Europa Oil & Gas Limited

Environmental permit application EPR/YP3735YK/A001

to drill at Leith Hill, Surrey:

Response to the Environment Agency in the context

of relevant geology and hydrogeology

by

David K. Smythe

Emeritus Professor of Geophysics, University of Glasgow

La Fontenille
1, rue du Couchant
11120 Ventenac en Minervois
France

www.davidsmythe.org

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SUMMARY

Europa Oil & Gas (Holdings) plc (the Applicant) has applied for a permit from the Environment Agency (EA) to drill its Holmwood prospect, centred below Coldharbour village, Surrey. The wellsite is offset by over 1 km to the north; therefore it proposes to drill a highly deviated well.

Comparison of the geological structure of the area, undertaken firstly by BP in the 1980s, then by Teredo Petroleum in the early 1990s and lastly by the Applicant in several phases since 2004, shows that the Holmwood structure remains poorly understood. The database available has not changed significantly since 1990, but the interpretations have varied. The viable target structure has gradually been narrowed down to a small fault-bounded anticline, but there are not enough seismic lines to characterise this structure adequately. The Applicant's drilling proposal relies on just one seismic line.

The Applicant claims that the geological interpretation of the prospect had to be updated because of the drilling of Horse Hill-1 in 2014. This is incorrect. I show that the correct prediction of the geology from seismic reflectors could (and should) have been carried out at any time since about 1990, by tieing in to any of several existing wells.

The Applicant originally proposed drilling of conventional sandstone hydrocarbon prospects in the Holmwood structure, but has recently added unconventional low permeability 'micrites' to the list, despite claiming that the drilling will be restricted to conventional resources. It misleadingly identifies these thin layers as 'limestones', and claims that acidisation will be required, using hydrochloric acid, for cleaning and for 'stimulation' of the rocks around the wellbore. The volume of hydrochloric acid used can be quantified to distinguish between an acid wash (conventional) and stimulation (unconventional); I propose that the permitted volume and strength of acid be restricted to that required for the acid wash only. There is no justification for requiring hydrochloric acid to wash the sandstone reservoirs.

A Principal Aquifer, the Hythe Formation, underlies the drillsite, and will be inadequately protected from contamination. The Applicant, by miscalculation of geological depths and the use of out-of-date maps from the British Geological Survey (BGS), proposes a 50 m long conductor casing (of 20 inches in diameter) which I show does not penetrate deeply enough to reach the impermeable Weald Clay Formation. The Applicant's understanding of the shallow groundwater flow though the

Hythe Formation is also seriously in error; there will be a major risk of outflow from the base of the Hythe to the east into the Mole catchwater and not to the west into Pipp Brook, as claimed.

The surface-mapped faults around the Leith Hill area are poorly understood. The BGS has revised its mapping in recent years, but old information seems to have been forgotten. A crucial piece of evidence overlooked by the Applicant shows that there is field evidence of thrust-faulting within 50 m of the wellsite. The Applicant needs to commission a dedicated resurvey by the BGS to examine all the evidence.

There is direct hydraulic continuity (i.e. a permeable underground pathway) all the way from the wellsite at shallow depths to the public water supply boreholes at Dorking, in contradiction to the Applicant's claim. Thus there is a risk of leakage or contamination at the wellsite reaching the public water supply by this path, in addition to outflow from the Hythe Formation into the Mole catchment.

The highly deviated wellbore is at the limits of permissible technology. Although the path has been allegedly redesigned to avoid faults, I show that it cuts a major fault. This fault extends further upwards to the near surface, and in turn cuts the Hastings Beds, another aquifer. This will probably give rise to technical problems such as washouts (over-enlargement of the borehole) during the drilling, as has happened with a similarly inclined borehole in similar geology at Broadford Bridge.

There will be a problem in sealing the casing of the deviated portion of the wellbore due to its shallow inclination. Inadequate cementing of wellbore casings is recognised as a major problem, giving rise to pollution of groundwater aquifers. Geological faulting is another source of upward migration of contaminants, but the Applicant does not have a robust understanding of the faulting in the target area.

The information supplied by the Applicant is incomplete and misleading. I am led to the inescapable conclusion that the Applicant has a poor understanding of the geology, and of the technical problems that it is likely to encounter in drilling. In turn, its understanding of the hydrogeology is seriously defective. In consequence there is a serious and unacceptable risk that the drinking water aquifers in the district may be contaminated by the Applicant's proposed activities, both in the short term and in the long term.

The EA should refuse present application.

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1 INTRODUCTION

1.1 Relevant personal details from my CV

I am Emeritus Professor of Geophysics in the University of Glasgow. Although I am now a French resident I remain a British citizen, and take an active interest in UK, French and foreign affairs, as well as in various facets of scientific research.

Prior to my taking up the Chair of Geophysics at the University of Glasgow in 1988 I was employed by the British Geological Survey (BGS) in Edinburgh from 1973 to 1987. I was a research scientist, rising to the post of Principal Scientific Officer. My work in the BGS from 1973 to 1986 was funded by the UK Department of Energy as part of a Commissioned Research programme on the geology of the offshore UK region. I also gave geological advice to the Foreign & Commonwealth Office on matters pertaining to UK territorial claims offshore. This was during the exciting phase of early discoveries and development of the North Sea. I led a team of seismic interpreters working mainly on the prospectivity of the western margins of the UK, using the industry seismic and well data supplied to the Department of Energy. As a result I became the UK's leading expert on the deep geology of the continental margin west of the British Isles. Although our interpretation groups in the BGS were never able to commission our own wildcat wells, we had many 'virtual successes', where our independent interpretations were confirmed by subsequent drilling, and where the industry operator was proved spectacularly off-course.

In the 1990s I was closely involved in the search for a UK underground nuclear waste repository, and conducted for Nirex (the nuclear waste disposal agency) an experimental 3D seismic reflection survey. This took place in 1994. The survey encompassed the volume of the proposed rock characterisation facility (RCF) – a deep underground laboratory planned as a precursor to actual waste disposal. This was a double world 'first' – the first ever 3D seismic survey of such a site, and the first academic group to use this method, which at the time was just emerging as an essential tool of the oil exploration industry.

Since my retirement from the university in 1998 I have carried out private research, acted as a consultant to the oil industry for conventional exploration (2002-2011), and maintained an interest in the geological problems raised by nuclear waste disposal, shale gas exploration and coal-bed methane exploration. My tools for this work are up-to-date; I have my own licence for ProMAX 3D (seismic data processing), and currently hold on loan industry-owned licences for SMT Kingdom (seismic and well interpretation) and ModelVision (gravity/magnetic modelling including tensor fields).

1.2 Declaration of interest, independence and non-liability

I have no interests to declare. This document was requested by *A Voice for Leith Hill*, which is paying me a modest honorarium. I am not connected to, nor am I a member of, any activist group, political party, or other organisation. I am solely responsible for the contents of this submission. It is supplied in good faith, but I can accept no liability resulting from any errors or omissions.

For the avoidance of doubt, given the unacceptable public comments made about my status by the CEO of one of the Applicant's partners, my legal dispute with the University of Glasgow (2016-2018) has been settled amicably, and the Secretary of the University has stated (5 January 2018) :

> *"I have no reason to doubt your integrity as a scientific researcher, and hope that you will continue to be as productive in your research as you have been since your retirement in 1998."*

He has also confirmed that I am free to continue to use the title of Emeritus Professor of Geophysics without hindrance. I remain a member of the College of Science and Engineering, but not attached to any specific school or group within the University, and the views expressed are my own.

2 THE HOLMWOOD PROSPECT

2.1 Evolution of the prospect

2.1.1 Introduction

Europa Oil & Gas (Holdings) plc (Europa; hereinafter the Applicant) holds the PEDL143 licence awarded in the 12th onshore licensing round, for which applications closed on 9 June 2004. The area of the licence is the OS grid square TQ14, minus the existing PL235 Brockham licenced area. Information supplied to DECC as part of the application (Europa Oil & Gas Limited 2004) describes the Holmwood prospect as being identified on three seismic lines. The targets were the Portland Sandstone (two horizons) and the Corallian Sandstone. It has recently added Kimmeridgian micrites to the list of targets.

The Applicant asserts that the drilling operation is conventional in nature. The evolution of the mapping of the Holmwood prospect is described below by reference to maps of the Top Portland horizon.

2.1.2 Identification by BP: 1980s

The earliest publicly available maps of the hydrocarbon prospect in question are by BP (Thompson 1987) in a relinquishment report for PL235 and PL236. The rationale behind the retention of certain areas included three prospects in order of priority, of which 'Coldharbour' (the Holmwood prospect) was second. BP's Holmwood prospect at Top Portland level is outlined in Figure 2.1. The Applicant's proposed well is shown by the red dot in this and succeeding maps. BP had available essentially the same seismic database as the Applicant has at present, lacking only the seismic lines obtained in 1990 prefixed TWLD. BP identified a large faulted dome-like structure, shown by the closure at 500 ms (TWT) in the south-central part of the area shown in Figure 2.1, plus a small closure within a large but faulted area to the north of the E-W fault zone shown in the centre of the Figure. The domal area is defined over a much larger area than shown in Figure 2.1, at about 550 ms TWT, but it is open to the north-east. BP never drilled the prospect.

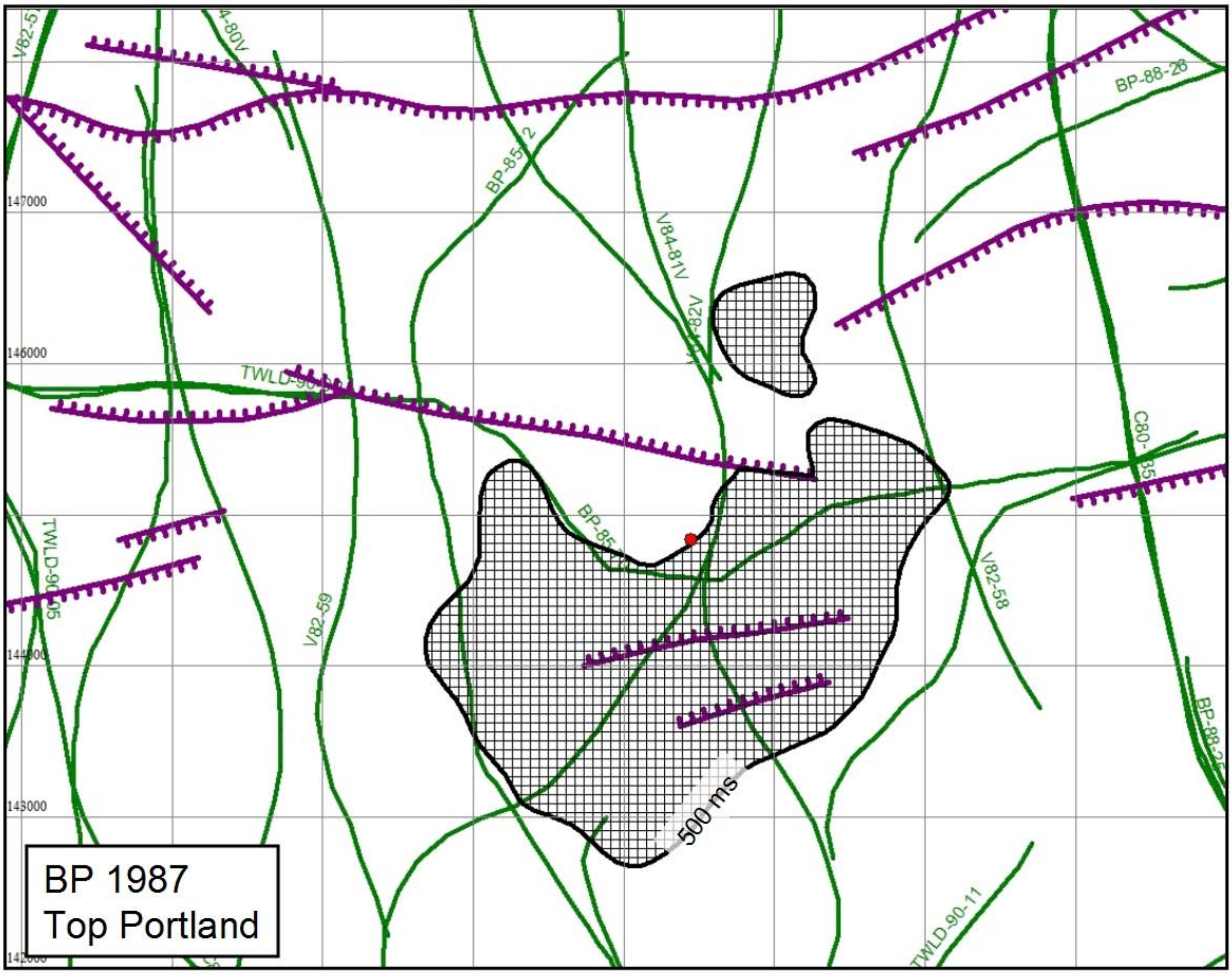

Figure 2.1. Top Portland structure (cross-hatched areas) mapped by BP in 1987. Seismic lines are shown in green, faults in purple with tick marks on the downthrown side. The Applicant's proposed wellsite is shown by the red dot. Closure is at 500 ms TWT.

2.1.3 *Teredo: early 1990s*

Teredo Petroleum PLC (1991) applied for the area in the fourth onshore round of licensing of June 1991. Its map (Figure 2.2) of the prospect described a "*large extensional anticline formed in the hanging wall of a basin bounding fault (Enclosure 3). It has the form of a four-way dip closure with some fault modification.*" The 670 m depth contour outlining the prospect is described as a maximum, because its closure on the NE near seismic line V82-58 is doubtful, as indicated by the question marks in Figure 2.2. The minimum area of the prospect is bounded by the 650 m depth contour. There is another small fault-bounded high bounded by the 660 m contour some 3 km NE of the Applicant's proposed well.

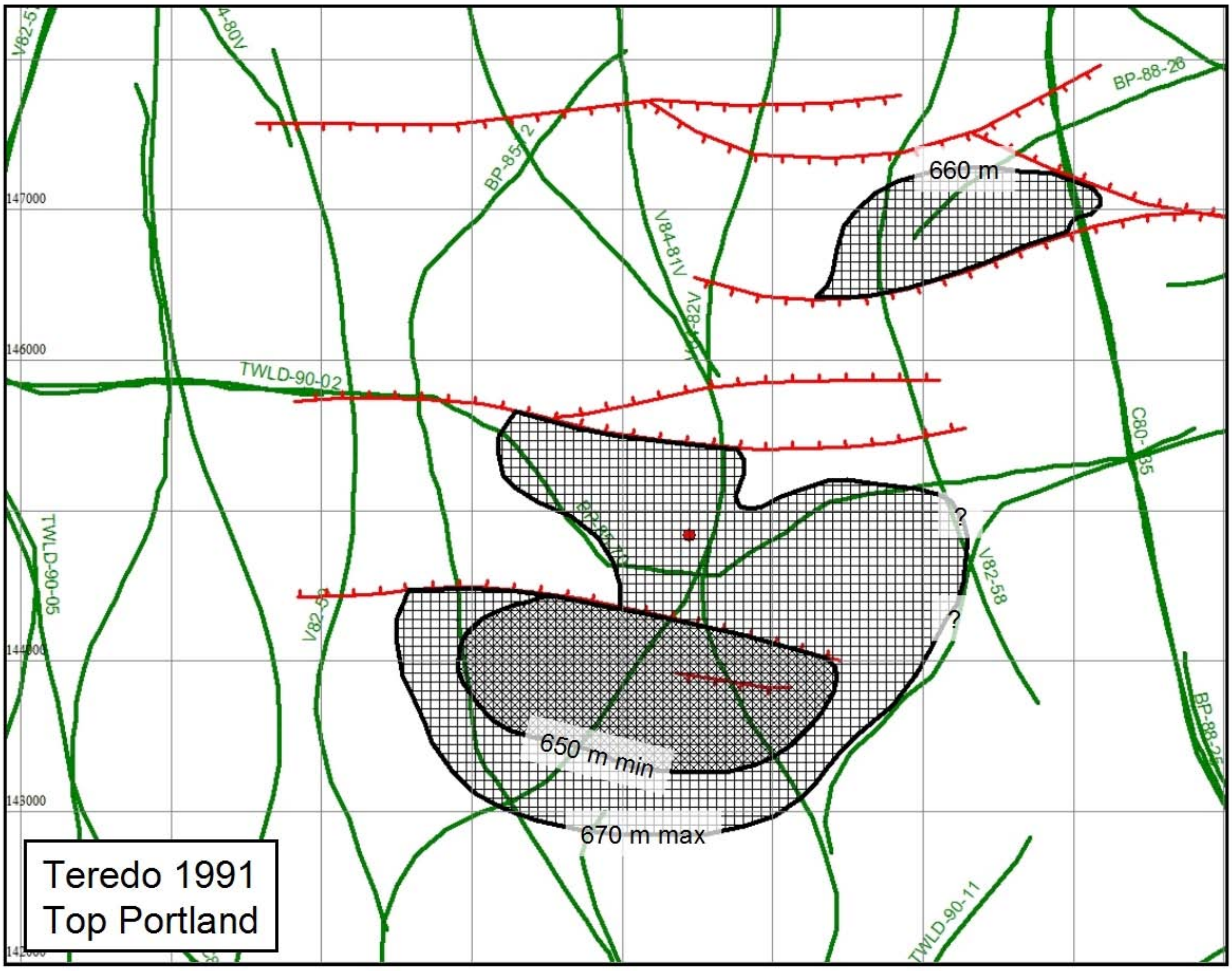

Figure 2.2. Top Portland structure (cross-hatched areas) mapped by Teredo in 1991. Seismic lines are shown in green, faults in red with tick marks on the downthrown side. The Applicant's proposed wellsite is shown by the red dot. Closures are at 670 m bsl for the main structure, but there is doubtful closure in the east, indicated by question marks. The more robust closure is the double cross-hatched area, closing at 650 m.

2.1.4 Europa Oil & Gas: 2004 - present

The Applicant outlined the Holmwood prospect in its application for the PEDL in the 12th round of onshore licensing (Europa Oil & Gas Limited 2004). Its Top Portland structure map (Figure 2.3) showed two large fault-bounded closures, Holmwood South and Holmwood North, bounded by the 490 ms and 510 ms contours, respectively.

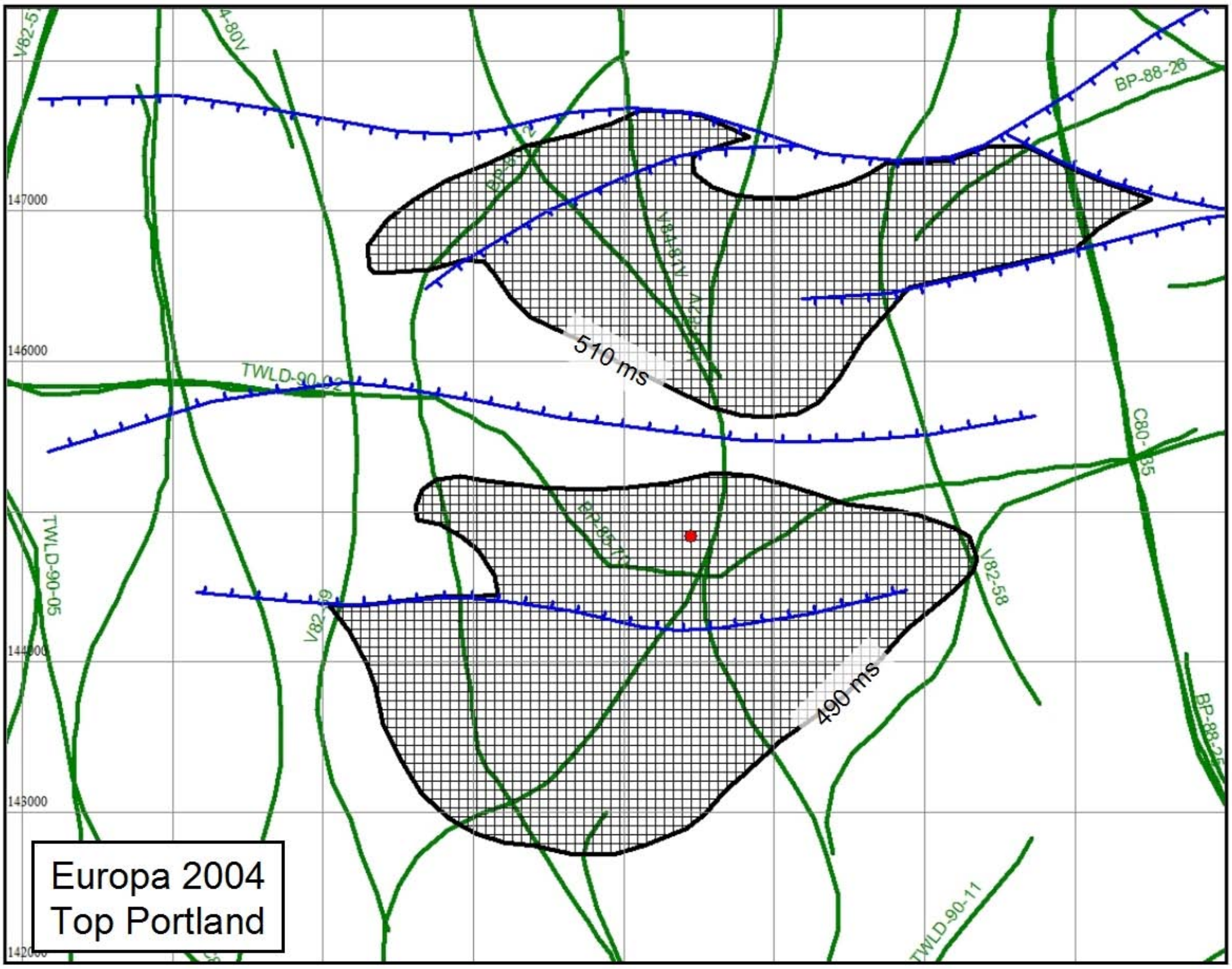

Figure 2.3. Top Portland structure (cross-hatched areas) mapped by Europa in 2004. Seismic lines are shown in green, faults in blue with tick marks on the downthrown side. The Applicant's proposed wellsite is shown by the red dot. Closures are at at 510 ms and 490 ms TWT (Holmwood North and Holmwood South, respectively).

By 2014 the prospect had been reduced to the small fault-bounded target area below Coldharbour (Figure 2.4).

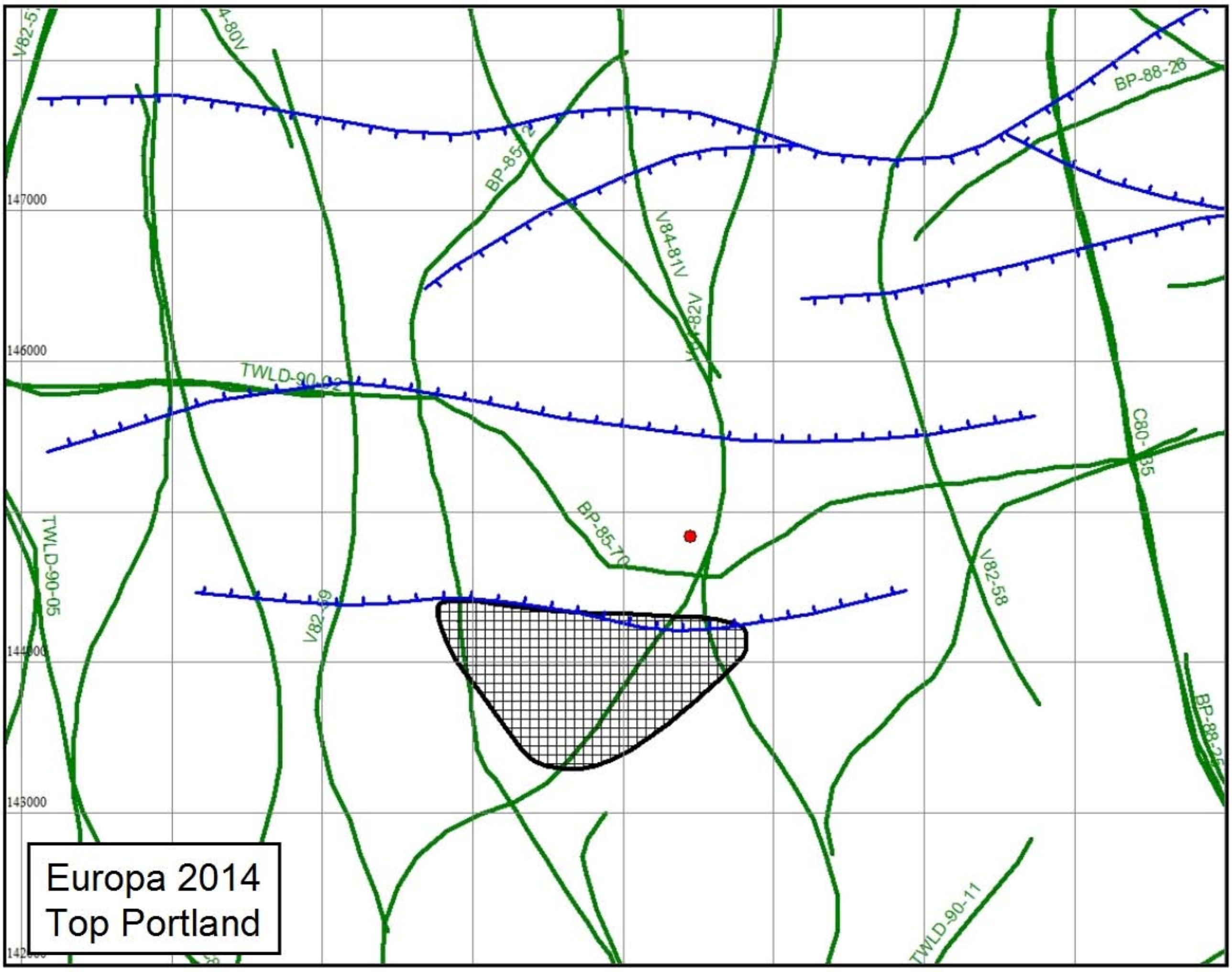

Figure 2.4 Target area (cross-hatched) mapped by Europa in 2014. Seismic lines are shown in green, faults in blue with tick marks on the downthrown side. The Applicant's proposed wellsite is shown by the red dot.

2.2 Discussion

The three epochs of interpretation, covering some 35 years, all use essentially the same database. There is general consistency in the identification of a large approximately equi-dimensional structural high, shown in Figure 2.5 by the dashed black ellipse. However, the details differ. Figure 2.5 shows the three different fault interpretations all superimposed on the seismic database. The E-W fault running some 600 m north of the proposed wellsite, herein referred to as fault zone P, seems to be robust, as is the fault zone O to the north. Note that these are all mapped using at least six seismic lines running north-south. But the more easterly part of fault zone Q, south of the Applicant's wellsite, is poorly defined. The reason for this is clear; there are only two seismic lines here on which the faults can be mapped.

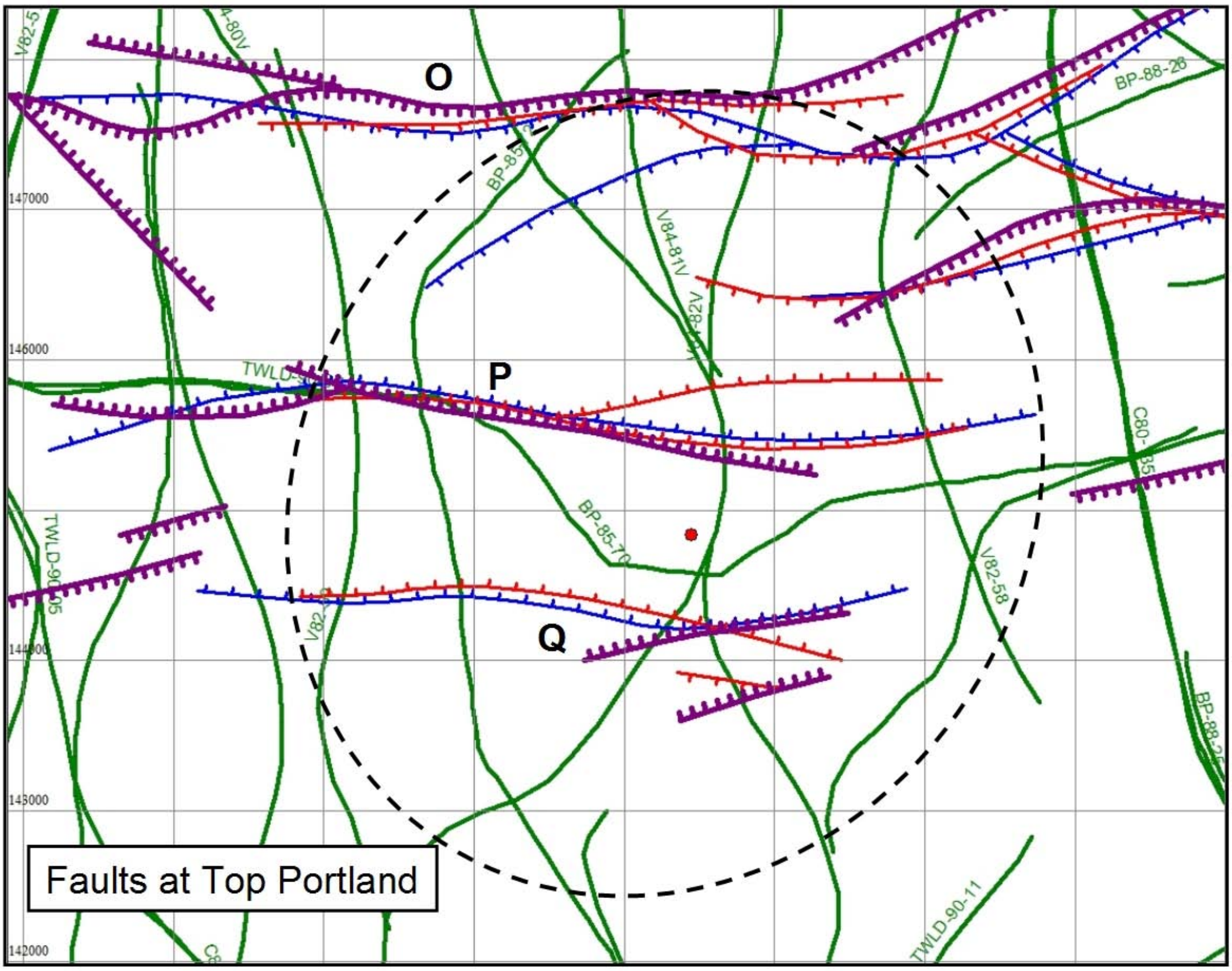

Figure 2.5. Compilation of faults at Top Portland as mapped by BP (purple), Teredo (red) and the Applicant (blue), tick marks on the downthrown side. Seismic lines are shown in green. The Applicant's proposed wellsite is shown by the red dot. The three main faults zones are labelled O, P and Q. The Holmwood structure is located under the dashed ellipse.

The reasonably robust closure mapped by BP lies south of fault zone P and encompasses fault zone Q, where, in contrast to later interpretations, BP mapped only two minor faults trending ENE-WSW. The main closure mapped by Teredo resembles the Holmwood South prospect mapped by the Applicant in 2004, but is offset to the north by about 1 km. There are no public data to enable a determination of whether Europa's 490 ms contour (Figure 2.3) east of the wellsite, near seismic line V82-58, is robust, or else has been optimistically closed off.

The attempts to map a closure between fault zones O and P (Figure 2.5) have been unsuccessful, or have resulted in only very minor closures. Europa's North Holmwood Top Portland prospect depends upon sealing on the downthrown side of fault zone O. However, there may be some validity in a deeper target such as the Corallian straddling the central fault zone P as a valid but faulted closure. Integrity of the caprock to such a reservoir would then depend on the faults acting as seals.

The current target of the Applicant, 2.3 km^2 in area (Figure 2.4), resembles the area of 3.0 km^2 outlined by Teredo as its more robust closure at 650 ms (Figure 2.2). However, the Applicant's expected closure area may be somewhat larger than 2.3 km^2.

In conclusion, the large Holmwood structure originally identified by BP as the Coldharbour prospect has been whittled down by later interpretations to become a rather minor fault-bounded elongate fault-bounded dome south of fault zone Q. Proof of its existence relies on just three seismic lines. The validity or otherwise of the structure is examined next.

3 UNCERTAINTY OF THE GEOLOGICAL INTERPRETATION

3.1 Seismic reflector ties to nearby existing wells

Tha Applicant has altered both its interpretation of the stratigraphy (the geological labels, or horizons, applied to seismic reflectors) and the faulting (the displacement of the reflectors) between 2004 and the present date. It states (Europa Oil & Gas Limited 2018):

> *... the borehole design has changed to reflect evolving seismic interpretations and the availability of new offset well information, including the HH1 exploration well drilled in late 2014. Raised formation depths and targets have, in turn, necessitated changes to the well design, ...*

HH1 in the above quotation refers to Horse Hill-1, drilled by its partner UK Oil & Gas Limited in 2014.

The statement above is surprising, because, although it is true that the horizons have been raised to shallower depths, the correct tie-in of horizons could, and should, have been done correctly at the time of the initial licence application in 2004. Here is a table of the nearest wells, with the operator, date of drilling and distance from the Applicant's wellsite:

Albury-1	Conoco, 1987	10 km
Brockham-1	BP, 1987	5 km
Leigh-1	Esso, 1966	7 km
Collendean Farm-1	Esso, 1964	9 km

In other words, all the data required for a robust tie have been available since about 1990.

Figure 3.1 shows one of the many possible paths along seismic lines to tie the horizons identified in one of the wells above to the Applicant's proposed well. Any one of these ties could have been made from 1990 onwards, assuming that the Applicant had access to the seismic database. The tie that I have selected runs SW along line C80-130, 135 m from Collendean Farm-1, then west along TWLD-90-04, then back in a north-easterly direction along V81-53 to the wellsite. The two-way times for the seismic tie at Collendean Farm-1 are available on the UK Oil and Gas Library (UKOGL) website, as are high-quality images of the seismic data themselves.

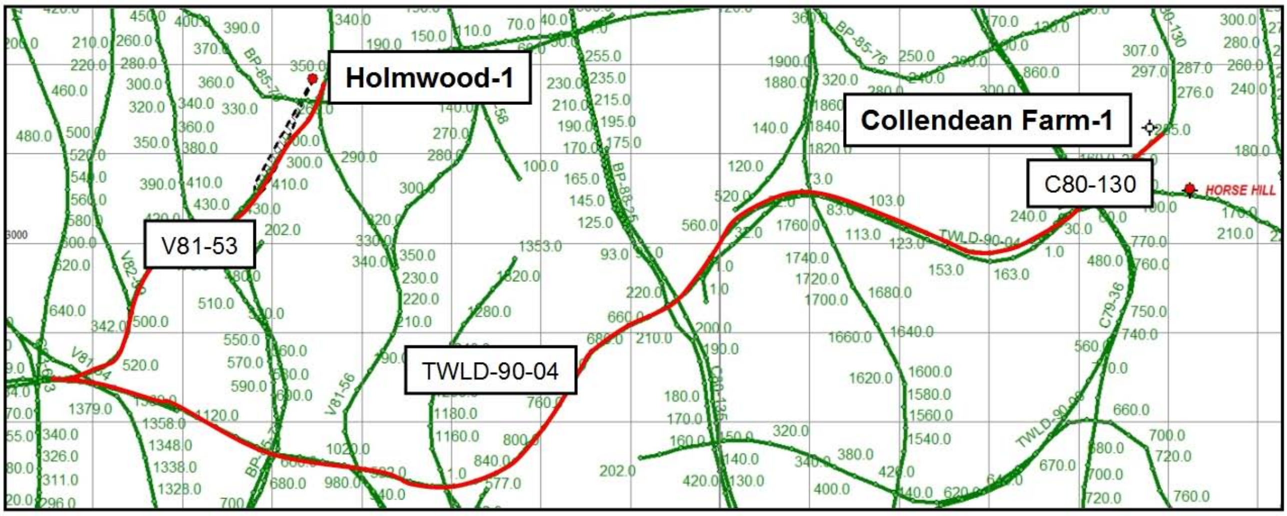

Figure 3.1. Seismic tie map (red lines) on the seismic basemap (green lines) from Collendean Farm-1 to Holmwood-1 (proposed).

The seismic correlation is shown in Figure 3.2 in a horizontally highly compressed image.

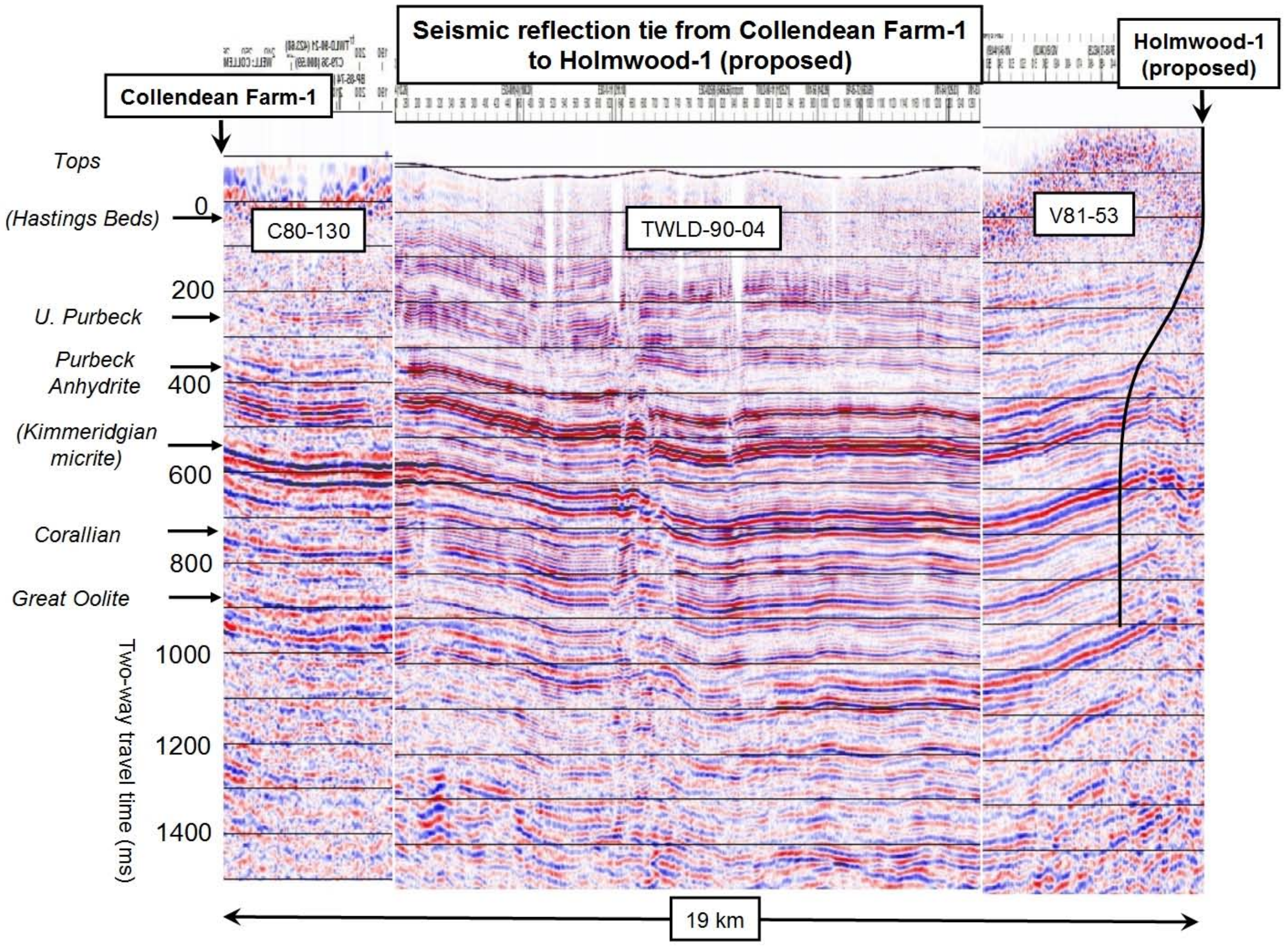

Figure 3.2. Seismic tie from Collendean Farm-1 along seismic lines C80-130, TWLD-90-04 and V81-53 to Holmwood-1 (proposed).

I have added the two horizon two-way times shown in brackets at Collendean Farm-1, by interpolation. The Hastings Beds tie is approximate, as can be seen by the poor quality of the shallow seismic data on C80-130, but lies just above the better-quality high-frequency reflectors seen on the link to TWLD-90-04 at around 100 ms TWT. The TWLD-90 survey, dating from 1990, is clearly superior in quality to the two other survey lines of 1980 and 1981 vintage. The top of the upper Kimmeridgian micrite is easily identified as a very strong reflector, which is characteristic throughout the Weald Basin. All six marked tops at Collendean Farm-1 can thus be traced to the Applicant's proposed well track (superimposed upon V81-53) with a reasonable to high degree of confidence.

3.2 Importance of static corrections

The Applicant states that it has tied the wellsite back to Horse Hill-1, amongst others. Firstly, it has been shown in the previous section that it was not necessary to wait until Horse Hill-1 was drilled (November 2014) to enable a reliable tie, and secondly, no details of the tie have been presented to justify the alteration of the horizons between 2014 and 2018.

It can be seen in Figure 3.2 that the three seismic panels have been offset slightly relative to each other in a vertical sense to enable a visual match of the reflectors. This correction has been applied because the different vintages of seismic survey have different static corrections applied. Within any one survey, that is to say, the set of seismic lines surveyed and processed by one company during a particular campaign, the static corrections will be consistent. However, with different methods of acquisition and processing across several different surveys, the final corrections (normally referred to sea level as the datum) are often different. The application of correct statics to each separate survey, to make them match up, is labour-intensive but crucial. There is no evidence that the Applicant has carried out this work.

The Applicant's tie to Horse Hill-1 is now examined. I show a map of the short seismic tie between Collendean Farm-1 and Horse Hill-1 in Figure 3.3.

Here there has been a severe misinterpretation of the data both before and after drilling of the latter well by the Applicant's partner at Holmwood-1, UK Oil and Gas Limited (UKOG). So it is not clear whether the Applicant has simply taken the UKOG interpretation on trust, or else has made its own interpretation. The seismic tie between the two wells is simple (Figure 3.4), but requires a relative static correction of +25 ms to be applied to the BP line.

Has this correction (and other similar necessary adjustments) been applied around the Horse Hill / Collendean Farm area by the Applicant, before tying further west to Holmwood? No evidence has been furnished to the EA to suggest that this work has been done.

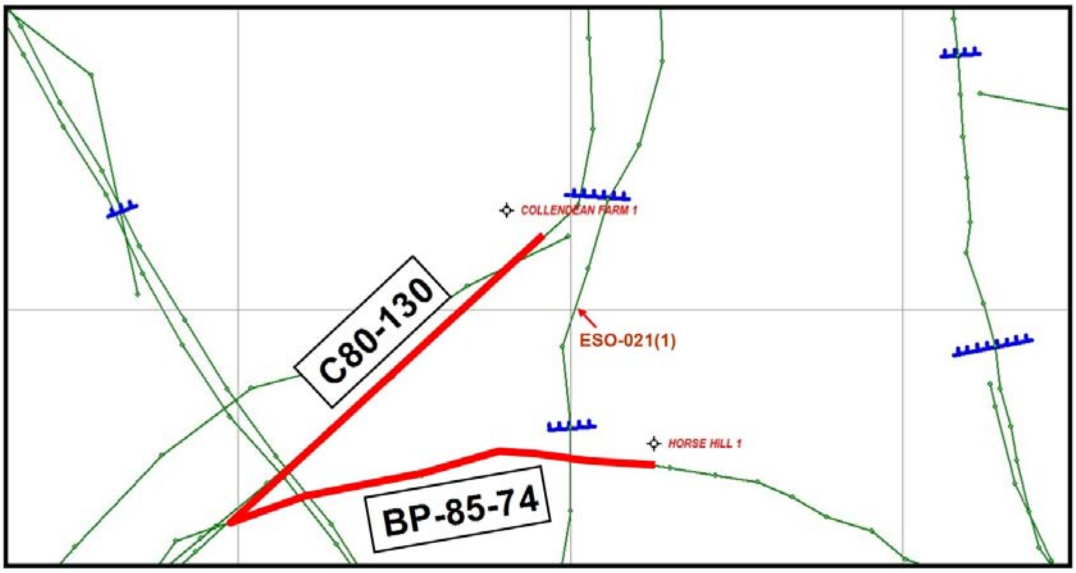

Figure 3.3. Well tie (red lines) from Collendean Farm-1 to Horse Hill-1 via seismic lines C80-130 and BP-75-74. CF-1 is 135 m offset to the NW from C80-130, and HH-1 is 65 m north of BP-85-74. National Grid squares are at 1 km interval. Short blue toothed lines indicate faults seen on the seismic data (green lines).

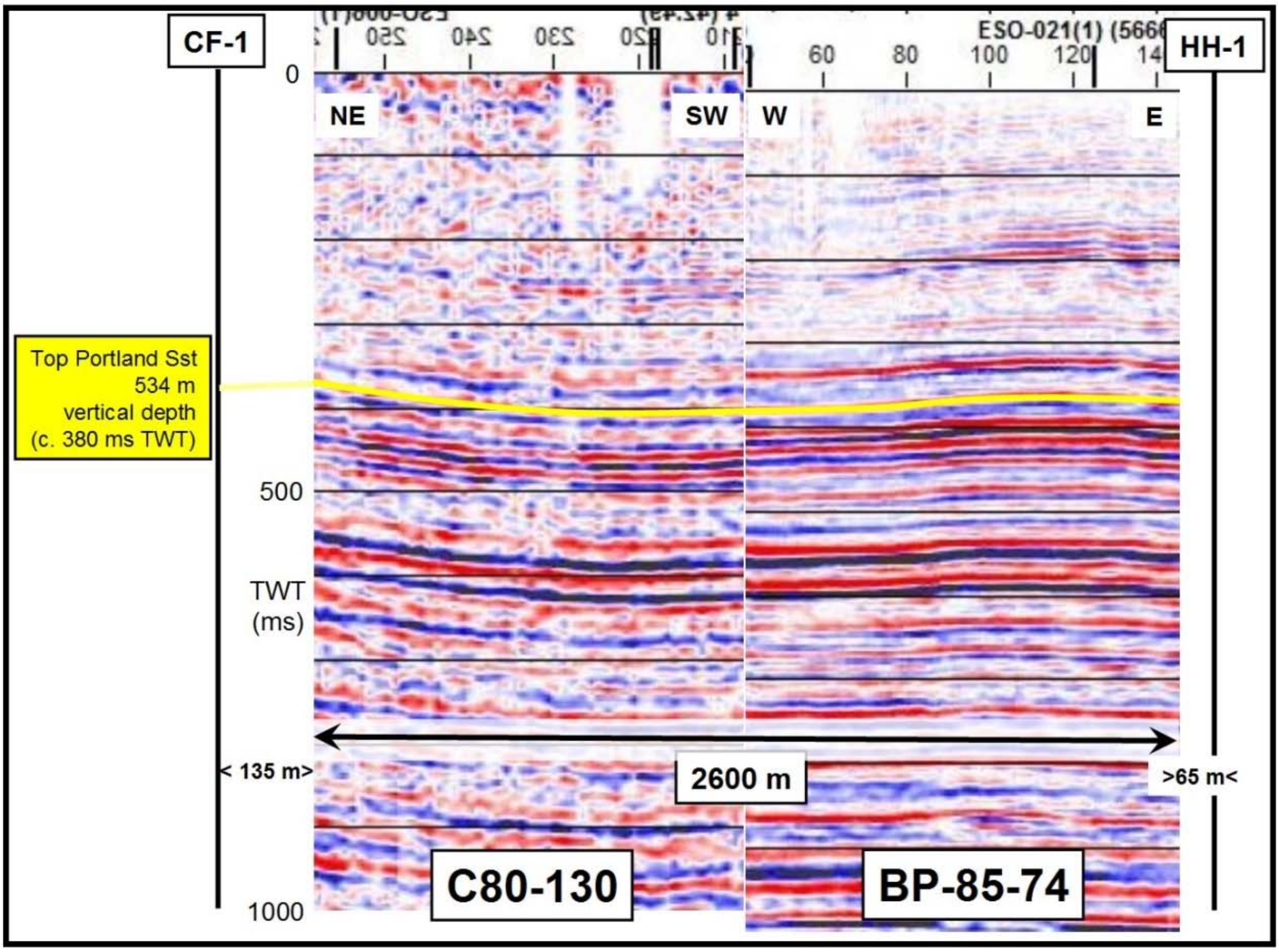

Figure 3.4. Seismic lines C80-130 and BP-85-74 tying CF-1 to HH-1. A static correction of +25 ms has been added to the BP line. The Top Portland horizon (yellow) can be traced easily from 380 ms TWT at CF-1 to about 390-400 ms at HH-1. There are no faults cutting this tie polygon.

3.3 Time to depth conversion

The Applicant states that the new seismic interpretation was made after the Horse Hill well data became available to it in 2016. These data have in turn been converted to depth using a set of seismic velocities for the intervals. However, despite the admission that there is an "*uncertainty in the seismic velocity time/depth conversion*", no details have been provided. In summary, the Top Portland horizon has been raised by some 80-85 m, and

> *"... the most conservative worst case time/depth conversion [was] adopted for the trajectory design, which would lift the top Portland horizon by a further 60m".*

Given that the design parameters for the new deviated wellbore are crucial, the EA should have been supplied with far more detail to justify the new interpretation of the geology.

3.4 Commitment to acquire more seismic data

The Applicant stated in its application for the PEDL (Europa Oil & Gas Limited 2004):

> *" Assuming success with the planning process for the well, and more crucially an indication that planning permission would be forthcoming for any future development, Europa plan to acquire two new vibroseis 2D seismic lines and drill the Holmwood Prospect, testing both the Portland and Corallian targets. A commitment would be made by the end of the 3rd year of the licence to complete a well to test both Protland* [sic] *and Corallian levels by the end of the licence term."*

The final terms and conditions of the PEDL award are not available; however, it would be surprising if DECC had waived the offer to acquire the additional seismic data, a work commitment which is at the bare minimum of what is generally considered acceptable for obtaining a PEDL. Naturally the new seismic data would (and should) have been acquired before drilling site selection. But no additional seismic data have been acquired.

In conclusion, there is no evidence supplied to substantiate the Applicant's recent changes to its seismic interpretation and depth conversion along V81-53.

4 FAULTING

4.1 Faulting in the neighbourhood of the wellsite

Figure 4.1 shows the seismic database around the target zone of the Applicant's proposed well. It also shows the Applicant's version of the district faulting (cf. Figure 2.4 above) in more detail.

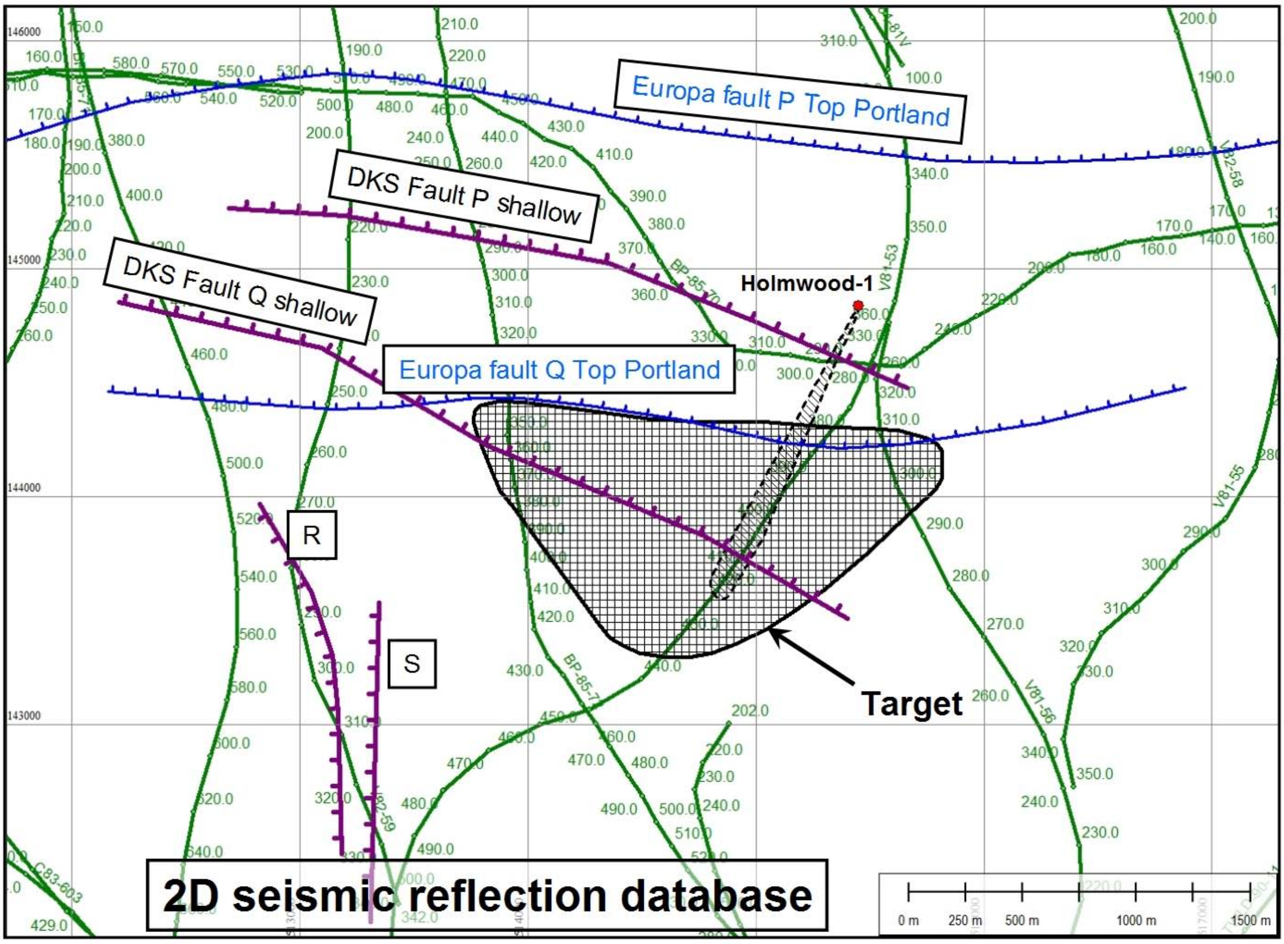

Figure 4.1. Seismic data (green lines) around the Applicant's target area and wellsite (red dot). The wellbore trajectory is shown by the dashed-line hatched area extending SSW from the wellsite. The Applicant's interpretation of faults at Top Portland level is shown by blue lines; my version of faults (at a shallower depth) is shown by purple lines.

My version of the two main faults P and Q (see Figure 2.5 above) is shown in Figure 4.1 by purple lines. My fault P at shallow depth probably corresponds to Europa's fault P at Top Portland level; it is mapped further south than the latter because of the northerly dip of the fault plane. In contrast, my version of fault Q runs at an angle of about 30° to the east-west trend of Europa's fault Q. Recall also that BP's version of the faults at Q (Figure 2.1) trend towards the ENE, i.e. different again.

The problem with correlating the faults from one seismic line to another is basically that we do not have enough data. The E-W spacing the the seismic lines running N-S is between 1 and 2 km, which is insufficient for identifying structures accurately at the sub-one-kilometre scale. In addition, there is only one seismic line (BP-85-70) running E-W, and even that line takes a very sinuous path.

4.2 Faulting along the well trajectory

Figure 4.2 shows seismic line V81-53, on which the wellbore trajectory design is based, in a horizontally compressed form, and with various faults identified by the termination and/or offsets of seismic reflectors. The green line is the topography, converted to a pseudo-reflection time.

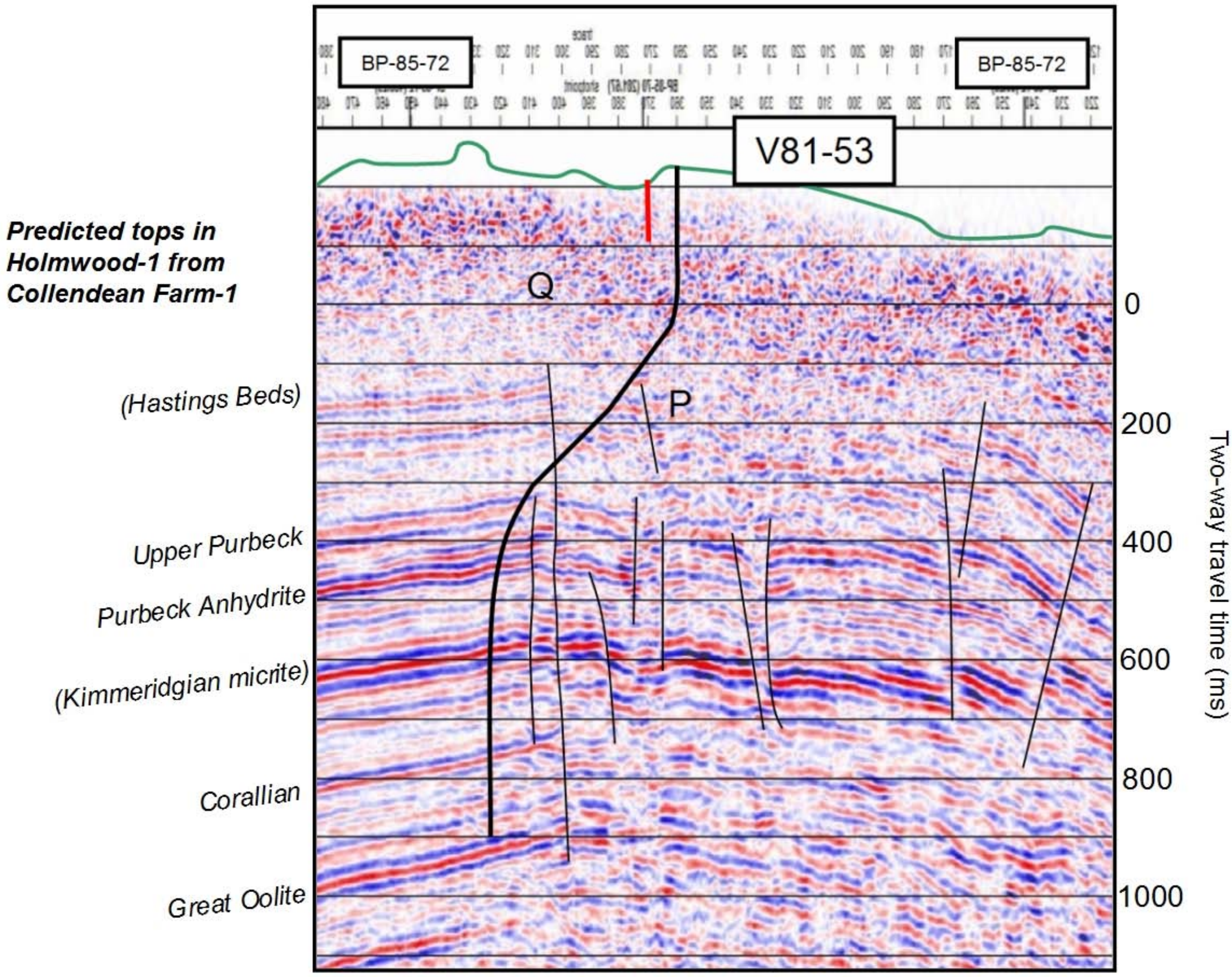

Figure 4.2. 'Squash-plot' of V81-53 along the wellbore track (heavy black line). Faults are indicated by thin black lines. The horizons at the south side (left hand side) are tied in from Collendean Farm-1. Not that fault Q extends upwards to 100 ms, and could be imaged even shallower, but for the poor quality of the shallow seismic data.

The wellbore trajectory is shown by the Z-shaped path; the exact shape of the bend is approximate, because I do not have access to an accurate time-depth conversion; however, the initial and final points are accurate. The vertical red line at the top just south of the wellbore is a

BGS-mapped surface fault, which appears in the 1933 published geology map, but is omitted from the 1:10K digital database.

The principal point of note is that fault Q clearly cuts the wellbore, and displaces the Hastings Beds. Tha fault trace can be identified in the upward direction to about 100 ms TWT. Above that depth it is not necessarily absent; it is just not imaged (if it is present) on the shallowest portion of the seismic data.

4.3 The Applicant's version of the geology along the well trajectory

Figure 2.3 shows the Applicant's new version of its well trajectory and revised horizons superimposed upon the geology as interpreted three years earlier.

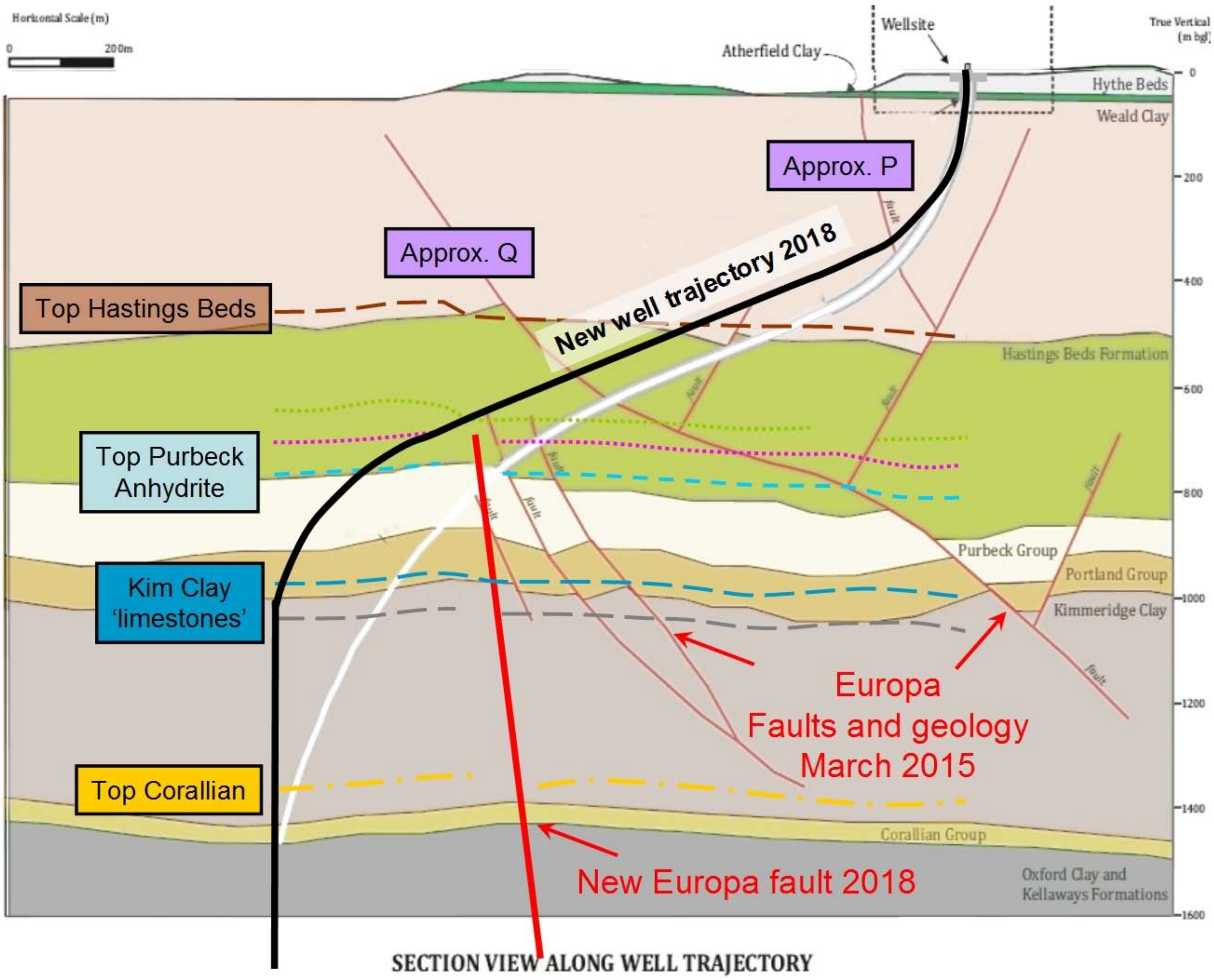

Figure 4.3. Revised well trajectory (black line) and revised horizon tops (coloured dashed lines, labelled), superimposed upon the Applicant's previous version (2015) of the geology. The approximate positions at shallow depth of faults P and Q from Figure 4.2 are marked by labels in purple boxes.

The new position of a fault (bold red line in Figure 4.3) has necessitated the upward shift of the deviated portion of the wellbore from that shown in white. In addition the Applicant has designed the wellbore to intersect the Top Purbeck Anhydrite just south of the new fault.

Firstly, it appears that almost all of the faults from 2015 (thin red lines in Figure 4.3) have now been discarded, as shown by the fact that the revised tops now run across the cross-section with no offsets. This suggests that the Applicant's interpretation of the geology was unsound in 2015, and there is no reason to suggest that it is any more sound now.

Secondly, the Applicant's new fault corresponds to my location for fault Q, as can be seen by comparison of Figures 4.2 and 4.3. However, in my interpretation it continues upwards to cut the Top Hastings Beds (Figure 4.3) where the Applicant indicates merely a small monoclinal feature in that horizon at around 420 m bgl. So this fault cuts through the geology at a crucial location in the cross-section, some 50 m north of the 'design point' of the wellbore, and where the inclination of the wellbore is running at what the Applicant concedes to be at the limit of its technical capacity. The limits of the new wellbore design have been pointed out independently in the hydrogeological review by EGG (2018).

5 CONVENTIONAL AND UNCONVENTIONAL HYDROCARBON PLAYS

5.1 Introduction

A discussion of what is meant by unconventional hydrocarbon resources is required, because the Applicant has recently introduced the low-permeability Kimmeridge Clay Formation micrites as an additional exploration target. These rocks will require acidisation.

The micrites of the KCF are very impure limestones, being composed as much of shale or mudstone as of carbonate, and thus they could equally well be termed calcarous mudstones. There are three or four of these thin layers (of 30 m or less in thickness) throughout the KCF. Within each layer there is a varying percentage of limestone.

These so-called micrites of the Weald do not feature in the BGS lexicon of recognised rock types. They can be traced eastwards on well logs from the classic Kimmeridge Bay outcrop on the Dorset coast, where the equivalent formation is seen in cliff faces as an interbedded layering of shales (including oil shale) with thin (sub-metre) bands of limestone. The micrites can be recognised in the subsurface on well logs by the divergence of gamma ray, which decreases, and sonic velocity, which increases, relative to the shale above or below; however cuttings and sidewall cores often fail to recogise the micrites explicitly. This is due to the mixed shale/limestone nature of the rock.

Drilling at Balcombe illustrates the difficulty of characterising and following a micrite layer. The upper micrite was identified by Conoco in its Balcombe-1 well (1986) as 110 ft (33.5 m) thick, whereas the BGS, using the same well data, considers it to be 25% thicker, at 42 m. At Arreton-2 on the Isle of Wight, drilled by British Gas in 1974, the two micrites can be interpreted by the gamma ray / sonic pattern, but in the cuttings the limestone content of the upper micrite was not seen at all, and the lower micrite was interpreted just as three bands of limestone, 2 ft, 5 ft and 4 ft thick, respectively, over a 70 ft thick zone. It has become a fashion with the current operators in the Weald, including the Applicant, to identify so-called 'micrites' within the Kimmeridge Clay Formation, and, despite their meagre proportion of calcium carbonate, to then label them as 'limestones'.

5.2 Acidisation

Acidisation is described in the Applicant's waste management plan (Europa Oil & Gas 2018) at section 5.3.5.1. An acid wash and an 'acid squeeze' are described. The latter term is unusual, because it occurs neither in industry usage nor in common definitions to be found in the relevant pages of websites such as those of Halliburton, Schlumberger, PetroWiki, or Rigzone. It should not be confused with a squeeze job. However, an acid squeeze is referred to in the context of unconventional, low permeability carbonate stimulation treatments, for example by Rees et al. (2001) and by Vasquez et al. (2015).

The draft EA decision document defines an acid wash and an acid squeeze as follows:

> *"An acid wash is defined as the application of acid under low pressure and will be used primarily to clean the near wellbore environment to remove damage from drilling activities. This activity will precede any further acid squeeze.*
>
> *Acid squeeze is defined as the application of acid under pressure that does not exceed the fracture pressure of the formation. The pressure that the acid can be applied at, so that it does not exceed the fracture pressure of the formation will be established by pressure testing during drilling operations. The acid squeeze is designed to clean the natural pores and fractures of the near wellbore environment (i.e. 1m radius from the well) which may have been damaged by drilling operations. Depending on the extent of existing fractures within each formation acid may pass beyond 1m radius of the borehole, but will be recovered as production water when pumped back to the surface."*

The definition (and need for) an acid wash is not in contention. However, the definition given above of an acid squeeze states that it is merely a further cleaning process in the near-wellbore environment of a formation "*which may have been damaged by drilling operations*". No improvement of the intrinsic permeability of the formation is implied.

The so-called 'acid squeeze', as defined above, is identical to matrix acidisation, which, according to PetroWiki, has two distinct purposes; (1) to remove damage, and (2) to enhance productivity. The mechanisms used for these two purposes are the same, and what they have in common is that the pumping pressure is below the fracture strength of the rock. According to the PetroWiki account they can be differentiated because the latter procedure requires a "*large volume of acid*" to "*improve*" the formation permeability, whereas, in contrast, acidising to remove damage, which is the stated purpose of the acidising in the present application, merely "*restores*" permeability. So the volume of acid, allied to some extent with its rate of injection, is the crucial criterion.

The EA (Environment Agency 2018) "*does consider matrix acidisation to be a form of stimulation. Matrix acidisation does treat the geological formation, with the aim of stimulating flow in the oil and/ or gas reservoir.*"

The volume of acid used is of potential environmental concern, because hydrochloric acid (HCl) is known to attack the cement sheath between well casing and rock, and degrade it (see for example Aghajafari et al. 2016).

Figure 5.1 is modified from a PetroWiki article, with annotations and additions. The original is shown in the inset, which shows the linear relationship (a straight line) between the pumping pressure of the fluid being injected and the rate of injection.

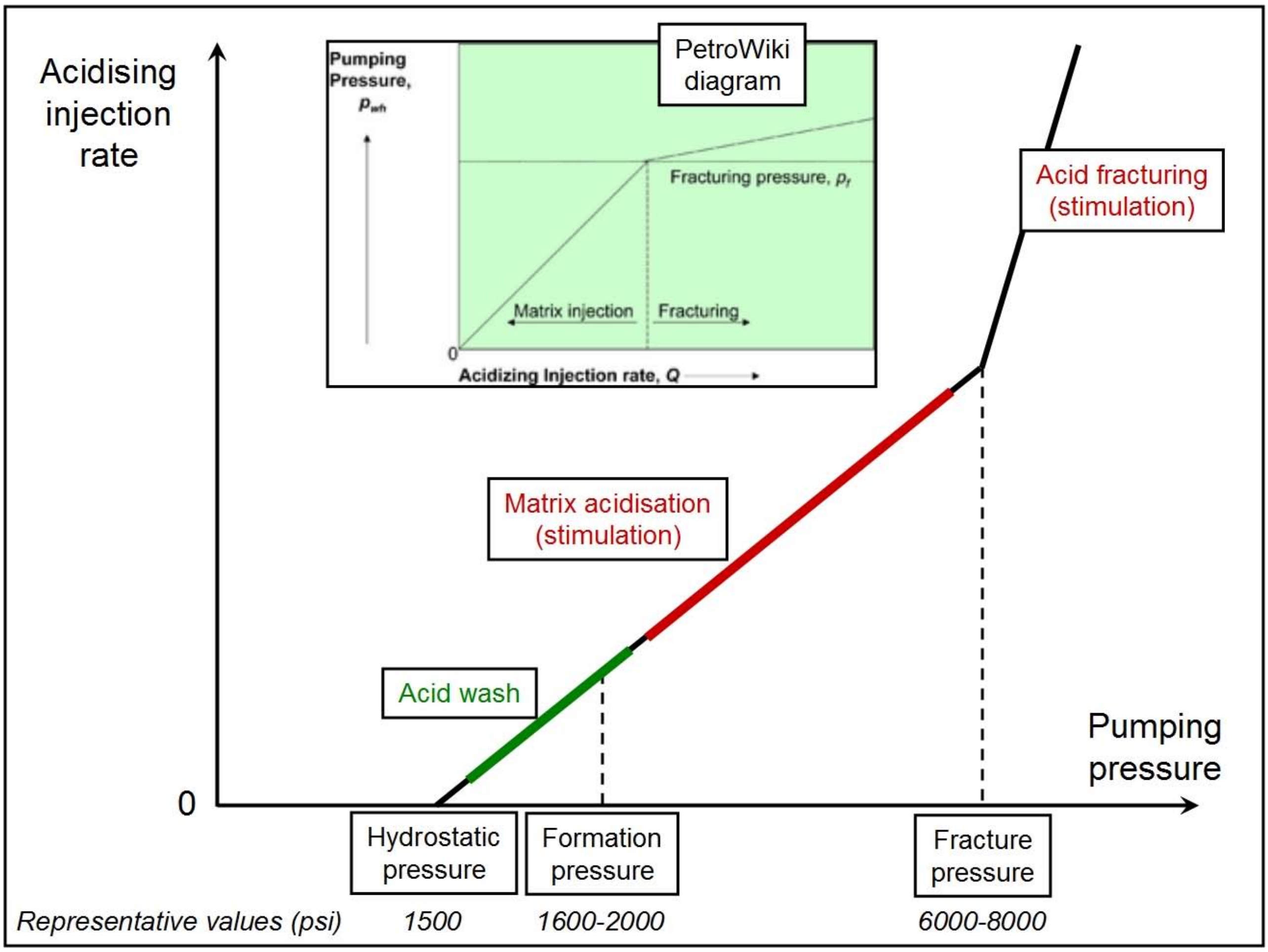

Figure 5.1. Graph of acidisation injection rate vs. pumping pressure, modified from the PetroWiki diagram shown as an inset. NB the axes of the main graph have been interchanged from the original. Green line indicates acid wash, and red line matrix acidisation. The latter may overlap into the acid wash zone.

The PetroWiki axes are the wrong way round, because the injection rate depends on the pumping pressure; also, the line in the original graph goes through the origin, implying that any finite pumping pressure will result in a flow. This is clearly not the case, because there will be no flow until the hydrostatic pressure at the injection point is exceeded. The graph ordinate of zero is perhaps intended to be the hydrostatic pressure at the formation depth, but this is not made explicit. Therefore in the modified graph I have put the dependent variable (rate of injection) as the vertical axis. The hydrostatic pressure, or 'normal' pressure, is the pressure due to an equivalent column of slightly saline water. The linear graph intersects the pumping pressure axis at a finite positive value, the hydrostatic pressure. Below that pressure there will be no injection.

At the depth of interest, the Kimmeridgian micrites are about 1000 m deep, and the hydrostatic pressure is approximately 1500 psi. The formation pressure, also known as pore pressure, is often somewhat higher than hydrostatic pressure. Representative values of pressure are indicated along the ordinate axis. The drilling mud used will have been designed with a density to balance the formation pressure; however, this rule only applies to permeable formations, so that in drilling the Kimmeridge Clay Formation a drilling mud of little more than hydrostatic density will suffice. It follows that the pressure required for an acid wash, to clean out around the drill string and hole, will be of around the same magnitude as the mud pressure used to drill the hole. This is shown schematically by the green line in Figure 5.1.

The zone of matrix acidisation is shown by the red line in Figure 5.1. In practice this may overlap with the green zone. Now the intent of the Applicant's use of matrix acidisation is stated to be merely for cleaning up damage, and not for enhancing permeability, but how can we differentiate between the two actions? We can further ask, why is there a need for the so-called 'acid squeeze' at all? The only feasible solution to this problem, to ensure that the Applicant does limit its activity to near-wellbore damage repair, is to limit the permitted volume and concentration of HCl to values that will suffice for cleaning. The figures for the volumes and strengths of acid allegedly required appear to differ greatly between the original and the revised application. These discrepancies have been discussed in a separate consultation submission by Ms Adriana Zalucka, which I include herein as Appendix A. Her submission refers to a California Department of Conservation (2014) discussion paper on the calculation of the acid volume threshold, to which I now refer.

The California paper discusses and defines an Acid Volume Threshold, below which the acid treatment will not be classed as a stimulation. The reason for the paper is stated as follows:

"Although Public Resources Code section 3158 expressly identifies acid matrix stimulation as a form of well stimulation treatment, the statute calls for a threshold volume of acid, below which an acid matrix stimulation treatment is not subject to regulation because it does not pose a significant risk."

The basis for the threshold is the volume of rock surrounding the wellbore which is to be treated, together with the rock porosity. Such a threshold is necessary in the UK regulatory framework, because at present there is a contradiction between the EA's understanding of matrix acidisation, which it correctly defines as a form of stimulation, and the Applicant's assertion that the hydrocarbon exploration project is conventional in nature. We can circumvent this contradiction by defining a threshold volume for acidisation, below which the process may be assumed to be for purposes of wellbore cleaning only , and not for rock formation stimulation.

The California paper states:

"The amount of acid used in the well can be used as an indication of the design and purpose of the use of acid in the wellbore. Acid used to increase the permeability of the formation must come into contact with the formation and is designed to alter the formation, typically to dissolve constituents in the formation, in order to increase the formation's permeability. Therefore, the amount of acid used is directly related to the area that is anticipated to be altered, i.e. the more acid placed in the well for every treated foot, the larger the area that will be impacted by the acid."

The paper goes on to conclude, based on various research sources, that the radius of formation damage is empirically known to be between 20 and 50 inches, and then conservatively selects 36 inches as the threshold radius. In the UK framework we can assume 1.0 m as an approximate equivalent. For every meter length of wellbore, the void space in the 1 m radius from the well is simply $\pi r^2 \times \phi$, where r is the radius (= 1 m, measured outwards from the hole) and ϕ is the porosity, minus the volume of the wellbore itself. The porosity ϕ of the Kimmeridgian micrites is 0.1 (and often less). Assuming a borehole diameter of 8-1/2 inches and a porosity ϕ of 0.1 yields an acid threshold volume of 0.35 cu. m per linear metre, so for the 30 m thick upper micrite the threshold acid volume will be 10.5 cu. m.

A similar calculation can be made for the lower micrite, which is about 25 m thick, yielding a threshold acid volume of 8.7 cu. m. It is difficult to see why HCL acidisation in a so-called squeeze will be required at all for the other targets, which are sandstones, and therefore not susceptible to chemical reaction with HCl.

In conclusion, if the so-called 'acid squeeze' is justified at all for well cleaning purposes, the volume of acid used should be limited to what is required to clean the two Kimmeridgian micrites, and should total no more than about 20 cu. m. It should also be limited to the lesser concentration of 7%, which is all that is required for an acid wash.

5.3 Conventional vs. unconventional resources

This section is a summary, in the context of the present application, of Appendix 2, which comprises an updated extract of my submission to the West Sussex County Council minerals local plan consultation of March 2017 on the definition of conventional and unconventional hydrocarbon resources.

The UK Planning Practice Guidance, published in October 2014, states:

> *"Conventional hydrocarbons are oil and gas where the reservoir is sandstone or limestone. Unconventional hydrocarbons refers to oil and gas which comes from sources such as shale or coal seams which act as the reservoirs."*

This attempt to define the difference between conventional and unconventional hydrocarbons conflates the mineral itself ("*hydrocarbons*") with the process ("*comes from*") and the supposed source or reservoir rock. But the difference between the two terms is fundamentally one of resource extraction method. The guidance fails to recognise this point. The two definitions quoted above are simplistic.

There are various ways of defining the difference between conventional and unconventional hydrocarbon exploitation. In summary, the most important and widely applied criterion is the permeability of the host rock. So-called 'tight' sandstones or limestones are those reservoir rocks which require stimulation treatments such as acidisation and/or fracking to artificially increase the natural permeability, Shale, along with tight reservoirs, is classed as unconventional. Thus the Kimmeridgian micrites of the Weald are also classed as unconventional, because of their low permeability (see Figure A2.2 of Appendix 2).

Another criterion is whether or not the target is a finite, well-defined volume, or is widely distributed; the former is the case with a conventional reservoir, the latter is an unconventional play. Again, the Kimmeridgian micrites fall into the unconventional category on this measure.

Lastly, another criterion is whether the hydrocarbon resource flows naturally or requires stimulation to extract it. Once again, the micrites fall into the category of unconventional, because their permeability is too low to permit the hydrocarbon to flow without treatment of the rock.

Therefore it is misleading of the Applicant to claim that its micrite target is a conventional oil play. If it were indeed conventional, then several dozen existing oil wells drilled in the Weald Basin since the 1980s would already be producing from the Kimmeridge Clay Formation micrites (see Andrews 2014), but they are not.

HYDROGEOLOGY

5.4 Hythe Formation

The Hythe Formation is a Principal Aquifer within the Lower Greensand Group. It crops out at the wellsite. It is unconfined, and underlain by the Atherfield Clay Formation.

Envireau Water (2015) prepared a hydrogeological risk assessment for the Applicant in March 2015. It stated:

> *"Several springs are indicated on the OS map to be present in the valleys to the east and west of the wellsite. Whilst there are no mapped springs in close proximity to the wellsite, it is reasonable to assume that a spring line may be present along the intersection between the permeable sandstone bedrock (Hythe Beds) and the underlying mudstone (Atherfield Clay Formation). Springs may be present in closer proximity to the site than indicated by the OSmap. The significance of springs is described in more detail in Section 5.1."* [section 3.2]
>
> ...
>
> *"The regional groundwater flow direction is expected to be northwards and locally, flow direction is expected to be variable on account of topography and surface water features. Groundwater flow directions in the Hythe Formation in the vicinity of site are likely to be westwards towards Pipp Brook.*
>
> *As described in Section 3.2, the Ordnance Survey map indicates that several springs are present in the valleys to the east and west up to 500m from the site. The springs are most likely issuing at the intersection between the Hythe Formation and the underlying Atherfield Clay Formation. Whilst there are no mapped springs in close proximity to the wellsite, it is reasonable to assume that a spring line may be present along this intersection and springs may be present in closer proximity to the site in addition to those indicated on the Ordnance Survey map.*
>
> *The springs provide baseflow to Pipp Brook, which has eroded the Hythe Formation and exposed the Atherfield Clay Formation at surface. The Hythe Formation at the site is therefore effectively disconnected from the Hythe Formation northwest of Pipp Brook. It is however hydraulically possible that some of the groundwater issuing from springs and flowing into Pipp Brook could infiltrate into the Hythe Formation northwest of Pipp Brook,where it is targeted for public water supply downstream of the wellsite.*

The absence of a direct groundwater pathway between the downstream public water supply and the wellsite is consistent with the view of Peter Brett Associates; as outlined in Sections 3.2 and 3.5 of their letter to Surrey County Council in January 2015 [Ref. 3]." [section 5.1]

The assessment goes on to describe a conceptual hydrogeological model, supported by a map and cross-section (fig. 4a) which I reproduce for reference in Figure 6.1.

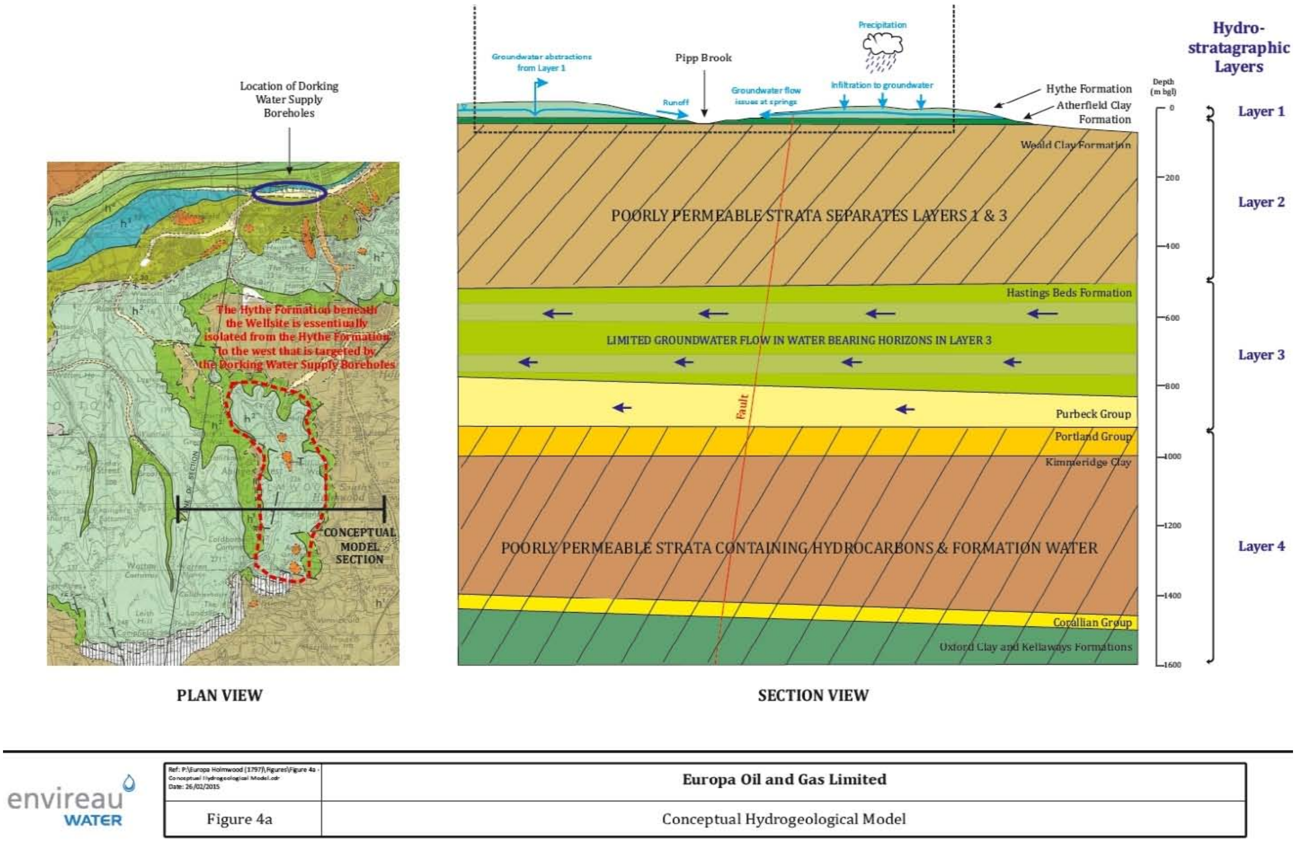

Figure 6.1. Envireau map and E-W cross-section figure 4a.The location of the Dorking public supply boreholes is shown in the elliptical area in the geology map on the left. The geological cross-section on the right is located by the horizontal bar in the map (contains British Geological Survey materials © NERC 2018).

There are several serious errors with this model. Firstly, it relies on an out-of-date version of the solid geology, the Reigate sheet no. 286, for which the geological field mapping was carried out 90 years or more ago. As a result, the E-W cross-section shown in Envireau's figure 4a is inaccurate. In addition, the claim that there is no groundwater pathway between the well site and the public water supply is incorrect.

I have mapped the base of the Hythe Formation, using the modern BGS 10K digital database together with the best available DEM. The contoured result is shown in Figure 6.2a. The control points for the contours are the elevations along the outcrop of the base of the formation, together with the constraint that to the west of Pipp Brook the contours must be below ground level. I have taken account ot the correct sense of throw of the four faults shown in the digital database.

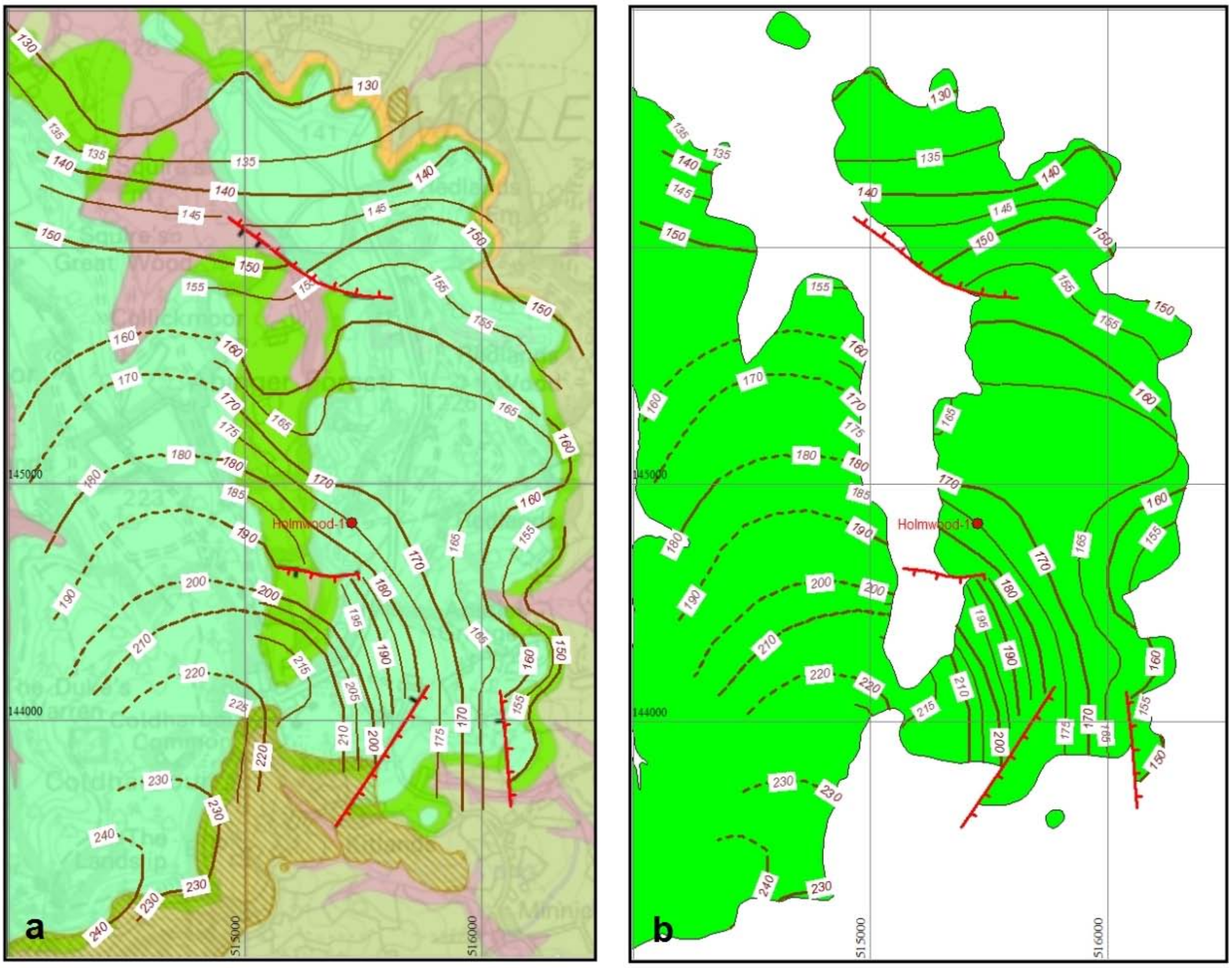

Figure 6.2. a. Contour map of the Base Hythe Formation, labelled in meters above sea level, on the BGS roaming solid and superficial geology image. The Hythe Formation is shown in bright green, the underlying Atherfield Clay in darker green.

b. Contour map of 6.2.a cropped to the Hythe Formation outcrop (contains British Geological Survey materials © NERC 2018).

It must be noted that the linear features, including faults, in the BGS digital database do not necessarily show the correct sense of throw. The BGS roaming images constructed from this database have about 50% of the faults showing a throw in the wrong sense. I communicated this problem to Professor John Ludden, Executive Director of the BGS, a couple of years ago. The faults need to be individually examined in context in order for the correct throw sense to be marked.

Three of the four faults in Figure 6.2a have the wrong sense of throw, as can be discerned from the black tick mark visible from the underlying roam image. Only the E-W fault just south of the wellsite is correct. The contours run into the air across the Pipp Brook valley; this is done for continuity; the resulting map with the above-ground contours cropped to the Hythe outcrop is shown in Figure 6.2b.

It is evident from the contours that the E-W cross-section by Envireau is seriously defective. Furthermore, the statement by Envireau that there may be unmapped springs along the western edge of the Hythe outcrop is incorrect, since the consistent easterly to north-easterly dip of the Base Hythe horizon explains why there are no springs just west of the drillsite. This is shown in Figure 6.3, where all the springs, wells and issues taken from the OS 10K map have been marked.

There is one issue in the Pipp Brook valley at Crockers Farm some 650 m SSW of the wellsite, which evidently originates at the NE-dipping base of the Hythe Formation at around 220 m elevation about 200 m to the SW. The only other issue in the Pipp Brook valley is north of the wellsite at Collickmoor Farm, and probably originates at the base of the formation some 125 m to the west.

Therefore there are no springs or issues which could be said to originate at the west side of the Hythe Formation outcrop encompassing the wellsite. In contrast there are about ten issues along the eastern flank of the Hythe outcrop to the east of the wellsite, and a further eight along the northern flank, adjacent to where the dip is northerly. In conclusion, the potential problem of contaminated run-off is not to the west, into Pipp Brook, as presumed by the Applicant, but to the east into the Mole catchment.

An accurate geological cross-section along the E-W line of Envireau (see Fig. 6.1) is shown in Figure 6.4, at a vertical exaggeration of x5 (lower section) and compared with the Envireau version compressed horizontally to about the same scale (upper section). The main error in the Envireau cross-section lies in portraying the Atherfield Clay as flat-lying in E-W profile.

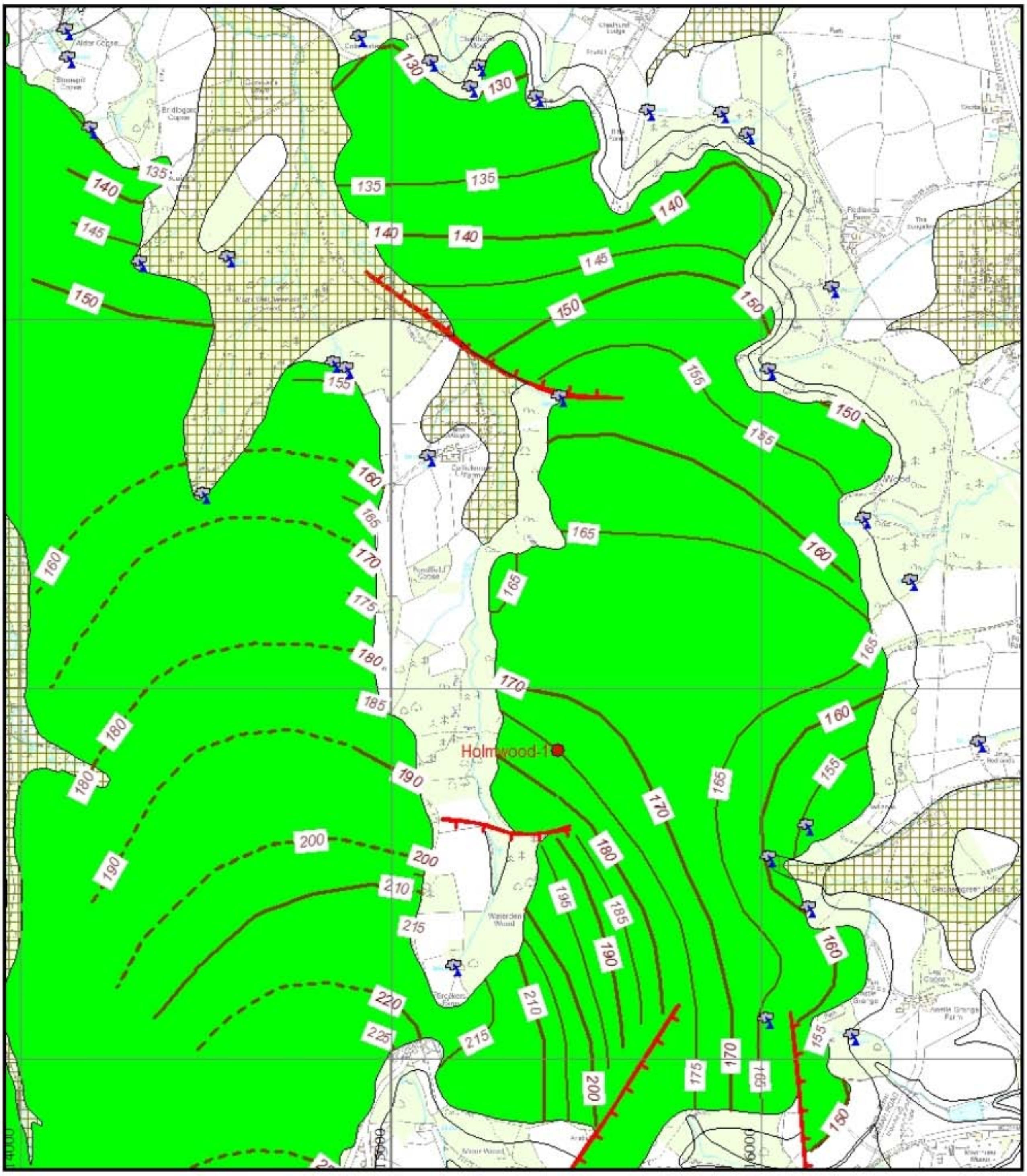

Figure 6.3. Springs and issues (spouting water symbol) around the Hythe Formation outcrop (green). Faults are shown in red; the Applicant's wellsite is shown by the red dot. Superficial deposits are shown by cross-hatching (contains British Geological Survey materials © NERC 2018).

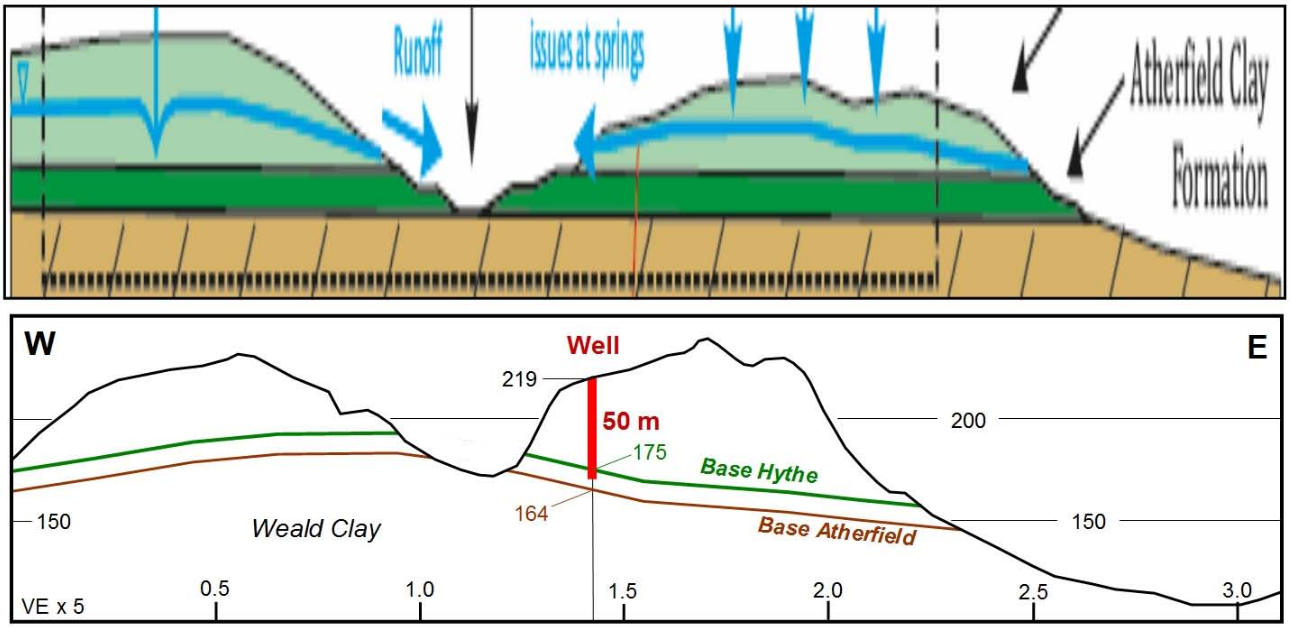

Figure 6.4. Revised and corrected E-W cross-section along the line shown in the map of Figure 6.1 (lower) compared with the Applicant's version (upper) scaled to approximately the same dimensions.

5.5 Hydraulic continuity to the public supply wells

The Applicant asserts that the Hythe Formation outcrop at the wellsite is hydraulically isolated from connection to the public supply boreholes at Dorking. This is incorrect. Figure 6.5 shows a combined solid and superficial geology map, in which only the permeable solid formations have been coloured, and superimposed on those are the superficial Head and Alluvium deposits indicates by cross-hatching. There is a continuous permeable pathway from the well, northwards and with a downdip component, to the water supply boreholes indicated by the mauve triangles at the top of the map. One such path is illustrated in cross-section along the blue line A-G, of which the part A-F is shown in Figure 6.6.

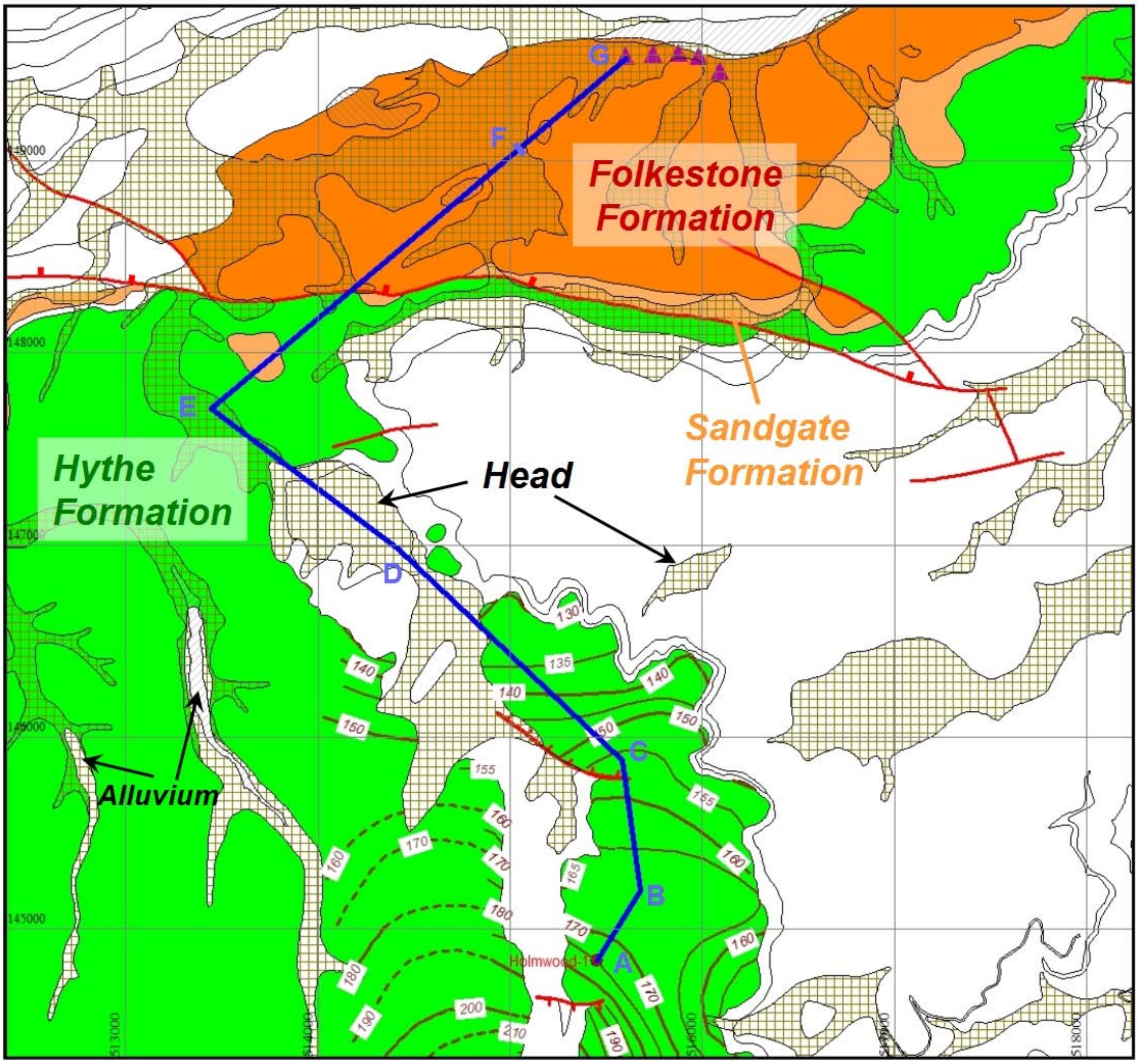

Figure 6.5. Permeable solid geology formations coloured: Hythe Formation - green; Sandgate Formation - orange; Folkestone Formation - orange-red. Other impermeable formations are left uncoloured. Cross-hatched areas over the solid geology comprise permeable Head and Alluvium. The blue path A-G from the Applicant's wellsite at A to the most westerly public water supply well at G is shown in Figure 6.6. Digital data from the BGS (contains British Geological Survey materials © NERC 2018).

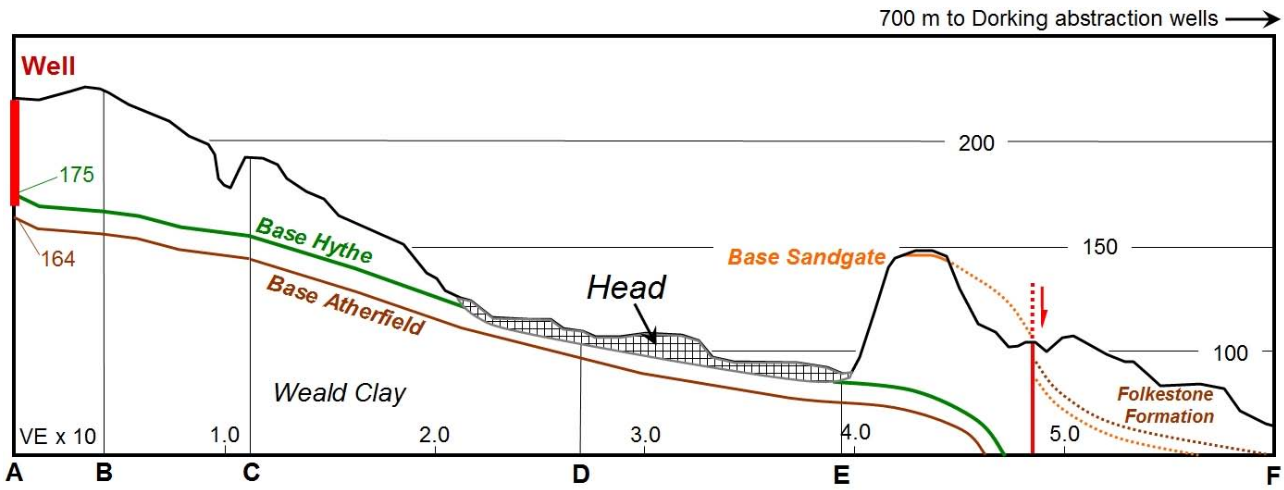

Figure 6.6. Shallow geological profile along section A-F shown in Figure 6.5. The proposed well is at A. Vertical exaggeration x10.

Figure 6.6 shows the connection northwards from the Hythe Formation into the Head, for some 2 km, and then back into the Hythe. The profile is constructed only from points A to F, but the profile continuation to point G, some 700 m further to the NE, stays within the permeable Folkestone Formation at outcrop. Note the presence of the major fault running for some 6 km in an east-west direction through Dorking. This fault was not recognised on the old BGS published 1:50,000 sheet. It cuts a northerly-verging monocline with a downthrow to the north, and in the area of interest it appears to have a vertical component of displacement of at least 20 m, as estimated from nearby outcrops of the Sandgate Formation along either side of the fault trace.

Therefore the claim by the Applicant that the Hythe Formation around the wellsite is hydraulically isolated is wrong.

5.6 Protection of the Hythe Formation at the wellsite

The Base Hythe Formation is at 175 m (Figure 6.3). The error in this figure is probably no more than ±1 m or so. The ground surface at the wellsite is at 219 m, therefore the base of the proposed 50 m of 20 inch conductor casing will be at 169 m above datum. The Hythe Formation is supposed to be protected by a 20 inch conductor casing to a depth of 50 m TVD from ground level (Europa 2018, table 5.1). However, the accurate shallow geological cross-sections of Figures 6.4 and 6.6 show that this is insufficently long (the red line in the figures). The bottom of the conductor at 169 m ASL terminates within the Atherfield Clay Formation, and does not penetrate through to the top of the Weald Clay at 164 m ASL. Does the Atherfield Clay Formation act as a robust aquitard?

Several of the mapped springs shown in Figure 6.3 around the eastern edge of the Hythe Formation outcrop appear to originate, not at the base of the Hythe, but at the base of the Atherfield Clay Formation. This formation is depicted in Figure 6.3 by the uncoloured narrow outcrop around the edge of the Hythe outcrop. That some of the spring locations are at the base of the Atherfield, and not at the base of the Hythe, has been independently pointed out in the submission by EGG Consulting Limited (EGG 2018, p. 22).

The BGS memoir for the Reigate sheet 286 (Dines and Edmunds 1933) describes the Atherfield Clay Formation thus:

> *"The beds are of marine origin, and consist of red-brown, blue or yellow clays, sometimes mottled and often sandy or silty. A sandy basement bed is known as the Perna-Bed, in which nodules of fossiliferous ironstone are frequently found, particularly near the base. Godwin-Austen noted that the Atherfied Clay of Surrey contains "subordinate nodular concretions in the lower part of the bedding of great size and thickness, and cemented into an exceedingly hard rock by calcareous matter." "*

The modern BGS lexicon describes it as:

> *"Generally massive yellowish brown to pale grey sandy mudstone throughout most of its outcrop, with an impersistent phosphatic pebble bed with vertebrate bones, gritty sandstone or very shelly sandy mudstone with glauconite, at the base."*

So the formation is not simply a pure clay as implied by its name. Therefore the Atherfield Clay Formation may not be the impermeable layer assumed by the Applicant.

In conclusion, the termination of the 20 inch conductor casing within the Atherfield Clay Formation at 169 m above datum provides inadequate protection of the Hythe Formation.

5.7 Shallow faulting

One spring seems to be controlled by a fault. This lies 1 km due north of the wellsite (Figure 6.3). This fault, trending NW-SE, appears on both the old BGS solid geology map and on the new digital database. But other BGS faults are problematic, because many have been modified or removed between the two mapping epochs. The comparison is shown in Figure 6.7. Around the foot of the Leith Hill escarpment the four or five mapped faults have each remained in approximately the same location and with the same sense of downthrow, but with a somewhat different trend. Near to the Applicant's proposed wellsite, more severe changes have been made.

The north-south fault mapped on the 1933 version, very near to the wellsite, is of particular interest and relevance. The memoir for the Reigate sheet (Dines and Edmunds 1933) discusses whether the faults around Leith Hill have resulted in landslips, or have been created by the landslips:

> *"It appears more probable that landslips here have taken place on account of the presence of disturbances in the strata, than that the disturbances are the result of landslips. Overthrust faults may be seen in a series of quarries south of Redlands Wood where beds are overthrust from the east: those below the thrust-plane dip west at an angle of 45° ".*

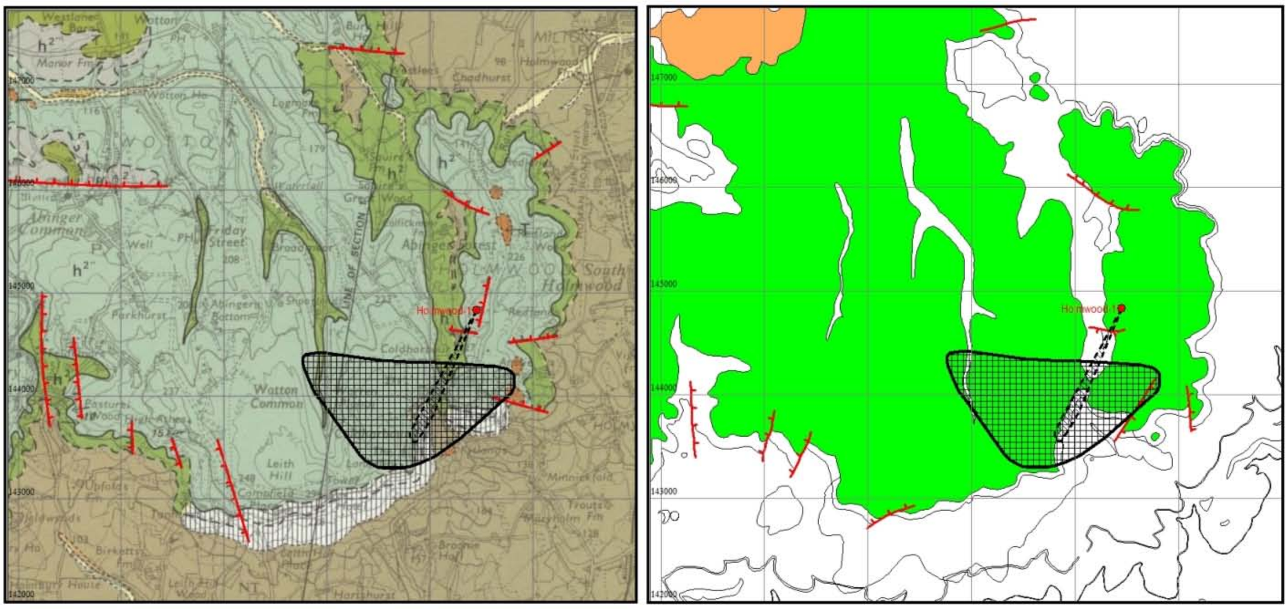

Figure 6.7. Leith Hill area BGS solid geology map (left) with faults highlighted in red, compared with the same area (right) using the BGS digital database. The Hythe Beds are shown in green. On both maps the wellsite, well trajectory and subsurface target area are shown using the symbols as on previous maps (contains British Geological Survey materials © NERC 2018).

Three such quarries have been mapped on the OS historic 1:10,560 scale map made in the period of the first revision, 1888-1914. They are less visible on later editions, and the modern 1:1000 Mastermap omits them completely, presumably because they are by now overgrown and/or filled in. The historic OS map, with the quarries highlighted in green, is shown in Figure 6.8.

The early twentieth century geological field mapping, done at a time when there were many more solid rock exposures than exist today, suggests a structural complexity which has not been resolved by modern remapping. The nearly N-S trending fault may be the thrust fault referred to in the memoir. Figure 6.8 shows that it is mapped as passing within 50 m of the wellsite.

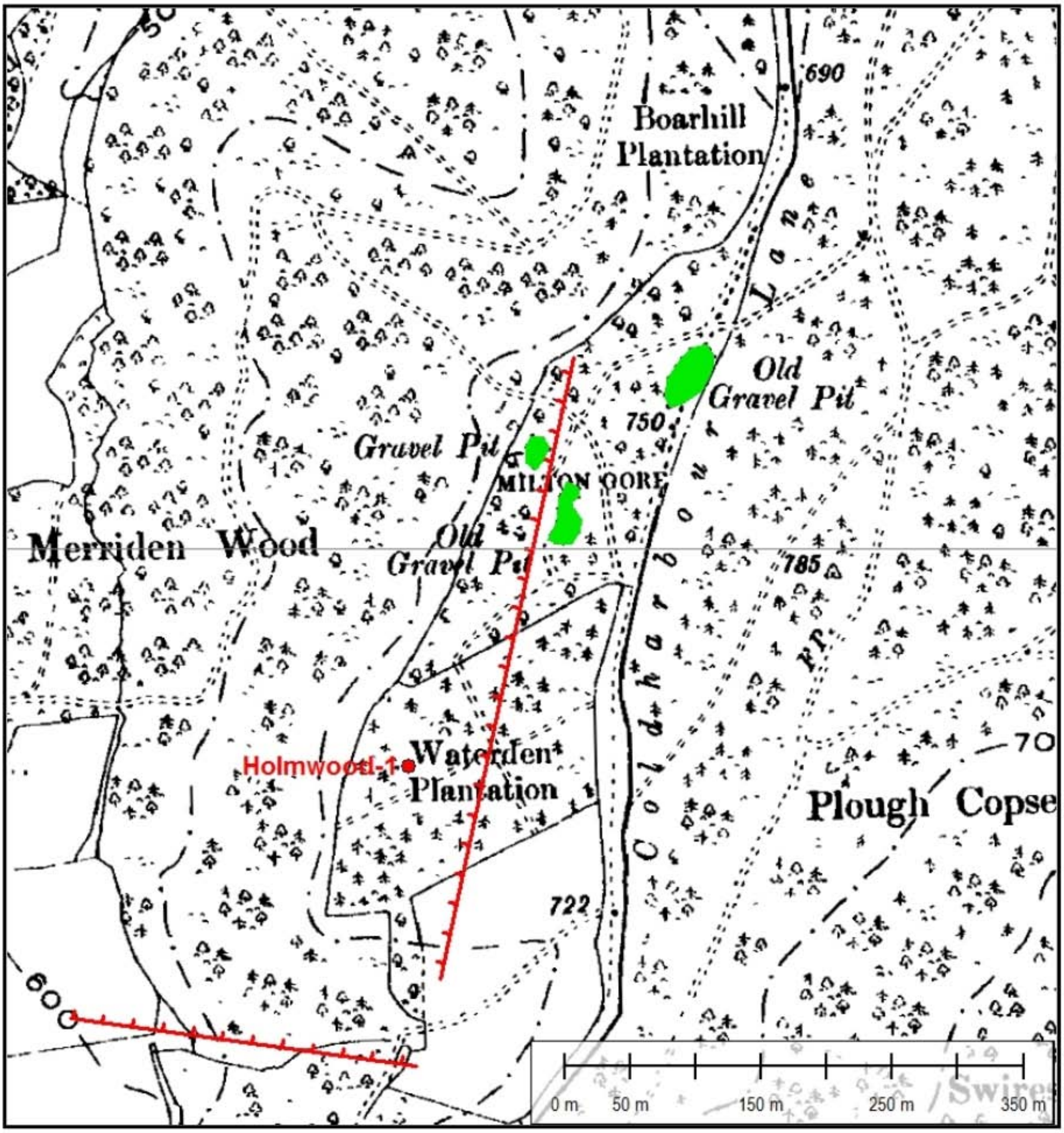

Figure 6.8. Quarries (green; labelled as gravel pits) shown on the late nineteenth century 1:10,560 scale OS map discussed in the BGS Reigate sheet memoir (Dines and Edmunds 1933) with two of their fault lines superimposed. The Applicant's wellsite is shown by the red dot (© Crown Copyright and Landmark Information Group Limited (2018). All rights reserved. (1888-1914).

In view of the evident unresolved complexity of the shallow geological structure, it is incumbent on the Applicant to resolve the uncertainties around the wellsite. This could be achieved by commissioning the BGS to re-examine the historical evidence, to re-open old quarries, and/or conduct trenching excavations across the areas of suspected faults.

6 FAULTS AND WELLBORES AS CONTAMINATION PATHWAYS

6.1 Failure of wellbore sealing

The Applicant intends to drill a very shallow-angle wellbore through a critical zone. This is likely to lead to problems in cementing the wellbore, that is, sealing the annulus between the outer drilled rock and the inner steel casing. Dusseault et al. (2014) have noted:

> *"Failure to adequately displace drilling mud during the initial construction of the wellbore may result in the development of microannuli, channels and generally poor cement quality ...*
>
> *So, mud-contaminated cement slurry may result in undesirable behavior. ...*
>
> *Eccentric casing placement, as illustrated in Figure 3.4,* [reproduced below in Figure 7.1] *is a critical factor contributing to inadequate mud removal in deviated wellbores. A difference in annular space thickness on the two sides of the casing makes displacing the drilling mud and placing the cement slurry more difficult, especially when the interior casing is in direct contact with the exterior casing or the rock wall over a considerable distance. Residual mud may be left behind in the thinner annulus (contact zone) because turbulent displacement will be inhibited and the cement slurry will preferentially flow up the wider side of the annulus ... In Figure 3.3, the effects of an eccentric casing are observed to be particularly detrimental to full mud removal in the deviated part of the borehole. Note on the thinner side of the annulus, the microannulus is much more significant than on the wider side of the annulus."*

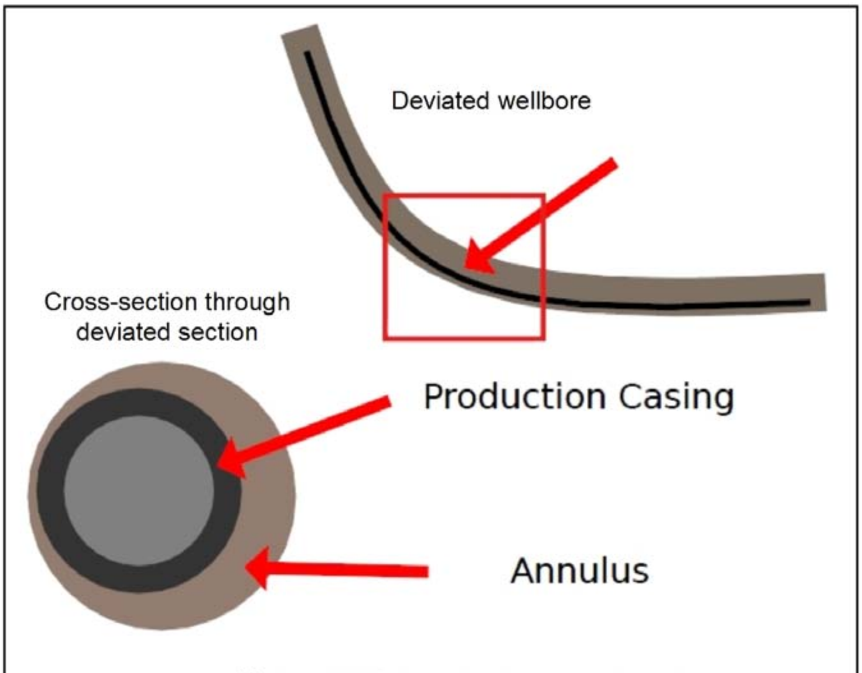

Figure 3.4. Schematic of an eccentric casing

Figure 7.1. Annotated version of Dusseault et al. (2014) fig. 3.4, showing excentric casing in a deviated wellbore. Cement is shown in brown, casing in black.

There is a large literature discussing this problem. The Applicant has not provided any evidence that it understands this problem, nor how it proposes to deal with it.

As shown above, the Applicant will further be drilling through a fault zone containing a sequence of limestones in the Purbeck and Portland Groups, interbedded with arenaceous rocks. The carbonates will be particularly at risk of wellbore washout, and in the lower part of the highly deviated wellbore (see Figure 4.3 above) this problem may be very difficult to resolve. The hole will in consequence be difficult to seal. It is likely that the same problem arose when the Applicant's partner UKOG drilled the Broadford Bridge-1 well, and was forced to sidetrack into Broadford Bridge-1z to try to cirumvent the washout.

There is a large literature on the problem of wellbore leakage, whether in the short or long term. The review by Davies et al. (2014) covers both conventional and unconventional drilling worldwide, and with emphasis on the UK. It was criticised by Thorogood and Younger (2014). This critique was rebutted in turn by Davies et al. (2015). Davies et al. (2014) studied 2152 hydrocarbon wells in the onshore UK. They estimate that between 50 and 100 of these wells are 'orphan', in that the current owners cannot be identified.

Davies et al. (2014) state:

> *"In the UK there have been a small number of reported pollution incidents associated with active wells and none with inactive abandoned wells. This could therefore indicate that pollution is not a common event, but one should bear in mind that monitoring of abandoned wells does not take place in the UK (or any other jurisdiction that we know of) and less visible pollutants such as methane leaks are unlikely to be reported. It is possible that well integrity failure may be more widespread than the presently limited data show."*

They conclude:

> *"Only 2 wells in the UK have recorded well integrity failure (Hatfield Blowout and Singleton Oil Field) but this figure is based only on data that were publicly available or accessible through UK Environment Agency and only out of the minority of UK wells which were active."*

Note that Singleton is 40 km SW of the Applicant's wellsite, in very similar geology. In summary, the review does not suggest that the long-term monitoring of hydrocarbon wells by the EA or any other government agency is robust. This failing should be of special concern in an environmentally sensitive district like Leith Hill, where the geology is a great deal more complex and subtle than the Applicant seems to appreciate.

6.2 Faults as pathways for contamination

There are several studies in which the migration of stray gas and produced water up pre-existing faults from fracked shale layers has been quantified by computer modelling. I reviewed and summarised them (Smythe 2016). It may be argued that these studies apply only to fracked shale, but the details of the results concerning the migration up pre-existing faults is applicable whatever the source of the hydrocarbons. In brief, all the studies agree that fluids migrate upwards, potentially to reach groundwater resources, but the transit timescales vary enormously, from less than 10 years to 1000 years. The differences between the modelling studies are due to different parameters used in constructing the model, and the geology in particular.

Empirical evidence for faults acting as pathways for fluid migration includes the recently developed direct imaging of the migration of gas from hydrocarbon reservoirs seen on high-quality 3D seismic surveys (Aminzadeh et al. 2013), and the long-standing evidence of oil seeps in the UK, including the Weald (Selley 1992).

It is therefore crucial that the Applicant has a robust knowledge of faulting in and around its prospects, in order that the risks of such contaminant migration be well understood. But it is clear from the evidence made public that the Applicant does not possess this knowledge, and, in my view, will not be able to acquire it without first obtaining more seismic data.

7 CONCLUSIONS

The Applicant claims that its permit is for a purely conventional exploration drilling programme, when in fact its new proposals include unconventional testing by matrix acidisation. The Kimmeridge Clay Formation, with its tight thin semi-limestone 'micrite' bands, is an unconventional target.

Whether in pursuit of conventional or unconventional targets, the Applicant should be required to acquire additional 2D seismic data, or preferably 3D seismic, and interpret them before pursuing its objectives at the Holmwood-1 site. The application for a permit has the following serious weaknesses and problems which need to be addressed:

- Use of out-of-date geological mapping information.
- Problems of shallow faulting from old and new BGS information not considered or reconciled.
- Poor understanding of shallow geological structure of the Hythe Formation principal aquifer below the wellsite, leading to misleading conclusions on groundwater flow directions.
- Proven hydraulic continuity *via* Lower Greensand formations and unconsolidated deposits from the wellsite to public supply wells at Dorking.
- Shallow geological structure includes poorly-understood faulting, with a thrust fault near the wellsite.
- Conductor casing too short and does not penetrate into the Weald Clay.
- Hastings Beds cut by a fault in vicinity of the wellbore.
- Insufficient seismic reflection information properly to define the faulting and target structures.
- Lack of evidence presented to justify geological structures.
- Lack of justification for seismic ties to existing wells.
- No evidence presented for time to depth conversion of the seismic data.

- Two promised seismic reflection lines never obtained.
- Equidimensional and complex faulted nature of the target structures necessitates a 3D seismic survey for accurate characterisation.
- Redesigned wellbore at the very limit of technical capacity, with no leeway for manoeuvre.
- Likelihood of cement bond failure along wellbore at shallow angle.
- Unconventional (tight, low permeability) target micrites added to the work programme at a late stage despite claim that prospects are conventional.
- Confusion between acid wash to clear borehole and stimulation of unconventional formations to enhance flow.

The information supplied by the Applicant is incomplete and misleading. The problems summarised above lead to the inescapable conclusion that the Applicant has a poor understanding of the geology, and of the technical problems that it is likely to encounter in drilling. In turn, its understanding of the hydrogeology is seriously defective. In consequence there is a serious risk that the drinking water aquifers in the district may be contaminated by the Applicant's proposed activities, both in the short term and in the long term.

In conclusion:

The Environment Agency should refuse the environmental permit.

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APPENDIX 1

CONSULTATION RESPONSE FROM MS. ADRIANA ZALUCKA

Consultation Response: RH5 6HN, Europa Oil and Gas Limited, EPR/YP3735YK/A001: Environmental permit draft decision advertisement

Dear EA permitting team,

My comments relate to the decision document, section on "Groundwater protection – Acid wash and squeeze" I have included relevant parts of it below and bolded the main points.

*"The initial proposal suggested that the acid wash would be to clear any formation damage caused during the drilling and that the **acid squeeze would travel further back in to the target formation (possibly up to 14 metres)** and may result in "stimulation" of flow. While the Environment Agency were satisfied that the acid wash would result in no impact on the groundwater environment in the target formations we raised further questions around the risk to the groundwater environment from the proposed acid squeeze. We asked the applicant to clarify the details of the proposed "acid squeeze" at this specific site. The applicant has explained that their only intention is to clear any damage in the target formations caused by drilling, that the pressures to be exerted will not be at a level to cause fracturing of the rocks, that their intention is to clear the drilling damage near the well bore **(approximately 1 metre**) and that all of the dilute acid solution will return to the surface once it has reacted, leaving no discernible trace of product in the groundwater. **They have reviewed their submission, decreased the expected distances that the acid may travel in to the formation (which relates the amount of pressure they can apply when the acid is applied)** and revised their Waste Management Plan accordingly."*

"The waste management plan (WMP) describes two procedures to clean out the wellbore contents, perforation and borehole facing which have been potentially blocked as a result of the initial drilling operations. These are listed as acid wash and acid squeeze. "

"An acid wash is defined as the application of acid under low pressure and will be used primarily to clean the near wellbore environment to remove damage from drilling activities. This activity will precede any further acid squeeze.

*Acid squeeze is defined as the application of acid under pressure that does not exceed the fracture pressure of the formation. The pressure that the acid can be applied at, so that it does not exceed the fracture pressure of the formation will be established by pressure testing during drilling operations. The acid squeeze is designed to clean the natural pores and fractures of the near wellbore environment **(i.e. 1m radius from the well)** which may have been damaged by drilling operations. Depending on the extent of existing fractures within each formation acid may pass beyond 1m radius of the borehole, but will be recovered as production water when pumped back to the surface.*

*It is anticipated that a total of **95m^3 of HCl** will be pumped into the formation over a maximum of three acid wash and squeeze operations in the following targeted formations; the Portland Sandstone, Kimmeridge Micrites and the Corallian Sandstone and possibly the limestone in the Great Oolite Group. "*

1. It is interesting that Europa Oil are have managed to reduce the projected distances the acid will penetrate into the formation during acid squeeze from 14 meters to 1 meter while using much more acid than stated in their original application. The original Waste

Management Plan, Revision No. R1, DOCUMENT NO: EOG-EPRA-HW-WMP-005, page 16 says that:

"The proposed dilution of hydrochloric acid is 15%, which is circulated across the perforations using 1m3 of HCl solution. The process of washing the perforations is repeated a further four times. Following the washing of the perforations, HCl is then selectively squeezed into the formation at 1m3 of HCl per metre of perforation.

It is anticipated that between 6m3 to 11m3 of HCl will be pumped into the formation during the operation, with all spent acid being recovered to surface."

Not focusing on the fact that this statement is inconsistent, in one instance referring to HCl solution (assuming this means only 15% of the solution is HCl) and in another to HCl itself (meaning presumably that 1m3 of HCl would be mixed with c. 5.67m3 of water to produce a 15% solution), the volumes presented in the original WMP are vastly smaller than in the revised plan, which refers to a "total of 95m3 of HCl will be pumped into the formation over a maximum of three acid wash and squeeze operations" in four different geological formations.

The original statement gives the volume of 1m3 of acid per metre of formation, but the updated WMP does not, only referring to one aggregate number. Without knowing the length and number of perforations envisaged in the two versions of WMP it is difficult to compare the two, but on the face of it, it seems rather impossible that the distance the acid will travel from the wellbore into the formation will be reduced by using more acid and not less.

2. Secondly, the decision document refers to 1 metre radius for the penetration of the acid during acid squeeze, but this is inconsistent with what is written in the revised WMP. It says that "based on the information available, maximum formation invasion depths of circa 2-3m may be possible for spent acid" in the Portland Sandstone, 4-8m in the Kimmeridge micrites, 2.5- 4m in the Corralian Sandstone and up to 4m in the Great Oolite. Should these inconsistencies not be clarified to make sure the information in the decision document is correct?

3. Thirdly, the decision document refers to both acid wash and acid squeeze treatments, following what is written in the WMP. However, according to the EA's understanding of acid squeeze in this document as intended to remove formation damage only approximately 1 metre from the wellbore, there should be no difference between this procedure and acid wash, which the EA confirmed to us in a phone conversation on 1st November 2017 is also intended to penetrate the formation only up to 1 metre from the wellbore. As per the detailed "Discussion of Calculated Acid Volume Threshold" document, which I attach along with this submission, the distance from wellbore relates to pressure of fluid, which in turn relates to volume so all would have to be similar to achieve the same penetration distance.

Including acid squeeze as a permitted activity introduces a grey area that potentially makes it open to abuse by the operator. Indeed, the description of acid squeeze that Europa included in their revised WMP, refers to acid being pumped at a pressure that **does not exceed the fracture pressure of the formation**, which is at odds with the EA's FAQ document on acidisation published in January 2018 that says acid wash is done at pressure that **slightly exceeds the formation pressure** while matrix acidisation is performed at pressure that is **above formation pressure but below formation fracturing pressure.**

Europa's description of acid squeeze seems more consistent with the EA's description of matrix acidisation (i.e. a stimulation method) and not that of acid wash.

Therefore, would the EA not agree that it is a logical conclusion that acid wash should be called just that and if this procedure only is intended at Leith Hill site, then this procedure only should be listed as permitted in this EA permit?

4. There are doubts about how the EA will actually enforce the different methods using acid in practice. The decision document explains that the fracture pressure of the formation (and presumably the formation pressure?) will be established by pressure testing during drilling operations, and that acid injection operations will be monitored via reports shared by the operator with the EA and/or the HSE after they have performed an operation. It is unclear however what the mechanism here is, for example what information these reports contain, whether they are mandatory and how frequently they are shared with the EA and/or HSE. It is not clear either what happens if reports are not shared or if the prescribed pressure limits are exceeded.

Kind regards

Adriana Zalucka

[end of Appendix 1]

APPENDIX 2

THE DEFINITION OF CONVENTIONAL AND UNCONVENTIONAL HYDROCARBON RESOURCES

A2.1 National planning practice guidance

The Minerals section of Planning Practice Guidance, published on 17 October 2014, states:

> *"Conventional hydrocarbons are oil and gas where the reservoir is sandstone or limestone. Unconventional hydrocarbons refers to oil and gas which comes from sources such as shale or coal seams which act as the reservoirs."*

This attempt to define the difference between conventional and unconventional hydrocarbons conflates the mineral itself ("*hydrocarbons*") with the process ("*comes from*") and the supposed source or reservoir rock. But the difference between the two terms is fundamentally one of resource extraction method. The guidance fails to recognise this point.

The definition is unsound for the following reasons:

1. It uses overly-simplistic rock types to differentiate between the two resources - "*sandstone*", "*limestone*", "*shale*", "*coal seams*" - without defining them properly. Such nomenclature is too black and white; in practice, there are gradations between end-member rock types; for example, geologists can describe a muddy sandstone, a sandy limestone, or a sand-prone shale. The end-members themselves, for example, 100% pure limestone, are rather rare in nature.

2. There is no mention of the geological context within which any of these rock types occur, for example, basin position, trap geometry, layer thickness, etc., nor the source where the hydrocarbons have been generated. Figure A2.1, from the US Energy Information Administration, illustrates the various geological settings in which natural gas resources occur. The diagram is similar for oil.

3. There is no mention of the physical properties of the rock types, such as permeability and porosity.

4. It omits mention of the physical and chemical properties of the "hydrocarbons" themselves, e.g. viscosity, API gravity (oil), or alkane (gas).

5. It omits to mention the processes by which the hydrocarbon is extracted, in particular the difference between hydrocarbons which are extracted from the rock with little or no treatment, versus those requiring extensive treatment to make them flow - e.g. steam heating, acidising, or hydraulic fracturing, or whatever forms of reservoir stimulation.

6. There is no mention of the economic aspects of the production process.

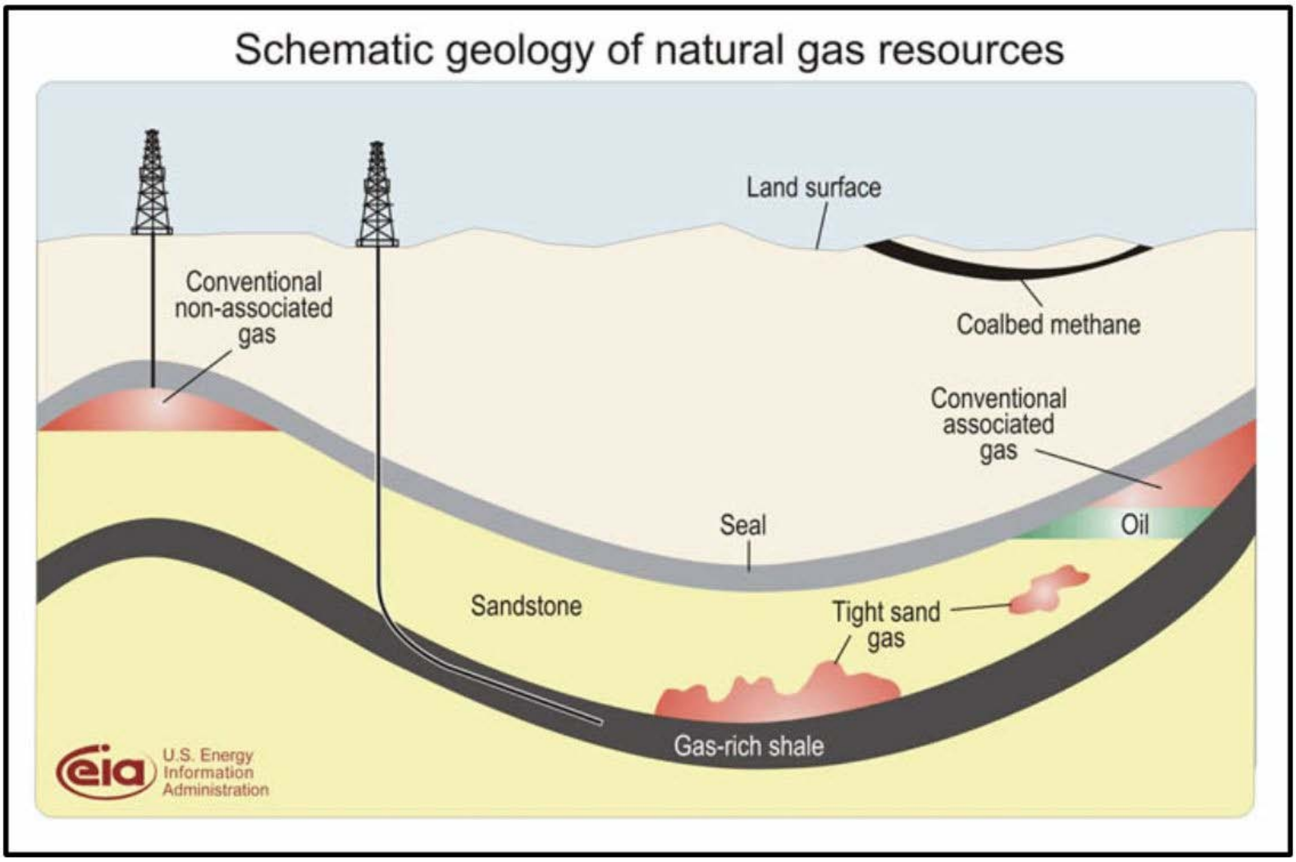

Figure A2.1. Schematic geology of gas resources, from US Energy Information Administration.

A2.2 Other definitions

There is no universally agreed definition of the difference between conventional and unconventional hydrocarbon mineral extraction; various versions in the scientific and technical literature emphasize different aspects mentioned in points 1-6 above. However, all reasonable definitions that I am aware of include, eitherimplicitly or explicitly, the permeability of the host rock.

The figure of 0.1 mD (milliDarcies) for the host rock is generally agreed to differentiate between the two extraction procedures, although the Society for Petroleum and Coal Science and Technology of Germany defines a higher value of 0.6 mD. Given the vast range of possible permeabilities and the limited precision in estimating permeability, the scale is usually presented in logarithmic form, so that units (decades) on the scale are 0.001, 0.01, 0.1, 1, 10 ... mD and so on. Figure A2.2 illustrates the permeability spectrum. Below 0.1 mD the process required to extract the hydrocarbons is unconventional, whereas above that value it is considered to be conventional. Note that the measured range of Kimmeridge Clay micrites unambiguously falls into the unconventional area of the spectrum. A version of this diagram has been adopted by the Oil and Gas Authority (OGA) and published on its website in June 2017.

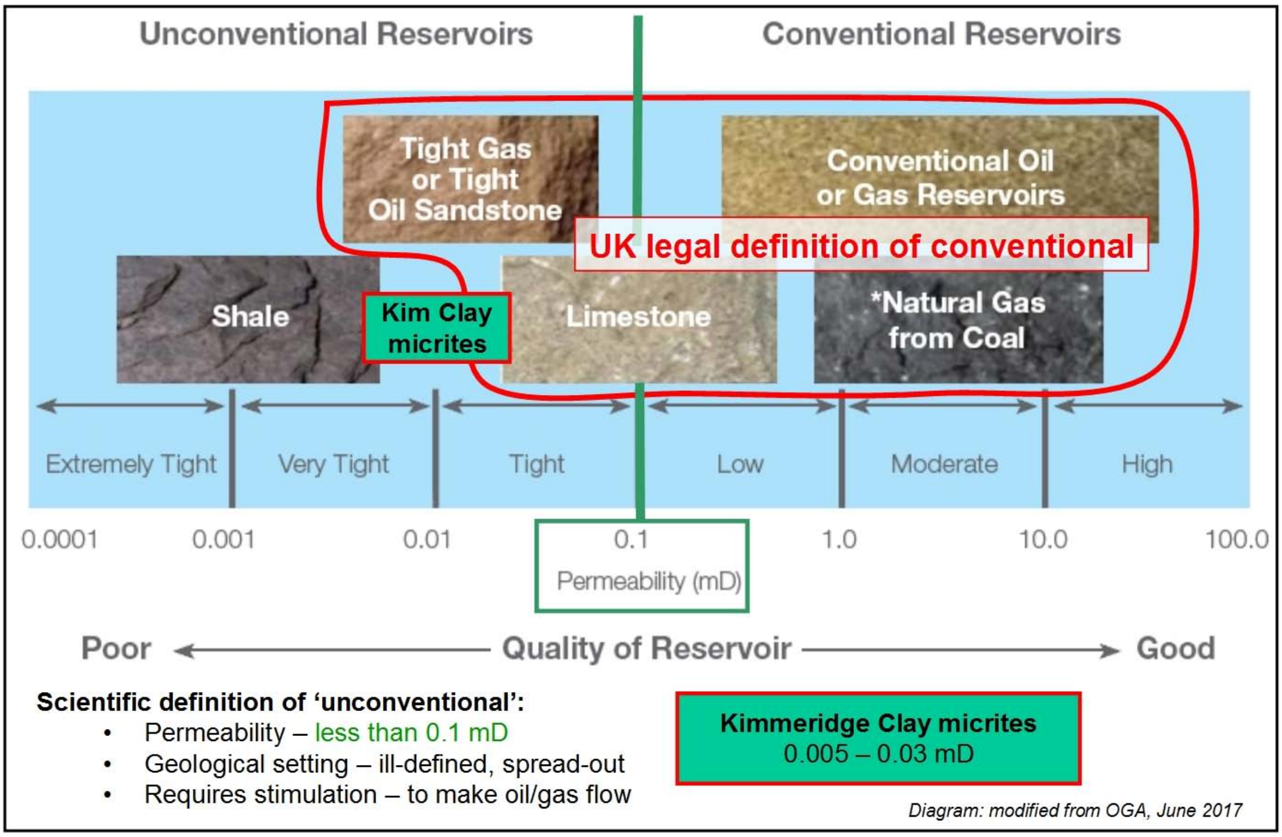

Figure A2.2. Spectrum of permeabilities used to differentiate between unconventional and conventional reservoirs (Canadian Society for Unconventional Resources). The UK legal definition is outlined in red. The Kimmeridge Clay micrite range of permeabilities has been added (green box).

Next in importance to a quantitative definition using permeability comes the geological setting in which the hydrocarbon-bearing rock occurs. Thus conventional resources are found in finite and well-defined traps, whereas unconventional gas or oil is distributed throughout a widespread layer with no clear-cut boundaries.

Along with the two criteria above, the process of extracting the hydrocarbons is important. It is variously described as fracking, acidising, massive stimulation, additional extraction or conversion technology, or assertive recovery solution. Although different in detail, what they all have in common is the aim of making the hydrocarbon flow when it would otherwise not do so.

A2.3 Discussion and conclusion

No definitions of which I am aware (see list below) regard so-called "*sandstone*" or "*limestone*" reservoirs as automatically conventional, as has been simplistically defined by the national Planning Practice Guidance. On the contrary, many sandstone and limestone reservoirs are called 'tight', meaning that unconventional extraction methods are required.

Given the unscientific and imprecise nature of the Planning Practice Guidance definition, the EA should ignore it as being unsound, and adopt instead the permeability-based definition endorsed by the OGA.

[end of Appendix 2]