Planning application no. WSCC/083/13/KD

by Celtique Energie to drill at

Boxal Bridge, Wisborough Green, West Sussex:

Critique of environmental statement 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

June 2014

Version 1.3

NON-TECHNICAL EXECUTIVE SUMMARY

I have been asked by Kirdford Parish Council to supply it with information. This paper is both an appendix to its submission, but is also being submitted in its own right as an **OBJECTION** to the development. Its submission supersedes and replaces the paper I submitted to West Sussex County Council (WSCC) on 22 October 2013. In particular, this new version incorporates comments on firstly, the additional material by Celtique Energie in support of the application (requested by WSCC in December 2013 and eventually supplied on 15 May 2014), and secondly, the BGS study for DECC of the Jurassic shales of the Weald by the BGS, released on 23 May 2014.

The present application to drill a test vertical well, followed by a contingent horizontally deviated well along an unspecified geological formation, is the first stage of a progression towards hydraulic fracturing ('fracking') of the Kimmeridge Clay and/or Liassic shales below the area. There is no other possible outcome to this initial exploration phase, apart from withdrawal from the site after this stage. *Therefore the application should be considered in the context of the intention to frack.*

A written record of discussions between the Applicant and DECC (see Appendix) confirms that the current exploration is in pursuit of unconventional resources. By 'unconventional' we mean a geological formation which will require horizontally directed wells which will have to be fracked to release the oil (or gas). But Celtique Energie misleadingly claims that the well is 'conventional', even though the target oil is held in an 'unconventional' rock formation. There is no finite prospect of the exploration resulting in conventional (orthodox) oil production, that is, fluid which would flow of its own accord.

If it were indeed the case that the proposed oil resource is conventional in nature, then it is probable that it would have been successfully exploited twenty to thirty years ago, during the previous main phase of exploration activity. The fact that the central Weald area has lain dormant since that time implies that it was not amenable to the exploration and development methods of that era; in other words, the oil is an **unconventional resource**, as the BGS study clearly states.

No satisfactory explanation has been supplied as to why the site was chosen. The explanation of how the primary and secondary search areas were defined remains

misleading and vague even after additional information was supplied. The choice of search areas conflicts with the data from the recent BGS Weald report. The seismic data line furnished as an example does not relate directly to the present application, but lies some 10 km to the west of the site. There are not enough seismic data near the site for safely drilling the horizontal well. This well will in effect be drilled 'blind'.

The geological cross-section through the proposed well is in error by between 80 and 100 m in the vertical direction. The Applicant's predicted depth to the shallowest horizon of interest, the base of the Weald Clay, is between 80 and 100 m too deep, when compared with the BGS data that Celtique has used. There is also an internal discrepancy of around 15 m within the ES information. There still confusion within the documentation as to whether the horizontal well will be drilled along the upper or the lower of the two limestones within the Kimmeridge Clay. Such errors are unacceptable.

There were other material and severe errors and omissions in the planning application documentation dated December 2013, including depth errors of hundreds of metres. Many, but not all, of these errors have been corrected in the additional information. This is evidence of a careless approach to the planning application on the part of the Applicant.

In sum, the errors and omissions remaining, even following the supply of further information, suggest that the Applicant is treating the planning system with contempt. It would be reasonable and rational to refuse the application on the ground that the proposed work has not been adequately described and that the additional information requested is inadequate for the purpose of determining the application. **To allow the application in spite of these material errors may expose such a decision to judicial review.**

Geological faults are complex and unpredictable structures. In the absence of strong evidence to the contrary, faults at depth are assumed to be leaky. Some of the oil and gas seeps at the surface of the Earth in East Sussex are directly linked to leaky faults. In the Weald basin it is therefore likely that some faults will leak fracking fluids and/or methane both to groundwater resources and to the biosphere. Gas seepages up faults and up through permeable cover rocks above a source can now even be imaged directly using modern geophysical techniques.

The crucial question of faulting was ignored by advisory committees in the UK, including the Royal Society. In addition, the reports from such committees have accepted uncritically the results of a US industry-funded study, based on confidential data, purporting to show that fracking is safe. I have shown by an extensive review of the four principal shale gas basins in the USA used by the American study that, in effect, there are no faults in these US basins that connect the fracked shale to the surface. But in the Weald, a myriad of near-vertical faults cut through from the surface to depths much greater than the shale deposits. **The density of faulting in the Weald is 400 times greater**, as measured by length of surface fault trace per unit area, than the average for the US shale gas and shale oil basins. No faulted basin like the Weald has ever been fracked; therefore the Weald would be a guinea-pig for testing the safety or otherwise of such operations.

Although the groundwater resources below the licence area are minor, they are not negligible. Even where faults are locally absent at the surface there is the possibility of upward leakage from depth, because the cover rocks above the shale layers do not form a good seal, or 'cap'. This is proven by the abundant natural upward escapes of deep water onto the surface in the area around the proposed well. Recommended baseline studies of groundwater, natural gas emissions and seismicity should be undertaken before any drilling.

In addition to the finite risk of severe environmental pollution as a result of fracking, there is the risk of earthquake damage; from the fracking process, from subsequent production of oil or gas, and from injection of waste fracking fluid back underground. All three cases have been demonstrated in the USA, and the first of these also in Lancashire.

A large German study of the environmental risks of fracking advises that the method be banned from any area which is faulted. This supports my view that any application which is aimed at fracking should not be permitted in geological structures such as the Weald Basin.

I have estimated the cost in terms of damage to the road infrastructure if full-scale fracking for oil production is ever developed in the UK. The financial inducements currently on offer do not even cover the costs of the road repairs required as a result of the increased HGV traffic. For every barrel of oil produced by unconventional methods three barrels of produced (contaminated) water have to be taken away. I have modelled the road transport load over the expected 20 year life of such a project. At one bottleneck in the model, where the oil and water trucks must converge and pass along a short stretch of B-road before

reaching the trunk road network, there will be one 30-tonne 3-axle truck passing in each direction every 3 minutes, 12 hours a day, 7 days a week, for 20 years. In summary, the strain on the countryside infrastructure of B- and C-class roads is intolerable.

The value of the housing stock in a typical DECC licence in the south of England is of the order of £20 billion. So a reduction in total overall value of this property of 10%, for example, due to the loss of amenity, would be a cost to the community of £200 million. The proposed community benefits offered by the oil industry will barely cover the extra cost of increased household insurance premiums.

It may be argued that the planning committee must base its decision purely on the documents presented, and that since fracking is excluded from the present application, the certitude or likelihood of future fracking cannot be used as an argument to dismiss the current application. But what if, for example, a planning application came forward to excavate the foundations of a skyscraper in an area where the applicable planning policy includes height restrictions on construction? The proposal itself would not exceed the height restriction, but its sole aim is to prepare for the skyscraper. There is no conceivable social or economic benefit to the community of having some boreholes drilled and trenches cut. Would such a preliminary planning development be permitted? Since the ultimate aim – the skyscraper – is *a priori* not permitted, and there are no intrinsic benefits to the community in the excavation itself, the planning committee would be justified in refusing the preliminary application.

So it is with the present application, which should be refused firstly, on the narrow ground of being incomplete and erroneous, but also, secondly, on the broader ground that it is preparation for an intensive industrial process which will wreck the intrinsic natural beauty of the region.

TABLE OF CONTENTS

FIGURES

following text:

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 headed 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. I served on the BNFL Geological Review Panel from 1990 to 1991. I was invited to join the panel by one of its members, Professor John Lloyd, a hydrogeologist from the University of Birmingham. I served on this panel to support BNFL's case for a Sellafield site for a Potential Repository Zone (PRZ), at the time when Nirex was investigating both Dounreay and Sellafield. I resigned from the panel after the case for Sellafield had been successfully made.

I was closely involved with Nirex at this epoch, and conducted for Nirex an experimental 3D seismic reflection survey, which 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, 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 on a Linux workstation (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 and non-liability

I have no interests to declare. This document was requested by Kirdford Parish Council, 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 its contents. It is supplied in good faith, but I can accept no liability resulting from any errors or omissions.

2 THE WISBOROUGH GREEN SITE

2.1 The geology database

I have access to the online BGS digital map database. This is available in two flavours:

- 'Digimap' - a coloured image of the 1:50K solid and/or superficial geology
- Digital outlines and areas for incorporation into graphic mapping packages.

The fault-lines in the latter database do not indicate a sense of throw. The Digimap faults have tick-marks to indicate the downthrow side, but approximately 50% of these are wrong. This serious error is due to the erroneous assumption that the progression of vertices marking the fault, from beginning to end, have always been digitised such that the downthrow side is on the right. This problem is national, not just local to the present review. Therefore all faults shown on the Digimap images have either been checked against the paper copy of the solid geology map, or else have been corrected by inspection.

All the released 2D seismic data are available in preview form online via the UK Onshore Geophysical Library. This data library excludes seismic data recently acquired by the Applicant, Celtique Energie Weald Ltd, hereinafter referred to as 'Celtique' or 'the Applicant'. However, there are no such data in the area of the proposed well.

2.2 Relevant aspects of the geology

The geology of the site and its environs out to a radius of 10 km comprises flat-lying layers of sediments of Jurassic to Tertiary age, cut by minor faults. The density of faults varies throughout the PEDL234 licence area (Fig. 2.1), but the proposed site is surrounded by faults. Figure 2.2 shows the faults in red from the digital database. The Lower Cretaceous Weald Clay is at outcrop over the whole area. It comprises clay up to 457 m thick in the area of the BGS Haslemere 1:50,000 Sheet 301 (Solid and Drift Geology), with subsidiary sandstones and limestones.

Celtique has mismapped the depth of geology of the Weald Clay and layers immediately below.

Figure 2.3 shows an extract from the ES, fig. 11.4, to which I have made additions and corrections. The lower part of the figure purports to be a cross-section drawn along the line marked SW-NE shown in the map above. The location of the profile runs approximately through the proposed well. The map is taken from an inset map to the BGS Haslemere Sheet 301. The inset shows contours on three shallow horizons; the red horizons in the east, where the well and profile are situated, are depths above sea level of the base of the Weald Clay. I have marked the contours with bigger figures in crimson. These depths are in metres; the negative sign is because the scale is in meters *above* sea level, so that greater depths below sea level are increasingly negative. This is the normal convention. Celtique's cross-section shows the base of the Weald Clay (the ochre colour) at about -120 m in the NE, deepening to -330 m in the SW. But the correct depth to this horizon, as interpreted from the very contours that Celtique has used, is about 80 m higher than shown by Celtique. It is shown by the white dotted line.

Not only are the depths to the base of the Weald Clay in error, they are inconsistent with the expected depths to be drilled (ES table 11.1). The cross-section shows the depth at the borehole to be about -260 m above Ordnance Datum (i.e. sea level). To get the driller's depth of the table we need to add to this figure the height of the land above sea level (21 m) and the height of the drilling platform above the ground (about 7 m). So the cross-section implies a driller's depth of about 290 m, whereas the table gives 304 m – a small but significant error. Using the BGS contour map discussed in the previous paragraph (Fig. 2.3) the true driller's depth is about 203 m (= 275 + 21 + 7 m). This is a serious discrepancy.

Figure 2.4 shows a detail from a regional study of the hydrocarbon potential of the Weald Basin by Butler and Pullan (1990). Although this paper is based on work of 25 years ago it remains the latest published synthesis of information on the region. It is not too out-dated, because thereafter the area went through a fallow period for more than twenty years during which there was little or no exploration activity. One of the authors, Dr. Chris Pullan, is currently the Exploration Manager of Celtique Energie.

Figure 2.4 shows that there is a strong set of E-W trending normal faults at depth traversing the Weald, even though few of them have a surface expression. Both of the proposed Celtique wells lie in the area where the Jurassic basin is deepest. The green line in Figure 3 shows the location of a north-south geological cross-section drawn by Butler and Pullan. It passes 1400 m

to the west of the proposed wellsite. The central part of this section is depicted in Figure 2.5, with the Wisborough Green-1 and Fernhurst-1 wells projected onto the section.

Celtique's recent geological studies in the SE corner of PEDL 234 have identified a conventional oil prospect named Willow. The Top Triassic map of this area is equivalent to the Base Jurassic map of Figure 2.4. In this area more E-W trending faults than previously recognised have now been mapped. Celtique's structural cross-section for the Willow prospect is shown in Figure 2.6. It shows faults extending from Palaeozoic (Carboniferous) up to the Ashdown Beds of the Lower Cretaceous, about 300 m below the surface. This illustrates that the western Weald is, in general, cut by many such faults which do not break the surface and cannot therefore be mapped by surface geology. Therefore the BGS maps underestimate the prevalence of faulting, and it is essential that detailed seismic profiles are available for any locality where drilling is proposed. This is not the case in the current application (see Fig. 2.2).

2.3 What are Celtique's targets?

Figure 2.7 shows the Wisborough Green-1 proposed horizontal well plan according to Celtique (ES fig. 11.1), shown as the solid blue line. Surface faults as mapped by the BGS are shown by red lines with tick marks on the downthrown side. The subsurface positions of these faults will be slightly different. According to the ES map the horizontal will extend 825 m SW of the wellsite, as shown here. In the original ES text it was described as 5000', or 1524 m, in length, as shown by the range ring drawn around the vertical wellsite (black circle). There was also confusion in the Celtique ES about the intended direction of the horizontal well (whether towards the NE, NW or SW). Note that if drilled in any direction except NE it will penetrate and cut through one or more faults. The revised version of the ES (chapter 11A) states in the text that it will be directed to the SW for 762 m. The direction now matches the map, but the distance still mismatches the map, being 62 m shorter than shown on the map. This difference may be unimportant, geologically, but could be crucial if there is a question of passing under land owned by possible objectors to the proposal.

The horizontal well was described in the original ES documentation as starting the deviation from the vertical at 515 m depth. It is now stated as starting at 884 m depth, some 369 m deeper. Given this change, and given the 80-100 m error in vertical depth to shallow layers,

discussed in section 2.2 above, it appears that the Applicant's measurements of what it intends to do is somewhat shambolic.

Celtique is inconsistent about which limestone is to be the target of the contingent horizontal well. The revised ES (ch. 11, p. 5) states:

> *"11.19 However as explained in Chapter 4A (Project Description) there is a contingency proposal to drill a horizontal well at the same location, in which case, a horizontal hole will be formed, starting at approximately 884 m depth and will progress in a south westerly direction (225°) for a distance of 2500 ft. (762 m). This lateral horizontal hole will mostly be formed in the Upper Kimmeridge Limestone (reference Table 11.1). At its point of termination (Figure 11.1A) the horizontal well will be approximately 1310 m below ground level. The horizontal well configuration is shown in Figure 11.2A in a geological context."*

The revised project description (chapter 4A, para. 4.43a) also states that the Upper Kimmeridgian Limestone will be the target of the horizontal drilling. But the diagram referred to, fig. 11.2, shows that the Lower Kimmeridge Limestone is the target of the horizontal drilling. This diagram also shows the deviation starting at the top of the Ashdown Beds and not at the revised deviation start depth of 3000' or 884 m. So we do not know which limestone is the target, because the ES documentation is internally inconsistent.

Regionally, the well area lies in the centre of a large geological depression or syncline, as illustrated by Celtique and reproduced here as Figure 2.8. The syncline also coincides with the region of thickest Kimmeridge Clay as mapped by DECC (2010). However, the diagram, although schematic, is misleading, because the central area of the Weald at depth is practically flat-lying and not synclinal (bowed downwards) in shape. This is demonstrated as follows:

1. The regional cross-section shown in Figure 2.5 shows that the central deepest part of the basin is flat.
2. The regional seismic section published on exhibition boards by Celtique shows a similar flat central area.
3. The detailed seismic section shown on the exhibition boards by Celtique shows planar flat-lying layers.

The deepest part of the Jurassic-Cretaceous Weald basin owes as much or more to down-faulting as to down-folding.

Figure 2.2 shows that the nearest seismic line to the proposed wellsite lie 70 m to the north. Near the wellsite there are two practically coincident seismic lines running E-W, which were obtained by survey equipment at the surface occupying the Kirdford Road west of Wisborough Green (for technical reasons the *subsurface*, or geological, location of the lines, as shown here, turns out to be slightly different from the surface position of the survey equipment line). One of these two seismic lines is essentially a duplicate of the other. But the 8 sq km area including the vertical and horizontal wells, west of Wisborough Green (the column of three OS squares at the right-hand side of the map) is entirely devoid of seismic data.

A single detailed sample of flat-lying seismic data has been used both for the Wisborough Green-1 and for the Fernhurst-1 proposed wells. It is not evident, therefore, whether this sample of seismic data relates closely (or at all) to either well. It can hardly be construed as being 'close' to either well. It lies from 6.5 to 13.5 km west of the proposed Wisborough Green-1 well. It appears to be the western half of an east-west line TER-91-06, reprocessed, which runs in a wavy line from east to west (Fig. 2.9). If so, it is misleading to use the line as being relevant either to Fernhurst-1 or to Wisborough Green-1. Best practice, in contrast, is to illustrate the proposed well by a seismic line running *through* the well.

The seismic line sample as used by Celtique is reproduced in Figure 2.10. It was recorded in 1991 by Geco-Prakla using a group of four vibroseis trucks as the seismic source. In Figure 2.11 I have compressed it horizontally and displayed it side by side with the original image of the relevant part of TER-91-06. Both versions of the line are *migrated*, which means a better image than a more basic *stacked* section. The vertical offset between on and the other of about 220 ms is due to a different *static correction* having been applied in each case. The original version was obtained for Teredo Petroleum PLC and processed locally by Digital Exploration Ltd of East Grinstead.

In my view the original version of TER-91-06 is better than the reprocessed version used by Celtique, because it shows the faulting that is present. The reprocessed version used by

Celtique has a smeared-out quality; the fine detail of the faulting has been obliterated. Figure 2.12 shows a fault (red curve) that can be interpreted on the original version, cutting very obliquely through the section between 1600 and 1900 ms. The fault is probably planar; it is the seismic line that is curved and hence intersects the fault-plane twice. The central part above the 'smile' is the upthrown side. Detail within the black rectangle is shown in Figure 2.13. There are two faults in the Middle Jurassic and Lower Cretaceous, extending upwards at least in one case into the Weald Clay. This is important evidence, because the Weald Clay is supposed to act as the impermeable cover-rock layer to prevent any upward migration. The problem of faults, sealing of hydrocarbons, and seepages of hydrocarbons are discussed in subsequent sections.

The Upper and Middle Lias Clays are presumably also targets of the Applicant's exploration programme, in addition to the Kimmeridge Clay, because the well will be drilled to 8750' (2667 m) and cores taken in these aforementioned formations. However, no further details are provided. These Lower Jurassic clays have been identified in the BGS Weald report (Andrews 2014) as a likely oil-rich unconventional resource. Since there are no conventional hydrocarbon traps in the area at these levels, it can be concluded that these formations are also the target of *unconventional exploration* by Celtique.

2.4 Unconventional nature of the exploration

It is my view that Celtique's opacity concerning what resource it intends to explore here at Wisborough Green, but also at Fernhurst, is designed to shield from view the fact that the company is seeking to exploit the unconventional shale gas (or oil) resource of the Weald. This will ultimately require fracking, even though the two exploratory well drilling applications state explicitly that fracking will not be carried out <u>at present</u>. Both applications leave open the possibility that fracking may have to be used at some point in the future.

Celtique has presented exhibition boards for public consultation with reasonable definitions of 'conventional' or 'unconventional' oil or gas <u>fields</u>, below the heading *"So, is this <u>well</u> Conventional or Unconventional?"* [my underlining]. Note that whereas Celtique defines the two terms in the context of <u>fields</u>, it refers to the <u>well</u> which is the subject of the planning application, and claims that the well is conventional technology. This is correct as far as it goes.

There are a variety of discussions and definitions of what is meant by 'conventional' and 'unconventional'. IHS, a major oil information management company, stresses that the meaning of the terms may evolve (Chungkham 2011) – exploitation techniques that were once termed unconventional may later become commonplace, or conventional. Matt Hall (2011), an industry geologist, shows that the terms vary depending upon which class of expert is defining them – geologist, geophysicist, economist, etc. Cander (2012) of BP shows that unconventionals can be clearly defined if one plots viscosity of the oil or gas against permeability of the host rock. The two classes of resource lie on different areas of the graph.

Celtique's map of its licences in relation to existing discoveries (Fig. 2.14) shows why the proposed development is different. All the existing discoveries occur on local high spots corresponding very approximately to the elliptical shape added to the map. This is because the high structures are found around the edge of the basin. The present application is right in the centre of the basin, where the rock formations are deepest. Other wells have indeed been drilled in the deeper parts of the basin, but these were targeting true conventional resources, and all turned out to be unproductive.

Conversely, if the Kimmeridge Clay limestones in central flat-lying area of the Weald were a conventional oil prospect, why was this rock never targeted in the 1980s when there was a great deal of interest in the region? The technology for the drilling of 'long reach' horizontal wells was in place by that time, so it cannot be argued that such technology was unavailable. The answer is simple; it has had to wait until the advent of fracking, because it is an unconventional resource.

Both of the Kimmeridge Limestone layers are an **unconventional resource**, whatever flavour of definition is used. It is misleading of Celtique to label it as a 'conventional stratigraphic trap'. It will require both horizontal drilling and high-volume slickwater hydraulic fracturing ('fracking') to exploit. There is no realistic expectation that oil or gas will be discovered and produced by conventional methods – i.e. that the hydrocarbons will flow under their own pressure through rock which is adequately permeable without being fracked.

However, I believe that shales, not merely limestones, are being targeted by the proposed drilling of Wisborough Green-1. This is explained in the next section.

2.5 Evidence that Celtique is targeting shales

Celtique Energie's exhibition boards for both Wisborough Green and Fernhurst horizontal drilling show the same diagrams and montages. This is misleading, as it implies that the same Kimmeridge Limestone horizon will be tested. There is no rational reason or justification for re-testing the same geological layer at two sites separated by 16 km; the geology is substantially identical at both sites.

Celtique's revised project description (chapter 4A) states:

> *"A 6" hole is then drilled with cores taken in the Upper and Middle Lias formations"*

If the Upper and Middle Lias shales were not of interest, money would not be wasted drilling that far down, nor would cores be taken, which is expensive. On the other hand, if the well were really designed as a so-called 'stratigraphic' test, to obtain a more regional picture of the deep part of the Weald Basin, then it would have been essential to propose drilling somewhat deeper than is actually the case, to prove the existence of the Triassic rocks (the top of which is marked in brown in Figures 2.10 and 2.11). Triassic sandstones are a target of Celtique's conventional exploration programme elsewhere in the Weald.

It is instructive to consider information previously published by Celtique and its partner Magellan Petroleum. Some of this information has since been withdrawn from view. Celtique's website, as of December 2012 stated:

> ***"Shale oil potential***
> *The shale oil play of the Upper and Middle Liassic in the Weald Basin is believed to be directly comparable to the Bakken and Paris Basin analogues. Both the Weald Basin and the Paris Basin are sub-basins of the Anglo-Paris Basin and the two basins have a common origin and geological history.*
> *With the emergence of horizontal drilling and multi-stage hydraulic fracturing in the US, production from the limestone layers in the Bakken shale has become highly commercially viable, opening up a recoverable resource potential of up to 4.3 bn bbls of oil according to the US Geological Survey. Oil and gas companies have also started exploring the shale oil potential at similar prospects outside of the US, and a joint venture between Hess and*

Toreador is currently exploring and developing the vast oil resource potential of the Liassic shales in the Paris basin."

A thin Kimmeridge Limestone layer, embedded in the Kimmeridge Clay, was the target of Cuadrilla's well Balcombe-2, drilled in late 2013, and also of the proposed Wisborough Green-1 well.

Both of Celtique's targets are analogous to the Bakken Formation of North America. This is a very thin dolomite rock layer (a hard magnesium-rich limestone) embedded in shales above and below. It has low permeability (but much higher than the shales), and is endowed with vertical fractures, so that **when it is fracked** it acts as a sink for the oil from the shales above and below. The area of the Bakken oil 'play' is large, a play being defined as a group of hydrocarbon prospects in the same region that are controlled by the same set of geological circumstances. The wikipedia web page states that the Bakken occupies an area of 520,000 sq km, over twice the area of the entire United Kingdom, but this figure is grossly in error by a factor of around 8. For the purpose of comparison I use the much smaller area of about 62,000 sq km within which practically all the Bakken wells have been drilled to date, and compare this with the thermally mature area of the Kimmeridge Clay as defined by the BGS. The ratio of the two areas (Weald/Bakken) is 0.36%.

The Bakken Formation was dicovered in 1952, but produced only very modest quantities of oil until the revolution in unconventional drilling and completion technology (including fracking) arrived in around 2000.

A letter from Celtique to DECC dated 15 December 2011 (reproduced in the Appendix) reveals that the chief prospects in PEDL234 are **unconventional**:

"The best quality Liassic source rocks with the highest maturity lie in the central licence, PEDL 234,

…

As we have shown in the presentation we gave you, the unconventional prospectivity we have defined at Kimmeridigian [sic]*, Middle Liassic and Lower Liassic levels are all laterally extensive. The rich, mature source rocks will extend well outside any areas we will be able*

to retain after the relinquishment at the end of the First Licence Period. As a result our planned drilling will prove the plays extending into acreage within our licence and beyond. Within our licence area we will be forced to relinquish an unconventional trend proven by drilling, under the 50% area relinquishment rule."

This letter proves that the Applicant is seeking unconventional resources, or plays, within PEDL234. It also demonstrates that these plays are very large, of the same order of area as a DECC licence block. This fact makes a mockery of the site selection exercise, which is discussed next.

2.6 Site selection

WSCC wrote to the Applicant on 3 December 2013 :

> *"With regard to the above application, West Sussex County Council formally requests further information before the Application can be determined.*
>
> *…*
>
> ***Site Selection Assessment***
>
> *"Further clarification is sought with regard to <u>how the primary and secondary search areas were defined, in particular, the extent and nature of geological data used</u> and drilling manager/operations manager selection criteria/constraints."* [underlining added]

It is clear from this request that WSCC was unsatisfied with the information supplied in the original chapter 5 (Need and alternatives), in particular the information supplied under the following subheadings:

- Assessment of alternative sites
- Search area
- Geographical location
- Methodology
- Sites identified

In both the original ES chapter 5 and the revised version chapter 5A, reference is made to Appendix 5.1, which has not been revised. Similarly, chapter 9 (Alternatives, p. 14) of the revised non-technical summary (April 2014) remains unaltered from the original. Under the first three subheadings nothing has been changed. Under 'Methodology', five new paragraphs have been inserted (paras. 5.38a to 5.38e, respectively). Lastly, the 'Sites identified' subheading information is unchanged from the original.

So does the additional information supplied in chapter 5A, paras. 5.38a to 5.38e, satisfy the request for more information, in particular the part that is underlined in the WSCC request quoted above?

Celtique's para. 5.38c expands upon its schematic picture of the supposed limestone trap at the base of a syncline (the Applicant's diagram is reproduced herein in Fig. 2.8). Regarding the Kimmeridge Limestones (micrites), the explanation states:

> *"These beds occur across the basin, but towards the margin of the basin they are contaminated by influxes of clay which reduce the porosity and permeability, and therefore reduce the suitability of the area for hydrocarbon exploration. The best reservoir quality will be encountered in the centre of the basin. This change from relatively high porosity and permeability in the centre of the basin to low porosity and permeability at the margins of the basin creates a trap."*

This statement, read in conjunction with the area of the Weald Basin, the diagram shown in Figure 2.8, and the defined primary and secondary search areas within PEDL234, is misleading for several reasons:

1. There is no evidence that the carbonates, which are somewhat argillaceous coccolith limestones, are in any way purer (i.e. less contaminated by clay) towards the margins of the basin.
2. The supposition that the limestones will be more 'clayey' at the margins is speculative.
3. The margins are in any case ill-defined; the northern margin of the Weald Basin may have been in Kimmeridge time (specifically, the Bolonian stage) somewhere in the region of the London-Brabant massif, which was a relatively high area, possibly an

island, with its southern margin running E-W in the area of the present-day Thames.

4. The sedimentary environment of deposition of the micrites is in a lowstand systems tract, i.e. above an unconformity, with sea level rising, probably in an epicontinental sea (Taylor *et al.* 2001); this is not an environment where 'margins' can be precisely or locally defined.
5. Celtique assumes that the more argillaceous micrite will have lower porosity and permeability; while it is likely that the increased clay content will reduce the porosity (which can be quite high for a tight limestone), it will not necessarily change the permeability, which in coccolith limestone is extremely low in the first place.
6. The best example of the micrites being argillaceous is at Balcombe-1 and Balcombe-2 – right in the centre of the basin, not at the edge.
7. The fence diagrams produced by the BGS (Andrews 2014, Appendix F) show only minor changes in the thickness and log character of the two main micrite horizons across the Weald. The maximum thickness of the upper 'I-micrite' can be contoured at around 40 m, in the region at and north of the Southwater-1 and Balcombe-1 wells. This zone is some 10 to 25 km ENE of the proposed Wisborough-1 well, and corresponds to the more easterly part of the oval zone defined by the BGS as the most mature Kimmeridge Clay.

I conclude that the so-called 'stratigraphic trap' formed by a syncline of permeable limestone in the basin centre, passing laterally into impermeable limestone, is a fiction, designed to disguise the fact that the limestone-within-shale sequence is an unconventional play akin to the Bakken. The Applicant is therefore misleading both the public (by way of its public presentations and exhibition boards) and WSCC itself.

Paragraph 5.38b of the Applicant's additional information defines the 'primary search area' as (1):

> *"the surface expression of where the centre of the original source of the hydrocarbons is found at its deepest position today"*

Paragraph 5.38e refines the definition by declaring it to be (2) the intersection of the present-day Top Kimmeridgian depth map with a 'restored' depth map. The latter map is a contour map of the base of the Jurassic basin as it would have looked at end-Jurassic time. The construction

of this 'palaeo-depth' map is obtained by standard procedures. The intersection is the (variable) area at the surface of the earth where these two maps overlap. It is like the definition of 'intersection' in mathematical set theory, which is often depicted as the area of overlap of two overlapping circles.

The first problem with these two definitions is that they are different from each other and mutually exclusive. But more importantly, definition (2) is vague to the point of having no meaning without some ancillary definitions, not supplied, of how much of each of the two basins (present-day and historic) is to be defined as 'deep' or 'deepest'. No maps have been supplied to enable us to judge this. After all, in the extreme cases, the 'deepest' part of each basin could be a single point, in which case there can be no overlap between the two points. Conversely, the 'deep' parts of the basins could include practically the whole of the modern Weald basin and its end-Jurassic equivalent, in which case the overlap area would comprise most of the modern-day Weald.

In the absence of satisfactory information from the Applicant, we can repeat the exercise using relevant Kimmeridge Clay data from the BGS report (Andrews 2014). Figure 2.15 shows the BGS map of Kimmeridge Clay maximum maturity (black hatching) along with depth to the base of the Kimmeridge Clay. The depth contour is 3000' (upper diagram) and 3500' (lower diagram). A search area criterion is to take the area of intersection of depth and maturity, implying that the conjunction of the two factors will be more favourable to hydrocarbon exploration. In the upper diagram, the less stringent case, the intersection area occupies most of Celtique's licence (PEDL234, shown in green). In the more stringent case (lower diagram) the area of intersection is confined to the very western limit of the licence. Celtique's primary and secondary site search areas are marked as oval areas around the proposed Wisborough Green-1 well (pink and black dot-dash lines, respectively). They evidently bear no relation to the BGS data.

The Applicant is, of course, free to make its own interpretation of the available data, and this may differ from that made using the BGS data. But the differences between the Celtique search area result and the version illustrated above are so acute that it would appear that different criteria for search, possibly non-geological, have in fact been used from those described in the 'additional information' paragraphs discussed above.

A further limitation of the available geological data (wells and seismic). Figure 2.16A shows the seismic coverage (green lines) around PEDL234 (green block). Detail from 2.16A is shown in 2.16B, in which the primary search area is marked by the pink dotted ellipse and the secondary search area by the black black-dot-dash ellipse around the proposed well. There are three N-S seismic lines at the eastern edge of the ellipse and a pair of E-W coincident seismic lines running across the ellipses. Most of both search areas is therefore devoid of seismic data. The seismic database is useful for mapping the thickness and depth of gross units like the Kimmeridge Clay, but cannot be used for assessing any finer details of the thickness or lithology of the micrite limestones. This is because these layers are at the limit of seismic resolution. For that assessment we are dependent on the well database.

Figure 2.16C shows the existing wells in the region surrounding PEDL234. There is only one well within the licence block, Aford-1. Assessment of the quality of the target micrites within Celtique's search areas therefore has to depend entirely on interpolation of data from wells spaced typically at from 5 to 20 km apart, and with no wells anywhere near these two search areas. The primary search area is 4.3 sq km in area and the secondary is 10 sq km. It is therefore difficult to see how such precise search areas were arrived at by Celtique.

Even if the primary and secondary search areas were defined by reference to the Liassic , and not to the Kimmeridgian unconventional play, as is assumed here, the arguments above still apply. It is the fault of the Applicant for failing to clarify this issue.

In conclusion, the Applicant has completely failed to explain and justify how and why the primary and secondary search areas were chosen. It is probable that a realistic search area is the bulk of the licence area, as shown by the upper diagram of Figure 2.15. This large area also accords with Celtique's views as expressed to DECC (see Appendix and the quotation reproduced in section 2.5 above). The small oval search areas around Wisborough Green are artificially and unjustifiably restrictive.

2.7 Conclusion on Celtique's targets

Therefore the well, although 'conventional' in its technology, is merely **the first step in planning for unconventional resource exploitation**, and serves no other purpose. I believe that

WSCC Planning Committee should consider this fact as germane to the determination of the application. There is no goal other than this end result. There is no alternative outcome to be expected such as free-flowing conventional oil or gas. The fact that fracking will necessarily be used, if this first step shows that the rock physical properties are promising, applies to all the target formations, whether they comprise a thin limestone layer sandwiched between clays or shale, or the Kimmeridge Clay and deeper Lias shales themselves.

An analogy might be useful here. Let us say that a planning application came forward to drill for and excavate test trenches for the foundations of a skyscraper in an area where the applicable planning policy included height restrictions on construction. The test drilling and trenching would not exceed the height restriction, but they will have no purpose other than to inform the Applicant whether or not the envisaged skyscraper can technically be built. If the test results are unfavourable the site would be returned to *status quo ante*. Would such a preliminary planning development be permitted? I would think not, because there is no conceivable social or economic benefit to the community of having some boreholes drilled and trenches cut. Since the ultimate aim – the skyscraper – is *a priori* not permitted, and there are no intrinsic benefits in the excavation itself, the planning committee would therefore refuse the preliminary application.

2.8 Horizontal drilling

The contingent horizontal well will be drilled in the complete absence of data apart from the prior results from the vertical well. This is potentially risky, because two assumptions have to be made; first, that the geology is flat-lying, and second, that no faults will be encountered.

No information has been provided by the Applicant as to how the horizontal well will be directed. A bare outline is given in para. 4.43a of the sidetrack starting in the Lower Purbeck and (presumably) 'landing' (flattening out to the horizontal) at the base of the Upper Kimmeridge Clay, which is also the top of the upper micrite to be drilled horizontally. A 7” liner is run this far, but it is not clear whether the horizontal hole through the micrite will be the same diameter or smaller, and whether or not it will be lined.

We are left to assume that a 'measurement while drilling' (MWD) tool will be used to guide

the drill bit out of the initial downward vertical direction, to land horizontally in the limestone horizon and remain there as the drill bit moves forward. The system uses gamma ray logging, exploiting the fact that gamma ray emissions in limestone are an order of magnitude lower than in the shales above and below.

The gamma ray MWD system is relatively inexpensive, and is designed to work properly only in unfaulted geology. It is unable to cope with the eventuality of the drill bit hitting a fault with a throw (displacement) of about the same magnitude or greater than the thickness of the layer being drilled, which is about 35 m. There exist more sophisticated so-called 'geosteering' systems for guiding the drill bit in real time while drilling horizontally. But these require a pre-existing high-resolution image of the geology, such as might be obtained from a 3D seismic survey, and onto which the position of the drill bit can be plotted and continuously updated.

It can be seen from Figure 2.2 that the horizontal well is being drilled completely 'blind', with no seismic data to guide it. At the very least it should have been drilled following the plane of a 2D seismic section. So why is it not planned to be drilled due west from the vertical well, so that its trajectory would intersect at a low angle the existing pair of seismic lines? I conclude that the southwesterly direction has been chosen instead because that is at right-angles to the maximum principal horizontal component of tectonic stress in the earth, which is aligned roughly NW-SE. The selected drilling trajectory is, for that reason, the preferred direction for later fracking. So the direction of the horizontal well is further evidence that the whole application is a preliminary exercise to test the feasibility of future fracking.

2.9 Summary of misleading statements, errors and omissions

1. A letter from Celtique to DECC in 2011 clearly states that the prospects in PEDL234 and elsewhere are unconventional.
2. No drilling details are provided for the contingent horizontal well.
3. The horizontal well will be drilled 'blind' into an area where there are no seismic data.
4. No information is supplied as to how the horizontal well will be steered.
5. The probable reason for the SW trajectory of the horizontal well has been witheld (i.e. that it is the best direction for later fracking).
6. The exhibition boards for the public consultations misled the public on the nature of the limestone 'trap'.

7. An unlikely scenario has been concocted to 'explain' the supposed stratigraphic trap formed by lithological variations in the Kimmeridgian limestone.
8. The block diagram for the horizontal drilling shows the lower Kimmeridgian limestone being drilled; but text states that the upper limestone is the target.
9. Both targets (Kimmeridgian and mid-Liassic limestones with organic shales above and below) are analogous to the Bakken unconventional oil play of North America, but this fact has not been mentioned in the application.
10. Three different directions were stated for the trajectory of the horizontal well (this error was corrected in the additional information).
11. The geological cross-section to illustrate the uppermost few hundred meters of the geology at the wellsite is in error by 80-100 m vertically.
12. The sample seismic data used to support the application lies between 5 and 13 km west of the drill site, not through the site, as is normal best practice.
13. Despite a specific request for more information, the evidence to justify the location of the primary and secondary search areas has not been provided.
14. Both of the Applicant's search areas conflict severely with the recent BGS survey of the Weald.
15. Two separate definitions are offered for the search area criterion; these are mutually inconsistent.
16. The two search areas are unnaturally small, suggesting that undisclosed non-geological criteria may have been used in their selection.

The remainder of this document concerns the implications for the environment if and when the PEDL234 licence development is permitted to reach the stage at which fracking will prove necessary.

3 FRACKING TECHNOLOGY

3.1 Introduction

Given that the ultimate and sole purpose of Celtique's activities in here Sussex is **production of oil by fracking**, it is justifiable to examine this process, and whether or not there is evidence to show that it can safely be applied in the Weald**.**

3.2 Fracking – old or new?

Proponents of fracking for hydrocarbons often claim that it is 'old' technology, and has therefore been thoroughly tried and tested over the 60 years or so since it was first developed. But this claim is a sleight of hand; modern fracking techniques are very different both qualitatively and quantitatively from those used before the 1980s. Some of the differences between modern and 'traditional' fracking include (King 2010):

- Horizontal drilling, not vertical
- 20 - 50 times greater volume of water used
- Extensive used of viscosity reducers and other chemical additives
- Each horizontal well leg is successively fracked, in 'stages'
- Simultaneous or delayed fracking employing real-time stress changes to control fracture directions.

The differences between this modern *high-volume slickwater fracking* (which is the method that would be used at Fernhurst) and fracking used for non-hydrocarbon resource development (e.g. water wells) is even more pronounced.

Pro-fracking academics such as Styles (2013) and Verdon (2013) have reported that around 200 onshore oil or gas wells in the UK have been fracked. These allegedly include the 'extended reach' horizontal wells drilled out out under Bournemouth Bay from Poole into the Wytch Farm oilfield (Verdon, op. cit.). The quoted figure of 200 is misleading; here is a detailed response obtained from Ms Toni Harvey, senior geoscientist in charge of onshore exploration and development at DECC, obtained in response to email questions from the refracktion.com

website about where Professor Styles obtained the figure:

> *"DECC has records of some kind of the drilling of 2159 onshore wells (which we add to when a new one is spud, see "basic onshore well data" on https://www.gov.uk/oil-and-gas-onshore-exploration-and-production*
> *We do not however have records of how many of these were fracked, because until recently fracking was regarded as a fairly routine oilfield operation and not subject to specific consent. From enquiries to the operators, we believe that at least 200 did have hydraulic fracturing treatments of some kind, but we would emphasise that these non-shale fracs are not comparable, in the volumes of fluid employed, to Cuadrilla's operations at Preese Hall in 2011 – the non-shale fracs are much smaller."*

The message here from this authoritative source is clear – that the non-shale fracking operations are of a different and much smaller order. With the sole exception of the Preese Hall-1 well in Lancashire, drilled by Cuadrilla in 2011, all these wells are vertical.

Concerning the alleged fracking at Wytch Farm; the initial publication on the Wytch Farm oil field, Dorset (Colter and Havard 1981) makes no mention of hydraulic fracturing in the field. Its later development is described by Hogg *et al.* (1999). The extended reach wells attain a maximum horizontal distance of 10 km from the surface drillsite, but they have never been hydraulically fractured. They are designed to inject water low down into the oil-bearing aquifer (a 'bottom waterflood') to help the oil flow. This has no relevance to fracking of any sort.

It is reasonable to conclude that the kind of fracking that will be employed in the Weald (subject to approval of the present and any future planning applications by Celtique) is a new technology (approximately post-2000, or twenty-first century). Furthermore, **it has never been employed in the geological conditions which pertain in the potential oil and shale gas basins of the UK**. Therefore to quote the US experience of the last thirteen years or so as evidence of potentially safe operation in the UK is invalid, as I shall show below.

3.3 Comparison of US fracked basins with UK potential shale gas basins

I have investigated the geological structure of the four principal shale gas basins in the USA; the

Marcellus, Barnett, Eagle Ford and Woodford shales. In total there are over half a million horizontally deviated and fracked well in these regions. The states concerned are principally Texas (TX), Oklahoma (OK) and Pennsylvania (PA). It is important to remember the scale of these states in comparison with the UK. Texas is somewhat larger in area than metropolitan France, but with a bit under half the population. Oklahoma is bigger than England and Wales combined, by 20%, but has only one fourteenth of the population of the latter. Pennsylvania is 90% as large as England in area, but with a quarter of the population.

My research has been driven mainly by the desire to investigate the claim made by Fisher and Warpinski (2012), who work for a subsidiary company of Halliburton, that fracking in the four US shale basins mentioned above includes areas of complex geology. In particular, the Halliburton engineers state:

> *"The Woodford's geologic structure can include substantial faulting, highly dipping bedding planes, overturned beds where a vertical wellbore could intersect the same series twice, and all manner of geologic complexity."*

I looked at all four shale basins presented by the Halliburton study, using all available geological maps, cross-sections, and published seismic data. The geological maps of the surface sometimes include detailed United States Geological Survey (USGS) 'quadrant' maps at 1: 24,000 scale. This is twice as large as the 1: 50,000 scale available from the BGS for the UK. There are also digital databases available in the USA of both geological boundary outlines and faults. I confirmed that the latter datasets include surface faults down to lengths of less than 1 km with throws (displacement of one side relative to the other) of a few metres. In effect, no fault data are missing from the digital database.

Except for Texas, my study uses online digital well databases, not just the Halliburton study data, for which the well locations are confidential and only located down to county level. I conclude from this study, which is in preparation for peer-reviewed publication, that the following wells lie within 1 km of a surface fault:

- 3 wells in the Woodford Shale, Coal County, Arkoma Basin, OK
- A further six or so wells in the Woodford Shale, Hughes County, OK near trivially small

faults

- 9 wells in the Marcellus Shale, Bradford County, PA.

Any truth in the Halliburton assertion quoted above lies in the occasionally complex geological structure at the level of the fracking, but it is not the case that any faults from the fracked levels extend up to the surface. The only exceptions to this rule are the three examples listed above, comprising about 20 wells out of more than half a million fracked wells.

The Halliburton study, which has been widely quoted in support of the environmental safety of fracking, aims to show that the upward propagation of the fractures created by fracking is limited in extent, and that, in all cases of the c. 10,000 fracked wells used in the study, the highest fracture height lies well below the deepest water well in each county. Therefore, the argument proceeds, fracking *per se* cannot affect near-surface groundwater resources.

But one of the limitations of this study is that the extent of the fracture progress is measured by microseismic activity recorded during each fracking stage. The erroneous assumption here is that no microseismic 'noise' equals non-propagation of the fracture fluid upwards (or downwards). This is discussed in section 4.

The crucial difference, then, between the USA fracked shales and the UK potential shale gas basins is that in the latter, **the faults extend from the shale layer all the way to the surface**. This difference is due to the tectonic (mountain-building, structural) environment of the UK being completely different from all the US shale basins. In addition, the density of surface-mapped faulting in the Weald and north of England is 400 times greater than the average for the US basins.

There is another fundamental difference between the shale basins or layers of the USA and those of England, and that is their dimension, both vertically and horizontally. In fact, a couple of the UK basins are called *troughs* and not *basins*; this implies that they are narrow and deep, and typically with faulted margins. Figure 3.1 illustrates this difference with a graph in which both axes are plotted logarithmically. This shows that in general the UK basins are 5 to 50 times thicker than the US basins, but 10 to 100 times smaller in surface area. The Weald basin, extending from Kent to Dorset is 2 to 100 times smaller in area than the US shales basins, but

its Kimmeridge Clay shale layer is between 3 and 8 times thicker than any of the US shale layers.

The depths at which fracking has taken place in the US, compared with the depth at which the Kimmeridge Limestone would be fracked if the Celtique development goes ahead, are as follows:

- US shale basins: 1000-4300 m depth; 90% of wells greater than 1600 m depth.
- UK Kimmeridge Limestone: 730 m (Balcombe), 1200 m (Wisborough Green). 1400 m (Fernhurst).
- UK Middle Lias shales: 2400 m (Fernhurst).
- UK Bowland Shale, Lancs.: vertical well tested between approx. 2300 and 2650 m.

Celtique's current application is in the area where the Kimmeridge Limestone which would eventually be fracked is at its deepest, at about 1200 m depth. So the proposed fracking of the Kimmeridge Clay in the Weald, if this limestone (or micrite, as Cuadrilla Resources label it at Balcombe) is used as the target, has practically no overlap with fracking depths in the USA, 90% or so of which are at depths greater than 1600 m. Only 2 to 3% of the 10,000 US wells studied by Halliburton are as shallow or shallower than 1300 m.

The West Sussex County Council (2013) website page about fracking states, concerning the USA:*"the shale gas formations are generally at a shallower depth than they are in the UK, leaving less of a 'geological buffer'."* This statement is clearly completely wrong, because the figures quoted above demonstrate that the opposite is the case. About 97% of the US wells have a thicker cover than pertains at the Wisborough Green site, and, furthermore, there is not the additional problem of faults connecting to the surface as in Sussex.

3.4 Earthquake triggering

Because no fracking will be used *in the present application*, there will be no problem of earthquake triggering. However, in the next phase of development, where fracking will have to be used, US and British experience shows that earthquakes may be triggered by:

- The fracking process iself

- Gas production
- Injection of waste water into disused wells.

Note that some of the earthquake triggering correlations are also with activity at conventional oil and gas wells.

3.5 Critique of presentation by Professor Peter Styles to LDNPA

Professor Styles made a presentation to the South Downs National Park Authority on 15 October 2013. He is a prominent proponent of fracking, and has particular expertise in the problem of earthquakes generated by fracking activity. I have no access to what he said, only a pdf copy of his slides. Based on what can be inferred from the slides, there appear to be a number of errors and omissions:

1. He appears to argue that one cannot distinguish between conventional and unconventional exploration (slides 9-10). This is incorrect, as the discussion in sections 2.4 and 3.2 above show.
2. He implies that fracking is not new (slides 14-15) – this is untrue. Fracking of the high-volume slickwater type in horizontally deviated wells has only been around for less than 15 years. Previous types of fracking (which are generally safe) consume only modest quantities of water by comparison with what the public is concerned about.
3. His slide no. 18 illustrating by a cross-section of a fracking well omits any depiction of faults. The geology is grossly oversimplified.
4. Micro-seismic mapping of the progress of fracking is not the whole picture (slide 20). There is evidence of frack fluid progressing up a fault to a new level; this progress is silent, i.e. unaccompanied by the tell-tale signs of microseismic tremors, because a pre-existing fracture has been used.
5. He uncritically quotes a paper by Professor Richard Davies of Durham University (slides 21-23) on the empirical limit of how far fracks can progress upwards, which in turn refers uncritically to a questionable earlier study by Halliburton. This is discussed in the next section.
6. Styles suggests that 'good quality cementing' will protect wells from leaks (slides 23-25). This ignores the fact that all wells will degrade and leak in the long term. His attempt to

use the Roman Pantheon as an example of the supposed longevity of concrete is inappropriate.

7. He suggests (I presume) that the Wytch Farm oilfield development in Dorset and below Bournemouth Bay is environmentally safe. I agree with this, but there is no valid comparison with the kind of fracking proposed in the UK shale basins.The 'extended reach' wells drilled out eastwards under the bay are through (or targeting on) the Sherwood Sandstone, the oil reservoir, and have never been fracked (Hogg *et al.* 1999).
8. He points out that the magnitude 2.3 Blackpool earthquake of 2011 is exceptionally large (slide 41), by comparing it with the thousands of far smaller earthquakes generated by fracking in the Barnett Shale of the USA. No explanation is offered (in the slides) as to why this Blackpool earthquake is so exceptional.
9. He quotes the main conclusions of the Royal Society report of 2012 (slides 50-51), but this report failed to discuss the differing geological regime in the UK compared with the US. The failings of this report are discussed in section 4.1 below.
10. Slide 42 states *"Characterisation of any possible active faults in the region using all available geological and geophysical data (BC always has 3-D seismic)"*. This statement, citing a report of which he was a co-author (Green *et al*. 2012) is incomplete, as it should have included all faults, not just 'possible active faults'.

In summary, I find Style's views on the risks of fracking to be complacent, incomplete (because of his partiality), and in places erroneous. The precautionary principle suggests that any region or rock volume cut by faults, whether active or inactive, should not be fracked. This view is developed further in the next section.

4 THE IMPORTANCE OF FAULTS

4.1 Introduction

The Royal Society and the Royal Academy of Engineering issued a combined report into the risks of fracking in the UK (Royal Society and Royal Academy of Engineering 2012). Much of the report concentrated on the risk of induced seismicity. The problem of pre-existing faults was barely discussed at all, even though it was introduced as a subject for concern by a submission to the expert committee by the Geological Society of London.

Instead, the Royal Society report accepted uncritically the Halliburton study (Fisher and Warpinski 2012) discussed above, as did Green *et al*. (2012) in their report commissioned by the Department of Energy and Climate Change (DECC).

This uncritical attitude towards an industry publication is surprising and somewhat naïve, given that:

- Halliburton has not published its database, which remains confidential.
- Wells are only located to county level.
- Individual wells cannot be identified on the four main graphs presented.
- We do not know whether inconvenient results have been omitted.
- We do not know how complete is the database.
- There are essentially no wells in areas of complex geology (faults or tight folds) extending to the surface.

There are some surprising facets to the database; for example Cleveland County (OK) has just one fracked well, but is listed in the graph for the Woodford Shale, whereas several other counties in the Anadarko/Arkoma basin of Oklahoma, with dozens of wells apiece, have been omitted. The answer may simply be that Halliburton did not have contracts for the operators in these counties, but the problem remains that we simply cannot know.

Even if we accept Halliburton's main thesis at face value – that creation of new fractures by fracking has a natural upward limit above the horizontal wellbore of around 500 m, perhaps

1000 m at the most – the account is erroneous at several places:

1. Plotting fractures by microseismic monitoring is incomplete. Pettitt *et al*. (2009) show that a sequence of microseismic events can jump 'silently' up a fault plane to another level, in their example about 100 m higher. Therefore **microseismic activity does not record the passage of fracking fluid up a fault.**
2. Such **leakage up faults could be a slow process**, not necessarily occurring at the time of fracking.
3. The authors argue that, in effect, **if faults were conduits they would have leaked all the gas away by now. This is clearly false**; the whole point of fracking is to release gas which is trapped and therefore unable to migrate.

In conclusion the Halliburton study is severely flawed, even when considered on its own terrain of US geology. It is certainly inapplicable to the UK.

In the UK some publicity was given to the paper by Davies *et al*. (2012) of Durham University, in which natural hydraulic fracture pipes were studied and shown to have a limiting upward extent of about 1100 m. The paper appears to give support to the idea that fracking is safe. But the study is a side issue, because the principal concern regarding fracking safety, not addressed hitherto, is the effects of natural faults, not natural pipes. The latter are a freak phenomenon, geologically speaking, and of no real importance.

4.2 Identification of faults

Faults are mapped at outcrop by field geologists. Identification at depth requires geophysical methods, of which imaging by the seismic reflection method is by far the best. Two-dimensional seismic profiles can image faults having a vertical displacement of one side relative to the other (if the fault cuts near horizontal layers) of 30 m or greater. So the 'resolution'- the finest detail that can be seen - is at least 30 m in length. Strictly speaking, it is this offset of layers one side with respect to the other across a fault which is usually seen, and not the fault itself. With the 3D seismic technique the resolution is brought down to the order of 4-5 m (i.e. improved).

Faults are often missed even when a vertical well is drilled. This is because the drilling process grinds up the rock, which is identified only by the cuttings coming back up with the returning drilling fluid. So it is not surprising that a fault, which is characterised in detail by ground-up, crushed and fractured rock, often cannot be seen. This is what probably happened with Balcombe-2; The vertical section of that well will have cut through the Paddockhurst Park Fault without being recognised, and Cuadrilla was (luckily) then able to drill horizontally to the along the limestone layer without encountering the fault.

Even if a well is cored, which involves the taking of a solid intact cylinder of rock from the inner zone of the drilling, faults can be difficult to recognise with certainty. In oil exploration coring is only done over a few limited intervals of a vertical well, because of the extra costs.

4.3 Permeability, hydraulic conductivity and vertical flow in faults

Permeability is a general term applied to fluids (liquids and gases); it is a measure of how easily the fluid can flow through the medium. Hydraulic conductivity is a more restricted term referring to specifically to water flow, and more frequently used by civil engineers; however it measures the same thing as permeability, but using different units. I frequently find that civil engineers speak of permeability when the parameter they speak of is really hydraulic conductivity. The units used are the key to spotting the difference.

The literature on the fluid sealing or conducting properties of faults in sediments is large and confusing. Research is driven by the need to understand sealing of hydrocarbon reservoirs at depths of 2-3 km on the one hand, and engineering properties of faults in the near-surface (down to a few hundred metres), especially in unconsolidated sediments. In addition, the subset of research into the effects of faulting in pelitic rocks (e.g. mudstones) is very limited.

There are dozens of academic research groups and oil-industry service companies working on the problem of whether faults act as *conduits* or as *barriers* to fluid flow. The default position in the hydrocarbon industry is the conservative one, that faults do not act as seals; in other words, they are leaky unless proved otherwise. In oil or gas exploration, if a fault is wrongly judged to be a seal when in fact it is permeable, no damage is done, other than to the bank balances and share prices of companies and individuals. However, in the case of shale gas exploitation, the

consequences of over-optimistically assuming that faults act as seals may be extremely damaging to the environment.

My brief and necessarily incomplete review of this large field of research and development (R&D) leads me to the following impressions and tentative conclusions:

1. There are field measurements of faults at outcrop and at shallow depth; it is realised that small-scale structures associated with faults dominate the bulk hydrogeological properties. These are characteristically fractures sub-parallel to the master fault plane, which are collectively termed the 'damage zone'. Such zones can be several metres to tens of metres in horizontal width, and are often the locus of fluid flow up or downwards, rather than across the master fault plane. This is illustrated in diagrammatic form in Figure 4.1.
2. In an unconsolidated mixed sand/clay stratigraphy, the conductivity in the damage zone can be enhanced by several orders of magnitude, but clay smearing along the core fault plane reduces the bulk conductivity.
3. Iron oxide re-precipitation in the core fault, due to the enhanced flow in the damage zone, is another mechanism which can reduce the core conductivity.
4. The relative hydraulic conductivity of a fault cutting indurated low-conductivity clays is neutral; i.e. the conductivity of the fault zone remains within the same order of magnitude as the unfaulted clay. An example is the set of measurements across the Down Ampney fault, made by the BGS, in which Oxford Clay is juxtaposed against Oxford Clay or Forest Marble Clay (Sen and Abbott 1991).
5. However, the same dataset shows that the conductivity of the fault zone as a whole is enhanced by one or two orders of magnitude, because the succession includes limestones and sandstones as well as the aforementioned clays.
6. Smectite in shear zones can be dehydrated to anhydrous illite minerals as a shear fabric develops; this in turn can account for overpressure build-up. This mechanism accounts for high hydraulic conductivity observed in accretionary wedges, but contradicts laboratory experimental studies suggesting that sheared clays in fault zones represent aquitards.
7. Laboratory measurements of permeability or hydraulic conductivity usually give results that are an order of magnitude lower than *in situ* measurements. Tellam and Lloyd

(1981) studied the hydraulic conductivity of British mudrocks. The laboratory measurements gave values 2 to 3 orders of magnitude lower than the *in situ* values.

Lunn *et al.* (2008) have modelled the fluid flow pathways across models derived from detailed outcrop observations. Starting with their summary that:

> "*Faults can be barriers to flow, conduits, or combinations of the two, and their hydraulic properties vary considerably over both space and time*".

They conclude from their study that the *micro* properties as opposed to the *average* hydraulic properties in a fault zone are crucial, but that these properties are *unmeasurable at depth*. A multi-variate stochastic approach is the only way forward, they say, which:

> "*implies that a very large database of fault architecture is needed to accurately characterize fault permeability distributions. This can only be achieved by pooling a large number of field datasets. This would require an international consensus on the recording of the gross parameters (e.g., lithology, offset, stress history) and the architectural detail at each site*." [NB authors' emphasis on *very large*].

From Lunn *et al.*'s observation (which was already widely known across the hydrocarbon exploration industry) that "*faults can be barriers to flow, conduits, or combinations of the two*", one can construct a cartoon of how normal faults cutting sediments will affect flow direction (Figure 4.1). I have indicated in this cartoon the general flow parallel to sedimentary bedding, in this case down-dip. But when the flow encounters a fault zone it will be redirected upwards; this fact is irrespective of whether the fault is acting as a barrier or as a conduit to fluid flow.

4.4 Summary of the fault problem

Faults are near-planar surfaces cutting through rock layers. In Sussex the fault planes are nearly vertical, cutting through rock beds which are not far from horizontal in attitude. Their key characteristics include:

- Faults are complex and unpredictable in their hydrogeological behaviour.

- Faults have to be regarded as leaky (conduit for fluids) unless proven otherwise.
- Earthquakes occur on pre-existing faults.
- Pre-existing crustal stress and fracking-induced stress is concentrated along faults.
- Fracking activities can induce earthquakes.
- USA fracking history provides no guide for the UK geological environment.
- Leaks of released methane up faults, once started, may continue for decades.

5 IMPLICATIONS FOR ENVIRONMENTAL CONTAMINATION

5.1 Migration up faults and natural fractures

The US fracking experience tells us that faults at the fracking level are to be avoided if possible, because they reduce the effectiveness of the fracking treatment and can divert stresses away from desired trends. According to Baker Hughes (2013), a major service company like Halliburton, **re-activated faults are usually conduits to fluid flow**. The problem of environmental contamination by fugitive methane and/or fracking fluids reaching the surface never arises in the USA because there are practically no faults in the shale basins studied which extend from the fracking level up to the surface.

Controversy over contamination in the USA due to fracking operations has therefore concentrated on the problem of faulty well casings, leading to fugitive methane emissions. There is no question that in some localities, for example at Dimock (PA), there have been severe problems. In the scientific literature there are well-funded (industry-sponsored) papers purporting to show that methane emissions are natural (pre-dating the advent of drilling and/or negligible). One example of this is a just-published paper purporting to show low methane emissions – but the confidential sites were pre-selected by the industry. The most telling paper to date in my view is by Jackson *et al*. (2013), who analysed 141 drinking water wells in Pennsylvania. Their study shows that elevated (and often dangerous) methane levels correlate with nearness to well sites, at a probability level of well under 1% (i.e. the chances of this correlation being by random chance) *and* they prove by its characteristic signature that the methane comes from the Marcellus Shale, and is not a shallow biogenic product.

In the area studied by Jackson *et al*. there are no faults. Even if the source of the methane leak is due to faulty drilling completion, the interesting fact remains that the fugitive methanee is not found just at the wellbore, but up to several kilometres away. This suggests that the cover rocks above the fracked Marcellus Shale, which here is at depths of 1500 to 2100 m, do not make a perfect seal.

Modern imaging techniques applied to 3D seismic datasets are now even capable of imaging gas seepages up faults and through permeable overburden (cover rock) above a hydrocarbon

source (Aminzadeh *et al.* 2013). In fact the evidence of seepage and upward escape is being used by the oil exploration industry as anew exploration tool.

5.2 Are the rock layers above the fracking levels in Sussex an adequate seal?

How much rock is required above a fracked zone to seal it? In the East Irish Sea Basin it is reported that at least 600 m of Mercia Mudstone Group (MMG) is required for it to be an effective hydrocarbon seal there, due to the inversion uplift (Duncan *et al.* 1998). However, the MMG is an effective seal in the Wessex Basin, where 300 m of MMG caps the oil of the Wytch Farm field, together with another 200 m of Liassic mudstone above. The difference in the latter case is that the Tertiary uplift has never taken the MMG into the brittle tensional strength regime, which is the reason for the higher hydraulic conductivity in the Irish Sea region.

The figures used in the following discussion are approximate, taken from a Celtique public relations diagram. If the Kimmeridge Limestone is fracked at a depth of 1200 m below ground level, at least the 200 m of Upper Kimmeridge Clay overlying it will be fractured, and therefore cannot act as a seal. Above that there are 800 m of Upper Jurassic and Lower Cretaceous sediments below the Weald Clay, comprising around 50% sandstones and limestones. None of the more pelitic (mudrock) sequences making up the remaining 50% is individually thick enough to make a reliable seal.

One cannot simply add up the total thickness of the mudrocks (the potentially good sealing rocks) in this sequence, to conclude that we have around 400 m of mudrock in total. The reason is that one layer of rock may be linked to another across a fault, because the fault is leaky to fluids. So even small faults are important here. The faults are, in effect, short-circuiting the individual sealing layers.

The Weald Clay lying above the aforementioned layers is about 200 m thick, and occurs at outcrop (the Earth's surface). It has a measured horizontal hydraulic conductivity range of the same order of magnitude as the Mercia Mudstone Group, which acts as a reasonable seal in the Wessex Basin, but is ineffective in the Irish Sea Basin. However, the Weald Clay is full of sandy and silty laminations, which means that the effective bulk horizontal conductivity is likely to be at least an order of magnitude higher than the measured clay conductivity. Together with the

fact that the crustal stress regime in the topmost few hundred metres is tensional, this means that the Weald Clay will also be an ineffective seal or barrier.

In conclusion, there is no effective seal, or caprock, above the fracking zone in PEDL234, because of the presence of faults. A full 3D seismic survey around the region of the proposed Wisborough Green-1 well could, in principle, demonstrate that there are no faults in the area. Such a form of imaging provides detail which is several times more precise than the cheaper and simpler 2D seismic surveys. However, the limited evidence available from the existing data shows that many more faults are present at depth than are mapped at the surface, even in this deep flat central part of the Weald Basin (Figs. 2.1, 2.2, 2.4, 2.6, 2.12, 2.13).

5.3 Evidence of seeps

Selley (1992) has described and tabulated 173 occurences of surface petroleum seepages and impregnations in the UK. Eleven of these occur in East Sussex, the nearest one to PEDL231 being at Cuckfield. Two of these (Hawkhurst and Netherfield) are occurrences of natural gas.

In three instances the seepage is clearly related to migration up faults from the presumed Lias source rocks below. An alternative source could also be deeper Coal Measures (Carboniferous), even though the Weald is within the outer part of the Variscan fold belt. The Variscan tectonic event (folding and faulting) post-dates the Carboniferous, but it is now thought that the metamorphism (heating and 'cooking' of the rocks) may not have been as severe as previously believed, so that the Coal Measures may have survived nearly intact as a source for seeps.

Selley (2012) discusses in more detail the migration of gas up pre-existing faults elsewhere in the UK, in relation to shale gas basins. At the international level, hydrocarbon seepage is now proven as an exploration tool, and the upward migration of gas can even be directly imaged using high-quality (usually 3D) seismic reflection data combined with clever computer visualisation methods. Aminzadeh *et al.* (2013) provide an up-to-date review of developments. The most important lesson to be learned from their wide-ranging review is that faults are crucially important in providing migration pathways. The next most important lesson is that cap rocks are rarely 100% effective. Petroleum systems with continuous leakage upwards, balanced by continuous replenishment from a source below, are common. The new imaging methods

show that gas migration can be diffuse, and is not necessarily confined just to identified faults. The Earth is far from perfect at keeping hydrocarbons underground.

5.4 Groundwater

The Environmental Statement (ES), Chapter 11, discusses the aquifers that will be penetrated by the vertical well. But in view of the fact that the aim of the development will be to frack within the Kimmeridge Clay Formation and/or the Middle and Lower Lias clays over a wide area of the 400 sq km licence, we are justified in looking more generally at the risk to groundwater resources.

The sandstones and limestone units within the Weald Clay are classed as Secondary A Aquifers. A map of the minor beds within this formation is shown in Figure 5.1 from the BGS Horsham map memoir (Gallois and Worssam 1993). Celtique's Table 11.3 describes the aquifers within the Weald Clay as *"Sandstone inferred to have moderate primary and secondary porosity and permeability with resource value constrained by limited lateral extent"*. In fact there are several sandstone horizons; we are concerned principally with those numbered 5c down to 1a (see Figure 5.1) because these are below the top of the well in the vicinity of the wellhead. Some of these horizons, such as 3a and 3c have a regional extent of at least 20 km in both north-south and east-west directions, as shown in Figure 5.1 and the accompanying cross-section in the memoir. They are therefore much more extensive than is misleadingly implied by the word 'lenses' employed by Celtique (ES, chapter 11, p.11).

The underlying Tunbridge Wells Sands are divided into two, Upper and Lower, separated by the Grinstead Clay. According to the well prognosis provided by Celtique (ES, Fig. 11.5) the top is at around 300 m below ground level, and totals about 180 m in thickness including the thin clay member. The sands are classified as Secondary A aquifers.

Celtique's ES ignores the fact that there are a number of natural 'issues' (water emerging from depth) and/or springs within a few kilometres of the well (Fig. 5.2). This strongly suggests that there is a natural groundwater discharge system in the area of the well.

We do not know whether this discharge emanates from the permeable horizons within the

Weald Clay, or from the deeper Tunbridge Wells Sands. However, it would appear that both of the following statements by Celtique on groundwater flow (ES, chapter 11, p. 12) are erroneous:

> *"groundwater in the superficial deposits and in the Secondary Aquifer sandstones in the Weald Clay … is locally recharged and unconfined at outcrop with subsequent down-dip flow into a confined zone"*

> *"groundwater in the deeper Secondary Aquifers, starting with the Upper Tunbridge Wells Sand … will be recharged on the outcrop area, which is some 10-12 km to the north east and beyond; … will flow southwards according to the regional dip of the strata; and … has no practical connection with groundwater beneath the site or through which the proposed hydrocarbon exploratory borehole will penetrate."*

In addition there are four wells producing acceptable domestic or agricultural quantities of water from the Weald Clay within a few kilometres of the proposed drillsite (Fig. 5.2). The well depth varies between 30 and 51 m, and flow rate is between 0.5 and 2.5 m^3/h. A fifth well, at Wisborough Farm, 500 m NE of the proposed drillsite encountered saline water within the 39 m drilled, so was not completed.

The existence of saline groundwater near the surface can be an indication that there are connections to great depth (Ewen *et al*. 2012), since brine should only be encountered deeper than perhaps 500 m.

The evidence cited above shows that Celtique has taken a complacent view of current groundwater resources. The risk to the groundwater is probably low from the drilling of the vertical well Wisborough Green-1 itself, but if and when a much wider area is developed for shale oil by fracking, then these resources will be put at serious risk.

6 DISCUSSION AND CONCLUSIONS

6.1 Implications of the faulted geology for environmental contamination

Celtique's clear intention is to investigate and then frack the Kimmeridge Clay shale for oil or gas, using the Kimmeridge Limestone as a guide layer. The present application is just the first stage of this process. Fracking technology is not only unconventional; it has never been tested to any degree in a highly faulted shale basin such as the Weald. Faults are complex features, and difficult to understand. In the USA faults at the frack level are avoided because they reduce the efficiency of the fracking process. In addition, no faults within any fracking province of the USA extend all the way to the surface.

In NW Germany, a thorough study of fracking risks has been carried out by neutral academic experts (but funded by ExxonMobil), which includes the question of fracking through faulted zones (Borchardt *et al*. 2012). I have not completed translating this report, which is in German and runs to some 140 pages; however, there is an English-language summary (Ewen *et al*. 2012), one of the main conclusions of which is that fracking in fault zones should be banned. It states:

> *"The following hydrofracking fluid transport barriers are crucial:*
>
> - *The presence of massive sealing clay strata and other strata.*
> - *The barriers resulting from the fact that salt fractures close up naturally.*
> - *The absence of faults or fault zones, i.e. underground areas that are more porous owing to fractures in geological materials."*

Note that the Celtique drill site area lacks the first requirement (massive sealing strata, discussed in section 5.2), and in addition has many faults (section 4 above). There are no salt layers in Sussex, so the beneficial effect of salt as a barrier to migration does not apply here. The presence of oil and gas seepages in East Sussex (section 5.3) is evidence that faults in the Weald Basin cannot be assumed to be barriers to migration.

6.2 Baseline surveys

The Royal Society and others have called for baseline surveys to be conducted before any fracking operation. This means establishing what the environmental state is before any work is undertaken that might alter this state. The surveys that it would be appropriate for Celtique to undertake before the drilling envisaged in the present application include monitoring of groundwater and possible natural leakages of methane. Seismicity should also be monitored.

There is no 3D seismic reflection survey over the licence area. Such a survey could image faults down to a resolution of a few metres, and would go some way to mitigating the very incomplete knowledge of faulting in this area. In my view this would need to be a semi-high resolution survey targeted at the uppermost two kilometres or so.

Monitoring of groundwater and potential natural leakages of methane should be carried out before any drilling is undertaken. Seismicity should also be monitored.

6.3 Social costs of a fully-developed unconventional oil industry

I have estimated the cost in terms of damage to the road infrastructure if full-scale fracking for oil production is ever developed in the UK. The financial inducements currently on offer do not even cover the costs of the road repairs. For every barrel of oil produced by unconventional methods (using the Bakken of the USA as a model) three barrels of produced water have to be taken away.

I have modelled the road transport load over the expected 20 year life of such a project. The model area comprises one-ninth of a standard DECC licence block, and has 11 fracking pads each with 25 wells. For example, at one bottleneck in my model, where the oil and water trucks must converge from seven fracking pads, and pass along a short stretch of B-road before reaching the trunk road network, there will be one 30-tonne 3-axle truck passing in each direction every 3 minutes, 12 hours a day, 7 days a week, for 20 years. The road will have to be resurfaced every two years or less. In summary, the strain on the countryside infrastructure of B- and C-class roads is intolerable.

The value of the housing stock in a typical DECC licence block (400 sq km) in the south of England is of the order of £20 billion. So a reduction in total overall value of this property (which excludes a valuation of farmland and public open spaces) of 10%, for example, would be a cost to the community of £200 million. This is of the same order as the profits to be made by the oil company, assuming that the current oil price ($110 per barrel) is maintained, plus further favourable assumptions about the recovery factor and so on. But these putative profits will not be fed back to the community.

I have had several enquiries from prospective house purchasers in the south of England, Wales and Lancashire, who are worried that a future unconventional oil or gas industry might impinge upon their property. There are examples of householders who are either unable to get insured against any damage due to fracking, or who have seen their premiums more than double in order to get the cover. DECC has considered this evidence and asserts that it does not see a problem. The proposed community benefits offered by the oil industry will barely cover the extra cost of increased household insurance premiums.

6.4 Conclusions

West Sussex County Council must consider the present application in the context of what logically must follow on if the phase of testing proves encouraging. **That means fracking, and no other outcome is possible.**

Celtique has divided up its exploration programme into small chunks as a way of manipulating the Council into permitting fracking. The present application, stage 1, has been couched in terms of being a simple straightforward oil exploration well test – but it is not. If it were, I would have no objection to it. But if the present test boring, including horizontal drilling, is permitted, then Celtique's next application will be presented as a simple extension to what has already been done, but with some 'stimulation' added (this being the new word adopted by by the shale gas industry, to avoid mention of hydraulic fracturing, or fracking). The Council must not permit itself into being bounced by this tactic into an agreement to frack.

Celtique has been evasive about its intentions. As a result, among other things, the Alternative Sites Assessment cannot be judged as having any validity. Based on the incomplete evidence supplied by the Applicant, we just do not know.

The Weald's geology is intrinsically unsuitable for fracking. No similar geology been fracked before. The USA experience is completely irrelevant. Fracking poses a direct threat to groundwater resources, and there is the possibility that fugitive methane may even reach the surface.

The Council should bear in mind when determing this application:

- What benefits to the community arise (if any) from the present application?
- Will any of these benefits (if they exist) outweigh the clear inconvenience to the community?
- Can Celtique prove that fracking in Sussex will be environmentally safe?
- Conversely, can Celtique provide a legally-binding promise that fracking will not be used?
- Why should parts of West Sussex be put at potentially grave environmental risk, when the main beneficiaries will be the Applicant and the Exchequer?
- Would the financial benefits of any putative Community Benefit Scheme based on a share of royalties outweigh the costs of possible accidents, leakage and other deleterious effects on the environment?
- What do the constituents wish?
- Why have countries such as France and Bulgaria banned fracking outright, while Germany and several US states have moratoria until the environmental and health impacts have been assessed?

On the technical and environmental safety grounds discussed above, **the current planning application should be refused.**

REFERENCES

Aminzadeh, F. *et al.* 2013. *Hydrocarbon seepage: from source to surface.* Geophysical Developments Series no. 16, Society of Exploration Geophysicists and American Association of Petroleum Geologists, Tulsa, OK, 244 pp.

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

Baker Hughes 2013. Fault Seal Analysis: Improve reservoir understanding with fault seal analysis. Web page available at: http://www.bakerhughes.com/products-and-services/reservoir-development-services/consulting-services/geomechanics/fault-seal-analysis

Cander, H. 2012. What are unconventional resources? A simple definition using viscosity and permeability. *Am. Assoc. Petrol. Geologists, Search and Discovery Article #80217*.

Chungkham, P. 2011. The unconventional and IHS. Web page available at: http://www.ihs.com/products/oil-gas-information/source-newsletter/international/july2011/unconventional-ihs.aspx

Colter, V.S. And Havard, D.J. 1981. The Wytch Farm oilfield, Dorset. In Illing, L.V. And Hobson, G.D. (eds), *Petroleum geology of the continental shelf of north-west Europe*. Heyden and Sons, London, pp. 495-503.

Davies, R.J. *et al*. 2012. Hydraulic fractures: how far can they go? *Mar. Petrol. Geol.* **37**, 1-6.

Duncan, W.I., Green, P.F and Duddy, I.R. 1998. Source rock burial history and seal effectiveness: key facets to understanding hydrocarbon exploration potential in the East and Central Irish Sea Basins. *Am. Ass. Petrol. Geologists Bull*. **82**, 1401-1415.

Borchardt, D. *et al*. 2012. *Abschätzung der Auswirkungen von Fracking-Maßnahmen auf das oberflächennahe Grundwasser- Generische Charakterisierung und Modellierung* (Assessment of the impact of fracking operations on the near-surface groundwater - Generic characterisation

and modelling).[full report, in German, available at www.dialog-erdgasundfrac.de].

Ewen, C. *et al*. 2012. *Hydrofracking Risk Assessment Executive Summary* [English summary version of Borchardt *et al*. 2012, available at www.dialog-erdgasundfrac.de].

Fisher, K. and Warpinski, N. 2012. Hydraulic-fracture-height growth: real data. Society of Petroleum Engineers Annual Conference Paper SPE 145949, Denver 2011. *SPE Production & Operations*, February 2012, pp 8-19.

Gallois, R.W. And Worssam, B.C. 1993. *Geology of the country around Horsham. Memoir for 1:50 000 geological sheet 302 (England and Wales).* British Geological Survey (HMSO, London).

Green, C.A. *et al*. 2012. *Preese hall shale gas fracturing review & recommendations for induced seismic mitigation*. Report to DECC.

Hall, M. 2011. What is unconventional?
http://www.agilegeoscience.com/journal/2011/2/7/what-is-unconventional.html.

Hogg, A.J.C. *et al.* 1999. Reservoir management of the Wytch Farm Oil Field, Dorset, UK: providing options for growth into later field life. *In:* Fleet, A. J. & Boldy, S. A. R. (eds) *Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference, pp.*1157-1172. Geological Society, London.

Jackson, R.B. *et al.* 2013. Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. Proc. Nat. Acad. Sci. *PNAS Early Edition*, available at: www.pnas.org/cgi/doi/10.1073/pnas.1221635110.

King, G.E. 2010 Thirty years of gas shale fracturing: what have we learned? Society of Petroleum Engineers Annual Technical Conference Presentation.

Lunn, R.J., Shipton, Z. K. and Bright A. M. 2008. How can we improve estimates of bulk fault zone hydraulic properties? *Geol. Soc. London, Spec. Publ.* **299**; 231-237

Pettit, W. *et al*. 2009. Using continuous microseismic records for hydrofracture diagnostics and mechanics. *Soc. Explor. Geophys. Ann. Meeting Expanded Abstracts.*

Refracktion.com website. *Peter Styles. Those 200 wells continued.* http://www.refracktion.com/index.php/tag/peter-styles/ . Posted 23 August 2013.

Royal Society and Royal Academy of Engineering 2012. *Shale gas extraction in the UK: a review of hydraulic fracturing.* DES2597. Available online: www.royalsociety.org/policy/projects/shale-gas-extraction

Selley, R.C. (1992). Petroleum seepages and impregnations in Great Britain. *Mar. Petrol. Geol.* **9**, 226-244.

Selley, R.C. (2012). UK shale gas: the story so far. *Mar. Petrol. Geol.* **31**, 100-109.

Sen, M.A. and Abbott, M.A.W. 1991. Hydrogeological investigation of a fault in clay. *Quart. J. Eng. Geol. Hydrogeol.* **24**, 413-425.

Taylor , S.P. *et al.* 2001. A sequence stratigraphy of the Kimmeridgian and Bolonian stages (late Jurassic): Wessex–Weald Basin, southern England. *J. Geol. Soc. Lond*. **158**, 179-192.

Tellam, J.H. and Lloyd, J.W. 1981. A review of the hydrogeology of British onshore non-carbonate mudrocks. *Quarterly Journal of Engineering Geology and Hydrogeology*, **14**, 347-355.

UK Onshore Geophysical Library. http://maps.lynxinfo.co.uk/UKOGL_LIVEV2/main.html#

Verdon, J. 2013. *Shale gas extraction and 'fracking'. Talk for Glastonbury.* Slideshow available at www1.gly.bris.ac.uk/~JamesVerdon/PDFS/Glastonbury_talk.pdf

West Sussex County Council (2013). *Oil and gas exploration and fracking*. Website page: http://www.westsussex.gov.uk/default.aspx?page=33315

APPENDIX

Celtique Energie Weald Ltd

76-78 Charlotte Street
London
W1T 4QS

P +(44) (0) 20 7255 6100
F +(44) (0) 20 7255 6110

E enquires@celtiqueenergie.com
W www.celtiqueenergie.com

Department of Energy & Climate Change
3rd Floor
Area B
3 Whitehall Place
London
SW1A 2HD

Thursday 15th December 2011

Dear

It was good to meet with you at your offices on 30th November. We found our discussions very useful.

At that meeting we discussed two key issues; well obligations and relinquishment at the end of the first licence term.

On our Central Weald Licences (PEDLs 231, 234 and 243) we currently have an obligation to drill one well on each licence in order to be eligible to hold each licence into the second licence term. However, as we explained, there are technical reasons as well as planning permission constraints that lead us to formally request your approval to modify the obligation to a floating obligation to drill three wells across three licences, not one well in each Licence.

The technical reasons are predicated on the following:

- The best quality Liassic source rocks with the highest maturity lie in the central licence, PEDL 234,
- The most attractive Triassic conventional prospects lie to the east as does the Kimmeridgian oil shale potential,
- The planning permission problems have become more difficult in the west with the creation of the South Downs National Park. As a result we now realise that the already slow process of getting permissions has slowed even more and this means that whilst planning permission should eventually be obtainable, the timing is such that approvals will not be forthcoming within the current licence timeframe. Of course this also means we will not have sufficient time to fully evaluate post drilling.

The second issue is the 50% relinquishment at the end of the First Licence Term. Such a relinquishment schedule is not a problem in the 'conventional exploration space' where the prospect extent can be defined with some confidence. However in the 'unconventional exploration space', where the hydrocarbon accumulations are continuous and cover a large area, the extent of any discovery is difficult to define exactly but clearly has the potential to extend over a large area. As we have shown in the presentation we gave you, the unconventional prospectivity we have defined at Kimmeridigian, Middle Liassic and Lower Liassic levels are all laterally extensive. The rich, mature source rocks will extend well outside any areas we will be able to retain after the

Celtique Energie Weald Ltd
Registered in England No: 07055133

relinquishment at the end of the First Licence Period. As a result our planned drilling will prove the plays extending into acreage within our licence and beyond. Within our licence area we will be forced to relinquish an unconventional trend proven by drilling, under the 50% area relinquishment rule. The very long lead times for the obtaining of planning permission, with respect to the Licence term, will not allow us to optimise the relinquishment with outpost wells to prove the trend and to better define the limits of the prospectivity within the first licence period.

We would therefore appreciate your guidance on the two issues described in order that we can best plan our exploration activities in the Central Weald. We request your agreement to allow 3 wells drilled in the Central Weald area in any licences to qualify and hold all three licences in to the next licence term. We further request your position on relinquishment policy and areas as applied to unconventional resources proven by drilling.

If you have any questions please do not hesitate to contact me,

Yours sincerely

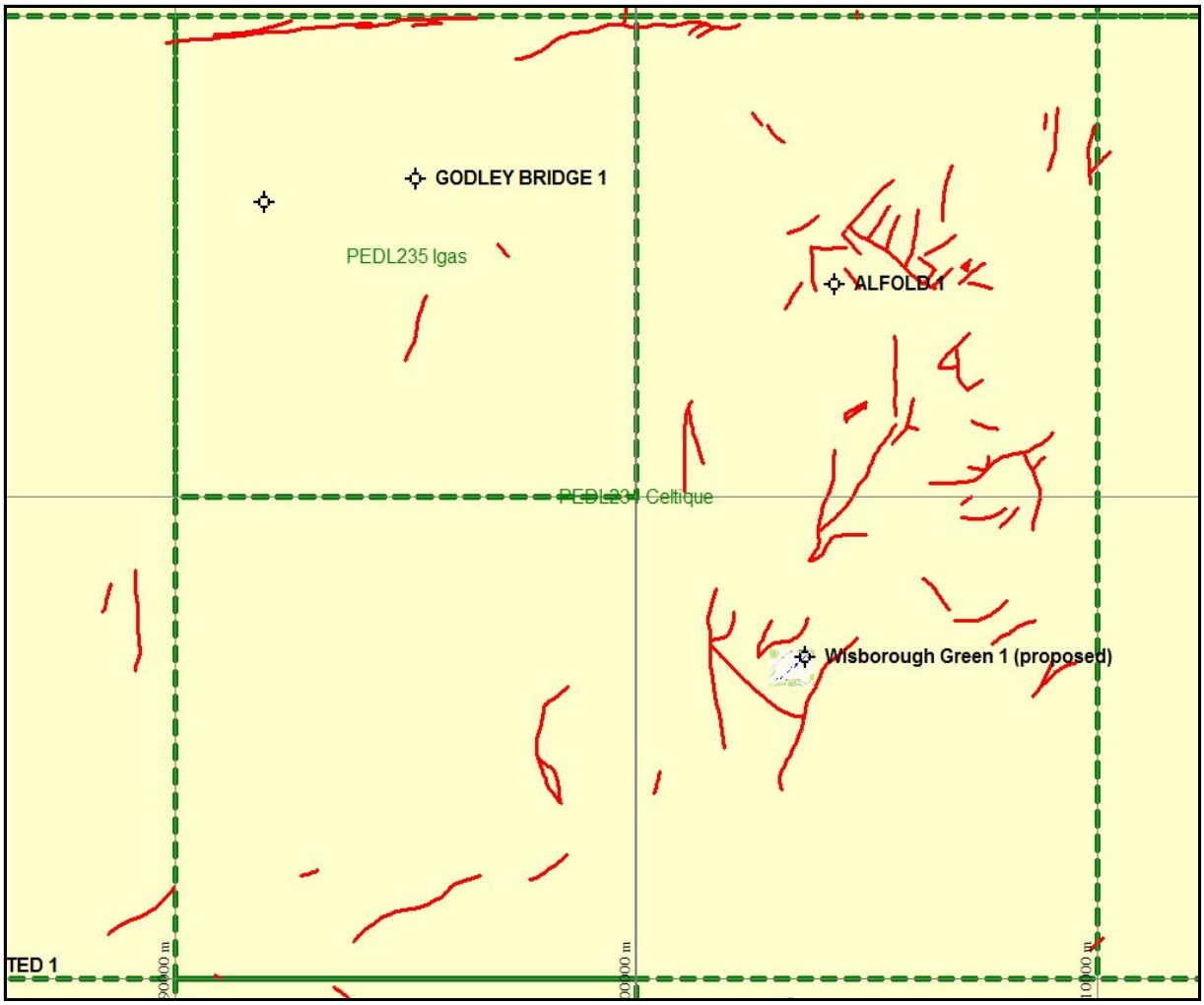

Fig. 2.1. The Celtique PEDL234 licence area showing proposed Wisborough Green-1 wellsite and surface-mapped faults (red). The licence is L-shaped; the square at the top left is a different licence (IGas PEDL235).

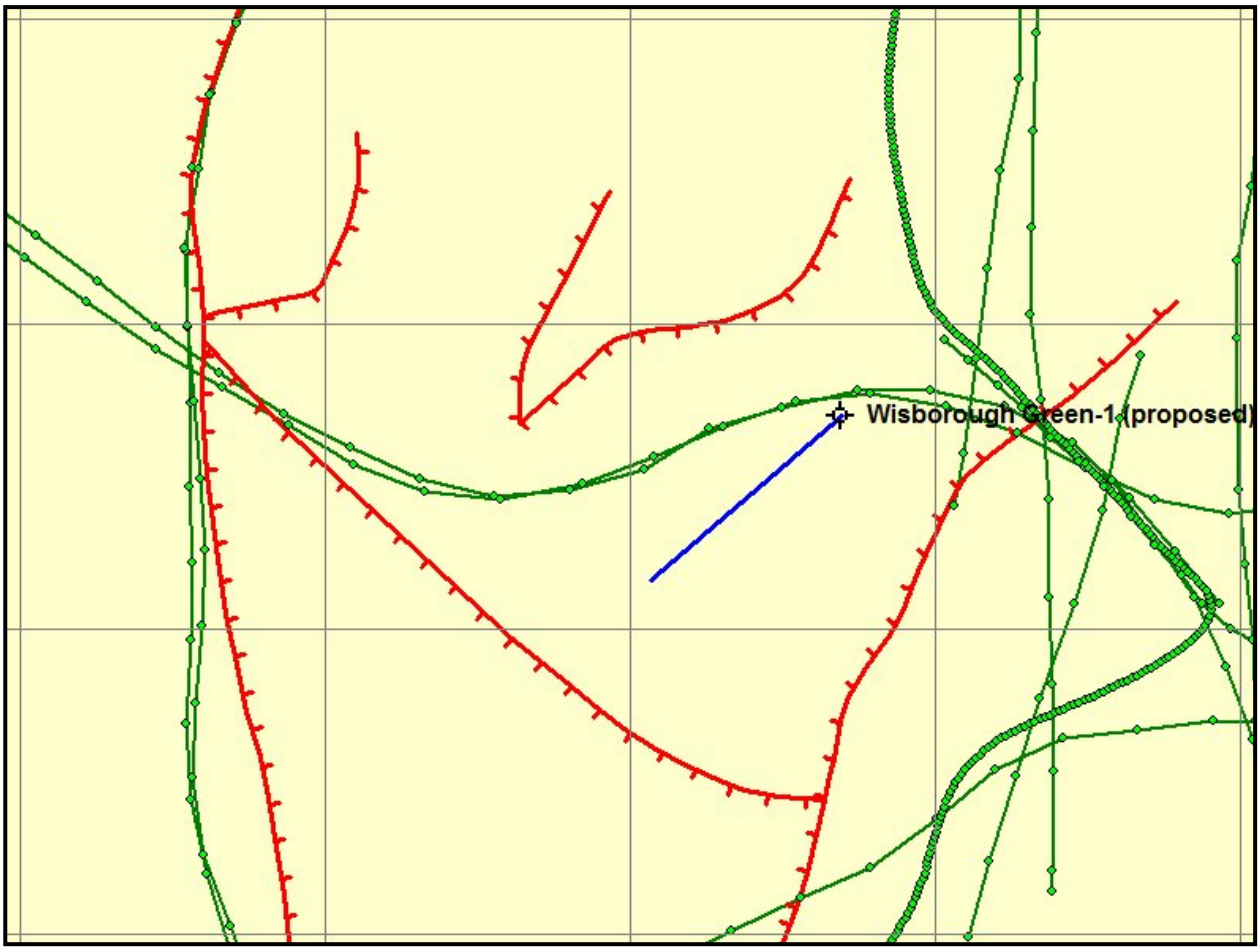

Fig. 2.2. Faulting (red) and seismic profiles (green) in the vicinity of the proposed wellsite. National grid shown at a 1 km interval (squares). Tick marks show the downthrown side of faults. The blue line is the proposed horizontal well taken from the Celtique ES map, fig. 11.1. Here it is 825 m long, but in the text it was originally described as 5000', or 1524 m, in length. The revised version of the ES (chapter 11A) states in the text that it will be directed to the SW for 762 m. Near the wellsite there are two practically coincident seismic lines running E-W, which were obtained by survey equipment occupying the Kirdford Road west of Wisborough Green. One of these lines is essentially a duplicate of the other. But the 8 sq km area including the vertical and horizontal wells, west of Wisborough Green (the column of three OS squares at the right-hand side of the map) is entirely devoid of seismic data.

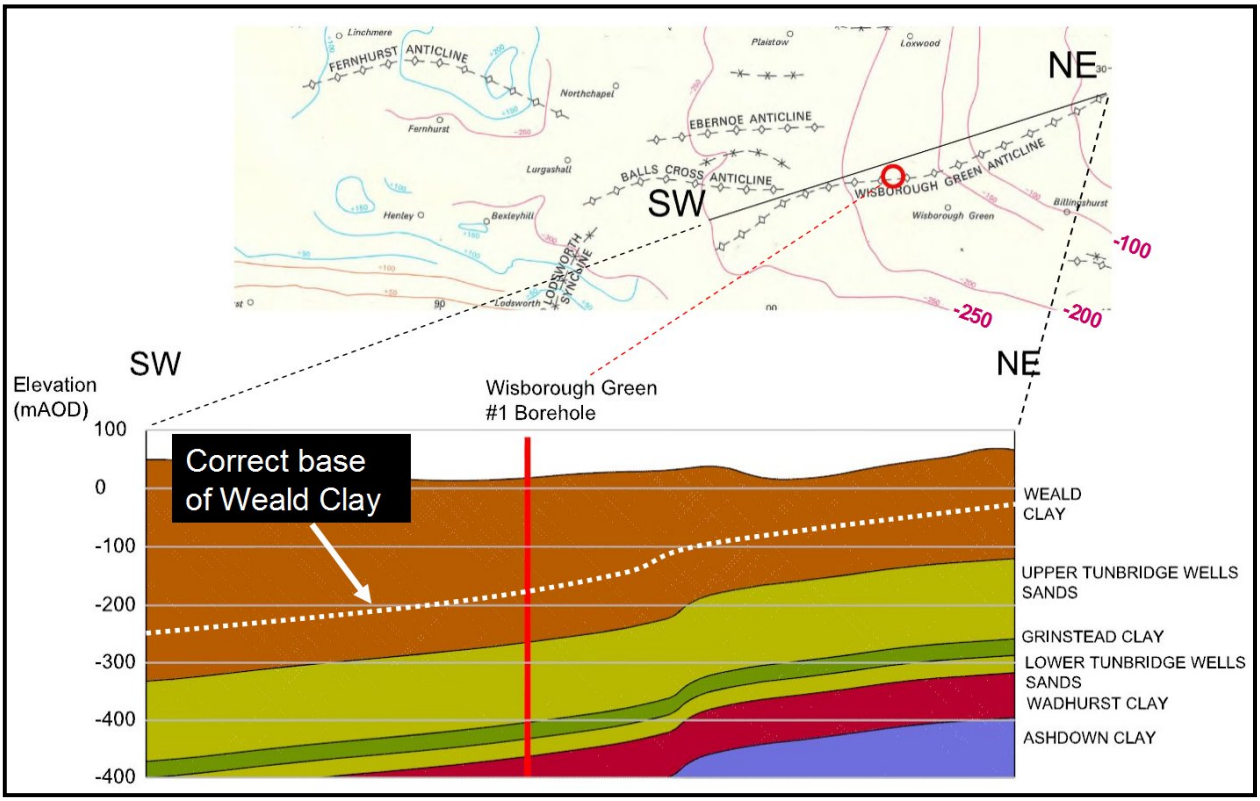

Fig. 2.3. Extract from Celtique Energie Wisborough Green ES, fig. 11.4, with additions and corrections. Top: extract from BGS map showing contours on base of Weald Clay in red. Bottom: cross-section drawn by Celtique Energie. The base of the Weald Clay (brown) is 80 m too deep, as can be seen by inspection of the BGS contour map above. The correct depth according to the BGS is shown by the added white dotted line. Also, the step in the layers to the NE of the well is less marked than suggested by Celtique.

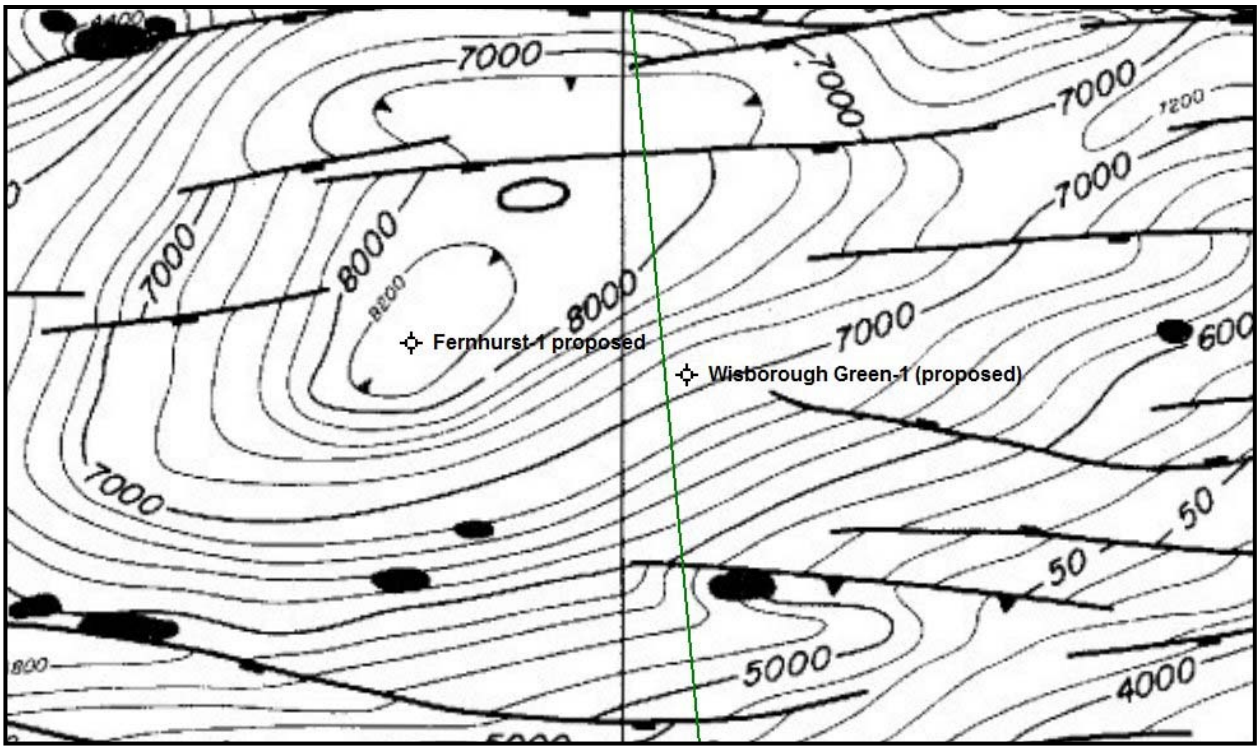

Fig. 2.4. Faulting at Base Jurassic level (thick lines running E-W). Structure contours (finer lines) are labelled in feet. The green line shows the location of the geological profile shown in the next figure.

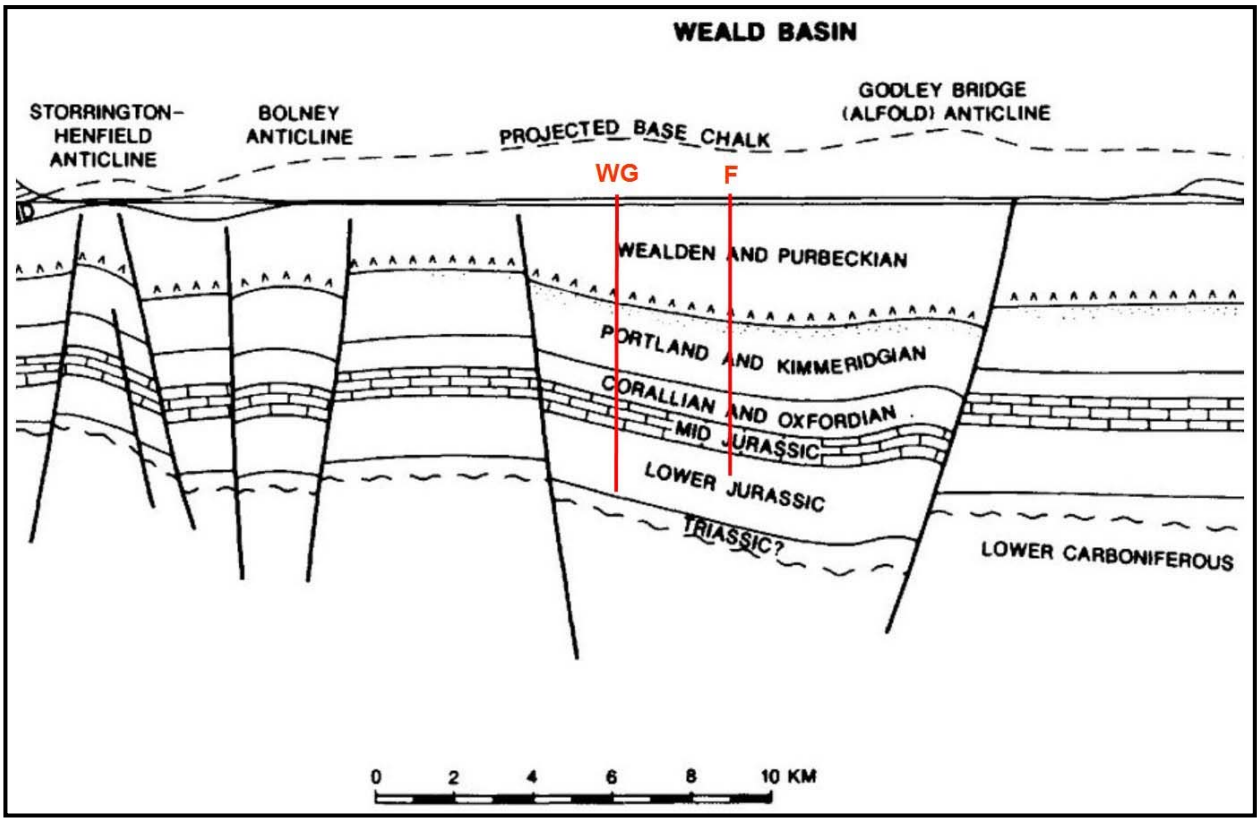

Fig. 2.5. Central part of regional north-south cross-section across the Weald (Butler & Pullan 1990). South is at the left. WG – Wisborough Green-1 proposed well, projected west by 1.4 km; F – Fernhurst-1 proposed well, projected east by 14 km.

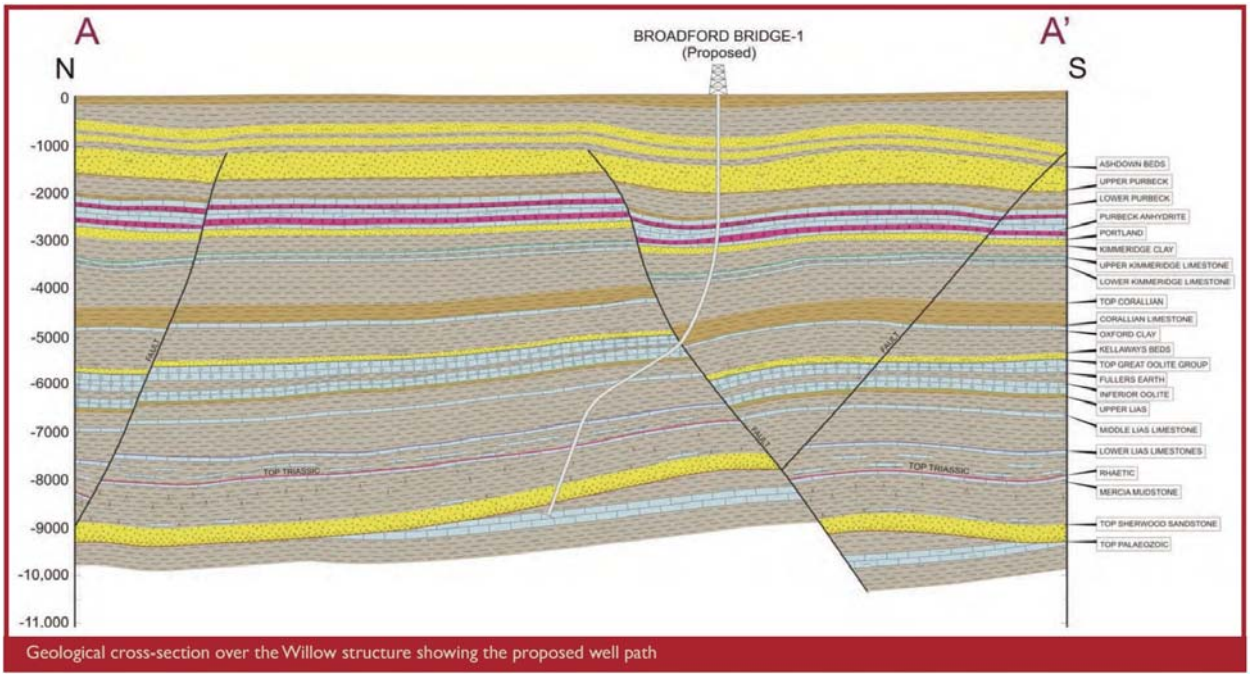

Fig. 2.6. Geological cross-section through the Willow conventional oil prospect, south-eastern PEDL234, taken from a Celtique exhibition board. It illustrates large E-W trending faults which extend upwards to about 300 m below the surface.

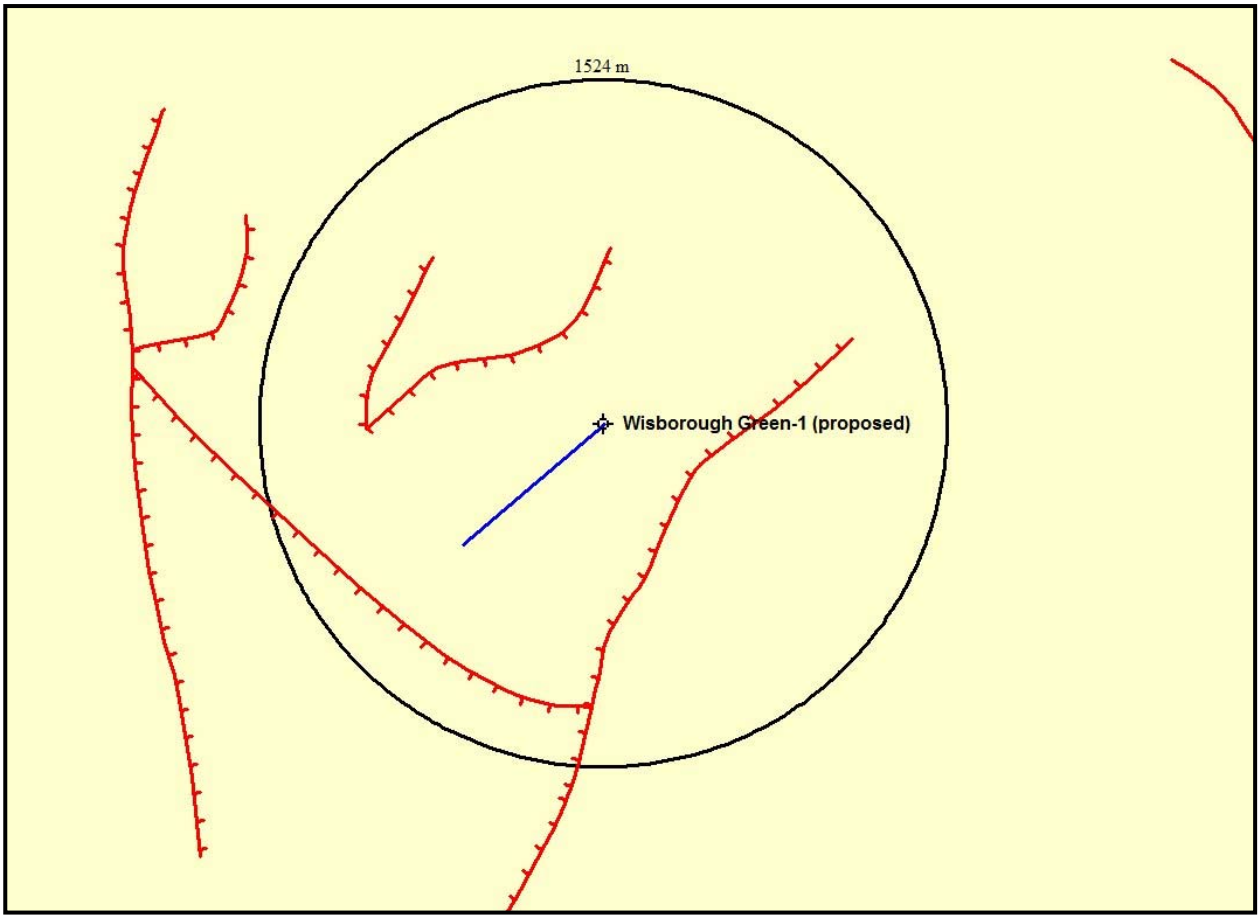

Fig. 2.7. Wisborough Green-1 proposed horizontal well plan according to Celtique (ES fig. 11.1), shown as the solid blue line. Surface faults as mapped by the BGS are shown by red lines with tick marks on the downthrown side. The subsurface positions of these faults will be slightly different. According to the ES map the horizontal will extend 825 m SW of the wellsite, as shown here. In the original ES text it was described as 5000', or 1524 m, in length, as shown by the range ring drawn around the vertical wellsite (black circle). There was also confusion in the Celtique ES about the intended direction of the horizontal well (whether towards the NE, NW or SW). Note that if drilled in any direction except NE it will penetrate and cut through one or more faults. The revised version of the ES (chapter 11A) states in the text that it will be directed to the SW for 762 m. The direction now matches the map, but the distance still mismatches the map, being 62 m shorter than shown on the map.

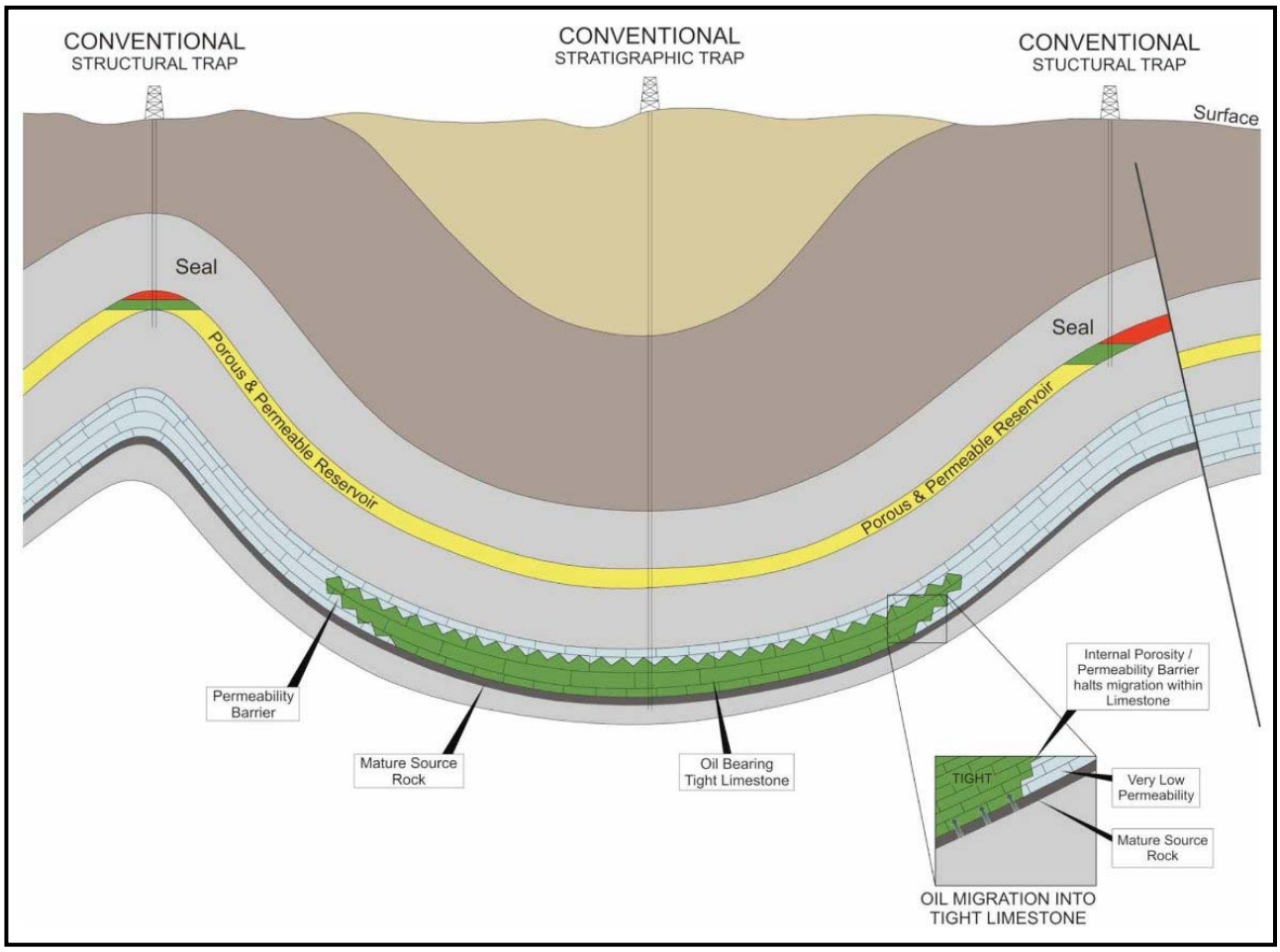

Fig. 2.8. Celtique schematic cross-section showing that the oil-bearing 'tight' (very low permeability) limestone (one of the targets in the present application, shown in light blue) is an *unconventional* resource. It is in contrast to the two examples shown at either side of *conventional* structural traps (green – oil; red – gas). The central oil bearing zone (green) within the limestone is <u>not</u> a conventional trap, as misleadingly labelled at the top of the figure.

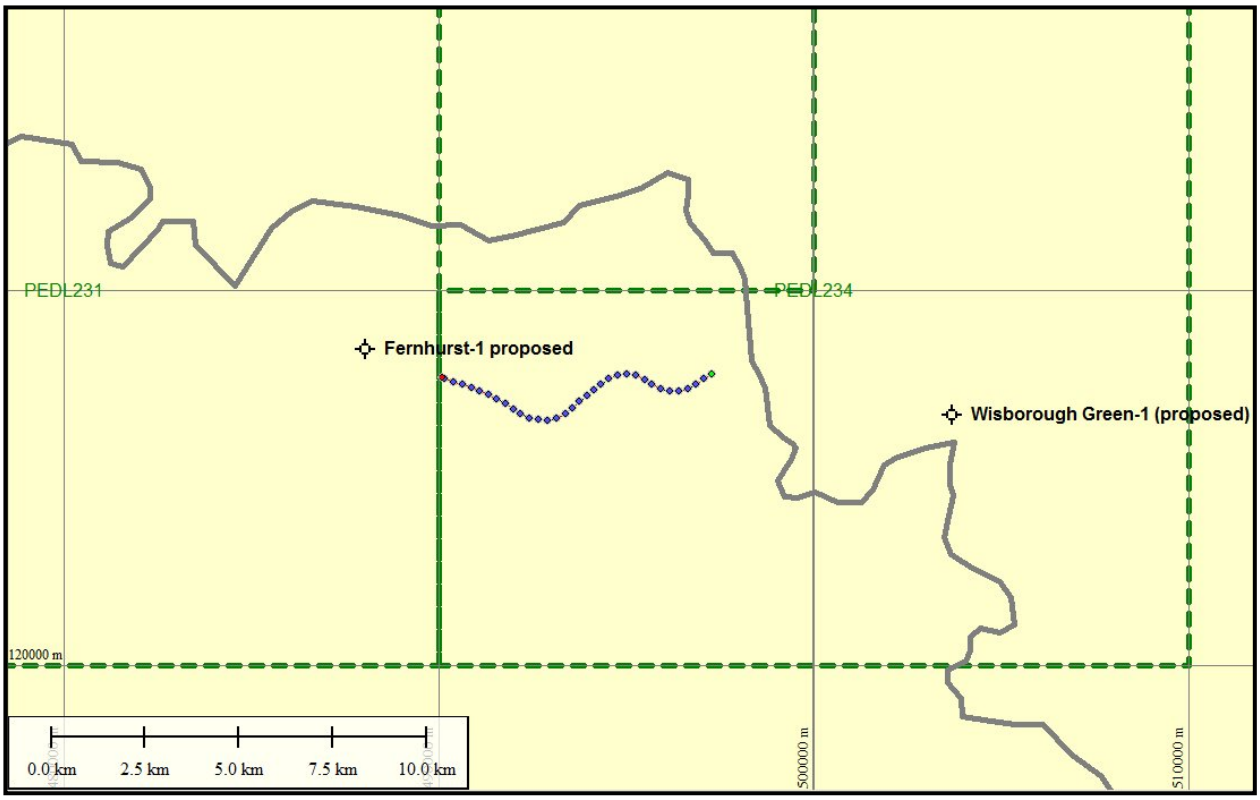

Fig. 2.9. Location map of seismic line TER-91-06 used by Celtique (blue dots) to illustrate both the Wisborough Green and the Fernhurst prospects. It lies from 6.5 to 13.5 km west of the proposed Wisborough Green-1 well. The grey line is the South Downs National Park boundary.

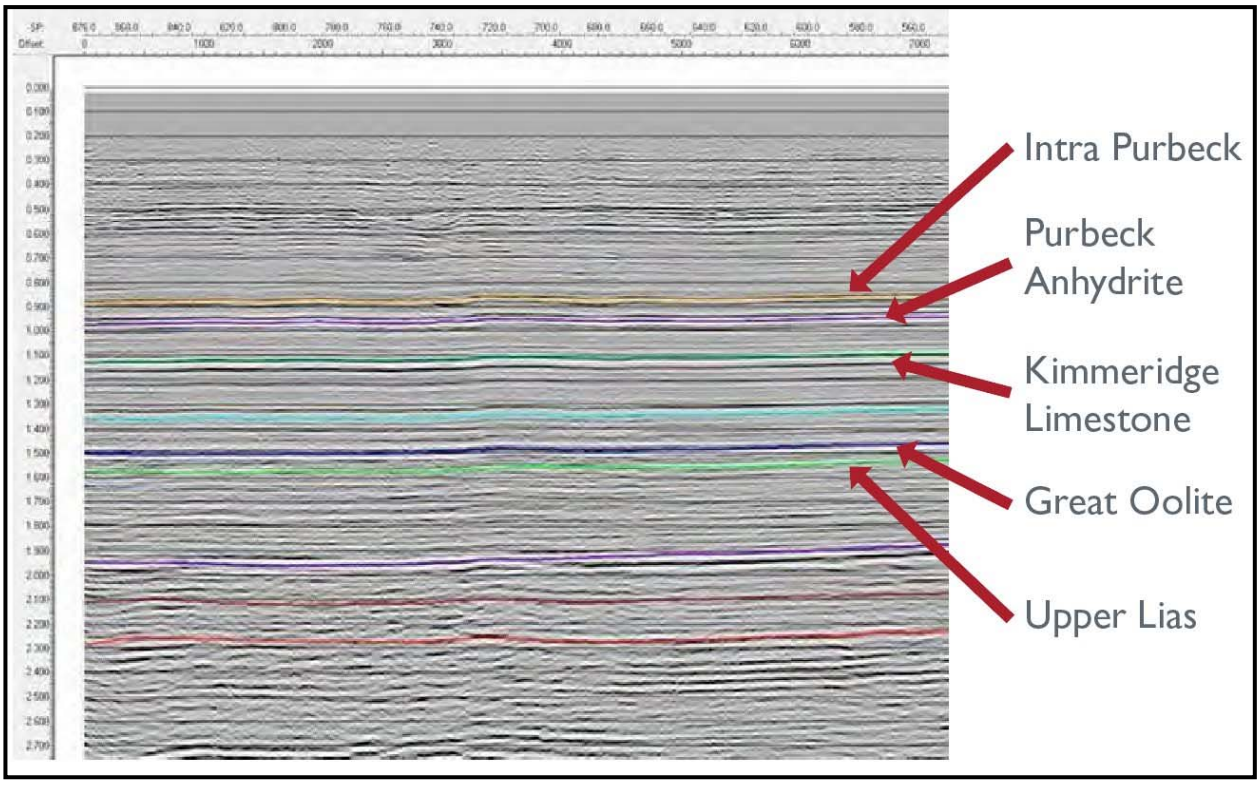

Fig. 2.10. Seismic line sample used by Celtique. This appears to be a reprocessed version of line TER-91-06, located in the previous figure.

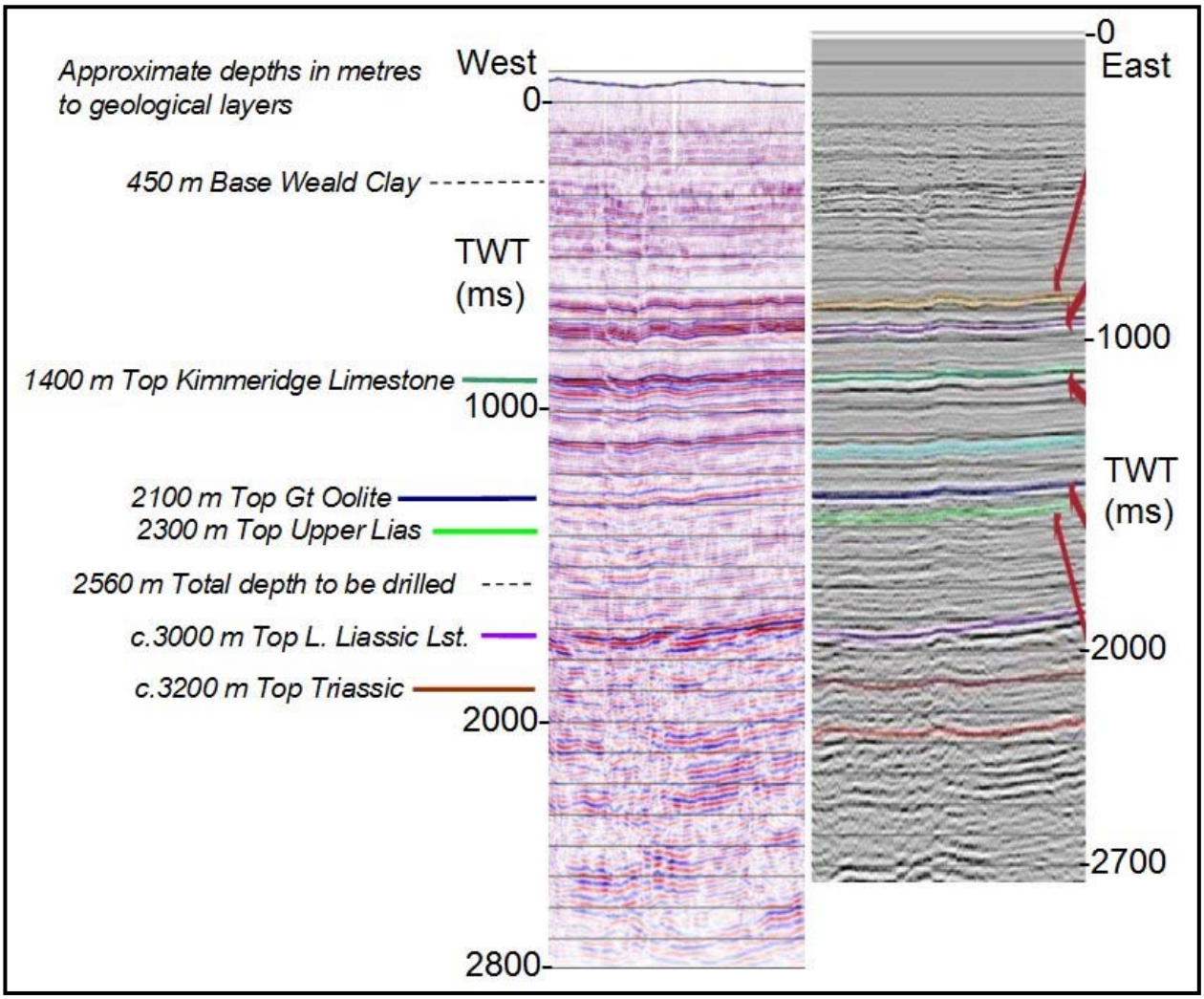

Fig. 2.11. Comparison of original version of TER-91-06 (left) and the reprocessed version used by Celtique (right). Both versions have been trimmed to approximately the same data area, from shot-points 1400 to 2046 and down to 2700 ms two-way time (TWT), and compressed horizontally. Details of the faults evident only in the original version are shown in the next two diagrams.

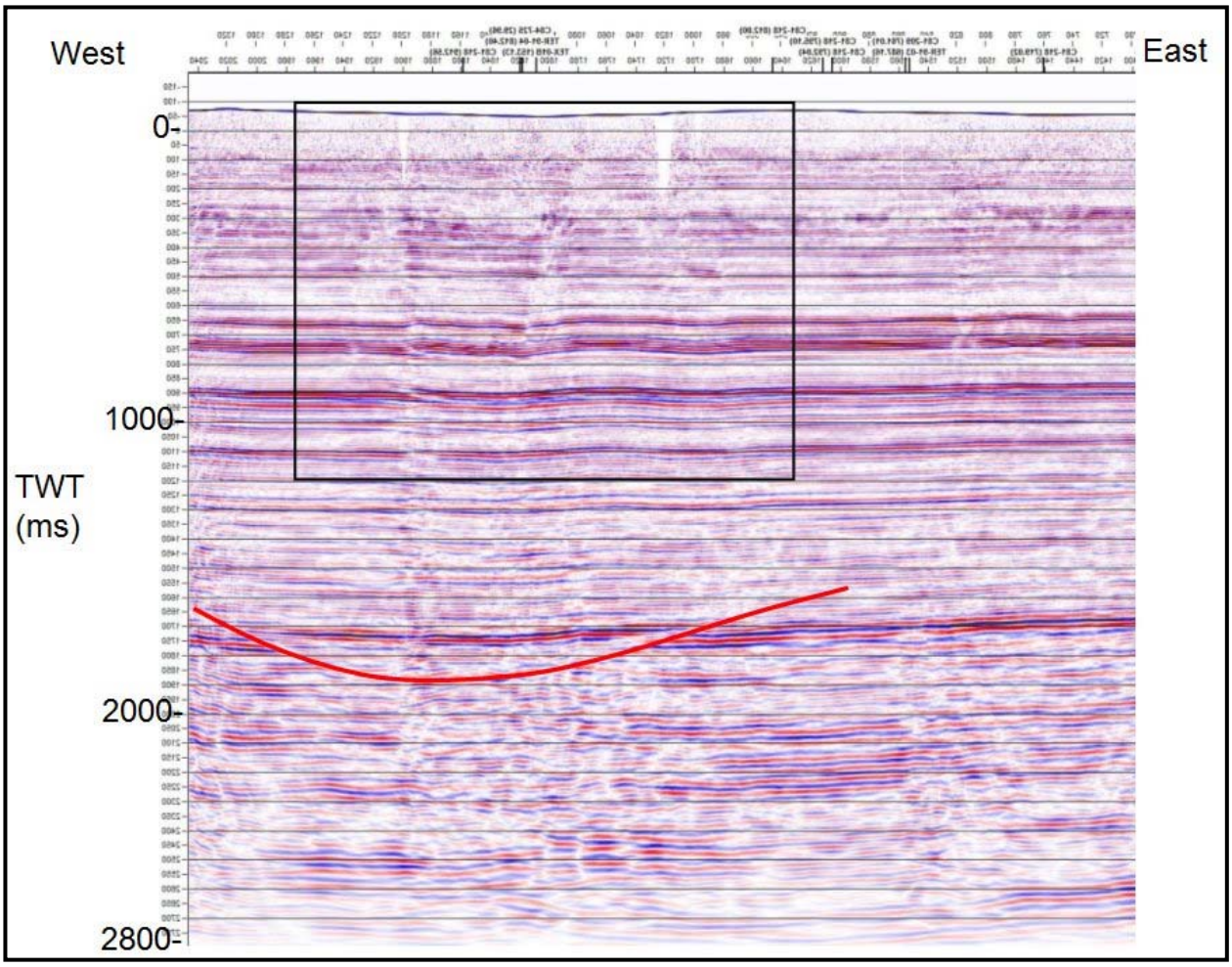

Fig. 2.12. Original version of TER-91-06. This shows clear evidence of a fault (red curve) cutting very obliquely through the section between 1600 and 1900 ms. The fault is probably planar; it is the seismic line that is curved and hence intersects the fault-plane twice. The central part above the 'smile' is the upthrown side. Detail within the black rectangle is shown in the next figure.

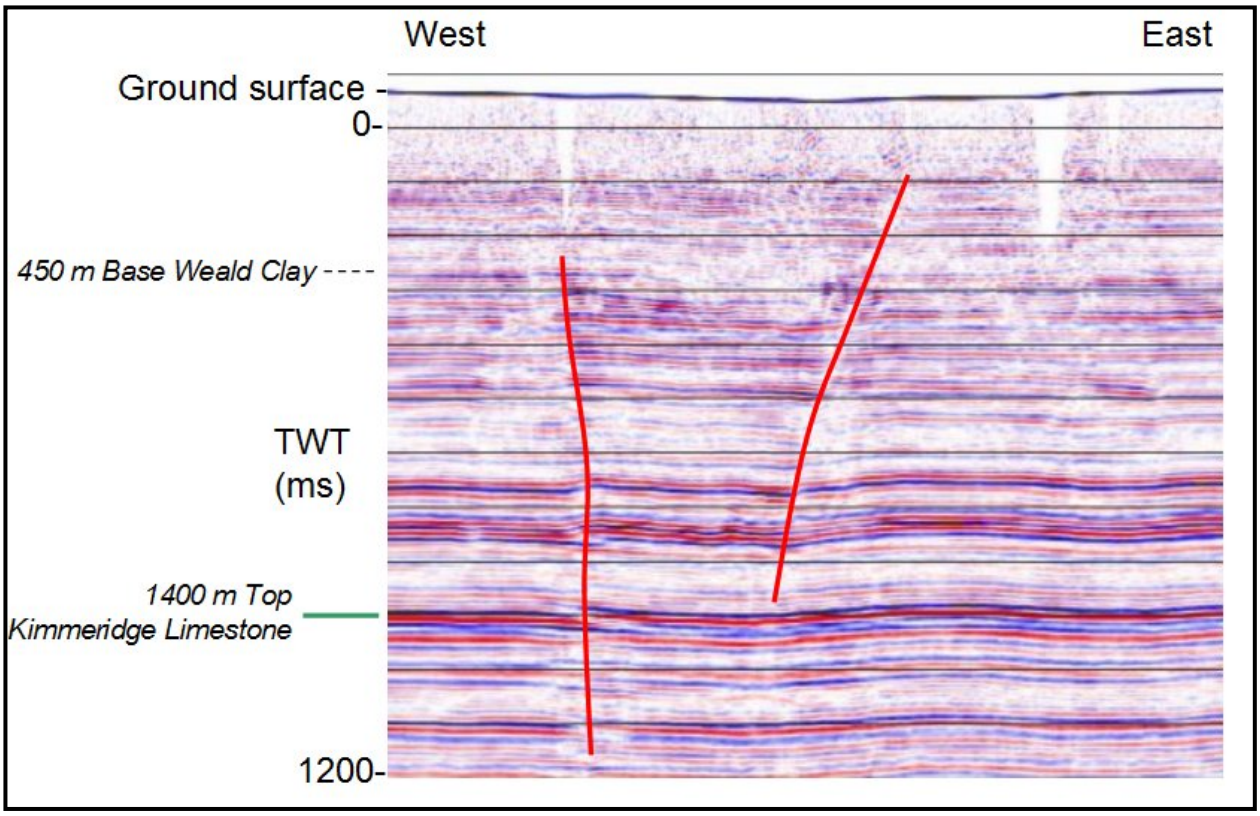

Fig. 2.13. Detail from preceding figure showing faults at shallow depth, penetrating upwards into the Weald Clay.

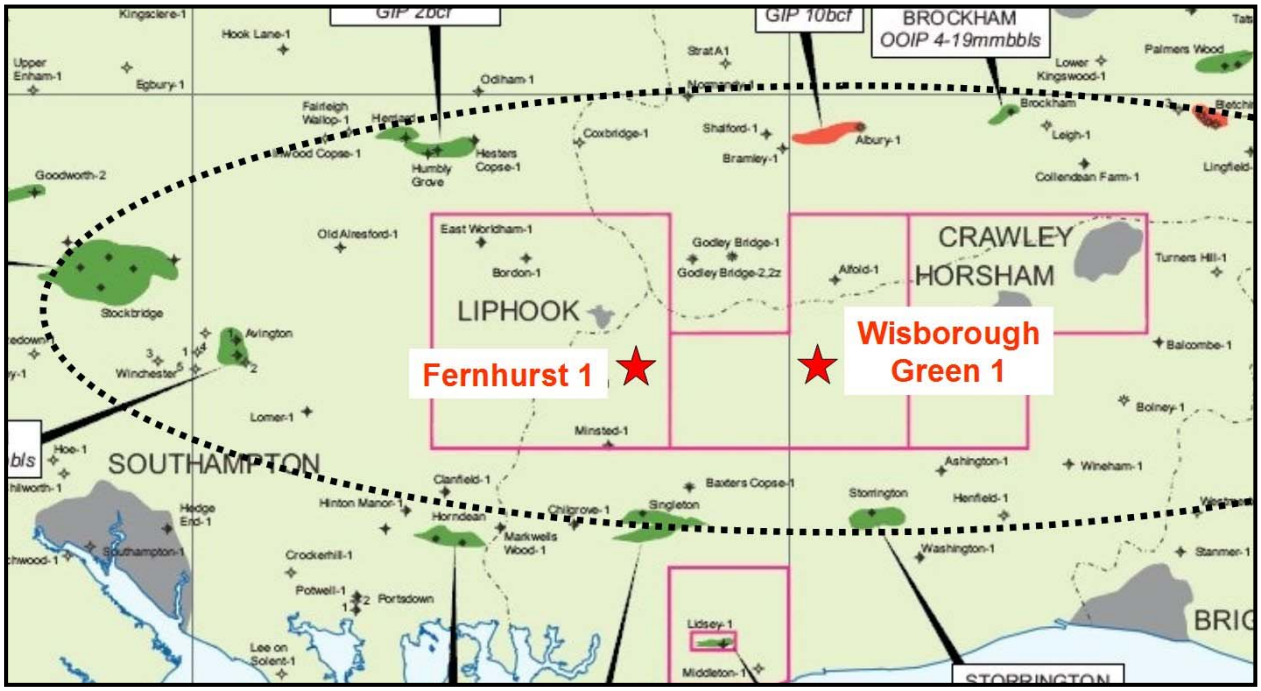

Fig. 2.14. Celtique map showing how conventional oil and gas already discovered in the Weald occurs in local high spots (green or red) around the edge of the basin (near the dotted elliptical line), whereas Celtique's proposed wells (red stars) lie in the centre of the basin.

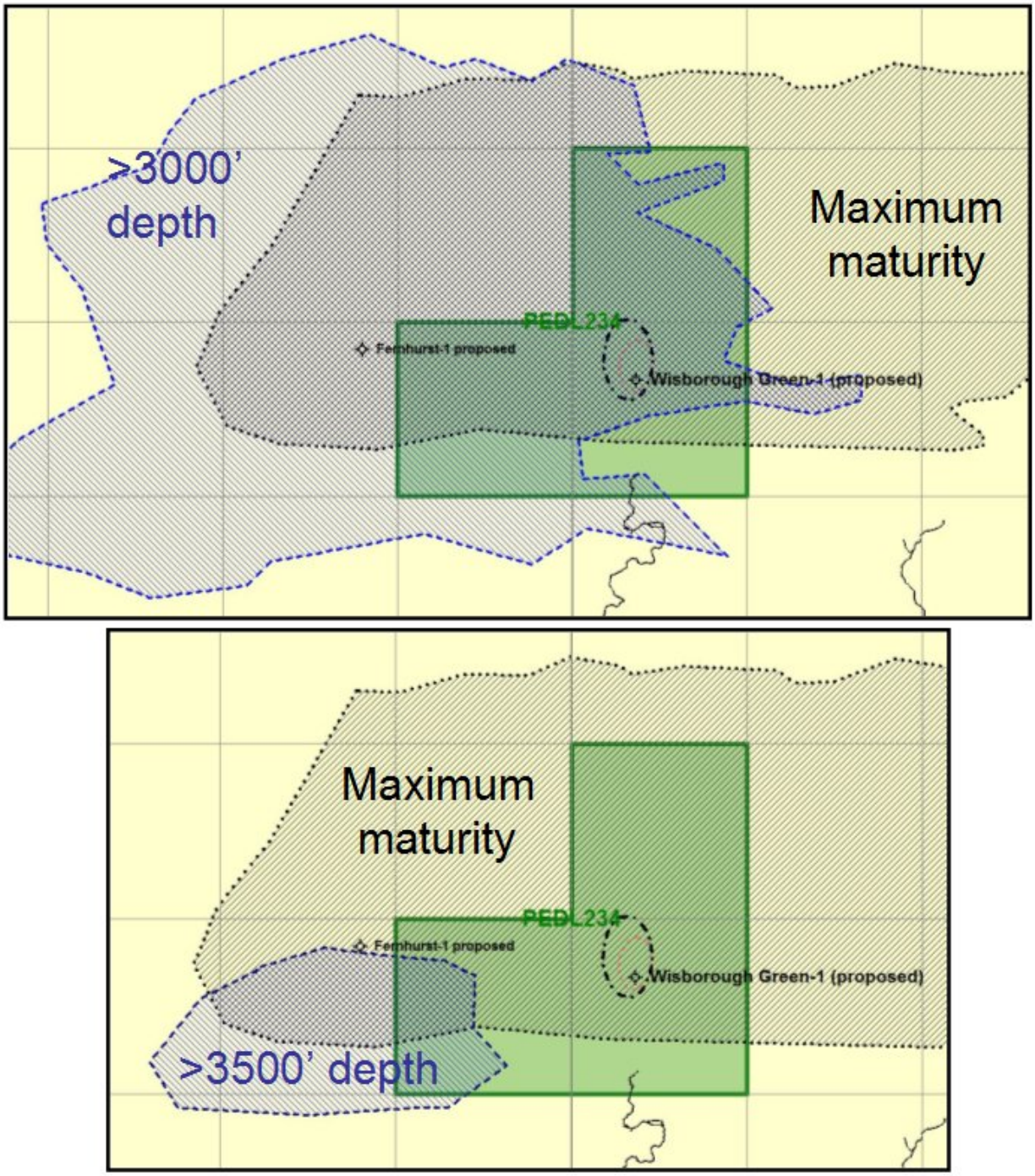

Fig. 2.15. BGS map of Kimmeridge Clay maximum maturity (black hatching) with depth to the base (3000' upper diagram, 3500' lower diagram). A search area criterion used by Celtique is to take the area of intersection of depth and maturity. In the upper, less stringent case, the intersection area occupies most of Celtique's licence (PEDL234, in green). In the more stringent case (lower diagram) the area of intersection is confined to the very western limit of the licence. Celtique's primary and secondary site search areas are marked as oval areas around the proposed Wisborough Green-1 well (pink and black dot-dash lines, respectively). They seem to bear no relation to the BGS data.

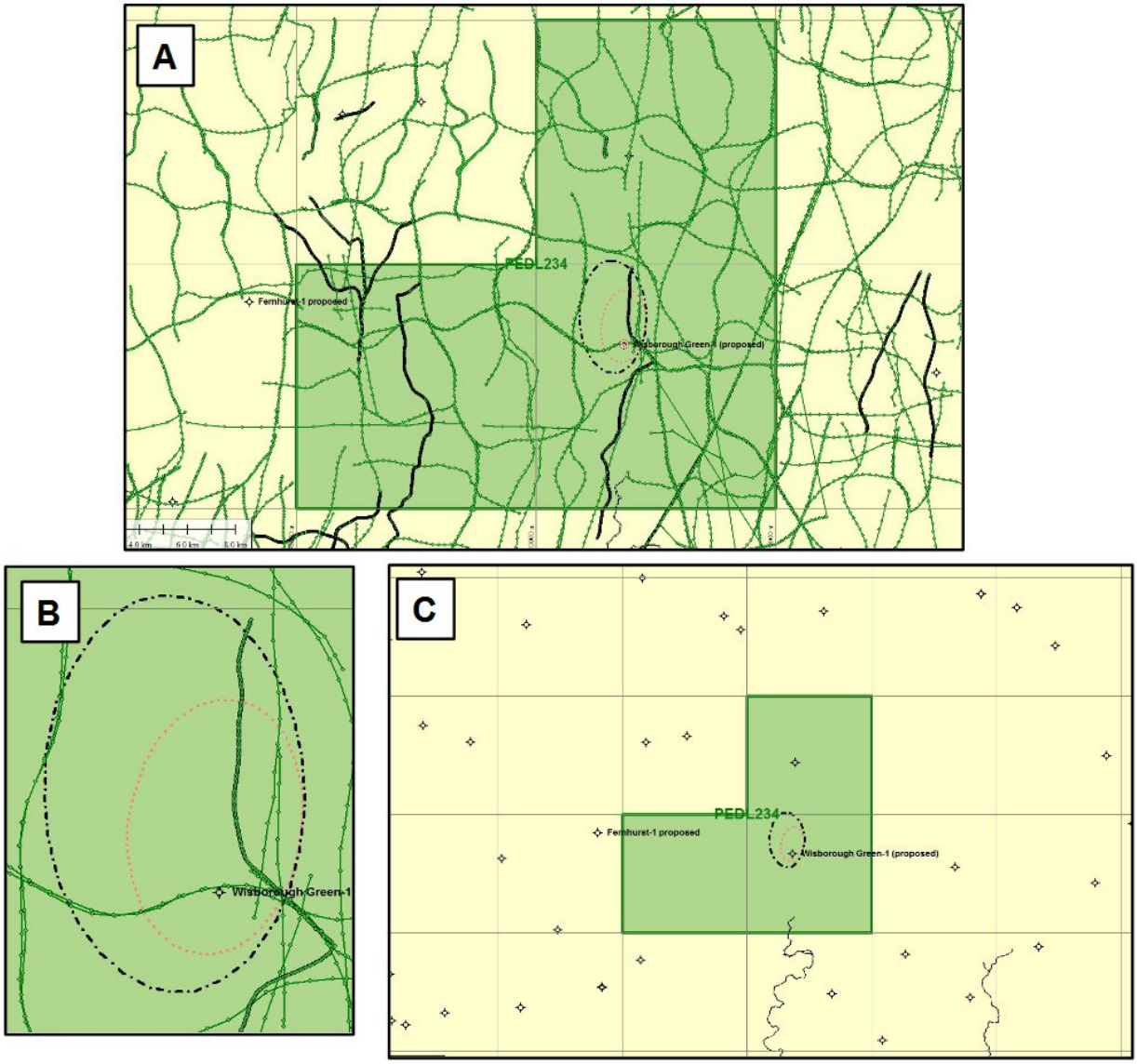

Fig. 2.16. A. Seismic coverage (green lines) around PEDL234 (green block).

B. Detail from A, showing the primary search area (pink dotted ellipse) and secondary search area (black-dot-dash ellipse) around the proposed well. C. Existing wells in the region surrounding PEDL234.

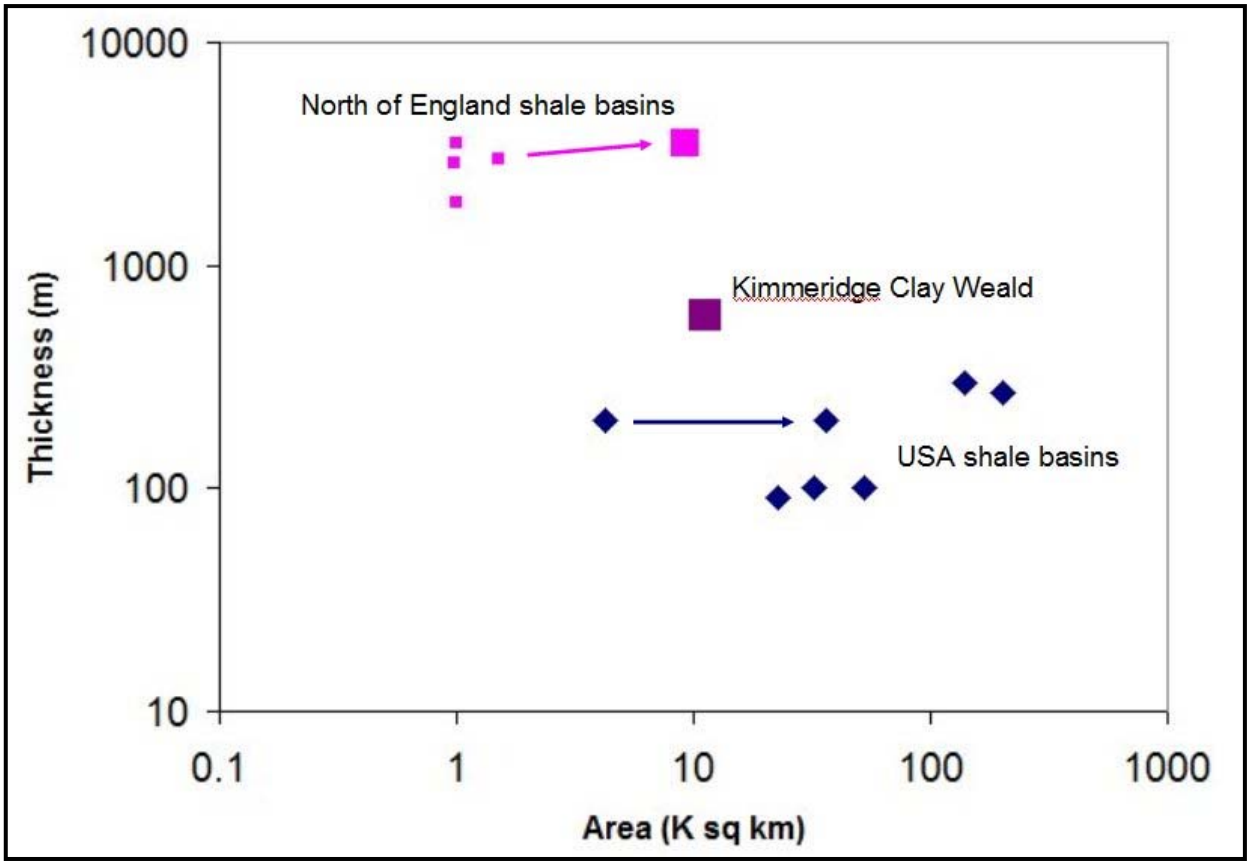

Fig. 3.1. Log-log graph of the maximum thickness of shale layer *vs.* basin area. Lilac arrow shows four north of England basins combined as one; blue arrow indicates that the smallest US basin (Arkoma) is in fact part of the bigger Anadarko Basin to the right. In general the UK basins are 5 to 50 times thicker than the US basins, but 5 to 100 times smaller in surface area. The density of surface-mapped faulting in the Weald and north of England is 400 times greater than the average for the US basins.

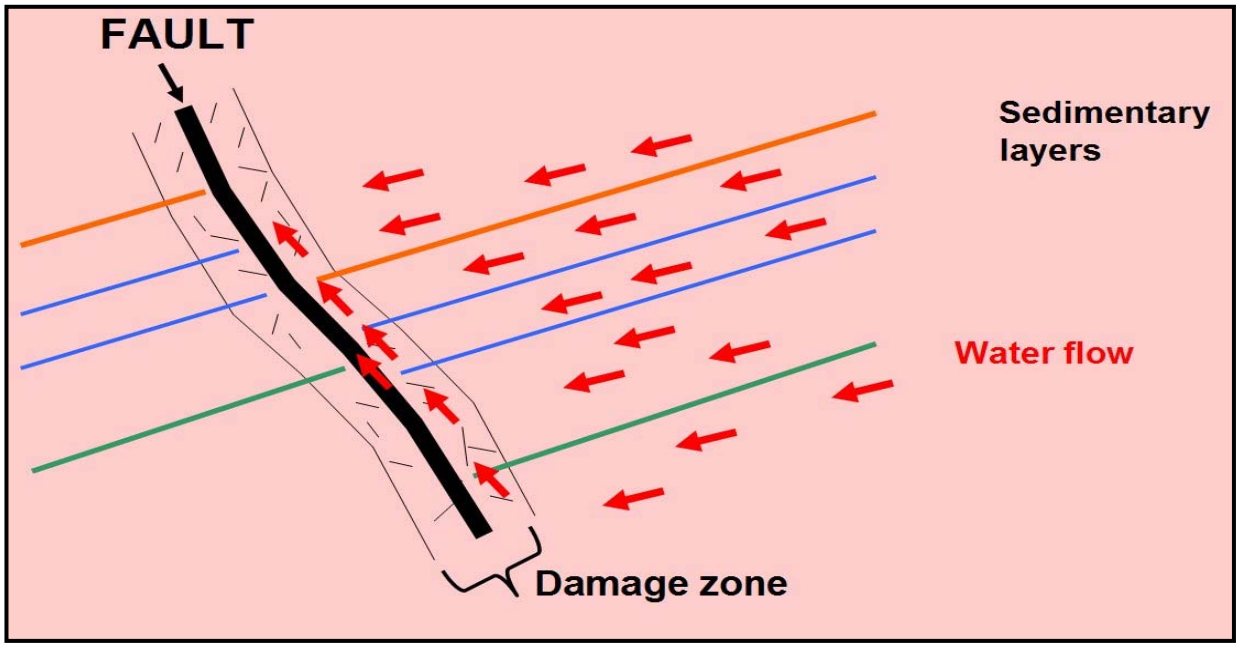

Fig. 4.1. Cartoon of a fault zone and resulting fluid flow (red arrows). The core zone (black) could be a barrier, or it could be a conduit. The damage zone on either side is always a conduit because it is fractured.

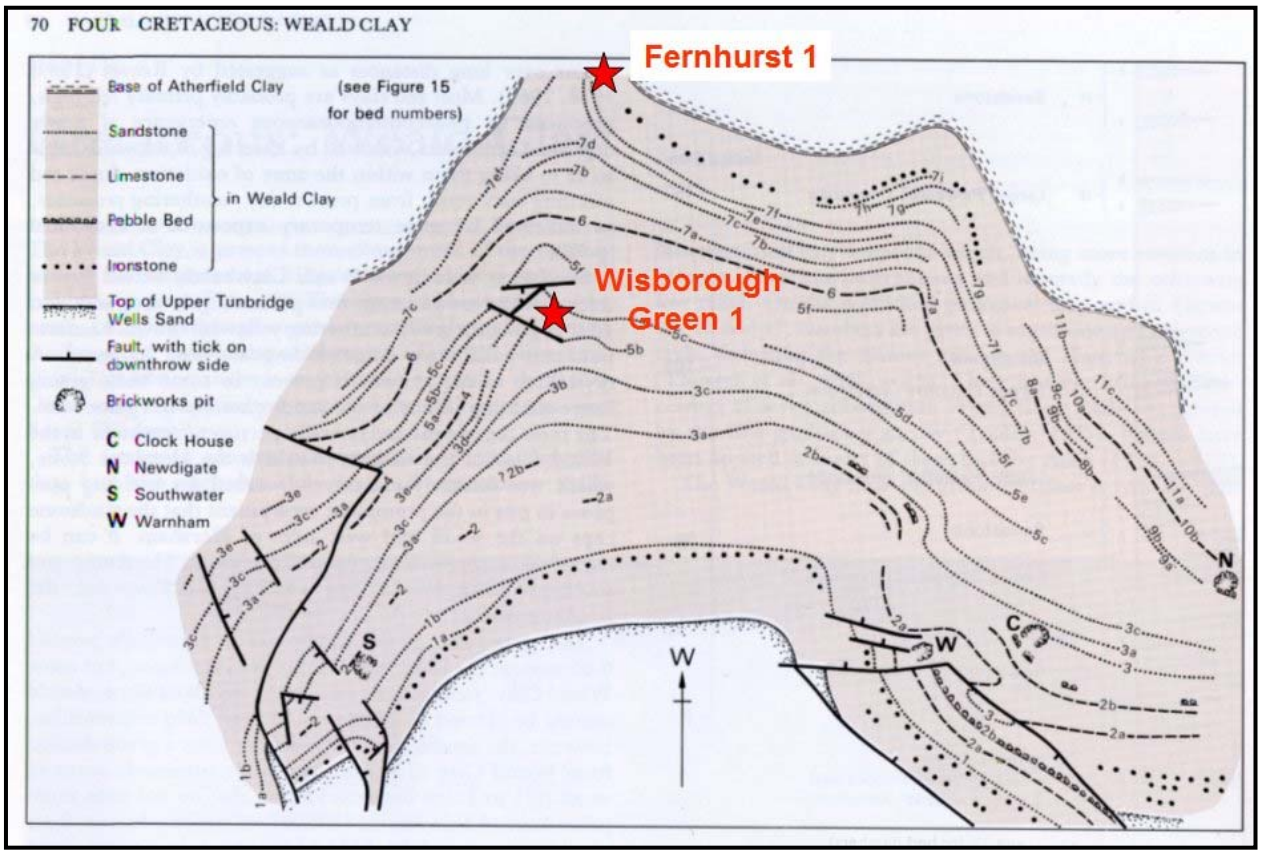

Fig. 5.1. BGS map of the Weald Clay. West is up, and the map is anamorphic; it has been highly compressed in the E-W direction. Celtique's other proposed well, Fernhurst-1, is 16 km west of Wisborough Green-1. Fernhurst-1 is almost at the top of the Weald Clay succession; Wisborough Green-1 is in the middle of the succession.

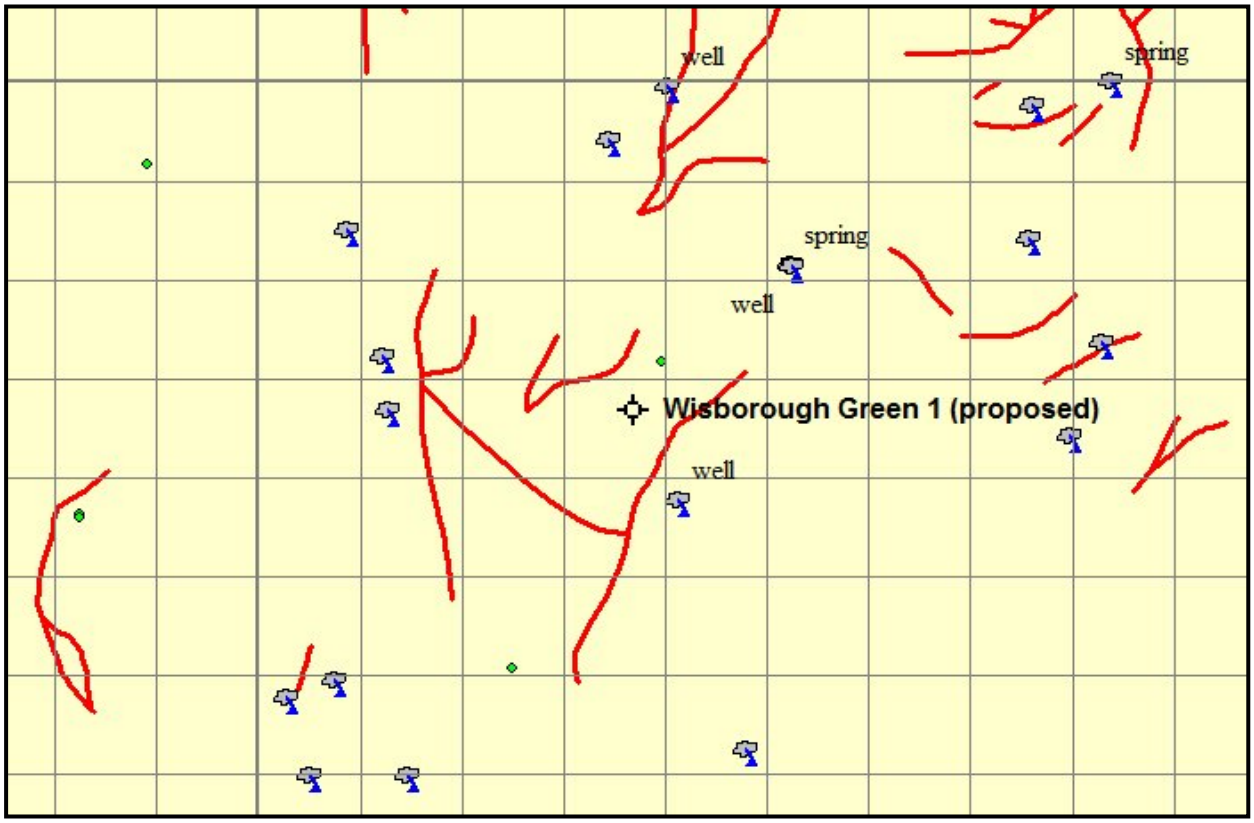

Fig. 5.2. Escapes ('Issues') of water (grey/blue symbol) around the proposed well location, from OS 1:10K maps. Two features are labelled 'spring', and two labelled 'well' by the OS. There are 15 natural issues or springs within about 5 km of the proposed well. Surface-mapped faults are shown in red. Four water wells producing water are shown by a green dot. OS grid spacing 1 km.