Reply to Andrew Kingdon (se-2015-134-SC15)

Mr Kingdon is a geophysicist by training and works in mathematical modelling, digital imaging, and statistics at the British Geological Survey. He has commented on two aspects of my paper.

1. Preese Hall-1 faulting

Firstly, Mr Kingdon discusses the CMI borehole imaging data, referring to figure 31 of de Pater and Baisch (2011), reproduced here as Figure 1 for convenience.

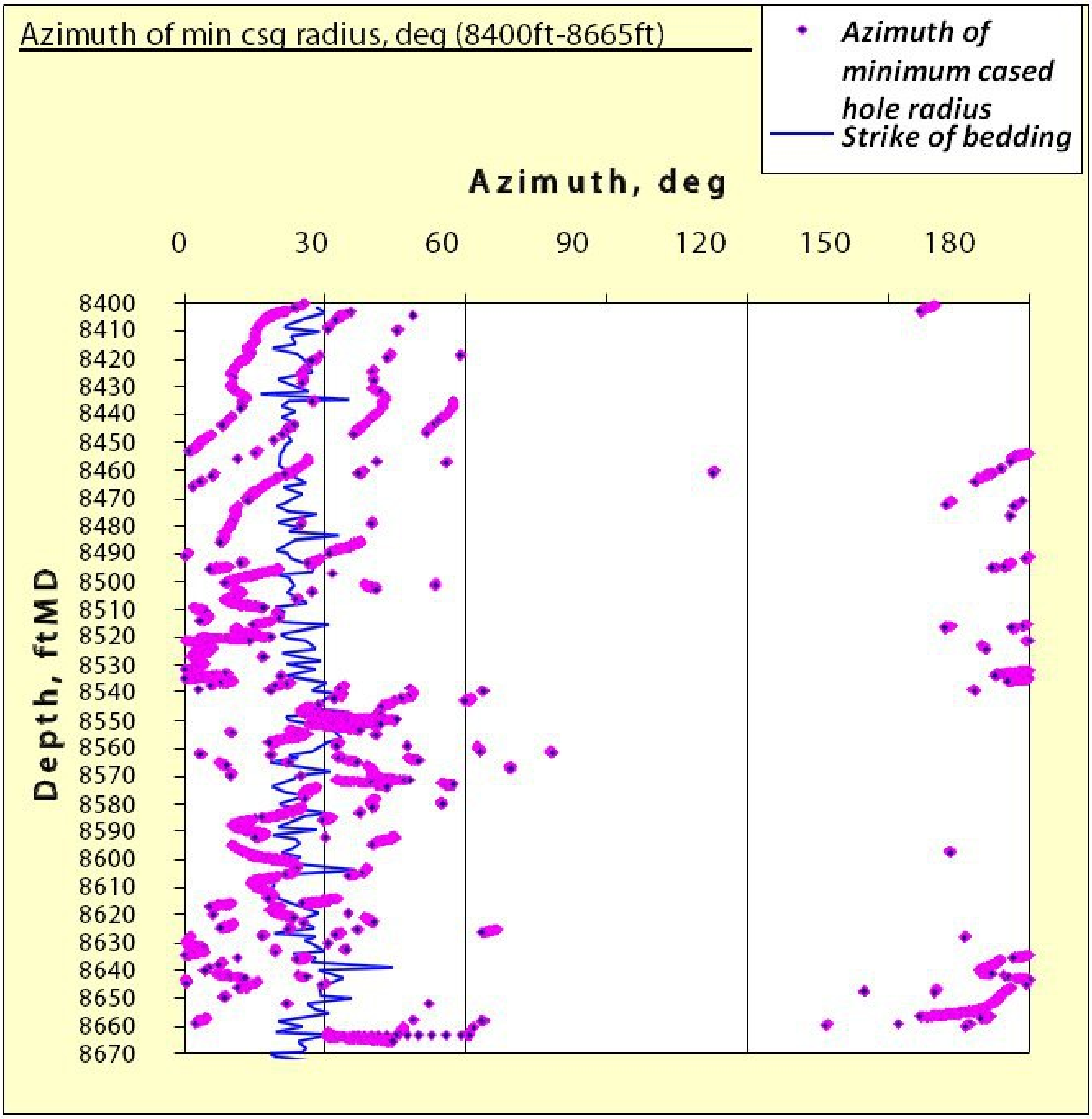

Figure 1. Reproduction of de Pater and Baisch fig 31, for Preese Hall-1, showing well log azimuths (lilac) and interpreted bedding strike from CMI imaging (blue).

Mr Kingdon states:

> *"Their Figure 31, which highlights the borehole ovalisation, includes interpreted **dip data** directly derived from the CMI imaging tool; this figure is included in Smythe's paper (his version included as figure 6), though with this **dip data** omitted. Therefore the author must have been aware of the availability of this borehole imaging data."* [my emphasis].

The blue line shows bedding **strike**, not dip as Mr Kingdon states. The blue bedding strike line as shown in Figure 1 is uninformative regarding the presence or otherwise of faults.

I am aware of the existence of the CMI imaging data, because two samples were reproduced in figure 19 of de Pater and Baisch, but as I have pointed out in my reply to Mr Huw Clarke of Cuadrilla (AC5) I do not have these data. They were not included in the Preese Hall-1 released data package which I obtained in April 2015. However Mr Kingdon has kindly published the image data for the section of interest (his figure 1; log from 8500 to 8640 feet). The image clearly shows bedding in the Lower Bowland Shale, apparently flat-lying relative to the wellbore, but the true dip is slightly to the west because the borehole is inclined steeply to the east in this section. There is no evidence of cross-cutting faults, nor of break-outs or fractures. I shall discuss this valuable new evidence in my reply to Dr Westaway.

I disagree with Mr Kingdon that my digital erasure of the narrow V-shaped labelling feature indicating frack stage 2 in the wellbore leads to ambiguity in the interpretation of the 3D seismic image. There cannot be any sudden disruption or alteration in the seismic data at this locality, because of the very band-limited nature and spatial sampling of the data. In addition, the erased V-shape is sub-parallel to the gently east-dipping seismic layering below the deviated portion of the well. Figure 2 shows a new version of the detail of interest, in which I have also removed the thick black line indicating the wellbore (I originally prepared this figure for my reply, AC5, to Mr Huw Clarke of Cuadrilla).

Any interpretation of such seismic data is, of course, imprecise, but within the limits of the data as seen objectively in Figure 2, there is a clear and important difference between the Clarke et al. (2014) fault location XX and my version YY. The general point is that my version YY separates the two different packages of reflectors - west-dipping to the east of the wellbore and east-dipping under the wellbore – where one might expect the fault to lie, whereas the Cuadrilla interpretation XX crosses the seismic layering, and is therefore incompatible with the presence of any fault with a throw of more than a few metres, i.e. below the resolution of the seismic. Both interpretations assume that there is a fault passing somewhere through the earthquake hypocentre. Imprecision is due to the vertical component of wavelength of the seismic, of the order of 60-80 m, and the horizontal sampling (trace spacing), which appears to be 25 m.

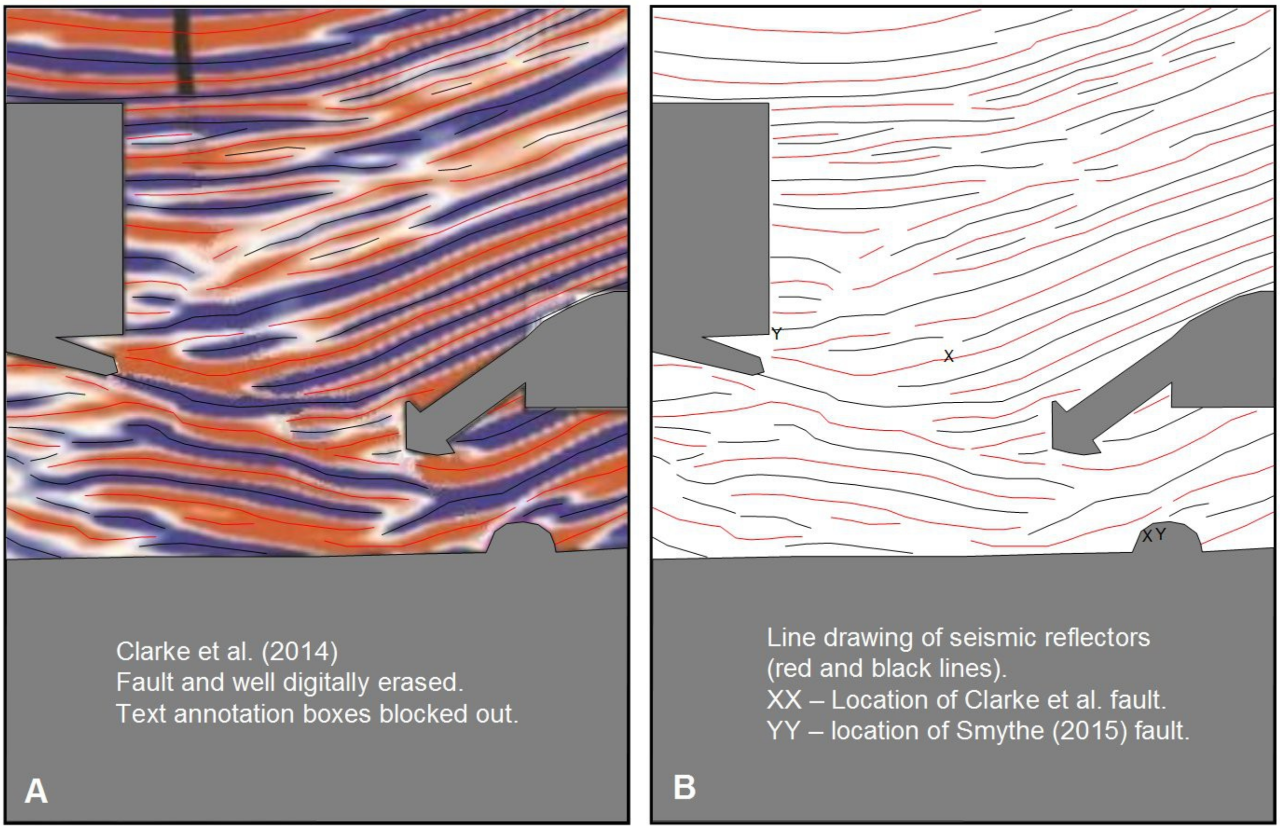

Figure 2. A. Clarke et al. (2014, fig. 4) sample of east-west 3D seismic through the Preese Hall-1 well. B. Line drawing of reflectors with alternative fault positions noted. The semicircle on the lowermost blocked-out area is the upper half of the hypocentral location.

One can argue about the precise location of a fault (or other geological feature) intended to separate the two main seismic sequences. My version YY cuts the wellbore around two seismic cycles below the X shown in the central part of Figure 2B. But there is no merit in trying to locate the fault any more precisely than I have done, not least because there is an inconsistency in the superimposition of the wellbore onto the seismic image.

2. Balcombe-1 faulting

On the question of my demonstration that the Paddockhurst Park Fault, identified from BGS surface mapping, can be inferred in the Balcombe-1 well log, Mr Kingdon states:

> *"He therefore postulates a fault to account for a hypothesised missing section. Examination of the log data used to demonstrate this 10m fault in Balcombe 1 highlights that some degree of*

exaggeration is apparent as about 3m of the raw log data has just been omitted. Adding that back in, the fault should have a thrown of about 6m. Whilst this may seem pedantic, this constitutes a 60% exaggeration."

His assertion of a supposed 60% exaggeration is 100% wrong, as I now demonstrate.

Figure 3 shows the BGS version of part of the Balcombe-1 log in the area of interest, within the Kimmeridge Clay above the I-micrite. The red line shows where I cut the log to match it to that of Southwater-1. Figure 4 shows detail from my discussion paper, figure 8A, in which I matched up the Balcombe-1 wireline logs to those of Southwater-1 by cutting and separating vertically the Balcombe-1 logs.

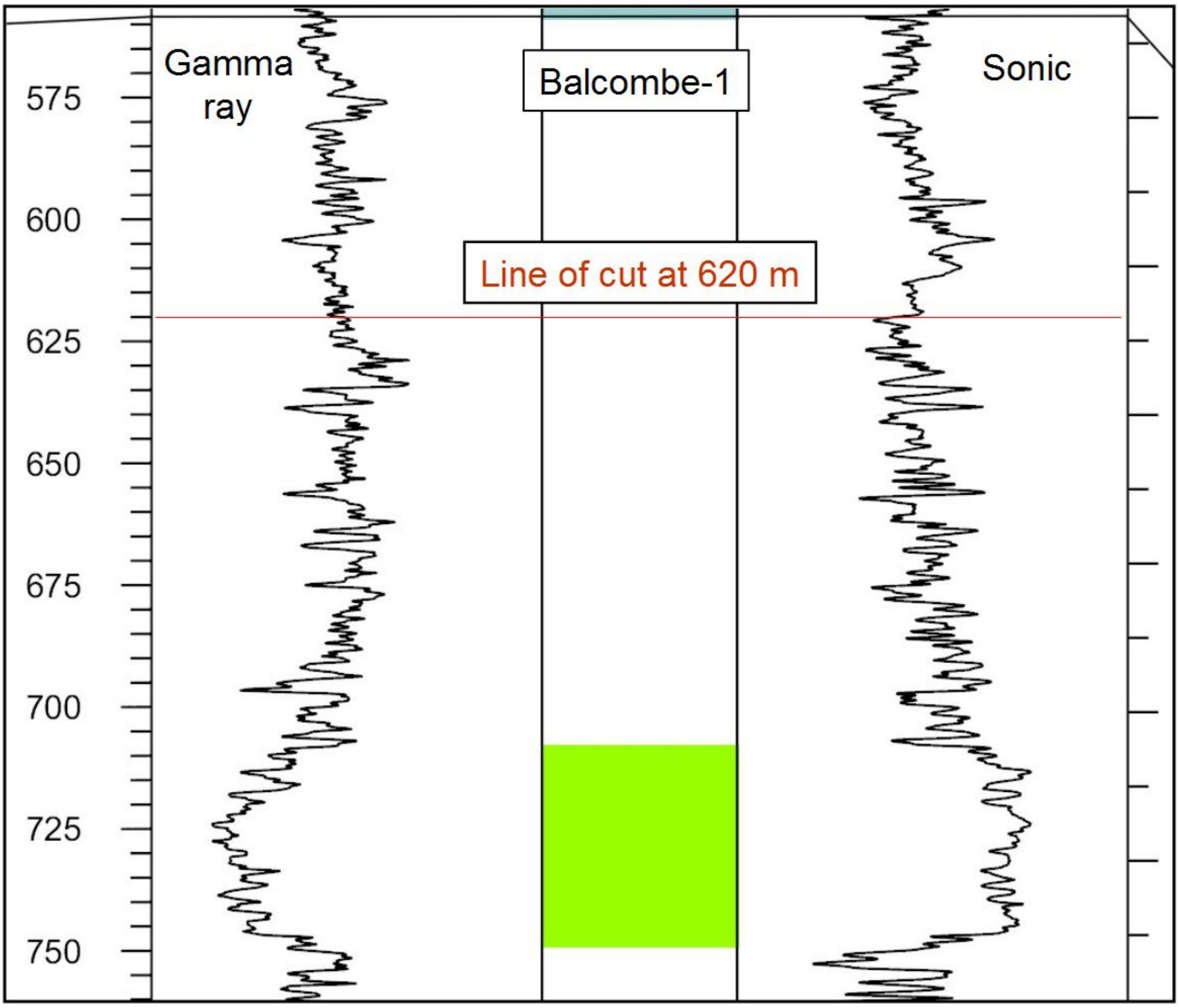

Figure 3. Reproduction of detail of litholog (centre) and wireline logs from Andrews (2014). White on litholog is Kimmeridge Clay, green is the I-micrite. Depth on metres subsea. Red line shows where the cut has been made to match the logs to the Southwater-1 well (Fig. 4).

The cut was made in Balcombe-1 at 620 m. Figure 4 shows the near-perfect match of the logs once a gap of 10 m has been introduced. This represents the missing secion due to the fault. In Figure 4 I have added a second, uncut, version of the Balcombe-1 log, to show the match above 620 m (upper figure) and below 620 m (lower figure). In the latter case the log has been displaced downwards by 10 m.

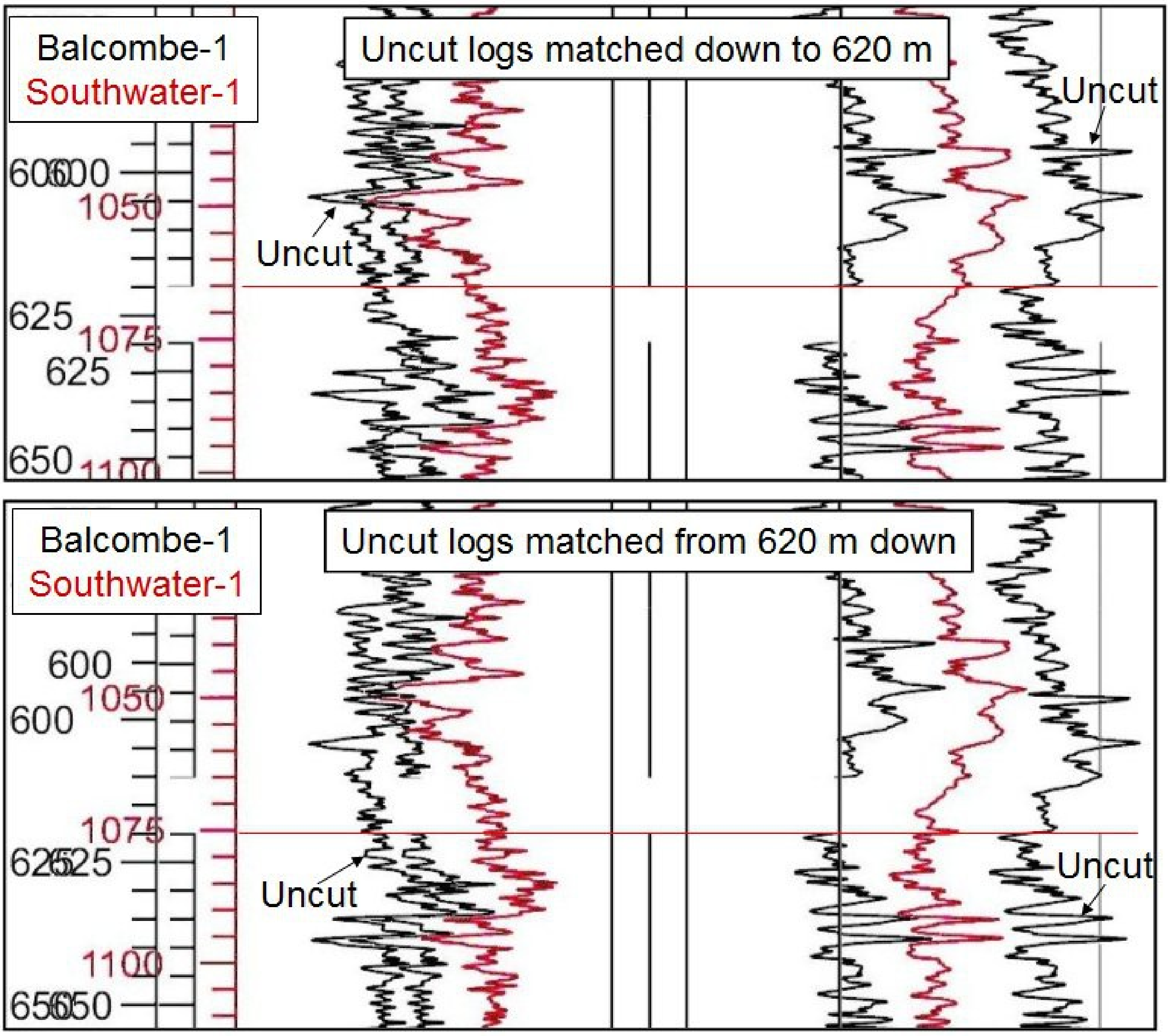

Figure 4. Detail from Smythe discussion paper figure 8A to demonstrate the process of matching up Balcombe-1 (logs in black), with its missing section, to Southwater-1, with its presumed complete section (logs in red).

Nothing is missing from the wireline log images, as wrongly implied by Mr Kingdon. Any vertical imprecision in the logs will be of the order 1 m, which is approximately the thickness of the scale bar lines on the original BGS image.

Conclusions

I thank Mr Kingdon for supplying the Preese Hall-1 CMI image data, which is not, as he states, freely available, although it is nominally in the public domain. I shall take the new data into account in modifying my fault interpretation. Regarding the alleged missing log data in my interpretation of Balcombe-1, Mr Kingdon is wrong; no data have been cut from the logs. He should withdraw his comment.

References

Andrews, I.J. 2014. The Jurassic shales of the Weald Basin: geology and shale oil and shale gas resource estimation, British Geological Survey for Department of Energy and Climate Change, London, UK.

de Pater, C.J. and Baisch S. 2011. Geomechanical Study of Bowland Shale Seismicity, Synthesis Report for Cuadrilla Resources Limited. http://www.cuadrillaresources.com/wp-content/uploads/2012/02/Geomechanical- Study-of-Bowland-Shale-Seismicity_02-11-11.pdf