Geological analysis of the Horse Hill prospect

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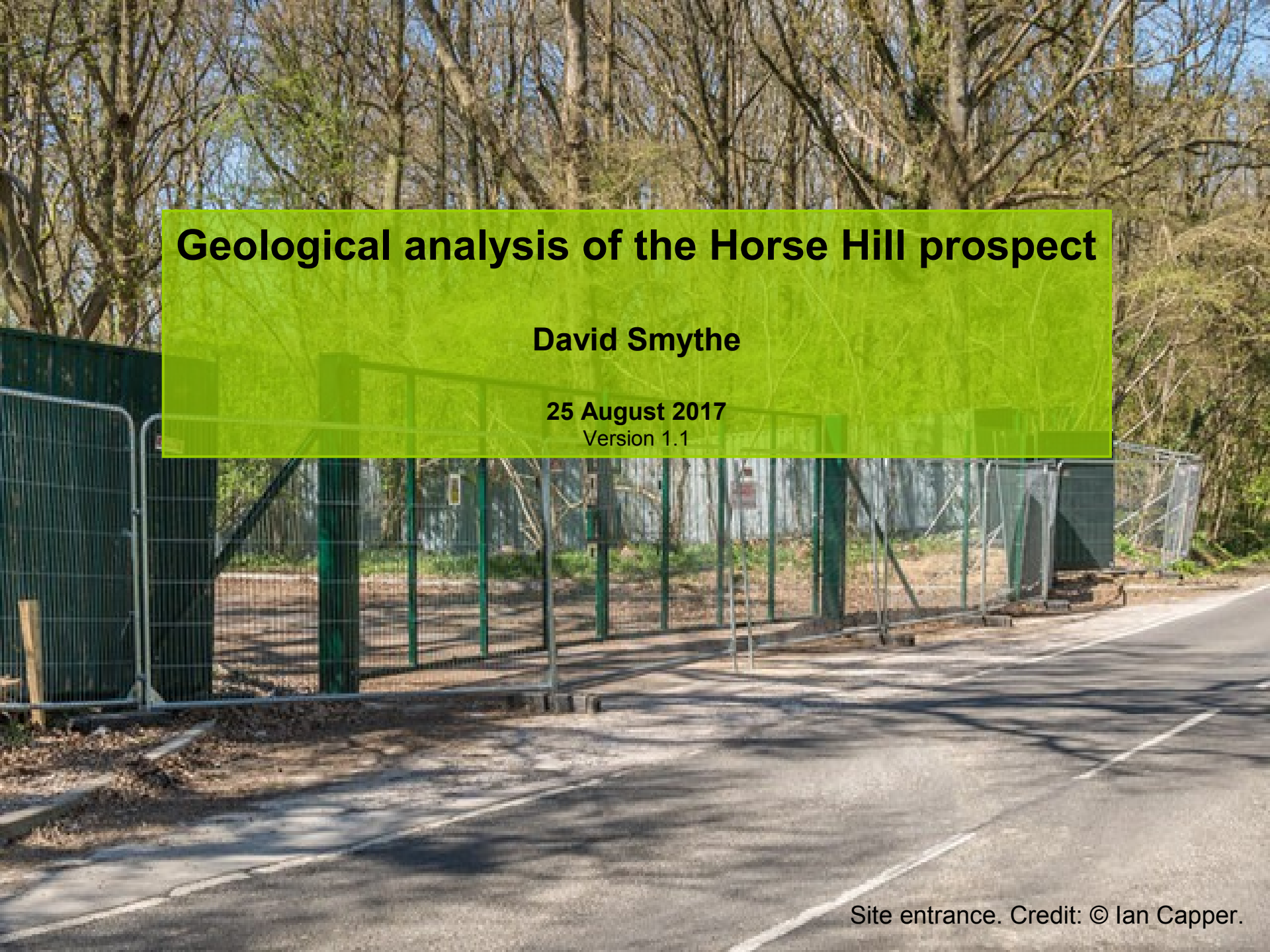
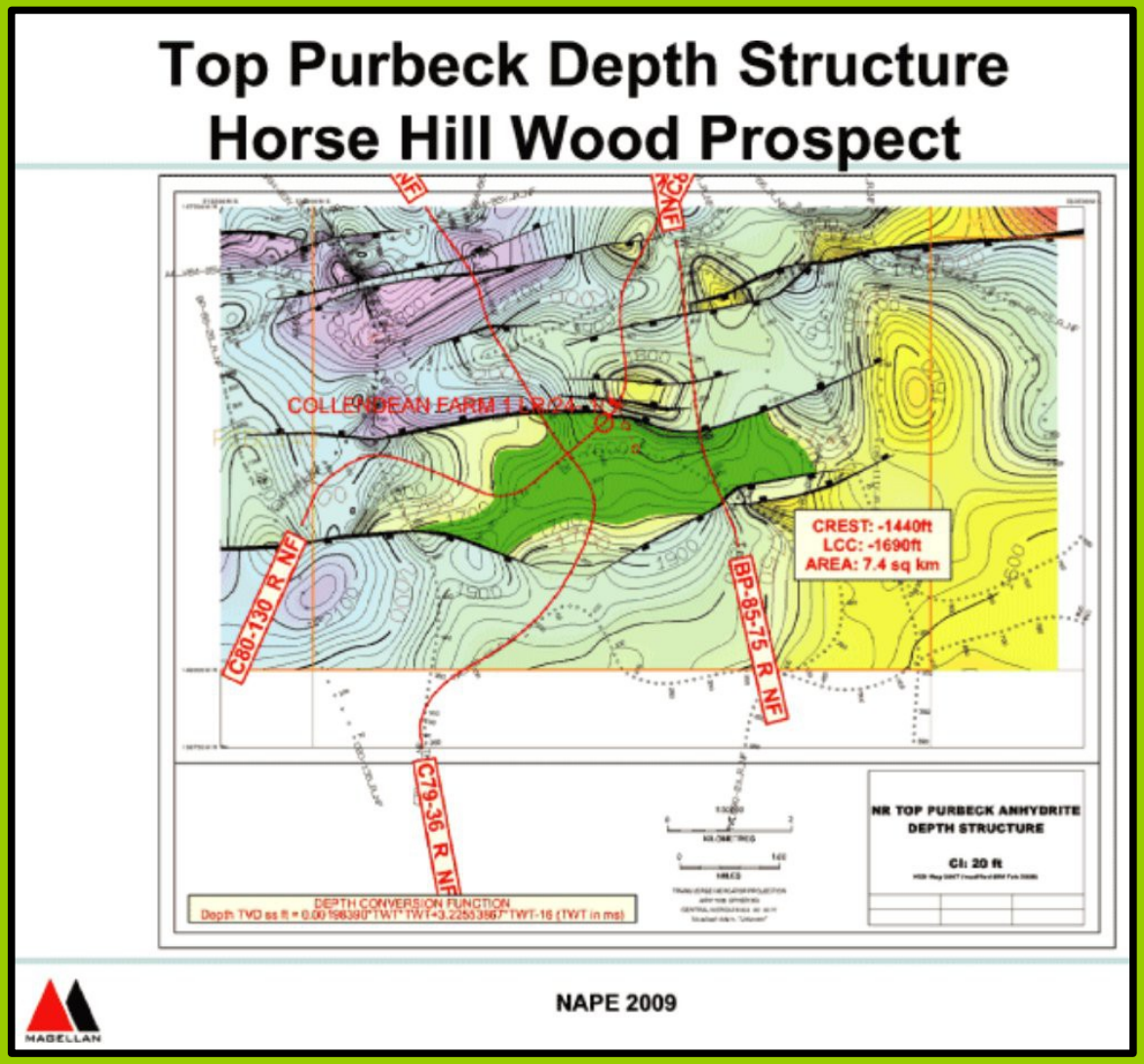
Version 1.1



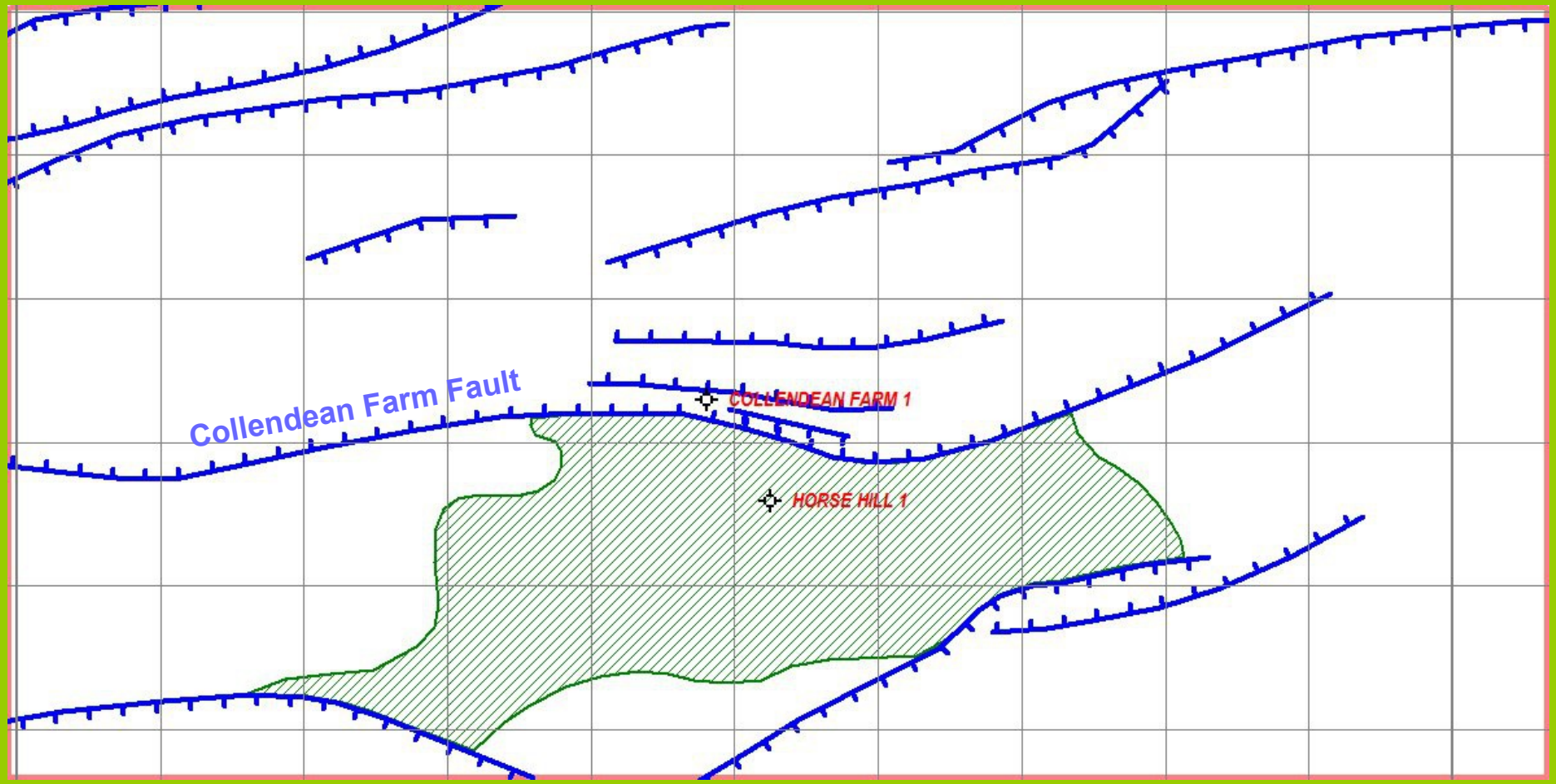
Site entrance. Credit: © Ian Capper.

UK Oil & Gas Investments Plc (UKOG):
"*Farm in to UK onshore oil Investment - Horse Hill in the Weald Basin.*

The newly defined Horse Hill prospect covers an area of up to 16 km^2 in the south-west quadrant of PEDL 137. It is a tilted horst structure, similar to the Palmers Wood oil field structure which lies only about 20 km to the northeast. The Collendean Farm-1 well was drilled by ESSO in 1964 on the northeastern edge of the Horse Hill structure and found good oil shows. Recent seismic re-interpretation shows the Collendean Farm-1 well was drilled on the wrong side of a significant fault." [RNS no. 1248W, 20 December 2013]

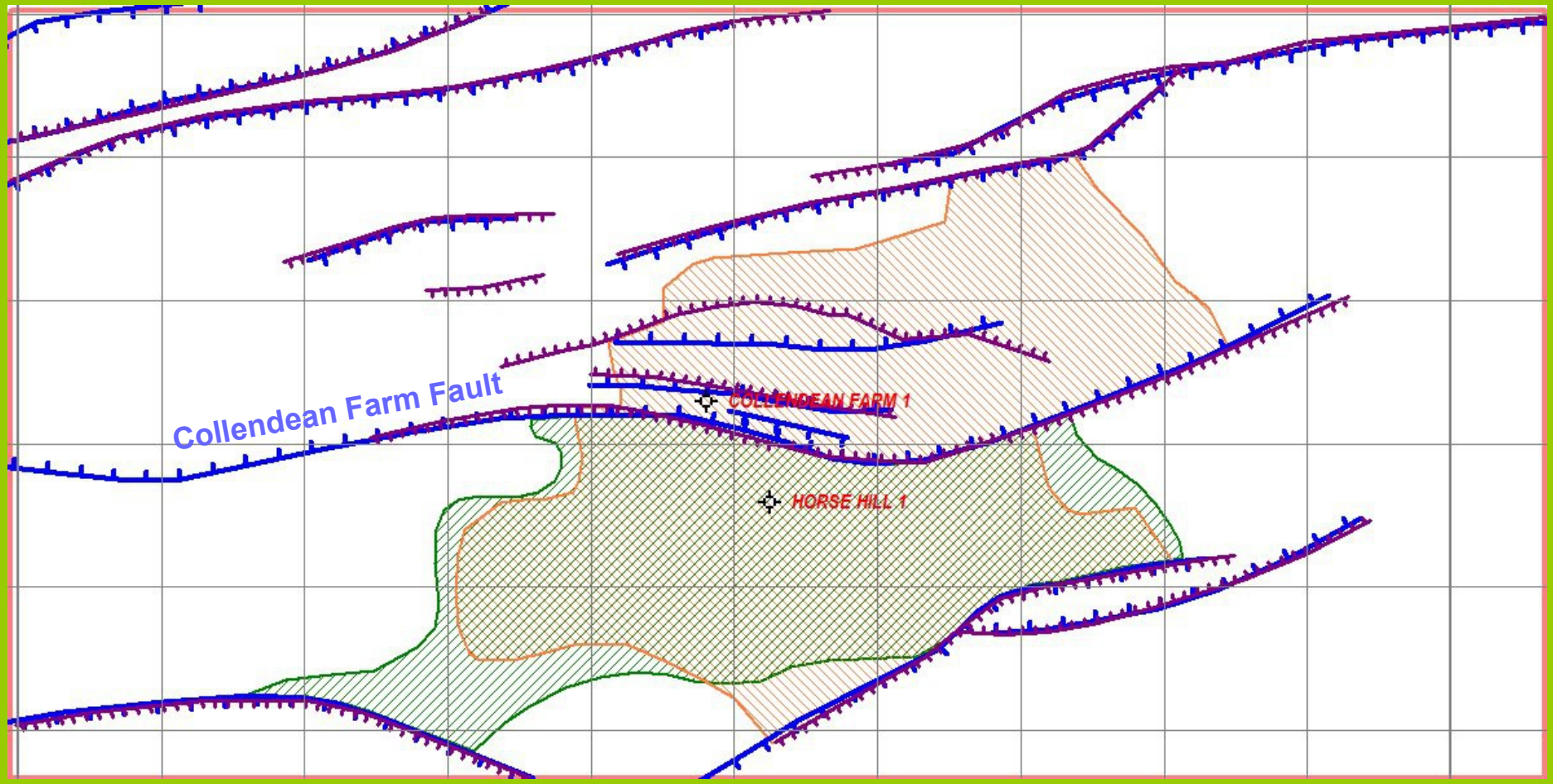


This structure map by Magellan Petroleum, a partner in the Horse Hill prospect, dates from 2009. The area of predicted closure is coloured green. Note that the closure area is based on just three 2D seismic lines, shown in red.

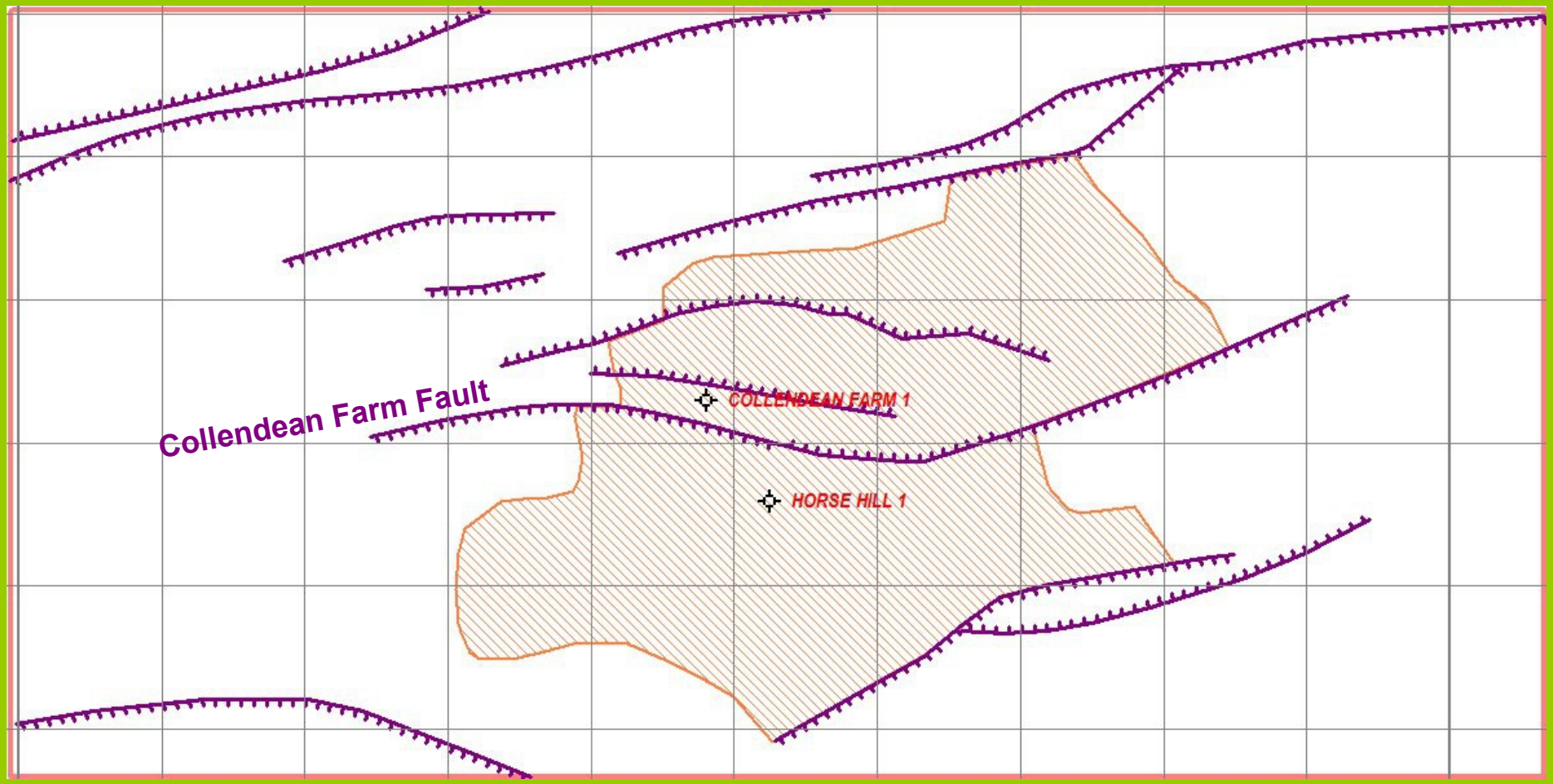


These are the Magellan faults from 2009 (blue, with teeth on the downthrown side), along with the structural closure at Top Purbeck level (green hatching). There is a similar closure deeper, at Top Triassic. In this interpretation the main Collendean Farm Fault runs to the south of the 1964 Collendean Farm-1 well, swings ESE near to Horse Hill-1, and then ENE, directly away from Horse Hill-1.

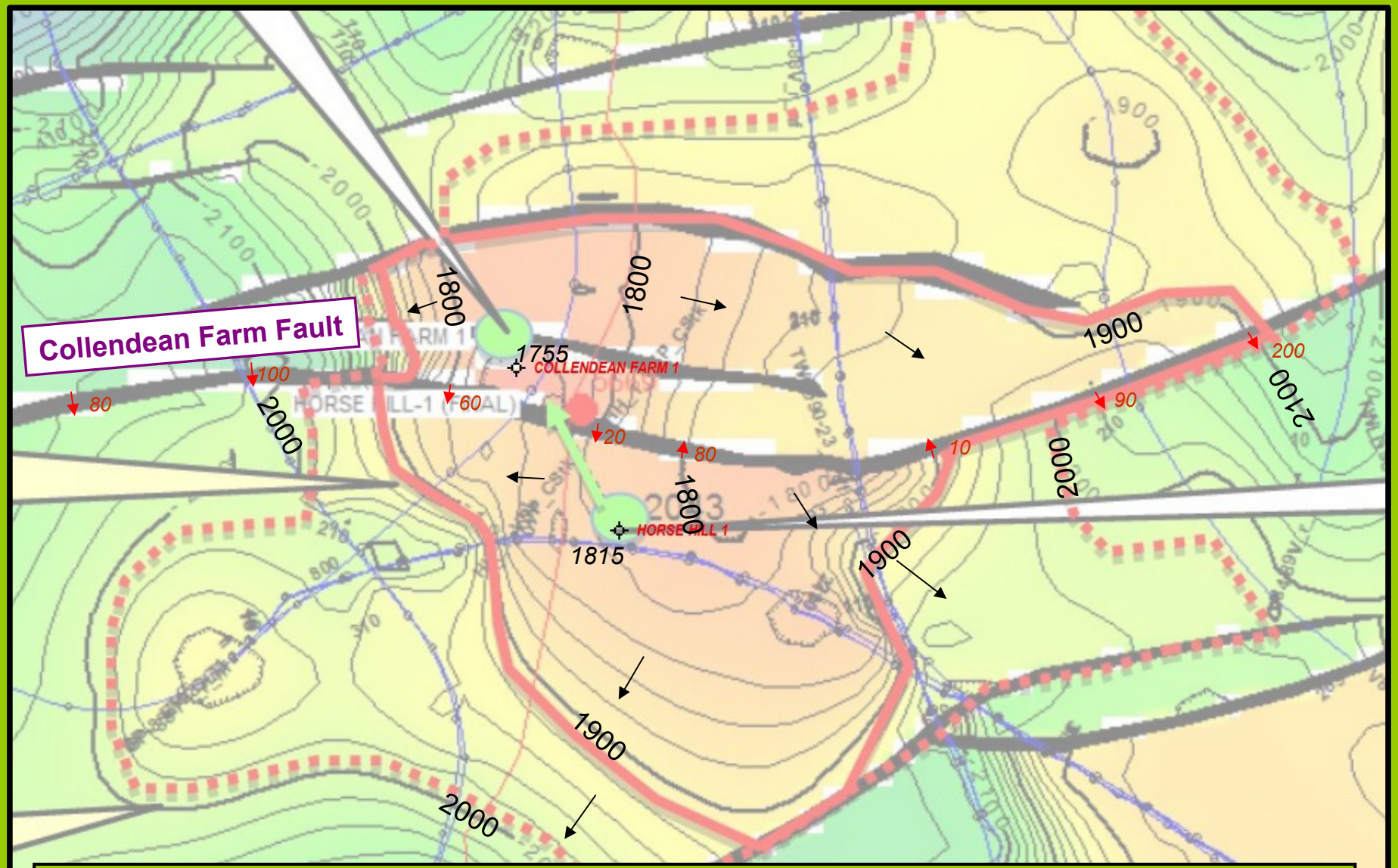
Horse Hill-1 was drilled in late 2014. This analysis shows that the fault interpretation in the area of the two wells shown above is untenable. The revised fault pattern is very different.



The February 2015 UKOG revised version of the structure and prospect, after Horse Hill-1 was drilled, is superimposed on the Magellan prediction. The depth of the Top Upper Portland (orange hatching) at HH-1 is very slightly (18 m) deeper than at Collendean Farm-1.The UKOG faults are shown in mauve. They are essentially identical to the Magellan faults, except for two instances discussed below.



This map shows just the UKOG faults (mauve) and Portland Sandstone prospect (orange hatching). The second fault north of Collendean Farm-1 now has a bulge to the north. This serves to increase the volume of the Portland oil reservoir. The Collendean Farm Fault presumably continues to the west as in the Magellan version, but is obscured in the UKOG map by a label, so I have omitted it. But note that it now has a downthrow to the south, except for a 1500 m long segment NE of Horse Hill-1, where it swaps sense, downthrowing to the north. Such fault behaviour is highly unusual except in strike-slip tectonic terrain. The fault-bounded horst block mapped by Magellan has more or less disappeared.

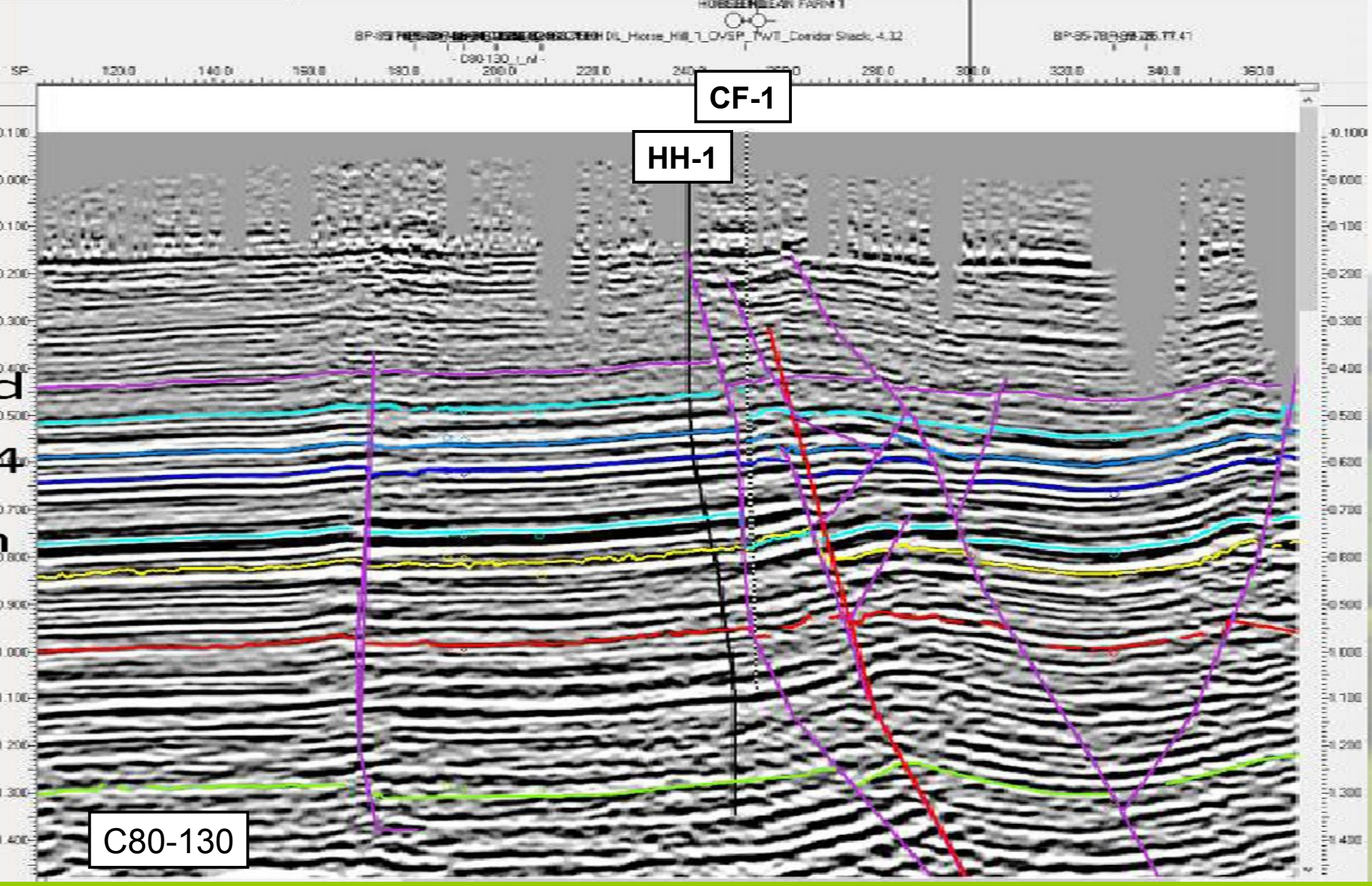


This detail from the UKOG map has been annotated to clarify the structure. Labelling is in feet below sea level. The dashed red line corresponds to the maximum closure shown in the previous slides. Local dip directions are shown by black arrows, and the local throw along the Collendean Farm Fault is shown by the red arrows. Note the local change of sense of throw, NE of HH-1. The depth at the two wells is marked. Note that the Top Portland at HH-1 is <u>deeper</u> than at CF-1 by 60 ft (18 m).

Comment on UKOG interpretation, post–Horse Hill-1

The mapping of the Collendean Farm Fault is fundamentally flawed. How can a large fault with a downthrow to the north be plausibly re-interpreted with a mainly opposite sense of throw? In addition, the automatic contouring program within the Kingdom mapping and interpretation program has produced geologically unlikely results (even if geometrically correct), because it has been constrained to contour within separate domains on either side of the continuous fault.

We have to go back to the seismic data to examine the evidence for the existence of this fault.



Magellan/UKOG interpretation of line C80-130, with annotations. This version has been reprocessed and migrated. CF-1 is the projected location of Collendean Farm-1 (dashed line), just to the south of the red fault. Most of the other mauve faults are not credible, in particular the one drawn between HH-1 and CF-1 with a downthrow to the north of 50-100 ms.

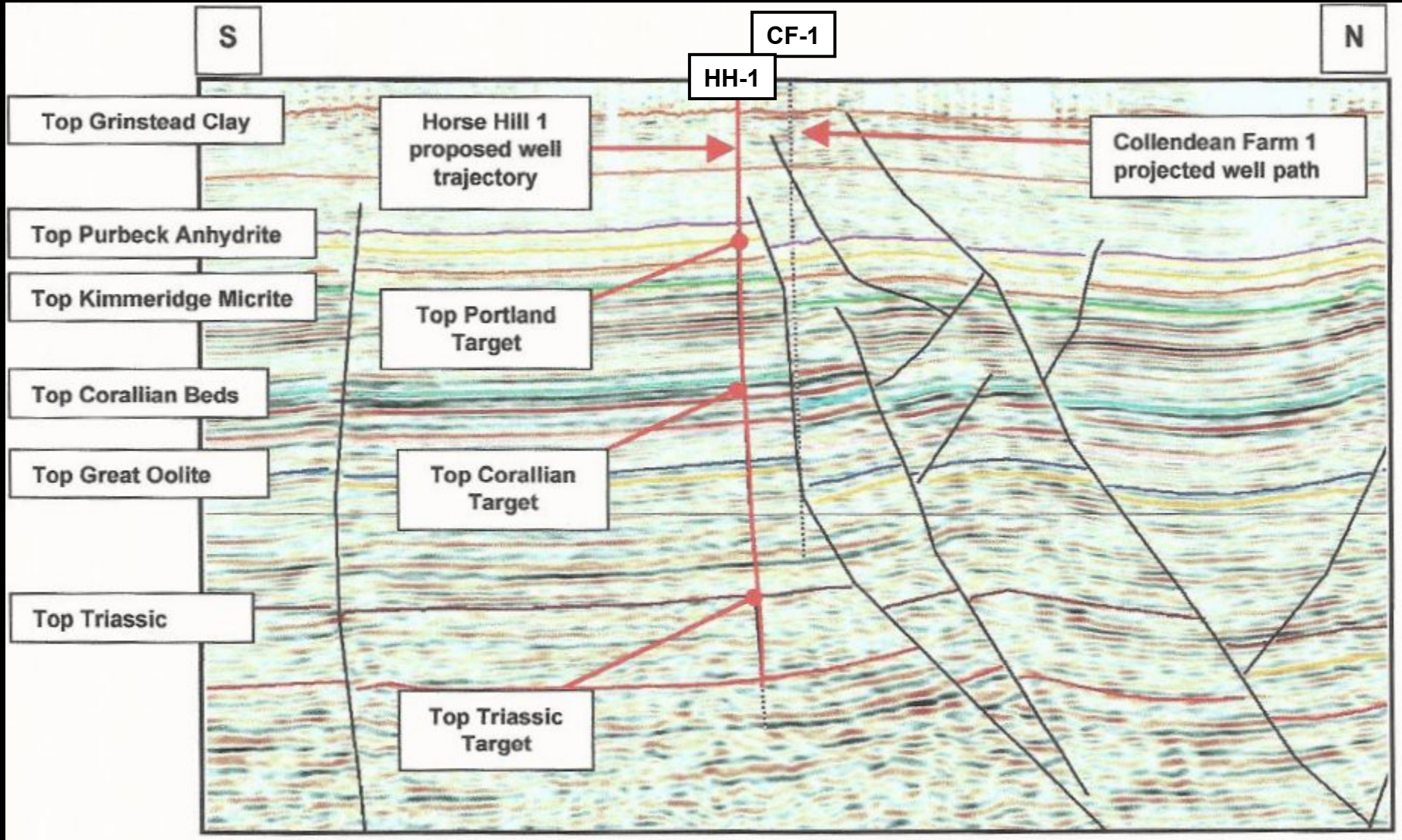
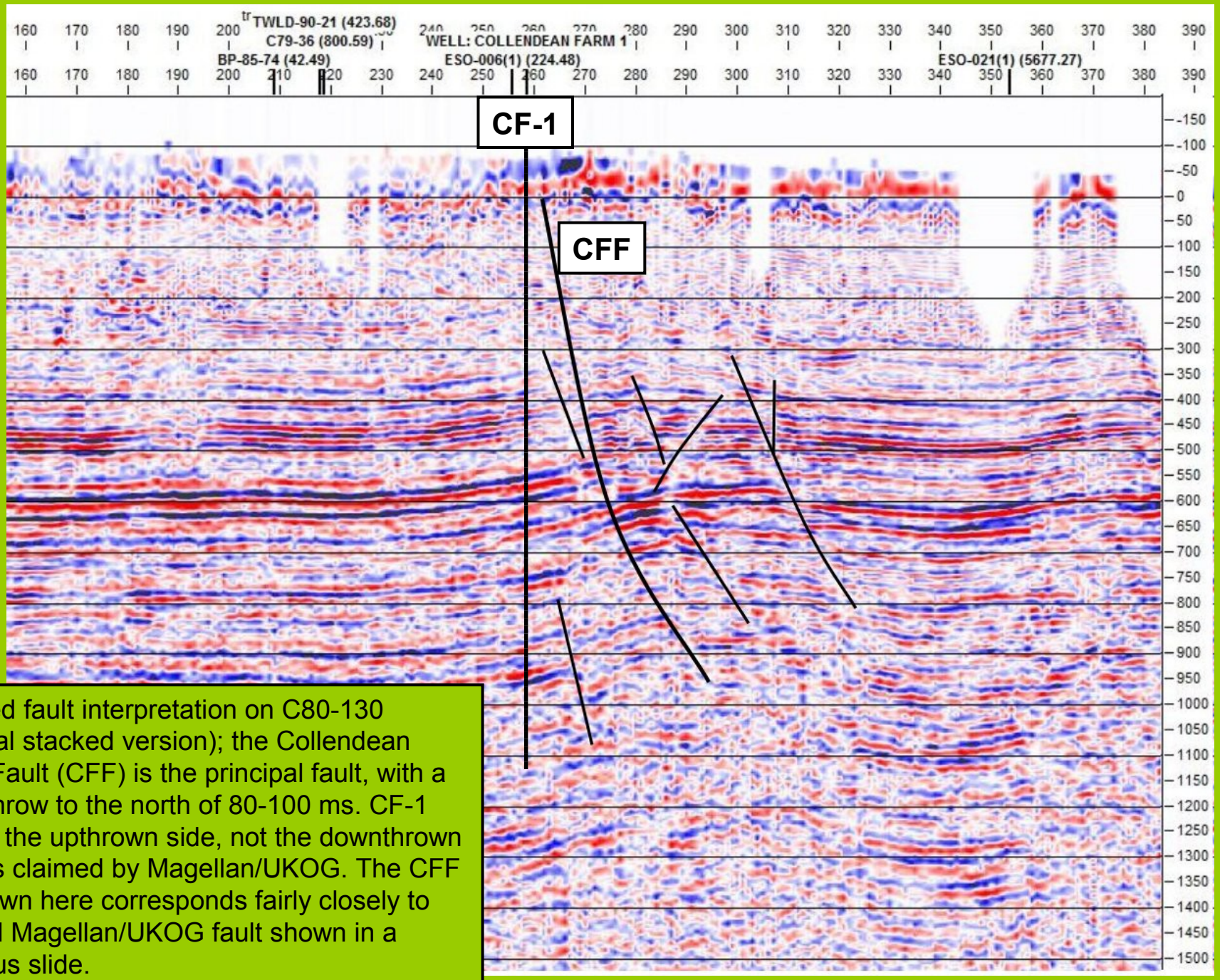
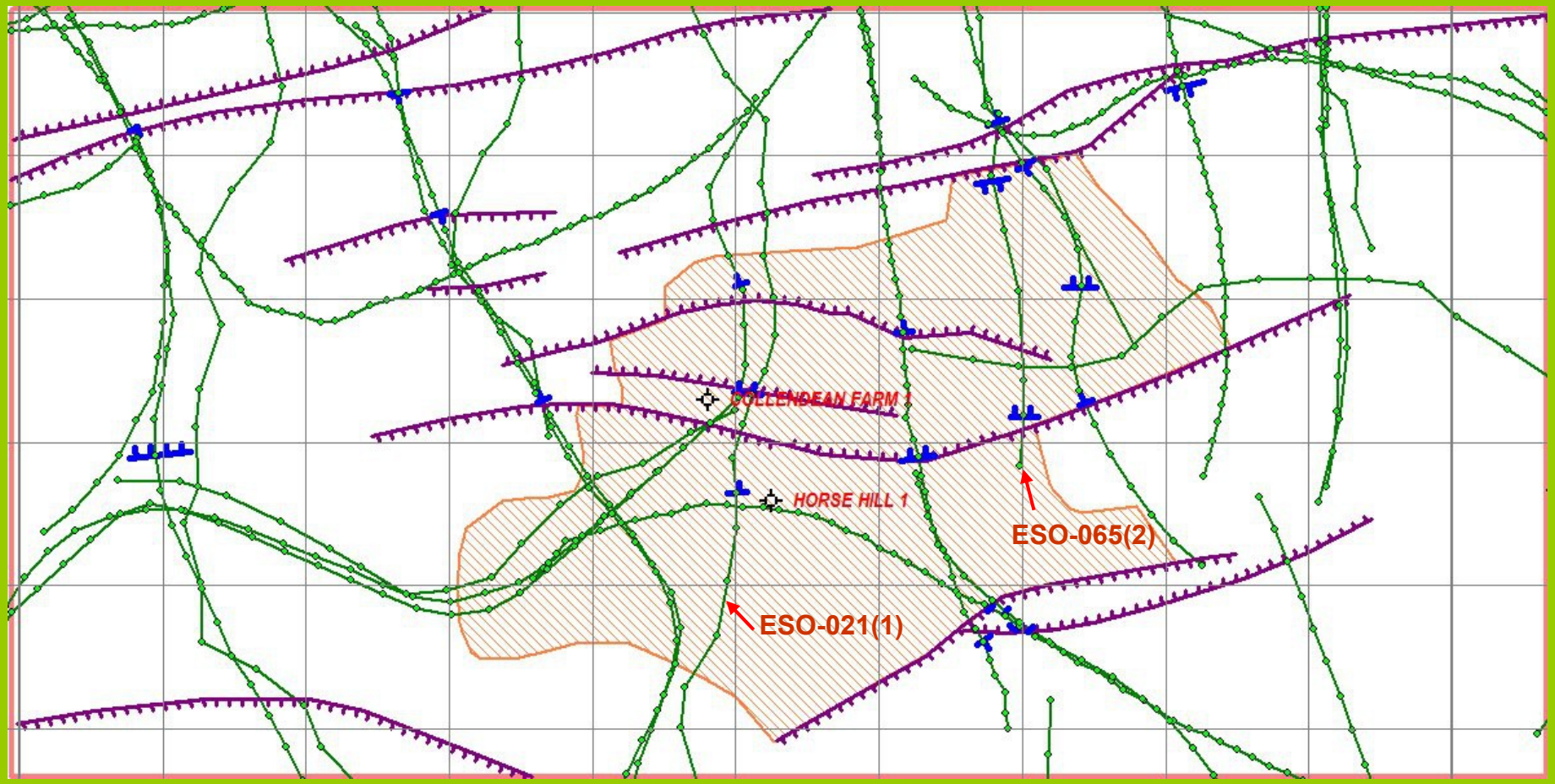


Figure 7a: Seismic Line C80-130 showing proposed Horse Hill 1 well-bore trajectory and targets at Top Portland, Top Corallian and Top Triassic.

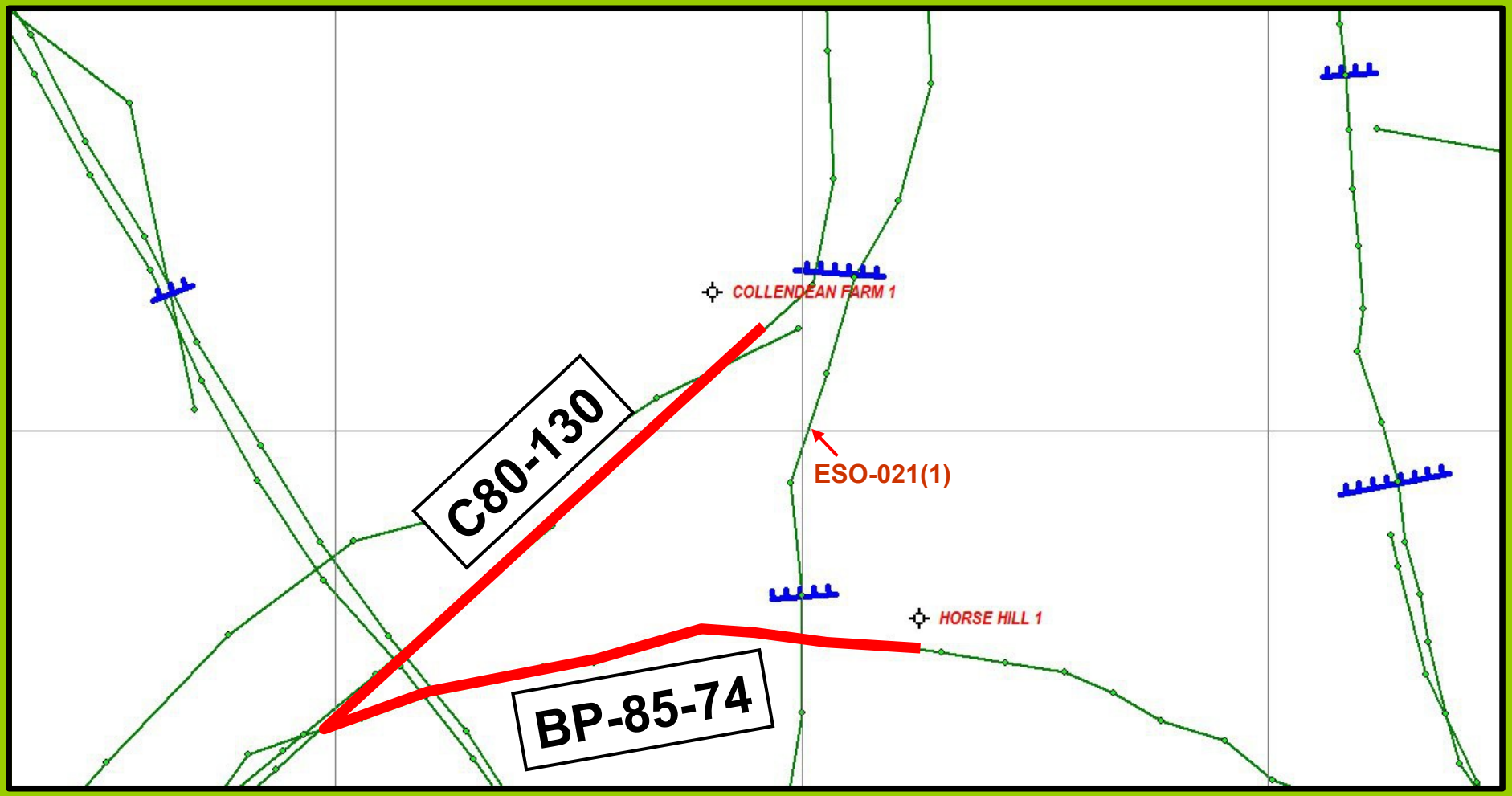
UKOG predicted trajectory and tops for HH-1. Note that the two wells CF-1 and HH-1 are on opposite sides of the most southerly fault, with the Top Purbeck at CF-1 being about 100 m deeper than at HH-1. In this and the preceding slide HH-1 is depicted as vertical down to the Kimmeridgian.



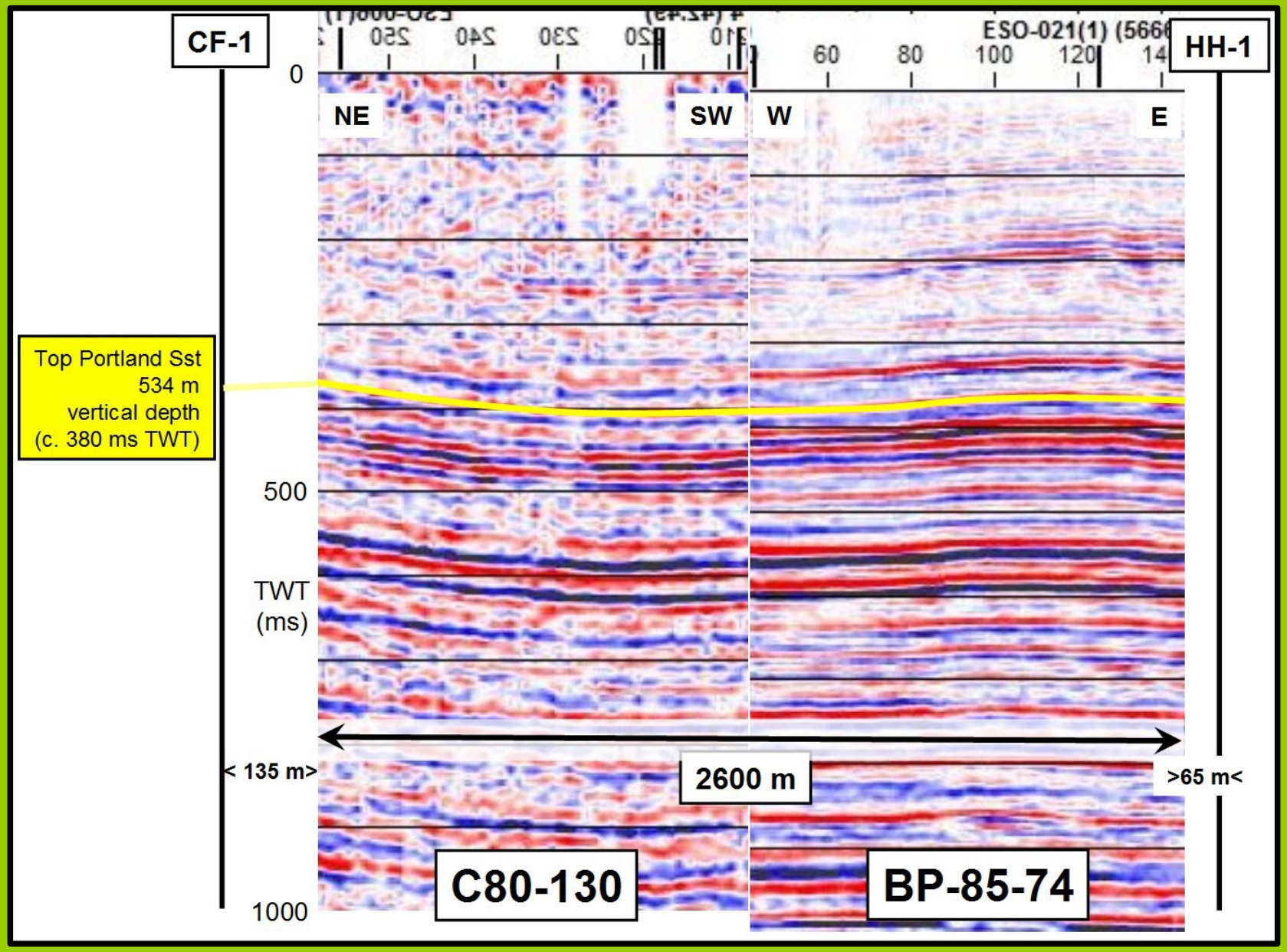
Revised fault interpretation on C80-130 (original stacked version); the Collendean Farm Fault (CFF) is the principal fault, with a downthrow to the north of 80-100 ms. CF-1 lies on the upthrown side, not the downthrown side as claimed by Magellan/UKOG. The CFF as shown here corresponds fairly closely to the red Magellan/UKOG fault shown in a previous slide.



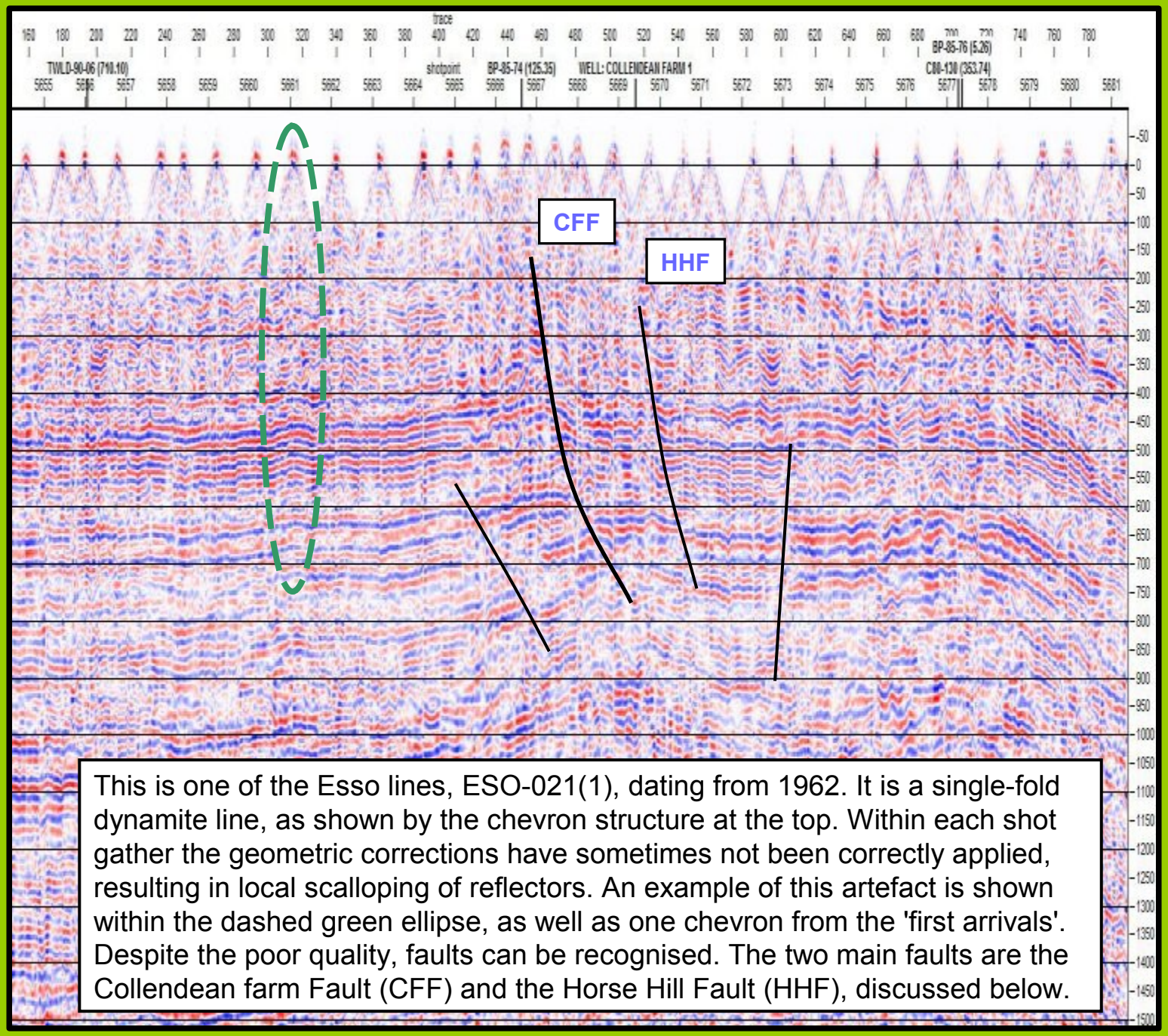
This is the UKOG maximum prospect (orange) with the available seismic data (green lines with shot-points marked). Not all of these lines were used in the UKOG interpretation of faults, shown by purple toothed lines. I have marked with short blue toothed lines my version of the locations of faults at around 400 ms depth, at approximately the Top Portland. Two very old Esso seismic lines dating from 1962 are labelled (prefixed ESO-); they were not used by Magellan/UKOG.



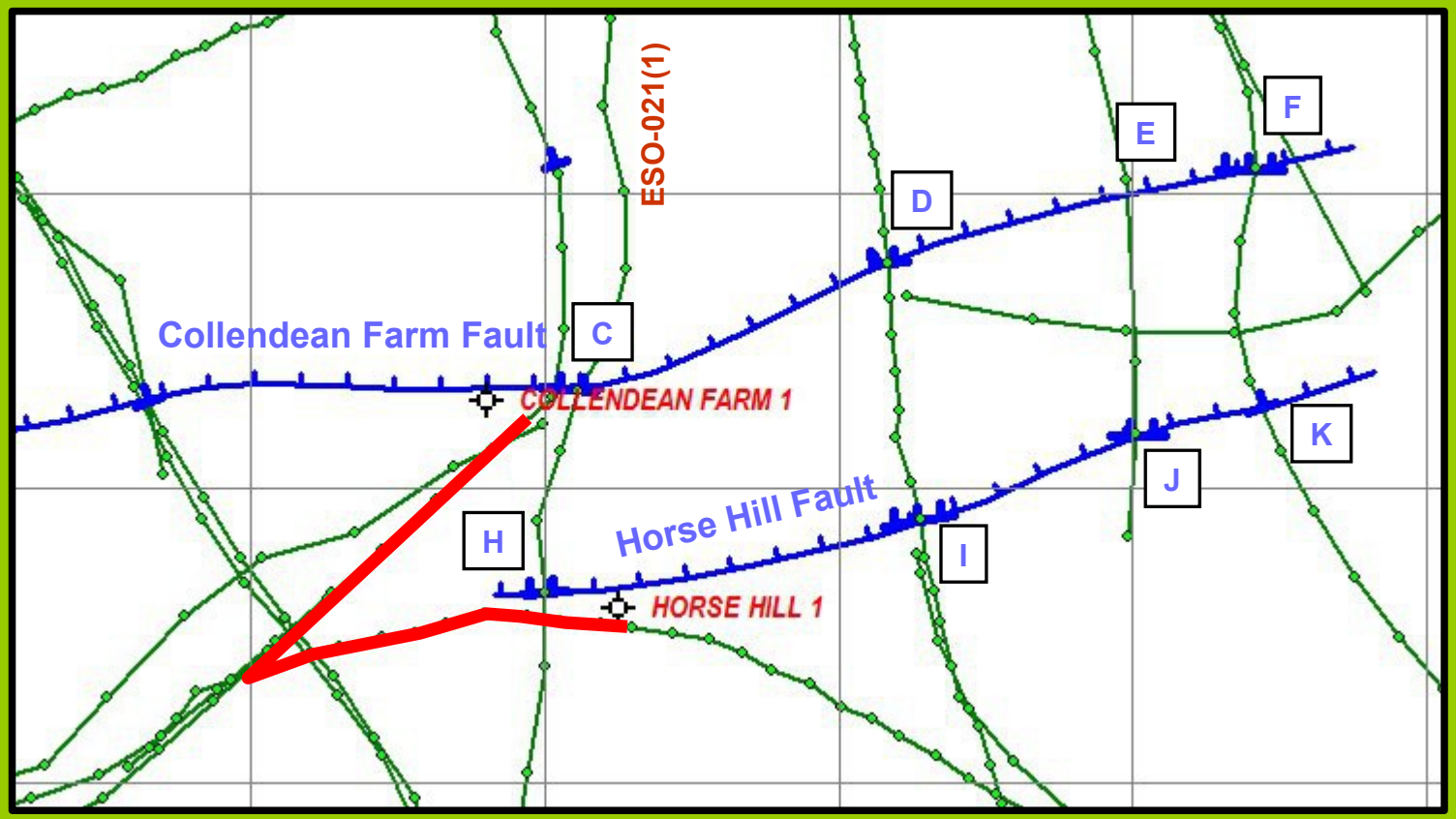
Well tie (red lines) from Collendean Farm-1 to Horse Hill-1 *via* seismic lines C80-130 and BP-75-74. CF-1 is 135 m offset to the NW from C80-130, and HH-1 is 65 m north of BP-85-74. National Grid squares are at 1 km interval. Blue toothed lines show my interpretation of fault intersections at c. 400 m depth. ESO-021(1) is a line not used by Magellan or UKOG.



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



This is one of the Esso lines, ESO-021(1), dating from 1962. It is a single-fold dynamite line, as shown by the chevron structure at the top. Within each shot gather the geometric corrections have sometimes not been correctly applied, resulting in local scalloping of reflectors. An example of this artefact is shown within the dashed green ellipse, as well as one chevron from the 'first arrivals'. Despite the poor quality, faults can be recognised. The two main faults are the Collendean farm Fault (CFF) and the Horse Hill Fault (HHF), discussed below.



Re-interpretation of faults in the vicinity of CF-1 and HH-1

The Collendean Farm Fault (CFF) lies just north of CF-1 (locality C), and continues to the ENE, as proved on seismic lines at D and F. It is not observed at E, on a very old seismic line, but that does not mean that it is absent, simply that the data are not good enough.

The Horse Hill fault is seen on the old seismic line ESO-021(1) at H (previous slide), and can be traced eastwards as seen at localities I, J and K. It dies out just west of H, as proved by the lack of faults on the red tie lines.

The Magellan/UKOG interpretation of faults in this area, with a quasi-CCF running from C to I then to J and K, is untenable.

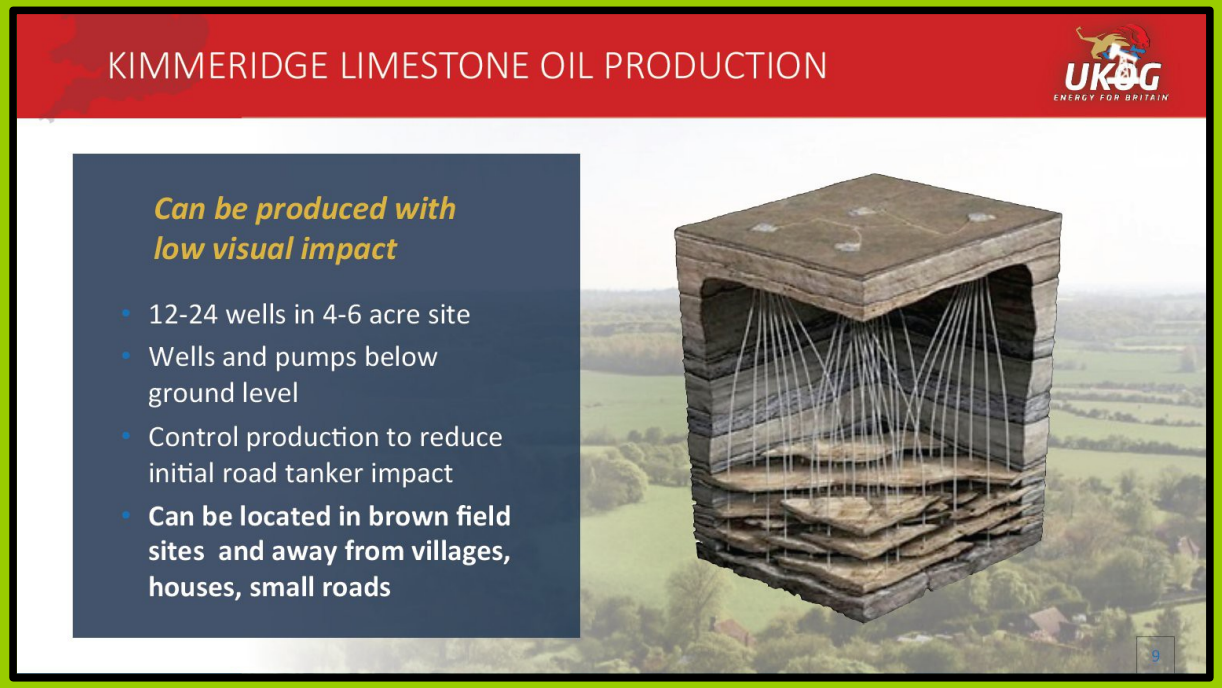
Implications of the fault re-interpretation

Following the drilling of Horse Hill-1, UKOG's geological interpretations of its prospects are untenable. The whole geological interpretation should have been revised from scratch, but instead the geologists have merely tried to modify their pre-existing fault maps to fit the new well results. This results in internal inconsistencies.

UKOG has made a minor conventional discovery in the Portland, but the reserves will need to be re-estimated after revised mapping has been carried out.

The discovery of free-flowing oil in the Kimmeridgian limestones and shales is due to the new well having been drilled in the close vicinity of the Horse Hill Fault. The fracture permeability has been enhanced by the fault, but this effect is just local, and confined to the fractured zone around the fault plane. If the well was deviated slightly to the NW as originally planned by Magellan in 2010, the wellbore may have even penetrated the main fault plane.

A Schlumberger report dated June 2015 for UKOG estimated 176 million barrels (MMBO) of oil in place per square mile within the Kimmeridge Clay Formation. This is 68 MMBO/km^2. The well could conceivably drain a 1 km stretch of the fault zone, which we might assume, optimistically, to be 250 m wide. That gives 17 MMBO. If 1% of that oil in place is recoverable by free flow (i.e. no fracking) from this tight formation, then this segment of the fault zone might produce 170,000 barrels from the naturally fractured Kimmeridgian.



UKOG: Kimmeridge Clay Formation

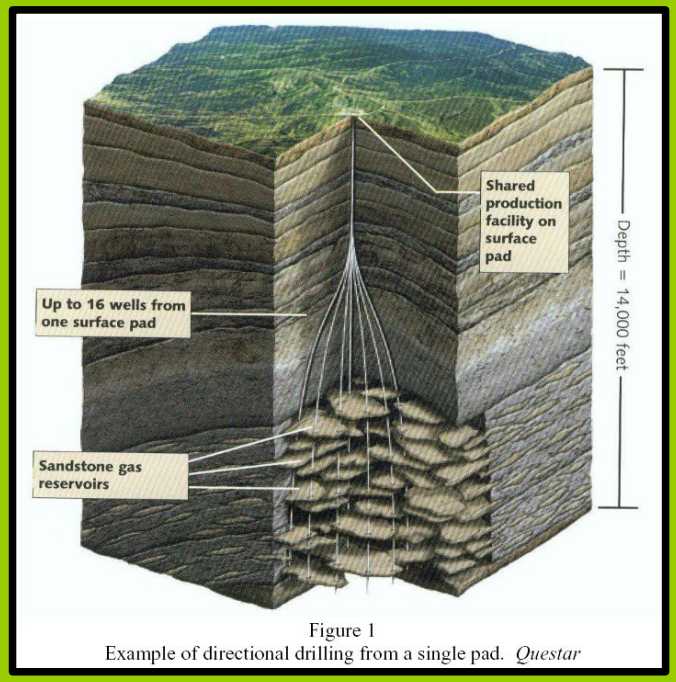


Figure 1
Example of directional drilling from a single pad. *Questar*

Questar, 2005: tight sandstone gas reservoir, Wyoming

UKOG's plans for Kimmeridgian production

UKOG claims to be able to produce from the Kimmeridge Clay Formation by drilling multiple deviated wells from each pad. The UKOG diagram above portrays a curious, geologically unrealistic view of the KCF as comprising a series of stacked lenses. The concept appears to have been inappropriately copied from the exploitation of the Pinedale Anticline in Wyoming by Questar (whose assets were spun off to QEP Resources in 2010). But the QEP production wells range from 2500 to 4500 m depth, whereas the KCF at Horse Hill is only 650-1100 m depth. The deviations will either have to be much more extreme than in Wyoming, and/or more well pads will be required. In Wyoming the gas is produced from the isolated tight sandstone lenses by fracking the deviated wells.

Conclusions

Because of the peculiar location of Horse Hill-1 within a likely fault zone, extrapolations of Kimmeridge Clay Formation reserves cannot be made from this well's flow tests to the wider area of the Weald, as UKOG and others have done.

If it is desired to exploit the localised natural fracturing of the KCF produced by faulting, then many drill pads, located along fault lines, and each with multiple wells drilled into the fault zone, will be required to produce such oil without stimulation.

The deviated multi-well pad model of UKOG can never be realistically applied to the KCF, and would in any case require fracking. Such vertical wells are also inappropriate for targeting the limestones, for which horizontal drilling is clearly required. The UKOG production concept is ill-conceived.

Oil production from the fortuitous discovery of fractured Kimmeridgian at Horse Hill-1 might go some way towards recovering the costs of exploration, but it is very far from proving a new giant reserve below the Weald.

UKOG should now re-map its minor conventional Portland Sandstone discovery, based on the insights provided above, and then inform its investors whether or not it has a commercial discovery.

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