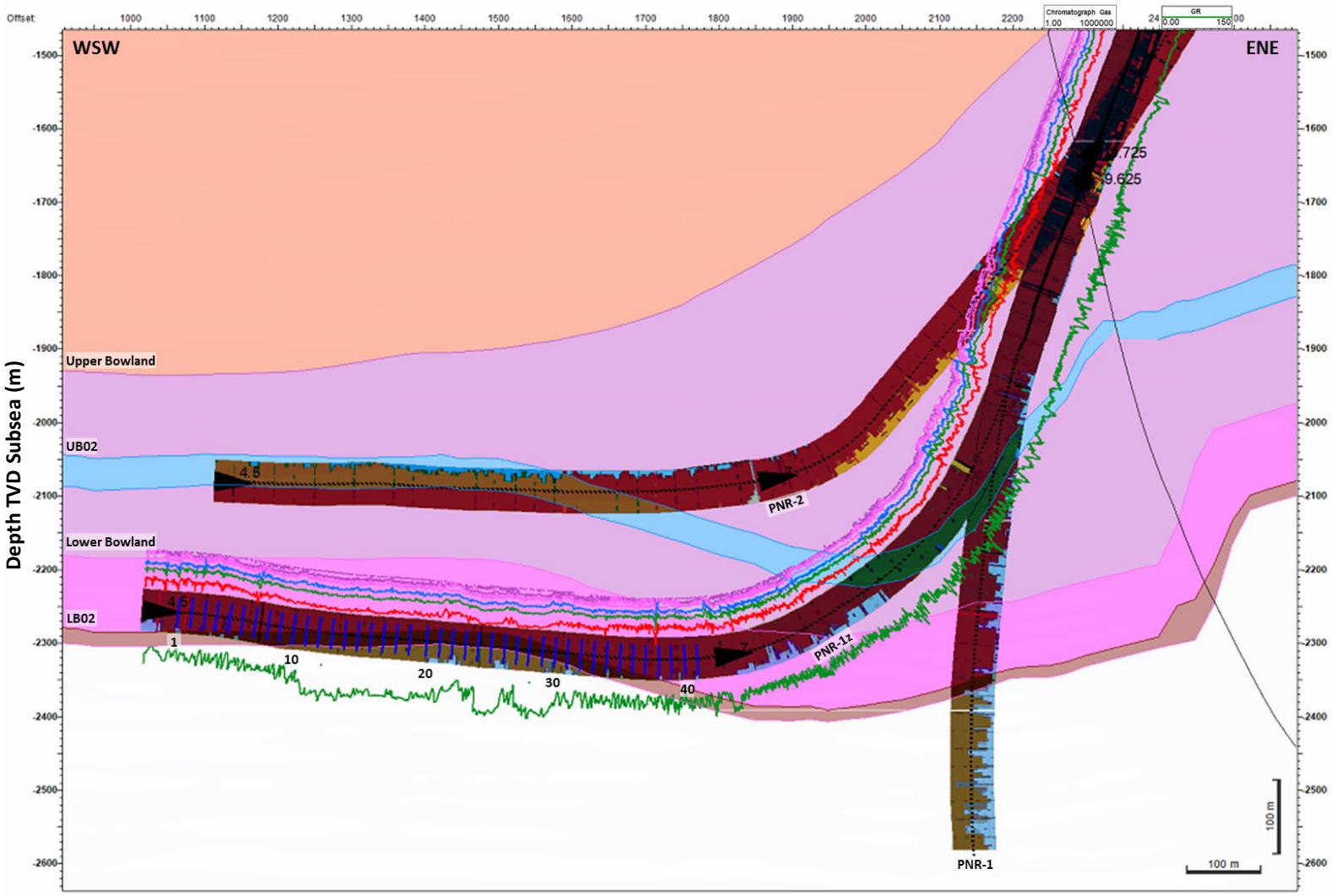

Figure 3 Geological cross section of PNR-1/1z/2. Well profiles projected onto arbitrary line following PNR-1z azimuth. Gas chromatograph (left hand side of wellbore): C1 - red, C2 - green, C3 – blue, IC4 - pink (solid), NC4 - pink (hashed), IC5 - purple (solid), NC5 - purple (hashed). Gamma Ray (GR) (right hand side of wellbore): green . Frac sleeves shown in blue. Lithology track colours: dark brown - claystone, light brown - siltstone, blue - carbonate

6 WIRELINE IMAGES OF ZONES

No wireline log images were collected within PNR1z.

7 GAS CHROMATOGRAPH LOG

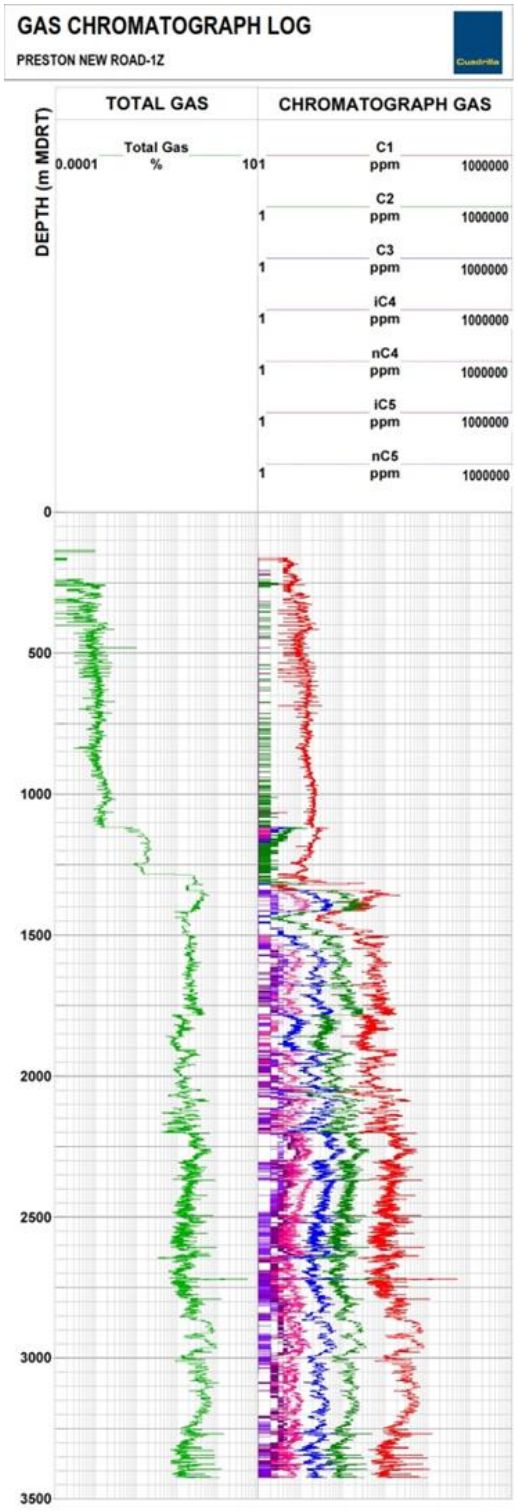

Figure 4. PNR-1z gas chromatograph

8 GAS COMPOSITION

Although gas analysis was carried out, due to the need for Nitrogen to lift the water, an uncontaminated gas sample was hard to obtain. Three gas samples were taken; one from a build up in the separator, one from a flowing sample with Nitrogen, and one from the wellhead post buildup after purging the N_2 from the wellbore. By normalising the Nitrogen component to the molar percentage that was seen in an offset well gas sample (Preese Hall-1), the average gas composition was:

C1: 96%, C2: 1.6%, C3: 0.2%, C4: 0.02%, H2S: 0%, CO2: 0.15%, N2: 1.6%

MW: 16.5, SG: 0.57

9 MINERALOGY FROM CUTTINGS (XRD)

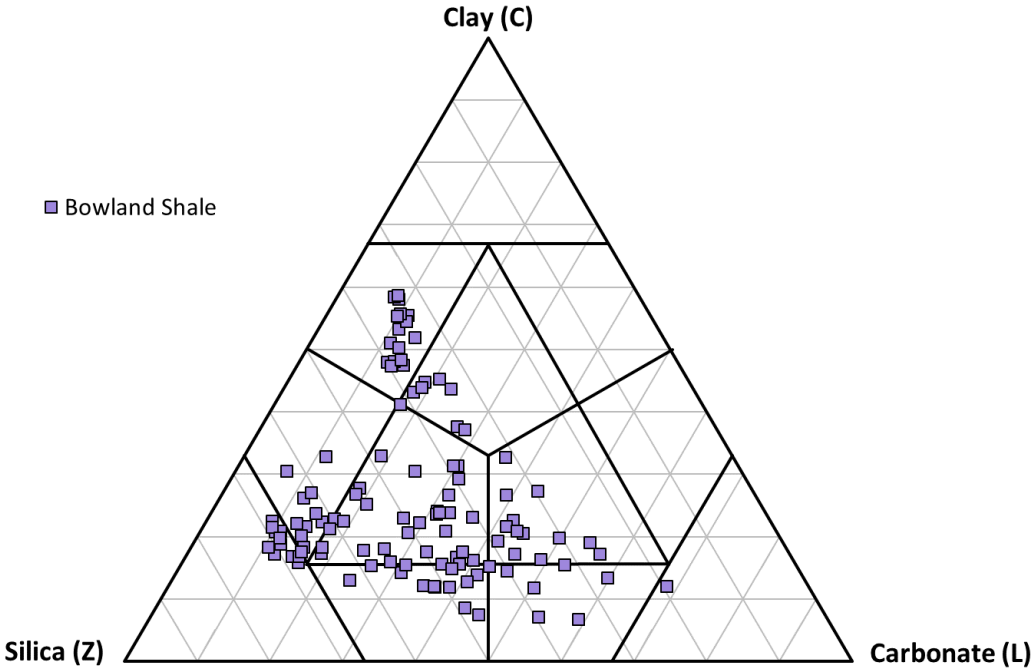

Figure 5. Ternary plot of PNR-1z cuttings XRD

10 ROCK PROPERTIES

Preese Hall-1	Bulk Density ($g\ cm^{-3}$)	Total Porosity (%)	Effective Porosity (%)	Matrix Perm (mD)	Water Saturation	TOC (%)	Maturity (Tmax)	Desorbed gas content scf/ton	Quartz	Carbs	Clay
Lower Bowland	2.61	3.31	2.39	1.15×10^{-5}	27.3	2.99	534.5	41.4	50.8	23.8	25.4

Table 2 Preese Hall-1 Average Lower Bowland Rock Properties, Clarke et al 2018 (PNR data analysis ongoing, results thus far consistent with Preese Hall-1 data)

11 MINIFRAC ANALYSIS

A minifrac involves injecting very small volumes of fluid (without proppant) into the formation to allow key properties to be identified in a shorter period of time than a main frac. Minifrac analysis is used to determine reservoir and rock properties by using diagnostic plots from the pressure response. Key properties such as instantaneous shut in pressure (ISIP), closure pressure and pore pressure (estimated using after closure analysis to identify different flow regimes) can be interpreted. Depending on the leakoff rate, it is not always achievable to see all the properties in a reasonable period of time. In the examples below fracture closure could be deduced from the pressure decline, it was also possible to obtain an indication of pseudo radial flow, which allowed for an estimation of formation pore pressure. Minimum stress was picked using G-Function analysis.

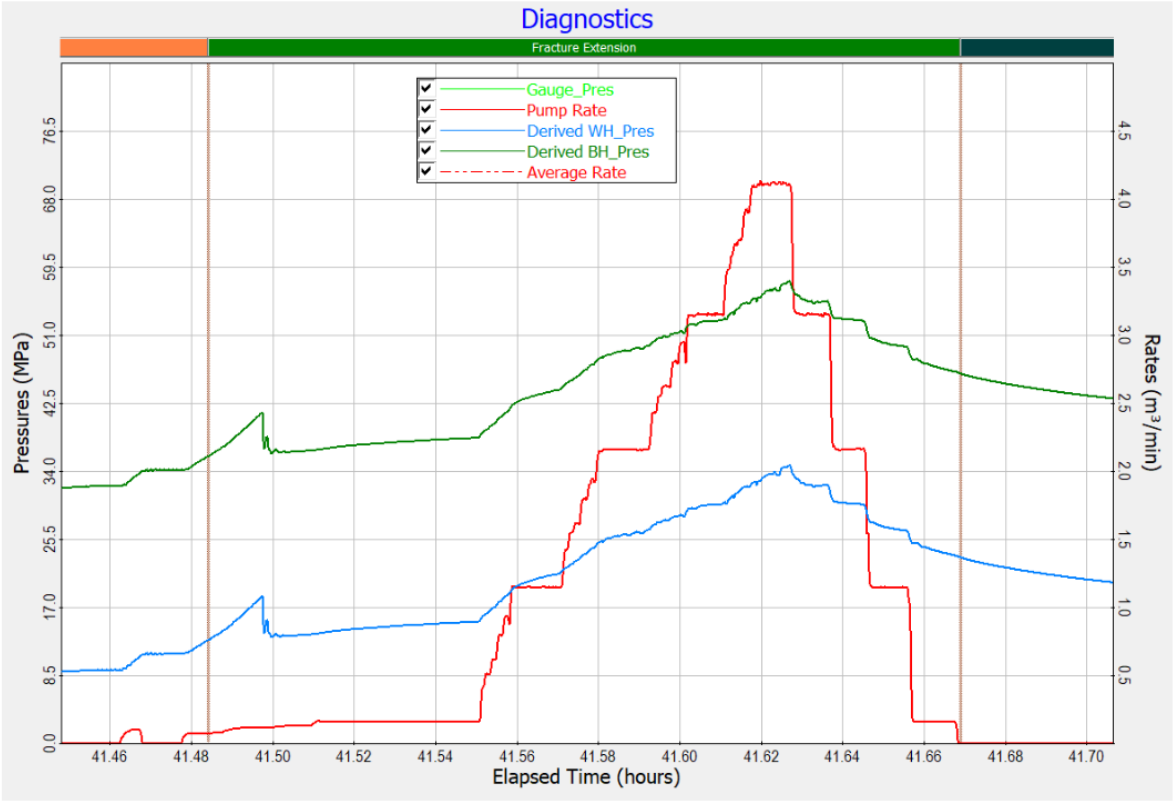

Figure 6 Representative pumping chart (taken from sleeve 39)

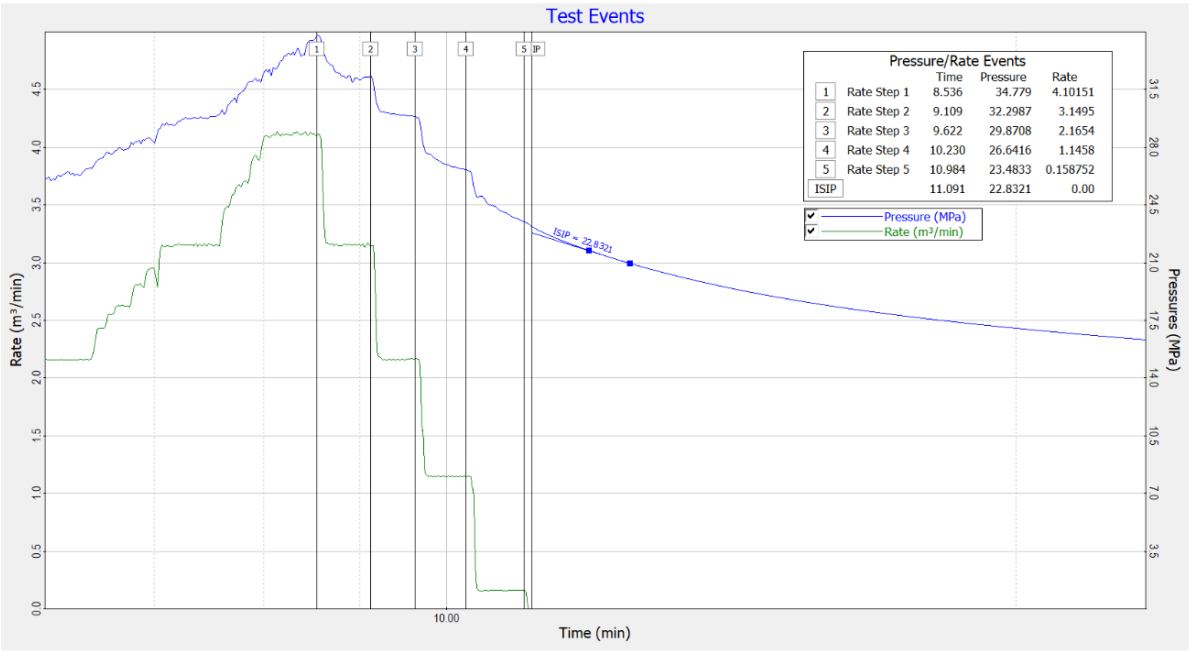

Figure 7 Representative Step Rate Plot (for ISIP) (taken from Sleeve 39)

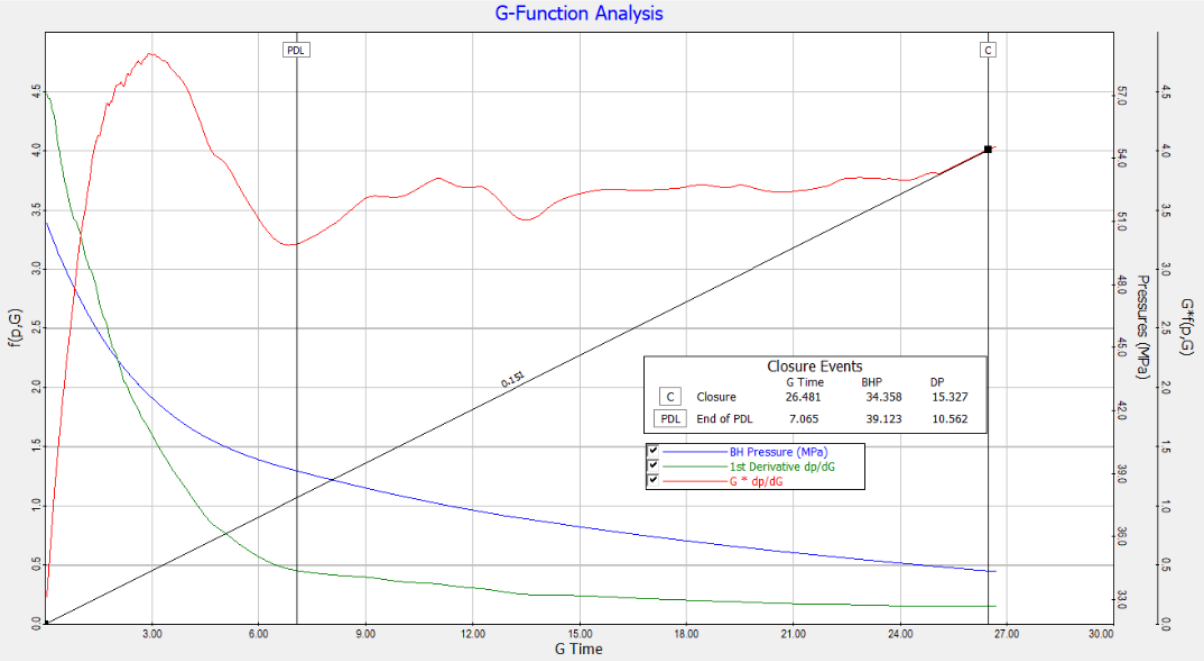

Figure 8 Representative G-Function Plot (for frac closure) (taken from sleeve 38)

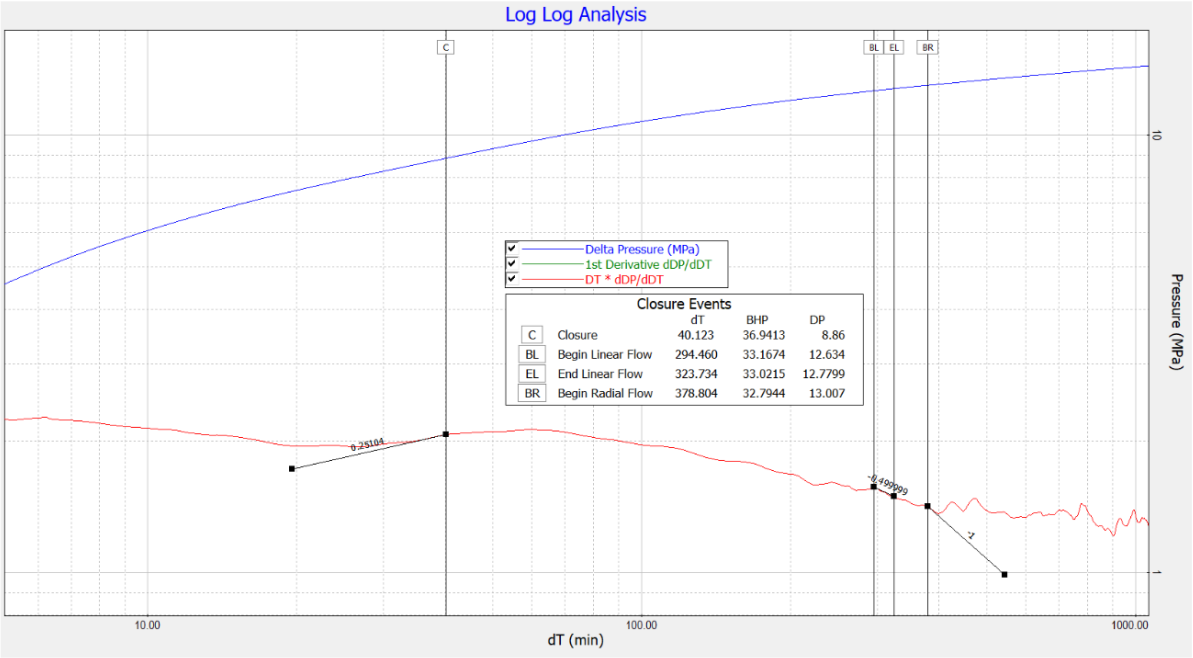

Figure 9 Representative Log-log Plot (linear and radial flow) (taken from Sleeve 39)

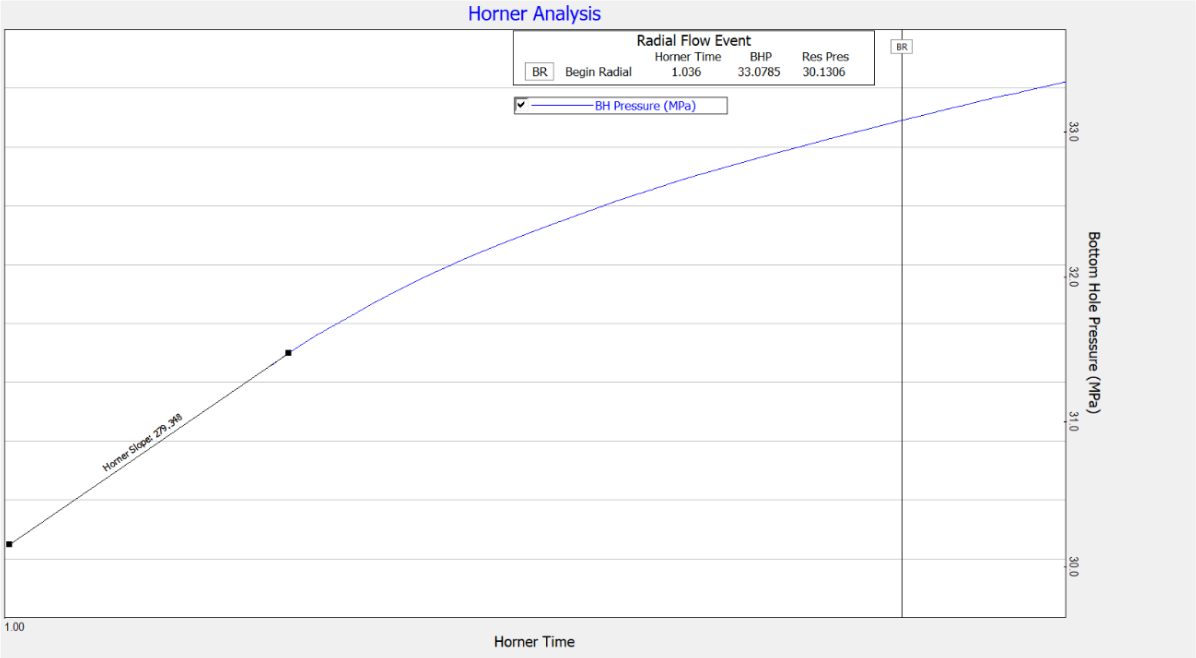

Figure 10 Representative Horner Plot (for reservoir pressure) (taken from Sleeve 39)

From these representative sleeves the following was determined:

ISIP	0.86 psi/ft
Average Reservoir Pressure	0.57 psi/ft

Table 3 Minifrac Analysis

11.1 STRESS INTERPRETATION

SHmin = 0.65 psi/ft (interpreted from minifrac analysis of sleeve 38)

SHmax azimuth = 0°N (estimated from fracture growth detected by microseismic)

12 VISUALISATION OF FRACTURE EXTENT ON MICROSEISMIC

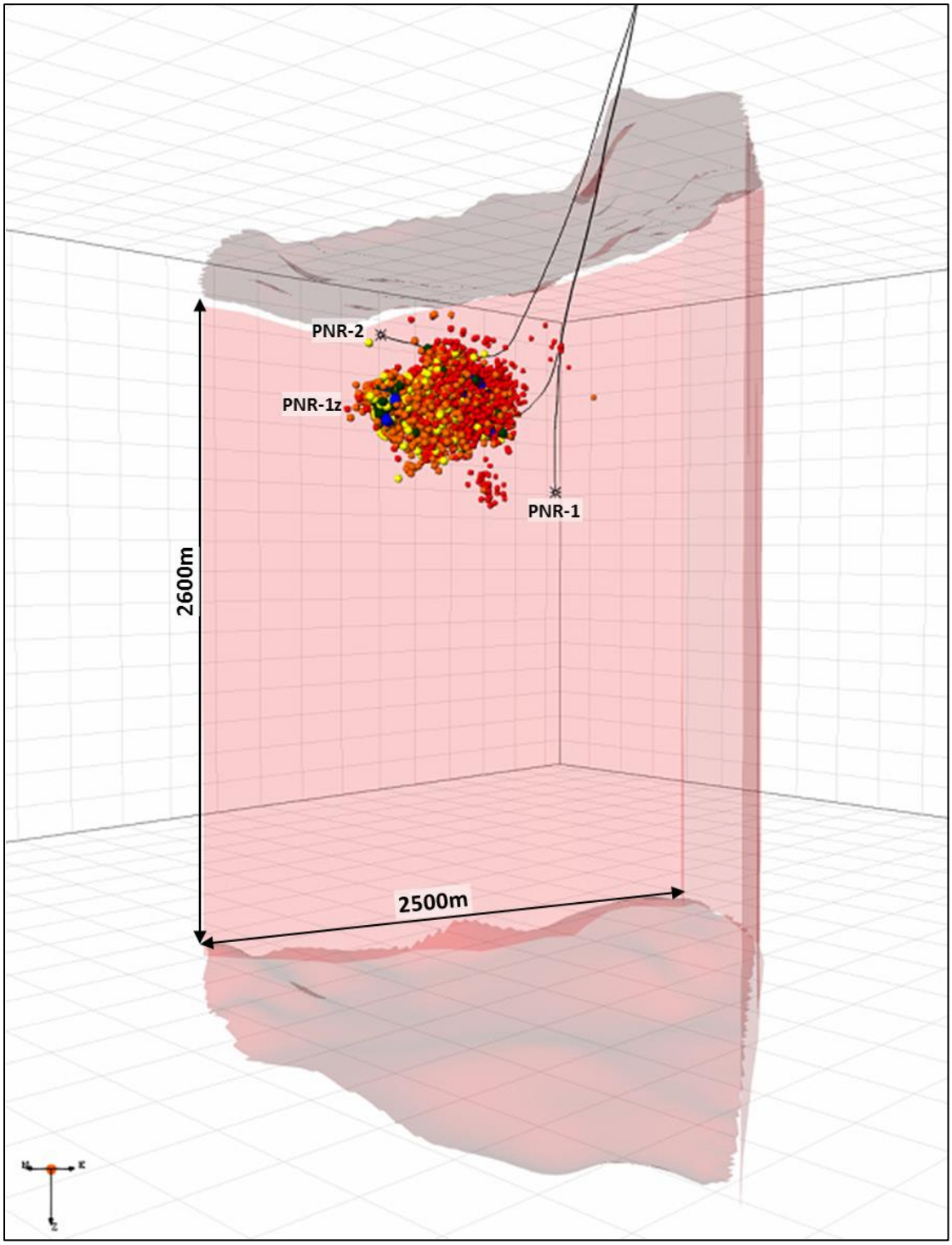

Figure 11 Microseismic event cloud with respect to EA redline permit boundary shown in red. Upper and Lower boundary Upper Bowland and Top Clitheroe Limestone respectively. Microseismic events coloured via magnitude (M_w). Red - -2.5, Purple - 1.5

13 MODELLED VS ACTUAL STIMULATED RESERVOIR VOLUME

Kinetix 3D fracture simulation model of high density discrete fracture network (DFN) based on PNR1z geology						
Sleeve # (modelled)	**Pre job Modelled Propped Width (mm)**	**Post job Modelled Avg Propped Width (mm)**	**Pre job Modelled Avg Fracture Height (m)**	**Post Job Modelled Fracture Height (m)**	**Pre Job Modelled Avg Fracture Half Length (m)**	**Post Job Modelled Fracture Half Length (m)**
1	2.7	2.26	154	70.55	64	77.88-144.87
12 (8)	2.7	-	66	98.9	211	201.6 (max)
18 (11)	1.9	-	55	51.98	193	129.44 (max)
30 (27)	2.3	-	44	69.98	189	241.8 (max)
41	1.3	3.12	25	77.46	313	152.9-217.83

Table 4. Summary of modelled vs actual (post job modelled) stimulated reservoir volume

14 TRAFFIC LIGHT SYSTEM MONITORING

SLEEVE #	DD/MM/YYYY hh:mm:ss	TLS M_L	PUMPING / TRAILING	ACTIONS TAKEN
14	23/10/2018 15:45:32	**0.40**	Pumping	Stopped injection, flushed well, opened casing to testers and started to flow back at 0.75bbl/min, slowed to 0.25bbl/min, verified well integrity
30	26/10/2018 12:36:59	**0.76**	Pumping	Stopped injection, flushed well, opened casing to testers and started to flow back at 0.5bbl/min, verified well integrity
31	27/10/2018 11:55:25	**0.78**	Trailing	Opened casing to testers and started to flow back at 0.5bbl/min, verified well integrity
32	29/10/2018 11:30:39	**1.00**	Pumping	Stopped injection, flushed well, opened casing to flow to testers at 0.75bbl/min, verified well integrity

SLEEVE #	DD/MM/YYYY hh:mm:ss	TLS M_L	PUMPING / TRAILING	ACTIONS TAKEN
35	04/11/2018 16:24:06	**0.66**	Trailing	Informed regulators event red event occurred post pumping, verified well integrity
38	11/12/2018 09:53:31	**0.10**	Pumping	Informed regulators event amber event occurred during pumping, verified well integrity
38	11/12/2018 10:18:46	**0.00**	Pumping	Informed regulators event amber event occurred during pumping, verified well integrity
38	11/12/2018 11:21:15	**1.5**	Trailing	Informed regulators event red event occurred post pumping, verified well integrity
40	14/12/2018 13:41:05	**0.86**	Pumping	Stopped injection, flushed well, opened casing to flow to testers at 0.15bbl/min, verified well integrity

Table 5 Summary of reported TLS seismicity and action taken. Events colour coded via TLS. Event time shown in BST/GMT

15 INJECTION/FLOWBACK VOLUME

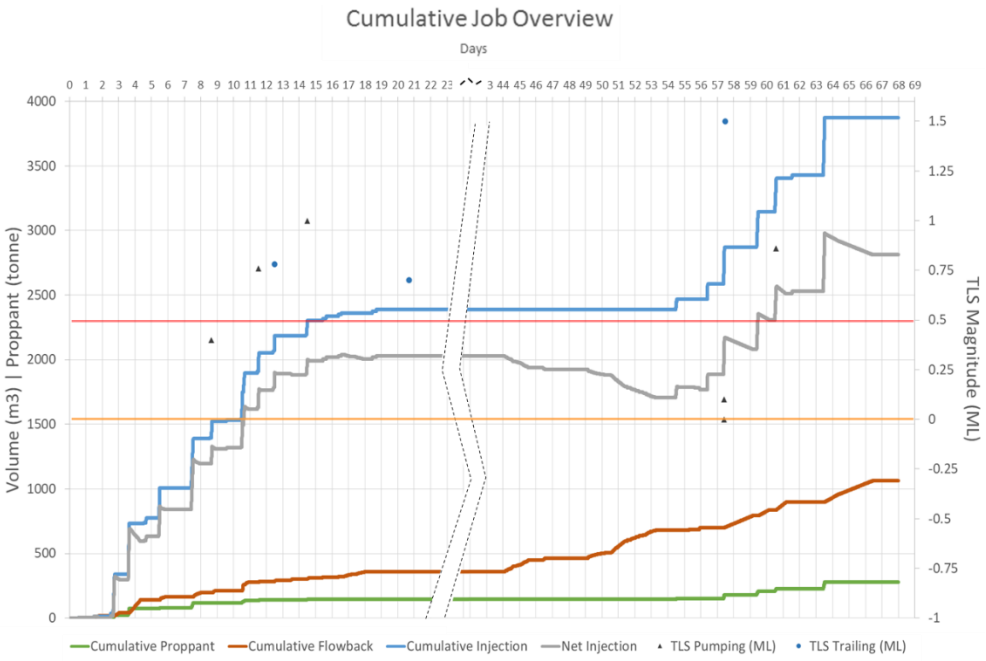

Figure 12 Plot summarising injection / flowback volumes in addition to seismicity related to Traffic Light Mitigation System. Hiatus in operations due to preparation for further stimulation and data analysis

16 KEY LEARNINGS

The data collected within the Bowland Shale during drilling and hydraulic fracturing operations reveal it to have good reservoir and completion properties. When considering hydraulic fracturing operations, the microseismic data collected demonstrates a relationship between injection activities and induced micro-seismicity. A total of 38,383 microseismic events were detected within the redline permit boundary at Preston New Road, (Figure 11), in addition to this a total of nine events were reported to regulators as part of the Traffic Light Mitigation System (see Table 5). Interpretation of the microseismic data identified two additional features (Table 6).

Name	Type	Distance to nearest injection point m	Dip	Strike	Throw m	Slip Tendency	Coulomb Stress Change	Sleeve	S_H [°N]
MSPNR1z_i	N/A	0	90°E	165°	<40	N/A	N/A	N/A	N/A
MSPNR1z_ii	N/A	0	85°E	050°	<40	N/A	N/A	N/A	N/A

Table 6 Additional features identified by interpretation of microseismic data

Of the planned 41 injection sleeves (400m^3 and 50mT), only 17 were hydraulically stimulated (mini and /or main frac), 15 of which placed proppant, (ranging from 2 to 51mT). Six of the nine TLS events occurred during pumping, and four resulted in the premature termination of the associated frac jobs. This resulted in just 14% of the intended proppant being injected into the formation.

17 REFERENCES

Clarke, H, Turner P., Bustin. R.M., Riley, N. and Besly, B. (2018) Shale gas resources of the Bowland Basin, NW England: a holistic study. *Petroleum Geoscience*, Vol 24, pp. 287-322

APPENDIX 1 – OGA CONSOLIDATED ONSHORE GUIDANCE – JUNE 2018 – HFP REPORT DATA REQUIRMENT

The HFP report required (in .pdf format) should include:

- operations summary including result of well integrity monitoring
- well diagram with perf stages
- deviation survey
- wireline log images of zones
- gas chromatograph
- core intervals
- mineralogy from cuttings
- summary of stress interpretation
- location of frac stages posted on seismic display
- visualisation of fracture extent on micro-seismic and/or optical fibre data
- plot containment within permitted boundary
- comparison of modelled vs actual Stimulated Reservoir Volume
- summary of Traffic Light System seismicity monitoring and actions taken
- injection/flowback volume plotted vs induced seismicity over time
- summary of key learnings

Digital file (in .xls format) should include the following profile data over time:

- Bottom Hole pressure
- Injection rate
- Well Head pressure
- Proppant concentration
- Injection volume
- Flowback volume

APPENDIX 2 – RELEASED DATA

In accordance with Section F.13 of the Consolidated Onshore Guidance Version 2.2, June 2018 the following data is publically available:

- PNR-1z Definitive Deviation Survey
- Frac Sleeve Depths
- Pumping Data
- Pumping charts
- Microseismic events

- Video of microseismic events
- Daily Water Summary

APPENDIX 3 - SLEEVE DEPTHS

Frac Sleeve #	Top Location Z m (MSL)	Bottom Location Z m (MSL)	Mid Location Z m (MSL)
1	-2258.01	-2257.84	-2257.925
2	-2259.6	-2259.4	-2259.5
3	-2261.49	-2261.26	-2261.375
4	-2263.69	-2263.42	-2263.555
5	-2266.26	-2265.94	-2266.1
6	-2269.08	-2268.74	-2268.91
7	-2272.2	-2271.82	-2272.01
8	-2275.5	-2275.13	-2275.315
9	-2278.39	-2278.08	-2278.235
10	-2280.97	-2280.69	-2280.83
11	-2283.11	-2282.88	-2282.995
12	-2285.06	-2284.84	-2284.95
13	-2287.02	-2286.79	-2286.905
14	-2289.01	-2288.79	-2288.9
15	-2290.57	-2290.41	-2290.49
16	-2291.83	-2291.69	-2291.76
17	-2293.07	-2292.92	-2292.995
18	-2294.33	-2294.19	-2294.26
19	-2295.55	-2295.4	-2295.475
20	-2297.47	-2297.27	-2297.37
21	-2299.16	-2298.97	-2299.065
22	-2300.82	-2300.61	-2300.715
23	-2302.73	-2302.5	-2302.615
24	-2304.61	-2304.41	-2304.51
25	-2306.12	-2305.96	-2306.04
26	-2307.49	-2307.33	-2307.41
27	-2308.84	-2308.67	-2308.755
28	-2310.17	-2310.01	-2310.09
29	-2311.45	-2311.3	-2311.375
30	-2312.74	-2312.58	-2312.66
31	-2314.29	-2314.09	-2314.19

Frac Sleeve #	Top Location Z m (MSL)	Bottom Location Z m (MSL)	Mid Location Z m (MSL)
32	-2316.07	-2315.87	-2315.97
33	-2317.75	-2317.57	-2317.66
34	-2319.27	-2319.1	-2319.185
35	-2320.67	-2320.52	-2320.595
36	-2321.85	-2321.73	-2321.79
37	-2322.64	-2322.57	-2322.605
38	-2322.99	-2322.98	-2322.985
39	-2322.88	-2322.91	-2322.895
40	-2322.42	-2322.48	-2322.45
41	-2321.51	-2321.66	-2321.585

APPENDIX 4 – NOMENCLATURE

10% HCl	10% Concentration Hydrochloric acid
AN_B	B annulus Pressure
Azi	azimuth
bbl/min	Barrels per minute
BH	Bottom Hole
BHP	Bottom Hole Pressure
C1	Methane
C2	Ethane
C3	Propane
IC4	Isobutane
NC4	Normal-Butane
NC5	Normal-Pentane
IC5	Isopentane
C6	Hexane
C7	Heptane
C8	Octene
C9	Nonene
C10	Decene
C11	Undecane
C12	Dodecane
C13	Tridecane
C14	Tetradecane
C15	Pentadecane
CO2	Carbon dioxide
calc	Calculated
Circ Press	circulating pressure
CON	concentration
CT	coil tubing
dd:mm:yy	Day:month:year
DLS	Dog leg severity

E.	Eastings
EXL	Exploration Licence
FR	Friction Reducer
H2	Hydrogen
He	Helium
HFP	Hydraulic Fracture Plan
hh:mm:ss	hours:minutes:seconds
hrs	hours
in	inches
Inc	inclination
INJ	Injection
ISIP	Instantaneous Shut-in Pressure
kgPA	kilogram per cubic meter
km^2	square kilometre
lbf	pound force
m	meter
m^3	cubic meter
m3/min	cubic meter/minute
max	maximum
mD	Millidarcy
MD RT	Measured depth from Rotary Table
min	minute
M_L	Local magnitude
mm	millimetre
mol%	Mole percentage
MPa	Megapascal
MPa/m	Megapascals per meter
MSL	Mean sea level
mT	metric tonne
Mw	Moment magnitude
N.	Northing
N2	Nitrogen
PEDL	Petroleum Exploration Development Licence
PNR	Preston New Road
PROP	proppant
RT	Rotary Table
Scf/ton	Standard cubic feet per Imperial ton
SLUR	Slurry
TLS	Traffic Light System
Tmax	Indicator of thermal maturity
TOC	Total organic content
TVD	True vertical depth
VS	Vertical section
wt %	weight %
X	Eastings
XRD	X-ray diffraction
Y	Northings
Z	Depth

APPENDIX 5 – PUMPING AND MICROSEISMIC HEADING ABBREVIATIONS/UNITS

Abbreviation	Meaning	Unit
JobTime	Job time in British Summer Time (BST), changes to Greenwich Mean Time (GMT) on 28th October 2018 at 02:00. Microseismic data uses same time format	day:month:year:hours:minutes:seconds
UTC Time	Coordinated Universal Time	day:month:year:hours:minutes:seconds
TR_PRESS	Frac Pressure down the annulus	Bar
CIRC_PRESS	Circulating Pressure in the coiled tubing	Bar
An_B_PNR1	B Annulus Pressure, Outside 5.5" casing	Bar
BHP_CALC	Calculated Bottom Hole Pressure, Using Coil as dead string	Bar
SLUR_RATE	Slurry rate, (proppant and water) fluid rate down the annulus	M^3/min
PROP_CON	Proppant concentration, surface measurement	Kg/m^3 water
BH_PROP	Proppant concentration, Downhole measurement	Kg/m^3 water
INJ_RATE	Total Injection rate (total fluid rate coil and annulus)	M^3/min
JOB_INJ	Cumulative total injected volume	M^3
CT_RATE	Water rate injected down coil	M^3/min
CT WEIGHT	Weight of the coil	LBF
CT PRESSURE	Pressure in the coil. This includes the frictional pressure as it is the pressure required to pumped the fluid down the coil tubing string	Bar
JOB_SLUR	Cumulative fluid volume pumped down annulus	M^3
JOB_PROP	Cumulative Proppant pumped in weight at surface	Kg
JOB_BH_PROP	Cumulative Proppant pumped in weight downhole (into formation)	Kg
Sleeve No	Number of frac sleeve injected	
Frequency	Number of microseismic events per minute	Per minute
QC_LOC_X	Qc'd eastings of microseismic event	m
QC_LOC_Y	Qc'd northings of microseismic event	m

Abbreviation	Meaning	Unit
QC_LOC_Z	Qc'd subsea depth subsea of microseismic event	m
SP_MAGNITUDE	Magnitude of microseismic event	Mw
MS_SNR	Signal to noise ratio	

N.B. Due to an interruption in the power supply to the wireline unit, the following data gap is present in the microseismic data:

Start Time day:month:year:hours:minutes:seconds	14:12:18:21:00:17
End Time day:month:year:hours:minutes:seconds	15:12:18:02:02:03

Table 7 Data gap in microseismic data. Time is GMT

This power shortage occurred out of hydraulic fracturing operational hours, no events were recorded on the independent and operational surface array during this time. Other apparent gaps were covered by the processing window, in some cases no identifiable events were recorded for 2 – 3 hours.

APPENDIX 6 – PNG PUMPING FILES

PNG files of each sleeve show microseismic events overlain on injection charts. Job time is in British Summer Time (BST), and changes to Greenwich Mean Time (GMT) on 28th October 2018 at 02:00.