The Breagh Field, Blocks 42/12a, 42/13a and 42/8a, UK North Sea

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Abstract

The Breagh Field is in UK Blocks 42/12a, 42/13a and 42/8a. It is a gas field with multiple reservoir intervals within sandstones of the Early Carboniferous Yoredale Formation (equivalent to the Middle Limestone Formation within the Yoredale Group onshore). It was the first and is presently only field developed within these sandstones, offshore UK. Breagh was discovered in 1997 by well 42/13-2 and proved by development well 42/13a-A1. Its crest is at 7110 ft TVDSS (true vertical depth sub-sea), marked by the unconformity between the base Zechstein and the subcropping Middle Limestone Formation. It has a free water level at 7690 ft TVDSS, a maximum column height of 510 ft and a field extent of 94 km^2. Breagh was developed using ten wells from a 12 slot normally unattended platform, five of the wells have been stimulated by hydraulic fractures with proppant injection. The unprocessed gas flows through a 110 km 20" diameter pipeline to the Teesside Gas Processing Plant. Production started in 2013, reached a peak rate of 150 MMscfgd in 2014 and by the end, 2018 had produced 140 bcf. The field is operated by INEOS Oil and Gas UK Ltd (70%) with partner ONE-Dyas B.V. (30%).

Key words: Breagh, Early Carboniferous, Yoredale Formation, Middle Limestone Formation, tight gas, fracture stimulation.

Historically, exploration for petroleum in Early Carboniferous reservoirs had been very limited in the UK offshore. In contrast, hundreds of wells have targeted Permian Rotliegend Gp. sandstones, Triassic Bunter sandstones and Late Carboniferous sandstones (Glennie and Provan, 1990; Ketter, 1991; Besly *et al*., 1993; Rodriguez *et al*., 2014) (Fig. 1). However, in the past couple of decades discoveries in Carboniferous age reservoirs, such as Pegasus in 43/13b, Crosgan in 42/10b and 42/15a in addition to the large fields - Breagh and Cygnus, have now upgraded the potential of the area.

The Breagh Field (Fig. 2) contains a low permeability sandstone reservoir. The field lies approximately 40 miles west of the decommissioned Esmond Field (Block 43/13a), 32 miles north-west of the Garrow Field (Block 42/25a and 43/21a), 38 miles north-east of Flamborough Head on the Yorkshire coast and 53 miles west-north-west of the INEOS Oil and Gas UK operated Cavendish Field (Block 43/19a). It lies within Quadrant 42 of the UK Southern North Sea (SNS), immediately to the north of the Sole Pit Basin. It is very close to the southern edge of the Mid North Sea High (Glennie, 1986). It is the also most westerly of the fields with Carboniferous age reservoir in the SNS and northeast of the pinchout of the Lower Permian Rotliegend Group sandstones (Fig. 1).

The field has an area of 94 km^2 below a four-way dip closure at the Base Permian Unconformity (BPU); (Fig. 3). The field has gas-initially-in-place (GIIP) of approximately 1 tcf in the Early Carboniferous (Mississippian) Yoredale Formation also known as the Middle Limestone Formation of the Yoredale Group onshore UK (Mclean, 2011).

History of exploration and appraisal:

The first well on the Block, 42/13-1, was drilled in 1968 by a BP/Phillips/Amax joint venture on the eastern edge of the then BP concession (Fig. 2). The well penetrated an elevated structure identified on a two-way-time map at the BPU. The objective was to drill to the Carboniferous interval as well as to evaluate the Triassic Bunter Sandstone Formation and Permian Rotliegend Group sandstone reservoirs. However, Bunter and Rotliegend strata were absent and the Namurian (lowermost Upper Carboniferous) section was largely shale (thickness of 330 ft). As a consequence, the well was terminated in Lower Carboniferous Limestone at 8243 ft TVDSS. It was plugged and abandoned as a dry hole on the 30th August 1968 and the block was then relinquished.

Twenty-nine years later in 1994, Mobil acquired 3D seismic data over Block 42/13a and subsequently drilled and cored well 42/13-2 in 1997; a gas discovery that was eventually to become the Breagh Field (named in 2007). The prospect drilled by well 42/13-2 was a large base Zechstein closure and part of a deliberate test of the Yoredale Formation as a potential reservoir interval (Maynard *et al*., 1997; Maynard and Dunay, 1999a). It proved a gas column of at least 400 ft containing approximately 66 ft of net pay (McPhee *et al*., 2008). The well found five gas-bearing sandstones in the Yoredale Fm. (Middle Limestone Fm.) between 7410 ft TVDSS and 7800 ft TVDSS, but all tested at low rates of 3 to 4 MMscfgd. The discovery was not thought to be commercial and again the block was relinquished (21st August 1997).

Sterling Resources (UK) ('Sterling') was the next company to operate the block. The company acquired a Promote Licence in 2005 based upon the work of the late Frank Barker who had re-evaluated the Carboniferous gas-bearing interval in 43/13-2, and the likely reservoir continuity based upon reservoir analogues exposed on the Northumberland coast (Jones, 2007). Sterling Resources (operator, 45%) in turn farmed out equity to joint venture partners (Encore - 15%; Regenesys - 15%; Stratic - 10% and Petroventures - 5%) in the second year period of the Promote License.

Following the evaluation of well 42/13-2, the new operator considered that the low-rate well-test had been caused by reservoir damage prior to testing, but the field contained considerable upside potential (McPhee *et al*., 2008). An integrated study of the subsurface data followed, and the new operator decided to drill well 42/13-3 using oil-based mud to prevent water-related formation damage. Well 42/13-3 is of critical importance as it was a license obligation well with a primary objective to prove the commercial viability of the Breagh discovery by drilling and testing the Early Carboniferous section.

Well 42/13-3 was spudded in September 2007, one mile northeast of the 42/13-2 discovery well. It successfully tested two gas-bearing sandstone intervals in the lower part of the Carboniferous section, establishing a combined flow rate of 17.6 MMscfgd. Such a rate was considered sufficient for a commercially viable development of the field. The well also proved the presence and continuity of sandstones between 42/13-2 and 42/13-3 and so gave rise to a potential framework for a broader correlation of the Carboniferous strata over the Breagh area.

Following this success a vertical appraisal well, 42/13-4, was spudded 2.5 miles SE in 2008. It successfully tested gas-bearing sandstone within the same Early Carboniferous reservoir interval at 7531 ft TVDSS, a similar depth to the earlier two wells and flowed gas at 1.6 MMscfgd (lower interval only) and 10.2 MMscfgd (upper and lower interval). The well was drilled to a terminal depth within the Scremerston Formation at 8140 ft TVDSS.

Appraisal well 42/13-5 was drilled ahead of field development. The well had a 68.9° inclination and was drilled from the same surface location as 42/13-3 as a pilot hole for a horizontal sidetrack well 42/13-5Z. It penetrated the same Lower Carboniferous gas bearing sandstones tested previously. Well 42/13-5Z was completed with a 2500 ft reservoir section and tested gas at rates of up to 26 MMscfgd. Despite the difficulty of maintaining the well bore in the reservoir, due to the occurrence of small faults along the well track, the flow rate achieved gave confidence that development of Breagh would be commercially viable. Sterling thus drew up a development plan involving an unmanned platform and tieback to Teesside and marketed the field.

RWE Dea acquired a 70% interest from Sterling and the other non-operating partners and took operatorship in 2009. Sterling was the remaining partner with 30%. The Field Development Plan (FDP) was submitted in 2010. By 2011, a down-dip appraisal well 42/13a-6 was drilled and cored to appraise the eastern side of the field. It found two gas-bearing sandstones appearing similar in thickness to those seen in the western part of the field. This well terminated at a depth of 8,622 ft TVDSS.

Development

Following the discovery of the field in 1997 it was thought that developing the field was not economically or commercially viable and the license was subsequently relinquished. The entry of Sterling in 2005 and further studies led to the drilling of the four appraisal wells discussed above and a decision to develop the field in 2010/11. A phased development was chosen for the Breagh Field as uncertainties presented themselves due to the complex overburden and its effect on the depth conversion. These in turn had implications for the way in which the structure was mapped as well as the identification of field closure and subcrop patterns. The FDP specified two phases, an initial phase of ten wells (Fig 2) followed by a provision for a possible second phase of development.

In spring 2012 development wells A1 and A2 were drilled at an inclination of 45° as sidetracks of appraisal well 42/13-3 (42/13-3z and 42/13-5y respectively). Subsequently, in the summer of 2012-2014 wells A3, A4, A5z and A6 were drilled at an inclination of 65° and conventionally completed, all of which produced at a combined rate of approximately 100 MMscfgd for the first year. The decision to drill at this angle was in part to increase the flow rates compared to the vertical appraisal wells, as the greater along-hole section through the sandstones was anticipated to increase productivity. The sandstones were, however, of lower permeability than originally expected. From operator experience and success on the Clipper South Field, it was thought that hydraulically fracturing the wells would increase flow rates in the lower permeability sandstones. Fracture stimulation was implemented after drilling A7 as the rig had a period of maintenance allowing the operator to plan for fracturing wells A7 and A8 (drilled in 2013-14).

The stimulation programme was as follows: (1) diagnostic fracture injection test to assess the formation properties, (2) breakdown and stepdown test to analyse formation strength and what pressures and injection rates would be required, (3) ‘minifrac’ to test the hydraulic fracture design, and (4) main fracture. However, hydraulically fractured wells were not planned when the Breagh Alpha platform (minimum facilities normally unattended installation) was installed so no solids production could be handled. Therefore, following clean-up where special precautions were taken to protect the hydraulic fractures, ceramic sand screens were installed downhole. Although the stimulation programme posed challenges, the fractured wells performed strongly contributing approximately 45% of the average daily production. At this point, the use of hydraulic stimulation was considered a viable option for developing the field (Jones *et al*., 2015).

In 2017-2018, following the acquisition and interpretation of the new 2013 3D seismic data, wells A9z, A10z and A4z were drilled and hydraulically fractured. The wells were drilled as 'S-shaped' wells penetrating the reservoir at near vertical to maximize the efficiency for hydraulic stimulation.

Regional context

Underhill (2003) documented how changes in Caledonian and Variscan orogenic regimes, climate, eustasy and sediment supply combined together to influence the tectonic structure and reservoir sedimentology of the sandstones that now host the gas fields in the SNS and the rest of the UK Continental Shelf (UKCS). In addition several other authors have also described the complex geological evolution of the SNS area (Glennie, 1986, 2005; Fraser and Gawthorpe, 1990; Leeder and Hardman, 1990; Collinson *et al*., 1993; McLean, 1993; Underhill, 2003; Nesbit and Overshott, 2010). This section will only focus on key events specific to the Breagh field within the framework of the SNS.

Devonian and Carboniferous rocks within the SNS occur in a large ESE-plunging anticline termed the Southern North Sea Carboniferous Basin (SNSCB) (Leeder and Hardman, 1990; Glennie, 2005). The SNSCB, along with the onshore East Midlands area of England and the Netherland Basins, form a single post-Paleozoic syn-rift megasequence termed the Variscan Cycle (Underhill, 2003) and characterized by major strike slip zones such as the Sole Pit and Market-Weighton axis in the UK (Fraser and Gawthorpe, 1990; Underhill, 2003). The SNS inherited the strong NW-SE structural trends from Paleozoic Caledonian orogeny (Pharaoh *et al*., 1987), which strongly influenced the pattern of sediment deposition during the Carboniferous.

Carboniferous sedimentation within the SNS changed progressively from mixed marine and paralic sedimentation with limestones, sandstones and shales deposited in the Early Carboniferous (Yoredale Fm.), to pro-delta and delta front sedimentation in the earliest Late Carboniferous (Besly, 1998). These sedimentary rocks are in turn overlain by delta top sediments during the Westphalian (A and B) and ultimately continental fluvial and alluvial deposits (Westphalian C and D); (Besly *et al*., 1993). (Fig 3).

The Carboniferous period closed with the Variscan Orogeny, caused by the formation of Pangea (Cameron *et al*., 1992; McCann *et al*., 2008). Subsequent Permian age sedimentation in the SNS began with Rotliegend Group continental sandstones and their basinal temporal equivalent lacustrine mudstones (aeolian, fluvial and sabkha) belonging to the Leman Sandstone Fm. and Silverpit Formation respectively. These Early Permian deposits are absent from the heavily eroded Breagh area (Booth *et al*., 2017) (Figs. 3, 4 & 5), which was only overstepped in the Late Permian by Zechstein carbonates and evaporites deposited after the Southern Permian Basin connected to the Tethyan Ocean. The Mesozoic stratigraphy of Breagh and the surrounding area is comparable to that of the nearby Esmond, Forbes and

Gordon fields with a thick Triassic section overlain by attenuated Jurassic and Cretaceous sections (Ketter, 1991).

The source of gas in the Breagh area is not entirely certain. Elsewhere in the SNS, coals within the paralic sequences of the lowermost Late Carboniferous are considered to be the source of gas (Barnard and Cooper, 1983; Ritchie and Pratsides, 1993). However, at Breagh, Permian Zechstein strata lie direct upon Early Carboniferous strata. The gas that now fills Breagh could have arrived via long distance migration from structurally deeper, but stratigraphically younger Late Carboniferous coals. The source could also be the Namurian mudstones containing disseminated organic material to the east or there may be as yet an uncharacterized source in the Early Carboniferous such as the Mid-Dinantian Scremerston Formation(Chadwick *et al*., 1993; Milton-Worssell *et al*., 2010; Booth *et al*., 2017).

Nonetheless, gas generation probably occurred in the Late Cretaceous-Early Tertiary (Cameron *et al*., 2005), but since the SNSCB was tilted into its present configuration in the Late Tertiary, adequate understanding of Mesozoic burial and inversion postdating trap forming events in SNSB is critical for the exploration success of its hydrocarbon province (Fraser and Gawthorpe, 1990).

Database

The Breagh Field database includes 6 exploration/appraisal wells and 11 production wells. While drilling these wells a series of measurement while drilling, logging while drilling and wireline logs were obtained. These included the caliper, gamma ray, sonic, density, neutron, resistivity, and acquisition of formation pressures and well test data. These data were used to establish lithologies, shale volume, total and effective porosity and permeability, formation water resistivity and water saturation, pressure gradients, fluid contacts and saturation height functions. Furthermore, core and core plugs were acquired in 42/13-2, 42/13-4, 42/13a-6, 42/13a-A4 and 42/13a-A5z and routine core analysis and special core analysis have been carried out. Data from these studies include overburden corrected porosity and permeability, petrographic analysis and relative permeability.

There are two main seismic surveys that have been acquired over the Breagh area; the 2013 Polarcus seismic survey that covers an area of 480 km^2 (data owned by TGS), and the older, 1995 Geco-Prakla seismic volume covering 387 km^2 (Fig. 2). The 2013 3D survey was acquired using a 6 km cable with a nominal fold of 80 and a record length of 6.2 seconds. Post-acquisition, the 2013 Polarcus survey was infilled at the platform site with the vintage 1995 data to give a final dual azimuth seismic volume. This new seismic cube provided better data quality than the vintage 1995 data, and with the well data gave an improved image of the overburden, the Base Permian Unconformity and intra-Carboniferous reflectors.

The seismic interpretation of the intra-Carboniferous section is based on correlatable biostratigraphic and chemostratigraphic limestone markers which are named according to the onshore stratigraphic terminology (Fig. 3). A palynology study was carried out on the 42/13a-

6, Crosgan 42/10b-2 and Macanta 42/14-2 wells and was used to correlate all the Breagh wells in the block. Based on limestone markers the reservoir has further been divided and correlated into four zones. However, on a reservoir scale, there are remaining issues with achieving reliable regional correlation of the sandstone bodies because with an average thickness of 30 ft they are too thin to resolve on seismic data. Moreover, correlation was further made ambiguous in places by variable erosional levels beneath the BPU.

Trap

The main trap-forming event in the Breagh area was the late Carboniferous – Early Permian Variscan Orogeny which created inversion anticlines in the hanging walls of the major graben boundary faults (Fraser and Gawthorpe, 1990).

Later Mesozoic and Cenezoic tectonic events associated with rifting in Atlantic and Tethyan provinces have modified the trapping geometries (Fraser and Gawthorpe, 1990; Cameron *et al*., 1992; Besly *et al*., 1993) in the Breagh structure. These created a closure of erosionally truncated and highly faulted reservoirs at Base Permian Unconformity (BPU) level, which are then sealed by Upper Permian (Zechstein Group) evaporites.

The field itself lies within a large-scale inversion structure and comprises tilted fault blocks with fault closure to the southwest and 3-way dip closure in other directions. The trap is polygonal and has an area of 94 km^2.

In addition to the structural complexity, there were significant challenges in imaging the trap because of the presence and geometry of the overlying Zechstein (Late Permian) sequence. The resulting depth uncertainty has caused difficulty in mapping the reservoir structure, as a consequence the perceived gas in place volume is not well constrained.

Reservoir and petrophysics

The primary reservoirs are fluvio-deltaic sandstone units in the Middle Limestone (Yoredale) Formation of the Carboniferous (Visean stage) (Booth *et al*., 2017; Monaghan *et al*., 2017). The onshore stratigraphic terminology is here adopted to subdivide the reservoir package. The Middle Limestone Formation itself comprises of a series of 'Yoredale' type cycles with each cycle typically ~120 ft thick. Each cycle consists of thin marine limestones with coral fragments and brachiopods, succeeded by fine-grained shales and siltstones, coarsening up into fine-medium grained sandstones. In many cases the coarsening-up intervals are capped by a fining-upwards sequence of thin shales and coals before the next cycle, marked by a limestone band. These cycles have been interpreted as the product of marine transgression into the intermontane basin, forming the limestones, followed by a prograding paralic system of pro-delta shales, silts and fine sandstones (Maynard and Dunay, 1999b; Jones et al., 2015; Booth et al., 2017).

The reservoir is subdivided into four zones (based on chronostratigraphic and biostratigraphic studies) with the primary reservoir being the topmost zone - Zone 1 (Fig. 5). Well 42/13a-6 contains all four zones (Fig. 6) and has been used as a type section for reservoir correlation (Jones *et al*., 2015). The Zone 1 reservoir is a series of channel sandstones and sheet sandstones that are separated by mudstones, heterolithics and local coal beds. The sandstones in most cases form isolated simple channels or may be superimposed on top of one another to form complex, stacked multi-story channels or composite channels. Individual sets range in thickness from approximately 1-2 ft to a maximum of approximately 30 ft and display sharp and locally scoured bases (Fig. 7).

Reservoir quality is primarily controlled by depositional facies, which controls grain size, sorting and volume of diagenetic clay (Jones *et al*., 2015) (Fig. 8). The best reservoir intervals have permeabilities in the range 0.1-100 mD; (average 1-10 mD in Zone 1), and porosities in the range of 9.5% - 19.6% (average 11.6%). Net-to-gross ratio varies across the zones, averaging 56% in Zone 1, 34% in Zone 3 and 14% in Zone 4. Despite these variations, petrophysical results across the field are comparable for the same reservoir units. In particular, a 'mini-DST' was conducted in three zones on well 42/13a-6, which found formation permeability in 42/13a-6 in the eastern part of the field to be in line with those of 42/13-2 and 42/13-4 at the western part of the field.

For the Field Development Plan a free water level (FWL) of 7750 ft TVDSS was used to derive a saturation height function based on the exploration/appraisal wells 42/13-2, 42/13-3 and 42/13-4. This, however, was later superseded by a contact that was established in the 42/13a-6 well (post FDP), which showed a well-defined gas gradient and water gradient, with free water level at 7690 ft TVDSS (Fig. 9). Based on this FWL, P90, P50 and P10 GIIP were computed as 751, 909, 1040 bcf respectively. The Breagh Field reservoir is normally pressured and has a reservoir temperature of 185 ºF (85 ºC) at 7200 ft TVDSS. The field has a gas column of 510 ft based on the deeper FWL described above.

The Breagh Field gas is rich in CO_2 (~2-3%) relative to its neighbouring Permian (Rotliegend Group) reservoirs - Ravenspurn South and North Fields (Corbin *et al*., 2005). The gas is sweet as it does not contain any H_2S and has methane content of around 91% and N_2 content of 2.53%. The condensate content is approximately 3 bbl/MMscf of gas.

Production history and reserves

The Breagh Field received its FDP approval in July 2011 after commercial viability was confirmed from the appraisal wells. The FDP specified a two-phase development; the first phase began in 2011 with seven wells drilled from the Breagh Alpha platform with quoted P50 reserves of 552 bcf.

The Alpha platform has a dedicated 20-inch diameter 100km long export pipeline to transport gas and liquids from the Breagh Field to landfall at Coatham Sands near Teesside. From there the natural gas is transported through a 10km pipeline to the Teesside Gas Processing Plant (TGPP) at Seal Sands in Middlesbrough before entering the National Transmission

System. The plant, consisting of two gas processing trains, has a total capacity to process 675 MMcfgd.

First gas from the field was achieved in October 2013 with an initial total flow rate of 99 MMscfgd. By November 2014, the field production had increased to 156 MMscfgd but due to natural decline of the field, production fell to 135 MMscfgd by January 2015. By the second quarter of 2015, production rates were at 111 MMscfgd of sales gas and condensate at 3.6 bbl/MMscf. Production remained high into the third quarter of the same year with daily sales rates at 109 MMscfgd net, which was higher than forecasted in the reserve evaluation. By the first quarter of 2016, production from the field had fallen to 84 MMscfgd gross and continued to drop to an average of 72 MMscfgd for the remainder of 2016, again due to natural decline. An average annual production volume of 86 MMscfgd between January 2014 and December 2017 has been reported (Fig 10), and INEOS Oil and Gas UK expects Breagh to remain in production until 2040. Currently, an onshore compression project is ongoing to enhance the production of the field to end of field life.

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Figure Captions

Fig 1: Location Map for the Breagh Field and neighbouring areas.

Fig 2: Map of the Breagh field (solid red) and licence area (solid dark blue) indicating the extent of the Geco-Prakla 1995 seismic survey (blue) and the 2013 Polarcus seismic survey (orange).

Fig 3: Left- Lower Carboniferous stratigraphy with Breagh zonation (modified from (Cameron, 1993); Right- onshore stratigraphic terminology of the Yoredale Gp., as utilised in the Breagh field area, including the key limestone markers

Fig 4: Distribution pattern of the Base Permian subcrop facies on the UKSNS areas. Breagh (in the red box) lies in the area of Dinantial subcrop (modified from Underhill, 2003).

Fig 5: An illustrative geo-seismic section SW-NE through the Breagh Field showing the structure and erosion of the Zone 1B reservoir.

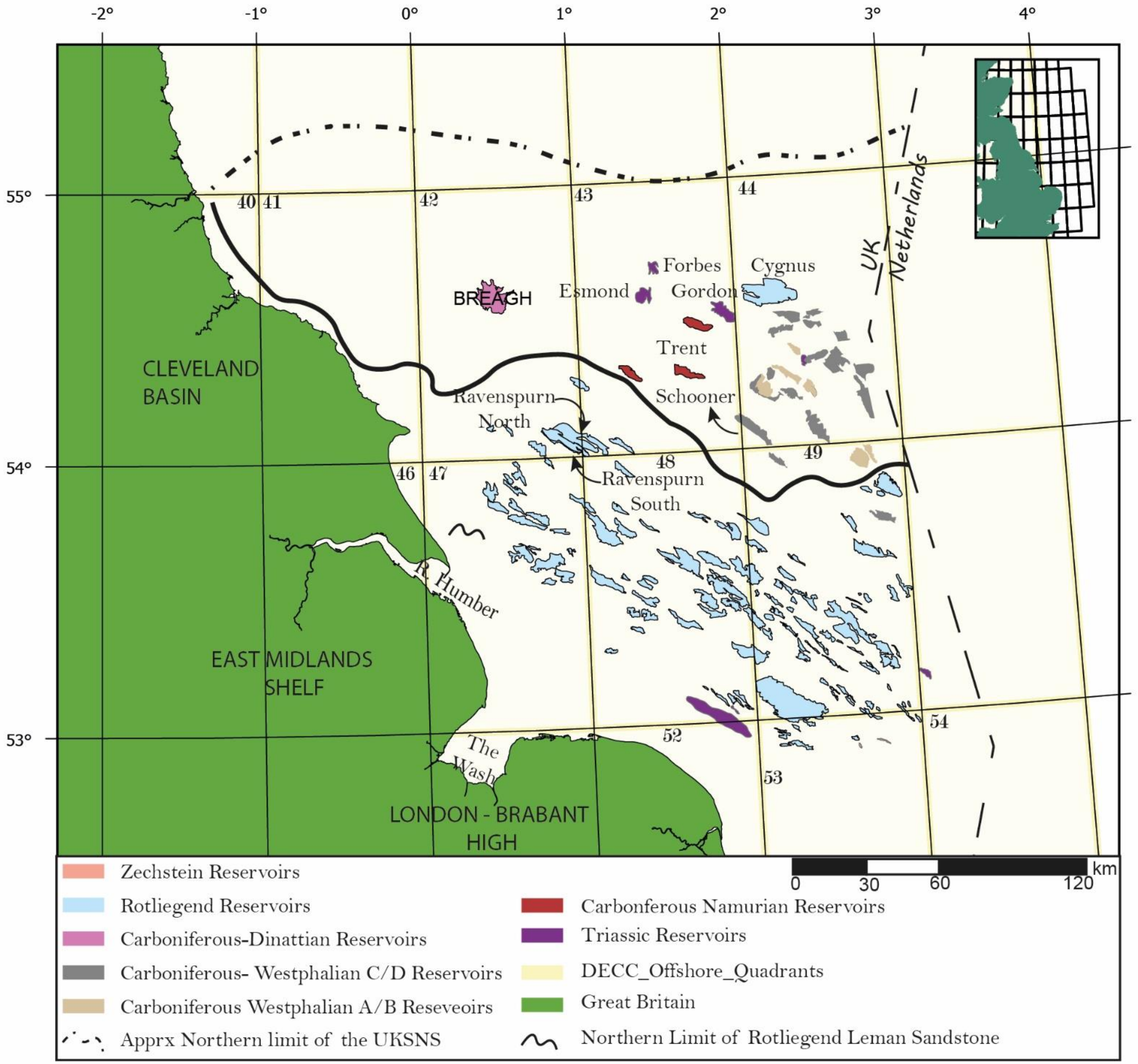
Fig 6: Appraisal well 42/13a-6 log responses and reservoir zonation.

Fig 7: A well correlation panel across the Breagh field. The orange wells are Zone 1A wells and the green wells are Zone 1B wells. Each zone is subdivided by limestone bands.

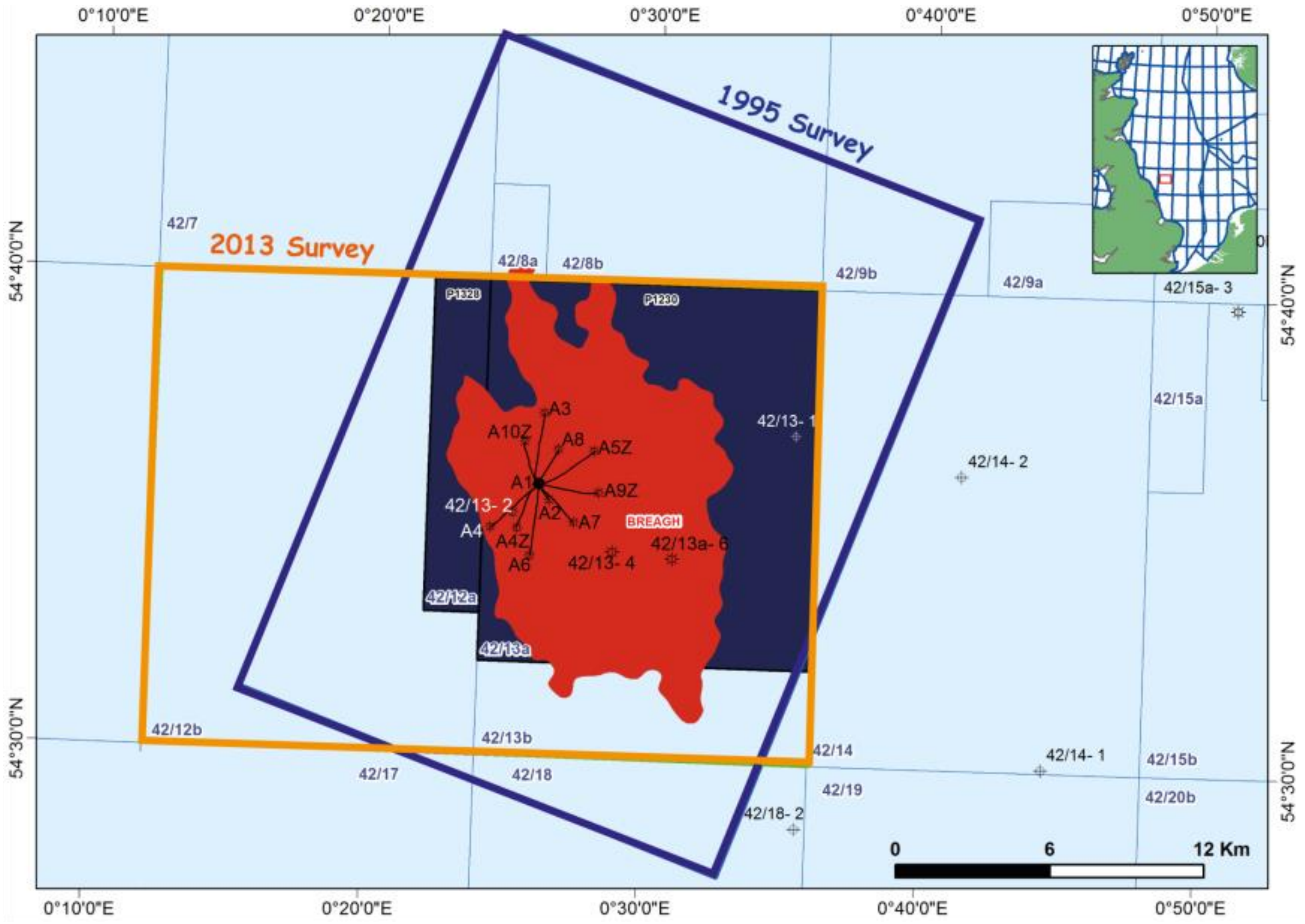
Fig 8: Porosity-permeability cross plots from the Breagh field. Left a) well 42/13-2 in the west of the field; Right – b) well 42/13a-6 in the east of the field.

Fig 9: Base Zechstein maps illustrating the contact at -7690 ft TVDSS in dark blue and fault pattern (the stair-stepped fault traces are the output from Petrel model, with location and geometries from seismic interpretation). Appraisal wells are vertical marked by a black circle, development wells are all deviated marked in red/grey.

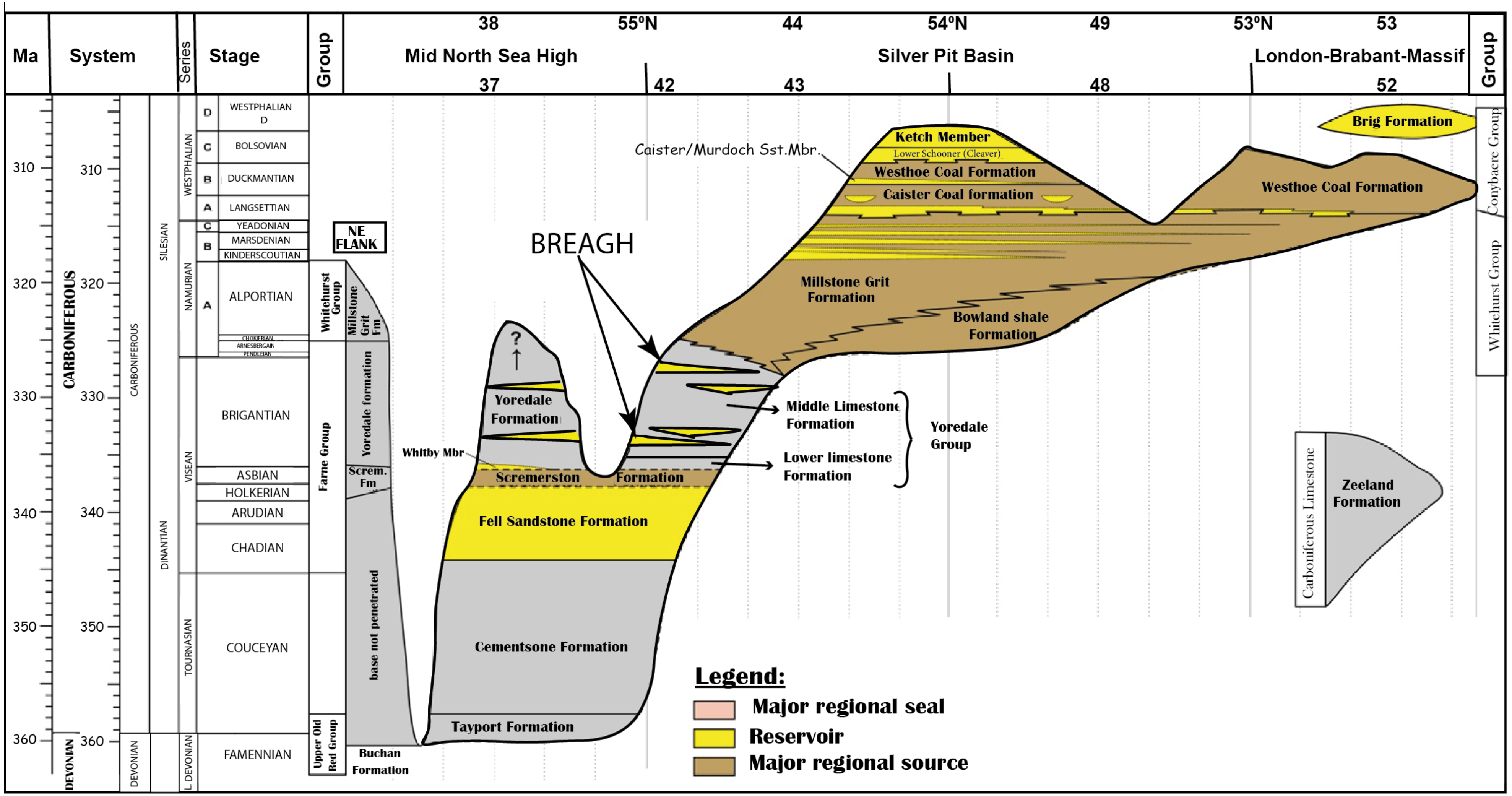
Fig 10: Breagh Field production history.



-2°
-1°
0°
1°
2°
3°
4°
55°
54°
53°
40 41
42
43
44
46 47
48
49
52
53
54
UK
Netherlands
BREAGH
Forbes
Cygnus
Esmond
Gordon
Trent
Schooner
Ravenspurn North
Ravenspurn South
CLEVELAND BASIN
EAST MIDLANDS SHELF
LONDON - BRABANT HIGH
R. Humber
The Wash
0 30 60 120 km
Zechstein Reservoirs
Rotliegend Reservoirs
Carboniferous-Dinattian Reservoirs
Carboniferous- Westphalian C/D Reservoirs
Carboniferous Westphalian A/B Reseveoirs
Apprx Northern limit of the UKSNS
Carbonferous Namurian Reservoirs
Triassic Reservoirs
DECC_Offshore_Quadrants
Great Britain
Northern Limit of Rotliegend Leman Sandstone



1995 Survey
2013 Survey
42/7
42/8a
42/8b
42/9b
42/9a
42/15a- 3
P1328
P1230
A3
A10Z
A8
A5Z
A1
A9Z
42/13- 2
A2
A7
A4
A4Z
A6
BREAGH
42/13a- 6
42/13- 4
42/13- 1
42/14- 2
42/15a
42/12a
42/13a
42/12b
42/13b
42/14
42/17
42/18
42/19
42/14- 1
42/15b
42/20b
42/18- 2
0
6
12 Km
0°10'0"E
0°20'0"E
0°30'0"E
0°40'0"E
0°50'0"E
54°40'0"N
54°30'0"N



Quad Peaks Limestone

Middle Limestone Formation

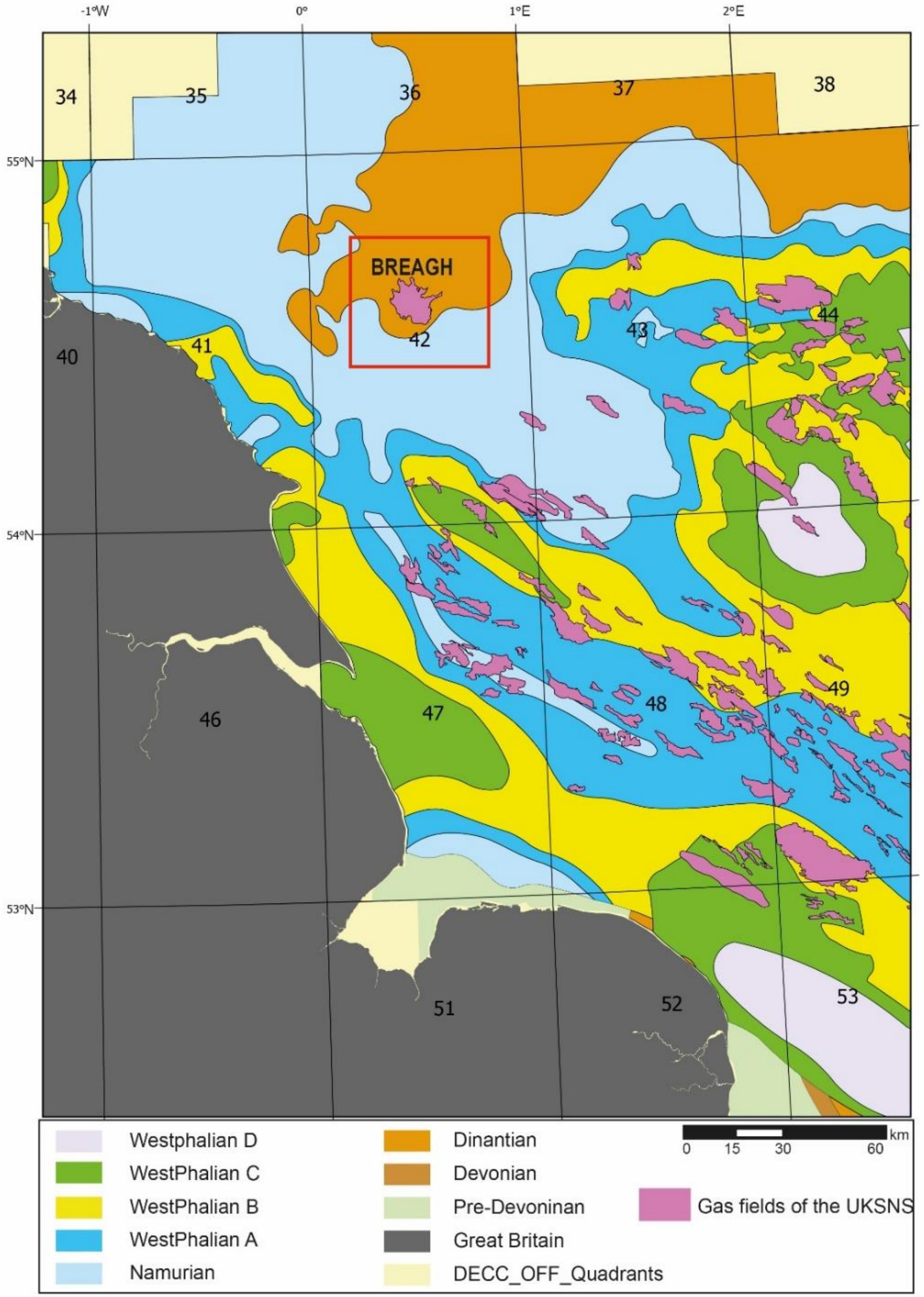
Oxford limestone

Lower Limestone Formation

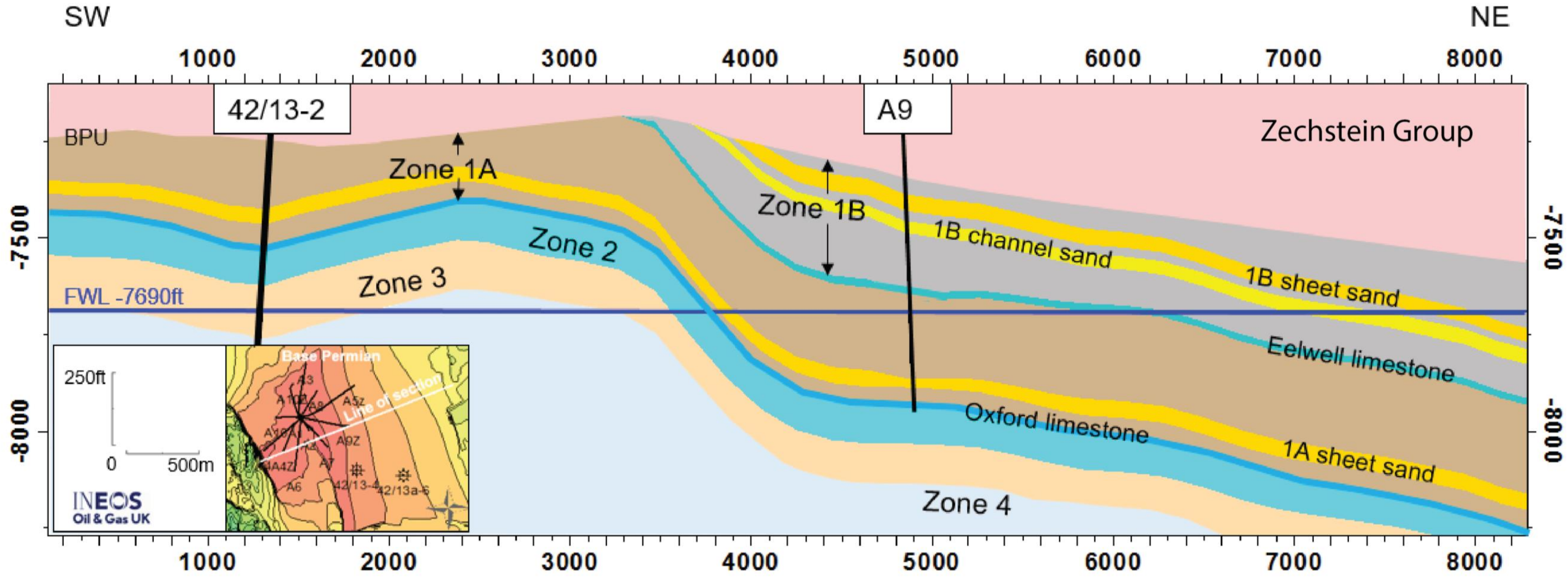
Watchlaw limestone

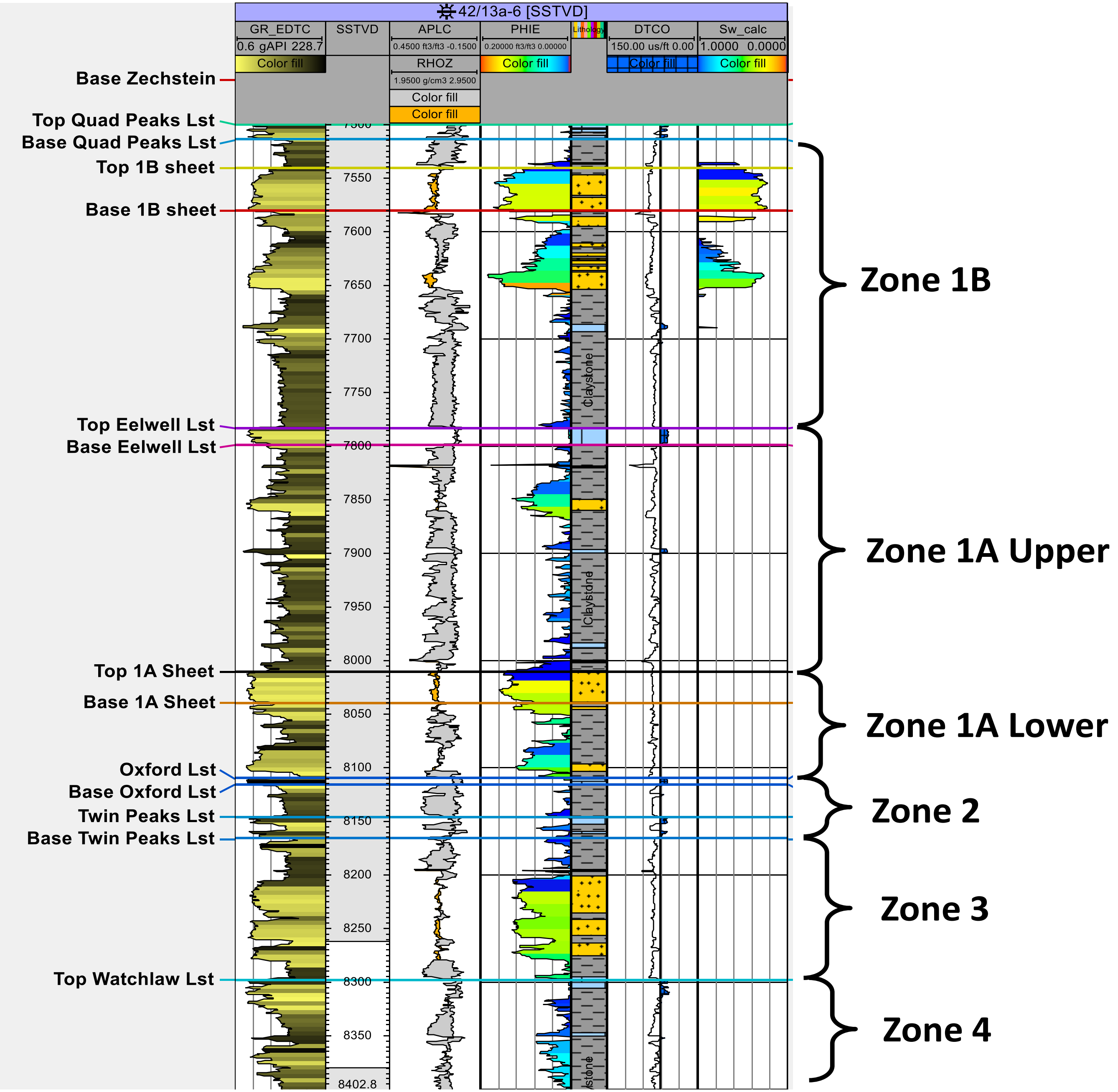
Dun Limestone

Scremerston Formation

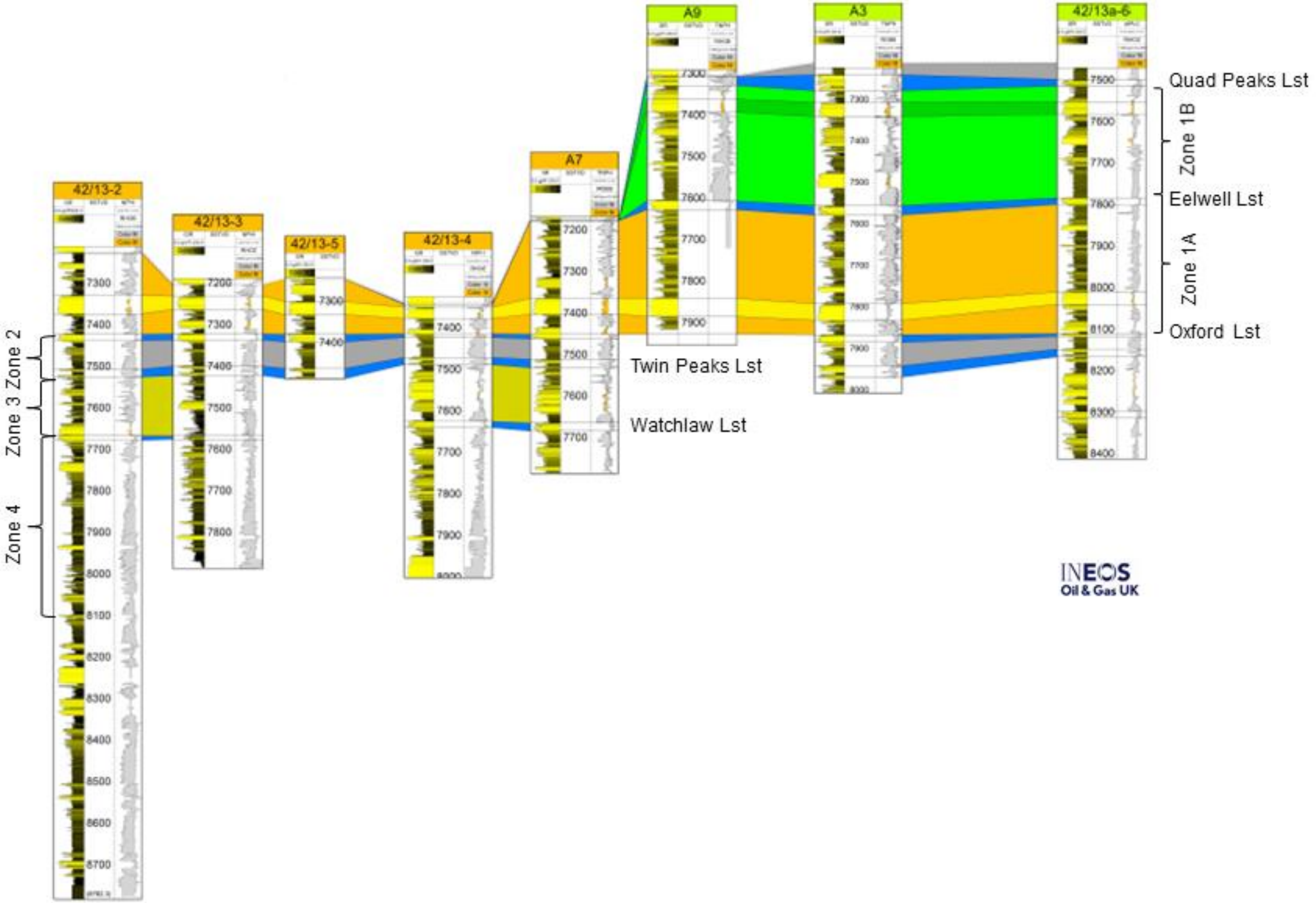


-1ºW
0º
1ºE
2ºE
55ºN
54ºN
53ºN
34
35
36
37
38
BREAGH
40
41
42
43
44
46
47
48
49
51
52
53
0 15 30 60
km
Westphalian D
WestPhalian C
WestPhalian B
WestPhalian A
Namurian
Dinantian
Devonian
Pre-Devoninan
Great Britain
DECC_OFF_Quadrants
Gas fields of the UKSNS

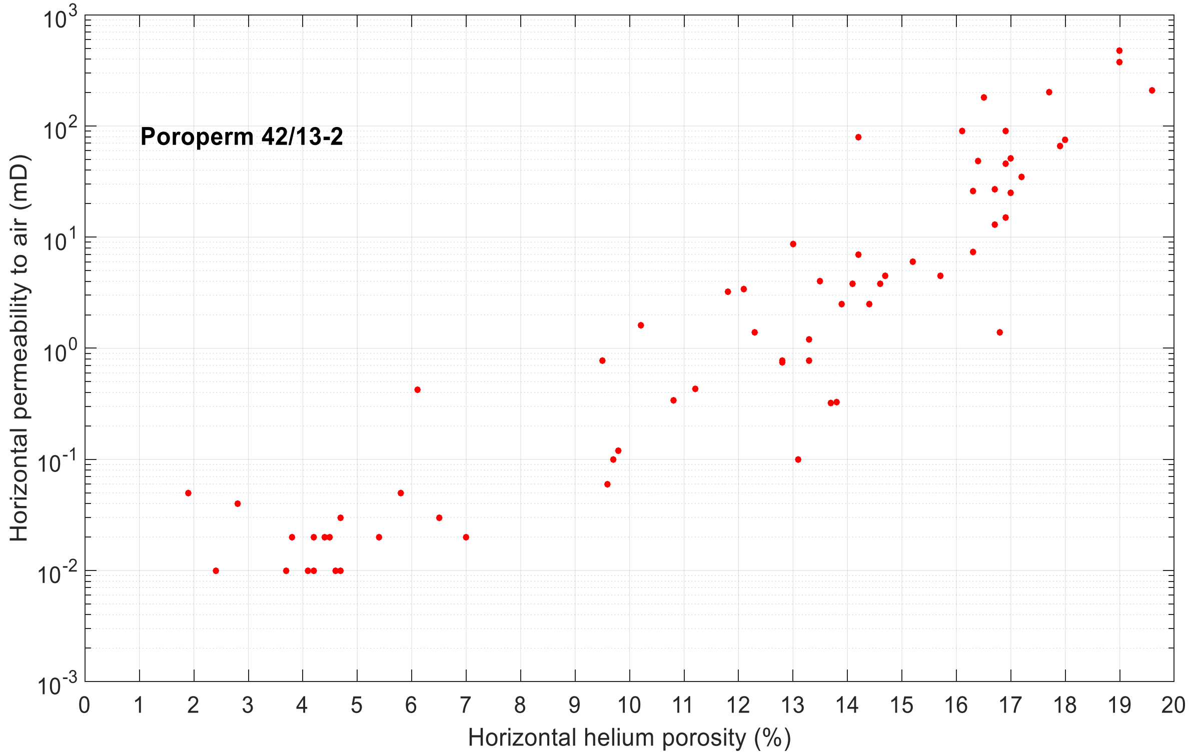

SW
NE
1000
2000
3000
4000
5000
6000
7000
8000
42/13-2
A9
BPU
Zechstein Group
Zone 1A
Zone 1B
Zone 2
Zone 3
Zone 4
1B channel sand
1B sheet sand
Eelwell limestone
Oxford limestone
1A sheet sand
FWL -7690ft
-7500
-8000
250ft
0
500m
INEOS
Oil & Gas UK
Base Permian
Line of section
42/13-4
42/13a-6

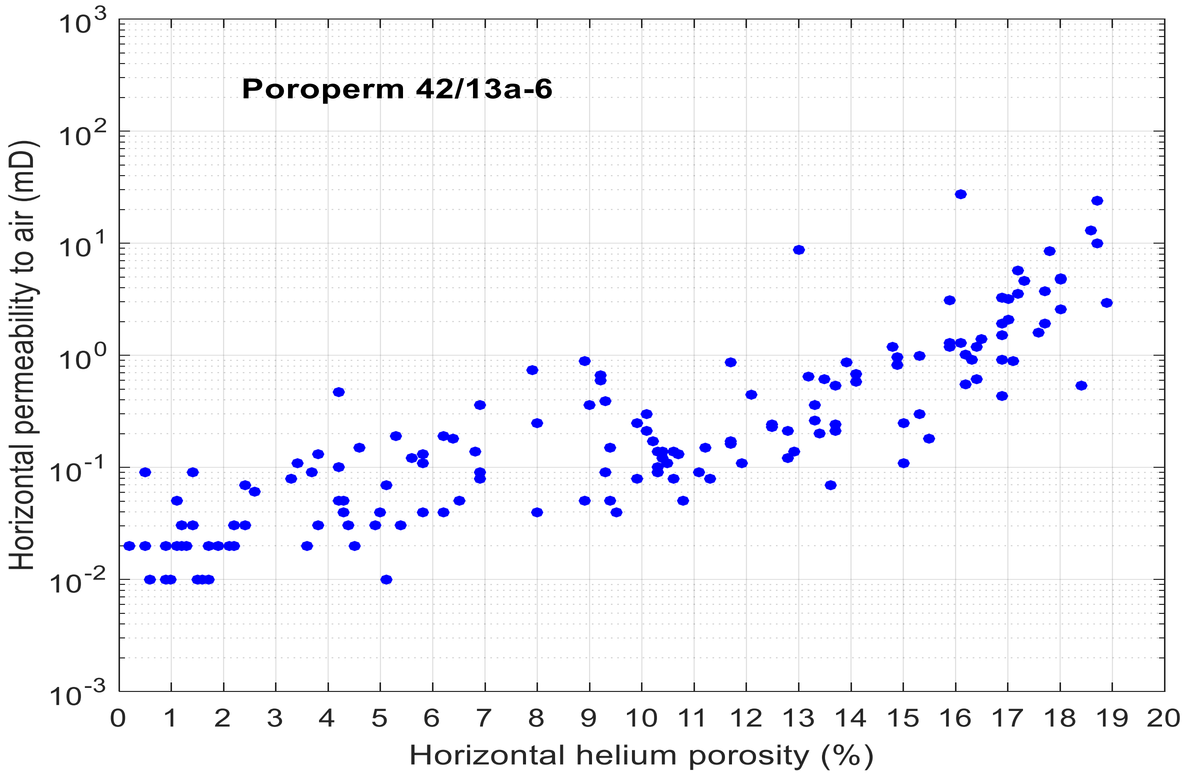


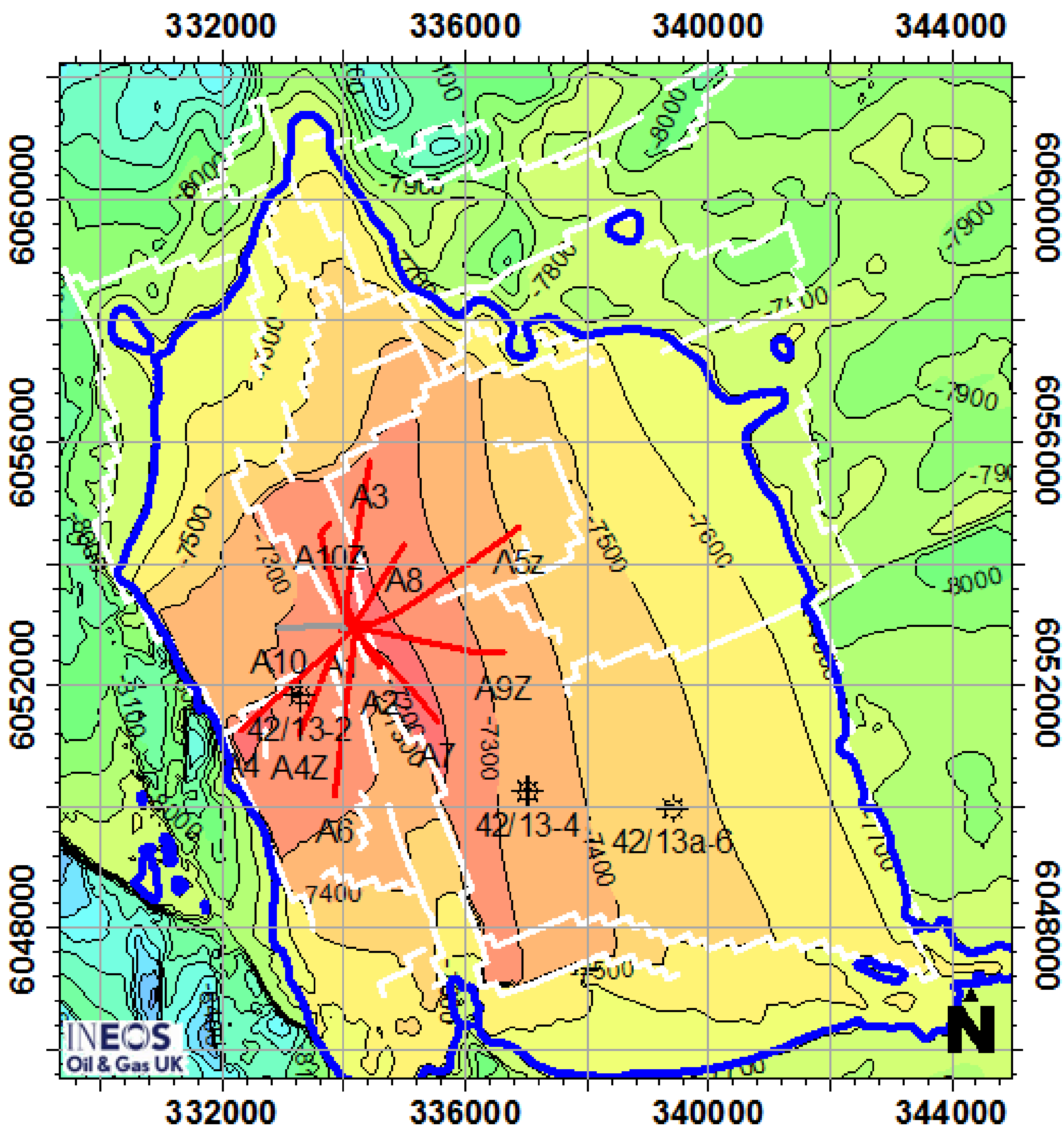
42/13a-6 [SSTVD]
GR_EDTC
0.6 gAPI 228.7
Color fill
SSTVD
APLC
0.4500 ft3/ft3 -0.1500
RHOZ
1.9500 g/cm3 2.9500
Color fill
Color fill
PHIE
0.20000 ft3/ft3 0.00000
Color fill
Lithology
DTCO
150.00 us/ft 0.00
Color fill
Sw_calc
1.0000 0.0000
Color fill
Base Zechstein
Top Quad Peaks Lst
Base Quad Peaks Lst
Top 1B sheet
Base 1B sheet
Top Eelwell Lst
Base Eelwell Lst
Top 1A Sheet
Base 1A Sheet
Oxford Lst
Base Oxford Lst
Twin Peaks Lst
Base Twin Peaks Lst
Top Watchlaw Lst
7550
7600
7650
7700
7750
7800
7850
7900
7950
8000
8050
8100
8150
8200
8250
8300
8350
8402.8
Claystone
Claystone
Zone 1B
Zone 1A Upper
Zone 1A Lower
Zone 2
Zone 3
Zone 4



42/13-2
42/13-3
42/13-5
42/13-4
A7
A9
A3
42/13a-6
Quad Peaks Lst
Zone 1B
Eelwell Lst
Zone 1A
Oxford Lst
Twin Peaks Lst
Watchlaw Lst
Zone 2
Zone 3
Zone 4
INEOS
Oil & Gas UK


Poroperm 42/13-2
Horizontal permeability to air (mD)
Horizontal helium porosity (%)


Poroperm 42/13a-6
Horizontal permeability to air (mD)
Horizontal helium porosity (%)


332000
336000
340000
344000
6060000
6056000
6052000
6048000
A3
A10Z
A8
A5z
A10
A9Z
42/13-2
A4 A4Z
A7
A6
42/13-4
42/13a-6
-7300
-7400
-7500
-7600
-7700
-7800
-7900
-8000
N
INEOS
Oil & Gas UK

Filtered Fluid Production or Injection (boe/d)
25K
20K
15K
10K
5K
0K
2014
2015
2016
2017
2018

BREAGH SUMMARY TABLE

Breagh Field	*(Data and suggested Units)*	*(Author's explanatory comments)*
Trap		
Type	Combination of tilted fault block with dip closure	
Depth to crest	8400 (ft MD) 7110 ft TVDSS	
Hydrocarbon contacts	Free Water Level at 7690 (ft TVDSS)	Gas-Down-To (GDT) levels are established as follows 42/13-2: 7668ft TVDSS 42/13-3: 7503ft TVDSS 42/13-4: 7599ft TVDSS 42/13-5: 7347ft TVDSS
Maximum oil column thickness	NA	
Maximum gas column thickness	510 ft	
Main Pay Zone		
Formation	Middle and Lower limestone	
Age	Visean, Early Carboniferous	
Depositional setting	Fluvial-deltaic setting	Distributary channels and sheet sands
Gross/net thickness	66 ft	
Average porosity	11.60% Zone 1B: 14% Zone 1A: 13%	Interbedded sandstones and claystones
Average net:gross ratio	Zone 1B: 0.35 Zone 1A: 0.30	:
Cutoff for net reservoir estimation	Phie 0.075 Vclay 0.4	
Permeability range	0.1-100 mD	
Average permeability	Zone 1: 1-10 mD	
Average hydrocarbon saturation	Zone 1B: 0.65 Zone 1A: 0.7	
Productivity index range	NA	
Hydrocarbons		
Fluid type	Dry Gas	
Gas specific gravity	0.618	
Bubble point (oil)	NA	At reservoir depth (185˚F) no condensate will appear over the field life
Dew point (condensate)		
Condensate /gas ratio	3 bbl/MMscf	
Water/gas ratio	2 bbl/MMscf	
Formation Volume Factor (oil)	NA	
Gas Expansion Factor	0.00444	
Formation Water		
Salinity	~188,500 ppm NaCl equivalent	
Resistivity	0.056 ohm.m @ 60˚F	
Water gradient	0.49 psi/ft	From 42/13a-6
Reservoir Conditions		
Temperature @ Top reservoir	185˚F at 7200 ft TVDSS	
Pressure @ Top reservoir	3,744psia at 7200 ft TVDSS	
Gas gradient	0.088 psi/ft	From 42/13a-6
Field Size		
Area	94 km^2	
Gross Rock Volume	1220 Mm^3	
GIIP	P90: 751 bcf P50: 909 bcf P10: 1040 bcf	
Drive mechanism (primary, secondary)	Depletion	
Recovery to date - oil	NA	
Recovery to date - gas	125 bcf	
Expected ultimate recovery factor/volume - oil	NA	
Expected ultimate recovery factor/volume - gas	50% (2040)	
Production		
Start-up date	Oct-13	
Number of Exploration/Appraisal Wells	6	
Number of Production Wells	10	
Number of Injection Wells	NA	
Development scheme	Phased development	
Highest rate - gas	158 MMscf/d (November 2014)	
Planned abandonment	*Undeveloped*	