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Interactive comment on "Hydraulic fracturing in thick shale basins: problems in identifying faults in the Bowland and Weald Basins, UK" *by* David K. Smythe

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The Smythe manuscript is an example of advocacy-based science. This is the branch of science where one goes to prove that Gödel's incompleteness theorem is false. A qualitative statement of Gödel's incompleteness theorem is that science does not provide the absolute truth.

America's public radio, NPR, is revered by many in university communities like Penn State as the most likely source of accurate news and information. After several years of gas extraction by hydraulic fracturing (i.e., fracking) in Pennsylvania, NPR's science reporter, Christopher Joyce, gave a talk at Penn State during which he stated, "I have been in science journalism for more than 30 years and I have never seen more scientific disinformation on any topic as fracking. I am amazed at the level of both inadvertent and purposeful disinformation. There is such an agenda on everyone's mind." (Joyce, 2013). This statement is an implicit reference to the peer-reviewed literature in which there is no consensus on whether its risks should steer mankind toward a ban on fracking or whether fracking's benefits should help relax the public intolerance of the risks (Howarth et al., 2011). After all, no human activity is completely risk free.

The risks associated with fracking are abundantly evident in the six major mistakes that industry made in the early years of the development of the Marcellus gas field in the Appalachian Basin, North America (Engelder, 2014a, b). In no particular order these mistakes include: 1. A failure of collect adequate baseline data on groundwater chemistry before development of the Marcellus gas field. 2. An indiscriminate use of air drilling and chemicals such as AirFoam during drilling through the water table. 3. Inadequate lining of water storage ponds and surface installations to prevent leakage into groundwater. 4. An unwillingness to reveal the composition of additives used in hydraulic fracture stimulation. 5. A willingness to dispose of large enough volumes of waste water that ultimately generated earthquakes. 6. A failure to cement casing the entire vertical section of wellbores. It is a fact that industry has moved to correct all six of these major mistakes although it can be argued that industry did not move fast enough.

Given the abundance and frequency of these mistakes, it is understandable that the peer reviewed literature has yet to converge on a consensus concerning fracking. This is so because circumstances are still ripe for papers in the peer reviewed literature that continue to contribute disinformation of the type mentioned by NPR's Joyce. Well-meaning scientists with agendas are as much to blame as anyone. The result is advocacy-based science. When science moves toward conclusions without caving into the pressures of an agenda, the result is science-based advocacy. For example, a preconceived agenda was unlikely when scientists first made a connection between aerosols as a greenhouse gas and global warming (Charlson et al., 1992). However, when reviewing David Smythe's recent manuscript submission to Solid Earth, I developed the uneasy feeling that Smythe's work was agenda driven and thus advocacy-based science.

I best understand the geology of the Marcellus gas shale and my conclusions about Smythe's agenda are based purely on his assertions concerning the Marcellus (Engelder et al., 2009; Engelder et al., 2011; Kohl et al., 2014; Lash and Engelder, 2007; Lash and Engelder, 2011). The general premise of Smythe's paper is that there is risk of groundwater contamination by flow along faults during or after unconventional resource appraisal and development. To make his case, Smythe uses, as the only example of a fracking-driven leaking faults he could find, a recent study which detected 2-BE (2-n-Butoxyethanol) in groundwater in Bradford County, Pennsylvania (Llewellyn et al., 2015). The assertions in Smythe's paper are strong. According to Smythe, the Llewellyn paper "proves beyond reasonable doubt that contamination of drinking water was caused by passage of frack fluid and/or produced water in part through the geology". This statement is more or less consistent with the results of Llewellyn et al. (2015) only in so far as they detected 2-BE in groundwater. Llewellyn et al. state, "it is possible that (fracking) fluids used at the Welles 1 pad contaminated the drinking water aquifer".

Any reasonable layman will recognize the difference between Smythe's assertion that the presence of frack fluid is proven "beyond a reasonable doubt" and Llewellyn's careful statement that the presence of frack fluid "is possible". Furthermore, Llewellyn et al. add, "It is not possible to prove unambiguously that the UCM and 2-BE were derived from shale". Given the difference between Smythe's assertion about Llewellyn (i.e., proven beyond a shadow of a doubt) and the facts found in Llewellyn's exact words (it is not possible to prove), the layman is likely to conclude that Smythe is writing with, as NPR's Joyce put it, an agenda on his mind concerning gas-related activities. In my opinion the willful rewriting of history (i.e., Llewellyn's interpretation) is an example of advocacy-based science.

Smythe's agenda becomes even more obvious when he takes issue with another paper that provides a summary of Llewellyn's conclusions (Birdsell et al., 2015). Birdsell paraphrased Llewellyn's claims in stating that "if fracturing fluid did contaminate the shallow aquifer (in Bradford County), it is much more likely that the fluid came from a surface spill or from a shallow subsurface leak rather than from the Marcellus." Smythe says that Birdsell's interpretation of Llewellyn is "completely wrong and misleading. In fact Llewellyn et al. 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 finally by travelling vertically upwards along bedrock joint planes and fractures." Completely wrong and misleading are strong words. How could Bridsell et al. (2015) have been so muddled in their paraphrasing of Llewellyn et al.?

I showed Smythe's statements to three of the coauthors of Llewellyn et al. who happen to be colleagues of mine at Penn State. One coauthor wrote back saying, "Smythe has grossly misinterpreted what we said and what Birdsell correctly paraphrased. My belief is that drilling fluids (i.e., drilling foam) leaked away during the drilling process, with the other theory that a pit leaked, or perhaps a combination of the two. We clearly stated that fracturing fluids did not migrate from the depth of the Marcellus as there is not a chloride/high TDS signature. Isotopically the methane in the private wells and in the gas wells' annular space matched, so that's the only link from depth."

So, if Birdsell got it right, how could Smythe have so completely misunderstood Llewellyn et al.? One possibility is that Smythe did not carefully read Llewellyn et al., unless Smythe read Llewellyn with an agenda in mind. People with an agenda suffer by not knowing the location of the line between science-based advocacy and advocacy-based science. A characteristic of advocacy-based science is to reach beyond what the data allow. In Smythe's case, the hope was that the literature contained at least one case of unambiguous fracking-induced fault leakage and not finding one, he had to manufacture it. To the best of my knowledge, the literature does not contain a case.

The peer review process is not perfect. When a flawed paper gets through the peer review process it is often spotted and commented upon by others. This is the case with Myers' model for leaking faults in the Appalachian Basin (Myers, 2012). It is worth repeating that Myers' boundary conditions were too simple to have any meaningful application to the geological circumstances in the Appalachian Basin. For starters, Myers misrepresented a shale-dominated overburden with sandstone (Van Tyne, 1983). The Marcellus is covered by an overburden with as many as six black shales, each with sub micro-darcy permeability (Ettensohn, 1985). Then, Myers cut the sandstone with vertical faults when the tectonics of the Appalachian Mountains evolved as an overthrust foreland with low angle faults (Scanlin and Engelder, 2003). The impact of just these two geological characteristics of the Appalachian Basin dominates the physics of regional flow for a much different outcome than Myers' simple boundary conditions.

After critical comments by at least four groups, one would think that such treatment in the peer-reviewed literature should have been sufficient to bury the Myers paper (Birdsell et al., 2015; Cohen et al., 2013; Flewelling and Sharma, 2014; Saiers and Barth, 2012). The best treatment for a flawed paper is to ignore it. Yet, Smythe rehashes Myers result by stating, "When fracking occurs (in the Appalachian Basin) the transport times of contaminated fluid from the fracked shale to the near surface can be reduced to a few tens of years or less". What is the purpose of repeating a flawed result that ignored geological conditions in the Appalachian Basin? In the case of the Smythe paper it was an implicit assumption that a flawed model becomes less flawed if the Appalachian Basin is replaced by the Bowland and Weald Basins.

But, it gets even worse than rehashing Myers (2012). Smythe constructs an organogram for fluids leaking up faults starting with three reports that did not benefit from peer review. One report came from an environmental group with a known agenda. The second came from a fellow (Northrup) who is neither a geologist nor a hydrologist nor has he ever studied the Appalachian Basin. A web site lists him as a 'Texas-oil-investor-turned-anti-fracker'. Northup's report is filled with innuendo and there is nothing that offers any constructive help in understanding leaky faults. The best that Northup can do on the issue of leaking faults is write, “HHF may open faults and may increase permeability along laterally and vertically extensive fault planes and fault zones – thereby increasing the risk of contaminant and gas excursions.” How can Smythe be taken seriously when he places Northrup at the pinnacle of scientific priority on the subject of leaky faults? Indeed there are a basketful of geologists and geophysicists who have contributed to the peer-reviewed literature about leaking faults long before Northrup’s web posting in 2010.

There are three other major reasons why faults might not be as much of a conduit for frack fluid that Smyth makes them out to be. First, imbibition immediately removes a large fraction of the frack fluid from the inventory of freely circulating water in a gas shale (Engelder, 2012; Engelder et al., 2014). Once free fluid is lost to imbibition it is no longer capable of leaking along faults. In general, numerical modeling has shown that combined influence of imbibition and well suction significantly reduce the risk of aquifer contamination (Birdsell et al., 2015). Second, once flowback starts a steep inward pressure gradient is set up which immediately controls flow inward toward the well (Reagan et al., 2015). Third, buoyancy forces set up a tiered water profile in the upper crust down to gas shales like the Marcellus with fresh water over brackish water over brine. Because of the immediate diffusion of salt into the frack fluid, it becomes less buoyant than fresh water (Balashov et al., 2014). Buoyancy has also been discounted in numerical models as a driving mechanism (Birdsell et al., 2015). In this context, faults may behave much like the water-over-gas reservoirs of the western US where the less buoyant fluid is held in place (Spencer, 1987).

As a further note, I might amplify on risks that come with fossil fuel extraction. It is not possible to penetrate the water table without disturbing groundwater or introducing something foreign into it. Certainly, this starts with water-well drillers who, at very least, leave local a turbidity than may take hours if not days to clear. If the water well is subsequently grouted, a good practice in Pennsylvania, then groundwater is exposed to the chemical products of leaching of that grout, maybe forever as rain seeps downward along the outside of casing grout. Certainly, people who drink from water wells may be consuming very small amounts of the grout chemistry for some time.

The extent of the local turbidity and disturbance of groundwater chemistry depends on the size and depth of the boring. A typical water well in Pennsylvania is a little more than 15 cm in diameter. If, like my water well, it penetrates to 56 m, then 0.3 m3 of soil and possibly bed rock will be disturbed with a concomitant disturbance of groundwater around the orifice. In a Marcellus gas well, surface casing is installed completely through the fresh groundwater which might extend downward 330 m. The diameter is surface casing is 34 cm which means that to penetrate fresh groundwater, on the order of 9.5 m3 of soil and bed rock are disturbed, over 31 times that volume of rock that was disturbed during the drilling of my water well. To efficiently remove 10 m3 of material, operators in the Appalachian Basin have used a product called AirFoam as they drill down 330 m. One of the components of AirFoam is 2-BE (2-n-Butoxyethanol), the very component that Llewellyn et al. (2015) detected in the groundwater of Bradford County.

There have been a few instances where AirFoam has bubbled out of shallow bedrock at distances of several hundred meters from the nearest wellpad in Pennsylvania. This is not surprising given the volume of rock that is removed while penetrating fresh groundwater and the force of air against the borehole wall. Controlling the spread of AirFoam in the immediate vicinity of a wellbore is one of the six mistakes that industry made during its early days in the Marcellus (Engelder, 2014a). The release of AirFoam while drilling through groundwater is not a manifestation of either frack fluids or flowback as Smythe would have his readers believe. This is probably an example of Joyce's inadvertent disinformation from someone who has not devoted a career to understanding the nuances of the problem.

There has been lots of publicity associated with 2-BE as a toxic component of fracking activities. There are suggestions that 2-BE is an endocrine-disruptor (Colborn et al., 1993). However, the US National Library of Medicine's open chemistry data base is markedly silent on this issue. Furthermore, 2-BE is commonly used as a solvent in spray lacquers, enamels, varnishes, and latex paints and as an ingredient in paint thinners and strippers, varnish removers, and herbicides and degreaser in many household products such as dry-cleaning compounds, household cleaners, liquid soaps, and cosmetics. In some of these household products 2-BE has a surprisingly high concentration.

2-BE is one of the polycyclic aromatic hydrocarbons (PAH) used as a dispersant following the 2010 Deepwater Horizon oil spill (Ylitalo et al., 2012). After the Deepwater Horizon cleanup, PAH was detected in seafood with a maximum concentration of about 1 ng/g of wet weight. This is at least two orders of magnitude lower than the level of concern for human health risk. The level of detection of 2-BE in Bradford County was a maximum of 0.42 ng/g of water, even lower than the maximum reported for the seafood of the Gulf of Mexico following the Deepwater Horizon cleanup. The reason that Llewellyn et al., (2015) may have hedged their interpretation - "It is not possible to prove unambiguously that the UCM and 2-BE were derived from shale" – resides in the possibility that the source of the very low amounts of 2-BE in local groundwater are local septic fields into which household products with 2-BE may have been flushed for years and years. Presently, there is no way to finger print the 2-BE of household products relative to the 2-BE from AirFoam. Either way, the concentrations are so low that they are not of concern. This is the same conclusion concerning concentrations of 2-BE in seafood after the Deepwater Horizon event (Ylitalo et al., 2012).

In summary, Smythe attempts to turn a possibility that 2-BE came from fracking, and it is not the only possibility, into a fact. This is an example of a scientist who ought to know better appearing to willfully ignore the caveats that other careful, considered scientists have put into the discussions of their research results. This is what Joyce meant by 'purposeful disinformation'. This is advocacy-based science.

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