Reply to Professor Paul Younger (SC6)

I am responding to Professor Younger's comments under headings which follow his own subject headings as far as possible.

My erroneous assumption no. 1: inherent risk of groundwater resource contamination via faulting during or after unconventional resource development

Professor Younger cites several hydrogeology textbooks to deny that faults 'inherently' act as pathways. Perhaps we are not talking the same language; to me, 'inherent' means built-in, innate, or intrinsic, qualifying adjectivally the noun 'risk', or chance, probability. The phrase 'inherent risk' does not imply that faults are necessarily permeable to flow, and I am of course aware that any particular fault may behave differently over different segments of its track, and over different geological periods. But there is a built-in risk, which needs to be assessed and, if possible, quantified.

So if the 'inherent risk' of faults acting as pathways in shale development is very low, as Professor Younger seems to imply, then why have so many quantitative modelling papers been published about the very problem in the last few years? Why is the English summary of the extensive 2012 German study called 'Hydrofracking Risk Assessment'? That document concludes, regarding groundwater:

> *"Hydrofracking can entail considerable environmental risk, particularly when it comes to water resource conservation, which we strongly feel absolutely must take precedence over energy production."*

I am well aware that the French work I cited concerns – in part - karstified limestones, an extreme kind of rock formation, hydrogeologically speaking. However, it is demonstrated there that deep pathways down to greater than 2 km depth involving faults do exist, and limestone plays little or no part in the flow systems at depths greater than 1 km. The studies show that upward fault pathways exist through Lias shales, which were the target of a Total exploration licence (since annuled) for fracking.

Similar geological terrain was licensed for fracking by DECC in Somerset, where there is a proven deep flow system through the Carboniferous Limestone, recharged in the Mendips, flowing north at depth, and coming up to the surface along faults at Bath. The southern French and the Somerset examples, which both involve thermal springs known since at least Roman occupation times, also both show that unconventional exploration companies will simply disregard any groundwater risk if they can get away with it. At least the French government learned fast, unlike its UK counterpart, and decided in 2011 to cancel all the licences it had previously awarded for unconventional exploration.

In conclusion, there is an 'inherent risk' in unconventional resource exploitation.

My erroneous assumption no. 2: hydraulic gradient favouring upflow

I refer Professor Younger to my review of the literature that has appeared since 2010 on the quantitative modelling of groundwater flow from fracked shale up fault zones. I shall be adding a brief review of Birdsell et al. (2015). All these studies concur that upward flow is possible; the questions which remain the subject of debate are the precise mechanisms, and the timescales. In conclusion, upflow can happen, driven by several different forces.

My erroneous assumption no. 3: saline springs as an example of dilution

Professor Younger makes an analogy with saline springs to show that even if contaminating fluids did reach shallow groundwater resources, the contaminants would be "*diluted beyond detectability*". Even if such an analogy were appropriate, it evidently excludes gas (especially methane) migration.

Such an argument is reminiscent of the days when it was thought acceptable for nuclear waste to be dumped in the oceans, justified by the so-called 'dilute and disperse' principle. It is invalid, not least because one of the modelling studies I cited (Gassiatt et al. 2013) mentions, *en passant*, that contaminated fluid reaches the near-surface *via* the specified pathway at 90% of its original concentration. It would be complacent of anyone to assume that such fluid would then somehow get "*diluted beyond detectability*" as Professor Younger hopes.

In conclusion, it seems to me that Professor Younger is taking a general stance, regarding the so-called erroneous assumptions that I have made, that is rather out of the mainstream thinking on the hydrogeology of unconventional resource exploitation. Since arriving at Glasgow nearly four years ago he will have had the resources of a research group to set up some numerical modelling studies of his own, if he disagrees with certain aspects of the mainstream.

Royal Society and Royal Academy of Engineering report of 2012

I took the report to task for failing to consider the fault problem properly. Professor Younger initially (in 2014) accused me of simply not reading it thoroughly; however, in trying to defend this aspect of the report, he now resorts to generalities concerning the eminence of the two societies.

I shall rephrase my summary statement (section 6.2.4) referring to the report having a "*perceptible* *pro-industry bias*"; this was alluding only to the uncritical comments the committee made about the upward growth of fracks in the Halliburton paper (Fisher and Warpinski 2012), and on re-reading the report I do not find any other instance of there having been such a bias.

Potable groundwater below the Mercia Mudstone Group (MMG)

My doubts about the Environment Agency (EA)'s claim (*inter alia*) that groundwater in the Sherwood Sandstone Group (SSG) at 300 m depth below the MMG in the Fylde is saline, and therefore not of concern, are dismissed by Professor Younger; however he does not offer a detailed rebuttal, because he apparently does not have time to deal with my *"unsubstantiated opinions"*.

Professor Younger states, in particular:

> *"Smythe's claims about the possibility that fresh groundwater occurs in the Sherwood Sandstones beneath saline water in the Mercia Mudstones is* ***at odds with all known sites in the UK where this setting has been monitored*** *(e.g. in many English coalfields)."* [my emphasis].

I hesitate to take issue with this strong claim by one of the UK's leading hydrogeologists. So let us first be clear what is being said:

- The "*setting*" is my claim that there could be fresh groundwater in the SSG below saline water in the MMG (in the Fylde), and
- Such a setting does not exist anywhere in the UK.

There are three other basins, apart from West Lancashire Basin within which the Fylde is situated, which have halite within the MMG. These are the Avon/Somerset, Worcester/Gloucester, and Cheshire basins (Hobbs et al. 2002). So Professor Younger is claiming that because the setting occurs in three of the four halite-bearing basins it must necessarily be true of the fourth, the Fylde. Firstly, this is a *non sequitur*, and secondly, it is not even necessarily correct in the three other basins, as I now demonstrate.

I have looked briefly, but not systematically, at the Cheshire Basin. The regional flow through the SSG is to the NW, towards the Irish Sea, and "*flow probably tends to follow peripheral routes, around the deeper area, where the permeability is better and is enhanced by fractures*" (Downing et al. 1998).

A groundwater baseline study of the sandstones of west Cheshire by Griffiths et al. (2002) concerns mainly the outcrop of the SSG of west Cheshire and the Wirral, west of the central part of the

Cheshire Basin where the MMG crops out. Griffiths et al. cite one component of the present day groundwater flow regime, as follows:

> *"At the centre of the basin where the SSG is covered by the MMG. Density variations in the groundwater as a result of halite dissolution and mixing of freshwater at the margins influences the groundwater flow. The division of the flow field into a number of mixing cells results in* ***quite large salinity variations*** *across the basin."* [my emphasis].

Although concentrating on the western SSG outcrop, their study does include seven locations within the central outcrop of the MMG (Griffiths et al., fig. 6.7). Chloride levels within four of these boreholes is in the range 30-50 mg/l, two are in the range 50-105 mg/l, and the seventh is of the order of 200 mg/l. So they all appear, in principle, to provide potable water. Details of some of these boreholes can be found on the BGS Borehole Viewer. The two adjacent boreholes in the centre of their map (with Cl c. 30-50 mg/l) are on the outcrop of the Tarporley Siltstone (MMG), and about 1-2 km east and SE of the Helsby Sandstone Formation (SSG), formerly the Lower Keuper Sandstone. The top of the SSG is at 68 m in the borehole. The principal borehole of this pair is named Eaton Crewe Waterworks, from which it is evident the use to which the resource is (or was) put.

There are many other boreholes on the outcrop of the MMG, not necessarily penetrating to the SSG, but which are licensed for agricultural abstraction, including irrigation and golf course watering. It is unlikely that these are producing saline water. In conclusion, Professor Younger's generalisation about the 'setting' of MMG with halite over SSG does not stand up to scrutiny.

Now let us examine the Fylde evidence, without accepting Professor Younger's evidently over-general conclusion. For the benefit of the Editors and any other readers, let me first summarise and expand upon what I wrote about the Fylde. Firstly, I noted that the only evidence that the EA seems to consider is the hypersalinity in the Kirkham geothermal test borehole, which penetrated the SSG at 366 m. I pointed out that this evidence is invalid because two of the three hypersaline samples were taken from levels within the MMG, where the observed *hyper*salinity (and not simply salinity) can be explained by perched relict halites known to exist within the MMG. The groundwater within the SSG was never sampled. Surely this is a fundamental point which Professor Younger should have taken on board.

I then alluded to two other boreholes which penetrated to (and presumably abstracted from) the SSG, writing *"*[they] *suggest that potable water was formerly exploited within the SSG"*. For the record, these two boreholes are Rowe's Model Dairies at Inskip, and Phoenix Mill at Kirkham. They are part of a group which I examined, comprising some 39 relevant wells west of the Woodsfold Fault, of depth greater than 30 m, which are available on the BGS borehole mapper website. I think it is a reasonable conclusion to draw that it is unlikely that hypersaline water was used either for the cheesemaking at the dairy or for cotton spinning at the mill. About five of these borehole records are confidential, and/or there is no information. In addition, I studied the water composition records of 56 boreholes, which I obtained from the EA.

In conclusion, my concern that the EA has written off a past and future potential groundwater resource in the Fylde is justified. Before any unconventional exploitation begins it would be prudent for the EA and/or the BGS to sample the water at SSG levels.

My criticism of the EA

I carried out my study of the Fylde before coming to my conclusion about the EA's potential failure to protect groundwater resources below the Fylde. I am critical of the organisation, not of any individual employees, as Professor Younger implies.

Since I submitted my discussion paper more evidence has emerged which casts the EA's views on the risk to Fylde groundwater resources in an even worse light than I had viewed it with previously. I append below as an Appendix part of a comment I submitted to the Local Planning Inquiry in March 2016. In brief, the EA never responded to my comments of April 2015 on the hypersalinity readings in the Kirkham well. Moreover, the agency tried to justify its *laissez-faire* stance by quoting a then-confidential study it had made of the SSG aquifer of NW Lancashire. It turns out that this study is twenty years old, was carried out for the EA by the BGS, and that a crucial part of the study (the basemap) has been lost. However, it highlights the fact that the location of the important Woodsfold Fault is uncertain. In conclusion, my criticism of the EA is based upon sound evidence.

UK regulation

Under this heading Professor Younger once again quotes the joint committee report (Mair et al. 2012) discussed above, and also cites the Scottish independent report on unconventional gas (Masters et al. 2014). I am sorry to say that I count three of the latter report's authors among my former colleagues. This report also barely mentioned fault pathways, although it did comment:

> *"6.78 Other pathways for leakage may also exist, such as through faulting, mine workings or other boreholes which may be some distance from the wellhead. However, this requires artesian groundwater pressures."*

I have discussed the question of UK regulation further in my replies to Dr Verdon and Dr Westaway.

Comments and conclusions on Professor Younger's comment

Overall, I find Professor Younger's comments to be somewhat dogmatic in tone, and although I have tried to consider them seriously – for example, spending a day investigating the Cheshire Basin - I find little reason as a result of his comments to alter and improve my discussion paper, other than in minor ways.

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Masters, C., Shipton, Z., Gatliff, R., Haszeldine, R.S., Sorbie, K., Stuart, F., Waldron, S., Younger, P.L., and Curran, J. 2014. *Independent Expert Scientific Panel – Report on Unconventional Oil and Gas.* Scottish Government, Edinburgh. 102pp.

Appendix

Extract from appendix to *Comments on faulting: Appeal against refusal of planning applications by Cuadrilla Bowland Limited to drill at Preston New Road and Roseacre Wood (LCC/2014/0096, 0101)*, submitted to the Local Planning Inquiry on 10 March 2016.

3. Approval by the Environment Agency

On 19 May 2015 the EA responded to LCC regarding my comments of 20 April incorporating new information:

> "*We are satisfied that our technical assessment remains correct and that the consultation response from Professor Smythe does not alter our assessment.*
>
> ...
>
> *Points 1 to 4 relate to the geological complexity of the area being greater than that shown on published geological maps. The Environment Agency agrees with this statement. This is the reason that additional work was commissioned by us during the water resources modelling work to improve the understanding particularly in the southern area of the Fylde aquifer where modelling difficulties were encountered. This work was subsequently supplemented by the sinking of two exploratory observation boreholes which were also used in conjunction with a large number of seismic lines, hydrogeological responses and the model output to reinterpret the understanding of the geology. 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. As stated in the permit decision documents the water resources modelling outcomes have informed our decisions at the two sites.*"

In my view this response misleadingly implies that new geological work had been commissioned by the EA in the recent past, whereas it transpires that the work had been undertaken twenty years ago. The two new observation boreholes are in the Preston area, and have no direct bearing on the modelling of water flow under the Fylde.

The report in question was confidential, therefore a relevant question to ask is, did it have any bearing on the interpretation of Fylde geology in general, and of the Woodsfold Fault in particular? I asked the EA for a copy of the report on 21 June 2015. After initially refusing my request, the EA released a slightly redacted version of the report on 25 August 2015 (NEW EVIDENCE). The report had been undertaken by the British Geological Survey (BGS) for the NW Rivers Authority in 1996, and parts of it were redacted because the BGS claimed that some of it was 'Commercial in

Confidence'. This referred to commercial seismic data reproductions contained therein.

I asked the BGS on 15 December to supply the redacted page and the map missing from the report, on the ground that the commercial data had long since been released under DECC rules. The BGS duly supplied a copy of the report, including the page previously redacted, but wrote of the map:

> "*Unfortunately we no longer appear to hold a copy of figure 8 and this is after exhaustive searches made at BGS. The statement on page 13 of the report, 'This is a confidential diagram held at the British Geological Survey, Keyworth, Nottingham' was contained in the original report that was delivered to the National Rivers Authority (NRA) and appears in our archived copy of the report. The actual diagram itself was shown to the NRA at the time the report was delivered but was never included in the report. We have spoken to the lead author of the report who has been unable to find the original diagram and tells us that we no longer hold it.*"

So the current position is that an essential part of the geological remapping work referred to by the EA has been lost. Fortunately the colour geological map resulting from the BGS remapping survives, although the underlying data cannot now readily be identified due to the missing map. This revised map shows that the Woodsfold Fault at outcrop (at the surface of the earth) is now placed 1 km west of its position found on the BGS Garstang 1:50,000 solid geology sheet, dating from 1990.

The BGS digital database still uses the 1990 epoch geology; no attempt has been made to update the digital database to incorporate the 1996 work. However, remapping of the faults in the region has been undertaken once again by the BGS, this time as part of the Bowland Shale study (Andrews 2013). This work results in yet another new position for the Woodsfold and other faults. The various versions of the fault outcrops are shown in Figure 1. It is clear from the inconsistencies in this map that the understanding of the major fault structures and layering (the 'architecture' of the Bowland Basin) is still inadequate. The area of the 3D seismic survey commissioned by the Appellant (not shown in Figure 1) is approximately a portrait-format rectangle aligned with the grid, just enclosing the Preston New Road site and Preese Hall-1 well to the west, just enclosing the Thistleton and Mid Elswick Fault label boxes to the north and south, but not extending quite as far east as the Roseacre Wood site.

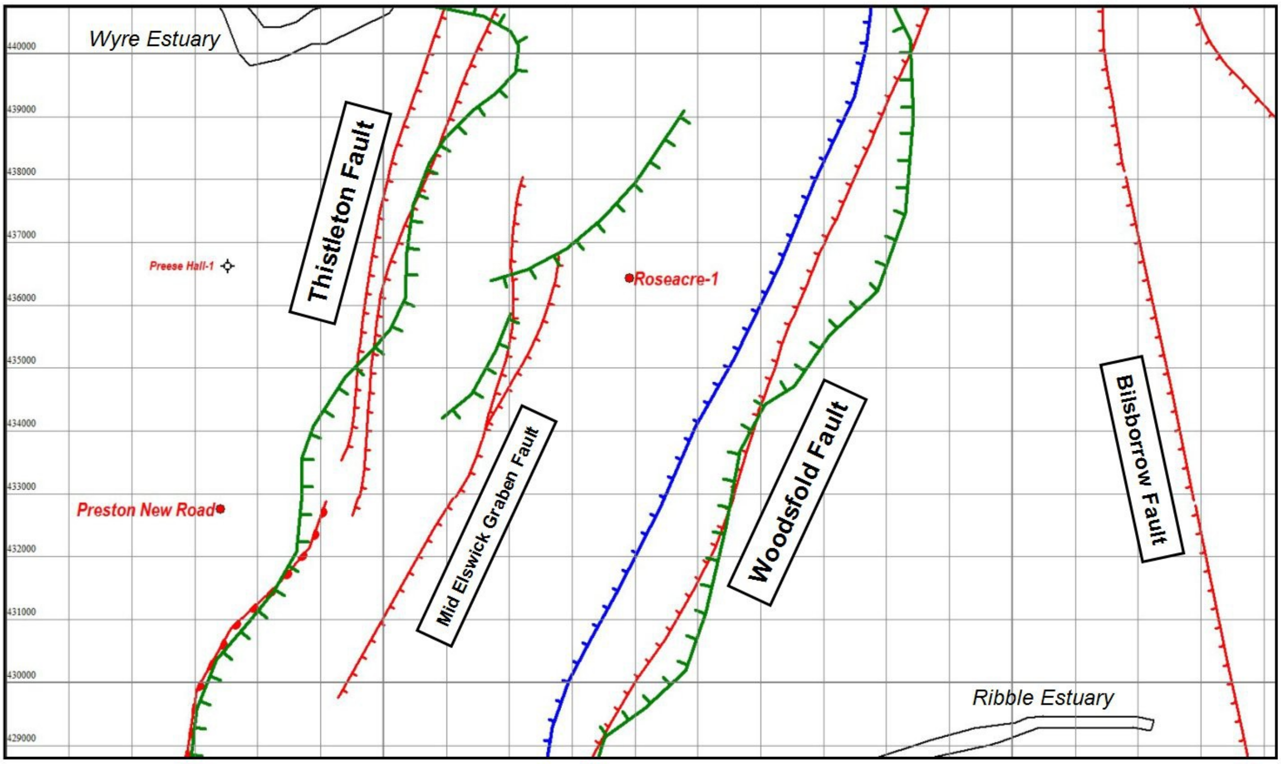

Figure 1. Various interpretations of outcrop of major faults in the Fylde. Red with ticks – BGS solid geology maps and digital database. Green with ticks – BGS Bowland Shale study, faults at depth extrapolated to surface. Red with semicircles – interpreted by David Smythe from gravity data. Blue with ticks – BGS 1996 remapping for EA. Grid is at 1 km interval.

So the existence of the 3D survey cannot be used as a reason for justifying the Appellant's assertion that it understands the geology. The Appellant has never published the raw 3D data, so that the drilling applications depend on line-drawing interpretations of the Applicant's <u>interpretation</u> of the dataset. This is unacceptable. The one very small sample of the 3D data published by the Applicant (Clarke et al. 2014) has merely served to incite more argument and conflicting interpretations about faulting in the Preese Hall-1 well area (e.g. Smythe 2016, Westaway 2016).

Appendix references

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