

Reply to Dr James Verdon (SC8)

I respond under headings following as far as possible the structure and order of his comments.

General comments

The logical, scientific presentation of my thesis – that there is a problem of faulting in the UK shale basins if shale exploitation is to proceed – follows a perfectly orthodox logical pattern:

- US shale play geology is simple and unfaulted ('foreland' basins).
- UK basins are highly faulted ('extensional' basins).
- Therefore US shale exploitation experience cannot be emulated in the UK.
- Fault identification in the Fylde, Lancashire.
- Hydrogeological risks in the Fylde.
- Inadequacy of the developer's technical work in the Fylde.
- Faulting in the Weald Basin, SE England.
- Inadequacy of technical work by two developers in the Weald.
- Importance of faults – review of quantitative modelling studies to date.
- Case history at Bradford County, Pennsylvania.
- Failings of UK regulation.
- Discussion - new exploration techniques and tighter regulation required in the UK.

Dr Verdon's view that my discussion paper is “*not really a scientific paper at all, in any normal sense of the term*” perhaps says more about his own prejudices than it says about my work. In his own blog Frack-land he has also published potentially libellous *ad hominem* comments about me; for example, for the last 18 months he has permitted an anonymous comment to appear online, castigating my alleged shortcomings in teaching some twenty years ago. The comment, claiming to be by a Glasgow graduate, is factually incorrect, and therefore worthless. Its continuing presence on his blog says more about Dr Verdon than it does about myself.

Faulting in US shale plays

I have thought long and hard about how (and whether) to publish a review of faulting in the US shale basins. It is a desk study, limited to public domain sources, although many of the latter are

incomplete and/or partial samples of proprietary seismic and well data. My study took about two months' full-time work.

The two principal problems about how to publish such a review are firstly, that it would depend on very many copyright sources which cannot simply be reproduced without permission, and secondly, that the main result – that there is practically no faulting in areas where shale oil/gas exploitation has been undertaken, is a negative result. Am I to be expected to publish a series of blank structure maps? There is no *Journal of Negative Results in the Earth Sciences*, although I was astonished to discover that at least two such journals do exist in other fields.

Dr Verdon quotes Younger and Westaway (2014), who argue that because the USA is so much larger than the UK, it is unlikely to have been mapped geologically to the same degree. So mapping quality may have affected the outcome. I accept that parts of the UK have been exceptionally well mapped, particularly where there have been coalmine workings, but the main problem is that sedimentary basins, whether in the UK or the US, are generally poorly exposed. But I cannot accept that a US field-mapping geologist, whether employed by the State or by the USGS, will on average have missed 99% or 99.9% of faults compared to his/her BGS counterpart, in terrain which is otherwise similar. The answer, in my view, is that there is a real difference in fault density, and that this real difference is explicable by the simple words 'foreland' vs. 'extensional'. Furthermore, the geometric differences in area and depth of the respective shale plays, of one to two orders of magnitude (discussion paper fig. 1 and table 1), which I presume these critics do accept as real, also tie in with the fault density difference of 2 to 3 orders of magnitude.

It is noteworthy that neither Dr Engelder nor any other American earth scientist has sought to question my conclusion. But there is a solution; if Drs Verdon, Westaway and Younger (three commentators who have either here or elsewhere criticised my review as being unpublished, and, worse! 'un-peer-reviewed') then they are free simply to search for and offer up one or two examples to refute my assertion.

If the Editor insists, I could add a supplement listing all the sources consulted for my US basin fault study, arranged by shale play, and with a few notes appended where required.

The Fisher and Warpinski study of frack height growth

I agree with Dr Verdon (and with Dr Westaway) that partial disclosure of the Halliburton dataset is better than non-disclosure. It is a common problem in earth science to be aware of expensive and valuable industry data, which for often sound commercial reasons cannot be published. We

academics sometimes have to beg for samples to be released.

But when the industry itself chooses to publish, we are right to ask, what is the agenda? A typical industry paper, peer-reviewed or not, almost certainly has an agenda, which is normally to promote the excellence of the company's products or services. In the case of Fisher and Warpinski (2012) the agenda is clearly the promotion of fracking, by demonstrating (and I accept their views, within the limits of what they have chosen to release) that fracture growth is highly unlikely to propagate upwards so as to contaminate groundwater resources. I do not impugn the integrity of Messrs Fisher and Warpinski, but it is legitimate to ask, as I did, commenting:

“This uncritical attitude towards an industry publication is surprising, as well as naïve, given that:

- *Halliburton's database remains confidential.*
- *Wells are located only to county level.*
- *Individual wells cannot be identified on the four main graphs presented.*
- *We do not know whether inconvenient results have been omitted.*
- *We do not know how complete is the database.*
- *There are no wells in areas where complex geology (faults or tight folds) at the shale horizon extends to the surface.”*

I also asked some other valid and pertinent questions about their database. For example, there is no reason why they could not have released their well locations, since well tops (and in some states, bottoms) are, in principle, in the public domain. Why do more academics not take a more critical, sceptical view?

In case the reader retains a belief in the benevolent nature of large companies in the hydrocarbon sector, this list of the top fines (year and amount in millions of \$US) for corrupt practices imposed by the US Department of Justice and by the Securities and Exchange Commission might make them reconsider (hydrocarbon-related industries in bold):

1. Siemens	2008	800
2. Alstom	2014	772
3. Halliburton	2009	579
4. BAE	2010	400

5. Total	2013	398
6. Eni + Snamprogetti	2010	365
7. Technip	2010	338

[source: *Le Monde*, 20 January 2015].

Microseismic data, pathways to faults

Dr Verdon claims that my example of a stealth zone (fluid moving along a path not marked by microseismic activity) is self-contradictory. I disagree; the use of the word 'stealth' shows that the fluid went somewhere silently. The presence of a fault had to be inferred by the fact that microseismic activity had jumped to a new location. I conclude correctly that the deployment of a microseismic array, although essential, is no guarantee that all faults will be identified.

I agree that Hammack et al. (2014) is a useful paper, which I read first in October 2014 during my search for faults in US shale basins. It has a nice example of seismic data illustrating faulting at Marcellus level in western Pennsylvania, and also depicts many examples of microseismic activity. However, I am not so concerned with fracture growth, or even interaction with faults down at the shale level. This study demonstrates that upward growth, although penetrating beyond the Tully Limestone, nevertheless stopped well below Upper Devonian reservoirs and 2 km below any potable aquifers. But there are no through-penetrating faults in the monitored area; therefore it has no direct relevance to the main thrust of my discussion, which is that through-going faults from a fracked shale to the near-surface can put water resources at risk.

Development of hydraulic fracturing in the UK

Dr Verdon complains that in my section 2 I am seeking to 'settle scores' with other UK academics. I am certainly not, but when I read of senior academics presenting misleading or erroneous information to public bodies, whether by slide-show or not, critical comment is required, if only in order to lay to rest the kind of misinformation which these academics often accuse the anti-fracking lobby of promoting. I have had the whole Wytch Farm 3D seismic dataset, all the surrounding 2D data for the Bournemouth Bay and onshore area, and most of the wells on my computer interpretation database for the last eight years, for the purpose of conventional oil prospecting. I am fed up with reading about Wytch Farm in the misleading context of fracking, environmentally safe though it may be. This includes a newspaper report quoting Dr Verdon.

Re-interpretation of Preese Hall-1 faulting

I like Dr Verdon's assessment that 10 geophysicists, given the (minor) earthquake seismic data for the Preese Hall events, would come up with 10 different interpretations. The issue of the location of the hypocentre(s) and the fault that slipped has certainly not yet been resolved satisfactorily, but in my view my proposal that the fault was intersected by the wellbore is both novel and worth examining. I discuss this in more detail in my response to Dr Westaway, who has recently published on the same subject.

The history of the interpretation of the earthquake triggering and attempts to locate the fault serves to illustrate that understanding of the Bowland Shale is still very incomplete. I have never promulgated the view that earthquakes triggered by fracking is a problem to worry about; my concern has always been the risk of upward fluid flow *via* faults. A sensible approach would be for baseline monitoring to be set up in the Fylde, to run for two years or more, and for the 3D seismic dataset to be released now rather than in a year's time, when it nominally falls into the public domain. Perhaps then the various interested parties could then converge on a consensus view.

Fracking in the Weald Basin

Dr Verdon states:

*“This section discusses **conventional** oilfield activities in the Weald Basin at Balcombe. The UK’s 2015 Infrastructure Bill precludes hydraulic stimulation taking place at depths of less than 1,000m. The wells in question are at depths of approximately 800m. It is therefore difficult to see the relevance of this section to the development of hydraulic fracturing in the UK.”* [my emphasis].

The statement is disingenuous. Dr Verdon maintains that the aborted well drilling in the Weald was “conventional” in nature. But he knows that Cuadrilla originally intended the drill horizontally and frack the limestone at Balcombe, as described in its successful planning application of 2010. Cuadrilla later assured the county council that it would not frack either Balcombe-2 or the deviated Balcombe-2z at those stages in the appraisal, but as Dr Verdon noted in his blog post dated 31 July 2013:

*“In the last few weeks I’ve ...[been] deploying seismometers around Cuadrilla’s planned Balcombe well. ... the current Cuadrilla plan is to drill into limestone for conventional oil, with **no intention of hydraulic fracturing at this stage**, but we wanted to get some experience deploying seismometers for this sort of situation.”* [my underlining].

Dr Verdon explained that the deployment of seismometers in 2013 was intended to obtain baseline, or background, data on environmental noise levels. But I can only assume that this (sensible) experiment was in preparation for a future phase of fracking, which in the event never took place. If no fracking was ever intended, then there would be no risk of triggering earthquakes, and therefore the *raison d'être* of the baseline survey collapses (one does not need earthquake monitoring for conventional drilling).

Similarly, Celtique Energie said in its two applications to drill horizontally that it would not frack the wells in appraisal, but reserved the right to do so at a later stage.

The statement is irrelevant. His reference to the Infrastructure Act (which he wrongly calls a Bill) is irrelevant, as it only came into force in February 2015. I discussed the case histories of Cuadrilla drilling at Balcombe and the proposed drilling by Celtique Energie at two other sites in West Sussex to demonstrate the technical incompetence of the operators – wells misplaced on maps; misleading seismic data, faults ignored, and licence boundaries grossly in error. At the time that these proposals or actions happened there was no legal limit in place regarding a minimum depth for fracking. The 1000 m depth limit would now rule out fracking of the two Kimmeridgian micrites at Balcombe, and also at the currently controversial Horse Hill well north of Crawley, but would permit fracking in the Lower Kimmeridge Clay and in deeper targets such as the Oxford Clay and Lias. It would not have prevented fracking of the Kimmeridgian micrite at either of the two Celtique Energie sites.

Modelling studies

I did not cite the Hammack et al. (2014) paper here because it does not concern the possibility of fluid migration up to the near-surface *via* faults. The observations, interesting though they may be, were in an area which, as the authors demonstrate, the faulting is confined to sub-Tully Limestone levels.

I did allude to the Flewelling et al. (2013) paper by way of my organogram (fig. 9), in the context of a critique of Myers (2012), but forgot to add it to the reference list. Incidentally, Flewelling et al. repeat the error of Fisher and Warpinski (2012) in arguing that permeable faults cannot exist where hydrocarbons are present; an argument which conflates conventional and unconventional methods.

Bradford County study

I have provided a substantial re-interpretation of this important case history in my second response to Dr Engelder (AC3).

Regulation

Criticism of the UK unconventional oil and gas regulatory system might appear superficially to be out of place in an earth science journal, but if the criticism entails detailed technical analysis, understandable only by earth scientists, then an earth science journal is the only appropriate forum. How could a social science or legal journal handle such evidence?

Dr Verdon agrees with two other commenters (Younger and Westaway) that such comments are not appropriate, but I disagree with all three. It should be the duty of disinterested academics to comment upon perceived failings in the regulatory system, and if that extends to 'discrediting' certain agencies or government departments, as Dr Verdon implies, then so be it. I never identify individuals for criticism, unless it is completely unavoidable, because I know from my own experience of 14 years as a public servant with the BGS that such people have to work under certain constraints. But Dr Verdon and I are free of such constraints.

Declaration of interest in acknowledgments

I am flattered that Dr Verdon takes a close interest in my work, to the extent of guessing (albeit incorrectly) how much funding I allegedly get from objectors' groups. I am happy to declare the work I have been asked to undertake for such groups, in challenging unconventional exploration planning applications, or for appearing at local planning inquiries. I have also given several (unfunded) talks about fracking to the general public in the UK and in France.

Unfortunately, contrary to Dr Verdon's beliefs (expressed elsewhere), I make practically no money out of these ventures. I declare my consultancy income, which includes the small honoraria I have been given, to the UK tax authorities. From the tax year 2013-2014 onwards, my UK tax liability has been zero. In the last three or four years my research into fracking has been remunerated by these groups at an average rate of well under £1 per hour. However, my travel expenses have usually been reimbursed when I appear before county councils or planning inquiries.

I propose to declare my interests as follows:

'Declaration of interest: I work from time to time *pro bono publico* to assist groups of objectors in challenging unconventional hydrocarbon planning applications. These groups usually fund travel expenses, and I have sometimes been paid small honoraria.'

References

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