Professor Stuart Haszeldine, University of Edinburgh 12 April 2016

Title

~~Hydraulic fracturing in thick shale basins: problems in identifying faults in the Bowland and Weald Basins, UK~~

Suggested title

Hydraulic fracturing in thick shale basins: do faults need to be identified, and problems in the Bowland and Weald Basins, UK

Conclusion

This is a topic of very high public and scientific interest. I recommend the article should be published. No huge rewrite is necessary. But a re-ordering of present sections is suggested to construct an argument flow and testable hypothesis or scenarios: A) Science case that faults are important, and hypotheses of processes, B) a priori evidence of faults and flow in fracking, C) discussion of case study 1, D) discussion of case study 2, E) learning from these examples on the difficulties of fault identification and how better data and workflows may be needed, F) commentary about potential failures of enforcement of regulation and how that could be improved (shorter than present if possible – or pace some into Appendix). G) Conclusions

Summary

This article makes assertions that faults may act as leakage conduits for gas or frack fluids, and that these are more likely to occur in intensely faulted basins. Evidence is produced that geoscience investigations in the UK, including fracking have failed to recognize these potential hazards ahead of drilling and even after fracking. The regulatory oversight of such drilling applications and industrial activity appears to be inadequate and needs to be significantly strengthened. Similar geologies exist in other EU basins proposed for fracking.

This is an unusual article, which mixes scientific observations, potential hazards and regulatory requirements. It is skeptical of high volume fracking, but also provides evidence and new insights to the quality of basic geological evaluation undertaken in the UK. The two case studies of different basins are novel and new compilations. The article proposes that existing geological data is insufficiently detailed to proceed, and presents an hypothesis that pre-existing faults may act as fluid or gas conduits from deep shales to shallow aquifers. A concluding summary outlines an improved technical and regulatory process which is recommended to reduce the identified hazards from poor geological evaluation and engineering practice.

Notes for Editor
I expect this article to be very unpopular amongst some sections of the UK geoscience community, as its goes against the vocal majority academic view that high volume fracking can be made secure by tightly controlled monitoring.

My own view is that the article is not perfect, several sections need editorial re-ordering (detailed below). But the scientific information and insights contained in the case studies, from two different shale basins spanning several different shale development Operators, are remarkable and even shocking as examples of how current practice has not produced anything like technically adequate assurance of high quality for UK citizens. This is very clearly of the strongest public interest, and so should be published and publicly available.

The question of "is this article correct" can not be answered until several years of additional development, experience and monitoring have occurred. So that is not the correct question to ask. The scientific process of proposition, evidence gathering and debate, followed by modified hypothesis can occur here, just as with any less publicly contentious issue. To take the counterfactual view that "this should not be published until proven" means that alleged poor practices in shale evaluation would be allowed to continue without challenge until accidents or contamination of groundwater have been legally proven. That would not be a morally or scientifically ethical position to take. If Smythe is correct, then UK citizens will be grateful that this was compiled and published. If the academic criticism is correct, then that truth will gradually emerge, and Smythe will be corrected by his critics. That is how science should work, but often does not.

Is the academic and scientific standard high enough? The article is notable for its closeness of referencing. Sources are attributed for most of the key statements. Because of the rapidly evolving nature of the topic, several of these references are websites, or "grey literature" reports. But there can be little doubt that there is a body of information to support Smythe's case study compilations and interpretations of geology, fault identification, and drilling practise. The two case studies of UK shale basins are well supported by publicly available data. Part of the point of the case studies, in my assessment of this article, is not that they are "right" or "wrong" – although a very good case is made for the correctness of Smythe's interpretation. But that multiple interpretations have been made of the same site, for basic geological features which form a crucial part of the geological system by which gases, frack fluids, or deep waters, can be contained – or can form pathways to the shallower agricultural and potable aquifers. The observations made, of pressure leakage at Preese Hall, and of basic subsurface ignorance and technically bad seismic processing at Fernhurst and Wisborough Green are shocking, and could be investigated for mandatory cleanup. The fact that enforcement has not occurred points to me that the UK regulatory system in practice is less than fit-for-purpose, as Smythe suggests, and needs a re-design.

I think it is also important to state there are several hypotheses here – it is not just about proving or disproving gas flow across or up faults. There are questions of subsurface evaluation competence, about recognizing faults before of after drilling, about the inadequacy of current legacy information to position fracking boreholes, and about the state of knowledge of fluid and gas flow along faults penetrating towards the land surface

What is the article about ?
Although the present ordering of the argument may not be ideal (see below), I think it is clear that the basic question is "Can faults and fractures through shale act as fracking fluid and gas conduits ? " This is a key hypothesis of Smythe's article, yet is counter intuitive to many geologists and hydrogeologists, who routinely consider shales to be seals to fluids and gases. Smythe compiles a suite of modeling and observation studies to support his position, whilst pointing out that this is a new field of investigation.

Does Smythe make a compelling case for frequent leakage of frack fluids occurring now, bringing deep waters, and gases to surface along steeply dipping faults? I think not. But I think that enough of a case is made that this hypothesis is worthy of much greater investigation, because the consequences of getting this wrong can be serious or terminal for drinking water supplies in the USA, the UK, or indeed across many EU Member States.

Recommendations to author
I think the evidence in the article is well worth publishing. But this could very helpfully be re-framed into more of an hypothesis driven approach.

I suggest a re-ordering

1) Introduction

2) Hypothesis that faults (steep and shallow dip) could be conduits for gas ascent and for pressure driven ascent of deep waters or fracking fluids. Examination of how this may work, which needs to distinguish flow across fault plane (often difficult and sealing) with gas ascent upwards along a fault plane (common in many geopressured hydrocarbon regions). Simple critiques by some commentators that "faults are impermeable" don't stand up to clear evidence deep gas migration to surface. This should also consider that
A) gas ascent is inherently by buoyancy – and finds pathways along or parallel to fault planes, even if perpendicular to the fault plane is "sealing"
B) the ascent of deep basin fluid is very unlikely along a fault plane – as the basinal fluids are typically more saline and dense than the overlying fresher fluids – though of course the temperature gradient also affects density and can induce ascent, as can regional potentiometric surfaces.
C) the ascent of frack fluids "forced " by pressure up the fault planes to the SURFACE is also very difficult to calculate, as the volume of frack fluid is very small (on a basin scale), the frack operations would normally avoid known fault planes as thief zones, if frack fluid was being lost into a fault plane then the bottom hole pressure would drop - circulation would be stopped and frac terminated. To test this it may be possible to

simplistically calculate how much frac fluid can ascend across formations upwards, driven by 10,000 psi pressure and a typical frac volume.
D) If there is an poor quality uncemented top hole, then its possible that frac fluids from the uppoer part of the hole may be driven laterally into open fractures in shallow depth formations. Its not clear if that has occurred – there are several cases Pavillion Wy, Llewellyn Bradford county article PA etc where there is clear shallow contamination by frac fluid – I'd like to see a bit of critique on the quality of evidence if those contaminations originate from the frac or from surface spillages
E) can the frac open up new fractures to surface ? There is a lot of evidence that frac opening (of already present joints, or of newly created fractures) is intended to travel only 100-150m from a borehole lateral. There isn't a lot (any ?) evidence I know of yet which shows that distance being exceeded to transport frac fluids. There is very strong suspicion and a developing evidence base that deep gas can travel further than the fracs seem to extend. Also to be considered is the basic stress ratio in the crust where, deeper than about 700m, the fractures and joints will open up in two vertical planes - perpendicular to the least compressive stresses which are horizontal. Whereas shallower than about 700m, the least compressive stress is normally vertical, so faults and fractures open in a horizontal plane. This ratio change is very important as it means it is normally considered impossible mechanically to open new steep/vertical fractures to the surface. For shallow dip thrusts that's more possible The orginal reference I think is

Stacey, T.R. and Wesseloo, J. 2004. Updated stress database for South Africa. Proceedings of the International Symposium on In-situ Rock Stress, Trondheim, Norway, 19-21 June 2006. Lu, M. Li, C.C., and Dalde, H. (eds.) Taylor and Francis, London. pp. 46-471.

And an open access image can be found at http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0038-223X2014001000004

In summary, I am suggesting that gas ascent to surface up steep faults is expected and natural. Whereas deep water ascent up steep faults is very unusual – and would need something extra to drive it – like a gravity head potential drive from topography (similar to "artesian"). And frac fluid ascent to surface would require the frac job to continue pumping for a long time after a thief zone should have been detected and to use very large quantities of fluids. Not impossible, but unlikely.

Based on the hypothesis framework, the author can assert that faults could act as conduits for gas in fracked basins, and need to be considered as conduits for deep or frack fluids.

3) Testing the occurrence of faults in Frack basins: Compile this from existing text and diagrams – these are suggestions: **part of current**

section 1.1 relating to the authors comparison of the USA "simple" basins with the "complex basins of UK and Europe. I'm not entirely convinced by the simplification, although there is some truth in that. For example in some regions of the "simple" Marcellus basin, there are thrust planes spaced at 2km outcrop, and associated faulted anticlines from the Alleghanian orogeny. So saying these are unfaulted is over-claiming (and I expect the author would argue he hasn't actually claimed that). **Current section 5 –** what evaluations have been made of faults in other basins, part of current section 1.1 – what evidence base used (Halliburton study) other baisns eg the german and french studies may need more explanation – are their cautions based on theory or modeling or also supported by observational evidence.

4) Case study – present section 3

5) Case study – present section 4

6) How can faults be adequately identified before drilling, during and after fracking – parts of section 6 especially 6.3

7) Deficiencies in regulation and what could be improved – part of section 6 and 7, maybe shortened or additional material into Appendix, as the commentary has value if laid out in a scientific evidence or theory based recommendations

8) Conclusions – 3 to 6 short points, not a multipage re-appraisal of the above sections, framed in testing the hypotheses and recommendations for improvement.