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Summary of potential oil and gas formations in England for use in groundwater vulnerability assessments

Groundwater Programme

Open Report OR/16/020

BRITISH GEOLOGICAL SURVEY

GROUNDWATER PROGRAMME

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Summary of potential oil and gas formations in England for use in groundwater vulnerability assessments

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Foreword

This report is a short summary of onshore hydrocarbon formations identified by the British Geological Survey (BGS) in the context of the sub-surface assessment of 3D groundwater vulnerability. it has been produced as part of a joint BGS – Environment Agency (EA) project entitled “3D Groundwater Vulnerability”.

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The 3DGW Vulnerability project is a co-funded project between the British Geological Survey and the Environment Agency. The authors would like to thank the Environment Agency for their financial support for the project as well as contributing to the project vision. In particular, they would like to acknowledge the role of Ian Davey and Alwyn Hart, in proposing and supporting the joint initiative.

This work has benefitted significantly from the contribution and involvement of the project Steering Group: Lynn Foord, Jan Hookey, Rudi Lui, Sara Mathews and Paul Doherty.

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Summary

The joint Environment Agency (EA) and BGS project "3D Groundwater Vulnerability" (3D GWV) will develop a methodology for attributing vulnerability of groundwater to pollution from sub-surface oil and gas exploration and production activities, including unconventional, conventional and hybrid plays. It will also take account of Coal Bed Methane (CBM) and Underground Coal Gasification (UCG) exploration, in addition to both near surface and deeper aquifers and groundwater. Outputs will include descriptions and visual representations of potential sources of sub-surface contamination of groundwater from different sources of hydrocarbons. These outputs are designed for use by the EA, Defra, other government departments, local planning authorities, environmental consultants and the public. The project will involve creating an attributed version of UK3D for England with source rock formations and aquifers identified.

This report describes the hydrocarbon bearing units in England. The units have been identified primarily from three BGS reports commissioned by DECC (the Department for Energy and Climate Change) in 2013 (DECC, 2013a; 2013b; 2013c) and three additional area-specific reports on shale gas prospectivity in the Bowland Shale (Andrews, 2013), the Weald (Andrews, 2014) and the Wessex area (Greenhalgh, 2016). Note that this report is not intended to be an exhaustive summary of the occurrence of hydrocarbon units in England, rather a high-level overview for hydrogeologists interested in the potential for groundwater contamination. If further detailed information is required about the hydrocarbon characteristics of the units the reader should refer to the source documents (and references therein). The source documents identify units that have potential as conventional oil and gas reservoirs and source rocks (DECC, 2013a), for Coal Bed Methane (CBM) (DECC, 2013b) and shale gas (DECC, 2013c). There is no similar report for Underground Coal Gasification (UCG) and therefore coal units have been identified from (DECC, 2013b).

This report gives a summary of the potential hydrocarbon resource types; identifies or attributes specific hydrocarbon source rocks on the Generalised Vertical Section (GVS), which identifies the main geologic units for England from BGS' National Geological Model (NGM) (UK3D v2015 and Waters et al., 2016); and, summarises features of each of the units in the context of the 3D GWV project.

1 Introduction

The joint Environment Agency (EA) and BGS project "3D Groundwater Vulnerability" (3D GWV) will develop a methodology for attributing vulnerability of groundwater to pollution from sub-surface oil and gas exploration and production activities, including unconventional, conventional and hybrid plays. It will also take account of Coal Bed Methane (CBM) and Underground Coal Gasification (UCG) exploration, in addition to both near surface and deeper aquifers and groundwater. Outputs will include descriptions and visual representations of potential sources of sub-surface contamination of groundwater from different sources of hydrocarbons. These outputs are designed for use by the EA, Defra, other government departments, local planning authorities, environmental consultants and the public. The project will involve creating an attributed version of UK3D for England with source rock formations and aquifers identified.

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This report gives a summary of the potential hydrocarbon resource types; identifies or attributes specific hydrocarbon source rocks on the Generalised Vertical Section (GVS), which identifies the main geologic units for England from BGS' National Geological Model (NGM) (UK3D v2015 and Waters et al., 2016); and, summarises features of each of the units in the context of the £D GWV project.

1.1 POTENTIAL HYDROCARBON RESOURCE TYPES

Conventional hydrocarbons – Conventional hydrocarbons include known petroleum systems for both oil and gas. Source rocks are rocks that have a high proportion of organic material and have been buried deep enough to reach sufficient temperatures to form hydrocarbons, this is higher for gas than for oil. Reservoirs are rocks that oil or gas has migrated into and generally have high porosity and permeability. Reservoirs have relatively impermeable cap rocks and or faults that bound their upper surfaces preventing the upward migration of the free phase oil and gas. Stimulation of the rocks is generally not needed in order to extract the oil or gas.

Coal Bed Methane (CBM) – Gas can be bound within coal by adsorption – in which gas molecules adhere to the surfaces within the coal. In CBM a well is drilled into the coal seam and water is pumped out to lower the pressure in the seam. This allows methane to desorb from the internal surfaces of the coal and diffuse into the cleat where it is able to flow, either as free gas or dissolved in water, towards the production well. (DECC, 2013b). CBM production can be subdivided into three categories: Coal Mine Methane, CMM (from new or operational mines), Abandoned Mine Methane, AMM (from abandoned mines) and (virgin seam) Coal Bed Methane, (V)CBM (produced via boreholes from virgin coal seams). Permeability (imparted mainly by the cleat) is necessary to achieve CBM production. The natural permeability of coal

seams can be low, so some CBM wells are stimulated (hydrofractured) to improve connectivity between the borehole and the cleat system. Wells may have many subsurface horizontal or multilateral side tracks drilled from one surface location to penetrate more coal (DECC 2013b).

Shale gas and oil – Gas can be found in the pores and fractures of shales and also bound to the matrix, also by adsorption. During enhanced fracture stimulation drilling technology, fluid is pumped into the ground to make the reservoir more permeable, then the fractures are propped open by small particles, and can enable the released gas to flow at commercial rates. By drilling multilateral horizontal wells, a greater rock volume can be accessed (DECC, 2013c).

Underground Coal Gasification – Underground coal gasification (UCG) is the process whereby the injection of oxygen and steam/water via a borehole results in the partial *in-situ* combustion of coal to produce a combustible gas mixture consisting of CO_2, CH_4, H_2 and CO, the proportions depending on temperature, pressure conditions and the reactant gases injected. This product gas is then extracted via a producing well (Jones, et al., 1999).

An up to date guide to the geologic units and areas that are currently licensed or under consideration for hydrocarbon exploration and production can be found on the UK Government's website https://www.ogauthority.co.uk/data-centre/data-downloads-and-publications/licence-data/.

2 Methodology

The names of prospective hydrocarbon rock formations, members or groups were identified from the three DECC (2013) reports (DECC, 2013a; 2013b, 2013c) and from Andrews (2013; 2014) and Greenhalgh (2016). Where the potential hydrocarbon unit cited was not indicated on the GVS it was mapped back to a parent unit (usually group or age-group and lithology), on the GVS, using the BGS Lexicon (http://www.bgs.ac.uk/lexicon/). Each rock unit identified on the GVS is also summarised in the table below. A description of the hydrocarbon potential of each identified rock unit is included in this report.

These rock units will also be identified on the National Geological Model (NGM) (UK3D 2015) sections and will guide the user in identification of the possible hydrocarbon potential of rock units in the area of interest and allow comparison with groundwater-bearing formations. It should be noted that often potential reservoir units are also groundwater-bearing units and vice-versa; this report does not specify possible oil/gas-water contacts within the units.

The method for identifying the rock types with hydrocarbon potential differs slightly for each exploration method and is indicated in each subsection.

3 Potential hydrocarbon groups

Potential oil and gas units in England are identified on the accompanying GVS and described in this report. Units are presented in the Table 1 from the youngest to oldest in age. Note that the groups identified in Table 1 might not be prospective in all areas. The distribution of the prospective rock units are described in section 3.1 on a Group or Formation basis.

Table 1 Groups identified as prospective for conventional oil and gas, CBM, shale oil and gas and UCG. Groups might not be prospective in all areas; the location of prospective rock units and sources of the attribution are included in section 3.1. Note the Quaternary is not identified in this version of UK3D and hence not in the GVS (seen here in grey). See Appendix 1 for lithological description of GVS codes.

Period	GVS	GVS Unit	Unit with hydrocarbon potential	Conventional oil and gas	CBM	Shale gas and shale oil	UCG
Quaternary	Not identified	Not identified	Shirdley Hill Sand Formation	Reservoir			
Cretaceous	W-SDSL	Wealden Group	Wealden Beds, Tunbridge Wells Sand Formation	Reservoir			
	W-MDSS	Wealden Group		Reservoir			
Jurassic-Cretaceous	PB-LSMD	Purbeck Group	Purbeck Group	Reservoir			
Jurassic	PL-LMCS	Portland Group	Portland Sand Formation, Portland Group, Portland Stone Formation	Reservoir			
	KC-MDST	Kimmeridge Clay Formation	Kimmeridge Clay Formation	Source/ Reservoir			
	AMKC-MDST	Ampthill Clay Formation and Kimmeridge Clay Formation		Source/ Reservoir			
	CR	Corallian Group	Corallian Group	Source/ Reservoir			
	KLOX-MDSS	Kellaways and Oxford Clay Formation (undifferentiated)	Oxford Clay Formation	Source			
	GOG-MDST	Great Oolite Group - mudstone	Fuller's Earth Formation, Frome Clay limestone, Forest Marble, Cornbrash Formation	Source/ Reservoir			

Period	GVS	GVS Unit	Unit with hydrocarbon potential	Conventional oil and gas	CBM	Shale gas and shale oil	UCG
	GOG-SLAR	Great Oolite Group - sandstone, limestone and argillaceous rock		Source/ Reservoir			
	INO-SDLI	Inferior Oolite Group - sandstone, limestone and argillaceous rocks	Inferior Oolite Group	Source/ Reservoir			
	INO-LSSM	Inferior Oolite Group - limestone, sandstone, siltstone and mudstone	Inferior Oolite Group	Source/ Reservoir			
	IOGO-SLAR	Inferior Oolite Group and Great Oolite Group (undifferentiated)	Inferior Oolite Group and Great Oolite Group, Fuller's Earth Formation	Source/ Reservoir			
Triassic-Jurassic	LI-MSLS	Lias Group - Mudstone, siltstone, limestone and sandstone	Bridport Sand Formation, Lias clays, Lower Lias Shales, Blue Lias Formation	Source/ Reservoir			
Triassic	MMG-MDSS	Mercia Mudstone Group - mudstone, siltstone and sandstone	Tarporley Siltstone Formation and Mercia Mudstone Group	Source/ Reservoir			
	OMS-SDST	Ormskirk Sandstone Formation	Ormskirk Sandstone Formation	Reservoir			
	WLSF-SDST	Wilmslow Sandstone Formation	Wilmslow Sandstone Formation	Reservoir			
	SSG-SDSM	Sherwood Sandstone Group - sandstone, siltstone and mudstone	Sherwood Sandstone Group	Reservoir			
	KNSF-SDST	Kinnerton Sandstone Formation	Kinnerton Sandstone Formation	Reservoir			
Permian	ZG-DLDO	Zechstein Group – Dolotimised limestone and dolomite	Roker or Seaham Formations, Kupferscheifer/Marl Slate	Reservoir			
	APY-SCON	Appleby Group - interbedded sandstone and conglomerate	Collyhurst Sandstone Formation	Reservoir			
	Not identified	Not identified	Yellow Sands Formation, Basal Permian Sands Formation	Reservoir			

Period	GVS	GVS Unit	Unit with hydrocarbon potential	Conventional oil and gas	CBM	Shale gas and shale oil	UCG
Carboniferous	WAWK-SISDM	Warwickshire Group - siltstone and sandstone with subordinate mudstone	Halesowen Formation, Upper Coal Measures, Westphalian C-D	Source/ Reservoir			
	WAWK-MSCI	Warwickshire Group - mudstone, siltstone, sandstone, coal, ironstone and ferricrete		Source/ Reservoir			
	WAWK-SISDM2	Warwickshire Group - siltstone and sandstone with subordinate mudstone		Source/ Reservoir			
	PUCM-MSCI	Pennine Upper Coal Measures Formation	Pennine Coal Measures Group, Westphalian A-B	Source/ Reservoir			
	PSMCM-MSCI	Pennine Middle Coal Measures Formation and South Wales Middle Coal Measures Formation (undifferentiated)		Source/ Reservoir			
	PSLCM-MSCI	Pennine Lower Coal Measures Formation and South Wales Lower Coal Measures Formation (undifferentiated) - mudstone, siltstone, sandstone, coal, ironstone and ferricrete		Source/ Reservoir			
	PCM-MDSS	Pennine Coal Measures Group		Source/ Reservoir			
	MARR-MDSD	Marros Group mudstone and sandstone	Marros Group				
	MG-MDSS	Millstone Grit Group	Silsden Formation, Pendleton Formation, Namurian Shales	Source/ Reservoir			

Period	GVS	GVS Unit	Unit with hydrocarbon potential	Conventional oil and gas	CBM	Shale gas and shale oil	UCG
	AG-LSSA	Alston Formation - Limestone with subordinate sandstone and argillaceous rocks	Asbian and Brigantian substage rocks	Source/ Reservoir			
	CRAV-MDLM	Craven Group	Bowland Shale Formation, Lower Bowland Shales, Widmerpool Formation, Bee Low Limestone, Upper Bowland Shale Formation	Source			
	YORE-LSSA	Yoredale Group- limestone with subordinate sandstone and argillaceous rocks	Yoredale Group shales				
	DINA-LMST	Dinantian rocks	Asbian and Brigantian substage rocks, Woo Dale Limestone	Reservoir			
	CARB-ROCK	Carboniferous rocks undifferentiated	Pennine Coal Measures Group, Namurian Sandstones, Namurian Shales, Asbian and Brigantian substage rocks, Bowland Shale Formation, Lower Bowland Shales, Widmerpool Formation, Bee Low Limestone , Mid-Dinantian shales and Milldale Limestone, Craven Group, Yoredale Group	Source/ Reservoir			
	DINA-LSSA	Dinantian Rocks (Undifferentiated) – limestone with subordinate sandstone and argillaceous rocks	Asbian and Brigantian substage rocks, Bowland Shale Formation, Lower Bowland Shales, Widmerpool Formation, Bee Low Limestone , Mid-Dinantian shales and Milldale Limestone, Craven Group, Yoredale Group	Source/ Reservoir			

Period	GVS	GVS Unit	Unit with hydrocarbon potential	Conventional oil and gas	CBM	Shale gas and shale oil	UCG
	DINA-SLAR	Dinantian Rocks (Undifferentiated) – sandstone, limestone and argillaceous rocks	Asbian and Brigantian substage rocks, Bowland Shale Formation, Lower Bowland Shales, Widmerpool Formation, Bee Low Limestone , Mid-Dinantian shales and Milldale Limestone, Onecote Sandstone, Minera Formation, Craven Group, Yoredale Group	Source/ Reservoir			

3.1 CONVENTIONAL HYDROCARBONS

Information on these units is sourced from DECC 2013a unless otherwise indicated.

There are two main petroleum systems in England:

- Southern England – Early Jurassic shales in southern England have matured to generate oil and some gas in the Wessex and Weald basins. Migration has occurred largely within Jurassic strata to the margins of both basins into carbonate reservoirs. Younger immature shales provide the seals to these reservoirs and very few shows are present above the Cimmerian (early Cretaceous) unconformity. Alpine inversion was more intense in the Wessex Basin, juxtaposing older (early Jurassic and Triassic) clastic reservoirs against the early Jurassic source rocks. The producing fields are located on Jurassic-early Cretaceous palaeo-highs concealed by post-Cimmerian unconformity strata. Some later migration of hydrocarbons into Alpine structures has occurred, but many of the surface anticlines are dry. Surface shows are limited to where erosion has exposed Jurassic-early Cretaceous strata.
- Northern England –The southern part of the Pennine Hills contains the inverted Pennine Basin. In the Pennine Basin, there are oil-prone source rocks in early Namurian shales, and gas-prone source rocks include Westphalian coals. Oil shows are almost wholly restricted to Carboniferous strata in the East Midlands. Farther north oil has migrated into Triassic reservoirs, where shows are present in Mesozoic strata. Gas has probably been generated from source rocks older than Westphalian in the Cleveland and West Lancashire basins. This gas has been mainly trapped in Permian reservoirs.

Conventional hydrocarbons are only expected to be found in five known basins as follows: the Weald, Wessex, East Midlands, West Lancashire and Cleveland basins. A decision was made by the project Steering Group that the UK3D model delivered as part of the 3D Groundwater Vulnerability project will be cut to these basins, using the current licensed areas, such that the groups/formations listed below will not show as prospective outside these areas. These areas will be identified using the DECC 14th Round of licence areas and existing licenses.

There is no limit of exploration applied to conventional oil and gas reservoirs because oil and gas can migrate and accumulate at any depth depending on the rock types and structure in the subsurface. For example, production was obtained at, or above, 50 m depth in the Formby Oilfield (DECC 2013a). Despite the necessity for burial to depths sufficient to achieve the oil or gas window no limit has been applied to source rocks either because of the possibility of widespread basin inversion in the UK onshore basins.

3.1.1 Shirdley Hill Sand Formation

The Late Pleistocene (Quaternary) **Shirdley Hill Sand Formation**, part of the British Coastal Deposits Group, is a shallow reservoir of the Formby Oilfield in the southeastern East Irish Sea Basin. It is also present in the West Lancashire Basin. This unit is not identified on the England-only GVS, which only covers bedrock.

3.1.2 Wealden Group

Sands of the Lower Cretaceous **Wealden Beds** (part of the Wealden Group) of the Weald Basin have numerous shows of oil and gas (Bolney, West Sussex (Andrews 2014)) and are possible reservoirs, although they are secondary, less predictable reservoirs than others in the basin. Enhancement of reservoir characteristics by fractures may provide additional or improved reservoir characteristics. Oil shows are found in exposures in Kent and Sussex in the **Tunbridge Wells Sand Formation,** also part of the Wealden Group. These units are identified at the group level on the GVS, as both W-SDSL and W-MDSS.

3.1.3 Purbeck Group

Sands and limestones in the Upper Jurassic **Purbeck sequence** form a gas reservoir at Albury, on the northern margin of the Weald Basin. **Purbeck Group** inliers of the Weald basin are also reported to have indications of hydrocarbons. The Purbeck Beds produced gas at Heathfield, but quantities were insufficient for further development. This unit is identified at the group level as PB-LSMD (limestone and interbedded mudstone) on the GVS, and predominantly occurs in the Weald Basin.

3.1.4 Portland Group

The **Portland Sand Formation** of the Jurassic Portland Group form a local reservoir in the Wessex Basin. The **Portland Group** is largely represented by limestones in the Wessex-Channel Basin. These beds have minor shows on the Isle of Wight. The **Portland Stone Formation** (previously Portland Limestone Formation) on Portland Island, Dorset also has minor shows. Reservoir facies may be developed as a reservoir in the Weald Basin. Oil is produced at Brockham 1, Surrey, Godley Bridge, Surrey, is productive for gas and gas was discovered at Crowden 2 in Kent, and in Ashdown 1, East Sussex there were gas shows in the Portland Beds (Andrews 2014). This is identified at the group level as PL-LMCS (limestone and calcareous Sandstone) on the GVS, and predominantly occurs in the Weald Basin.

3.1.5 Kimmeridge Clay Formation

The **Kimmeridge Clay Formation**, has source rock potential in the Wessex and Weald Basins, such as at the Wytch Farm Oilfield, in the Wessex Basin. However, the Kimmeridge Clay is thought to be immature regionally across the Wessex Basin (Greenhalgh, 2016). It is most mature along the axes of the sub-basins and just entering the oil window in Arreton 2 well and on the Isle of Wight.

The mid-Kimmeridge Micrites form the main reservoir for two recent hybrid-play oil discoveries in the Weald Basin. These are thickest in the centre of the Weald Basin, but pinch out towards the basin margins and do not extend into the Wessex area (Greenhalgh, 2016). The Kimmeridge Clay Formation is present throughout the Weald and Wessex Basins and is identified at formation level on the GVS as KC-MDST.

3.1.6 Ampthill Clay Formation and Kimmeridge Clay Formation

As described above, the **Kimmeridge Clay Formation** has source rock potential in the Wessex and Weald Basins. In this unit the Kimmeridge Clay Formation is not differentiated from the Ampthill Clay Formation. Since it is identified directly adjacent to the region with the Kimmeridge Clay Formation, to the north of the Wessex Basin, this unit has also been identified as a potential source rock on the GVS as AMKC-MDST.

3.1.7 Corallian Group

A number of beds provide reservoirs in the Upper Jurassic **Corallian Group** in the Wessex Basin. Corallian limestone and sandstone form the reservoir of several conventional oil and gas fields in the northern and eastern parts of the Weald Basins. A lower limestone unit forms the reservoir in the Bletchingley discovery, Surrey, from which gas is being produced. The Palmers Wood Oilfield, south of London, produces from upper Corallian sandstone where the thickest sands are developed. There have been hydrocarbon indications at Edenbridge in Surrey and in Ashdown 1, East Sussex.

Some good source intervals are present in limestones of the Corallian in the Wessex Basin (Greenhalgh, 2016) and high TOCs have been recorded in the Corallian Group in the Weald Basin; the Corallian Clay may have contributed to various reservoirs here (Andrews 2014).

This group is identified in the GVS as CR-LSSM (limestone, sandstone, siltstone and mudstone) and primarily occurs in the Weald and Wessex Basin, but also to a lesser degree in the northeast of England.

3.1.8 Kellaways Formation and Oxford Clay Formation (undifferentiated)

The **Oxford Clay Formation** has source rock potential in the Wessex and Weald Basins, particularly along the axes of sub-basins. The oil generating potential of the Oxford Clay Formations is variable, but it is mature in parts of the Weald and Wessex Basins. Oil has been encountered in fractures in the Oxford Clay in the Kimmeridge Oil field and might be actively recharging the Cornbrash reservoir (Greenhalgh, 2016). There were gas shows in the Oxford Clay and Kellaways Formation in Wareham 2, Wessex Basin (Greenhalgh, 2016). Oil in the Coombe Keynes 1 well encountered small amounts of oil in the Oxford Clays. The most significant organic-rich shales in the Weald Basin occur in the lowermost Oxford Clay (Andrews, The Jurassic shales of the Weald Basin: geology and shale oil and shale gas resource estimation, 2014).

In this mudstone unit the Oxford Clay Formation and underlying Kellaways Formation are not differentiated. Since it is identified in the Wessex and Weald Basins, and has a mudstone, siltstone and sandstone lithology, the unit has been identified as a potential source rock on the GVS as KLOX-MDSS.

3.1.9 Great Oolite Group

Limestones of the Middle Jurassic Great Oolite Group, in particular the Great Oolite limestone (old name), are the main reservoir at the Humbly Grove Oilfield and other discoveries in the Weald basin such as the Horndean, Stockbridge, Storrington, Goodworth and Singleton Oilfields and the Baxter's Copse and Lidsey discoveries. The **Frome Clay** limestone is a local reservoir in the Wessex basin. The **Cornbrash Formation** and **Forest Marble Formation** are also reservoirs in the Wessex Basin.

Occasionally good source intervals are present in the **Frome Clay Formation** and **Fuller's Earth Formation** in the Wessex Basin (Greenhalgh, 2016).

The group is recognised as GOG-SLAR or GOG-MDST in the GVS.

3.1.10 Inferior Oolite Group

Minor gas shows have been found in the middle Jurassic **Inferior Oolite Group** in the Wessex basin. The discovery well in the Wareham Oilfield produced oil from the Inferior Oolite (along with the Bridport Sand Formation of the Lias Group) and the Arreton 2 well, Wessex. It has also had interesting shows in the Weald Basin.

Good source intervals are occasionally present within limestones of the Inferior Oolite Group (Greenhalgh, 2016).

In the Weald and Wessex Basins this unit is identified as INO-LSSM and INO-SDLI on the GVS.

3.1.11 Inferior Oolite Group and Great Oolite Group (undifferentiated)

As described above, both the **Great Oolite Group** and **Inferior Oolite Group** could be reservoirs and source rocks. This unit has a similar lithology (sandstone, limestone and argillaceous rocks). The unit is identified in the north of the Weald Basin through into Norfolk, and thus is identified on the GVS as IOGO-SLAR.

3.1.12 Lias Group – mudstone, siltstone, limestone and sandstone

The Lias clays have source rock potential in the Wessex and Weald Basins. The **Lower Lias** is the source rock for most oil to the south of the Purbeck-Isle of Wight monocline (Wessex Basin). It is the source of the Kimmeridge, Wytch Farm, Wareham and Humbly Grove oilfields. There may also have been contributions from higher in the Lias. Basin modelling predicts that the Lias falls within the zone of oil generation across much of the Wessex and Weald Basins, being over-mature in its deepest axial parts. The Lower Lias shales may also have entered the gas generation window in the deepest part of the Weald Basin but is not considered to ever have been sufficiently deeply buried to have generated significant amounts of gas onshore (Greenhalgh, 2016).

The **Bridport Sand Formation** of the Lias Group is a primary reservoir in the Wessex Basin, providing the main reservoir for smaller discoveries and contributing to oil produced in the Wareham Oilfield and Wytch Farm. There is only marginal prospectivity for this formation in the Weald basin.

The Lias Group is identified as LI-MSLS on the GVS.

3.1.13 Mercia Mudstone Group

Wells in the Triassic **Tarporley Siltstone Formation** of the Triassic Mercia Mudstone Group encountered oil at the Formby Oilfield, East Lancashire Basin. The **Mercia Mudstone Group** is within the oil window in the Cheshire Basin. Here the unit is identified both as a potential source and reservoir. The rest of the Mercia Mudstone Group is neither a source nor a reservoir. This unit is identified as MMG-MDSS on the GVS.

3.1.14 Helsby (previously Ormskirk) Sandstone Formation

The **Helsby Sandstone Formation** of the Lower Triassic Sherwood Sandstone Group is a potential reservoir in the West Lancashire Basin. Production was obtained from the Helsby (or Ormskirk) Sandstone play in the Formby Oilfield. This is also viewed as a secondary target in the Cheshire basin, although has so far been unsuccessful. This unit is still identified as the Ormskirk Sandstone Formation, OMS-SDST, on the GVS.

3.1.15 Wilmslow Sandstone Formation

The **Wilmslow Sandstone Formation** of the Sherwood Sandstone Group is a potential reservoir in the Cheshire basin. This formation is identified as WLSF-SDST on the GVS.

3.1.16 The Sherwood Sandstone Group

The Helsby (Ormskirk) Sandstone Formation and Wilmslow Sandstone Formation of the Triassic **Sherwood Sandstone Group** are reservoirs in the West Lancashire Basin and Cheshire basin, as described above. The Sherwood Sandstone aquifer is a major Triassic reservoir in the Wessex Basin, and light gas was found within it at the Wytch Farm Oilfield. There is some potential in the west of the Weald Basin. This group is extensive across the country but is limited in the basins of interest. It is identified as SSG-SDSM in the GVS.

3.1.17 Zechstein Group – Dolomitised limestone and dolomite

The upper Permian Zechstein Group limestones are a main reservoir in the Cleveland Basin, including for the Malton and Eskdale gasfields. These limestones were previously known as the Upper Magnesian Limestone and are currently known as the **Roker or Seaham Formations**. The Upper Magnesian Limestone also contains small amounts of gas in the East Midlands province. This group is identified as the ZG-DLDO on the GVS.

3.1.18 The Kinnerton Sandstone Formation

The Early Triassic **Kinnerton Sandstone Formation** does not belong to a group. It is a potential reservoir in the Cheshire basin. It is identified as KNSF-SDST on the GVS.

3.1.19 Appleby Group – interbedded sandstone and conglomerate

The **Collyhurst Sandstone Formation** of the Permian Appleby Group is a potential reservoir in the Cheshire and West Lancashire basins. The reservoir at the Elswick Gasfield might also be in the Collyhurst Sandstone Formation. The group is identified as APY-SCON on the GVS.

3.1.20 Rotliegendes Group

The Rotliegendes Group (**Yellow Sands Formation** and **Basal Permian Sands Formation**) is not identified on the GVS. The group is a main reservoir in the Cleveland basin. The Yellow Sands Formation is productive in the Caythorpe gasfield.

3.1.21 Warwickshire Group

The **Halesowen Formation** of the Warwickshire Group is a known reservoir. There is an oil seep from Westphalian-aged sandstones near Ironbridge in the Cheshire basin. Shales and oil shales within the **Upper Coal Measures** of the Potteries Coalfield have been used for oil production. This unit is identified as the Warwickshire Group on the GVS by a siltstone and sandstone with subordinate mudstone (WAWK-SISDM) overlying a mudstone, siltstone, sandstone, coal, ironstone and ferricrete (WAWK-MSCI) which overlies another siltstone and sandstone with subordinate mudstone (WAWK-SISDM2).

3.1.22 Pennine Coal Measures Group

There are gas prone source rocks in Westphalian-aged coals of the East Midlands Province, the **Pennine Coal Measures Group**, which have supplied gas to reservoirs in most northwest European countries. The Westphalian Coal Measures form the major reservoirs in the East Midlands Oilfields such as Eakring-Duke's Wood, Gainsborough, Beckingham, Caunton, Egmanton, Corringham, South Leverton, Plungar, Bothamshall and Welton and East Glentworth. Production was possible from seepages in the Coal Measures at Riddings Colliery, Derbyshire in 1847.

Coal Measures are not present in the main part of the West Lancashire Basin but all the main oil shows in this basin were found in Westphalian Coal Measures. In the Cleveland Basin the Westphalian Coals are only present to the east and are only marginally mature for gas generation.

This group is identified in the GVS as the Pennine Upper Coal Measures Formation (PUCM-MSCI), Pennine Middle Coal Measures Formation (PSMCM) and South Wales Middle Coal Measures Formation (undifferentiated) (PSMCM-MSCI), Pennine Lower Coal Measures Formation and South Wales Lower Coal Measures Formation (undifferentiated) - mudstone, siltstone, sandstone, coal, ironstone and ferricrete (PSLCM-MSCI), Pennine Coal Measures Group (PCM-MDSS).

3.1.23 Millstone Grit Group

The **Namurian sandstones** of the Carboniferous Millstone Grit are producing reservoirs in a number of oilfields in the East Midlands Province, including at Eakring-Duke's Wood, Gainsborough-Beckingham and Bothamsall. Production has also been obtained from the Plungar Oilfield, Egmanton Oilfield, Corringham Oilfield, South Leverton and Glentworth and Rempstone Oilfields. Non-economic quantities of oil and gas have been observed in Namurian sandstones in numerous boreholes. Gas is produced from the Upper and Lower Follifoot Grits (of the **Silsden Formation**) in the Kirby Misperton gasfield in the Cleveland basin. The Pendle

Grit Member (of the **Pendleton Formation**), Grassington Grit (of the **Pendleton Formation**) and Red Scar Grit (of the **Silsden Formation**) of the Millstone Grit Group are potential reservoirs in the Cleveland Basin. The Millstone Grit Group is also a potential reservoir in the Cheshire basin.

In the West Lancashire Basin and the East Midlands Province the Sabden Shales (**Namurian shales**) of the Millstone Grit Group are extensions of the Holywell shale, a source in the East Irish Sea basin.

These units are identified as the Millstone Grit Group – mudstone, siltstone and sandstone (MG-MDSS) on the GVS.

3.1.24 Alston Formation – limestone with subordinate sandstone and argillaceous rocks

Late Dinantian (Early Carboniferous) **Asbian** and **Brigantian** substage rocks such as the Alston Formation have undergone dolomitisation in places therefore might form reservoirs in the East Midlands Province. Brigantian basinal shales and shaly ramp carbonates are possible source rocks in the Cheshire basin. This unit is identified as the Alston Formation – limestone with subordinate sandstone and argillaceous rocks (AG-LSSA) in the GVS.

3.1.25 Craven Group

The **Bowland Shale Formation** (previously Edale and Holywell Shale Formations) is part of the Craven Group and is a Carboniferous source rock. These shales are thought to be source rocks of the East Midlands and East Irish Sea oilfields. Late Dinantian shales (lower **Bowland Shales** and the **Widmerpool Formation**) and limestones (**Bee Low Limestone**) are source rocks in the East Midlands Province. Mid-Dinantian shales and some limestones at outcrop may also be classed as source rocks (e.g. **Milldale Limestone**) in the East Midlands Province. The Bowland shales are considered the principal source rocks in the Craven Basin. Thick sequences of oil-prone late Dinantian shales occur in the Widmerpool, Edale and Gainsborough troughs. Dinantian aged (previously the Worston Shale Group) shales are potential source rocks in the Cleveland Basin. In the Bowland, Cleveland, Edale, Gainsborough, Humber and Widmerpool basins significant amounts of gas have been discovered in conventional plays (Andrews, 2013). The Namurian Holywell/Bowland Shales are source rocks in the Cheshire Basin. The Bowland Shales are considered the principal source rock in the West Lancashire basin and is at oil maturity in the Formby oilfield. These units are identified as the Craven Group on the GVS (CRAV-MDLM).

3.1.26 Dinantian Rocks

Dinantian rocks of limestone lithology (DINA-LMST) have been identified as potential reservoirs. The identified unit is extensive within basins of England form north to south. This unit could include rocks of the **Asbian** and **Brigantian substage** that have undergone dolomitisation in places therefore might form reservoirs in the East Midlands Province. The **Woo Dale Limestones** (of the Dinantian Peak Limestone Group) are also possible reservoirs where they have been dolomitised in the East Midlands Province. The original discovery at Hardstoft, East Midlands Province was in a Dinantian Carboniferous Reservoir and small quantities of oil have been produced from the top of the Dinantian Carboniferous Limestone (e.g. Hardstoft, Eakring, Duke's Wood, Plungar, Nocton). This is identified as DINA-LMST on the GVS.

3.1.27 Carboniferous Rocks Undifferentiated

This unit is found in the East Midlands Province. It could include rocks from any Carboniferous group present in the East Midlands province – **Pennine Coal Measures Group** (source and reservoir), **Namurian Sandstones** (reservoir), **Namurian Shales** (source), **Asbian and Brigantian substage rocks** (reservoir), **Bowland Shale Formation** (source), **Lower Bowland Shales** (source), **Widmerpool Formation** (source), **Bee Low Limestone** (source), **Mid-**

Dinantian shales and Milldale Limestone (source). However it is only identified on a few sections. This unit is identified as CARB-ROCK on the GVS.

3.1.28 Dinantian Rocks (Undifferentiated) – limestone with subordinate sandstone and argillaceous rocks

This unit is identified throughout of England. It could include rocks of the **Asbian** and **Brigantian substage** or the **Woo Dale Limestones** (of the Dinantian Peak Limestone Group) which have undergone dolomitisation in places therefore might form reservoirs in the East Midlands Province, see descriptions above. In the Cheshire basin Dinantian Reservoirs include the **Onecote Sandstone** (productive at Nooks Farm) and sandstones of the **Minera Formation** of the Clwyd Group.

This unit might also contain the source rock **Bowland Shale Formation** of the Craven Group, see description above. This unit is identified as DINA-LSSA on the GVS.

3.1.29 Dinantian Rocks (Undifferentiated) – sandstone, limestone and argillaceous rocks

This unit is identified predominantly north of the English Midlands. This unit is identified predominantly in the north and west of England. It could include rocks of the **Asbian** and **Brigantian substage** or the **Woo Dale Limestones** (of the Dinantian Peak Limestone Group) which have undergone dolomitisation in places therefore might form reservoirs in the East Midlands Province, see descriptions above. In the Cheshire basin Dinantian Reservoirs include the **Onecote Sandstone** (productive at Nooks Farm) and sandstones of the **Minera Formation** of the Clwyd Group.

This unit might also contain the source rock **Bowland Shale Formation** of the Craven Group, see description above. This unit is identified as DINA-SLAR on the GVS.

3.2 COAL BED METHANE (CBM)

Information on units with CBM potential is sourced from DECC (2013b). In England, south of the Stainmore-Cleveland Basin, coals are largely confined to strata of Westphalian age. Further north a large number of coals also occur in the Namurian and Dinantian strata but these are considered to be thin and mined-out. Neither the previous pre-Permian subcrop map nor the coal mapping has attempted to predict the occurrence of coal measures beneath Variscan thrusts in southern Britain. There is a possibility coals might exist at much greater depth than drilled in the Weald Basin, south of the Berkshire syncline and the Mendips, if there is a thin-skinned element to the tectonics. However this would be too deep for CBM exploration. The Bude and Bideford Formations of Westphalian age crops out in SW England. These were mined up to 1969 but no modern drilling or logging has taken place here.

Coals are assigned ages in DECC (2013b) therefore coal measure units with potential have been identified according to their age. It should be noted that CBM exploration is still at an early stage in the UK therefore much of the information about their potential originates from the USA.

CBM exploration from virgin seams is likely to be constrained to depths of 200-1200 m bgl (below ground level) (Jones, et al. 2004). CMM will be restricted to the depth of planned mines whereas AMM will be restricted to the depth of existing mines, generally both < 1200 m in the UK (Jones, et al. 2004). Westphalian-aged coal measures

Analogues for Westphalian coals are found in the Black Warrior Basin, Alabama and the Appalachian Foreland Basin. Coal fields in the Black Warrior Basin lie within the oil window (the temperature at which oil is generated and expelled from source rocks). The Black Warrior Basin coals areare comparable to North-Staffordshire-Lancashire coals in terms of their gassiness.

CBM potential varies across the country. Estimated volumes of methane in coal seams are 3 m^3/t (or less) for south Staffordshire and the south Midlands, up to 9 m^3/t for the east Midlands and 11 m^3/t for south Lancashire and up to 15 m^3/t for North Staffordshire. Generally older and deeper coals have been shown to have a greater gas content since gas content increases with maturity. There is a progressive increase in the gas content of coals northwards; from Oxfordshire towards the Pennine basin margin in Warwickshire and South Staffordshire and the depocentre of the Pennine Basin, in Lancashire. There is also a slight increase in gas content southwards from Oxfordshire to the Carboniferous foreland basin in Kent and probably into Somerset.

Two Westphalian-aged coal measure groups are identified:

WARWICKSHIRE GROUP (WESTPHALIAN C-D)

This group is Duckmantian in age and comprises coal in the Pennine Basin in Staffordshire, Warwickshire, Shropshire, Lancashire, Nottinghamshire and South Yorkshire. The Group is thick at crop in the Warwickshire Coalfield and in the subsurface to the south. Maturity and gas content is low where measured, as the basin straddles the Wales-Brabant Massif. Maturities may increase near the southern boundary but no gas content measurements were acquired here. A shallow well has been drilled for exploration in the west of the Warwickshire coalfield. In the Somerset Coalfield naked-light working was common in these coal measures suggesting low methane. These coal measures are identified as the Warwickshire Group on the GVS with either siltstone and sandstone with subordinate mudstone (WAWK-SISDM); mudstone, siltstone, sandstone, coal, ironstone and ferricrete (WAWK-MSCI) or siltstone and sandstone with subordinate mudstone (WAWK-SISDM2).

PENNINE COAL MEASURES GROUP (WESTPHALIAN A-B)

This group is from Langsettian to Westphalian B in age and comprises units previously known as the Coal Measures Group.

This group is present in central and northern England. In the Midlands and northwest England CBM exploration is underway in this group. There has been drilling at the Keele Campus in North Staffordshir A gas content of 6-9 m^3/t is indicated in the Cheshire-Staffordshire Basin and a permeability of < 5 mD. The Doe Green CBM pilot production site has produced electricity from the Lancashire Coalfield.

The Cumbria-Canonbie coalfields have a high gas content and large subsurface area between the two coalfields has never been mined. This area is being explored for CBM.

Eastern England coalfields have lower gas contents than west of the Pennines, despite being part of the same basin. However, small conventional oil and gas fields indicate that porosity and permeability of units adjacent to CBM reservoirs are adequate for production. The Selby coalfield has an estimated methane gas potential of 13.3 x 10 m^3/km^2, with an assumed gas content of 5.3 m^3/t. In the Yorkshire and Nottinghamshire coalfield gas content and total thickness of the Westphalian coals increase to the northwest. This area is being explored by three companies.

Thick coals occur beneath the Warwickshire Group in the Warwickshire Coalfield. While coals are present in the Kent Coalfield, no part is considered to have “good” coalbed methane potential although more gas measurements need to be made. In the Somerset Coalfield extensive problems with methane were encountered during mining of this group, but no measured gas contents are available.

This group is identified in the GVS as the Pennine Upper Coal Measures Formation (PUCM-MSCI), Pennine Middle Coal Measures Formation (PSMCM-MSCI) and South Wales Middle Coal Measures Formation (undifferentiated) (PSMCM-MSCI), Pennine Lower Coal Measures Formation (PSLCM-MSCI), South Wales Lower Coal Measures Formation (undifferentiated) -

mudstone, siltstone, sandstone, coal, ironstone and ferricrete (PSLCM-MSCI) and the Pennine Coal Measures Group (PCM-MDSS).

3.3 SHALE GAS AND OIL

This information is from DECC (2013c) and includes potential shale gas and oil units that are of interest in the current licensing round (March 2016). The report states that the lowest risk shale gas exploration is where shale gas prospects are associated with conventional hydrocarbon fields. In the UK this includes the Upper Bowland Shale of the Pennine Basin, the Kimmeridge Clay of the Weald Basin, and possibly the Lias of the Weald Basin. Deeper Dinantian shales should also be tested in the Pennine Basin.

Older shales such as those from the Upper Cambrian on the Midlands Microcraton are higher risk targets because they have not been found to source conventional fields and are not currently of prospective interest. In addition, where prospective shales occur in the Variscan and Caledonian fold belts the risks is considered too high. These shales have been discounted because they are not currently licensed.

In the USA shale gas and oil is generally exploited from between 1000 to 3,500 m bgl. The 2015 Infrastructure Act states that fracking cannot take place at < 1000 m bgl (http://www.legislation.gov.uk/ukpga/2015/7/contents/enacted) or at < 1200 m bgl in protected areas (http://www.legislation.gov.uk/uksi/2016/384/note/made).

3.3.1 Purbeck Group

Shales of the Jurassic-Cretaceous **Purbeck Group** may have been a source of some oil and gas shows in several wells of the Weald basin. A Purbeck Group oil-shale outcrops in the Purbeck inlier on the Wealden anticline. Source richness has been identified in the Purbeck Group but these are not considered prospective in the Wessex Basin due to their immaturity basin-wide (Greenhalgh, 2016). This is identified at the group level on the GVS as PB-LSMD (limestone and interbedded mudstone) on the GVS, and predominantly occurs in the Weald Basin.

3.3.2 Kimmeridge Clay Formation

The **Kimmeridge Clay Formation**, part of the Ancholme Group in onshore eastern and southern England, is potentially prospective for shale oil and biogenic gas because it contains ubiquitous oil-shale beds. The Kimmeridge Clay of the Weald basin is associated with conventional hydrocarbon fields and therefore has one of the best shale gas potentials in the onshore UK. Five basins show thickening in response to syn-sedimentary faulting (Weald, Wessex, English Channel, Cleveland and Lincolnshire-Norfolk) however it is immature for thermogenic gas generation onshore and only marginally mature for oil generation in the Weald Basin depocentre.

After the first OPEC oil price increase in 1973 Kimmeridge Clay oil-shales were assessed but deemed uneconomic because of the thin beds and high sulphur content. This might be overcome by horizontal drilling and exploitation of thinner beds. The English Channel basin, particularly south of Purbeck and on the southern Isle of Wight, contains more mature source rocks than in the area near the Wytch Farm oil field. There are already precedents for deviating wells from the onshore to the offshore to access the main part of this basin for shale gas (DECC, 2013a). Shows of oil and gas in several Weald Basin wells indicate a Kimmeridge Clay or Purbeck shale source. There are also some small gas fields and gas discoveries in a line along the northern Weald Basin (Albury, Bletchingley, Lingfield and Cowden), with Godley Bridge, Baxter's Copse and Heathfield fields in the centre and south of the basin. This mudstone formation is present in the Weald and Wessex Basins and is identified as KC-MDST.

3.3.3 Ampthill Clay Formation and Kimmeridge Clay Formation

As described above, the **Kimmeridge Clay Formation** has some shale oil and gas potential. In this mudstone unit the Kimmeridge Clay Formation is not differentiated from the Ampthill Clay Formation, both belong to the Ancholme Group. Since it is identified directly adjacent to the region with the Kimmeridge Clay Formation, to the north of the Wessex Basin, this unit has also been identified as a potential oil shale and gas rock on the GVS as AMKC-MDST.

3.3.4 Kellaways Formation and Oxford Clay Formation (undifferentiated)

The **Oxford Clay Formation** has a relatively high Total Organic Carbon (TOC) content (7.83%) in the Weald Basin and lies within the oil window at the basin's depocentre. Shelly horizons in the Oxford Clay Formation in the Wytch Farm Oilfield contain free oil, although this might represent migrated oil. A bituminous horizon is present at the base of the formation in southern and Central England, but this is absent in Yorkshire. In central England TOC's are over 4% but they are immature for oil generation.

In this mudstone unit the Oxford Clay Formation is not differentiated from the Kellaways Formation. Both Formations belong to the Ancholme Group in the south of England. Since this unit is identified in the Wessex and Weald Basins, and has a mudstone, siltstone and sandstone lithology, this unit has been identified as a potential source rock on the GVS as KLOX-MDSS.

3.3.5 Great Oolite Group - mudstone

The **Fuller's Earth Formation** in the Great Oolite Group has good TOC values in the Weald basin but it has only reached oil maturity in the basin's depocentre. The unit GOG-MDST has been identified as having shale gas and oil potential on the GVS because it is dominated by mudstone.

3.3.6 Great Oolite Group - mudstone

As above, the **Fuller's Earth Formation** in the Great Oolite Group has good TOC values in the Weald basin but it has only reached oil maturity in the basin's depocentre. The unit GOG-SLAR has been identified as having shale gas and oil potential on the GVS because in places it comprises argillaceous rocks which might contain the Fuller's Earth Shales.

3.3.7 Inferior Oolite Group and Great Oolite Group (undifferentiated)

As described above, **Fuller's Earth Formation** in the Great Oolite Group has good TOC values in the Weald basin but it has only reached oil maturity in the basin's depocentre. While mostly identified to the north of the Weald Basin through into Norfolk, it has also been identified to the northern boundary of the Weald basin. The unit IOGO-SLAR has been identified as having shale gas and oil potential on the GVS because in places it comprises argillaceous rocks which might contain the Fuller's Earth Shales.

3.3.8 Lias Group – Mudstone, siltstone, limestone and sandstone

Shales in the Lower Jurassic **Lias Group** of the Weald basin have some possible shale gas and oil potential. The Lias Group is the source rock for the Weald basin petroleum system and the Wessex Basin, with migration into three different reservoirs in Wytch Farm oil field. The **Lower Lias Shales** lie within the oil window over a wide area; maturity is lower on former highs of syn-sedimentary faults. However, sampled TOCs are not high throughout. The area of Liassic source rock within the gas window is believed to be >467 km^2 at exploitable drilling depths between 2750 and 3950 m. The mid-case resource estimate is 10 tcf (trillion cubic feet) plus condensate.

Bituminous shales at the base of the **Blue Lias** in Dorset contain 3.9-7% carbon and laminated marls 8% carbon. Lias oil-shale is present at Kilve on the southern side of the Bristol Channel

but both sides of the channel are immature for oil. Lias is immature for shale gas in all of these areas. In the Cleveland basin the Lias is within the oil window and there are extensive oil shows, but no gas, in its iron-ore mines. In the Godley Bridge 1 well gas readings in the Lias were fairly low. The Lias Group is identified as LI-MSLS on the GVS.

3.3.9 Zechstein Group

The Kupferschiefer/Marl Slate of the Zechstein Group is a basal upper-Permian unit with a very high organic and metal content for shale. Samples from Durham show that these are correlated. This unit is unlikely to be prospective as it is thin and would need to be treated more like a coal in CBM than shale. This is identified as the ZG-DLDO on the GVS.

3.3.10 Marros Group

The Namurian aged Marros Group shales are equivalent to the Lower and Upper Bowland shales in the Pennine Basin (see below). These shales are in the South Wales-Bristol basin and have high gamma-ray responses on geophysical logs, indicating a high organic content, such as in the Ashton Park borehole. However the shales are interbedded with thick sandstones. It is thought that the shales thicken to the south thus could be a realistic shale gas target. This group is identified as MARR-MDSD on the GVS.

3.3.11 Millstone Grit Group

In the West Lancashire Basin and the East Midlands Province the **Sabden Shale Formation** (Namurian shales) of the Millstone Grit Group are extensions of the **Holywell Shale Formation**, a source in the East Irish Sea basin. The Sabden Shale is not sufficiently deeply buried onshore to be considered as a source of shale gas (Andrews, 2013). These units are identified as the Millstone Grit Group – mudstone, siltstone and sandstone (MG-MDSS) on the GVS.

3.3.12 Craven Group

The late Dinantian to Namurian **Bowland Shale Formation** (with local names of Bowland, Edale, Holywell shales, top part of Craven Group) belonging to the Craven Group in the Pennine Basin offers the best potential for shale gas in the UK because they have previously sourced hydrocarbons and have a high TOC. These shales are also more extensive than Dinantian-aged shales. A combined resource estimation was made by Andrews (2013) for the Bowland Shale Formation and Hodder Formation. The organic content of these shales is typically in the range 1-3%, but can reach 8%. Where they have been buried to sufficient depth for the organic material to generate gas, they have the potential to form a shale gas resource analogous to the producing shale gas provinces of North America. Where they have been less deeply buried, there is potential for a shale oil resource (but there is inadequate data to estimate the oil-in-place) (Andrews 2013). The Bowland-Hodder unit is divided into two; a lower, syn-rift unit, largely undrilled, and an upper post-rift unit which is more prospective. A large volume of gas has been identified in this unit (P90 23.3, P50 37.6 and P10 54.6 tcm (trillion cubic meters)) but not enough is known to estimate the potential reserves (Andrews 2013).

The Bowland shale Formation is a source rock for the southern East Irish Sea gas and oil fields and also the Formby oil field. Gas is sourced from Namurian shales at the Elswick Gasfield, in the West Lancashire basin and gas in other basins may have originated from Namurian strata, for example at the Nook Farm and the Marishes to Malton gas fields along the southern margin of the Cleveland Basin.

The Craven Group has been shown to be within the gas window in boreholes drilled in the Cheshire Basin, southeast of Milton Green and in the Gainsborough 2 borehole in the Gainsborough Trough. These units are identified as the Craven Group on the GVS (CRAV-MDLM).

3.3.13 Yoredale Group – limestone with subordinate sandstone and argillaceous rocks

The late Dinantian to early Namurian **Yoredale Group** and **earlier formation** shale rocks may have some shale gas potential in the Northumberland and Stainmore Troughs because they have high TOCs in a largely gas-prone facies. However these shales tend to be thin in the basins. A possible play was indicated by the Errington well and thicker, shalier sequences might occur. This group is identified as YORE-LSSA on the GVS.

3.3.14 Carboniferous Rocks Undifferentiated

This unit is identified in a small region of the East Midlands Province. It could include rocks from any Carboniferous group present in the East Midlands province; **Bowland Shale Formation** of the Craven Group or Yoredale Group. This unit is identified as CARB-ROCK on the GVS.

3.3.15 Dinantian Rocks (Undifferentiated) – limestone with subordinate sandstone and argillaceous rocks

This unit is identified primarily in the centre-northeast of England. It might contain the source rock **Bowland Shale Formation** of the Craven Group, see description above. This unit is identified as DINA-LSSA on the GVS.

3.4 UNDERGROUND COAL GASIFICATION (UCG)

There has been no individual assessment for UGC potential from the UK Government or BGS therefore all Coal Measures have been included, as for the CBM. It should be noted that UCG exploration is considered unlikely in the coming years. For this process seams of 2m or thicker are required, at assumed depths of between 600 and 1200 m from the surface (Jones et al., 2004). All the current licences are offshore.

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British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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Appendix 1

Lithological codes used in the GVS, see Table 1.

Lithology code	Lithological description
SDSL	Sandstone, siltstone
MDSS	Mudstone, siltstone and sandstone
LMSD	Interbedded limestone and mudstone
LMCS	Limestone and calcareous sanstone
MDST	Mudstone
SLAR	Sandstone, limestone and argillaceous rocks
SDLI	Sandstone, limestone and ironstone
MSLS	Mudstone, siltstone, limestone and sandstone
SDST	Sandstone
SDSM	Sandstone, siltstone and mudstone
DLDO	Dolomitised limestone and dolomite
SCON	Interbedded sandstone and conglomerate
SISDM	Siltstone and sandstone with subordinate mudstone
MSCI	Mudstone, siltstone, sandstone, coal, ironstone
MDSD	Mudstone and sandstone interbedded
LSSA	Mudstone with subordinate sandstone and argillaceous rocks
LMST	Limestone
LSSM	Limestone, sandstone, siltstone and mudstone

Appendix 2

GVS for England with oil and gas formations indicated, frozen February 2016.

LEX-RCS	DESCRIPTION	Oil and gas		Coal bed methane		Shale gas	
SUPD-UNKN	**SUPERFICIAL DEPOSITS - UNKNOWN**						
CRAG-PESA	CRAG GROUP - PEBBLY SANDS						
SOLT-CLSISA	SOLENT GROUP - CLAY, SILT AND SAND						
BRBA-SSCL	BRACKLESHAM GROUP AND BARTON GROUP (UNDIFFERENTIATED) - SAND, SILT AND CLAY						
EOMIO-CLSSG	EOCENE TO MIOCENE ROCKS (UNDIFFERENTIATED) - CLAY, SILT, SAND AND GRAVEL						
THAM-CLSSG	THAMES GROUP - CLAY, SILT, SAND AND GRAVEL						
LMBE-CLSSG	LAMBETH GROUP - CLAY, SILT, SAND AND GRAVEL						
TAB-SSCL	THANET FORMATION - SAND, SILT AND CLAY						
PGU-CLSSG	PALAEOGENE SEDIMENTARY ROCKS (UNDIFFERENTIATED) - CLAY, SILT, SAND AND GRAVEL						
UIG-FELSR2	UNNAMED IGNEOUS INTRUSION, PALAEOGENE - FELSIC-ROCK						
UIG-MFIR	UNNAMED IGNEOUS INTRUSION, PALAEOGENE - MAFIC IGNEOUS ROCK						
UEXG-LATM	UNNAMED EXTRUSIVE ROCKS, PALAEOGENE - MAFIC LAVA AND MAFIC TUFF						
PCK-CHLK	PORTSDOWN CHALK FORMATION - CHALK						
CCK-CHLK	CULVER CHALK FORMATION - CHALK						
NCK-CHLK	NEWHAVEN CHALK FORMATION - CHALK						
SECK-CHLK	SEAFORD CHALK FORMATION - CHALK						
SNCK-CHLK	SEAFORD CHALK FORMATION AND NEWHAVEN CHALK FORMATION (UNDIFFERENTIATED) - CHALK						
LECH-CHLK	LEWES NODULAR CHALK FORMATION - CHALK						
NPCH-CHLK	NEW PIT CHALK FORMATION - CHALK						
HCK-CHLK	HOLYWELL NODULAR CHALK FORMATION - CHALK						
ROWE-CHLK	ROWE CHALK FORMATION - CHALK						
FCK-CHLK	FLAMBOROUGH CHALK FORMATION - CHALK						
BCK-CHLK	BURNHAM CHALK FORMATION - CHALK						
WCK-CHLK	WELTON CHALK FORMATION - CHALK						
WHCK-CHLK	WHITE CHALK SUBGROUP (UNDIFFERENTIATED) - CHALK						
ZZCH-CHLK	ZIGZAG CHALK FORMATION - CHALK						
WMCH-CHLK	WEST MELBURY MARLY CHALK FORMATION - CHALK						
GYCK-CHLK	GREY CHALK SUBGROUP (UNDIFFERENTIATED) - CHALK						
CK-CHLK	CHALK GROUP (UNDIFFERENTIATED) - CHALK						
HUCK-CHLK	HUNSTANTON FORMATION - CHALK						
GUGS-MDSL	GAULT FORMATION AND UPPER GREENSAND FORMATION (UNDIFFERENTIATED) - MUDSTONE, SANDSTONE AND LIMESTONE						
LGS-STMD	LOWER GREENSAND GROUP - SANDSTONE AND MUDSTONE						
W-MDSS	**WEALDEN GROUP - MUDSTONE, SILTSTONE AND SANDSTONE**	**Reservoir**	**Wealden beds, Tunbridge Wells Sand Formation**				
W-SDSL	**WEALDEN GROUP - SANDSTONE AND SILTSTONE, INTERBEDDED**	**Reservoir**	**Wealden beds, Tunbridge Wells Sand Formation**				
SYS-SDST	SPILSBY FORMATION - SANDSTONE						
PB-LSMD	**PURBECK GROUP - INTERBEDDED LIMESTONE AND MUDSTONE**	**Reservoir**	**Purbeck Group**			**Shale Gas**	**Purbeck Group Shales**
LOCR-SSML	LOWER CRETACEOUS (UNDIFFERENTIATED) - VARIED						
PL-LMCS	**PORTLAND GROUP - LIMESTONE AND CALCAREOUS SANDSTONE**	**Reservoir**	**Portland Sand Formation,Portland Group, Portland Stone Formation**				
KC-MDST	**KIMMERIDGE CLAY FORMATION - MUDSTONE**	**Source/Rese**	**Kimmeridge Clay Formation**			**Shale Gas**	**Kimmeridge Clay Formation**
AMKC-MDST	**AMPTHILL CLAY FORMATION AND KIMMERIDGE CLAY FORMATION (UNDIFFERENTIATED) - MUDSTONE**	**Source/Rese**	**Kimmeridge Clay Formation**			**Shale Gas**	**Kimmeridge Clay Formation**
CR-LSSM	**CORALLIAN GROUP - LIMESTONE, SANDSTONE, SILTSTONE AND MUDSTONE**	**Source/Rese**	**Beds within the Corallian Group**				
WWAK-MDSS	WEST WALTON FORMATION, AMPTHILL CLAY FORMATION AND KIMMERIDGE CLAY FORMATION (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
JURU-MDSS	UPPER JURASSIC ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
KLOX-MDSS	**KELLAWAYS FORMATION AND OXFORD CLAY FORMATION (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE**	**Source**	**Oxford Clay Formation**			**Shale Gas**	**Oxford Clay Formation**
GOG-MDST	**GREAT OOLITE GROUP - MUDSTONE**	**Source/Rese**	**Fuller's Earth Formation, Frome Clay limestone, Forest Marble, Cornbrash Formation**			**Shale Gas**	**Fuller's Earth Formation**
GOG-SLAR	**GREAT OOLITE GROUP - SANDSTONE, LIMESTONE AND ARGILLACEOUS ROCKS**	**Source/Rese**	**Great Oolite Limestone, Fuller's Earth Formation, Frome Clay limestone, Cornbrash Formation, Forest Marble**			**Shale Gas**	**Fuller's Earth Formation**
INO-LSSM	**INFERIOR OOLITE GROUP - LIMESTONE, SANDSTONE, SILTSTONE AND MUDSTONE**	**Source/Rese**	**Inferior Oolite Group**				
INO-SDLI	INFERIOR OOLITE GROUP - SANDSTONE, LIMESTONE AND IRONSTONE						
IOGO-SLAR	**INFERIOR OOLITE GROUP AND GREAT OOLITE GROUP (UNDIFFERENTIATED) - LIMESTONE, SANDSTONE AND MUDSTONE**	**Source/Rese**	**Inferior Oolite Group and Great Oolite Group, Fuller's Earth Formation**			**Shale Gas**	**Fuller's Earth Formation**
RAG-SDSM	RAVENSCAR GROUP - SANDSTONE, SILTSTONE AND MUDSTONE						
JURM-MDSL	MIDDLE JURASSIC ROCKS (UNDIFFERENTIATED) - MUDSTONE, SANDSTONE AND LIMESTONE						
JURA-MDLM	JURASSIC ROCKS (UNDIFFERENTIATED) - MUDSTONE AND LIMESTONE, INTERBEDDED						
LI-MSLS	**LIAS GROUP - MUDSTONE, SILTSTONE, LIMESTONE AND SANDSTONE**	**Source/Rese**	**Bridport Sand Formation, Lias clays, Lower Lias Shales, Blue Lias Formation**			**Shale Gas**	**Lower Lias shales and Blue Lias**
MMG-MDSS	**MERCIA MUDSTONE GROUP - MUDSTONE, SILTSTONE AND SANDSTONE**	**Source/Rese**	**Tarporley Siltstone Formation and Mercia Mudstone Group**				
BMS-SDST	BROMSGROVE SANDSTONE FORMATION - SANDSTONE						
OMS-SDST	**ORMSKIRK SANDSTONE FORMATION - SANDSTONE**	**Reservoir**	**Ormskirk Sandstone Formation**				
WRS-SDST	WILDMOOR SANDSTONE FORMATION - SANDSTONE						

WLSF-SDST	**WILMSLOW SANDSTONE FORMATION - SANDSTONE**	**Reservoir**	**Wilmslow Sandstone Formation**				
KDM-SCON	KIDDERMINSTER FORMATION -SANDSTONE						
SBS-SDST	ST BEES SANDSTONE FORMATION - SANDSTONE						
SSG-SDSM	**SHERWOOD SANDSTONE GROUP - SANDSTONE, SILTSTONE AND MUDSTONE**	**Reservoir**	**Sherwood Sandstone Group**				
TRIA-MDSS	TRIASSIC ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE	TRIASSIC					
BRI-SDST	BRIDGNORTH SANDSTONE FORMATION - SANDSTONE						
ZG-DLDO	**ZECHSTEIN GROUP - DOLOMITISED LIMESTONE AND DOLOMITE**	**Reservoir**	**Roker or Seaham Formations**			**Shale Gas**	**Kupferschiefer/Marl slate**
KNSF-SDST	**KINNERTON SANDSTONE FORMATION- SANDSTONE**	**Reservoir**	**Kinnerton Sandstone Formation**				
CCO-MDSS_2	CUMBRIAN COAST GROUP - MUDSTONE, SILTSTONE AND SANDSTONE						
APY-SCON	**APPLEBY GROUP - INTERBEDDED SANDSTONE AND CONGLOMERATE**	**Reservoir**	**Collyhurst Sandstone Formation**				
PRMT-SARL	PERMIAN AND TRIASSIC ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
PUND-MDSS	PERMIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
PUND-SCON	PERMIAN ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
WAWK-SISDM	**WARWICKSHIRE GROUP - SILTSTONE AND SANDSTONE WITH SUBORDINATE MUDSTONE**	**Source/Rese**	**Halesowen Formation, Upper Coal Measures**	**CBM/UCG**	**Westphalian C-D**		
WAWK-MSCI	**WARWICKSHIRE GROUP - MUDSTONE, SILTSTONE, SANDSTONE, COAL, IRONSTONE AND FERRICRETE**	**Source/Rese**	**Halesowen Formation, Upper Coal Measures**	**CBM/UCG**	**Westphalian C-D**		
WAWK-SISDM_2	**WARWICKSHIRE GROUP - SILTSTONE AND SANDSTONE WITH SUBORDINATE MUDSTONE**	**Source/Rese**	**Halesowen Formation, Upper Coal Measures**	**CBM/UCG**	**Westphalian C-D**		
PUCM-MSCI	**PENNINE UPPER COAL MEASURES FORMATION - MUDSTONE, SILTSTONE, SANDSTONE, COAL, IRONSTONE AND FERRICRETE**	**Source/Rese**	**Pennine Coal Measures Group**	**CBM/UCG**	**Westphalian A-B**		
PSMCM-MSCI	**PENNINE MIDDLE COAL MEASURES FORMATION AND SOUTH WALES MIDDLE COAL MEASURES FORMATION (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE, SANDSTONE, COAL, IRONSTONE AND FERRICRETE**	**Source/Rese**	**Pennine Coal Measures Group**	**CBM/UCG**	**Westphalian A-B**		
PSLCM-MSCI	**PENNINE LOWER COAL MEASURES FORMATION AND SOUTH WALES LOWER COAL MEASURES FORMATION (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE, SANDSTONE, COAL, IRONSTONE AND FERRICRETE**	**Source/Rese**	**Pennine Coal Measures Group**	**CBM/UCG**	**Westphalian A-B**		
PCM-MDSS	**PENNINE COAL MEASURES GROUP - MUDSTONE, SILTSTONE AND SANDSTONE**	**Source/Rese**	**Pennine Coal Measures Group**	**CBM/UCG**	**Westphalian A-B**		
CM-MDSS	COAL MEASURES FORMATION - MUDSTONE, SILTSTONE AND SANDSTONE						
MARR-MDSD	MARROS GROUP - MUDSTONE AND SANDSTONE INTERBEDDED					**Shale Gas**	**Marros Group**
MG-MDSS	**MILLSTONE GRIT GROUP - MUDSTONE, SILTSTONE AND SANDSTONE**	**Source/Rese**	**Silsden Formation, Pendleton Formation, Namurian Shales**				
SMGP-LSSM	STAINMORE FORMATION - LIMESTONE, SANDSTONE, SILTSTONE AND MUDSTONE						
UIICP-DBAT_3	UNNAMED IGNEOUS INTRUSION, CARBONIFEROUS TO PERMIAN - DOLERITE AND THOLEIITIC BASALT						
SMGP-LSSM_2	STAINMORE FORMATION - LIMESTONE, SANDSTONE, SILTSTONE AND MUDSTONE						
AG-LSSA	**ALSTON FORMATION - LIMESTONE WITH SUBORDINATE SANDSTONE AND ARGILLACEOUS ROCKS**	**Source/Rese**	**Asbian and Brigantian substage rocks**				
UIICP-DBAT	UNNAMED IGNEOUS INTRUSION, CARBONIFEROUS TO PERMIAN - DOLERITE AND THOLEIITIC BASALT						
AG-LSSA_2	ALSTON FORMATION - LIMESTONE WITH SUBORDINATE SANDSTONE AND ARGILLACEOUS ROCKS						
CRAV-MDLM	**CRAVEN GROUP - MUDSTONE AND LIMESTONE, INTERBEDDED**	**Source**	**Bowland Shale Formation, Lower Bowland Shales, Widmerpool Formation, Bee Low Limestone**			**Shale Gas**	**Upper Bowland Shale Formation and Lower Bowland Shale Formation**
YORE-LSSA	**YOREDALE GROUP - LIMESTONE WITH SUBORDINATE SANDSTONE AND ARGILLACEOUS ROCKS**					**Shale Gas**	**Yoredale Group Shales**
TYLS-LMAS	TYNE LIMESTONE FORMATION - LIMESTONE, ARGILLACEOUS ROCKS AND SUBORDINATE SANDSTONE, INTERBEDDED						
UIICP-DBAT_2	UNNAMED IGNEOUS INTRUSION, CARBONIFEROUS TO PERMIAN - DOLERITE AND THOLEIITIC BASALT						
TYLS-LMAS_2	TYNE LIMESTONE FORMATION - LIMESTONE, ARGILLACEOUS ROCKS AND SUBORDINATE SANDSTONE, INTERBEDDED						
BDR-SARL	BORDER GROUP - SANDSTONE WITH SUBORDINATE ARGILLACEOUS ROCKS AND LIMESTONE						
UEXCL-LATM_3	UNNAMED EXTRUSIVE ROCKS, DINANTIAN - MAFIC LAVA AND MAFIC TUFF						
INV-SDSM	INVERCLYDE GROUP - SANDSTONE, SILTSTONE AND MUDSTONE						
DINA-LMST	**DINANTIAN ROCKS - LIMESTONE**	**Reservoir**	**Asbian and Brigantian substage rocks, Woo Dale Limestone**				
DINA-MDLM	DINANTIAN ROCKS - MUDSTONE AND LIMESTONE, INTERBEDDED						
HOWY-MDSS	HOLSWORTHY GROUP - MUDSTONE, SILSTONE AND SANDSTONE						
TEVYT-MDSS	TEIGN VALLEY GROUP AND TINTAGEL GROUP (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
CARB-ROCK	**CARBONIFEROUS ROCKS (UNDIFFERENTIATED) - VARIED**	**Source/Rese**	**Pennine Coal Measures Group, Namurian Sandstones, Namurian Shales, Asbian and Brigantian substage rocks, Bowland Shale Formation, Lower Bowland Shales, Widmerpool Formation, Bee Low Limestone , Mid-Dinantian shales and Milldale Limestone**			**Shale Gas**	**Bowland Shale Formation**
DINA-LSSA	**DINANTIAN ROCKS (UNDIFFERENTIATED) - LIMESTONE WITH SUBORDINATE SANDSTONE AND ARGILLACEOUS ROCKS**	**Source/Rese**	**Asbian and Brigantian substage rocks, Bowland Shale Formation, Lower Bowland Shales, Widmerpool Formation, Bee Low Limestone , Mid-Dinantian shales and Milldale Limestone**			**Shale Gas**	**Bowland Shale Formation**
DINA-SLAR	**DINANTIAN ROCKS (UNDIFFERENTIATED) - SANDSTONE, LIMESTONE AND ARGILLACEOUS ROCKS**	**Source/Rese**	**Asbian and Brigantian substage rocks, Bowland Shale Formation, Lower Bowland Shales, Widmerpool Formation, Bee Low Limestone , Mid-Dinantian shales and Milldale Limestone, Onecote Sandstone, Minera Formation**			**Shale Gas**	**Bowland Shale Formation**
UEXCL-LATF	UNNAMED EXTRUSIVE ROCKS, DINANTIAN - FELSIC LAVA AND FELSIC TUFF						
UEXCL-LATM	UNNAMED EXTRUSIVE ROCKS, DINANTIAN - MAFIC LAVA AND MAFIC TUFF						
UEXSD-LATM	UNNAMED EXTRUSIVE ROCKS, SILURIAN TO DEVONIAN - MAFIC LAVA AND MAFIC TUFF						
UDEV-BRCMBR	UPPER DEVONIAN ROCKS - ROSELAND BRECCIA						
UIID-UMFT	UNNAMED IGNEOUS INTRUSION, DEVONIAN - ULTRA MAFIC IGNEOUS-ROCK						

SAG-SCON	STRATHEDEN GROUP - INTERBEDDED SANDSTONE AND CONGLOMERATE						
UIID-MFIR	UNNAMED IGNEOUS INTRUSION, DEVONIAN - MAFIC IGNEOUS-ROCK						
UDEV-MDSS	UPPER DEVONIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
UDEV-SCON	UPPER DEVONIAN ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
UDEV-MDSS_2	UPPER DEVONIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
MUDEV-MDSS	MIDDLE AND UPPER DEVONIAN (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
MDEV-SCON	MIDDLE DEVONIAN (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
MDEV-MDSS	MIDDLE DEVONIAN (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
LDEV-SCON_1	LOWER DEVONIAN ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
MDEV-SCON_2	MIDDLE DEVONIAN (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
MDEV-MDSS_2	MIDDLE DEVONIAN (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
UEXSD-LATM_1	UNNAMED EXTRUSIVE ROCKS, SILURIAN TO DEVONIAN - MAFIC LAVA AND MAFIC TUFF						
LDEV-MDSS	LOWER DEVONIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
LDEV-SCON	LOWER DEVONIAN ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
LDEV-MDSS_2	LOWER DEVONIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
LORS-CSSM	LOWER OLD RED SANDSTONE - CONGLOMERATE, SANDSTONE, SILTSTONE AND MUDSTONE						
DEV-MDSS	LOWER DEVONIAN ROCKS (UNDIFFERENTIATED)- MUDSTONE, SILTSTONE AND SANDSTONE						
DEV-HBSCH	DEVONIAN ROCKS (UNDIFFERENTIATED) - HORNBLENDE SCHIST						
DEV-ROCK	DEVONIAN ROCKS, UNDIVIDED - VARIED						
DEV-SCHM_1	DEVONIAN ROCKS (UNDIFFERENTIATED) - MICA SCHIST						
UIICP-FELSR	IGNEOUS INTRUSION, PERMO-CARBONIFEROUS - GRANITE						
UEXD-MFTUF	UNNAMED EXTRUSIVE ROCKS, DEVONIAN - MAFIC TUFF						
PRID-MDSS	PRIDOLI ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
LUDL-MDSS	LUDLOW ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
SILU-LMCM_2	SILURIAN ROCKS, UNDIFFERENTIATED) - LIMESTONE (AYMESTRY AND WENLOCK LIMESTONES						
LUDL-MDSS_2	LUDLOW ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
UEXSD-LATM4	UNNAMED EXTRUSIVE ROCKS, SILURIAN TO DEVONIAN - MAFIC LAVA AND MAFIC TUFF						
RCN-WACKE	RICCARTON GROUP - WACKE						
SILU-LMCM	SILURIAN ROCKS (UNDIFFERENTIATED) - LIMESTONE, MUDSTONE AND CALCAREOUS MUDSTONE						
WEN-MDSS_2	WENLOCK ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
WEN-SCON_2	WENLOCK ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
WEN-MDSS	WENLOCK ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
HWK-WACKE	HAWICK GROUP - WACKE						
LDVY-MDSS	LLANDOVERY ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
LDVY-SCON	LLANDOVERY ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
LDVY-MDSS_2	LLANDOVERY ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
UEXSD-LATF	UNNAMED EXTRUSIVE ROCKS, SILURIAN TO DEVONIAN - FELSIC LAVA AND FELSIC TUFF						
SILU-SCON	SILURIAN ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
SILU-MDSS	SILURIAN ROCKS, UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
WEN-SCON	WENLOCK ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
SILU-MDSS_2	SILURIAN ROCKS, (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
ASHL-MDSS	ASHGILL ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
ORD-FTUFF	ORDOVICIAN VOLCANIC ROCKS AND SILLS (UNDIFFERENTIATED) - TUFF						
CARA-MDSS	CARADOC ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
UIIOS-FELSR_2	UNNAMED IGNEOUS INTRUSION, ORDOVICIAN TO SILURIAN - FELSIC-ROCK						
ORD-FTUFF_3	ORDOVICIAN VOLCANIC ROCKS AND SILLS (UNDIFFERENTIATED) - TUFF	ORDOVICIAN					
ORD-FTUFF_4	ORDOVICIAN VOLCANIC ROCKS AND SILLS (UNDIFFERENTIATED) - TUFF						
UIIOS-MFIR_2	UNNAMED IGNEOUS INTRUSION, ORDOVICIAN TO SILURIAN - MAFIC IGNEOUS-ROCK						
LLVN-MDSS	LLANVIRN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
ORD-FTUFF_5	ORDOVICIAN VOLCANIC ROCKS AND SILLS (UNDIFFERENTIATED) - TUFF						
LLVN-MDSS_2	LLANVIRN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE	ORDOVICIAN					
ARNG-MDSS	ARENIG ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
UEXO-MFLAVA_2	UNNAMED EXTRUSIVE ROCKS, ORDOVICIAN - MAFIC LAVA						
ORD-MDSS_2	ORDOVICIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
TREM-MDSS	TREMADOC ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
ORD-FLAVA	ORDOVICIAN ROCKS (UNDIFFERENTIATED) - FELSIC LAVA						
UEXO-MFTUF	UNNAMED EXTRUSIVE ROCKS, ORDOVICIAN - MAFIC TUFF						
ORD-MDSS_3	ORDOVICIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
CAOR-MDSS	CAMBRIAN AND ORDOVICIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
CAMN-MDSS	CAMBRIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
UC-MDSS	UPPER CAMBRIAN, INCLUDING TREMADOC - MUDSTONE, SILTSTONE AND SANDSTONE						
UIIO-GN_4	INTRUSIVE IGNEOUS ROCKS, ORDOVICIAN - GRANITE, FOLIATED						
MC-MDSS	MIDDLE CAMBRIAN - MUDSTONE, SILTSTONE AND SANDSTONE						
LRC-SCON	LOWER CAMBRIAN ROCKS (UNDIFFERENTIATED) - INTERBEDDED SANDSTONE AND CONGLOMERATE						
LRC-MDSS	LOWER CAMBRIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTOE AND SANDSTONE						
UEXAZ-FTUFF	UNNAMED EXTRUSIVE ROCKS, NEOPROTEROZOIC - PADARN TUFF						
UIIN-GN	INTRUSIVE IGNEOUS ROCKS - GRANITE, FOLIATED						
CAOR-MDSS_2	CAMBRIAN AND ORDOVICIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE						
LPRU-ROCK	LOWER PALAEOZOIC ROCKS, UNDIVIDED - VARIED						
UIICP-FELSR_1	IGNEOUS INTRUSION, PERMO-CARBONIFEROUS - GRANITE						
APRZ-ROCK	PROTEROZOIC TO PALAEOZOIC ROCKS (UNDIFFERENTIATED) - VARIED						
AZRU-ROCK	NEOPROTEROZOIC ROCKS, UNDIVIDED - VARIED						
AZRU-GD	AVALONIAN PROTEROZOIC CRYSTALLINE BASEMENT- IGNEOUS ROCK, MAFIC						

UIIEO-FELSR	UNNAMED IGNEOUS INTRUSION, CAMBRIAN TO ORDOVICIAN - FELSIC-ROCK						
CHA-VCSD	CHARNIAN SUPERGROUP - VOLCANICLASTIC ROCKS (BOTH PYROCLASTIC & REWORKED VOLCANIC ROCKS)						
UIAZ-UMR	UNNAMED IGNEOUS INTRUSION, NEOPROTEROZOIC - ULTRAMAFIC-ROCK						