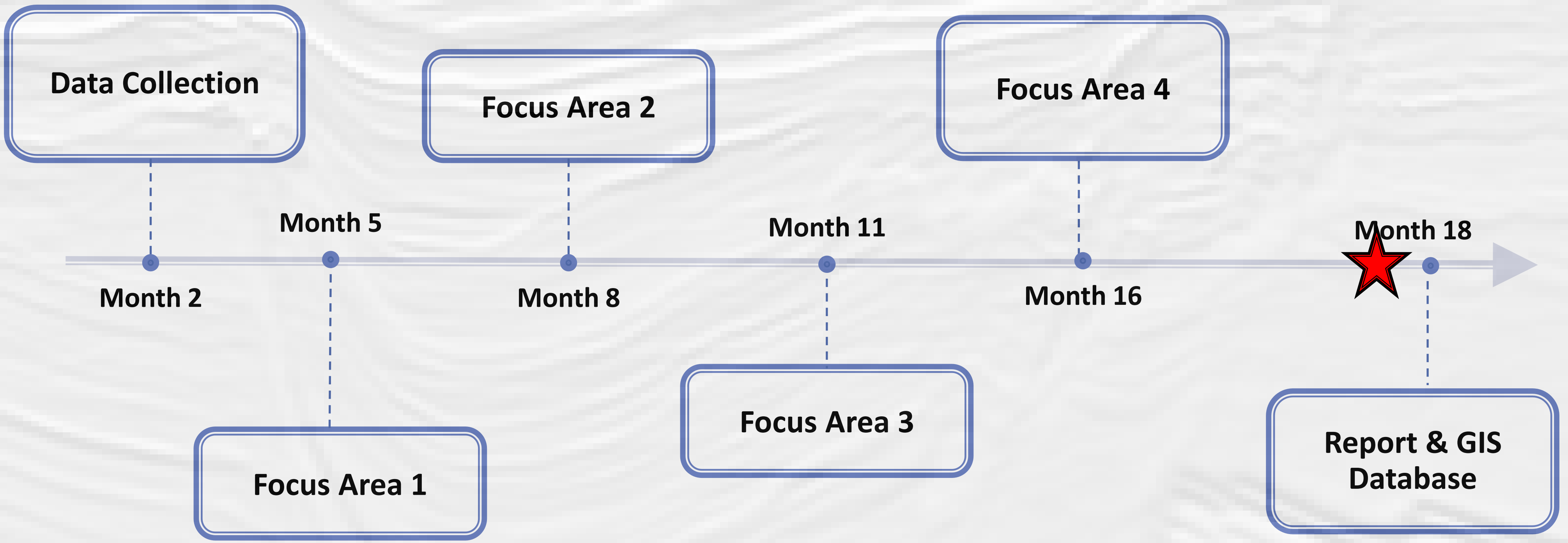
Hydrogen Salt Storage Assessment (HYSS)
Grant Agreement – 21/RDD/673

Feb 2024

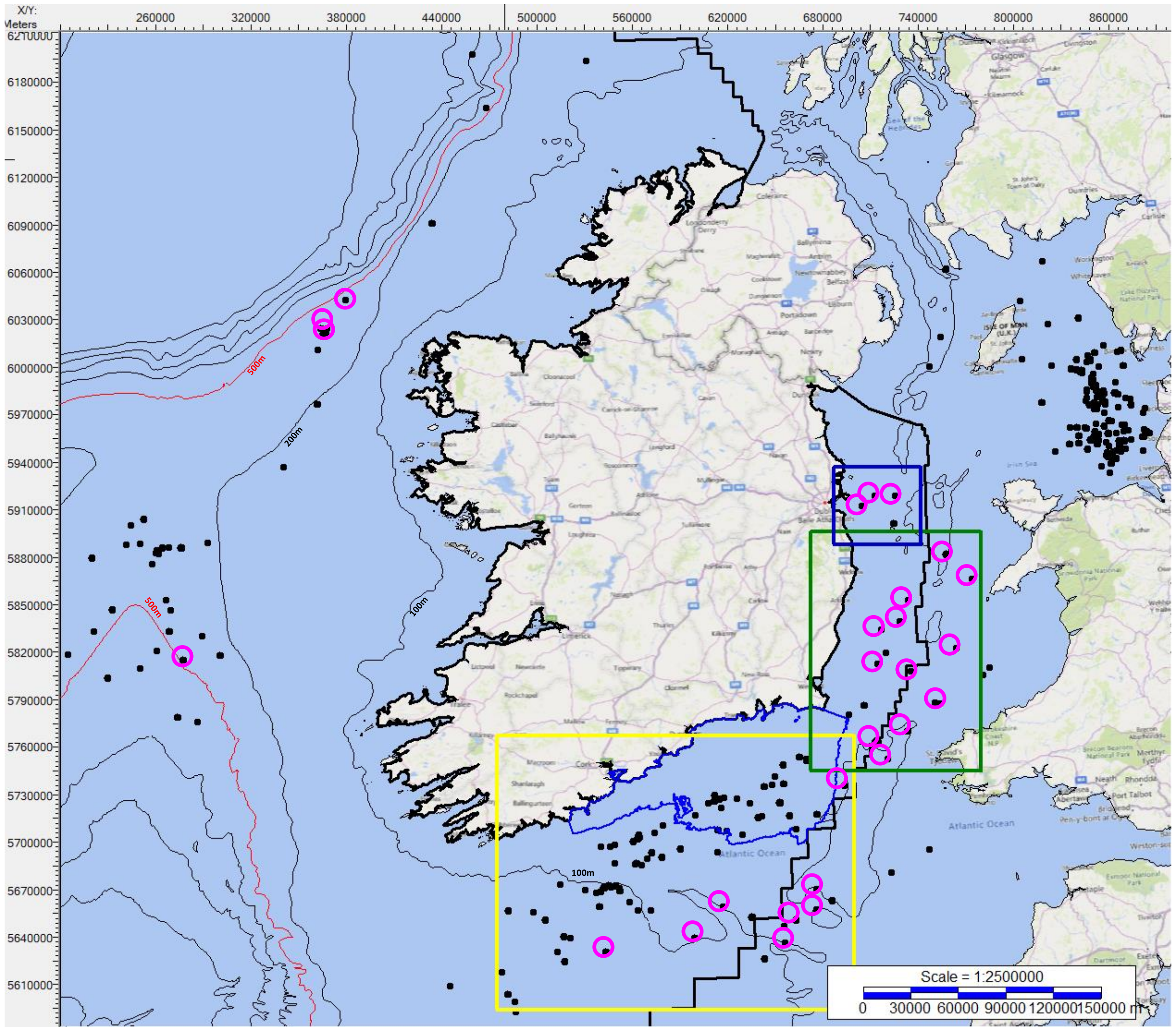
Objectives

- Assess hydrogen storage potential within manmade salt caverns offshore Ireland.
- Identify potential surface, subsurface and environmental risks.
- Focused on areas suitable for offshore wind projects-
  - Focus Area 1: Kish Bank Basin
  - Focus Area 2: Irish Sea Basins
  - Focus Area 3: Celtic Sea Basins
  - Focus Area 4: Atlantic Margin Basins
- Fill identified data gaps in reports on potential of hydrogen storage offshore Ireland.
- Repurpose existing hydrocarbon industry datasets & engage with ORE industry.
- Assessment of saline aquifers still needs to be assessed.

Project Timeline



Known Halite in existing wells



Kish Basin Focus Area

Irish Sea Basins Focus Area

Celtic Sea Basins Focus Area

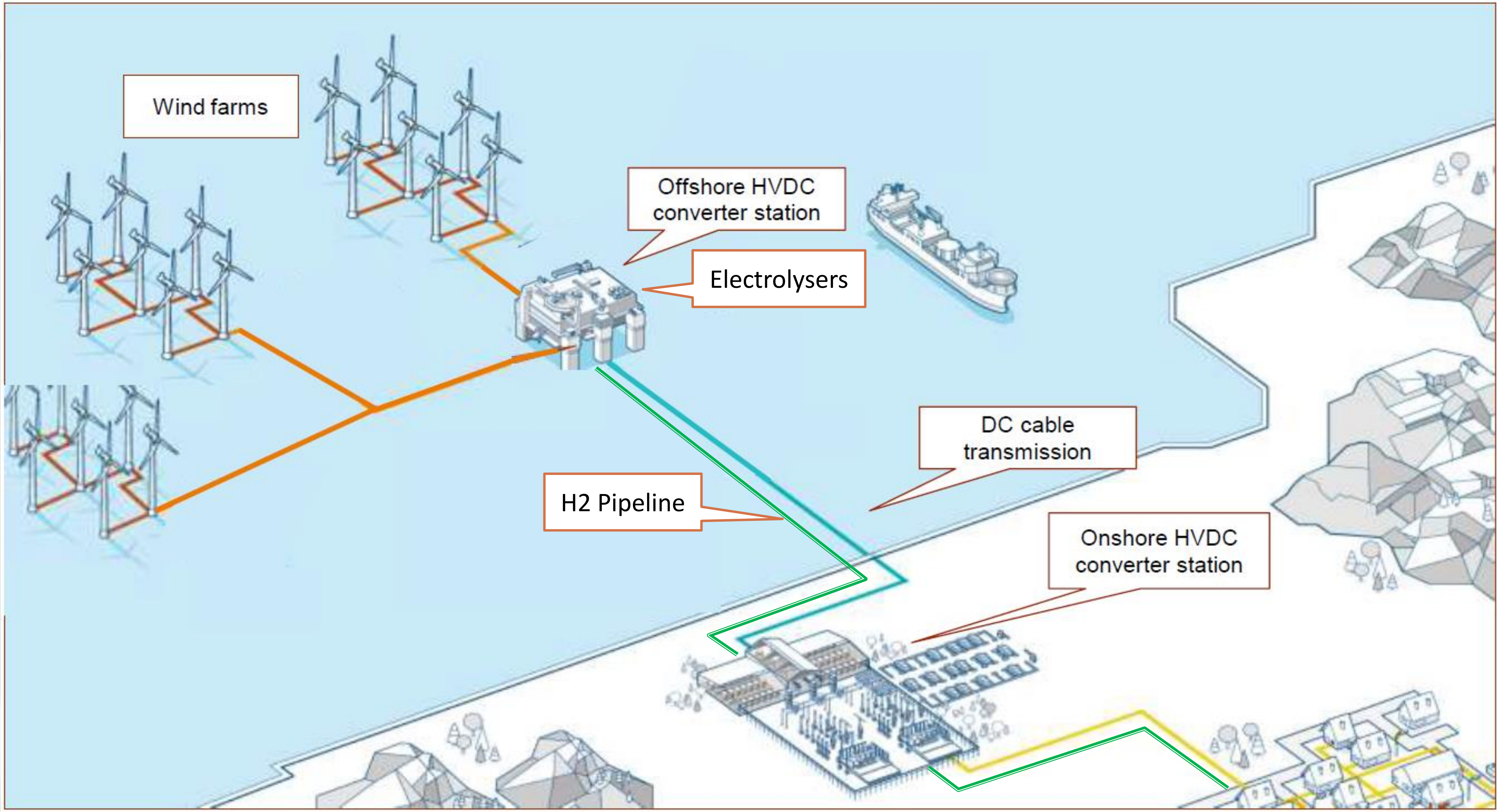
Historic Wells

Proven Halite

Water Depth Contours

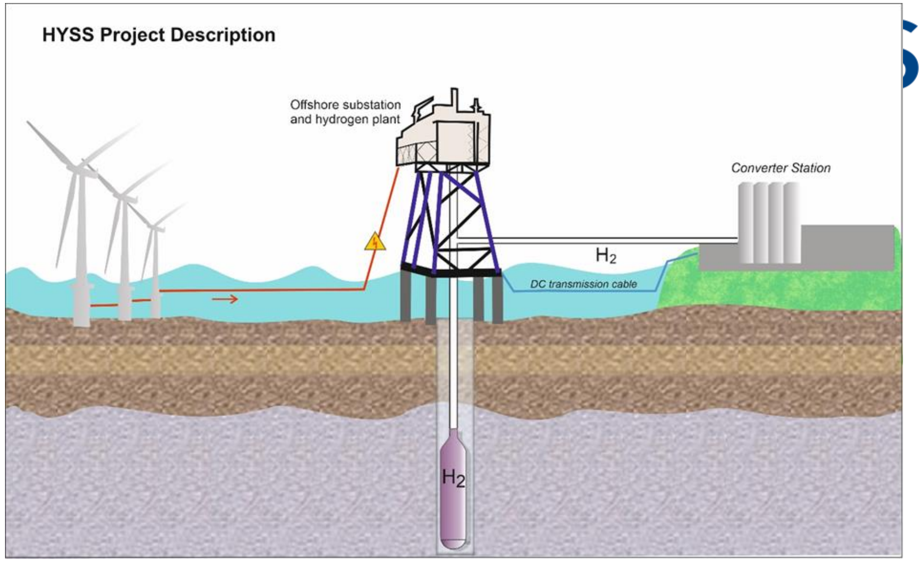
South Coast DMAP

Green Hydrogen Model



Courtesy: ABB Power Systems, Nov 2016; Modified.

Figure 3 Hydrogen Production Platform. Source Poshydon



Stage 1 Construction of Offshore Wind Farm

- seabed foundations
- turbine installation
- offshore substations
- inter turbine array cables
- export DC cable to shore
- onshore substation

Year 1 to 3

Stage 2 Geological Site Characterisation of Subsea Salt Cavern

- 3D seismic survey acquisition
- 3D processing & interpretation
- drill appraisal well
- data analysis & interpretation
- salt cavern modelling

Year 1 to 4

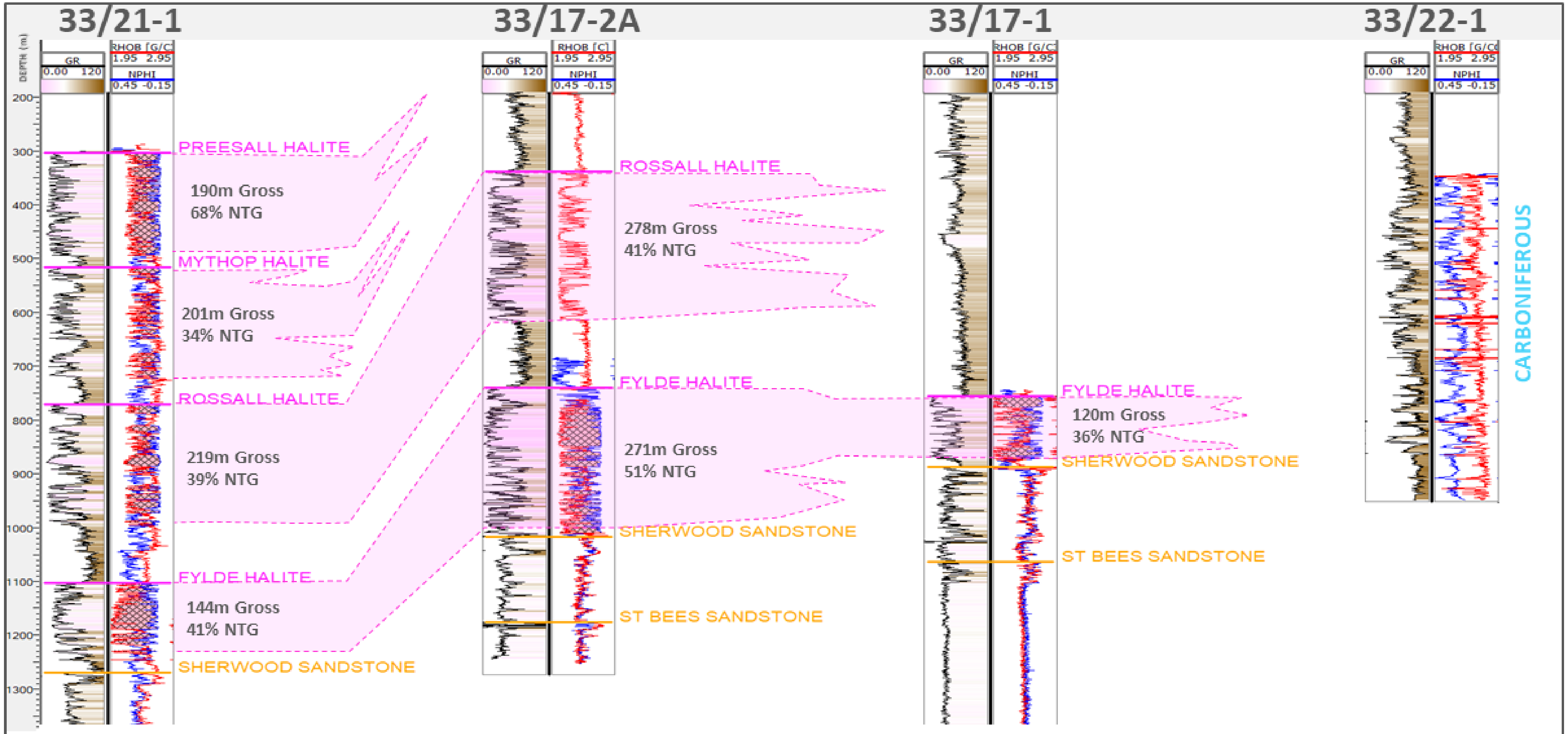
Stage 3 Cavern Solution Mining and Installation of Hydrogen Plant Offshore Platform

- re-enter appraisal well
- cavern solution mining
- completion of production well
- installation of hydrogen production platform
- export hydrogen pipeline to shore

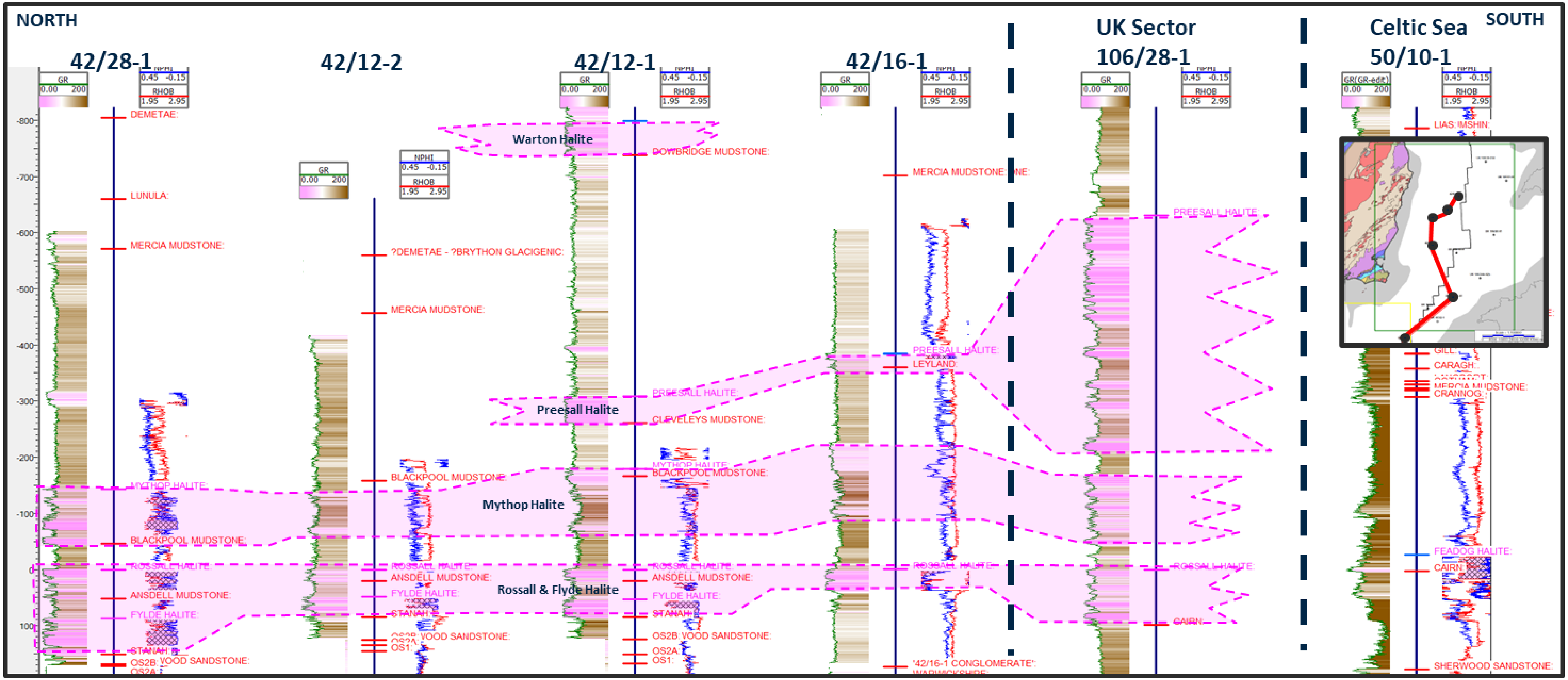
Year 4 to 7

Figure 5 Kish Basin Offshore Green Hydrogen Production Facility Construction

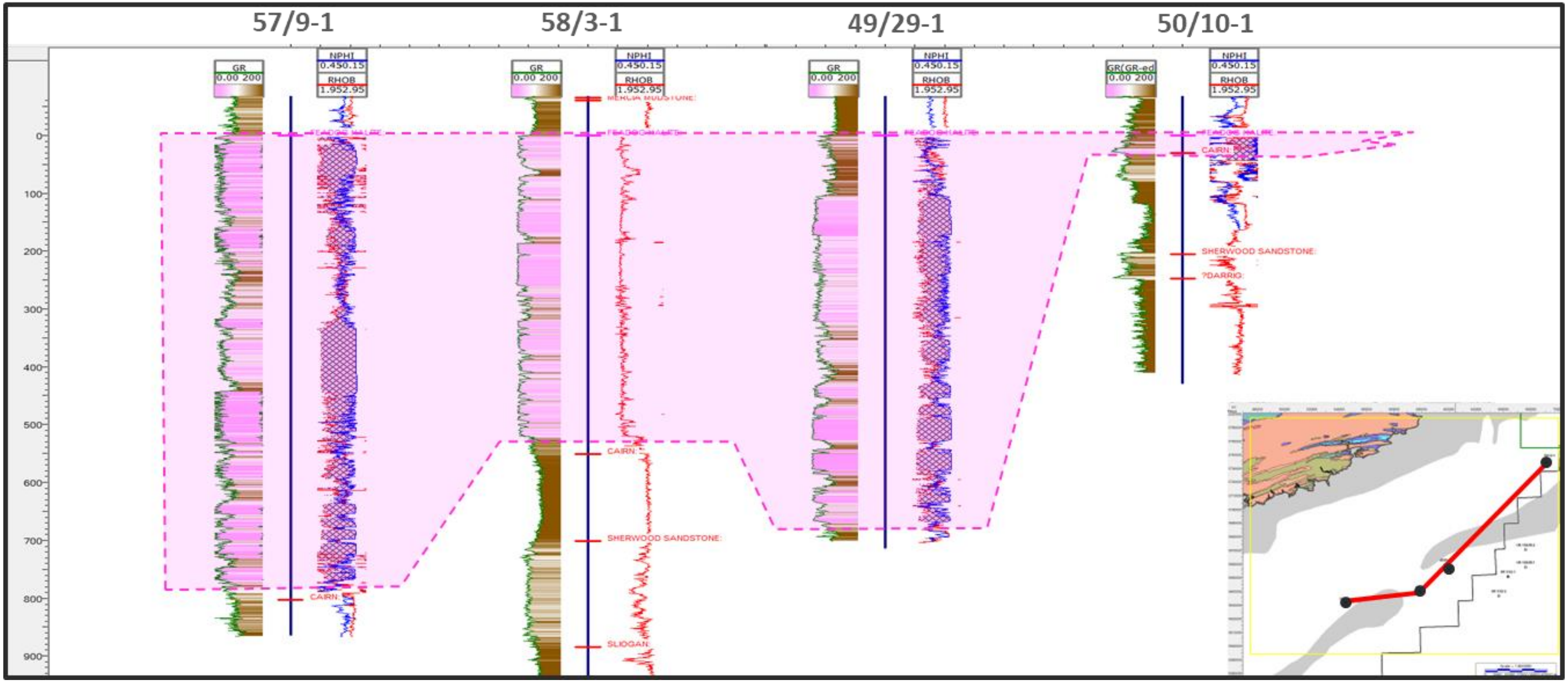
Known Halite in Kish Bank



Known Halite in Irish Sea

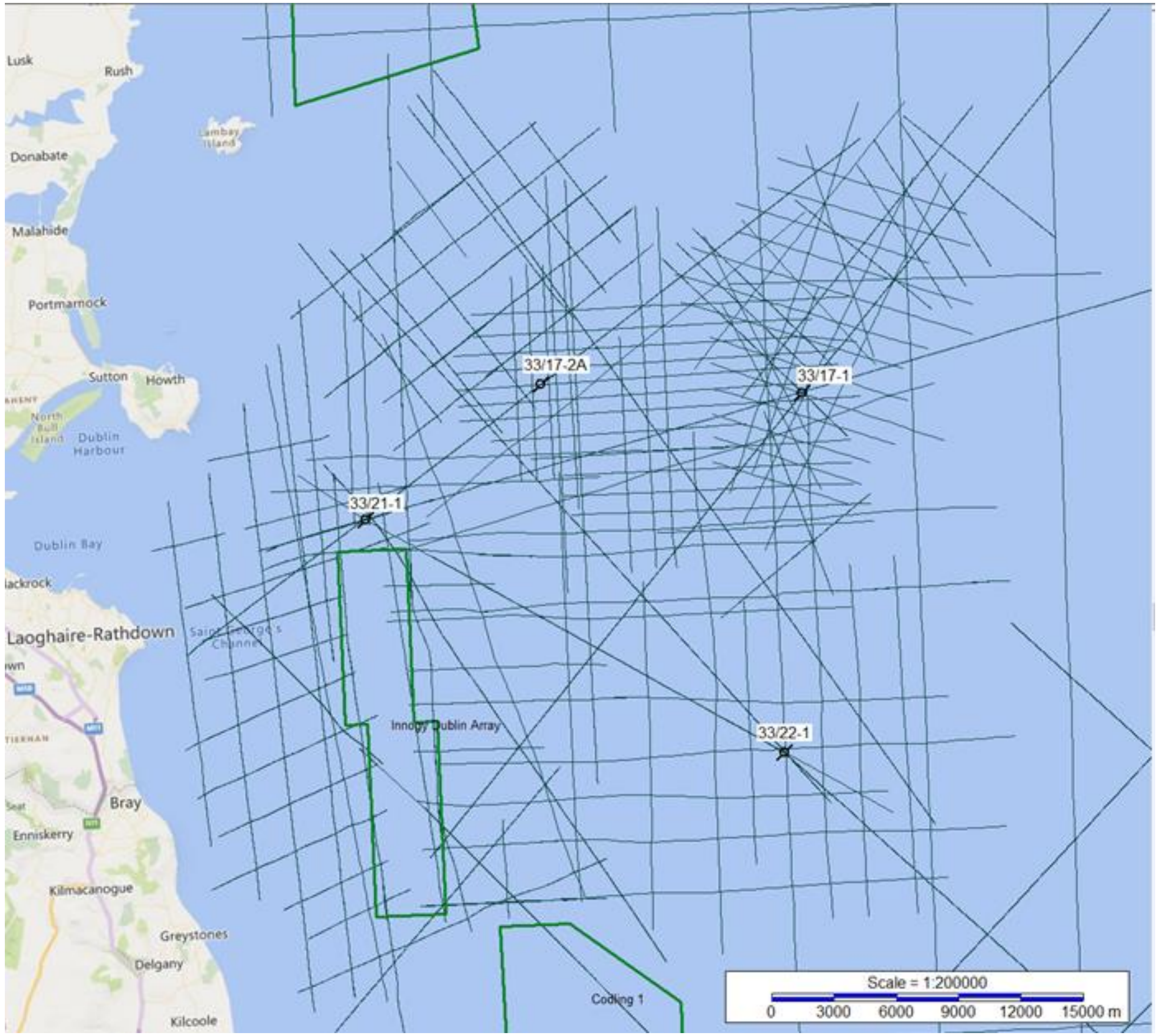


Known Halite in Celtic Sea



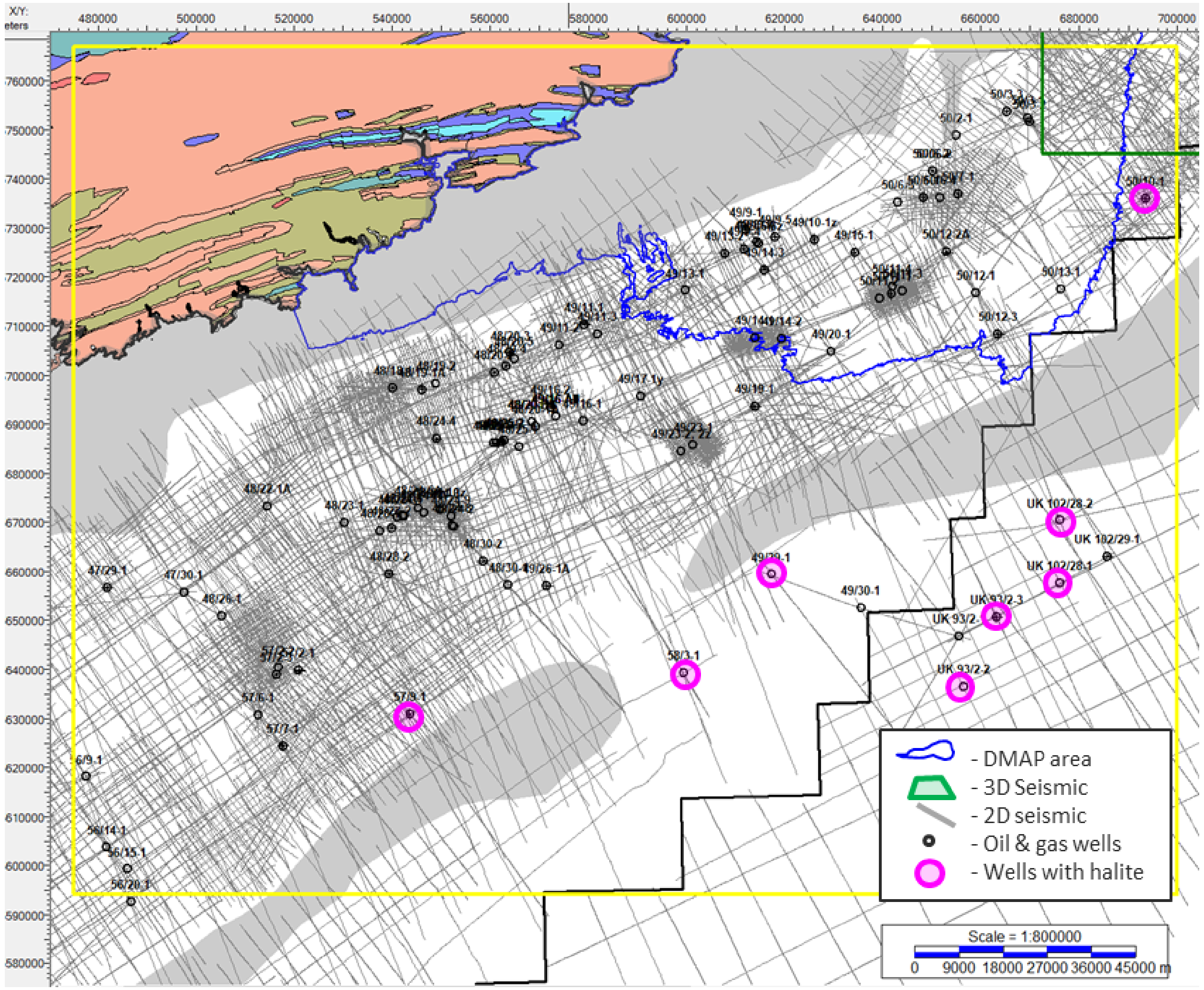
Database Utilised

Kish Basin Dataset

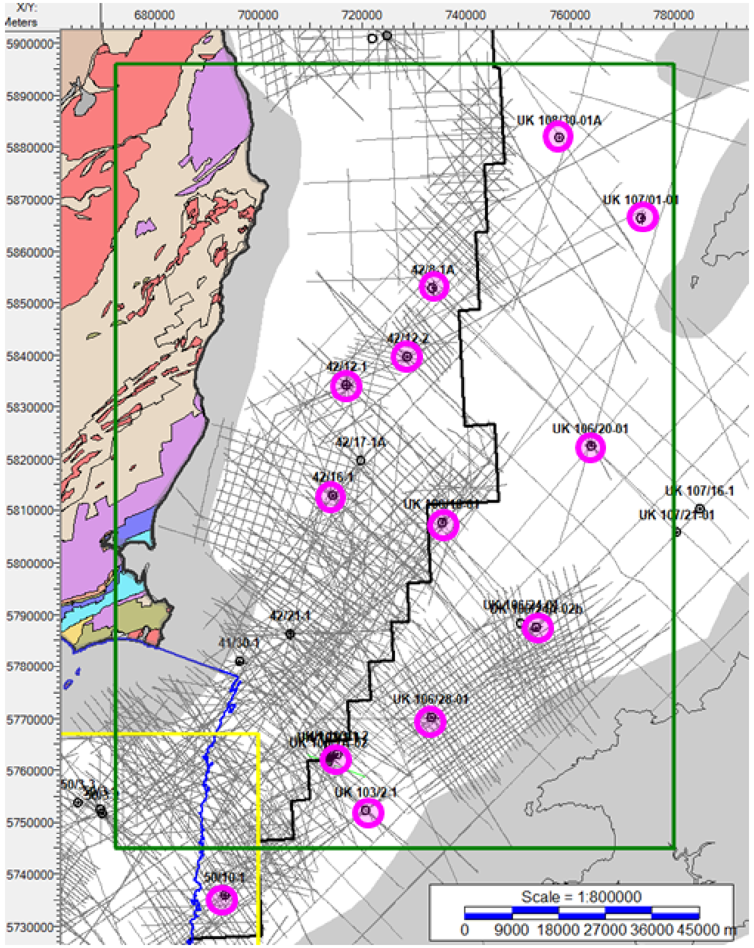


Database Utilised

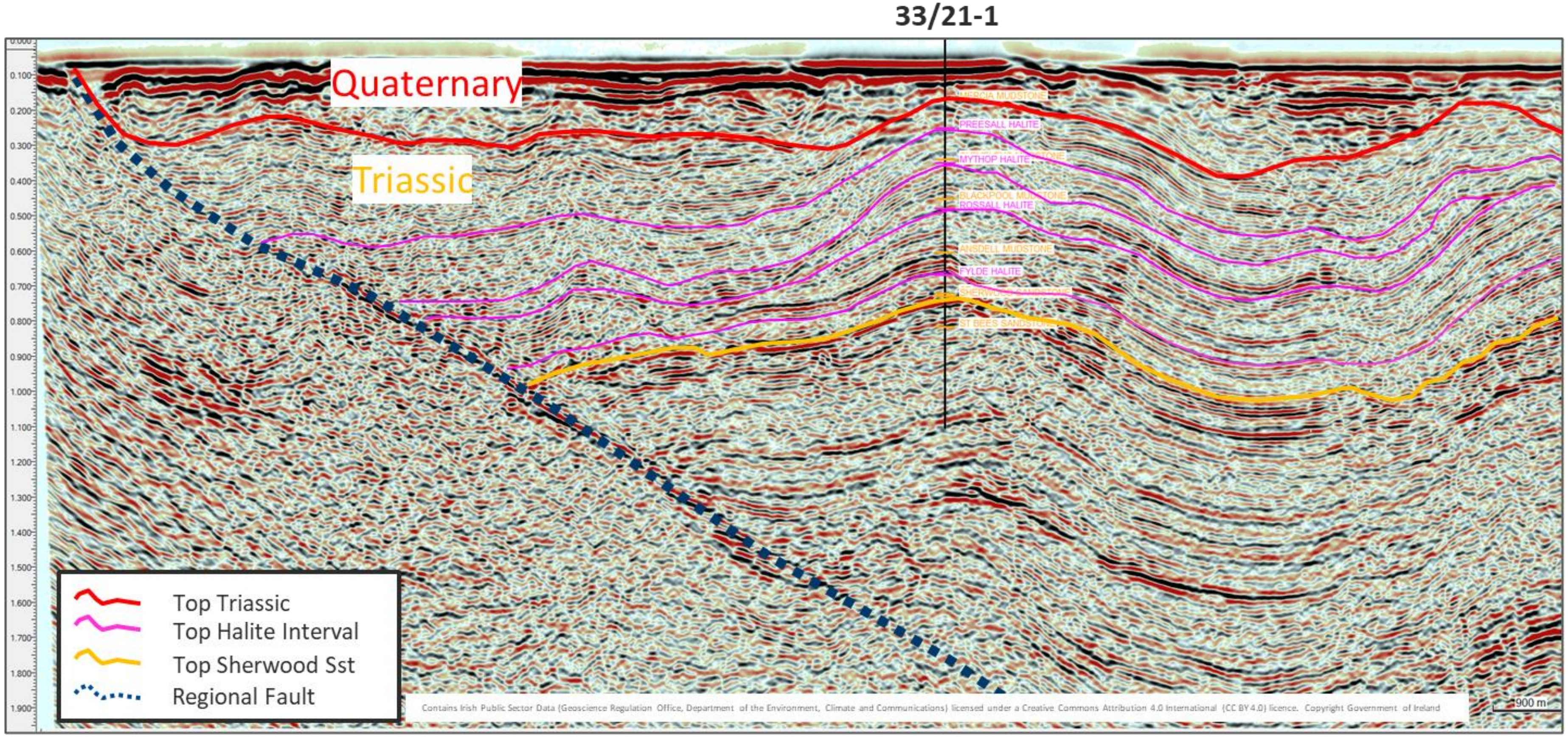
Celtic Sea Basins Dataset



Irish Sea Basins Dataset



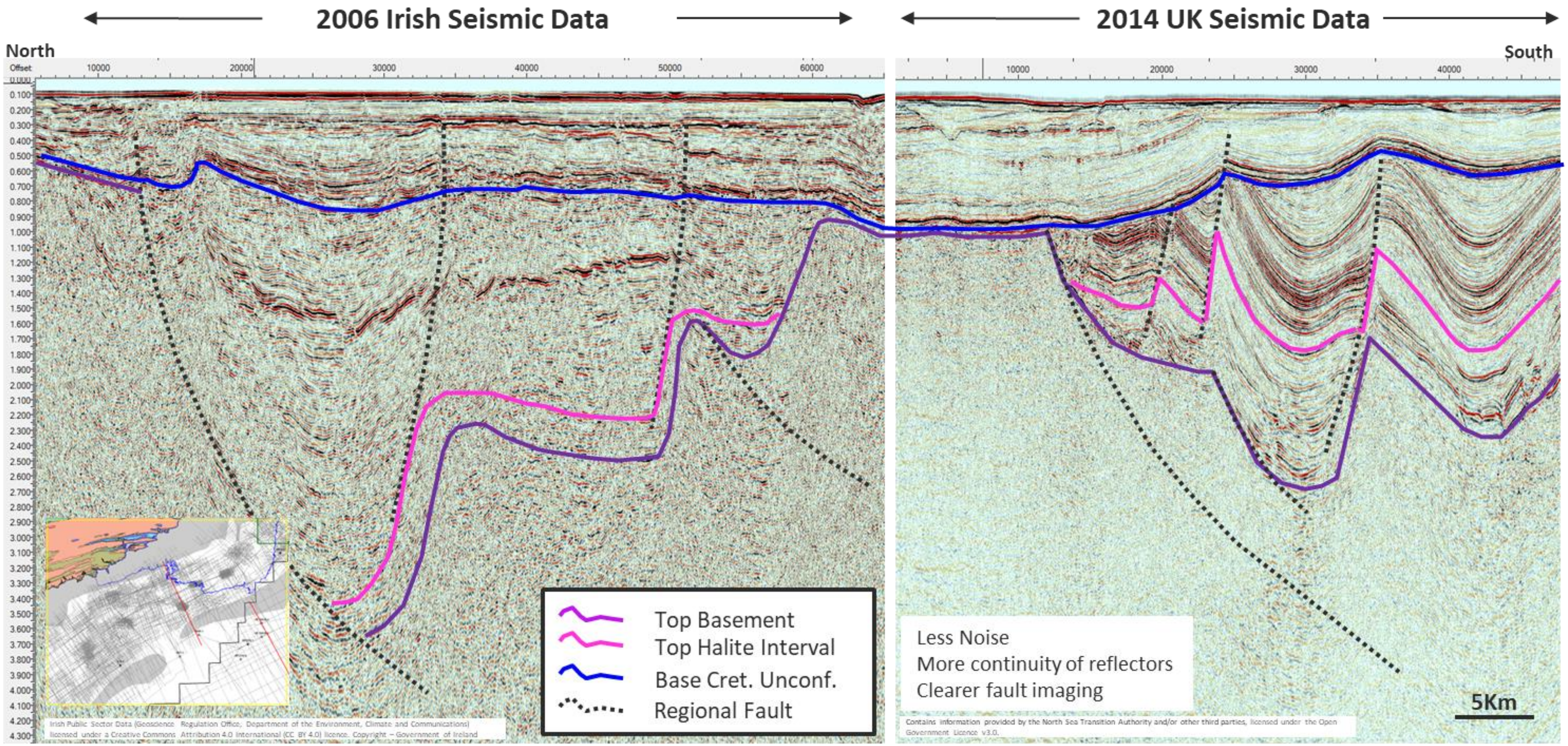
Example Data Quality – KISH



Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

SEAI SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Example Data Quality – CELTIC Best Quality



Example Data Quality – Typical Irish Data

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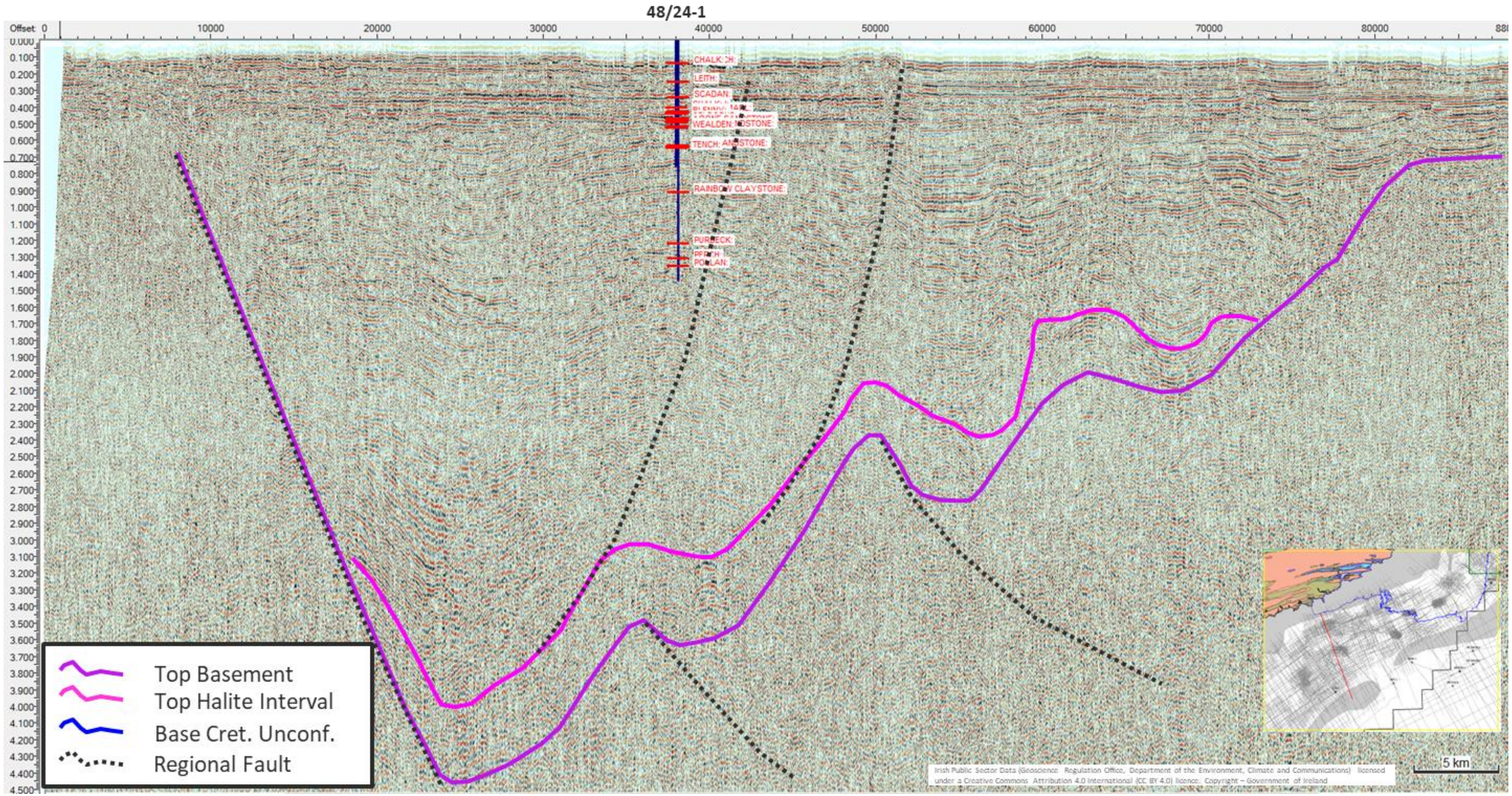
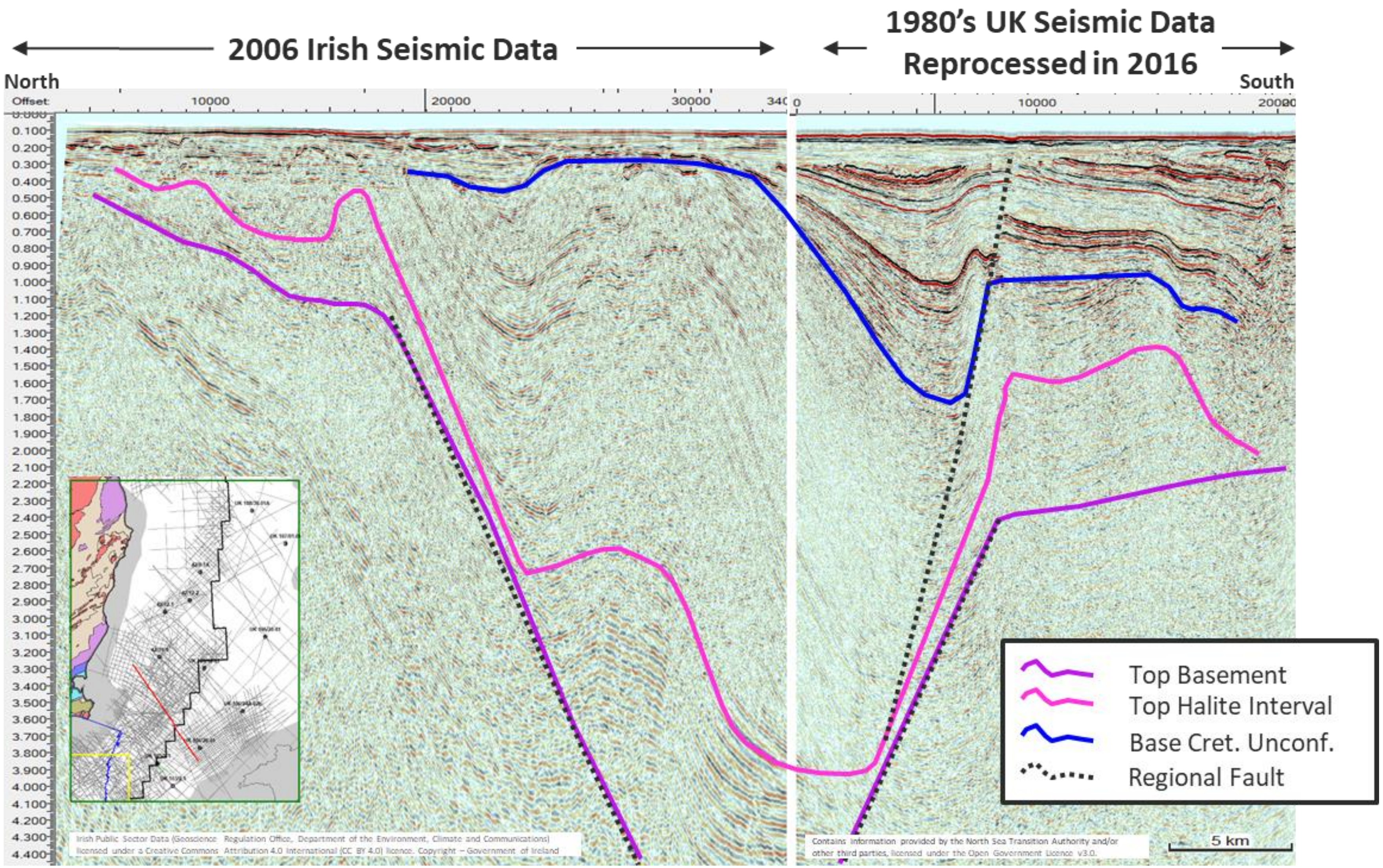
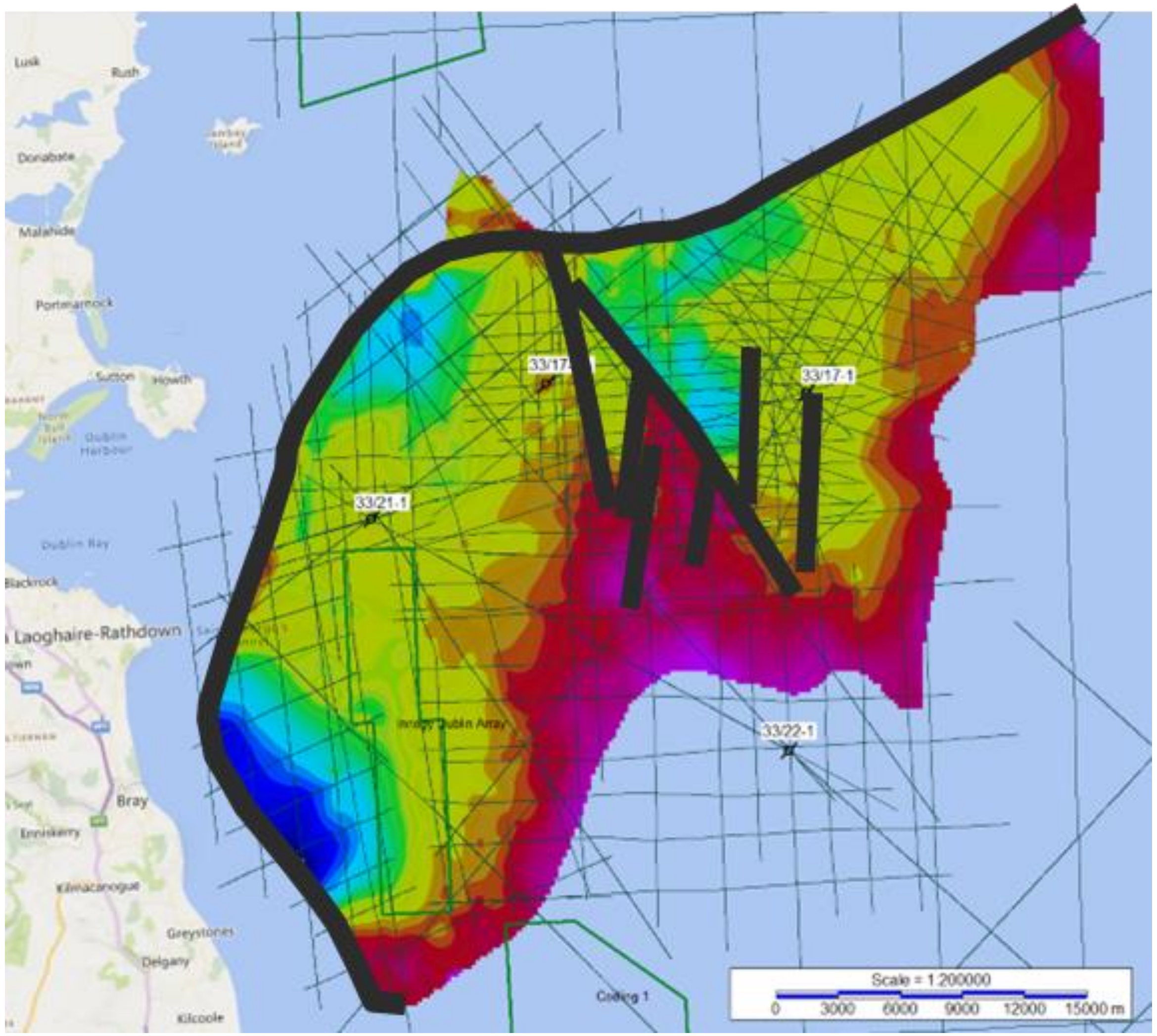


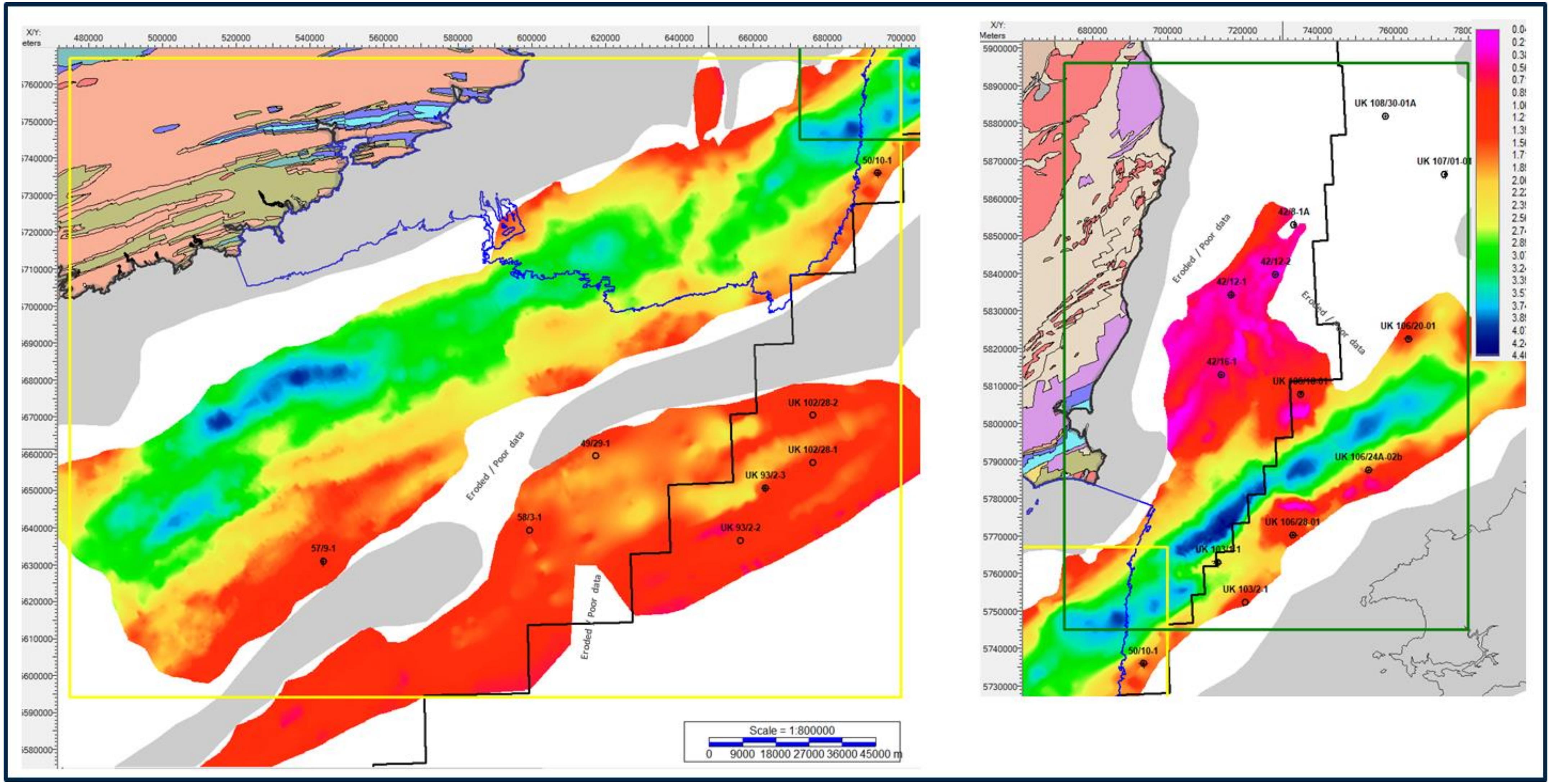
Example Data Quality - Reprocessing



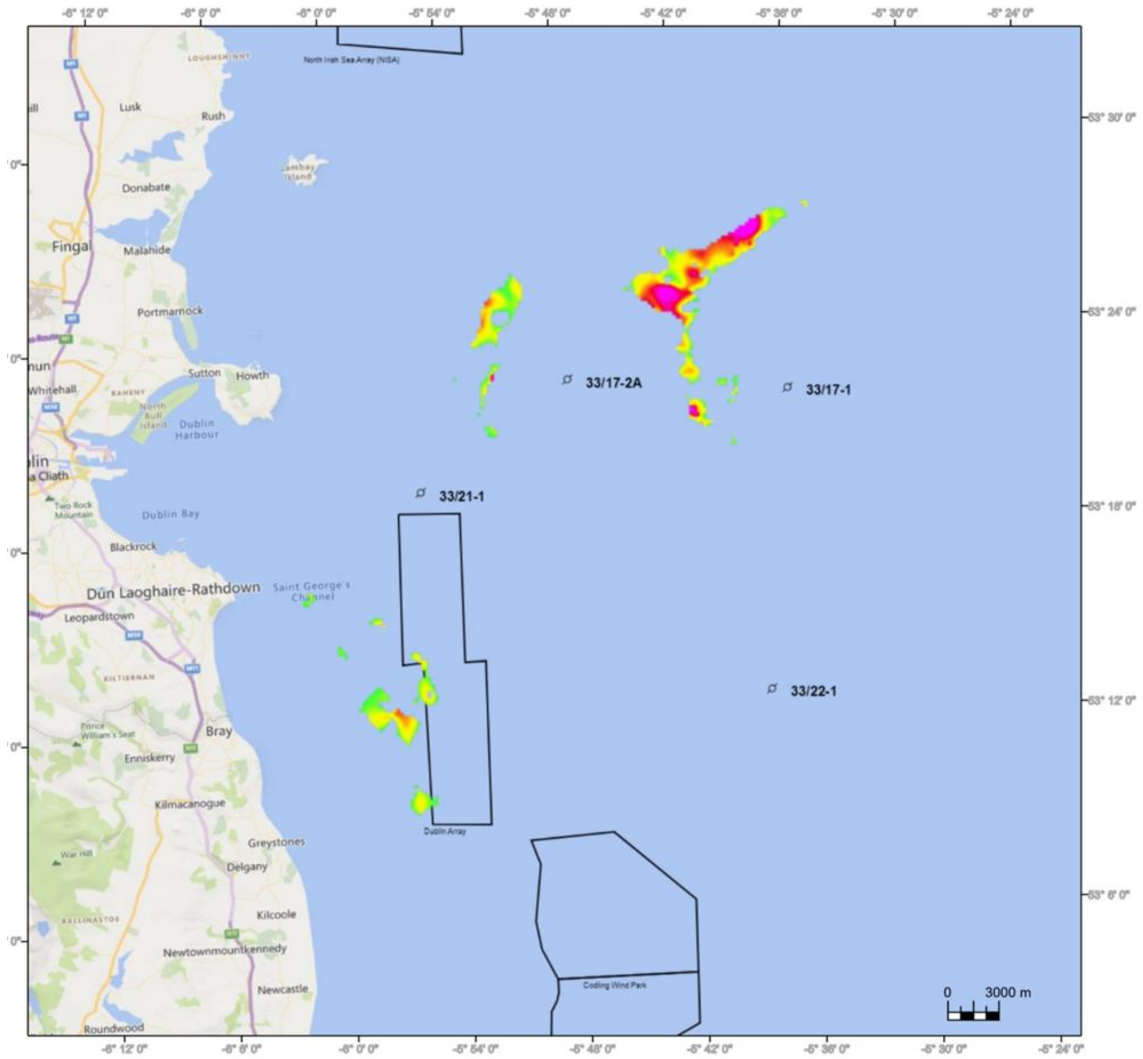
Top Halite Interpretation – Time Domain



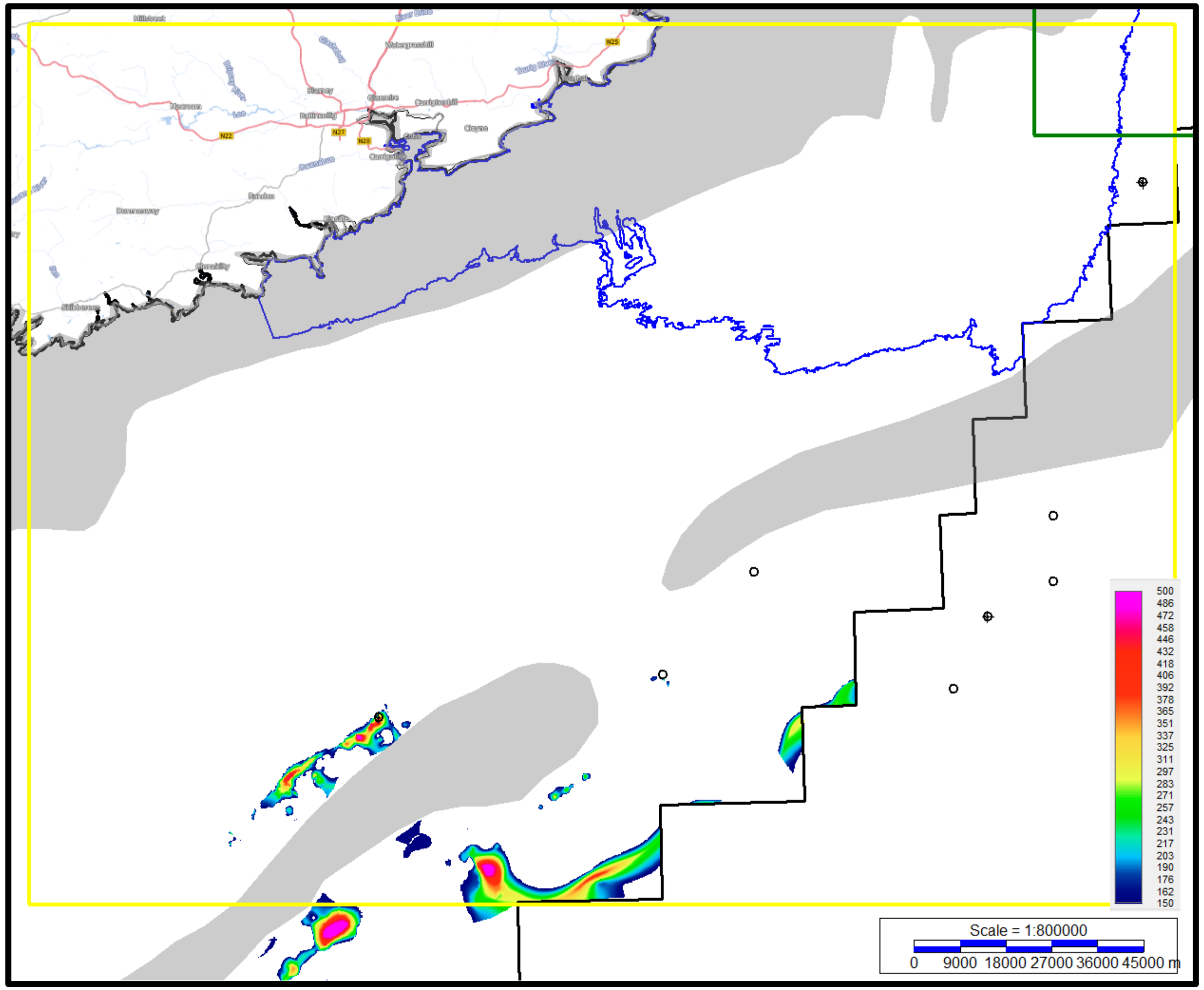
Top Halite Interpretation – Time Domain

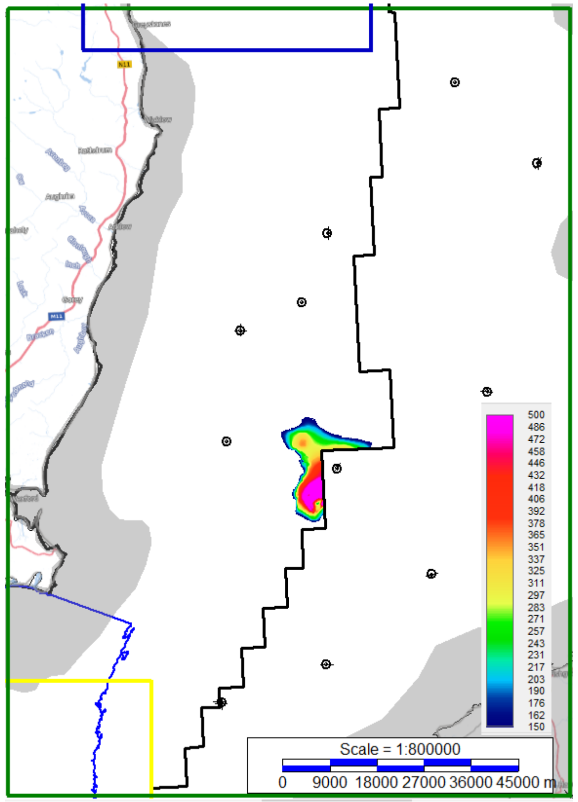


Halite within Zone of Interest



Halite within Zone of Interest

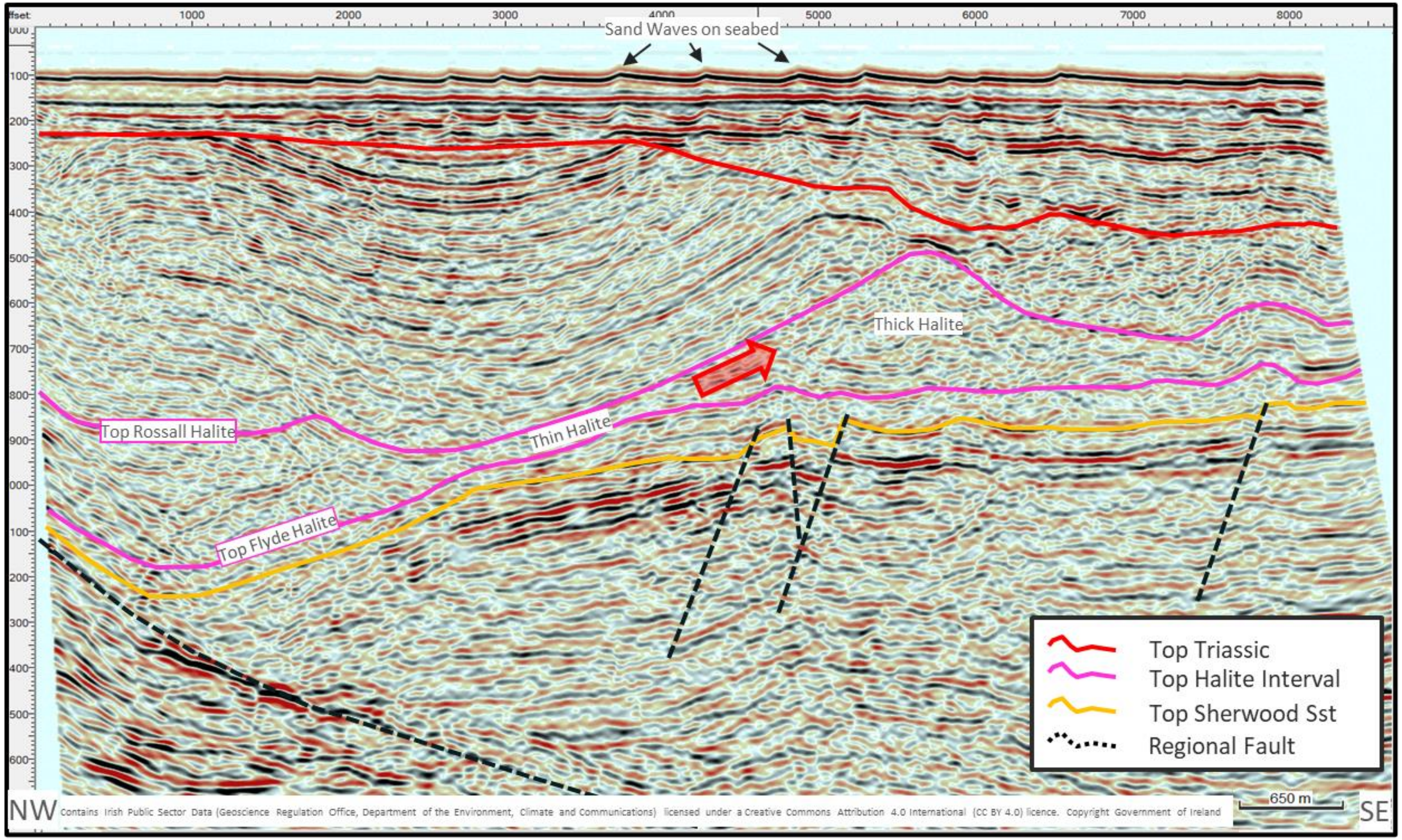




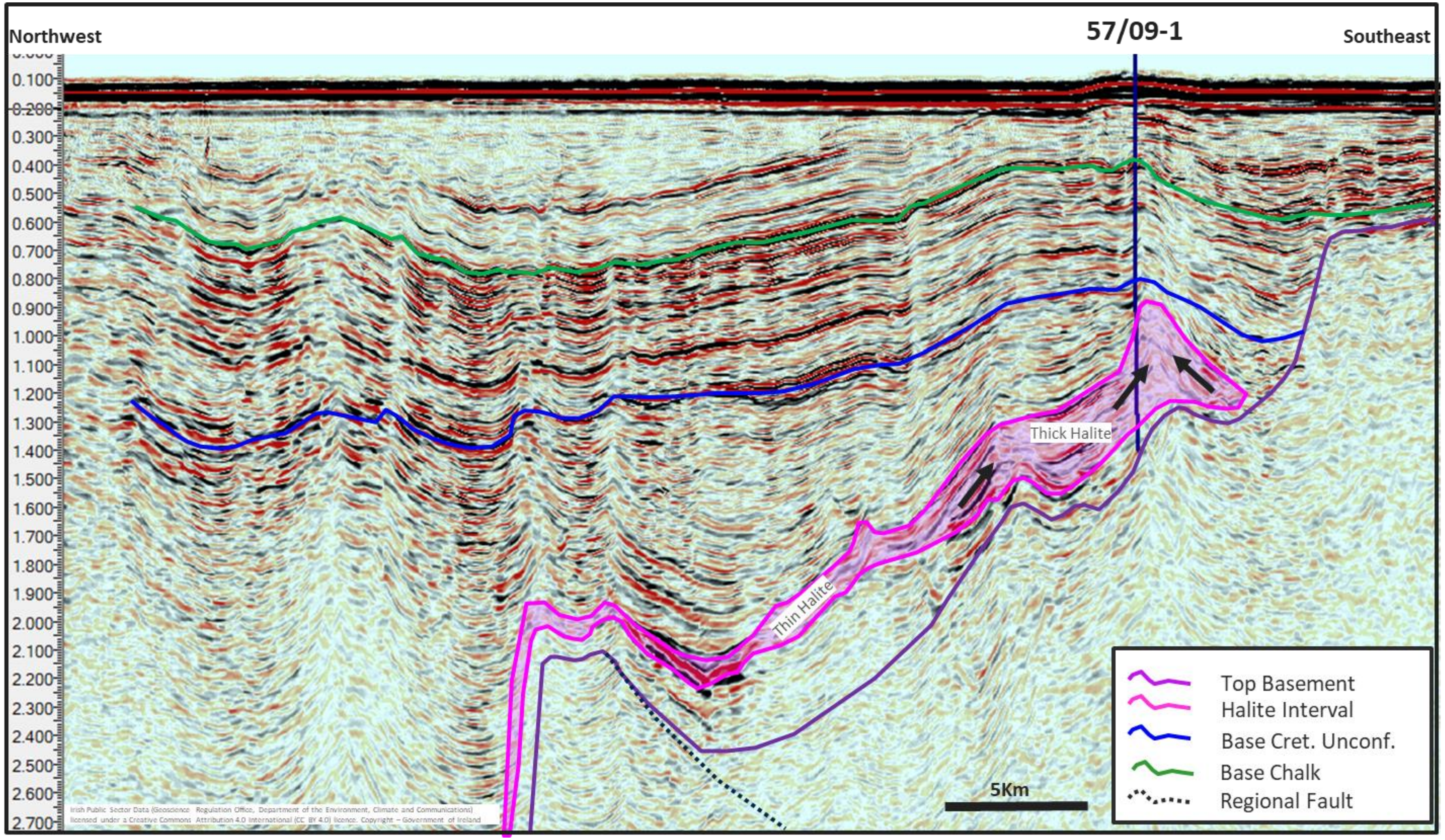
Celtic Sea and Irish Sea Halite with a depth of 1 to 1.5km, and thickness >150m

Evidence of Salt Thickening – Celtic Sea

Halokinesis evident where halite has moved from thin area to thick area, as annotated by red arrow

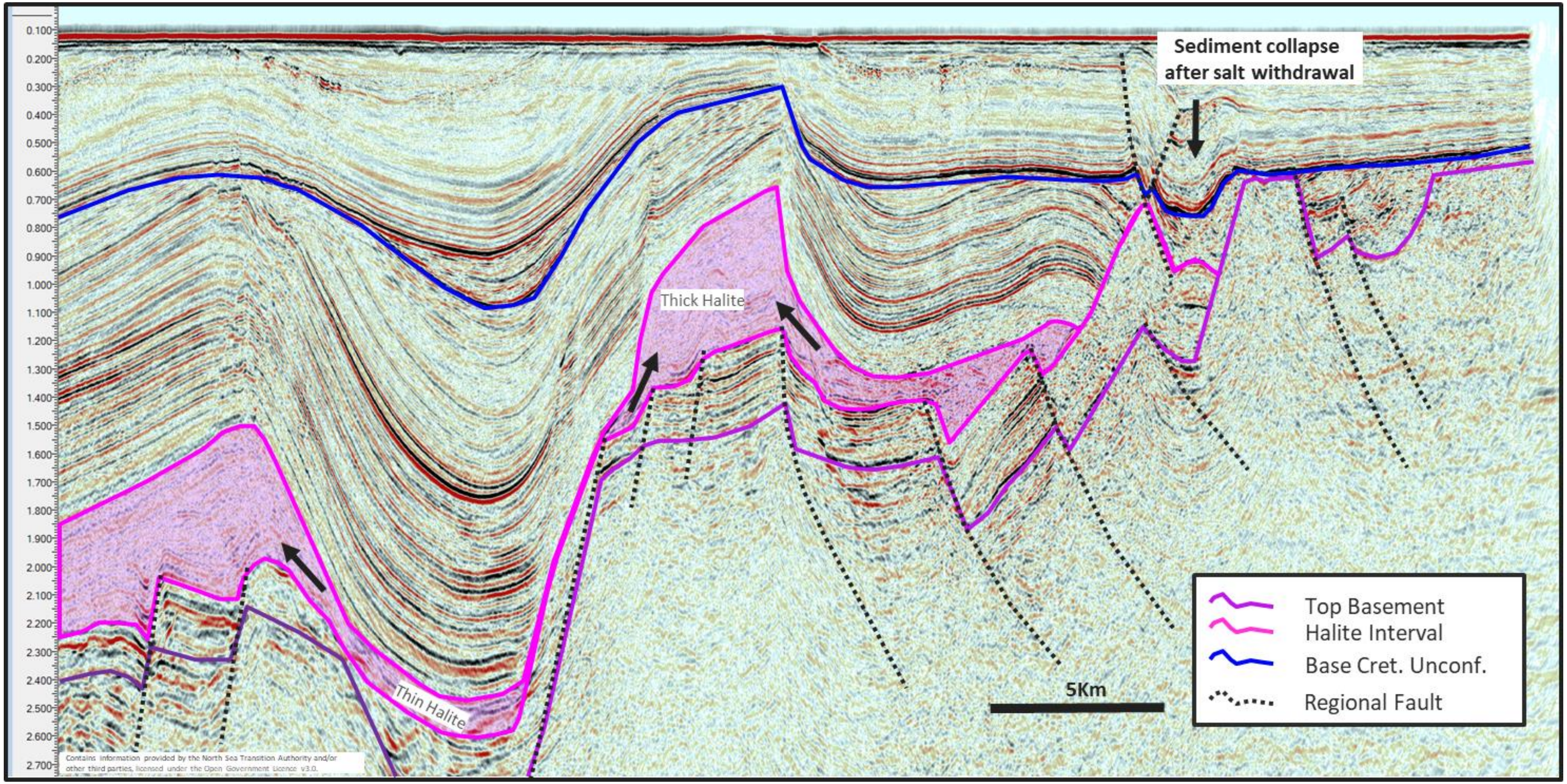


Evidence of Salt Thickening – Celtic Sea

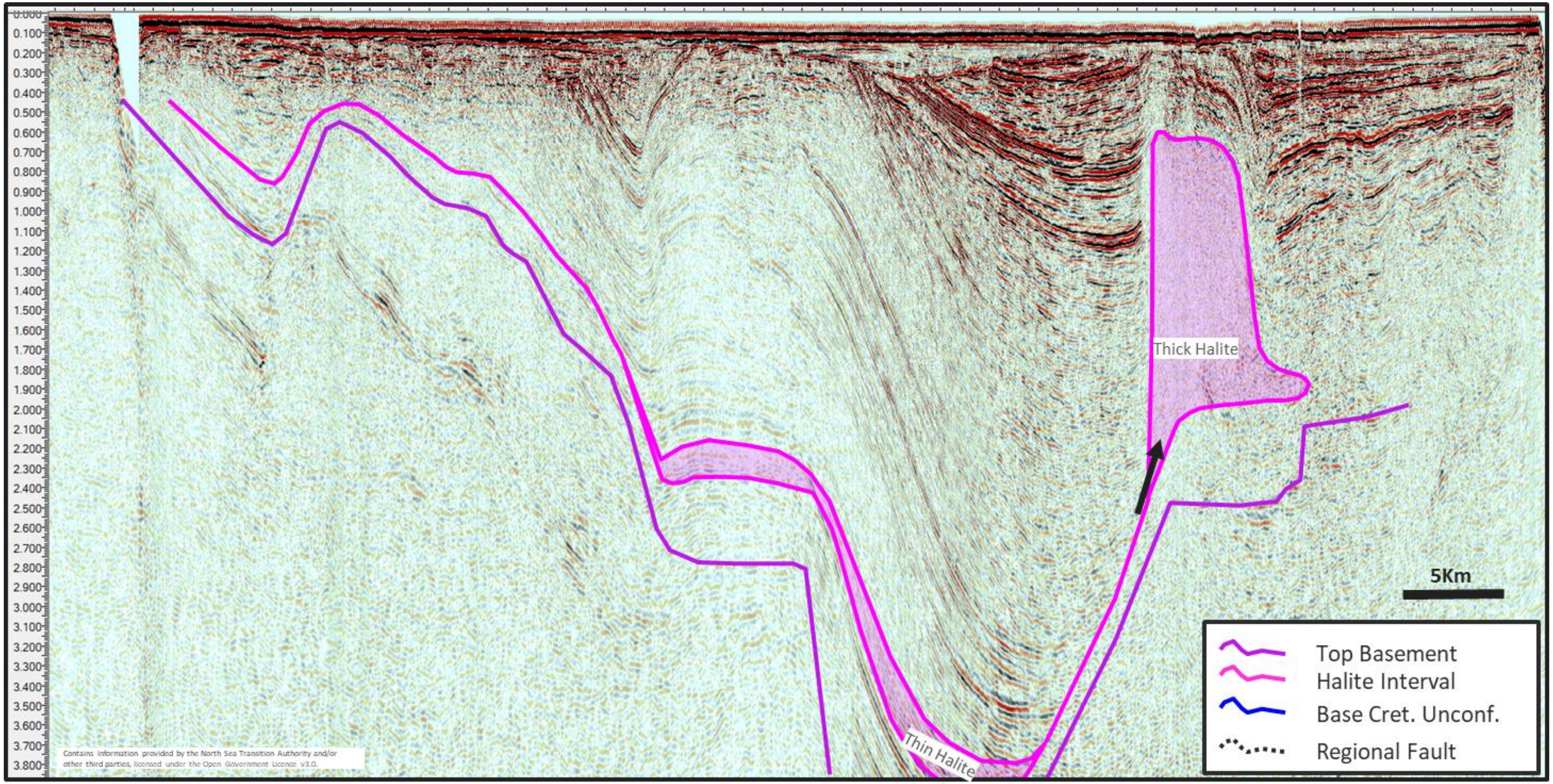


~800m Gross salt interval proven in 57/9-1 well

Evidence of Salt Thickening – Celtic Sea



Evidence of Salt Thickening – Irish Sea



Cavern Specification

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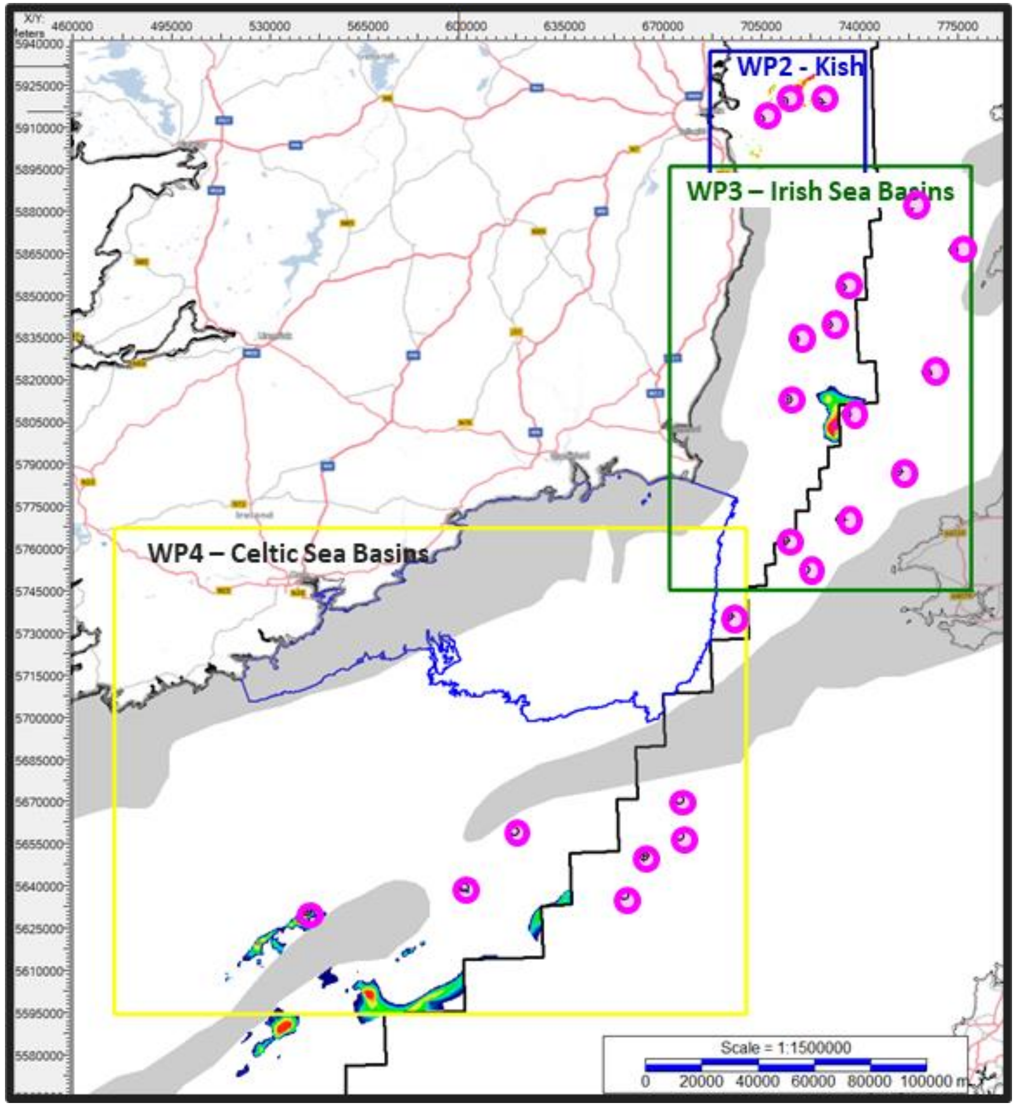
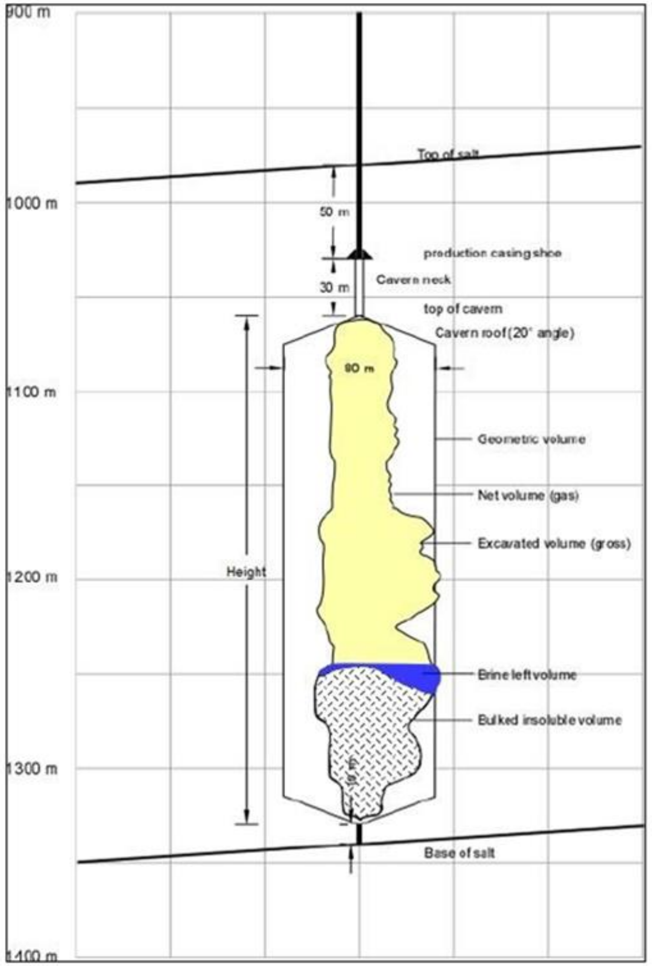


Areas with colours have sufficient thickness of salt, at a depth of 1000m to 1500m, suitable for a 120m high potential cavern development.

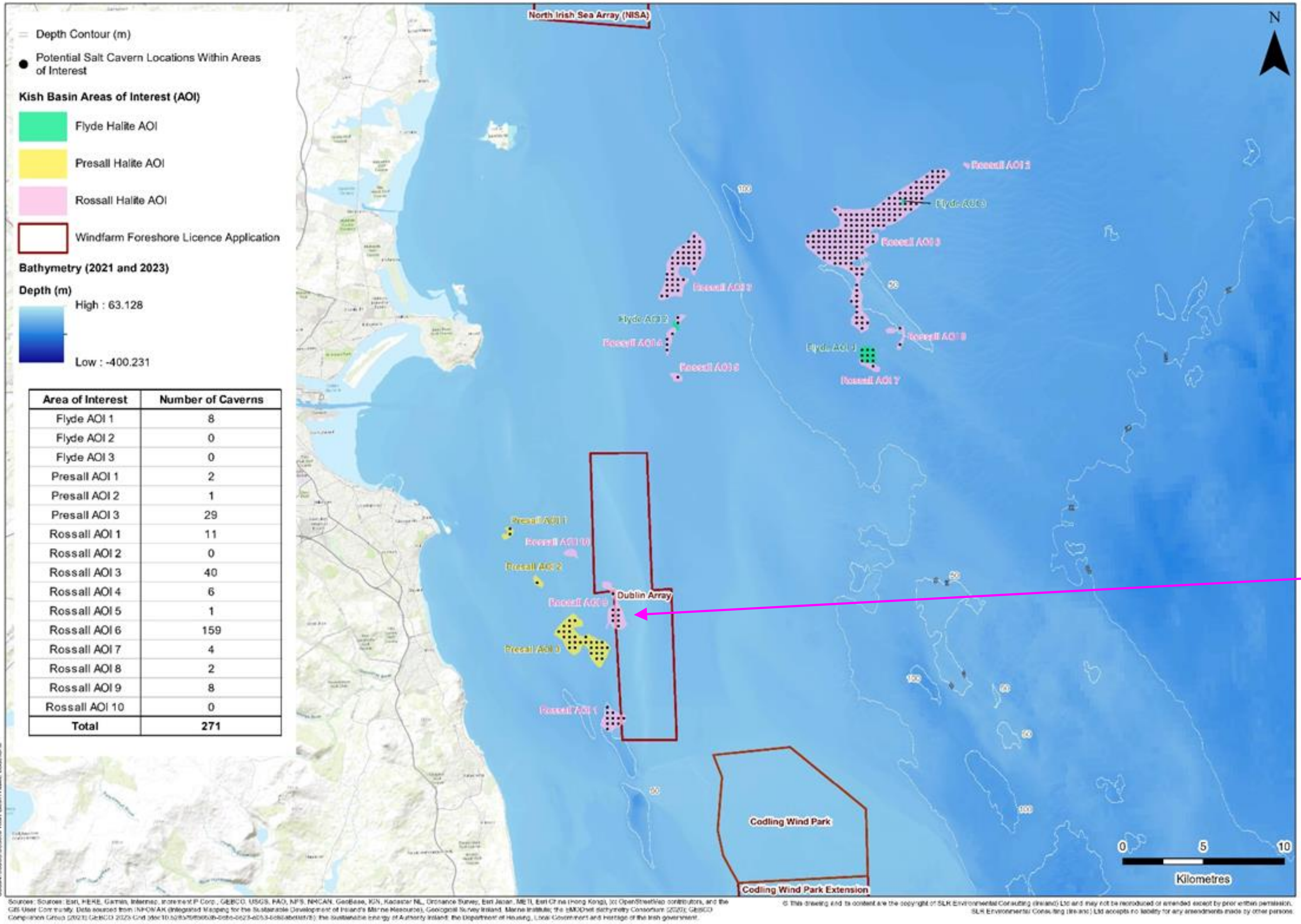
With each potential cavern of 85m diameter, with a 330m standoff between caverns.

A typical salt cavern can store between 105 GWH and 146 GWH of Hydrogen.



Cavern Geometry. Source: Hystories

Cavern Potential Locations - Kish



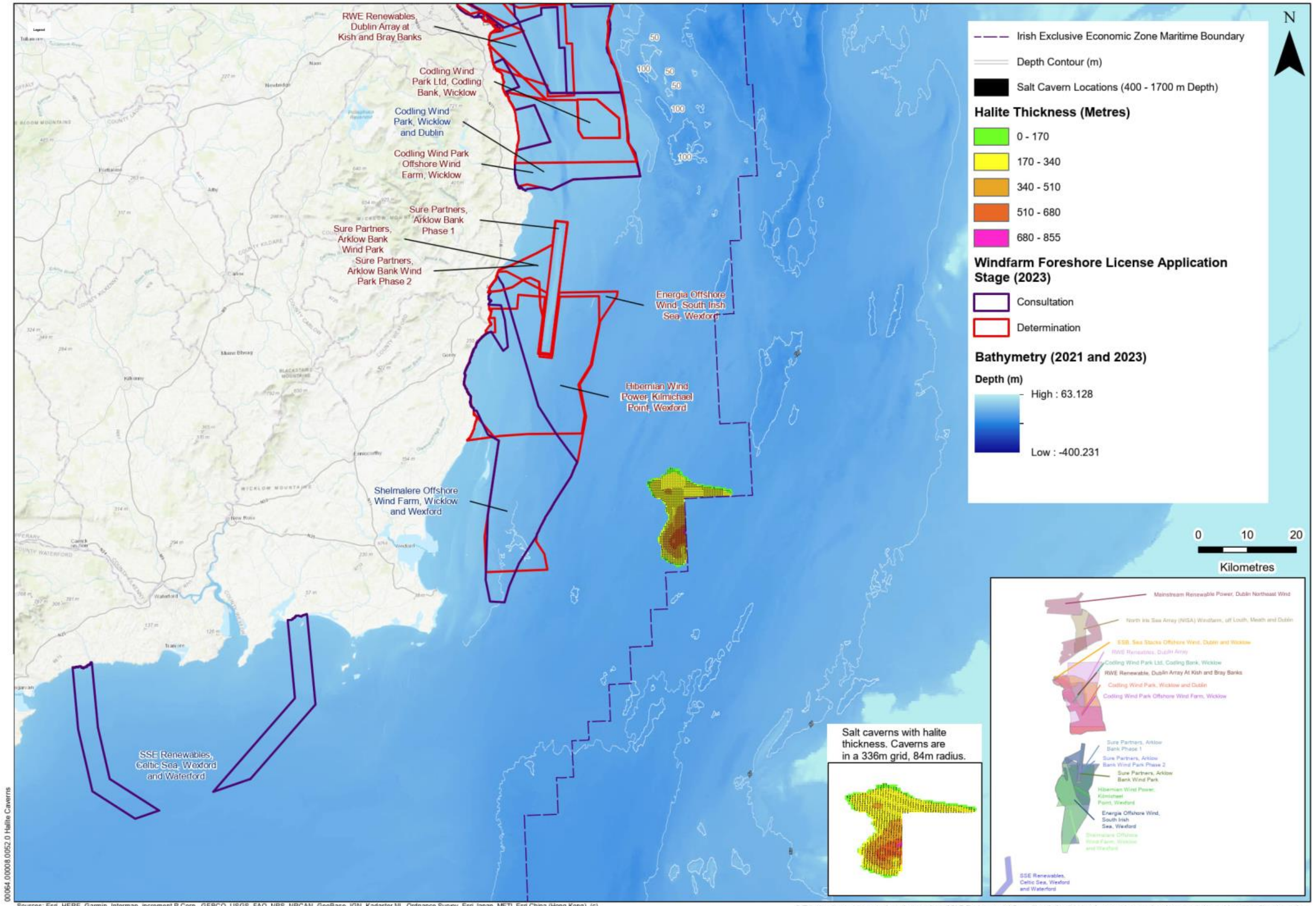
Area of Interest	Number of Caverns
Flyde AOI 1	8
Flyde AOI 2	0
Flyde AOI 3	0
Presall AOI 1	2
Presall AOI 2	1
Presall AOI 3	29
Rossall AOI 1	11
Rossall AOI 2	0
Rossall AOI 3	40
Rossall AOI 4	6
Rossall AOI 5	1
Rossall AOI 6	159
Rossall AOI 7	4
Rossall AOI 8	2
Rossall AOI 9	8
Rossall AOI 10	0
Total	271

Total potential of ~270 caverns.

If only 1% of caverns (3) were developed this would represent up to 0.4TWh of Hydrogen storage.

If only the 8 caverns adjacent to the Dublin Array were developed this could represent approximately 1TWhH2 storage

Cavern Potential Locations – Irish Sea

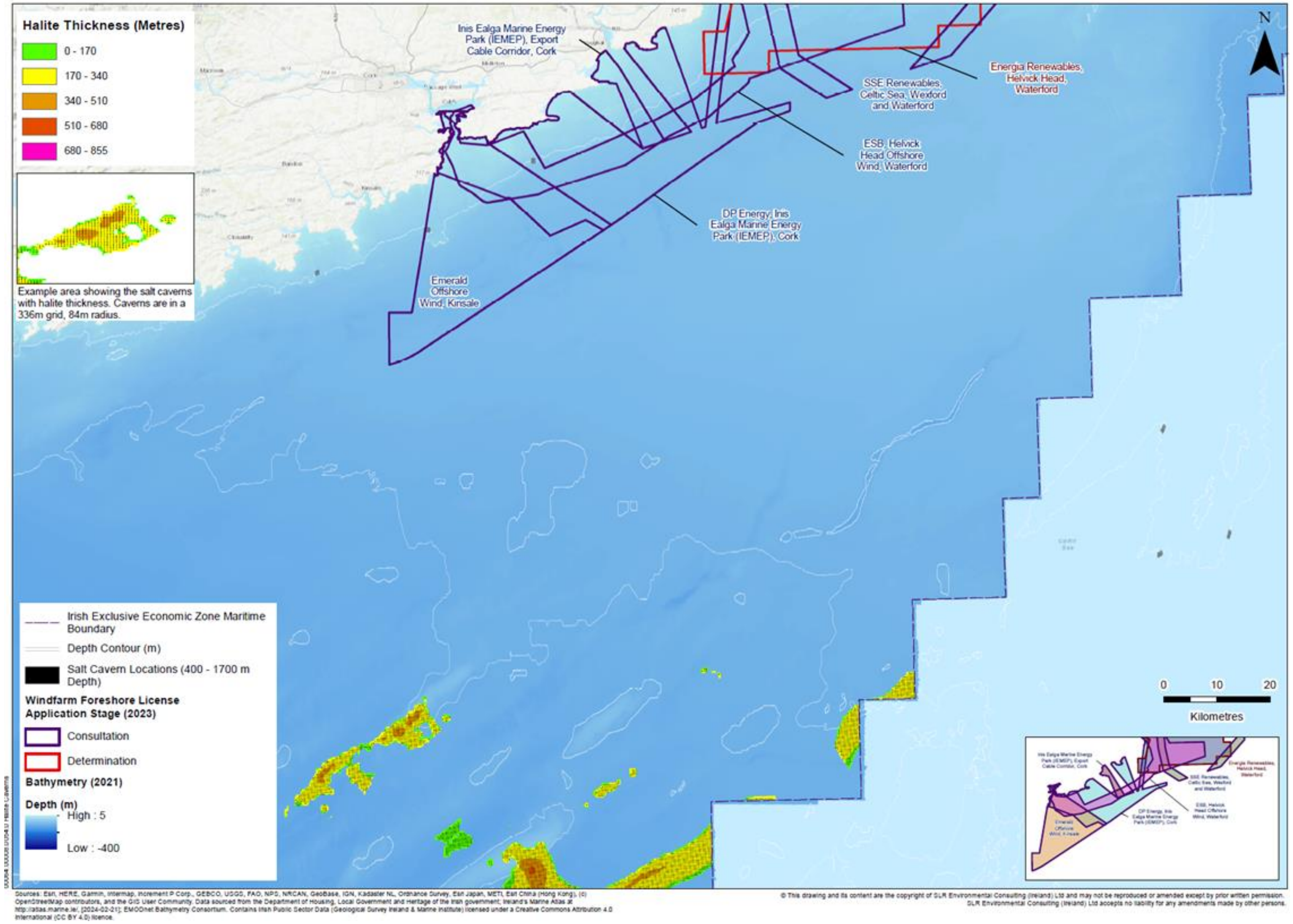


Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community. Data sourced from the Department of Housing, Local Government and Heritage of the Irish government; GEBCO Compilation Group (2023) GEBCO 2023 Grid (doi:10.5285/f98b053b-0cbc-6c23-e053-6c86abc0af7b); Ireland's Marine Atlas at http://atlas.marine.ie/, [2024-02-21]; EMODnet Bathymetry Consortium. Contains Irish Public Sector Data (Geological Survey Ireland & Marine Institute) licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence.

Total potential of 1069 caverns.

If only 1% of caverns were developed this could represent up to 1.5TWh of Hydrogen storage.

Cavern Potential Locations – Celtic Sea



Total potential of 5237 caverns.

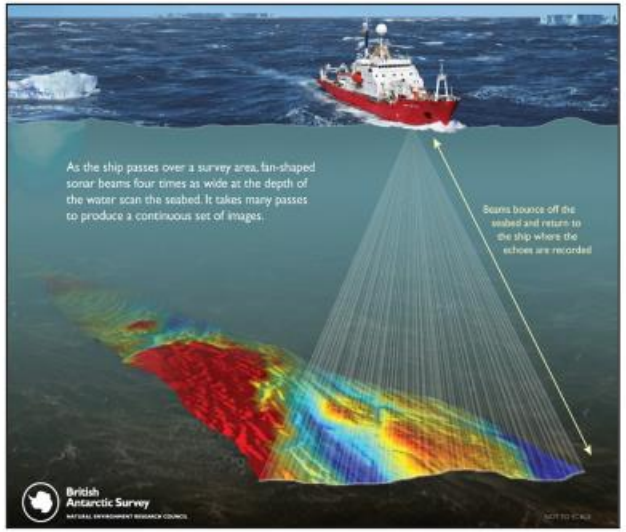
If only 1% of caverns were developed this could represent ~7TWh of Hydrogen storage. This is sufficient for a seasonal store.

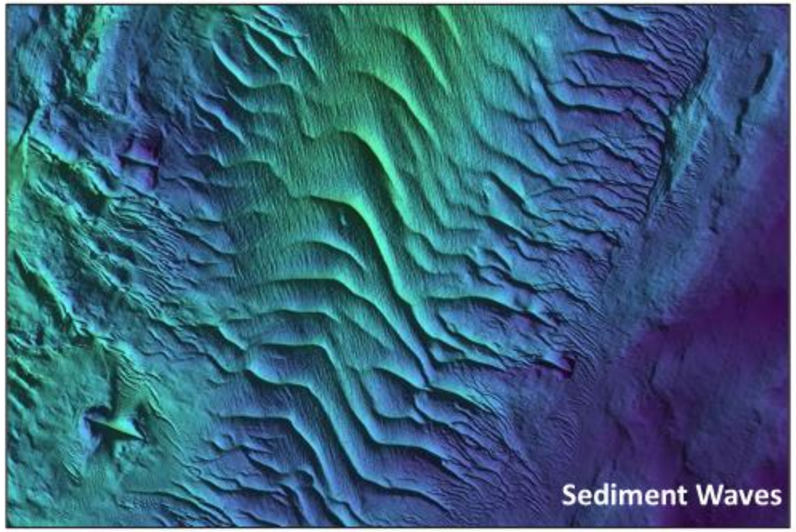
If 3% of potential caverns in this area were developed, this would exceed Ireland's projected requirements of 18TWhr of energy storage in 2050, while still providing potential for energy export.

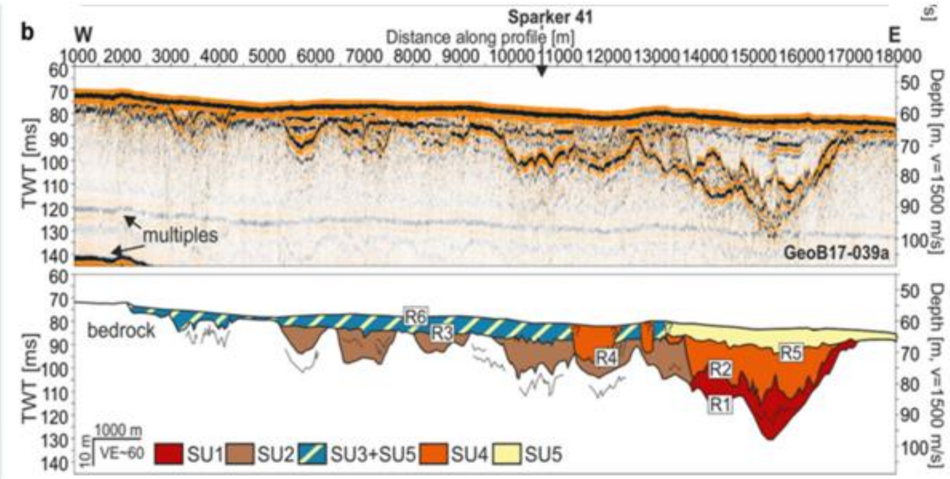
Environmental impact of Cavern Solution Mining and Installation of Hydrogen Plant Offshore Platform

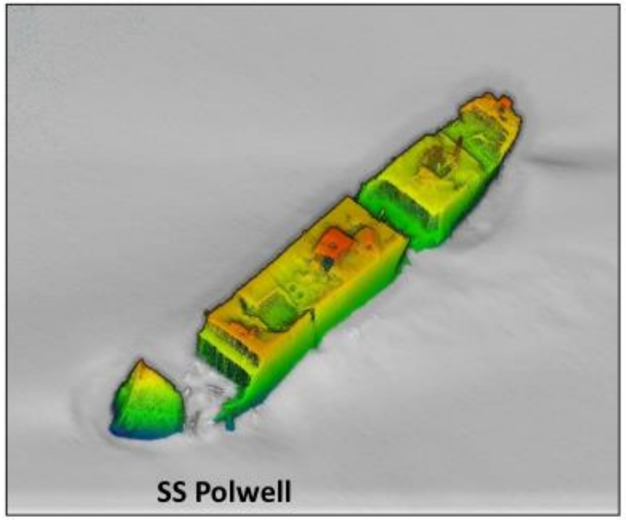
Activity		Output	Impacts			Mitigation	
Nature	Duration	Type	Nature	Importance	Type	P/Y/N	Description
Re-enter appraisal well to enable installation of a leaching completion to create the salt cavern	Estimated 10 days using jack up drilling rig	This is an extension of the drilling operation with the same outputs as above – oil spill, engine & solid waste emissions, noise & habitat disturbance	Marine & air pollution, disruption to shipping & fishing operations, impact on biological environment	L-M	D,C	Y	As above for drilling operation
Cavern solution mining dissolves the naturally occurring salt formation using nitrogen gas as a blanket to prevent dissolution in the salt cavern roof	Estimated 2.5 years using jack up drilling rig	Impacts on water quality due to produced brine	Marine pollution, impacts on biological environment & wild life & fisheries	H	D,C	P	Dilute brine with seawater before disposal; disperse brine where currents are strongest;
		Oil spill	Marine Pollution	L	D,C	Y	Oil spill contingency plan in place, Probability of a major accidental spill of hydrocarbons during the exploration drilling is very low therefore little chance of transboundary and cumulative effects.
		Engine emissions	Air pollution	L	D,C	Y	Regular maintenance
		Physical presence	Disruption to fishing/shipping operations	M	D,C	Y	Notifications of operational schedule
		Impacts on water quality due to solid waste	Marine pollution	L	D	Y	Shore disposal at port No Impacts
		Habitat disturbance, pollution, displacement	Marine, air, noise pollution impact on Wild life	L	D,I,C	Y	Implementation of management procedures to ensure environmental controls are operating effectively and efficiently
		Noise	Impacts to Biological Environment	L	D,C	Y	The potential sound impacts from drilling operation are considered to be minimal and will not contribute to cumulative effects.
Completion of production wells	Estimated 10 days per well using jack up drilling rig	This is an extension of the drilling operation with the same outputs as above –oil spill, engine & solid waste emissions, noise & habitat disturbance	Marine & air pollution, disruption to shipping & fishing operations, impact on biological environment	L-M	D, C		As above for drilling operation
Installation of offshore substation and hydrogen production platform	Estimated three months using heavy lift barge to install steel jacket platform	Physical presence	Disruption to shipping & fishing operations,	L-M	D, C	Y	
		Oil spill	Marine pollution	L	D, C	Y	Oil spill contingency plan in place
		Engine & solid waste emissions,	Marine pollution	L	D, C		Regular maintenance and waste disposal to shore
		Noise – pile driving	Impact on cetaceans	H	D	Y	Soft starts, acoustic buffers/screens
		Seabed disturbance	Habitat disturbance	L			Enhanced marine habitat on artificial reef
Lay export hydrogen pipeline to shore	Using pipe laying barge	Physical presence	Disruption to shipping & fishing operations,	L-M	D, C	Y	Notifications of operational schedule
		Seabed disturbance	Impact on marine areas of conservation	L-M	D, C	P	Adjust operational schedule to minimise impact
		Habitat disturbance	SPA, SAC, Annex IV	L-M	D, C	P	Adjust operational schedule to minimise impact
Beneficial impacts							
Substation & H2 production platform	20 years	Physical presence	Impact on marine life	M	D, C		Enhanced marine life habitats due to artificial reef affect

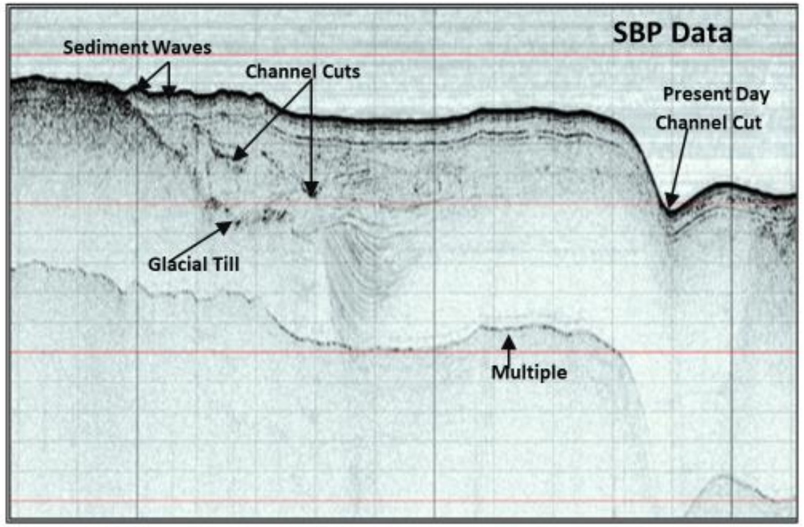
Phase 1: Integrating Geo Datasets





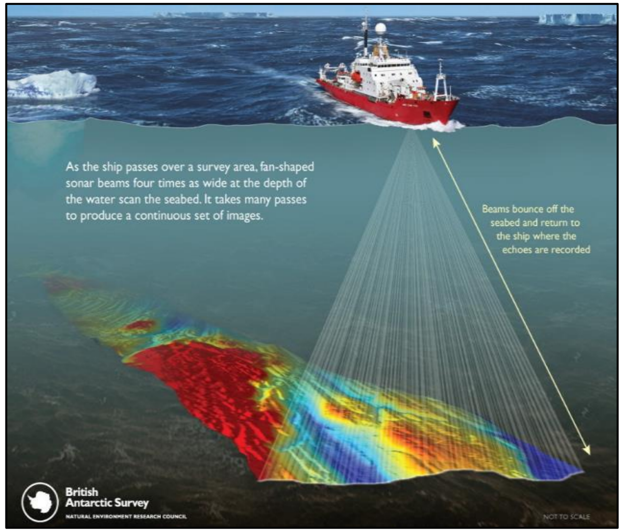




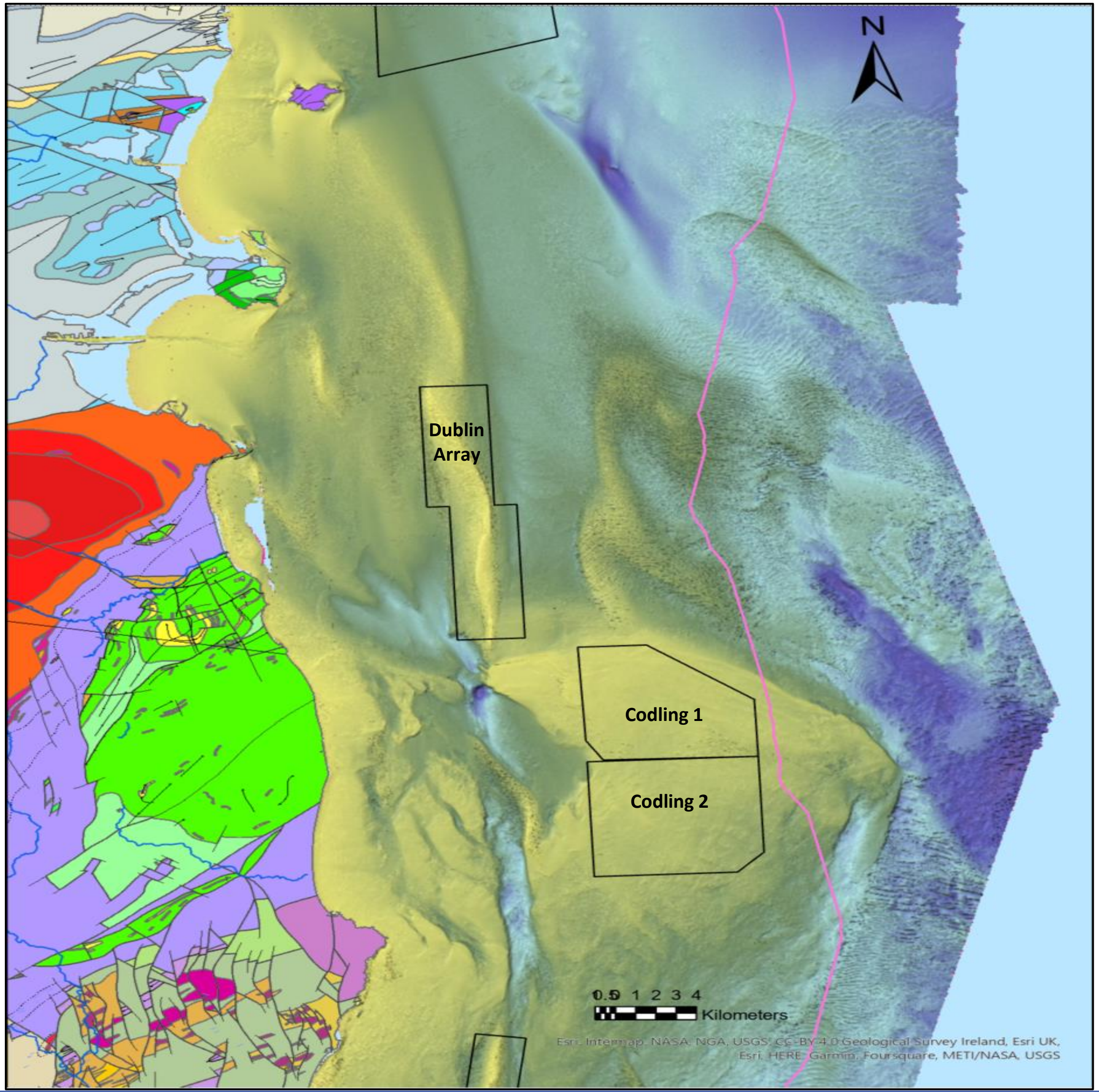


- The primary acoustic devices used by the INFOMAR programme are Multibeam Echosounder (MBES), Singlebeam Echosounder (SBES), Shallow Seismic / Sub Bottom Profiler (SBP), and Side Scan Sonar (SSS).
- The bathymetric data is a dataset that has being acquired and processed is to international hydrographic standards. It produces high quality digital maps that are easily accessible through the INFOMAR data portal.
- The SBP/HRSS are the most valuable geophysical datasets when constructing an accurate ground model particularly for offshore fixed bottom installations and cabling onshore. Data acquisition gaps should be considered, as there are areas where data still needs to be acquired as part of programme strategy to end 2026.

Phase 1: Integrating Geo Datasets

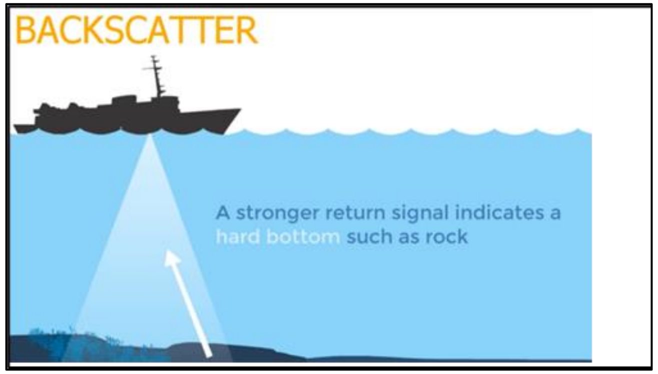


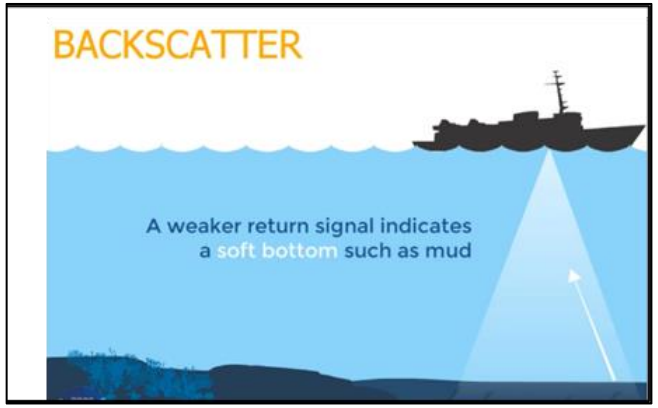
The primary aim of INFOMAR as a marine mapping project is to describe the physical features of the seabed. This includes the measurement of water depth (bathymetry), definition of seabed structures and identifying sediment type and distribution, both on and below the seabed.

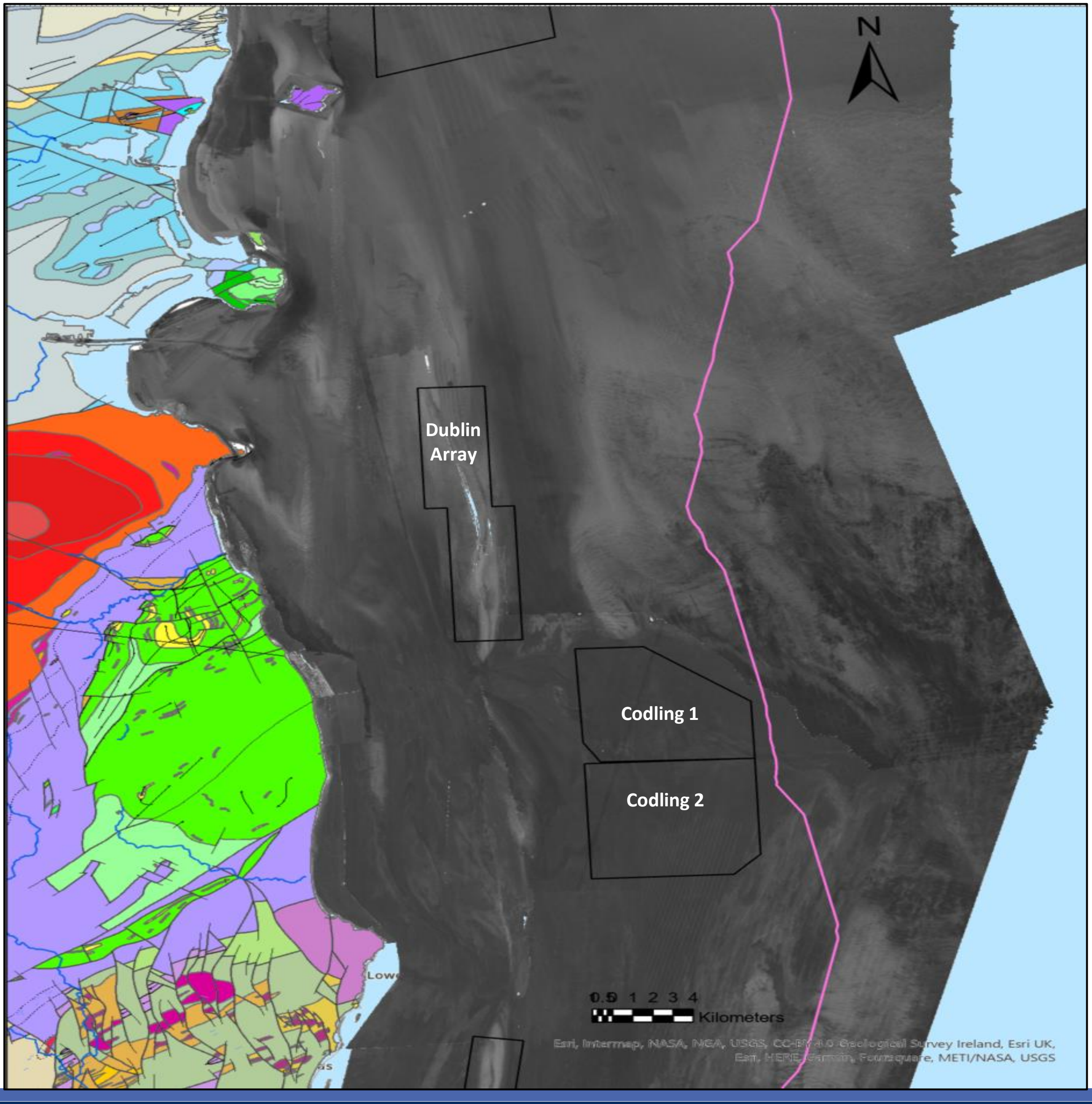


The bathymetry map is achieved using a range of hydrographic and geophysical instruments. Acoustic devices emit sound energy, in a series of continuous pulses, into the water column and detect the returning echoes. This is called sonar. Different echo strengths indicate different seabed features (or morphology) and the different physical characteristics of the seafloor. By knowing the speed at which sound travels through water (approx. 1500 m per second), depth can be calculated from the echo return time. This method produces extremely accurate measurements, which when coupled with accurate positioning systems and motion sensors can be used to produce accurate seafloor maps.

Phase 1: Integrating Geo Datasets







Backscatter Intensity

- High
- Medium
- Low

Multibeam systems also collect information about the type of seafloor and can distinguish between mud, sand, gravel, and rock. Different seafloor types return the signal with different levels of energy, this is known as backscatter.

This information can be used to determine the physical nature of the seabed, because different bottom types “scatter” sound energy differently. For example, a softer bottom such as mud will return a weaker signal than a harder bottom, like rocks or gravel. These differing values in intensity are used to examine the nature of the seafloor in a backscatter chart.

Phase 1: Integrating Geo Datasets

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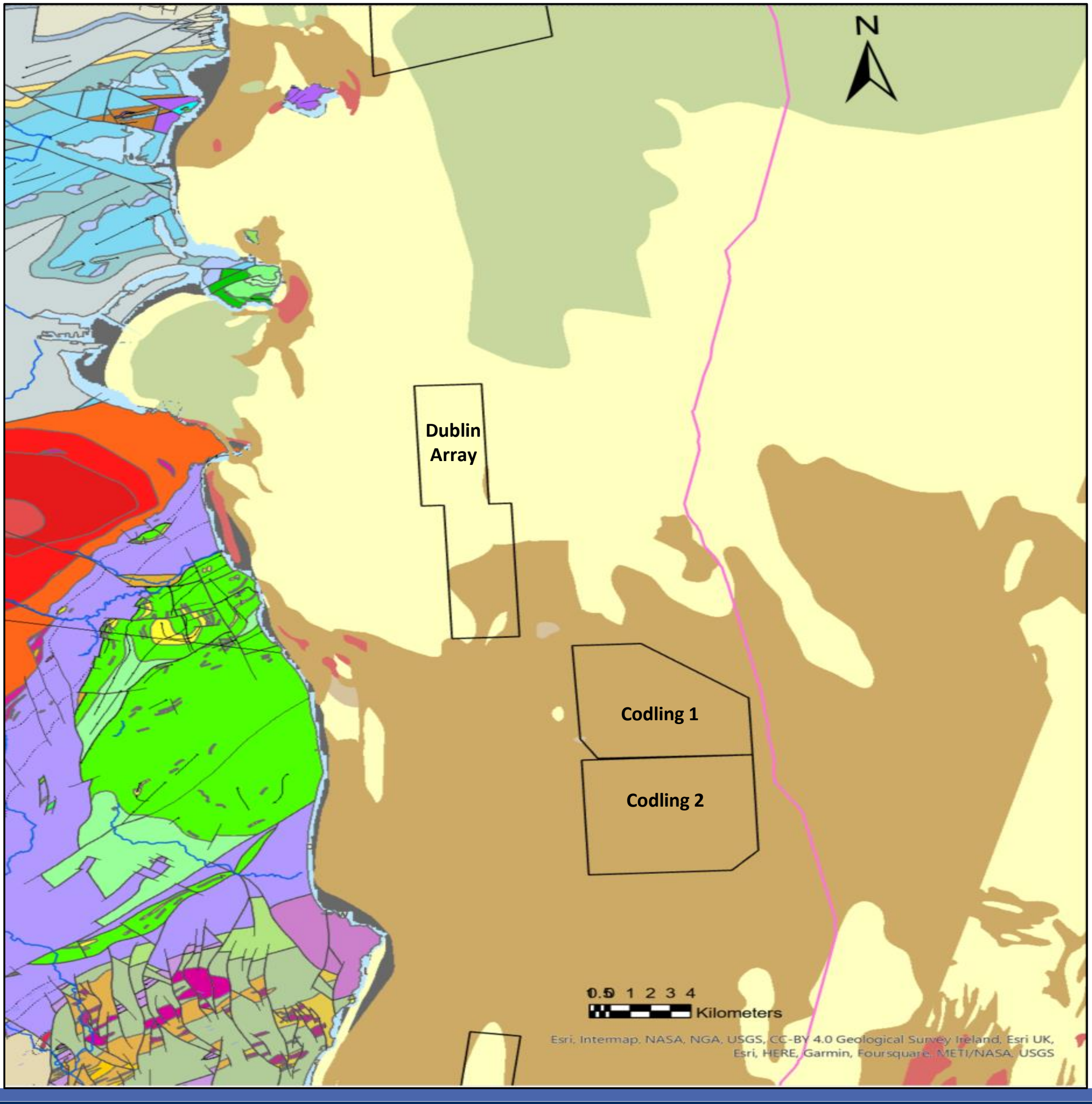
Combining bathymetry, backscatter and grab samples allows for the creation of 'sediment classification' maps. These provide information on the type of seabed substrate with application to marine spatial planning.

Care must be taken when integrating these datasets as the backscatter is only a relative property and can easily lead to misinterpretation of the ground conditions.

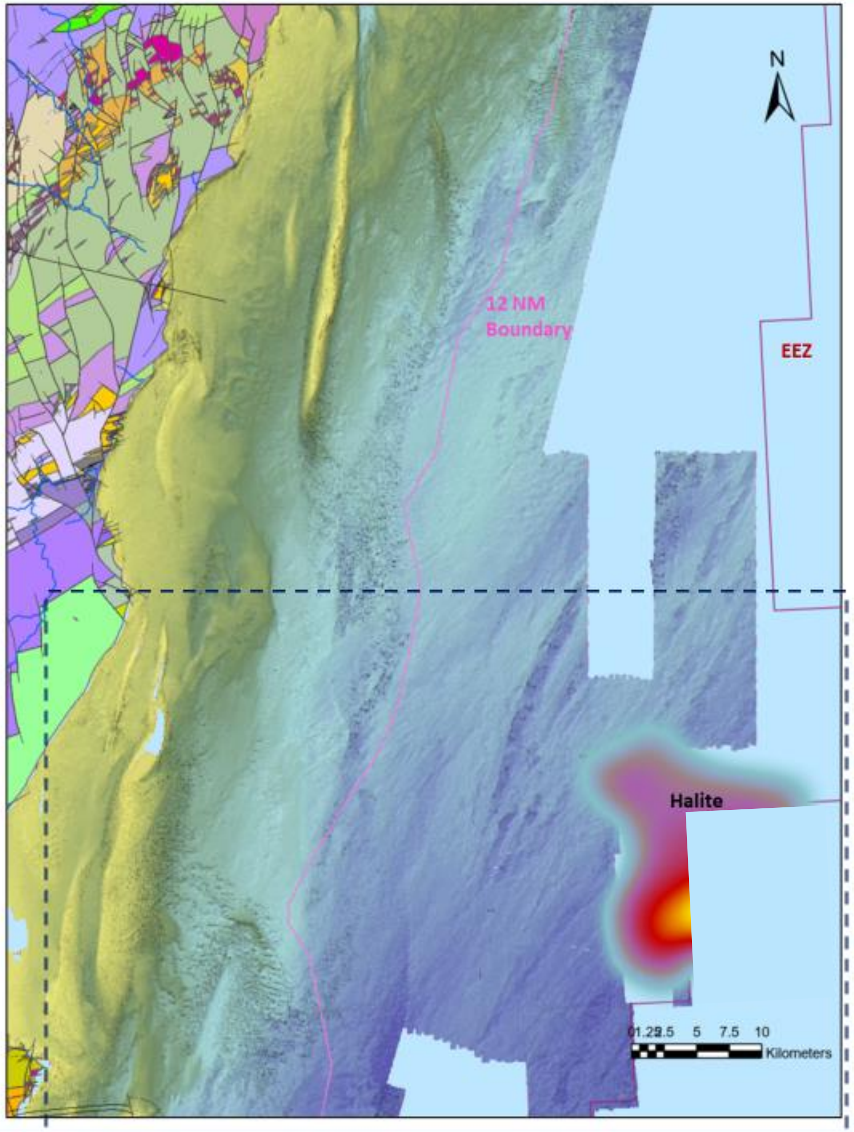


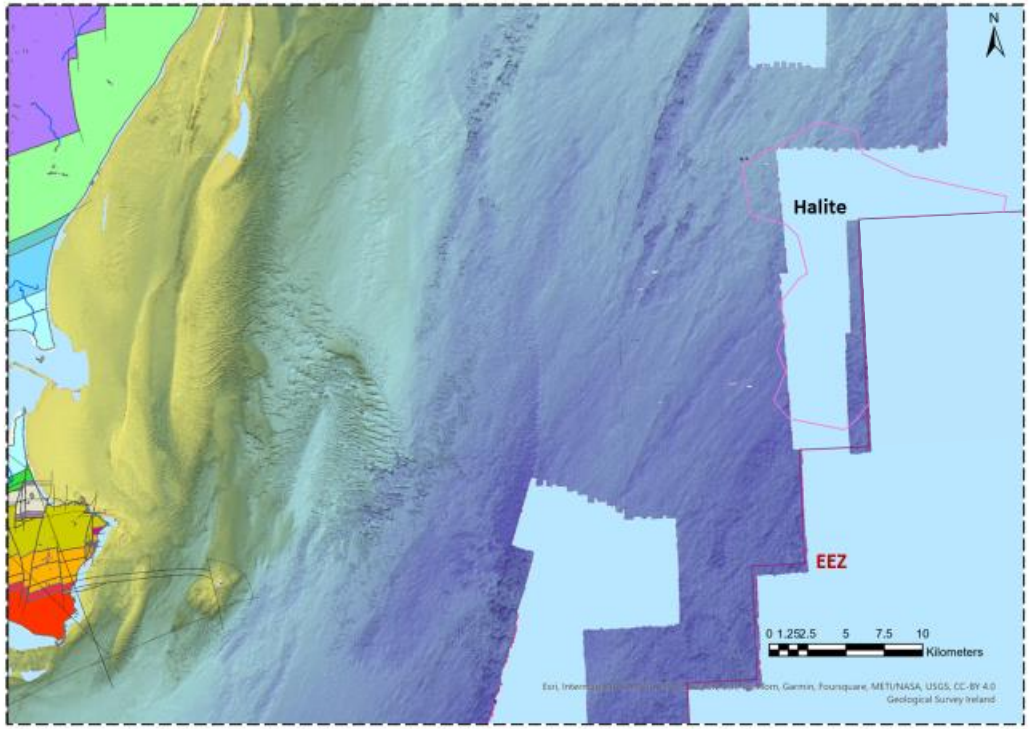
INF_Class
- Coarse sediment
- Mixed sediment
- Mud
- Rock
- Sand
- Unclassified substrate
- sandy Mud/muddy Sand

The sediments recorded in the grab samples may not be in situ and representative of the local seabed.

It's important to integrate these datasets correctly to understand the complex relationships between sediment deposition and erosion. It is essential to understand the regional onshore geology, drainage systems in conjunction with the tidal currents and weather patterns to build a dynamic seabed model.

Phase 1: Integrating Geo Datasets





INFOMAR Bathymetry Map over Halite Area.

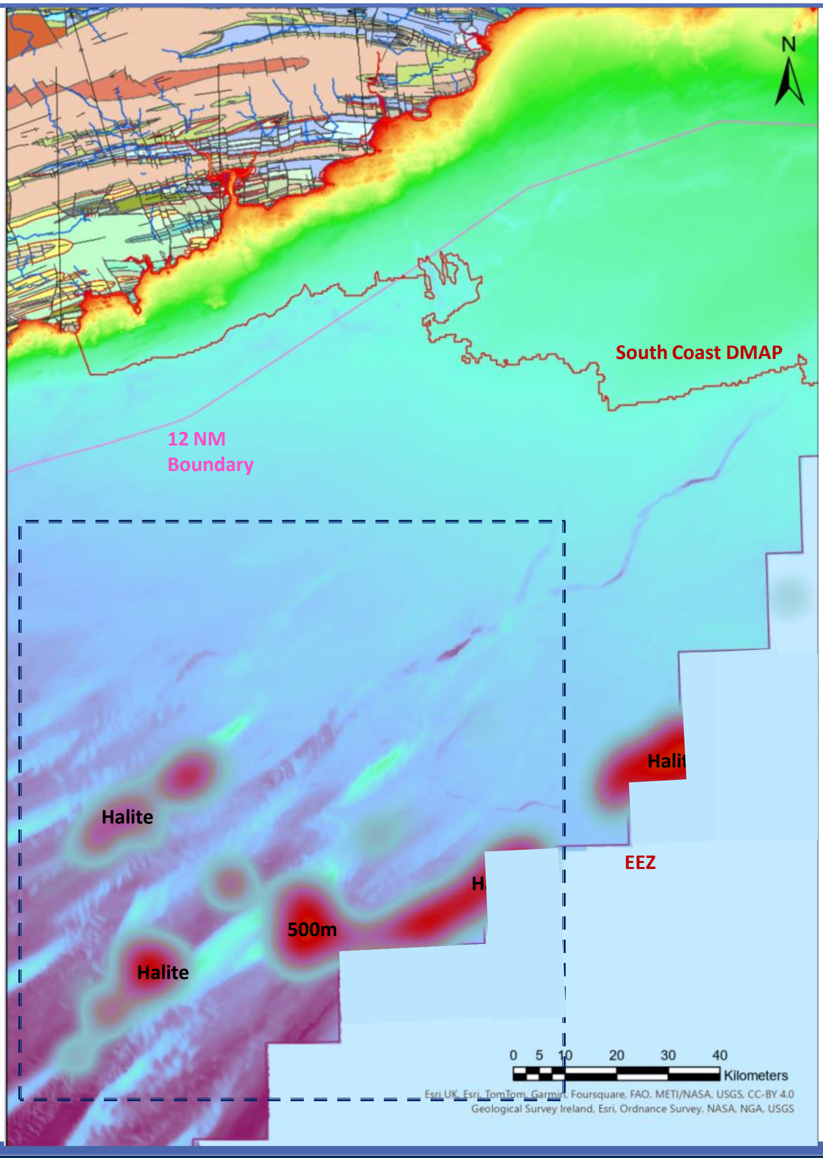
The Halite that has been mapped in this area sits primarily over an INFOMAR data acquisition gap, that will to be need to be filled before the programme ends in 2026.

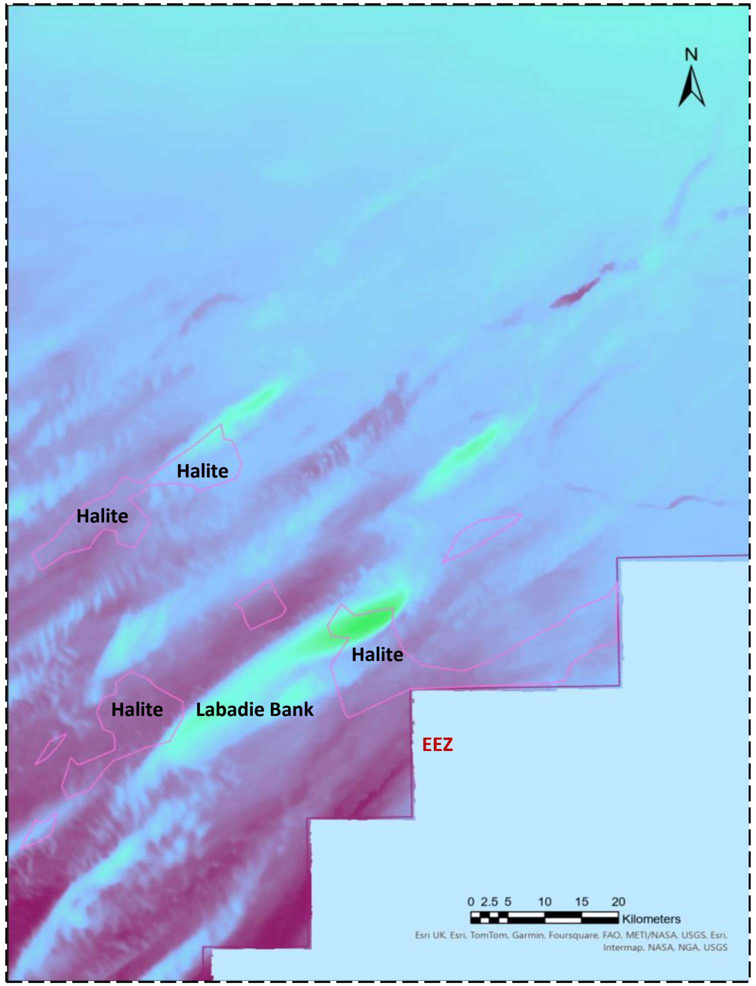
The inshore area appears to have a lot of sand sequestered on the shelf. With many active sedimentological processes at play, notable features such as sand banks, sand bars, mega ripples and sediment waves highlighting the interplay between the onshore geology and the offshore metocean conditions.

As we move further offshore past the 12NM maritime boundary, the seabed appears to be more sediment starved with less depositional features and an increase in erosional features such as channels and canyons.

In general areas with high stress result in high erosion and coarser sediment.

Phase 1: Integrating Geo Datasets





INFOMAR Bathymetry Map over Halite Area.

The onshore geology varies from Carnsore granite to lower Carboniferous Limestone at Hook Head to Devonian Sandstone at the old head of Kinsale. The many rivers in the area are eroding, transporting and depositing these sediments.

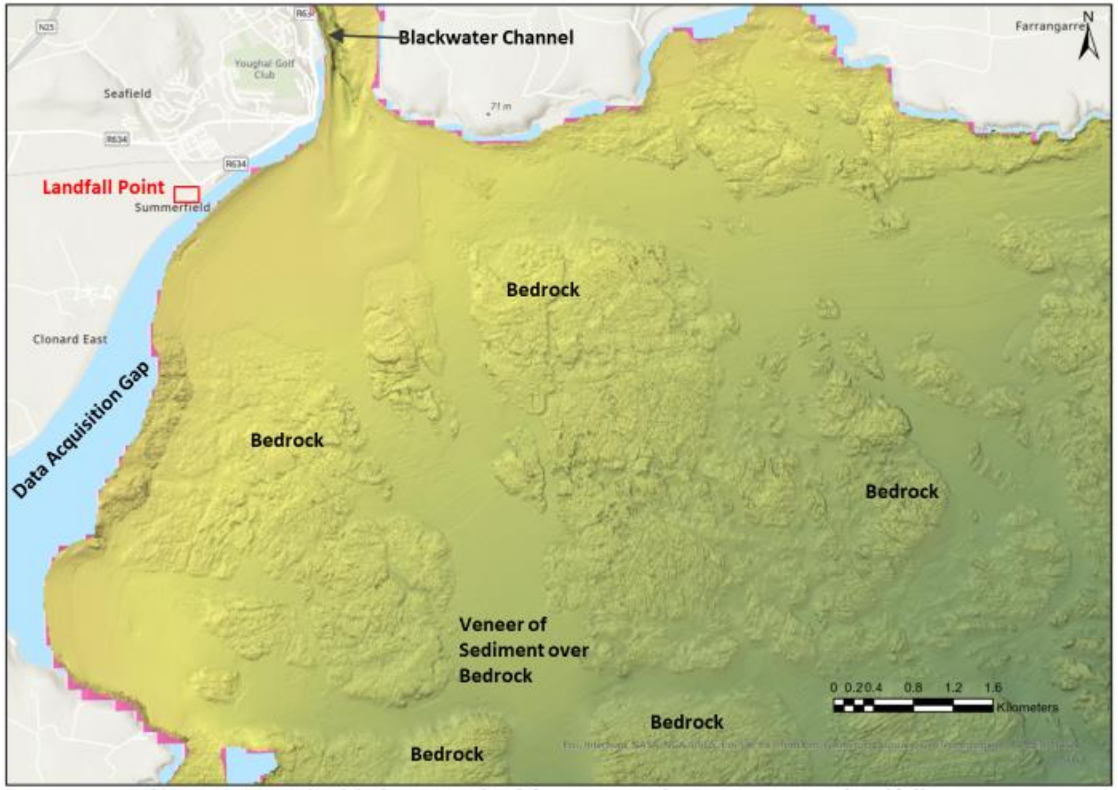
Seabed canyons, channel cuts, sand banks, point bars mega ripples as well as exposed bedrock are some of the many features that are visible.

The bathymetry shallows to 62m in the area approximately around where the halite has been deposited subsurface .

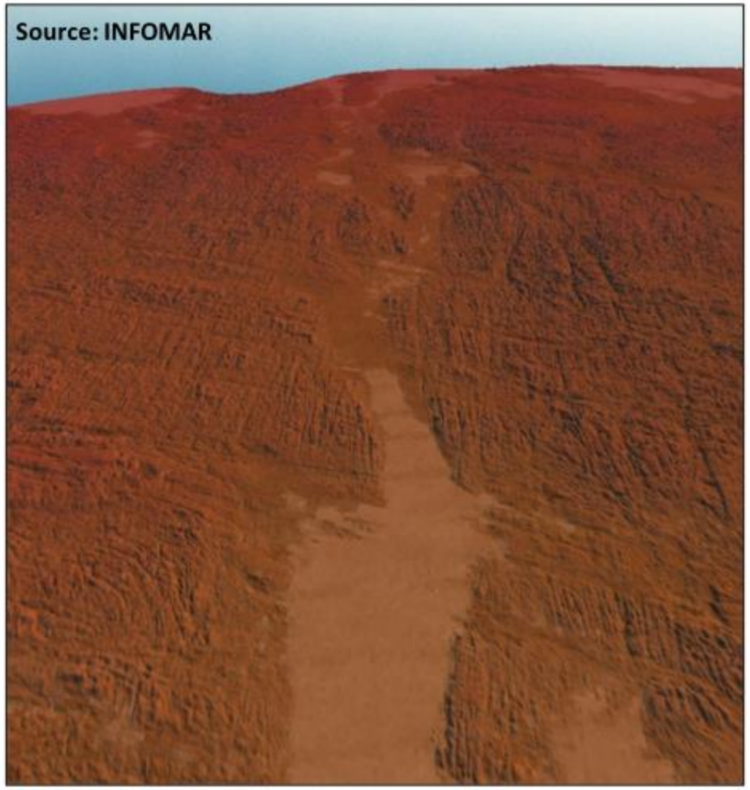
There are several sand banks in the vicinity as well as sediment waves seabed channels.

Given the shallow depths there could be the possibility to co-locate fixed foundation (Jackets) wind turbines.

Case Study: Celtic Interconnector



Bathymetry Map highlighting seabed features and interconnector landfall point .



3D Visualization of the seabed in the area.

In 2018 the RV Keary acquired data as part of INFOMAR's national inshore surveying programme. This data delivery was fast-tracked at the request of the Celtic Interconnector project so that it could be incorporated into assessments for potential landfall locations.

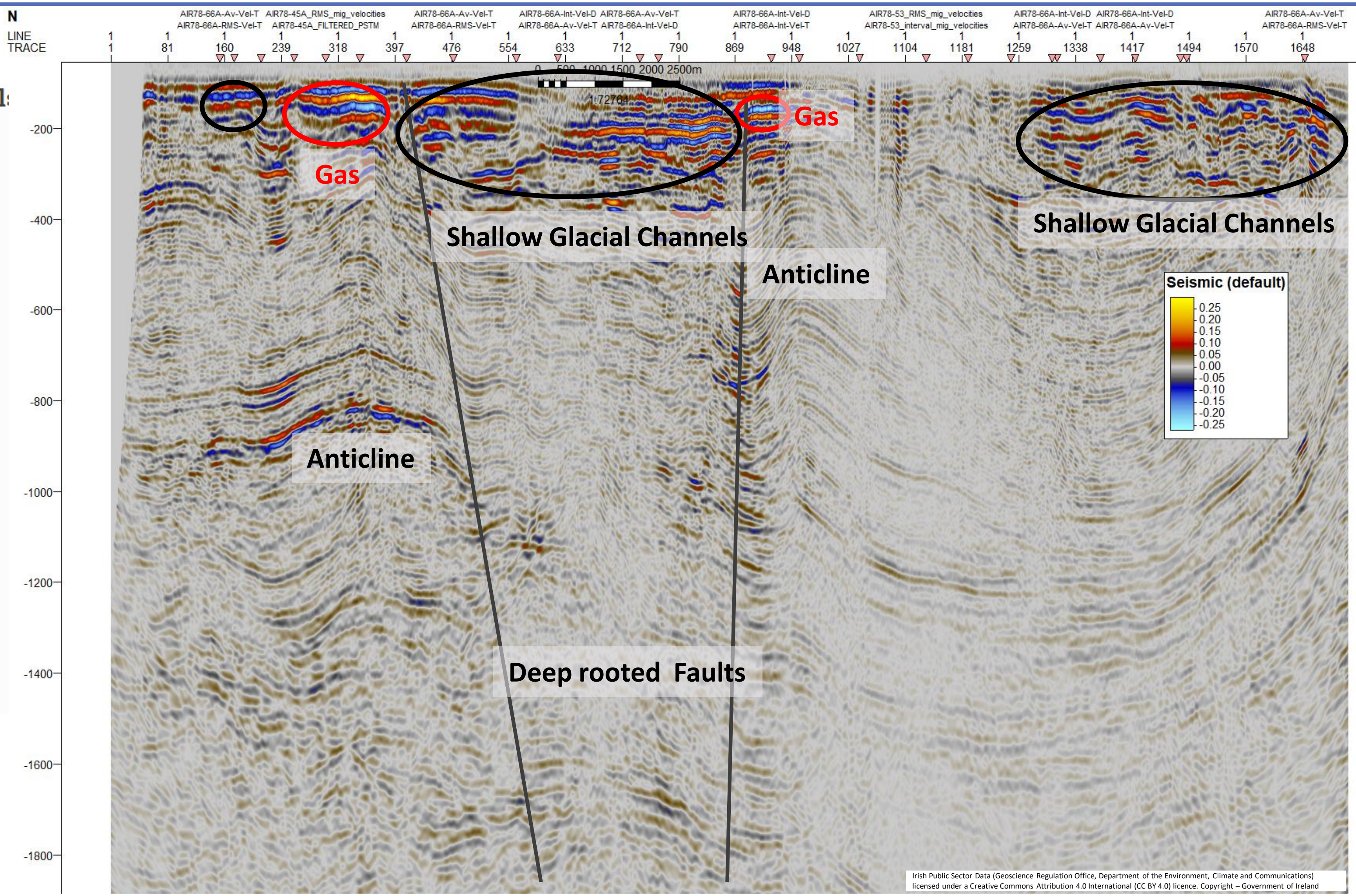
The study area consisted of extensive rock outcrop, featuring inclined and deformed bedding intercut by sediment filled channels and heavy faulting. A smooth veneer of sediment overlaying bedrock is the dominant seafloor characteristic to the west of the study area which highlighted the seafloor complexity which could prove challenging for marine infrastructural projects such as the Celtic Interconnector.

This data assisted the Celtic route development for the marine landfall which is now more favourable as an offshore installation solution compared to the original surveyed routes. It is estimated that this will deliver marine installation savings of approximately €8.5 million by avoiding 10-15km of rock cutting and remedial protection. It will also result in lower impacts to the environment as it avoided the use of specialist rock cutting tools and external cable protection.

Regional Geohazards Study -2D Seismic

Seismic Velocities of Rocks and Various Materials

Material	P-wave (m/s)	S-wave (m/s)
Air	343	N/A
Water	1450 - 1500	N/A
Ice	3400 - 3800	1700 - 1900
Oil	1200 - 1250	N/A
Vegetal Soil	300 - 700	100 - 300
Dry Sands	400 - 1200	100 - 500
Wet Sands	1500 - 2000	400 - 600
Saturated Shales and Clays	1100 - 2500	200 - 800
Porous and Saturated Sandstones	2000 - 3500	800 - 1800
Marls	2000 - 3000	750 - 1500
Chalk	2300 - 2600	1100 - 1300
Coal	2200 - 2700	1000 - 1400
Salt	4500 - 5500	2500 - 3100
Anhydrites	4000 - 5500	2200 - 3100
Limestones	3500 - 6000	2000 - 3300
Dolomites	3500 - 6500	1900 - 3600
Granite	4500 - 6000	2500 - 3300
Basalt	5000 - 6000	2800 - 2400
Gneiss	4400 - 5200	2700 - 3200



Regional Geohazards Study – Velocity Interp

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Seismic Velocities of Rocks and Various Materials

Material	P-wave (m/s)	S-wave (m/s)
Air	343	N/A
Water	1450 - 1500	N/A
Ice	3400 - 3800	1700 - 1900
Oil	1200 - 1250	N/A
Vegetal Soil	300 - 700	100 - 300
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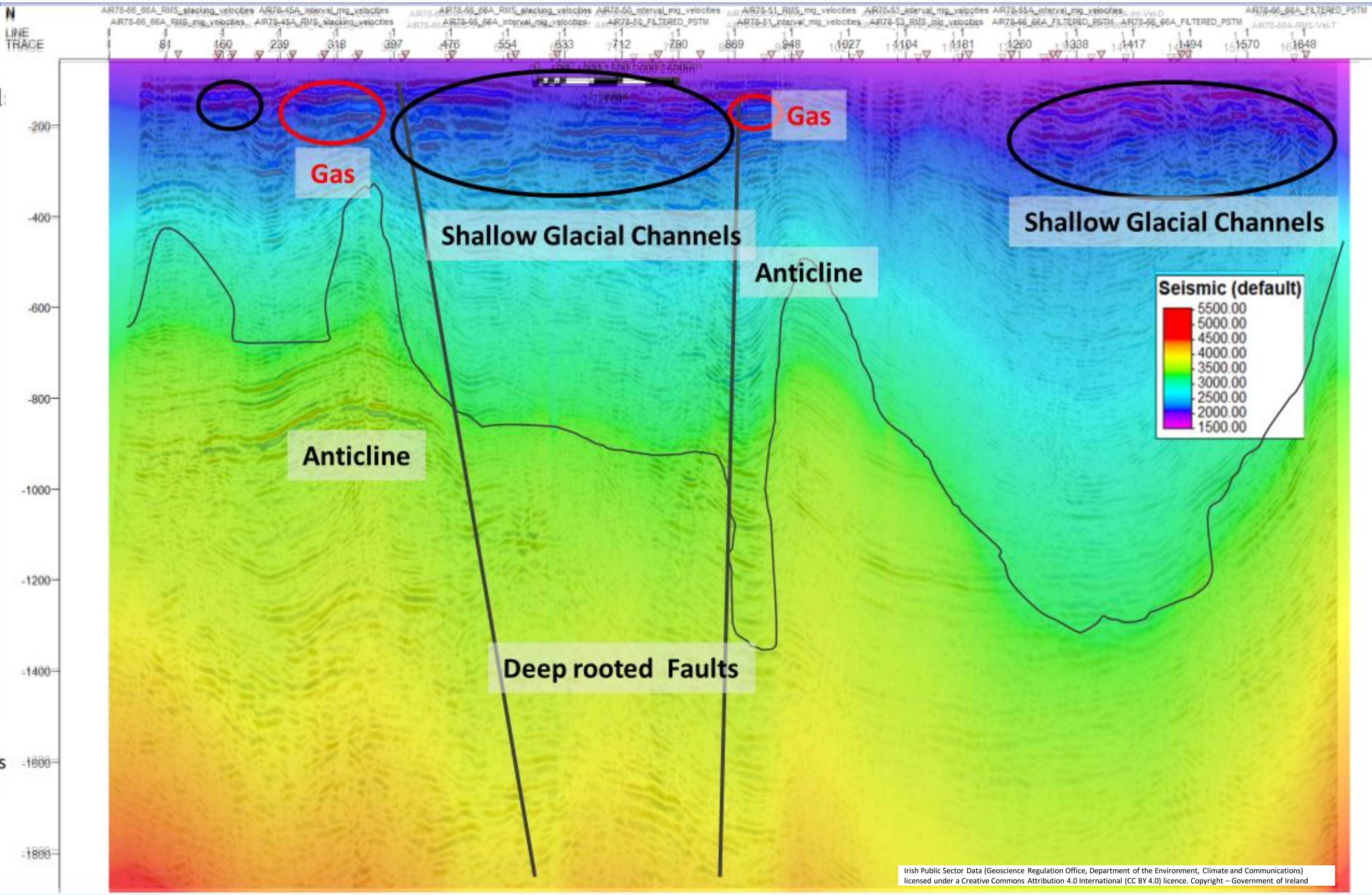
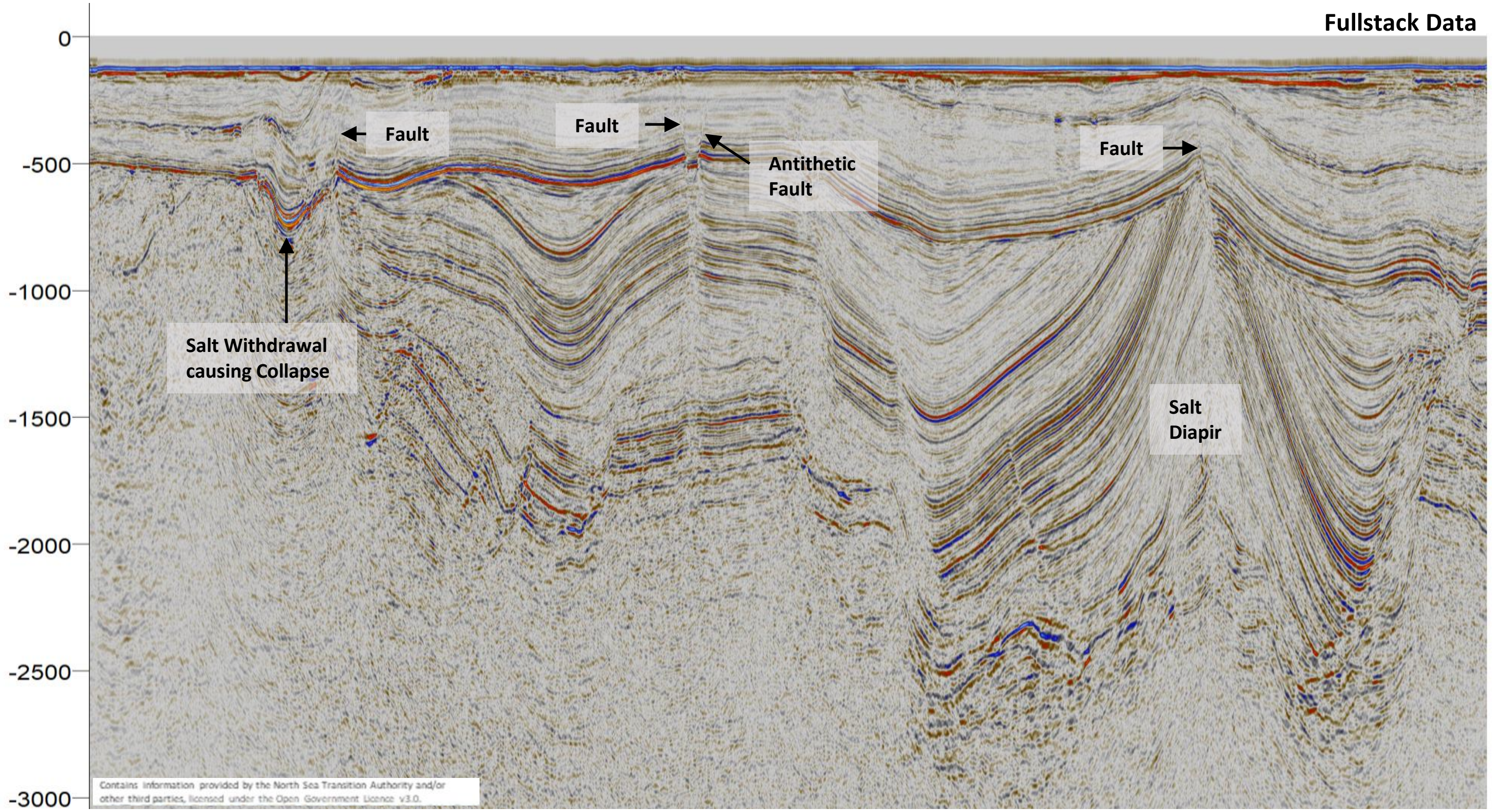
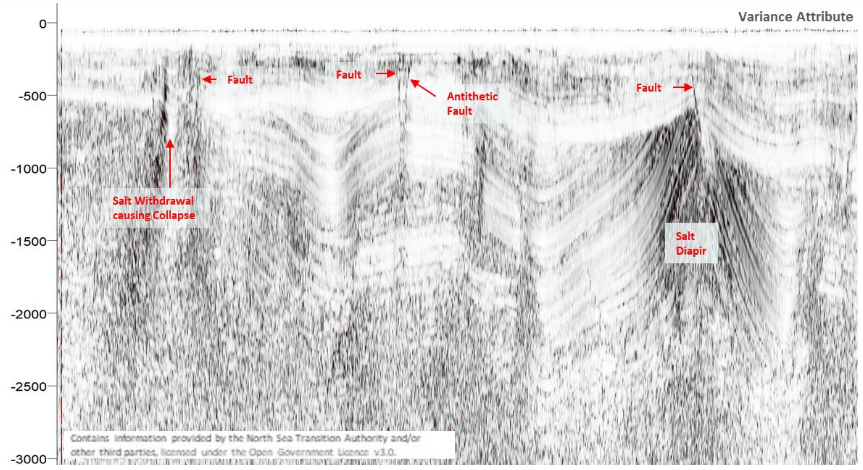
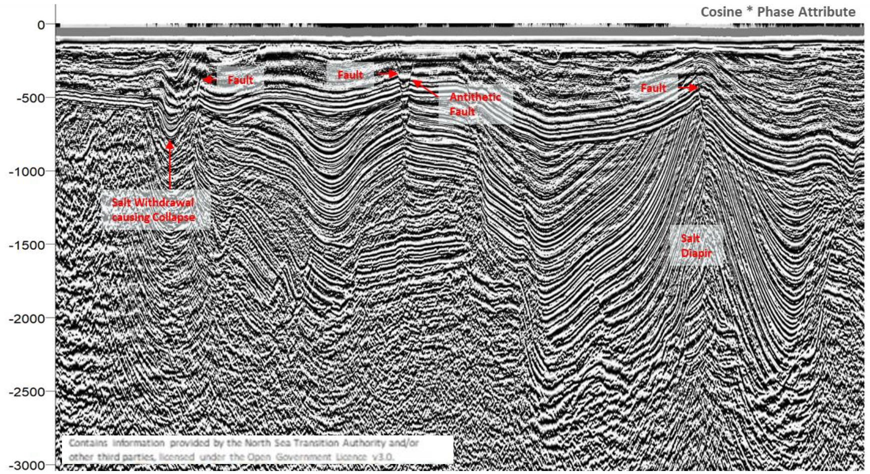
The deeper part of the Jurassic in the Celtic Sea can be overpressured to some extent and at least two wells have had small kicks. Other wells have encountered high gas levels, and occasionally high mud weights have been used to reduce drilled and connection gas. The overpressure would appear to be predominantly in shales. The well control incidents have been infrequent, however, and have not resulted in any significant lost time.



Regional Geohazards Study – Containment



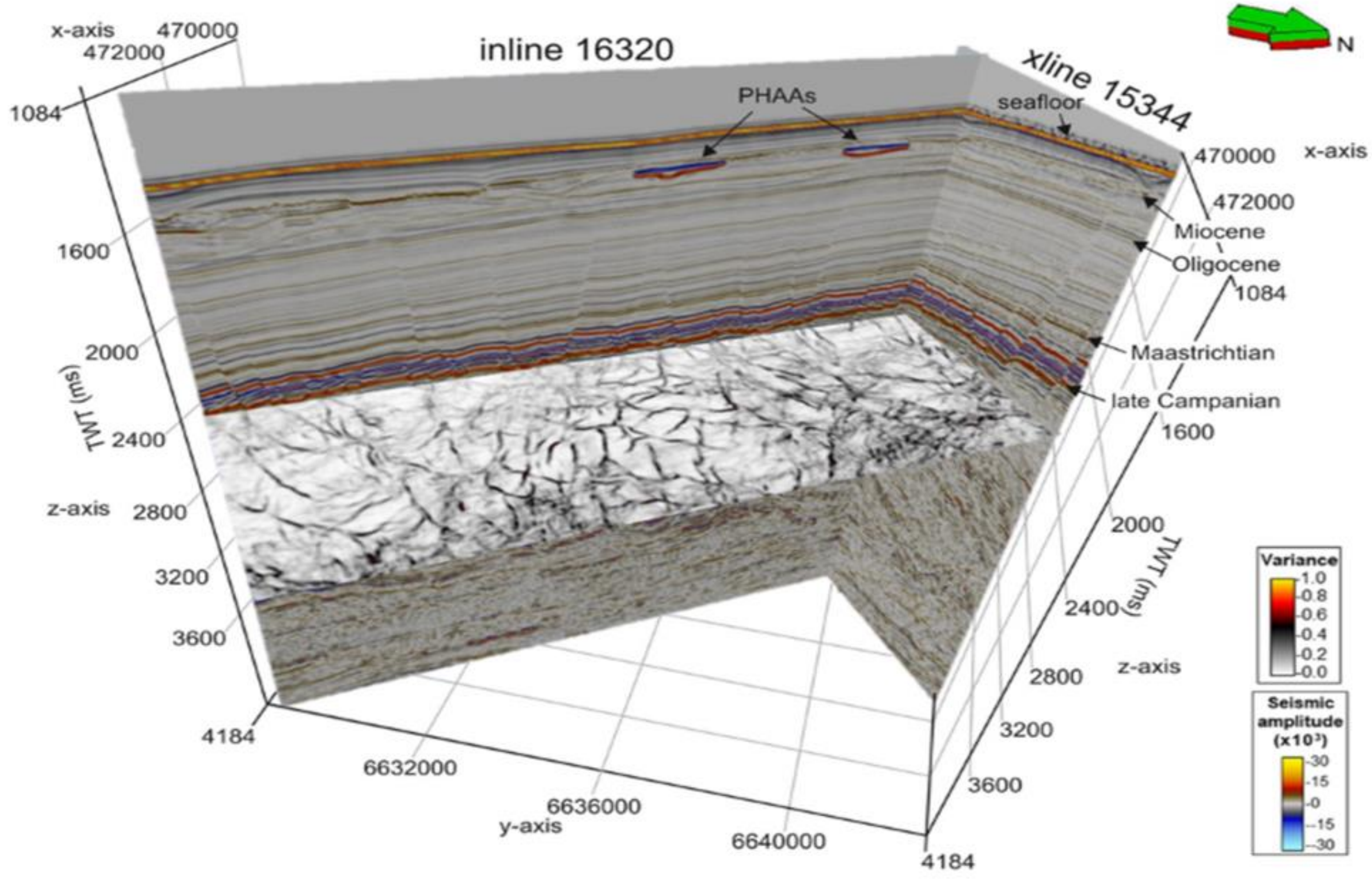




Halokinesis is clearly visible on the seismic line above, with the halite thickening to the North (right) and thinning to the South (left).
A salt diapir is visible on the North of this seismic line, this is causing disruption to the stratigraphy that directly overlies it.
From the 2D seismic line above there appears to be a large-scale fault that is terminating close to the seabed.

Movement of the halite is causing salt withdrawal on the South of the seismic line leading to collapse of the overlying stratigraphy.
It is essential to acquire, process and interpret a high-resolution 3D survey over this area to understand the containment risk posed by the salt tectonics in the South Celtic Sea.

Regional Geohazards Study – Containment



3D seismic can be a useful tool to understand the fault trends and predict potential containment risks. Maduna et al 2023.

The quality of the geophysical datasets in the Irish Sea and Celtic Sea are highly variable and there is a paucity of high-quality geotechnical and geophysical data over the areas identified that contain halite.

Once a potential Hydrogen storage area has been identified, high quality data must be acquired over the site-specific area.
This must include MBES bathymetry data, multi channel Sparker, CPT's, and a high resolution muti component 3D seismic survey.

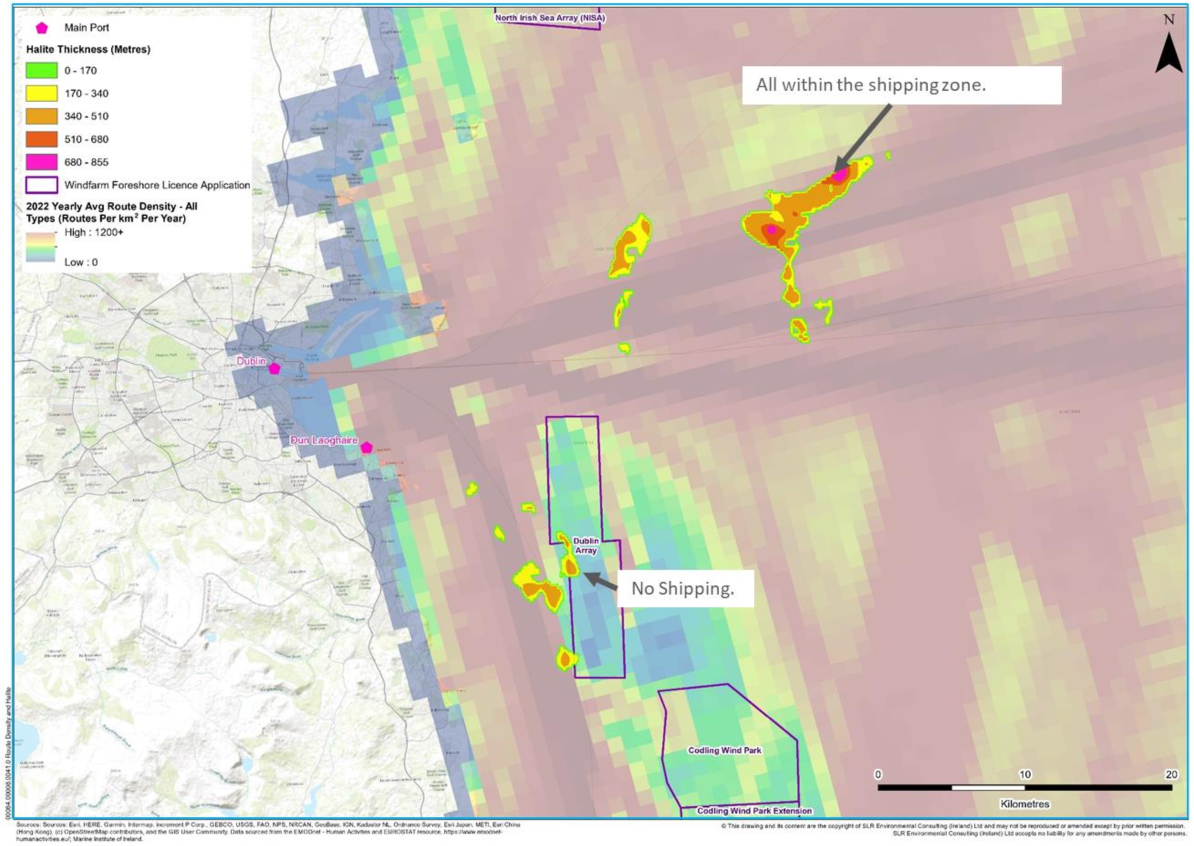
To ensure the best possible survey is acquired an illumination study should be undertaken beforehand to understand what is the optimal azimuth for the survey to be acquired in to image the subsurface correctly.

Once acquired the seismic will need to be brought through modern processing flows including Q compensation, 3D SRMRE, FWI and iterations of velocity model building.

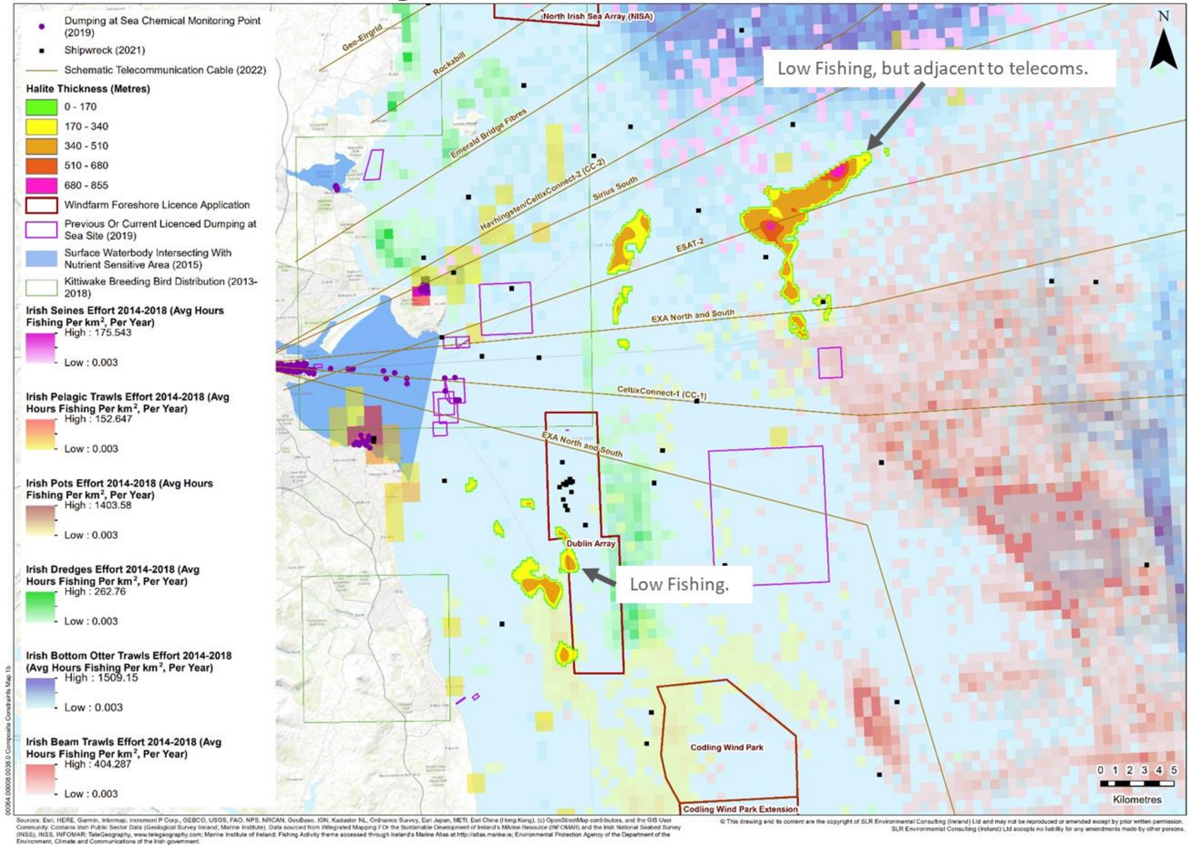
Finally, a comprehensive seismic interpretation will need to be completed and integrated with the other project disciplines.

Example Constraints Maps - Kish

Shipping Density

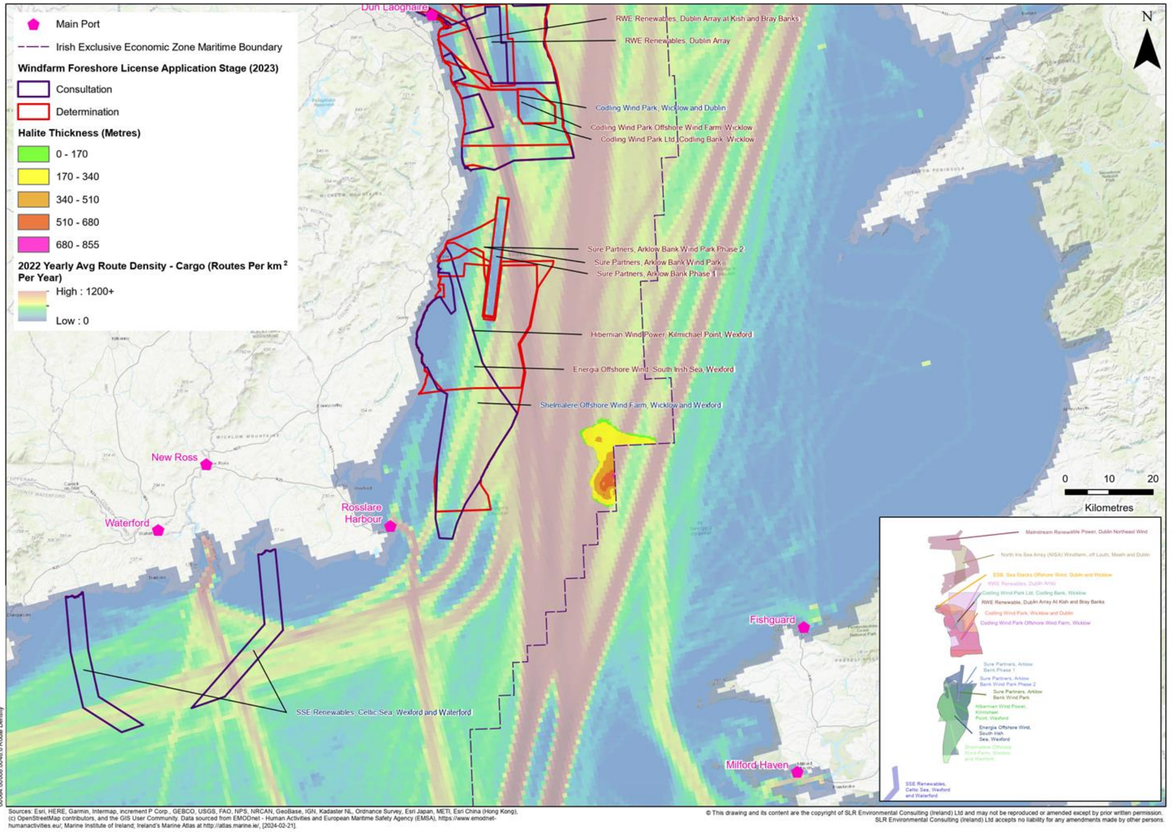


Fishing Effort, Telecoms, Wrecks

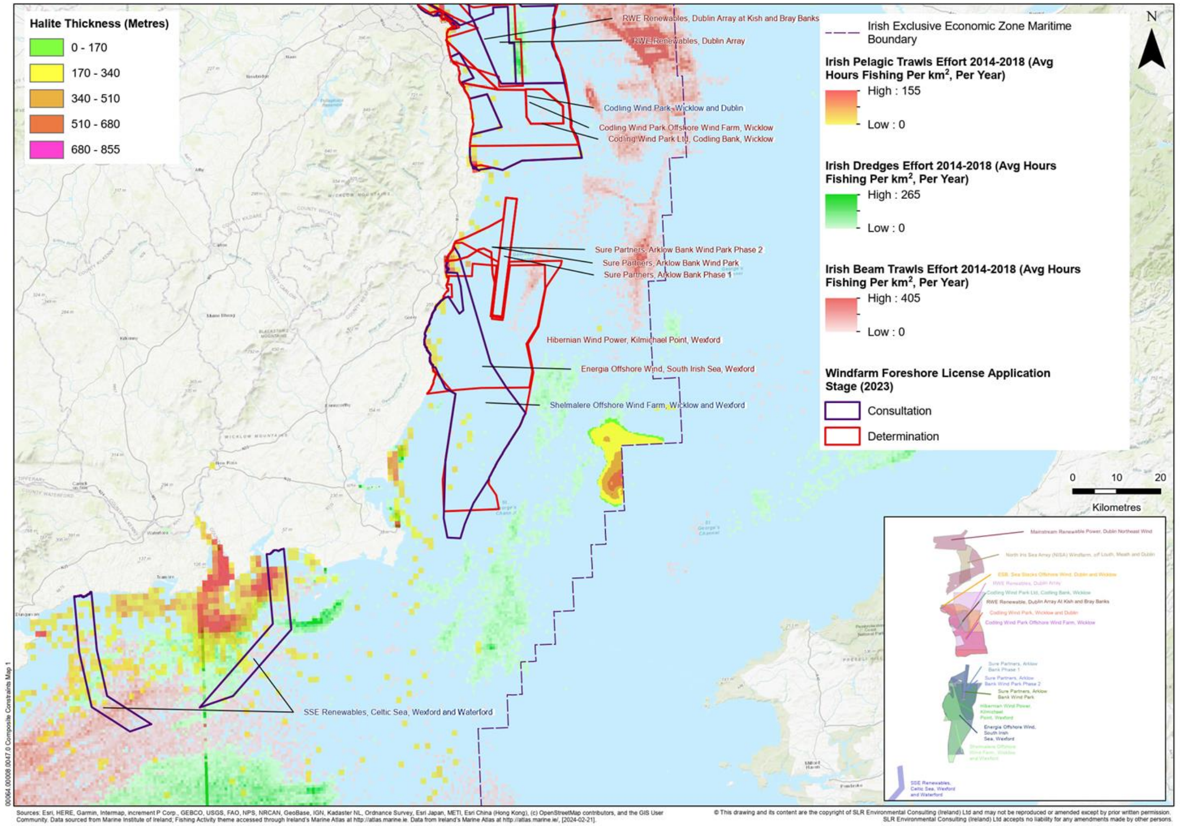


Example Constraints Maps – Irish Sea

Shipping Density

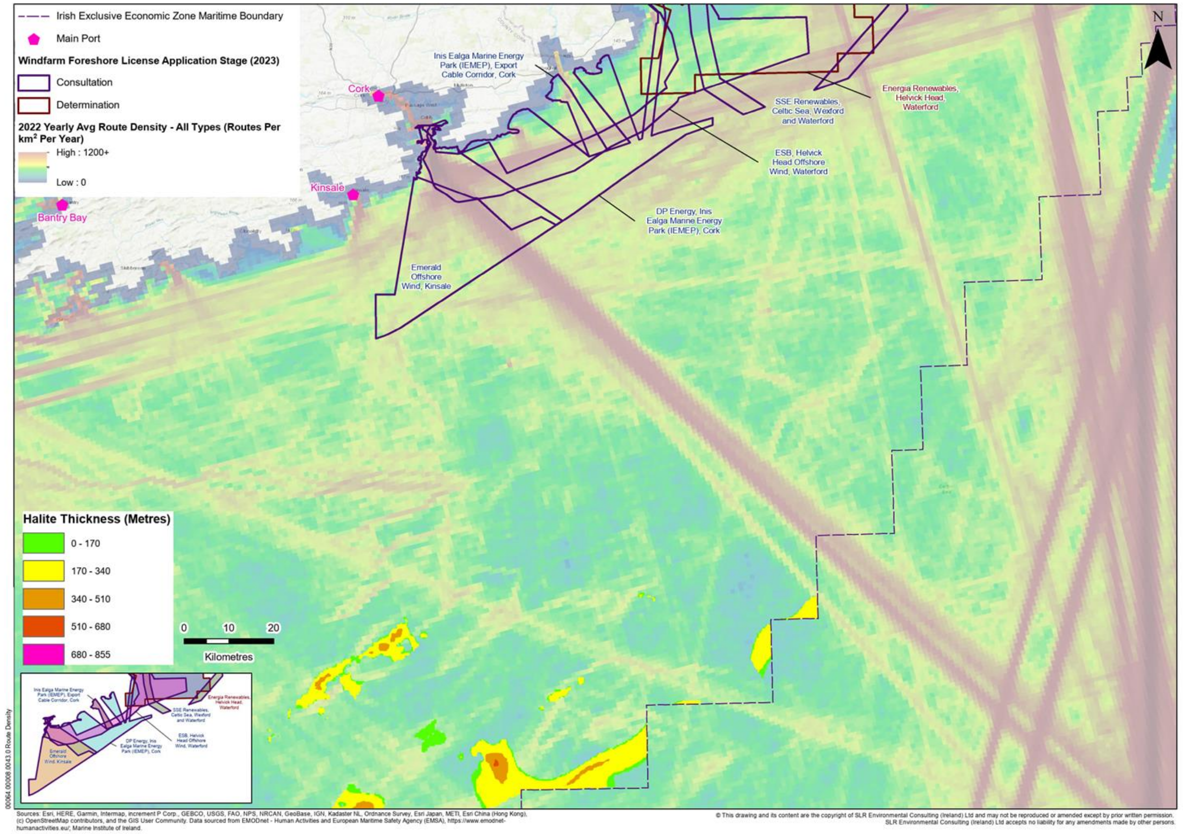


Fishing Effort

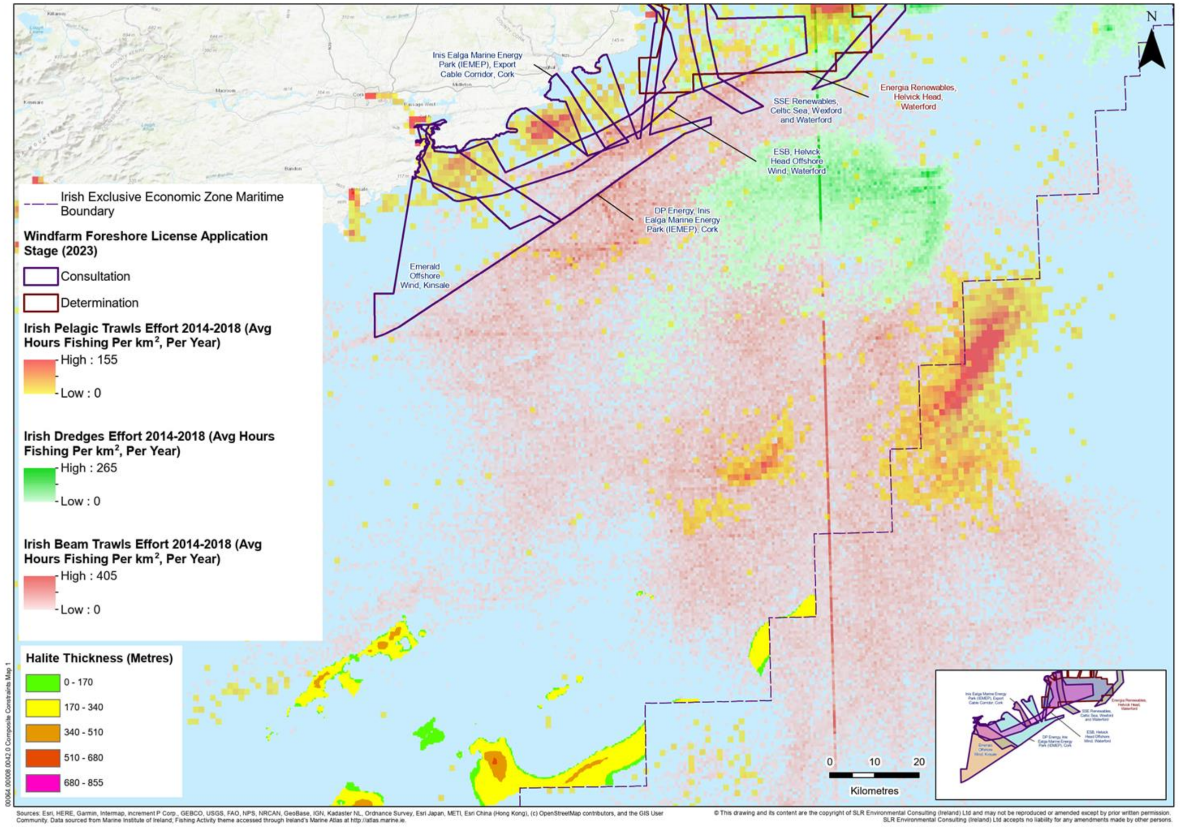


Example Constraints Maps – Celtic Sea

Shipping Density



Fishing Effort



Questions?

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