APPENDIX 3

GEOLOGICAL EVALUATION OF THE SPRINGS ROAD BOREHOLE SITE

Nottinghamshire County Council

Review of Hydrocarbon Exploration Wells in Nottinghamshire

Geological Evaluation of the Spring Road Borehole Site

REP/249790-00/001

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Job number 249790-00

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Appendix A

Geological Overview

Executive Summary

IGas Energy Plc (IGas) has permission from the Oil and Gas Authority (OGA) to explore for hydrocarbons within the Petroleum Exploration and Development Licence (PEDL) 139 and 140, in Nottinghamshire. IGas has submitted a planning application to Nottinghamshire County Council (NCC) for the drilling of an exploration borehole, comprising one vertical borehole and one deviated borehole, at Springs Road, located in the northern part of Nottinghamshire. As part of a formal request for further information under the Environmental Impact Assessment Regulations 2011 (a Regulation 22 request) NCC sought additional detailed information from IGas. NCC subsequently commissioned Arup to analyse and interpret any information pursuant to the following information that NCC requested from IGas:

- Geological review and analysis of past data, including published geological data and information, past boreholes (e.g. any offset wells) and 2D seismic data;
- The basis for the location and extent of the 3D seismic survey;
- A review and analysis of the 3D seismic survey results with an explanation for setting the boundaries of the areas of search; and
- A reasoned justification as to why drilling outside the areas of search using directional drilling techniques would not achieve the objectives of the exploration programme.

IGas have identified a site for the drilling of an exploratory borehole with the objective of determining whether it may be commercially viable to produce gas and hydrocarbons from the Bowland Shale Formation and associated strata. These are contained within the Gainsborough Trough, which is a deep and concealed geological basin in the East Midlands.

Geological information was presented by IGas to Arup and NCC at a meeting on Tuesday 7th June 2016 and then supplied in the form of a summary report for subsequent evaluation by Arup. This included information on past coal, coal bed methane and hydrocarbon exploration boreholes and examples of 2D and 3D seismic reflection results.

IGas adopted a phased methodology to identify the most favourable site for an exploration borehole. Their approach and the criteria assessed is generally consistent with a reconnaissance hydrocarbon exploration strategy. This has enabled IGas to identify an ‘Area of Search’ within PEDL 139 and 140. Some of the outer boundaries for the ‘Areas of Search’ were delineated to intersect the thickest sequence of Bowland Shale Formation, to avoid areas of past mining and geological structures, such as faults. However, those boundaries that were inferred by IGas on the basis of poor quality 3D geophysical data cannot be fully justified on a geological basis alone.

The drilling of a deviated borehole from outside the ‘Area of Search’, whilst not impossible, is considered by Arup to be likely to compromise geological data quality and core recovery. We agree with IGas that an initial vertical borehole at this exploratory stage increases the likelihood of providing higher quality geological data with increased levels of assurance.

An evaluation of the environmental factors including flood risk that influence the ‘Areas of Search’ and the Springs Road site rest beyond the scope of this report.

Introduction

1.1 Appointment

On 12th May 2016, Nottinghamshire County Council (NCC) commissioned Ove Arup and Partners, Limited (Arup) to undertake a review of geological data and information that NCC received from IGas Energy Plc (IGas) to support a planning application for the drilling of a hydrocarbon borehole site at Misson, Bassetlaw, in Nottinghamshire. Arup's specialist sub-consultants were Geomekon GMBH and Moorhouse Petroleum Limited.

1.2 Background

IGas is an oil and gas exploration and development company based in the UK with interests to develop onshore unconventional oil and gas resources. In October 2015 IGas submitted a planning application to NCC to explore natural gas reservoirs within Petroleum Exploration and Development Licenses (PEDLs) 139 and 140 through the drilling of two exploratory boreholes; one vertical and the other deviated.

It should be noted that the term horizontal, inclined and deviated are sometime incorrectly used synonymously. The term 'deviated' borehole as used in this report refers to a borehole advanced vertically and then deviated towards a horizontal direction.

It should be noted that the term 'well' refers to the drilling installation whereas 'borehole' refers to the hole drilled into the ground for the purpose of extracting core. In this report 'borehole' is primarily used although in parts of this report the two terms are used in a similar context, for example when referring to past investigations.

1.2.1 IGas Objective

IGas objective is to evaluate if it is possible to commercially produce gas and hydrocarbons from the Bowland Shale Formation, which is the principal target.

Additional secondary targets are the Millstone Grit Group that overlies the Bowland Shale Formation and the Carboniferous Limestone Supergroup (CLS), which underlies the Bowland Shale Formation.

1.2.2 Planning Application

In October 2015 the planning application for the Springs Road exploration borehole was validated by NCC. Consultations were conducted with statutory and non-statutory organisations and the public.

The proposed development is located in an area that is categorised by the Environment Agency as having a high probability of flooding (Flood Risk Zone 3a - land which has a 1 in 100 year or greater annual probability of river flooding). Only where there are no reasonably available alternative sites in Flood Zones 1 or 2 should the suitability of Flood Zone 3 be considered.

As part of a formal request for further information under the Environmental Impact Assessment Regulations 2011 (a Regulation 22 request), NCC requested additional detailed information from IGas.

1.3 Areas of Search

IGas has identified two locations, known as ‘Areas of Search’, for the drilling of a vertical borehole, followed by a deviated borehole from the same drilling platform.

The delineation of these ‘Areas of Search’ was explained by IGas in an Environment Statement submitted to NCC. The Environmental Statement also addresses the geology and numerous environmental constraints, including; flood risk, national parks, areas of outstanding natural beauty, conservations areas, special protection areas, nature reserves, sites of special scientific interest, ecology, access, location of residential properties, woodland, wildlife, registered battlefields, ancient monuments, archaeology, parks and gardens, listed buildings, groundwater source protection zones, air quality management areas, agricultural land quality, green belt and roads.

NCC has requested that Arup limit its assessment to geologically based criteria to assess the justifiability of the ‘Areas of Search’ identified by IGas. NCC has expertise to evaluate all of the other constraints noted above either through external or 'in-house' consultees. The two ‘Areas of Search’ are identified in Figure 1.

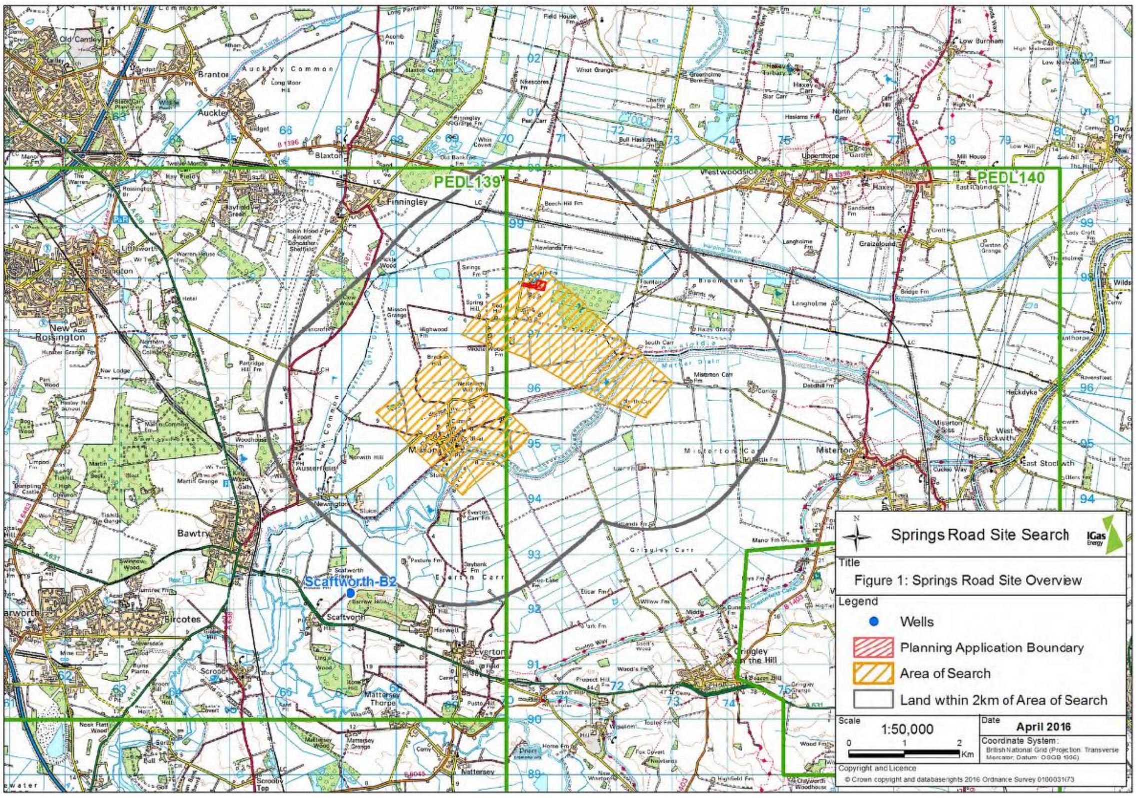

Figure 1. Location of proposed IGas Borehole in PEDL 139 and 140, Springs Road, Misson, Nottinghamshire (Source: IGas Energy Plc [11])

1.4 NCC Scope

The scope of this report is to analyse and interpret the information that NCC has requested from IGas:

- Geological review and analysis of past data, including published geological data and information, past boreholes (e.g. any offset wells) and 2D seismic data;
- The basis for the location and extent of the 3D seismic survey;
- A review and analysis of the 3D seismic survey results with an explanation for setting the boundaries of the areas of search; and

- A reasoned justification as to why drilling outside the areas of search using directional drilling techniques would not achieve the objectives of the exploration programme.

1.4.1 Gap Analysis

In May 2016 Arup conducted a Gap Analysis of available data and information provided to NCC by IGas, which included the following:

- Review the completeness and suitability of the data provided by IGas;
- Identify additional information required; and
- Facilitate a meeting with IGas and NCC to discuss the data type, format, quality and quantity.

1.4.2 Review Meeting

A project review meeting took place at the IGas office in London on 7th June 2016, attended by the Arup team and NCC. At this meeting IGas presented their rationale for selecting the location of the 'Areas of Search'. Additional geological data and information was requested by Arup and this was provided by IGas, in the form of a summary document on 10th June 2016. Although, it is noted that this document did not form part of the planning application. Subsequently, a subsurface technical information document was submitted to NCC following a second Regulation 22 request for further information.

1.5 Limitations

The assessment has been prepared on behalf of and for NCC. It has been prepared based on formal documents provided to NCC (listed in Table 1, Section 1.6) and discussions held during the project review meeting on 7th June 2016 (described above).

Due to the limited nature of Arup's scope of work and role at this stage, no detailed technical auditing has been performed by Arup to verify the accuracy of the various reports provided.

In addition, the selection of alternate 'Areas of Search' or recommendations to extend the existing areas of search are beyond the scope of Arup's commission to the NCC. Finally, as noted, the scope of work was to evaluate the geologic basis for selected 'Areas of Search'. The selection of the actual drilling location within the 'Areas of Search' and basis for that selection has been excluded from Arup's scope of work.

Arup does not hold any interests either direct, indirect or contingent with NCC or IGas.

1.6 Sources of Data and Information

The data and information used in this report is based on personal inspections, requested and presented data and information, as summarised in Table 1, with appropriate dates and authors where appropriate, and discussions with NCC and the Technical Staff of IGas.

Table 1. Relevant information provided by IGas to Nottinghamshire County Council

Title of Document	Date of Document	Format & No. Pages	Source	Sender	Date Received
[1] Technical Note A. A Site Selection and Sequential Test, Land off Springs Road, Misson	Not dated	Pdf, 20 pages	IGas	NCC	6.05.2016

Title of Document	Date of Document	Format & No. Pages	Source	Sender	Date Received
[2] Figure 1. Spring Road Overview Map. 1:50,000	April 2016	Pdf, 1 page	IGas	NCC	6.05.2016
[3] Figure 2. Rock Quality (CLS Isochore) Map. 1:50,000	April 2016	Pdf, 1 page	IGas	NCC	6.05.2016
[4] Figure 3. Geological Map for Spring Road Map. 1:50,000	April 2016	Pdf, 1 page	IGas	NCC	6.05.2016
[5] Figure 4. Flood Risk Map	April 2016	Pdf, 1 page	IGas	NCC	6.05.2016
[6] Figure 5. Bassetlaw District Council Strategic Flood Risk Assessment Map. 1:40,000	July 2009	Pdf, 1 page	Jba (IGas)	NCC	6.05.2016
[7] Figure 6. Planning Constraints for Springs Road	April 2016	Pdf, 1 page	IGas	NCC	6.05.2016
[8] Figure 7. Agricultural Land Classification	April 2016	Pdf, 1 page	IGas	NCC	6.05.2016
[9] Figure 8. Flood Risk and Residential Areas	April 2016	Pdf, 1 page	IGas	NCC	6.05.2016
[10] Figure 9. Alterative Site Options	April 2016	Pdf, 1 page	IGas	NCC	6.05.2016
[11] Planning Application to Develop a Hydrocarbon Well site and to Drill up to Two Exploratory Wells for a Temporary Period of up to Three Years. Land off Springs Road, Misson. Town and Country Planning (Environmental Impact Assessment) Regulations 2011 Submission of Supplementary Information Requested by Nottinghamshire County Council under Regulation 22	April 2016	Pdf, 30 pages	IGas	NCC	6.05.2016
[12] Temporary shale gas exploration at Springs Road Subsurface Technical Information for NCC	9.06.2016	Pdf, 25 pages	IGas	NCC	10.06.2016
[13] Further information submitted in response to Reg 22 request – Subsurface Technical Information for NCC	5.07.2017	Pdf, 25 pages	IGas	NCC	8.07.2016

2 Area of Search Selection Criteria

This section is divided as follows:

- Section 2.1 provides the methodology which IGas used to define the boundaries of the 'Areas of Search' identified;
- Section 2.2 provides an overview of the development of the 'Areas of Search' boundaries;
- Section 2.3 provides a discussion of how IGas delineated the 'Areas of Search' boundaries; and
- Section 2.4 provides Arup's comments on IGas method, rationale, and results of the 'Areas of Search'.

2.1 Methodology

IGas selected the 'Areas of Search' by systematically assessing the following criteria:

- Limits of the PEDL139 and 140 boundary area;
- Evaluation of available data and information (i.e. BGS and other reports, data from nearby boreholes) as referred to as a 'desk study stage';
- Results from existing 2D geophysical surveys (performed by others); and
- Results from 3D geophysical surveys (acquired by IGas).

2.2 Development of Areas of Search Boundaries

The following sections provide an overview of the geologic basis for the 'Areas of Search' identified as well as details on how the 'Areas of Search' were selected.

An overview of the geology of the Gainsborough Trough is presented in Appendix A

2.2.1 PEDL 139 and 140

The boundaries for PEDL 139 and 140 provided the initial constraints for the 'Areas of Search', since this defined the limits for the IGas license.

2.2.2 PEDL Licence Area

The Springs Road borehole site is within PEDL 139 and 140 in Nottinghamshire. These blocks define an area of land awarded by DECC to the joint venture currently operated by IGas Energy Plc for the purposes of hydrocarbon exploration (Figure 2).

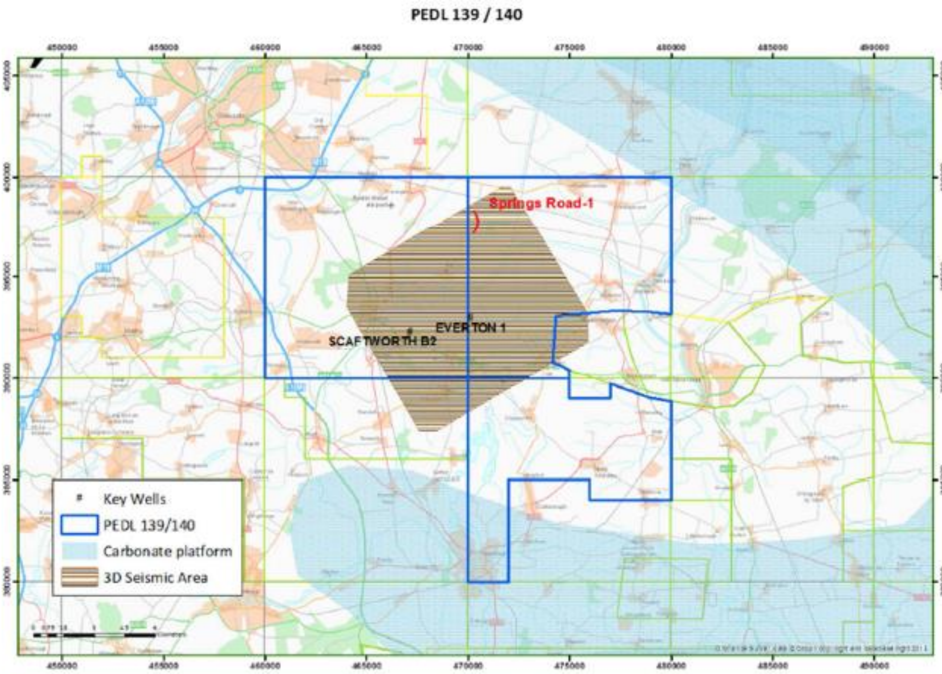

Figure 2. Location of PEDL 139 and 140, the proposed Springs Road borehole and key offset wells (Source: IGas Energy Plc [13])

2.2.3 Constraints Based on Available Information

IGas has selected the Gainsborough Trough (a deep geological basin) as the preferred commercial target given the likelihood that the shale in this location will be at its thickest as well as having geological processes associated with the presence of gas. Therefore, the 'Areas of Search' were further constrained by the boundaries of the Gainsborough Trough.

The locations of known faults as determined from data and information published by the British Geological Survey past 2D seismic surveys have also been documented during the desk study stage which, as indicated below, have also been used to constrain the 'Areas of Search'.

2.2.3.1 Past Boreholes

Four off set wells (boreholes) have been previously drilled in PEDL 139 and 140. These are; Scaftworth-B2, Everton-1, Everton-2 and Misterton-1. Scaftworth-B2 was drilled by BP in 1982 to a depth of 2,312m. This borehole intersected the Bowland Shale Formation and included approximately 70m of the Carboniferous Limestone Supergroup (CLS).

Everton-2 and Misterton-1 were drilled by GP Energy in 2010 to evaluate coal bed methane and these reached 1,224m and 560m respectively. Test work in the Everton-1 borehole (depth not provided) are reported to have detected gas and condensate flows in the Millstone Grit Group.

Several numerous coal exploration boreholes also intersect formations associated with the Westphalian stage including the Rocket borehole, located approximately 500m to the south, south-east of the Springs Road site (Figure 3).

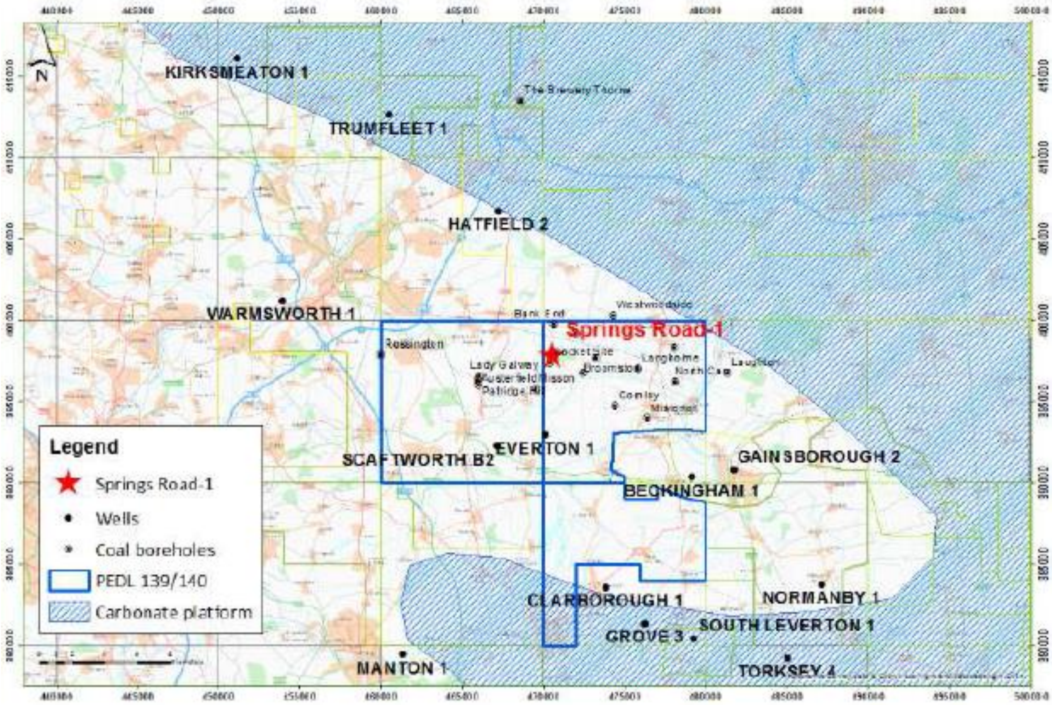

Figure 3. PEDL 139 and 140 showing the location of past boreholes (Source: IGas Energy Plc 2016 [13])

2.2.3.2 2D Geophysical Data

Archive 2D seismic data within PEDL139 and 140 was collated and evaluated by IGas. This comprises seismic reflection data that was acquired for the purposes of previous mineral and petroleum exploration or collated for research conducted by the British Geological Survey. The 2D seismic reflection data provided a general overview of the geology and in particular the structure of the Gainsborough Trough. The stratigraphy was verified by IGas using previously drilled boreholes noted above (Figure 4, Figure 5 and Figure 6).

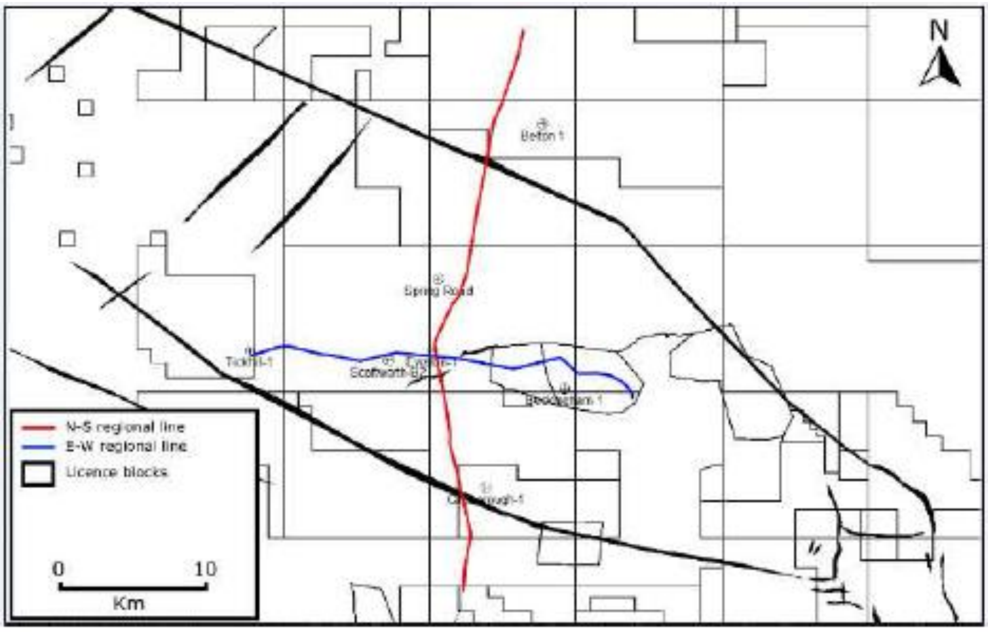

Figure 4. Cross section locations based on 2D seismic data and the position of Springs Road proposed borehole site (Source: IGas Energy Plc 2016 [13])

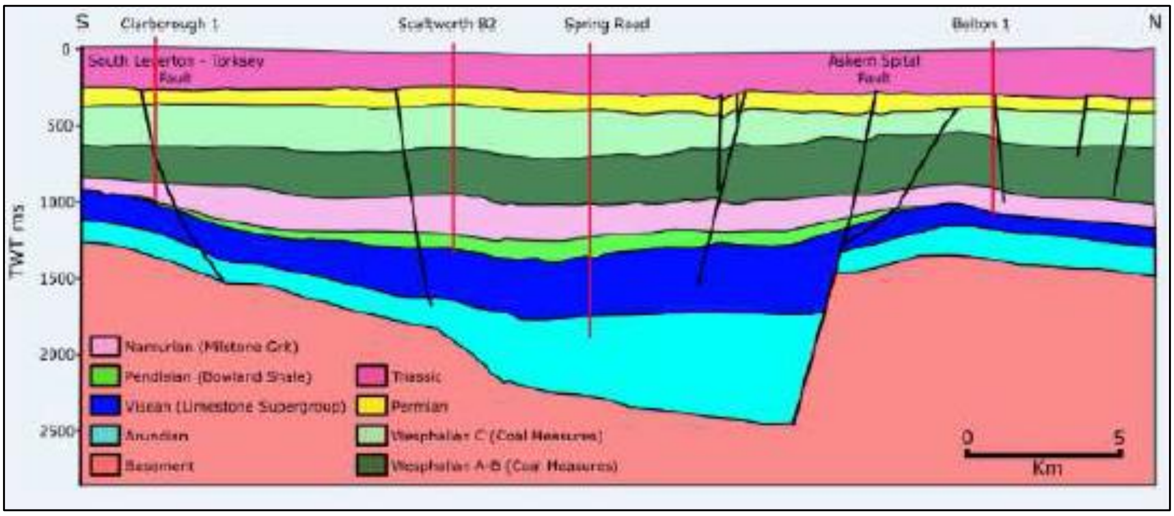

Figure 5. South to north section across the Gainsborough Trough and a geological interpretation of 2D geophysical data showing the Askern-Spittal boundary fault, the increase in thickness of strata to the north, the proposed Springs Road borehole and past boreholes (Source: IGas Energy Plc 2016 [13])

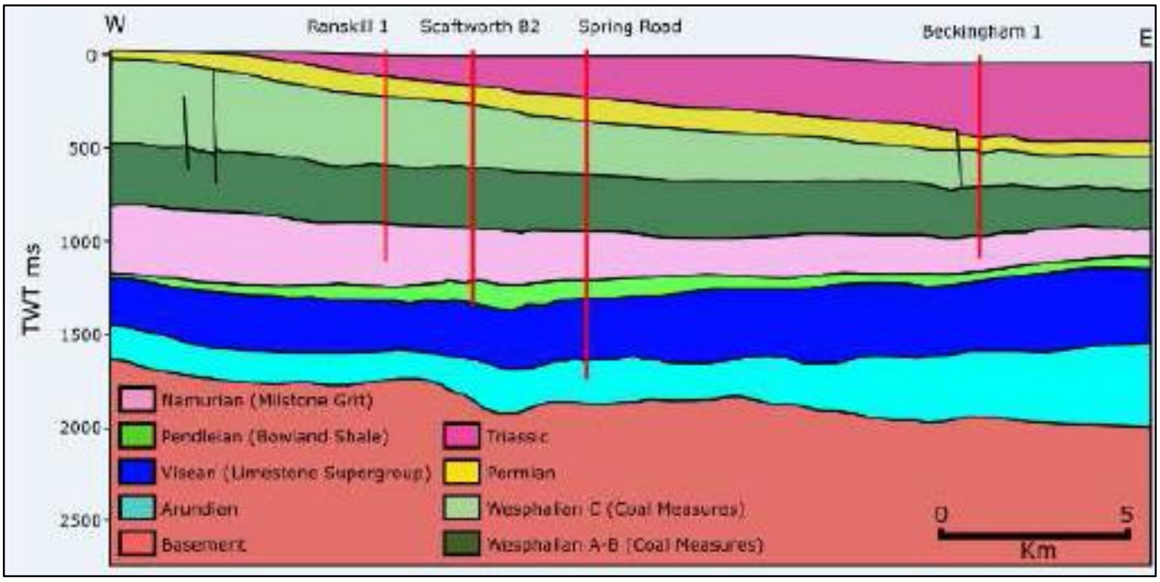

Figure 6. West to east section across the Gainsborough Trough and a geological interpretation of 2D geophysical data showing the Askern-Spittal boundary fault, the increase in thickness of strata to the north, the proposed Springs Road Boreholes and past boreholes (Source: IGas Energy Plc 2016 [13])

2.2.4 3D Geophysical Data

Analysis by IGas of past boreholes and 2D seismic reflection data gave the initial location, thickness, structure and geological characteristics of the Bowland Shale Formation and other secondary targets, noted above. This provided the basis for the selection of the 3D geophysical survey (seismic reflection) area, acquired by IGas in 2014, over an area of approximately 7000 km^2. This location of the 3D seismic survey was constrained by the following:

- The 3D survey area was set within the Gainsborough Trough. Based on the conceptual understanding of geologic formation factors, the 3D survey would encompass the deepest area of the trough, and therefore improve the likelihood for discovery of thicker shale formations;

- The 3D survey area was set to include existing borehole locations (namely the Scaftworth-B2 and Everton-1) in order to use the data from these and other boreholes to calibrate the results of the geophysical survey;
- The limits of the 2D seismic survey were used to constrain the extent of the 3D seismic survey in order to build upon the geologic characterisation provided by the 2D surveys;
- The 3D survey was oriented to best match the orientation of the geologic stress field (discussed in Section A.5); and
- The north-western limit of the 3D seismic area was further constrained to avoid areas of historical mine (coal) workings (Figure 7).

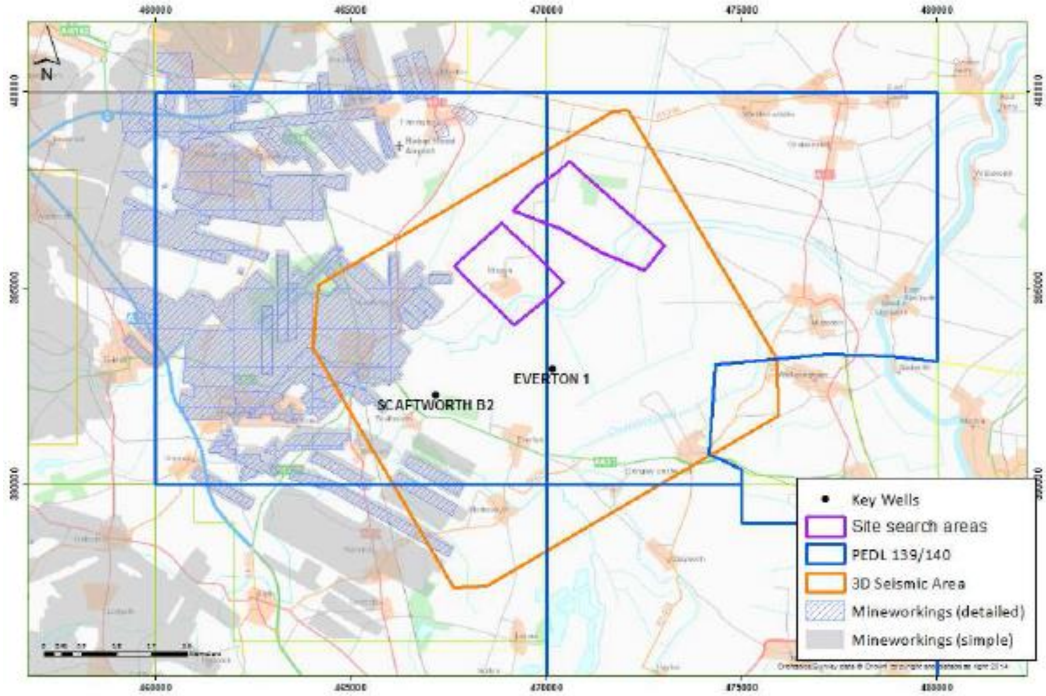

Figure 7. Areas of past mine workings (Source: IGas Energy Plc [13])

The results of the 3D geophysical survey has indicated the following:

- A cut-off depth of 1,800m (assumed by Arup to be 1,800mbgl) was believed by IGas to delineate the point where the Gainsborough Trough fully develops and possibly reaches a maximum thickness;
- Within the surveyed areas, and within the detection limits of the geophysical surveys, no major faults and few minor faults were identified;
- There is a reduction in the quality of the 3D geophysical data around the perimeter of the area of acquisition. This has been referred to by IGas as a '20 fold contour' (IGas Energy Plc [13]);
- Evaluation of the 3D seismic data indicated a region within the Bowland Shale Formation considered to be unrepresentative of the overall formation. This is referred to by IGas as a 'stratigraphic feature' that extends north-west to south-east, and has been reported to be around 3800m long and around 600m wide. As the stratigraphic feature is unrepresentative of the formation, it is not a preferred target for an initial exploration campaign. Therefore, IGas have elected to avoid this region and have further placed a boundary (of around 200m, Figure 1010) around the feature to account for the inherent uncertainty within 3D seismic surveys; and

- There is a range of data quality (i.e. confidence in the accuracy of the seismic images) across the survey as evaluated using a variety of techniques, principally amplitude mapping of the seismic data. For example, data quality is generally poor in the southern portion of the survey area.

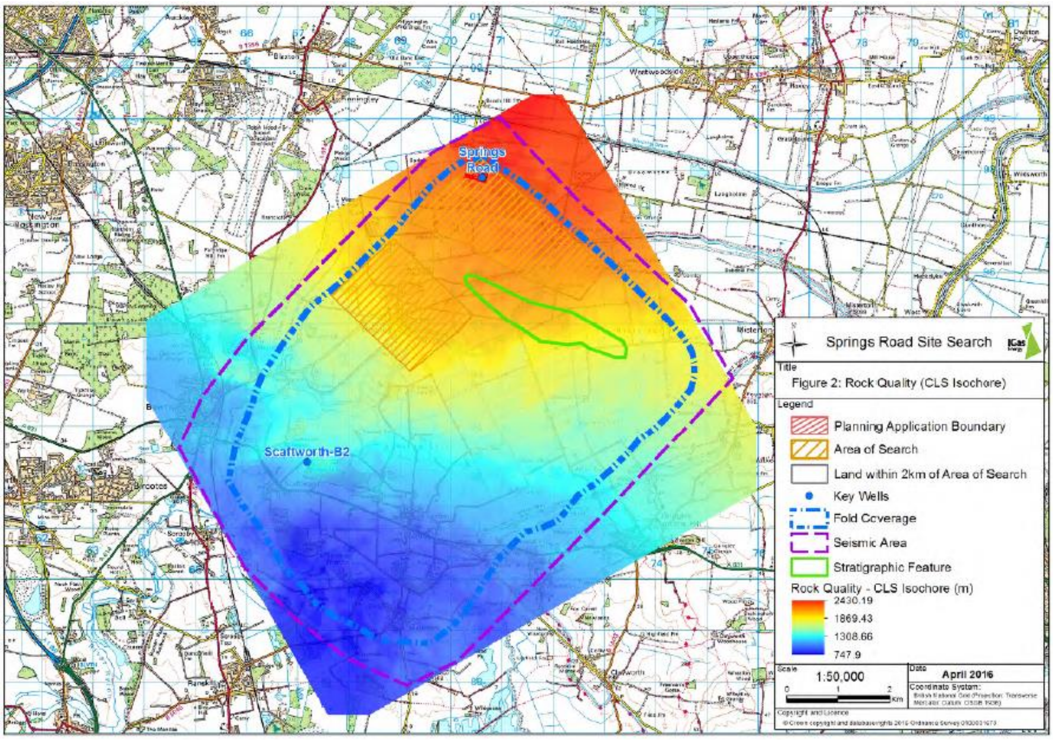

Figure 8. Rock quality isochore showing the thickening of the Gainsborough Trough to the north, the position of a stratigraphic feature detected by 3D seismic reflection surveys and the areas where 3D seismic data was poor (Source: IGas Energy Plc [3])

2.3 Delineation of the Areas of Search

The boundaries of the 'Areas of Search' identified by IGas are presented in Figure 1 and comprise two distinct areas, A and B:

2.3.1 Area A

The boundaries for Area A have been delineated by IGas as follows:

- **North-east boundary:** This runs approximate north-west to south-east and was delineated by poor quality 3D seismic data, the proximity of the Askern-Spittal fault zone and associated faults, which limits the northerly extent of the Gainsborough Trough;
- **South-east boundary:** This runs approximate north-east to south-west and was delineated by poor quality 3D seismic data;
- **South-west boundary:** This runs approximate north-west to south-east and was delineated to avoid a structural anomaly observed from the 3D seismic refection data. The cause of the geophysical anomaly is unknown. It has been speculated by IGas this could be any of a number of geological structures, including for example a possible reef; and
- **North-west boundary:** This runs approximate north-east to south-west and was delineated by poor quality 3D seismic data and deep mine workings, probably related to coal.

2.3.2 Area B

The boundaries for Area B have been delineated by IGas as follows:

- **North-east boundary:** This runs approximate north-west to south-east and was delineated to avoid the structural feature identified on 3D geophysical survey data;
- **South-east boundary:** This runs approximate north-east to south-west and was delineated by poor quality 3D seismic data;
- **South-west boundary:** This runs approximate north-west to south-east and was delineated by poor quality 3D seismic data and the 1,800m Isochore, which marks the point where the Gainsborough Trough fully develops and increases in thickness to the north; and
- **North-west boundary:** This runs approximate north-east to south-west and was constrained by poor quality 3D seismic data and deep mine (coal) workings further to the north-west.

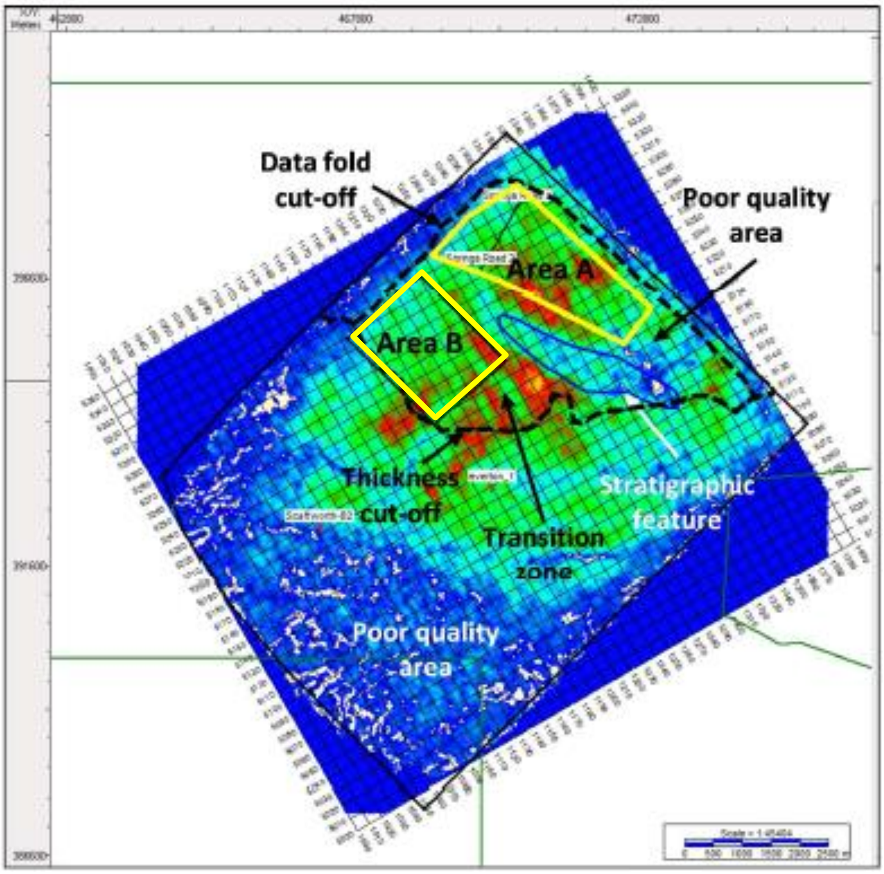

Figure 9. Selection criteria for the Areas of Search (Source: IGas Energy Plc 2016 [13])

2.4 Comments on Areas of Search Criteria and Boundaries

IGas must comply with the terms of the PEDL license issued by the OGA and therefore the 'Areas of Search' must be within the PEDL boundary limits, which has been achieved.

The past boreholes are located several kilometres from the Springs Road site, for example Scaftworth-B2 is situated over 6km to the south-west. The extrapolation of geological data from this borehole over these large distances can at best only provide 'inferred' information. However, the data provided by these past boreholes is critical to understand and characterising geological information generated from 2D and 3D seismic surveys.

The general location of the 3D geophysical traverses towards the centre of PEDL 139 and 140 and above the Gainsborough Trough is accepted as reasonable.

The presence of poor quality geophysical data around the edge of the area of acquisition was presented by IGas on a 'fold coverage map'. It should be noted that the term 'fold quality' used here is not related to structural folds and only indicates a delineation between 'good' and 'poor' quality seismic data due to effects from the edges of the seismic area. Therefore, the justification of boundaries related to the limit of the 3D seismic 'good' quality data is related to data quality, rather than a geological reason.

The identification of a structural anomaly (or feature) using 3D seismic data has been clearly demonstrated to Arup by IGas. The potential that this features extends beyond what has been identified by the 3D seismic survey (including to the north-west direction) is justifiable given the inherent uncertainty in seismic data. The separation of the 'Areas of Search' into two areas is based on IGas' preference to avoid this structural feature as it is not considered representative of the Bowland Shale Formation. Given that this is the only exploration campaign it is completely reasonable for IGas to target both the thickest and most representative locations within the target reservoir.

Areas of past mine workings have been shown to the north-west of the 'Areas of Search'. These are likely to be associated with the mining of coal. However, the date when this mining took place and the source, completeness and reliability of this data and information has not been provided.

The south-west boundary of Area B has been set to coincide with the point at 1,800m (assumed by Arup to represent 1,800mbgl) where the Bowland Shale and the Carbon Limestone Supergroup Formations have been shown by the 3D geophysics to thicken towards the base of the Gainsborough Trough.

3D seismic survey data have been used to verify existing available information and to define the boundaries for the 'Areas of Search'. The geological justification for many of these boundaries is considered reasonable. However, the delineation of some boundaries appear to be based on the quality of available data, rather than due to a specific geological constraint. We note that there will be some geological areas which do not allow for clear seismic interpretations.

3D seismic data have also been used to evaluate the relative thickness of the Bowland Shale Formation within the 'Areas of Search'. While review of the selection criteria of the actual borehole site within the 'Areas of Search' is outside of Arup's scope, we do note that the targeting of the thicker region of the Bowland Shale Formation is a reasonable goal for an exploration campaign.

Within the 3D seismic region surveyed there is an absence of any observable faults. From the perspective of drilling design, the absence of faults reduces risks to consider in the design. However, the observation of faults is controlled by the detection limitations of the geophysical surveys, which was reported by IGas to be on the order of 50m. The presence of major strike slip faults with vertical displacements of less than 50m should therefore still be considered in the drilling design and cannot be completed ruled out.

Area A is preferred by IGas over Area B given the increased thickness of the target reservoir within Area A. In the absence of any further conflicting data Arup generally considers the overall strategy for the delineation of the outer boundaries for zones A and B to be logical and reasonable. However, not all of the boundaries can be justified on a geological basis but appear to have been determined on data quality. We also point out that, strictly based on geological conditions, the borehole site within the 'Areas of Search' could be reasonably drilled at any location within Area A or Area B. We further note that there are other reasons (e.g. environmental) reviewed by others for the ultimate selection of the drilling site location referred to within the 'Areas of Search'.

The constraints and justification for the 'Areas of Search' are summarised on Figure 10 and in Table 2.

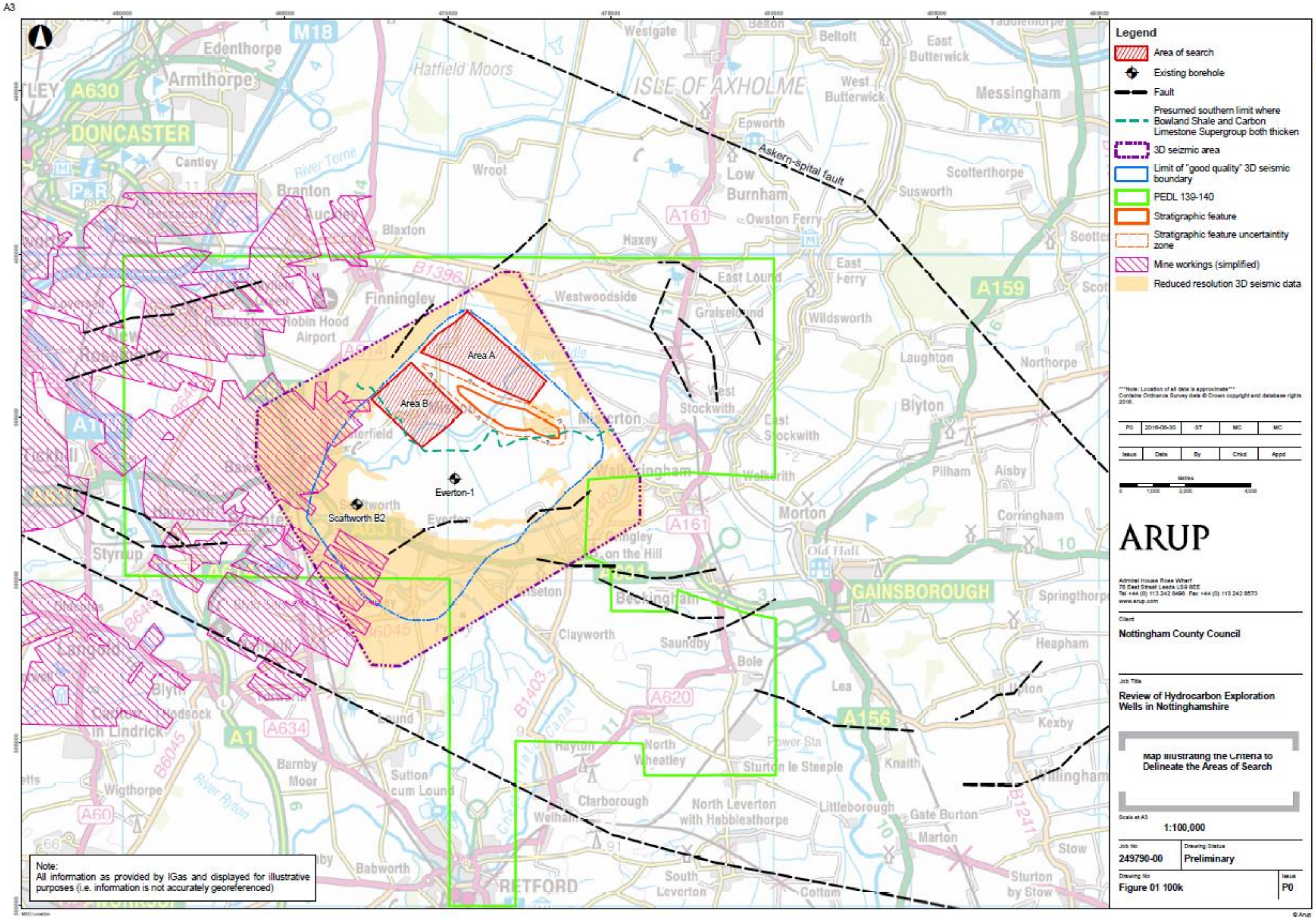

Figure 10. Graphical summary of Areas of Search Constraints (Based on information provided by IGas Energy Plc 2016 [13])

Table 2. Summary of Areas of Search constraints and justification

ID	'Areas of Search' Constraint	IGas Justifications	IGas Justification Basis	Arup Evaluation
1	Within PEDL license	IGas can only work within the PEDL license	Regulatory Constraint	**1**
2	Within the Gainsborough Trough	Potential gas bearing formations will be thickest within the Gainsborough Trough	Geological Consideration	**1**
3	Within 3D seismic area			
3a	NW boundary of 3D seismic area	Constrained by extent of 2D seismic data	Data Verification	**2**
		Constrained by location of deep historical mine workings	Drilling Risk Reduction	**3**
3b	NE boundary of 3D seismic area	Constrained by extent of 2D seismic data	Data Verification	**2**
		Avoidance of Askern-Spittal fault	Geological Consideration	**1**
3c	SW boundary of 3D seismic area	Constrained by extent of 2D seismic data	Data Verification	**2**
		Constrained by PEDL license boundary	Regulatory Constraint	**1**
3d	SE boundary of 3D seismic area	Constrained by extent of 2D seismic data	Data Verification	**2**
		Constrained by PEDL license boundary	Regulatory Constraint	**1**
4	Within Area A or B boundaries			
4a	NW boundary of Area A	Limited by data quality boundary of 3D seismic data	Data Quality	**2**
		Constrained by location of deep historical mine workings	Drilling Risk Reduction	**3**
4b	NE boundary of Area A	Limited by data quality boundary of 3D seismic data	Data Quality	**2**
		Constrained by Askern-Spittal fault	Drilling Risk Reduction	**1**
4c	SW boundary of Area A	Limited by data quality boundary of 3D seismic data	Data Quality	**2**
		Constrained by structural feature, which is unrepresentative of target formation and should thus be avoided as an exploration target (the purpose of the activity)	Geological Consideration	**1**
4d	SE boundary of Area A	Limited by data quality from 3D seismic data	Data Quality	**2**
4e	NW boundary of Area B	Limited by data quality boundary of 3D seismic data	Data Quality	**2**
		Constrained by location of deep historical mine workings	Drilling Risk Reduction	**3**

ID	'Areas of Search' Constraint	IGas Justifications	IGas Justification Basis	Arup Evaluation
4f	NE boundary of Area B	Limited by data quality boundary of 3D seismic data	Data Quality	**2**
		Constrained by structural feature, which is unrepresentative of target formation and should thus be avoided as an exploration target (the purpose of the activity)	Geological Consideration	**1**
4g	SW boundary of Area B	Limited by data quality boundary of 3D seismic data	Data Quality	**2**
		Constrained by change in depth of basin of Gainsborough Trough	Geological Consideration	**1**
4h	SE boundary of Area B	Limited by data quality boundary of 3D seismic data	Data Quality	**2**
5	Initial borehole should be vertical and thus placed within Areas of Search	Deviated boreholes inherently increase drilling risks, particularly in exploration campaigns	Drilling Risk Reduction	**1**
		Vertical boreholes provide highly accurate depth data to improve 3D seismic calibration	Data Verification	**2**
6	Deviated borehole should be initiated from within Areas of Search	Increase in deviation length would increase drilling risks	Drilling Risk Reduction	**1**
		Placing deviated borehole in separate location from vertical borehole increases surface risks	Surface Constraint	**2**

ID	'Areas of Search' Constraint	IGas Justifications	IGas Justification Basis	Arup Evaluation

Notes:

1. Refer to Figure 10 for graphical summary of constraints.
2. Refer to Figure 10 for 'Area of Search' boundaries.
3. Regulatory Constraint indicates that justification provided is based on regulatory requirements.
4. Geological Consideration indicates justification provided is based on site specific geology.
5. Data Verification indicates that justification provided is based on limitations of existing data which constrains the development of a larger 3D seismic area.
6. Data Quality indicates that justification provided is based on constraint which is due to uncertainty in data obtained from the 3D seismic survey.
7. Drilling Risk Reduction is a specific geologic consideration which indicates constraint reduces overall risk of exploratory drilling.
8. Surface Constraint indicates justification is related to surface issues and not geologic or other geologic-related considerations.
9. Arup assessment of the appropriateness of IGas justifications is based on the following criteria:
   - **1** Justification is reasonable based on either geological reasons or regulatory constraints;
   - **2** Justification is reasonable, however rationale is based on non-geological issues;
   - **3** Justification provided is reasonable but lacking verifiable data sources;
   - 4 Justification provided is not reasonable; and
   - 5 No justification has been provided.

3 Influence of Drilling Design on Areas of Search

IGas have proposed the drilling of two exploration boreholes, the first being a vertically drilled borehole and the second being deviated. Subject to favourable sub surface results, a second borehole is planned to be drilled immediately in succession and is planned to be a deviated borehole. The shallowest anticipated depth for the Bowland Shale Formation is reported by IGas to be at approximately 1,800mbgl.

Within the planning application, there is no plans to hydraulically fracture or flow test either borehole. A separate planning application will need to be submitted should IGas wish to hydraulically fracture or flow test either borehole. Similarly, a separate application would be necessary for any commercial production activity.

3.1 Vertical Borehole

IGas propose the first borehole at Springs Road to be vertically drilled. This vertical borehole is to be drilled for geological data collection purposes. We assume this borehole will be suspended after drilling and later possibly used as a monitoring borehole during future exploration and/or production operations on the horizontal borehole subject to separate planning permission being granted.

Downhole geological formation and fluid data is generally collected from boreholes using the following techniques:

- Electric logging tools (also known as wireline logs, or downhole geophysics), normally run on an electrically conducting wire line from surface. It is anticipated that up to 8 wire line runs will be required to collect data from the hole section targeting the Bowland Shale Formation; and
- Core recovery, where cylinders of rock approximately 100mm outer diameter, are cut and recovered to surface intact. This is achieved by allowing the cylindrical core to travel into the drill string whilst being cut. The core can then be recovered by taking the drill string back to surface, or running a (non-electrically conducting) wire line down the inside of the drill string to latch and pull the core to surface. It is expected that at least 100m length of core will be cut and recovered.

Downhole data collection is the primary reason for drilling deep boreholes. Interpretation of the data enables;

- The functionality of the borehole to be defined; and
- The basis for planning future boreholes to access the same geological formations.

The core data is particularly important for IGas' exploration aims, particularly since electric logging data is open to interpretation. Physical formation recovery, in the form of cores, allows the electric logging data to be verified and calibrated. Obtaining accurate depth data is important to improve on the depth calibration of seismic surveys.

Of special interest to IGas on this project is information from cores in the Bowland Shale Formation relating to natural fractures, gas desorption (gas delivery) and defining an area of relatively high Total Organic Content (TOC) in which to land the horizontal borehole. To support the exploration goals of the project, the cores will be crucial. In addition, borehole logs from vertical boreholes provide the most accurate data on lithological depths. Obtaining accurate depth data is important to improve on the depth calibration of seismic surveys.

The drilling of a vertical borehole provides the least risk for data collection. In contrast, some of the risks associated with collection of data in deviated boreholes (which are reduced or avoided with vertical boreholes) are as follows:

- Hole instability is more likely to occur in all geological formations due to relative borehole stress orientation;
- Mechanical sticking in build and drop sections due to wearing a groove in the top and bottom of the borehole (referred to in the industry as ‘key seating’);
- Hydraulic differential sticking in permeable formations due to increased wall contact of the drilling assembly lying on the low side of the hole (referred to in the industry as ‘differential sticking’);
- Formation ledges, created at the interfaces between geological formations, which prevent tools from being run in the borehole. Specifically detrimental to down-hole electric logging on wire line;
- Cylinders of cored formation fracture as they travel up inside the drilling string. This causes the core to wedge / jam inside the drill string and the formation is then ground away at the cutting face and not cored. This can lead to loss of valuable core recovery; and
- Drill string instability during rotation for core cutting operations can cause the core to wedge / jam.

Increased risk for data collection for each of the above situations is difficult to quantify but qualitatively any borehole inclination or deviation can, and often does, increase risk substantially. In some instances, planned data collection is forfeited.

Drilling a vertical borehole substantially reduces down-hole risk. It has the added benefit of reducing planned days on site for the drilling rig, and minimises the risk of additional unplanned days on site.

3.2 Deviated Borehole

Following the completion of the initial vertical borehole, a second borehole will be constructed which will be deviated from the vertical to evaluate the lateral variability of the Bowland Shale Formation. The direction of the deviated borehole has been selected by IGas on the basis of the regional tectonic stress regime and the results of borehole break out measurements conducted in the off-set borehole, Everton-1 (see section A5). The deviated borehole will be drilled in the direction of the least principal (i.e. least horizontal) stress. This defines a zone depicting a cone in a general south-west direction (Figure 11). IGas have designed the deviated borehole to be drilled from the same borehole pad as the initial vertical borehole. The target for the deviated section of the borehole is within the thicker portion of the Bowland Shale Formation identified in existing information and verified by the 3D seismic data.

The deviated borehole has to be drilled in the direction of least principal stress to maintain borehole stability. Failure to adopt this principle may render the horizontal section impossible to drill. The deviated section of borehole will be drilled from a specific vertical depth after review of the data collected during drilling of the initial vertical borehole. IGas have planned to drill a deviated section with a length of around 1.5 km through the Bowland Shale Formation. Where drilling at approximately horizontally (the deviated case), the drilling direction has to be maintained, therefore the drilling location at surface can only be moved in an approximate north north-east / south south-west direction from the vertical borehole location.

Figure 11. Position of the proposed deviated borehole (Source: IGas Energy Plc 2016 [13])

3.3 Comments on Placement of the Boreholes

Given the exploratory nature of the drilling, it is considered reasonable to reduce drilling risks associated with the advancement of the first borehole. The results of the drilling of this initial borehole will provide important data for reduction of risks associated with drilling the second, deviated, borehole. In addition, the accuracy of depth data and ability to improve core recovery from a vertical core will aid IGas in its exploration goals.

As part of this review, Arup has assessed the potential limits of how far a deviated borehole could be drilled from the proposed 'Areas of Search' to still reach a similar target at depth. To support this estimate, the following industry best practice was applied.

- Drilling of an 'S' shaped deviated borehole (Figure 12) to maximise vertical coring in the targets;
- Inclination build up and drop off rates of 3º per 30 m of drilling;
- Maximum borehole inclination of 60º to vertical (this is the maximum borehole angle where down hole electric logging on wireline is feasible in an open hole); and
- Start of inclination build after surface loss and permeable zones are isolated behind casing, to minimise water use on the site, and thus reduce road tanker movements.

Based on these assumption an upper estimate of approximately 1.7km would be the maximum displacement requirement to reach the target for an S-shaped deviated borehole. Using the same assumptions, the maximum lateral displacement for a laterally deviated borehole (also referred to as a horizontal) borehole would be around 2.1km. Where the drilling deviates from vertical (i.e. lateral drilling), the drilling direction has to be maintained, thus the borehole pad location at surface can only be moved in an approximate north northeast / south southwest direction from the vertical borehole location.

Drilling the deviated borehole from the proposed site (i.e. the proposed site at Springs Road) allows the horizontal section to be achieved in the chosen direction and in the thickest sequence of shale (as inferred from the seismic interpretation). Should the deviated borehole location be separated from the vertical borehole site and moved to the north northeast of Area A, a portion of the deviated borehole would likely protrude into the Asken-Spittal fault zone. This would greatly increase drilling risks and should reasonably be avoided. Should the borehole pad be moved to the south southwest portion of Area A, drilling risks associated with the associated deviated boreholes would increase significantly to reach the preferred exploration target.

Based on the information provided and the high-level assessment performed, from a drilling perspective, the sub surface location and direction of the deviated borehole does not allow the proposed borehole pad location to be moved significantly. Therefore, the proposed Springs Road site is an optimal location to access the targeted location for the deviated borehole section.

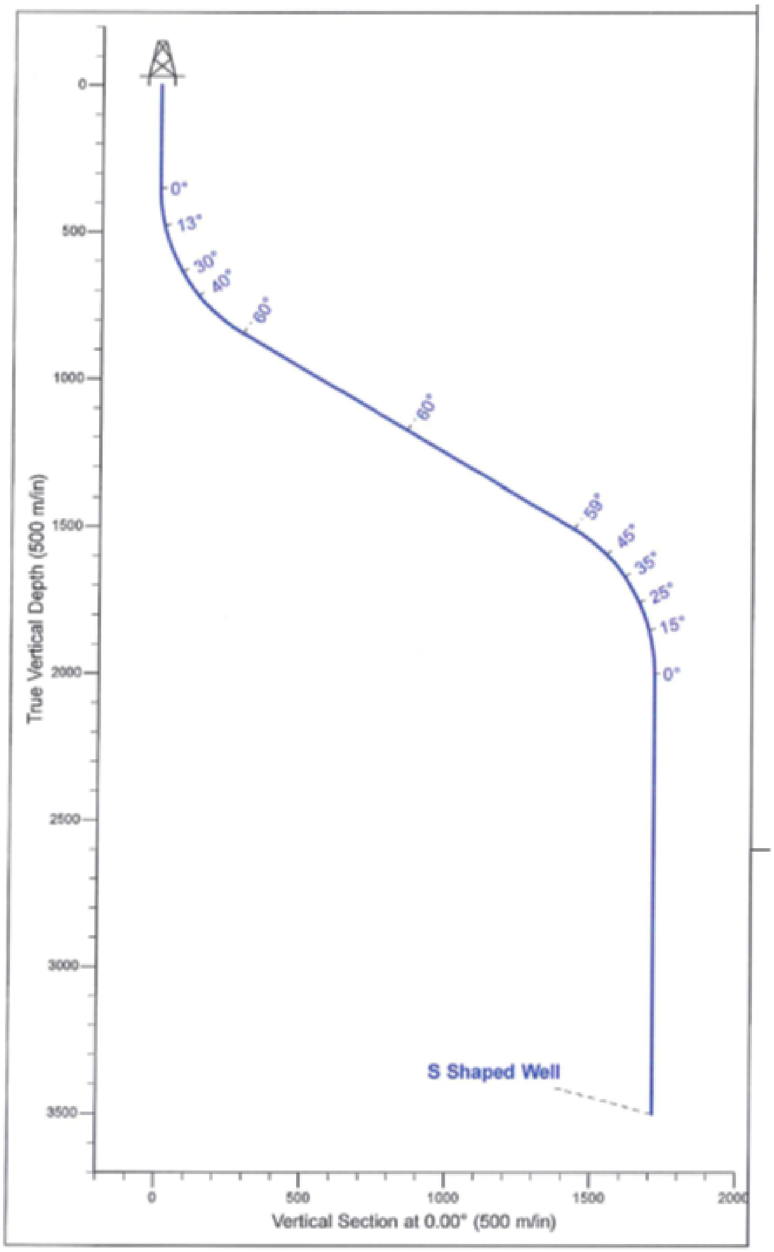

Figure 12. Hypothetical borehole trajectory as an 'S' shaped borehole which could potentially be used to reach the target reservoir from outside the 'Areas of Search' (Source: Courtesy of Target Well Control)

4 Conclusions

In October 2015 IGas Energy (Plc) (IGas) submitted a planning application to Nottingham County Council (NCC) to drill a vertical and deviated borehole from the same location at Springs Road in Nottinghamshire, within PEDL 139 and 140. NCC formally requested from IGas additional data and information under the Environmental Impact Assessment Regulations 2011 (a Regulation 22 request).

In May 2016 NCC appointed Arup to undertake an independent review and evaluate the geological information submitted by IGas as part of their planning application. NCC commissioned Arup to analyse and interpret the following information held by IGas:

- Geological review and analysis of past data, including published geological data and information, past boreholes (e.g. any offset wells) and 2D seismic data;
- The basis for the location and extent of the 3D seismic survey;
- A review and analysis of the 3D seismic survey results with an explanation for setting the boundaries of the areas of search; and
- A reasoned justification as to why drilling outside the areas of search using directional drilling techniques would not achieve the objectives of the exploration programme.

It should be noted that Arup has not checked or audited the technical data and information supplied by IGas and NCC to verify its accuracy, precision and validity, as this extends beyond this project's scope and objective. In addition, environmental and other surface related constraints such as flood risk have not been reviewed by Arup as these also extended beyond the scope requested by NCC.

Desk study

The results of a geological desk study was presented by IGas to Arup and NCC on 7th June 2016 from which a reasonable conceptual geological model has been developed by IGas. Information was subsequently provided to Arup in the form of summary documents, which included: reference to past borehole logs from drilling for coal; coal bed methane and petroleum exploration; cross section examples 2D seismic sections; and limited information on areas where coal mining had taken place. Detailed data such as a formal desk study report, borehole logs, geophysical interpretative reports and details of past mine abandonment evaluations were not provided.

3D seismic survey and 'Areas of Search'

An 'Area of Search' has been delineated by IGas based on: the boundaries of PEDL 139 and 140; the location of the Gainsborough Trough (a deep geological basin in the East Midlands which contains the Bowland Shale Formation); the location of past boreholes, past 2D seismic reflection data, the analysis of 3D seismic reflection data that was acquired by IGas in 2014; the thickest sequence of Bowland Shale Formation; the avoidance of areas where geophysical data was poor, the avoidance of geological structural features (such as faults) and the prevailing north-west to south-east direction of maximum principal stress.

The strategy adopted by IGas to identify the 'Areas of Search' is reasonable from a geological perspective and on the basis of the desk study data and information that we have reviewed. The geological justification for many of the 'Search Area' boundaries is also considered reasonable, however, some boundaries have been defined on data quality and not an identifiable specific geological constraint. It should be noted that there will be geological areas which do not allow for clear seismic interpretations.

Clarification as to whether directional drilling to the identified targets from areas of lower flood risk would be possible

As noted above, the strategy adopted by IGas to locate the 'Areas of Search' in PEDL 139 and 140 appears to be logical and reasonable. In general, this phased approach is consistent with reconnaissance geological exploration for the siting of an initial borehole, for the purposes of investigating the geology and the gas and hydrocarbons in the Bowland Shale Formation, and in the underlying and overlying Carboniferous strata. The detailed drilling designs should be later reviewed to confirm their consistency with the goals of the drilling programme outline in the planning application and supporting documents.

From a geomechanical and geological perspective, and in the absence of any further data and information, the location of the 'Areas of Search' selected by IGas and the drilling of a second horizontal borehole in a south-westerly direction seem to be justified in the prevailing stress fields.

The drilling of a vertical and deviated borehole outside the 'Areas of Search' and beyond the flood risk zones has been evaluated at a high-level. Based on our evaluation, there is no suitable location outside the 'Areas of Search' which either would not encounter a known sub-surface fault, or have suitable geophysical data to support an exploration drilling campaign.

5 References

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World Stress Map: http://dc-app3-14.gfz-potsdam.de/index.html

Appendix A

Geological Overview

A1 Geographical Location

The proposed IGas borehole is located on agricultural land off Springs Road, approximately 2-3km northwest north from Misson and about 4-5km east from Robin Hood airport, in Nottinghamshire (Figure A1).

Figure A1. General location of proposed IGas Energy Plc borehole in Nottinghamshire (Source: Google Maps)

A2 Tectonic Setting and the Gainsborough Trough

The Gainsborough Trough is a north-west to south-east trending sub-Pennine foreland basin located in the East Midlands and extending into Nottinghamshire, Lincolnshire and the West Riding or Yorkshire. This was generated during the Carboniferous era in an extensional phase associated with subduction and the Hercynian (Variscan) orogeny (A2).

During the Brigantian stage (c325Ma) gas bearing shales were deposited in the UK on a passive margin of the Laurasian plate. Subsequently, during the Namurian (c326-313Ma) and Westphalian (c313-304Ma) stages subsidence and sedimentary infilling of the Gainsborough Trough took place within a single and extensive Pennine Basin (Blakey 2011) (Figure A3).

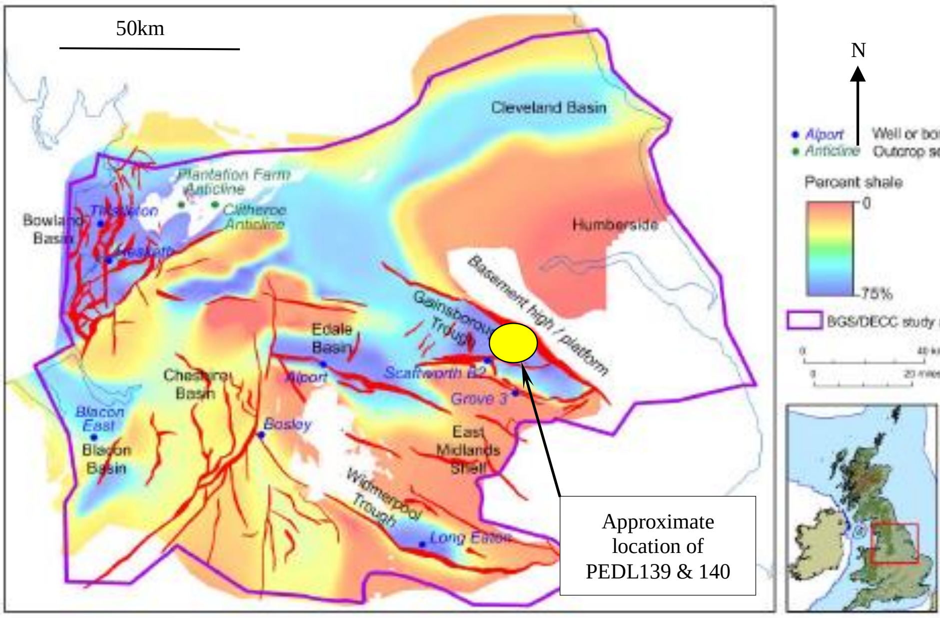

Figure A2. Location of the Gainsborough Trough (Source: BGS & DECC 2013)

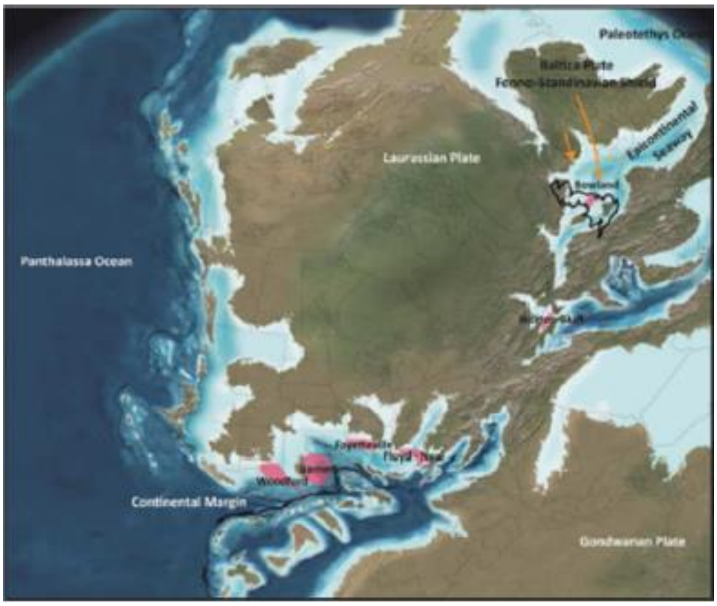

Figure A3. Palaeogeographical setting in the Brigantian (c325Ma) and deposition of the Bowland Shale formation in the Gainsborough Trough (Source: Blakey 2014 modified by IGas Energy Plc 2016 [13])

The evolution and geomechanical development of the Gainsborough Trough has been subjected to several phase of rifting, burial, sedimentation and uplift leading to the possible generation of gas and associated hydrocarbons.

Rifting was initiated in the Midlands during the Late Devonian (c380Ma), which developed a series of half-grabens including the Gainsborough Trough and Widmerpool Gulf (located to the south of the 'Areas of Search'). During the Visean and early Namurian (c350-320Ma) the Carboniferous Limestone Supergroup (CLS) and the Bowland Shale Formation were deposited. In the late Namurian and Westphalian stages (c320-300Ma) regional subsidence led to the deposition of the Millstone Grit and Coal Measures. Subsequently, in the late

Carboniferous the inversion (uplift) of the Gainsborough Trough, as associated with the Hercynian (Variscan) orogeny (c300Ma), parts of the Coal Measures were eroded, which is marked by a distinct unconformity. Rifting, sedimentation and approximately 1km of burial took place during the Permian, Mesozoic and Tertiary (c275-65Ma). During the Alpine Orogeny (c65Ma to present) the Gainsborough Trough became uplifted (Andrews 2014, Fraser and Gawthorpe 1990) (Figure A4).

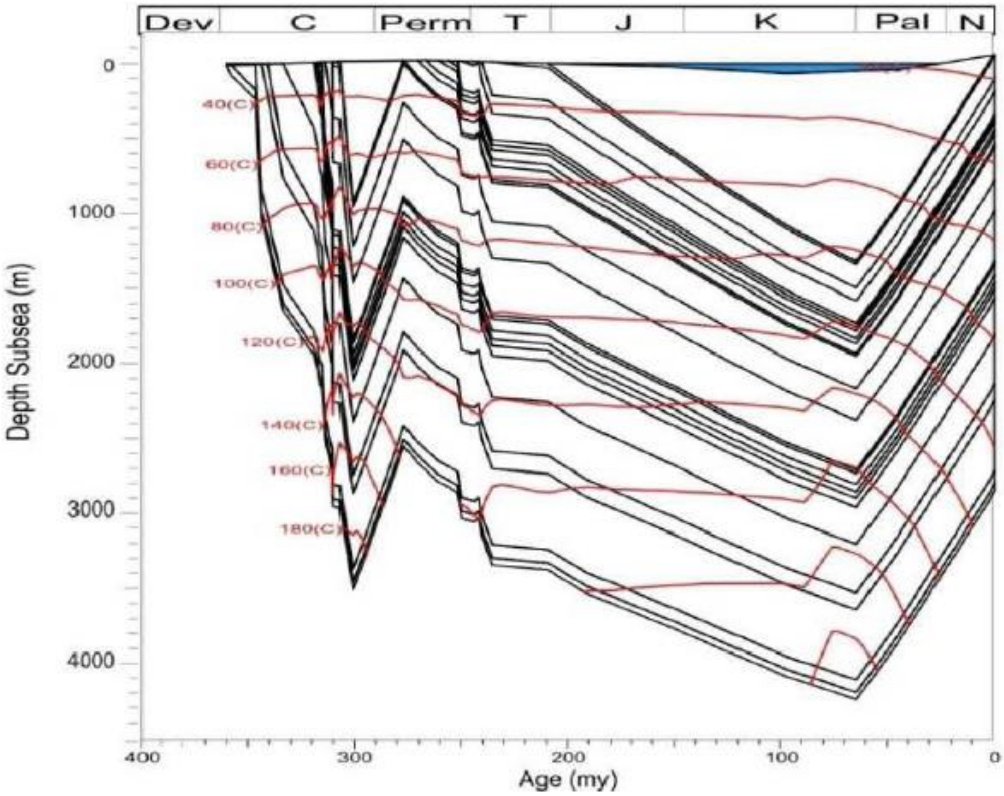

Figure A4. Evolution of the Gainsborough Trough (Source: Andrews 2014)

A3 Stratigraphy

The chronostratigraphic division of the Gainsborough Trough comprises strata of Namurian, Westphalian and Stephanian stages of the Carboniferous period (Doornenbal and Stevenson 2010) (Figure A5).

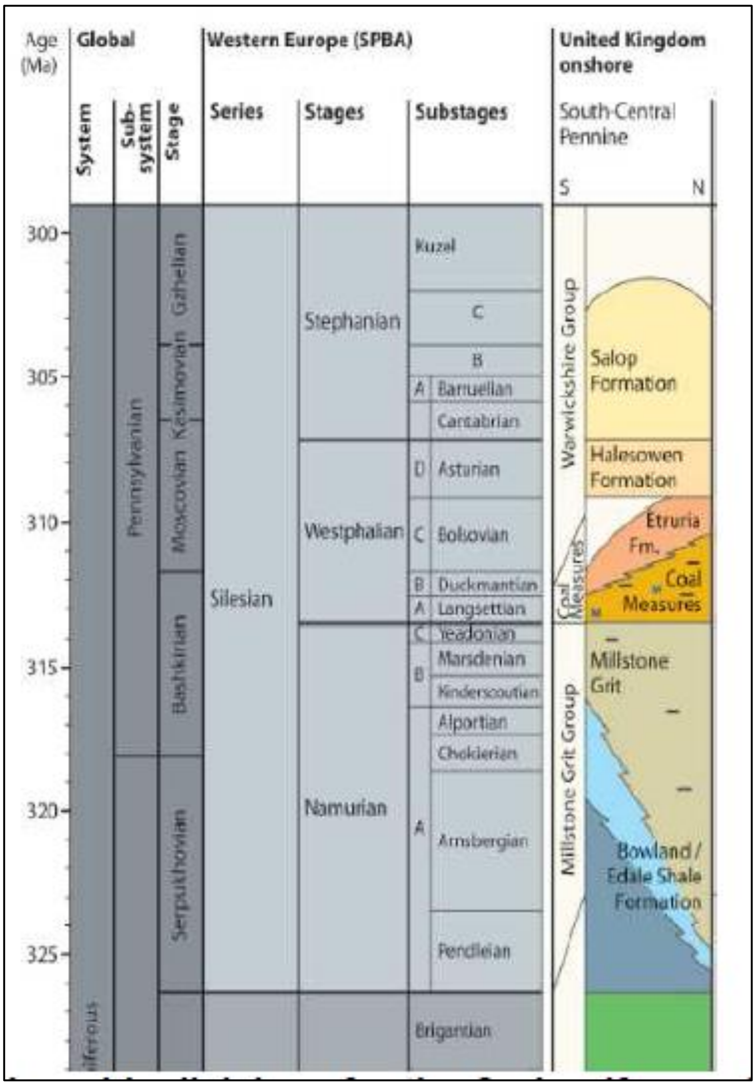

Figure A5. Idealised chronostratigraphical division for the Carboniferous (Source: Doornenbal and Stevenson, 2010)

A4 Structure

Pre-existing Caledonian thrusts in the deeper geological basement possibly underwent normal fault reactivation, which subsequently influenced the structural evolution of the Gainsborough Trough. This led to the development of north-west to south-east structures in the East Midlands. Sedimentation, subsidence, uplift and partial basin inversion that took place in the Namurian and Westphalian stages was likely to have been controlled by these north-west to south-east faults and localised reverse faults (Figure A6). The Gainsborough Trough is a wedged shaped basin that opens to the north-west. The Askern-Spittal fault defines the north-eastern extent of the Gainsborough Trough (Figures A7 and A9). This represents a fault zone approximately 80km long with associated en-echelon fault arrays and possible splays and runners that reach up to 10km long. The Leverton-Torksey fault defines the southernmost extent of the Gainsborough trough. This comprises three fault segments, with one striking approximately 135° and the other two striking approximately 90° (IGas Energy Plc 2016 [13]).

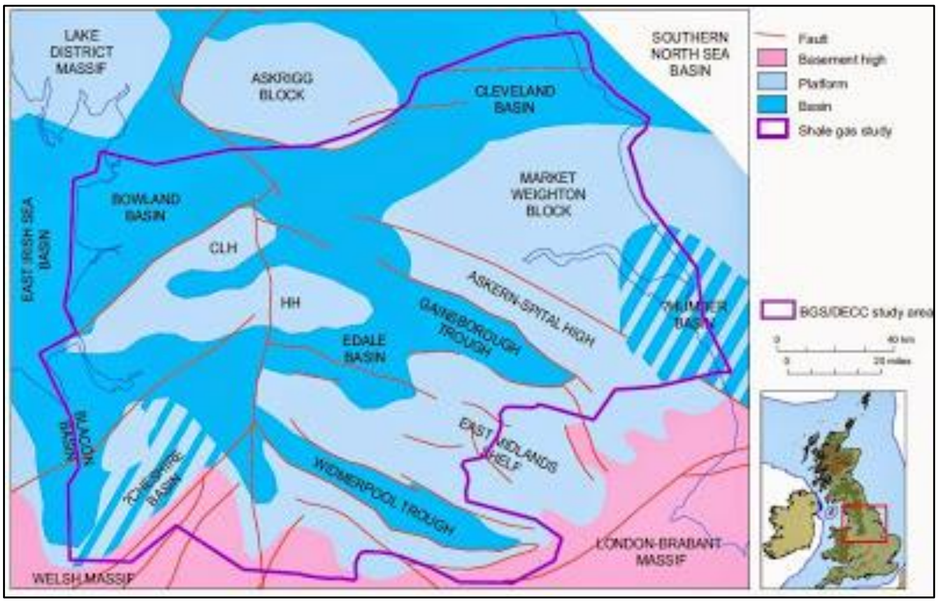

Figure A6. Generalised geological structural setting of the Gainsborough Trough (Source: Andrews 2013)

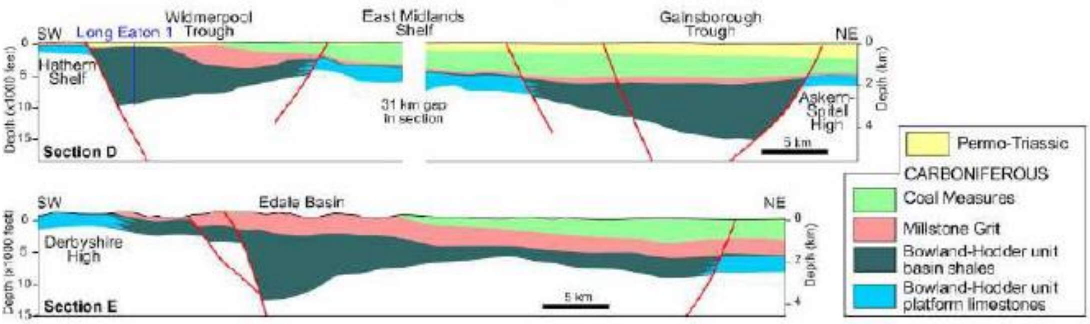

Figure A7. Cross section through the Gainsborough Trough and surrounding region (Source: Andrews 2013)

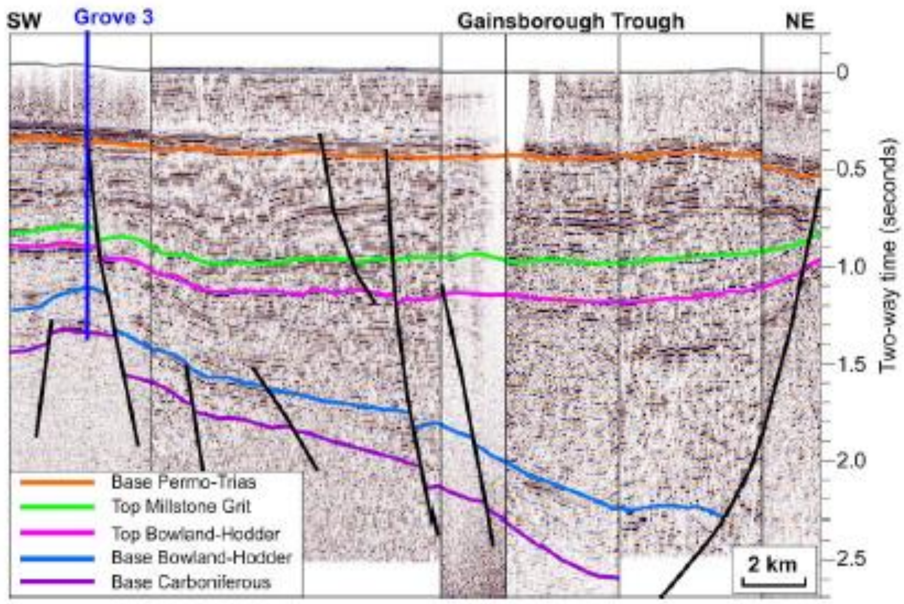

Figure A8. Geophysical cross section across the Gainsborough Trough showing the location of the Bowland Shale formation, the general thickening of the basin to the north and the main faults (Source: BGS & DECC 2013)

A5 Stress Model

IGas reported that at the Everton-1 off-set borehole a four arm calliper log was undertaken to evaluate borehole breakout. The orientation of the breakouts suggest a maximum horizontal stress direction of approximately 120°. The minimum horizontal stress (Sh) gradient is 17 MPa/km and the maximum horizontal stress (SH) gradient is 27 MPa/km (10).

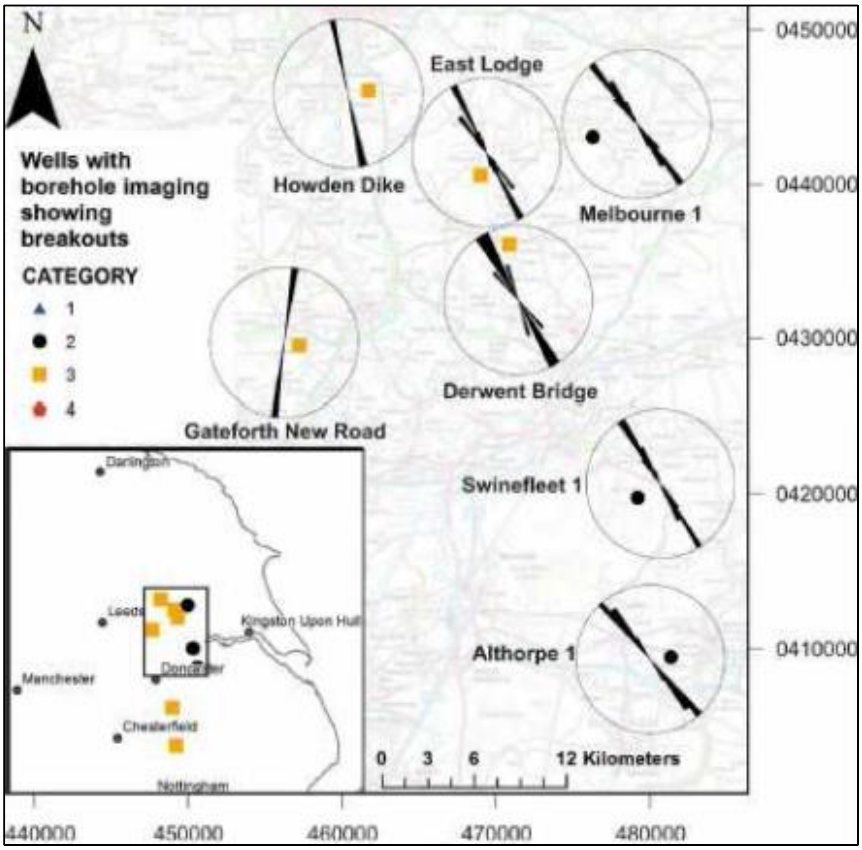

Figure A9. Regional stress orientations of SHMax derived from breakouts observed on borehole for Yorkshire showing a mean SHmax orientation of 147.5o and a circular standard deviation of 7.4º (Source: Kingdom 2016).

Arup Comments on Stress Regime

The world stress map provides crustal stress data from various sources. In addition, published available stress data for Great Britain is presented in Figure A10. Within the Nottinghamshire area there are several data points reported that show an orientation supporting the 120° analysis by IGas. For most of these available data points, the stress regime was not resolved (i.e. verified from breakout measurements), however, one data point indicates strike slip conditions from hydraulic testing. Baptie (2010) reported strike-slip conditions for England and Wales (Figure A11) and the Market Rasen earthquake event gave an indication of thrust to strike slip movement (Figure A12).

A four arm calliper can be assumed to be accurate for the determination of breakout orientation. The arms will align with the oval axis of the borehole walls and if the readings are first order symmetric, they can be assumed to be indicative of breakouts in homogenous or sparsely fractured rock mass. If that is the case, the maximum horizontal stress direction will be 90° to the orientation of the breakouts. However, depending on the fracture density and orientation, the breakout orientation may not be indicative of the stress direction, as the distinct fracture network may lead to breakouts that are oblique to the local stress state. If the breakouts were analysed in combination with formation microimaging (FMI) logs, they may be accurate for determination of the stress direction also. If no FMI or similar data was used, the stress orientation may be uncertain.

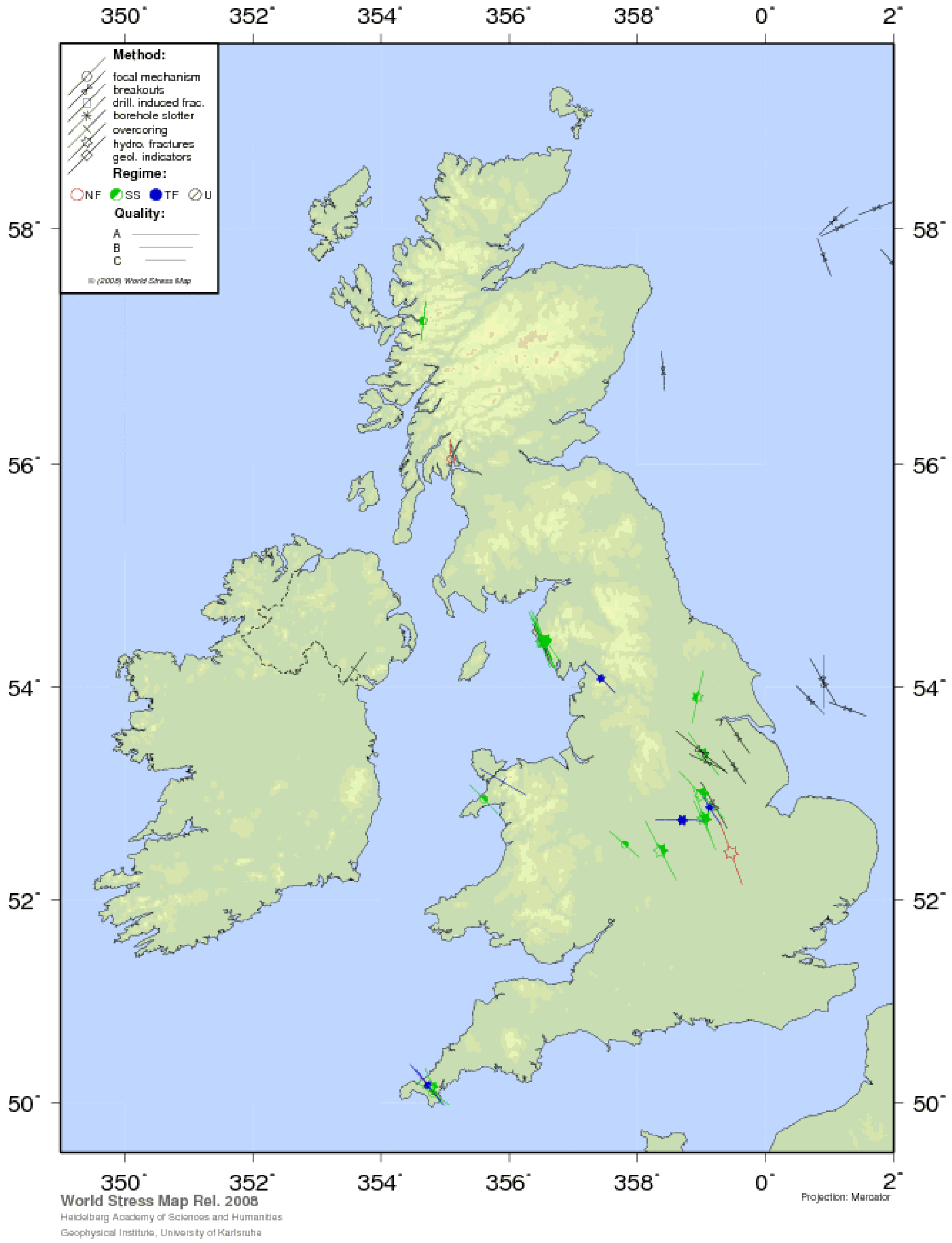

Figure A10. Stress data in the UK (Source: World Stress Map, 2008)

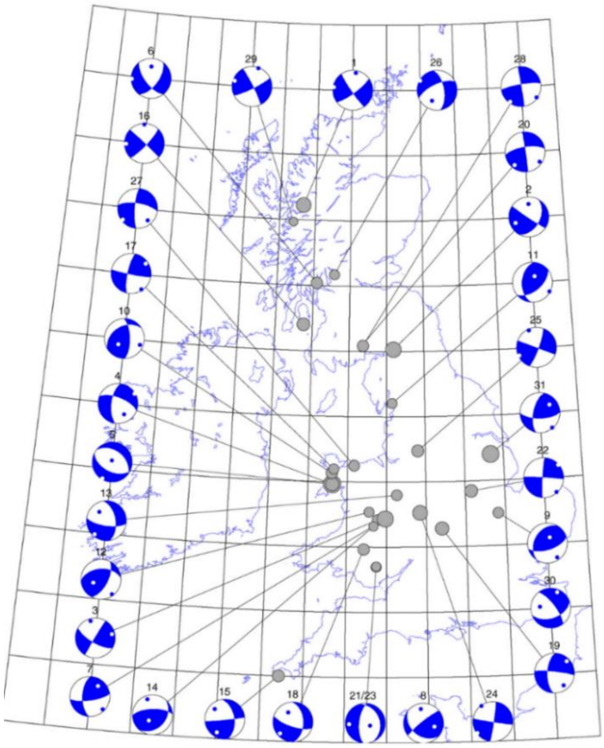

Figure A11. Focal mechanisms for selected earthquakes in the UK. For England a general trend indicates strike slip fault movements. (Source: Babtie 2010)

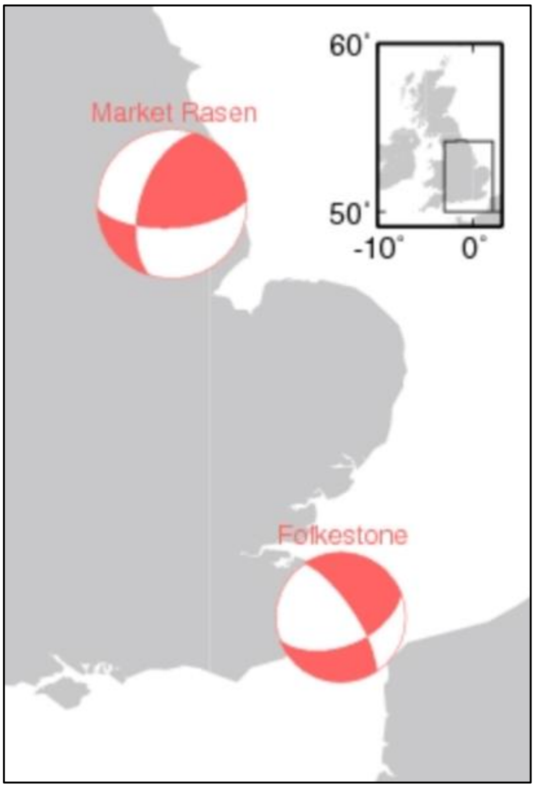

Figure A12. Focal mechanism for the Market Rasen and Folkestone earthquakes (Source: British Geological Survey)

Given the localised tectonic setting and basinal structures the stress regime would be expected to be extensional with normal faulting, although with possible strike-slip faulting (as noted above). Therefore, a preferred drilling direction from borehole stability considerations is north-east to south-west, which coincides with IGas' design for their deviated borehole.

A6 Exploration Target Horizons

The horizons being targeted by IGas in chronological sequence are: the Millstone Grit Group, Bowland Shale Formation and Carboniferous Limestone Supergroup (CLS):

- **Bowland Shale Formation**: This is the primary target and it is envisaged by IGas to be the principal hydrocarbon source rock for the East Midlands. During the drilling of Scaftworth-B2 borehole the thickness was approximately 160m. The shales are considered by IGas to be late oil to gas mature, with high Total Organic Carbon (TOC) of 2.6% towards the base of the formation (IGas Energy Plc 2016 [13]).
- **Millstone Grit Group**: This is a secondary target and overlies the Bowland Shale Formation. It comprises interbedded sequences of shales and sandstones that were deposited in a deltaic environment. According to the results of past boreholes analysed by IGas, the sandstones could contain tight gas (IGas Energy Plc 2016 [13]).
- **Carboniferous Limestone Supergroup**: This is a secondary target horizon, which underlies the Bowland Shale Formation. It was penetrated by c70m by the Scaftworth-B2 borehole and comprises shale, fine sandstones and siltstones, with small amounts of gas (IGas Energy Plc 2016 [13]).

Boreholes drilled into the Widmerpool Gulf, located to the south of the Gainsborough Trough also encountered TOCs. The presence of TOCs are considered by IGas to represent the possibility for the presence of gas (IGas Energy Plc 2016 [12]).

A7 Conceptual Geological Model

IGas has developed an appropriate Conceptual Geological Model, which is based on the geological development and evolution of the Gainsborough Trough. This considers the trough to have been subjected to multiple phases of rifting burial, uplift and partial inversion. The Gainsborough Trough developed during the Carboniferous and trends north-west to south-east beneath PEDL 139 and 140 in Nottinghamshire. Structurally, the Gainsborough Trough was possibly influenced by deeper and older Caledonian thrust faults, which underwent normal reactivation. The trough is defined by the Askern-Spittal and Leverton-Torksey faults to the north-east and south-west, respectively. Past boreholes drilled for oil exploration, coal exploration and coal bed methane provide the basis for the stratigraphic and lithological control of 2D and 3D seismic data (in other words, these boreholes are used to calibrate the data from seismic surveys). Past testwork on some of these deep boreholes have indicated the possibility of the presence of gas and Total Organic Carbon [TOC] in the Bowland Shale Formation, which has been identified by IGas as a primary target horizon (IGas Energy Plc 2016 [13]). An organic shale must contain organic carbon. The TOC value (in %) determines the resource potential of a shale. Shales (and other rocks) that have a greater TOC value are organically richer but may not yield methane gas. Generally, exploration targets have TOCs in the range 2 to 10%. Rocks that have TOCs above 10% are too immature for development (Table A1) (Alexander et al. 2011).

Table A1. Relationship between total organic Carbon (TOC) and resource potential (Source: Alexander et al. 2011)

Total Organic Carbon TOC) (weight %)	**Resource Potential**
<0.5	Very poor
0.5 – 1.0	Poor
1.0 – 2.0	Fair
2.0 – 4.0	Good
4.0 – 10.0	Very good
>10.0	Unknown