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Appendix 2: An assessment of the potential for subsurface CO₂ storage in two regions of the Central Irish Sea Basin.

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Appendix 2: An assessment of the potential for subsurface CO₂ storage in two regions of the Central Irish Sea Basin.

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) and was undertaken under the joint BGS and Geological Survey Ireland (GSI) Irish Sea Carbon Capture and Storage project.

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Summary

This report describes work done as part of the British Geological Survey (BGS) and Geological Survey Ireland (GSI) joint Irish Sea Carbon Capture and Storage (CCS) project. It focuses on two seismic surveys a well defined area of 2D seismic in the Irish Sector of the Central Irish Sea Basin (CISB) and a 3D seismic survey in the central area of the CISB (UK sector). It acts as a case study for the whole CISB in assessing the potential for CO₂ storage. The work identified a number of small closed structures within the Ormskirk Sandstone Formation which may have the potential to store up to a maximum of 50 Mt of CO₂. However, risk of leakage via faulting in the area is considered to be high.

1 Introduction

This report results from work carried out as part of the co-funded Irish Sea Carbon Capture and Storage Project between the Geological Survey of Ireland (GSI) and the British Geological Survey (BGS). The overall aim of this project is the creation of a seamless integrated knowledge resource of Ireland-UK Irish Sea Carbon Capture and Storage (CCS) opportunities, to facilitate informed decision making. A transnational GIS and training also form part of the deliverables.

It follows on from the ‘All Ireland Study’ (2009) – a high level study using publically available data to calculate the theoretical capacity for the subsurface storage of CO₂ both offshore and onshore Ireland. The All Ireland study identified that the Central Irish Sea Basin (CISB) has the potential to store CO₂ in the Triassic Ormskirk and St Bee’s Sandstone Formations. This study calculated a large maximum theoretical capacity in the Central Irish Sea Basin (CISB), but indicated that more detailed work would be needed to better understand the storage potential and risks of storage. This report summarises the results of investigations to achieve this.

2 Regional setting and stratigraphy

The Central Irish Sea Basin lies mid way between Wales and Ireland in water depths of between 30 and 100 m, and straddles UK and Irish waters (Figure 1). It has a similar geological setting to the East Irish Sea Basin in UK waters, which is an established hydrocarbon province; however there have been no significant hydrocarbon discoveries to date in the Central Irish Sea Basin.

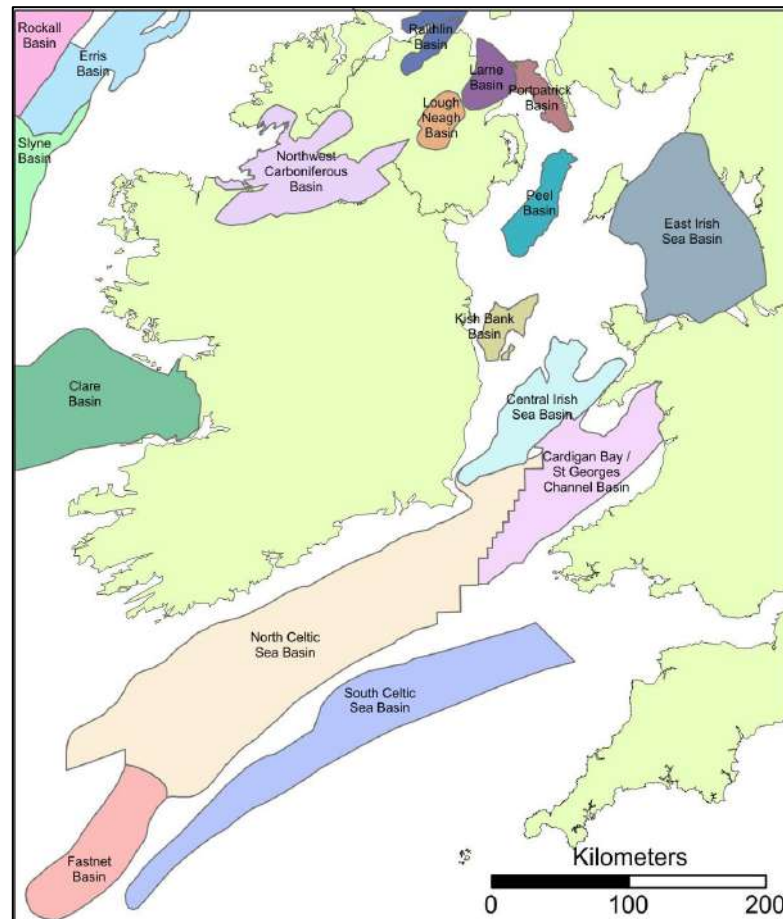


Figure 1 Sedimentary basins around Ireland

The Central Irish Sea Basin forms a NE–SW trending graben 130 km long by 50 km wide and is bounded by the Mid Irish Sea high to the NW, separating it from the Kish Bank Basin, and by the St. Tudwals Arch to the SE which marks the boundary with the Cardigan Bay Basin. Basin bounding faults have throws ranging to greater than 1 km. The southeastern bounding fault is thought to be an extension of the Menai Straits fault zone / Irish Sea lineament (Brewer et al. 1983, Tappin et al. 1994) and the NW bounding fault an offshore extension of the mylonite zone of SE Ireland (Max 1990). Structures within the basin have trends ranging from NE-SW to N-S.

The northern part of the basin is separated from the southern part by a major fault zone known as the Codling Fault Zone (Figure 2). This trends NW-SE and extends northwest into the Kish Bank Basin. In the Kish Bank Basin, strike slip movement on the Codling Fault was associated with two minor earthquakes in 1982 (Crocker et al. 2005). Gas seepages are also recorded in the area suggesting leakage of gas via faults to the seabed (Crocker et al. 2005). The nature and age of this fault zone is uncertain, but it is presumed to have been active principally during the late Paleogene / Early Neogene, while the Codling Fault in the Kish Bank Basin is still active (Crocker et al. 2005).

The primary reservoir target for CO₂ storage is the Ormskirk Sandstone and the underlying St Bees Sandstone Formations of the lower Triassic Sherwood Sandstone Group (Figure 3). There is little published information about the sedimentology of the Sherwood Sandstone Group in the CISB. The depositional environment is likely to be fluvial and aeolian (Maddox et al. 1995), the sequence consisting of interbedded sandstone, dolomites and siltstones. The Sherwood Sandstone Group has been the target for oil and gas exploration in the CISB (Floodpage et al. 2001), with the Ormskirk Sandstone Formation as the principle reservoir rock (Floodpage et al. 2001). It lies at the top of the Sherwood Sandstone Group immediately below the Mercia Mudstone Group caprock. Floodpage et al. (2001) suggest the Ormskirk Sandstone has generally

good reservoir properties with porosity values ranging from 15 – 17 % and net to gross values ranging from 65 – 95 %. This correlates with the well analysis undertaken in this study. The exception to this rule is found in the northern part of the CISB, outside of the study area where well data suggests a facies deterioration (this pattern is also seen in the well analysis).

Mudstones and halites of the overlying Mercia Mudstone Group are thought to provide potential sealing horizons. The Triassic succession is locally overlain by lower Liassic sediments in the southeast of the basin and this and the Triassic succession are unconformably overlain by Tertiary and then Quaternary sediments.

Other suitable reservoir rocks may exist in the underlying Carboniferous succession, which includes a reddened upper Carboniferous section, Coal Measure sediments of Westphalian C–D age and Dinantian limestones, although the distribution and nature of these is much less well-understood.

The all Ireland study of CCS potential suggested a significant storage potential for this basin, based on public-domain structural map data, and identified several closed structures, highlighted in Figure 2. This study has examined the seismic and well data in part of this basin so as to be able to better understand the nature and extent of any structures and to assess any risks to potential storage sites.

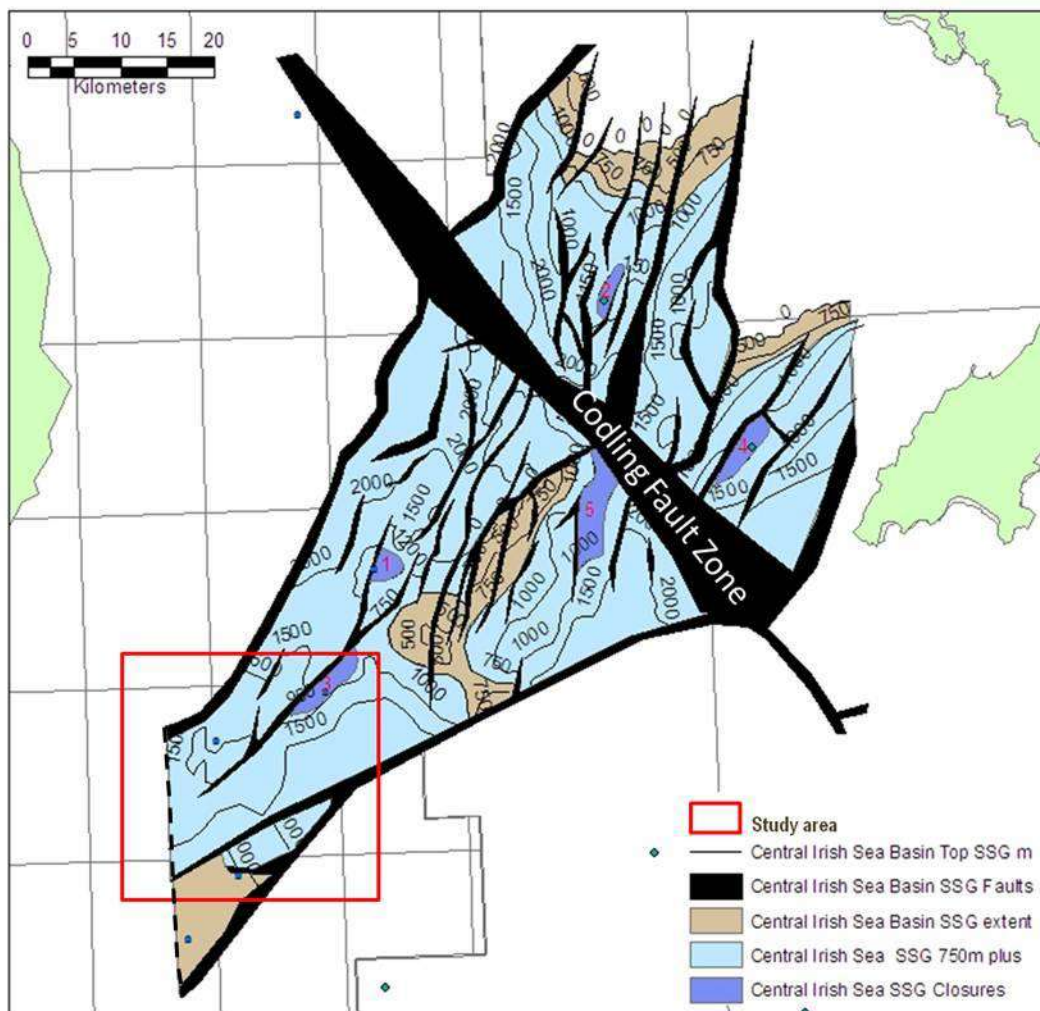


Figure 2 Central Irish Sea Basin structure (from 'All Ireland' study)

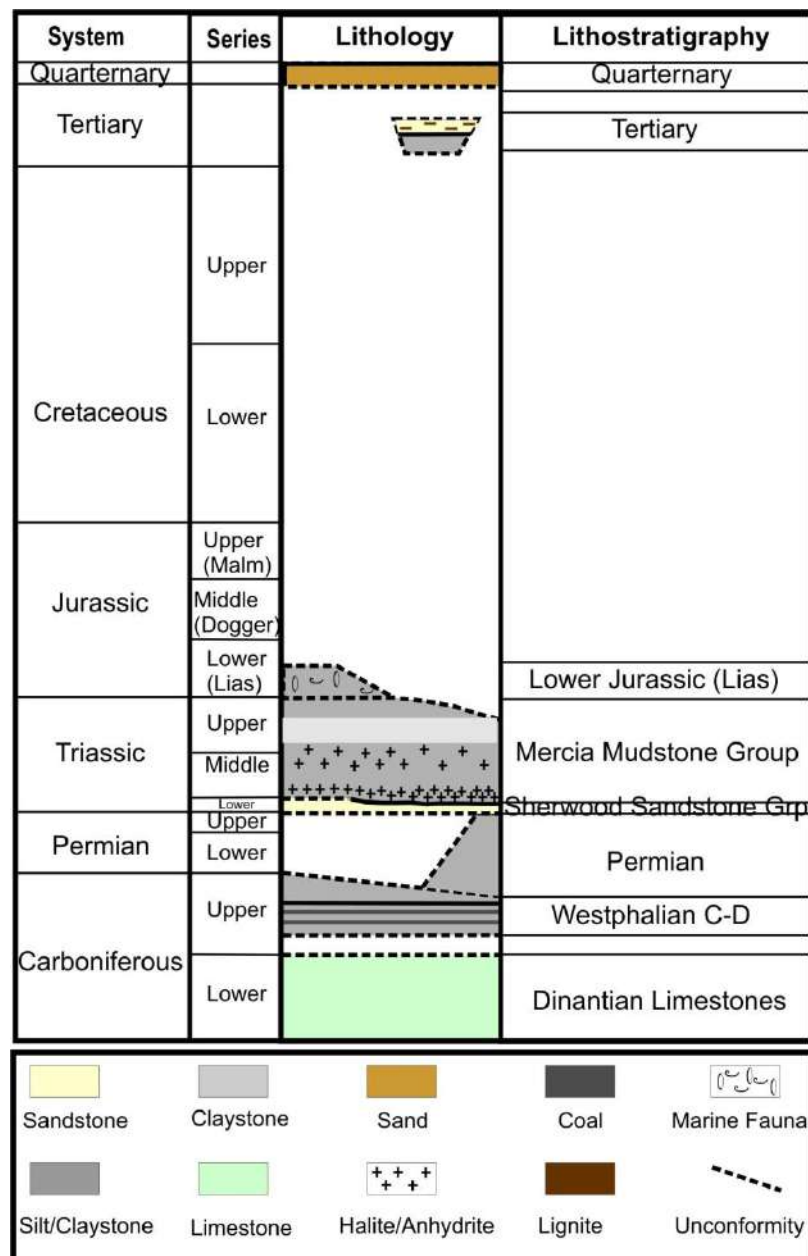


Figure 3 Stratigraphic framework for the Central Irish Sea Basin (adapted from Maingram et al. 1999)

3 Background to the study

The 'All Ireland' CCS project identified that the CISB had the potential to store CO₂. The aim of this study was to look in more detail at the storage potential of the CISB. Seismic and well data were obtained from the Petroleum Affairs Division Ireland (PAD) with coverage across the CISB in Irish waters. Additional seismic data were obtained from BGS' existing interpretation projects, along with well data obtained from the Common Data Access portal (www.ukdeal.co.uk), covering the part of the CISB in UK waters. The initial task in this project was to undertake seismic interpretation across the whole of the CISB, with the aim of identifying potential reservoirs and closures for utilisation as CO₂ stores. A coarse grid interpretation was produced over the whole basin. Analysis during the interpretation of the whole basin however established that the CISB is structurally complex and heavily faulted. The faults are aligned in a NE-SW and N-S direction and closely spaced, in some areas only 1 km apart (Figure 9). It was

therefore concluded that the CISB has a more limited potential for CO₂ storage than the original ‘All Ireland Study’ estimated as the risk of leakage through faults is likely to be high. The work programme was modified to take this information into account and it was decided to initially focus on a small 2D seismic survey in the SE of the basin in order to provide evidence of the structural style, reservoir distribution and CO₂ storage potential (study area A). This was extended to include the interpretation of a 3D seismic survey in the central region of the basin to help understand the faulting pattern in more detail (study area B).

4 Data

4.1 SEISMIC DATA

There are a number of 2D seismic surveys which together extend across the entire Central Irish Sea basin together with two 3D datasets in the central and northern part of the basin (Figure 4). Data quality varies from poor to good.

4.1.1 Seismic data in study area A

The spacing between 2D seismic lines is generally quite large (several km), which means that any structural map derived from such data will have significant uncertainties in terms of correlation of faults and extents of any structures defined. However, in the southwest of the basin, survey 1994-06 provides a dataset with a line spacing of less than 1km for lines oriented in a WNW – ESE direction. The data quality is good, faults and stratigraphy moderately well-imaged, and the dataset includes an area with 2 exploration wells (IR42/12-1 and 2). It was therefore decided that this dataset, together with any other 2D seismic lines in the same area would be used to define the area of study (Figure 5).

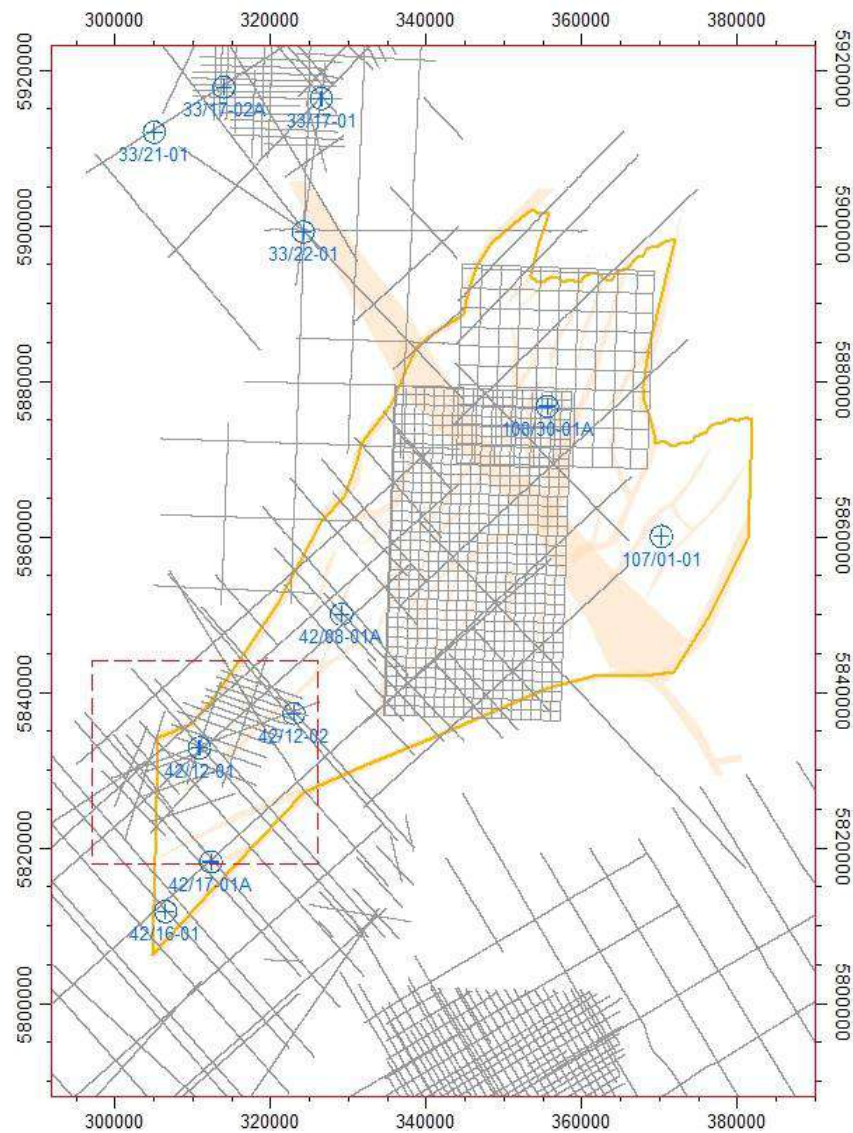


Figure 4 Location of seismic data in the CISB available for study. Red box indicates the study area A. The brown outline shows the extent of the Triassic taken from the 'All Ireland' study (Lewis et al. 2008).

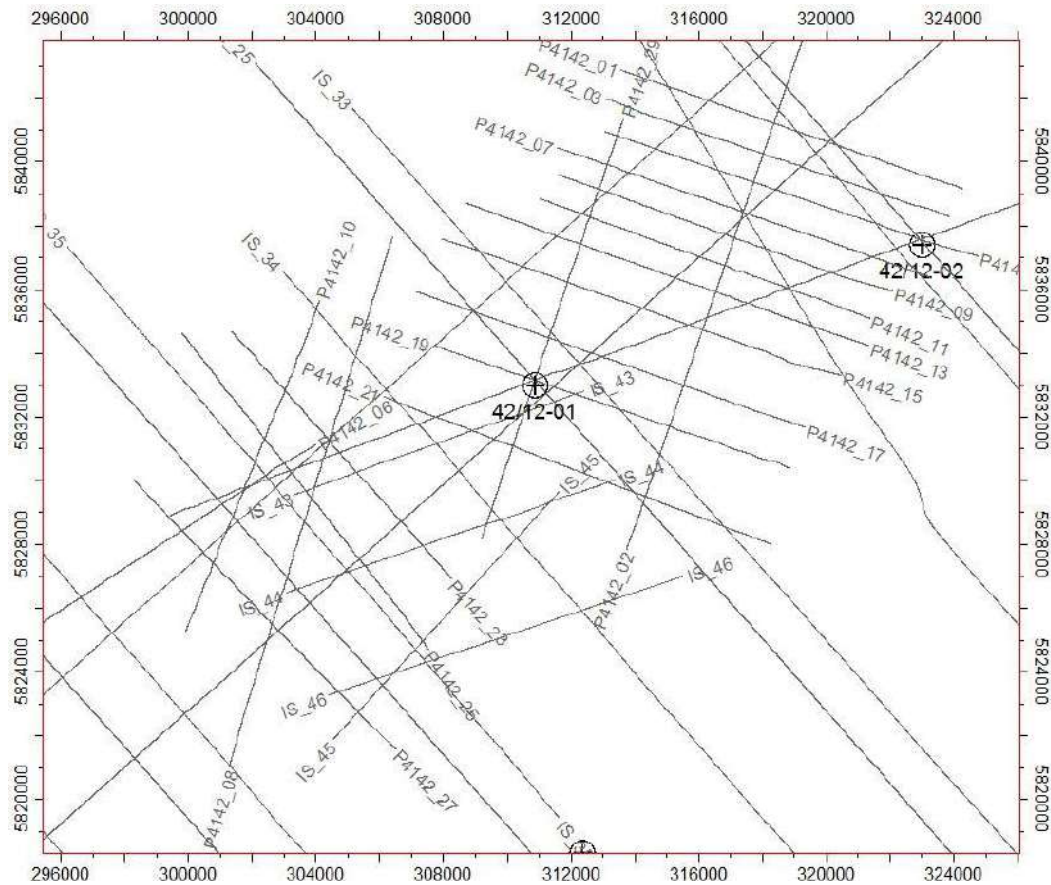


Figure 5 Extent of seismic survey used for this study area A.

4.1.2 Seismic data in study area B

Study area B concentrated on a 3D seismic survey in the UK sector which extends along the median line between UK and Irish waters (Figure 6). The 1810 inlines in the survey are orientated north-south and the 3841 crosslines are orientated east-west. The data quality is good in the majority of the survey however extensive faulting makes the imaging of the stratigraphy and faults difficult particularly in the Northern part of the survey.

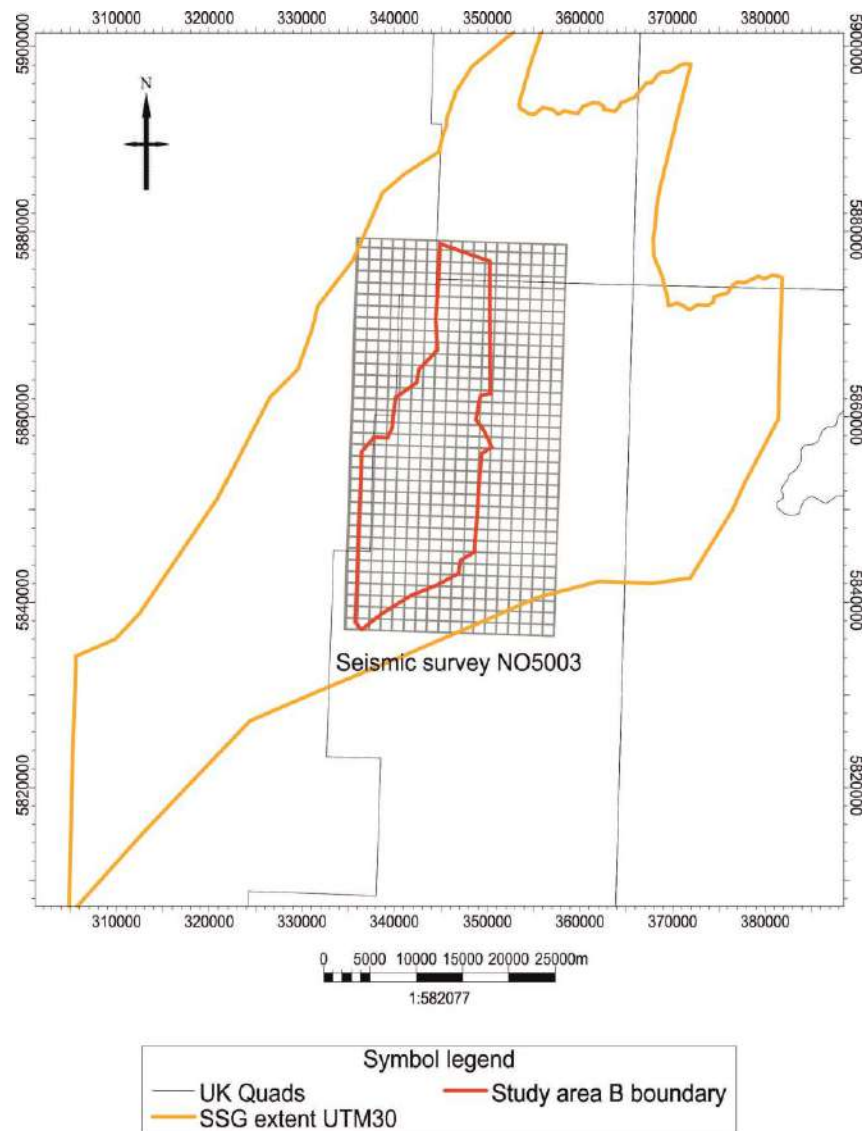


Figure 6 Location of seismic survey and extent of study area B

4.2 WELL DATA STUDY AREA A

There are three wells within the area of study and two additional wells within 7 km of the boundaries of the study area; these are listed in table 1 below.

Table 1 Well data available

Well	Composite	GR	Sonic	Density	Comments
42/08-01A	√	√	√	√	7km to NE of study area
42/12-01	√	√	√	√	In study area
42/12-02	√	√	√	√	In study area
42/16-01A	√	√	√	√	6.5 km S of study area
42/17-01A	√				Just in study area. SSG faulted out

4.3 WELL DATA STUDY AREA B

There are no wells which intersect the seismic data for study area B. The nearest wells are UK 108/30-01A, IR42/08-01A and IR 42/12-02 (5, 7 and 11 kms outside the study area boundary respectively) all are outside the boundaries of the study area. For the purpose of depth conversion the study boundary was increased to take into account these wells in order to produce velocity maps Figure 7.

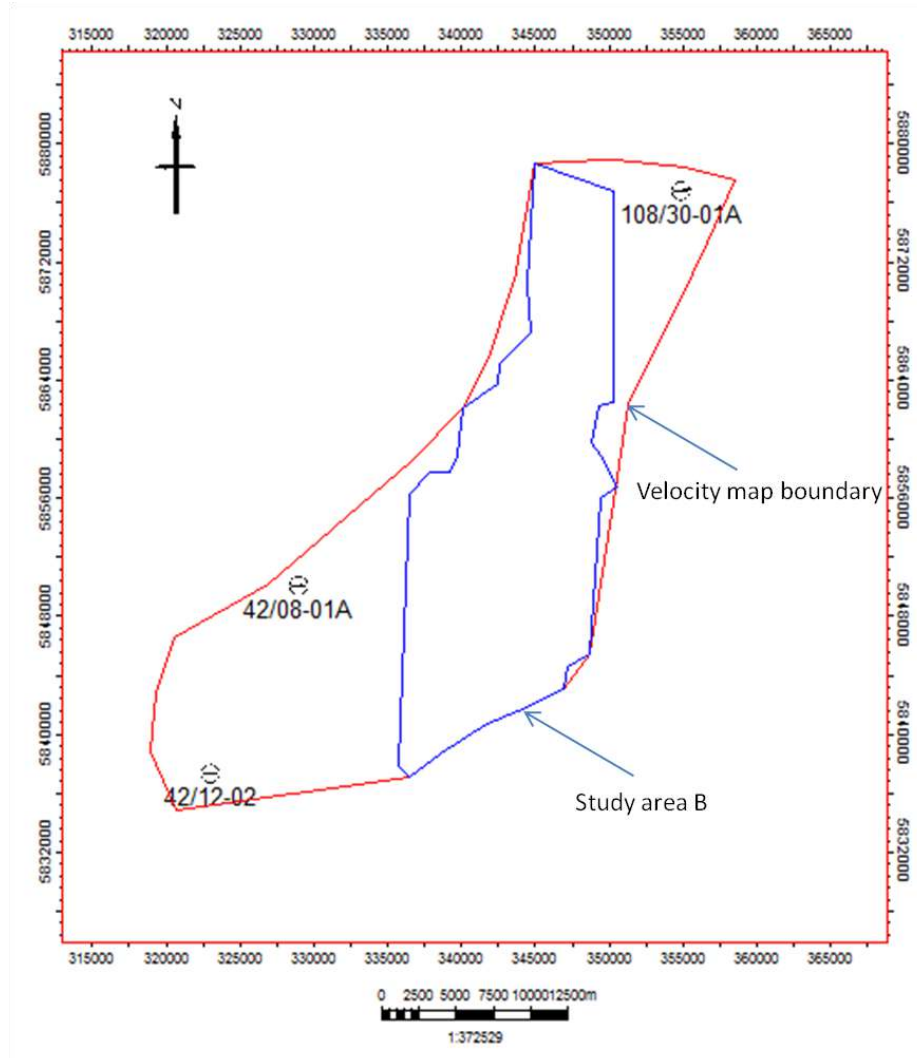


Figure 7 Showing the extent of the study area and the extent of velocity maps with the well locations indicated as circles.

5 Data Interpretation and Analysis in study area A

METHODOLOGY

The following methodology was used to interpret the seismic data, and to produce structural maps and models for use in assessing the potential to use structures for storage of CO₂. All seismic, borehole and relevant cultural data was loaded into a Petrel project, and interpretation carried out entirely using this software.

Stratigraphic correlation

- Transfer of stratigraphic picks from composite logs (where available) onto geophysical logs and correlation of logs using these picks and any lithological information as guides.

- Refinement of picks to ensure consistency, and addition of new picks where appropriate. This resulted in a correlation diagram (Figure 19) and a series of ‘well-tops’; depths to key stratigraphic levels in these boreholes – tabulated in Table 2.

Table 2 Key well tops

	Equivalent	Code
Top Mercia Mudstone Group		MMG
Top Ormskirk Sandstone Formation	Sherwood Sandstone Group (SSG). Top Thurstaston Member	OMS
Top St Bees Sandstone Formation		SBS
Top Manchester Marl		MM
Top Carboniferous		CARB
Top Dinaitian		DINA

Seismic interpretation

- Transfer of key stratigraphic picks from boreholes to 2D seismic lines: Top Ormskirk Sandstone, Top St Bees Sandstone, Top Carboniferous (Variscan Unconformity)
- Interpretation of grid of 2D and 3D seismic data, ensuring picks tie correctly where data permits
- Interpretation of additional seismic horizons where seismic data suggests key stratigraphic picks do not capture stratigraphic or structural complexities sufficiently
- Interpretation and correlation of key faults to produce fault framework.
- TWTT surfaces created within Petrel

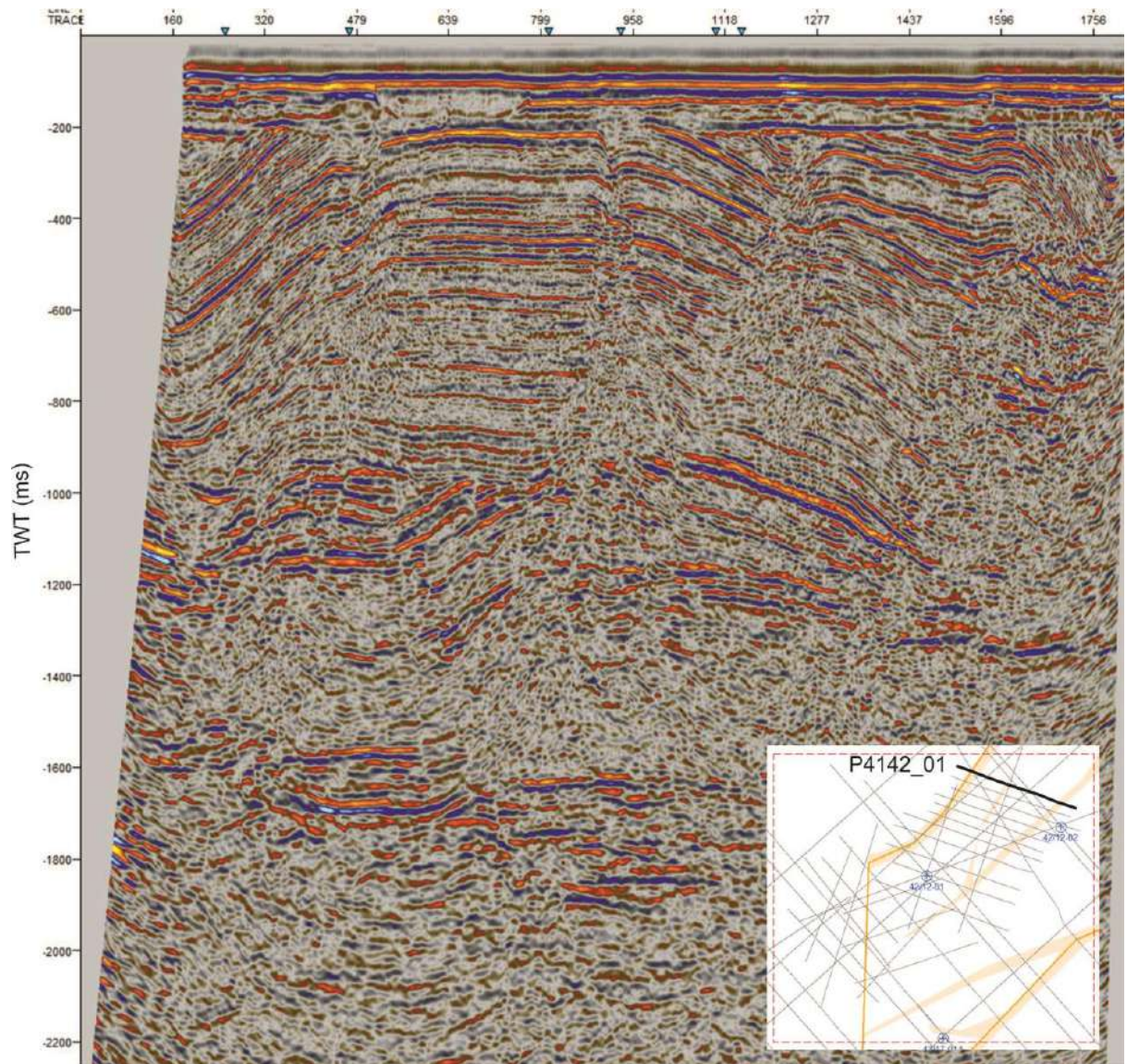


Figure 8 representative seismic section. P4142_01

BUILDING OF STRUCTURAL MODEL AND PRODUCTION OF DEPTH-CONVERTED STRUCTURAL MAPS

Model

- Faults picked on the seismic data were used in conjunction with the fault framework established during interpretation to produce a 3D fault model in Petrel.
- TWTT surfaces for top Sherwood Sandstone, top St Bees Sandstone and top Carboniferous (basement) imported into model, and adjusted to ensure surfaces intersect appropriately with faults (Figure 9).

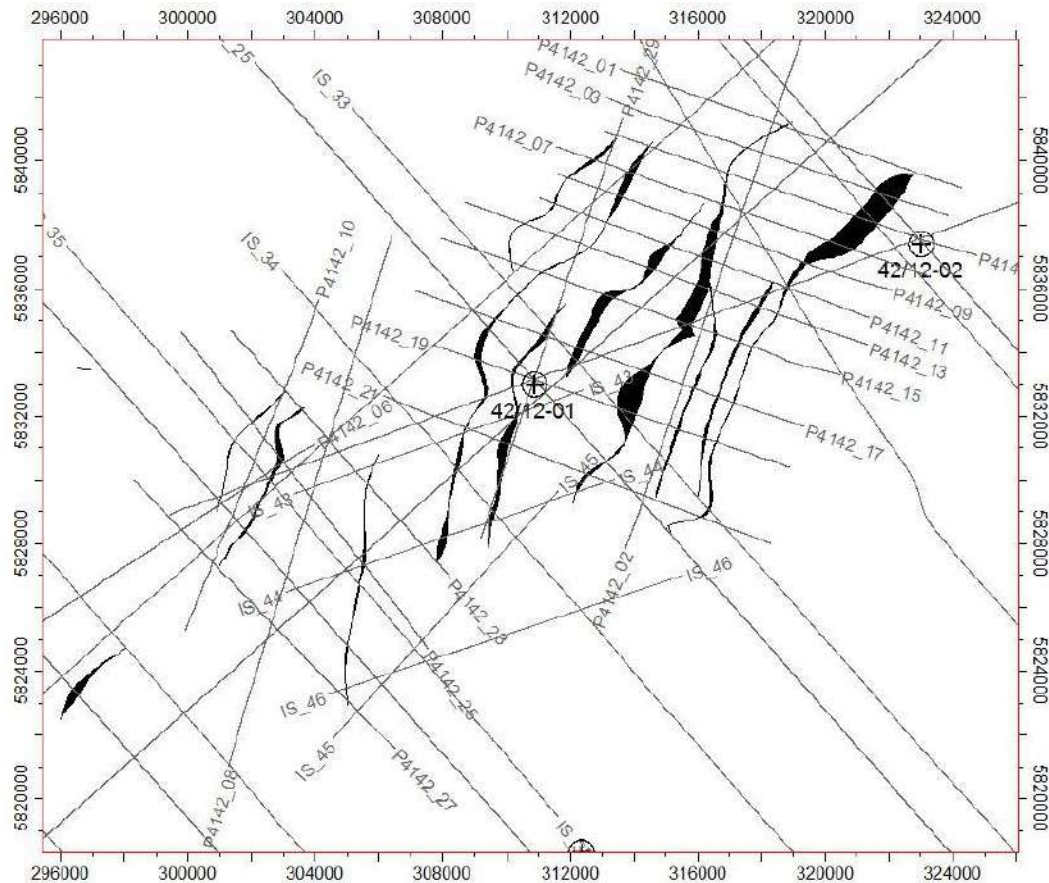


Figure 9 Faults modelled in the study area.

Production of structural maps

- Fault intersections at top Sherwood Sandstone, top St Bees Sandstone and top Carboniferous (basement) exported from model

TOP SHERWOOD SANDSTONE

- Top Sherwood Sandstone surface in model exported to create new TWTT surface that accurately reflects faults.
- Top Sherwood Sandstone TWTT surface depth converted using average velocity (2765 m per sec) determined from formation tops in wells 42/12- 01 & 2
- Top Sherwood Sandstone depth surface adjusted to fit well provings by application of residual correction taking into account the difference between the average velocity and actual velocities at individual wells. Appropriate fault intersections ensured by using fault polygons generated from the 3D fault model at Top Sherwood Sandstone level as input during the re-gridding process. Large residual error is seen within the southwestern portion of the surface, due to the lack of well depth control (Figure 10).

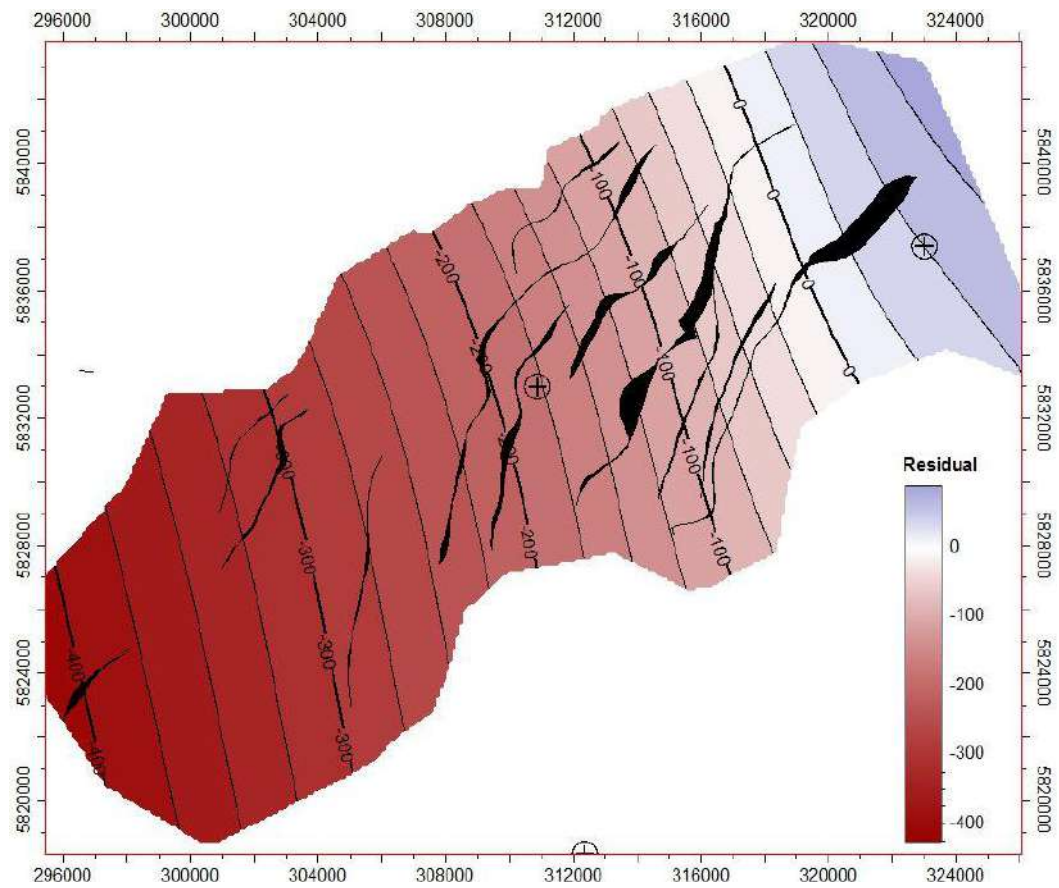


Figure 10 Residual velocity map of the top Ormskirk Sandstone Formation (Top Sherwood Sandstone Group equivalent).

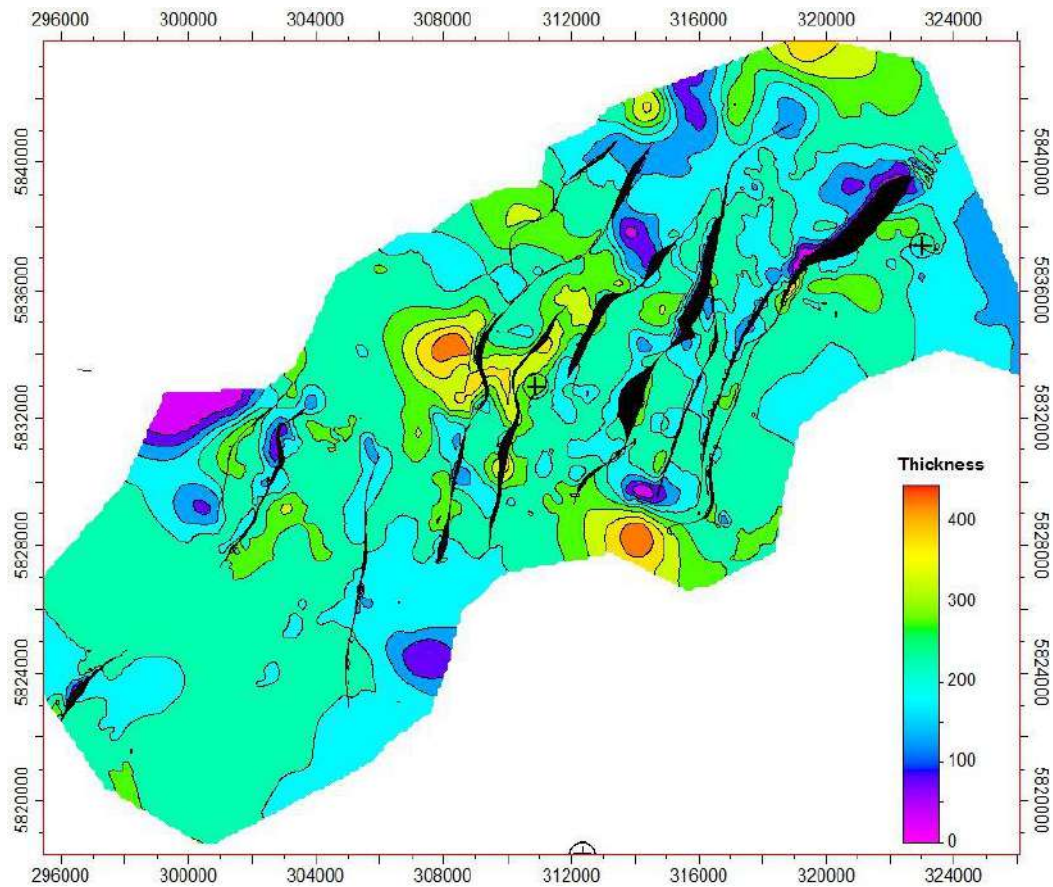


Figure 11 Ormskirk Sandstone Formation total vertical thickness.

TOP ST BEES SANDSTONE FORMATION

- TWTT thickness of Ormskirk Sandstone (i.e. TWTT difference between top Sherwood Sandstone and top St Bees Sandstone surfaces) determined from model
- TWTT thickness Ormskirk converted to true thickness using average interval velocity of Ormskirk Sandstone (3554 m per sec) determined from formation tops in wells 42/12- 01 & 2 (Figure 13)
- Depth surface for top St Bees Sandstone produced by subtracting Ormskirk thickness from top Sherwood Sandstone depth surface

Top St Bees Sandstone depth surface adjusted to fit well provings by application of residual correction taking into account the difference between the average velocity and actual velocities at individual wells (Figure 12). Appropriate fault intersections ensured by using fault polygons generated from the 3D fault model at top St Bees Sandstone level as input during the re-gridding process

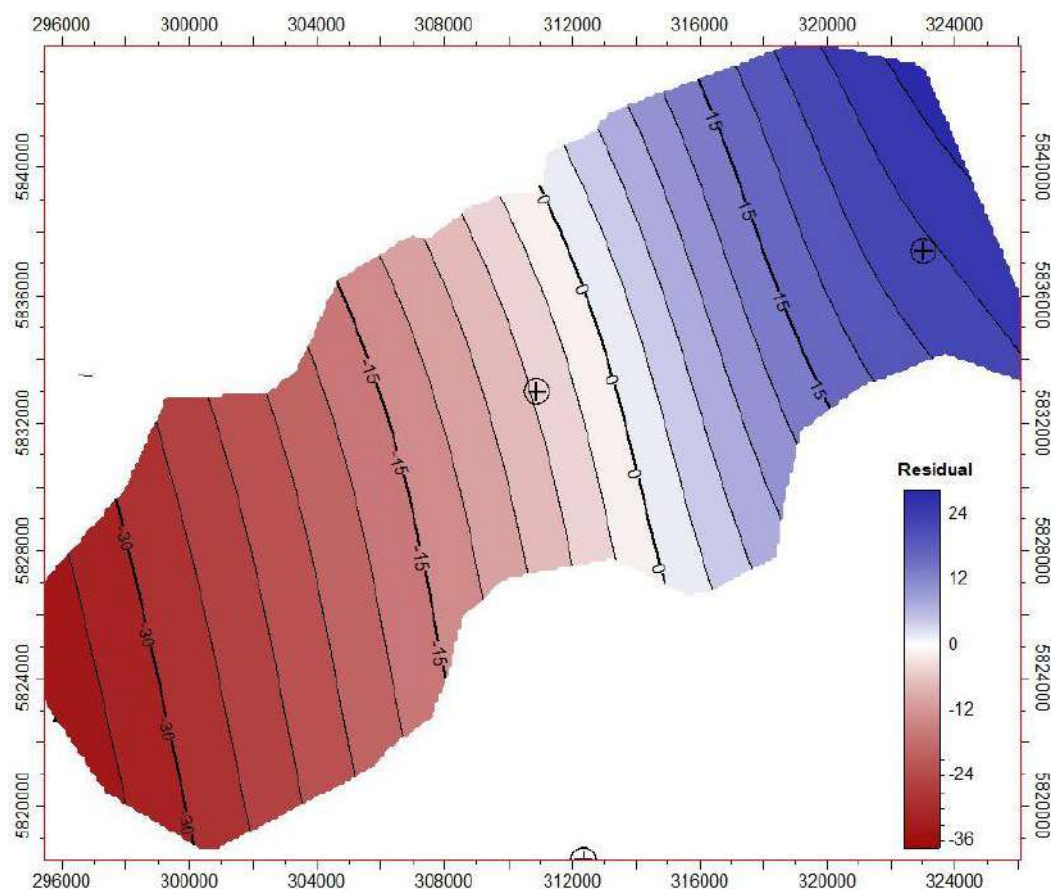


Figure 12 Top St Bees Sandstone Formation residual velocity map

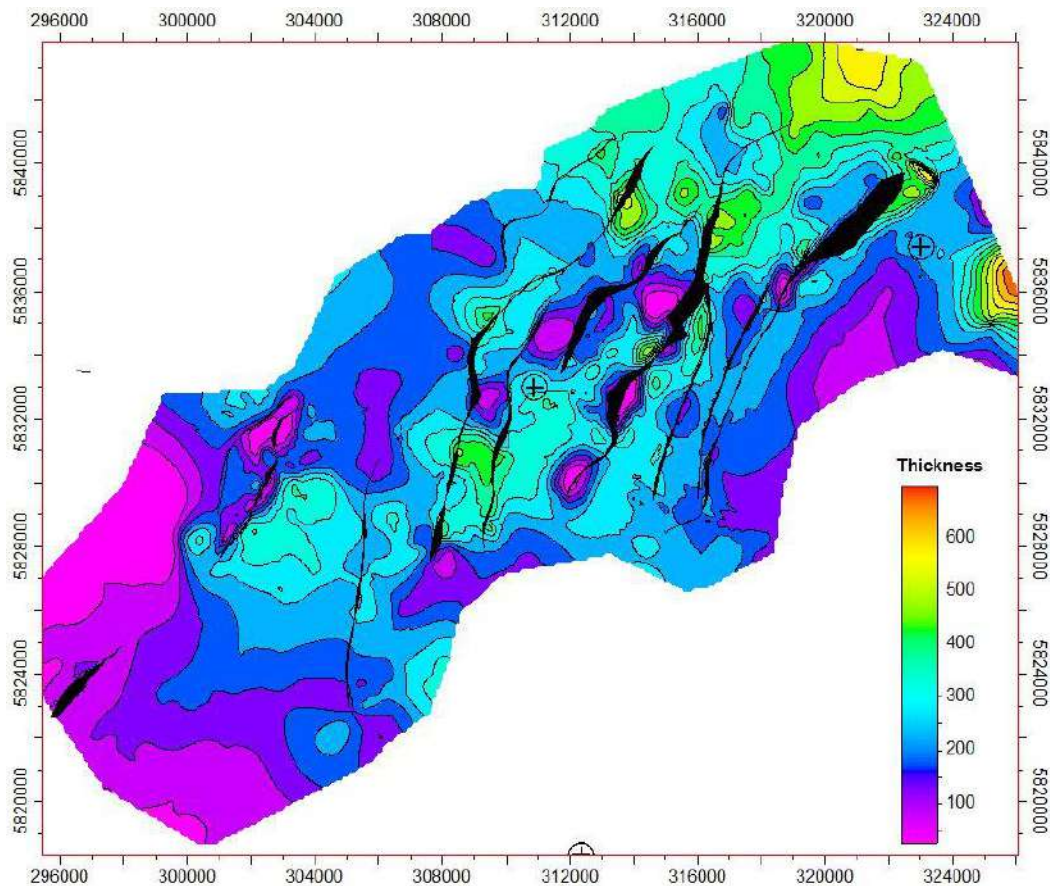


Figure 13 St Bees Sandstone Formation total vertical thickness.

TOP CARBONIFEROUS (BASEMENT)

- TWTT thickness of St Bees Sandstone (i.e. TWTT difference between top St Bees Sandstone and top Carboniferous surfaces) determined from model
- TWTT thickness St Bees Sandstone converted to true thickness using average interval velocity St Bees Sandstone (4220 m per sec) determined from formation tops in wells 42/12- 01 & 2
- Top Carboniferous depth surface produced by subtracting St Bees Sandstone thickness from top St Bees Sandstone surface
- Top Carboniferous surface adjusted to fit well provings by application of residual correction taking into account the difference between the average velocity and actual velocities at individual wells. Appropriate fault intersections ensured by using fault polygons generated from the 3D fault model at Top Carboniferous level as input during the re-gridding process

6 Geology of the study area A

6.1 STRUCTURE

Structural maps and models were produced by the process detailed in section. Results of this interpretation are presented here.

Three principal horizons were picked on the seismic data; top Ormskirk Sandstone Formation (equivalent to top Sherwood Sandstone Group), top St Bees Sandstone Formation and top Carboniferous (Variscan unconformity). Where useful for elucidating the structure, horizons

above and below these were also interpreted, but structural maps of these horizons were not produced. The top Ormskirk pick is a moderately strong and consistent seismic pick, on a positive reflector above a strong negative reflector overlying a less reflective unit. The top St Bees Sandstone is a more variable pick, occurring on a positive reflector below a poorly-reflective unit. The top Carboniferous pick is a very variable pick, often difficult to place with certainty. Unconformable relationships of underlying reflectors are seen locally.

Seismic data reveals a complex structure, with faults at the target reservoir horizons that do not appear to be connected to a series of higher level faults (Figure 14, 15).

Potential injection reservoir horizons show considerable vertical relief across and between dominantly NNE-SSW trending faults. Faults exhibit normal throws of variable magnitude (up to 500m), with horizontal separations ranging from less than 1 km to several km, creating a series of narrow tilted fault blocks, with elongate structural highs and lows. Although the fault trends are clearly-defined, with spacing between adjacent seismic lines being of the same magnitude, there is inevitably some uncertainty as to the correlation of faults, and some of the fine detail of structure within the fault blocks may not be fully captured. It is likely therefore that the maps in this report present a somewhat simplified view of the actual structure. Depths at the top Sherwood Sandstone Group within the study area (Figure 16) range from less than 800 m to greater than 1800 m, from 800 m to greater than 2200 m at top St Bees (Figure 17) and from less than 100 m to greater than 2400 m at top Carboniferous level (Figure 18).

There are seven mapped closures at top Ormskirk Sandstone level (Figure 22). There is a pronounced structural high at all mapped levels around well 42/12-02, with a small demonstrable closure ('A' on Figure 22); closure may extend further towards the northeast but seismic control is not available. There is a larger closure against the next fault towards the west, forming a north-north east trending elongate structure ('B'). The southern extension of this structure is cut by a north-south trending fault, and may form a separate closure ('B2'). Two smaller and elongate closures are associated with smaller faults to the west of these structures ('C' & 'D'). In the southwest of the study area there is a large partially fault-bounded structural high with two separate closures ('E' & 'F'). Volumes of these structures and potential storage capacities are presented in section 7.

Faults that displace the reservoir horizons extend downwards to cut distinct reflectors within the basement succession (uninterpreted on these sections but thought to be at a level around Dinantian Limestone). The majority of these faults however terminate upwards at the base of the overlying Mercia Mudstone Group succession; the few that appear to extend above this level die out within a few tens of milliseconds above the top Sherwood Sandstone Group reflector itself. It is possible that this reflects the presence of an unconformity at this level, as evidenced locally by the angular relationships between reflectors below as shown in Figure 15. However, the presence of a series of often listric faults at shallower depths within the overlying Mercia Mudstone succession that appear to 'sole' out at a series of distinct levels, most likely thought to be related to the presence of halite horizons, and the suggestion that a few larger faults sole out just above the Sherwood Sandstone reflectors, suggests that this is more likely to be due to structural dislocation. The exact nature of the sealing horizons directly above the target reservoir horizons is therefore likely to vary unpredictably laterally as for example is demonstrated in the stratigraphic well correlation (Figure 19), where geophysical logs show quite different responses in different wells above the top Ormskirk. These relationships were also observed by Floodpage et al. 2011.

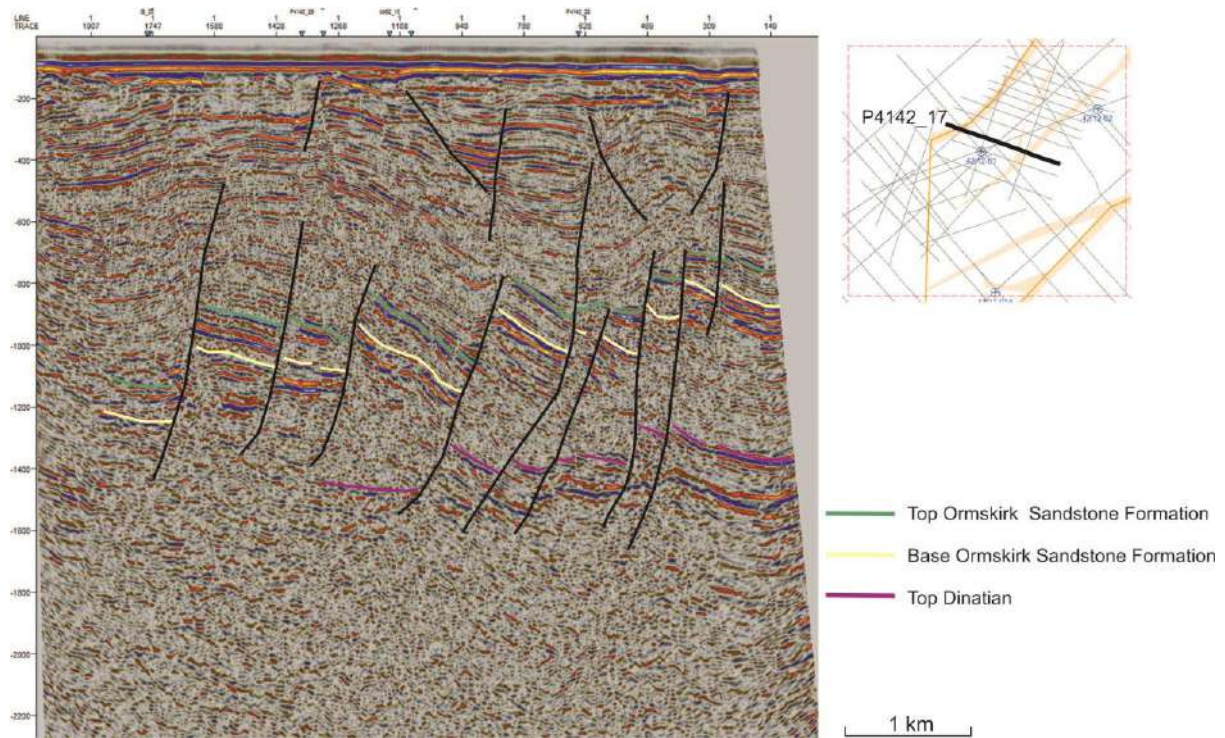


Figure 14 Seismic line P4142_17 showing closely spaced domino style faults and discontinuity in the faults.

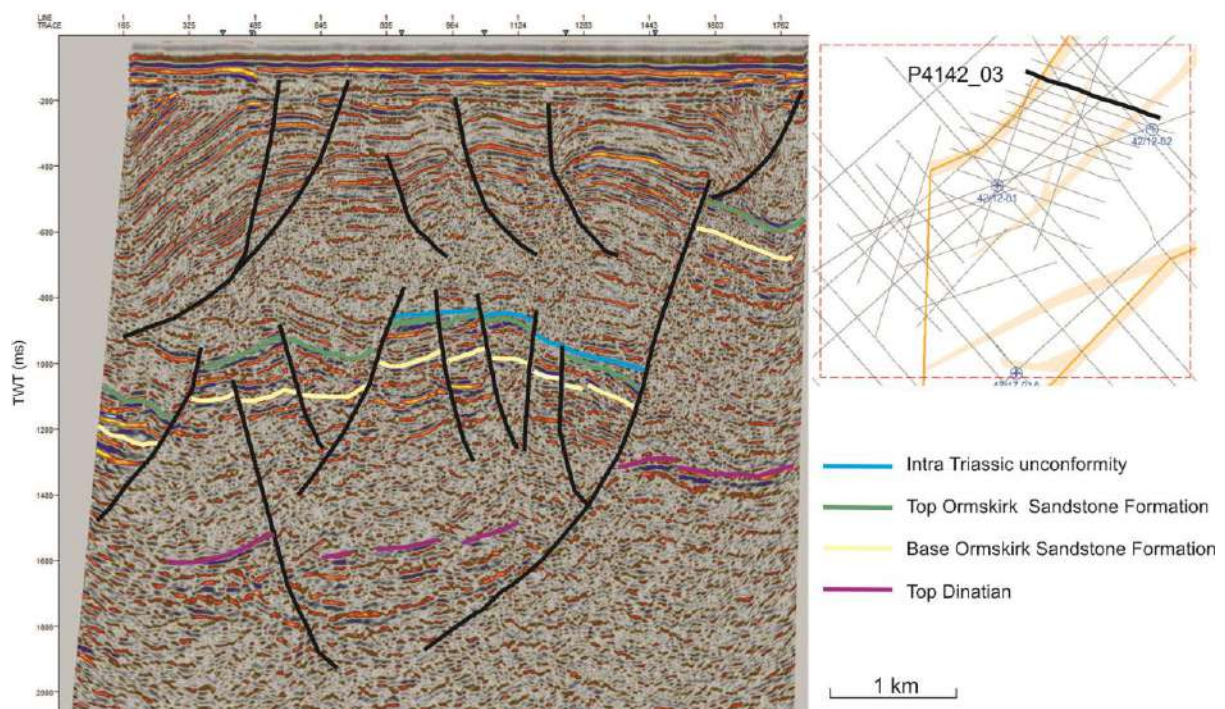


Figure 15 Seismic line P4142_03 showing angularities and listric faults.

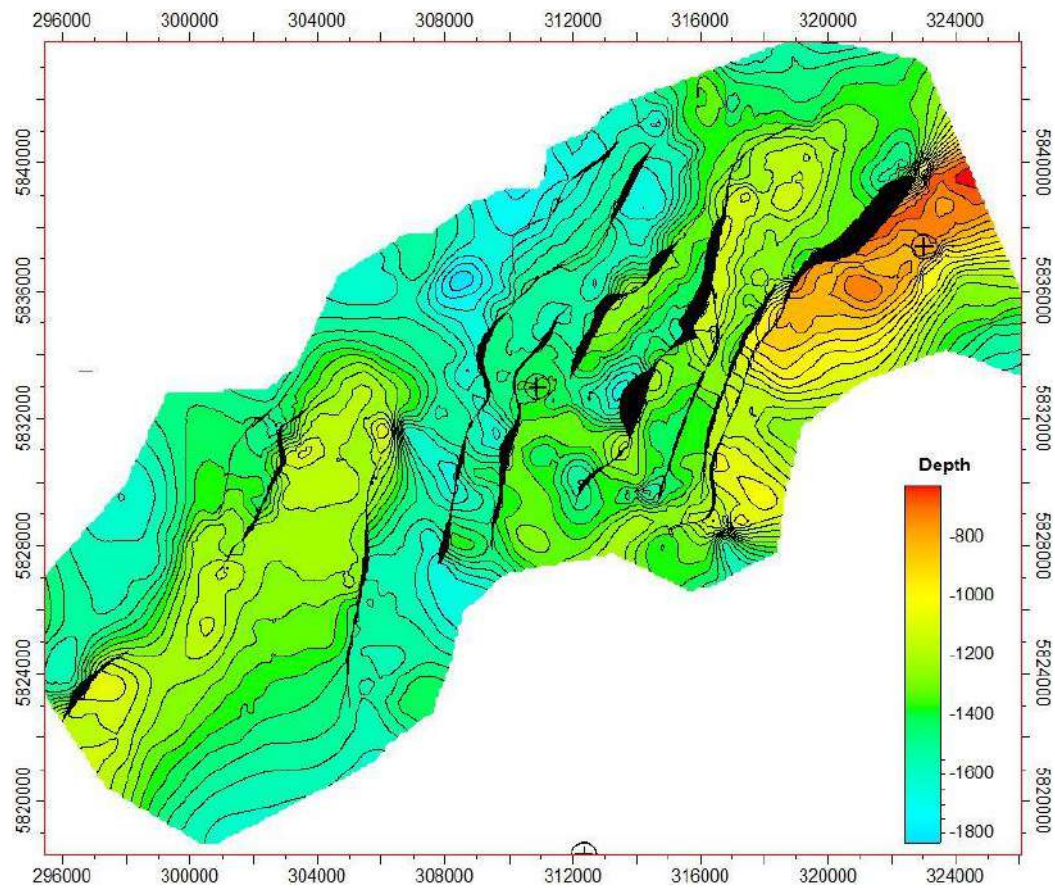


Figure 16 Top Sherwood Sandstone Group (Top Ormskirk Sandstone Formation equivalent). Contour interval 50 m.

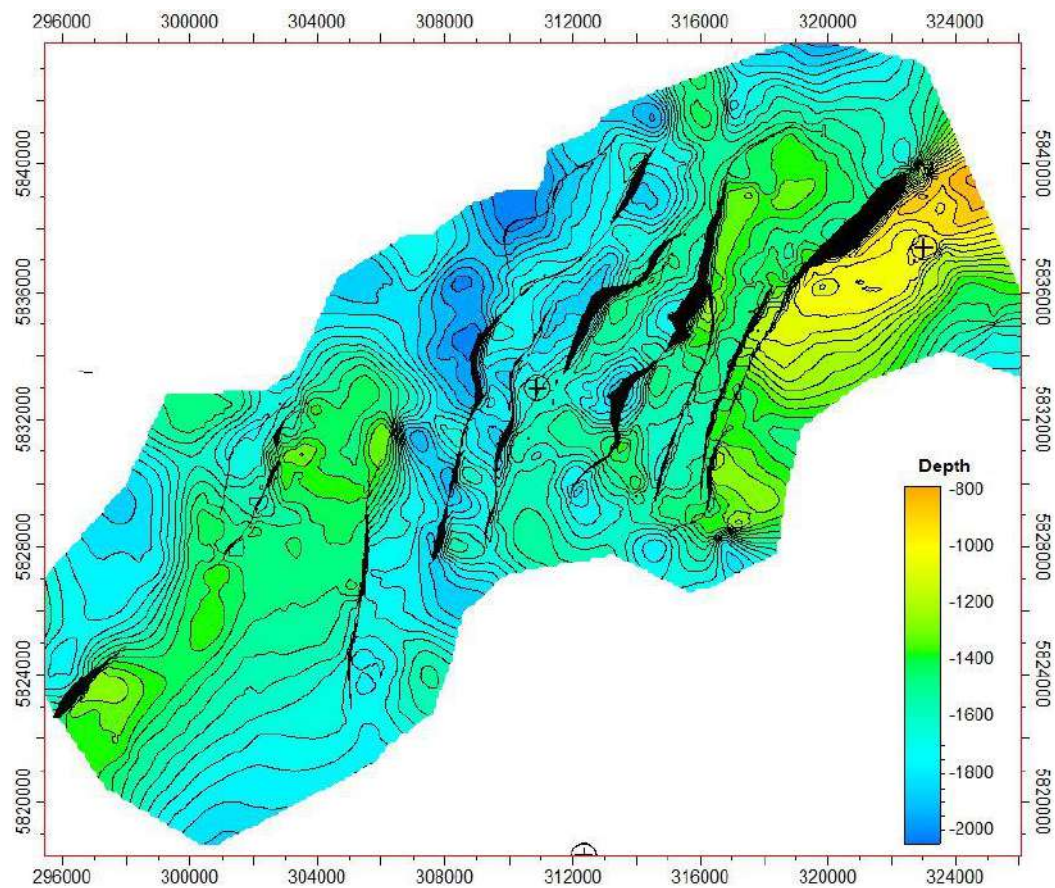


Figure 17 Top St Bees Sandstone Formation. Contour interval 50 m.

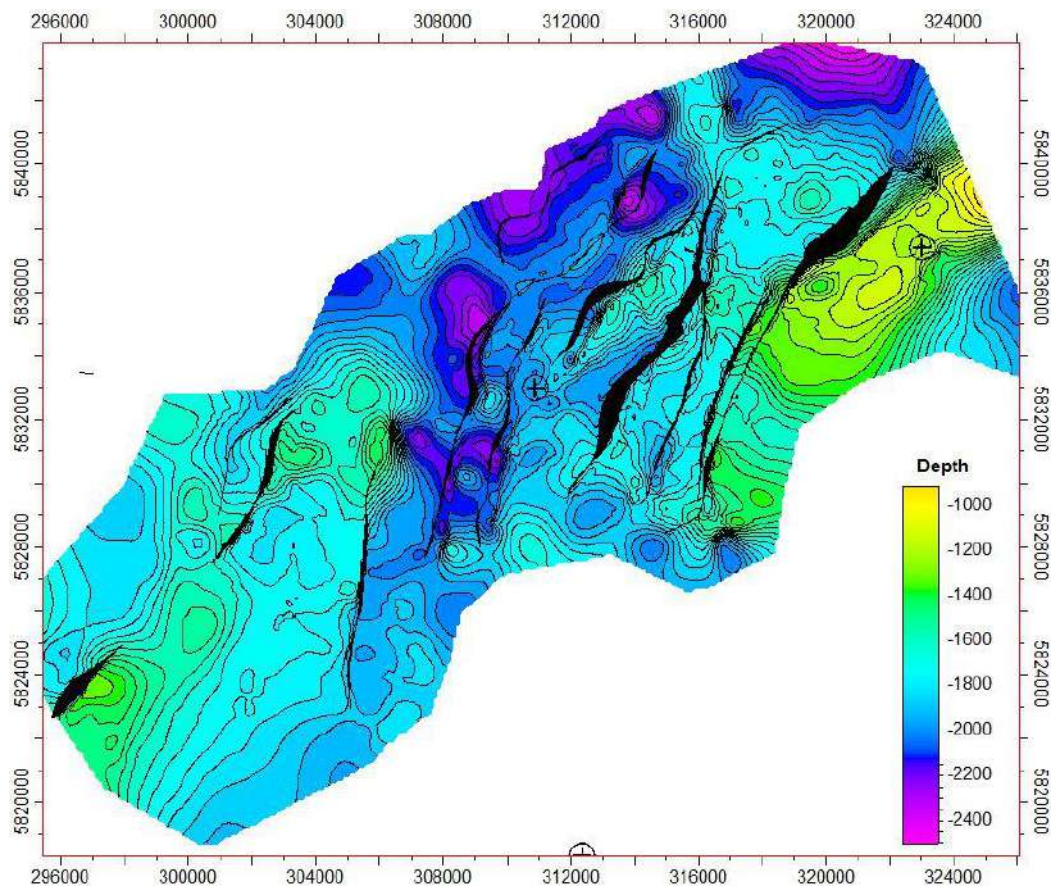


Figure 18 Top Carboniferous. 50 m contour interval.

7 Reservoir Well Interpretation of study area A and B

Correlation of the two wells in the study area A (IR42/12–01,02) with IR42/08-1A to the north reveals a consistent log signature for the top Ormskirk Sandstone Formation, with a sharply-marked boundary from high gamma ray values above to low values below. The base Ormskirk / top St Bees Sandstone Formation has a less consistent character, occurring above a dolomitic cemented zone in wells IR42/12-01 and IR42/08-1A, marked by higher velocities, and at the top of a sandstone succession with a more variable gamma ray signature in well IR42/12-2. The base of the Triassic sandstone succession is not thought to have been penetrated by well IR42/12-02; however both the Ormskirk and St Bees Sandstone Formations appear to thicken northwards between well IR42/12-01 and IR42/12-02, consistent with the known thickening into the basin.

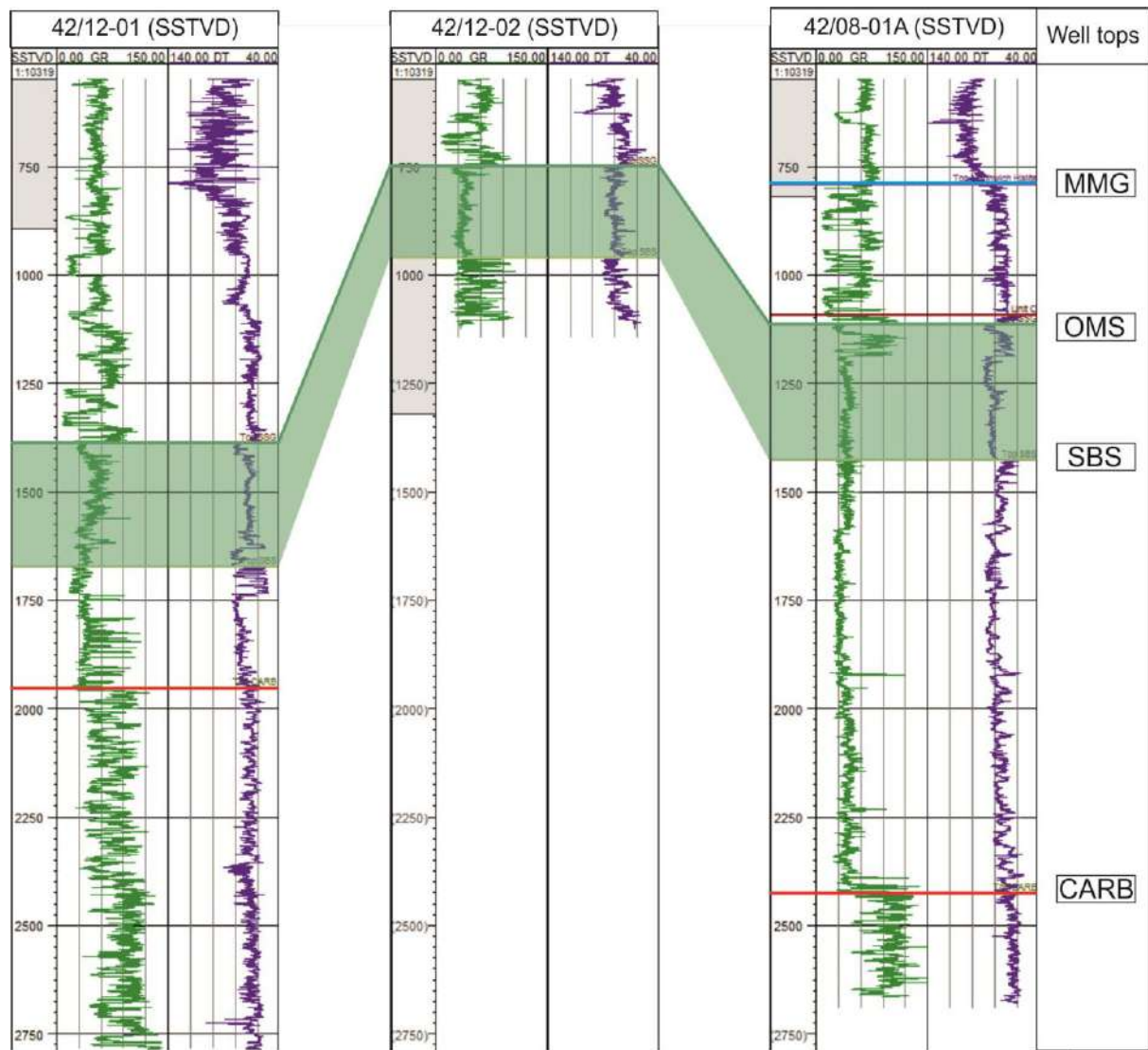


Figure 19 Correlation of the Ormskirk Sandstone Formation across the study area.

7.1 RESERVOIR PROPERTIES

Net to gross ratios of the Sherwood Sandstone Succession were calculated for all wells in the basin, using a Vsh (volume of shale) cut-off of 0.5. This reveals a broad trend of decreasing ratios northwards, with the sandstones in the area of study having high values, ranging from 83% – 86% in the two wells. An analysis of porosity variation across the basin was also carried out (using simple calculation using the sonic (SPHI output) and density curves (DPHI output)), and reveals a trend with a maximum of around 18% in the northern part of the study area, with values decreasing both to the south and to the north. Within the study area, values range from 18% in the north to less than 8% in the south. Note that the trends discussed here and displayed in Figure 20 and Figure 21 are based on relatively few data points: i.e. from the geophysical data interpretations of 6 wells only and using simple formulae in Petrel, rather than utilising specialised well log interpretation software.

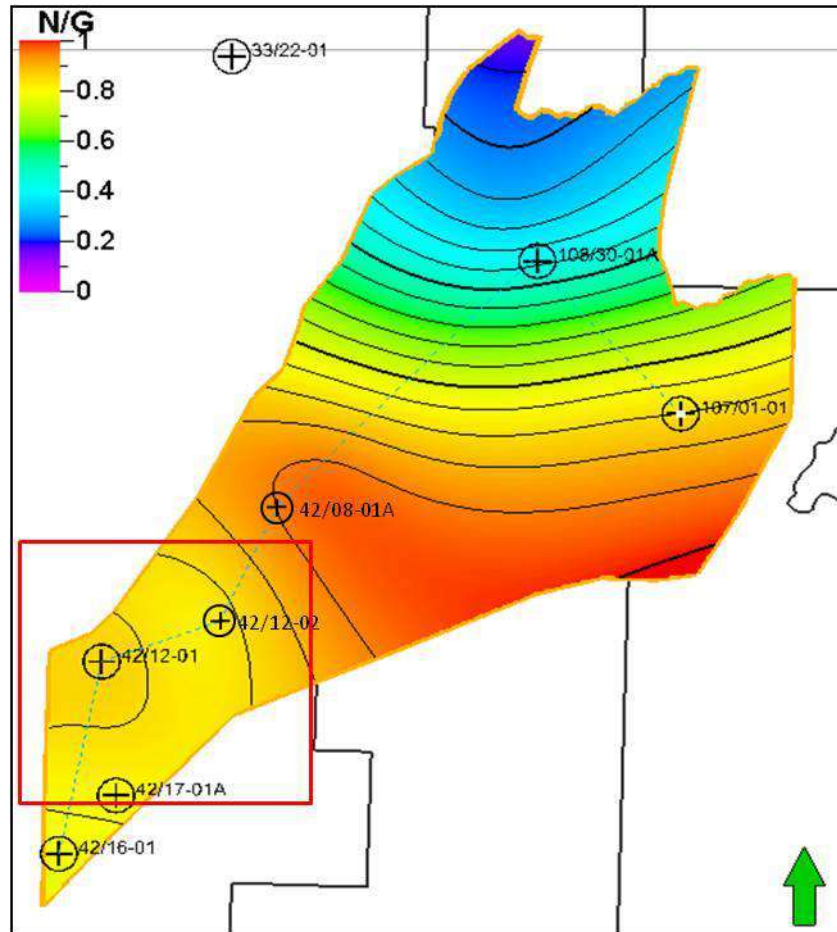


Figure 20 Calculated Net to Gross of the Sherwood Sandstone Group in the study area.

Table 3 Calculated Net to Gross values using a Vsh cut off of 0.5. Where GR is Gamma ray and NTG is net to gross.

Well	GR _{min}	GR _{max}	GR _{off} ^{log cut}	NTG
UK108/30-01A	30	100	65	0.44
UK107/01-01	30	90	60	0.85
IR42/08-01A	25	90	57.5	0.95
IR42/12-02	25	80	52.5	0.83
IR42/12-01	25	95	60	0.86
IR42/16-01	30	90	60	0.78
Mean				0.79

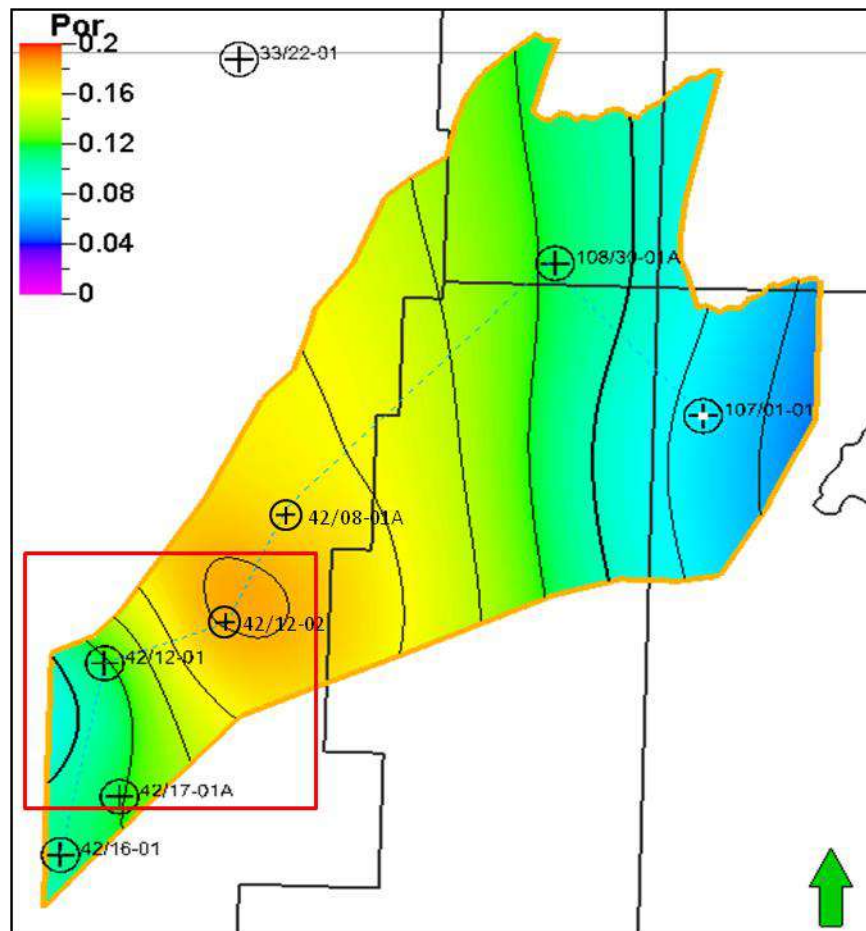


Figure 21 Calculated porosity of the Sherwood Sandstone Group for the CISB.

Table 4 Calculated porosities of the Sherwood Sandstone Group across the CISB.

Well	av SPHI	av DPHI
UK108/30-01A	0.12	0.07
UK107/01-01	0.07	N/A
IR42/08-01A	0.17	0.15
IR42/12-02	0.18	0.13
IR42/12-01	0.12	0.10
IR42/16-01	0.11	0.03
Average	0.13	0.10

Study area A focuses on the Ormskirk Sandstone Formation only in a small area of the CISB. For CO₂ storage capacities to be calculated the porosity and net to gross of the Ormskirk Sandstone Formation in this region is required. As a result the calculations were repeated for a subset of wells focusing on the Ormskirk Sandstone Formation. The results are shown in Table 5.

Table 5 Porosity of the Ormskirk Sandstone Formation based on two wells within the study area

	IR42/12-01	IR42/12-02
	OMS	OMS
av SPHI	0.11	0.19
SPIImin	0.00	0.03
SPIImax	0.22	0.29
av DPHI	0.09	0.16
DPHI min	0.00	0.00
DPHI max	0.23	0.26

There are no wells in Study area B. The average porosity of the Ormskirk Sandstone Formation is used in storage capacity calculations in this area.

8 Assessment of CO₂ storage capacity in the Ormskirk Sandstone Formation in study area A

8.1 IDENTIFICATION OF POTENTIAL STORAGE SITES

Chadwick et al. (2008) defined the geological setting required for a first pass screening of a geological storage site for CO₂. Indicators for successful geological storage sites are described in Table 6.

Table 6 Indicators for successful geological storage sites (after Chadwick et al. 2008).

	Positive indicators	Cautionary indicators
Reservoir efficiency		
Static Storage Capacity	Estimated effective storage capacity much larger than total CO ₂ to be injected	Estimated effective capacity similar to total amount of CO ₂ to be injected.
Dynamic storage capacity	Predicted injection-induced pressures well below levels likely to induce geomechanical damage to reservoir or caprock	
Reservoir Properties		
Depth	>1000 m <2500 m	>850 m <1000 m
Reservoir thickness	>50 m	<20 m
Porosity	> 20%	<10 %
Permeability	> 500 mD	<200 mD
Salinity	> 100 gl ⁻¹	<30 gl ⁻¹
Stratigraphy	Uniform	Complex lateral variation and complex connectivity of reservoir

		facies
Caprock efficiency		
Lateral continuity	Stratigraphically uniform, small or no faults	Lateral variations, medium to large faults
Thickness	> 100 m	<20 m
Capillary entry pressure	Much greater than the maximum predicted injection induced pressure increase.	Similar to maximum predicted injection-induced pressure increase.

Potential storage sites in the CISB have been indentified on the basis of the following criteria:

- They lie at a depth below 800 m where CO₂ would be in its dense phase.
- Structural closures have been identified which have the potential to retain buoyant fluids.
- They have good reservoir properties.
- They are sealed by a caprock.

For the purposes of calculating potential volumes of CO₂ that might be stored in the Ormskirk Sandstone Formation, it is assumed that injected CO₂ will migrate buoyantly from the injection point to accumulate in ‘closed’ structural highs where it would be permanently trapped. Structural maps of the top Ormskirk and St Bees Sandstone were therefore analysed to identify such structures. Identified closures are shown in Figure 22. It should be borne in mind that there is a high risk of leakage associated with these storage prospects because of the large number of faults observed on the seismic data.

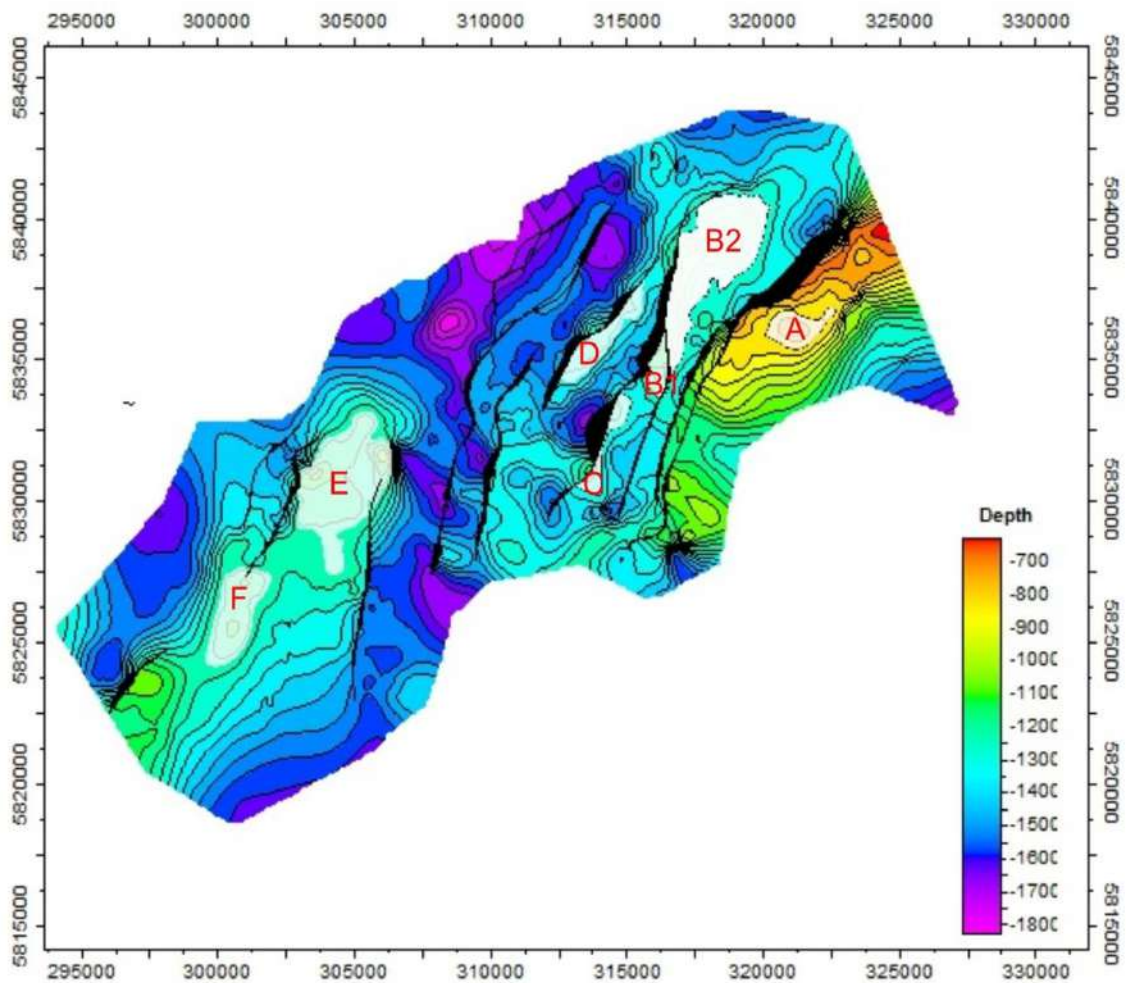


Figure 22 Top Ormskirk Sandstone Formation contoured at 100 m intervals. Closures are shown as transparent white areas,

8.2 STATIC CAPACITY CALCULATION AND ASSUMPTIONS

Simple estimates of CO₂ storage capacity were calculated for each of the closures. The net pore volume of each closure was estimated. Then the mass of CO₂ which could occupy the net pore volume was calculated by applying the calculated CO₂ density at reservoir conditions to the net pore volume (the CO₂ density was derived from an estimated reservoir temperature, a hydrostatic pressure gradient and the Span & Wagner equation of state) and finally a storage efficiency factor was applied, representing the sweep efficiency and CO₂ saturation considered to be achievable in a putative storage project. This methodology gives a ‘first pass’ theoretical static storage capacity. However, it does not take potential pressure limitations into account. More sophisticated “dynamic” capacity estimates using a numerical reservoir simulator were not made due to the lack of appropriate data.

The method used can be summarised as:

CO₂ storage capacity = net pore volume x density of CO₂ at reservoir conditions x Storage efficiency factor

8.2.1 Pore Volume (PV)

The volume of each structure was calculated by intersecting the top Ormskirk Sandstone surface with a flat surface at the level of the lowest closing contour, and by calculating the intervening volume using simple surface calculations in PETREL. Average Ormskirk Sandstone net to gross and porosity values (Table 8) were derived from the well log analysis and used to estimate the net pore volume.

8.2.2 Density of CO₂

Density of the CO₂ was calculated by applying the Span & Wagner (1996) equation of state for CO₂ to an estimate of pressure and temperature at reservoir conditions. Temperature data is sparse, only available in two wells in the CISB (Table 7). Both measurements were taken at the bottom hole and were recorded a number of hours after drilling during which drilling fluid was circulated, potentially reducing the ambient temperature of the reservoir. As a result the temperatures recorded may be inaccurate and a little lower than the true reservoir temperature, but in the absence of better quality data these measurements were used to estimate the geothermal gradient in the study area. The estimated average temperature gradient for the area is 31 °C/km.

Table 7 Temperature gradient in the study area.

Well Number	Depth of measurement (m)	Temperature (°C)	Temperature gradient (°C/m)	Temperature gradient (°C/Km)
IR42/17-01A	1508.46	48.89	0.032	32
IR42/16-01	1451.15	43.33	0.030	30

The reservoir pressure gradient was determined from well IR42/16-01.

8.2.3 Storage efficiency factors

Storage efficiency (E) is defined as the fraction (by volume) of the reservoir pore space that can be filled by CO₂ (free or dissolved). For a detailed discussion of storage efficiency, see IEAGHG (2009). Storage efficiency factors are site specific and are best estimated by numerical flow simulation.

Results are shown in Table 7.

Table 8 Data used for storage capacity calculations and storage capacity at 100 % storage efficiency.

Closure name	Total rock volume (Km3)	Mean N:G	Mean porosity	Depth to crest (m)	CO2 density (t/m3)	Storage capacity (Mt)
A	0.528468	0.79	0.15	705	0.82182	51
B1	2.41648	0.79	0.15	1062	0.79159	226
B1 + B2	2.17456	0.79	0.15	1062	0.79159	203
C	0.312158	0.79	0.15	1214	0.78069	29
D	0.604497	0.79	0.15	1238	0.78551	56
E	2.5547	0.79	0.15	1069	0.79159	239
F	1.07678	0.79	0.15	1137	0.78904	100

The CO₂ density was calculated using reservoir temperature and pressure data from wells IR42/17-01A (temperature) and IR42/16-01 (temperature and pressure). The calculated densities are uncommonly high, this is likely due to higher than average pressure gradient of 0.5 psia/ft calculated from well IR42/16-01. Normal hydrostatic pressure gradient is 0.45 psia/ft (Millennium Atlas, 2003). The higher than average pressure gradient could be due to overpressure, high salinity of the porewater or incorrect measurements in the well.

Using the data available and without carrying out detailed dynamic flow simulations, storage efficiency factors for the identified Ormskirk Sandstone Formation closures are largely unknown. This study has therefore used a range of storage efficiency factors from published work, in order to take into account the uncertainty (Table 9).

Table 9 Storage capacity at a range of different storage efficiency factors (static storage capacities of >50 Mt of CO₂ are highlighted).

	Storage efficiencies						
	Closed structure (Williams et al)	Site specific scale clastics P50 (Goodman et al)	Site specific scale clastics P90 (Goodman et al)	Homogenous Quarter dome (IEA GHG)	Homogenous Half dome (IEA GHG)	Homogenous Three quarter dome (IEA GHG)	Homogenous Dome (IEA GHG)
	0.042	0.0679	0.1498	0.17	0.18	0.24	0.25
	Mt						
Closure name							
A	2.16	3.49	7.71	8.75	9.26	12.35	12.87
B1+ B2	9.52	15.39	33.96	38.53	40.80	54.40	56.67
B1	8.57	13.85	30.56	34.68	36.72	48.96	51.00
C	1.21	1.96	4.33	4.91	5.20	6.93	7.22
D	2.36	3.82	8.43	9.57	10.13	13.50	14.07
E	10.06	16.27	35.90	40.74	43.14	57.51	59.91
F	4.23	6.84	15.08	17.12	18.12	24.16	25.17

These results can only be considered to be a rough guide to the potential storage capacity.

In the UK Storage Appraisal Project (Gammer et al. 2011), storage was considered uneconomic in storage units with an estimated static capacity of less than 50 Mt. If this cut-off is applied to the closures assessed in the study area only closures B and E would be large enough for significant storage of CO₂ and then only if the higher storage efficiencies of 0.24 and 0.25 are assumed. However, if the individual structures were to be considered as a potential cluster, accessed from a single platform, they would have sufficient storage capacity to be of economic interest, providing of course that the risks of leakage described below were considered to be acceptable.

As mentioned above, the storage efficiencies of the closures could be better determined by site specific dynamic modelling of CO₂ injection into these closures, but this is beyond the scope of this study.

8.3 RISKS AND LIMITATIONS OF THE METHODOLOGY

8.3.1 Faults

Due to the complexity of the faulting in the SW part of the CISB and the spacing of the available 2D seismic data, it is difficult to produce a definitive seismic interpretation. The close spacing of the faults on the seismic sections and the complex fault detachments within the geological succession means there is significant uncertainty of extent and trend of faults such that they

cannot always be extrapolated between adjacent seismic sections. Additionally, some faults may exist between the seismic grid spacing and therefore will have been missed.

As a result the structural maps represent the interpreter's best judgement given the data available and the structural complexity. They should not be considered definitive. For a more comprehensive fault interpretation, 3D seismic data would be required.

With the exception of closure A, at least one of the boundaries of all of the identified closures comprises a fault. Faults may act as conduits for fluid flow by:

- allowing the migration of fluids across the fault where the reservoir is juxtaposed with permeable formations (cross-fault migration), or;
- allowing vertical migration of fluids via the fault itself, to the surface or shallower formations.

Conversely faults can also act as barriers to fluid flow due to:

- the juxtaposition of the reservoir formation against impermeable sealing formations, or;
- the presence of low permeability fault rocks along the fault plane formed by movement of the fault.

The integrity of many of the closures relies on both the sealing capacity of the top seal (in this case the Mercia Mudstone Group) and the sealing capacity of one or more faults. The Mercia Mudstone Group is extremely thick in the CISB (e.g. 776 m in well IR42/16-1 and 1425 m in well IR14/25-1. There is little doubt that if this succession was unfaulted it would retain the necessary CO₂ columns, given that it retains significant gas columns in the East Irish Sea Basin (Seedhouse & Racey 1997), see also Table 5.

The nature and sealing capacity of the faults cutting the Mercia Mudstone Group is poorly known as (a) there is little if any core available from this formation in the CISB and (b) there are no hydrocarbon fields to demonstrate whether the faults can retain buoyant fluids.

The Mercia Mudstone Group caprock is formed of alternating layers of shales, mudstones and evaporites. Maingram et al. 1999, describe the Mercia Mudstone Group in the CISB as consisting predominantly of anhydritic and dolomitic claystones with interbedded halites and thin sandstones, which were probably deposited in a lacustrine environment. Therefore its lithology and depositional environment are similar to that of the MMG in the nearby East Irish Sea Basin (EISB).

In the East Irish Sea Basin (EISB) the Mercia Mudstone Group acts as an effective seal for numerous gas and oil fields. It has been suggested by Seedhouse and Racey (1997), that a thickness of greater than 610 m of Mercia Mudstone Group could act as an effective caprock for oil and gas in the East Irish Sea Basin. In the CISB, 776 m of Mercia Mudstone are recorded in well IR42/16-1 and 1425 m in well IR14/25-1, as indicated by Chadwick et al. 2008, it is likely that this thickness of caprock is sufficient for retaining CO₂ in its intact form (Table 6).

None of the faults observed in this study have an offset greater than the thickness of the caprock. If CO₂ were to migrate via the faults it is unlikely to reach the surface, unless a permeable horizon (thief zone) is encountered cap rock.

The juxtaposition of reservoir across faults associated with each closure was examined using seismic lines which transect the closures. The horizon which juxtaposes against the Ormskirk Sandstone Formation (OMS) reservoir was recorded (Table 10). Where reservoir (OMS) juxtaposes against caprock (MMG), it is likely that these faults will be sealing, unless the fault is open along the fault plane. When the reservoir juxtaposes with another permeable horizon for example, the Ormskirk Sandstone Formation (OMS), the St Bees Sandstone Formation (SBS) or the Carboniferous (CARB), this could provide a potential migration pathway out of the closure.

Table 10 Shows the juxtaposition of the Ormskirk Sandstone Formation (OMS) reservoir across faults associated with each closure.

		Horizon which juxtaposes with the Ormskirk Sandstone Formation								
Closure	Seismic line number	Fault F1	Fault F2	Fault F3	Fault F4	unmapped fault	unmapped fault	unmapped fault slightly off structure	unmapped fault to the south off structure	unmapped fault
B	P4142_ 3				MMG					
	P4142_ 5				MMG					
	P4142_ 7				MMG					
	P4142_ 9				MMG			SBS/CARB		
	P4142_ 11				MMG			SBS/CARB		
	P4142_ 13				MMG			SBS/CARB		
	P4142_ 15				MMG			SBS/CARB		
C	P4142_ 17				MMG					
	P4142_ 19				MMG				OMS	
D	P4142_ 15			MMG						OMS
	P4142_ 13			MMG						CARB
	P4142_ 11			MMG						OMS/SBS
E	P4142_ 23	MMG	MMG/OMS							
	P4142_ 4	MMG	MMG							
	P4142_ 25	MMG	MMG							
F	P4142_ 27					OMS	OMS			

Most of the faults within the closures (available for analysis on seismic) juxtapose against reservoir against caprock (F1, F3 and F4). Some of the faults do juxtapose reservoir (OMS) on both sides of the fault, for example closures C, E and F have faults which juxtapose the Ormskirk Sandstone against Ormskirk Sandstone. For faults in which reservoir is juxtaposed against reservoir the CO₂ will migrate out of the closures unless the faults are sealed along the fault plane. This analysis is limited to the 2D seismic lines available. 3D seismic data would allow the juxtaposition of faults to be analysed along the length of the fault.

In addition to the faults that cut the reservoir there are a significant number of large listric faults that sole out at different levels within the Mercia Mudstone Group, probably due to detachment along salt beds. These decouple the structure of the overlying strata from that seen in the reservoir and lower parts of the MMG (Figure 14 and Figure 15). Their relevance to the sealing properties of the MMG succession is not known.

In the Kish Bank Basin to the north of the CISB, strike slip movement is associated with the Codling Fault Zone (Crocker et al. 2005). If strike slip is the dominant sense of movement on the Codling Fault in the CISB then there is a good chance of very high vertical permeability at releasing bends (of all scales) along the fault. Evidence of gas seepage and tectonic movement in the Kish Bank Basin supports this theory (Crocker et al. 2005). Discussions with John Walsh from University College Dublin also suggested evidence for strike slip motion in the CISB.

In summary therefore, it is not known whether the faults that define the potential closures that could be used for CO₂ storage in the CISB are likely to be sealing. Analogies between the EISB and CISB, which suggest that faults in the MMG can seal significant gas columns, should be

balanced against indications that the Codling Fault Zone may be, or may have recently been, leaking gas in the CISB. Without further data and research, the sealing potential of the relevant faults is unknown and it must therefore be assumed that they present a significant risk to the storage integrity of the closures.

Finally, all of the closures were identified using 2D seismic data with an irregular line spacing of between 1 and greater than 10 km. Structural maps have been constructed by interpolation between these seismic lines and it is therefore inevitable that any geological features that happen to lie between the seismic lines, such as additional faults and changes in the morphology of the Ormskirk Sandstone will not appear on maps resulting from this study. It is therefore strongly recommended that if any of the closures are identified as having potential for CO₂ storage purposes, a 3D seismic survey should be acquired over the area of the mapped closure to improve the resolution of the data and to reduce geological uncertainty.

8.3.2 Depth conversion

Depth conversion is a key uncertainty in the depth surfaces produced during seismic interpretation. The TWTT surfaces, in particular the top Ormskirk Sandstone, were depth converted using a highly simplistic constant interval velocity for the overburden. The velocity of the caprock interval is highly sensitive to variations in lithology, and density contrasts caused by disparities between current and maximum burial depths. Laterally across the study area, both of these factors vary considerably.

Uncertainty in the top reservoir depth map (top Ormskirk Sandstone) will impact the delineation of structural closures and thus their estimated storage capacity. It is therefore strongly recommended that if any of the closures are identified as having potential for CO₂ storage purposes, a 3D seismic survey should be acquired over the area of the mapped closure to improve the resolution of the data and to reduce the potential error in the interpretation of top reservoir.

9 Geology and structure of study area B

Evaluation of study area A showed that the Ormskirk Sandstone and overburden has been subject to multiple phases of faulting. Interpretation of the 3D seismic data allowed further study of the abundance, distribution and orientation of the faults was required in order to establish the likelihood of secure CO₂ storage in the region.

9.1 SEISMIC INTERPRETATION

There are no wells in the study area B, horizons were picked based on the seismic character of the reflections and using 2D seismic lines which cross the area to link to wells. Four horizons were picked on the seismic data; near sea bed, top Ormskirk Sandstone Formation (equivalent to top Sherwood Sandstone Group), top St Bees Sandstone Formation (base Ormskirk Sandstone Formation) and top Dinatian. The near sea bed was picked on a strong positive reflector on a 10 line grid spacing and then autotracked over the study area. The top Ormskirk pick is a moderately strong and consistent seismic pick, picked on the upper positive reflector of a double peak separated by negative acoustic impedance, showing the contrast between the Mercia Mudstone shales and silts and sandstone of the Ormskirk. The top Ormskirk Sandstone was picked every 2 lines creating a dense grid of seismic picks, the formation was picked on a closely spaced grid in order to capture the complexity of the faulting. Even using such a closely spaced grid the uncertainty in the pick increases towards in the central and northern parts of the study area. The top St Bees Sandstone is less consistent pick, occurring on a positive reflector below a poorly-reflective unit. To create the top St Bee's Sandstone depth map the horizon was picked on a grid spacing of every 5 lines. The top Dinatian was picked to give structural context. It is a

high amplitude low frequency positive reflector associated with an acoustic impedance contrast between sandstones and carbonates. This reflector is difficult to pick across the whole survey, as a result the top Dinatian was picked on an irregular grid spacing.

All the picked horizons were then gridded as TWTT surfaces and then depth converted using the average interval velocities from the three nearest wells IR 42/08/01A, IR42/12-02 and UK 108/30-01A.

Individual faults were not modelled as the area is so densely faulted that it was not possible to model each fault. As a result fault patterns were established by evaluation of the top TWTT and depth maps of the top Ormskirk Sandstone Formation and top St Bee's Sandstone Formation.

9.2 FAULTING IN THE ORMSKIRK SANDSTONE FORMATION

The fault patterns of faults which offset the Sherwood Sandstone Group were evaluated on the TWTT and depth maps for the top Ormskirk Sandstone Formation.

The Sherwood Sandstone is deformed by faults exhibiting a range of fault trends, resulting in a complex fault pattern. Izatt et al, (2001) observed four fault trends in the region, these trends can be identified in study area B. Figure 23 shows the main fault trends which can be observed on the top Ormskirk TWTT map. Four fault trends can be identified, major NE-SW faults (marked as A on Figure 23), N-S trending faults (marked as B on Figure 23), high density NNE-SSW faults (marked as C on Figure 23) and low density WNW-ESE faults (marked as D on Figure XX). The major NE-SW faults align with the basin bounding faults and have significant offsets (up to 1000 m). The faults extend from the basement and are thought to have been initiated during the late Triassic (Izatt et al. 2001). They involve the Dinatian, Sherwood Sandstone Group and extend into the Mercia Mudstone Group. Faults B (Figure 23) are N-S trending transtensional faults which seem to link the major NE-SW 'A' faults (Figure 23), thought to have formed due to sinistral movement in the Late Cretaceous – Early Tertiary (Izatt et al. 2001). The faults throw to the west and have displacements of 200 – 300 m. The third trend observed is NNE-SSW trending faults. These high density transpressional faults are the most frequent faults in study area B. The faults are closely spaced with an average spacing of 500 m (C on Figure 23). The faults are steeply dipping and have maximum displacements of 200 m and are restricted to the Permian and Triassic formations. The fourth fault trend observed is WNW-ESE faults with minor offsets. (D, Figure 23).

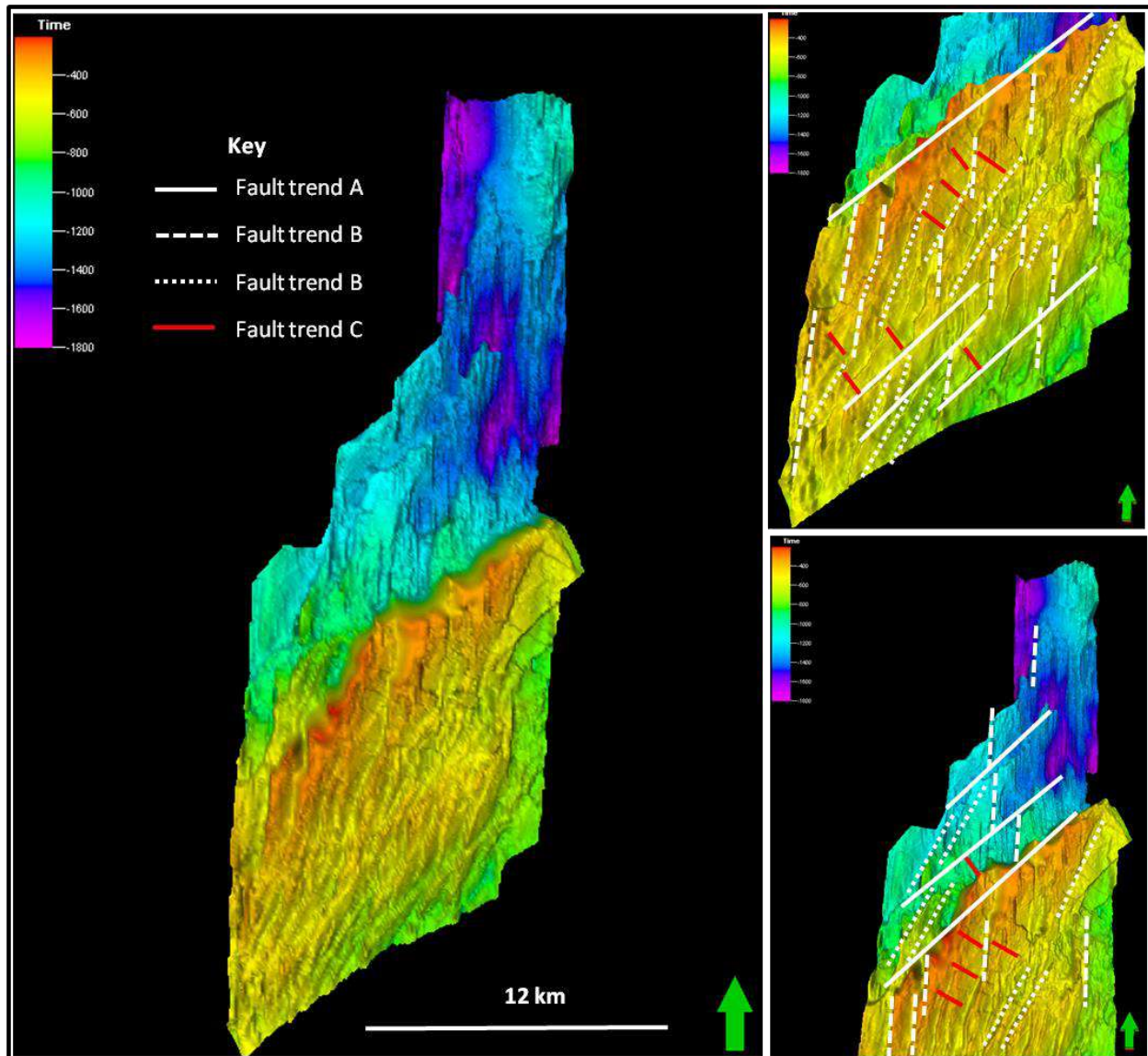


Figure 23 Fault trends in study area B (top Ormskirk Sandstone Formation TWT structure map).

9.3 THICKNESS AND DISTRIBUTION OF THE ORMSKIRK SANDSTONE FORMATION

In study area B the Ormskirk Sandstone Formation lies at depths between 265 and 2345 m (Figure 24) and the thickness ranges between 45 and 300 m (with a mean thickness of 200 m). The formation thickens to the north of study area B. Much of the Ormskirk Sandstone Formation in the South of the study area lies at a depth of < 800 m where the Ormskirk forms the footwall of a NE-SW trending fault with an offset of the fault is > 1000 m, the uplifted southern fault block forms a fault terrace.

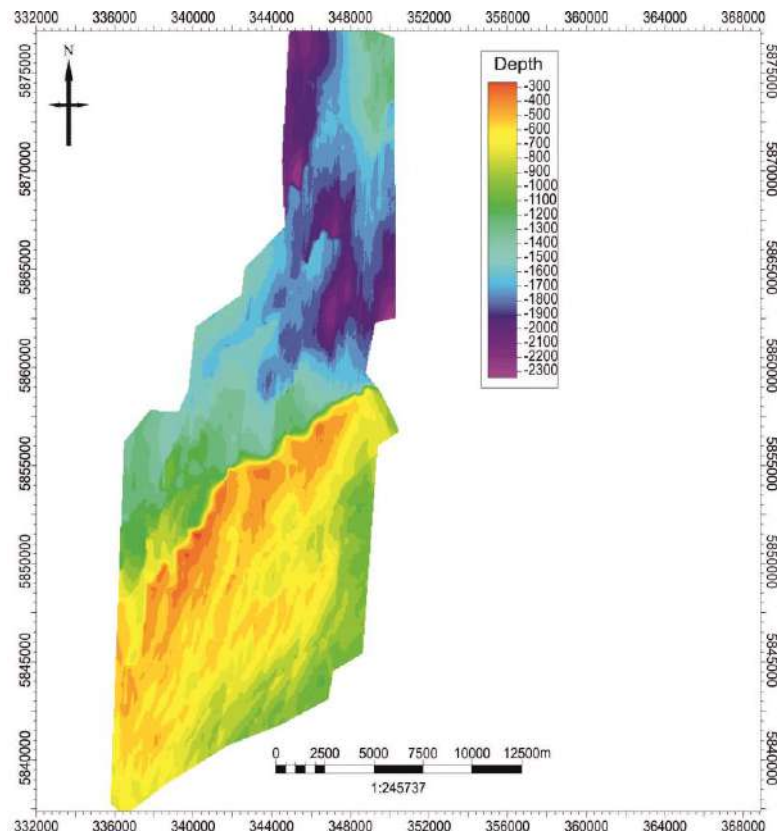


Figure 24 Top depth structure map of the Ormskirk Sandstone Formation (in meters)

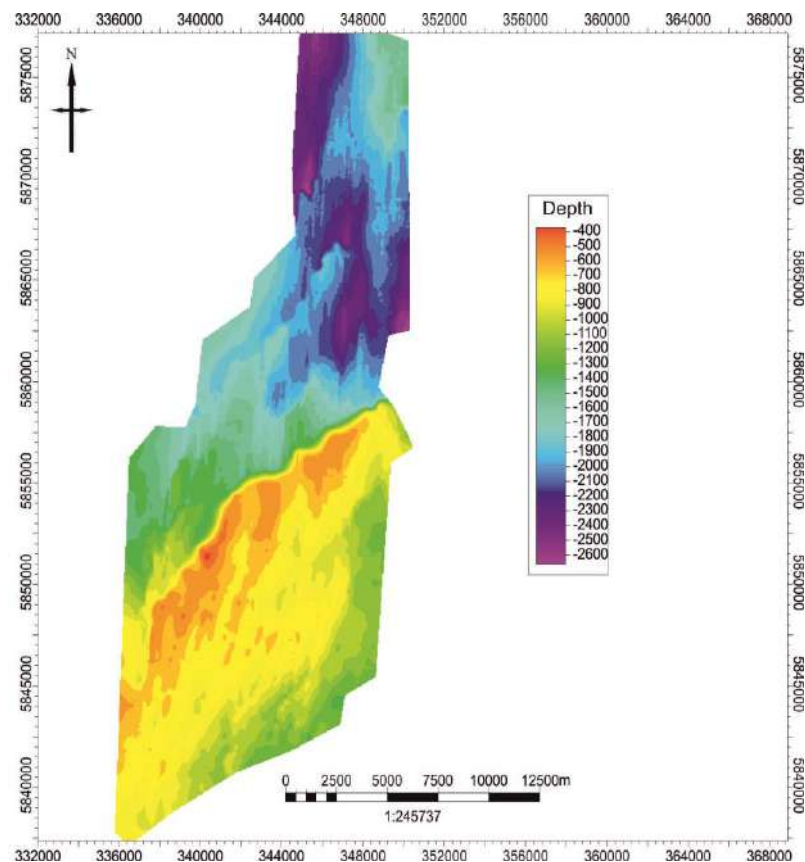


Figure 25 Figure 26 Top St Bees Sandstone Formation depth (m)

In the fault terrace region the Ormskirk Sandstone Formation lies at depth between 265 and 1000 m below sea bed, much of the Ormskirk Sandstone Formation could be regarded as too shallow for CO₂ storage.

The area at which the Ormskirk Sandstone Formation is less than 800 m below sea bed has been eliminated is shown in Figure 27, excluding much of the southern fault terrace for CO₂ storage. The Ormskirk Sandstone Formation on the northern down thrown fault block lies at a depth deeper than 800 m (range 800 – 2345 m) and is at suitable depths for CO₂ storage.

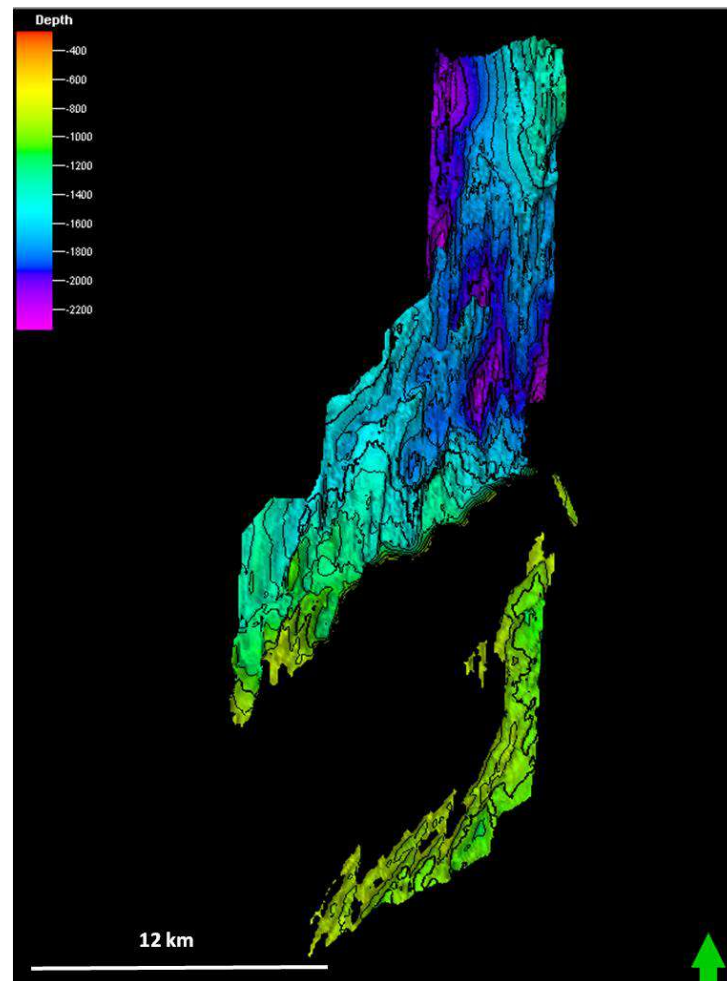


Figure 27 Top Sherwood Sandstone Group (top Ormskirk Sandstone Formation), showing areas within study area B deeper than 800 m below sea bed.

10 Assessment of storage potential of study area B

10.1 CLOSURES WITHIN STUDY AREA B

Seven structural closures which lie at a depth greater than 800 m can be identified in study B. The closures are shown on Figure 28. All seven closures are associated with faulting.

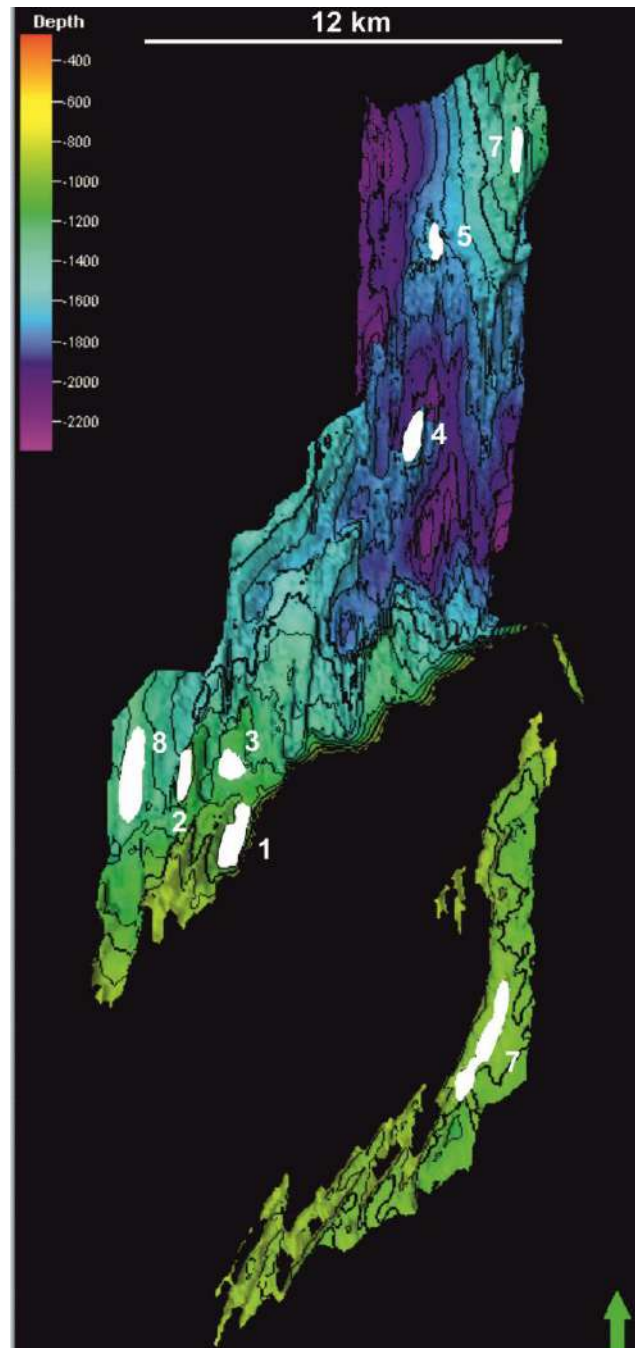


Figure 28 Top Sherwood sandstone Group depth map (m), structural closures are indicated by numbers 1 – 7.

10.1.1 Closure 1

Closure 1 is a small fault bounded closure (Figure 29). Figure 29 shows the Ormskirk Sandstone Formation is juxtaposed on both faults shown on the seismic line, if CO₂ were to be injected into this closure there would be a high risk of migration of CO₂ across the fault boundaries of the closure. There is also evidence of faulting in the caprock directly above closure 1. This closure is not suitable for CO₂ storage.

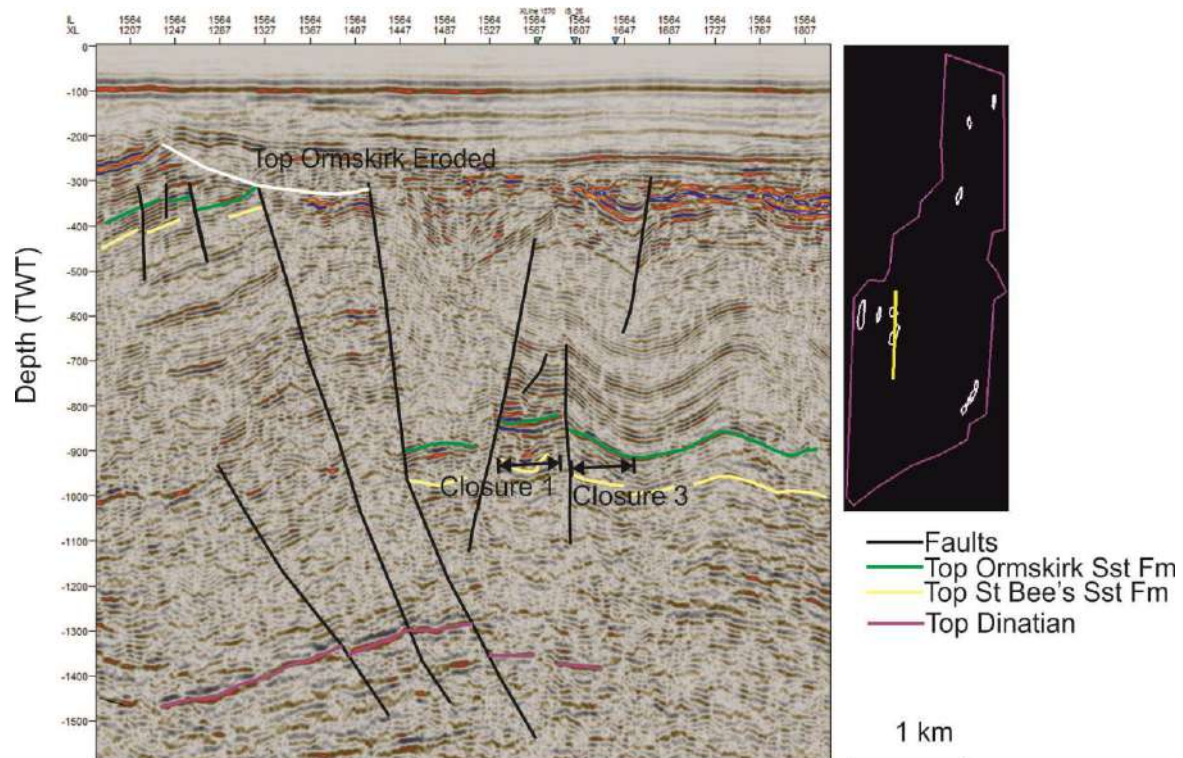


Figure 29 Seismic inline through closures 1 and 3. Showing multiple faults affecting the Orkskirk Sandstone Formation.

10.1.2 Closure 2

Closure 2 is a fault bounded anticline (Figure 30). The southern limb of the anticline is affected several small faults which affect the Ormskirk Sandstone Formation. The offset on the faults is small but to what degree they compartmentalise the reservoir is unknown. The square on Figure 30 indicates an area where seismic reflectors within the caprock are disrupted suggesting the presence of small faults. The uncertainty regarding the sealing capacity of the faults that bound the structure and the lack of information about reservoir compartmentalisation makes this closure unsuitable for CO₂ storage.

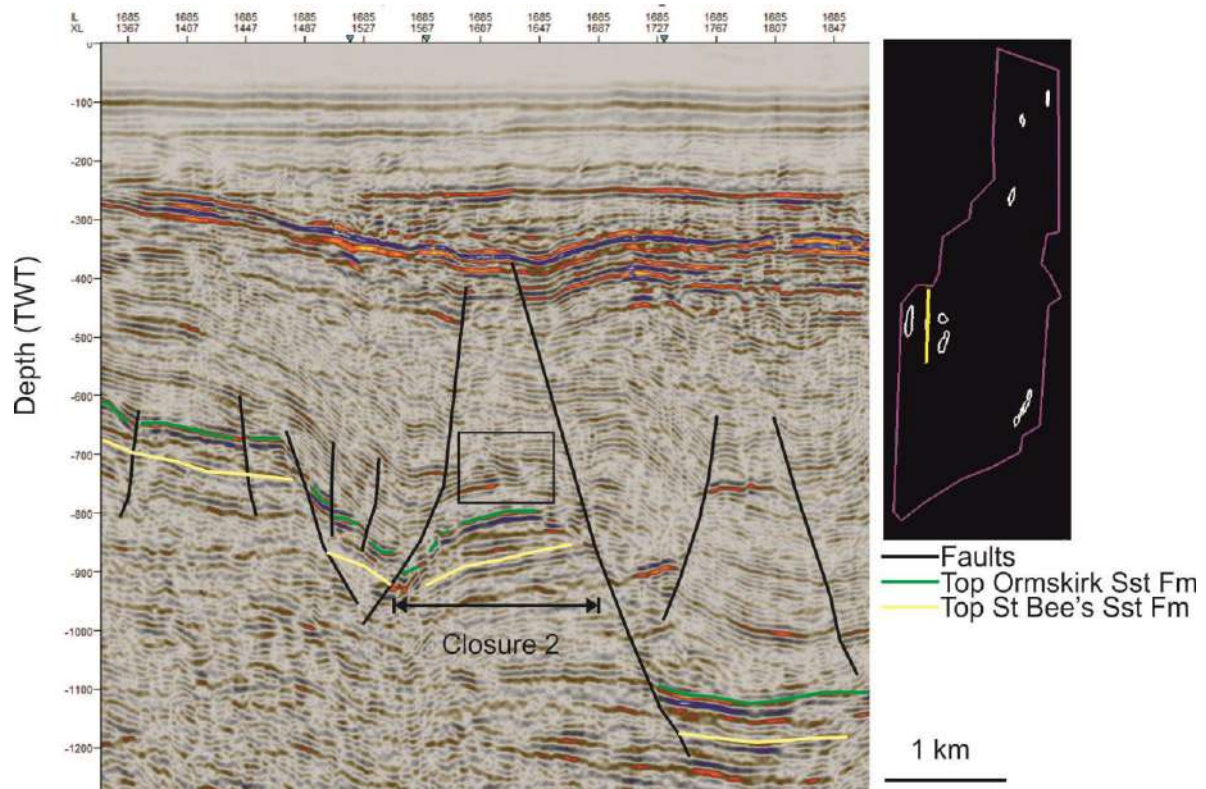


Figure 30 Seismic inline through closure 2. Showing multiple faults affecting the Ormskirk Sandstone Formation.

10.1.3 Closure 3

Closure 3 is formed by a fault to the south of the closure (Figure 29). The Ormskirk Sandstone Formation juxtaposes with Ormskirk Sandstone which forms closure 1 as a result the fault is likely to be open to the transmission of fluids and will not form an effective seal. Therefore this closure is not a good candidate for CO₂ storage.

10.1.4 Closure 4

Closure 4 is a low amplitude anticline with a NW-SE fault forming the NW boundary of the structure (Figure 31). Several faults affect and terminate in the caprock. All of the faults juxtapose against the Mercia Mudstone Group caprock. The integrity of this structure is dependent the effectiveness of the seal. The reflectors in this region are dimmed and it is difficult to interpret the Ormskirk Sandstone with any certainty. This adds further uncertainty as to the integrity of this closure.

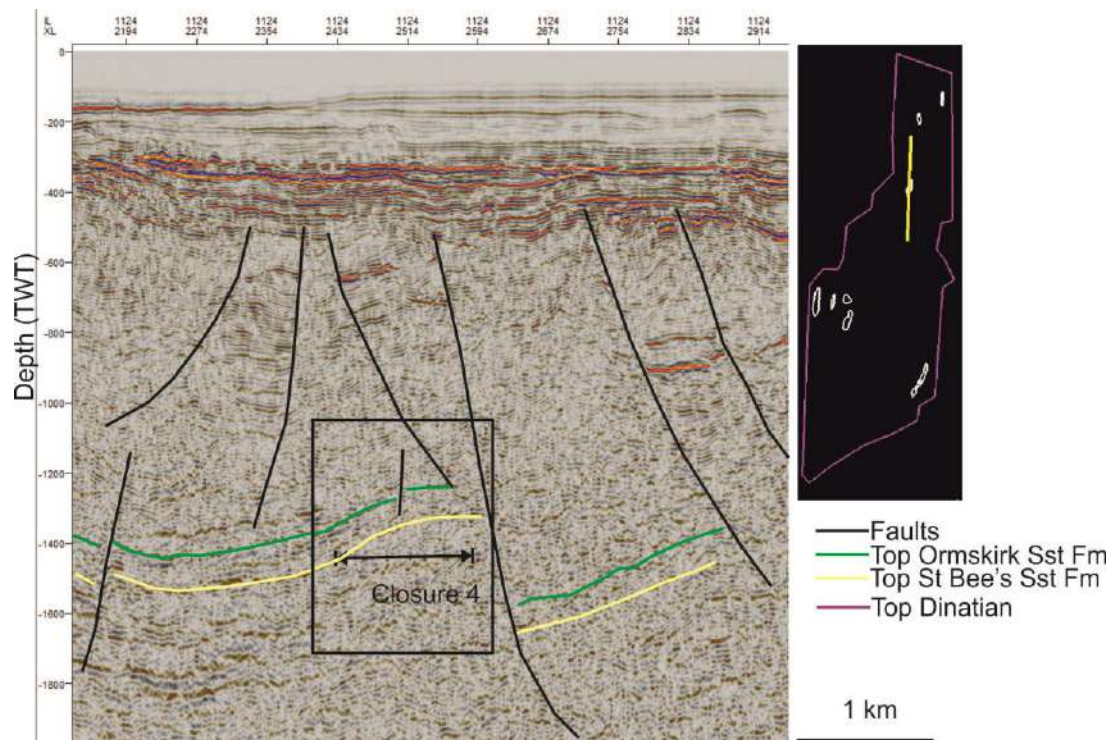


Figure 31 Seismic inline through closure 4. Showing multiple faults affecting the Ormskirk Sandstone Formation.

10.1.5 Closure 5

Closure 1 is a small fault bounded closure (Figure 32). The top Ormskirk Sandstone Formation and top St Bee's Sandstone Formation seismic reflectors are not clear in this area. As a result defining the position of the Ormskirk Sandstone Formation and identifying faults is difficult. One of the faults shows the Ormskirk Sandstone Formation is juxtaposed, if CO₂ were to be injected into this closure there would be a high risk of migration of CO₂ across the fault boundary of the closure. This closure is not suitable for CO₂ storage.

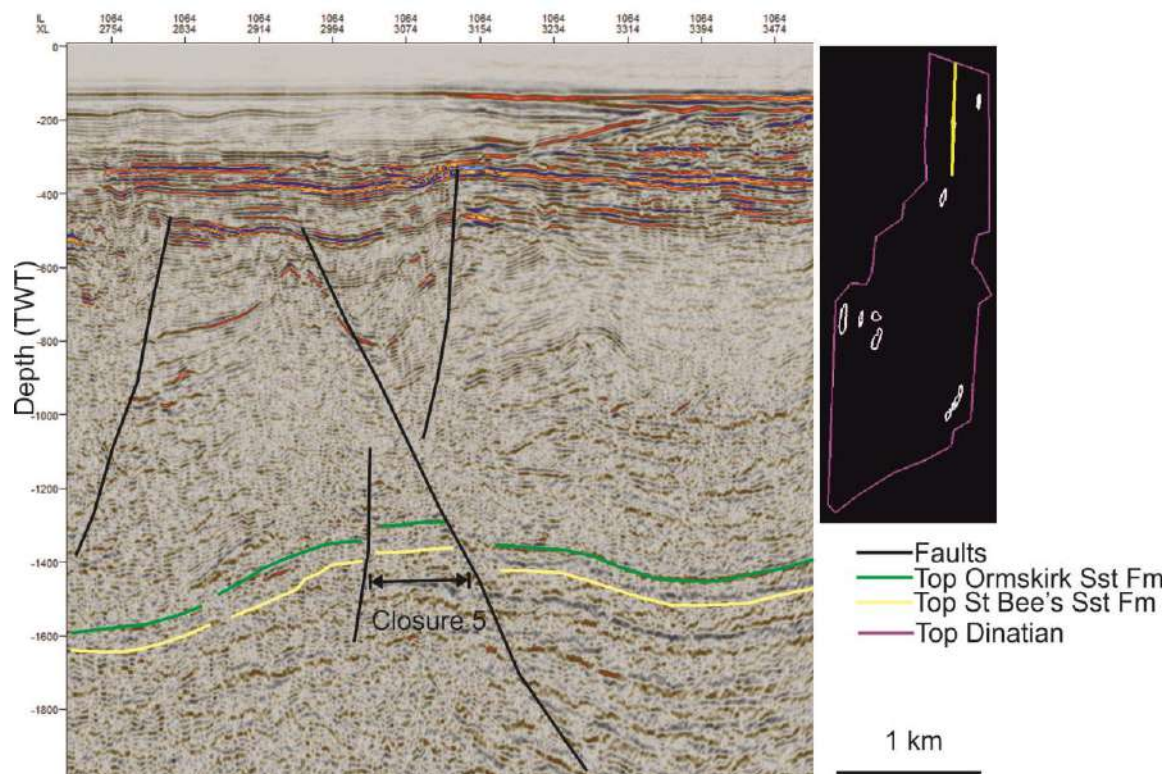


Figure 32 Seismic inline through closure 5. Showing multiple faults affecting the Ormskirk Sandstone Formation.

10.1.6 Closure 6

Closure 2 is a fault bounded anticline (Figure 33). The bounding faults juxtapose the Ormskirk on both sides, this may provide a migration pathway for CO₂ out of the closure. The reservoir is faulted. These faults may compartmentalise the reservoir. This closure does not make a promising target for CO₂ storage.

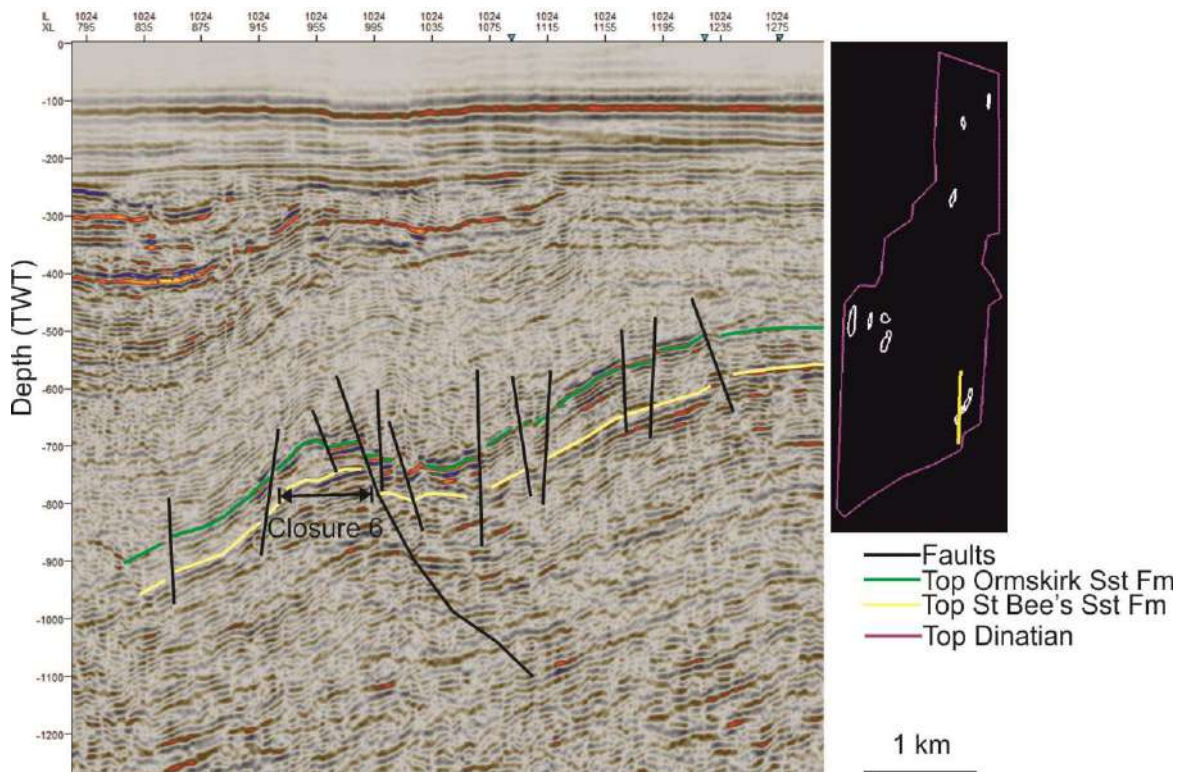


Figure 33 Seismic inline through closure 6. Showing multiple faults affecting the Ormskirk Sandstone Formation.

10.1.7 Closure 7

Closure 7 is a fault defined structural closure. Faults are visible on the seismic that affect the caprock (Figure 34). The reservoir is juxtaposed against reservoir this may provide a migration pathway which reduces the closure integrity. This is not a suitable storage site for CO₂.

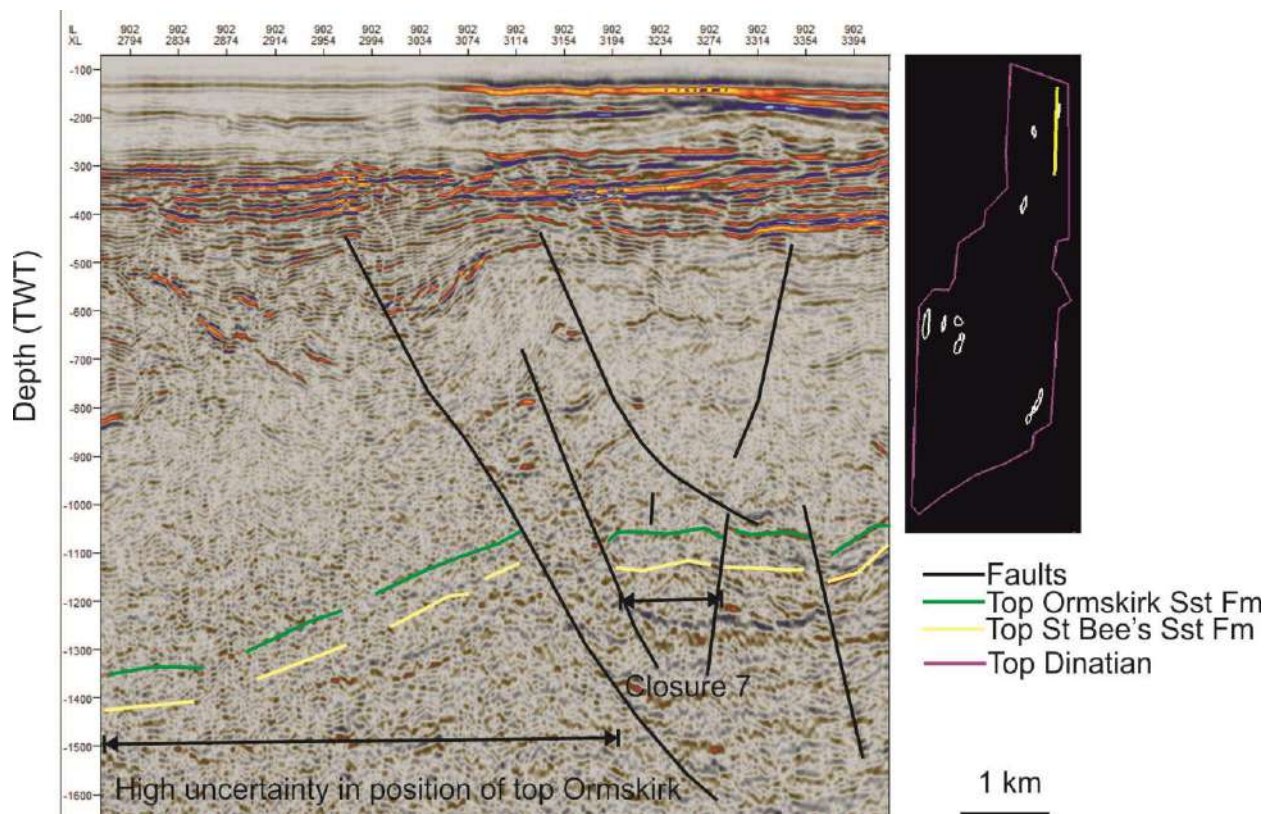


Figure 34 Seismic inline through closure 7. Showing multiple faults affecting the Ormskirk Sandstone Formation.

10.1.8 Closure 8

Closure 8 is a low amplitude anticline (Figure 35). A fault which lies to the south of the structure and has an offset of approximately 200 m may pose a threat to CO₂ stored in the structure should CO₂ migrate across the spill point. Faults in the overburden and caprock do not appear to extend to the reservoir. Slight disruptions in the reflectors above the closure may indicate faults in the caprock with small offsets. The integrity of the structure subject to the sealing capacity of the faults. This structure has some potential for CO₂ storage and has the most promising storage capacity (Table 11), but is still likely to be considered to be too small for CO₂ storage.

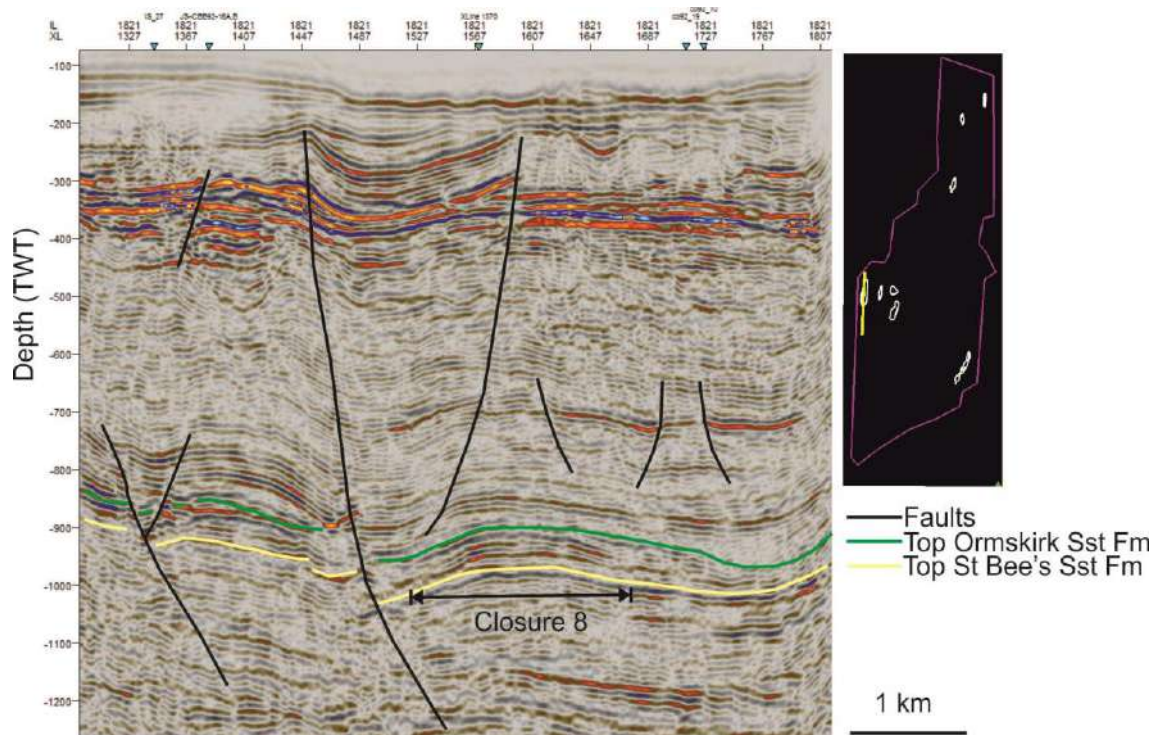


Figure 35 Seismic inline through closure 8. Showing multiple faults affecting the Ormskirk Sandstone Formation.

The calculated storage capacity of the closures are shown in Table 11. The calculation methodology is described in section 8.2. Even using unrealistic storage space utilisation of 1 the largest closure (closure 8) could only store 23 Mt of CO₂. Using a more realistic storage efficiency factor (but still optimistic) for a homogenous dome of 0.25 closure 8 could store 6 Mt.

Table 11 Storage capacity of closure in study area B.

Closure	Area (m ²)	Volume (m ³)	Porosity	Pore Volume (m ³)	Shallowest depth of closure (m)	Temperature (°C) (based on a temperature gradient of 0.031 °C/m)	Pressure bar (based on a pressure gradient of 1.3 bar/m)	CO ₂ Density (t/m ³)	CO ₂ storage capacity (Mt)
1	772975	1.39E+08	0.16	22306560.00	1111.00	34.44	144.75	0.81531	18.19
2	289650	4.82E+07	0.16	7708384.00	1036.00	32.12	134.98	0.81583	6.29
3	452050	7.05E+07	0.16	11272416.00	1199.00	37.17	156.21	0.80952	9.13
4	408700	1.12E+08	0.16	17841600.00	1592.00	49.35	207.42	0.79812	14.24
5	228350	6.60E+07	0.16	10566784.00	1669.00	51.74	217.45	0.79279	8.38
6	876825	1.43E+08	0.16	22932000.00	886.00	27.47	115.43	0.82452	18.91
7	228150	6.37E+07	0.16	10198064.00	1293.00	40.08	168.46	0.80539	8.21
8	1.17E+06	1.82E+08	0.16	29047840.00	1247.00	38.66	162.47	0.80418	23.36

10.2 CO₂ STORAGE POTENTIAL OF STUDY AREA B

Study area B has been evaluated using 3D seismic data. Top Ormskirk Sandstone Formation and top St Bee's Sandstone depth maps were created to evaluate the depth, thickness, structure and distribution of the Ormskirk Sandstone Formation. The area is densely faulted with faults exhibiting four fault trends with evidence of multiple faulting episodes. A major fault orientated NE-SW bisects the study area creating a footwall fault terrace in the southern region of the study area. On the fault terrace the majority of the Ormskirk Sandstone Formation is too shallow to be considered for CO₂ storage. Faults orientated N-S, NNE-SSW and WNW-ENE, segment the Sherwood Sandstone Group into small fault blocks. Within these fault blocks seven fault closure controlled closures were identified. All of these closures are too small to be considered for CO₂ storage. The size of the closures when considered with the risk to storage site integrity due to the high density faults makes this area unsuitable for CO₂ storage.

11 Conclusions

The Ormskirk Sandstone Formation has fair to good reservoir properties over the whole of the southeastern part of the Central Irish Sea Basin. Overlying mudstones, siltstones and halites of the Mercia Mudstone Group act as an effective seal to hydrocarbon accumulations in the East Irish Sea Basin and it is thought that this succession in the Central Irish Sea Basin could also act as an effective seal to CO₂ storage schemes. The study area however is structurally complex with closely spaced normal faults dissecting the Ormskirk Sandstone Formation, and these may challenge storage security. Evidence of gas seepage on the Codling fault in the Kish Bank Basin adds further uncertainty to the sealing capacity of similar faults in the CISB. Some faults detach along assumed evaporitic horizons at several levels, adding complexity to the area. Structural closures have been identified and the CO₂ static storage capacities have been calculated based on a range of storage efficiency factors from published research. The static storage capacities of the closures are estimated to range from 1.26 to 61.50 Mt of CO₂. To achieve specific storage efficiency factors for the Central Irish Sea Basin, numerical flow simulations would be required.

Many of the closures in the study areas may be too small for large-scale storage of CO₂ from industrial point sources. If the higher storage efficiency factors of 0.25 could be achieved in the larger closures, B and E could potentially achieve 10 years worth of CO₂ storage from a large point source such as the Moneypoint Power station which emits approximately 5 Mt of CO₂ per year. It may be that smaller sources of CO₂ could find niche storage in the area covered by this study.

A major source of uncertainty in the analysis is the accuracy of the depth conversion. Inaccuracies in depth conversion will affect the calculated dip of the Top Ormskirk Sandstone, this in turn will affect the geometries of the closures and ultimately the closure volumes. These inaccuracies will carry forward into the static capacity calculations.

Proving storage security in the CISB would be a major challenge. All the closures identified (with the exception of closure A) are affected in some way by faulting. They define the closure in for example, closures E, B 7 and 6 and are present within the other closures. The faults are closely spaced and could potentially provide migration pathways for CO₂ out of the storage closures. Due to the known distribution pattern of faults identified in study area A it is likely that faults exist 'between' the 2D seismic grid and will not therefore have been mapped in this study. The analysis of the 3D seismic survey in study area B shows that the faulting in this region is densely spaced in some areas less than 500 m spacing. As a result structural closures are small. Table 10 shows a summary of the suitability of the CISB for CO₂ storage.

Table 12 Summary of suitability of the study area for CO₂ storage.

Feature	Comment
Reservoir Quality	Fair to good
Reservoir compartmentalisation	Faults present in reservoir but compartmentalisation is unknown
Depth of reservoir	Large portions below 800 m
Storage capacity	In defined closures tiny to viable
Storage efficiency	Unknown
Closure	Study area A- Closure coarsely mapped on a 2D grid by precise architecture of the closures unknown. Study area B- Closures mapped by 3D data are fault defined and small.
Caprock	Present but sealing capacity unknown
Caprock thickness	In wells ranges between 776 m and 1425 m
Faulting	Closely spaced faults with unknown seal capacity
Tectonic activity	Not investigated in this study but Codling Fault Zone is active in nearby Kish Bank Basin.

In summary using study area A and B of the CISB as a case study for the rest of the CISB it is unlikely that the estimated static CO₂ storage capacity is as large as indicated in the All Ireland Study.

12 Recommendations for further work

- This report highlights the importance of faulting in the CISB on storage. Further could include:
 - Study of the faulting styles and patterns across the CISB.
 - Study of fault movement on the Codling fault zone with University College Dublin.
 - Review of tectonic activity in the basin .Review of faulting style in known hydrocarbon field in the EISB and comparison with CISB.
 - Review of the tectonic stress regime in the CISB.
- Study of the Mercia Mudstone Group in order to understand the lithology and distribution of the caprock, would help understand the sealing characteristics of the caprock and will provide information for further fault analysis.
- Sedimentological study of the Ormskirk and St Bees Sandstone Formations in the Central Irish Sea Basin. As reservoir facies changes and diagenesis of the reservoirs will affect injectivity, migration of CO₂ and compartmentalisation of the reservoir (lateral continuity).
- Static modelling and dynamic simulation of CO₂ injection into closure B or E to provide more realistic storage capacities.

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