Cautionary comments on groundwater contamination relating to high volume fracking, derived from recent published USA research

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Identification

I am a Professor of Geology at the University of Edinburgh. I have over 35 years research experience and co-operation with industry research. This experience includes oil and gas (hydrocarbon) exploration and extraction; radioactive waste disposal; and deep geological storage of carbon dioxide. I currently am engaged in several projects funded by research councils on fracking in the UK, Europe, Canada and USA.

1)Pennsylvania (Bradford County)

1.1) The first suite of commentary relates to the important investigation by Llewellyn et al, May 2015, published in one of the worlds top three geoscience journals related to fracking.

Llewellyn, G.T., Dorman, F., Westland, J.L. Yoxtheimer, D., Grieve, P. Sowers, T. Humston-Fulmer, E. and Brantley, S. 2015.Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development. Proc. Natl. Acad. Sci. Early Edition, www.pnas.org/cgi/doi/10.1073/pnas.1420279112

1.2) Background

The article describes and analyses reports by citizens of foam issuing from their groundwater drinking water springs in Pennsylvania. These sites were several kilometres distant from Fracking, which occurred in 2009. The State regulator failed to detect any contamination by chemical analysis, so the citizens resorted to hiring a consultant environmental science company to make investigations. The case went to Court, and the citizens won, convincingly. Lessons I draw from this include : i) clear evidence that Frack fluids and gas can travel several kilometres along fractures which were previously un-recognised; ii) the Regulator had insufficient analytical equipment or skill to detect contamination; iii) there was inadequate systematic or scientific investigation of the region before commercial Fracking occurred.

Do similar criticisms apply to the present-day propositions for commercial drilling in Lancashire ? This area is geologically complex, with many steep (near vertical) faults and fractures. This is like Pennsylvania, but even more fractured. It remains very unclear if the evidence provided by the potential developers is adequate, or unique, in its interpretation. The more survey evidence that is acquired, the more complex the region is known to be.

1.3) Evidence

In my opinion, this is a scientifically very rigorous case study.
But the result is disastrous for the homeowners who used to live near the

fracking sites. The article is written by the Consultants, and can be verified by the notoriously rigorous peer-review process for this journal.

The geology is convincing - the natural joint pattern oriented NNW is maybe open, or has been opened by the Frack. Pumping tests suggest that the natural fractures are open to groundwater flow at depths shallower than 1km, even with no Frack involved – which will have opened fractures deeper.

A thrust plane should intersect the boreholes at 300-600metres deep (if a 30-50 thrust dip) - the authors make a similar interpretation. However that is not well supported by the seismic evidence cited. So the most probable route for fluid migration from Fracking, is via steep natural fractures, where fluid is forced through upwards and laterally by Frack fluid pressures; and Frack pressures can also overcome the natural vertical load of the rock, to force open sub-horizontal (low dip) bedding planes which allow flow to pass.

There are at least three lines of geochemical fingerprinting which tie the surface effects to Fracking.

1) The added surfactant 2-Butoxyethanol is not a natural chemical, and is a well known component of Frack fluids. Its significant that this was below detection limits for the "commercial analyses" by a Regulator - so Penn State have acquired a more sensitive instrument to make the analyses. This is gas chromatography combined with mass-spectrometry and is much more sensitive.
2) The Cl:Br ratios (Fig 6) measured at surface are clearly not deep brines, but could maybe be compatible with a mix of near surface water (used in the Frack fluid ?) and the deep brine. A part (intermediate) mixing is measured in the flow-back water. This is not 100% sure - and the authors suggest contamination from a surface leak from a drilling fluid pit. But if that is the cause, its not clear to me why all this discharges together with deep-derived gases. So the surface leak is not a strong hypothesis, deep contamination is.
3) The isotopic signature of methane Fig S1 S2, has no deep methane in pre-drill boreholes, but after Frack has methane from deep source very similar to that measured from the deep boreholes

All this is in spite of a cement squeeze to seal boreholes 3, 4, 5 after very high pressures were measured in the annulus. In Fig S5 its clear that the casing should have isolated the well from the groundwater - but didn't

On point (2) the authors suggest that gas pressures from the deep Frack have moved up the bore, and laterally through fractures near-surface. Thus the deep gas is sourced from one place, and they suggest no evidence of deep fluid movement to the surface, but entraining of a spill into the shallow groundwater, which all degasses at the surface forming springs. That is possible - but needs better identification of the water to exclude deep water components at the surface. Deep Frack fluids are more probable.

It is significant that the Frack company ultimately had to buy the homeowners properties, and that was an out-of-court settlement, so the evidence was assessed to be legally strong. It can be inferred that purchase was much less cost than cleanup, which is likely to be impossible

1.4) Conclusions

There are three takeaways:
A) Deep gas can migrate up to hit the drinking water table
B) Pre-existing steep fractures can be gas and groundwater conduits to move contamination vertically and laterally
C) The regulator didn't have analytical equipment capable of detecting the contamination. Thats why Leco (the equipment manufacturer) has donated the analytical instrument ….. Everybody will now need to get one of these newer and more sensitive instruments GC-GC-TOFMS.

In terms of geological structure, there are three more takeaways
D) The thrust plane is not proven to be relevant, even if it is present – the seismic evidence is equivocal.
E) Bedding of sediment planes can feature as conduits at shallow depth. That is where the net load [minimum stress] component is vertical and sub-horizontal beds can be pushed apart vertically by the pressurized fluids.
F) Fractures which pre-exist and are steeply dipping cannot be imaged on seismic before drilling, but are the most likely conduits for movement of Frack fluid.

2) Other regions of the USA

The investigation of groundwater contamination, and inadequate geological understanding, is only just commencing. Because the USA has undertaken large numbers of high volume hydraulic Fracking boreholes since 2002, it is appropriate to look to the USA to learn what has worked well, what has worked badly. The USA Environment Protection Agency has (June 2015 http://www2.epa.gov/hfstudy) released draft analysis of groundwater and fracking covering all the USA. This concludes that between 1% and 6% of fracking boreholes fail to contain fluids and gases very soon after construction. Contamination of groundwater has certainly occurred. This is "minor" compared to the tens of thousands of boreholes drilled. There is also clear evidence of localized public health impacts via groundwater and surface water contamination. But no remedy is suggested to undertake prediction and assessment to identify the faulty boreholes. How will the UK do better, when there is minimal site specific information and measurement pre-fracking? And when most of the site specific information remains confidential?

3) Barnett Shale, Texas

In the original shale rock drilled for Fracking, the Barnett Shale of Texas, a groundwater study published in July (Hildenbrand et al 2015 Environmental Science and Technology http://pubs.acs.org/doi/abs/10.1021/acs.est.5b01526), sampled 550 water well groundwaters at shallow depths of 10-1,200 metres, from the Trinity and Woodbine aquifers overlying above the Barnett Shale. Analyses used a suite of standard laboratory instrumentation for chemical analysis. Contamination from 19 different fracking chemicals or from volatile hydrocarbons released from shales occurred in 381 separate samples, and 10 different contaminant metals exceeded maximum environmental safety levels – including arsenic, beryllium and molybdenum. The samples were collected from many different boreholes across a region of 50 x 100 miles. This is a regional contamination effect, not from one or two single boreholes. This shows that contamination from deep fracking is very common, and has clearly reached the near-surface, and affects drinking water and agricultural water.

4) Commentary in relation to Lancashire.

It is clear that Fracking can impose large stress and fluid pressure onto natural underground systems, far in excess of the present natural conditions. Understanding of natural equilibrium hydrogeology at the present day is essential, but insufficient. Prediction of fluid movement during and after Fracking is of minimal use unless those extreme imposed conditions are simulated. To my knowledge there is only one, preliminary, publication on the deep hydrogeology of this region (Cai & Ofterdinger 2014 Water Resources Research DOI: 10.1002/2013WR01494). This shows that a general upward water flow could exist, leading to the potential contamination of the overlying Sherwood Sandstone aquifer. Other interpretations are likely with narrower fractures. But that inadequacy is no basis for confidence in understanding how and where fracking could adversely affect deep and shallow groundwater. How will any contamination by Frack fluids be monitored along the relevant faults and fractures? More investigation is needed to understand the natural system, before any commercial exploitation can be agreed.

Lessons emerging from studies of recent fracking practice in some states of the USA, show that is has been difficult to predict the effects of fracking on fluid flow in some cases. It is of course clear that most fracked boreholes do not show evidence of adverse consequences. But those that do have not been cleaned-up and remain contaminated, permanently in human timescales.

It is possible to ask if more extensive geological surveying and measurement should be undertaken, to provide much better and relevant sub-surface information before commercial fracking is re-started. Examples of this would include

• Accurate measurement of the natural stress in the rock from surface through the depth range to be commercially drilled. This would include both the magnitude and the 3-D direction of stress.

• Surveying and mapping in 3-D of pre-existing faults and fractures in the rock to be commercially drilled has used pre-existing legacy seismic and boreholes in the UK. This has proven inadequate for such purposes (as shown by the Preesal-1 Frack borehole). Using specially acquired seismic and other remotely sensed geophysical techniques has not produced detailed fracture maps (if they exist) which have been made publicly available. It seems probable that three versions of geological interpretation exist for this part of Lancashire: i) An interpretation by the Applicant (where full evidence is not made public); ii) An interpretation made by the British Geological Survey (conclusions published); iii) An internal interpretation made by the Environment Agency (also not fully public). Which is correct?

• Subsurface tests of the ability of naturally fractured rock to permit flow of gases or aqueous brines, for example by test extraction or injection of brine and of gas from a borehole into the surrounding rock formation.

• Sampling before Fracking of uncontaminated deep groundwater, at all appropriate subsurface levels. These can be chemically and isotopically analysed to provide "baseline" indicators of water "fingerprints". Archive samples should be kept, and must be sterile and gas-tight, in case of future disputes, or the emergence of new analytical techniques.

These types of tests would produce information, which can be combined together to produce an understanding, specific to the sites being investigated of i) where the faults and fractures occur (so these can be avoided by drilling and fracking); ii) which faults and fractures have particularly adverse positions (especially orientations) which will be the first to become conduits for frack fluids; iii) the pathways of movement for highly pressurized Frack fluids, and their chemical discrimination from natural waters.

None of these types of test were undertaken in the Pennsylvania example. All of these types of test are technically possible in the UK. But this would mean deferring commercial drilling, to gain better quality scientific information. Clearly commercial pressures will claim a high probability of "success" by pressing ahead and learning on the job. The examples of Pennsylvania show that this can be a disastrously false economy, and that a "Precautionary Principle" is wise to invoke, to provide the very best chances of avoiding unintentional damage to subsurface and near surface water supplies and environment.

4) Recommendation

In concluding this note, I recommend a moratorium, so that truly scientific investigations can be undertaken. UK Government has allocated £31 Million for such purposes
(ESIOS http://www.bgs.ac.uk/research/energy/shaleGas/esios.html).

It has to be wondered why the science will not predate the commercial drilling, to inform the most secure and best result, but instead the science will follow after the commercial drilling. Fundamental uncertainties on faults, fractures, stress, movement of frack fluids, movement of frack gases and hydrocarbons, and basic understanding of deep hydrogeology remain unresolved in the sub-surface planning evidence submitted for fracking at Preston New Road and Roseacre Wood.