The Humbly Grove, Herriard and Hester's Copse Fields, UK onshore

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Abstract

The Humbly Grove Field has, for the UK a unique development history. It was discovered as an oilfield in May 1980 and produced as an oilfield until 2000 along with small satellite fields Herriard (developed) and Hester's Copse (not developed). Peak production of 2219 bopd was achieved during July 1986 but by October 1988 the rate had fallen to around 1000 bopd, a rate that was more or less maintained until October 1995 after which the production fell rapidly. At this point the decision was taken to reconfigure the field for gas storage facility. Significant renewed pressure depletion occurred between 2000 to 2005, following which first cushion and then storage gas was injected into two reservoirs: the Middle Jurassic, Great Oolite Group and the uppermost Triassic, Rhaetian Westbury Formation. Gas storage operations commenced in 2005 and

the reservoirs have undergone cyclic gas injection and gas withdrawal since that date. The cyclic injection of gas and re-pressuring of the Great Oolite reservoir causes mobile oil to be swept towards dedicated oil production wells. This operates effectively as an enhanced oil recovery scheme. The co-produced liquid hydrocarbons provide a valuable secondary income stream for the field.

Key Words

Humbly Grove, Hester's Copse, Herriard, gas storage, Great Oolite Group, Westbury Formation

The Humbly Grove oil and gas field and satellite oilfields Herriard and Hester's Copse are located close to the town of Alton in Hampshire, southern England (Figure 1). All three fields have oil in the Middle Jurassic (Bajocian-Callovian), Great Oolite Group limestone reservoir. Humbly Grove alone has a gas cap within the Great Oolite reservoir and an older, secondary reservoir in Rhaetian (Westbury Formation) calcareous sandstones of the Penarth Group. The Humbly Grove field crest is at about 3200 ft TVDSS and the deepest oil-water contact in the reservoir at about 4400 ft TVDSS. Production of oil and associated gas began in mid-1984 and ceased in 2005 by which time Humbly Grove had been reconfigured for gas storage. The field continues to operate in gas storage mode.

History of Exploration and Appraisal

Falcon and Kent (1960) summarised the results of the search for petroleum in Great Britain from 1945 to 1957. Between 1945 and 1957, exploration in the UK East Midlands delivered a suite of oil and gas discoveries following on from the successful first well at Hardstoft, Derbyshire drilled in 1919 (Craig et al, 2014). However, there was little to show for exploration efforts in the south of England in the Wessex, Hampshire and Weald basins despite surface shows of petroleum in Dorset and the serendipitous discovery of gas at Heathfield, Sussex in 1895 (Dawson, 1898; DTI, 2003). Petroleum exploration wells were drilled at eleven different locations in southern England during the first half of the 20th century.

The first of these wells was at Portsdown, Hampshire in 1936 and about 35km south of what would become the Humbly Grove Field. It terminated in Triassic strata at 6556 ft brt, but failed to find petroleum.

The Humbly Grove 1 discovery well (HG1-X1) was drilled in May 1980 on a horst structure identified from 2D seismic data acquired in 1977, 1978 and 1979 (Hancock and Mithen, 1987). The well found oil in limestones of the Middle Jurassic, Great Oolite Group. Three more seismic surveys were acquired in 1980, 1981 and 1982 ahead of drilling of three appraisal wells in 1982. The appraisal process confirmed the presence of oil in the Great Oolite and of a gas cap, while Humbly Grove 2 (HG2-A1) discovered gas in the deeper and older Triassic, Rhaetian aged, fine-grained sandstones and oolites of the Westbury Formation (Penarth Group). The Westbury Formation reservoir was subsequently proven to have an oil leg by development well X4 in 1985. Hester's Copse and Herriard are two small satellite structures also discovered in the 1980s, lying east and west of Humbly Grove respectively. Both satellites have a Great Oolite limestone reservoir.

Regional Context

The Humbly Grove Field lies on the northern side of the Weald Basin in southern England (Figure 1, 2). The oldest known strata found in the basin are Upper Paleozoic in age. Devonian, Lower Carboniferous and Upper Carboniferous strata do not occur at outcrop, but have been identified in boreholes and in the concealed Kent Coalfield (Johnson, 1972). Beneath Humbly Grove the oldest strata encountered are Lower Carboniferous (Tournasian) fractured and karstified limestones (Narayan, 2019). These Paleozoic rocks were deformed by north-south compression of the Variscan Orogeny that also led to the development of east striking thrusts and NW striking dextral wrench faults (Stoneley, 1982). A regional unconformity marks the top of the Palaeozoic succession.

Mesozoic N-S crustal extension began in the latest Triassic and Early Jurassic Periods, likely exploiting the older Variscan structural elements. In the area of the Weald, the London Platform remained a stable high while subsidence occurred to the south. The oldest Mesozoic strata in the area are calcarenites and sandstones of Rhaetian age. These are around 39 ft (12 m) thick in the Humbly Grove area but thin northwards towards the London Platform. The Westbury Formation at Humbly Grove has been interpreted from cores as shoreface deposits. The overlying Jurassic mudstones and limestones are 5000 to 8500 ft thick (1500 to 2800 m), and thicken southwards with south dipping listric faults. Three of the Jurassic mudrock prone intervals are enriched with organic matter (the Lias Group, Oxford Clay Formation and Kimmeridge Clay Formation intervals). Subsidence slowed at the end of the Jurassic and by early Cretaceous times the area was accumulating non-marine lacustrine shales and fluvial sandstones. By the end of the Cretaceous Period, marine conditions had returned and 1500 to 2000 ft (450-610 m) of chalk, claystone and sandstones were deposited (Trueman, 2003).

Strata of Tertiary age (Paleocene, Eocene and Oligocene) are absent over Humbly Grove but present in the London area to the north and coastal parts of Hampshire to the south (Figure 3). Reconstruction of the basin history indicates that maximum burial depth was achieved in the Early Tertiary by which point the Liassic age, organic rich mudstones were in the oil window (Ebukanson and Kinghorn, 1986; Penn et al, 1987; Figure 4). There appear to have been two phases of petroleum migration into the Humbly Grove structure (Sellwood et al, 1989) the first in the latest Jurassic and subsequently during the Late Cretaceous. The mature Liassic source rock is located east of the Humbly Grove location. The Hester's Copse Field is located east of Humbly Grove and has a deeper oil-water contact than Humbly Grove with the Herriard Field to the west having a shallower oil-water contact, implying migration of oil from the west.

Late Tertiary uplift and erosion occurred as Hampshire lies on the northern margin of the Alpine orogenic area. An ML = 3 earthquake was recorded close to Lasham, Hampshire on 19th July 1982, with a hypocentral depth of approximately 1.4 km below mean sea level. This earthquake occurred before any production from the field began, but suggests that faults in the vicinity of Humbly Grove may be critically stressed at the present day.

Database

A suite of 2D seismic surveys is located over the Humbly Grove Field (Figure 5). The surveys were acquired in the 1970s and 1980s using a Vibroseis source.

Twenty wells were drilled on Humbly Grove during the exploration, appraisal and development of the oil field. One was completed for production from the Westbury Formation reservoir and the remainder in the Great Oolite reservoir. Two wells in the Great Oolite Group reservoir were later reconfigured for water injection. For the gas storage and cycling phase there are four new horizontal wells in the Great Oolite reservoir and two new horizontal wells completed in the Westbury Formation reservoir (Figures 6, 7).

Vertical seismic profiles (VSPs) were shot in the exploration and appraisal wells. Wire-line log data (gamma ray, sonic, density, deep and shallow resistivity logs) are available from the wells and fourteen of the wells were cored.

Trap

The Humbly Grove structure is a horst-block, fault bounded to both the north and south with dip closure to both the east and west (Figure 6). Six horizons can be mapped on the seismic data and tied using the VSPs to the local stratigraphy; five in the Jurassic interval (top Westbury Formation, top Inferior Oolite, top Cornbrash, top Corallian and top Purbeck Limestone) and one in the Cretaceous (base Gault; Figure 8). The structure was formed during latest Jurassic to earliest Cretaceous rifting and subsequently uplifted (regionally) and partly inverted by the Alpine Orogeny.

Both the Great Oolite Group and Westbury Formation reservoirs have gas-oil and oil-water contacts. The maximum petroleum columns in the Great Oolite Group reservoir are 105 ft for gas and 255 ft for oil with the oil-water contact at 3480 ft TVDSS. The deepest closing contour, based on the 2D seismic data is mapped at about 3600 ft TVDSS implying that the Humbly Grove structure at the level of the

Great Oolite reservoir is not full to spill. For the Westbury Formation reservoir the crest is at 4240 ft TVDSS with a gas column of about 87 ft and an oil column of about 60 ft giving an oil-water contact at 4387 ft.

Reservoir and Petrophysics

The two reservoirs in Humbly Grove are very different. The Great Oolite Group is a predominantly oolitic limestone reservoir while the Westbury Formation is a calcareous sandstone. One of the most distinctive features of the Great Oolite Group at Humbly Grove is an abrupt change in reservoir quality above and below 3395 ft TVDSS (Figure 9). The change is from a reservoir with up to 1000 mD permeability above this level to <1 mD below this level. The boundary at 3395 ft TVDSS cross-cuts stratigraphy and is horizontal. The implication of this abrupt change in reservoir quality is that at some time in the past, the shallower, high-quality reservoir was petroleum bearing with a palaeo-oil water contact at what is now 3395 ft TVDSS. Diagenesis and reservoir quality reduction continued in the water leg but were slowed or stopped in the original hydrocarbon leg. This would further imply that either there was a late additional charge of petroleum post-diagenesis or that Alpine uplift of an original oilfield led to gas exsolution and consequent downwards displacement of the oil leg (Heasley et al, 2000).

The Great Oolite Group was deposited in the form of a carbonate shoal, in shallow water and located between the London-Brabant and Welsh massifs during a period of tectonic uplift in the Middle Jurassic (Sellwood et al, 1985). The Great Oolite Group comprises a basal and uppermost unit dominated by ooid grainstones (80%) with subordinate quantities of pellets and some micritised skeletal fragments (Heasley et al, 2000). The middle part of the interval is a transgressive wackestone to mudstone with dolomitized and heavily stylolitised skeletal and oncolite grains.

The diagenesis of the upper high permeability zone is markedly different from that observed in the deeper low permeability zone (above 3395 ft TVDSS, Heasley et al, 2000). The high permeability interval shows evidence of freshwater leaching and aragonite dissolution, isopachous blocky calcite syntaxial overgrowths and mixing zone dolomitisation. In addition to these effects, the low permeability zone has blocky ferroan calcite and ferroan dolomite cements as well as some sphalerite. There is also evidence, from thin section, of ferroan calcite replacing ferroan dolomite.

The deeper and older Westbury Formation reservoir interval is considerably more heterogeneous than the Great Oolite Group. The reservoir comprises calcareous sandstones and calcareous mudstones deposited in marine conditions. The underlying Pre-Variscan economic basement of the Carboniferous Limestone Supergroup is onlapped by a transgressive unit at the base of the Westbury Formation which fines upwards into a an argillaceous limestone, interpreted to have accumulated on a mud-prone carbonate platform. Locally the mudstones are chertified. Lower and subsequently middle shoreface deposits of burrowed and variably calcareous sandstones with scattered storm beds in turn overlie the mudstones. Above the Westbury Formation are Liassic mudstones of the Blue Lias Formation (source rock). The porosity of the Westbury Formation reservoir is low between around 5% and 10% and permeability typically <1 mD. However, permeability is enhanced by fractures and unlike the Great Oolite reservoir that has no aquifer, the Westbury Formation reservoir has a very active aquifer located in the underlying fractured and karstified Carboniferous Limestones (Narayan, 2019).

Production History and Reserves

Production from the Great Oolite Group began in June 1984 and a month later from the Westbury Formation. Peak production was 2219 bopd in July 1986. In broad terms, periods of higher production rate coincided with new wells being brought on stream. Average production was around 1000 bopd until 1996 and water injection into two converted production wells had little effect (Figure 10), though it is not known if injection was for waste water disposal rather than pressure support. During the period up to 1996, co-produced water was usually 200-300 barrels per day, though there were two periods when the water-cut reached about 50% (around 700 to 800 barrels per day) in 1986 and again in

1990. Herriard Field production was included in the Humbly Grove Field total. From 1996 onwards, production rate fell rapidly and from 2000 the field was blown down to create pressure-space for gas storage. By 2005 when the field was officially re-designated for gas storage it had produced 6 mmbbl of oil and 11.5 bcf of gas.

A second phase for the field began in 2005 when initially cushion gas and then gas for storage were injected into 6 new horizontal wells; 4 drilled into the Great Oolite Group and 2 into the Westbury Formation. The initial intention had been to inject gas during the summer months when demand is low and prices similarly low and produce at a premium in the winter when gas prices are higher. However, the gas market in the UK has proved to be substantially more volatile and so the injection and production phases do not properly align with the seasons (Figure 11). The cyclic injection of gas and re-pressuring of the Great Oolite Group causes mobile oil to be swept towards the perforations in dedicated oil producing wells and this process constitutes, in effect, an enhanced oil recovery scheme. In addition, injected dry gas picks up very small amounts of water in the reservoir and this water is produced to surface in the gas stream. The hydrocarbon liquids (oil and condensate) are sold as an additional product stream.

The Humbly Grove gas storage site has a working volume of about 10 bcf, with maximum withdrawal and injection rates of 260 mmscf/d and 300 mmscf/d respectively. Humbly Grove provides about 20% of the UK gas storage capacity (following the closure of the Rough Gas Storage facility in 2018) as well as 3% of the national transmission system daily demand. Since start-up in 2005 the field operator, Humbly Grove Energy has injected, withdrawn and treated around 30 bcf of gas per annum.

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Figure 1 regional location map of the Humbly Grove field within the Weald Basin, Inset, local configuration of the Humbly Grove, Herriard and Hester's Copse fields, showing the exploration, appraisal and some of the early development wells (adapted from Sellwood et al, 1985).

Figure 2 Generalised stratigraphic column for the Wessex basin illustrating the megasequences and stratigraphic nomenclature (JB, Junction Bed; CB, Cinder Bed; GAB, Green Ammonite Beds; PG, Penarth Group; BSPB, Budleigh Salterton Pebble Beds) (from Underhill and Stoneley, 1998).

Figure 3 Cross section of the Weald Basin showing regional thickness variation generated during latest Jurassic and earliest Cretaceous rifting as well as subsequent inversion structures. Section location shown in Figure 1.

Figure 4a Distribution of facies belts in the Great Oolite Group and likely migration direction of oil into the Humbly Grove trap (from Sellwood et al, 1985). 4b Burial history of the three candidate source rocks (Kimmeridge Clay Formation, Oxford Clay Formation and Liassic Charnmouth Mudstone Formation (adapted from Penn et al, 1987).

Figure 5 Seismic database for the Humbly Grove area

Figure 6 Top reservoir maps A Great Oolite Group, B Westbury Formation (datum feet TVD sub-sea level).

Figure 7 Schematic of wells drilled into the Great Oolite Group reservoir and Westbury Formation sandstone reservoir for the gas storage phase of field operations (OWC = oil water contact, GOC = gas oil contact)

Figure 8 Schematic cross section of Humbly Grove Field with lithostratigraphic intervals and seismic mapping surfaces identified.

Figure 9 Permeability discontinuity within the Great Oolite Group reservoir of the Humbly Grove Field. The discontinuity now lies within the gas leg of the field but marks a former oil-water contact beneath which diagenesis continued after oil emplacement.

Figure 10 Oil, gas and water production profiles and history matched curves for the period from field start-up in 1984 to 2005 when the field ceased to be an oilfield.

Figure 11 complete production and (gas) injection history for the Humbly Grove oilfield (to 2005) and Humbly Grove gas storage facility (from 2005).

Humbly Grove Field (Great Oolite Group)	*(Data and suggested Units)*	*(Author's explanatory comments)*
Trap		
Type	Horst – 2-way fault and 2-way dip closure	
Depth to crest	3220 (ft TVDSS)	
Hydrocarbon contacts	3325 (ft TVDSS) GOC 3480 (ft TVDSS) OWC	deepest closing contour 3680 (ft TVDSS)
Maximum oil column thickness	255 (ft)	
Maximum gas column thickness	105 (ft)	
Main Pay Zone		
Group	Great Oolite	
Age	Middle Jurassic	
Depositional setting	Shallow marine	
Gross/net thickness	201 ft gross, net 160 ft	
Average porosity (range)	18% (6-28%)	
Average net:gross ratio	average 0.8 (range 0.02-1)	
Cutoff for net reservoir	-	No cut-off used
Average permeability (range)	Arithmetic 20 mD, (0.1-2000 mD)	
Average hydrocarbon saturation	60% (15%-80%)	
Productivity index range	1.48 bbl/day/psi	
Hydrocarbons		
Oil gravity	39 (°API)	
Oil properties		Viscosity 1.15 cp
Bubble point (oil) Dew point (condensate)	1589 psig	
Gas/Oil Ratio or Condensate/Gas Ratio	2000	Start-up GOR for whole field gas and oil leg production
Formation Volume Factor (oil)	1.173	
Gas gravity	0.63	
Gas Expansion Factor	111 scf/rcf	
Formation Water		
Salinity	85,000 (ppm NaCl equiv.)	
Resistivity	0.057 ohm-m at 49 °C	
Pressure gradient - water	0.43 psi ft^{-1}	
Reservoir Conditions		
Temperature	49 (°C)	
Initial pressure	1480 psi	
Hydrocarbon pressure gradient - oil	not available	
Hydrocarbon pressure gradient - gas	not available	
Field Size		

Area	2965 (acres)	
Gross Rock Volume	Not reported (ac-ft)	
STOOIP	42 mmstb	
Associated GIP	Not calculated (bcf)	
Non-associated GIP	Not calculated (bcf)	
Drive mechanism (primary, secondary)	1. Exsolution drive 2. Water injection 3. Pressure depletion 4. Gas cycling	
Recovery to date - oil	6 (mmbbl) + 1 (mmbbl)	Includes Westbury Formation production. An additional 1 mmbbl oil has been produced during the gas storage phase of the field.
Recovery to date - gas	11.5 (bcf)	Includes Westbury Formation production
Expected ultimate recovery factor/volume - oil	31 (%) / 13 (mmbbl)	Forecast produced at field start-up, no subsequent revisions in public domain
Expected ultimate recovery factor/volume - gas	N/A (%) / 11.5 (bcf)	
Production		
Start-up date	June 1994,gas storage start-up 2005	
Number of Exploration/Appraisal Wells	2 E, 3A	
Number of Production Wells	18, 4	oil field phase, gas storage phase
Number of Injection Wells	2	converted from oil production
Development scheme	1. Exsolution drive 2. Water injection 3. Pressure depletion 4. Gas cycling	
Plateau rates – oil/gas	1400 bopd N/A mmcfgd	
Planned abandonment	*N/A*	

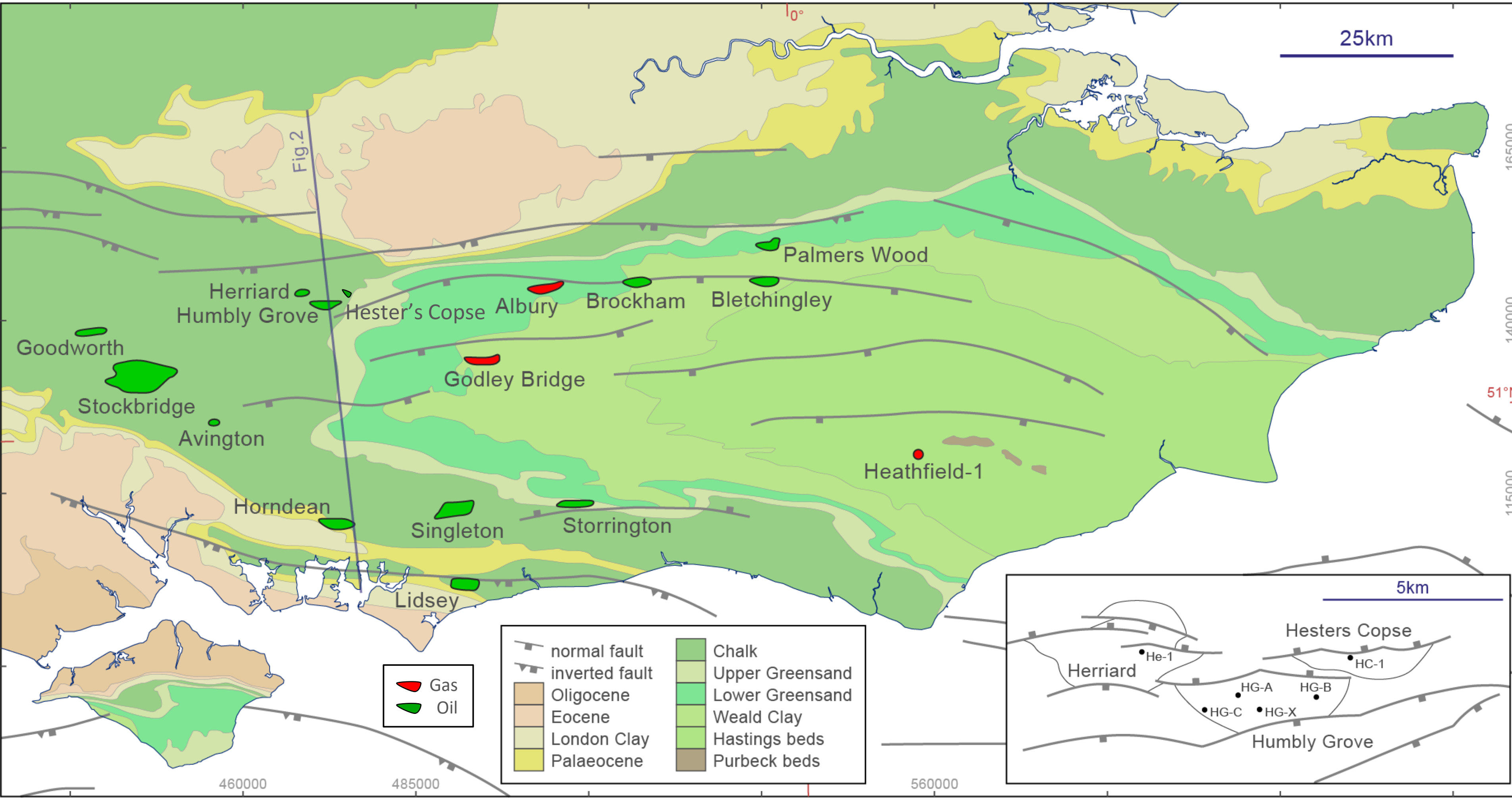
Humbly Grove Field (Westbury Formation)	*(Data and suggested Units)*	*(Author's explanatory comments)*
Trap		
Type	Horst	
Depth to crest	4240 (ft TVDSS)	
Hydrocarbon contacts	OWC 4387 (ft TVDSS)	
Maximum oil column thickness	60 (ft)	Minimum oil column
Maximum gas column thickness	87 (ft)	
Main Pay Zone		

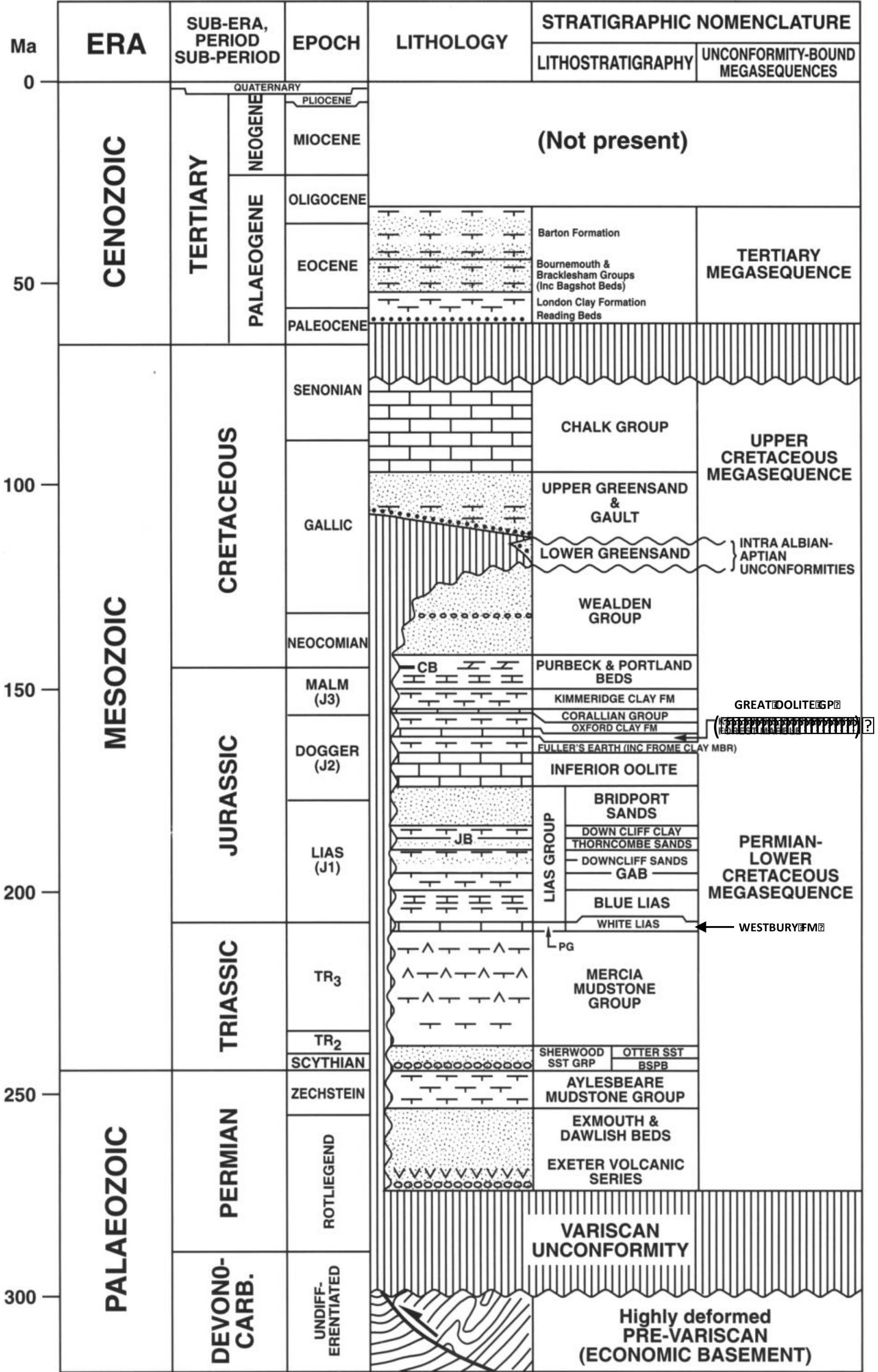
Formation	Westbury Formation	
Age	Upper Triassic	
Depositional setting		
Gross/net thickness	40 ft	
Average porosity (range)	12%	
Average net:gross ratio	0.40	
Cutoff for net reservoir	not available	
Average permeability (range)	<1 mD	
Average hydrocarbon saturation	50%	
Productivity index range	Not reported	
Hydrocarbons		
Oil gravity	49 (°API)	
Oil properties		
Bubble point (oil) Dew point (condensate)	- psig	
Gas/Oil Ratio or Condensate/Gas Ratio	- scf/bbl	
Formation Volume Factor (oil)	1.359	
Gas gravity	n/a	
Gas Expansion Factor	143	
Formation Water		
Salinity	- (ppm NaCl equiv.)	
Resistivity	- ohm-m at - °C	
Pressure gradient - water	psi ft^{-1}	Water not encountered
Reservoir Conditions		
Temperature	60 (°C)	
Initial pressure	2000 (psia at 4387 ft TVDSS)	
Hydrocarbon pressure gradient - oil	- (psi/ft)	
Hydrocarbon pressure gradient - gas	(psi/ft)	
Field Size		
Area	1000 acres	
Gross Rock Volume	Not reported (ac-ft)	
STOOIP	1.1 (mmbbl)	
Associated GIP	Not calculated (bcf)	
Non-associated GIP	3.48 (bcf)	
Drive mechanism (primary, secondary)		
Recovery to date - oil	- (mmbbl)	Included in Great Oolite production
Recovery to date - gas	- (bcf)	Included in Great Oolite production
Expected ultimate recovery factor/volume - oil	- (%)/ - (mmbbl)	
Expected ultimate recovery factor/volume - gas	- (%)/-(bcf)	

Production		
Start-up date	July 1984	
Number of Exploration/Appraisal Wells	1E, 2A	
Number of Production Wells	?1, 2	Condensate production phase, gas storage phase
Number of Injection Wells	-	
Development scheme	1. exsolution/expansion drive 2. natural aquifer inflow 3. gas cycling	
Plateau rates – oil/gas	500 bopd - mmcfgd	
Planned abandonment		

Humbly Grove Figures

Fig 1


25km
0°
51°N
Fig.2
Palmers Wood
Herriard
Humbly Grove
Hester's Copse
Albury
Brockham
Bletchingley
Goodworth
Godley Bridge
Stockbridge
Avington
Heathfield-1
Horndean
Singleton
Storrington
Lidsey
165000
140000
115000
460000
485000
560000
Gas
Oil
normal fault
inverted fault
Oligocene
Eocene
London Clay
Palaeocene
Chalk
Upper Greensand
Lower Greensand
Weald Clay
Hastings beds
Purbeck beds
5km
Hesters Copse
Herriard
He-1
HC-1
HG-A
HG-B
HG-C
HG-X
Humbly Grove



Ma
ERA
SUB-ERA, PERIOD SUB-PERIOD
EPOCH
LITHOLOGY
STRATIGRAPHIC NOMENCLATURE
LITHOSTRATIGRAPHY
UNCONFORMITY-BOUND MEGASEQUENCES
0
50
100
150
200
250
300
CENOZOIC
MESOZOIC
PALAEOZOIC
QUATERNARY
TERTIARY
NEOGENE
PALAEOGENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
(Not present)
Barton Formation
Bournemouth & Bracklesham Groups (Inc Bagshot Beds)
London Clay Formation
Reading Beds
TERTIARY MEGASEQUENCE
CRETACEOUS
SENONIAN
GALLIC
NEOCOMIAN
CHALK GROUP
UPPER GREENSAND & GAULT
LOWER GREENSAND
WEALDEN GROUP
UPPER CRETACEOUS MEGASEQUENCE
INTRA ALBIAN-APTIAN UNCONFORMITIES
JURASSIC
MALM (J3)
DOGGER (J2)
LIAS (J1)
CB
PURBECK & PORTLAND BEDS
KIMMERIDGE CLAY FM
CORALLIAN GROUP
OXFORD CLAY FM
GREAT OOLITE GP
FULLER'S EARTH (INC FROME CLAY MBR)
INFERIOR OOLITE
LIAS GROUP
BRIDPORT SANDS
DOWN CLIFF CLAY
THORNCOMBE SANDS
DOWNCLIFF SANDS
JB
GAB
BLUE LIAS
WHITE LIAS
WESTBURY FM
PG
PERMIAN-LOWER CRETACEOUS MEGASEQUENCE
TRIASSIC
TR3
TR2
SCYTHIAN
MERCIA MUDSTONE GROUP
SHERWOOD SST GRP
OTTER SST
BSPB
PERMIAN
ZECHSTEIN
ROTLIEGEND
AYLESBEARE MUDSTONE GROUP
EXMOUTH & DAWLISH BEDS
EXETER VOLCANIC SERIES
VARISCAN UNCONFORMITY
DEVONO-CARB.
UNDIFF-ERENTIATED
Highly deformed PRE-VARISCAN (ECONOMIC BASEMENT)

Fig 2

Fig 3

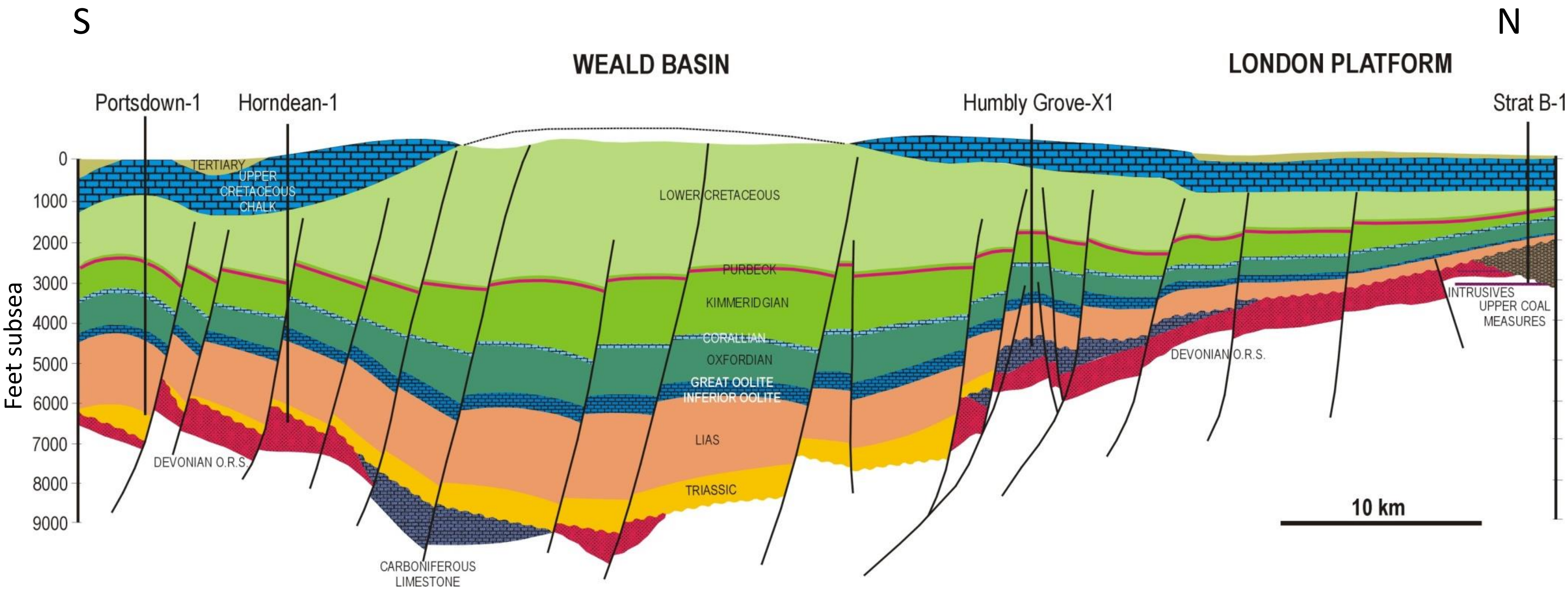

S
N
WEALD BASIN
LONDON PLATFORM
Portsdown-1
Horndean-1
Humbly Grove-X1
Strat B-1
Feet subsea
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
TERTIARY
UPPER CRETACEOUS CHALK
LOWER CRETACEOUS
PURBECK
KIMMERIDGIAN
CORALLIAN
OXFORDIAN
GREAT OOLITE
INFERIOR OOLITE
LIAS
TRIASSIC
DEVONIAN O.R.S.
CARBONIFEROUS LIMESTONE
DEVONIAN O.R.S.
INTRUSIVES
UPPER COAL MEASURES
10 km

Fig 4

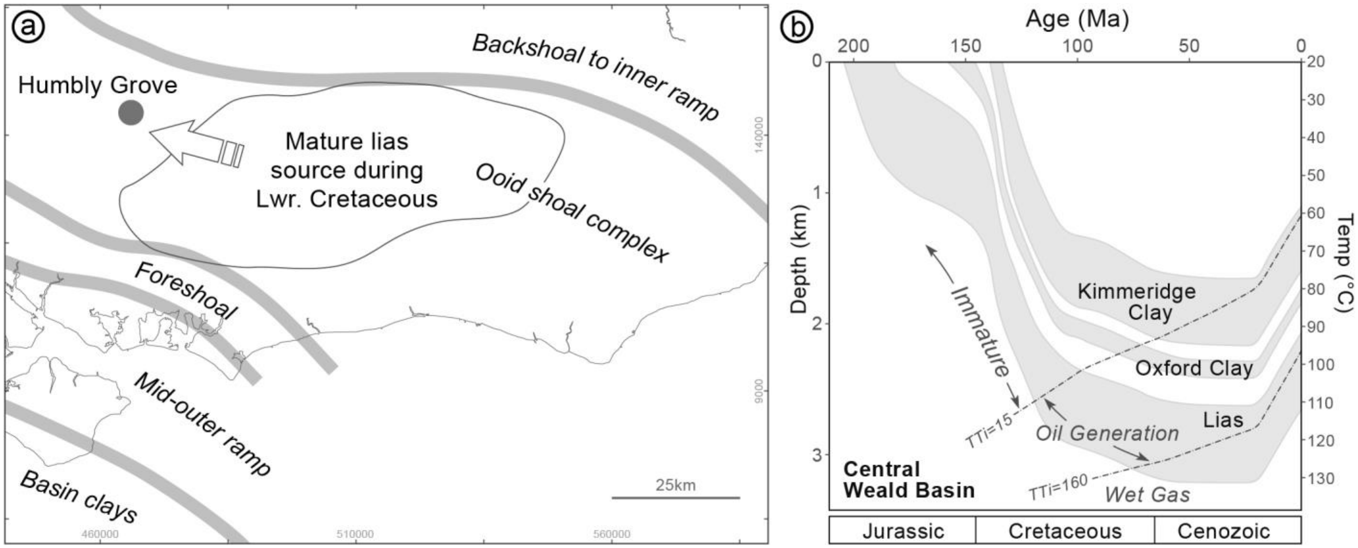

a
Humbly Grove
Backshoal to inner ramp
Mature lias
source during
Lwr. Cretaceous
Ooid shoal complex
Foreshoal
Mid-outer ramp
Basin clays
25km
460000
510000
560000
140000
9000
b
Age (Ma)
200
150
100
50
0
Depth (km)
Temp (°C)
Kimmeridge
Clay
Oxford Clay
Lias
Immature
Oil Generation
Wet Gas
TTi=15
TTi=160
Central
Weald Basin
Jurassic
Cretaceous
Cenozoic

Fig 5

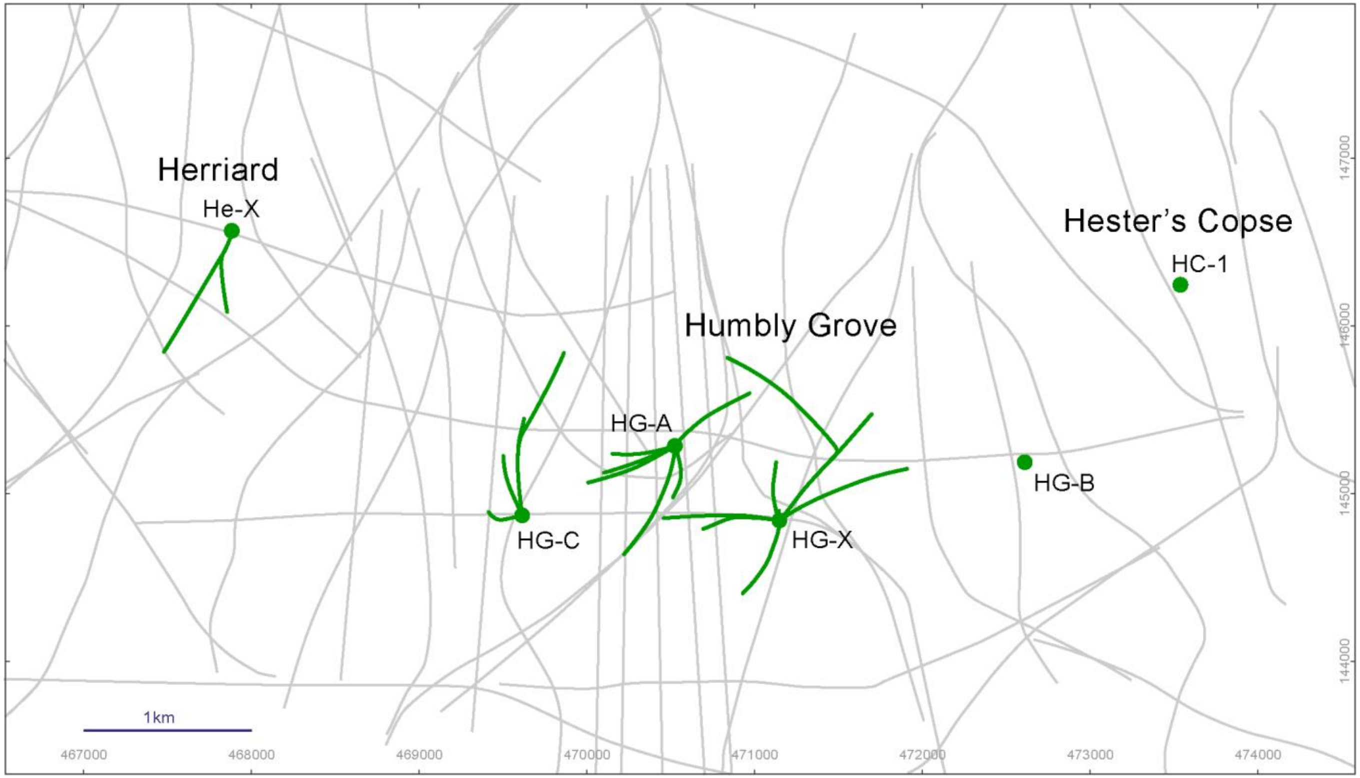

Herriard
He-X
Hester's Copse
HC-1
Humbly Grove
HG-A
HG-C
HG-X
HG-B
1km
467000
468000
469000
470000
471000
472000
473000
474000
147000
146000
145000
144000

Fig 6

A

B

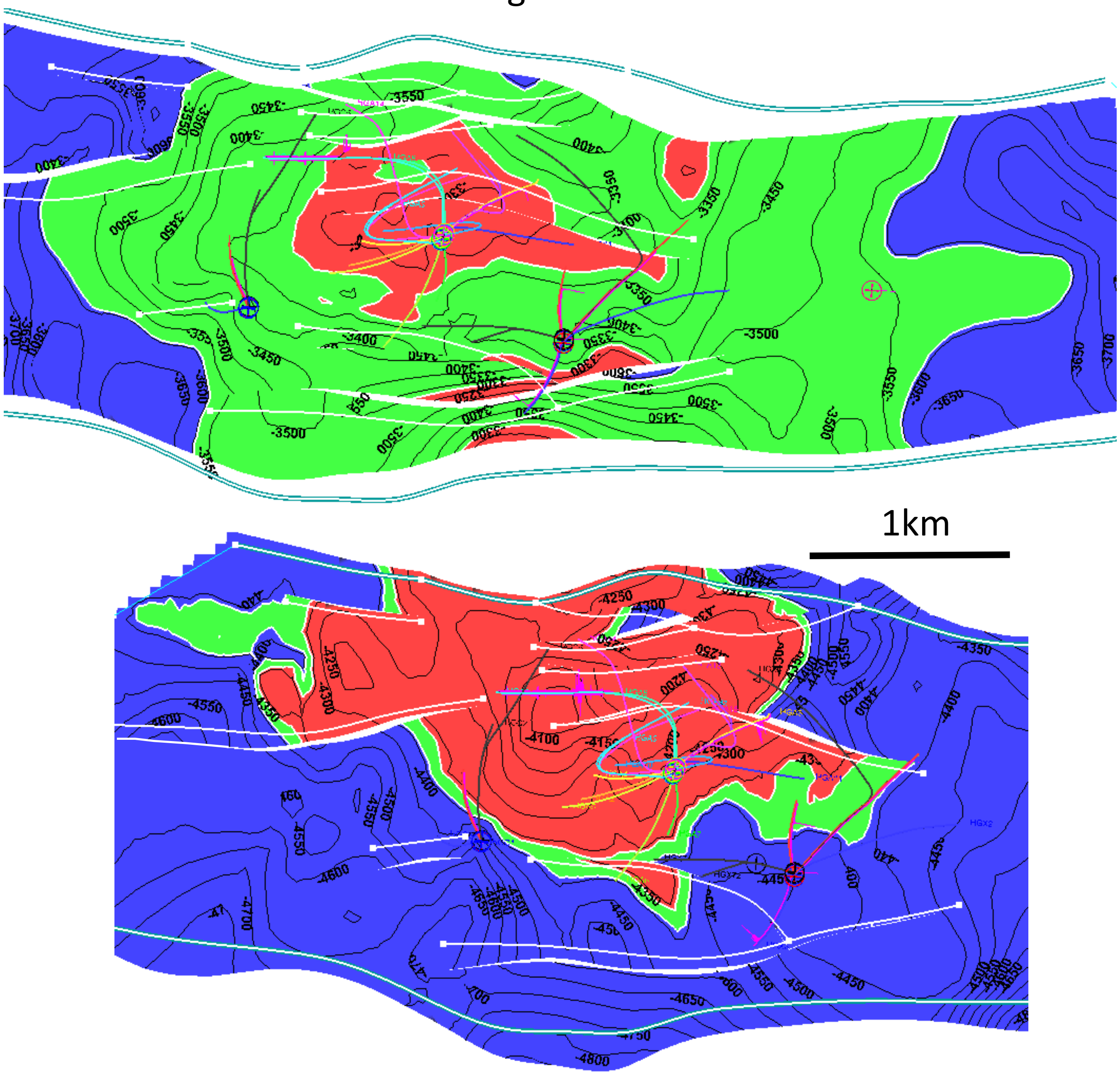


Fig 7

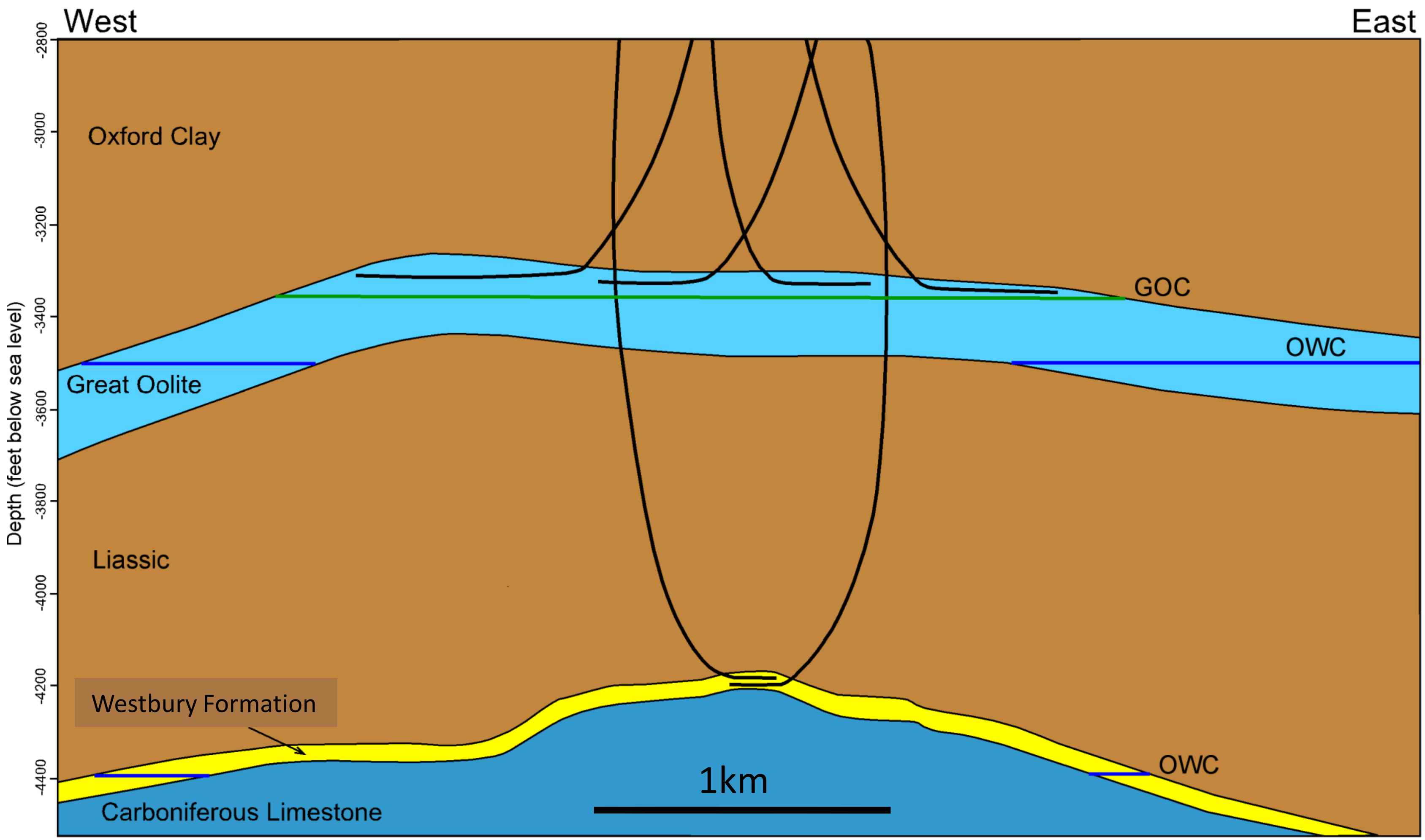
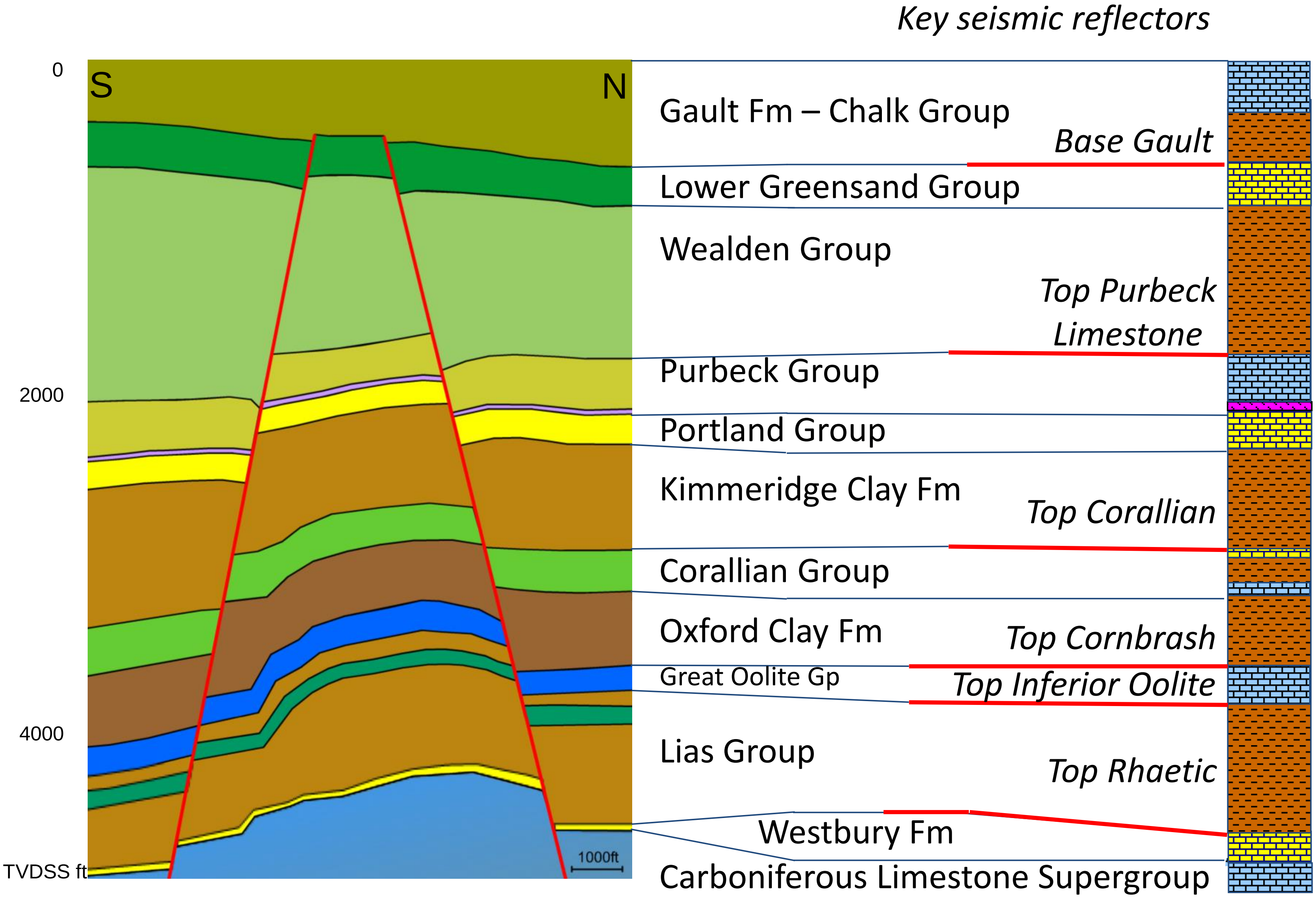
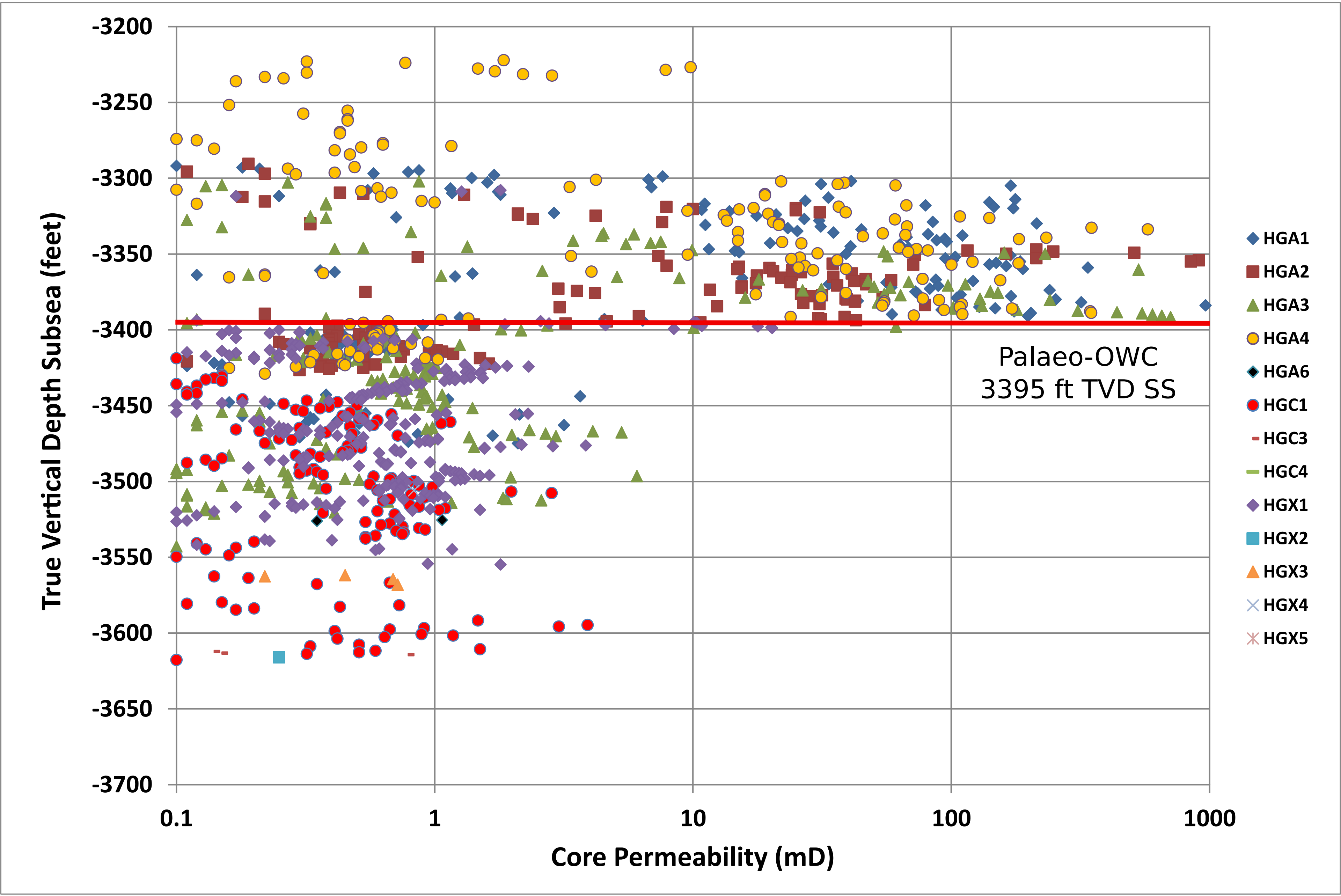

West
East
-2800
-3000
-3200
-3400
-3600
-3800
-4000
-4200
-4400
Depth (feet below sea level)
Oxford Clay
GOC
OWC
Great Oolite
Liassic
Westbury Formation
OWC
1km
Carboniferous Limestone

Fig 8



Key seismic reflectors
0
2000
4000
TVDSS ft
S
N
1000ft
Gault Fm – Chalk Group
Base Gault
Lower Greensand Group
Wealden Group
Top Purbeck Limestone
Purbeck Group
Portland Group
Kimmeridge Clay Fm
Top Corallian
Corallian Group
Oxford Clay Fm
Top Cornbrash
Great Oolite Gp
Top Inferior Oolite
Lias Group
Top Rhaetic
Westbury Fm
Carboniferous Limestone Supergroup

Fig 9



-3200
-3250
-3300
-3350
-3400
-3450
-3500
-3550
-3600
-3650
-3700
True Vertical Depth Subsea (feet)
0.1
1
10
100
1000
Core Permeability (mD)
Palaeo-OWC
3395 ft TVD SS
HGA1
HGA2
HGA3
HGA4
HGA6
HGC1
HGC3
HGC4
HGX1
HGX2
HGX3
HGX4
HGX5

Fig 10

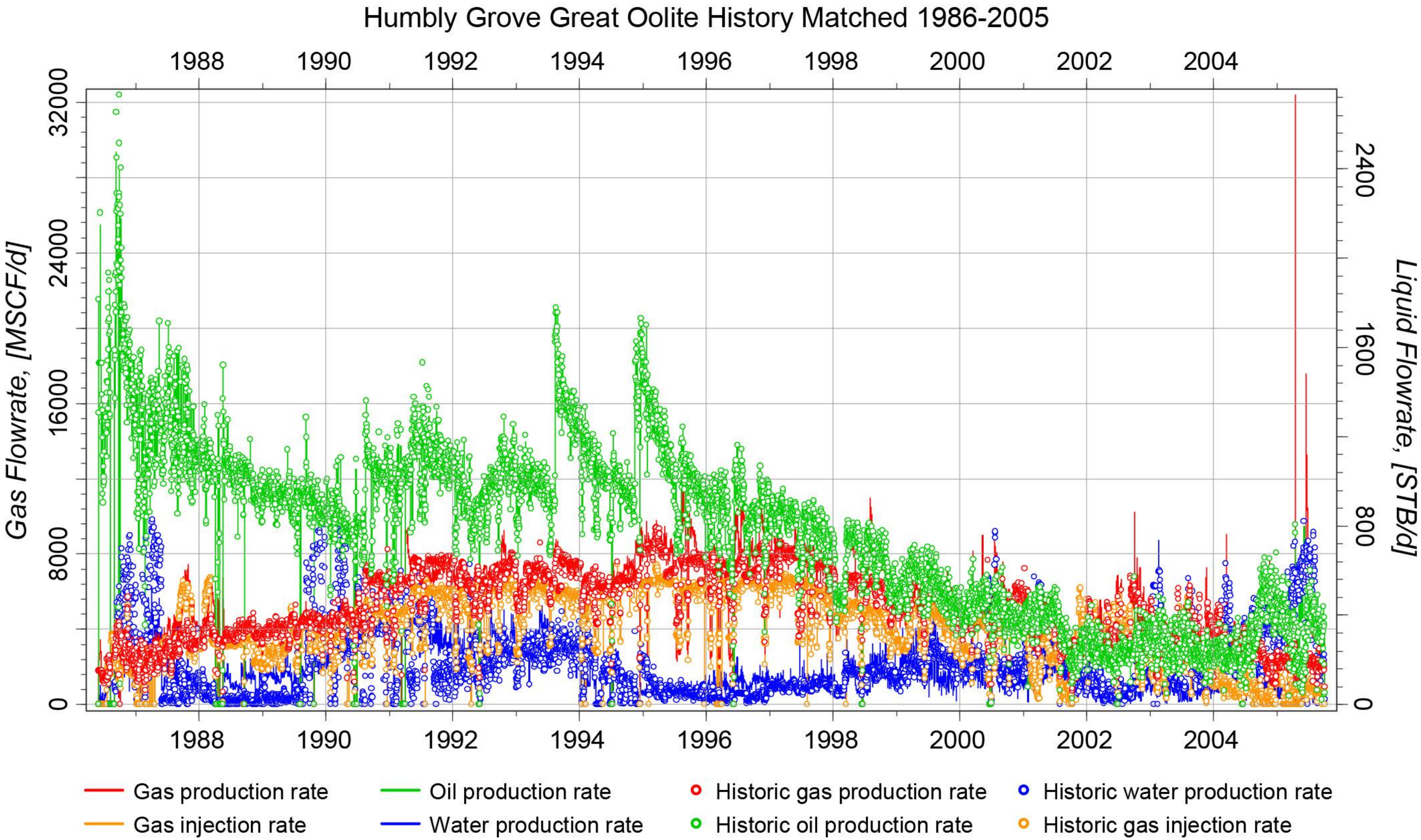

Humbly Grove Great Oolite History Matched 1986-2005
Gas Flowrate, [MSCF/d]
Liquid Flowrate, [STB/d]
0
8000
16000
24000
32000
0
800
1600
2400
1988
1990
1992
1994
1996
1998
2000
2002
2004
Gas production rate
Gas injection rate
Oil production rate
Water production rate
Historic gas production rate
Historic oil production rate
Historic water production rate
Historic gas injection rate

Fig 11 complete production history