Additional comments relevant to
Planning applications by Cuadrilla Bowland Limited to drill at
Preston New Road (no. LCC/2014/0096)
and
Roseacre Wood (no. LCC/2014/0101)
Objection on grounds of geology and hydrogeology
by

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Summary

Further new information has emerged following my previous submission to LCC in April 2015. Firstly, I respond to comments submitted to LCC by the Environment Agency (EA), which commented upon my previous report of April 2015. Secondly, I comment on a new peer-reviewed scientific paper proving for the first time that unconventional gas production has contaminated groundwater supplies via faults and fractures. Lastly, I briefly comment on a very recent draft report published the US Environment Protection Agency on the impact of fracking on drinking water resources.

The EA appears to be unaware that polyacrylamide, a friction reducer used in hydraulic fracturing (fracking) contains small quantities of highly toxic acrylamide. Given that: the friction reducer is used in large volumes; that 60-90% of frack fluid remains underground; and that such fluid may migrate, essentially undiluted, up to drinking water supplies, polyacrylamide should no longer be classed as a non-hazardous chemical *when used in fracking.*

The EA commented upon my eight concluding summary points of objection, but has failed to add any substantive new evidence. On the contrary, it agrees that the area around the application sites is geologically complex, and that the location of the Woodsfold Fault is problematic. There appear to be at least three different geological interpretations of the area. The EA has not resolved the question of how saline (or not) is the potential groundwater resource below the Fylde. The EA does not appear to see the requirement for a minimum safety, or 'respect' distance of the fracking zone from any fault, but instead mistakenly assures the Council that its own monitoring of the development work will suffice. In conclusion, my eight points of objection still stand.

At the time of writing Cuadrilla Resources Limited, the Applicant, appears not to have submitted a technical response to any of my previous comments.

A new paper outlining the history and hydrogeology of a fracking-related contamination incident in NE Pennsylvania, USA, proves beyond reasonable doubt that faults and/or fractures played a crucial part in the contamination of drinking water wells and the Susquehanna River. Prior to this study, incidents of groundwater contamination had been attributed to faulty well construction, whereas faulted geology had always been exonerated. The study reports a new ultra-sensitive method of fingerprinting the source of the contamination, which should be introduced to the UK.

I therefore continue recommend to LCC's Development Control Committee that it puts in place its own fracking moratorium until such time as the outstanding problems are resolved. This means that both the proposed developments should be refused.

Introduction

My objections to both of the developments are principally on grounds of potential contamination of groundwater resources. The decisions by the EA to approve the applications are crucially important, but I believe are wrong and misguided, and should therefore be disregarded by the Development Control Committee. I wrote to the Committee in April 2015 with new information (Smythe 2015), and the EA has since responded to this by an email to LCC dated 15 May 2015.

Here I comment on and rebut the EA comments on my previous report, and also discuss an important new peer-reviewed paper that was published on 4 May 2015.

Environment Agency comments on my submission of April 2015

The EA comment begins by stating that *"We will not permit the use of hazardous substances for any activity, including hydraulic fracturing, where they would or might enter groundwater and cause pollution."*

The EA draft decision document for both sites states: *"Polyacrylamide will be added to the fracturing fluid (approximately 0.05% by volume of the fracturing fluid). Polyacrylamide acts as a friction reducer ..."*

The EA considers this friction reducer to be non-hazardous, but I pointed out in my presentation about Roseacre Wood to the Development Control Committee on 26 January 2015 that it contains residual acrylamide, from which it is manufactured. Acrylamide is a highly toxic chemical for which the US Environmental Protection Agency states that there is no safe limit in drinking water. I submitted a pdf of my slideshow to LCC on 20 January 2015. Three slides therein (nos. 12-14) discuss the problem of pollution of drinking water by the presence of acrylamide in polyacrylamide. I concluded that there is a serious risk of drinking water contamination from fracking fluid containing polyacrylamide, as used by Cuadrilla, and showed by means of calculations and a diagram that fracking fluid would have to be diluted by a minimum of 2500 times to bring it below the 'acceptable' limit of acrylamide content (as defined, for example, by the state of Minnesota) in drinking water.

Since my calculations, and conclusions drawn from them, are in the public domain (they were also posted on my blog in December 2014; http://www.davidsmythe.org/frackland/?p=66) it is incumbent upon the EA to respond to these concerns about acrylamide. The EA has not, to my knowledge, yet done so.

The EA then goes on to agree with me (grouped under my points 1-4) that the geology of the southern Fylde area is complex, but at the same time justifies the conclusions reached in its two decision documents by alluding to its extra modelling work and the commissioning of two new exploratory observation boreholes: *"This work resulted in a revised understanding of the alignment of the Woodsfold Fault and an improved understanding of the geology of the Fylde sandstone aquifer and the groundwater flow regime."* But this somewhat self-congratulatory conclusion is not backed up by any new published information – it remains merely an assertion. In fact it suggests that there are probably now at least three mutually contradictory versions of the geological structure:

1. The British Geological Survey (BGS) interpretation prepared for its 2013 Bowland Shale assessment (Andrews 2013), which in part conflicts the BGS's own published solid geology maps regarding the location of the Woodsfold Fault,

2. Cuadrilla interpretations using its 3D seismic survey data – which were not available

for the BGS study above, and

3. An EA-commissioned revised mapping of the position of the Woodsfold Fault.

Although the EA claims that two (unspecified) new boreholes were drilled, they must have been included in the dataset that I obtained from the EA on 30 March 2015, and which I have therefore already discussed in my previous submission (Smythe 2015). The EA has failed to respond to my conclusion that the hypersaline groundwater measured in the Kirkham borehole is not representative of the groundwater in the Sherwood Sandstone Group (SSG) below the Fylde, west of the Woodsfold Fault.

The EA further agrees with me that the Cai and Ofterdinger (2014) modelling paper is flawed (my point 5), and it has discussed the work *"verbally"* with the two authors, who are inclined to accept that it was flawed. I concluded that, despite the flaws, the *"study found that the SSG aquifer could become contaminated on the order of 100 years under certain conditions"*. I also recommended that more realistic hydrogeological modelling should be undertaken before any further drilling is carried out. But on this issue the EA merely *"remain* [sic] *confident that the conditions set out in the permits are sufficient to ensure that fracturing activities will be controlled and monitored to protect groundwater quality in the wider area."* This attitude is complacent and unrealistic; how can activities be *"controlled and monitored"* during the fracking of imperfectly understood major geological elements, when the possible outcome could be the slow but irreversible contamination of groundwater many decades after Cuadrilla has completed its operations? I therefore cannot share the EA's confidence.

In responding to my points 6 and 7 (uncertainty in fault recognition, and the safety distance for avoiding faults, respectively), the EA misunderstands the issues. If the operator (or, for that matter, the BGS or the EA) has trouble even in correctly identifying the faults in advance of fracking, how can the vaunted Hydraulic Fracture Plan possibly function? The traffic light system of real-time microseismic monitoring may well be effective for mitigating the earthquake triggering risk – because that is what it is designed for – but cannot identify or track the migration of frack fluid along pre-existing faults. The EA ignores the need (acknowledged in the USA and Germany, for example) to set a minimum safe distance (whether of 850 m, 100 m, or greater) from a fault, within which no fracking will be permitted.

The last point (no. 8) raised by the EA concerns re-injection of *produced* water. *Wastewater* is a general term which includes *flowback* water (produced by the fracking process and subsequent flowback tests) and *produced* water (from production of unconventional gas or oil). The Lancashire EA decision documents clearly permit the re-use of flowback fluid by re-injection into the same geological formation that is been fracked, but the comment email of 15 May 2015 re-emphasises: *"There shall be no injection of hydraulic fracturing fluid (which may include reused flow back fluid) <u>for disposal</u>"* (my underlining).

The EA has not responded to my query under point 8, which concerns *produced* water and not *flowback* water. I accept that the question of disposal of produced water is not directly relevant to the two current planning applications; however, it will become highly relevant in the event of the Bowland Shale being exploited to produce unconventional gas. It is rational for the Committee to consider the current applications in the context of the longer view, i.e. the possible move to large-scale production. It is clear from Appendix A of my April 2015 document that *the EA does permit the disposal of produced water by re-injection*. Such activity will multiply many-fold the risk to groundwater resources, as well as triggering earthquakes. The latter could, if US and Canadian experience is any guide, be three units higher on the Richter scale than the minor tremors triggering by the fracking of the Preese Hall-1 well in 2011.

Returning to the re-injection of flowback water, which is to be permitted for re-use (but not for disposal), it is a moot point as to when re-use effectively becomes disposal. If up to 90% of the frack fluid remains in the formation, and only 10% flows back, then it could be said that 90% of the frack fluid is used, and permanently disposed of, at each stage of fracking. The proportion grows with each recycling of the flowback proportion. In addition there is no legislative control over an operator running a final frack stage, ostensibly for stimulation, but in reality for the purpose of emptying the surface flowback storage containers, and thereby saving on the cost of taking away the flowback remainder for treatment.

In conclusion, the current policies of permitting a product with a highly toxic component, acrylamide, to be injected in the first instance, combined with flowback recycling (re-injection), is a potential long-term risk to shallow groundwater receptors.

Contamination of drinking water supplies by unconventional gas production via faults and/or fractures

An important paper about contamination of groundwater resources by fracking was published in the prestigious journal *Proceedings of the National Academy of Sciences* (of the USA) on 4 May 2015 (Llewellyn *et al*. 2015). The relevance for fracking in Lancashire, and for the UK shale basins in general, is that the research proves beyond reasonable doubt that contamination of drinking water was caused by passage of frack fluid and/or produced water through the geology. Up till now only faulty well construction has been implicated in the contamination process in the many US water contamination case histories.

Here is a brief summary of the history and results of the research. Chesapeake Energy, one of the major players in the Marcellus Shale play of Pennsylvania, drilled five wells in Bradford County, NE Pennsylvania, in 2009 and 2010. Contamination of private water wells in the vicinity (1200 m away) started almost immediately. In May 2011 the Pennsylvania Department of Environmental Protection fined the company $900,000. Chesapeake promised to pay for water treatment equipment on selected wells (http://thedailyreview.com/news/dep-fines-chesapeake-1-1m-for-violations-chesapeake-and-dep-come-to-agreement-1.1148316), while maintaining that the problems arose from "*pre-existing detectable levels of methane*". The company had previously drilled three new water wells to replace three existing wells, but the contamination continued in these replacement water wells. In June 2012 the homeowners won a civil case against the company, which had to buy the properties and compensate the owners. The five gas wells were identified as the probable source of the stray gas.

The consultant hydrogeologists acting for the former homeowners are co-authors of the new research (Llewellyn *et al*. 2015). They used a sensitive analytical technique, novel in the field of environmental forensics, to identify the source of the contamination, which included white foam in the water wells, vapour intrusion in the basement of a house, and bubbling of gas in the Susquehanna River. The new technique identified a specific compound called 2-BE, used in drilling additives, as well as organic unresolved compound mixtures (UCMs) in the impacted wells, whereas no detectable levels of these compounds were found in the background and comparison samples. The analysis rules out the possibility of surface spills of drilling products or naturally occurring methane as sources of the contamination. The US Environmental Protection Agency (EPA) has suggested that 2-BE could be a useful indicator of contamination from fracking activities.

Figure 1 shows a schematic cross-section of the geology in the locality, redrawn and simplified from Llewellyn *et al*. Vertical exaggeration is about 2.5. The authors discuss how the contamination from the fracked layer, the Marcellus Shale, could have reached the water wells. The geological layers above the shale are gently folded, and a low-angle thrust fault (the solid red line in Figure 1) is interpreted from seismic data to run from the surface south at an angle of about 16º to 'sole out', or flatten asymptotically into, the Marcellus Shale.

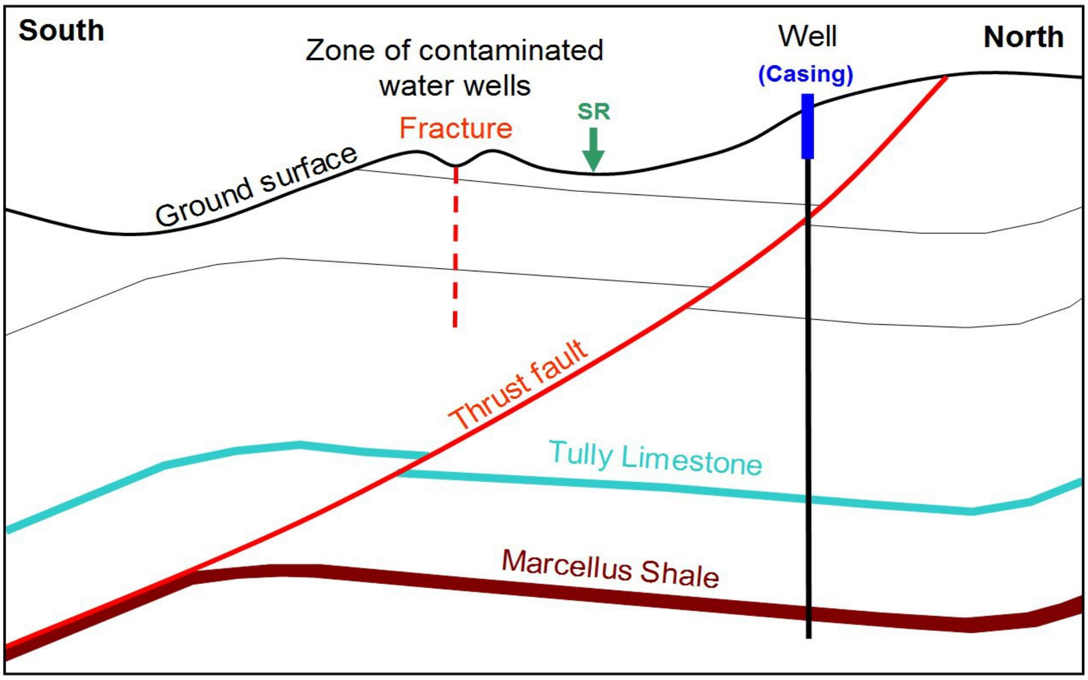

Fig. 1. Schematic cross-section to illustrate the salient features of the contamination pathways identified by Llewellyn et al. (2015) in Bradford County, Pennsylvania. The profile is about 10 km long, and the depth from the ground surface varies from about 2000 m to 2400 m. Representative geological layers, which are gently folded, are shown by thin black lines. Vertical exaggeration is about 2.5:1.

A NNW-SSE fracture zone (one of two), identified only by a linear topographic feature, is shown by the vertical dashed red line. It is not known how deep it penetrates. The thrust fault offsets the layering (the left side, above the thrust has been displaced upwards and to the right, relative to the rocks below). The schematic well (only one of the five is shown) penetrates vertically to the Marcellus Shale (the fracked layer), but is only cased to about 300 m below the ground surface (blue line). The Susquehanna River (SR), where gas bubbling was observed, is shown by the green arrow.

The water wells lie in a narrow linear valley, one of two such parallel features seen on very high-resolution digital elevation models (DEMs) and interpreted by the authors as fracture zones, but not previously mapped on published geology maps. The word *fracture* implies a break or crack in the geology, but where the offset of the rocks on one side relative to the other is either unknown or is zero. This contrasts with a *fault*, in which there is a measurable offset. The fracture interpretation may appear on its own to be somewhat weak; however, a pump test (a technique in which water is removed from a central well, and the effect on other wells around it is observed) showed that the water flow pattern in the district is aligned along the valley. This suggests a deep structural control such as the putative fracture zone. The authors cite the evidence of small-scale joints seen in the rock exposures at the surface, also running in the same direction. In addition, but not mentioned by the authors, there are small normal faults elsewhere in Pennsylvania running in the same direction, and occupying the same structural location (on the foreland just in front of the Appalachian thrust belt) as this part of Bradford County. The two fracture zones identified by Llewellyn *et al*. are therefore probably minor normal faults.

The authors rule out the thrust fault as being a conduit for the contamination, even though it intersects three of the five offending gas wells below the level of the casing shown schematically in blue in Figure 1. This is because the dip of the fault (angle to the horizontal) is low, meaning that vertical rock stress will tend to keep such a fault held tightly shut. In addition, the rate of progress of the contamination would be very slow along such a feature, although I disagree with the reference cited here in support by the authors, which claims that the migration time would be thousands to millions of years. The thrust fault is an interpretation from seismic data which are not publicly available. I believe that this interpretation is, in any case, questionable, because elsewhere in NE Pennsylvania the few published interpretations of the subsurface faulting suggest that the thrust faulting is divided into two zones; (1) an upper set of shallow-angle thrusts which sole out downwards into the Tully Limestone (light blue layer in Figure 1), (2) and a deeper, steep set of thrusts or reverse faults which cut the Marcellus Shale. In conclusion the thrust fault, even if it has been accurately identified, is not suspected to be a pathway.

The authors conclude that the most likely pathway for the groundwater contamination is initial passage up the wells from the Marcellus, followed by lateral passage along bedding planes, inclined gently upwards to the south, and vertically upwards along bedrock joint planes and fractures. Overpressured gas well annuli are implicated as one driving mechanism.

What are the lessons for the UK, and in particular the two applications to which I am objecting? The Bradford County experience shows that **faults and fractures can and do act as conduits for contamination by fracking and subsequent production**. This case history has occurred in geology that is far simpler than that in the Fylde region.

Pre-drill water sampling is essential. UK legislation should also include a requirement for a benign unique marker product to be added to fracking fluid at each well, so that any contamination can be traced back to a specific well. Knowledge of the geological structure is clearly crucial. In my view this knowledge is currently inadequate in the area of Cuadrilla's licence. The density of faulting and fracturing in NE Pennsylvania is two to three orders of magnitude lower than it is in the Bowland Shale basins, and yet a serious pollution incident occurred. The faults and fractures in the Fylde are normal faults dipping at steep angles, and will not be held shut by vertical pressure, as appears to be the case in the thrust fault shown in Figure 1.

UK legislation and monitoring is way behind jurisdictions like Pennsylvania, despite government claims to the contrary. For example, the high annular pressure (300 psi) discovered at Preese Hall-1 has been allegedly 'mitigated', and permission has been given to plug and abandon this well, with no ongoing monitoring. The Bradford County history also illustrates the long fight for remediation and justice that local residents have had to suffer. There is no reason to believe that the UK residents who become the victims of fracking contamination would fare any better.

The US Environmental Protection Agency (EPA) has just published a draft report (4 June 2015) entitled *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* (USEPA 2015). This large document, comprising 998 pages, has only a short review section (6.3.2.4) of 2.5 pages entitled *Migration via Fractures Intersecting Geologic Features.* I have not yet found anything of particular relevance in this document for the UK.

Conclusions

The eight points of objection summarised in my April 2015 submission all remain valid, despite the attempt by the EA to counter them and justify its granting of permits. The Applicant has not, to date, seen fit to submit any further comments on the geology or hydrogeology. In addition to my previous recommendations, the currently conflicting geological interpretations of the Fylde need to be reconciled and put into the public domain, preferably by the BGS, before any fracking is permitted.

The new information emerging from the USA confirms my view that faults and fractures are crucial factors to be considered in estimating the risk of groundwater and surface pollution from fracking.

I therefore continue to recommend to LCC's Development Control Committee that it puts in place its own moratorium, by refusing the two proposed developments.

References

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