Preston New Road 1z
Hydraulic Fracture Plan

Well Classification:	Exploration Onshore Horizontal Well
Well Name:	Preston New Road-1z
Operator:	Cuadrilla Bowland Ltd
Licence:	EXL269 (for site location), PEDL165 (for lateral well)
Partners:	PEDL165 Cuadrilla Resources Ltd – 51.25% Centrica- 25% AJ Lucas – 23.75%
	EXL269 Cuadrilla Resources Ltd – 50.1875%; Centrica – 22.75%, AJ Lucas 22.0625%, Warwick Energy - 5%
Expected Lateral Length [TVD]	1000 m [2180 m TVD]
Surface Coordinates:	Northing 432749.50 m Easting 337433.54 m [BNG - OSGB36]
	Lat 53° 47' 14.2827" N Long 02° 57' 04.0278" W [WGS84]
TD Coordinates:	Northing 432749.5m Easting 335620.70m [BNG - OSGB36]
	Lat 53° 47' 13.4857" N Long 02° 58' 43.0676" W [WGS84]

Local Faulting	Type | Distance to nearest injection point	Dip | Strike | Throw
Moor Hey	Reverse | 1200 m	53ºE | 041º | 730 m
Anna's Road	Reverse | 650 m	40ºE | 061º | 650 m
Haves Ho	Reverse | 1300 m	50ºE | 044º | 1700 m
PNR-1	Reverse | 500 m	60ºE | 019º | 200 m
Fault-2	Reverse | 1200 m	85ºE | 032º | 30 m
Thistleton	Normal | 2300 m	68ºE | 030º | 850 m

Seismic Discontinuities	Type | Distance to nearest injection point	Dip | Strike | Throw
SD1	Reverse | 200 m	53ºE | 021º | 30 m
SD2	Reverse | 600 m	73ºE | 070º | 40 m
SD3	Normal | 0 m	75ºE | 150º | 25 m
SD4	Reverse | 100 m	42ºE | 033º | 25 m
SD5	Reverse | 200 m	50ºE | 022º | 20 m
SD6	Normal | 550 m	67ºE | 030º | 60 m

Stress Analysis	Regional SHmax azimuth 173º (NNW-SSE) strike slip regime
Shmax	2.82 SG (23.5 ppg) EMW [1]
SHmin	1.72 SG (14.3 ppg) EMW [1]
Background Seismicity Results	12 months monitoring via 7 broadband seismometers. No seismicity within permitted boundary (19 events from 0.7-4.2 M_L detected outside the permitted boundary | Nearest event @ 36 km). Data provided to the BGS. [2]
Induced Seismicity Risk	The effects of induced seismicity associated with the project are not significant. The potential cumulative effects have also been addressed as not significant. See the PNR ES Chapter 12[10] for more detail.

Previous and Planned Operations	**Elswick-1**	**Preese Hall-1**	**Preston New Road-1z**
Well Type	Vertical	Vertical	Horizontal
Fluid Type	Gelled-water with CO_2	Slickwater	Slickwater
Stages	1	5	Up to 45
Hydraulic Fracturing Fluid Volume per Stage	163 m^3 water, 24.3 t CO_2	Maximum 2339 m^3	Up to 765 m^3
Proppant Volume per Stage	58.5 t	Maximum 116.6 t	50 t
Seismic Monitoring		BGS Network [11]	BGS Network
			Local real time 8 station array
			Real time downhole microseismic monitering array
Pre Operational Investigations	2D Seismic Interpretation	2D Seismic Interpretation	3D Seismic Interpretation [12]
			Geomechanical study [3]
Historic Seismicity	None noted	1.5 & 2.3 (M_L) Induced [11][4]	None noted within permited boundary during 12 months monitoring [2]

Proposed Injection Design	Slickwater | Sliding sleeve | Coil tubing
Injection / Stage	Up to 765 m^3 (Schedule 3 Table S3.2 EPR/AB3101MW) [5]
Proppant / Stage	Up to 75 t proppant per stage | 100 mesh Congleton sand and 30/50 mesh Chelford sand [6]
Additives	Polyacrylamide based friction reducer (maximum concentration 0.05%) | <10% HCl up to 3 m^3 per stage| UV in event of reuse | (As required in Schedule 1 A5 (EPR/AB3101MW) [5]
Estimated Pumping Pressure / Rate	Surface 51.7 Mpa [7500 psi] - 3.6 m^3/minute
Maximum Pumping Pressure / Rate	Surface 65.5 Mpa [9500 psi] - 6.375 m^3/minute (Schedule 3 Table S3.2 (EPR/AB3101MW)) [5]
Wellbore Deviation Plan / Injection Points	See Appendix 3

Fracture Modelling	P3D simulation model of planer propagation based on PH-1 geology		
	400 m^3 stage size	600 m^3 stage size	765 m^3 stage size
Fracture Total Height	78 m	85 m	133 m
Fracture Half Length	36 m	34 m	31 m

Mitigation Methods / Monitoring	TLS | Microseismic | Vibration		
Traffic Light System (TLS)	8 real time seismometers installed [13]	Combination of broadband seismometers and 4.5 Hz, 3 component geophones. Minimum of 6 required for operational TLS.[15]	Estimated detectability -0.5 (M_L), accuracy 300 m (X,Y) 300 m (Z) at estimated injection depth
TLS Monitoring Duration	Monitored 4 weeks before and 2 weeks after injection operations. During operations (24 hours) [13].		

TLS Array Location	Instruments installed in an array from 1.0 km to 3.9 km from the site and have been independently assessed as to quantity, location and redundancy [13].		
TLS Decision Tree	See Appendix 4		
Vibration Monitoring System	Minimum of 4 peak partial velocity (PPV) monitors active in addition to PPV data from 8 TLS stations		
Vibration Monitoring Duration	Monitored before and after operations (2 weeks). During operations (24 hours)		
Vibration Monitoring Decision tree	See Appendix 4		
Microseismic Array / Fracture Mapping	Real Time Downhole Microseismic Monitoring Array	12 slim hole, 3 component, 15 Hz Geophones	Estimated detectability -1.8 (M_L), accuracy 20 m (X,Y) 20 m (Z) at the toe of the well
Microseismic Duration	Real time monitoring throughout pumping operations		
Operational Boundary	Within the areal extent of the TLS		
Assurance	Microseismic monitoring will be installed and executed by a competent contractor specialising in microseismic monitoring. The contractor will follow its own quality assurance procedures for calibration and data gathering.		
Microseismic Monitoring / Induced Seismicity Mitigation	The HFP applies an evolutionary approach to risk assessment and mitigation (operational mitigation) [10]. This stepped progressive approach to hydraulic fracturing will consist of an initial mini-fracture stage and modest initial pumped volumes, building up to a maximum pump volume of 765 m^3 per stage. As this process continues, an understanding of the performance of the reservoir during hydraulic fracturing is developed by; 1) Monitoring the extent of fracture growth using a real time downhole microseismic array. If, during hydraulic fracturing, monitoring data indicates possible fault interactions with a preferential flow pathway, the pumping of fracturing fluid would be adjusted or terminated and the HFP would be modified as necessary. 2) Implementation of the Traffic Light System. As long as the induced seismicity is <0.0M_L (Green level) while pumping, operations will continue. If an induced seismicity event occurs in the range of ≥0ML to <0.5ML (Amber level) while pumping, the fracture stage can be completed. On completion of the injection the flowback procedure will be initiated. Pumping may then proceed with caution, possibly at reduced parameters. If an event occurs that is ≥0.5ML (Red level) while pumping, the fracture stage will be aborted and the flush and flowback procedure will be initiated. Should seismicity occur at or above the red 0.5 M_L level then a vibration monitoring array will be utilised to assess the impact in accordance with BS7358-2. The measurement recorded by the vibration monitoring array and traffic light system will then be used to assess the calibration of the ground motion prediction model [14] and amendments applied if required. Cuadrilla are anticipating that the horizontal well bore, or the area intended to be hydraulically stimulated, will encounter a number of small faults. [9] Modelling a worst case scenario (direct injection into a predicted or unpredicted critically stressed fault) and using 2000 m^3 stages the upper bound estimate for maximum magnitude possible would be 3.1 M_L [8], which is considered to be a very low likelihood [10]. If vibration occurs in excess of 3.1M_L and or PPV of 15 mm/s (as referenced in BS7358-2) due to injective operations, which is considered to be a very low likelihood, then future injection operations will be altered to mitigate below the PPV 15 mm/s level by adjusting fluid volume, rate, pressure, and or injection point. Where possible TLS data will be co-processed with any available BGS data, event magnitude determination will be calculated using the BGS methodology.		
Permit Boundary / Microseismic Monitoring	An evolutionary process as described in the PNR ES Chapter 12 [10] will be employed to understand the performance of the reservoir during fracturing. This stepped progressive approach to hydraulic fracturing will consist of an initial mini-fracture stage and modest initial pumped volumes building up to a maximum pump volume of 765 m3 per stage. As this process continues, an understanding of the performance of the reservoir during hydraulic fracturing is developed by monitoring the extent of fracture growth using a real time downhole microseismic array. If, during hydraulic fracturing, monitoring data indicate possible fracture growth with a preferential flow pathway towards the edge of the permitted boundary the pumping of fracturing fluid would be adjusted or terminated and the HFP would be adjusted as necessary to prevent future occurrences. If fracture fluid is interpreted (by an agreed methodology with the Environment Agency) to be outside of the permitted boundary injection will stop after flushing the well. Future injection operations will be altered to comply with the permitted boundary by adjusting fluid volume, rate, pressure, and or injection point.		
Groundwater Monitoring	The Waste Management Plan (HSE-Permit-INS-PNR-006) details groundwater monitoring approach and protection measures. Further details have been submitted and approved in PO4 and PO7 which provides groundwater borehole installation and monitoring. The frequency of monitoring is outlined within the Permit EPR/ AB3101MW.		

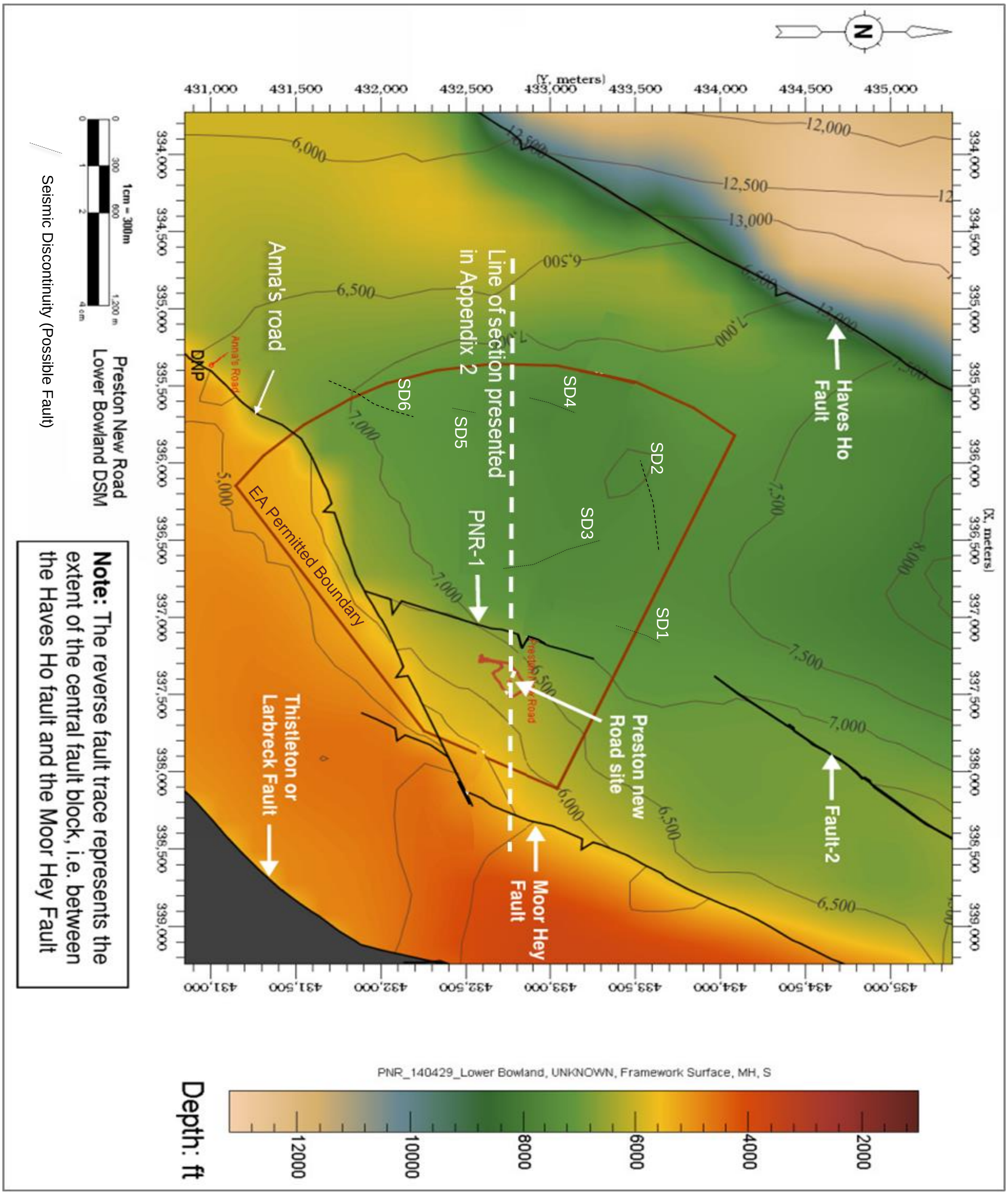
Reporting	TLS status reported without delay on Cuadrilla e-portal
Morning Report	Submitted daily during fracturing operations. Injection depth. Volumes and type of water, proppant, chemicals pumped. Schematic of fracture growth, including the location, orientation and extent of the induced fractures, in relation to permitted boundary. Proposed mitigation measures if required. Induced seismicity of note.
Post Frac Reporting	End of Well Report as per PON9b Quarterly report as per S4.1 (EPR/AB3101MW)

Seismic Level Requiring Integrity Check	See Appendix 4

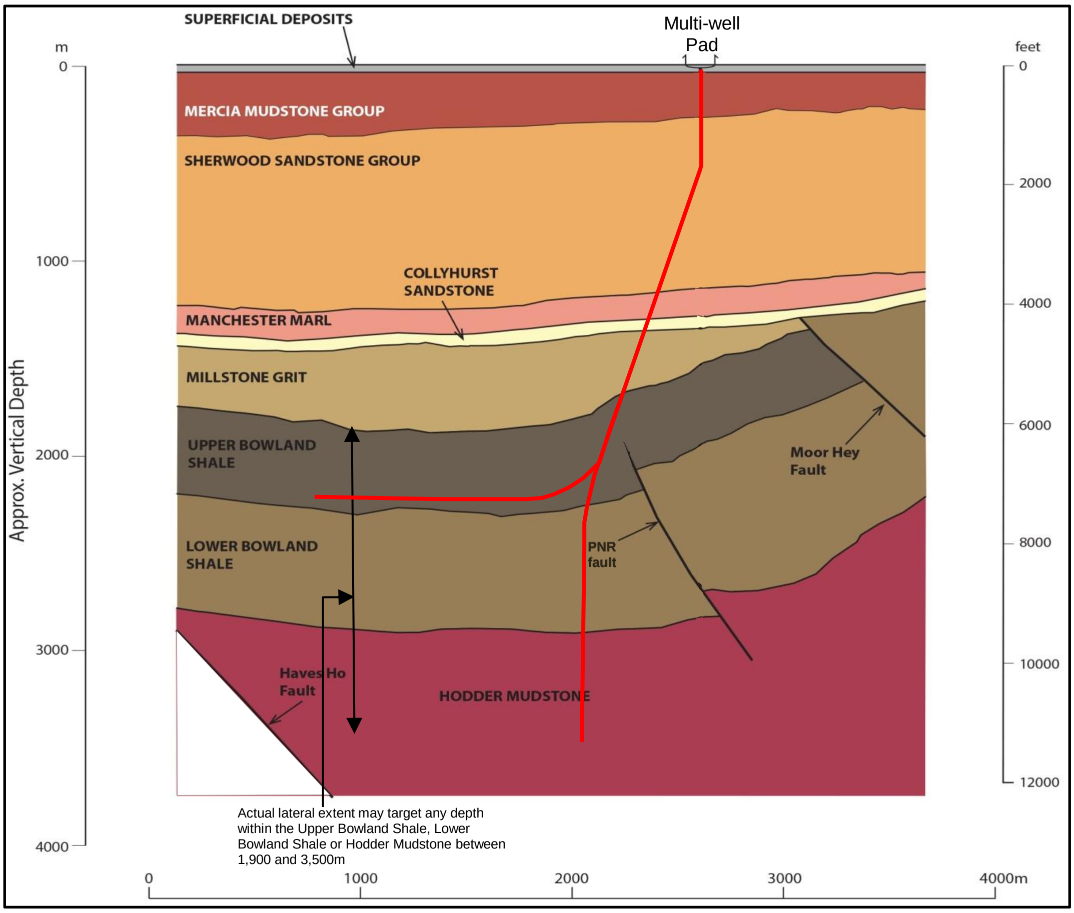
Verification Updates	Provided to the EA, OGA, HSE		
On TD of Pilot Well	Formation tops, stress azimuth.		
On Completion of Lateral Well	Deviation profile, target formation, injection points.		

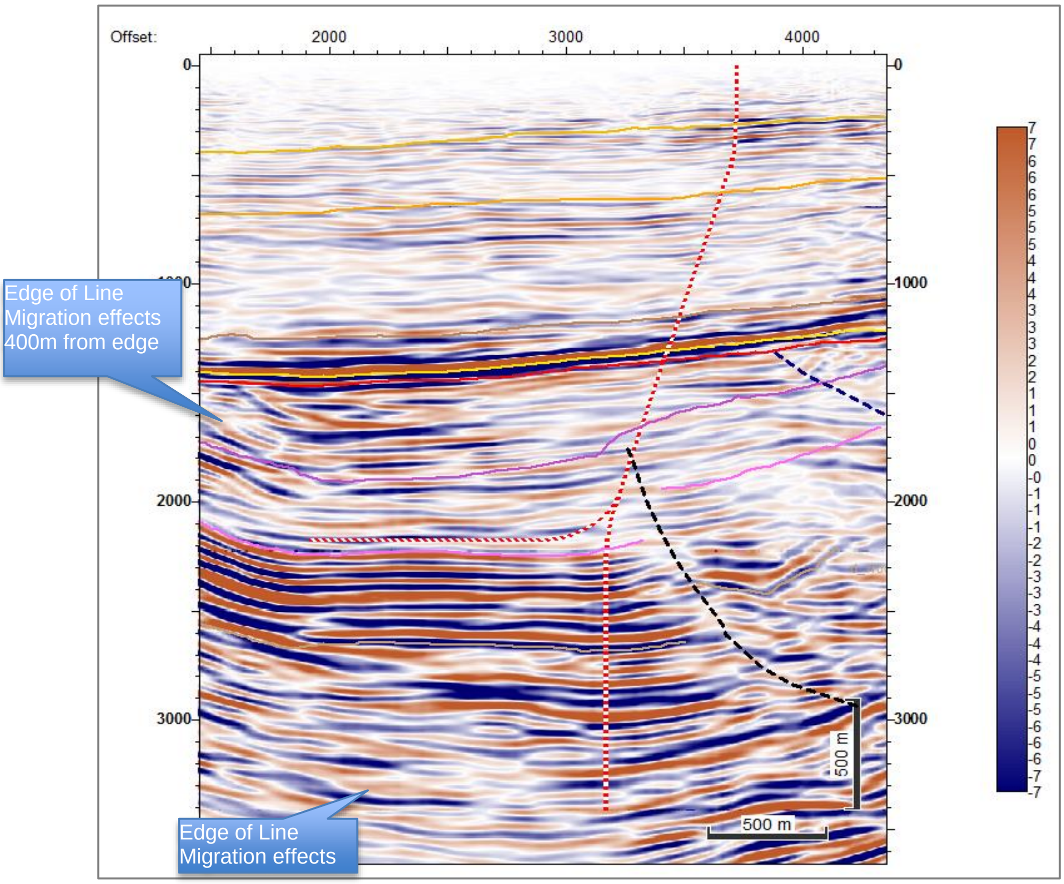
References / Related Documents

1: PNR Environmental Statement - Appendix L Fig. 12
2: http://www.bgs.ac.uk/research/groundwater/shaleGas/monitoring/seismicity.html
3: de Pater, H. & Baisch, S. 2011. Geomechanical Study of Bowland Shale Seismicity, Synthesis Report
4: Clarke, H., Eisner, L., Styles, P. and Turner, P. 2014. Felt seismicity associated with shale gas hydraulic fracturing: The first documented example in Europe, Geophysics. Res. Lett., 41, 23, 8308-8314.
5: Preston New Road Exploration Site Permit numbers EPR/AB3101MW
6: PNR Environmental Statement - Appendix B7
7: PNR Environmental Statement - Chapter 12
8: de Pater, C.J. & Baisch, S., 2011. Geomechanical Study of Bowland Shale Seismicity. Synthesis Report. For Cuadrilla Resources Ltd. 57pp. - Section 6.
9: PNR Environmental Statement - Chapter 12, para156
10: PNR Environmental Statement - Chapter 12, Summary
11: http://earthquakes.bgs.ac.uk/research/earthquake_hazard_shale_gas.html
12: PNR Environmental Statement - Appendix L10.2.2
13: PNR Environmental Statement - Appendix L10.7
14: PNR Environmental Statement - Appendix L8.2.2
15: PNR Environmental Statement - Appendix L10.8.01

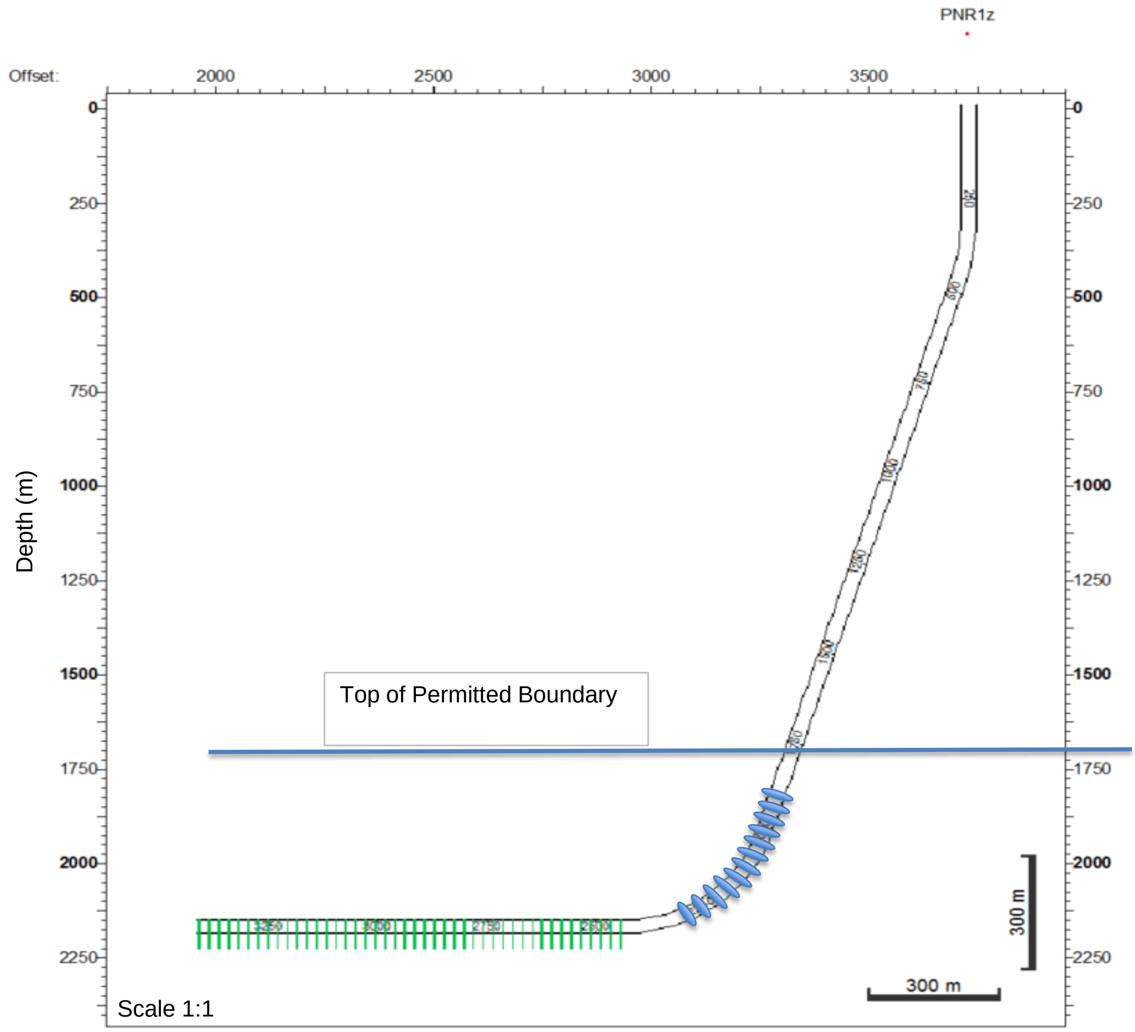

Haves Ho Fault
Fault-2
Moor Hey Fault
Preston new Road site
PNR-1
Line of section presented in Appendix 2
Anna's road
EA Permitted Boundary
Thistleton or Larbreck Fault
SD1
SD2
SD3
SD4
SD5
SD6
DXP
Preston New Road
Lower Bowland DSM
1cm = 300m
Seismic Discontinuity (Possible Fault)
Note: The reverse fault trace represents the extent of the central fault block, i.e. between the Haves Ho fault and the Moor Hey Fault
PNR_140429_Lower Bowland, UNKNOWN, Framework Surface, MH, S
Depth: ft

Appendix 2 Seismic Cross Section

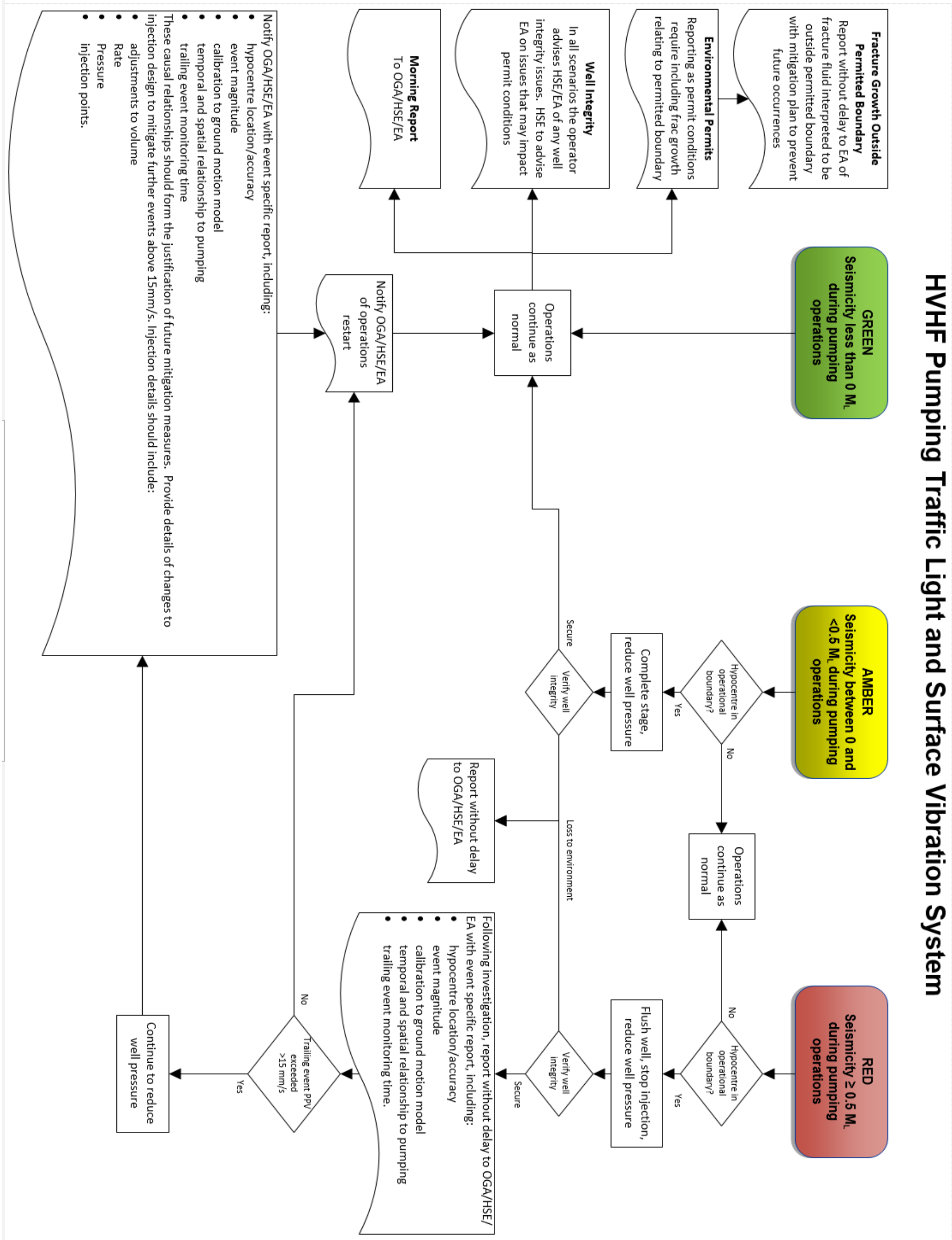




Appendix 3 Wellbore profile, hydraulic injection Locations, indicative microseismic array position
Note: microseismic monitoring will be performed from the observation well, not injection well.



Key: Green Injection points
Blue Microseismic observation points


HVHF Pumping Traffic Light and Surface Vibration System
GREEN
Seismicity less than 0 ML during pumping operations
AMBER
Seismicity between 0 and <0.5 ML during pumping operations
RED
Seismicity ≥ 0.5 ML during pumping operations
Fracture Growth Outside Permitted Boundary
Report without delay to EA of fracture fluid interpreted to be outside permitted boundary with mitigation plan to prevent future occurrences
Environmental Permits
Reporting as permit conditions require including frac growth relating to permitted boundary
Well Integrity
In all scenarios the operator advises HSE/EA of any well integrity issues. HSE to advise EA on issues that may impact permit conditions
Morning Report
To OGA/HSE/EA
Operations continue as normal
Notify OGA/HSE/EA of operations restart
Hypocentre in operational boundary?
Yes
No
Complete stage, reduce well pressure
Verify well integrity
Secure
Loss to environment
Report without delay to OGA/HSE/EA
Operations continue as normal
Hypocentre in operational boundary?
No
Yes
Flush well, stop injection, reduce well pressure
Verify well integrity
Secure
Following investigation, report without delay to OGA/HSE/EA with event specific report, including:
hypocentre location/accuracy
event magnitude
calibration to ground motion model
temporal and spatial relationship to pumping
trailing event monitoring time.
Trailing event PPV exceeded >15 mm/s
No
Yes
Continue to reduce well pressure
Notify OGA/HSE/EA with event specific report, including:
hypocentre location/accuracy
event magnitude
calibration to ground motion model
temporal and spatial relationship to pumping
trailing event monitoring time
These causal relationships should form the justification of future mitigation measures. Provide details of changes to injection design to mitigate further events above 15mm/s. Injection details should include:
adjustments to volume
Rate
Pressure
injection points.

BGS	British Geological Survey
EA	Environment Agency
EMW	equivalent mud weight
ES	environment statement
ft	feet
HCl	hydrochloric acid
Km	kilometres
Lat	Latitude
Long	Longitude
m	metres
m^3	cubic metres
MD	measured depth
M_L	local magnitude scale
mm/sec	milimetres per second
Mpa	megapascals
OGA	Oil and Gas Authority
PH	Preese Hall
PNR	Preston New Road
ppg	pounds per gallon
PPV	peak particle velocity
psi	pounds per square inch
SG	specific gravity
SHmax	maximum horizontal stress
Shmin	minumum horizontal stress
t	tonnes
TD	total depth
TLS	traffic light system
TVD	true vertical depth

OGA, EA Guidance

Required Item	Location in HFP
Map and seismic lines showing faults near the well and along the well path.	Appendix1 - Lower Bowland Depth Structure Map
Summary assessment of faulting and formation stresses in the area and the risk that the operations could reactivate existing faults	Local Faulting
	Stress Analysis
Information on the local background seismicity	Background Seismicity Results
Assessment of the risk of induced seismicity	Induced Seismicity risk
Comparison of proposed activity to any previous operations and relationship to historical seismicity	Previous Operations
Summary of the planned operations, including the techniques to be used, stages, pumping pressures, volumes and the predicted extent of each proposed fracturing event	Proposed Injection Design
Summary of the planned operations - the location of monitoring points	TLS Array Location
Proposed measures to mitigate the risk of inducing an earthquake	Mitigation Methods/Monitoring
Description of decision tree for a real-time traffic light scheme for monitoring local seismicity	Appendix 4 - TLS and Vibration Monitoring Decision Tree
The processes and procedures that will be put in place during hydraulic fracturing for fracture height monitoring to identify where the fractures are within the target formation and ensure that they are not near the permitted boundary	Microseismic Array/Fracture Mapping
	Permit Boundary/Microseismic Monitoring
In the event that the fractures extend beyond the EA permit boundary, the steps that would be taken to assess and if necessary mitigate the effect and limit further propagation outside the target rocks	Permit Boundary/Microseismic Monitoring
The type and duration of monitoring and reporting during and/or after hydraulic fracturing has taken place and the geologic data to be published	Vibration Monitoring Duration
Procedure for post fracturing reporting of the location, orientation and extent of the induced fractures to demonstrate that the EA permit has been complied with. This will need to include provision for reporting on proposed mitigation measures to prevent propagation should fractures extend to within a short distance of the permitted boundary	Reporting
Proposed level of seismic event above which fracturing cannot resume without consent after evidence is provided that the wells are not damaged and the groundwater remains protected	Seismic Level Requiring Integrity Check