EA Selecting an Appropriate Unconventional Play Analog for the Bowland Shale While Acknowledging Operational Constraints in the UK*

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Search and Discovery Article #11252 (2019)**
Posted October 14, 2019

*Adapted from extended abstract based on oral presentation given at 2019 AAPG Annual Convention and Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/11252Harrison2019

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Abstract

Accurate reporting of potential petroleum resources is vital to evaluate the future development plan and profitability of a petroleum discovery, but if the project needs more appraisal and production history are absent, one must turn to analogs for initial estimates of technically recoverable volumes. This article presents a workflow for selecting appropriate analogs for unconventional plays and using them to estimate the target play's potential. It then describes how local operational constraints should be incorporated, as they can have a dramatic effect on the estimated recovery. The proposed technique is demonstrated with a case study of the as-yet undeveloped Bowland Shale, which is the most prominent of the shale plays in the United Kingdom (UK) and is at the early stage of its assessment.

This article reports the current shale gas activity in the UK, highlighting the environmental constraints placed on Bowland Shale explorers. Concerns over induced seismicity had led to controls that impact on drilling and production operations. Also, the geographic proximity of urban developments, infrastructure and nature may limit the size of well pad footprint in the UK where land use is high. Studies have estimated the play's in-place resources for possible future development, but there are few estimates of its corresponding recoverable volumes due to lack of production history. A database was created with published minimum-average-maximum ranges of key parameters such as total organic carbon, maturity level, gas filled porosity, permeability, etc. that play a major role in resources estimation and recovery potential for all unconventional plays. A comparison of triangular distributions, key parameter by key parameter, between the target shale play and the analog database, is then carried out using novel graphical and statistical methods to establish a "confidence factor" relating to the analog's viability. The most appropriate analog for the Bowland Shale is chosen from an exhaustive list of North American shale gas plays. Analytical approaches are then used to transform a model of the published type well performance of the selected analog by exchanging key model parameters with those of the target shale play.

Introduction

The Bowland Shale, which is the most prominent of the largely under appraised shale plays in England, has received much publicity in recent years as an emerging shale gas resource, most famously when the UK government placed a national moratorium on hydraulic fracturing operations in 2011 when hydraulic fracturing-induced micro-seismic events were detected. However, shale gas has the potential to be a new domestic energy source in the UK, providing energy security, helping to cut CO_2 emissions, and boosting the economy. After many studies and reassurances, the UK government recently gave a green light to resume hydraulic fracturing operations in 2017, which has caused a resurgence of interest in the Bowland Shale play. Yet, the available information on this unconventional gas resource is scarce and dated; past studies have estimated its resources in-place for possible future development, but there are few published estimates of recoverable volumes. Until production experience is available, analysts and investors must continue to select appropriate analogs, usually from the US and Canada, to predict recovery, and they must give due consideration to the impact on recovery estimates of the stringent onshore operational constraints in the UK.

The Bowland Shale

The play, which stretches across the north of England, is a Middle Carboniferous organic-rich deep marine shale, interbedded with shallow water limestones and sandstones. It can be split into an upper unit and a lower unit, whose properties are given in Table 1.

The Bowland Shale is highly fractured and, being deeply buried initially to generate gas and then subsequently uplifted, has led to differing views of its commercial producibility. Laboratory analysis of core samples from the recently drilled appraisal wells at the Preston New Road site in Lancashire (PNR-1, PNR-1z, PNR-2) show the Bowland Shale to be a quartz-rich, brittle rock, which bodes well for hydraulic fracturing (Figure 1). The gas content and composition are 40 scf/ton and 96% methane, respectively, which is comparable to the Preese Hall exploration well (PH-1) drilled in 2011. With no H_2S and low CO_2 recorded, the gas could be delivered to the local grid with minimal processing requirements (Cuadrilla, 2019).

A study by the British Geological Survey (BGS) in 2013, using a ‘bottom up’ volumetric approach, provided in-place resource estimates shown in Table 2, with 80% present in the Lower unit of the Bowland Shale. This is far higher than the estimate of unrisked gas in-place of 632 Tscf, by the Energy Information Administration, who also suggested a potential recovery factor of almost 20% (EIA/ARI, 2013). Other estimates of recovery range from 5% to 25%, which reflect the inherent uncertainty associated with a shale play at its exploration stage. A recovery factor of 10% is widely considered to be a more realistic estimate (IoD, 2013).

Andrews (2013) suggested the Cambrian Conasauga Shale in the US is analogous to the Bowland Shale, based on age of deposition and structural intricacy. It is believed to hold 625 Tscf of gas in place, of which 80% was free gas (Pashin et al., 2012), but its development has not lived up to expectations. The Conasauga Shale is structurally complex, being deformed with large folds and faults, making it difficult to drill, and several wells have experienced blow outs indicative of highly pressurized accumulations. For example, the Big Canoe Creek Field was abandoned after producing only 187 MMscf of gas, rather than the forecast 1 Bscf (Drozd, 2016). If the Conasauga Shale is the only analog of the Bowland Shale, then it might not bode so well for potential shale gas developments in the UK. There may be other US shale plays that are more appropriate analogs to characterize the Bowland Shale, so to ascertain which ones might be more analogous, a systematic workflow was followed.

UK Shale Gas Regulation

The UK is making slow and tense progress towards commercial shale gas exploitation. Even though there has been onshore drilling in the UK since 1919 with over 2000 wells being drilled, 10% of which have needed to be hydraulically fractured or "fracked", there remains significant political and public opposition to shale gas development (EY, 2014). The UK government supports indigenous shale gas exploitation and has passed the Infrastructure Act 2015 to streamline the underground access regime and make it easier for companies to drill for shale gas. The Act gives automatic underground access rights (onshore) to shale gas operators to undertake horizontal drilling occurring at least 300 m below the surface and allows potential for secondary legislation to make companies pay for the right of access to benefit the community and to introduce a public notification system that sets out drilling proposals.

Following competitive bid rounds, Petroleum Exploration and Development Licences (PEDLs) for hydraulic fracturing in England were awarded by the UK government in the hope of creating a shale gas sector in the country. A PEDL provides exclusivity in an area of the UK to operators to explore and exploit hydrocarbons, subject to drilling and development consents, but other approvals are required also before hydraulic fracturing can occur: planning permission; access rights from landowners; mining waste permits for drill cuttings, spent drill muds, flow back fluids, waste gases and waste left underground from the Environment Agency; compliance with health and safety regulations and approvals from the Health & Safety Executive; and consent to drill and frack from the regulator, the Oil & Gas Authority (OGA). Unlike North America, where landowners own the minerals below the surface, the rights to all oil and gas in the UK and its territorial sea belong to 'the Crown', which describes the UK government carrying on in the name of the monarch, rather than such rights being the personal property of the monarch. This has been the case since the Petroleum Production Act 1934, but the UK government has recognized the need to invest in communities where shale gas potential is being evaluated and is considering direct payments to households (Petroleum Economist, 2018).

Managing Induced Onshore Seismicity in the UK

In May 2011, a company had its operation shut down by the UK government, when its hydraulic fracturing of a vertical Bowland Shale well caused two seismic events which were picked up by BGS monitoring equipment. In response to this widely reported event, the OGA has declared that operators must identify faults before hydraulic fracturing, monitor seismic activity in real time and stop if even minor earth tremors occur. This decree is enshrined in its "traffic light system" (Figure 3).

The operator must submit a hydraulic fracture plan (HFP) which sets out how it will monitor and control the process and locate and assess existing faults to prevent hydraulic fracturing from taking place near them. The HFP must be agreed with the EA and the OGA, who must be satisfied that controls are in place to minimize disturbance. The operator must carry out seismic monitoring before and during operations as agreed in the HFP, including recording levels of ground motion close to nearby dwellings and other structures. As long as the measured induced seismicity magnitude is in line with the HFP, this confirms geological understanding and hydraulic fracturing can proceed. Since the 2011 event, the UK government has set a threshold of 0.5 magnitude on the Richter scale while hydraulic fracturing is underway; any seismicity above this level will trigger a “red light” and hydraulic fracturing operations must stop while the operator reviews its operations and reports its findings to the OGA on the integrity of the well. The red-light level of 0.5 magnitude, which is far below what people can feel at the surface, is proving to be an operational challenge. Hydraulic fracturing red traffic light limits in other countries are much higher; up to 4.5 magnitude in North America and 2.9 in Switzerland (Cuadrilla, 2019).

UK Shale Gas Operators

Four companies are at the forefront of shale gas activity in the UK, namely IGas Energy, Ineos Shale, Third Energy, and Cuadrilla Resources (Figure 4). IGas (2017) has government permission for three wells in two sites in Nottinghamshire, Tinker Lane and Springs Road, and plans to evaluate the unconventional potential of the Gainsborough Trough. Also in this East Midlands region, Ineos, which acquired interests in UK onshore PEDLs from Total and Engie in 2017, has shot 250 km^2 of 3D seismic in the area. In Yorkshire, Third Energy has planning permission to frack its existing Kirby Misperton-8 well. It has met all 13 technical requirements stipulated in section 4A of the UK Petroleum Act 1998, but failed to arrange its project financing, leading to a financial resilience review by the OGA and the Infrastructure and Projects Authority, before a final consent is granted. In Lancashire, Cuadrilla has resumed hydraulic fracturing after having its operations suspended for causing small earthquakes (Times, 2018).

Recent Shale Gas Activity in the UK

After numerous consultations with local residents, environmental groups and regulatory bodies, and performing many mitigation studies, Cuadrilla drilled the UK’s first horizontal shale gas well at its exploration site in Preston North Road, Lancashire in April 2018, followed by a second well in July 2018. The well trajectories are shown in Figure 5. A vertical pilot well, PNR-1, was drilled through Bowland Shale to a depth of 8,576 feet to acquire data to locate the subsequent two horizontal wells. From over 980 feet of core samples taken from the shale, six prospective production zones were identified, three in the Upper Bowland Shale and three in the Lower Bowland Shale. The first horizontal well, PNR-1z, was in the Lower Bowland shale at 7,545 feet below ground level and extends laterally for 2,560 feet. The second horizontal well, PNR-2, was drilled through the Upper Bowland Shale at an approximate depth of 6,890 feet below the surface and has a lateral extent of 2,460 feet. There is planning consent for four wells on the site.

Cuadrilla obtained UK government consent to hydraulically fracture both horizontal wells and, in October 2018, began hydraulic fracturing well PNR-1z with an aim to inject 50 tonnes of proppant into each of the 41 stages, i.e. 2,050 tonnes in all. However, only 13% of the designed volume was pumped, resulting in just 2 stages being hydraulically fractured effectively, as numerous induced seismic events above the red-light level of 0.5 magnitude forced Cuadrilla to suspend hydraulic fracturing operations temporarily. In November 2018, Cuadrilla announced the production of natural gas and treatment water to surface at the Preston New Road site. In February 2019, Cuadrilla announced that natural gas flow from PNR-1z had peaked at of over 200,000 scf/d, then stabilized at over 100,000 scfd, and claimed that preliminary scaling up of results suggested a potential flow range of between 3-8 MMscf/d for an equivalent lateral section with all its stages effectively hydraulically fractured. More production data are needed to confirm this claim, but Cuadrilla believes the Bowland Shale may be comparable with US gas producing shale plays. UK shale gas operators continue to lobby the OGA to reconsider its red-limit to allow the Bowland Shale to be stimulated more effectively without compromising safety or environmental protection, but the UK government has so far refused. Depending on the outcome of such a review, Cuadrilla plans to complete its HFP and continue flow testing in 2019, but its operations are likely to continue to be monitored to an unprecedented level and watched closely by government, media and the public.

IGas (2018) confirmed its Tinker Lane-1 well in Nottinghamshire had failed to discover the primary target, the Bowland Shale, which had been estimated to be at a depth of 5545-5775 feet. Yet, IGas (2019) subsequently reported that its Springs Road-1 well nearby had encountered shales on prognosis, at around 7218 feet, including the Bowland Shale horizon, which serves to characterize the high variability of the play and the uncertainty of in-place estimates at this early stage of its appraisal.

Operational Constraints in the UK

Even after drilling and hydraulic fracturing the first shale gas wells in the UK successfully, Cuadrilla still faces many challenges. Operating in a densely populated region of England, with major traffic congestion, in close proximity to national parks, and ever-increasing demands on land use, will continue to pose difficulties. IoD (2013) estimated that a single well pad in the area, hosting 10 horizontal wells, would require 11 trucks accessing the site every day for the first 2 years of drilling and completion activity. Such concerns have led to studies by Clancy et al. (2017), which estimated the likely physical footprint of well pads if shale gas developments were to proceed in the UK, and their impact upon buildings and roads, the carrying capacity of the environment, and how resource recovery may be limited. The study calculated UK average values of conventional well site footprint, area per well, and access road length to be 2.5 acres (1 hectare), 5823 feet^2, and 755 feet, respectively.

To assess disruption to the existing infrastructure, well pads of the average footprint, with recommended setbacks, were placed randomly into the licensed blocks covering the Bowland Shale, showing a 33% probability of interacting with immovable infrastructure, rising to 73% if a 500 feet setback was used, and 91% for a 2000 feet setback. The minimum setbacks from a currently producing well in the UK are 70 feet and 150 feet from a non-residential and residential property, respectively, with mean setbacks of 1080 feet and 1465 feet, respectively. When surface and subsurface footprints were considered, the mean carrying capacity within the licensed blocks was 26%, which would impact on the potential recovery of shale gas resources. The study conservatively assumed a baseline well pad of 1 hectare with a single well drilled from it to a lateral distance of 1640 feet but acknowledged that up to six horizontal sections could be drilled from each well. Super well pads of two hectares would be considered by operators in the UK, as they can accommodate 20 wells or more, but they could meet with resistance from local residents and environmental groups. In comparison, operators in the Marcellus Shale regions typically drill laterals of 7000 feet to 10,000 feet, with a spacing of 750 feet, and have six or more wells on each pad, but they face far less areal and access constraints than operators in the UK.

Lack of production history from unconventional shale plays in the UK means that analogs must be used to estimate potential recovery, but analog selection is often subjective, particularly when using reference data from distant plays in the US. In addition to considering geologic parameters, pressure, temperature and reservoir drive mechanisms, the impact on forecast recovery of drilling and production operations in the geographic proximity of urban developments, infrastructure and nature, especially in countries with high land use such as the UK, should not be underestimated. A workflow is presented that addresses both these challenges to provide an estimate of recovery from the Bowland Shale.

Analog Selection

Reservoir analogs are ones which have already been developed and whose rock and fluid properties are similar to the play being studied. Analog selection begins with the creation of a comprehensive database of key parameters of the candidate formations. These parameters are compared systematically to those of the target play, both graphically and numerically, to rank which shale gas plays are more analogous. Multiple data sources for each play were investigated to avoid inconsistencies due to the region from which data were obtained, date of data retrieval, or differences in techniques between operators. To establish a relationship between two formations that extends beyond the static and descriptive reservoir characteristics one must compare properties that define the development and operations of different plays to assess the strength of the analogy. The analog screening criteria of Hodgin and Harrell (2006), which provide the geologic attributes and parameters that characterize a reservoir, were modified to better reflect the shale plays and are summarized in Table 3.

Using North American shale gas plays to compare with the Bowland Shale in the UK disregards the geographic proximity criterion when defining an analog. Also, some argue that analogs may not work in unconventional plays, as poor wells may offset good wells, and conclude that no shale resource is an analog for any other shale (Lee, 2014). Yet, analysts invariably turn to these North American shales for analog guidance, as these plays constitute the most developed and understood unconventional gas formations in the world. Constraints should be placed on analog selection, so that parameters that control production potential and recovery from the analog were equal to or lower than the corresponding values of the target play (Lee and Sidle, 2010). In this case study, twelve shale gas plays were proposed (Oueidat, 2017): Barnett (Texas); Woodford (Oklahoma); Marcellus (West Virginia, Pennsylvania, New York, Ohio); Utica and Point Pleasant (West Virginia, Pennsylvania, New York, Ohio); Haynesville (Texas, Louisiana, Arkansas); Bossier (Texas, Louisiana); Eagle Ford (Texas); Fayetteville (Arkansas); Montney (Alberta, British Columbia); Muskwa (Alberta, British Columbia); and Conasauga (Alabama). To quickly identify and reject poor analog candidates, a radar plot is used to visually represent the similarity between the quantitative parameters that were deemed to have the largest impact on resource estimation. Six shale plays were rejected, leaving the Barnett, Montney, Utica, Marcellus, Fayetteville and Woodford for further consideration. Figure 6 highlights the best observed agreement between the target and the Marcellus Shale, which is in marked contrast to the poorest correlation of the Eagle Ford Shale.

The remaining potential analog candidates are then compared with the target using minimum, most likely, and maximum values of the key parameters in triangular distributions to encompass the reported range of values. The overlap between the parameter distributions of the target play with those of the potential analog provides a ‘comfort factor’ (CF) that can range from 0 to 1, with 0 being completely dissimilar and 1 being exactly alike, as shown in Figure 7. The weighted average of the CF values shortened the list of analog plays which are analogous to the Bowland Shale to just two shale gas plays; the Marcellus has the highest CF value, followed by the Fayetteville. Charpentier and Cook (2011) suggest choosing multiple analogs, not just the single “best” analog, to give some measure of variability, but the Marcellus was some way ahead the rest (Oueidat, 2017).

The next step is to use a ‘top down’ approach to generate a type curve to model the estimated ultimate recovery (EUR) per well. As the Bowland Shale formation has no production history, published information for developed Marcellus Shale producing wells was used. Average values of EUR/1000 feet of lateral length drilled were gleaned from company presentations made in 2017 by several Marcellus Shale operators (Antero, Blue Ridge Mountain, Chesapeake, CNX, Eclipse) and are shown in Figure 8.

There is a wide range of recovery which underlines the highly variable nature of unconventional plays. Note that any EUR values quoted in cubic feet equivalent (Bscfe) were converted to Bscf at the wellhead. Empirical models have shown positive correlation between well length and shale gas EUR (Charpentier and Cook, 2013), so by assuming EUR varies solely with lateral length and ignoring other operations differences, the trend in Figure 8 can be used to scale the Marcellus EUR values to the assumed Bowland Shale lateral length of 1640 feet from the study by Clancy et al. (2017). The resulting Bowland Shale EUR per well are relatively low, ranging from 0.33 to 1.64 Bscf, but this reflects the conservative lateral lengths suggested in the study.

EUR from Bowland Shale when Constrained by Land Carrying Capacity

There are 127 license blocks leased in the north of England that contain the Bowland Shale. If they were all developed assuming the average carrying capacity of 26 well pads per each 100 km^2 license block, due to access restrictions, there would be 3302 well pads (Clancy et al., 2017). Operators in the UK have claimed that each well pad could accommodate 10 wells (Regeneris, 2011), which implies that the Bowland Shale might be developed with 33,020 horizontal wells. Depending on the assumed EUR/1000 feet and the lateral length of a typical development well, for a best estimate gas in place figure of 1329 Tscf given in Table 2, the potential recovery factor for the Bowland Shale as a function of EUR per well is shown in Figure 9.

Since the Cuadrilla press release, the UK Onshore Oil and Gas association has issued a 72% upgrade to the estimate of Bowland Shale potential (IoD, 2013) with a mid-case well EUR of 5.5 Bscf of “economically recoverable reserves” over a 20-year life, which is claimed to be in line with average Marcellus Shale well performance (UKOOG, 2019). The “preliminary” estimate by UKOOG is based on “analogous US shales type curves” and assumes pads having 40 laterals, which equates to 4000 laterals being drilled across Northern England over the lifetime of the Bowland Shale exploitation, but ignores UK land carrying constraints.

Conclusions

Analogs are vital when evaluating plays which are at the early phase of their appraisal. There is a need for a comprehensive database of key parameters that control in-place and technically recoverable volumes, along with screening tools to aid selection of the most appropriate analogs. North American unconventional plays are a primary source of data for potential analogs for under-appraised shale plays in the UK, but the latter’s stricter operational constraints will undeniably impact on potential recovery estimates. As the first horizontal shale gas wells in the UK have been drilled and hydraulically fractured in 2018, interested parties will be observing closely the subsequent long-term flow test results and monitoring any change in policy by the UK government.

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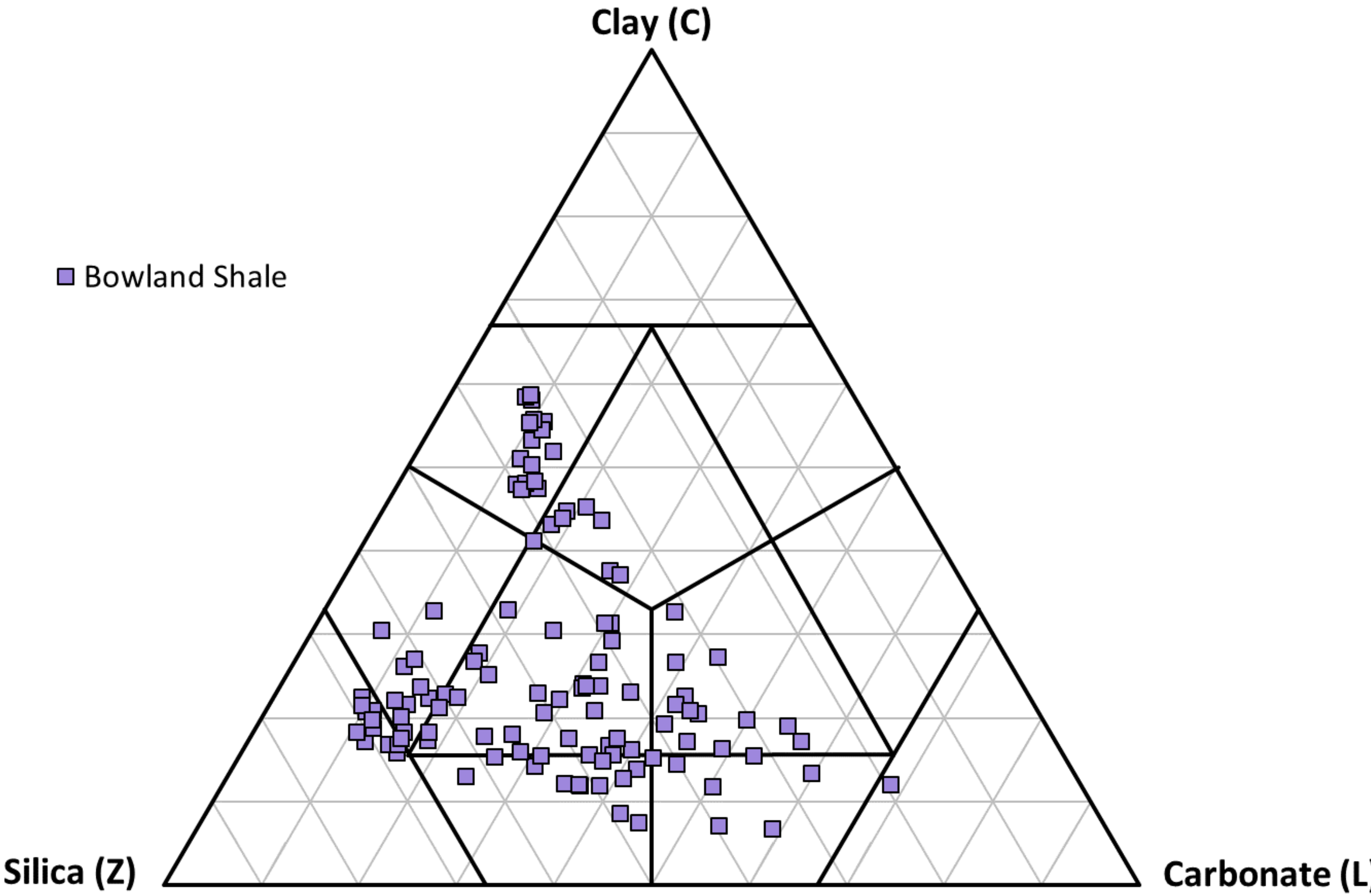

Figure 1. Tertiary diagram of Bowland Shale mineralogy from recent wells (after Cuadrilla, 2019).

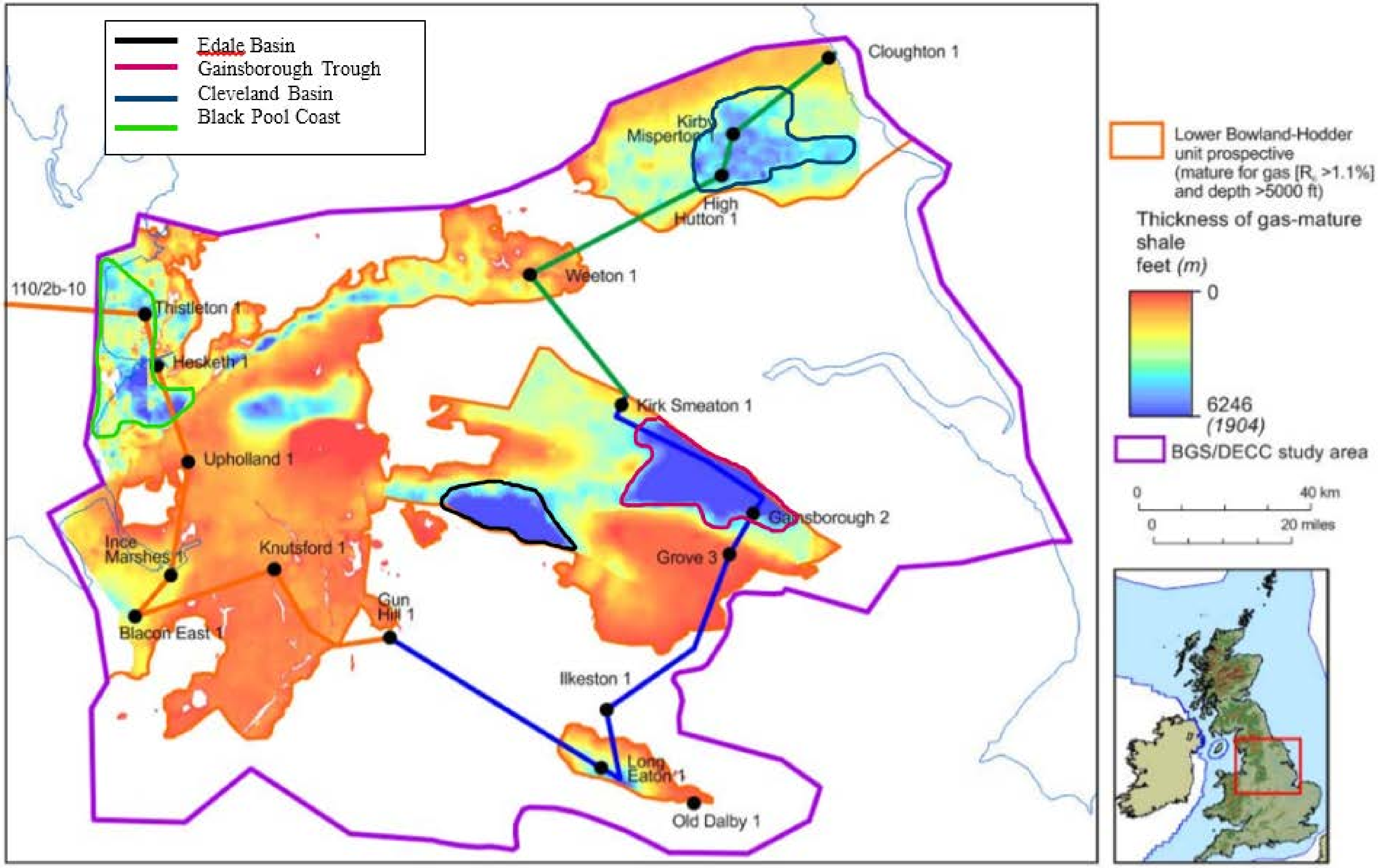

Figure 2. Map of Lower Bowland Shale net thickness and distribution of shale in the gas window, showing four 'sweet spots' derived from minimum depth cut-off below land surface and maximum hydrocarbon thermal maturity cut-off (Andrews, 2013).

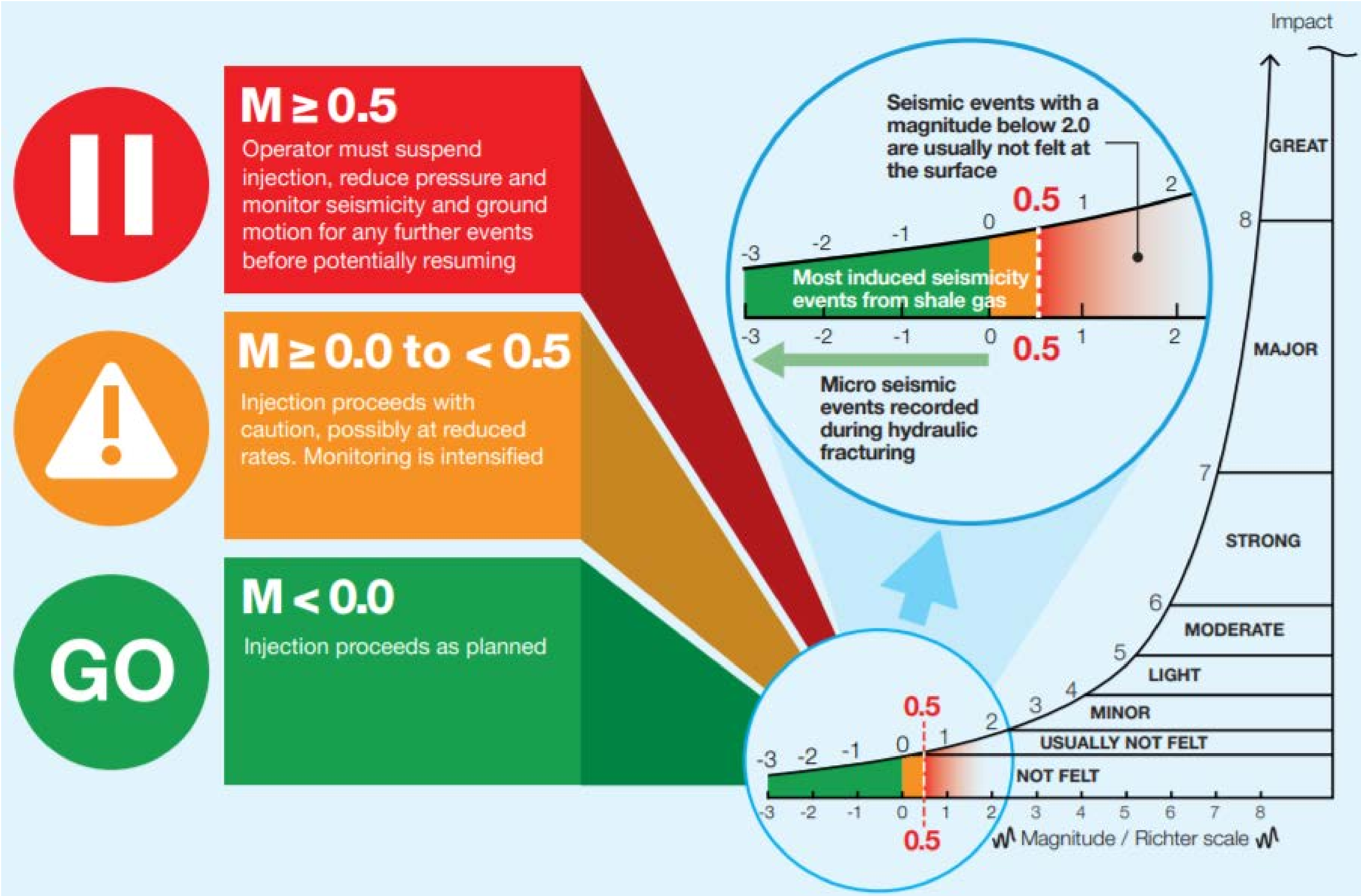

Figure 3. Management of induced onshore seismicity due to hydraulic fracturing operations using a traffic light system (OGA, 2013).

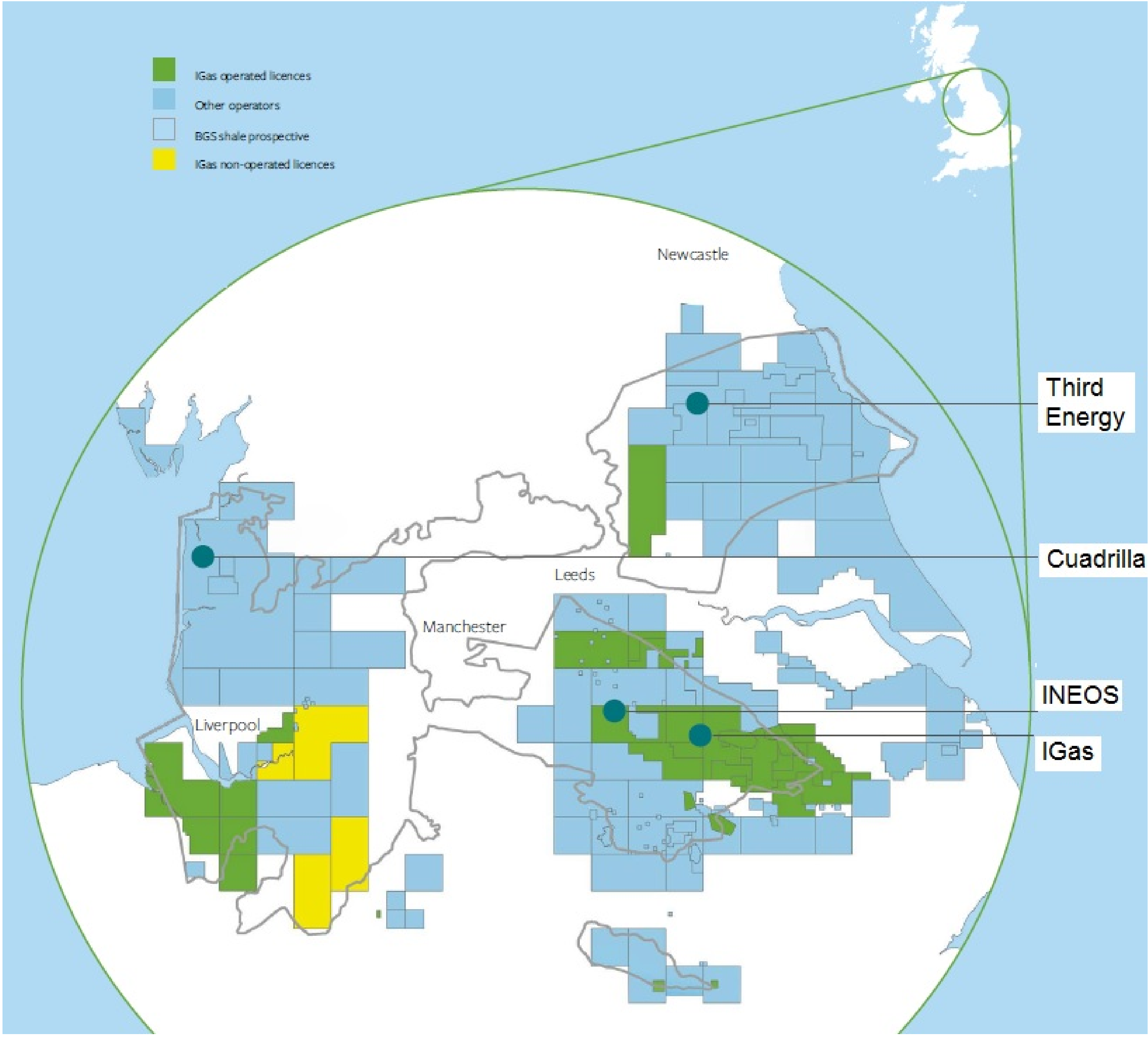

Figure 4. Location of shale gas activities in central and northern England of the four major operators. Shale gas exploitation is currently banned in Scotland, which reportedly has only a "modest amount" of unconventional resources (after IGas, 2017).

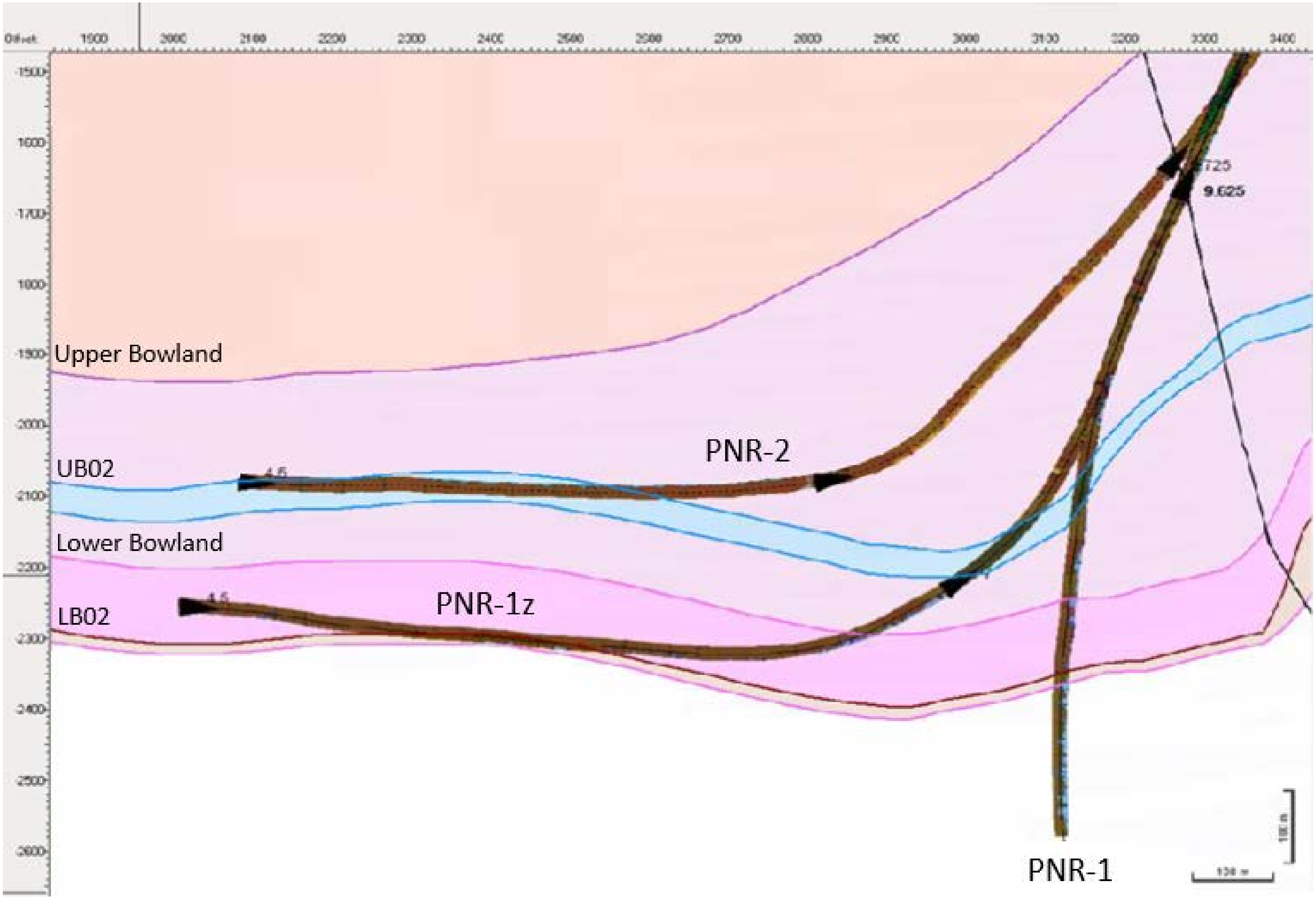

Figure 5. Schematic of the first horizontal shale gas wells to be drilled successfully in the UK (Cuadrilla, 2019).

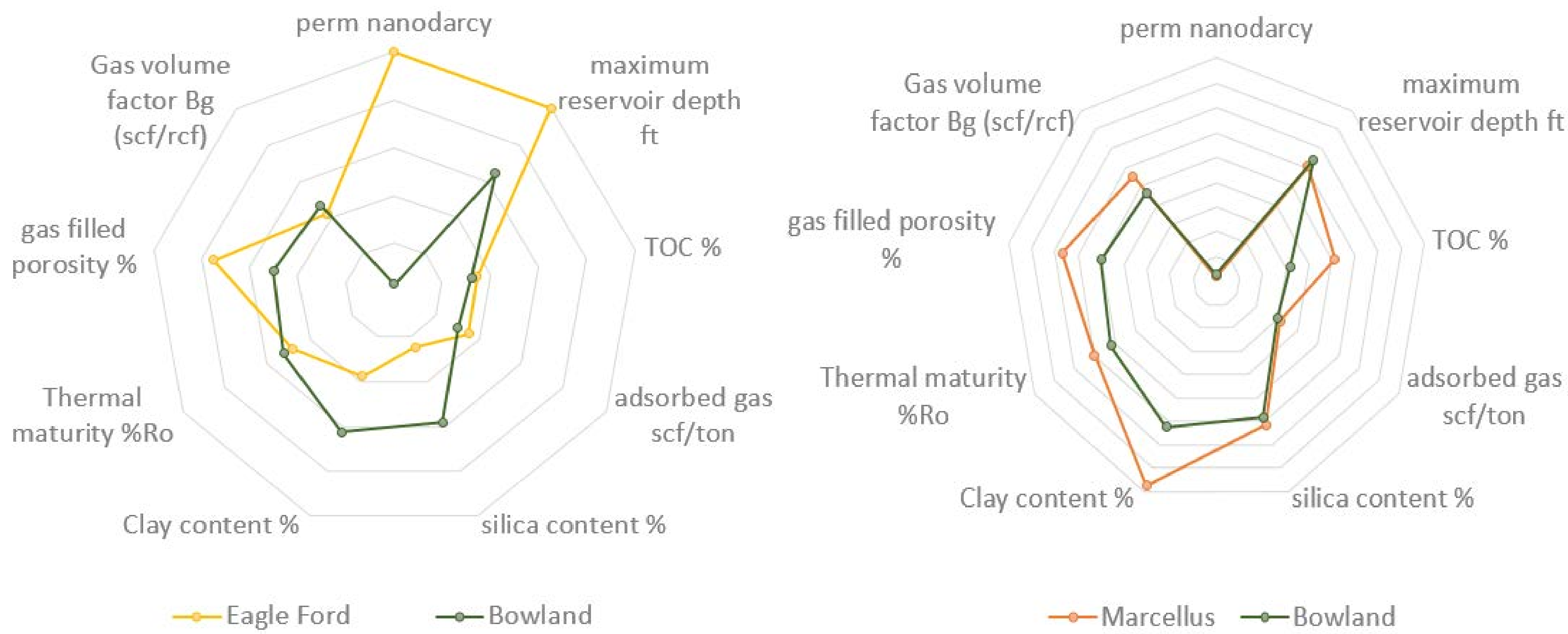

Figure 6. Radar plots of overlain shale parameters of potential analogs with the target Bowland Shale allow quick screening of inappropriate shale plays.

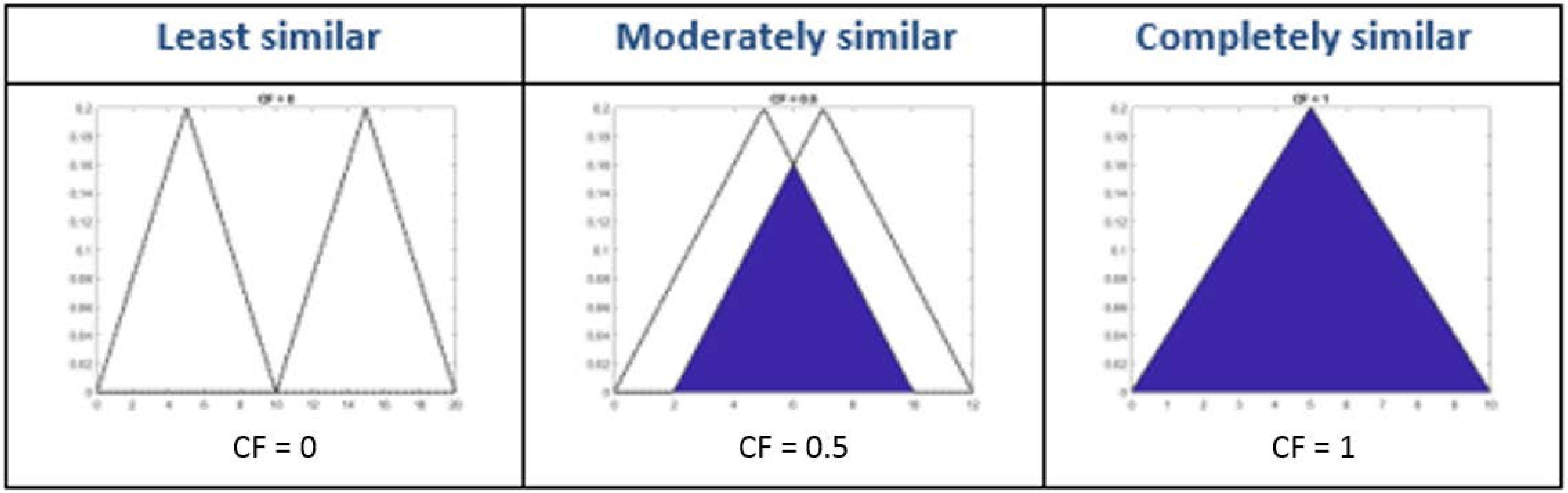

Figure 7. Comfort factors (CF) are calculated from the overlap of triangular distributions of reservoir parameters between the potential analog and the target play (after Alvadaro et al., 2008). The weighted average of the comfort factors is then used to rank and select potential analogs.

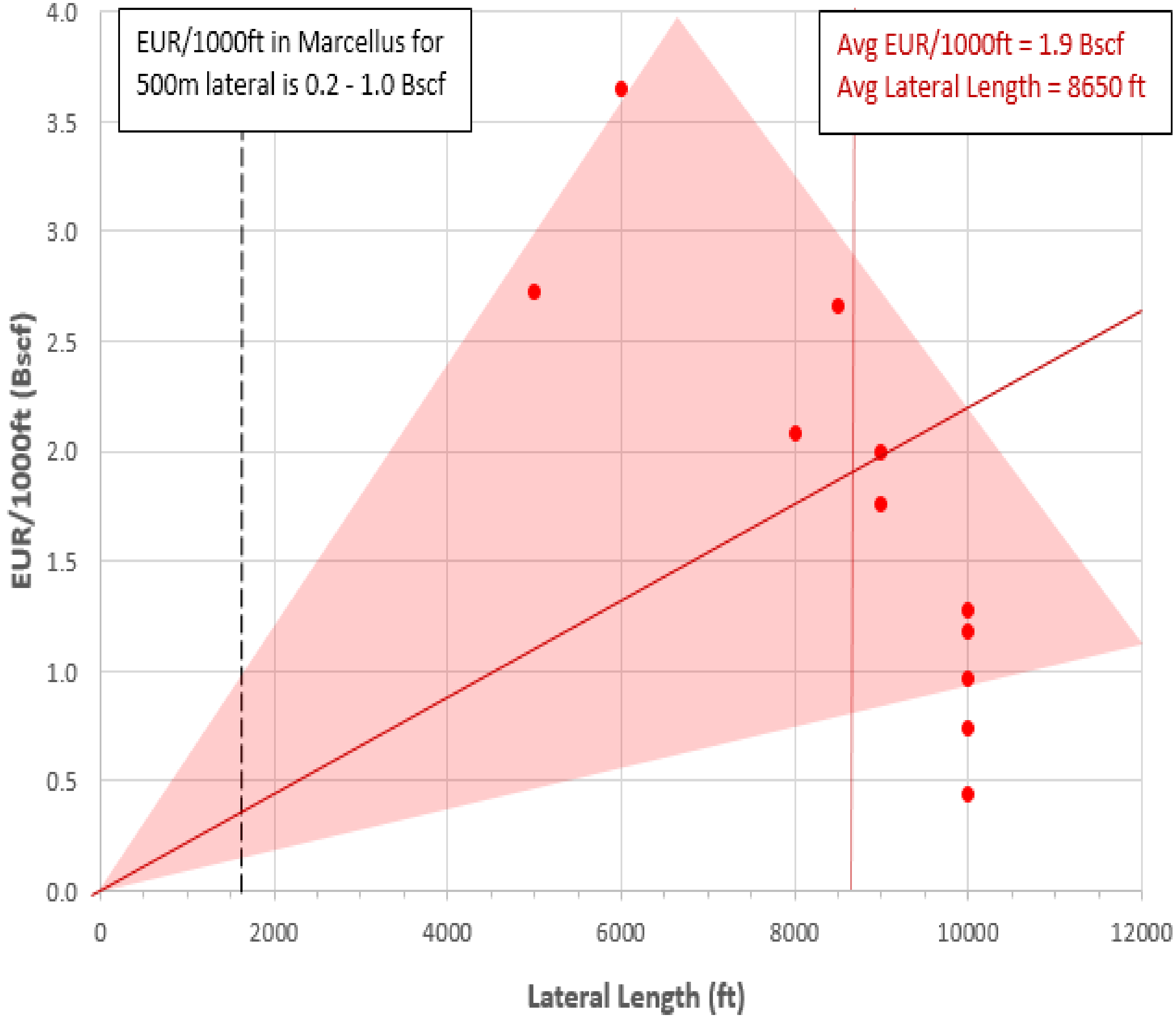

Figure 8. Range of estimated ultimate recovery of gas per 1000 feet versus average lateral length from several Marcellus Shale operator presentations in 2017. Current lateral lengths are 7000-10,000 feet and have 10 multi-stage fracture stimulations. The assumed Bowland Shale lateral length of 1640 feet (Clancy et al 2017) gives a conservative EUR range**.**

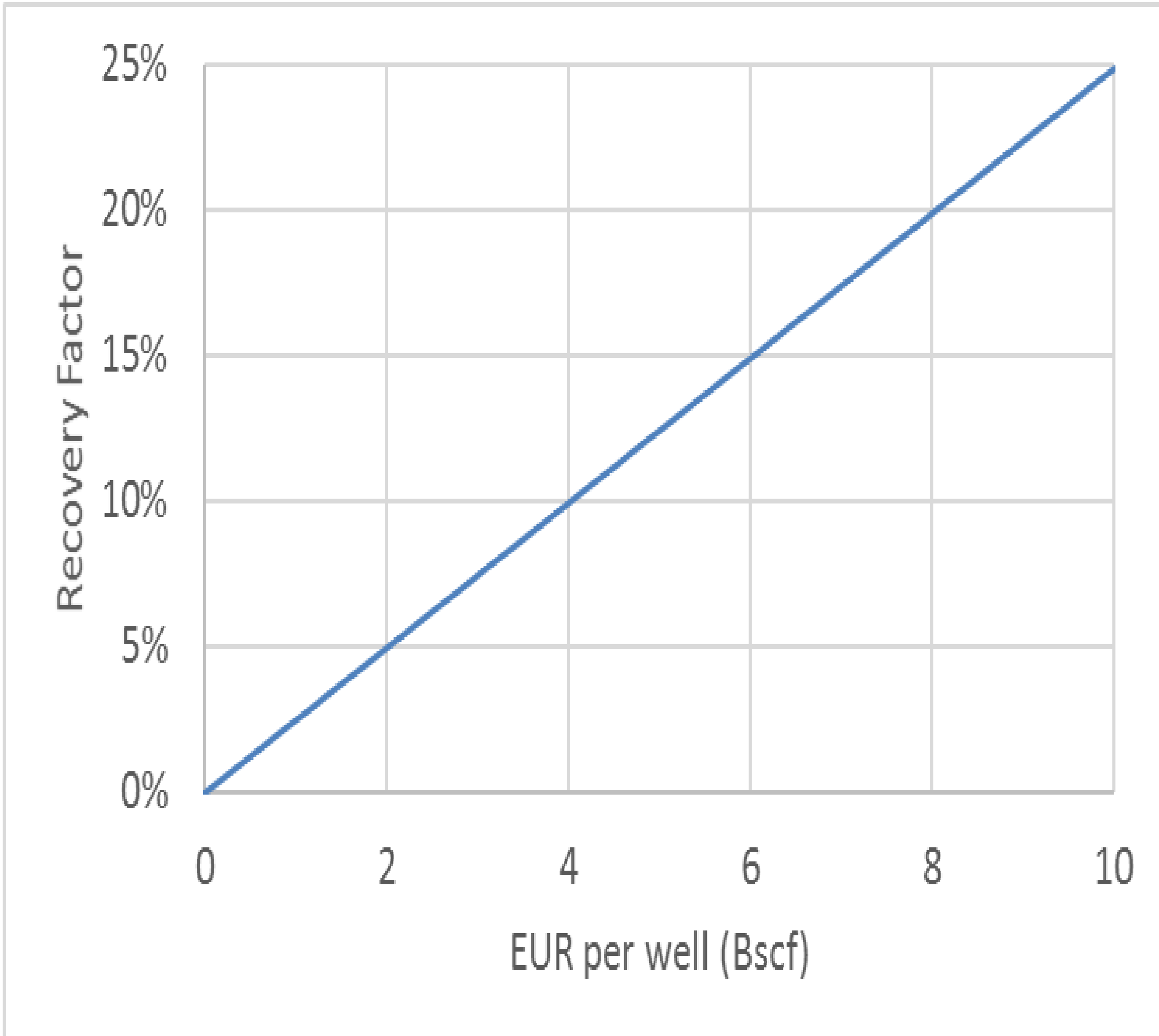

Figure 9. Potential recovery from the Bowland Shale for given EUR/well, assuming land carrying capacity constraint of 26 well pads/license block.

Bowland Shale Properties			
Property	**Min**	**Most Likely**	**Max**
Upper unit median depth (ft)	5905	6890	7875
Lower unit median depth (ft)	6890	7875	8860
Total Organic Content (%)	0.2	1 to 3	8
Gas-filled porosity (%)	0.5	3	10
Shale density (g/cm^3)	2.55	2.60	2.65
Adsorbed gas content (scf/ton)	18		71

Table 1. Ranges of key parameters of the Upper and Lower units of the Bowland Shale (after Andrews, 2013).

Bowland Shale Unit	Estimated Total Gas Initially In Place (Tscf)		
	P90	P50	P10
Upper	164	264	447
Lower	658	1065	1834

Table 2. Probabilistic estimates of GIIP for Upper and Lower units of the Bowland Shale from Monte Carlo simulation (after Andrews, 2013).

Rock/Fluid Properties	Description/Relevance
Clay content, Silica content	If clay content is high, the shale swells upon contact with frack fluids & reduce productivity. Rock brittleness is a function of its silica content, used to estimate fracturing potential
Formation depth	Drilling cost and constraints; provides knowledge of PVT properties
Total Organic Content	If sufficiently high (> 2%) will generate oil & gas; linearly related to gas content
Hydrocarbon thermal maturity	Where Ro > 1.1 hydrocarbon is considered mature enough for gas generation
Gross thickness	Total thickness defines the volume of the play
Net thickness	Limits gross thickness to gas mature shale with sufficient TOC; constrains producible volume
Permeability	Measured in nano-Darcies; related to pressure drop in the reservoir, affects productivity
Gas-filled porosity	Relatively low value in shale (< 15%); correlates to free gas content; Operator will overestimate resources if gas porosity is overestimated
Free gas	Gas contained in pore spaces; its volume is dependent on pressure, related to depth
Adsorbed gas	Gas adsorbed in the organic matter in the shale; its volume is dependent on the quantity, type and distribution of the organic content within the shale; it is pressure independent
Bulk density	Used in computation of the gas volume; a factor in calculating the adsorbed gas content
Gas expansion factor	Used to convert volumes of free gas under reservoir conditions to volumes under standard conditions; needed for commercial assessment of the play

Table 3. Geologic, rock, and fluid characteristics of shale gas plays used in similarity assessment for potential analogs.