

Seismicity induced by Shale Gas Hydraulic Stimulation: Preese Hall, Blackpool, United Kingdom .

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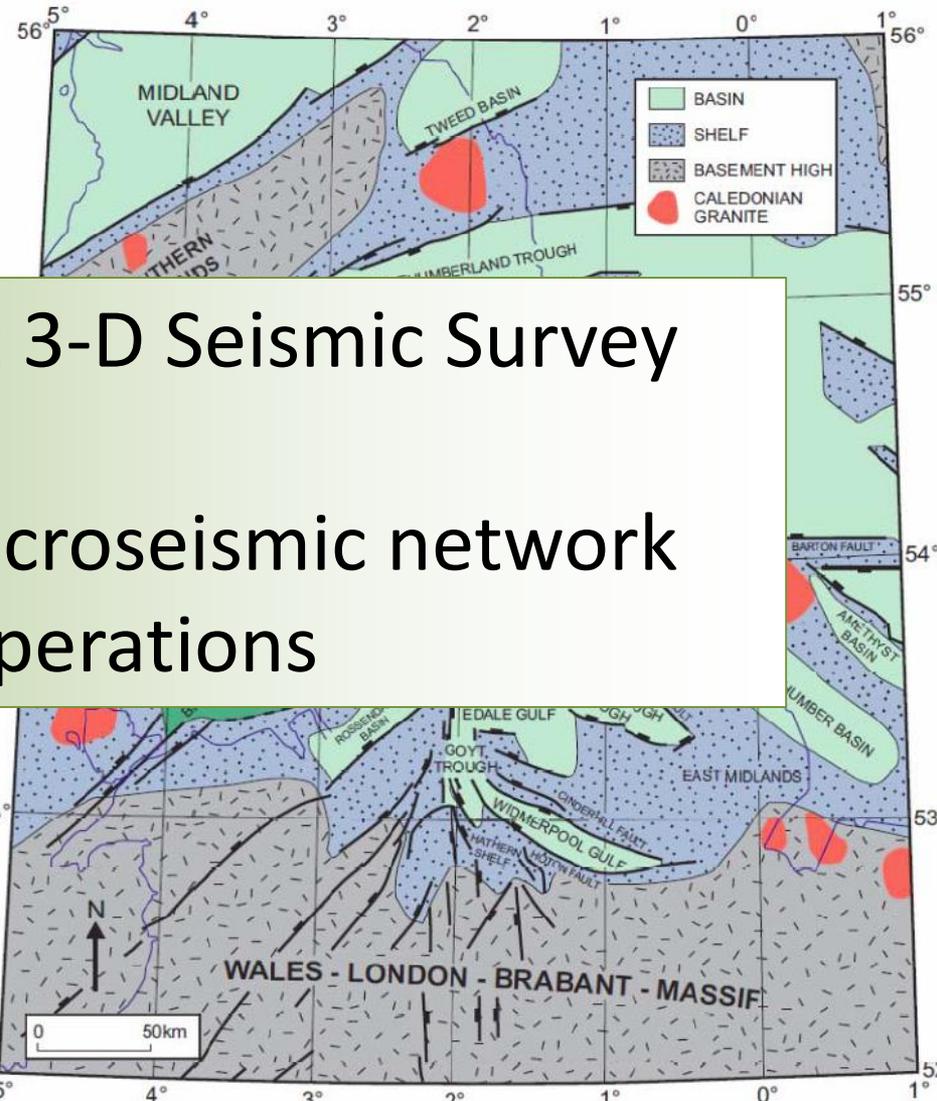
Professor Leo Eisner (Seismik)

Dr Huw Clarke (Cuadrilla Resources)

Dr Peter Turner (Brigantia Resources)



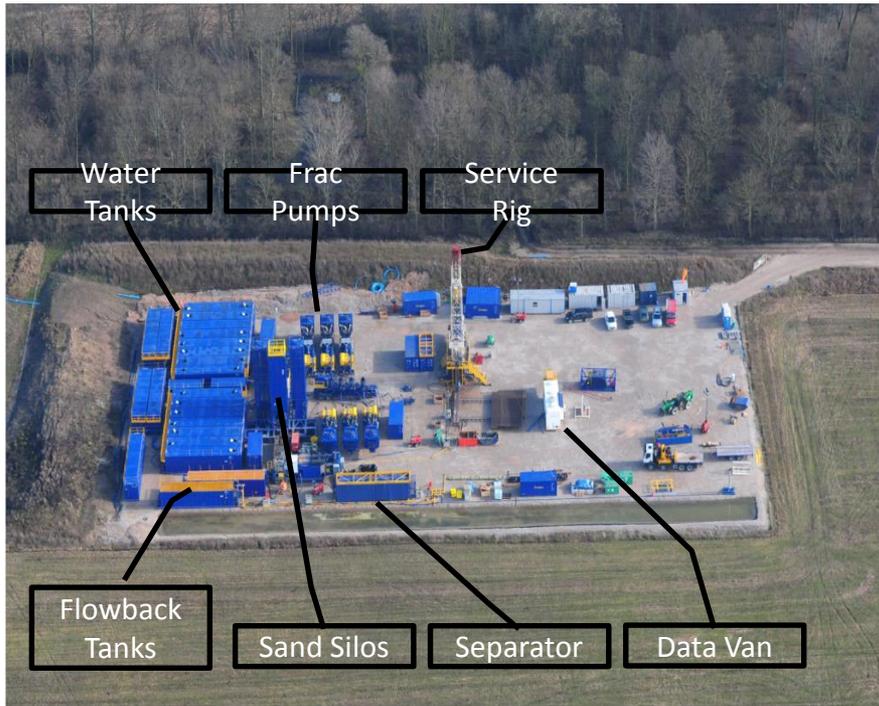
Cuadrilla: Preese Hall 1 Borehole



Advised to carry out 3-D Seismic Survey

Advised to install microseismic network prior to operations

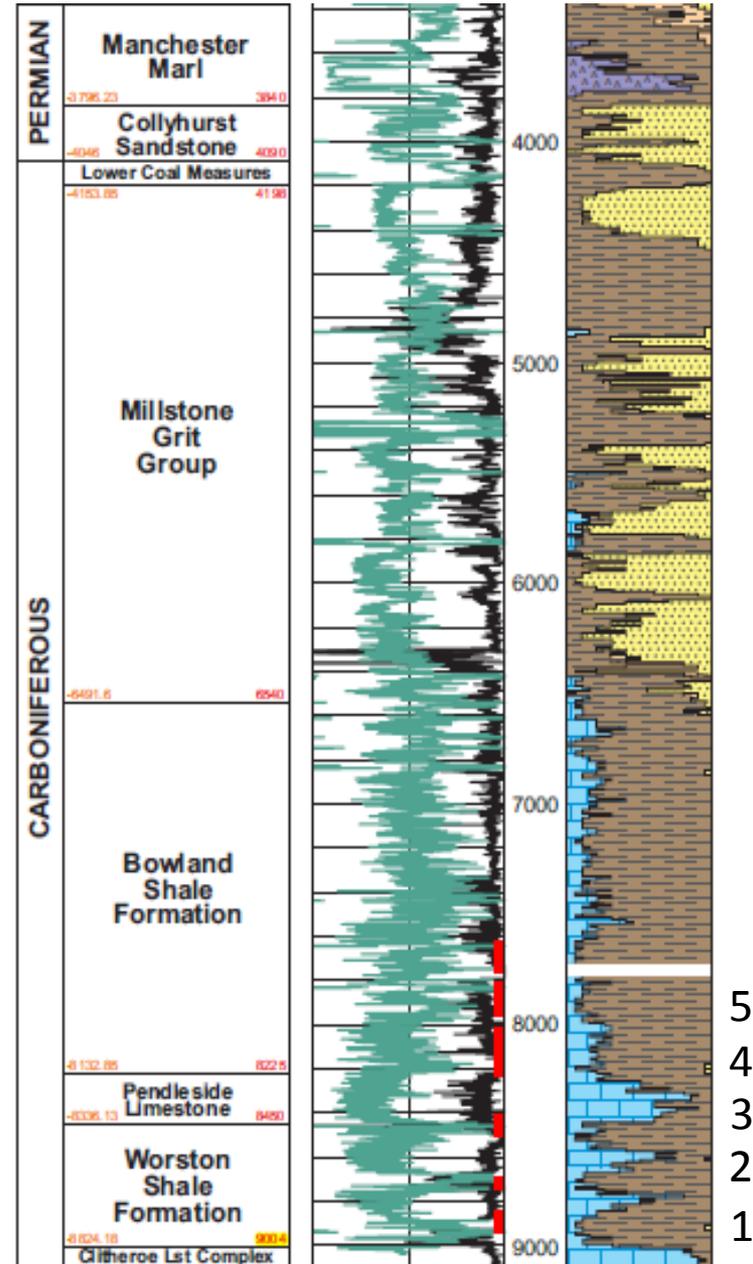
Figure 1: Regional setting of the Bowland basin (based on Fraser and Gawthorpe 1990)



- Frac pumped down 5.5 inch P-110 casing

Stage 1 Perfs 2695-2728 m (8842-8950')
 Stage 2 Perfs 2652-2670 m (8701-8760')
 Stage 3 Perfs 2566-2587 m (8419-8488')
 Stage 4 Perfs 2444-2517 m (8018-8258')
 Stage 5 Perfs 2380-2432 m (7808-7979')

- Proppant-40/70 and 100 mesh UK sand friction reducer and chemical tracer



Hydrofracturing Stages and Associated Seismicity at Preese Hall

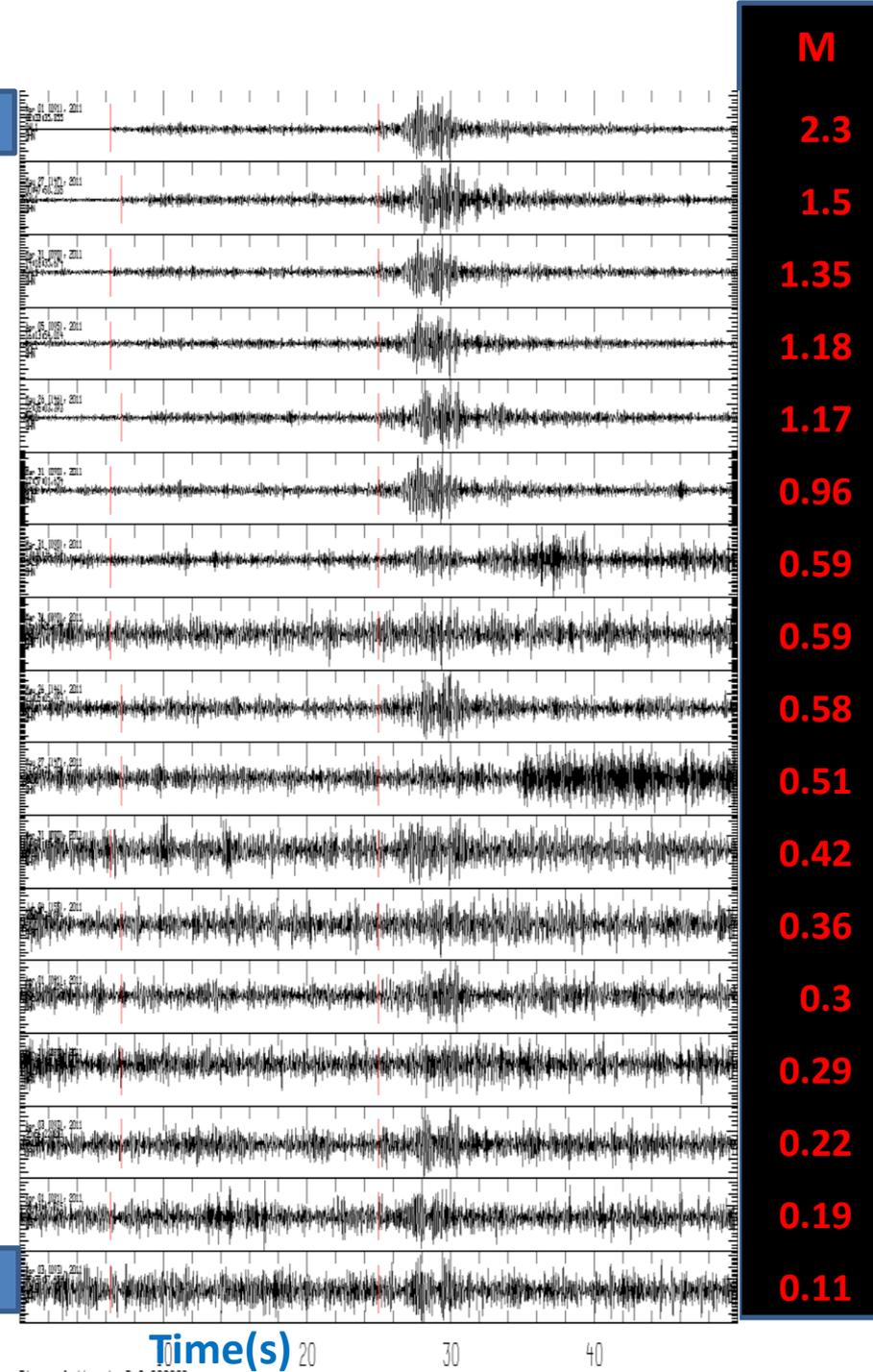
Stage	Description	Date	Perforations					Slickwater Volume			Proppant	
			Depth		Length	Number						
			Top	Bottom								
			<i>ft MD_{RKB}</i>	<i>ft MD_{RKB}</i>	<i>ft TVD_{SS}</i>	<i>ft</i>		<i>Gallons US</i>	<i>m³</i>	<i>bbls US</i>	<i>lbm</i>	<i>mton</i>
1	DFIT	26 March 2011	8,841	8,850		9	27	34,314	130	817		
	Job	28 March 2011	8,841	8,949	8,730	36	108	485,856	1,839	11,568	226,240	101
2	DFIT	30 March 2011	8,700	8,759	8,583	27	81	24,780	94	590		
	Job	31 March 2011						593,040	2,245	14,120	262,080	117
		01 April 2011	Magnitude 2.3 seismic event									
		04 April 2011	Deformed casing confirmed with caliper 8480-8640ft MD (just below zone 3)									
3	DFIT	08 April 2011	8,420	8,489	8,340	27	81	10,668	40	254		
	Job	09 April 2011						200,634	759	4,777	116,480	52
4	DFIT	25 May 2011	8,020	8,259	8,052	27	81	21,084	80	502		
	Job	26 May 2011						423,696	1,604	10,088	183,680	82
		27 May 2011	Magnitude 1.5 seismic event									
5	DFIT	27 May 2011	7,970	7,819	7,823	27	81	11,760	45	280		
	Job	27 May 2011						402,780	1,525	9,590	248,640	111
6	DFIT	31 May 2011	7,670	7,789	7,666	27	81	10,290	39	245		
TOTALS							513	2,218,902	8,399	52,831	1,037,120	463

Data

Strongest event

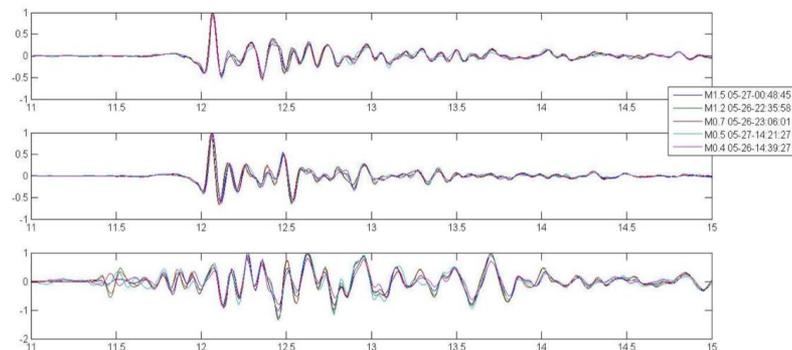
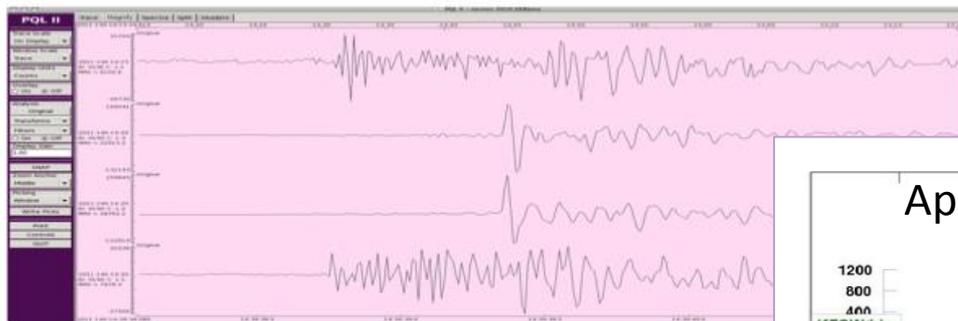
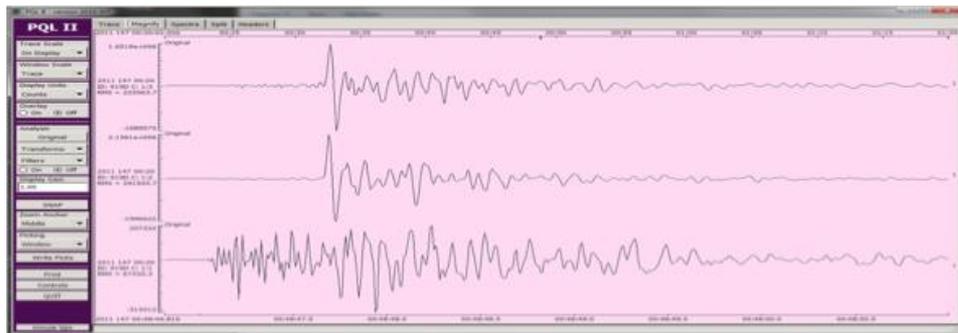
- NS component
- Similar locations
- Similar mechanisms
- Relative magnitudes
- 50+ Events detected similar to the two BGS reported events

Weakest event

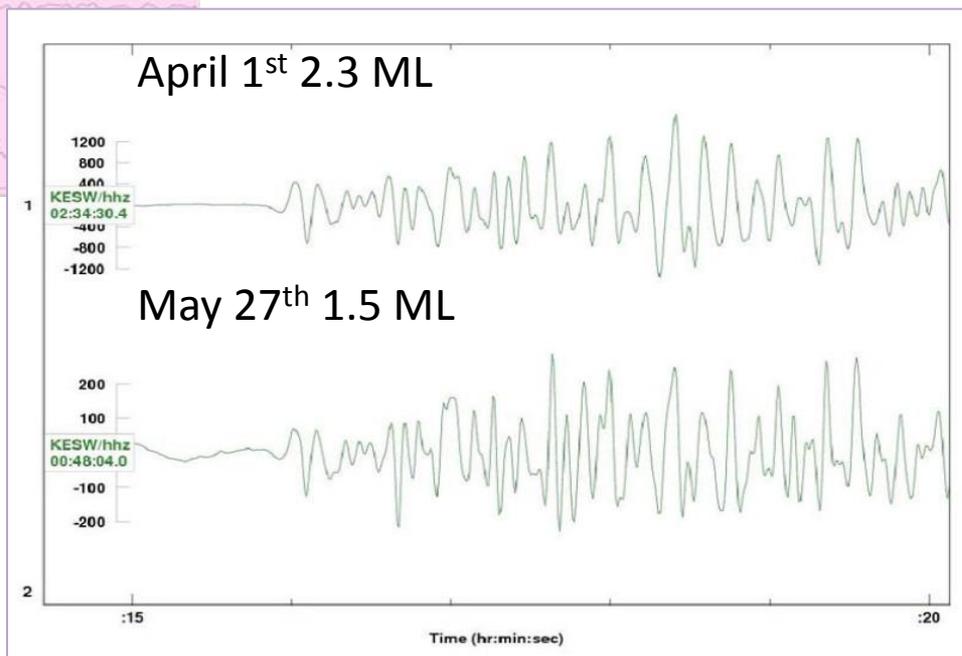


Blackpool Area Earthquakes

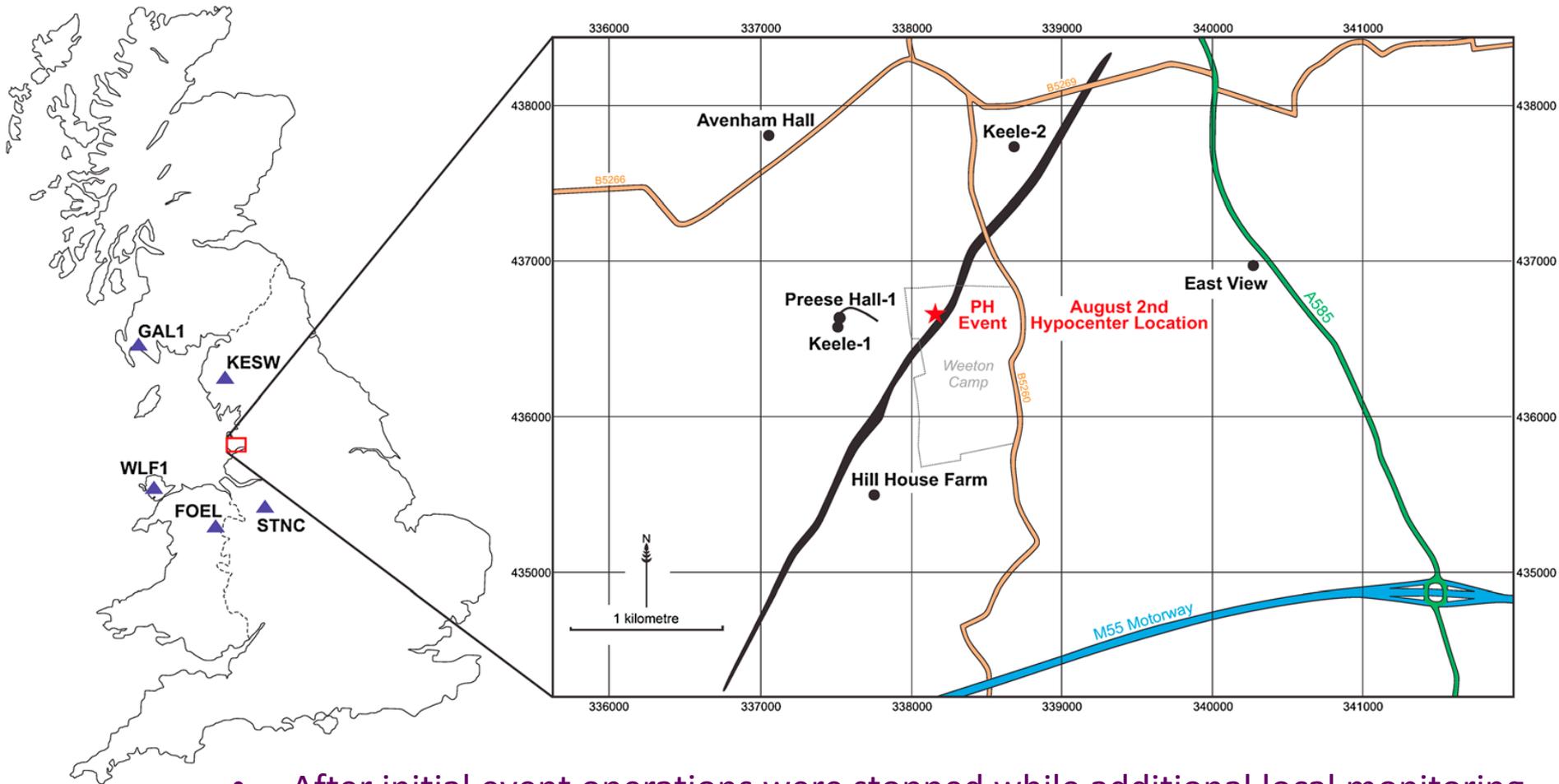
Surface GURALP 6TD Broadband, 3-C Seismometers



5 Largest Events Normalized and Superimposed

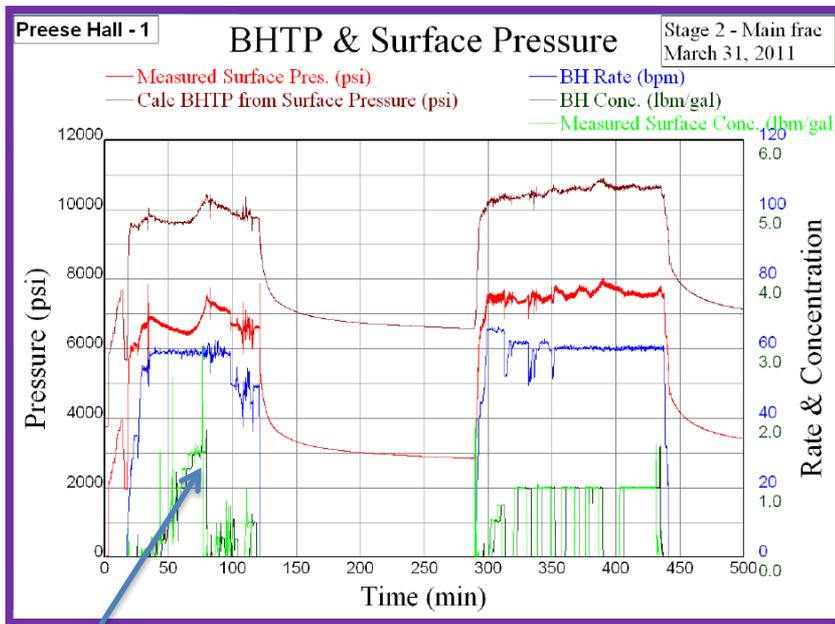


Location of PH1, April 1st Seismic Event

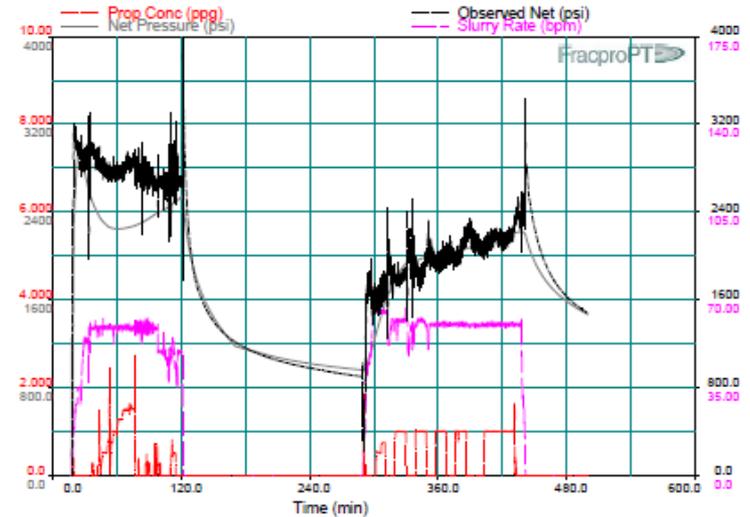


- After initial event operations were stopped while additional local monitoring stations were installed
- Third stage was pumped followed by a flow testing period

Stage 2

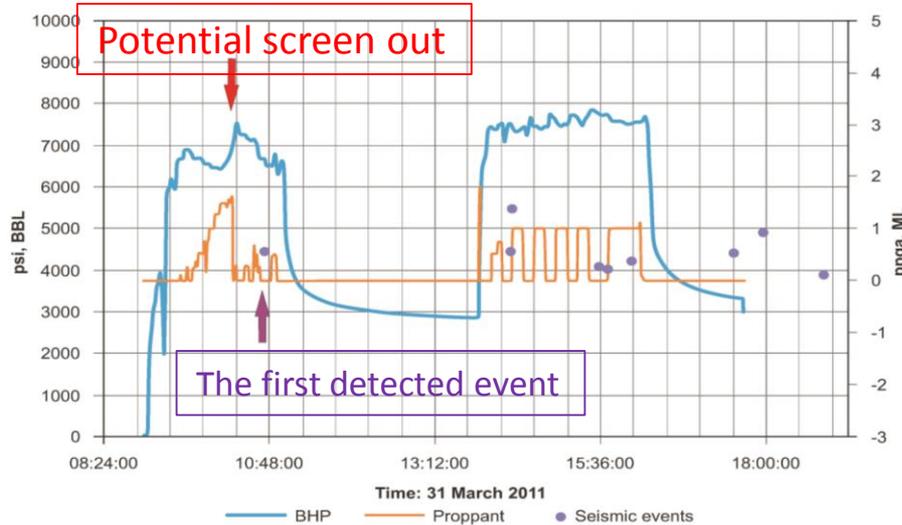


S2 low stress



SCREEN OUT?

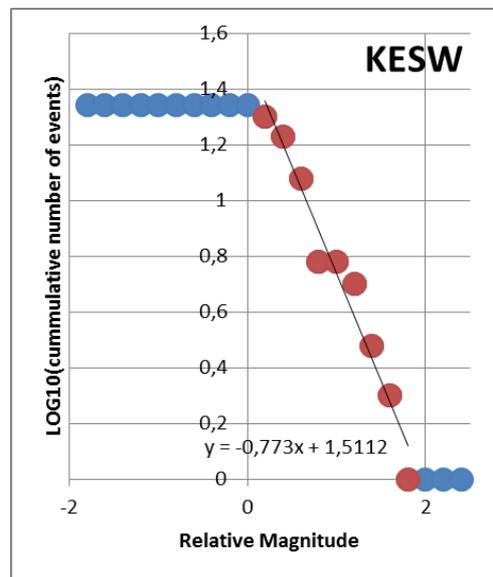
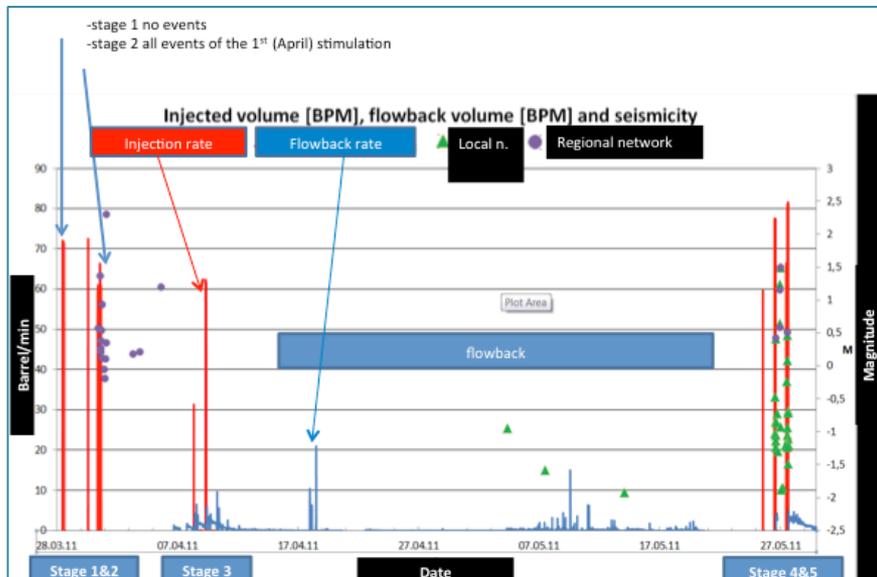
Figure 3: Bottom hole pressure, injected proppant and seismicity



Pressure match of stage 2 main frac, using a model with a minimum stress gradient of 0.66 psi/ft over the entire formation. The high net pressure was matched by assuming 35 multiple fractures. The reservoir permeability was 0.1 microD. (From de Pater et al)

14,710 bbl (including mini-frac), 116.6 metric tons prop

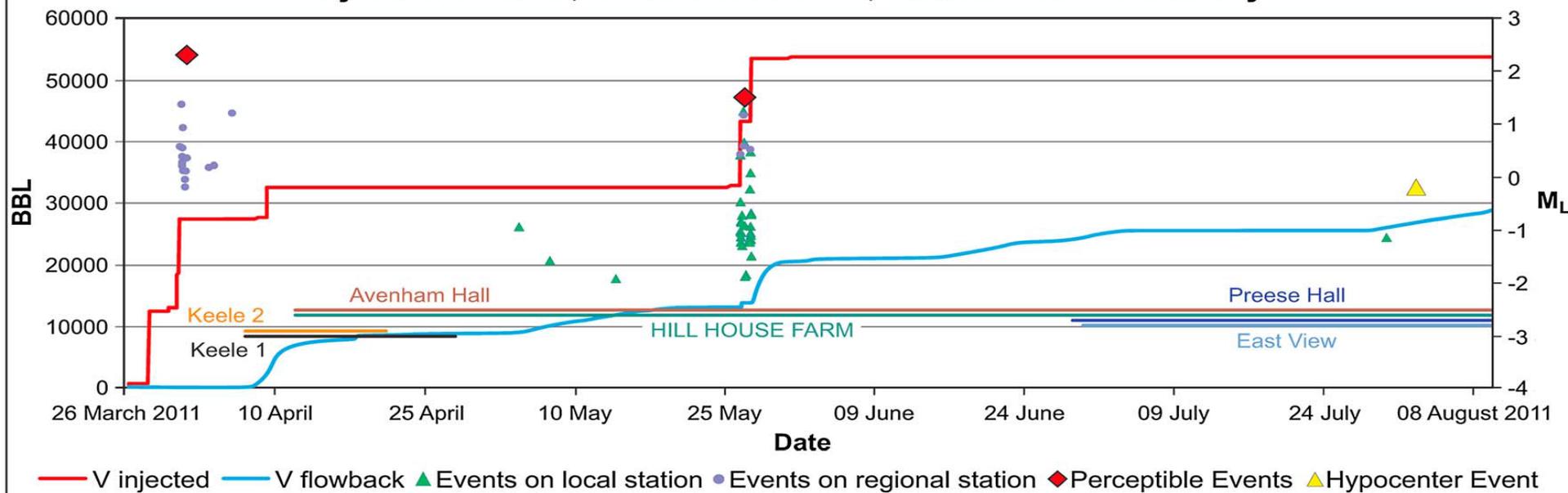
Seismicity and injection



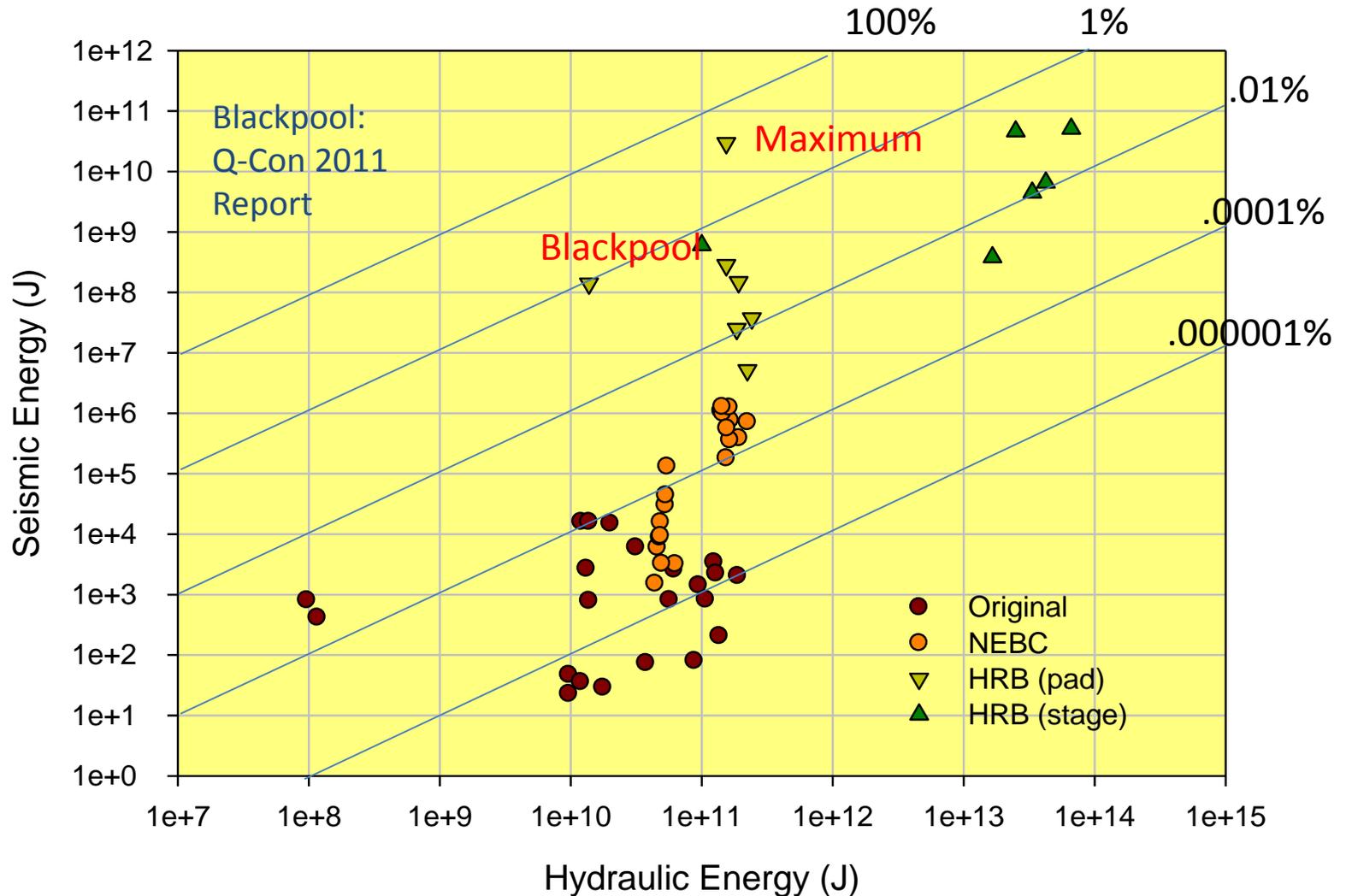
Completeness catalogue
M>0.3

B-value of 0.8
(uncertainty 0.3 from 14 events).

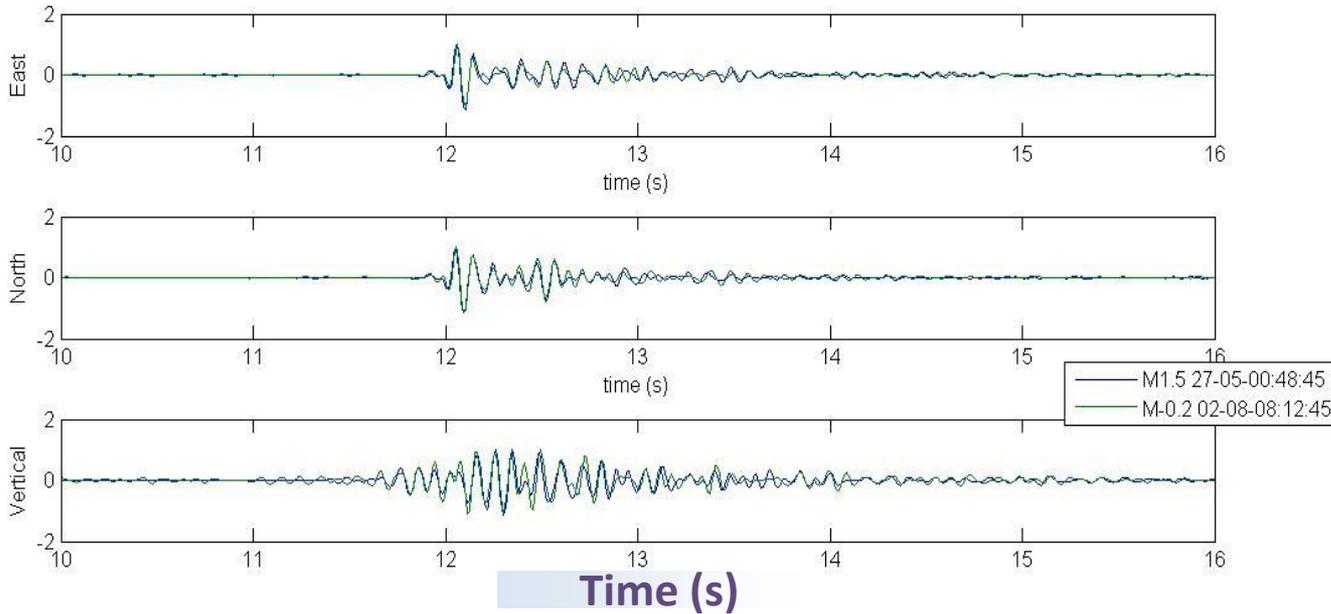
Injected volume, flowback volume, stations and seismicity



After QCon and Shawn Maxwell

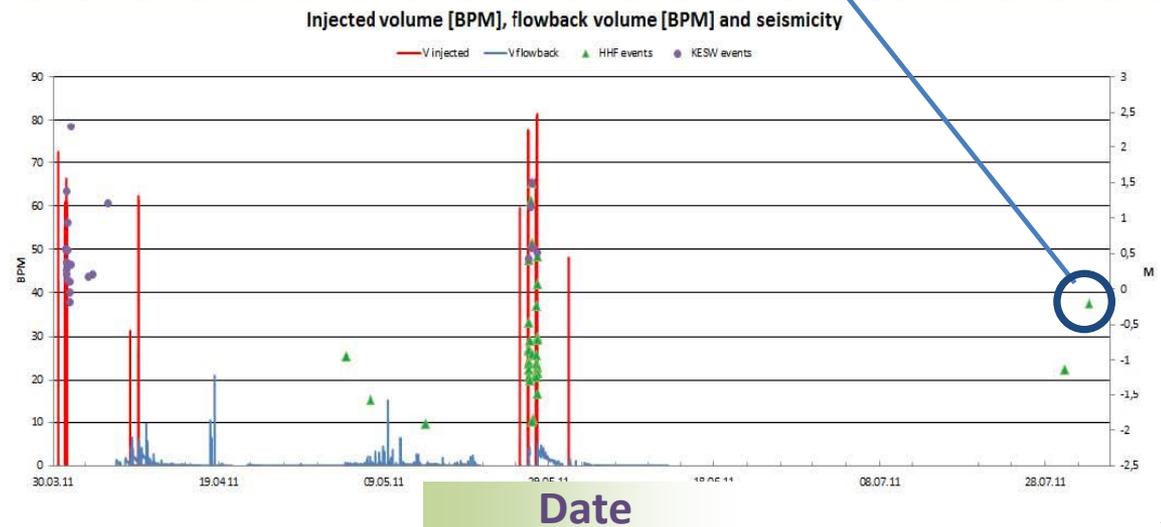


Rapid decay of seismicity



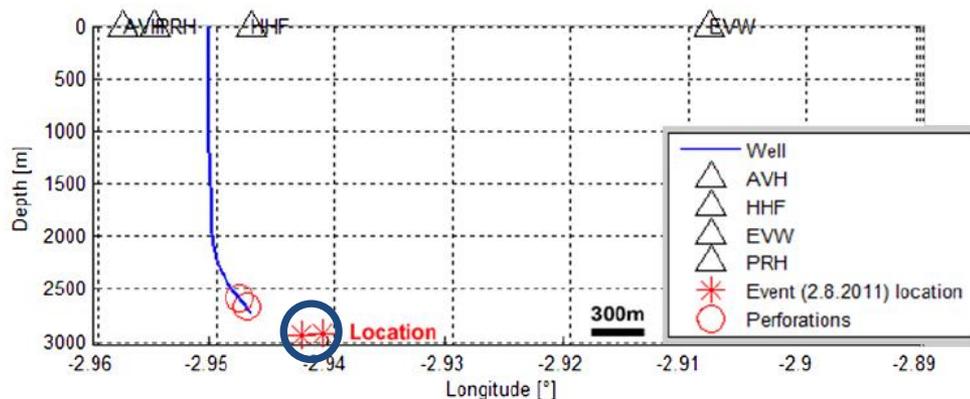
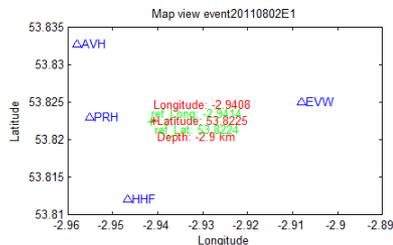
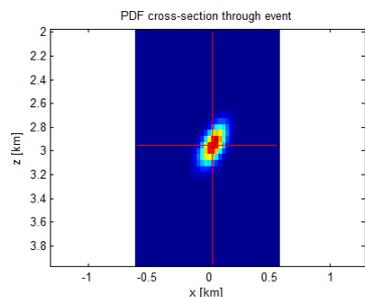
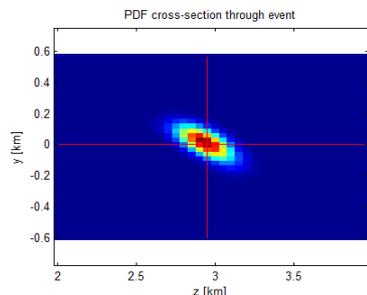
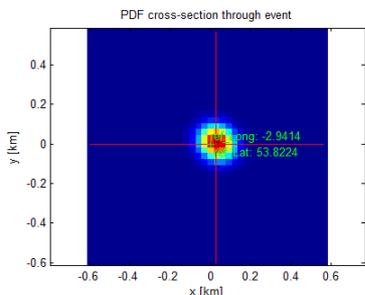
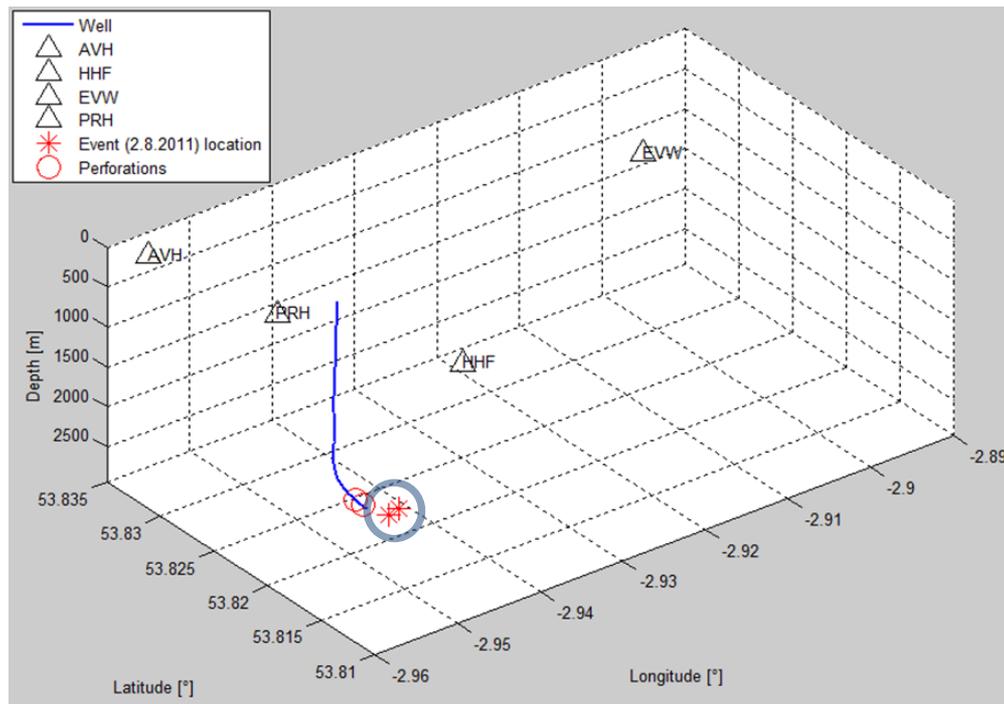
**Similar waveforms –
similar location, similar
mechanism**

**Newly detected event
was detected on 4
stations**

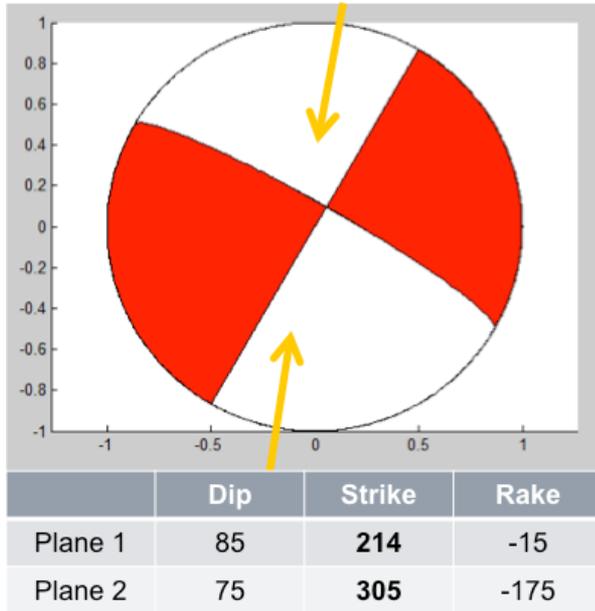


Location of the later aftershocks

- **RMS: 0.0407 sec**
- **PDF (ellipsoid of uncertainty)**
 - main semi-axis **123 m**
 - sec. semi-axis **108 m**
 - azimuth of main semi-axis **140°**
 - depth uncertainty **243 m**

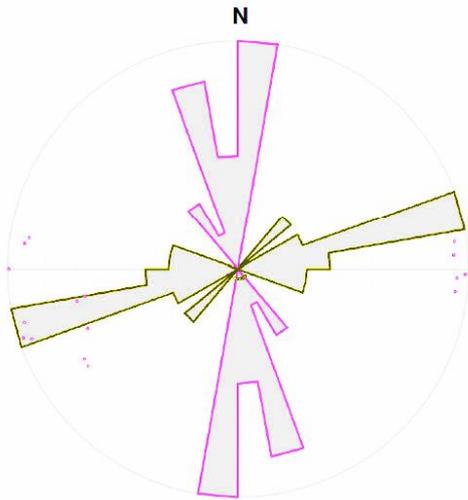


Focal Mechanism



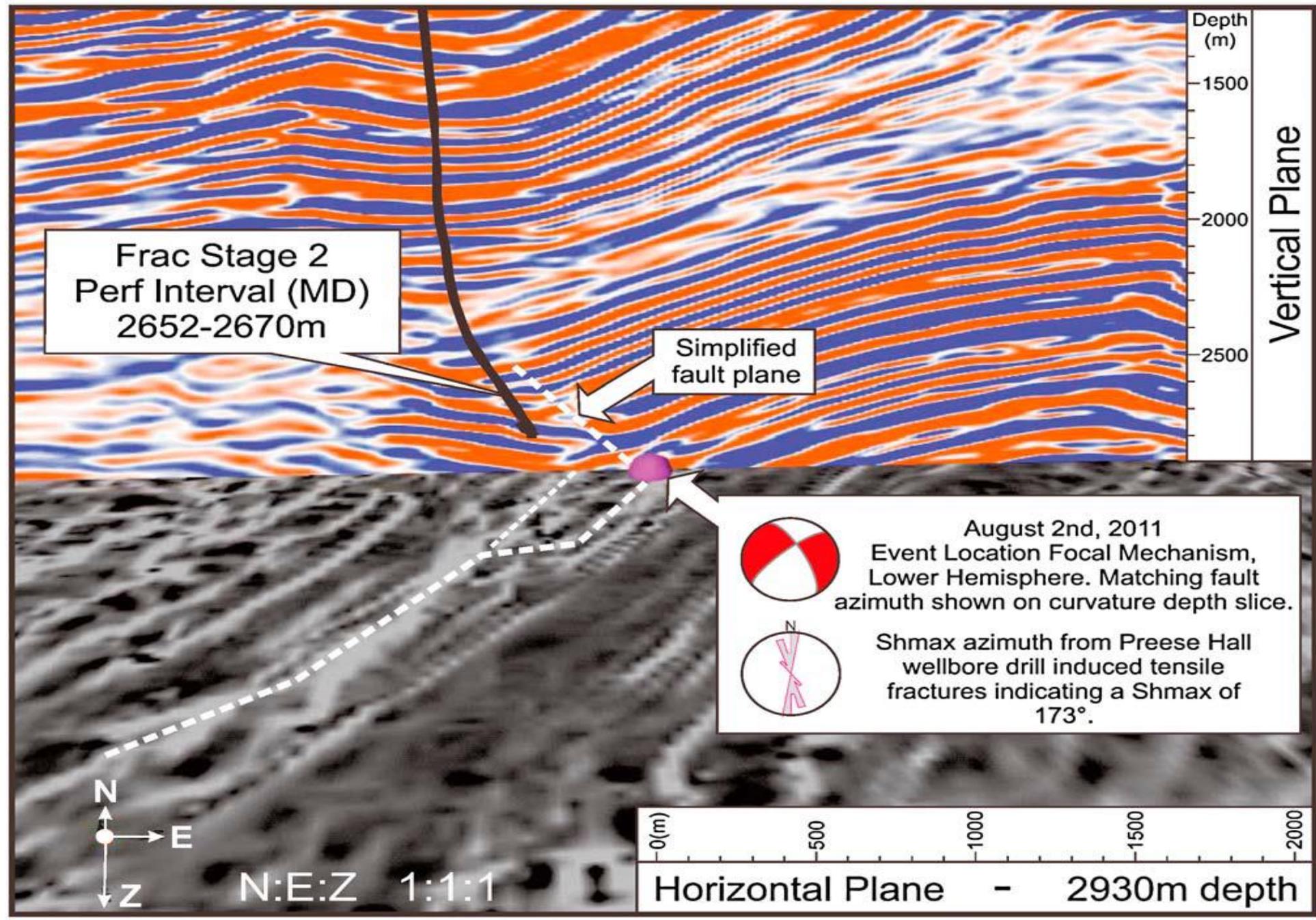
The azimuth of the maximum horizontal stress in the Hodder Mudstone, based on the induced fractures in the Worston Shale Group is **7.50** +/-16.10 for the interval 7370-9025ft.

Same Azimuth as Variscan Inversion Faults

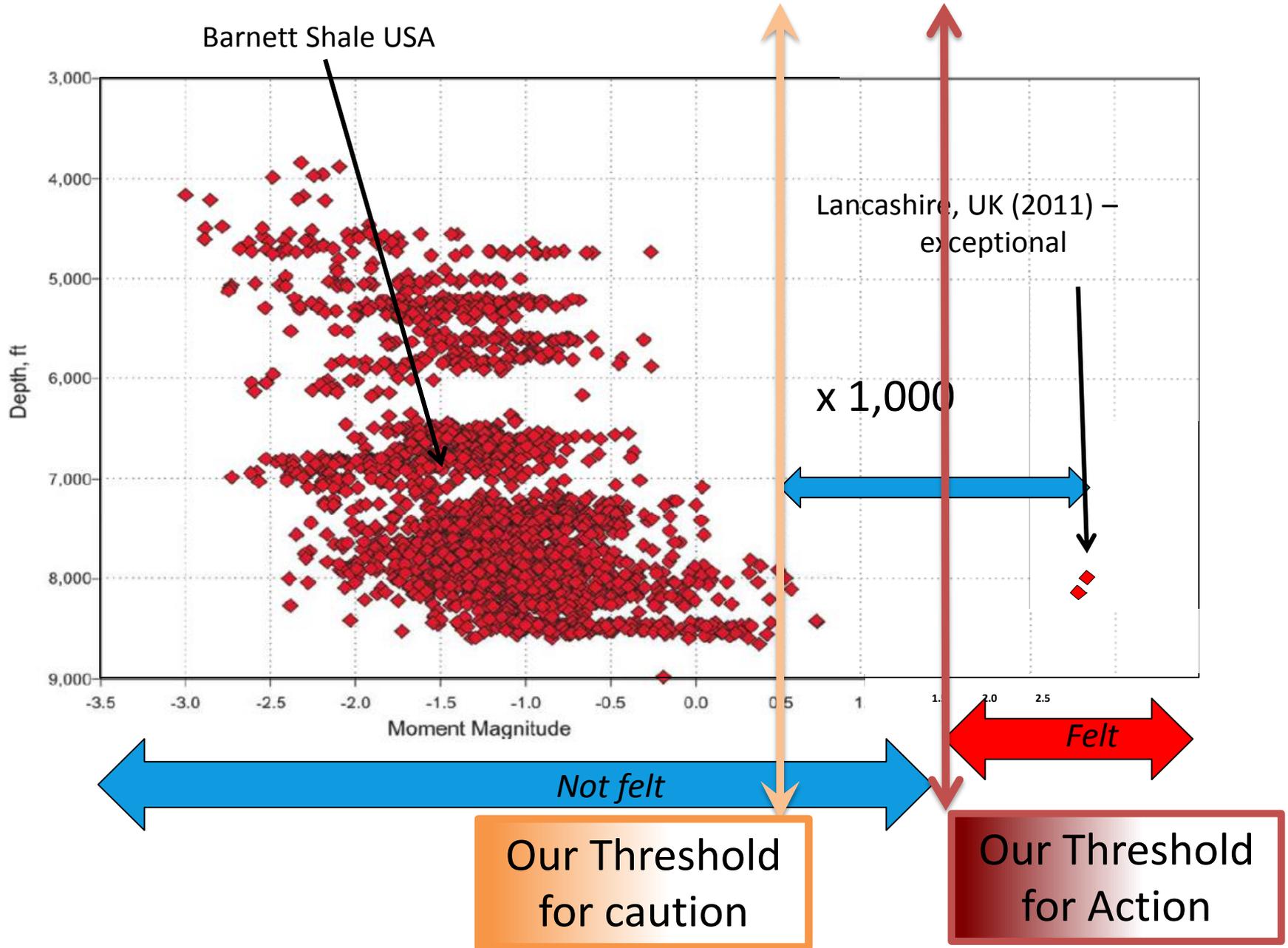


Slickensided and Polished Bedding Surfaces at
two levels in the Preese Hall Borehole
Left 8185 Feet : Right 6835 Feet

Preese Hall - 1



Seismicity: When shall we do something?

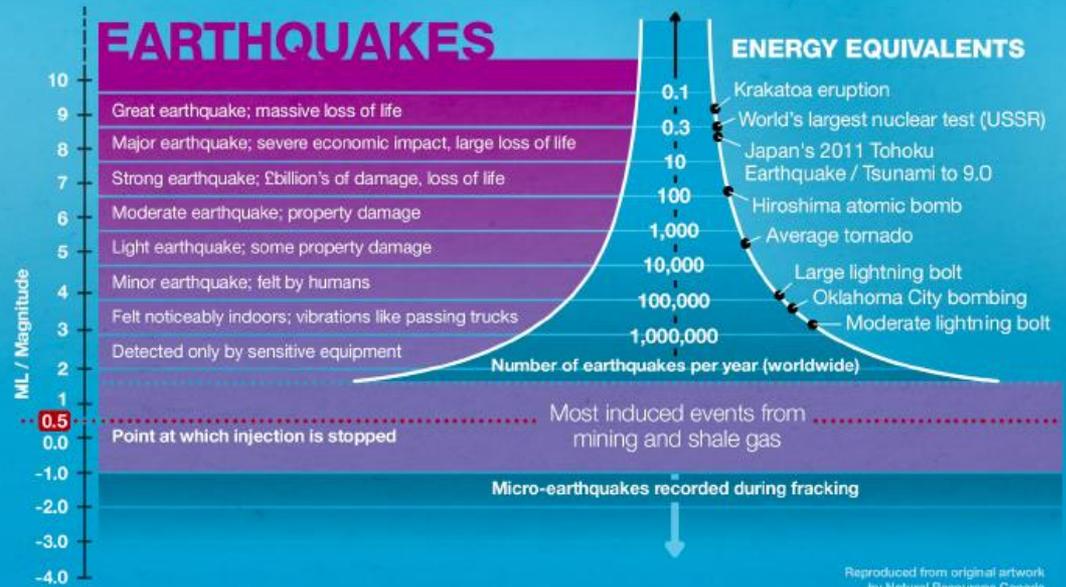


Traffic light monitoring system

Controls are in place so that operators will have to assess the location of faults before fracking, monitor seismic activity in real time and stop if even minor earth tremors occur.

If a magnitude greater than ML **0.5*** (0.5 on the Richter scale) is detected operations will stop and the pressure of the fluid will be reduced. This level should limit further earthquakes, known as 'induced seismicity', which may happen after the pumping is completed.

**subject to review and may change.*



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The Triangle of Truth for Shale Gas

Technically
possible?

Economically
Deliverable?



Societally
Acceptable?

Lardon and Guinevere

“The Nights of the Round Plastic Picnic
Table”

Barton Moss (iGas site)

Protestors blog:

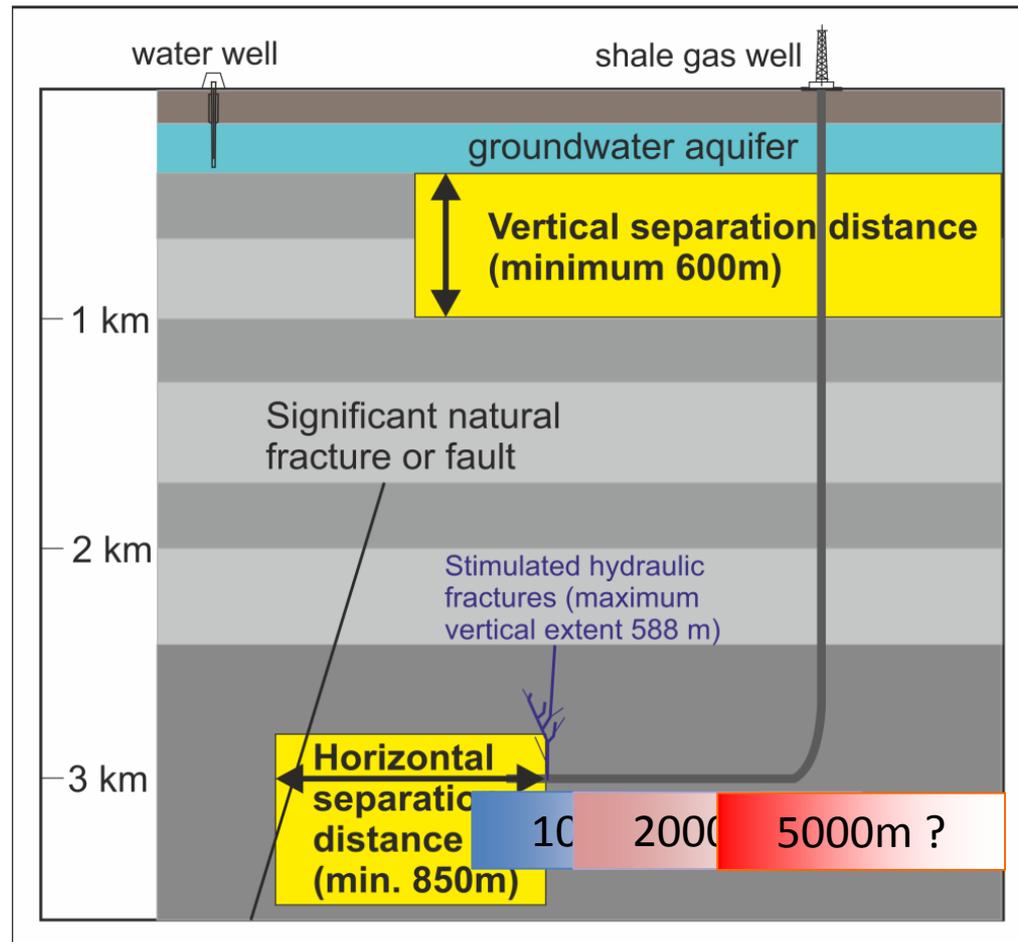
“We have run out of
Gas, please send
more” !

The warrior's call - pagans united against fracking

Conclusions

- Hydraulic fracturing can induce felt events in the UK from within the sedimentary (not basement) rocks:
 - Temporal correlation with injection: 0-1 hour time delay
 - Spatial location deeper than hydro-fracturing
 - Screen outs should be taken very seriously
- Monitoring is essential to enable mitigation
- Install local network as soon as possible before any activity starts
 - Detection, location and mechanisms
 - Ground motion scaling needed but not yet available
 - legal limitation eventually should be based on PSHA

Preliminary Recommendations to UK PM's Office



Fear and Trembling at Number 10!!

