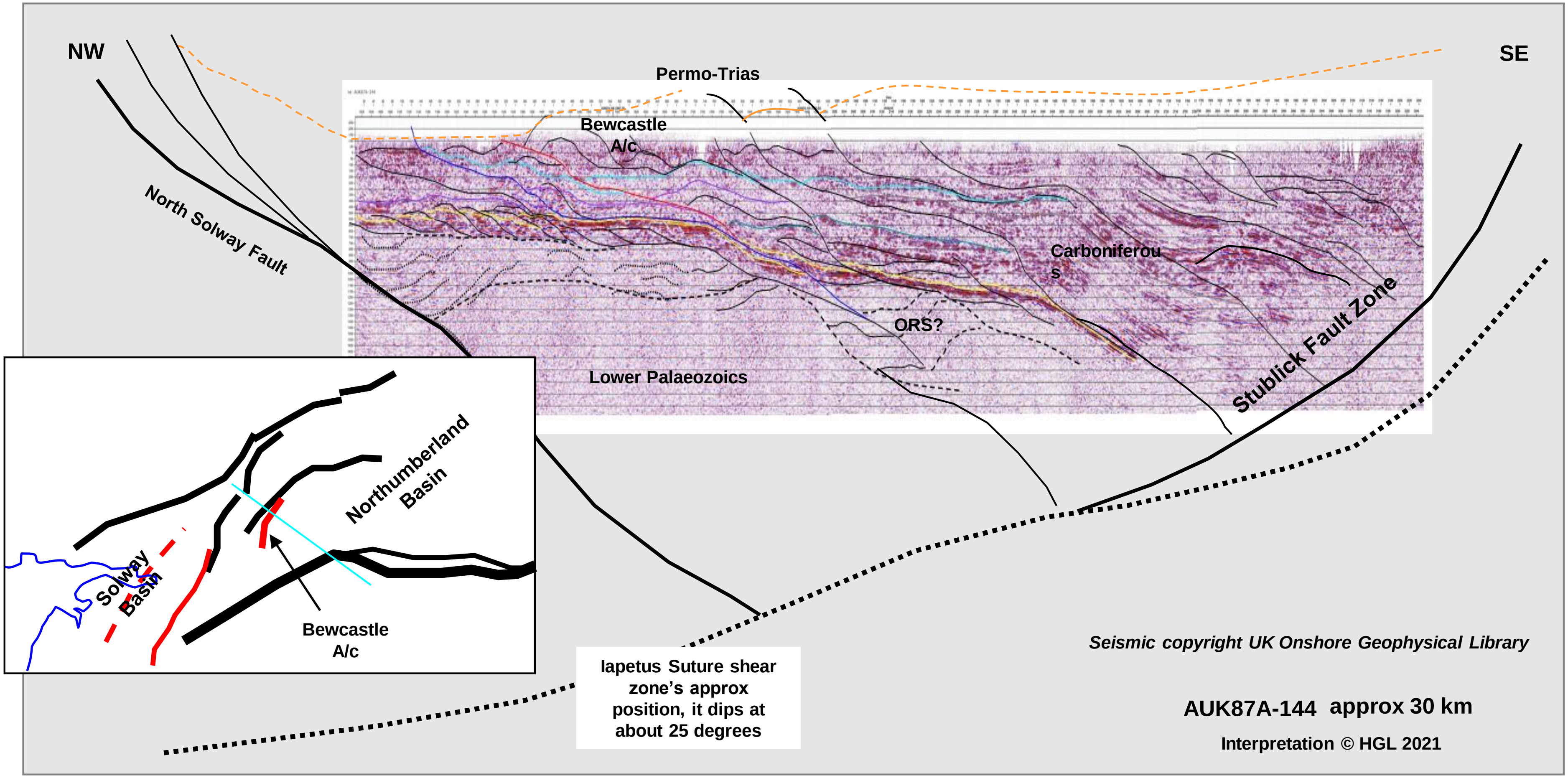
Some key points for review of the Northumberland and Solway Basins

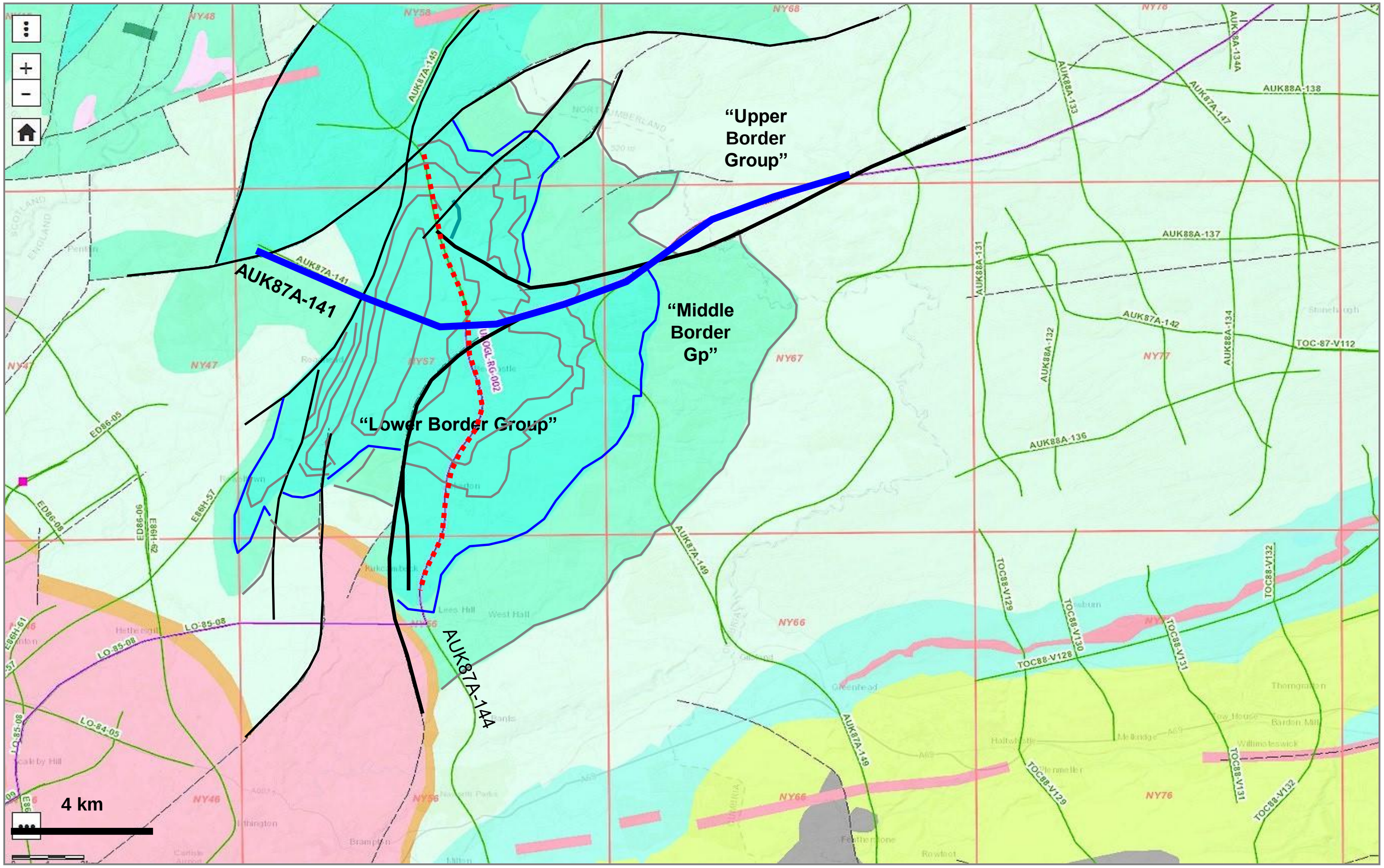


This north-south section across the Bewcastle area, near the boundary between Northumberland and Solway Basins, is a good representative model for their structure style. This is the setting for nationally important geothermal potential.

In Northumberland the Permian and Triassic is missing by erosion and the infill is mainly Carboniferous, which is about 4-5000 metres thick on the south flank, lying across Old Red Sandstone depocentres. The southern margin is defined by the syn-depositional Ninety Fathom and Stublick fault systems, separating it from the granitic Alston Block: these have very large throws, the rifting was mainly early Carboniferous. These major faults root onto the extensionally-reactivated Iapetus Suture, which was a plate boundary supporting Caledonian subduction of the Lake District northwards under the Southern Uplands.

The main structural block pattern is the same as in the Solway Firth, with huge ramp faults dipping southeast controlling sedimentation and subsequent deformation. The rifting and opening of northern North Sea in the early Permian was an east-west extension, so a simple model for the partial reversal of NE-SW faults rooting into the deep ramps is that it is transpressional and caused reactivation of the growth faults along with new faulting in cross-basin shortening. The compression shortened the Basin obliquely to create hangingwall rollovers on the steeper ramps.

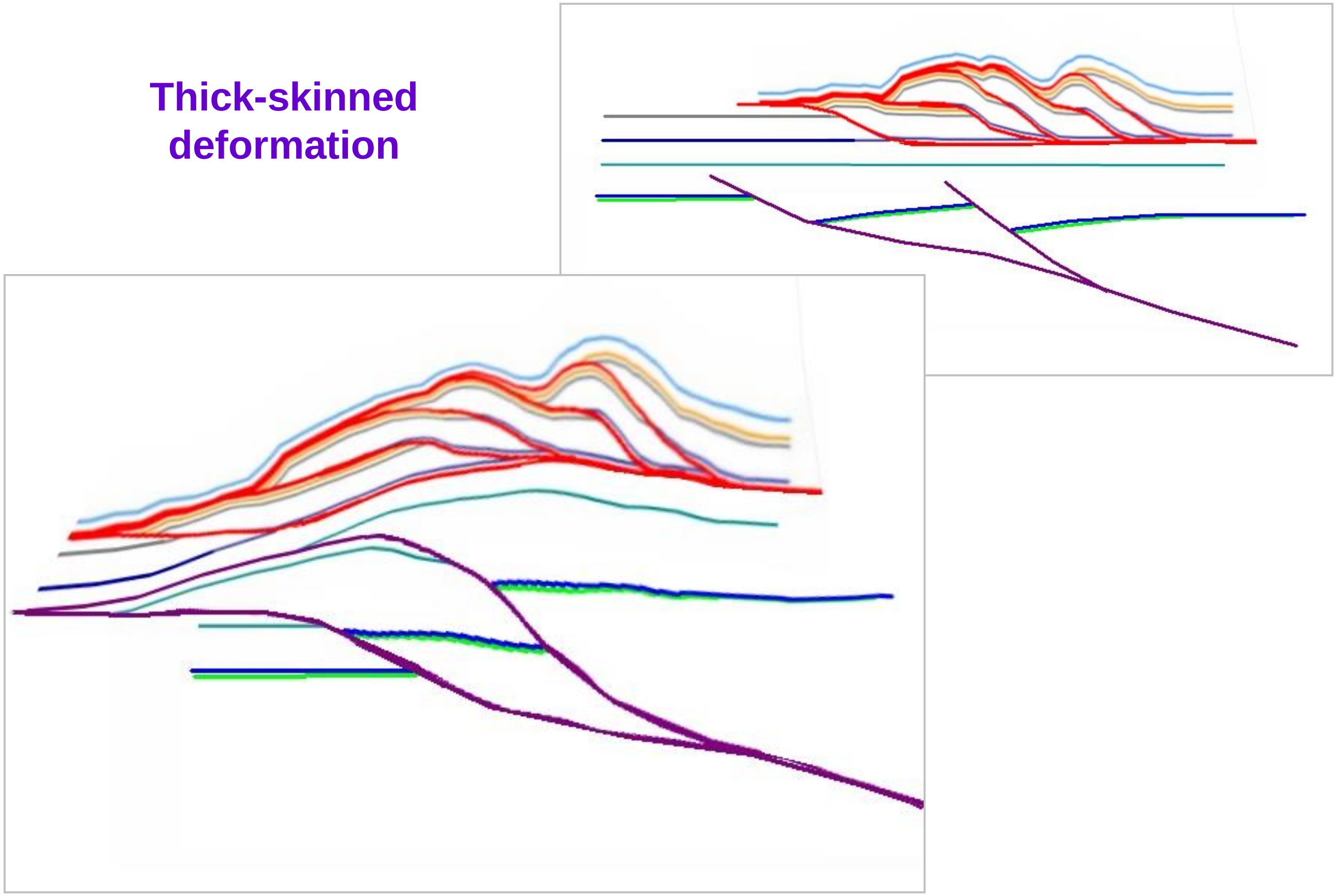
Geothermal potential of the Bewcastle Anticline



1. Bewcastle Anticline. **The Northumberland Basin is traditionally separated from the Solway Basin to the west by the 20 km length of the Bewcastle Anticline, culminating north of Brampton. Here the Carboniferous is about 4 km thick, very strongly eroded with several km removed in early Permian, its mostly comprised of the Inverclyde and Border Groups. The local formations in the Lower BG are outlined here in grey. Bewcastle has been shot only by wide-spaced recce vibroseis profiles, acquired by Amoco in the late 1980s, there is no deep well on Bewcastle structure to date: the nearest borehole is BGS Archerbeck to the west.**

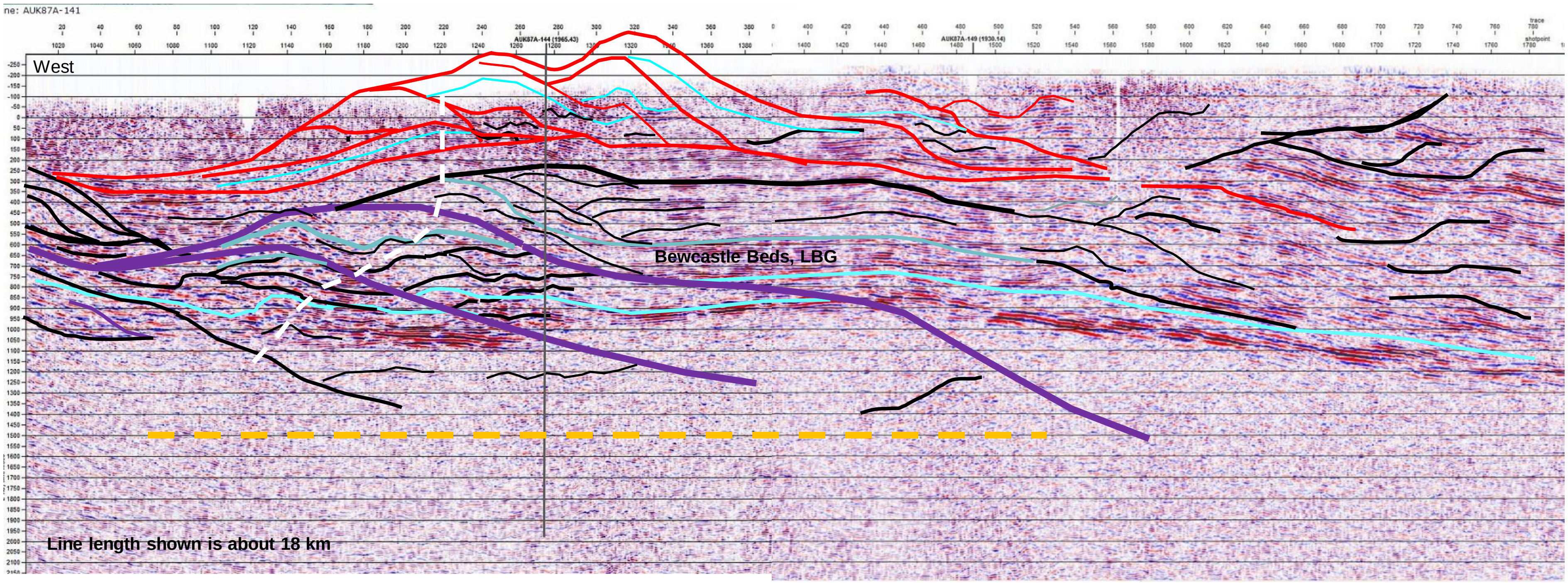
The folding at outcrop was developed by strong-inversion of the SE-dipping growth fault which defines the Bewcastle tilted block, as the blue part-line AUK87A-141 will show, next slide.

Thick-skinned deformation



The shortening on Northumberland-Solway ramps inverts old extensional structures beneath the upper carapace of duplexes, particularly strongly so in the Northumberland Basin. The deeper faults cut the basement and when they reverse they flex the overlying detached duplex trains. We see this process on a large scale at Bewcastle, its spectacular there.

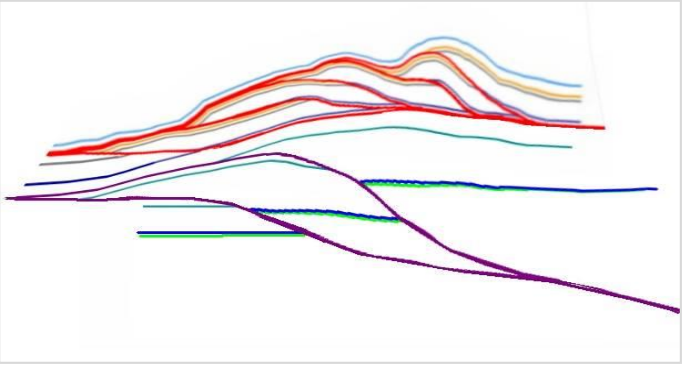
The details don't matter, but the seismic in the following profile which seems highly scrambled is actually good data showing real geology. With detachment surfaces separating Upper Border sediments from units below, the same amount of shortening is expressed differently in the various stacked rock units. Simple deformation models produce complex results, when repeated a few times: and bed lengths being greater in the shallower growth-fault depocentres, there is very obvious folding and thrusting at outcrop.



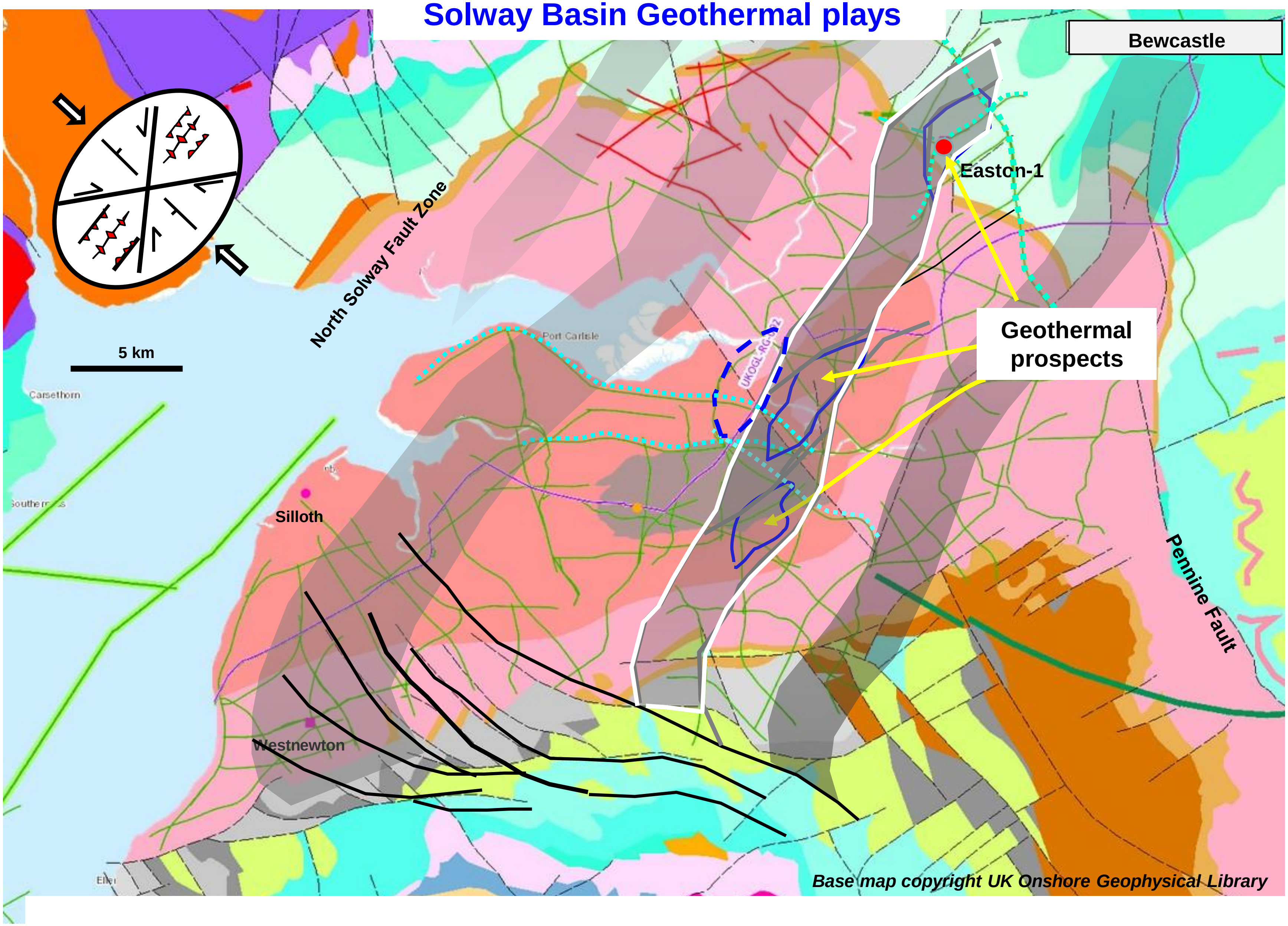
This profile is the western part of AUK87A-141, its crossing with line -144 is marked. Its shot obliquely to the NNE-SSW strike of the extension ramp on which the Bewcastle folds trend. The thick-skinned interpretation model for extension and inversion, inset, works convincingly to explain this rather complex area's structure. The Upper Border Group is detached on the red duplex fault system sole. The shortening in and below the various Border Group formations is achieved differently, but sketched so as to be about the same order of displacement, top to base.

Seismic velocities are similar to Bowland Basin, so an approximation to 100 degrees C isotherm is guessed at about 1.5 seconds for 3000 metres. (This seismic will re-process to show a lot more Carboniferous and top Devonian sediment, below the orange line. We'd estimate basement could be 4500-5000 metres below ground level, at Bewcastle).

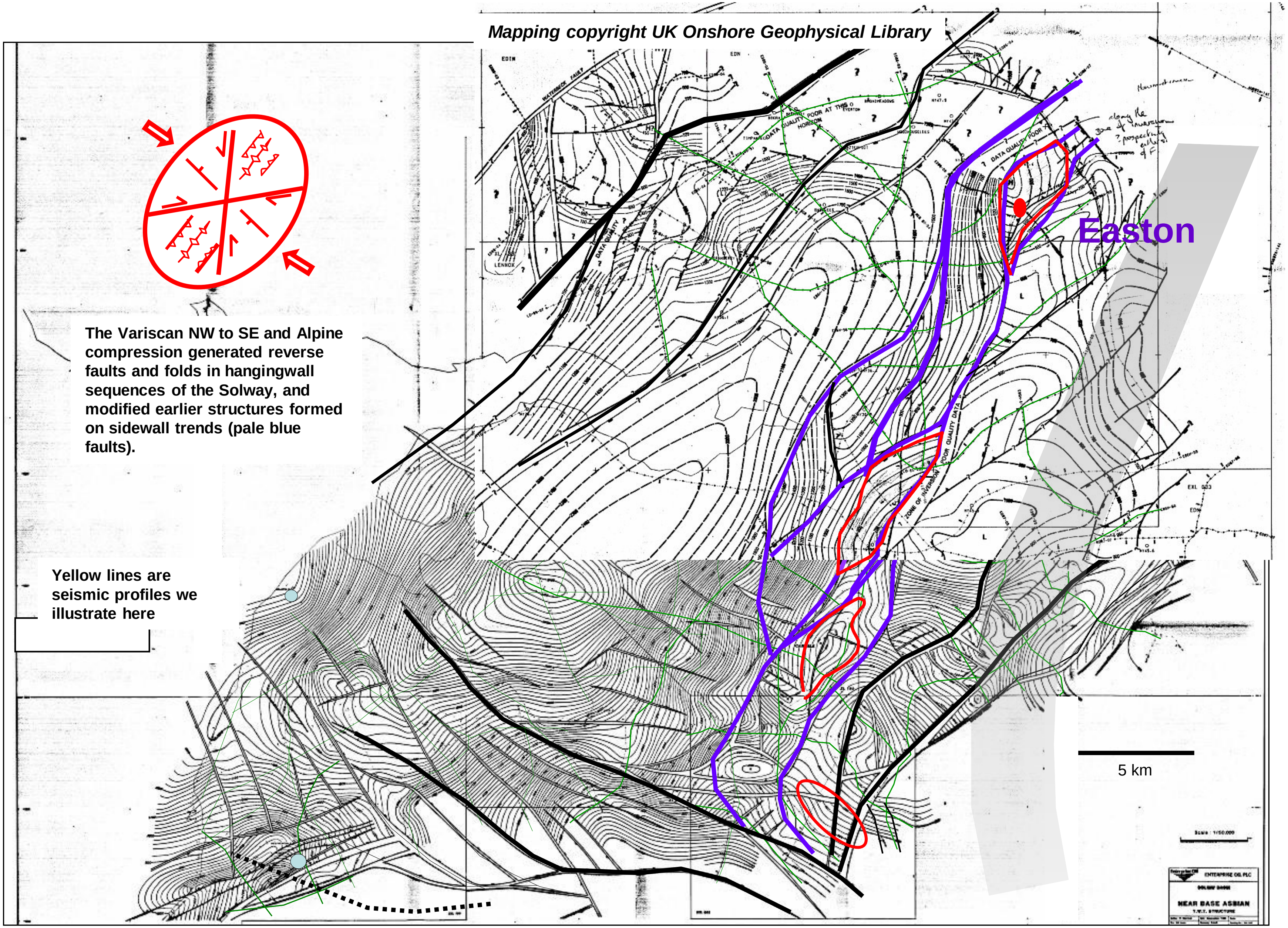
The white dashed line is a plausible track for a geothermal well to find hot water close to the 100 degrees isothermal, in very strongly fractured rocks.



Solway Basin Geothermal plays



2. Easton play. This onshore Solway Basin geological map and seismic cover, after UKOGL, shows a simplistic late Carboniferous-early Permian stress model for the basin inversion, which resulted in 3-4 km uplift and renewed extension as the Permo-Trias was deposited. Some of the major structural ramps are added by us, shaded grey, and we discuss the major Carlisle to Easton ramp outlined in white which has particular interest for geothermal plays.



Although it maps different events in different places and recognises only some of the major extensional fault ramps, this composite map pieced together from the relinquishment files on UKOGL tells us a lot about lower Carboniferous structure and prospective geothermal inversion plays in the Solway and western Northumberland Basins. In particular the ramp between Carlisle and Bewcastle/Easton with its red-outlined local highs is highly significant for geothermal targeting: it has all the ingredients for a successful play.

Easton-1 well

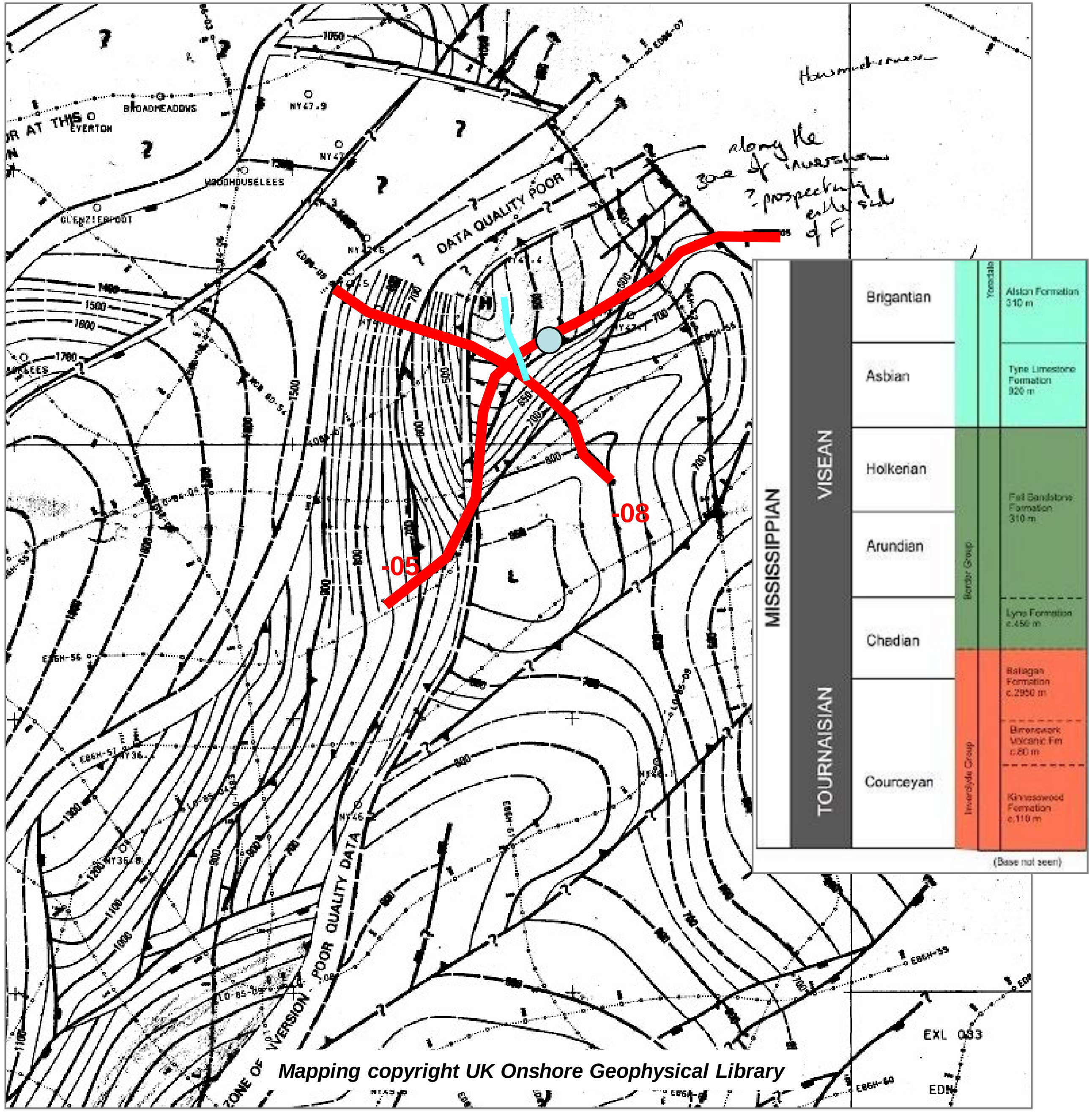
Edinburgh Oil & Gas's Easton-1 was drilled in 1990, TD was at 2260m brt. It spudded in the lower section of Upper Border Group, penetrated the Middle Border and terminated in the Lower Border Group.

Pre-drilling mapping for Easton structure, here, was based on a clear intra-Lower Border marker series, the two seismic lines shown in red are illustrated next. The well encountered gas highly correlated with fractures in Lower Border Group, and ran a series of tests, DST#1 flowed 95 mscfd of methane from two large fractures at 1126-1174m. No oil was reported. Some 15 mmscf in place was estimated by operator. Gas to supplement hot water production would not be a factor in geothermal economics, but a significant discovery would certainly be a commercial asset in funding a geothermal project.

(Gas was believed to be sourced from algal limestones of the Lower Border Group sequence. The trap, a fold (pale blue) where a large sidewall roots onto the reversed down-to-southeast frontal fault ramp, depended on updip cross-fault seal. Being highly fractured, that condition failed for commercial gas development).

Logs show the fractures are mainly in dense, brittle dolomite beds: the close-spaced and repeated alternation of lithologies help to create complex fracture systems which are best developed in the fold axial zones. A natural fracture trend like this one is a geothermal target extending outside local mapped closure.

Dropping the acreage was part-driven by the very low observed matrix porosity and perm. But with tight lithologies, the sustained 10+ ppg mud weights used to control the kicks from various levels created formation damage and loss of relative permeability to gas as a result of filtrate invasion, so it wouldn't be surprising if poroperms are higher than post-well report suggested.

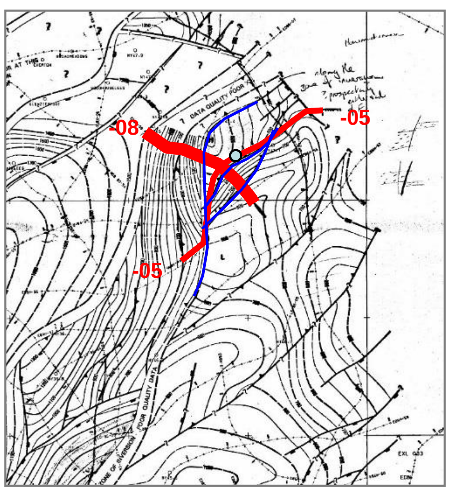


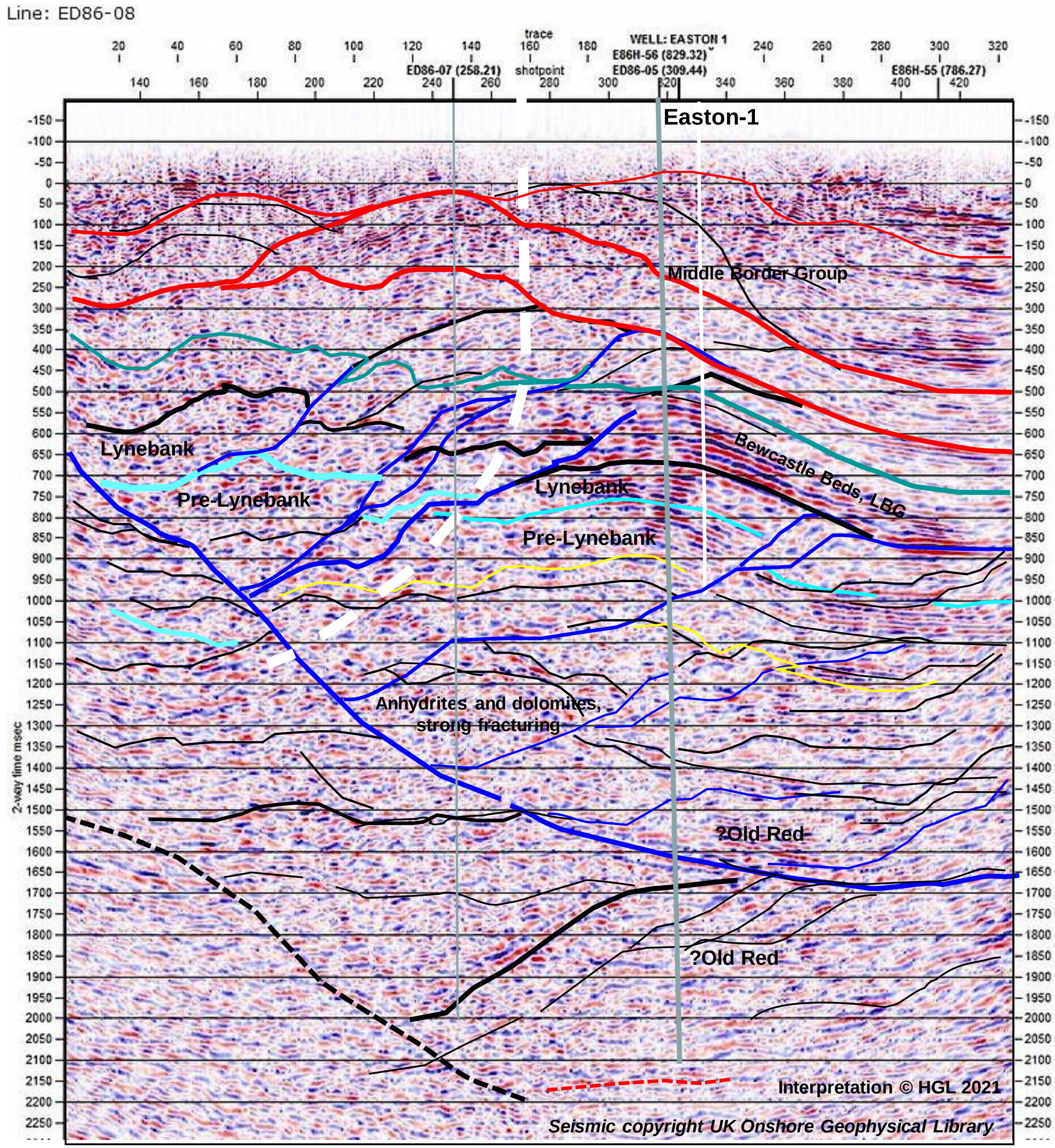
Edinburgh drilled the Easton well on a local inversion anticline, -08 here is a dip line, 5.7 km long.

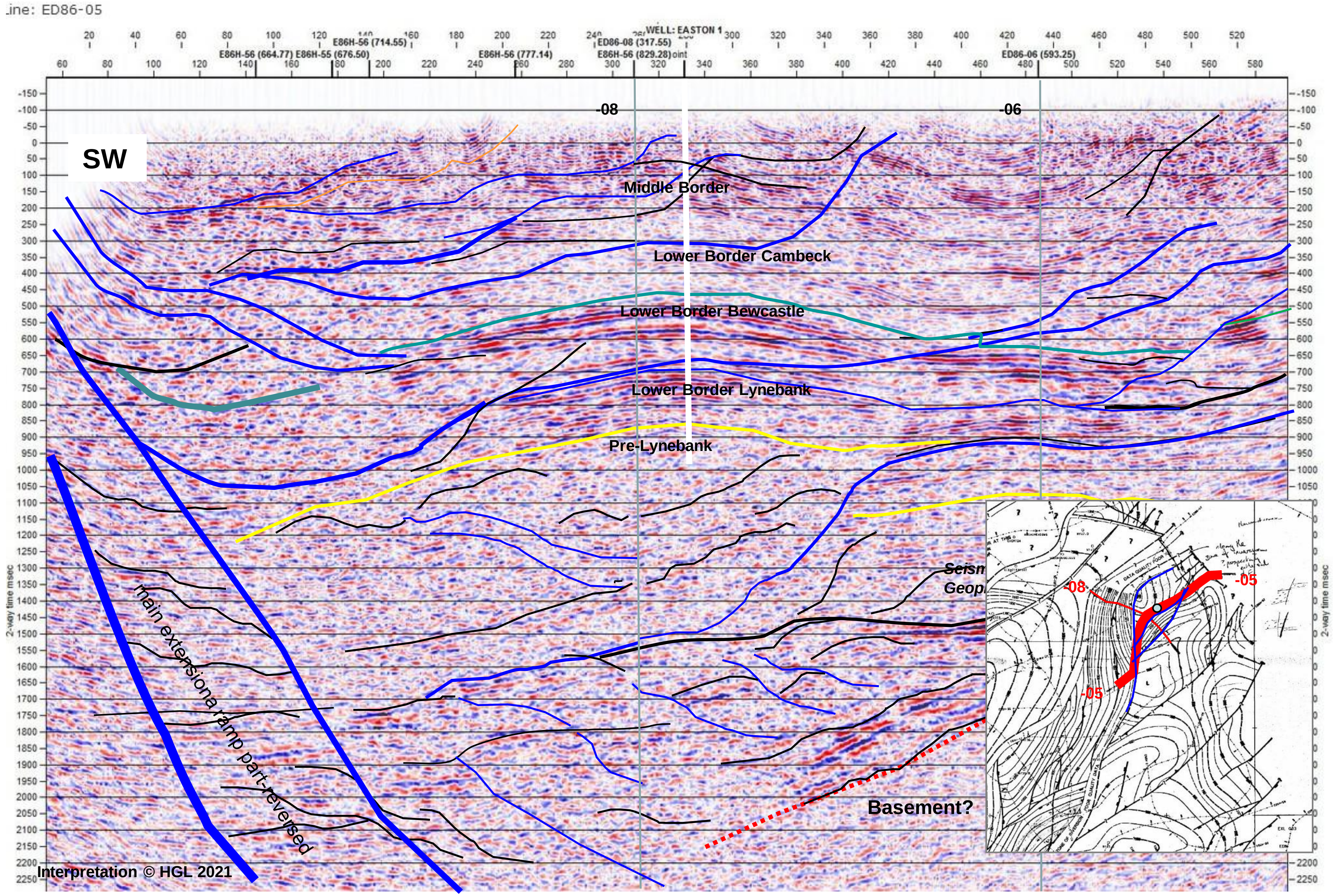
The anhydrite-rich, carbonate-clastic succession of vertical thickness 1150 metres (base not reached) in the Ballagan Formation and higher units was a surprise, as only indirect traces of evaporites were known at outcrop. Above the green marker there are about a dozen cyclic sequences of limestones, shales and sandstones with numerous interbeds of anhydrite which are up to 8 metres.

Poroperms are poor in the Border and Inverclyde Groups but "Bewcastle Beds", 500-600 metres of Ballagan between green and pale blue, are naturally fractured. The regional extent of these rocks is greater than 1000 square km.

<u>There will be a lot of hot water on this ramp</u>. A possible geothermal producer is drawn white-dashed.







This is the 9.4 km strike-line ED86-05 SW-NE crossing Easton dome hangingwall, blue faults are coming out of plane towards the eye, they are hangingwall collapse fractures, most of them are inversion, shortening faults, their density increases towards the base of the profile. Under pre-Lynebank is the Ballagan equivalent with brittle dolomitic limestones and interbedded anhydrites. One second twt is about 2 km depth. Large volumes of sediments are at and below likely 100 degree Centigrade level, from around 1400 msecs. The bright dotted red marker may be near basement.

Salient points on Carlisle-Easton play

Points supporting strong interest in this inverting ramp process are these:

The major sequence of Lower Carboniferous sediments is highly fractured on the ramps, with multiple hard limestones which can be acidized to re-open networks and improve fracture continuity. A significant proportion will be at or around 100 degrees C.

There are a number of these prospective zones on trend, so that multiple pads can be economic to drill in sequence, in a short time frame. Numerous sites will be readily available, each producing 1-2.5 megawatts. A major user, Carlisle, is close by.

Additional seismic, preferably 3D, is warranted at Easton, followed by a re-drill injector which is designed to minimise loss of matrix permeability by filtrate invasion.

The potential for finding commercial gas in these plays raises important aspects in designing a geothermal licensing framework, which should include terms clarifying commercial rights of the operator to sell hydrocarbons and information pertaining to a discovery, should there be one, whilst the block is not classed as a PEDL. Recognising the capital outlay of the operator, in deep drilling, this could simply be a right to convert the block into a PEDL where the obligation to drill a well is already met.