

Reply to Huw Clarke of Cuadrilla Resources Ltd [se-2015-134-SC9]

Mr Huw Clarke, Exploration Geologist of Cuadrilla Resources Ltd, has commented on my discussion paper (Smythe 2016) under the following headings, which all concern Cuadrilla's exploration in the UK:

- A. The position of the fault with respect to the Preese Hall-1 wellbore.
- B. The origin of the casing deformation at Preese Hall-1.
- C. Balcombe-2 faulting.
- D. Hydraulic fractures intersecting faults, regulation.

A. The position of the fault with respect to the Preese Hall-1 (PH-1) wellbore

Mr Clarke disputes my reinterpretation of the earthquake-triggered fault, stating that I merely repositioned the fault on Clarke et al.'s figure 4, so as to expound my views on the hydrogeological risks of fracking in the Bowland Basin. This is not the case; I repositioned the fault in relation to the Clarke et al. hypocentral location, so as to honour the small sample of 3D seismic data that has been published. Figure 1 illustrates this as objectively as possible.

I have digitally erased both the wellbore and the Clarke et al. version of the fault in Figure 1A, then illustrated in Figure 1B my line drawing of the seismic reflectors (which can be discerned in Fig. 1A). XX and YY denote the interpreted positions of the fault according to Clarke et al. and to myself, respectively. I lettered the Figure 1B in a very small font so as not to draw the eye unnecessarily. Both fault versions originate at the hypocentral location. The Clarke et al. version cuts across seismic layering, which is unacceptable as an interpretation, whereas my version takes the most feasible path between the major groups of reflectors.

Mr Clarke notes firstly that the stratigraphic columns of PH-1 and two other neighbouring wells match very well in the Lower Bowland Shale, in the area of interest of PH-1 around 8500-8700 feet. But these logs are only precise enough to rule out a very large normal or reverse fault with a throw of (say) a hundred metres or more. Furthermore, the identification of a repeat or missing section as a means of fault identification in a vertical well does not apply to strike-slip faults. The fault in question is of this type.

Secondly, Mr Clarke states that the image log for PH-1 is of high quality, shows no sign of faulting in the area of interest, and asks why I have not referred to these data. I have not referred to these image logs because, contrary to Mr Clarke's statement, they are not in the public domain. They do not form part of the well release package for PH-1 which I obtained in April 2015. The only

wellbore image data I am aware of is the example to illustrate borehole break-outs shown in figure 19 of de Pater and Baisch (2011), over the interval 4923-4930 feet within the Millstone Grit Group.

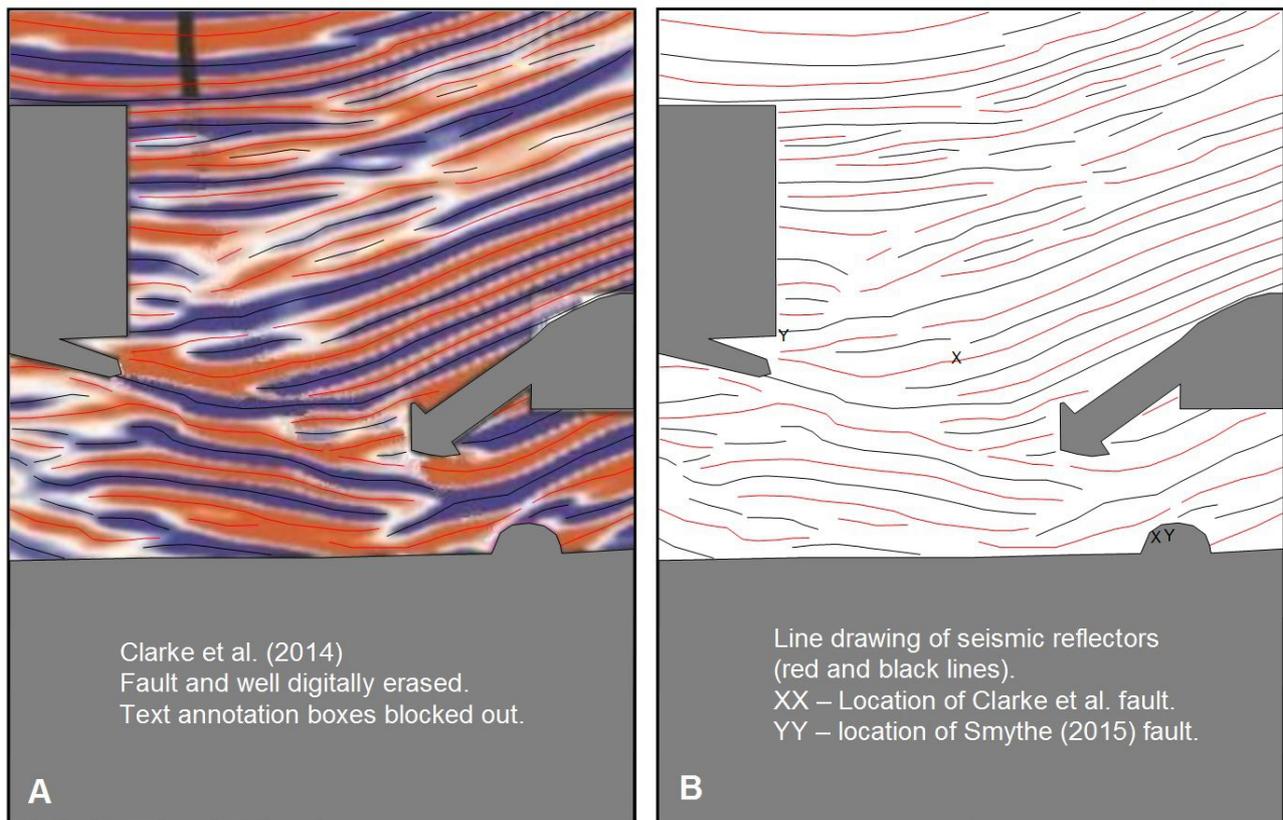


Figure 1. A. Clarke et al. (2014, fig. 4) sample of east-west 3D seismic through the Preese Hall-1 well. B. Line drawing of reflectors with alternative fault positions noted. The semicircle on the lowermost blocked-out area is the upper half of the hypocentral location.

The Lower Bowland Shale comprises “Mudstone, dark grey to black, blocky or shaly, calcareous, pyritic, petroliferous, with subordinate interbedded limestones and sandstones. Limestones in the lower part especially include conglomerates and turbiditic debris beds.” (Hird and Clarke 2012); therefore I question whether image data of dark grey to black mudstones can reliably image fault zones. But if Mr Clarke can make the image data available for public inspection I will gladly reconsider my view.

I discuss the problem of the earthquake hypocentral location and the fault dip in my reply to Dr Westaway.

Mr Clarke raises an objection to my fault placement, which is that if the well does indeed cut the fault, then why was the hypocentre not at the wellbore rather than 300 m away? I have already answered this in my discussion section 3.6, referring to the recent experiment by Guglielmi et al.

(2015). In fact, the hypocentre is *expected* to be at some distance from the fluid injection zone, because of the interplay of fluid injection and aseismic slip, before seismic slip is finally triggered.

B. The origin of the casing deformation at Preese Hall-1

Mr Clarke prefers the mechanism of bedding parallel slip over an extended portion of the wellbore, to account for the casing deformation. Bedding parallel slip is indeed a documented mechanism for wellbore deformation, but so are faults, as described in both papers he cites (Dusseault et al. 2011, Kaiser 2014). He does not seem to have appreciated that my analysis postulating the fault zone cut by the wellbore implicates four or five narrow fault strands between 8500 and 8640 feet depth. The total fault zone width is either 4.7 m or 7.1 m, depending on which strands are identified. The fault zone occupies a long segment of wellbore because it intersects the latter at an acute angle of just 23°.

I conclude that Mr Clarke's final statement on this subject that my "*argument is counter to that of currently held and accepted understanding of such observations and mechanical causes*" is wrong; my explanation fits in very well with current understanding of wellbore deformation.

C. Balcombe-2 faulting

Mr Clarke discusses my Figure 8B, which was re-drawn from Cuadrilla Balcombe Ltd (2013), fig. A01. I stated in section 4.1:

"The lithology log shows a gradational change from 100% clay to 100% micrite over 55 m, but the gradation is repeated below 2700 ft, this time over about 34 m. It is possible, but unlikely, to explain the repetition by assuming that two separate logging runs were made and then poorly spliced together; but an alternative and more plausible explanation is that the wellbore went through a normal fault with a downthrow to the east (wellhead side)."

I reproduce a detail from my Fig. 8B, with a scale of 10% increments in lithology added.

I preferred my second explanation (a normal fault) because I could hardly imagine that two separate logging runs could have been spliced together so poorly. I was, of course, aware that the repeat section coincided with the casing shoe set at exactly 2700 ft, and as can be seen I took care to include the shoe and liner in my diagram.

I agree with Mr Clarke's explanation that the repeat section is due to a drilling artefact, and is not evidence of a normal fault. But several questions remain, so I return to my separate logging run explanation.

Mr Clarke accuses me of a poor understanding of drilling processes, and explains that the drilling out of the cement shoe resulted in the apparent repeat of the Kimmeridge Clay to I-micrite transition. But his explanation fails to fit the facts. If the same wellbore was being drilled for the second time through the shoe there would be a mixture of cement and micrite in the cuttings, with the former decreasing from 100% as the latter increased. The cement is implied by the white area in Fig. 1 (it is a light grey in the original diagram, as also shown by the litholog higher up in the vertical portion of the well, where the 9-5/8 inch shoe was drilled through). But where has the clay below 2700 ft come from? At 2750 ft the litholog shows (as marked in percent in Figure 1) 30% micrite, 50% clay and 20% cement.

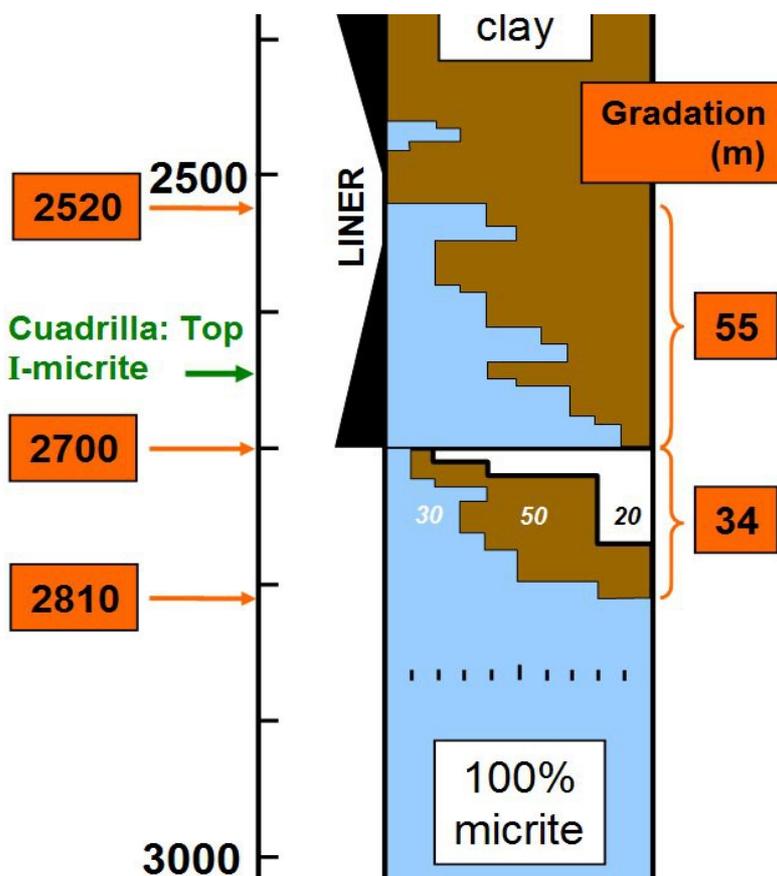


Figure 1. Detail of Balcombe-2z lithology log (modified from Smythe 2016 fig. 8B) showing transition of clay to micrite in the obliquely drilled well. Depths on the left are driller's depths in feet, as measured along the deviated wellbore.

Let us examine the depth log of the deviated well, also taken from Cuadrilla's fig. A01, reproduced with annotation in Figure 2. Here we see the cross-section accompanying the vertical section of Fig. 1. Referring to the lower part; the top I-micrite is taken as being at 2128 ft, as at Balcombe-1 (depths here are true vertical depth sub-sea). But there are two light blue lines indicating this

horizon running to the right. One intersects the wellbore at 2110 ft, and the other at 2138 ft., and separated by a horizontal distance of about 127 ft. The 2110 ft mark at the end of the upper blue line is the top micrite, which dips slightly to the left. The shoe, whose base is at 2138 ft, some 28 ft lower, was set where the proportion of micrite to clay was 90% (Fig. 1), and presumably increasing to 100% the farther (i.e. deeper) the wellbore was drilled. So the return to a high proportion of clay (40% micrite, 60% clay, discounting the cement proportion) is inexplicable.

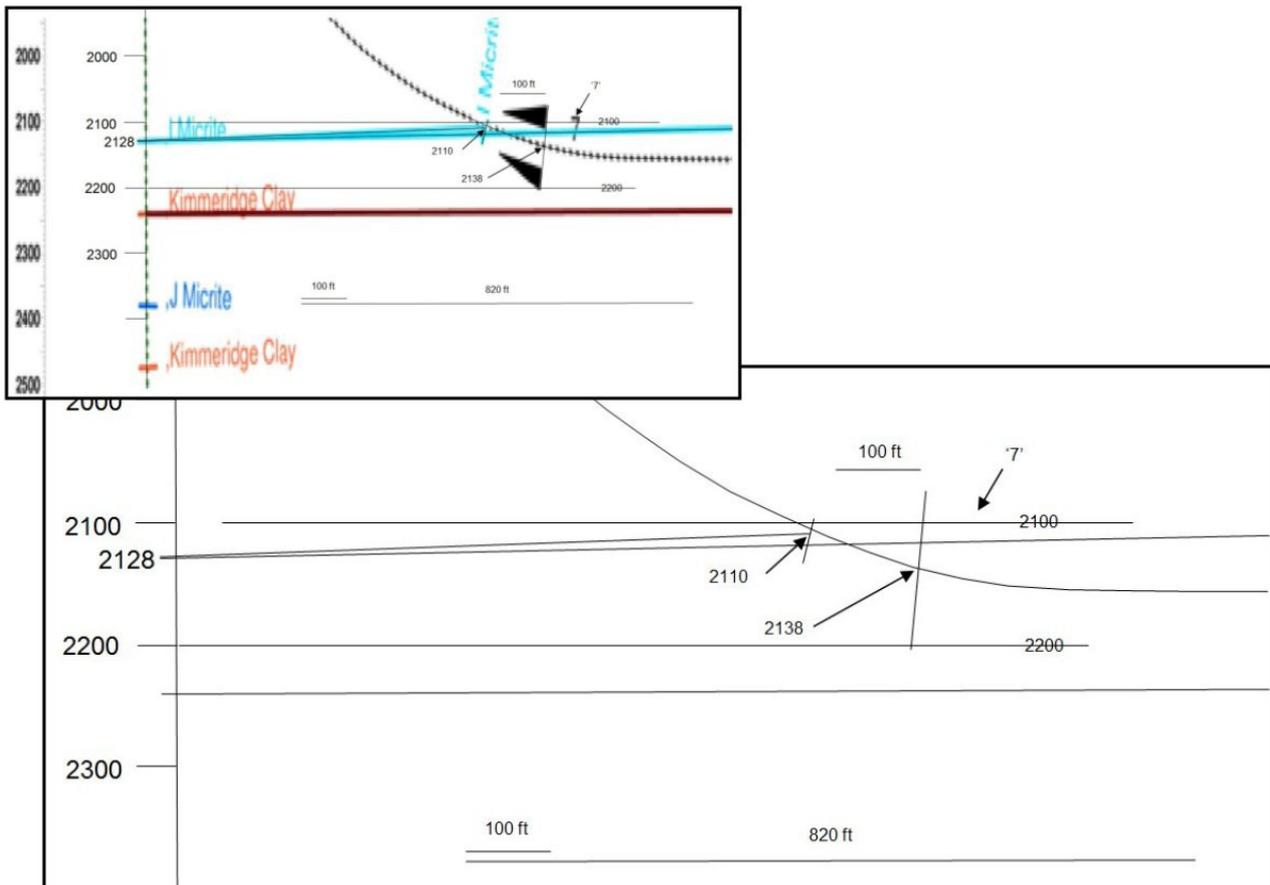


Figure 2. Cross-section of Balcombe-2z landing in the I-micrite (from Cuadrilla Balcombe Ltd 2014, fig. A01). Upper part shows the image with overlays added; lower part shows the overlays without the image, for clarity. Vertical scale is true vertical depth sub-sea. The section is compressed horizontally. The number 7 near the shoe symbol (two black triangles – see Fig. 1 above) indicates the width in inches.

In conclusion, we have:

- Two drilling runs, of which the second was allegedly drilled straight through the shoe,
- Two conflicting blue lines indicating the top micrite in the cross-section of Figure 2, and
- An apparent repeat entry through the transition zone of clay to micrite (as measured from

drill cuttings).

It is possible that the two conflicting blue lines shown in Figure 1, both purporting to represent the top of the micrite, could be due to the second drilling run being sidetracked out of the first, to land at a slightly different angle in the micrite. But this is speculation, without enough facts to go on.

If Mr Clarke could provide a little more detail of the drilling activities, including, for example, the gamma ray logs over the interval in question (which could prove that the wellbore remained in 90-100% micrite from the shoe onwards), it would go a long way to clearing up these discrepancies. In the absence of such evidence I rest with my two alternative explanations of (a) a fault, or (b) poorly spliced logs, but shall now favour the latter.

It is noteworthy that Mr Clarke fails to provide a substantive comment on my interpretation of well logs showing that the Paddockhurst Park Fault was cut by Balcombe-2. I therefore must assume that he agrees with my interpretation.

D. Hydraulic fractures intersecting faults, regulation

I did not write that monitoring of fracture-fault interactions is “*not possible*”, contrary to what Mr Clarke asserts. I merely said that it was “*incomplete*”. However, I should modify my statement citing Pettitt et al. (2009), to read “*Microseismic activity does not necessarily record the passage of fracking fluid up a pre-existing fault.*” [new word underlined].

Mr Clarke believes that UK oil and gas regulation is widely viewed as a global exemplar, quoting the Royal Society and Royal Academy of Engineering (2012). I refer him to my reply to Professor Younger, in which I discuss this unsatisfactory report in more detail.

General conclusions

The problems discussed here illustrates the insufficiency of information put into the public domain by Cuadrilla, the developer, even though the company has gone to the trouble of publishing some of its results in a peer-reviewed journal (Clarke et al. 2014). Dr Westaway [comment se-2015-134-SC2] and I are here in agreement, that we are trying to decipher elements of the geology, drilling and earthquake history based on fragmentary evidence and tiny diagrams, which is unsatisfactory. The 3D seismic will be released under UK licence regulations in 2017; I see no reason why it should not be released immediately for open study and scrutiny.

I propose to modify my discussion paper to take into account Mr Clarke's comments and my responses, where appropriate, and I thank him for taking the trouble to comment.

References

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