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Potential for storage of carbon dioxide in the rocks beneath the East Irish Sea

Sustainable and Renewable Energy Programme

Internal Report CR/05/127N

BRITISH GEOLOGICAL SURVEY

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INTERNAL REPORT CR/05/127N

Potential for storage of carbon dioxide in the rocks beneath the East Irish Sea

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Keywords

Carbon dioxide, East Irish Sea, Ormskirk sandstone formation, Sherwood sandstone group.

Bibliographical reference

K.L.KIRK. 2005. Potential for storage of carbon dioxide in the rocks beneath the East Irish Sea. *British Geological Survey Internal Report*, CR/05/127N. 24pp.

Keyworth, Nottingham British Geological Survey 2005

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) in conjunction with the Tyndall Centre for climate change research. This case study researches the potential storage of carbon dioxide (CO_2) beneath the rocks of the East Irish Sea Basin.

Acknowledgements

This paper is published with the permission of the Chief Executive of the British Geological Survey (NERC). The author would like to thank Michelle Bentham and Sam Holloway for their help.

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Abstract

This report considers the potential for storing CO_2 in the East Irish Sea Basin, which lies between the Isle of Man and the west coast of Cumbria, Lancashire and North Wales. The East Irish Sea Basin has good potential to store CO_2 in the Ormskirk Sandstone (upper Sherwood Sandstone Group), which contains oil and gas fields that prove its ability to store buoyant fluids for millions of years. The Mercia Mudstone Group forms an effective cap rock above the Ormskirk Sandstone. The best potential is likely to be in the larger gas fields such as Morecambe South and North when they are depleted. The calculated CO_2 storage capacity in the oil and gas fields of the East Irish Sea Basin is approximately 1047 million tonnes. Further storage potential may exist in non-hydrocarbon-bearing closed structures in the Ormskirk Sandstone. The total storage capacity of these structures is estimated to be 630 million tonnes. However, the very fact that they do not contain hydrocarbons suggests the possibility that they may not be gas-tight.

1 Introduction

1.1 SUBSIDENCE HISTORY

The East Irish Sea Basin began to subside during Permian times, approximately 210 million years ago. Basin subsidence continued for most of the Permian, Triassic and Jurassic periods, allowing sediments to accumulate within it, but it was uplifted and subjected to erosion in latest Jurassic and earliest Cretaceous times. Subsidence resumed but stopped at the end of the Cretaceous period when the basin was again subject to uplift and erosion, which may still be continuing (Stuart & Cowan 1991 figure 12), albeit at very slow rates. Thus there have been two periods of erosion in the East Irish Sea basin. The first, at the end of Jurassic times, removed any Upper and Middle Jurassic strata that were deposited. The second, which started some 65 million years ago at the end of the Cretaceous period, removed any Cretaceous strata that were deposited. Consequently, the youngest strata preserved in the basin are Lower Jurassic rocks.

1.2 OIL AND GAS GENERATION

Both oil and gas fields are found in the East Irish Sea Basin (Table 2 shows the producing fields and Figure 7 shows additional discoveries), indicating that reservoir rocks present are capable of storing buoyant fluids. Oil and gas generation probably started in Jurassic times, but the Jurassic accumulations of oil and gas that are believed to have developed in most of the fields is thought to have escaped during the first period of basin uplift and erosion - at the end of the Jurassic times (Bastin et al. 2003, Stuart & Cowan 1991, Cowan & Boycott-Brown 2003, Yaliz & Chapman 2003, Yaliz & Taylor 2003, Yaliz & McKim 2003). The oil and gas presently found, for example, in the South Morecambe field gas was probably trapped in latest Cretaceous to early Tertiary times (Bastin et al. 2003) and thus may have been stored for some 50 million years or so.

2 Reservoir unit

The main reservoir rocks in the East Irish Sea Basin form the Sherwood Sandstone Group. The Sherwood Sandstone Group extends westwards over most of the East Irish Sea Basin from onshore UK (Figure 1), and is the equivalent of the Bunter Sandstone Formation in the southern North Sea. It is more than 2000 m thick in the centre of the East Irish Sea Basin (Figure 2) and has an average thickness of 1450m (Jackson et al, 1987).

Most of the hydrocarbon discoveries are entirely within the uppermost unit of the Sherwood Sandstone Group; the Ormskirk Sandstone Formation. Discoveries also extend downwards into the upper parts of the St Bees Sandstone formation (Figure 4). The top of the Ormskirk Sandstone Formation lies at depths of 250-3000m (Figure 3). It has an average thickness of 250m (Figure 4). The Ormskirk Sandstone Formation demonstrates all of the required characteristics for CO_2 storage including closed structures (traps for buoyant fluids), high porosity and permeability, and it is overlain by an effective seal, the Mercia Mudstone Group.

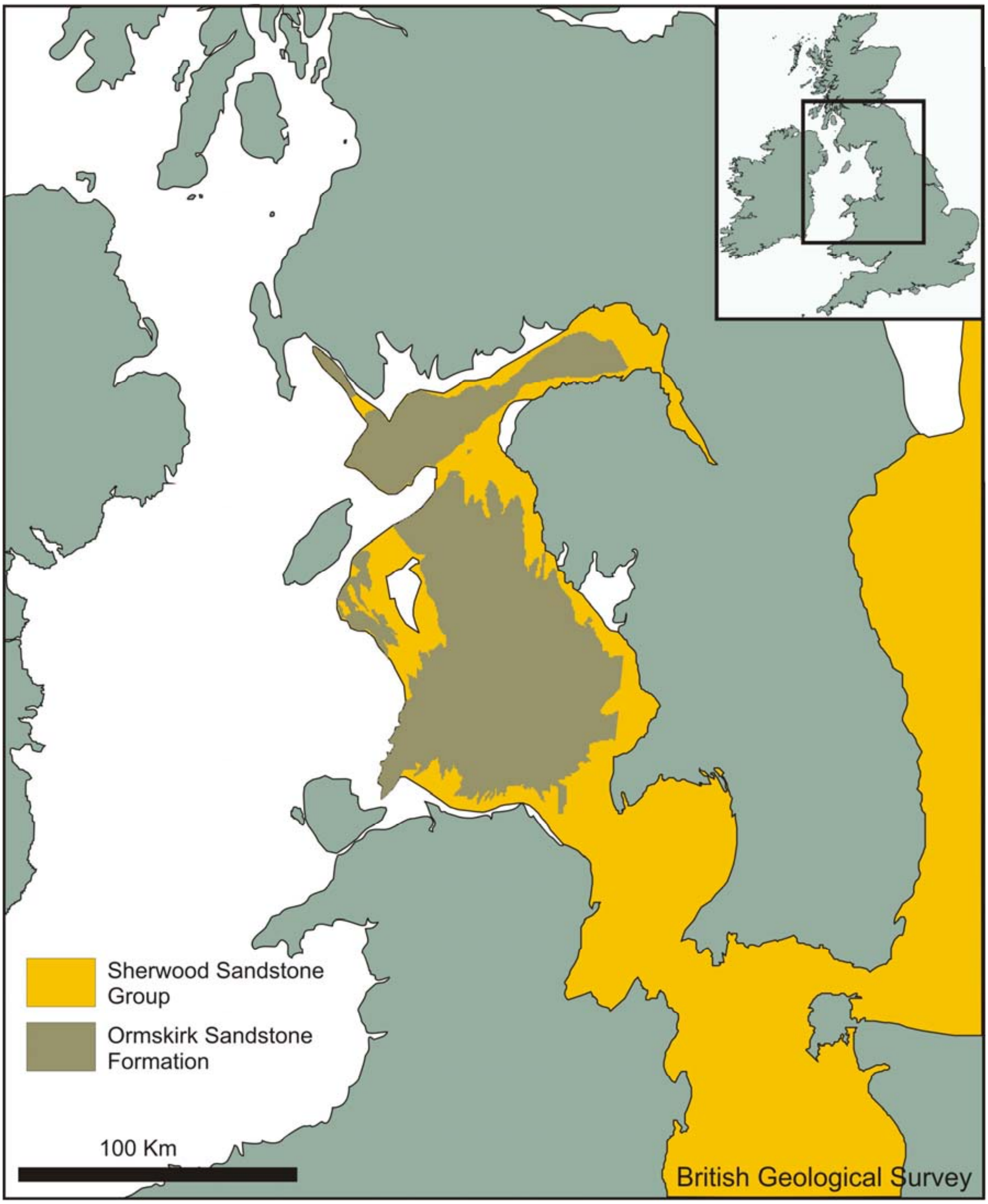

Figure 1 Map showing the extent of the Sherwood Sandstone Group and the Ormskirk Sandstone Formation

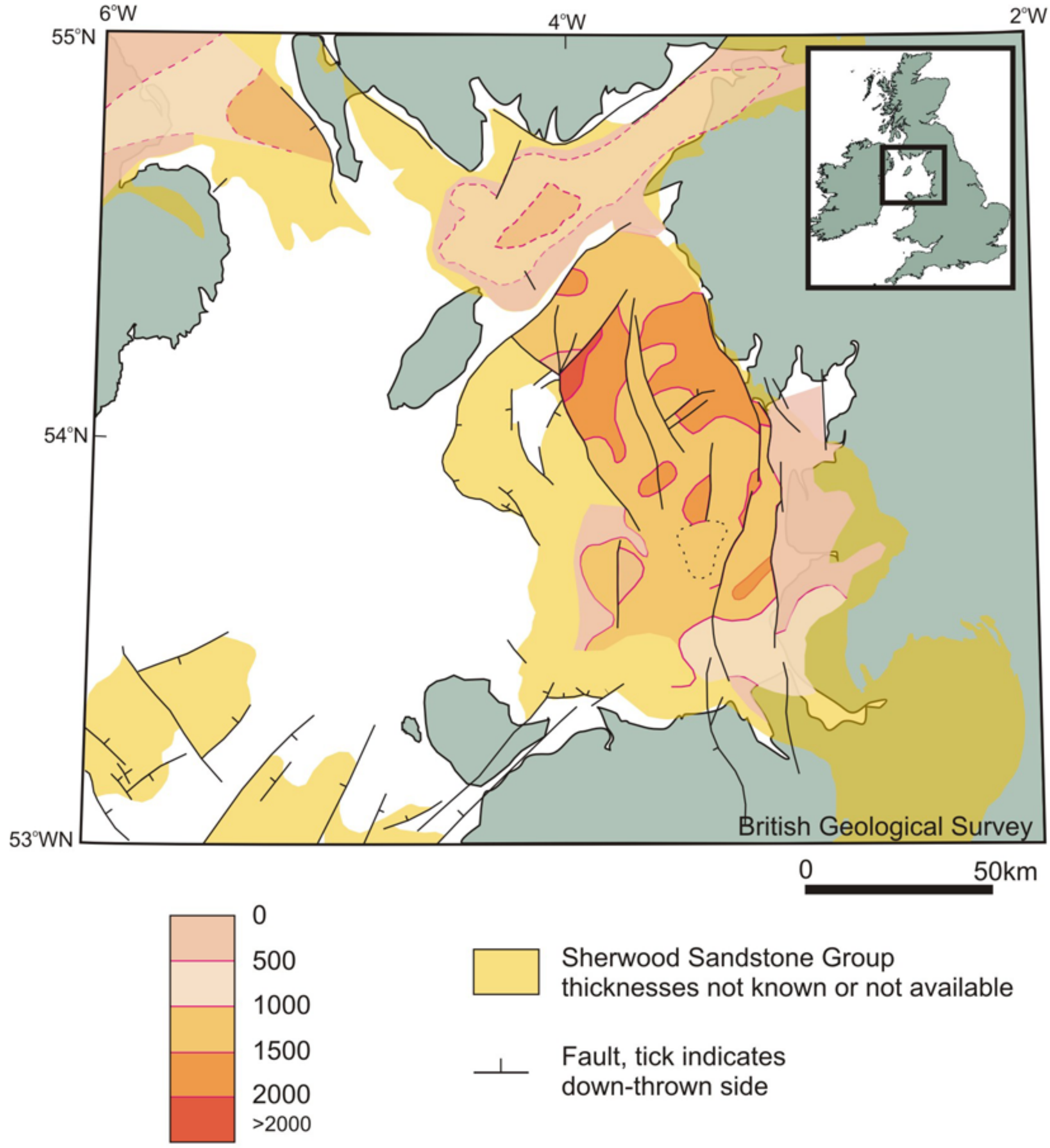

Figure 2 Thickness of the Sherwood Sandstone Group in and around the Irish Sea (adapted from Jackson et al. 1995)

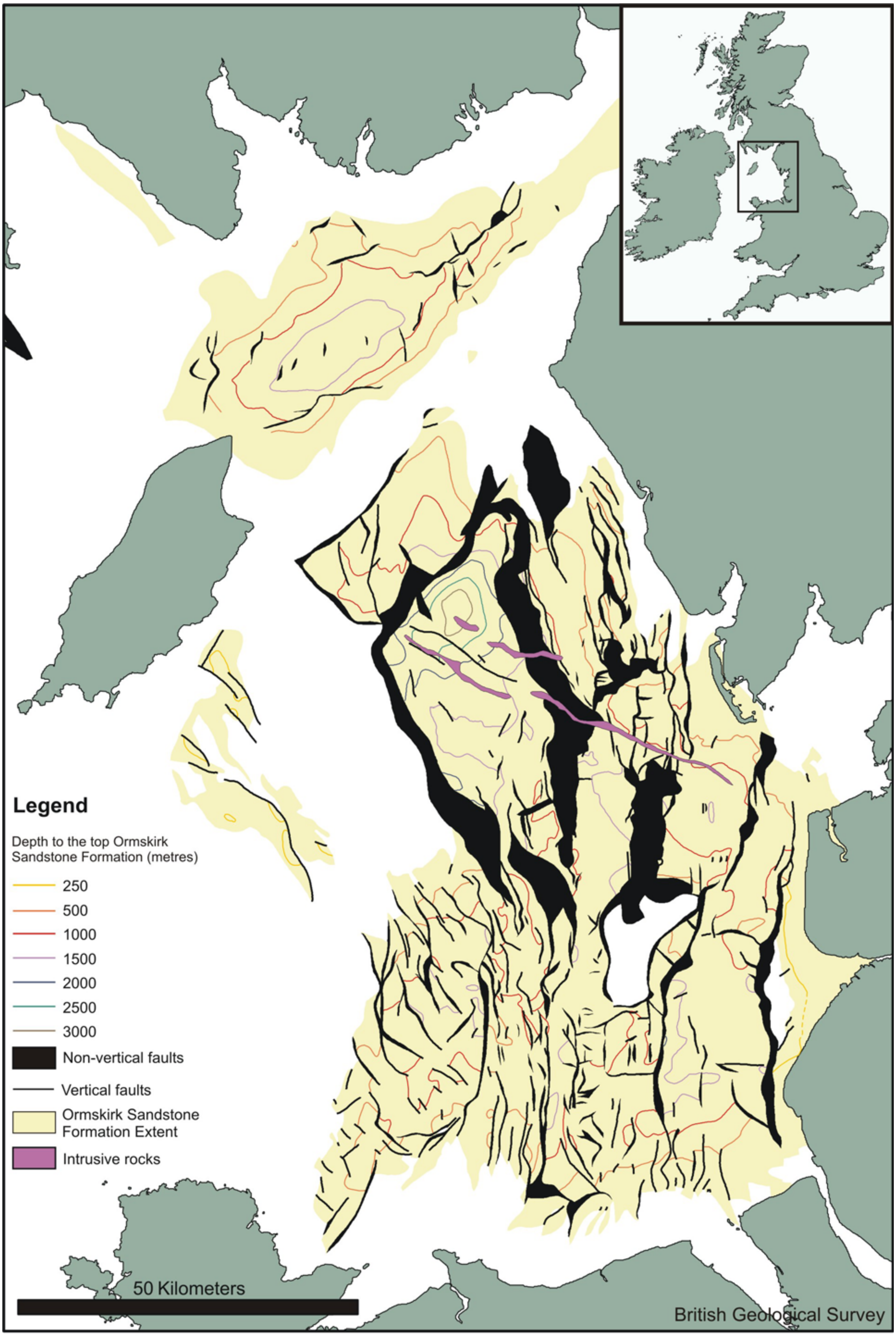

Figure 3 Depth map of the top Ormskirk Sandstone Formation in the East Irish Sea (adapted from the BGS East Irish Sea, special sheet edition)

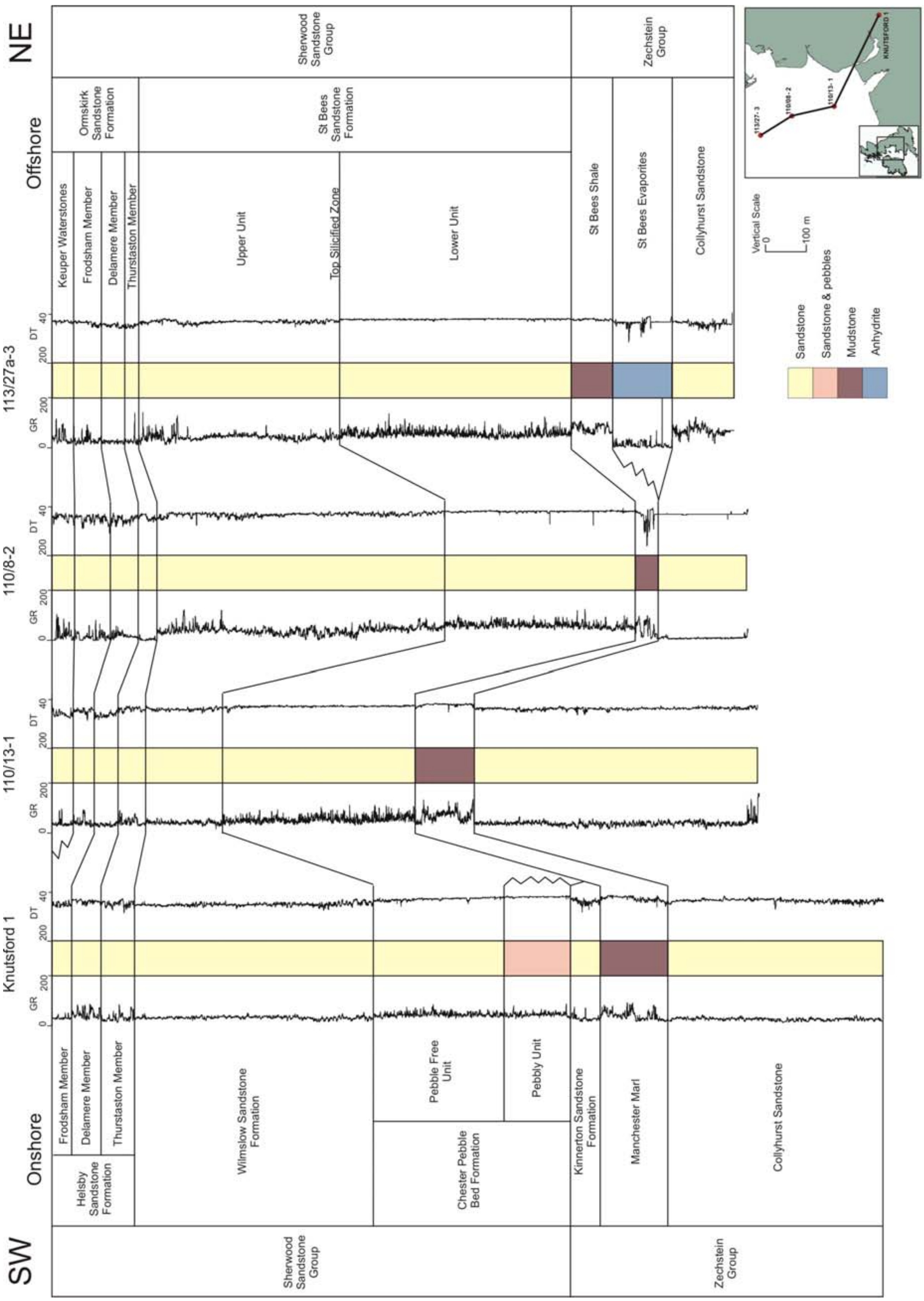

Figure 4 Correlation of the Sherwood Sandstone Group in the East Irish Sea and Cheshire Basins

2.1 POROSITY AND PERMEABILITY OF THE ORMSKIRK SANDSTONE

There are huge porosity and permeability variations in the Ormskirk Sandstone. These are the result of diagenesis - the post-burial alteration of the original sandstone (Levison, 1988; Meadows et al. 1993). Porosities range from 8–30%, and permeabilities from 0.05-10000 mD. The most important diagenetic effect is the precipitation of illite within the pore spaces. Thin illite crystals (small clay plates) can grow perpendicular to the sandstone grain faces, making it more difficult for fluids to pass through the reservoir. They clog up the pore throats (pathways between pore spaces) affecting the permeability rather than the porosity of the reservoir (Ebbern, 1981), Table 1.

Field Name	Average Porosity % (Illite-Free)	Average Porosity % (Illite affected)	Average Permeability mD (Illite-Free)	Average Permeability mD (Illite-affected)
Douglas	19	14	1000	250
Lennox	19.6	13	500	1
Millom	8-12	6-11	1	0.05
Morecambe North	9-15	12-17	1000	30
Morecambe South	8-12	9-15	180	25

Table 1 Known average porosities/permeabilities of the illite-free/illite-affected Ormskirk Sandstone

Illite precipitation occurred during burial, after hydrocarbons first migrated into the Ormskirk Sandstone. The illite-affected sandstones formed beneath a palaeo (ancient) - gas/water contact (Figure 5). Above this contact the sandstones remained illite-free because of the presence of gas, formed in early Jurassic times, in the pore spaces (Macchi et al. 1990; Woodward et al, 1987). Potassium-Argon radiometric dating indicates that illite precipitation occurred Early to Mid-Jurassic, approximately 180 million years ago (Stuart & Cowan 1991). The illite-affected layer in the South Morecambe field is >304 metres thick in the north of the field, but only about 137 metres thick in the south of the field, where it passes downwards into sandstones characterised by poorly developed fibrous illite. It is not, therefore, completely ubiquitous outside the oil and gas fields, giving hope that there might be reasonable permeability in some of the non-hydrocarbon-bearing closures. However, the presence of platy illite in the Sherwood Sandstone may greatly limit the amount of CO_2 which can be stored within the non-hydrocarbon-bearing closed structures that are described below.

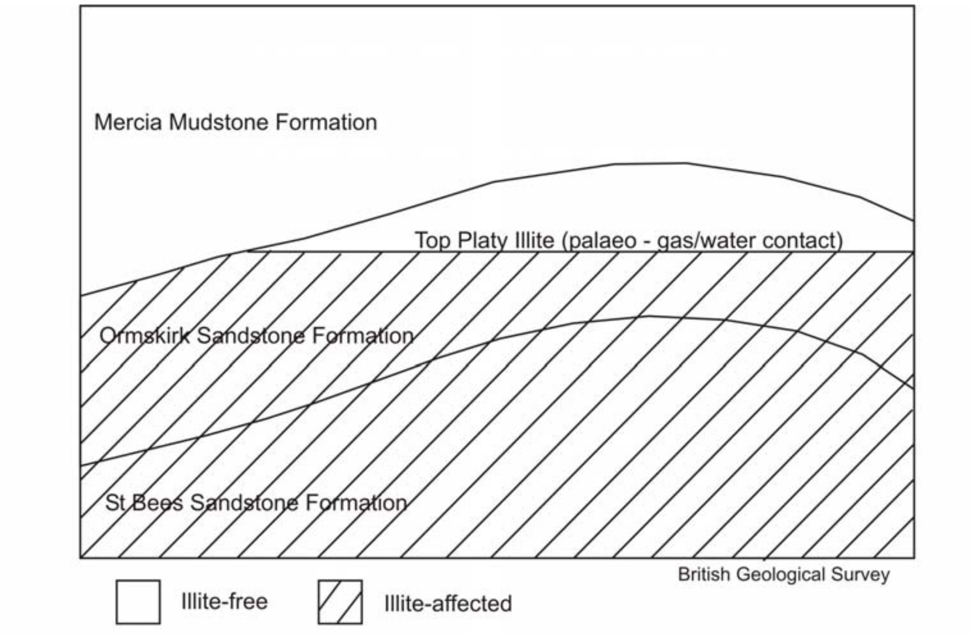

Figure 5 Simplified diagram illustrating the relationship of the palaeo-gas/water contact with the illite-free/illite-affected areas of the reservoir (not to scale)

2.2 CAPROCK/SEAL

The Mercia Mudstone Group forms an effective seal over the top of the Ormskirk Sandstone, this is proven by the hydrocarbon discoveries in this area. Up to 3200m thick in the East Irish Sea Basin (Jackson et al. 1987), it comprises silty mudstones interbedded with commonly thick units of halite (rock salt). Rock salt comprises some 35 to 55 percent of the Basinal Mercia Mudstone succession, and occurs at 5 levels (Jackson et al. 1995). It is almost impermeable unless fractured.

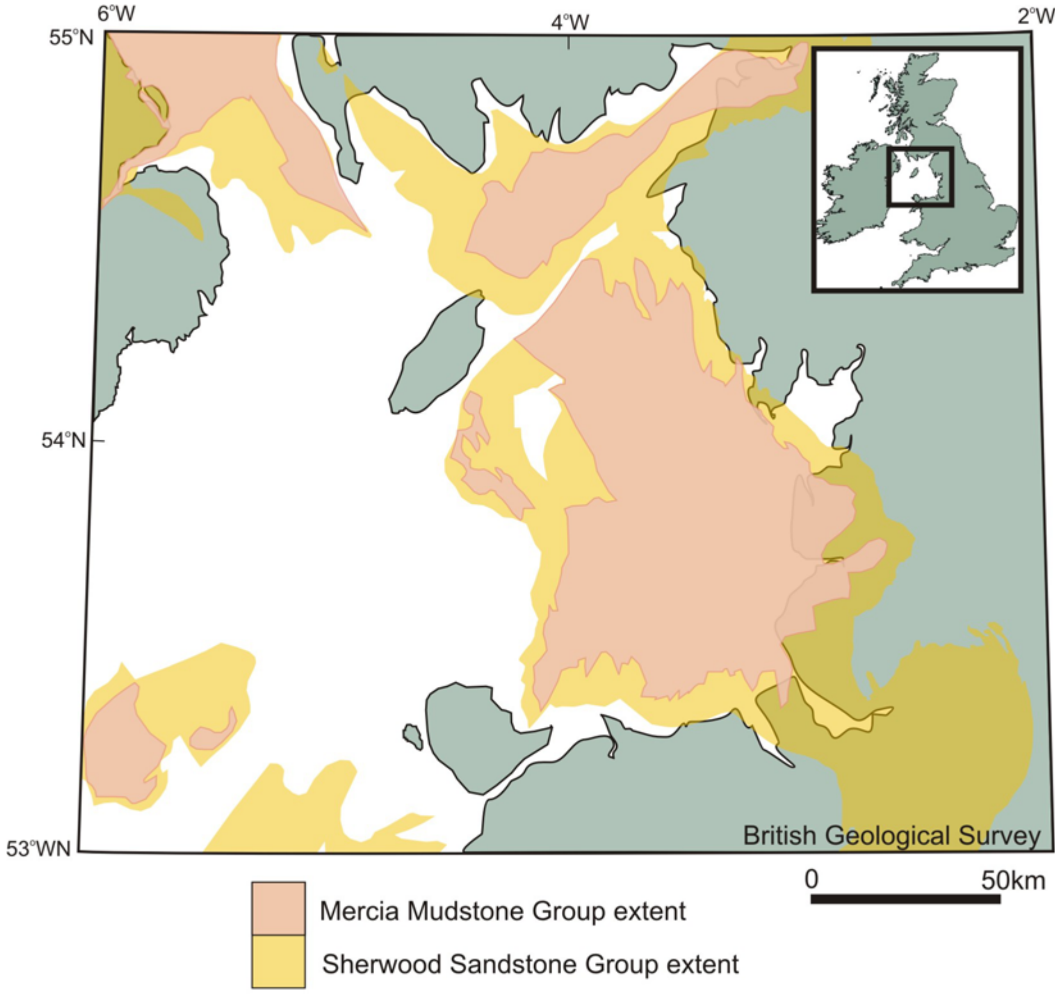

Figure 6 Extent of the Mercia Mudstone Group in and around the Irish Sea (adapted from Jackson et al. 1995)

3 CO_2 Storage Potential

The major CO_2 storage potential in the East Irish Sea Basin is within:

1. hydrocarbon fields
2. structures within which gas could potentially be trapped but which do not contain hydrocarbons (reservoir rocks that contain saline water in their pore spaces; the so-called saline aquifers).

3.1 CO_2 STORAGE CAPACITY OF THE OIL AND GAS FIELDS IN THE EAST IRISH SEA BASIN

Table 2 shows the estimated CO_2 storage capacity of the gas and oil fields in the East Irish Sea Basin. The storage capacity of the gas fields was estimated according to the following formula (Wildenborg et al. 2004):

$V_{CO2} = (V_{GAS}\ (stp) / Bg) \times \rho CO_2$ (Equation 1)

Where:

V_{CO2} = CO_2 storage capacity (10^6 tonnes)

Stp = standard temperature and pressure

V_{GAS} (stp) = volume of ultimately recoverable gas at stp (10^9 m^3)

Bg = gas expansion factor (from reservoir conditions to stp)

ρCO_2 = density of CO_2 at reservoir conditions (kg m^{-3})

V_{GAS} (stp) and Bg were obtained from the DTI oil and gas website, Meadows et al. (1997) and Gluyas J G & Hichens H M (2003). ρCO_2 was calculated from the reservoir temperature and pressure of the individual fields. The main problem with Equation 1 is that it assumes that all the pore space originally occupied by the ultimately recoverable reserves of natural gas could be filled with CO_2. There is uncertainty about this because the reservoir may compact slightly as the pore fluid pressure within it decreases. Moreover water invasion may reduce the pore space available for CO_2 storage. Ideally, the percentage of the pore space originally occupied by natural gas that could subsequently be filled with CO_2 would be determined using numerical reservoir simulations. However, no reservoir simulations were available and in their absence the following factors have been used to adapt Equation 1 (from studies by Bachu & Shaw (2003) on oil and gas fields in Alberta):

1. In gas fields with depletion drive, i.e. those where the wells are opened up and the pressure in the gas field simply depletes as it would if the gas were being produced from a sealed tank, it is assumed that 90% of the pore space could be occupied by CO_2.
2. In gas fields with water drive, i.e. those where water encroaches into the pore space formerly occupied by the produced natural gas reserves, it is assumed that 65% of the pore space could be occupied by CO_2.

The Douglas oil field has no gas cap and is being water-flooded to maintain reservoir pressure during production. This means that little of the pore space formerly occupied by the produced oil reserves will be available for CO_2 storage when water flooding ceases. The absence of a gas cap does not necessarily imply that the field is not gas tight. Gases originally present are believed to have been removed by a process called water washing, in which gas is dissolved by ground waters causing a low gas/oil ratio (Yaliz & McKim, 2003).

The storage capacity for Douglas was calculated by assuming that at some stage in its development the field would undergo enhanced oil recovery using CO_2 as an injectant. A 7% incremental oil recovery could be achieved as a result of enhanced oil recovery using CO_2.

The Lennox oil field consists of a thin oil column (44 m) overlain by a thick gas cap (232 m). In the early stages of production, the oil and its dissolved gas were produced. The dissolved gas was separated from oil, and injected into the gas cap, along with gas from the Douglas field, to maintain pressure during production of the oil. Gas production was scheduled to begin in 2004 (Yaliz & Chapman 2003). It is likely that water drive will be observed when gas production starts. Because the oil was to all intents and purposes replaced by gas during its production, the CO_2 storage capacity of the Lennox field was calculated by treating the field as a gas field with water drive.

Field name	Ultimately Recoverable Reserves – billion cubic metres (bcm)	Gas Expansion Factor (GEF)	Initial P psia	Initial P bara	Initial T Celsius	CO2 density (reservoir conditions) kg/m^3	drive mechanism	CO_2 storage capacity 10^6 tonnes
South Morecambe	146.8	**145**	1860	128	32	**806**	D	734.4
North Morecambe	27.9	**143**	1800	124	33	**792**	D	139.1
Hamilton	14.33	**108**	1404	97	30	**764**	W	65.9
Lennox (gas cap)	10.31	**125**	1620	112	30	**795**	W	42.6
Millom	6.07	*128*		0		*788*	U	24.3
Hamilton North	5.34	**120**	1535	106	30	**784**	W	22.7
Dalton	2.87	*128*		0		*788*	U	11.5
Bains	1.36	*128*		0		*788*	U	5.4
Calder		*128*		0		*788*	U	0.0
Darwen		*128*		0		*788*	U	0.0
Hamilton East		*128*		0		*788*	U	0.0
Lennox (oil)	0.01	**125**	1620	112	30	**795**	GI, W	0.0
Crossans		*128*		0		*788*	U	0.0
Subtotal								1045.9
	7% OOIP bcm	FVF						
Douglas (oil)	0.00224	1.08	1125	78	30	**685**	WI	1.4
Subtotal								1.4
Total								**1047.4**
Notes:								
where unknown, GEF (Gas Expansion Factor) is taken as average of known GEF's								
where unknown, CO2 density is taken as average of calculated CO2 densities								
drive mechanism: D = depletion, W = significant water drive, WI = water injection, GI = gas injection, U = unknown								

Table 2 CO_2 Storage capacities of the oil and gas fields in the East Irish Sea Basin

To put these figures in context, the nearby Connah's Quay power plant on the Dee Estuary, (Figure 7) emitted 4.3 Million tonnes of CO_2 in 2002. The estimated total CO_2 storage capacity available in the East Irish Sea Basin oil and gas fields amounts to some 243 years of emissions from this plant. However, given a plant lifetime of 25 years, and the fact that CO_2 capture would itself create significant extra emissions, it is clear that only the North Morecambe and South Morecambe fields have the potential to store the lifetime emissions from such a plant. The location of oil and gas fields accessible from the Point of Ayr and Barrow Shore Terminals is shown in Figure 7. Additional significant potential currently accessible from the Barrow terminal includes Millom and Dalton. A combination of the Hamilton, Lennox and Hamilton North fields, all currently accessible from the Point of Ayr terminal, could also be used. It is unlikely that any of the fields smaller than Dalton would be used for CO_2 storage from a large power plant such as Connah's Quay as they would have a very short operational lifetime. Moreover, under the assumptions made above, little CO_2 would be stored as a result of EOR in the Douglas field.

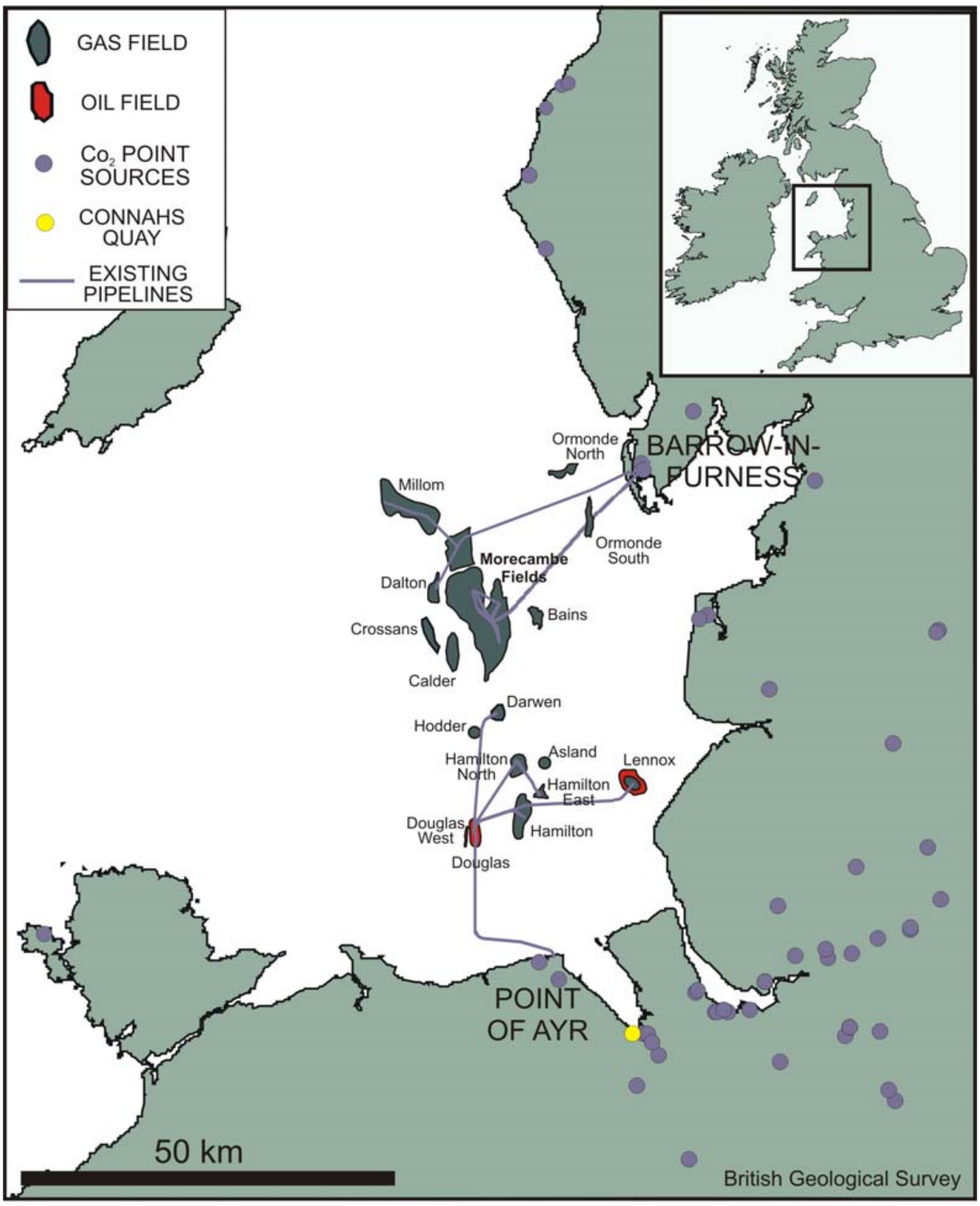

Figure 7 Map of the oil and gas fields near the Point of Ayr

3.1.1 Further information on the oil and gas fields of the East Irish Sea basin

The Morecambe field (Figure 7) is volumetrically the second largest gas field on the UK continental shelf. It contains 12.1% of the proven UK gas reserves and is divided into north and south fields by a deep narrow graben filled by the Mercia Mudstone Group. Morecambe's main reservoir lies within the Ormskirk Sandstone Formation, which on average is 250m thick, though in crestal parts of the South Morecambe field, the top 200m of the St Bees Sandstone Formation is above the gas-water contact (1143m). The north and south Morecambe fields together comprise approximately 83% of the available storage capacity in the oil and gas fields of the East Irish Sea.

The development plan for south Morecambe is based on using the facility for high rate seasonal gas supplies during the winter months; the first gas was produced in January 1985. South Morecambe has 34 producing wells, the top of the gas reservoir is 900m below sea level and the original recoverable reserves were 5.1 trillion cubic feet (tcf). It is believed that this reservoir shows tank-like behaviour in that there appears to be no evidence of water influx or of further significant gases being introduced from the surrounding rocks (Bastin et al. 2003). The design life for the facilities here is 40 years, and they were installed in 1990. This site is therefore not likely to be available for storing CO_2 until at least the year 2030.

Production at the Millom and Dalton fields began in 1999, with estimated combined recoverable reserves of 300 billion cubic feet (bcf). The expected lifespan of these two fields is 20 years. The earliest therefore that they would be expected to be available for CO_2 storage is approximately 2019.

The Rivers fields (Calder, Crossans, Darwen, Asland and Hodder) are only now being developed and coming on line. Production started at Calder in 2004, whilst Crossans and Darwen are to be implemented by 2007. The five fields are estimated to contain a combined total of 250 bcf of gas.

The Liverpool Bay fields (Douglas, Douglas West, Lennox, Hamilton, Hamilton East and Hamilton North) have estimated initial recoverable gas reserves of 1.2 trillion cubic feet of gas, and more than 160 million barrels of oil. Production began 1996.

The Bains field has estimated gas reserves of 50 bcf and only started production in 2002. Bains has no production platform and is remotely operated from south Morecambe. The gas produced from Bains and south Morecambe are mixed and transported onshore.

It is unlikely that the Rivers, Liverpool Bay and Bains fields will be available for storage for many years yet.

3.1.2 Oil and gas composition

Table 3 summarises the composition of the oil and gas fields in the east Irish Sea. A gas containing high levels of H_2S is referred to as a 'sour gas' and a gas containing low levels is referred to as a 'sweet gas'. Both the H_2S and CO_2 in gas are highly corrosive and therefore specialist chromium steels are required for transportation pipelines and for the casings in the production wells.

The gas from the Rivers fields contains high levels of H_2S. The Douglas Field, which produced the first offshore oil from the East Irish Sea basin, contains high levels of H_2S and other sulphur compounds that are removed during processing (Yaliz & McKim, 2003).

North Morecambe contains high levels of CO_2 (approx 6%), and due to the corrosive effects a new pipeline had to be installed. The CO_2 is removed during processing on the north Morecambe terminal (Cowan and Boycott-Brown, 2003).

Therefore, there are fields in the east Irish Sea where the infrastructure is already sufficient to cope with the corrosive effects expected whilst injecting CO_2.

FIELD NAME	FIELD TYPE	GAS/OIL COMPOSITION
Millom	Gas	Sweet
North Morecambe	Gas	High CO_2 & N_2
South Morecambe	Gas	Sweet
Dalton	Gas	Sweet
Hamlton North	Gas	Sweet
Darwen	Gas	Sour
Hamilton East	Gas	Sweet
Hamilton	Gas	Sour
Calder	Gas	Sour
Bains	Gas	Sweet
Crossans	Gas	Sour
Lennox	Gas	Sour
Asland	Gas	Sour
Douglas	Oil	High H_2S
Lennox	Oil	High H_2S

Table 3 Composition of the oil and gas in fields in the East Irish Sea Basin

3.2 STORAGE CAPACITY OF SALINE AQUIFERS IN THE EAST IRISH SEA

Table 4 shows the potential CO_2 storage capacity of closed structures in the Ormskirk Sandstone that do not contain oil and gas. Closed structures were identified from a map of the top Ormskirk Sandstone Formation derived from seismic data (British Geological Survey, 1994) and are shown in Figure 8. Because water has to be displaced from the pore space in aquifers, and the reservoir is heterogeneous, much of the pore space can be bypassed by migrating CO_2 when it is injected into such structures. This results in a less than perfect sweep of CO_2 through the pore space and relatively low CO_2 saturation of the reservoir rock. Based on reservoir simulation of closed structures in the Bunter sandstone (Obdam et al. 2003), it is expected that the maximum CO_2 saturation of the pore space that could be achieved is approximately 40%. Other parameters used in the calculation are given below:

Average surface temperature 10°C

Geothermal gradient 25°C km^{-1}

Porosity 15%.

Pressure gradient 1.1 bar m^{-1}

ID No.	Rock volume m^3	Pore volume m^3	Depth	Reservoir Temp C	Reservoir pressure bar	CO_2 density kg/m^3	CO_2 sweep efficiency	CO_2 storage potential Mt
4	1171184828	175677724.2	500	22.5	55	163.66	0.4	11.5
5	1870397001	280559550.1	687	27.2	76	730.96	0.4	82.0
6	8144809720	1221721458	750	28.8	83	735.06	0.4	359.2
7	5797513.8	869627.07	811	30.3	89	738.04	0.4	0.3
8	1331495519	199724327.9	500	22.5	55	163.66	0.4	13.1
9	7883750844	1182562627	542	23.6	60	195.13	0.4	92.3
10	164502223.3	24675333.5	679	27.0	75	730.34	0.4	7.2
12	2045018646	306752796.9	500	22.5	55	163.66	0.4	20.1
17	3479276619	521891492.8	500	22.5	55	163.66	0.4	34.2
18	8404501245	1260675187	100	12.5	11	21.825	0.4	11.0
Total								630.8

Table 4 CO_2 storage capacities of the non-hydrocarbon-bearing closed structures within the Ormskirk Sandstone saline aquifer of the East Irish Sea Basin. See Figure 8 for location map.

The combined total of CO_2 that it is estimated can be stored in the closed structures of the saline aquifer is 630 million tonnes (Mt). This is the equivalent of 146 years of emissions from Connah's Quay power plant.

Although the reservoir unit demonstrates all of the necessary properties required for geological storage, several of the structures do not lie at depths greater than 800m. The CO_2 therefore will not be in its dense supercritical phase where it occupies less space. This does not mean however that CO_2 cannot be stored; it just means that less will be stored (Brook at al. 2003).

The fact that they do not contain gas (or oil) suggests that either they are not gas-tight or they do not lie on the migration path of any oil and gas generated in the basin. Further work is required to establish which of these reasons accounts for the absence of oil and gas in the non-hydrocarbon-bearing structures.

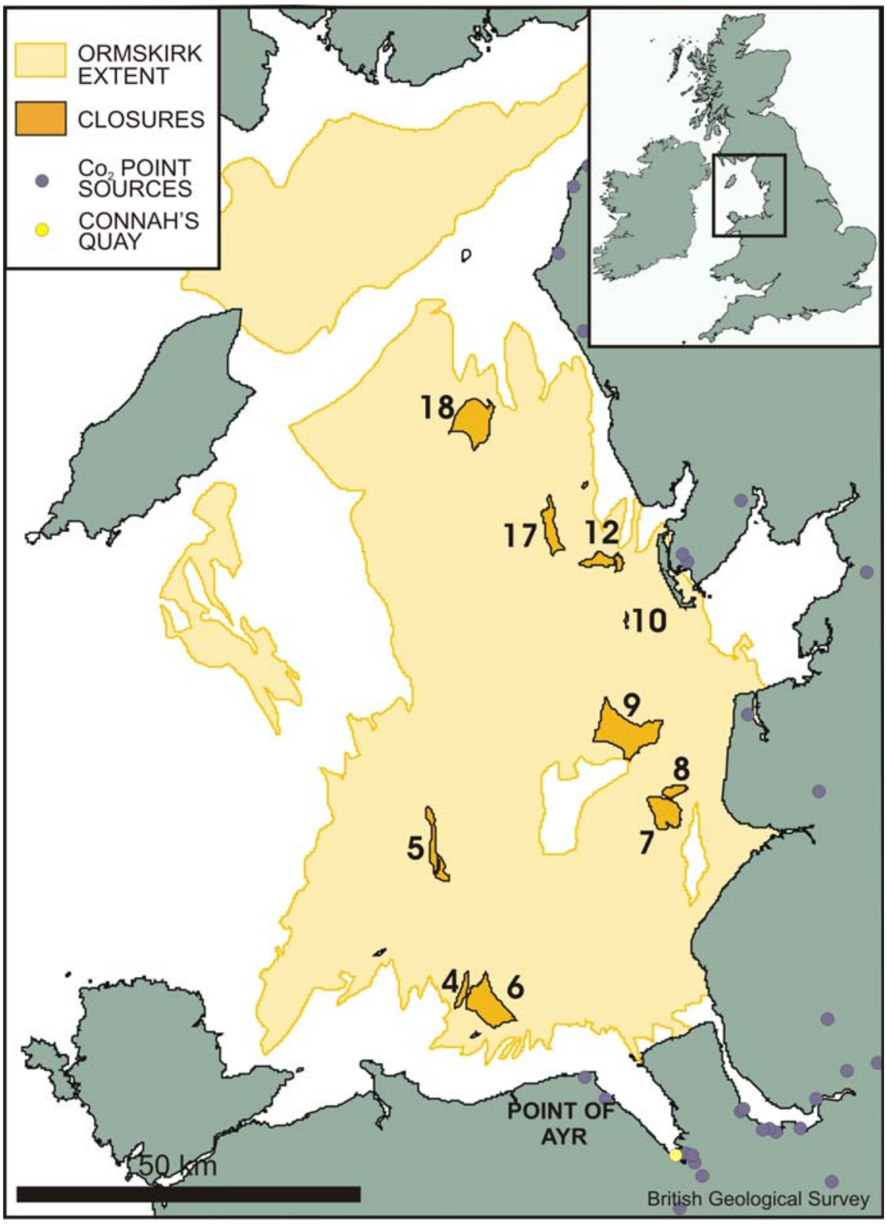

Figure 8 Map of the closed structures in the saline aquifer near the Point of Ayr

4 Conclusions

The East Irish Sea Basin has considerable CO_2 storage potential, particularly in its gas fields. On depletion these have a CO_2 storage capacity estimated to be in the order of 1046 million tonnes. More than half of this lies in the South Morecambe field, and more than 1040 million tonnes lies within fields with an estimated storage capacity of more than 10 million tonnes.

There is considerable further potential in the Ormskirk Sandstone aquifer. Here 630 million tonnes of CO_2 might be stored in mapped closed structures. However, further work is required to prove whether or not these structures are gas-tight.

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