Solid Earth Discuss.,
doi:10.5194/se-2015-134-SC6, 2016

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

P. L. Younger

paul.younger@glasgow.ac.uk

Received and published: 18 February 2016

In this article, Smythe repeatedly makes some sweeping and erroneous hydrogeological assumptions which he never justifies; indeed the text gives the impression that Smythe is not even aware that these ARE assumptions that require some justification.

The first of these erroneous assumptions is typified by the claim in the abstract that, because faults occur with and on the boundaries of shale basins in Europe "there is thus an inherent risk of groundwater resource contamination via these faults during or after unconventional resource appraisal and development". As a hydrogeologist of 30 years' standing this is the first time I have seen such a claim. Consultation of the principal groundwater textbooks (e.g. Todd 1980; Domenico and Schwartz 1997; Fetter

2001; Younger 2007) will reveal no support for the assumption that faults "inherently" represent potential pathways for groundwater contamination. Some do; many don't. The reality, as explained in those text books, is that faults are hydrogeologically ambiguous: some present permeable zones (most notably where they cut relatively hard rocks such as sandstone, limestone or igneous / metamorphic lithologies); many serve as profound barriers to groundwater flow. Fault zones acting as hydraulic barriers are not only commonplace in aquifers; they are well-known in oil basins (e.g. Spencer and Larsen 1990). The reasons why faults may actually serve as impermeable barriers to fluid movement range from the tendency (especially common where such faults cut shales) for the fault-planes to become tightly lined with 'fault gouge' (i.e. comminuted debris of the wallrocks; Younger 2007) to the compressional closure of otherwise unlined fault planes where these lie oblique to then present-day azimuth of compressive stress in the Earth's crust (e.g. Ellis et al. 2014). Even where optimum conditions exist for faults to display permeability, it is rare for this to be continuous over large vertical intervals: vertical hydraulic connectivity over 10s of metres is common (e.g. Clarke 1962, referring to the Carboniferous of northern England); over 100s of metres less so, though exceptions have been documented where the wall-rocks are particularly competent (e.g. Younger 2005); over 1000s of metres through sequences dominated by shales, which is the case claimed here by Smythe, I am not aware of any cases. Certainly Smythe cites no evidence for this. Indeed the two papers he cites in support of his claims over fault permeability (Bilcalho 2010; Bilcalho et al. 2012) both relate to karstified limestones – the most extremely permeable of all natural hydrogeological systems, in which fault apertures are widened by dissolution of the soluble wall-rocks! No such process occurs in shales. Nor does Smythe offer any evidence that hydraulic fracturing will produce a comparable effect. Rather, the hydraulic fractures produced in shale gas operations have to be propped open; it is physically infeasible for the sand grains used for this purpose to migrate thousands of metres up adjoining faults and prop them open over large vertical intervals.

But even if one were to believe that faults cutting thick shale sequences will defy common hydrogeological experience and become permeable throughout the vertical extent, this still does not mean that there is an “inherent risk of groundwater contamination”, as Smythe claims. This is because his analysis makes a second erroneous hydrogeological assumption, namely that there will always exist a hydraulic gradient that favours upflow of water (and any pollutants) to shallow aquifers. Many unconventional hydrocarbon reservoirs are, in the natural state, under-pressured, which means that the pre-development hydraulic gradient is not in itself sufficient to promote upward flow (such as may occur where conventional, over-pressured reservoirs are penetrated). Certainly in the UK, present-day tectonic conditions make under-pressured conditions likely in most shale gas plays. While a net upward gradient will locally be induced in close proximity to the well during the process of hydraulic fracturing, this is likely only to persist over a timescale of hours. Thereafter, shale gas wells are dewatered, to allow the (usually weak) partial pressure of gas in the fractures to overcome the hydraulic head in the production well and thus flow to up through the well to surface. Thus a net downward gradient is actively maintained for as long as the well remains in productive use. Indeed it is precisely because the gradient is oriented this way that shale gas developers avoid creating fractures that provide hydraulic connectivity to prolific aquifers: this would lead to flooding of their wells with unmanageable quantities of water. After a shale gas well ceases to produce economic quantities of gas, this downward gradient will lead to a gradual re-flooding of the dewatered fractures and, eventually, the borehole (though under UK regulations, at least, this will have been long-since blocked by pressure injection of cement). Thus after the end of shale gas production, a long period of slow re-equilibration of hydraulic heads in and around the fractured shale zones will occur. Given the extremely low permeabilities of shale (Yang and Aplin 2007), which will remain at pre-development values throughout the rock mass beyond the relatively modest zones affected by hydraulic fracturing, such a period of re-equilibration can be expected to take many decades, and more likely centuries. Thereafter, it is difficult to conceive of any mechanism by which an excess of head could build up sufficient to establish an upward hydraulic gradient towards shallow aquifers being developed. In

former coalfields, where permeable zones at created by mining at depth are connected up-dip via old workings to distant, elevated recharge zones, such head clearly has developed after the cessation of mining, giving rise to substantial outflows of polluted mine waters at surface (Younger et al. 2002). As deep shale gas zones are not connected up-dip to recharge areas by belts of equally permeable strata, no such through-flow can possibly be established after shale gas exploitation. By erroneously assuming that upward hydraulic gradients will be established, Smythe jumps to physically untenable conclusions.

But let us suspend disbelief, and accept Smythe’s tacit (and apparently unwitting) assumptions that faults are permeable enough throughout their vertical extent AND will be subjected to sustained upward hydraulic gradients: will groundwater contamination not then ensue, just as he proposes? No. Even if upward flow is occurring, the loading of pollutants must be sufficient to make a detectable difference in the chemistry of the overlying aquifer. At the most extreme imaginable rates of upflow along Smythe’s “through-penetrating faults”, the loadings of, say, salinity arriving in freshwater aquifers would need to be far greater than those of the few naturally occurring saline springs in northern England (Younger et al. 2015) to result in detectable changes in water quality in the prolific and fast-flowing freshwater aquifers of the region (which are, inter alia, documented by Younger 1995). These weak saline springs DO NOT contaminate their receiving freshwater bodies, as there flows are far so small that they are immediately diluted beyond detectability. (Incidentally, these natural saline springs DO NOT arise from thick shale sequences, but from sequences dominated by limestones, sandstones and igneous rocks).

Hence Smythe makes three erroneous hydrogeological assumptions that lead to badly mistaken conclusions. I leave the reader to consult my published works and decide whether Smythe is justified in his ’ad personam’ references to my work, suggesting I display a “misunderstanding of the fault problem” and “ignorance” of the relevant literature. Similarly, I leave to others to assess whether (p. 19, line 15) Smythe is in any position to offer readers "the hydrogeological perspective" to which he lays claim.

However, having served on the joint Royal Society / Royal Academy of Engineering panel to which Smythe refers in Section 6.2 of his manuscript, I feel some clarifications are in order. For the benefit of international readers, it is important to clarify that the Royal Society and the Royal Academy of Engineering are not simply "academic societies", as Smythe characterises them in section 6.2.4. Rather, they are the UK's national academies of science and engineering respectively. One cannot apply to join them; Fellowship in both is the highest professional honour in those disciplines in the UK. Nor is the Royal Academy of Engineering even predominantly 'academic' in membership: it is very much an academy of highly experienced, practicing engineers from all disciplines. The report to which Smythe refers was not born of some self-generated initiative; rather the two national academies were asked by the UK Government to independently review the evidence over the risks posed by 'fracking'. The membership of the panel specifically excluded anyone with interests in any shale gas company – which is at odds with Smythe's unsubstantiated opinion that the report (Mair et al. 2012) had "a perceptible pro-industry bias". What it DID have (unlike Smythe's work) is a perceptible grounding in engineering practice and genuine hydrogeological experience.

Smythe's paper includes many similar unsubstantiated opinions, and I frankly do not have time to deal with them all in detail. To mention but two: 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). Furthermore, Smythe pretends to knowledge of the CVs of all hydrogeologists working for the Environment Agency, and suggests they are ignorant of hydrogeological conditions deeper than "the upper few hundred metres of bedrock" (section 6.2.2). This is simply untrue; many EA hydrogeologists of my long-standing acquaintance have direct experience of ground water in former deep mines, for instance, as well as direct experience of deep drilling projects in many parts of the country.

Finally, his summary dismissal of the entire UK regulatory system as "not up to the task" is at stark odds with the findings of the two Royal academies (Mair et al. 2012), and indeed of the subsequent independent expert panel on unconventional gas convened by the Scottish Government (Masters et al. 2014) (on which I also served). I again leave it to readers to decide whether the anecdotal hearsay and unsubstantiated charges levelled by Smythe in section 6.2 should carry more weight than those of the panel of internationally-renowned professionals convened by the Royal academies.

In summary, Smythe's foray into the world of hydrogeology has led him to make several fundamentally erroneous assumptions that do not stand up to rational scrutiny. The result is a paper that pretends to be a serious hydrogeological analysis, but ends up as a pastiche of innuendo, wayward misinterpretation, 'ad personam' and 'ad societatem' slurs, and utterly misleading inferences. It is an exercise in para-hydrogeology, which should not be mistaken for anything more than a dismal parody of true hydrogeological science.

References

Bilcalho, C. C. (2010) Hydrochemical characterization of transfers in karst aquifers by natural and anthropogenic tracers. Example of a Mediterranean karst system, the Lez karst aquifer (Southern France), Thesis accomplished in the Laboratory: Hydro-Sciences Montpellier (UMR 5569, CNRSIRD- UM1-UM2),.

Bicalho, C. C., Batiot-Guilhe, C. Seidel, J. L., Van Exter, S., and Jourde, H. (2012) Geochemical evidence of water source characterization and hydrodynamic responses in a karst aquifer http://www.sciencedirect.com/science/article/pii/S0022169412003733

Clarke, A.M. (1962) Some structural, hydrological and safety aspects of recent developments in south-east Durham. The Mining Engineer, 122: 209 - 231.

Domenico, P.A. and Schwartz, F.W. (1997) Physical and Chemical Hydrogeology second edition, John Wiley & Sons, New York.

Ellis, J., Mannino, I., Johnston, J., Felix, M.E.J., Younger, P.L. and Vaughan, A.P.M. (2014) Shiremoor Geothermal Heat Project: reducing uncertainty around fault geometry and permeability using Move™ for structural model building and stress analysis. European Geosciences Union General Assembly 2014, Vienna, 27th April–2nd May 2014. EGU2014-15069.

Fetter, C.W. (2001) Applied Hydrogeology (4th edn), Prentice-Hall Inc., New Jersey.

Mair, R., Bickle, M., Goodman, D., Koppelman, B., Roberts, J., Selley, R., Shipton, Z., Thomas, H., Walker, A., Woods, E., and Younger, P.L. (2012) Shale gas extraction in the UK: a review of hydraulic fracturing. Royal Society and Royal Academy of Engineering, London. 76pp.

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.

Spencer, A.M., and Larsen, V.B. (1990) Fault traps in the northern North Sea. Geological Society, London, Special Publications, 55: 281-298, doi:10.1144/GSL.SP.1990.055.01.13

Todd, D. K. (1980) Ground Water Hydrology (2nd edn), John Wiley & Sons, New York.

Yang, Y., and Aplin, A.C. (2007) Permeability and petrophysical properties of 30 natural mudstones. Journal of Geophysical Research, 112, B03206 (doi:10.1029/2005JB004243).

Younger, P.L. (1995) Hydrogeology. Chapter 11. In Johnson, G.A.L., (Editor). Robson's Geology of North East England. (The Geology of North East England, Second Edition). Transactions of the Natural History Society of Northumbria, Vol 56, (5). pp 353 - 359.

Younger, P.L. (2005) Westfield pit lake, Fife (Scotland): the evolution and current hydrogeological dynamics of Europe's largest bituminous coal pit lake, Proceedings of the 9th International Mine Water Association Congress 2005, Oviedo. pp 281-288.

Younger, P.L. (2007) Groundwater in the Environment: An Introduction. Blackwell Publishing, Oxford.

Younger, P.L., Banwart, S.A., and Hedin, R.S. (2002) Mine Water: Hydrology, Pollution, Remediation. Kluwer Academic Publishers, Dordrecht. 464pp.

Younger, P.L., Boyce, A.J., and Waring, A.J. (2015) Chloride waters of Great Britain revisited: from subsea formation waters to onshore geothermal fluids. Proceedings of the Geologists' Association, 126: 453–465. (DOI: 10.1016/j.pgeola.2015.04.001)

Interactive comment on Solid Earth Discuss., doi:10.5194/se-2015-134, 2016.