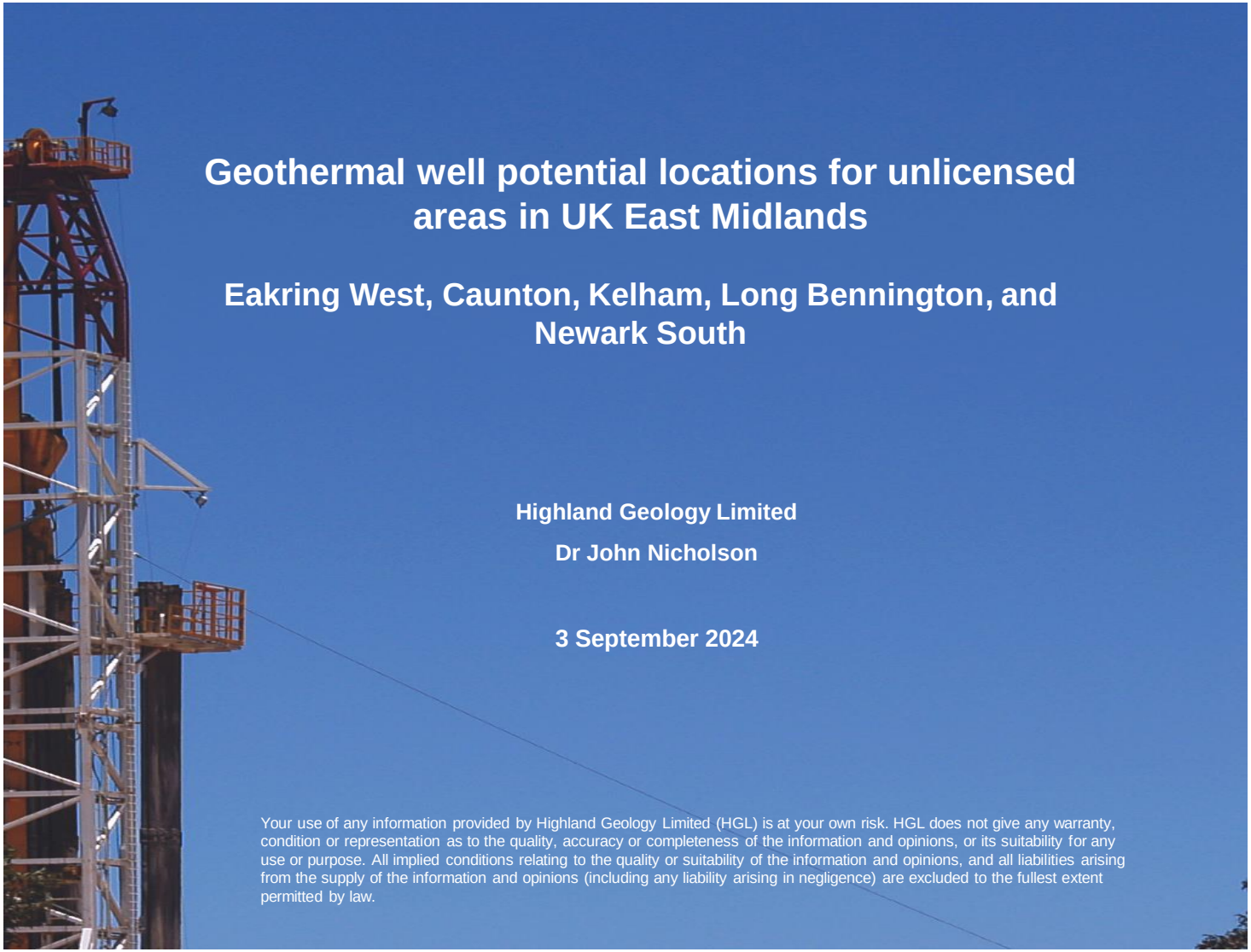


Geothermal well potential locations for unlicensed areas in UK East Midlands

Eakring West, Caunton, Kelham, Long Bennington, and Newark South

Highland Geology Limited

Dr John Nicholson

3 September 2024

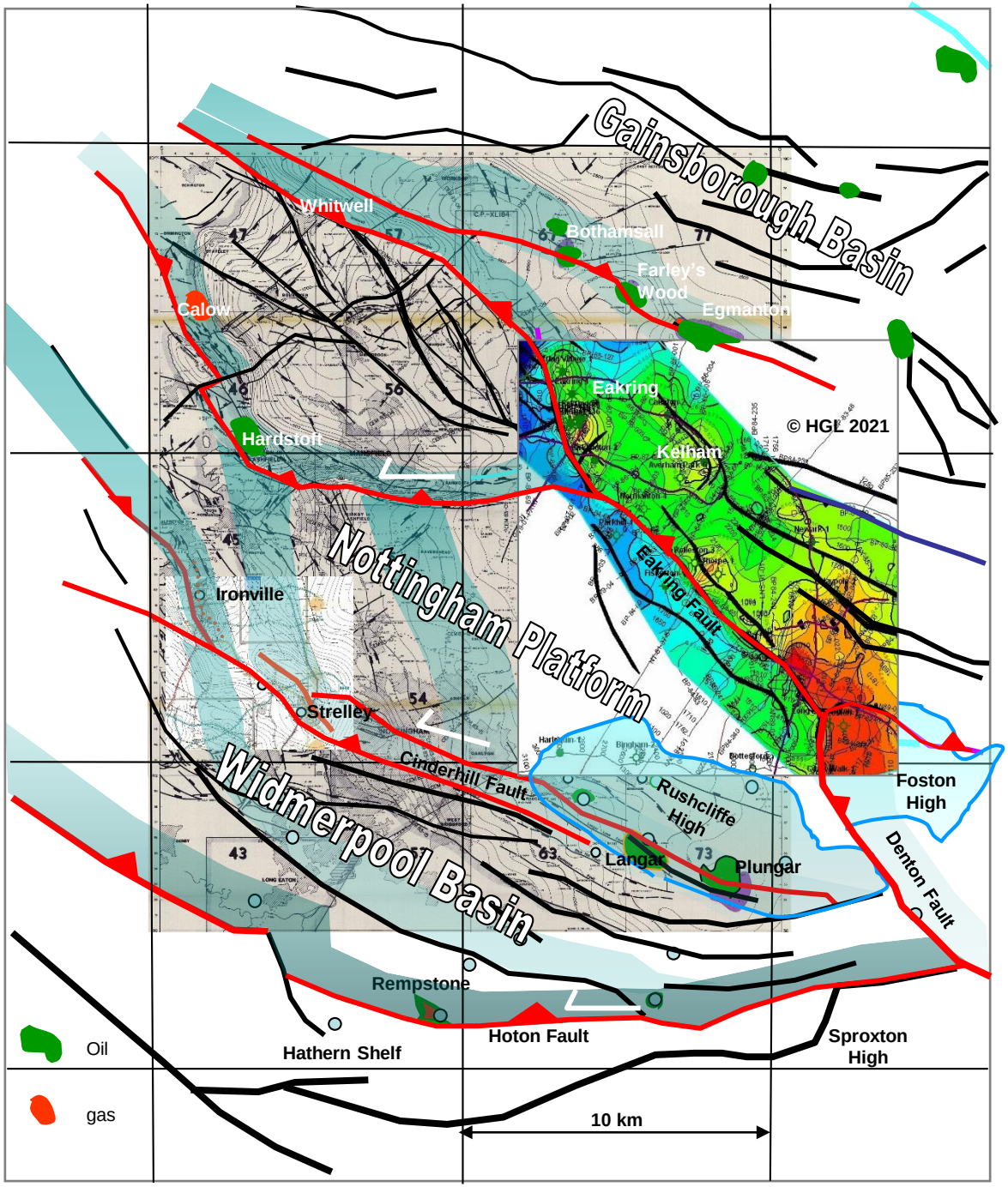
Structure of the Nottingham Platform and eastern half of Widmerpool Basin

What defines key areas for commercial geothermal drilling in East Midlands? This base map - its the 1984 Coal Measures Top Hard depth compilation of Charterhouse Group, file 40416 on UKOGL- holds our answer: red faults are the prime locations. Those trends are the main Carboniferous growth faults which have undergone the greatest subsequent structural inversion.

In particular it's the footwalls of those fracture trends which we consider to be particularly prospective for geothermal plays. Why? Because the late Carboniferous NW-SE to westerly shortening across the sub-basins produced strong faulting and footwall collapse in left-handed shear on the extensional growth faults with that trend, such as Eakring, Hoton and Denton.

The colour inset is our own Eakring to Foston two-way time mapping, and the areas highly rated by us in these notes are ones we have studied in detail. The conclusions are entirely ours. The bias in our comments is that we know more about the fracture patterns for those plays, than we do for prospects elsewhere in the northern onshore UK basins.

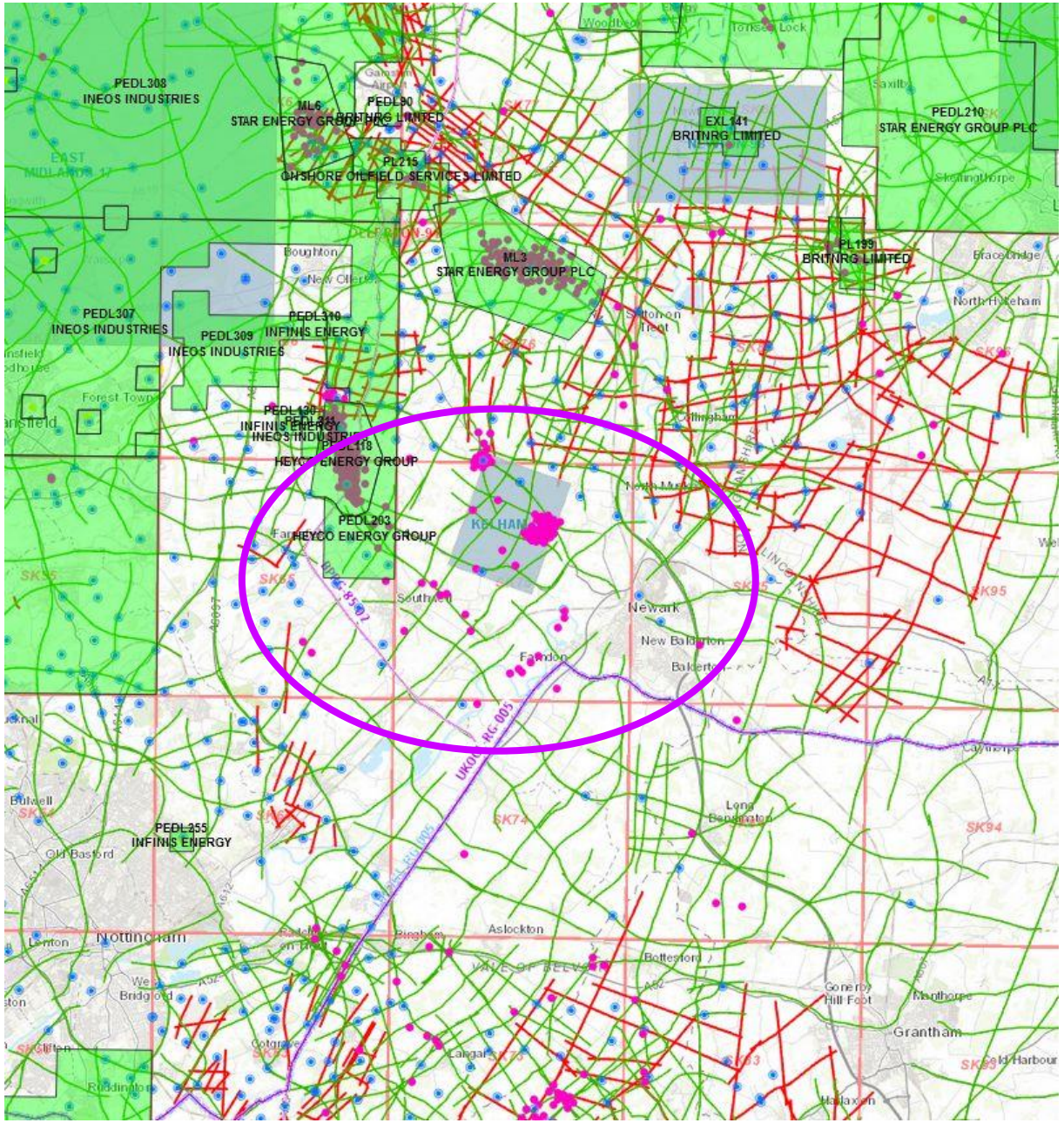
The definitive stratigraphic summary and regional depth mapping for East Midlands at top EC6 (top Visean), top Namurian and at Top Hard coal levels in depth is BGS's 2011 Subsurface Memoir "Structure and evolution of the East Midlands region of the Pennine Basin". The Memoir is indispensable.



We include this UKOGL map to show that nearly all of the areas described in this note, inside the purple ellipse, are unlicensed: the white blocks have all been relinquished. The Eakring Field PEDL203 still has stripper production but its flanked on three sides by open acreage.

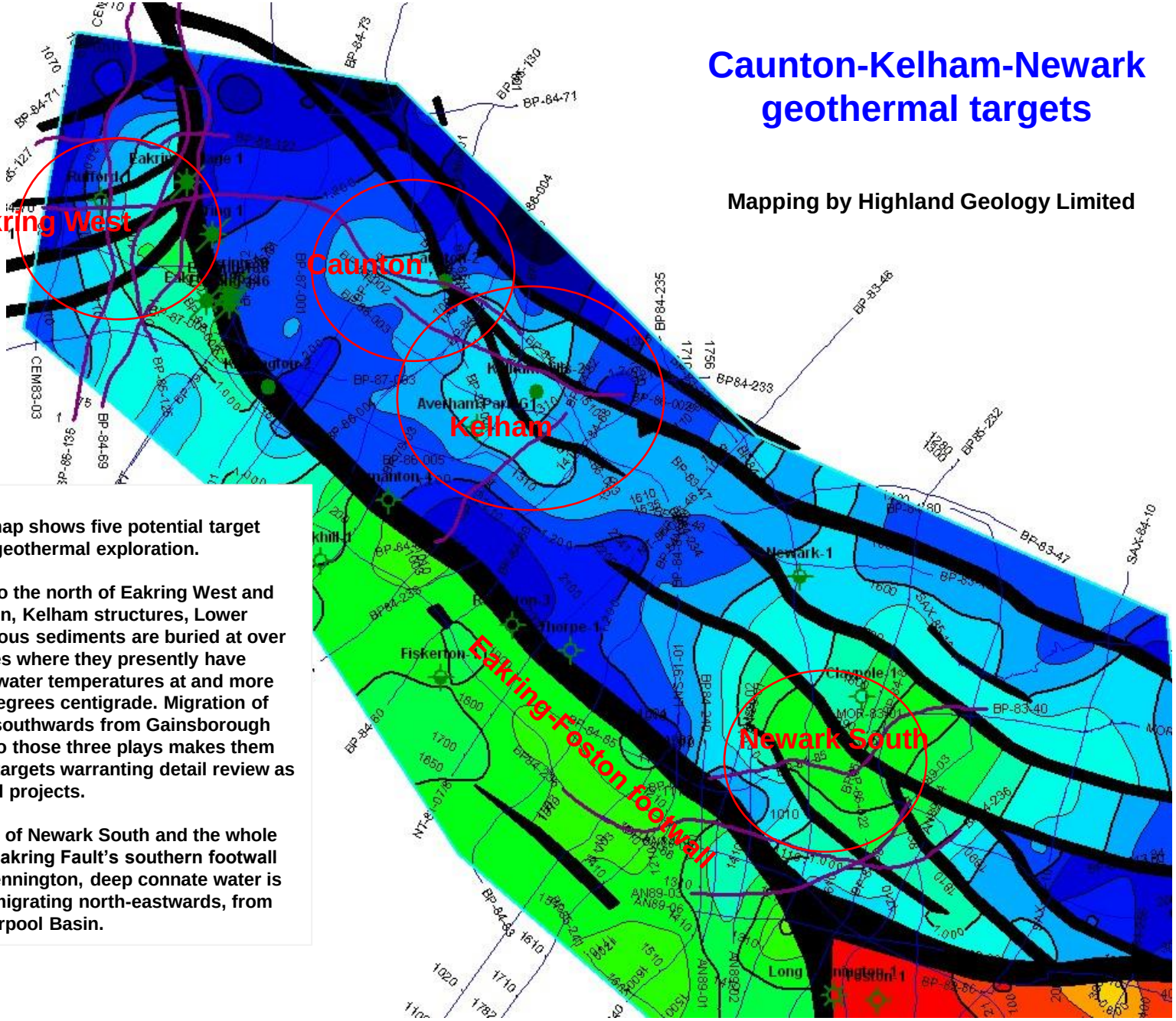
In green areas deep geothermal wells can be drilled now, under PEDL regulations: but of course new investors may want to see a new, dedicated framework go into place for geothermal projects.

Let's look first at the unlicensed footwall area immediately west of Eakring.



Caunton-Kelham-Newark geothermal targets

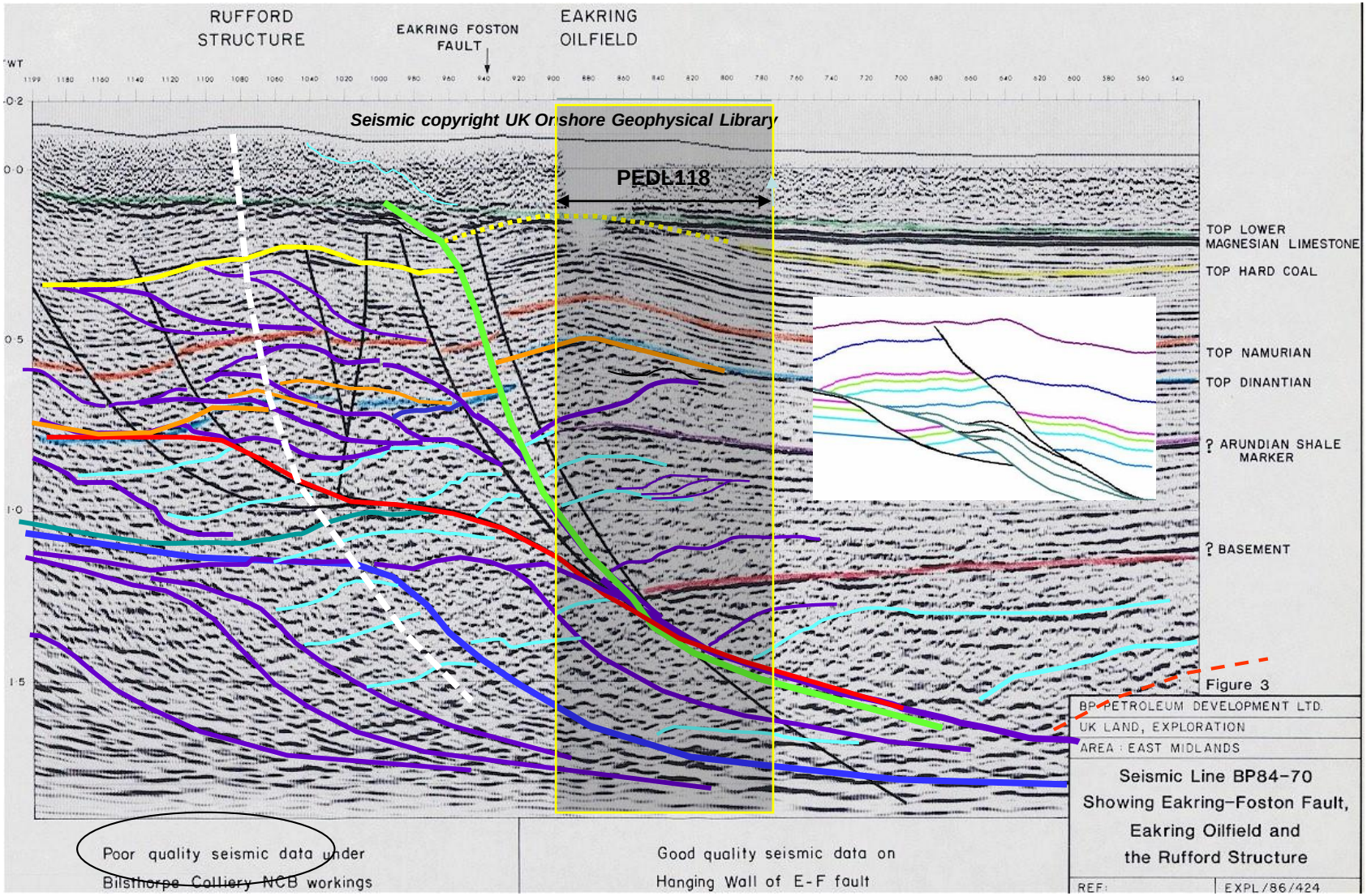
Mapping by Highland Geology Limited



This one map shows five potential target zones for geothermal exploration.

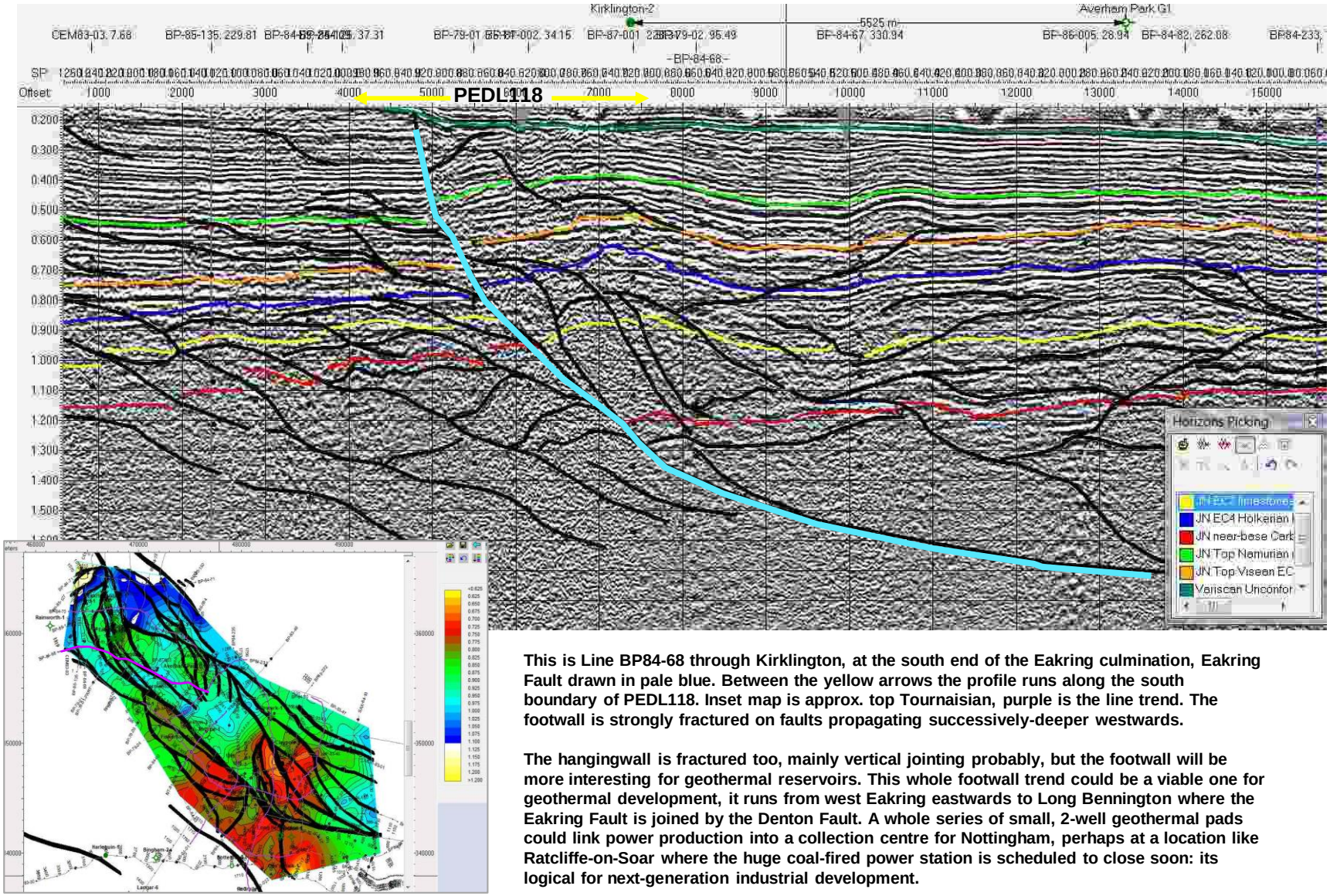
A few km to the north of Eakring West and the Caunton, Kelham structures, Lower Carboniferous sediments are buried at over 3000 metres where they presently have formation water temperatures at and more than 100 degrees centigrade. Migration of hot water southwards from Gainsborough Trough into those three plays makes them particular targets warranting detail review as geothermal projects.

In the case of Newark South and the whole length of Eakring Fault's southern footwall to Long Bennington, deep connate water is plausibly migrating north-eastwards, from the Widmerpool Basin.



The west Eakring footwall. This seismic from UKOGL presentation 41689 of 1986 is not really "poor quality": above the footwall collapse fault drawn in red there are compressional duplexes resulting from Variscan inversion, breaking down the footwall where the Eakring Fault becomes too steep to reverse; and more of them are evident below red. In our interpretation, movement over the red ramp created the drilled Rufford structure. Rufford-1 well terminated at orange top of Dinantian EC6 limestone. Eakring-Foston (bright green) fault sector has about 100 msecs reverse displacement at Top Hard, just north of the Eakring Field, and major net extension in Lower Carboniferous. BP "basement" event is probably around top of Tournaisian, the real footwall basement is somewhere around or below red-dash.

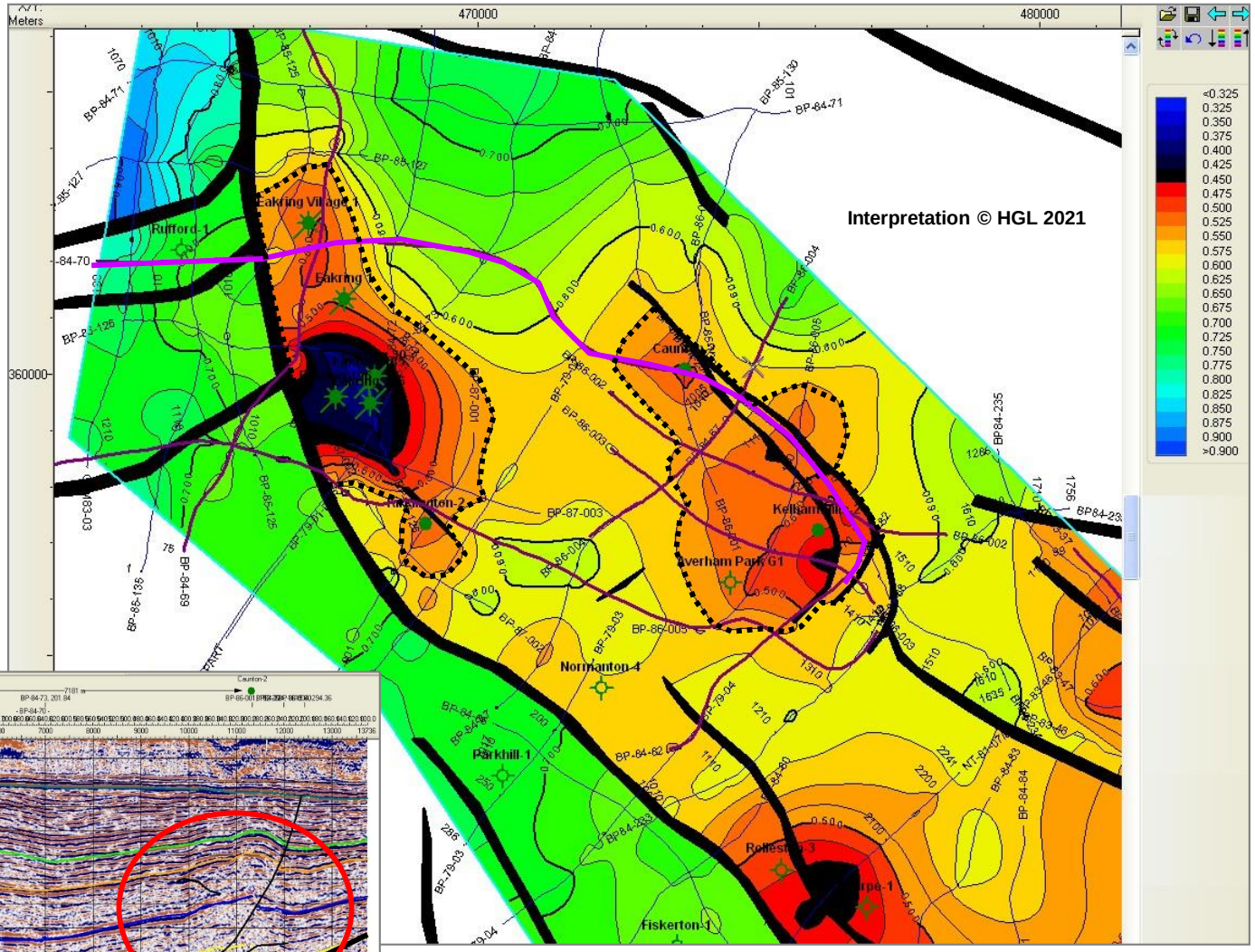
Eakring-146 proved a substantial thermal anomaly. Why not put a well with trajectory like the white dash track into the collapsing footwall below red?

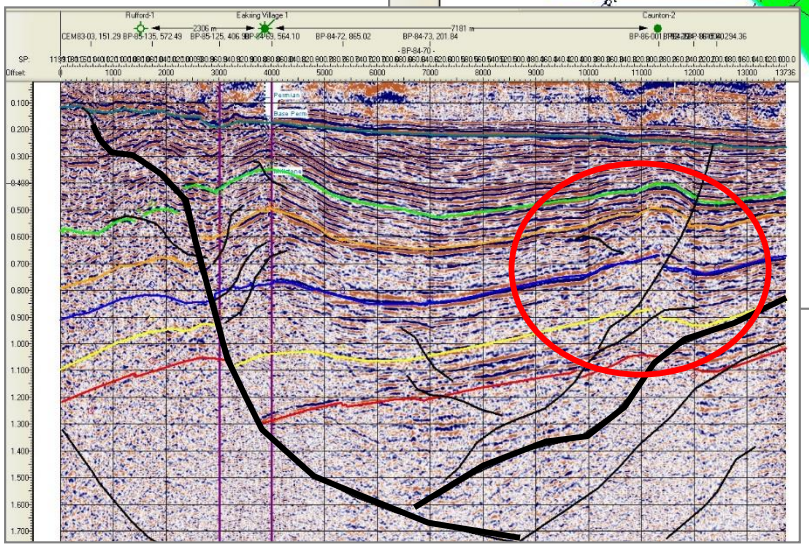


This is Line BP84-68 through Kirklington, at the south end of the Eakring culmination, Eakring Fault drawn in pale blue. Between the yellow arrows the profile runs along the south boundary of PEDL118. Inset map is approx. top Tournaisian, purple is the line trend. The footwall is strongly fractured on faults propagating successively-deeper westwards.

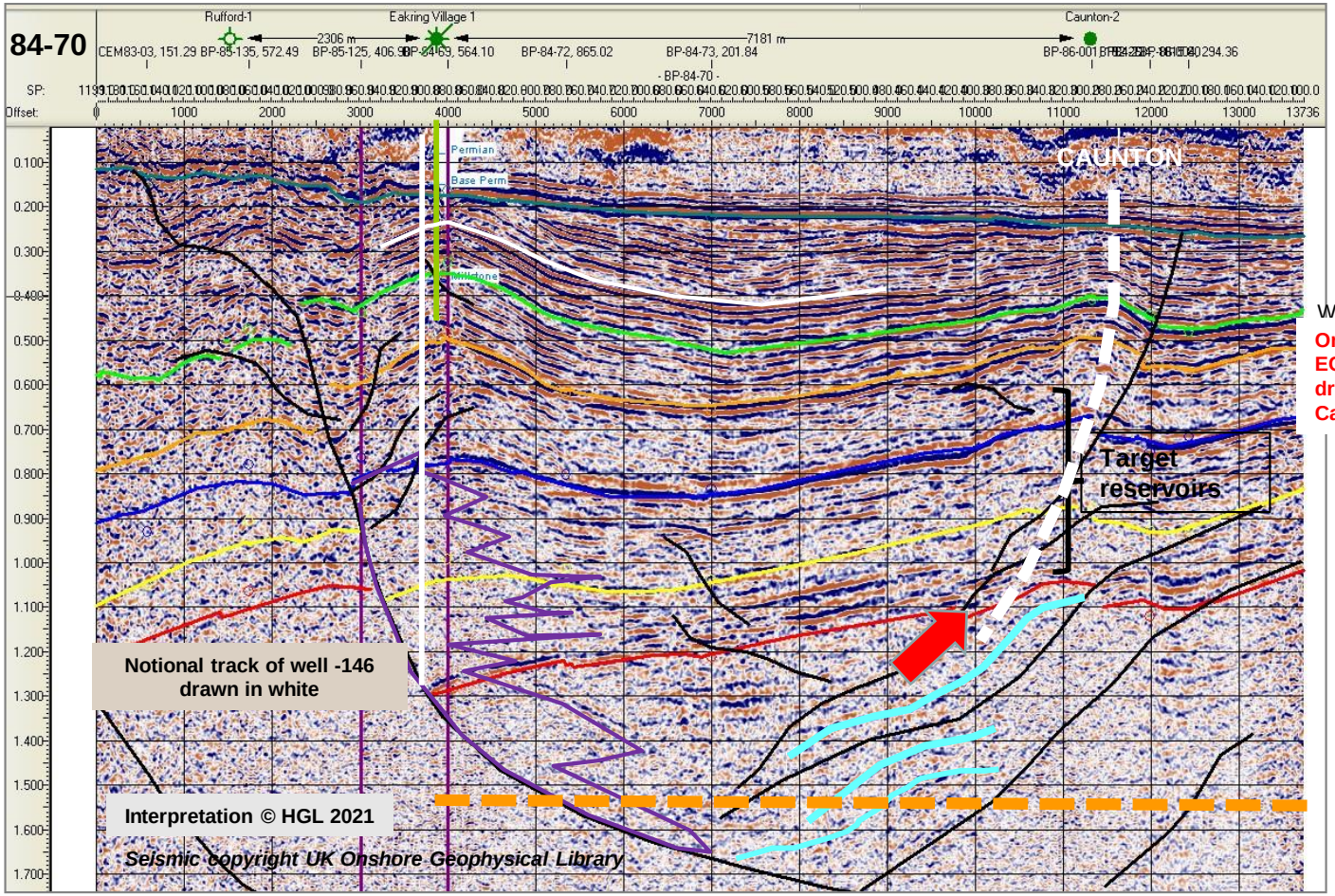
The hangingwall is fractured too, mainly vertical jointing probably, but the footwall will be more interesting for geothermal reservoirs. This whole footwall trend could be a viable one for geothermal development, it runs from west Eakring eastwards to Long Bennington where the Eakring Fault is joined by the Denton Fault. A whole series of small, 2-well geothermal pads could link power production into a collection centre for Nottingham, perhaps at a location like Ratcliffe-on-Soar where the huge coal-fired power station is scheduled to close soon: its logical for next-generation industrial development.

Caunton-Kelham targets mapped at top EC6





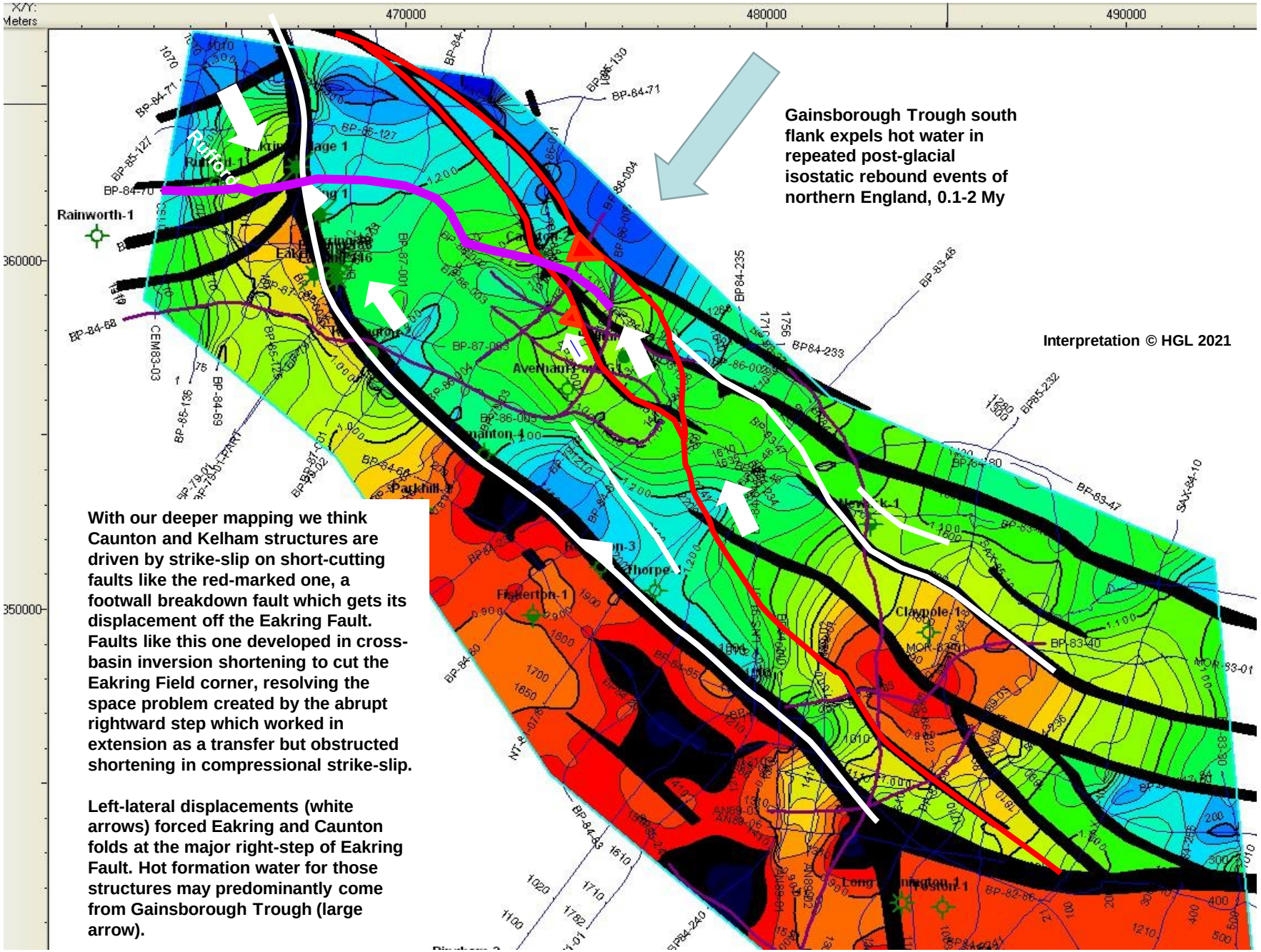
Caunton/Kelham closed area is large at EC6, it's a composite pair which hasn't had a Lower Carboniferous test. The marked line is BP-84-70, its about 14 km long.

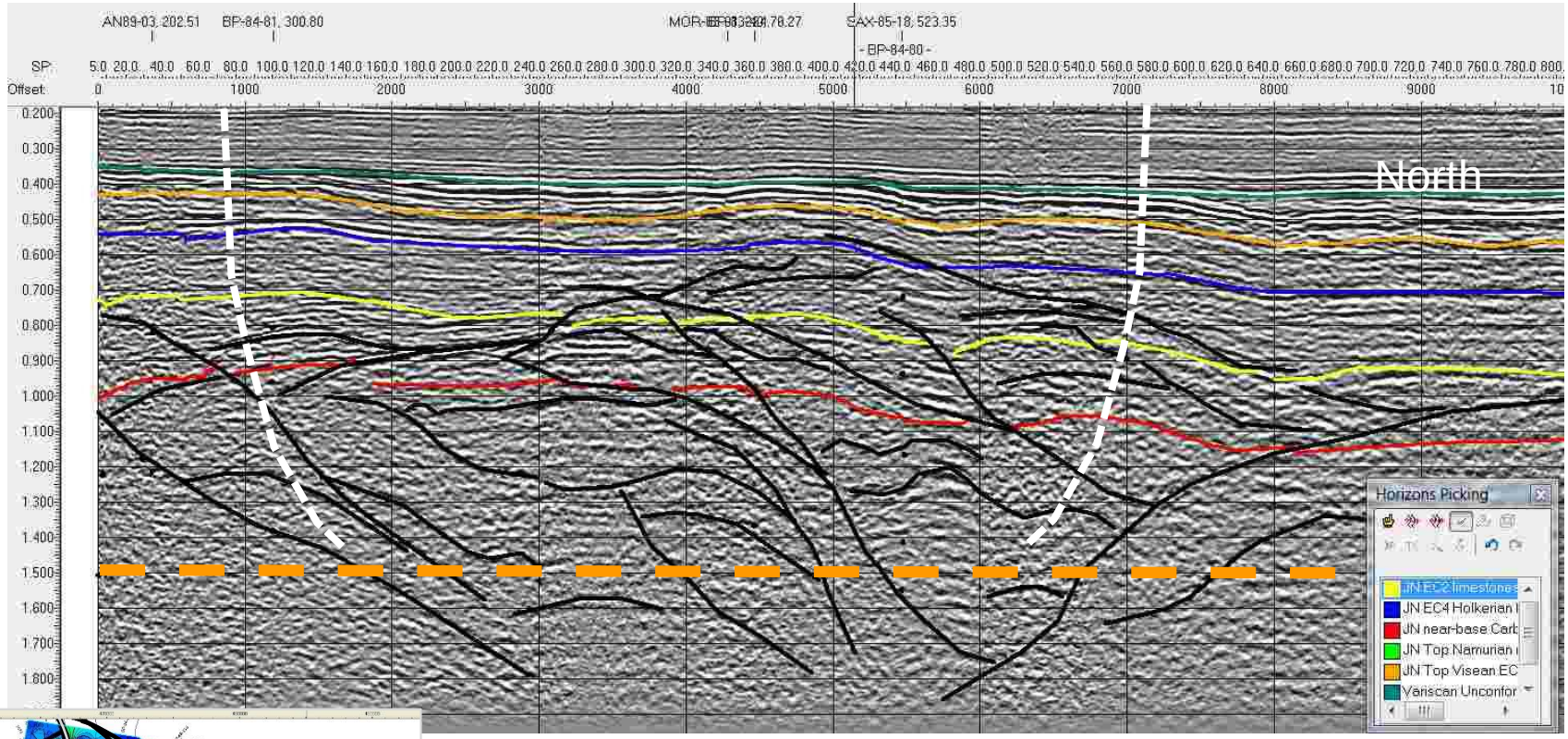


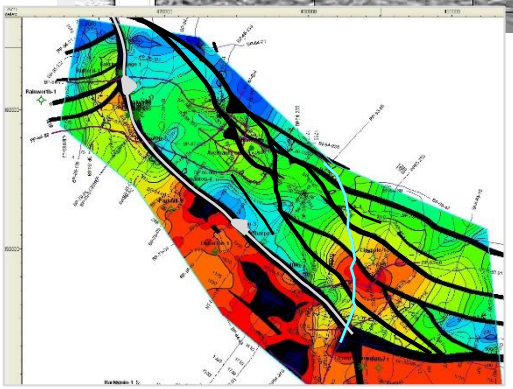
The dominant structure style is strike-slip, we think Caunton geometry is very similar to Kelham Hills. Our mapping indicates significant left-handed oblique slip, driving the Caunton and Kelham inversion structures with substantial fracturing which deep Tournaisian hot water can use to climb up the axial surface faults, as the red arrow suggests. A possible Caunton producer well is suggested by the white dashed well.

At approximately 1.5 – 1.6 seconds, heavy orange is the 100 degrees centigrade formation temperature. The yellow pick is probably fractured reservoir and could be a significant geothermal target horizon with Tournaisian anhydrites and algal limestones, equivalent to regional Ballagan Formation. There is a reverse-faulted doublet some two hundred msecs deeper than red, and below that there are signs of back-tilted reflectors, pale blues. Eakring-146 located 2 km to south is the only well drilled deeper than orange EC6. There is no hangingwall dip closure sub-blue (Arundian), and no hydrocarbon shows were reported below EC6. The bright 100 msecs interval above red is not penetrated by -146 well, because a local conglomerate is banked against the fault in a zone 2-3 km wide, outlined purple in our pick. The red marker is tagged as basement by -146 and is picked as such in the hangingwall by operators and by BGS in their memoir: but we think the -146 well drilled through the fault into footwall. Red pick here is not the hangingwall basement.

So, drill a fluids producer on a track like dashed white, into the fracture zones like pale blue? Cooled water can be returned at half that depth.


X/Y:
Meters
470000
480000
490000
360000
350000
Rufford
Rainworth-1
Gainsborough Trough south flank expels hot water in repeated post-glacial isostatic rebound events of northern England, 0.1-2 My
Interpretation © HGL 2021
With our deeper mapping we think Caunton and Kelham structures are driven by strike-slip on short-cutting faults like the red-marked one, a footwall breakdown fault which gets its displacement off the Eakring Fault. Faults like this one developed in cross-basin inversion shortening to cut the Eakring Field corner, resolving the space problem created by the abrupt rightward step which worked in extension as a transfer but obstructed shortening in compressional strike-slip.
Left-lateral displacements (white arrows) forced Eakring and Caunton folds at the major right-step of Eakring Fault. Hot formation water for those structures may predominantly come from Gainsborough Trough (large arrow).



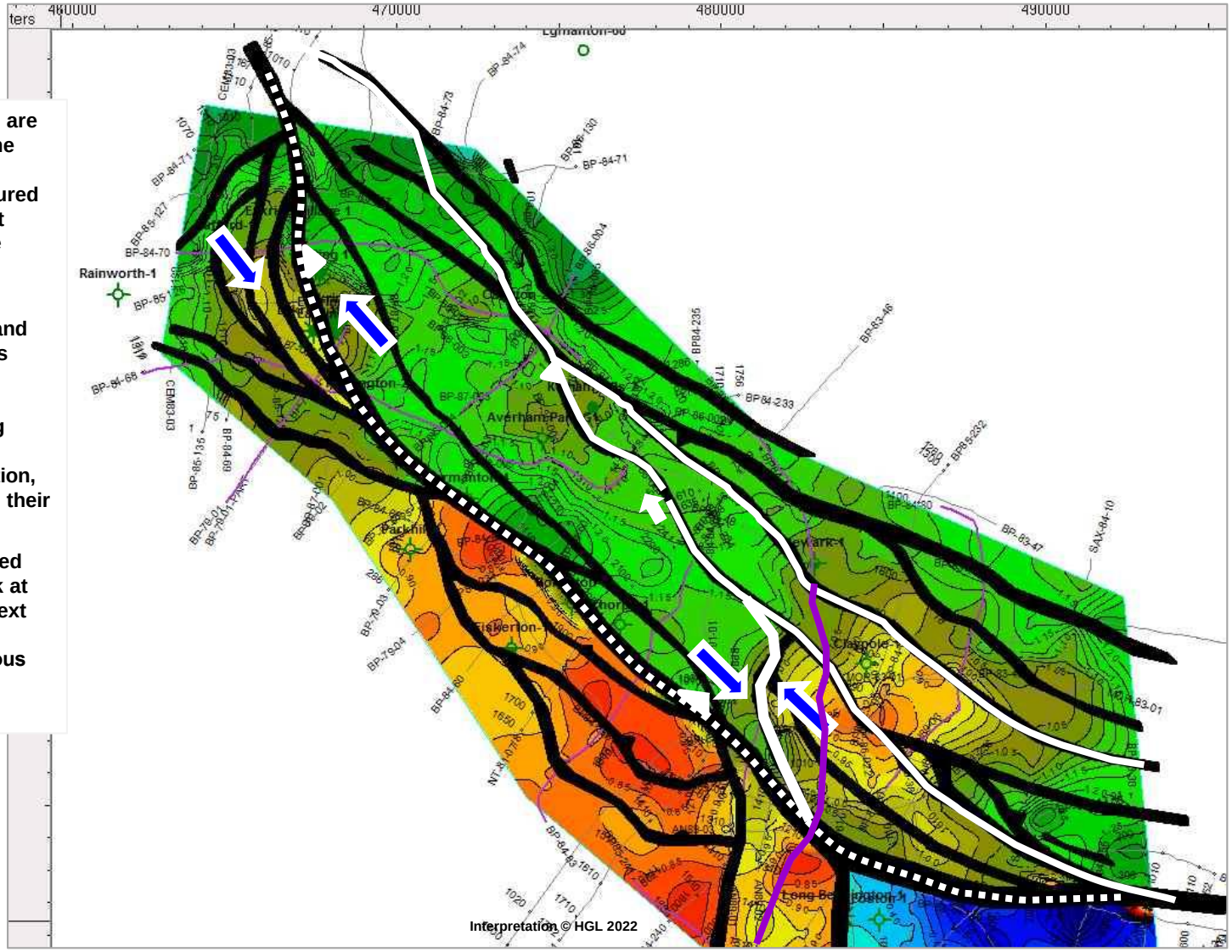


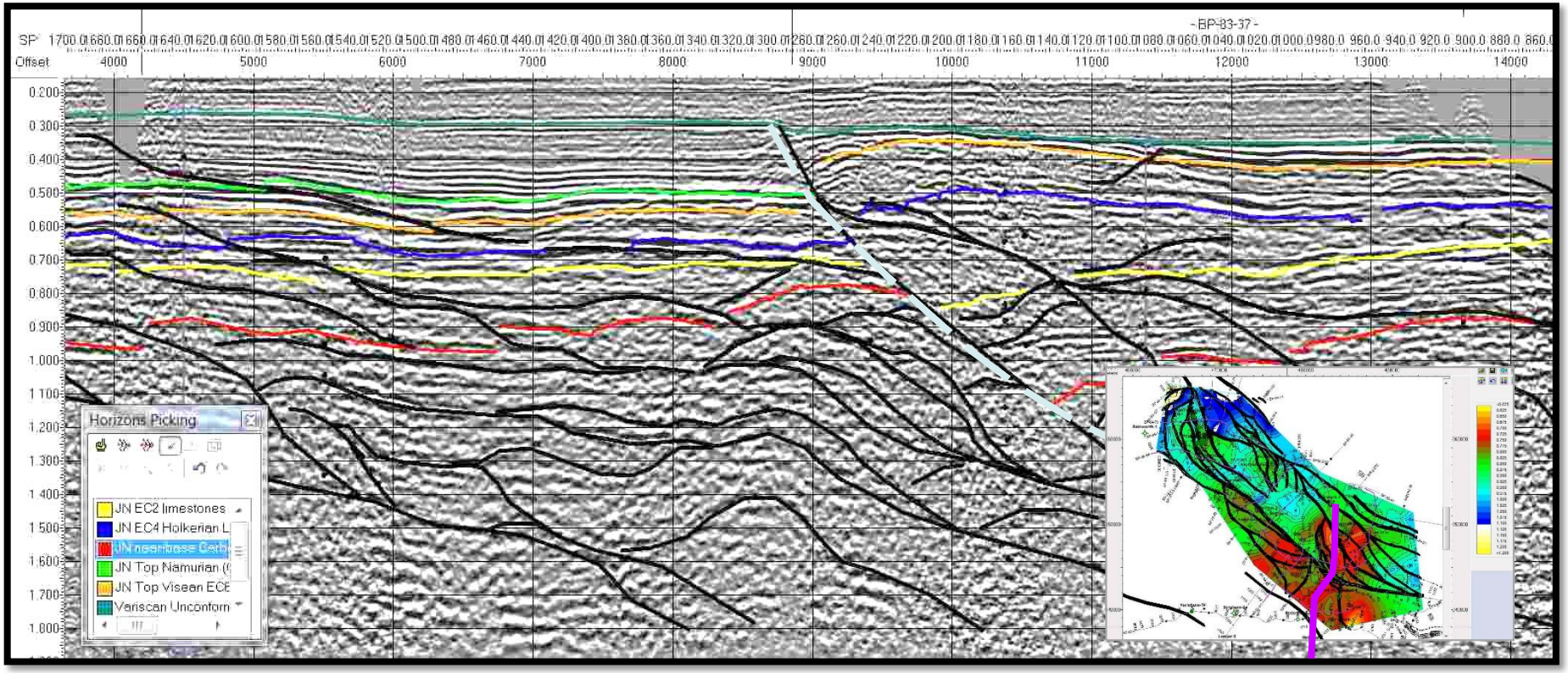
This part of the long north-south line 83-37 across the South Newark high shows its strike-slip flower geometry, transpressional in the upper part with local folding and thrusting to solve space problems; folds get tighter with depth, and out-of-syncline thrusting appears; and the style is transtensional in the root zone, where we expect angular rotations in the deep fault blocks, none of which has been drilled. This flower system is slicing and moving rock into the Eakring Fault zone. Potential fluid producer wells might be best drilled on the flank faults where tight folds will maximise fracture density.

Our deepest, Red map picks are less secure of course, but the overall picture is clear. The contour intervals are recoloured to clarify the junction area at Long Bennington, where the large north-trending Denton Fault meets Eakring Fault.

The seismic is sparse here and workstation software creates spurious local contours in projecting the data. But the indication is that the Eakring Fault south flank footwall is strongly uplifted at the junction, as the faults both contribute their displacement.

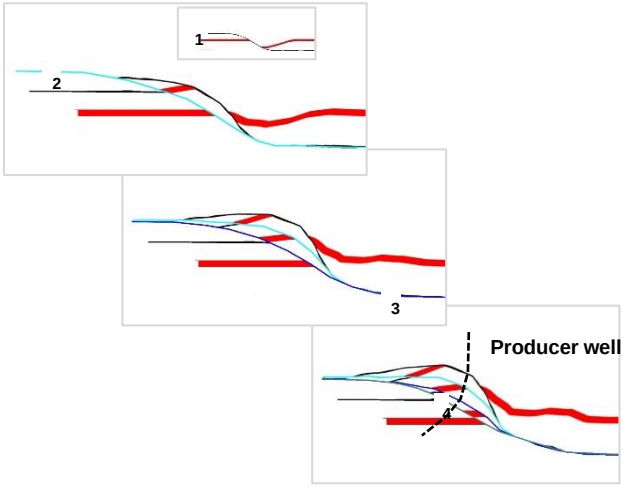
The high is massively inverted and fractured. When we look at lines like BP83-37 (purple, next slide), the causal process of uplift is clear. It's an enormous stack of footwall collapse duplexes.

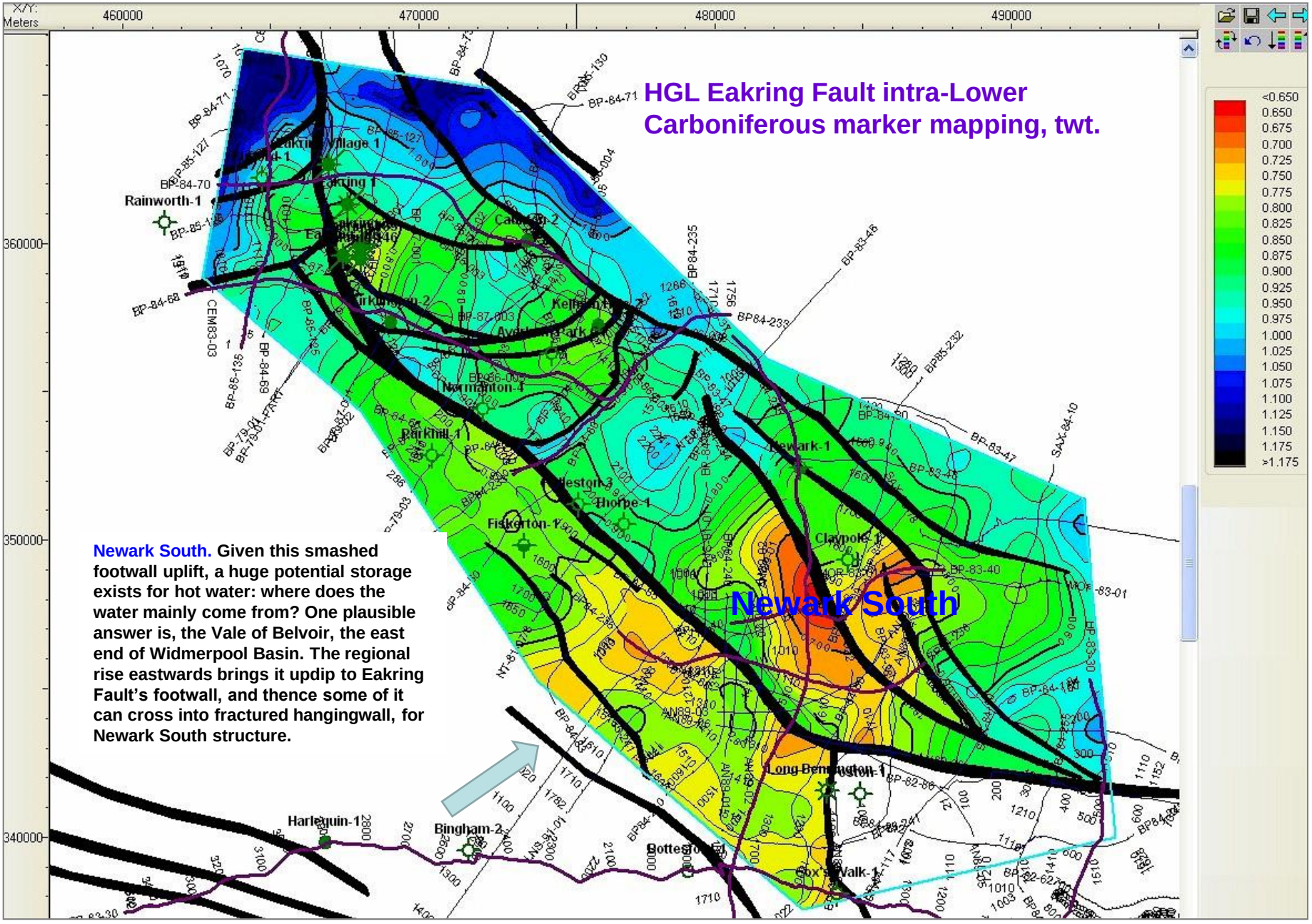


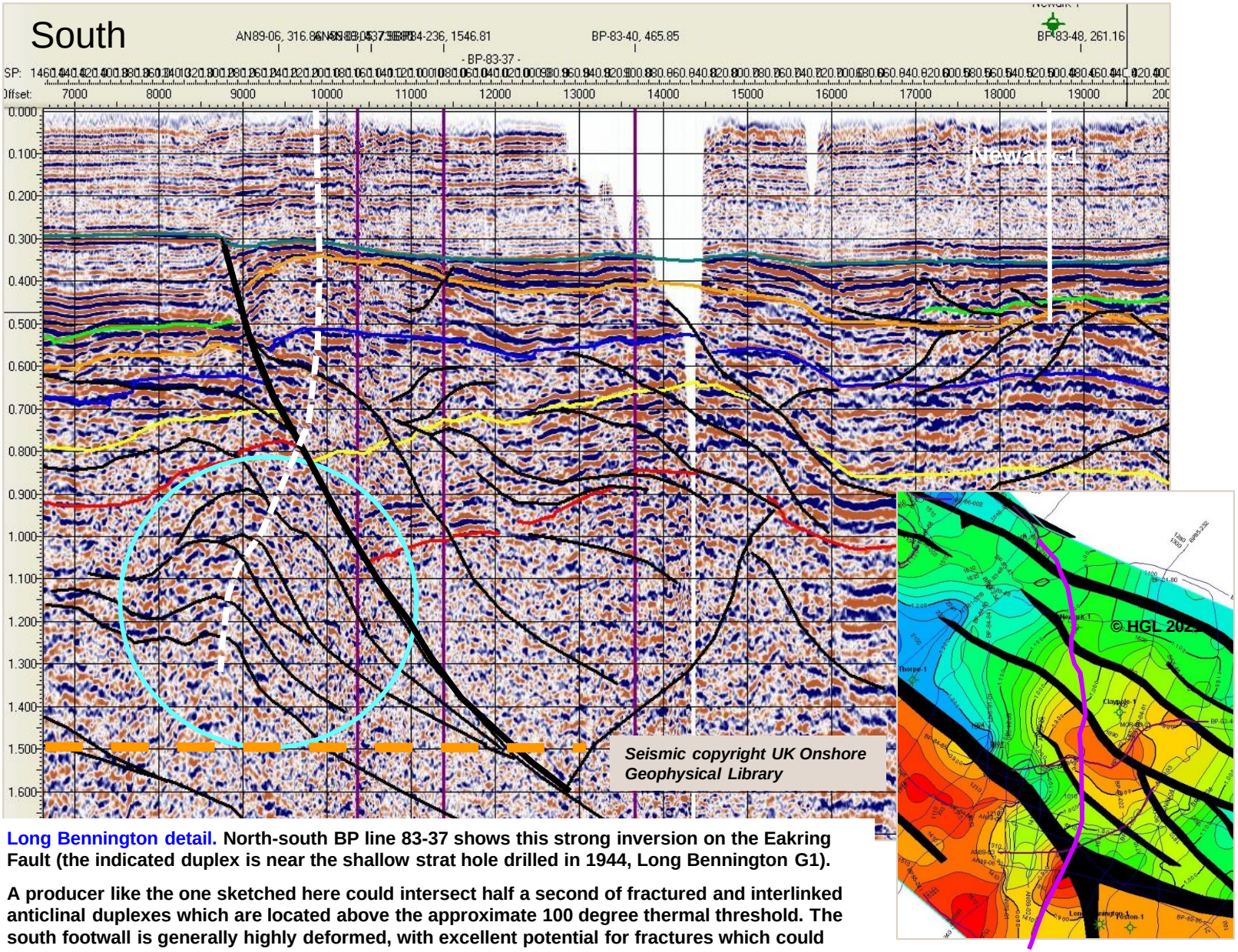


Looking at line BP83-37, it shows colossal footwall deformation, from 0.7 seconds two-way time down to base of the profile there is a mile-high stack of thrust-repeated slices of Lower Carboniferous sediments under the Eakring Fault (dashed) where it meets the Denton Fault. The footwall shortening can only be guessed at, but it must be substantial with both Eakring and Denton faults driving the deformation. It looks like a very strong candidate trend to drill for hot water.

Is this real structure, and is the interpretation reasonable? Yes it is. Inset we show again our model for the repeating footwall collapse that can develop overlapping passive-roof duplex fault slices like these.

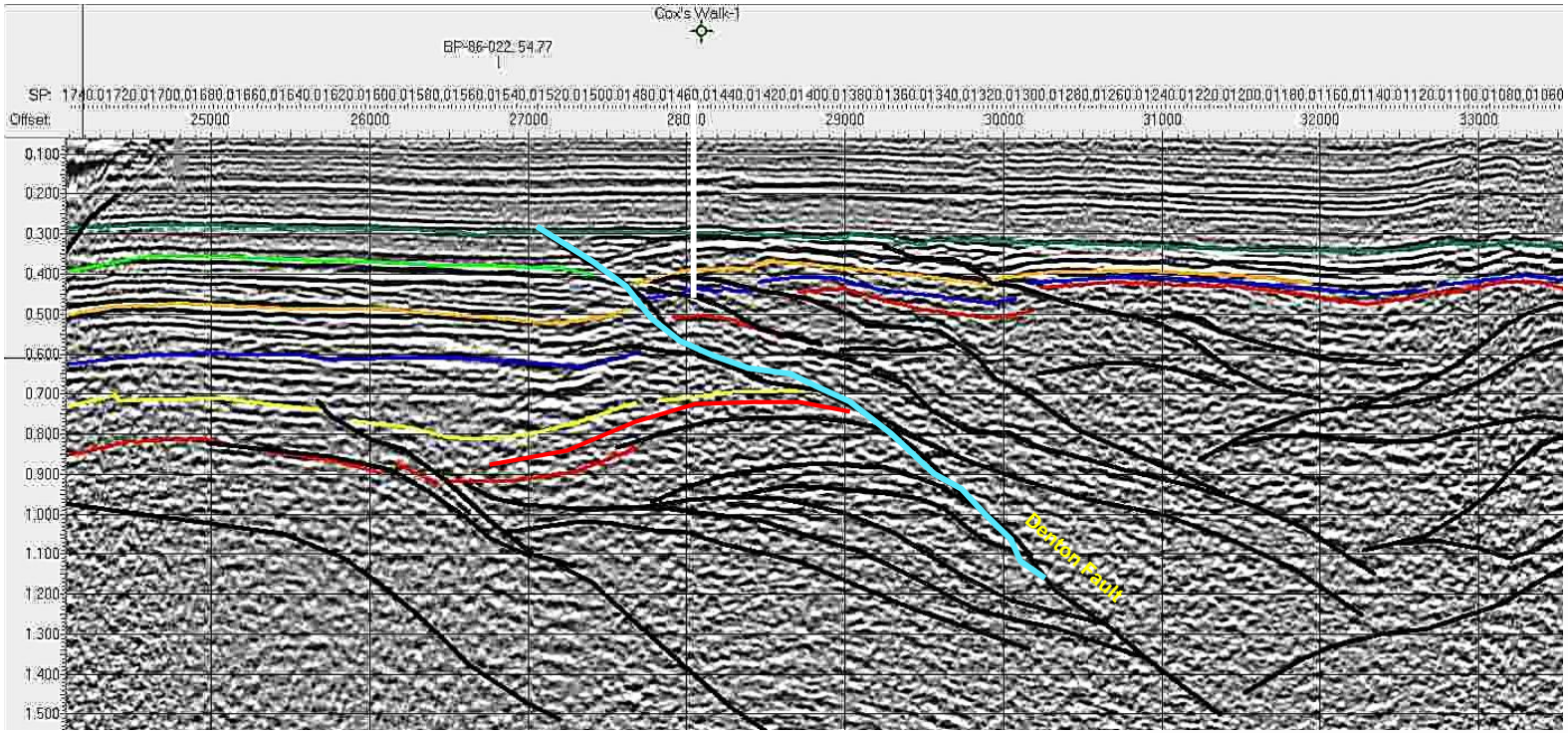



X/Y: Meters
460000
470000
480000
490000
360000
350000
340000
HGL Eakring Fault intra-Lower Carboniferous marker mapping, twt.
<0.650
0.650
0.675
0.700
0.725
0.750
0.775
0.800
0.825
0.850
0.875
0.900
0.925
0.950
0.975
1.000
1.025
1.050
1.075
1.100
1.125
1.150
1.175
>1.175
Newark South. Given this smashed footwall uplift, a huge potential storage exists for hot water: where does the water mainly come from? One plausible answer is, the Vale of Belvoir, the east end of Widmerpool Basin. The regional rise eastwards brings it updip to Eakring Fault's footwall, and thence some of it can cross into fractured hangingwall, for Newark South structure.
Newark South
Rainworth-1
Eakring 1
Kirklington-2
Normanton-1
Parkhill 1
Fiskerton-1
Thorpe-1
Newark-1
Claypole-1
Long Bennington-1
Harlequin-1
Bingham-2
Cox's Walk-1



Long Bennington detail. **North-south BP line 83-37 shows this strong inversion on the Eakring Fault (the indicated duplex is near the shallow strat hole drilled in 1944, Long Bennington G1).**

A producer like the one sketched here could intersect half a second of fractured and interlinked anticlinal duplexes which are located above the approximate 100 degree thermal threshold. The south footwall is generally highly deformed, with excellent potential for fractures which could deliver water at high rates. More seismic may confirm a series of targets along the footwall trend.



Confirmation of footwall fracturing comes from this borehole, Cox's Walk on west-east line BP-83-30 crossing the Foston High. The hole was drilled by NCB as part of their coal resource proving programme, and they cut substantial core including probably-Ordovician age andesitic volcanics. Numerous fracture zones were encountered between 500-800 metres, where the bore terminated.

Denton Fault is strongly inversion reversed in our interpretation, we see the Foston High as a strike-slip inverted structure with multiple footwall collapse duplexes. Though the high is high-velocity rock it nevertheless returns seismic reflections: we don't think these are processing anomalies, the fractures are water-bearing, hence the velocity variations are real.

Had the borehole drilled deeper we suggest it would have crossed the Denton Fault into footwall Lower Carboniferous sediments with target duplexing which has geothermal potential. Some trace hydrocarbons were reported, generated in the footwall shales to the west.