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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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I thank Smythe (2016a) for drawing my attention to the release in April 2015 of the Preese Hall-1 well log and associated stratigraphic report, in relation to the Westaway (2016a) online posting. I was already well aware of this release, however, although I was unaware (until I checked in the last few days) that the Cuadrilla Grange Hill-1 well log (from an adjacent site in Lancashire; likewise illustrated by Clarke, 2016) has also now been released (as of 9 February 2016, according to the well agents, TGS). The data sources for the illustrations presented by Clarke (2016) are, therefore, now clear; if this author had stated that these released documents (as opposed to other potential documents internal to Cuadrilla, possibly relating to their 3 D seismic survey, which

has not yet been released) were the sources of his illustrations, there would have been no need for further dialogue on this matter. The essential issue is that Clarke (2016) depicts the Bowland Shale Formation as extending to the base of the Preese Hall-1 well, at 2773 m MD, and depicts, at ∼2500 m MD, the Emstites leion Marine Band, which marks the Visean-Namurian boundary and thus separates the 'Lower Bowland Shale' from the 'Upper Bowland Shale'. In contrast, in the de Pater and Baisch (2011) stratigraphic scheme, adopted in the Westaway (2015, 2016b, 2016c) publications, the base of the Bowland Shale is at 2507 m MD, this formation being reportedly underlain by the Pendleside Limestone Formation and Hodder Mudstone Formation, with the well bottom supposedly in the Clitheroe Limestone Formation.

As regards the implications of these releases of data for my publications, I note that the Westaway (2015) paper was commissioned in December 2014 and the Westaway (2016b) paper was drafted in early March 2015, as is evident from the citation dates of the various online references. The point of my annotating the excerpt from the Cuadrilla 3 D seismic survey (after its publication by Clarke et al., 2014) was anyway to establish how it correlates with the various extant interpretations of the older 2-D seismic lines, notably the interpretation published by de Pater and Baisch (2011), which has informed most of the subsequent discussion regarding the Preese Hall-1 well. The aim of doing this was to show how several datasets (wellbore deformation, in situ stress measurements, seismic sections, induced seismicity, etc.) can be integrated, which no-one had done before. In order to be able to compare the old 2-D and new 3-D seismic sections they needed to be annotated consistently with each other, which was what I did. I suppose I could have also provided a second version of the 3-D seismic section, annotated consistent with the newly released stratigraphy, but (as Westaway, 2016a, already noted) that would merely have shown the whole of the lower part of the section labelled as 'Bowland Shale Formation', which would not have added anything. Since journal space is limited, the extra length that would have been added to my paper did not seem justified, not to mention the demands that production of an additional diagram would have made on my time. The essential point, as Westaway (2016a)

also noted, is that the Westaway (2016b, 2016c) interpretations have established a conceptual model for how the induced seismicity, wellbore deformation, and deformed stratigraphy are interrelated. I am sure that most people can see that it is immaterial to such an analysis what the rocks in which the wellbore deformation occurred happen to be called. Thus, rather than being a 'litho- and bio-stratigraphic mess', as Smythe (2016a) has claimed, the Westaway (2016b) analysis would appear to have something useful to say.

Smythe's (2016a) criticism of my work thus follows his now-familiar pattern, apparent from his (2016b) draft manuscript and many of his web pages (e.g., Smythe, 2014a, 2014b, 2014c, 2015), of claiming that research output that he does not 'like' is fundamentally flawed, when the issue at hand is insubstantive, often combining this process with personal attacks on authors; this is the flip side of his praise of outputs that contain fundamental errors, provided they support his agenda of opposing shale gas and fracking. Engelder (2016) referred to this tendency as 'advocacy-based science', whereas Westaway (2016c) called it 'selective citation of the literature'. A related issue is this author's lack of objectivity regarding the merits of his own contributions; for example, even though virtually every aspect of the Smythe (2016b) draft manuscript has been challenged by one or more subject specialists (not to mention earlier critiques, for example that by Younger and Westaway, 2014, of the Smythe, 2014c, document), one of his web pages (posted as Smythe, 2014a) continues to claim that 'no-one has ever challenged my findings in any detail. Instead, some pro-industry, pro-government geologists resort to ad hominem attacks, without even bothering to read what I have written.' I also note in passing that it is somewhat ironic for Smythe (2016a) to insist on citation of the new interpretation of the stratigraphy in the Preese Hall-1 well, when he has previously subjected its author, Dr Nick Riley, to particularly severe attacks; for example, Smythe (2015) describes his work in general as 'flawed' and 'misleading' and dismisses his 2012 report on Preese Hall-1, now released, as '. . .typical of the commercial links between the BGS and the oil industry', whereas Smythe (2014b) states 'Dr Riley seems to be blind to the obvious geological problems inherent in drilling through and adja-

cent to fault zones. He refuses to reveal his client list; my suspicion is that it includes companies currently prospecting in the UK for unconventional oil and gas.'

Furthermore, once the issue of inconsistent versions of the stratigraphy at Preese Hall-1 and in neighbouring localities had been raised by Smythe (2016a), I looked back through earlier outputs and discovered other inconsistencies in usage. The first publication incorporating any element of the 'new' stratigraphy was Andrews (2013): its page 30 states 'The Thistleton 1 well drilled 2911 ft (887 m) of the Bowland-Hodder unit, but terminated in Brigantian-aged shales and sandstones (N.J. Riley pers. comm.) and the lower part of the unit was not reached'; and its Fig. 28 shows the Bowland Shale Formation persisting to the well bottom, with the Visean-Namurian boundary (marked, as noted above, by the Emstites leion Marine Band) at $\sim$1540 m depth. Accompanying text states that an estimated 2800 feet or $\sim$850 m of the Bowland-Hodder unit remained undrilled, so its total thickness is locally $\sim$1740 m. In contrast, the seismic sections in Figs 7 and 8 of de Pater and Baisch (2011) show the well bottom in the Clitheroe Limestone Formation, it being so depicted in my recent publications (Westaway, 2015, 2016b, 2016c). However, the stratigraphic column in Fig. 4 of de Pater and Baisch (2011) depicts the well bottom in the Bowland Shale Formation, consistent with Andrews (2013) but inconsistent with the other illustrations by de Pater and Baisch (2011). I am not aware that this mismatch had previously been noted; I only just noticed it myself.

As regards the Preese Hall-1 well, I now also see that the depth of the base of the Bowland Shale Formation of 8225 feet MD or 2507 m MD in Fig. 3 of de Pater and Baisch (2011), which I have previously taken as definitive for use in my publications, is contradicted by the figure of 7460 feet MD or 2274 m MD in Fig. 4 of de Pater and Baisch (2011); both these values differ from the depiction in the 'new' stratigraphy of the Bowland Shale reaching the well bottom (Clarke, 2016), as already noted. The stratigraphic column in Fig. 3 of de Pater and Baisch (2011) indeed depicts the Bowland Shale between 6540 and 8225 feet or 1993 and 2507 m (MD), indicating a

thickness of ∼514 m, with the 'Worston Shale Formation' (i.e., Hodder Mudstone Formation) between 8450 and 9004 feet or 2576 and 2744 m (MD), indicating a thickness of ∼168 m. The combined thickness of these shale formations in this scheme is thus ∼680 m, whereas in the 'new' interpretation, illustrated by Clarke (2016), the ∼780 m drilled (between 1993 m MD and the well bottom at 2773 m MD) spans only part of the Bowland Shale Formation and did not reach the Hodder Mudstone Formation.

Similar discrepancies exist in other documentation, for example in documents submitted by Cuadrilla in support of their planning applications for shale gas developments in Lancashire (these development plans were rejected in 2015 but this decision is currently subject to appeal). Thus, for instance, at the proposed Preston New Road well site, Cuadrilla (2014a) reported the top and base of the 'Upper Bowland' at estimated depths (TVD) of 1350 and 1540 m, and the base of the 'Lower Bowland' at ∼1930 m, indicating an overall thickness of ∼580 m. On the other hand, Fig. 6 of Cuadrilla (2014b) depicts the top and base of the Upper Bowland Shale at estimated depths (TVD) of ∼1550 and ∼1960 m, and the base of the Lower Bowland Shale at ∼2830 m (Fig. 1(a)), indicating an overall thickness of ∼1280 m, more than double the other estimate. This seismic section also depicts almost 1000 m of the Hodder Mudstone Formation, the base of which is not shown, making the combined thickness of these two shale formations well in excess of 2000 m in this locality. The caption to this Figure states that 'the interpretation of the 3D geophysical (seismic) survey was made by Cuadrilla . . .', implying that it is based on the 3-D seismic reflection dataset that remains unpublished but is consistent with the 'new' stratigraphic interpretation that has now been released (cf. Clarke, 2016). I note in passing that Smythe (2014b) described the structural interpretation in Fig. 1(a), by Cuadrilla, as 'geologically improbable' and proposed the revised interpretation with more extensive faulting in Fig. 1(b), notwithstanding the fact that he has not seen the 3-D seismic reflection dataset on which the interpretation is based and the members of staff of Cuadrilla who produced the interpretation in Fig. 1(a) obviously had access to this dataset.

Finally, it goes without saying that the tone of Smythe's (2016a) comment was inappropriate for scholarly discourse, acceptable though this knockabout style might be for postings on his own website. Nonetheless, it would seem that this exchange has shed some light on the stratigraphy of the Preese Hall-1 well and its vicinity, so something useful has been accomplished.

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Figure 1. (a) Structural cross-section through the proposed Preston New Road shale gas well site, interpreted by Cuadrilla based on their 3-D seismic reflection survey, showing the 'new' interpretation of the thickness of the Bowland Shale Formation and the extent of its disruption by localized faulting. (b) Alternative interpretation by Smythe (2014c), prepared without access to the underlying 3-D seismic reflection survey, interpreting more extensive faulting. On the basis of this new interpretation, this author states that 'the direct paths 1 and 4 to the surface in the vicinity of the drillsite (say within 5 km horizontally of the fracked zone below) will lead to potential contamina-

tion of the minor groundwater sources within the Quaternary, as well as of rivers and streams', thus presenting inferences from his reinterpretation as fact. Modified from Fig. 5.2 of Smythe (2014c); part (a) is based on Fig. 6 of Cuadrilla (2014b) with the precise location of the cross-section depicted in Fig. 7 of Cuadrilla (2014b).

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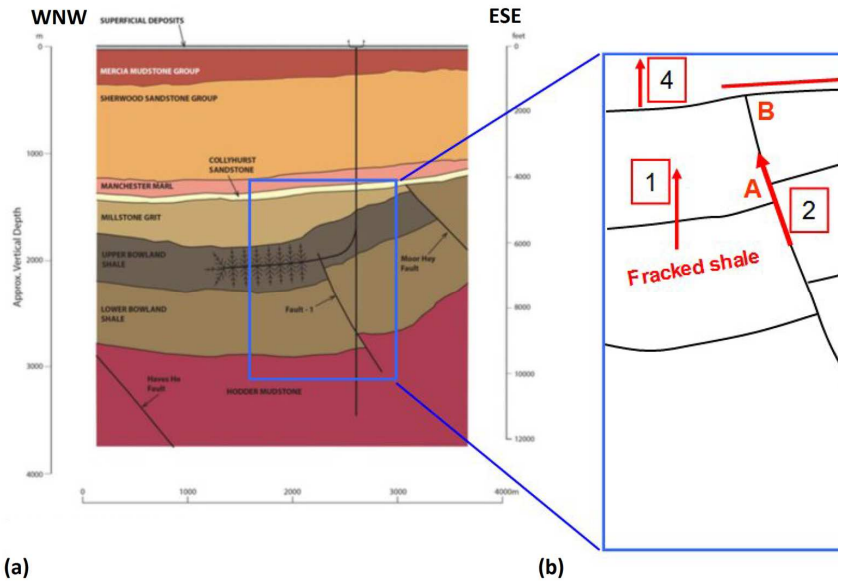

Fig. 1. Please refer to the main document for this Figure caption.