Submission to the APPG on the Impact of Shale Gas: The Traffic Light System to be held on 2 April 2019

by

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Relevant personal details from my CV

I am Emeritus Professor of Geophysics in the University of Glasgow. Although I am now a French resident I remain a British citizen, and take an active interest in UK, French and foreign affairs, as well as in various facets of scientific research.

My professional qualifications are: BSc Geology (Glasgow 1970), PhD Geophysics (Glasgow 1987); I was made a Chartered Geologist in 1991 but am no longer registered as such.

Prior to my taking up the Chair of Geophysics at the University of Glasgow in 1988 I was employed by the British Geological Survey (BGS) in Edinburgh, from 1973 to 1987. I was a research scientist, rising to the post of Principal Scientific Officer. In the 1990s I was closely involved in the search for a UK underground nuclear waste repository. I served on the BNFL Geological Review Panel from 1990 to 1991, to support BNFL's case for a Sellafield site for a Potential Repository Zone (PRZ), at the time when Nirex was investigating both Dounreay and Sellafield.

I was closely involved with Nirex at this epoch, and conducted for Nirex an experimental 3D seismic reflection survey, which took place in 1994. The survey encompassed the volume of the proposed rock characterisation facility (RCF) – a deep underground laboratory planned as a precursor to actual waste disposal. This was a double world 'first' – the first ever 3D seismic survey of such a site, and the first academic group to use this method, which at the time was just emerging as an essential tool of the oil exploration industry.

I have published around 70 technical and scientific papers and reports (44 papers in the peer-reviewed literature). Since my retirement from the university in 1998 I have carried out private research, acted as a consultant to the oil industry, and maintained a professional interest in the geological problems raised by nuclear waste disposal, unconventional hydrocarbon exploration and coal-bed methane exploration.

While at the BGS I worked closely with the Department of Energy (DEn) and occasionally advised the Foreign and Commonwealth Office.

I am probably the only person who has ever sat on both sides of the table at PEDL award interviews. I was once invited to join the panel at which the DEn (predecessor in hydrocarbon regulation to the DTI, DECC, BEIS and the OGA) interviewed BP for a licence west of the UK. I sat on the regulatory side with the Chief Geologist and the Chief Geophysicist of DEn. Some 25 years later, during the period when I worked as an oil industry consultant, I sat at the other side of the table representing an Applicant for an onshore licence in the south of England.

Declaration of interest, independence and non-liability

I have no interests to declare. This submission was requested by Lee Rowley MP for his APPG in lieu of my attendance at the meeting of 2 April 2019. I am not connected to, nor am I a member of, any activist group, political party, or other organisation. I am solely responsible for the contents of this submission. It is supplied in good faith, but I can accept no liability resulting from any errors or omissions.

Purpose of the traffic light system (TLS)

The purpose of the TLS is to mitigate, i.e. minimise as far as possible, the undesirable effects of induced earthquakes. Such earthquakes are induced by the passage along a pre-existing fault of fluid injected during hydraulic fracturing ('fracking'). The fault may then slip, depending on the pre-existing stress régime. The TLS comes into the category of environmental risk management.

In seismology the words tremor and earthquake are interchangeable; it should not be implied that tremors are necessarily 'small' earthquakes, however the magnitude may be defined. In the context of fracking, microseismic events, however, are those caused by the fracking process as the rock is split open. They are the cracking noise from deliberately created tensile fracture opening, without slip of one side of the newly created fracture, or 'frack', relative to the other side. The energy released by such microseismic events is hundreds or thousands of times lower than the energy released during a tremor or earthquake on a pre-existing fault.

Microseismicity is a useful way of monitoring the progress of the fracking process. In itself, it is benign, but there is a spectrum of energy release, extending from microseismic activity to macroseismicity. The latter is defined as earthquakes that can be felt without the aid of instruments.

An essential component of the TLS is that the monitoring takes place in near-real time during fracking, and that steps can immediately be taken to minimise adverse outcomes. These steps comprise firstly, cessation of pumping and secondly, start of flowback; that is, the well is not left 'shut in' under elevated pressure.

From microseismicity to macroseismicity

The TLS is misleadingly promoted, particularly by the fossil fuel industry, as having been designed only to mitigate the risk of macroseismic activity. This misunderstanding has been promulgated by comparisons of seismic magnitudes (implicitly, those in the unfelt category, or sub-macroseismic range) with everyday activity at the Earth's surface such as dropping a bag of flour or closing a door. The University of Liverpool survey commissioned by BEIS in 2018 (Edwards et al. 2018), is one example. It further confuses the argument, as it would be understood by the public, in not clarifying the fact that the measured ground velocities are compared only with a seismic event at 2.5 km depth. This corresponds approximately to the depth of earthquakes induced by fracking at PNR-1z, but has much less relevance to, for example, the Surrey Newdigate swarm, where many of the earthquakes are much shallower.

Mitigation of the possible macroseismic effects from induced seismic activity constitutes only one part of the TLS; equally important are the possible local underground consequences. These include creation of new pathways for contamination, and damage to the man-made structures. The latter, in turn can lead to formation of new contamination pathways.

Monitoring microseismicity during fracking, although essential, does not supply a complete picture. There are degrees of observation *via* microseismicity:

- A cloud of microseisms progressing away from the injection point,
- A line or plane of microseisms working their way along a pre-existing fault,
- A 'stealth zone', whereby passage along a presumed fault is not directly observed by microseisms, but is only inferred by the spatial and temporal gap between two distinct clouds of microseisms (Pettitt et al. 2009; Wilson et al. 2014a, b).

The pattern of microseismic events does not normally lead to the location of an induced earthquake. It is normal behaviour for the induced event to be located some distance (hundreds of metres) from the zone of microseismic events.

Operation of the current UK TLS

The current TLS operates with a threshold of M_L = 0.5 for the red light, and 0.1 for amber. Industry is currently lobbying for these numbers to be raised. But it is worth recalling what the authors of the TLS (Green et al. 2012) said. They recommended:

- *"a more detailed analysis of seismic activity is required, rather than application of a simple upper limit, so that numbers, magnitudes and mechanisms of any induced earthquakes are considered."*
- *"that these values are refined as more experience and data is acquired, to better understand the behaviour of any induced seismicity"*

To date only one UK onshore well has been horizontally fracked (PNR-1z). The first recommendation above, the detailed analysis, has not been done. The 57 induced earthquakes are currently located by the BGS local surface array, to a precision of 0.001° in latitude and longitude. This is about 110 m in latitude and about half that in longitude. Depths are given to a precision of 0.1 km. No focal plane solutions have yet been published, which would yield the orientation of the fault and the sense of slip.

Cuadrilla claims that it now has a database of 40,000 microseismic events from the well. The induced earthquake hypocentres could be vastly improved by combining the BGS data with information from the downhole array in PNR-2, and focal plane solutions should be estimated, at least for the larger of the induced events. A detailed spatially varying velocity-depth model should be used, taken from the 3D seismic reflection survey.

The recommended analysis should comprise:

- Repositioning the microseismicity and identifying pre-existing fault planes,
- Repositioning the induced earthquake hypocentres, and
- Trying to tie in the inferred fault planes, both from microseismic activity and focal plane solutions of the induced seismicity, to faults seen or inferred from the 3D seismic survey.

Therefore any consideration of altering the threshold values is premature before such work is undertaken.

The implementation of the TLS uses a narrow legalistic definition of fracking, restricted to the process of injection. So 'fracking' is timed to the second, and once fracking has stopped and flowback has started any subsequent induced earthquakes are counted as trailing events, and do not affect the operator's actions. This, in my view, is a misreading of the spirit in which the TLS was drawn up. It would be reasonable for any so-called 'trailing' events to be counted in as part of the fracking process, because even after fracking has stopped and flowback has begun, the excess stresses in the earth at some distance from the well caused by the injection will not have instantaneously reduced to their pre-fracking level. So-called trailing events should be included as part of the frack process for, say, up to 10 hours after cessation of fracking. A period of monitoring should then ensue starting at the time of the induced event.

Fault respect distance

No specific horizontal distance has been set for the minimum planned distance between fracks and a fault, the so-called respect or stand-off distance, despite several recommendations. Proposed respect distances vary from approximately 500 to 900 m. Verdon (2018), in a report commissioned by the OGA, criticises these recommendations and proposes that no such distance should be set.

The question of a respect distance raises the problems of what size of fault (if any) should be 'respected' and how faults are mapped. The geometry of fault systems, as well as their seismicity, has long been known to have a fractal distribution over several spatial orders of magnitude (e.g. Turcotte

1997). Another way of saying this is that in a given sedimentary basin the pattern of bigger and smaller faults will tend to look the same whether viewed at the basin scale or at a local outcrop scale.

In the UK, the OGA guidance for hydraulic fracture plans states:

> *"Operators are required to identify and assess the locations of existing faults to prevent hydraulic fracturing from taking place near them."*

No criteria are provided as to how the operator will identify such faults, by whom (and if) any independent vetting of the mapping is done, and what is meant by 'near'. It could be argued that it is in the operator's interest to wilfully ignore the existence of any inconvenient faults. However, the US experience is that faults (which are very rare in the US shale basins, compared to the UK) are normally avoided during fracking simply because they leak away hydraulic pressure which could otherwise be directed to 'useful' fracking of shale. So operators will try to avoid large faults.

A detailed German study of the risks of fracking (Ewen et al. 2012) recommended that no fracking at all be undertaken in basins with through-penetrating faults. Such faults are, of course, at a scale which can hardly be ignored. If this restriction were in place in the UK then few, if any, shale basins would be left available for exploitation.

The biggest fault in the Fylde, Lancashire, is the Woodsfold Fault. It is an important boundary fault, separating the most important groundwater aquifer in the north of England from the western Fylde currently under exploration by Cuadrilla (and an area which was formerly explored for conventional oil and gas in the 1980s). The fault is 40 km long, running north-south, and dips to the west under the Fylde. Yet along most of its length it cannot even be mapped at or near the surface to better than 1 km in an east-west direction.

In the western Fylde, there are several other important faults about which there is little consensus. Even more remarkable is the fact that the Wakepark Fault, situated at depth near the western boundary of Cuadrilla's licence, is absent both from Cuadrilla and BGS maps. I have mapped this fault initially using the available 2D seismic data and more recently using the 3D dataset in addition. It runs (coincidentally) from near Anna's Road-1 northwards to near Preese Hall-1 (two Cuadrilla wells) and crops out (below thick glacial till) above the toes of PNR-1z and PNR-2. It is unacceptable, in my view, that such a fault be omitted from the various maps and cross-sections supplied as part of Cuadrilla's permit applications. Early versions of the Wakepark Fault were mapped independently at depth by two exploration companies in the 1980s; it is not a figment of my imagination.

Given that even the biggest faults in the basin cannot be positioned accurately, one can have little confidence in OGA's guidance as quoted above. My own ongoing work on interpreting the Fylde 3D dataset shows not only that Cuadrilla has made major errors in the geology, but that it has not identified the many small faults in and around the PNR site.

Verdon's review (2018) of respect distances is flawed because he relies solely on microseismicity as the criterion for fault identification. It is surprising, given that he is an expert in microseismicity, that he makes no mention of stealth zones, which prove that frack fluid can migrate along fault planes without triggering microseisms.

In my view a variable respect distance should be defined, perhaps in a fractal or scale-invariant way. By way of illustration, the respect distance from the major through-penetrating faults in a basin might be set at (say) 1000 m. Then smaller faults, defined perhaps by their surface area, might have a respect distance of (say) 250 m. The smallest faults identifiable in shale with the help of 3D seismic have a surface are of less than 1 ha (e.g. 100 m x 100 m); perhaps the respect distance from these features could be set at (say) 100 m.

Comments on Cuadrilla's performance

Preston New Road (PNR)-1z is the only horizontal shale well in the UK that has been fracked, and the first and only well to date that has been fracked under the TLS. It is therefore pertinent to discuss how Cuadrilla has managed this process.

Cuadrilla claimed in a press statement on 6 February 2019 that only 2 out of 41 planned stages were fully fracked as planned, and that less than 14% of the planned volume of sand proppant was injected. It blames the unreasonably conservative thresholds in the TLS for the poor performance.

But the company is being mendacious; 16 stages were fracked, with an average of 230 m^3 (1450 barrels) of slickwater per stage (maximum: 417 m^3). So if all 41 stages had been fracked at that average water consumption, some 9400 m^3 would have been required. This is a typical figure for US shale wells, although the range of variation is wide. The problem lies with the 25 other stages which were not fracked, although preliminary tests, or mini-fracks, were done on two others (stages 18 and 35) without a full frack subsequently being done.

Cuadrilla needs to explain why stages 4-11, 15-17, 19-21, 23-29 and 33-36 were never even attempted. Furthermore, it has never admitted the fact that over half of the time onsite (3 November - 7 December inclusive; 35 days out of 64 in total) comprised downtime due to its own incompetence.

A highly unusual feature of the frack pattern from PNR-1z is its extreme asymmetry; essentially all the fracks are directed northwards. The 'classic' frack shape is like a pair of vertically aligned butterfly wings spreading out on either side of the wellbore; in the present case this would be one wing to the north and one to the south. Why is the southerly wing absent? If there is a horizontal tectonic stress gradient**,** decreasing northwards, it would bias the fracks to be directed northwards and not southwards. If correct, this is a natural phenomenon about which Cuadrilla can do little. To the best of my knowledge there is no frack stage sliding sleeve mechanism for directing the fracking in a particular direction; furthermore, there would be no reason for Cuadrilla to want to do so.

The daily PNR-1z frack coverage has been presented as maps showing fracks emanating from the relevant stage. The microseismicity is represented by straight line segments rather than as point clouds. It may be that these straight line segments are an interpretation of the fracked planes inferred from the microseismic events. Many of them are remarkably long and straight, with one segment being 150 m long. This strongly suggests that Cuadrilla has fracked into a network of pre-existing faults and fractures.

The combination of the horizontal stress gradient and the existence of pre-existing fault networks may in part explain Cuadrilla's failure to frack the whole shale volume around PNR-1z. While there may be some truth in Cuadrilla's plea that it was obliged to pump at a low rate to minimise the triggering of earthquakes, that does not explain the unusual and sparse results summarised above.

Conclusions

Only one well has been fracked since the TLS criteria were agreed by the industry. Any alteration to the threshold magnitudes of the TLS is premature.

There are many geotechnical studies and/or revisions of the geology of the Fylde, discussed above, which need to be undertaken using the datasets now available. If Cuadrilla and other operators wish to continue fracking they should do so under the existing TLS regime, at the same time as working up the results from the data obtained so far.

References

Edwards, B., Delvoye, A. and Brotherson, L. 2018. *Seismic Context Measurements for Induced Seismicity*. A technical report for the Department of Business, Energy and Industrial Strategy. http://datacat.liverpool.ac.uk/609/2/Seismic%20Context%20Measurements.pdf

Ewen, C., Borchardt, D., Richter, S. and Hammerbacher, R. 2012. *Hydrofracking Risk Assessment Executive Summary* [English summary version of Borchardt et al., www.dialog-erdgasundfrac.de, which needs to be consulted].

Green, C.A., Styles, P., and Baptie, B. J. 2012. *Preese Hall shale gas fracturing review & recommendations for induced seismic mitigation.* Report to Department of Energy and Climate Change, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/15745/5075-preese-hall-shale-gas-fracturing-review.pdf

Pettit, W., Reyes-Montes, J., Hemmings, B., and Hughes, E. 2009. Using continuous microseismic records for hydrofracture diagnostics and mechanics, *Soc. Explor. Geophys. Ann. Meeting Expanded Abstracts.*

Turcotte, D. L. 1997. *Fractals and chaos in geology and geophysics (2nd edn.).* Cambridge University Press, 398 pp.

Verdon, J.P. 2018. *Comments on the scientific basis, or lack thereof, for hydraulic fracturing fault respect distances*. University of Bristol report for OGA.

Wilson, T.H., Hart, A.K., Sullivan, P. and Patchen, D. 2014a. Integrated Microseismic and 3D Seismic Interpretation. Martz Summer Conference, Colorado School of Law. http://www.colorado.edu/law/sites/default/files/WVU.Integrated%20Microseismic%20and%203D%20Seismic%20Interpretation.pdf.

Wilson, T., Hart, A.K. and Sullivan, P. 2014b. 3-D Seismic Workflows Developed to Evaluate Out-of-Zone and Stealth Zone Microseismic Behaviors: Marcellus Shale, Central Appalachians, USA. Search and Discovery Article #41395. http://www.searchanddiscovery.com/pdfz/documents/2014/41395wilson/ndx_wilson.pdf.html