

Earthquakes and Unconventional drilling in the Weald Basin

David Smythe

Emeritus Professor of Geophysics, University of Glasgow

CV

Wallington County Grammar for Boys (1959-65)

- 12 O-levels, 3 A-levels

University of Glasgow (1965-73)

- BSc (Geology) 1970, PhD (Geophysics) 1986

British Geological Survey (1973-87)

- Marine Geophysics and Hydrocarbons groups

University of Glasgow (1988-98)

- Chair of Geophysics

- Onshore 2D and 3D seismic acquisition, processing

Post-retirement (1998-present)

- Consulting for oil industry (2002-11)

- Researching unconventional US and UK (2012-to date)

I know and love this area, having lived during my teenage years in Wallington (now part of the London Borough of Sutton)

Talk structure:

Weald oil exploration history

UKOG at:

Broadford Bridge

Horse Hill

Earthquakes

Conclusions / way forward

Once upon a time ...

Holmwood Station

DORKING HORSHAM & SHOREHAM BRANCH

Brick & Tile Works



Beare Green
Village Hall

Goods Depot

98

Brickkiln

... in the Weald – country people went about their business - blacksmiths, farriers, thatchers, farmers, woodmen, charcoal burners, stockmen, milkmaids, cobblers, maltmen, oilmen

BGS Weald report 2014*

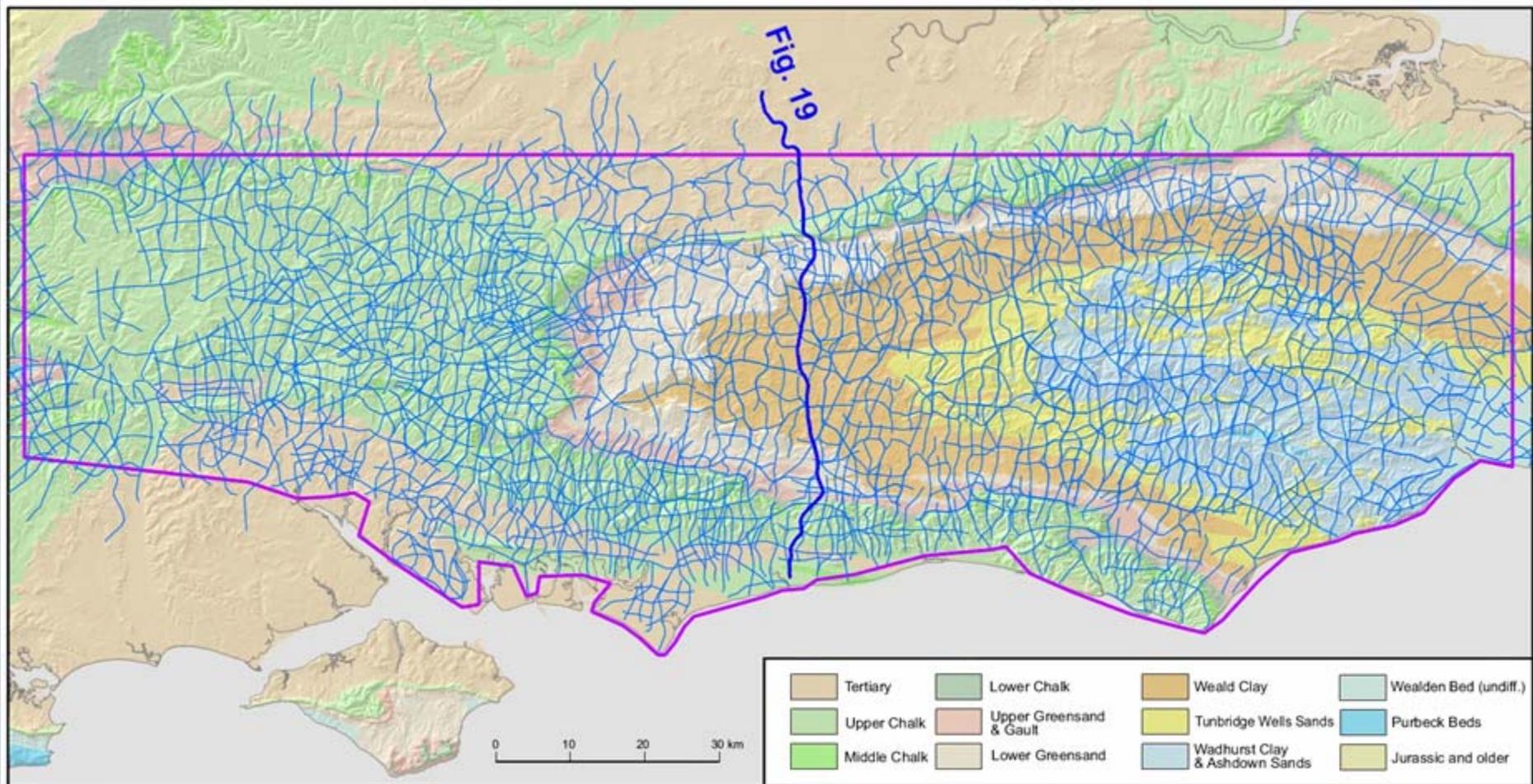


Figure 12. Location of 2D seismic profiles used to assess the shale potential of the Weald area, southern Britain. The location of the regional 2D line illustrated in Figure 19 is also indicated.

Between the 1960s and 1980s some 16,500 km 2D seismic lines were surveyed by the oilmen, working for the majors in the industry. At £10K/km in today's money these data cost about £165M. The regional line labelled Fig. 19 is shown below.

* <https://www.gov.uk/government/publications/bgs-weald-basin-jurassic-shale-reports>

BGS Weald report 2014

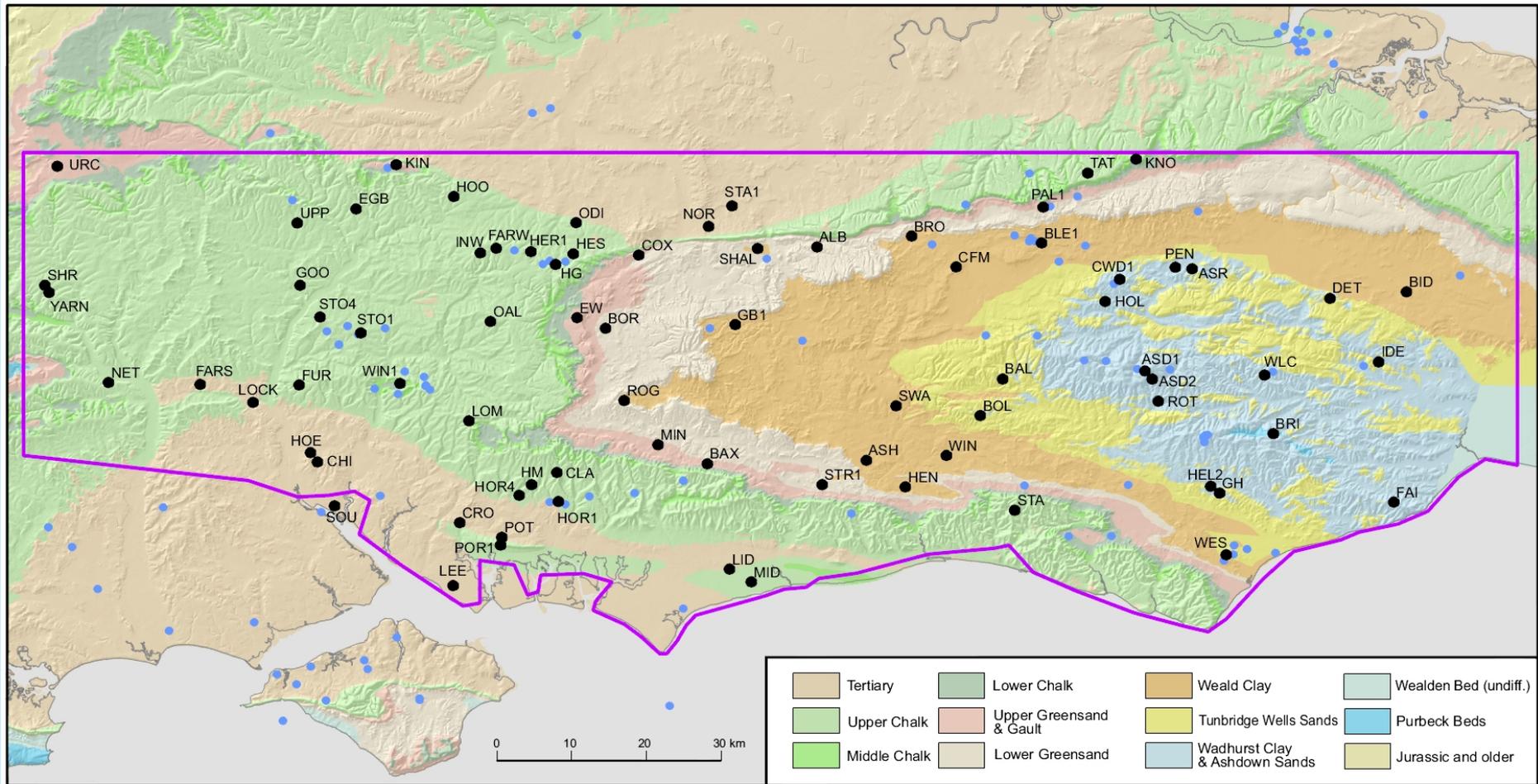


Figure 10. Location of key (black) and other deep wells (blue dots) used to assess the shale potential of the Weald area, southern Britain. See Appendix E for details of well name abbreviations and stratigraphic information.

They then drilled around 155 wells (@ £3M = £465M cost in today's money). All these data are released after a confidentiality period of 4 to 5 years, so that the next generation of explorers and academics can benefit from it. The data are not free, but cost of the order of 0.1-1% of the original price.

BGS Weald report 2014

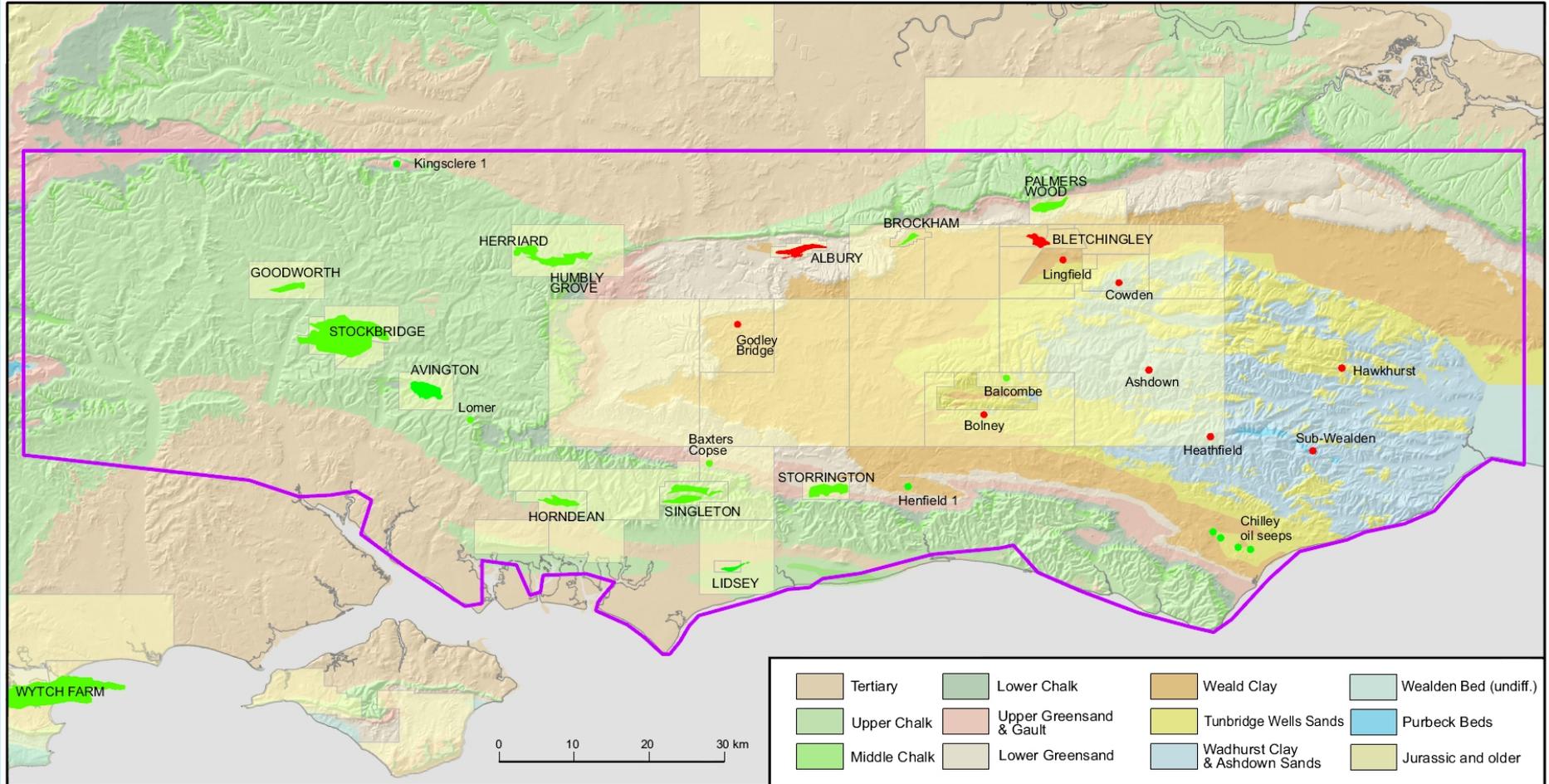
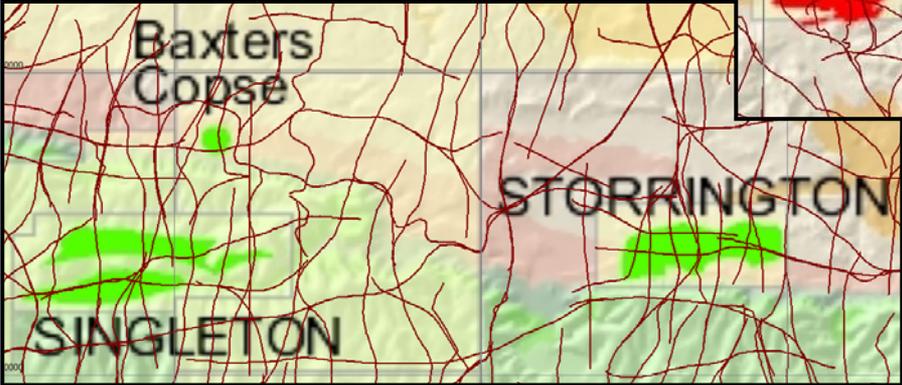
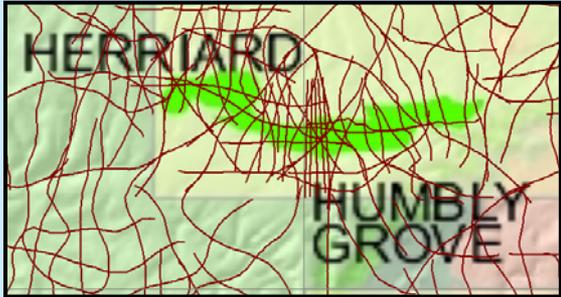


Figure 3. Distribution of producing oil and gas fields and other wells which have tested gas and oil in southern Britain (from DECC data). Green = oil, red = gas; capitals = producing, lower case = other discoveries. Minor surface oil seeps at Chilley (Sussex) are also indicated. Background is outcrop geology with hill shading, also showing petroleum licences as of April 2014.

Oil fields (green) and gas fields (red)

Weald **oil** and **gas** fields

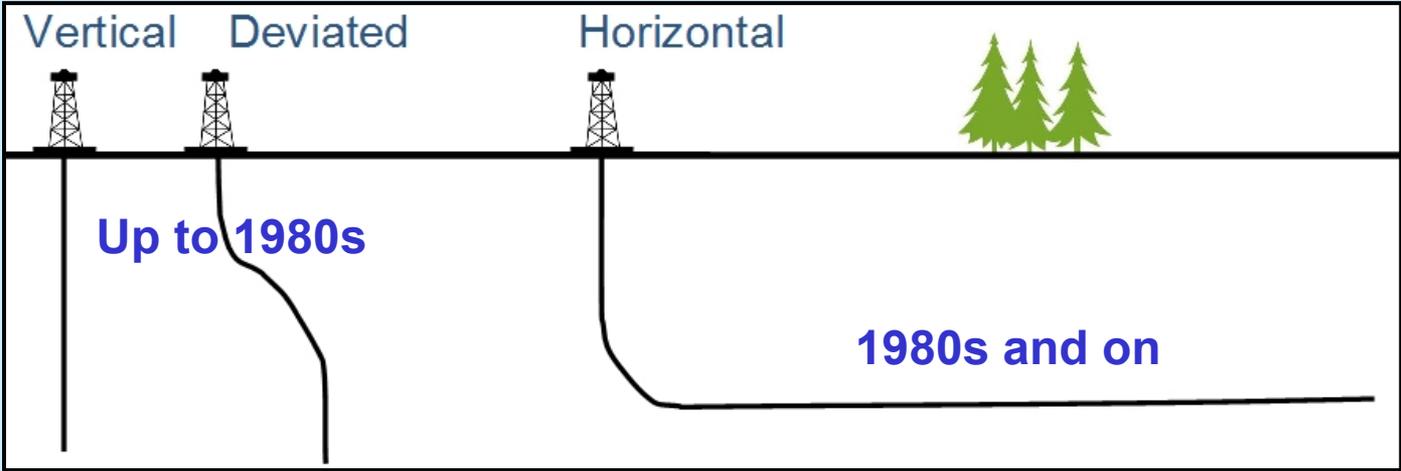


10 km

The conventional structures are typically 2-6 km long and 1-3 km wide

They are defined by **seismic lines** at 1-3 km spacing

They were then drilled with vertical or deviated wells by the majors ...



The oil majors in the Weald 1960-1990



*“an unobtrusive cottage industry”**

The majors may not necessarily be honest, but they are generally competent



* David Smythe and Stuart Haszeldine,
letter to *Nature*, 24 August 2017

2010 on – the cowboys* arrive



*Four-year old investment group
with no prior UK oil experience
finds **huge oil province***
below southern England*



The Weald

Amazingly, this had been overlooked by the oil majors for forty years !



****Three times size
of North Sea***

* Not in the sense of Tex Ritter, Roy Rogers, or the Lone Ranger, but in the sense of cowboy builders

Who are the industry cowboys?

Cowboy companies; current and former UK onshore operators

A note by Professor David Smythe

12 May 2019

Company	Well or Site	Incompetent	Misleading	Notes	
Igas	Ellesmere Port-1	1	1		
	Tinker Lane	2			
	Misson Springs	3	4		
	Barton Moss		4a		
Dart Energy	Airth CBM	5	6	7	
Ineos	All licences	8		9	
Cuadrilla	Anna's Road-1	10	11		
	Balcombe-1	12	13	Weald in red	
	Preese Hall-1	14	15		
	Preston New Road	16	17		18
	Roseacre Wood	19			20
Celtique Energie	Wisborough Green / Fernhurst		21	22	
UKOG	Broadford Bridge-1, 1z	23	24	25	
	Horse-Hill-1	26	27, 28,29		
Angus Energy	Brockham	30	31	32	

Cowboy companies: Notes

- 1 Inquiry
- 2 Failed to find expected Bowland Shale, December 2018
- 3 Misson Springs Fault through wellsite not identified
- 4 Risk to groundwater hidden by misleading geology (NB well not yet drilled)
- 4a Permit to drill to coal for CBM but drilled to Bowland Shale
- 5 No plan for avoiding/mitigating faults during horizontal drilling
- 6 Major faults omitted from cross-sections through site
- 7 Since taken over by IGas
- 8 CEO of Ineos Upstream is a chemical engineer; should be reservoir engineer or geologist
- 9 Impossible to fulfil all its licence obligations in agreed licence timeframe
- 10 Tool stuck, so well abandoned
- 11 Abandonment stated to be due to 'over-wintering birds'
- 12 Drilled blind through shallow fault known from BGS maps
- 13 Application for conventional approved then proposal to frack added
- 14 Fracking triggered 2.3 and 1.5 Ml quakes; wellbore flattened; well abandoned
- 15 Minister Charles Hendry called into question Cudrilla's performance and withholding information
- 16 300 m of predicted Millstone Grit found to be missing
- 17 Attempts to bodge up faulty interpretation for Hydraulic Fracturing Plan (HFP)
- 18 HFP currently under reconsideration following report to EA from Prof Smythe
- 19 Poor geological interpretation
- 20 Not yet drilled; HFPs not yet submitted
- 21 Seismic example used section with fault 'wiped out' by reprocessing
- 22 Both applications refused; licences sold to UKOG; Celtique has no more UK interests
- 23 Drilled through fault zone, had to sidetrack; still drilling problems; ; well suspended after poor shows
- 24 Drilled at different angle and to different target from that permitted
- 25 Inherited licence and permit to drill vertically from Celtique
- 26 Severe errors in geol interpretation; nearby old well mispositioned by 150 m; fault zone drilled
- 27 Target Kimmeridge 'Limestone' layers are micrite (calcareous shale)
- 28 'Gatwick Gusher' claims founded on conflating oil in place with recoverable reserves
- 29 Surrey earthquake swarm, summer 2018 may be due to HH-1 activities but daily logs withheld
- 30 Drilling attributed to mix-up over wellheads at wellsite
- 31 Brockham-X4 drilled without permission
- 32 Surrey CC allowed Angus to apply for and get retrospective planning approval

Who are the industry cowboys?

Cuadrilla

Celtique

UKOG

Angus

Problems with current operators/licensees in UK unconventional exploration

- **Potential benefits exaggerated (cf. USA)**
- **Short-term view (pump share price)**
- **Mendacious (e.g. Cuadrilla Lancs, Angus Brockham ...)**
- **Dodgy/underqualified management (e.g. Angus, INEOS Shale)**
- **Underfunded (IGas, Third Energy, Union Jack ...)**
- **Technically incompetent**
- **Arrogant, over-extended (e.g. INEOS)**

New exploration – the problem

Data spacing OK for simple oval structures, vertical drilling

Inadequate for highly deviated / horizontal drilling

Potential solutions:

Restrict drilling to plane of seismic section

Increase density of 2D seismic lines

3D surveys

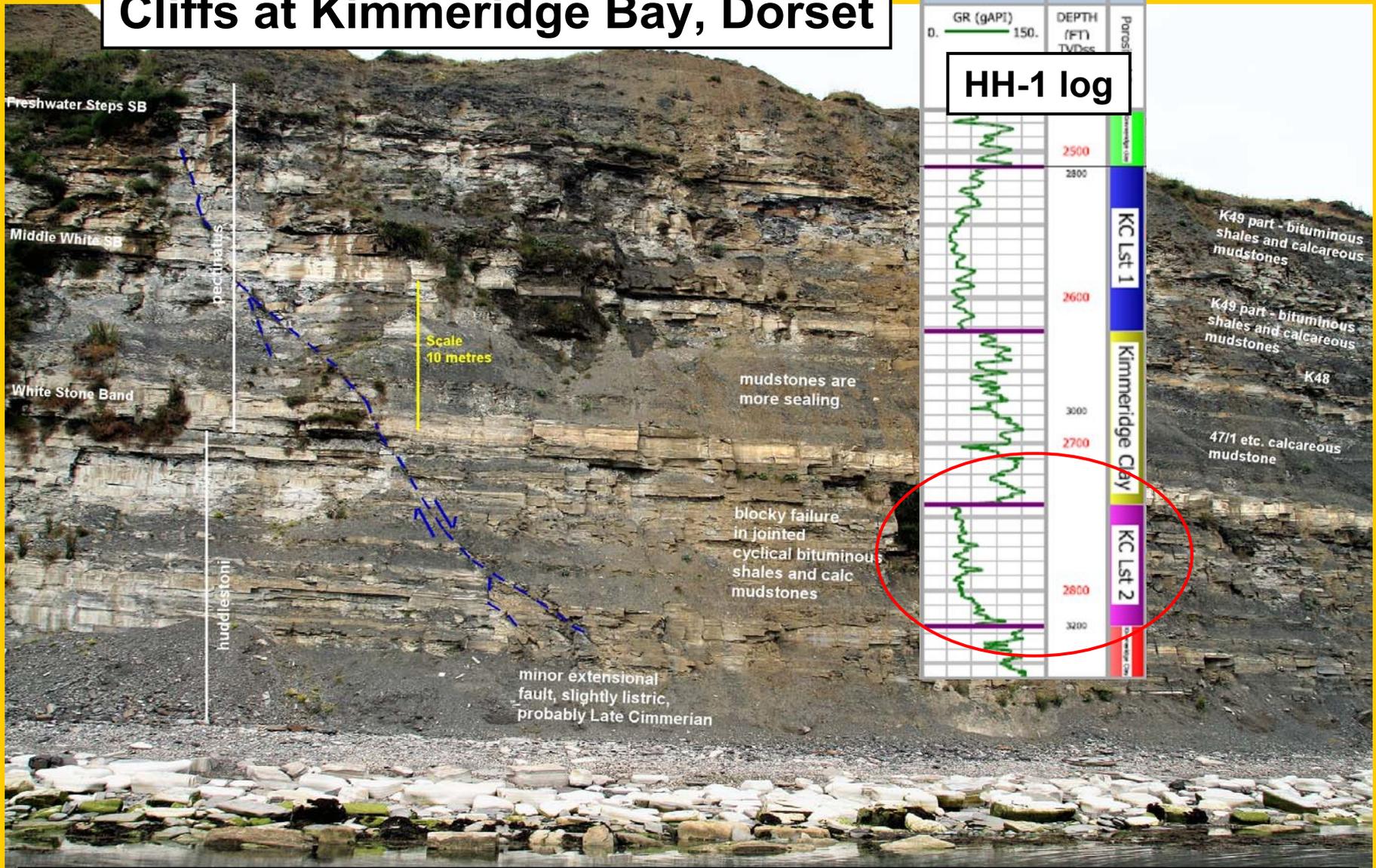
Next:

Problems illustrated by UKOG at Broadford Bridge and Horse Hill

UKOG

Broadford Bridge

Cliffs at Kimmeridge Bay, Dorset

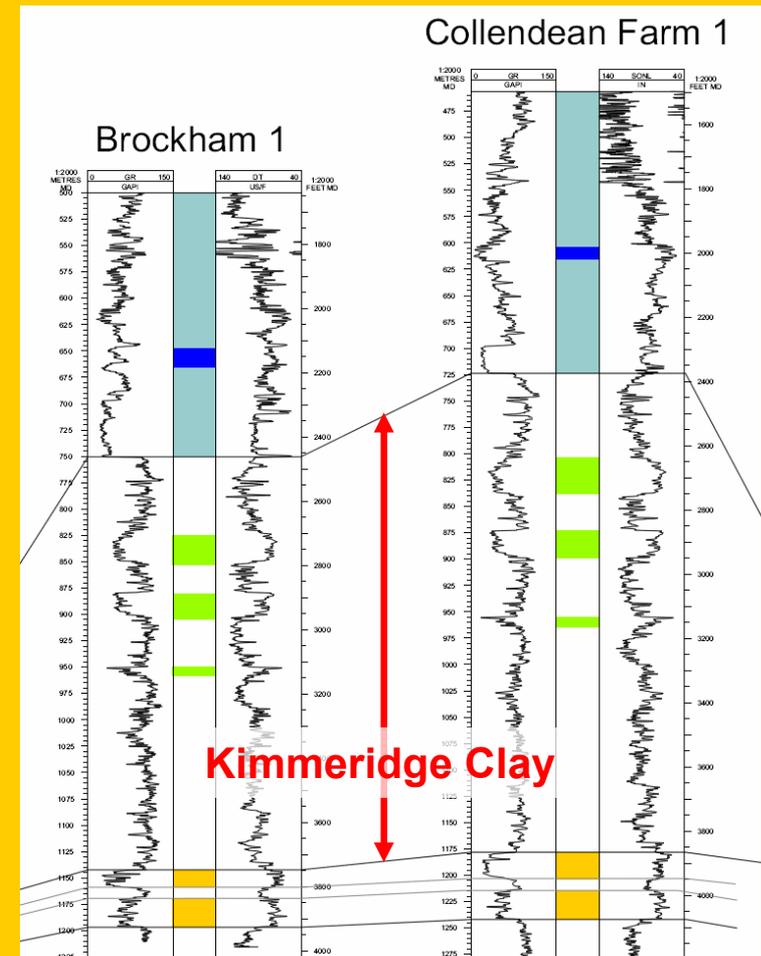


Exposure of lower micrite, 30 m thick, corresponding to UKOG Kimmeridge Limestone 2 in Horse Hill-1 log (circled, scale in feet). In detail, the exposure comprises calcareous mudstones with thin sandstone bands. My log correlation from the borehole at Southard Quarry, just inland from this picture, along 2D and 3D seismic via the Isle of Wight to the Weald confirms that the micrites at depth in the Weald are essentially the same as shown here. Photo © Ian West 2011.

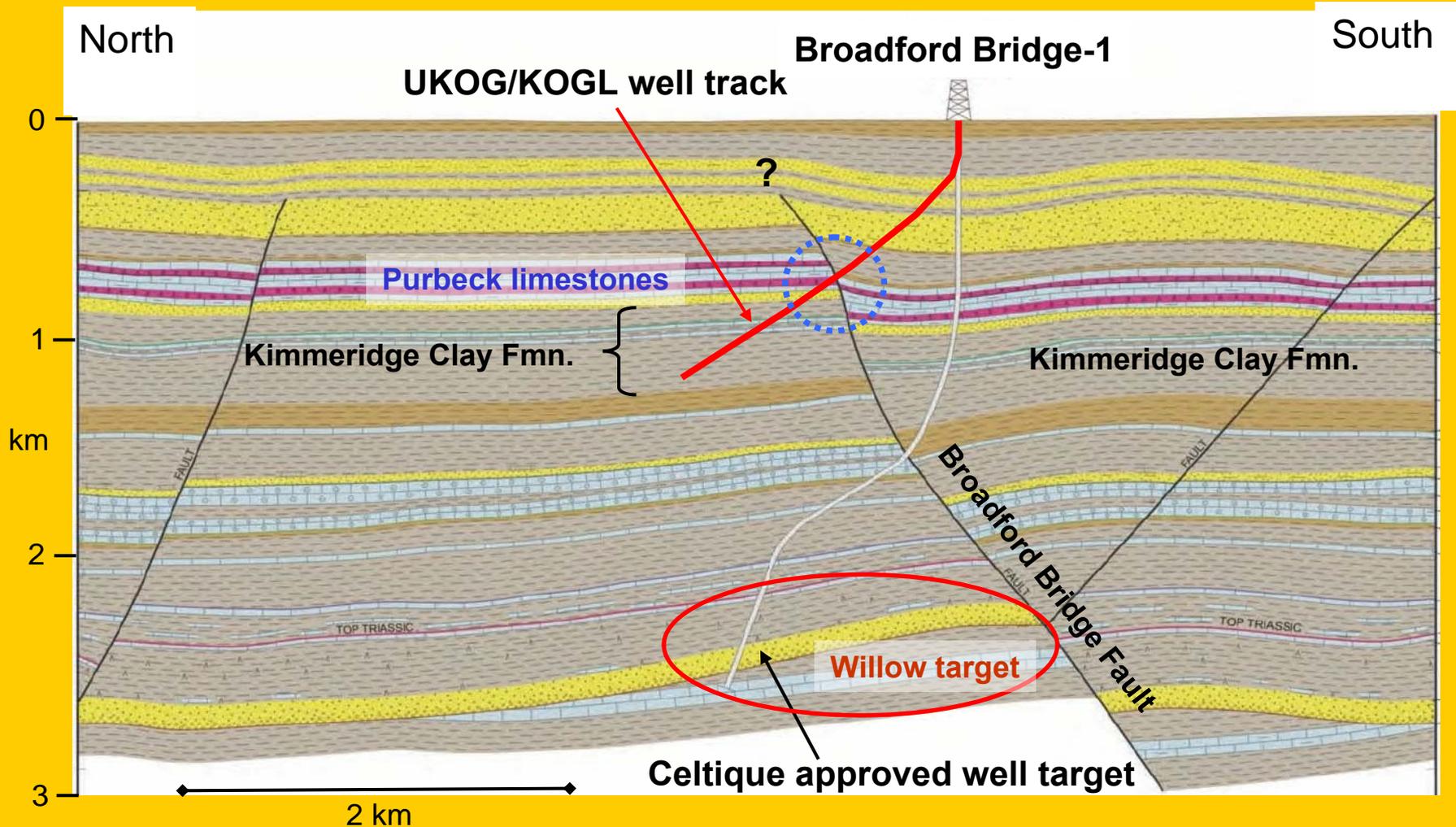
UKOG Kimmeridge target

- Kimmeridge Clay Formation is tight
- Traceable Kimmeridge Bay to Weald
- The majors found only oil shows at best
- The KCF is mostly shale
- The so-called 'limestones' up to 30 m thick (shown in light green) are micrites (calcareous mudstones)
- BGS recognises 2 main micrites + 1 subsidiary
- But UKOG sees five 'limestone' layers

BGS Weald well correlation- extract



Broadford Bridge

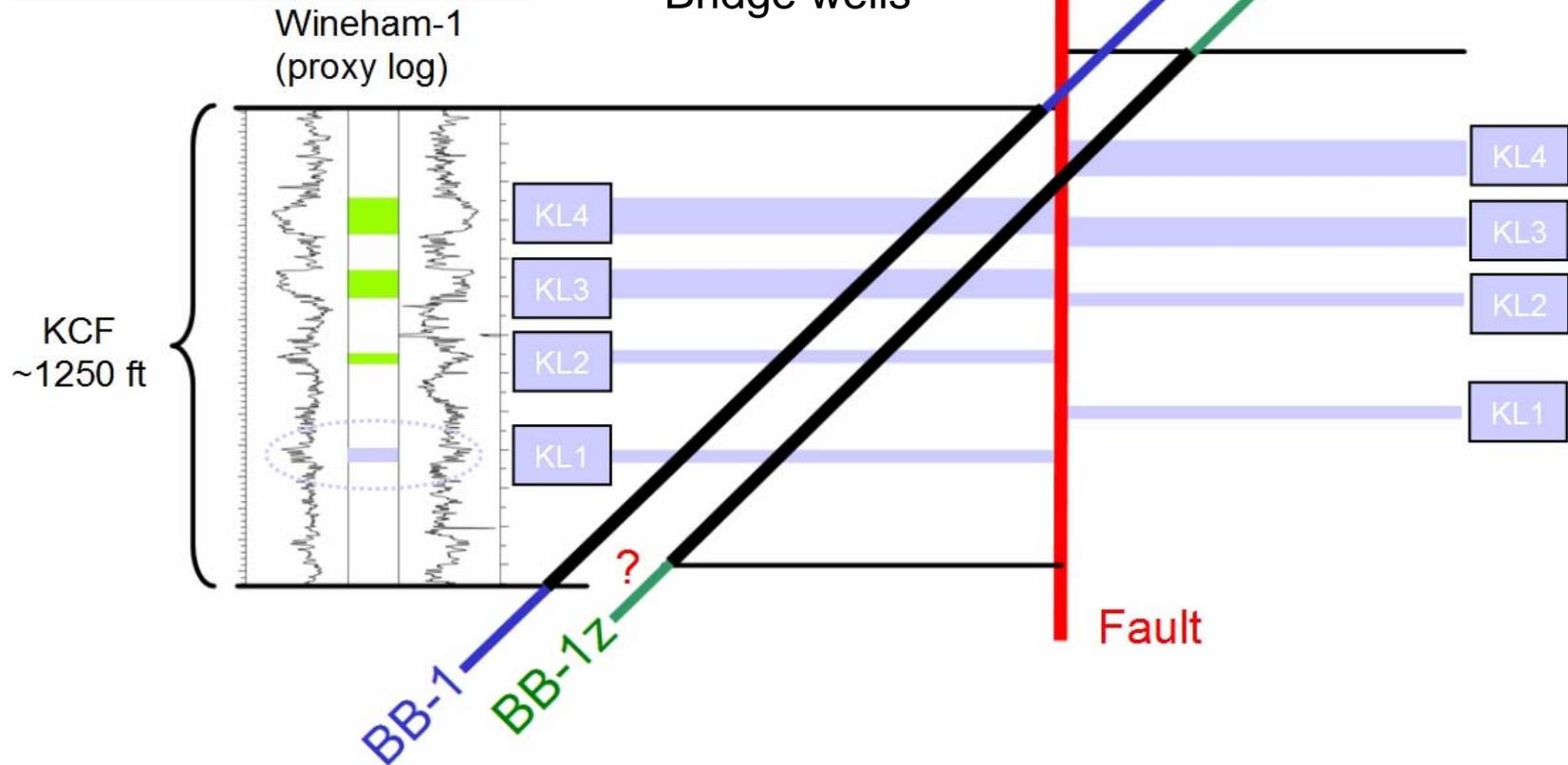


But UKOG subsidiary KOGL illegally flouted the permit, drilling a very steeply inclined well at a different azimuth to test the Kimmeridge Clay Formation. In doing so they encountered borehole washout problems because they were crossing the Purbeck Limestones at a fault zone. KOGL then had to sidetrack. The next diagram shows a reconstruction of the main well and the sidetrack.

Broadford Bridge

UKOG incompetence

Accurate cross-section through the two Broadford Bridge wells



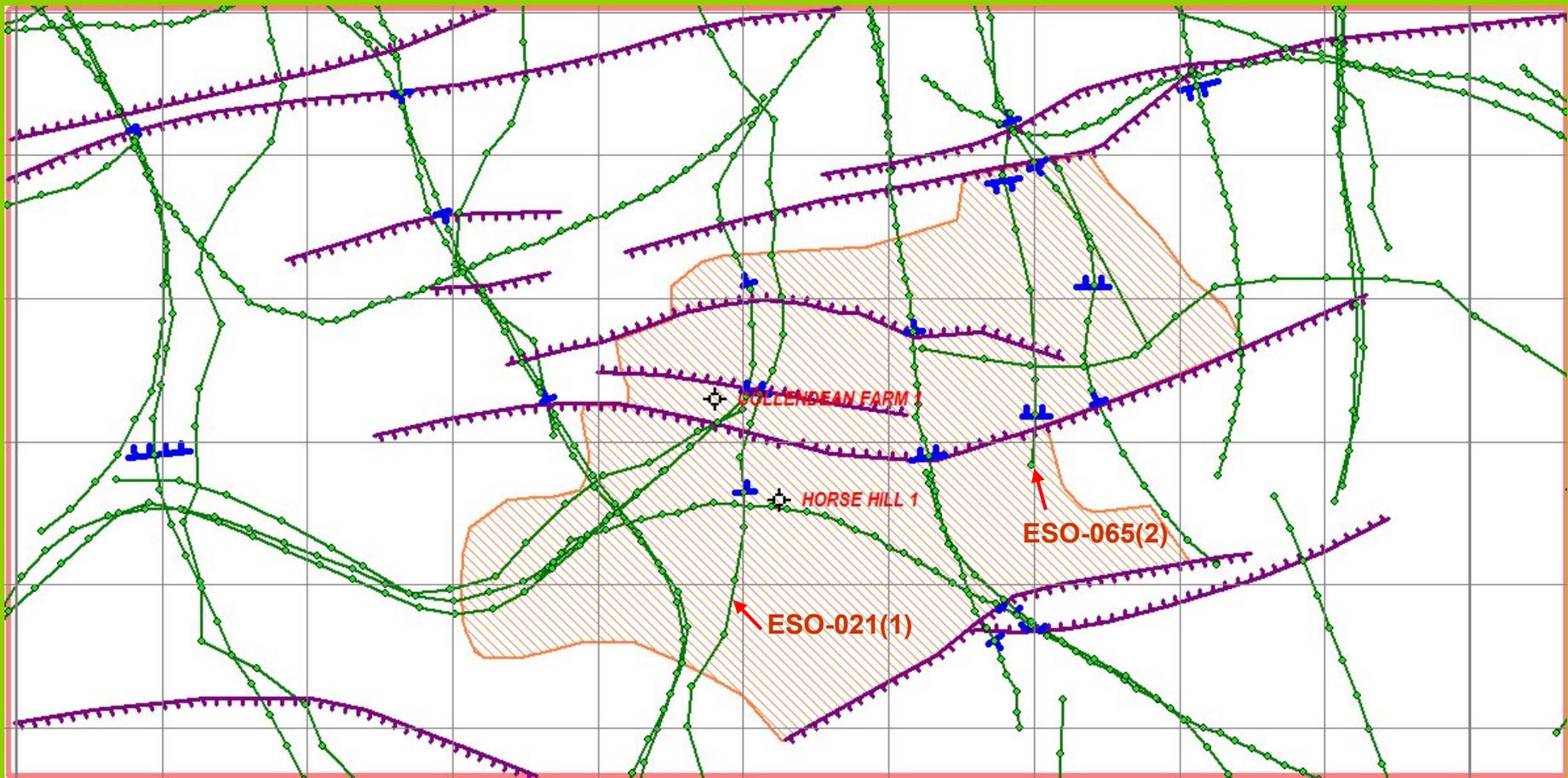
UKOG / KOGI Broadford Bridge drilling fiasco

I have interpolated the tops for the micrites by using nearby Wineham-1 as a proxy, scaled to the Kimmeridge Clay Formation thickness here. The light green micrites are as recognised by the BGS. KL1 is dubious; My explanation of the fifth 'limestone' seen by KOGI is that KL4 has been penetrated twice by going through a fault, so that UKOG's KL5 = KL4.

UKOG Horse Hill

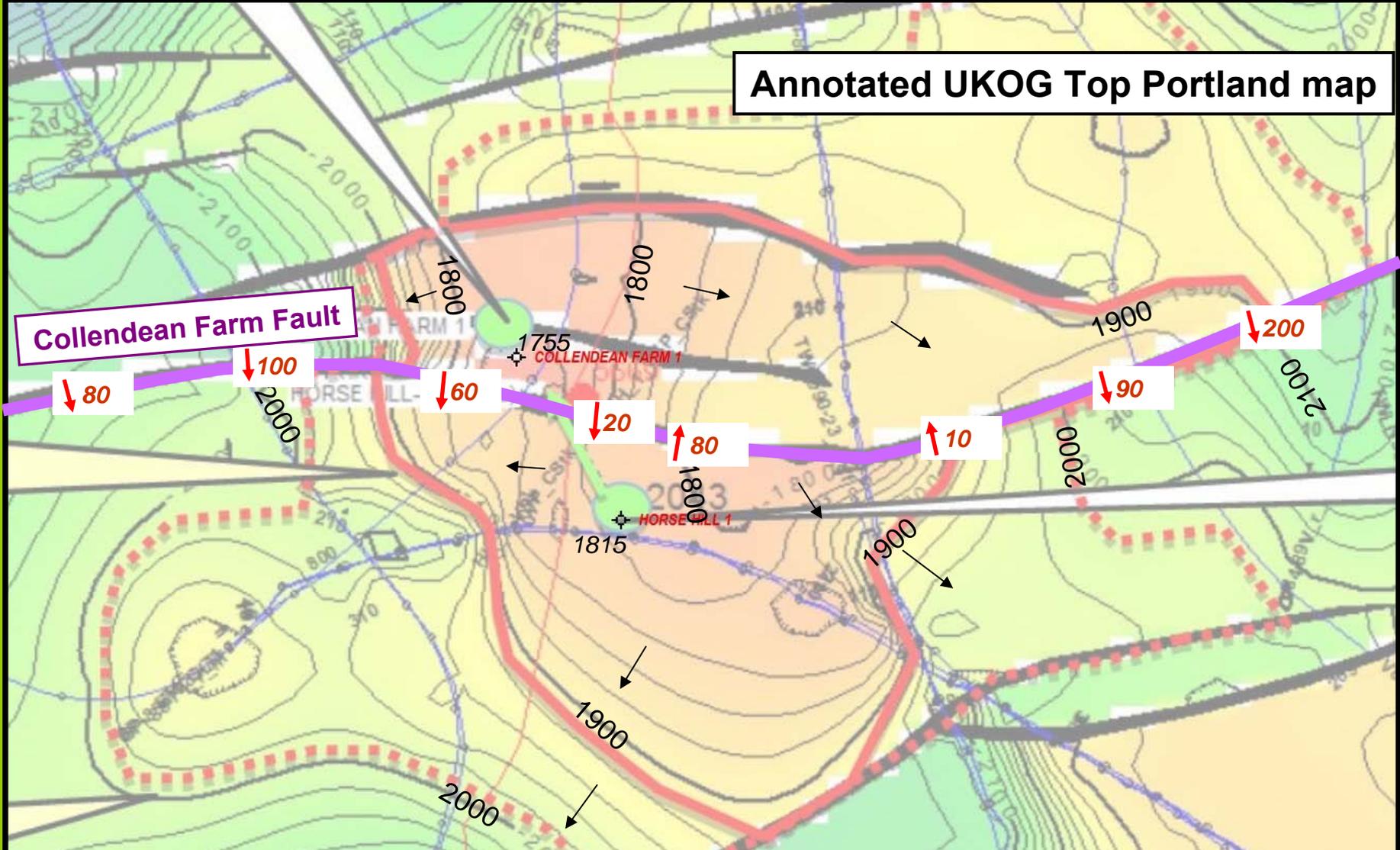


Site entrance. Credit: © Ian Capper.



This is the UKOG maximum Top Portland prospect (orange) with the available seismic data (green lines with shot-points marked). Not all of these lines were used in the UKOG interpretation of faults, shown by purple toothed lines. I have marked with short blue toothed lines my version of the locations of faults at around 400 ms depth, at approximately the Top Portland. Two very old Esso seismic lines dating from 1962 are labelled (prefixed ESO-); they were not used by Magellan/UKOG.

Annotated UKOG Top Portland map

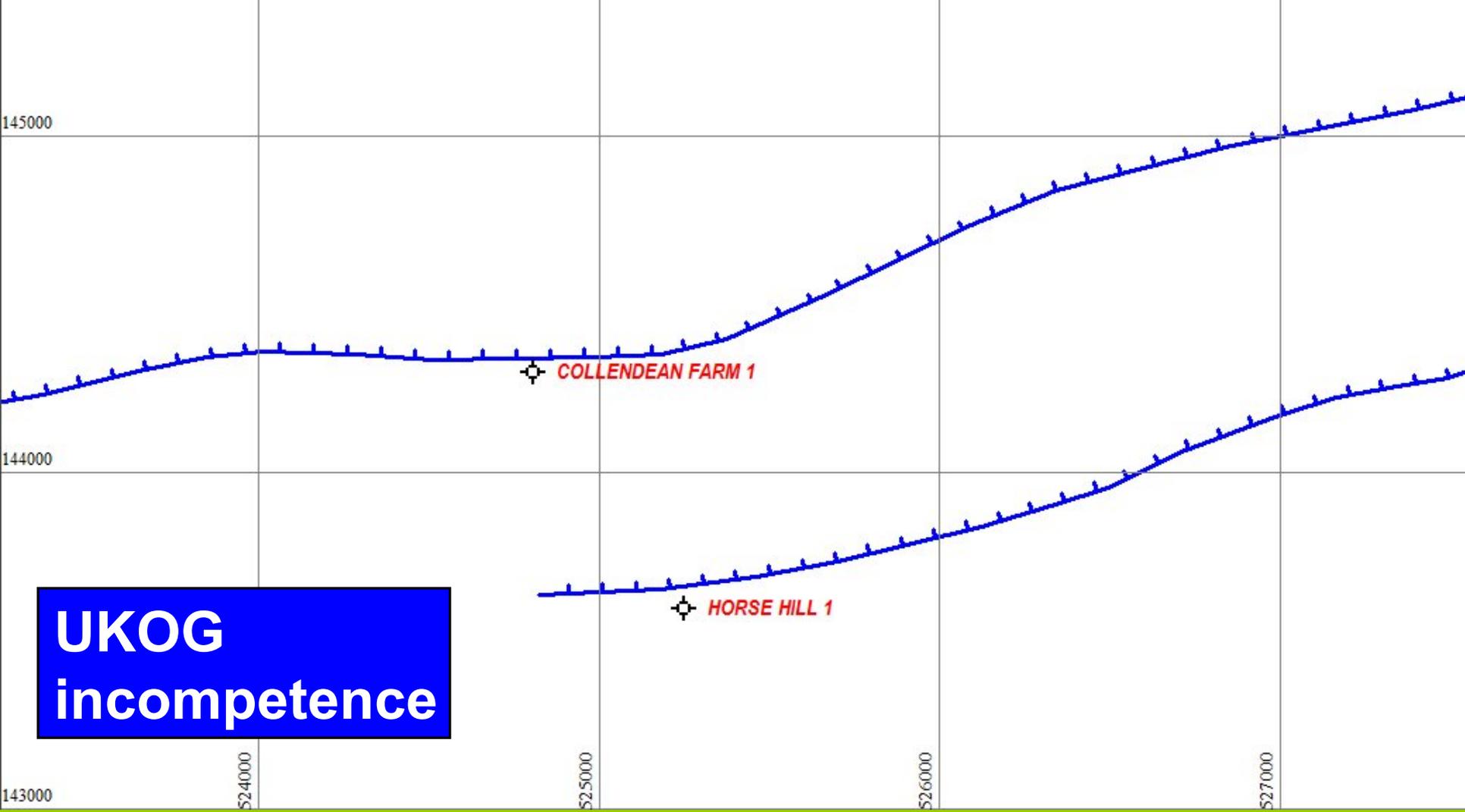


[Before HH-1 was drilled]. Labelling is in feet below sea level. The dashed red line corresponds to the maximum closure. Local dip directions are shown by black arrows, and the local throw (the vertical displacement) along the Collendeen Farm Fault is shown by the red arrows pointing to the downthrown side. Note the local change of sense of throw, NE of HH-1. The depth at the two wells is marked. Note that the Top Portland at HH-1 is deeper than at CF-1 (drilled by Esso in 1964) by 60 ft (18 m). The Magellan/UKOG location of CF-1 is in a stream, 150 m NW of its correct location, which is in a field next to Collendeen Farm.



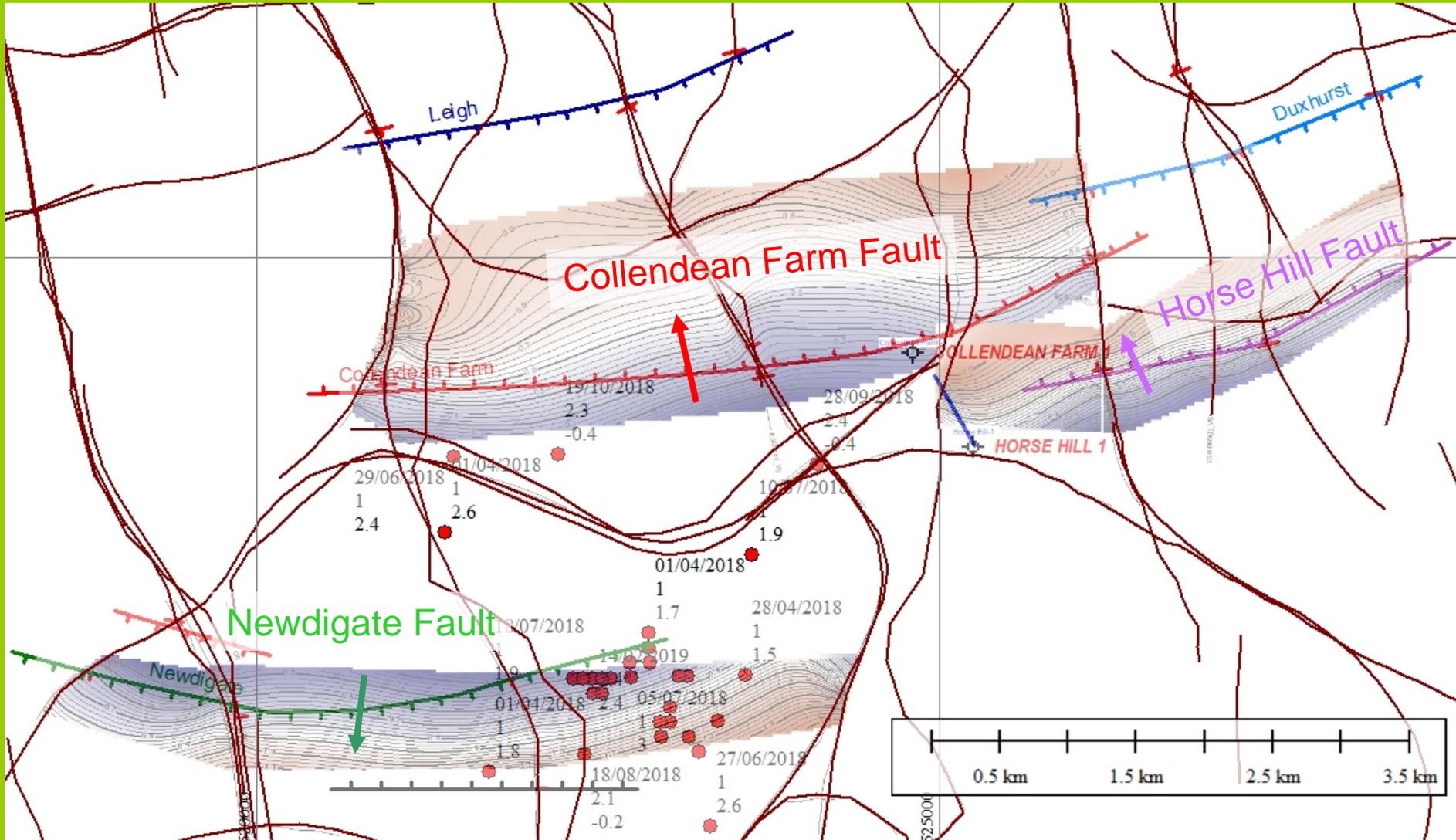
**UKOG
incompetence**

**Magellan / UKOG fault interpretation, after HH-1 drilled.
Fault now 'adjusted' to change sense of displacement (arrows)**



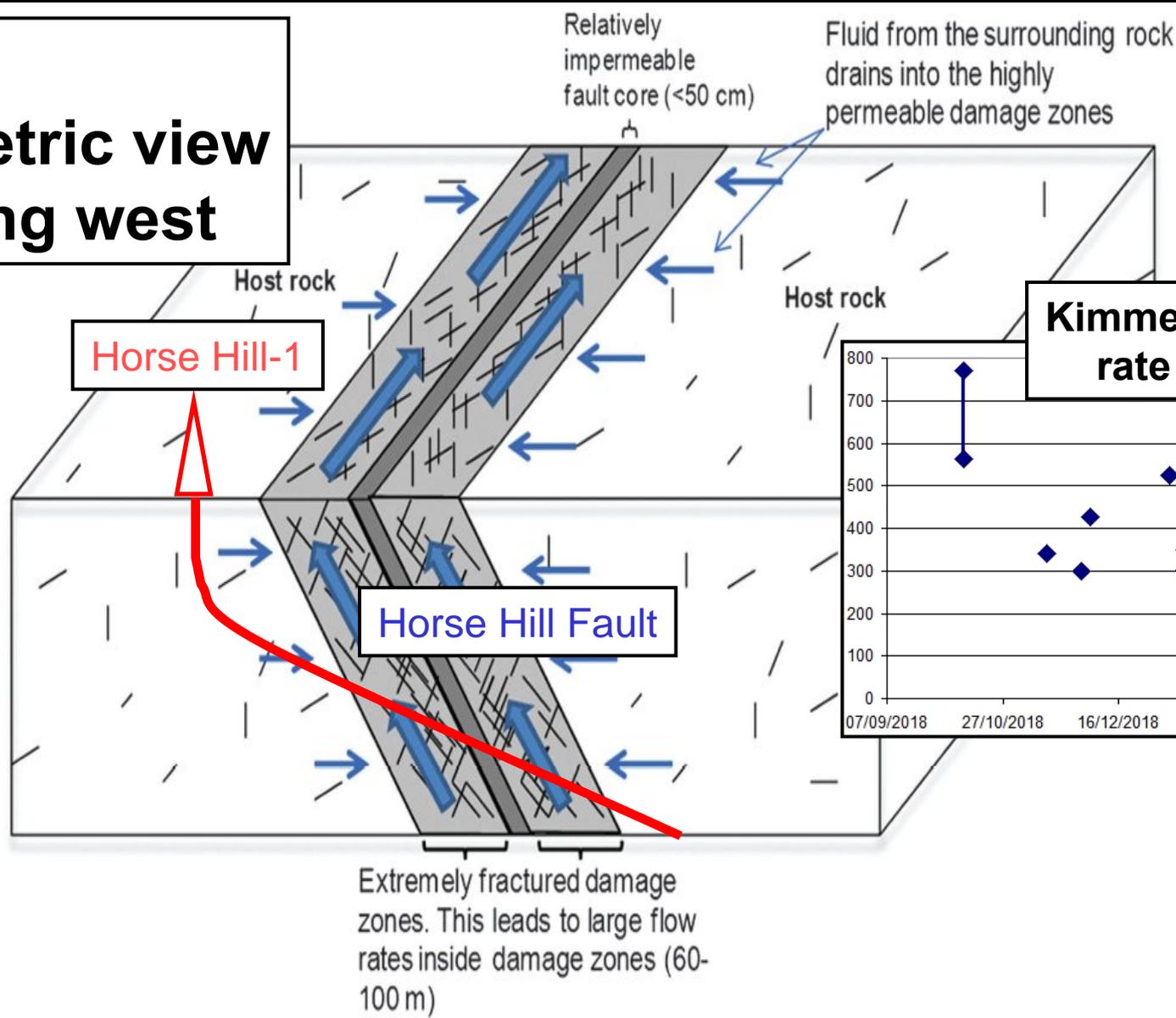
DKS fault interpretation

Fault surface maps and earthquake epicentres

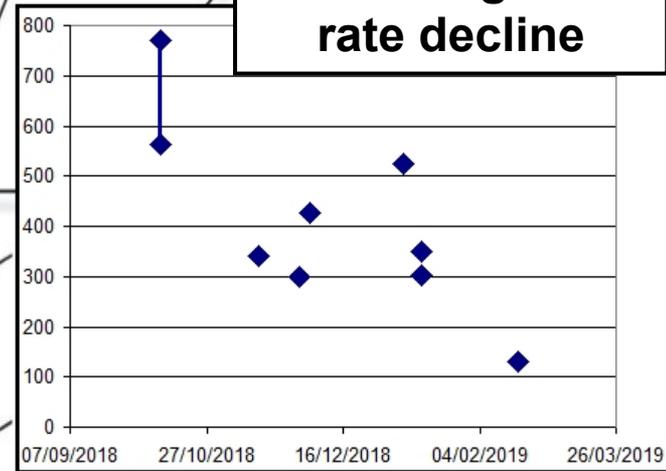


In my interpretation the Collendean Farm and Horse Hill Faults are clearly separate structures. Horse Hill-1 was drilled into the Horse Hill Fault. Most quakes (red) are associated with the Newdigate Fault. The coloured surfaces are the respective three faults, contoured. The toothed lines are the locations of the various faults at around Top Portland level.

HH-1 Isometric view looking west



Kimmeridge flow rate decline



HH-1 was drilled c. 100 m south of the Horse Hill Fault, and deviated north into fault damage zone, accounting for the temporary high flow in the Kimmeridge Clay Formation, as predicted by myself in August 2017. Similarly, the high flow was predicted to be of short duration. The rapid decline in flow of the Extended Well Test is shown in the inset, again, to be expected from drilling a fault zone.

Comment on UKOG interpretation, post–Horse Hill-1

- Mapping of the Collendean Farm Fault is fundamentally flawed.
- Large fault with a downthrow to the north been mapped with a mainly opposite sense of throw
- Automatic contouring program has produced geologically unlikely results
- Location of CF-1 is 150 m too far to NW, in a stream.
- Horse Hill-1 has been drilled obliquely into the Horse Hill Fault.
- Kimmeridge flow rate is declining rapidly as predicted.

Next – production plans

UKOG's original plans for Kimmeridgian production (2016)

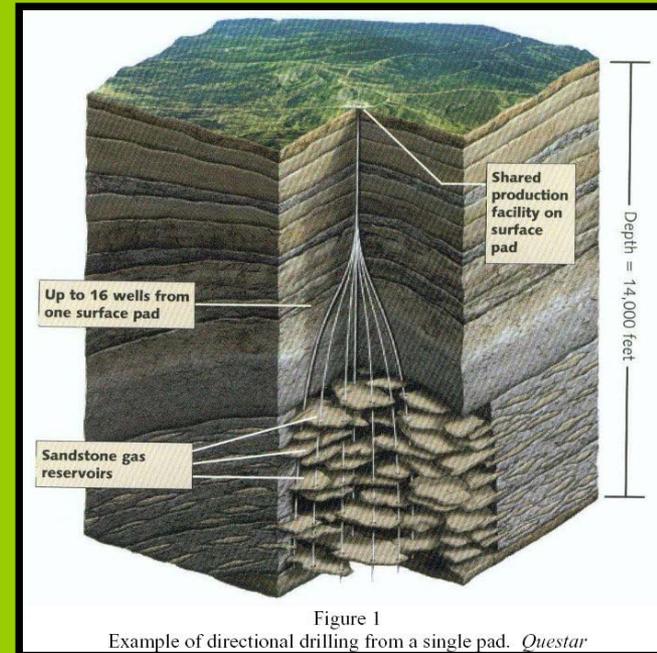
The UKOG production plan (below left) seems to have been copied from the tight sandstone reservoir exploitation in the Jonah Gas Field, Wyoming (below right). Note that the Wyoming wells are fracked, and that the Wyoming scale is five times bigger than the Weald picture.

KIMMERIDGE LIMESTONE OIL PRODUCTION



Can be produced with low visual impact

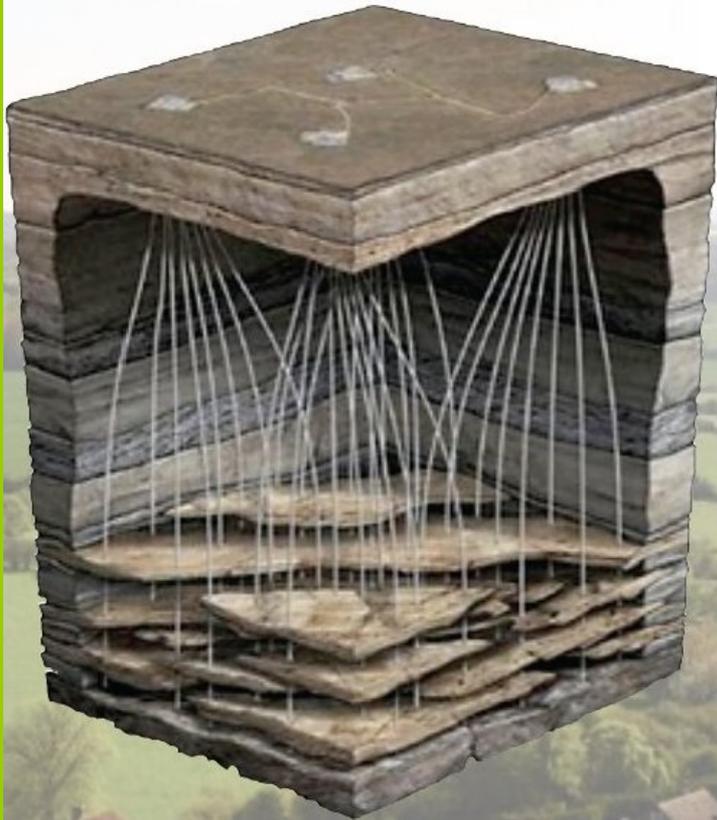
- 12-24 wells in 4-6 acre site
- Wells and pumps below ground level
- Control production to reduce initial road tanker impact
- Can be located in brown field sites and away from villages, houses, small roads



UKOG: Kimmeridge Clay Formation

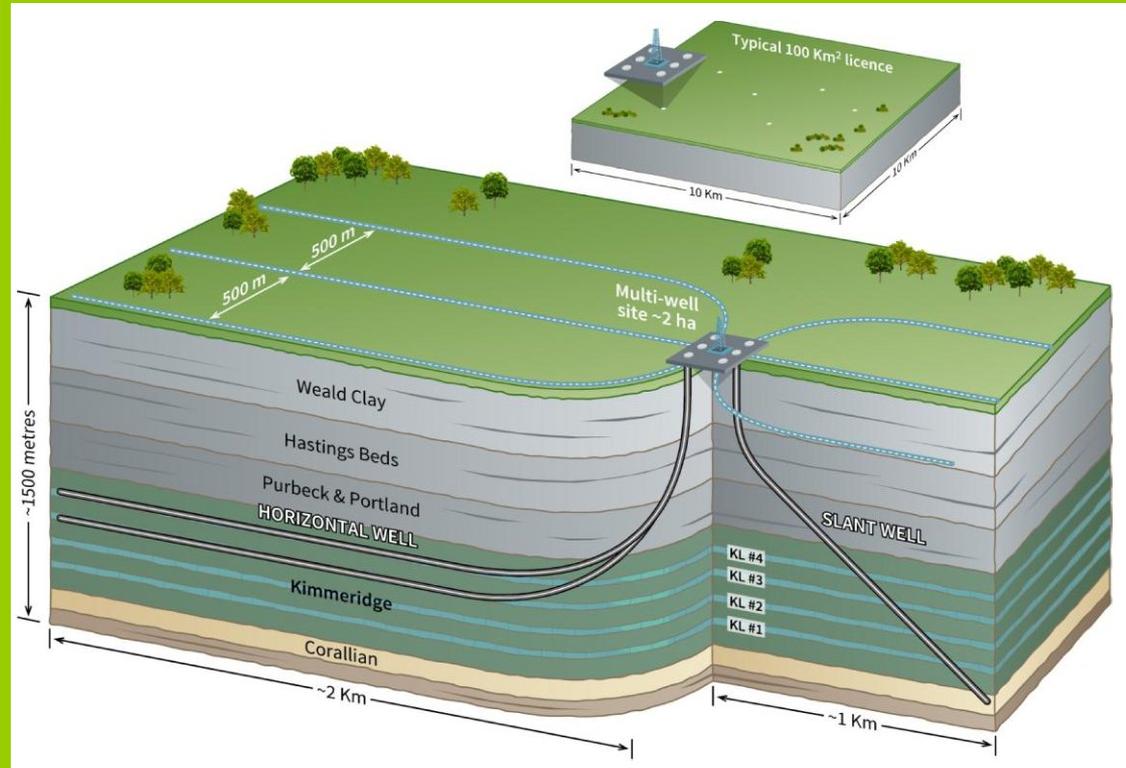
Questar, 2005: tight sandstone gas reservoir, Wyoming

UKOG: Evolution of schemes for multiple deviated wells from one wellpad



May 2016

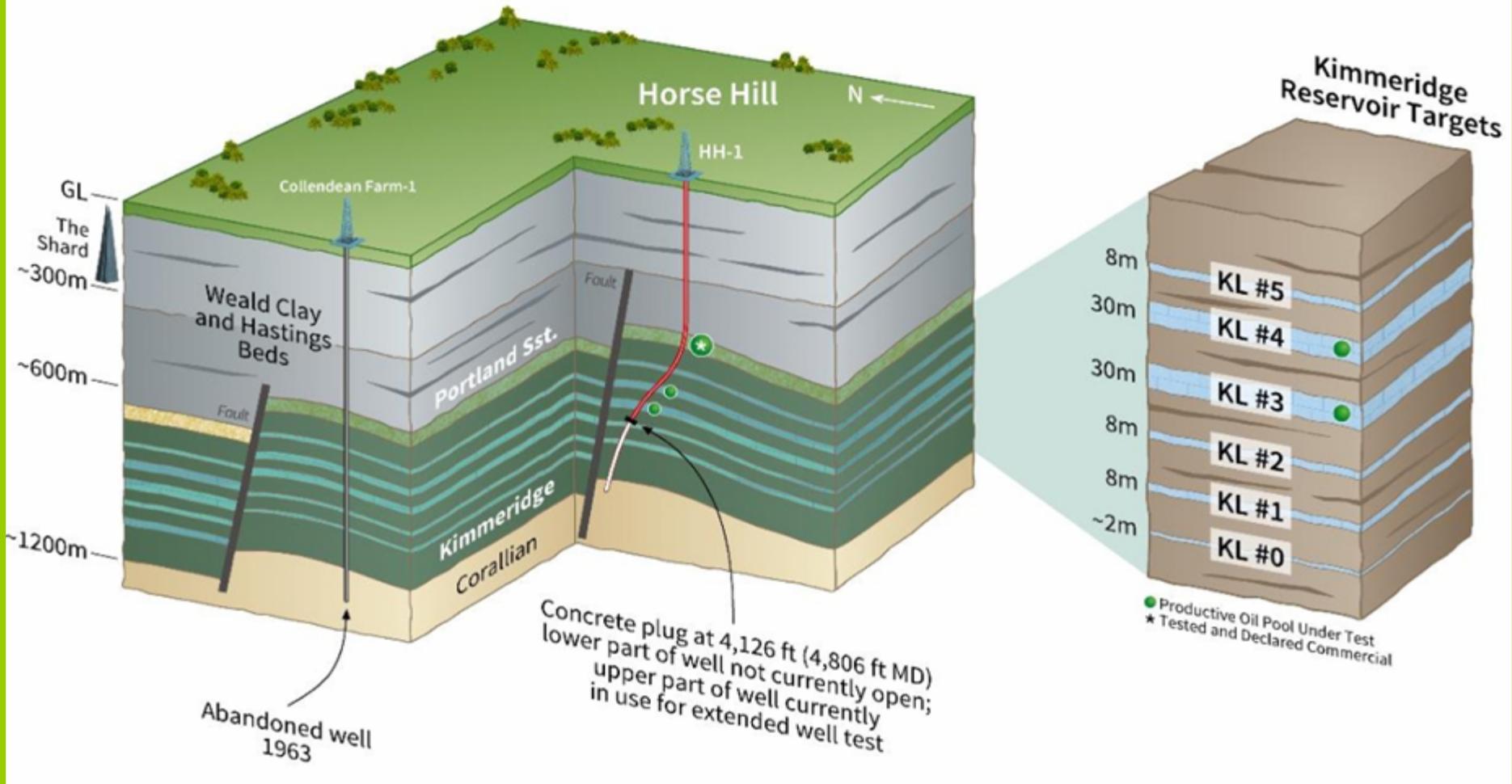
May 2017



But a year later UKOG completely modified its production scheme, now favouring slant and horizontal wells in an apparently unfaulted planar geology.

HH development plans

ES Figure 1: Current Status of Horse Hill Well Site¹²



This cartoon implies two separate faults, because if there were only one fault it would have to appear on the south-facing vertical section. But such cartoons are no substitute for proper maps. Note the new claim of a sixth 'limestone' (#0, lowest).

HH development plans

Plan view proving two faults

Old UKOG
fault
version

Collendean
Farm-1



Collendean Farm Fault

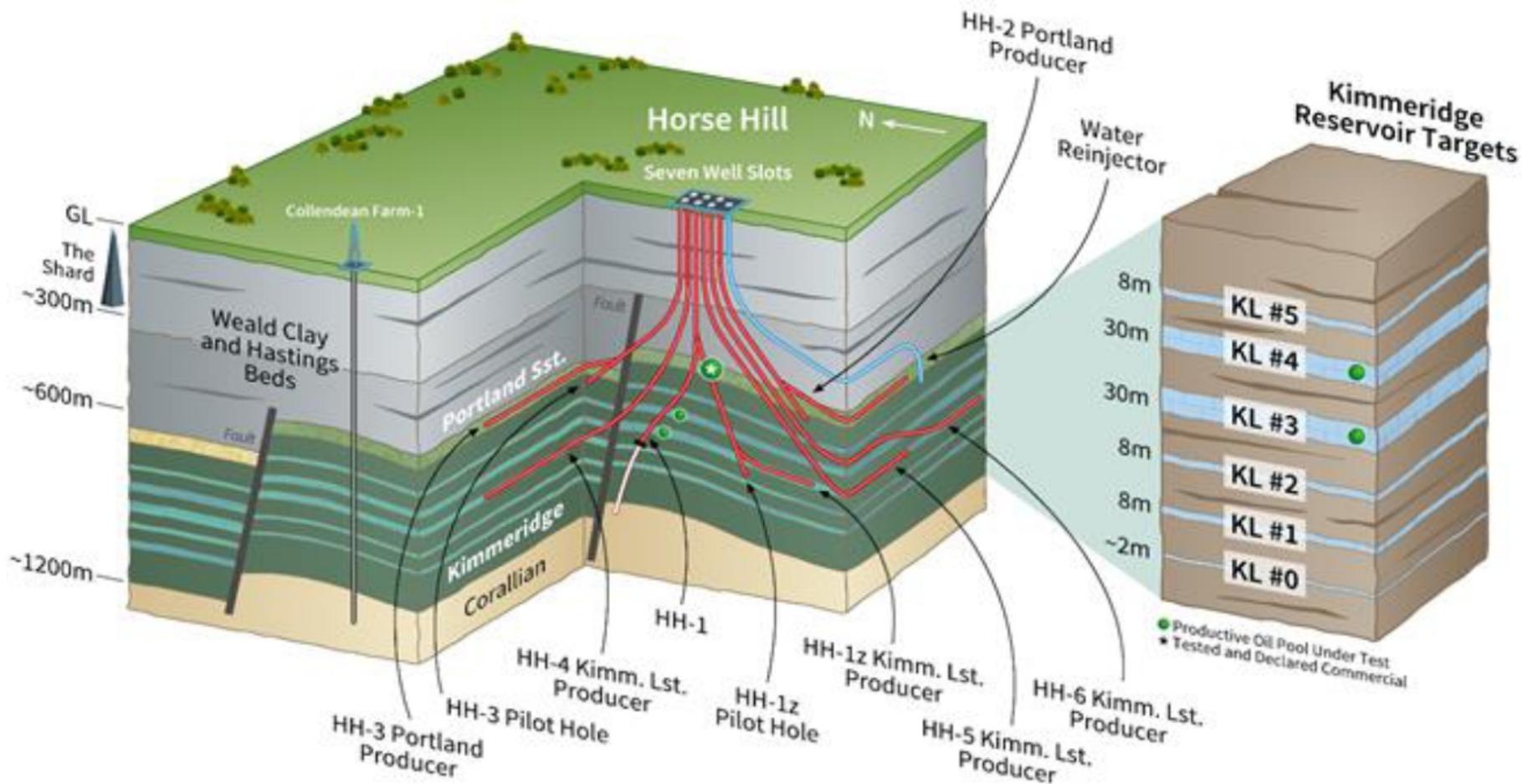
Horse Hill-1



Horse Hill Fault

This is a plan view of the previous diagram, demonstrating that the previous UKOG single fault story is no longer current. Presumably UKOG has now adopted the Smythe interpretation, but in any case UKOG needs to explain its revised geology in much more detail than just by a cartoon.

HH development plans, late 2018



ES Figure 5: Proposed Development at Horse Hill Well Site¹²

This cartoon grossly is insufficient in detail for a serious production planning application. But the required detail has not been submitted.

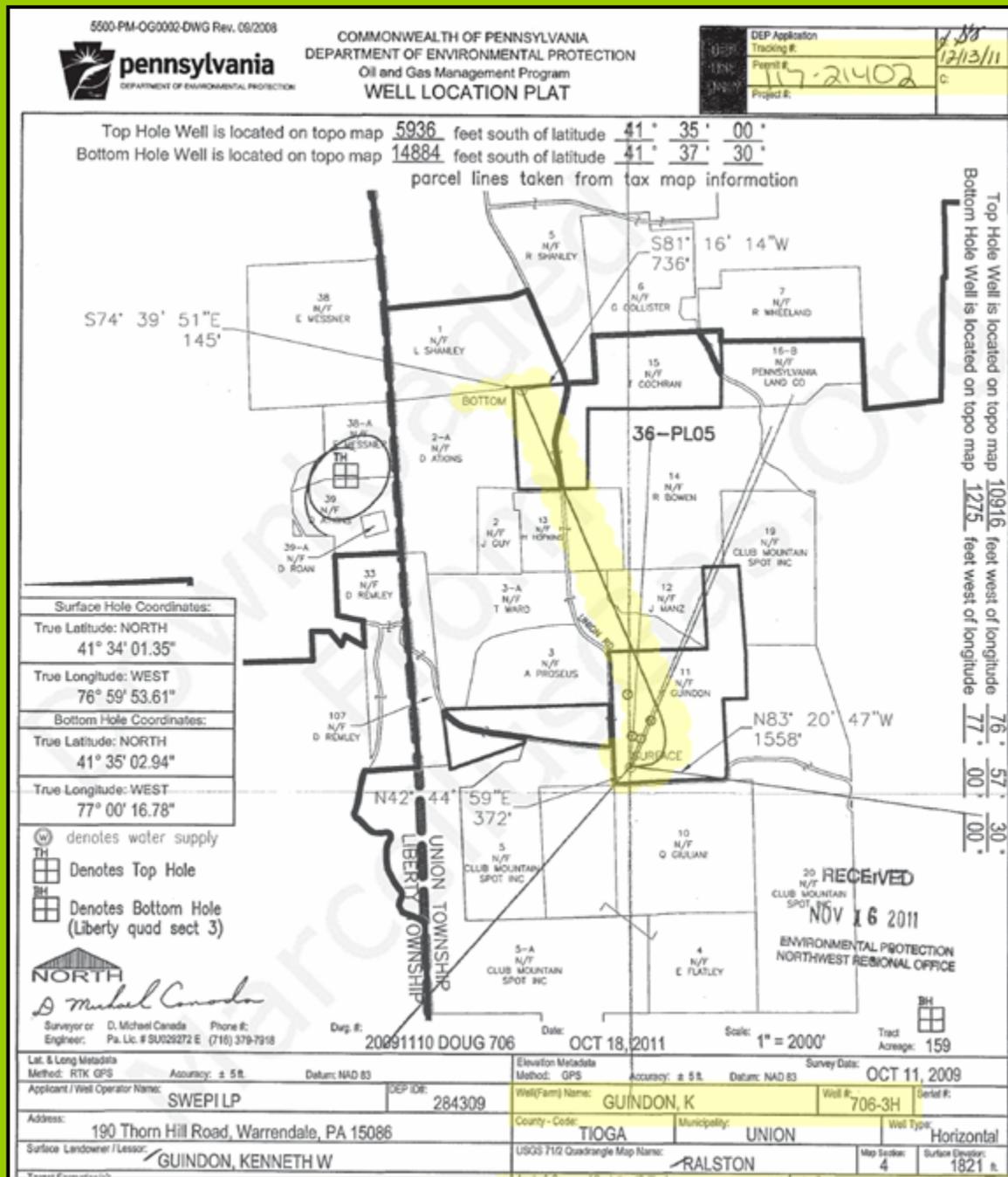
HH development plans

Compare UKOG's planning application with a typical US 'well plat'.

This is a plan showing the exact trajectory, land ownership, etc. of the proposed horizontal well.

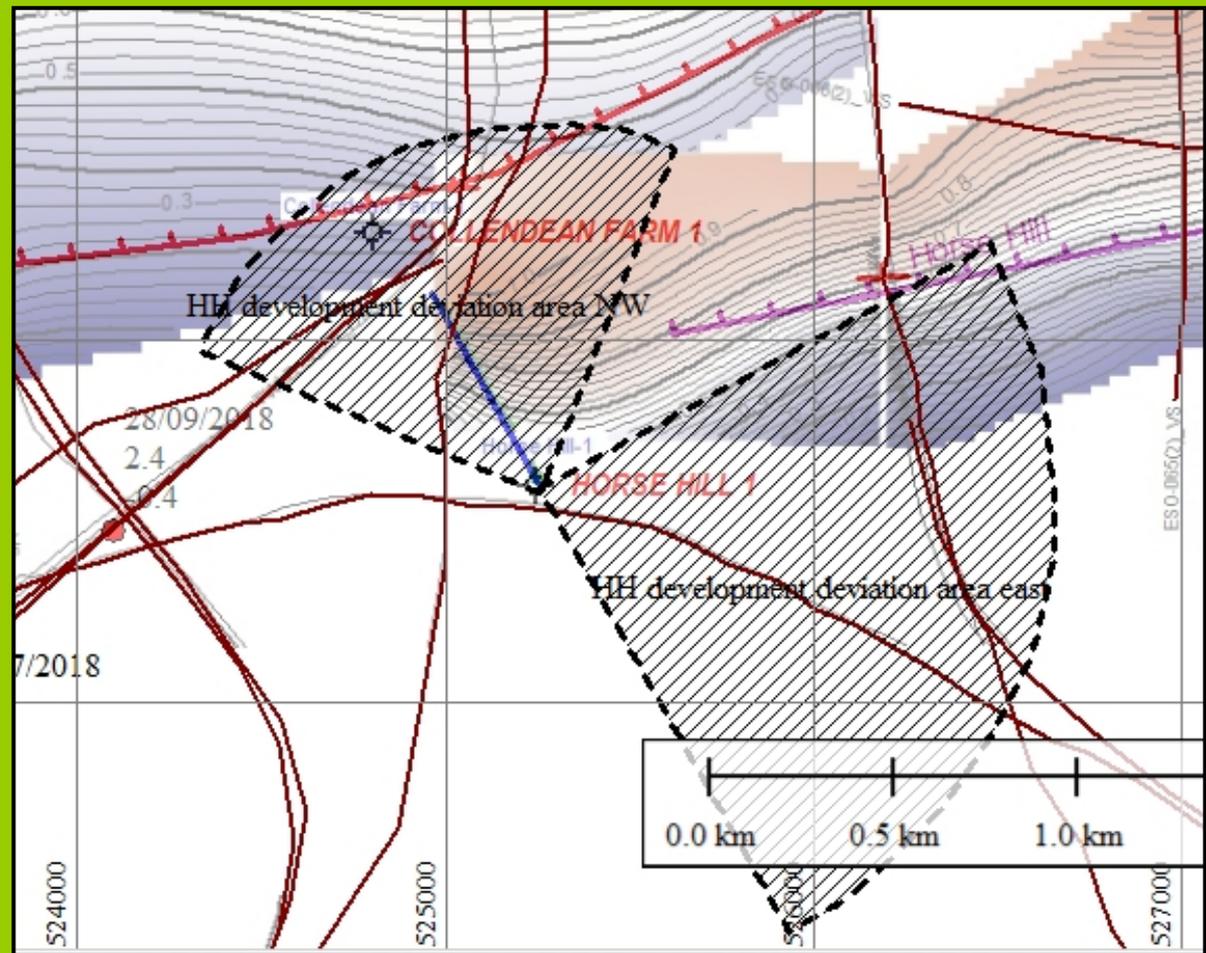
They are mandatory in Pennsylvania, Texas, Colorado, North Dakota, and no doubt other states as well.

UK regulation is far from the supposed 'gold standard'.



Comments on development plans

- Plans submitted are mere sketches.
- Wells have inadequate seismic (structural) control.
- Geology assumed flat, no faults.
- Wells deviating south go outside specified deviation sector.
- 3D seismic volume needed before drilling permitted.
- Geology needs to be re-interpreted from scratch.
- Learn from BB-1 fiasco.
- UKOG now claims neither fracking nor acidisation needed.



Horse Hill development deviation sectors (hatched).

2D seismic lines – brown.

HH-1 – blue line.

Collendean Farm Fault at c. Top Portland – red toothed line.

Horse Hill Fault at c. Top Portland – mauve toothed line.

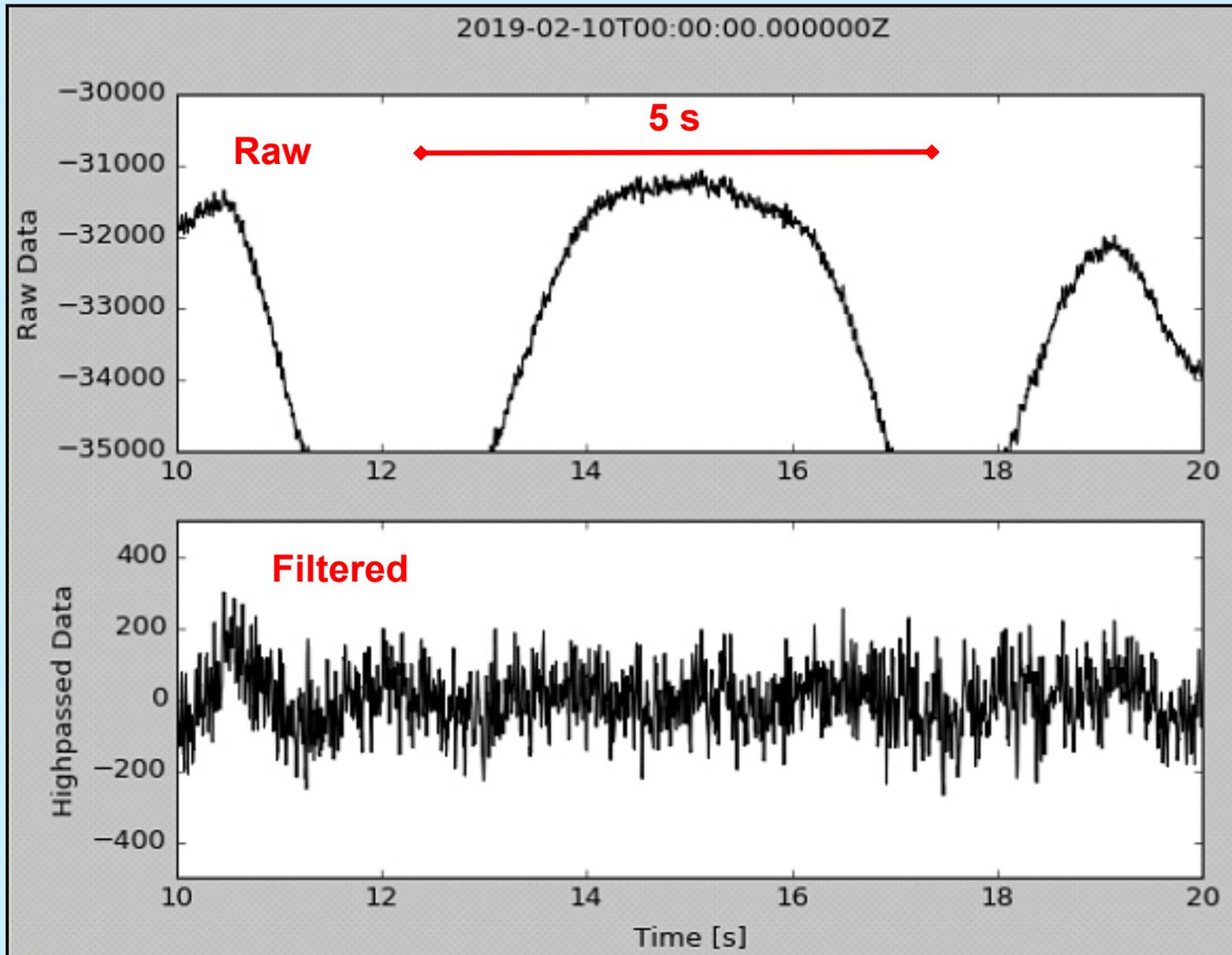
Contours on faults surfaces blue (shallow) to red (deep).

Earthquakes

The crust of the Earth is constantly in motion

Ocean swell – period 4-5 s

Horse Hill seismometer detail

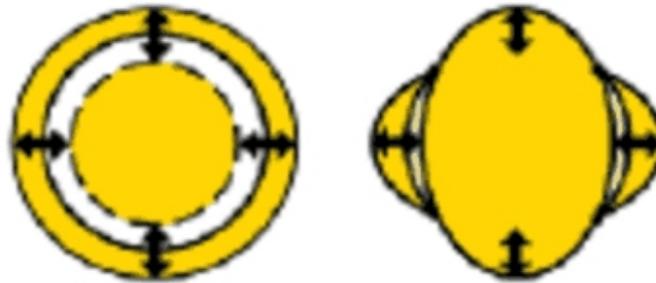


Whole earth modes of free oscillation

(periods 20 min to 1 hour)

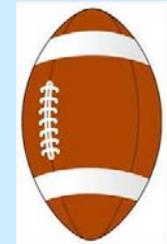
Earth rings like a bell for a day or so after a great earthquake

Breathing



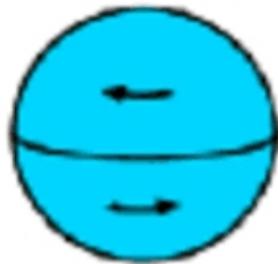
Spheroidal modes ${}_0S_0$ (20.5 min),
and ${}_0S_2$ (25.7 min)

Football

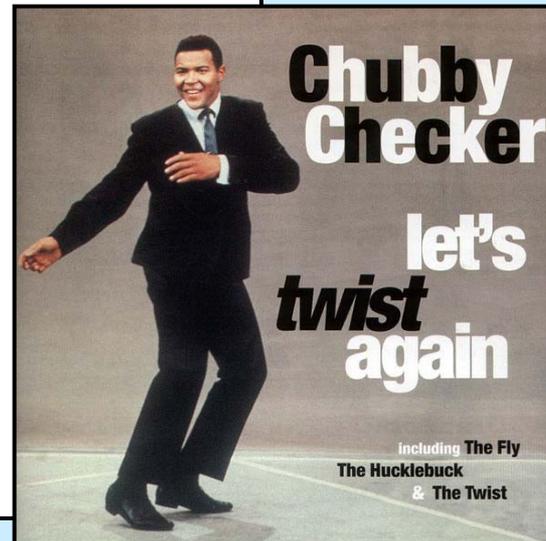


?

Twist

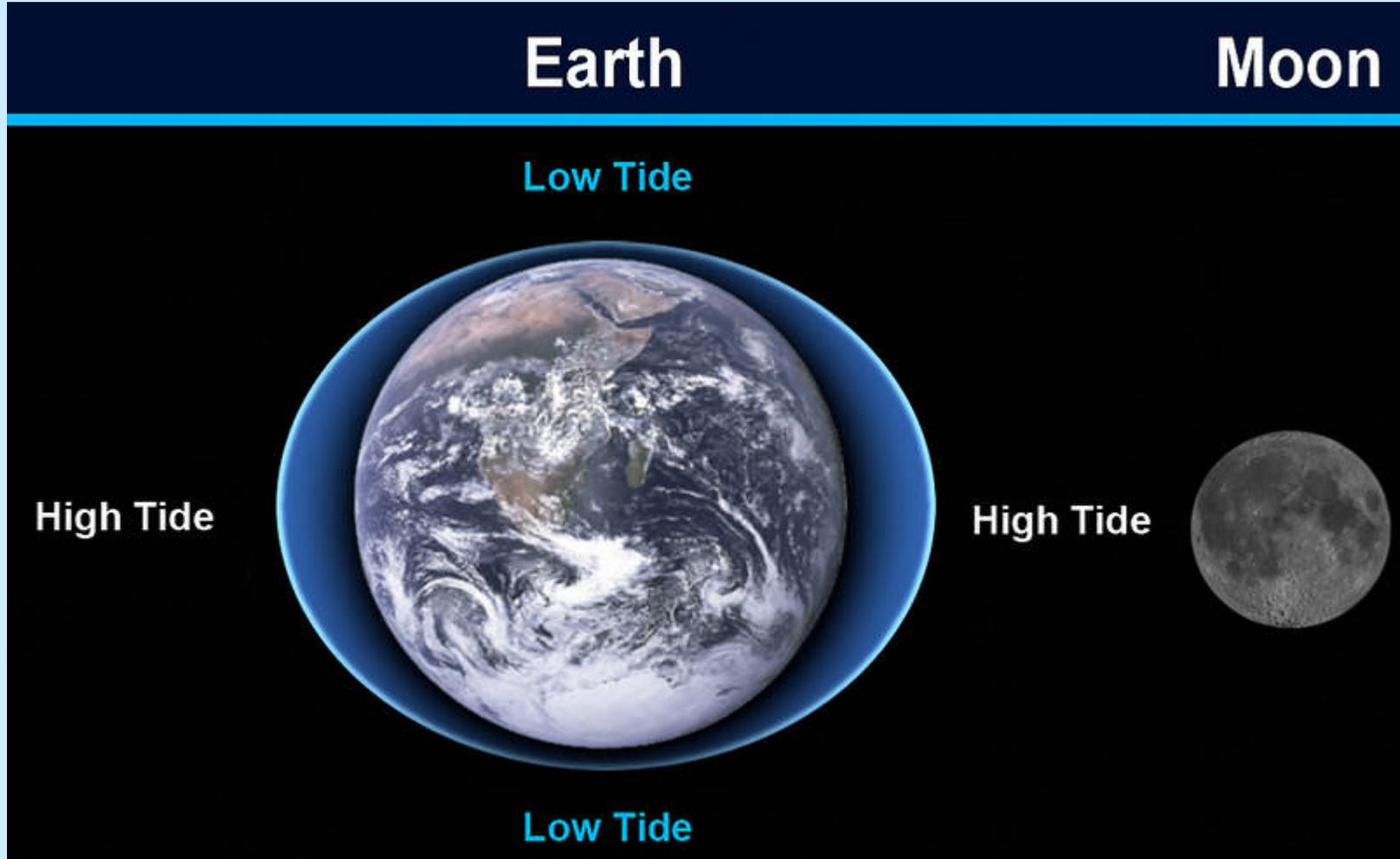


Toroidal mode



Solid Earth tides

Not just oceans; period 12.5 h
Crust moves vertically by about 1 m

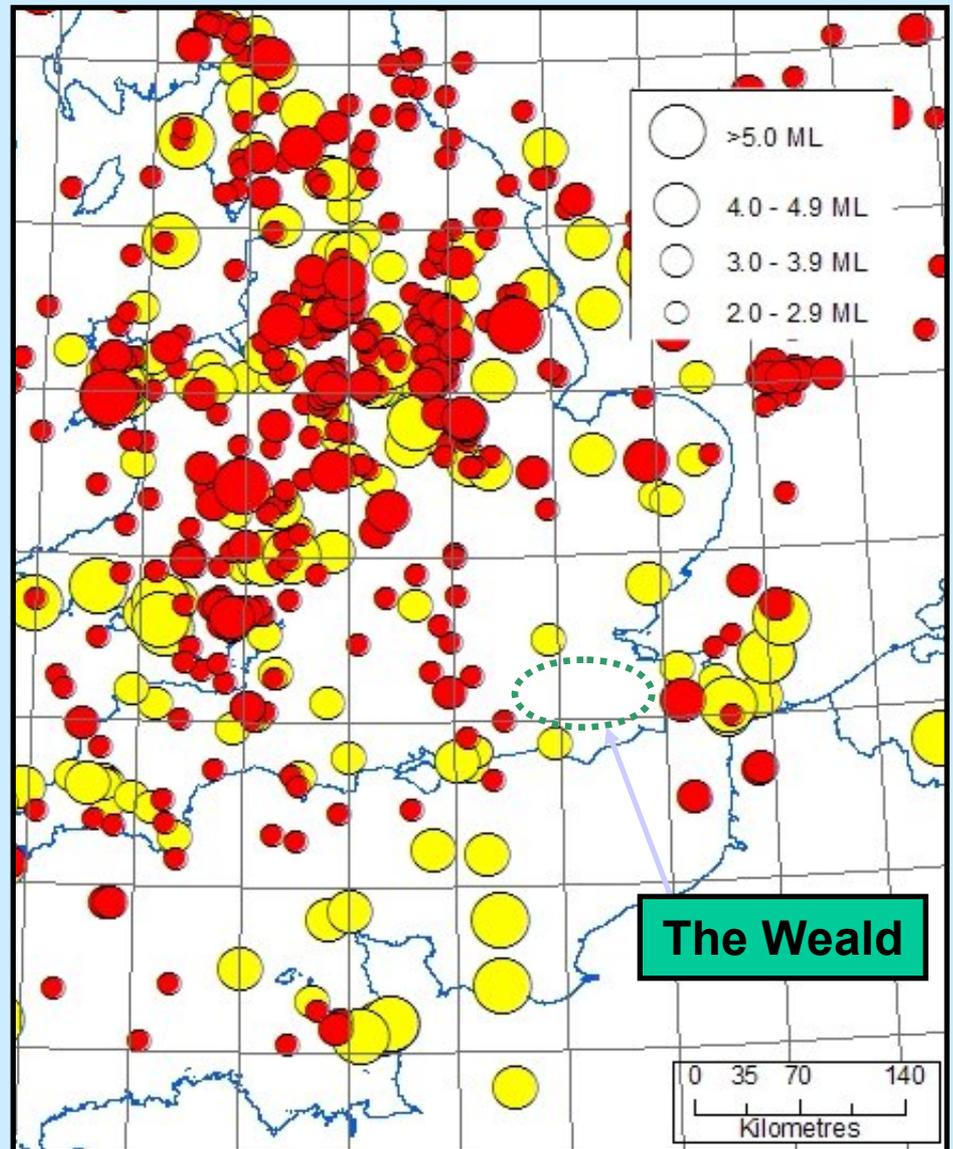


Can drilling trigger earthquakes?

This BGS map of historical earthquakes from 1832 to 1970 shows that the Weald was completely earthquake-free for 140 years.

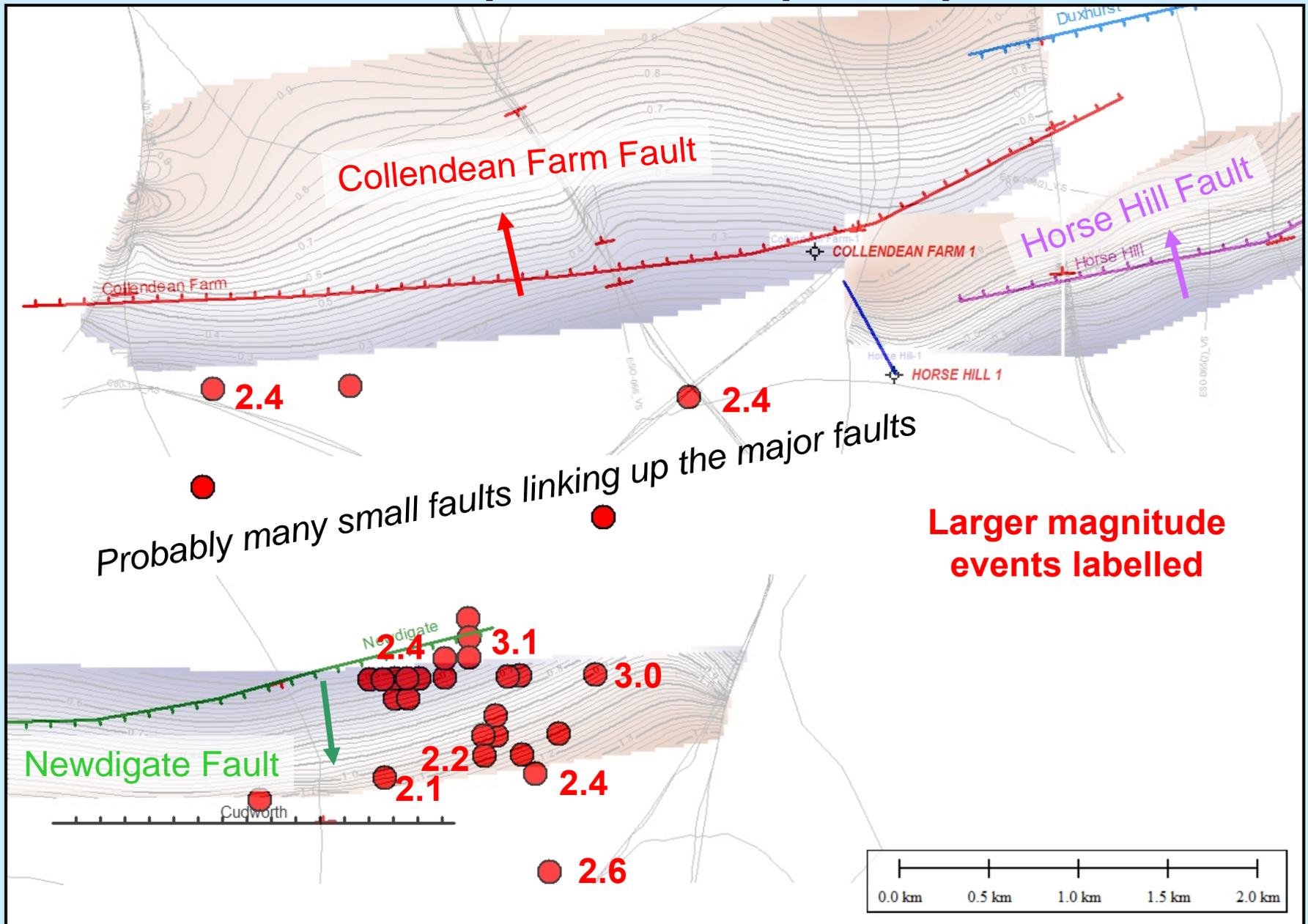
Earthquakes in previously non-seismic zones can be triggered by injection of fluids into wells.

It is *not yet known* whether fracking (*) in an area like the Weald, which is cut by many faults, could trigger shocks.



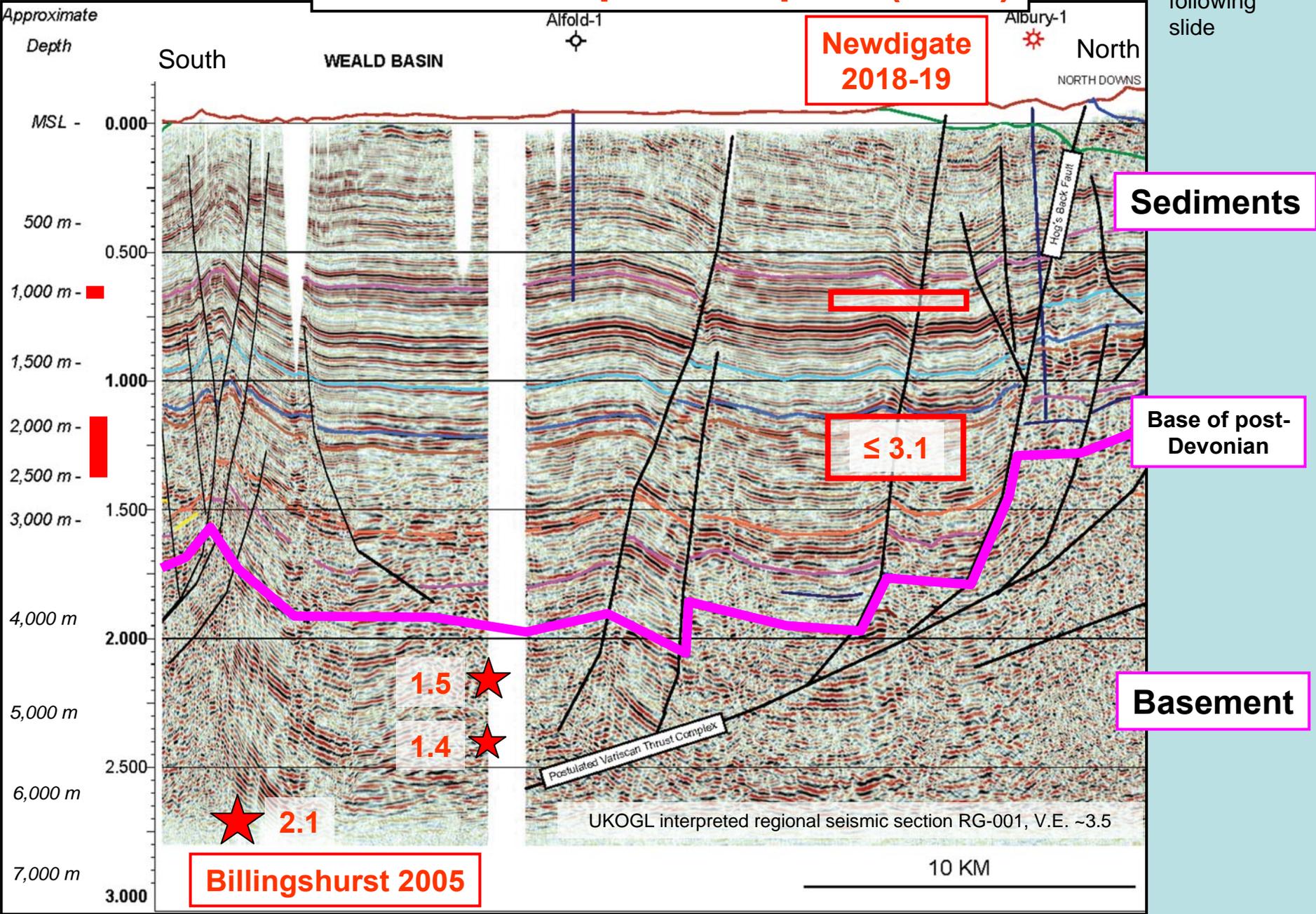
* Shorthand for unconventional stimulation of tight reservoir rocks

Fault surface maps and earthquake epicentres



Weald earthquake depths (BGS)

Discussed in following slide

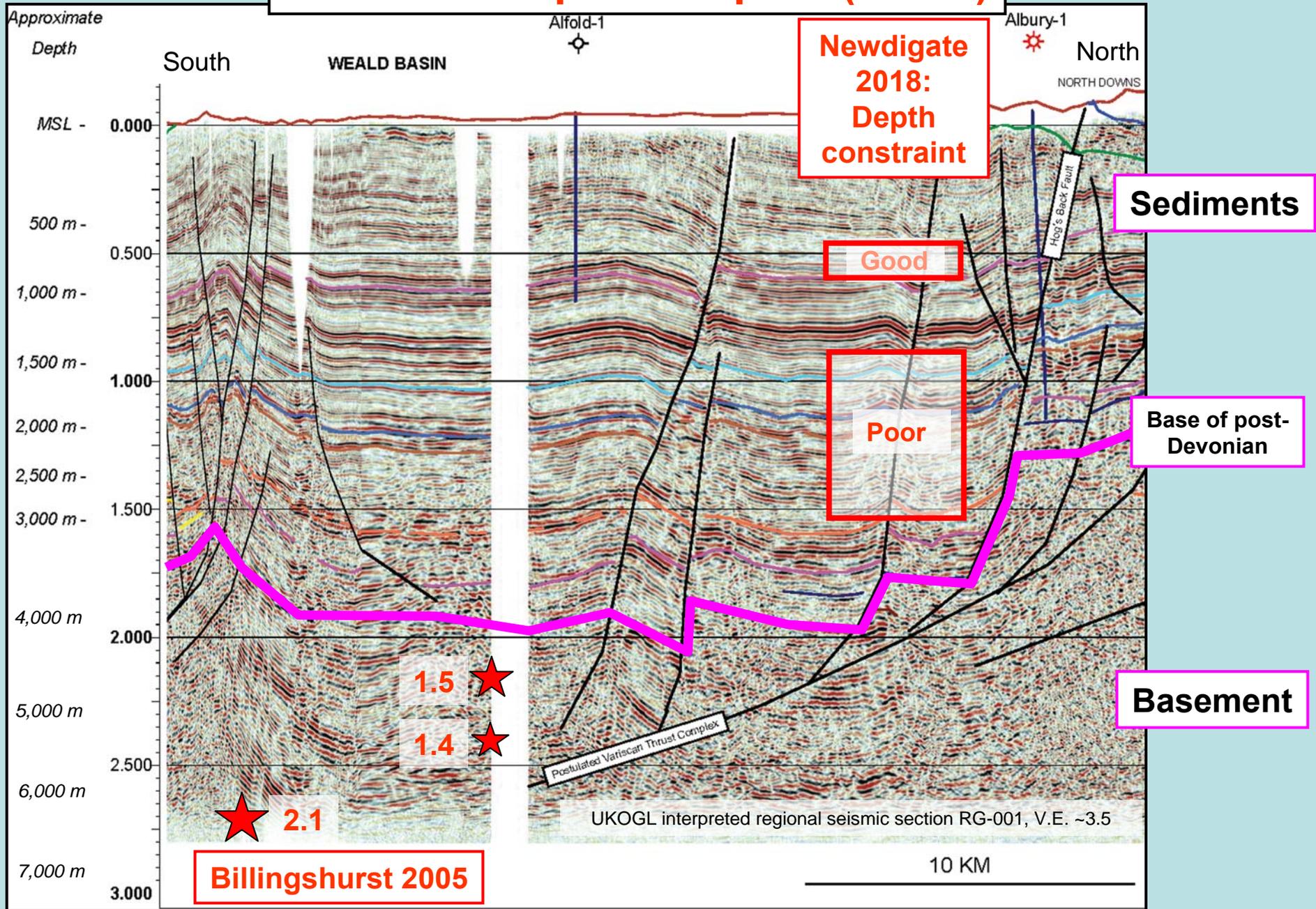


The previous slide shows the BGS depths of the Newdigate swarm, projected onto the regional seismic line shown in slide 3 above. Most earthquakes occur at 1.9 – 2.5 km depth. The very shallow quakes are marked at a nominal 1 km depth.

The three Billingshurst earthquakes of 2005, claimed by BGS to demonstrate that Weald earthquakes are not unknown, are of different character since they are on faults within the 'basement', the sub-sedimentary crystalline rock like that found in Devon and Cornwall (slates, granite, volcanics, etc.). In my view it is misleading of the BGS to have labelled these as 'shallow'.

The next slide shows depths (of the 2018 quakes only) re-located by Steve Hicks, at the time at Southampton University. He states that the best-located events are the shallow ones, at 800 – 1000 m, and that the deeper ones are located less precisely. So the shallow set is not an artefact of poor depth precision.

Weald earthquake depths (Hicks)



OGA expert meeting October 2018

Natural or induced?							
Davis & Frohlich criteria		BGS		Hicks		Edinburgh	
<i>Background</i>							
1	First known?	NO	Billingshurst 2005	YES	[ignores Billingshurst]	YES	[ignores Billingshurst]
<i>Temporal correlation</i>							
2	Clear correlation?	NO	HH injection started 9 July	YES	with Brockham	YES	with Horse Hill
<i>Spatial correlation</i>							
3a	Near wells (within 5 km)?	NO	Horse Hill ignored	YES	Horse Hill 4 km away	YES	Horse Hill 4 km away
3b	At/near injection depth?	B		YES*		YES	
3c	Known channel structures?	B		NO?	B	YES	
<i>Injection - changes in fluid pressure</i>							
4a	At well toe?	B		NO?	Horse Hill doubtful	?	Hypothesis proposed
4b	At hypocentre?	B		NO?			
B = Only Brockham considered				* Horse Hill injection unclear			

Comments

- Davis and Frohlich established criteria for trying to assess whether a particular earthquake swarm is natural, or might have been induced by injection. This set of Yes/No questions was discussed at the OGA meeting.
- Three differing sample views are shown above.
- OGA concluded no link (the majority view), but noted Edinburgh dissent. Hicks's submission implies that he was agnostic, but at the meeting he sided with the majority view.
- The Billingshurst events (Q1) are in crystalline rock, not the sedimentary basin, and much deeper than the latter.
- BGS categorically ruled out Horse Hill, claiming that there was no injection or extraction going on at the relevant period.
- The Edinburgh Uni. group (Prof Haszeldine) proposes a mechanical hypothesis to link the swarm to Horse Hill. It claims that the release of well pressure (like opening a bottle of champagne) could have been sufficient to trigger the swarm. I support this view, which at least deserves very serious consideration.

(My) conclusions on earthquakes

- **Crucial work programme logs withheld – why?**
- **OGA expert meeting outcome industry/govt biased**

- **Viable mechanism proposed by Edinburgh Univ.**
- **Strengthened by 14 Feb quake**
- **Balance favours link to Horse Hill**

- **Precautionary principle says halt while -**
- **More research undertaken**

The earthquake problem

SCC/locals – a way forward together

Accept that there is a problem:

- **Demand more information from UKOG on geology**
- **Detailed info on acid treatments**
- **All relevant activity logs (hourly basis) to be released**
- **Heed local concerns – not ‘carry on regardless’**
- **Refuse/delay consent / *de facto* moratorium**
- **Any future work to be independently monitored**

Lobby government:

- **Moratorium**
- **Bond**

Residents - collate systematic data on earthquake damage

Conclusions on future of unconventional exploration in UK

- Operators – penny-share cowboys**
- Government – Orwellian legal definitions**
- Regulation - fragmented, poor, self-reporting**
- Unconventionals will never be commercially viable**
- The energy future is in renewables + storage**