Why Earth Tremors in Surrey Should *Not* be Blamed on Oil Exploration

STATEMENT FROM **UK OIL & GAS PLC**, IN RESPONSE TO "UNSCIENTIFIC" CLAIMS MADE BY DR CAVANAGH, DR GILFILLAN AND PROFESSOR HASZELDINE

UK Oil & Gas PLC (UKOG) has numerous points of contention with a letter dated 5th February 2019 sent by Dr Cavanagh, Dr Gilfillan and Professor Haszeldine to Surrey County Council. The letter, entitled "Further Potential for Earthquakes from Oil Exploration in the Weald", was written by members of staff from The School of GeoSciences, University of Edinburgh, which we believe demonstrates both a worrying lack of scientific rigour and a poor understanding of induced seismicity, fault dynamics, petroleum geology, reservoir engineering, well operations and well engineering. The letter contains numerous factual errors, assertions, claims and conjectures that are not fully supported by data or evidence.

While the subject letter covers many specialist scientific areas, we note that these disciplines fall outside of the authors' specialist academic areas of expertise.

In our view Cavanagh et al's document reads more like a protester statement than a serious scientific document.

The most serious concerns are that the document:

- Was not peer reviewed by independent scientists as is the requirement for all published scientific papers.
- Makes no reference to any scientific papers to establish an acknowledged and relevant earthquake assessment criteria.
- Uses literature regarding earthquakes solely induced by fluid injection, whereas only extraction of hydrocarbons has taken place at Horse Hill, i.e. no fluid injection has occurred.
- Omits publicly available data that does not fit its narrative.
- Cites wholly inaccurate details about Horse Hill's operational timelines, techniques utilised and the fluid composition and reservoir pressures encountered.

This document will now go through each of the points discussed Cavanagh et al's letter, highlighting the technical errors and providing accurate information.

Earthquake Assessment Criteria

Cavanagh, Gilfillan and Haszeldine have loosely based their earthquake assessment criteria upon one published by Davis & Frohlich in 1993. **That paper is solely focused upon seismicity induced by fluid injection, which has not been undertaken at Horse Hill. It is therefore not an applicable set of criteria to use.**

Davis & Frohlich state (Page 208):

"Clearly, a series of seven or ten yes-or-no questions oversimplifies many of these issues. Thus, these profiles should not be used as an absolute predictor of whether fluid injection at a particular site will induce earthquakes. Rather, they provide a means for comparing specific injection projects with others that have or have not induced earthquakes"

Cavanagh *et al.* have used a 26-year-old earthquake assessment criteria, **the authors of which state that it should not be used in isolation and does not apply to fluid extraction. By failing to cite the Davis & Frohlich paper, Cavanagh *et al.* removed Surrey County Council's ability to review the source material and see that not only is it out of date but it is also not applicable.**

Precedence

Cavanagh et al state:

> *"Prior to 2018, there are no shallow earthquake clusters on record for the Weald since records began in 1969. It is reasonable to conclude that the 2018 Newdigate cluster sets a precedent for the Weald."*

This statement is both inaccurate and misleading. Firstly, although a relatively quiet seismic area, the Weald of SE England has recorded significant numbers of earthquakes in recent times, most notably in Chichester and Folkestone.

The publicly available records of the British Geological Survey (BGS) demonstrate that Chichester has recorded 9 events of up to a magnitude of 4.7 ML, Folkestone 13 events of up to 4.3 ML. Further events have been recorded around Billingshurst, East Grinstead, Lewes and Scaynes Hill. Of the 13 oil producing fields in the Weald, each located within a short distance of faults of similar orientation and nature to those at Horse Hill, none have been directly associated with significant recorded and repeated seismic events above 2.5 ML.

Secondly, shallow low magnitude earthquake detection is not a simple process and relies entirely upon the locations and number of local seismometers. To say that there have been no shallow earthquakes on record for the Weald is not a correct statement on the area's seismicity but more a comment upon its lack of monitoring history.

Southern England has one of the lowest densities of stations in the UK Seismograph Network. A map released in 2010 by the BGS (see Figure A) depicts how even nine years ago they were unable to accurately detect an earthquake with a magnitude of less than 2.5 ML. By the end of 2017 the detection capability of the network had increased sufficiently that it was capable of detecting an earthquake with a magnitude of 2.0 ML or above (Baptie, 2017).

Therefore, it is entirely possible that Southern England was subjected to many earthquakes of a similar magnitude to that of the Newdigate tremors (approximately 2 ML), but that the UK Seismograph Network was unable to detect them prior to the 2010-2017 period.

Another issue in the detection of earthquakes is that several seismometers must be located no further from the epicentre than twice the depth of the hypocentre (Bormann, 2002). This means that to accurately record an earthquake with a hypocentre depth of 2 km (i.e. the average depth of Newdigate tremors) there must be several seismometers less than 4 km away. Consequently, unless these shallow earthquakes occur in close proximity to a seismometer, they are unlikely to be recorded. It should be noted that a cluster of 5 seismometers now sits around the Newdigate fault making the detection of small seismic events possible for the first time.

By claiming that the Newdigate cluster sets a precedent for the Weald, Cavanagh *et al.* ignore both recorded events and the historical difficulties with recording low magnitude, shallow earthquakes. They correlate an increase of investigative precision with a variation in natural rhythm. This cannot be proven and to do so disregards the basic fundamentals of seismology and also the huge achievements of the BGS.

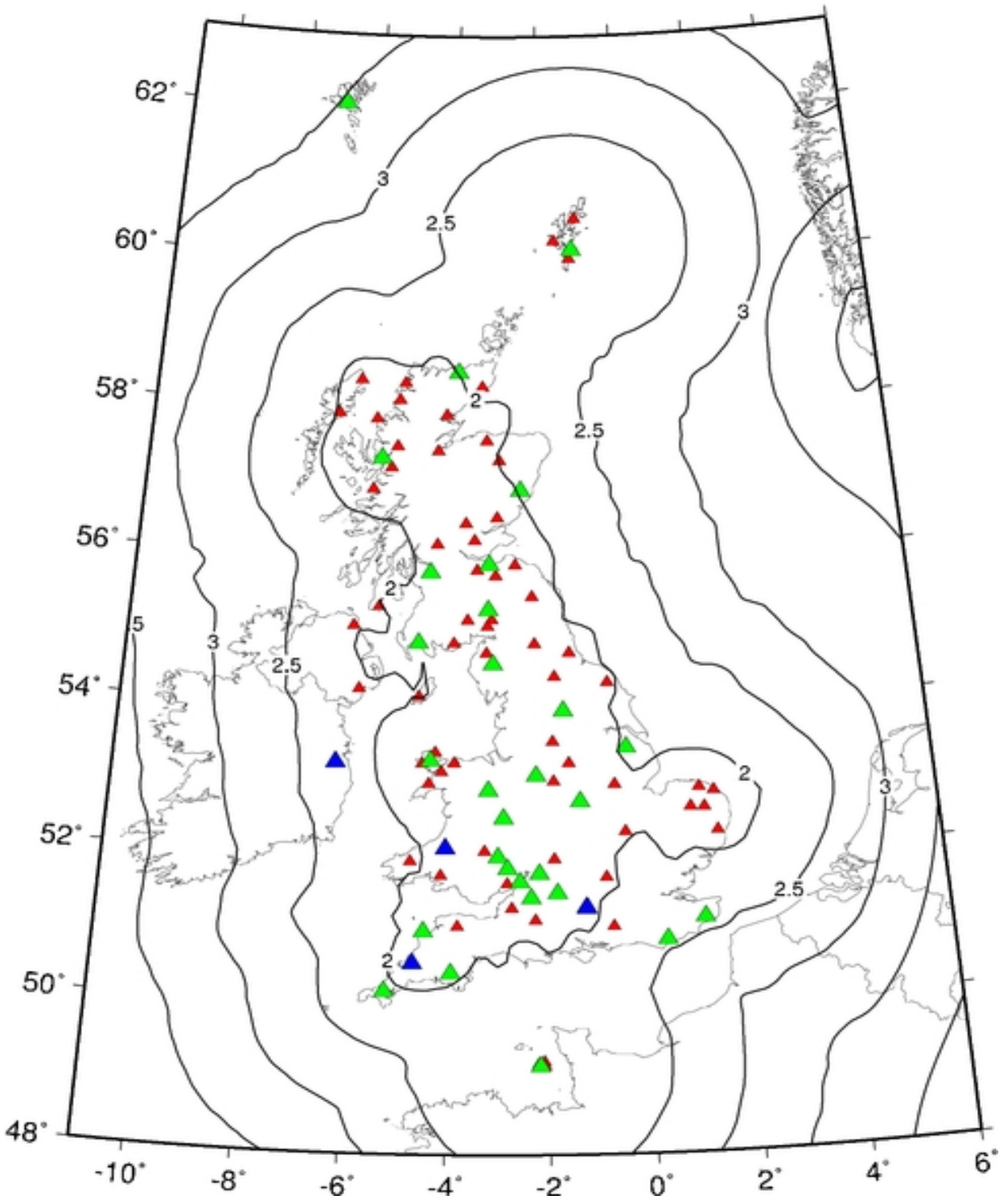

Figure A: Detection capability of the UK Seismograph Network (March 2010)
UK Seismograph Network. Green triangles are broadband stations, red triangles are short period stations and blue triangles are broadband stations operated by agencies other than BGS
Source: https://earthquakes.bgs.ac.uk/monitoring/detcon_2010_high.jpg

Timing

Cavanagh *et al state:*

> *"A detailed timeline of activity at Horse Hill indicates that the exploration well had recently commenced preparations for flow tests on oil-bearing targets prior to the earthquakes in April and July 2018 – see Figure A."*

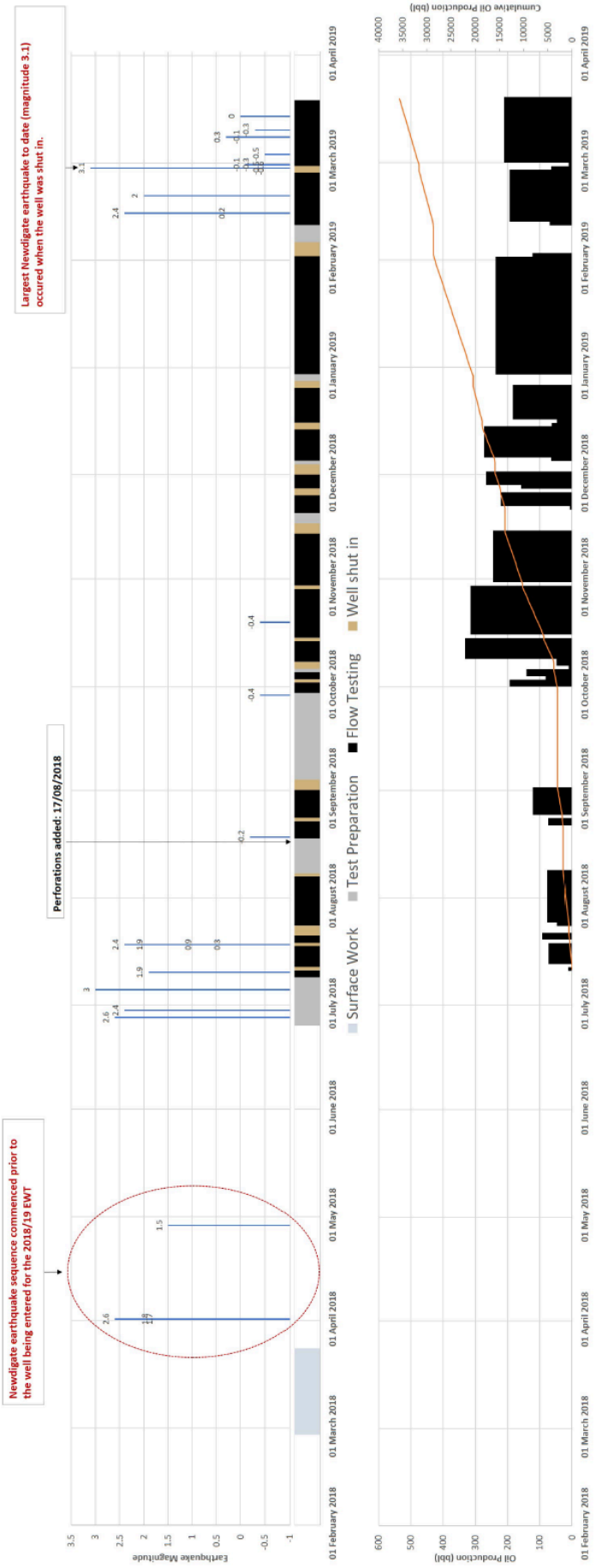

Figure B: Horse Hill operational and earthquake timelines

There is no evidence provided by Cavanagh *et al* to support their statement or timeline. It is demonstrably untrue. We provide an accurate timeline of operation and earthquakes in Figure B above, which also corresponds to information supplied to the Oil and Gas Authority (OGA) and experts in seismicity at Bristol and Southampton universities. **Figure B demonstrates that the first earthquakes at Newdigate started from 1 April 2018, when no subsurface operations or activities had commenced at Horse Hill.**

In accordance with AIM stock exchange rules, the start of operations at Horse Hill was put into the public domain via RNS media release on 27th June 2018 (RNS Number: 6830S). This was reported on various public websites, plus was immediately available on UKOG's website. The start/finish of specific test horizons was also similarly put into the public domain via further RNS releases.

Similarly, the grant by OGA of the permit to start operations, received on 13th June, was available in the public domain, two weeks prior to the actual start of operations. No testing equipment was on site prior to this date.

Furthermore, Professor Haszeldine, a co-author of the letter, was one of a group of 19 scientists who attended an Oil and Gas Authority (OGA) workshop on the Newdigate seismic events on 3 October 2018. The Horse Hill operational timings, which clearly demonstrate operations started some months after the first Newdigate seismic events, were made available to each of the meeting's participants, including Professor Haszeldine. Out of the group, 18 scientists including several independent experts on seismicity and seismic risk-assessment from UK universities, concluded that there was no demonstrable connection between oil and gas extraction operations at either Horse Hill or Brockham. Interestingly Dr Haszeldine, an expert in carbon capture, not seismicity, was the lone scientist insistent upon a direct causal effect.

Location of Events and Relationship to Faulting:

Cavanagh *et al* state:

> *"The areal distribution of the Newdigate earthquakes as a tight cluster close to Horse Hill is commonly established by all parties (OGA, 2018). The exploration well is 3 km away from the largest event, with eleven earthquakes occurring within 2 km of this event. Depth estimates indicate earthquakes clustering at around 1 km below the surface, close to the intersection of two faults. The best constrained events have a range of 0.5 to 1.5 km depth, coincident with Horse Hill exploration targets from 623 to 971 m depth."*

It should be noted that Dr Stephen Hicks, Imperial College London, an independent expert in seismology, is in the process of publishing an update on the Newdigate events with refined locations and depths of the tremors. This work calculates that the events occur at 2 km depth, not at the 1 km cited by Cavanagh et al.

Dr Hicks now interprets the movement on the Newdigate fault to lie within the Great Oolite limestone horizon (see Figure C), a mechanically brittle zone, some 1.1-1.4 km below the shallower Kimmeridge and Portland Sandstone oil producing intervals at Horse Hill. Furthermore, the Great Oolite is separated from the base of the Kimmeridge Limestones by some 600 m (1,800 ft) of impermeable mudstones of the Oxfordian and Middle Jurassic sections, making any downwards fluid and pressure connection from the Kimmeridge or Portland to the zone of Newdigate fault slip movement extremely problematic.

Cavanagh *et al's* assertion that the tremors lie *"close to the intersection of two faults"* is also incorrect and unsupported by any seismic mapping undertaken by the authors (see faulting section below).

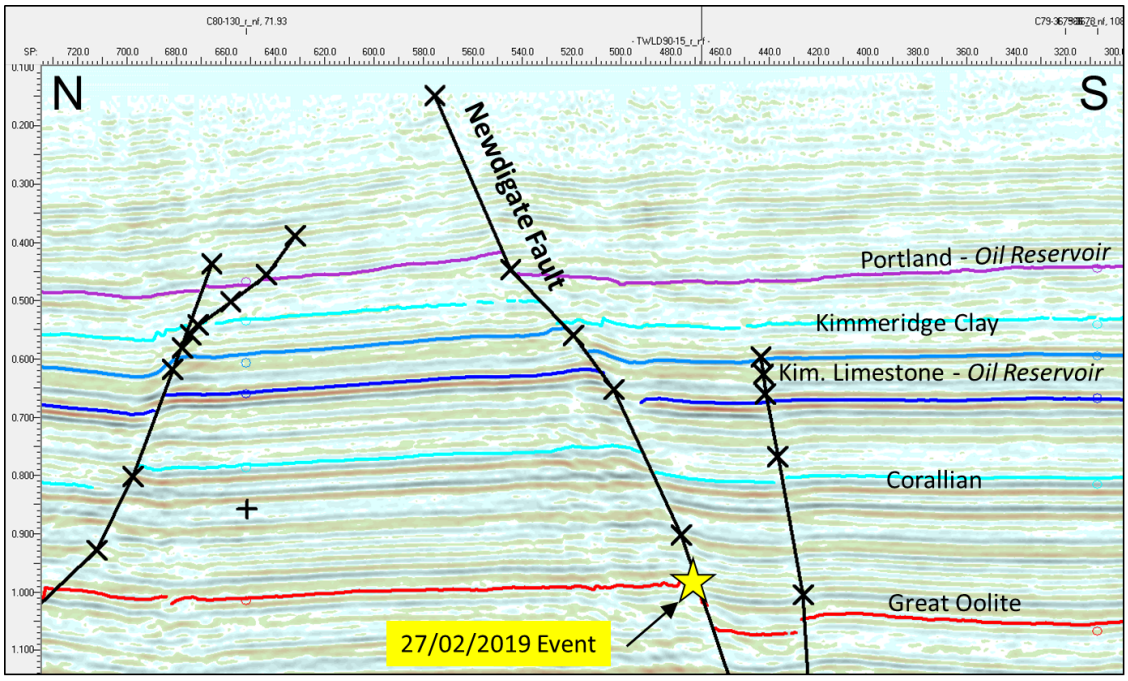

Figure C: Seismic Line showing the Newdigate Fault and earthquake location

Further incorrect assertions and claims regarding faulting are made as follows:

> *"A number of faults close to Horse Hill can be identified in seismic surveys (Smythe, 2018; Xodus, 2018). The Newdigate fault passes through the cluster and is highly likely to be the focal location for earthquakes. The Horse Hill fault intersects the well at the same depth as the exploration targets and continues towards the Newdigate fault, suggesting a likely conduit for pressure changes between Horse Hill and the Newdigate cluster."*

Figures D and E, using publicly available seismic data available from the UK Onshore Geophysical Library (https://ukogl.org.uk/), **demonstrate clearly that the Horse Hill-1 wellbore does not intersect a fault.**

Figure D clearly demonstrates that *the closest fault to Horse Hill does not intersect or join the Newdigate fault.* We have also previously demonstrated that the oil producing sections are now calculated to be significantly above the zone of fault movement at Newdigate and are also mechanically isolated via 600 m or more of intervening impermeable Jurassic claystones.

Pressure

Cavanagh *et al*. state:

"The perforation gun shots in August and September 2018 are the only stimulus applied to improve flow at Horse Hill. However, prior to flow testing in April and July, Horse Hill appears to have encountered a natural source of overpressure in the gas-rich oils of the Kimmeridge, as observed in the 'gas lift' reported for the well. We infer that management of this pressure (probably by bleeding the well annulus prior to testing) likely altered the Horse Hill fault stress balance, which then impacted on the Newdigate fault, causing the earthquakes."*

This section of the letter includes further significant inaccurate reporting of operational timings and techniques at Horse Hill-1. It also demonstrates a worrying lack of understanding of basic oil and gas techniques, petroleum geology and reservoir engineering.

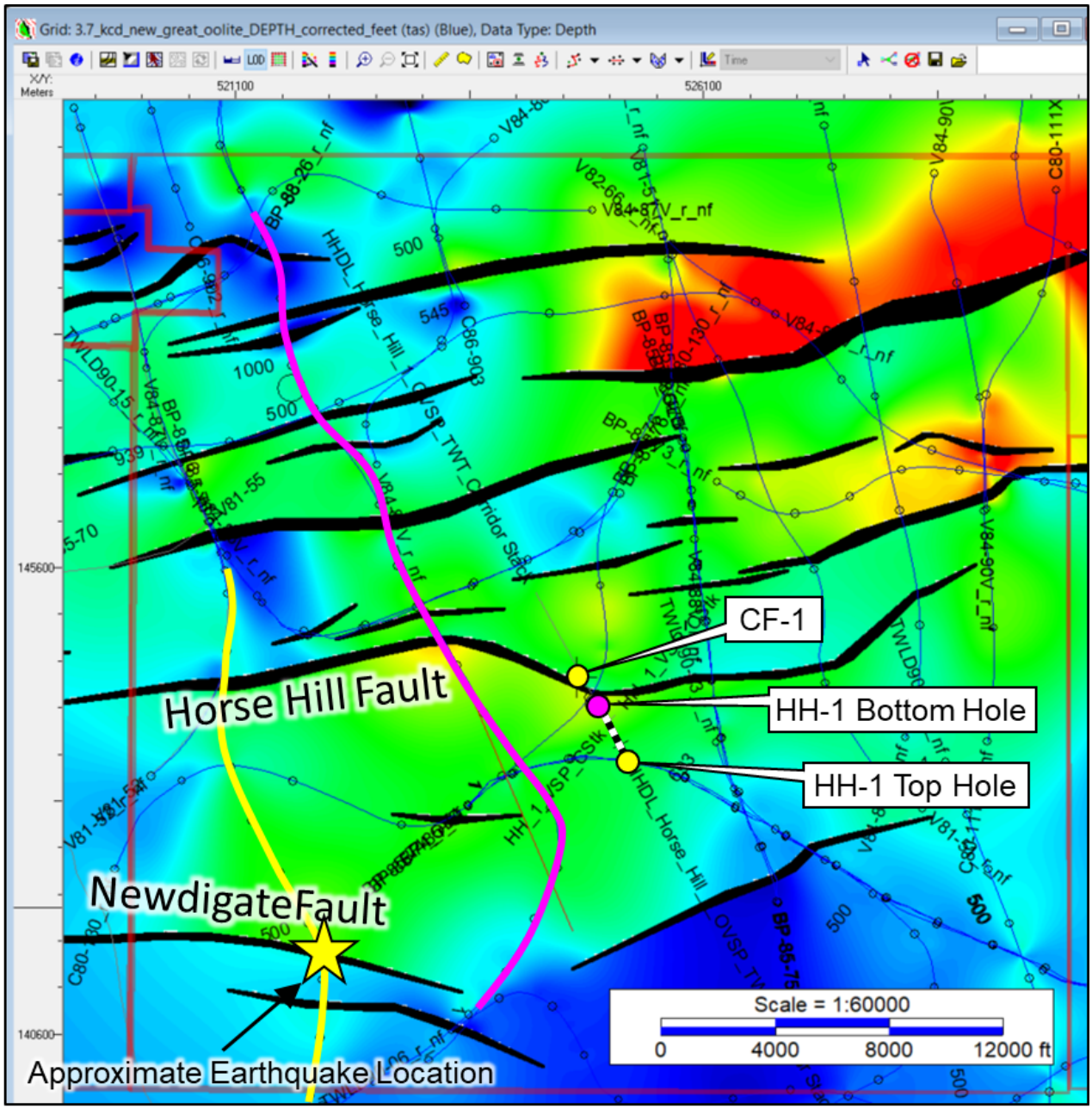

Figure D: Depth structure map of the top Great Oolite showing that the Horse Hill-1 well does not intersect a fault (see also Figure E) and that the closest fault to Horse Hill does not intersect with the Newdigate fault. *CF-1 = Collendean Farm-1, HH-1 = Horse Hill-1, 2D seismic lines are displayed as blue lines, Yellow line = Figure C, Pink line = Figure E.*

There was only one perforation run during the Horse Hill-1 extended well test on 17/08/2018 (see Figure B). The second perforation run in 2018 is therefore fictional and did not occur. Prior to 2018, perforation runs over three reservoir horizons were conducted in February and March 2016. There were no recorded seismic events associated with this activity or the oil flow in 2016.

Perforation is also not a method of stimulating a reservoir, it is the fundamental technique applied in every steel lined "cased" production well on planet earth. Perforation is the process which punctures through the steel tubing, known as casing, lining the well. The perforations permit fluids to flow into the well. The perforation process lasts for a few milliseconds and penetrates only some tens of inches into the rock. **It is completely false to imply that this process, conducted at every oil well in the UK, could induce seismicity.**

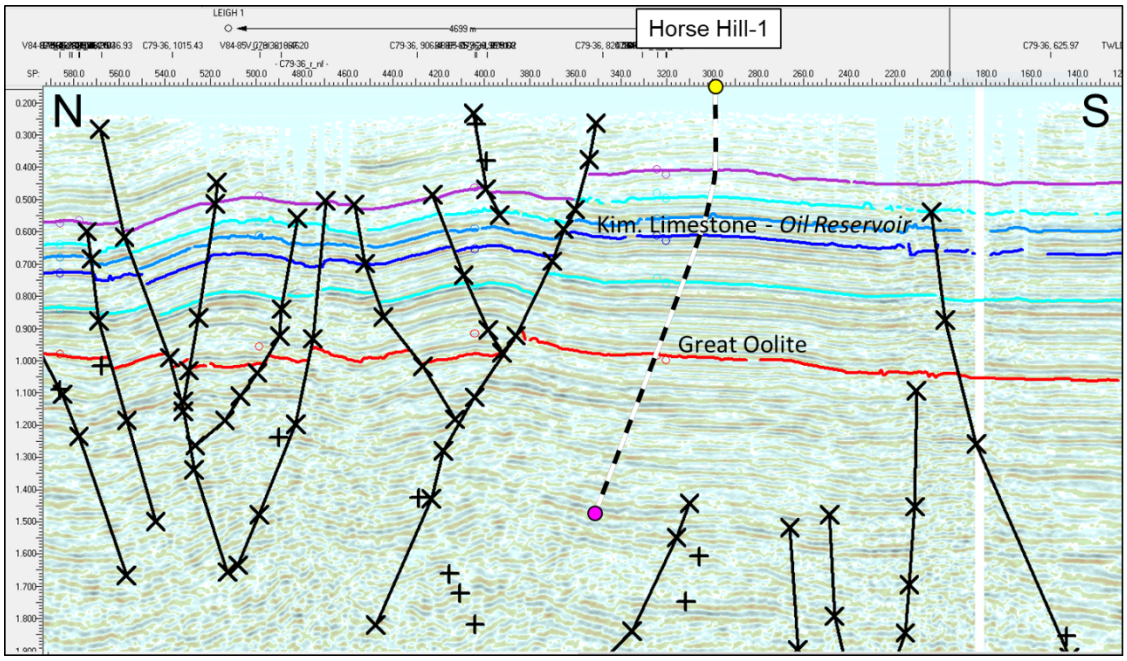

Figure E: Seismic line showing the Horse Hill-1 well and that it does not intersect any faults.

Cavanagh *et al.* also state that Horse Hill encountered "*overpressure in the gas-rich oils*". **This is also demonstrably untrue and misleading. Both the Portland and the Kimmeridge are normally pressured, not overpressured**, demonstrating pressure gradients of around 0.43 to 0.46 psi/ft, i.e. as would be expected from an overlying hydrostatic head of saline water.

The oil is not gas rich. Data shown and reported to OGA demonstrates that each barrel of oil (159 litres) of oil has approximately 150-300 cubic feet of gas dissolved within it under reservoir conditions. A gas rich oil would have 900-3,500 cubic feet of gas dissolved within it (see Figure F).

The statement referring to bleeding off of overpressure via the annulus is also inaccurate and demonstrates a poor understanding of basic well engineering, pressure control, operational practice and the nature of reservoir pressure itself. A cursory glance by the authors at publicly available information from the Health and Safety Executive would have revealed that the hydrocarbon bearing horizons in the well were completely isolated from the surface by three pressure tight plugs, as would be the case for any well suspended for future operations. The shallowest plug above the Portland was subsequently removed during operations in July 2018, the deeper plugs above Kimmeridge Limestone 3 and 4 were removed some months later. Therefore, there was no communication to the surface within the well until testing operations commenced.

Even if a well had encountered an overpressured section, the pressure could not be physically bled off as Cavanagh *et al.* assert, as by its very nature, overpressure is a regional physical state, not specific to a particular well. In any case, all pressures within the subsurface, including the Portland and Kimmeridge, are controlled in the well by the use of a fluid column, brine in the case of Horse Hill-1, which exerts a pressure marginally greater than the prevailing subsurface pressure at any given horizon. This is the standard pressure control process used by all wells, whether for oil or water. This is something of which the authors should have been aware.

TABLE 9.1—PETROLEUM FLUIDS AND THEIR CHARACTERISTICS

Characteristic	Oils			Gases	
	Heavy Oils and Tars	Black Oils	Volatile Oils	Gas Condensates	Wet and Dry Gases
Initial fluid molecular weight	210+	70 to 210	40 to 70	23 to 40	<23
Stock-tank-oil color	black	brown to light green	greenish to orange	orange to clear	clear
Stock-tank oil-gravity, °API	5 to 15	15 to 45	42 to 55	45 to 60	45+
C_7-plus fraction, mol%	>50	35 to 50	10 to 30	1 to 6	0 to 1
Initial dissolved GOR, scf/STB	0 to 200	200 to 900	900 to 3,500	3,500 to 30,000	30,000+
Initial FVF, B_{oi}, RB/STB	1.0 to 1.1	1.1 to 1.5	1.5 to 3.0	3.0 to 20.0	20.0+
Typical reservoir temperature, °F	90 to 200	100 to 200	150 to 300	150 to 300	150 to 300
Typical saturation pressure, psia	0 to 500	300 to 5,000	3,000 to 7,500	1,500 to 9,000	—
Volatile-oil/gas ratio, STB/MMscf*	0	0 to 10	10 to 200	50 to 300	0 to 50
Maximum vol% liquid during CCE**	100	100	100	0 to 45	0
OOIP, STB/acre-ft (bulk)	1,130 to 1,240	850 to 1,130	400 to 850	60 to 400	0 to 60
OGIP, Mscf/acre-ft (bulk)	0 to 200	200 to 700	300 to 1,000	500 to 2,000	1,000 to 2,200

*At bubblepoint pressure. **Constant composition expansion of reservoir fluid.

Figure F: Table of fluid characteristics for volatile (gas rich) and black oil
(https://petrowiki.org/Oil_fluid_characteristics)

The annulus pressure bleed-off cited by Cavanagh *et al.* relates to the annulus above the pressure tight plug set above the Portland, i.e. in the shallow part of the well inside unperforated steel casing that is isolated from the oil-bearing sections below. This is standard safety practice for all wells to ensure there is no build up of any biogenic gas from bacterial action in the near surface section. The annular bleed off, amounting to a few tens of psi, therefore, has no physical connection with anything in the deeper isolated oil bearing section below.

Conclusions

The letter demonstrates many significant factual errors by the authors on a subject (induced seismicity) which falls outside their specialist field and in which they are not recognised experts. The lack of peer review and failure to fully incorporate or fully test their hypothesis with relevant publicly available data presents a potentially worrying lack of adherence to the scientific method and raises significant concerns regarding the scientific credibility of the authors. All of the experts in earthquakes we have spoken to share our concerns over the letter's lack of scientific rigour and conclusion. We therefore believe the letter serves as a source of misinformation unworthy of the University of Edinburgh's high academic standards.

Given the high degree of public sensitivity and interest in this issue, we question why this letter was put in the public domain without the required checks and balances normally required for any scientific publication. We can only question the authors motives for submitting the letter to Surrey County Council and note that Professor Haszeldine has been an outspoken critic of the oil & gas industry in the past. We hope his political perspective has not unduly influenced the seemingly poor science that he has employed.

We also believe that the letter raises wider issues on the possible abuse of the general public's trust in science and scientific standards by those who are primarily motivated by political viewpoints. The University of Edinburgh, under whose umbrella and "brand" the letter was published, and the scientific community as a whole, should perhaps reflect that poor science transmitted into the public domain serves only to undermine the credibility of science and scientific experts and institutions as a whole.

We regard the promulgation of demonstrably false and poorly researched comments by persons occupying a position of public trust to be wholly unacceptable in any open and democratic society.

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