Project approved for funding
as part of the ERA-NET
GeoERA

Deliverable - D5.2b

Lessons learnt from applying the GeoConnect³d Structural Framework; the Irish case study

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Version: 13-08-2021

This report is part of a project that has received funding by the European Union's Horizon 2020 research and innovation programme under grant agreement number 731166.

Deliverable Data		
Deliverable number	D5.2b	
Dissemination level	Public	
Deliverable name	Learning from the case	
Work package	WP5	
Lead WP/Deliverable beneficiary	BRGM	
Deliverable status		
Submitted (Author(s))	28/07/2021	Russell Rogers (GSI)
Verified (WP leader)	12/08/2021	Harri Williams (BRGM)
Approved (Coordinator)	13/08/2021	Renata Barros (RBINS-GSB)

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1 PILOT AREAS DESCRIPTION

1.1 Traditional geological description

Precambrian rocks in the northwestern and southeastern corners of Ireland originated on different palaeo-continents (Laurentia and the Ganderia fragment of Gondwana, respectively), separated by the Iapetus Ocean.

As Iapetus closed by subduction during the Ordovician and Silurian periods, volcanic arcs collided with the continents, causing successive orogenies and forming mineral deposits. Final ocean closure and the resulting Caledonian Orogeny raised the vestiges of Iapetus into a composite mountain belt. Continental collision was accompanied by intrusion of voluminous granites – exposed, yet-to-be exposed and re-buried. Erosion of the Caledonian mountains supplied sediment to extensive 'Old Red Sandstone' alluvial plains; the Munster Basin is 6 km thick.

A Carboniferous transgression was followed by extensive limestone deposits in a shallow sea that was rich in invertebrate shelly life. Early Variscan extensional tectonics led to block-and-basin faulting and circulation of hot fluids, forming several large zinc and lead base metal deposits, including, at Navan, the largest zinc mine in Europe.

During later Carboniferous times, global sea level fluctuations brought coal measures, and deltaic sandstones and shales. Exposures of these rocks on the Cliffs of Moher coast of Co. Clare attract hydrocarbon geologists from around the world to study reservoir systems exposed in 3D. Ireland was on the northern edge of the Variscan orogenic belt and its effects were relatively slight.

Rocks of the Permian 'New Red Sandstone' desert and succeeding Mesozoic strata are preserved on land in the northeast, where they have been protected from erosion by a covering of Paleogene basalt lavas, but their main occurrence is offshore. Great thicknesses of Mesozoic sediments accumulated in subsiding basins, formed from tensional forces related to the beginning of North Atlantic opening.

Crustal stretching and the Icelandic plume created large volumes of basalt magma during the early Paleogene. Extensive suites of dykes intruded the northern half of Ireland and vast basalt lava flows issued from the fractures, including the world-famous columnar-jointed Giant's Causeway. Centralised magmatism built up large volcanoes, the roots of which are now exposed by erosion in the cross-border area of eastern Ireland.

The Pleistocene glaciations carved corries and U-shaped valleys that give the Irish mountains grandeur beyond their relatively low height. In the lowlands, the bedrock is mostly obscured by unconsolidated glacial deposits. Drumlin fields are well developed, and the Irish language gave the word 'Esker' to the long ridges of gravels deposited by sub-glacial rivers.

1.2 Specific Challenges

The GeoConnect³d structural framework includes the island of Ireland. A coastline is not a recognised limit in the structural framework method, in order to represent geology continuing offshore. This aspect of creating the structural framework was challenging, as we wanted to show the geology continuing offshore, but without implying a greater understanding of the offshore geology than we possess. Decisions, therefore, had to be made on which limits and units to continue offshore and how.

We used the Bedrock map of Ireland 1:1M scale, which includes the most recent compilation of the whole offshore geology. We extend only the limits offshore, using the fault and unconformity traces of the 1M map, but not the units.

1.3 Subsurface Management

Mineral and hydrocarbon extraction and natural gas storage are the only subsurface activities regulated in Ireland. Geothermal energy, renewable energy (heat, compressed air, hydrogen) storage and CO2 storage currently do not have permitting legislation or regulation.

GSI joined the GeoConnect³d project to explore options for modelling, characterisation and visualisation of the subsurface as a prelude to management of subsurface space and resources and, more directly, to develop methods for representing subsurface geology at multiple scales.

1.4 Starting Material

For the creation of the structural framework the following datasets were used (see vocabulary for appropriate references):

- GSI Mapping Bedrock unit shapefiles at 1:50k, 1:100k, 1:500k and 1:1M
- GSI Mapping Fault shapefiles at 1:50k, 1:100k,1:500k and 1:1M
- *In press* figures from publications on the Dinantian stratigraphy of Ireland
- Fault datasets provided by ICRAG, published as Guo and Walsh 2016
- Figures from explanatory texts for GSI 1 :100k Bedrock map series
- Selected Geological Survey of Northern Ireland publications

2 ADOPTING STRUCTURAL FRAMEWORK AND GEOMANIFESTATIONS

2.1 Adopting Structural Framework

The structural framework is composed of limits and units. Their relationship is that units are defined by limits. A unit must be bounded by limits, but not all limits need to bound units.

The structural framework should be viewed at 3 different levels: level 1 (1:10M – 1:2M), level 2 (1:2M – 1:500k) and level 3 (<1:500k). The work started from the more detailed zoom level (Level 3) and moved up to the more general ones.

The mulit-scale nature of the structural framework imposes a hierarchy on the associated vocabulary. This hierarchy, once completed for each scale, constrains and simplifies the construction of subsequent scales.

2.1.1 Level 3

Level 3 represents the more detailed areas of the structural workflow. Those areas correspond to the Dublin and Lough Allen basins at a 1:50,000 scale.

The limits for level 3 fall into three categories; stratigraphic or igneous contacts, faults and unconformities. At this most detailed scale we show a more complete picture of the faults, including faults that do not limit units. Not every fault from the existing detailed mapping was replicated in the structural framework, just enough to show the trends and complexities of the fault systems.

As the limits that we had chosen were from existing stratigraphic mapping, the units that they bounded were delimited by age as well as lithology. Units of Carboniferous age form the majority of both level 3 areas and are further subdivided into Tournaisian, Visean and Namurian units.

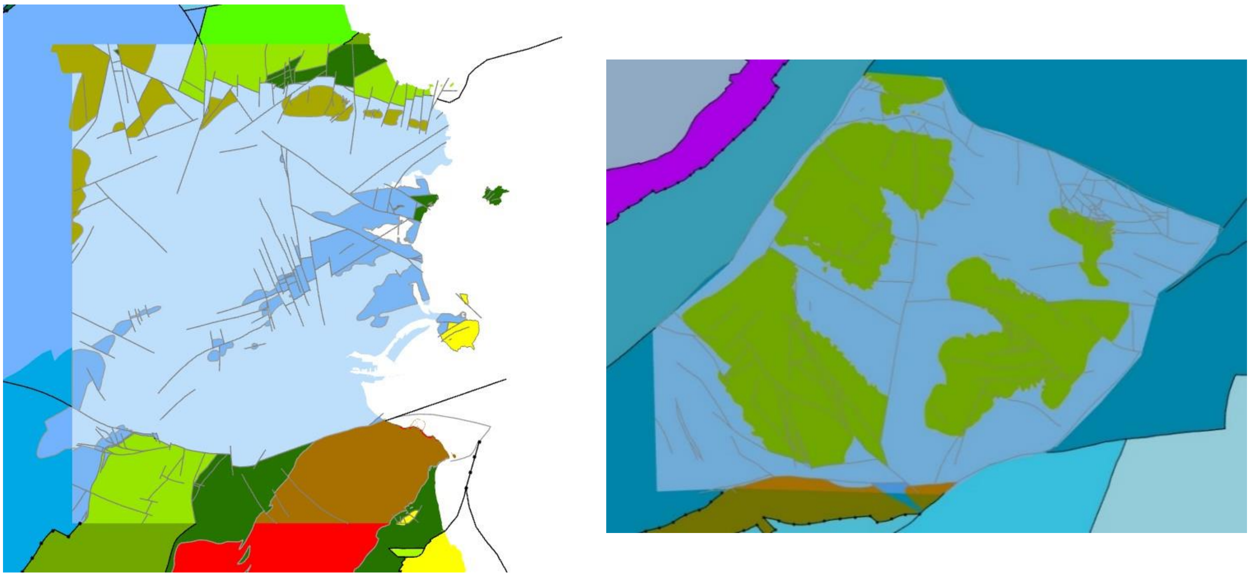

Fig. 1. Structural framework of level 3 (Dublin and Lough Allen basin)

2.1.2 Level 2

Level 2 is the most detailed level to cover the whole island of Ireland and is visible at scales 1:2M – 1:500k where there are no units from level 3.

The limits for level 2 fall into 3 categories; stratigraphic or igneous contacts, faults and unconformities. At this scale not every fault is shown, and many large faults are omitted if they do not limit a unit. As the limits are mostly taken from existing geological mapping the units are already separated by age.

Bedrock of Carboniferous age dominates at the surface of Ireland. For the structural framework at this level, the Carboniferous units are not separated by age but by basin extent, in order to best display the structural grain of Ireland. While basin extent varies over time, the Carboniferous basins shown in the structural framework are limited by the major faults or their greatest extent. In this regard, the structural framework differs from existing geology maps, as prominent Namurian sedimentary cover rocks are not visible at all, because the syn-sedimentary basin-bounding faults we chose to display run beneath them.

Units of older and younger rocks are sub-divided by age and lithology, typically inliers and outliers limited by unconformities and faults.

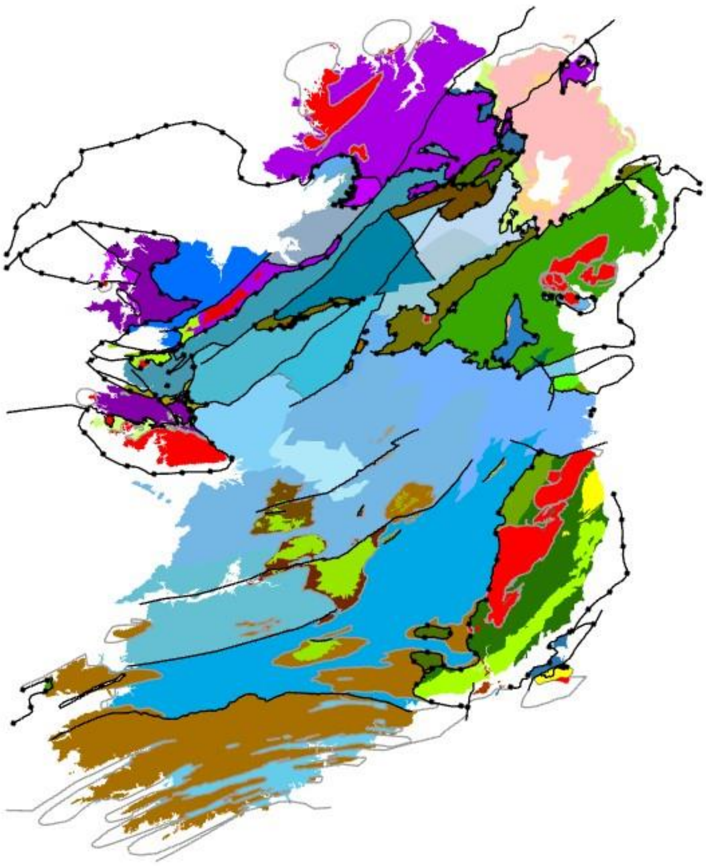

Fig. 2. Structural framework of level 2

2.1.3 Level 1

Level 1 is the least detailed level to cover the whole island of Ireland and is visible at scales 1:10M – 1:2M.

The limits for level 1 fall into 3 categories; stratigraphic or igneous contacts, faults and unconformities. At this scale not every fault is shown, and large faults are omitted if they do not limit a unit. As the limits are mostly taken from existing geological mapping the units are already separated by age.

The Carboniferous rocks are merged into one unit, limited by major faults and unconformities.

Units of older and younger rocks have been grouped by age and location, typically inliers and outliers limited by unconformities and faults.

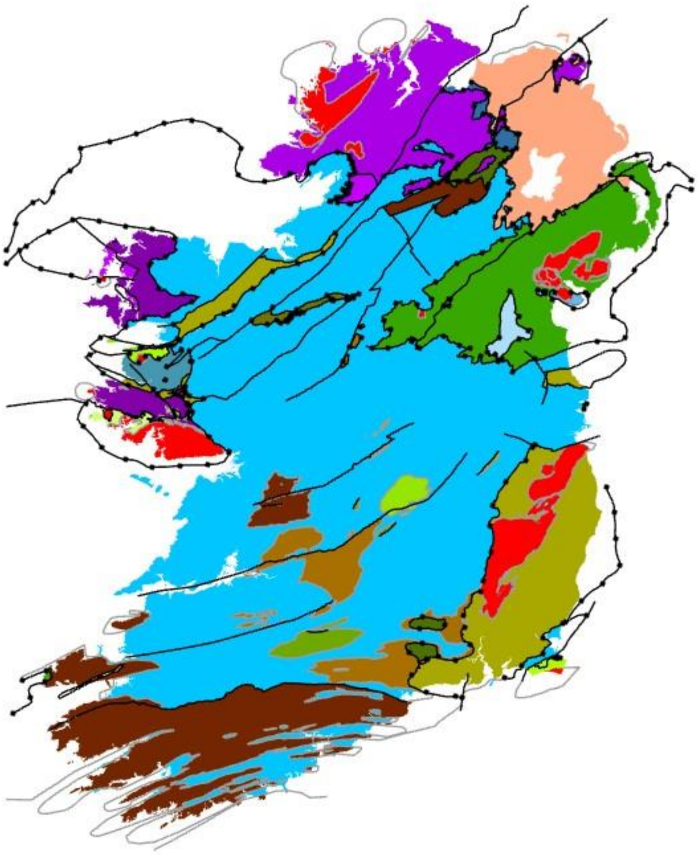

Fig. 3. Structural framework of level 1

2.2 Adopting Geomanifestations

The data selected to test the geomanifestations method were already edited, cleaned and stored in databases of Geological Survey Ireland and the Irish National Seismic Network. To produce GeoManifestations from these datasets was a simple database exercise.

The geomanifestations we selected can be grouped in four categories:

1. Mineral occurrences
    - Tungsten occurrences
    - Pb/Zn occurrences
    - Lithium occurrences
    - Fluorspar occurrences
    - Baryte occurrences

2. Karst features
    - Karst springs
    - Karst Influent features
    - Karst caves

3. Warm springs

4. Earthquake foci

The mineral types selected were based on the EU critical raw material list with the hope that studying these geomanifestations through the structural framework would demonstrate correlations that could promote prospectivity.

The three types of karst feature selected are the most common in Ireland, and analysing them with the structural framework may identify certain trends or relationships that would facilitate management of groundwater.

The hot springs dataset is the most sparse of the geomanifestations dataset, but also the least studied. The aim with this dataset was to establish trends or correlations with the structural framework that could be applied to a future, more comprehensive dataset.

The earthquake foci dataset includes a depth value, so this was compared with the 3D model. The aim was to show not only a correlation with certain faults, but also a depth relationship with those faults.

3 EVALUATING THE STRUCTURAL FRAMEWORK AND GEOMANIFESTATIONS

3.1 Added Value

The structural framework concept allowed us to highlight features that wouldn't be prominent on a traditional geology map. For example, an area of Namurian sedimentary cover rocks masks Dinantian basin structures on the geology map (Fig4A) that are apparent on the structural framework (Fig 4B).

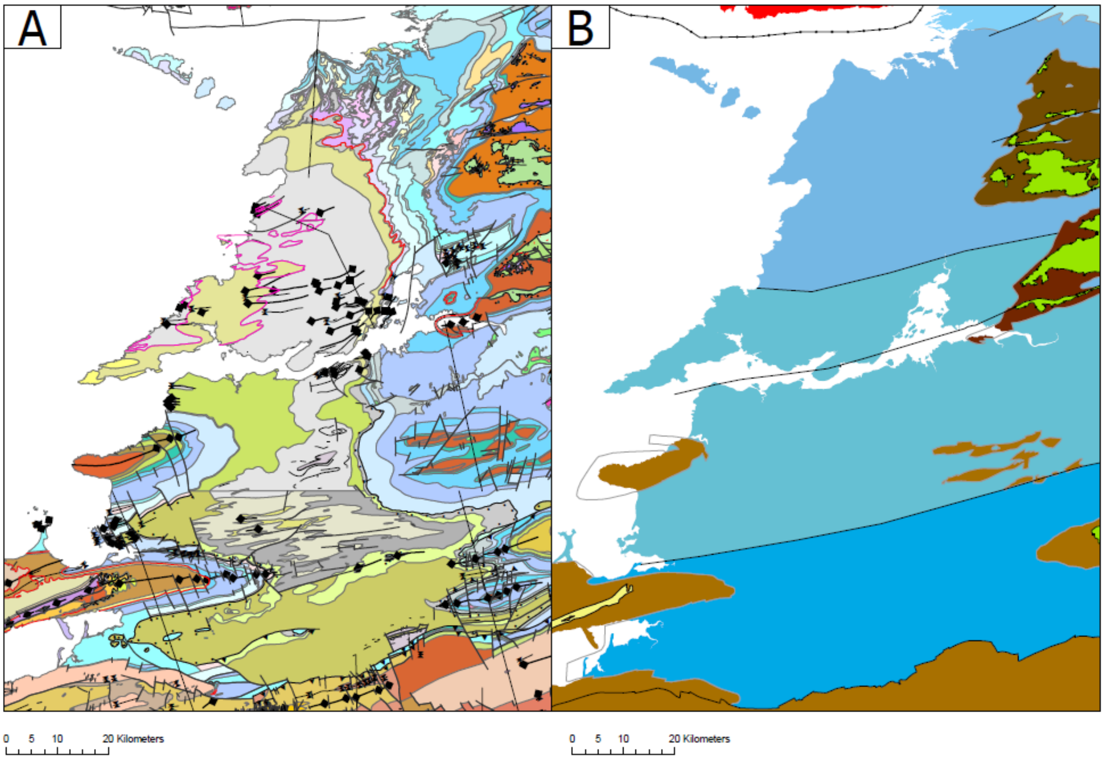

Figure 4. A) Geological Survey Ireland 1:100k geology map. B) Structural Framework in the same field of view.

The structural framework also gives us the ability to highlight features by removing the "noise" of a traditional geological map. For example the Longford-Down Inlier in the northeast of Ireland has a very complicated contact with the Carboniferous rocks surrounding it (Fig 5A), but the limit concept of the structural framework allows us to demonstrate that the contact is dominantly an unconformity (Fig 5B).

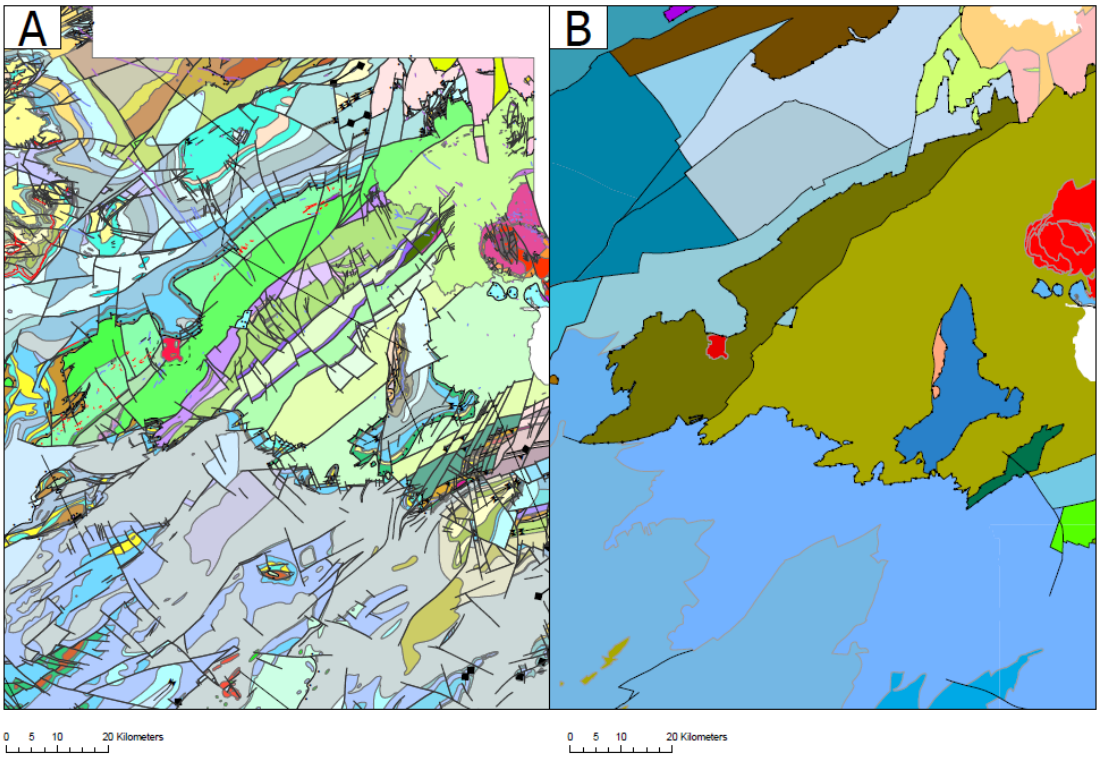

Figure 5. A) Geological Survey Ireland 1:100k geology map. B) Structural Framework in the same field of view.

The structural framework allows distinction between basin and shelf regions in the Carboniferous geology without the user needing to understand the implications of the lithology descriptions or be familiar with the stratigraphy (Fig 6A & B).

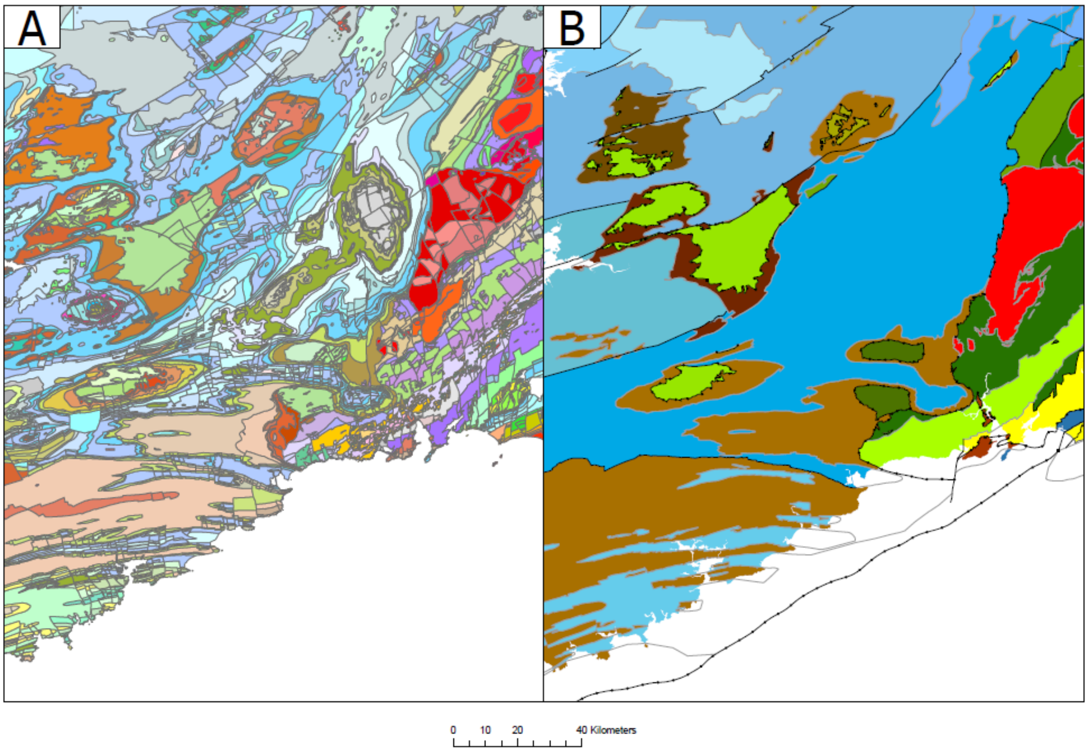

Figure 6 A) Geological Survey Ireland 1:100k geology map. B) Structural Framework in the same field of view.

The structural framework allows for clear distinction between faulted blocks and conformable or unconformable contacts. For example, the Drogheda block is a fault block amongst Silurian and Ordovician Inliers on the northern margin of the Dublin basin. This is readily apparent from the structural framework (Fig 7B), but would require careful study of the geology map (Fig 7A) for a user not familiar with the region.

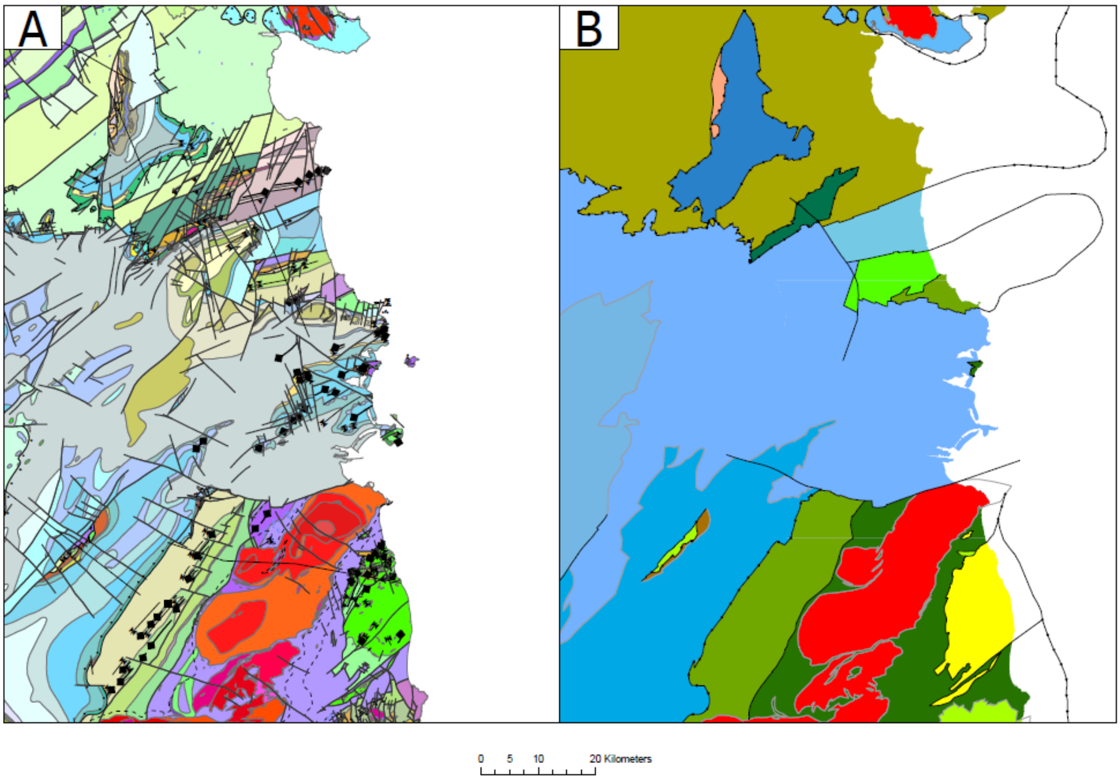

Figure 7 A) Geological Survey Ireland 1:100k geology map. B) Structural Framework in the same field of view

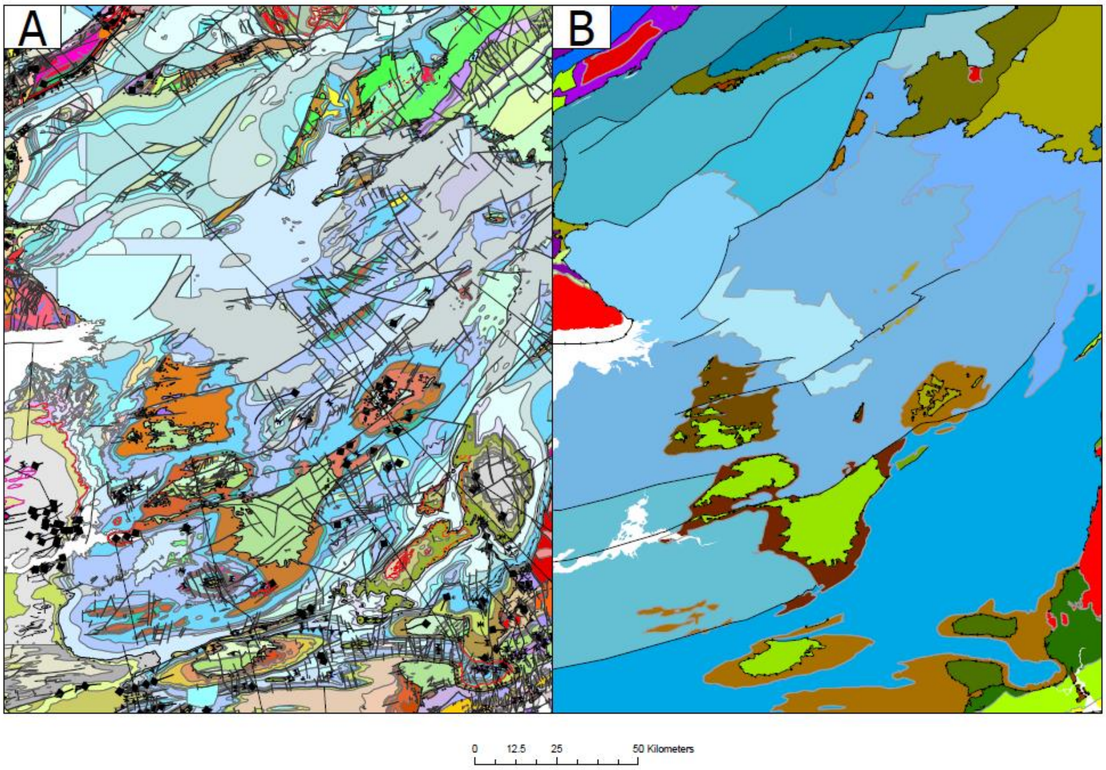

Figure 8 A) Geological Survey Ireland 1:100k geology map. B) Structural Framework in the same field of view.

The multi-scale nature of the structural framework is potentially a powerful tool for visualising the gross structural character within a geological map together with the detail and complexity of specific features of interest.

3.2 Problems – Structural Framework

Constructing the structural framework is a relatively straightforward process; the problems are confined to making the decisions that lead to the construction.

Practical issues we encountered when constructing the framework mainly featured the coast line. The different source materials from onshore to offshore were attempting to display different features and unifying these differences into a single limit in the framework could be a difficult process. Another practical consideration is that the structural framework cannot display folding, and in areas where the geology is controlled by folding this weakness leaves the framework looking unfinished.

Constructing the framework is a reductive process and is an inherently biased view or interpretation of the existing understanding of the geology. The decisions on what to display or leave out of the framework will determine the direction of the bias.

3.3 Problems – Geomanifestations

The bias in the structural framework makes the useful interpretation of geomanifestations more difficult. For example, the structural framework focuses on the basin and shelf features of the Carboniferous and effectively displays the major faults that controlled basin formation, but many later features do not appear.This feature of the framework means that some trends in mineral localities related in time to basin formation, such as Pb-Zn, can be observed, while karst features that may be controlled by later structures do not display a relationship to the structural framework.

For a structural framework to offer insight into a geomanifestation dataset it needs to incorporate all features that are, or may be, relevant to a specific geomanifestation and at an appropriate scale.

4 APPLYING THE STRUCTURAL FRAMEWORK TO PLANNING

The scale GeoConnect³d worked at is too small (necessitated by the desire to apply to cross-border regions) to be useful for most site-specific development applications. SFs are required at the scale of a subsurface project. However, the methods developed should be applicable at any scale and so remain valid.

The SF is a map rather than a 3D volume, so subsurface characterisation is not fully achieved. GSI developed an island-of-Ireland 3D model during the project, but our ambition of developing methods for nested multi-scale models could not be realised within GeoConnect³d.

5 CONCLUSIONS AND RECOMMENDATIONS

To combat the inherent bias in a structural framework, it is recommended that the structural framework method be applied to a specific goal. For example, a structural framework built to interpret karst features of a particular catchment would focus on facies and faults of all sizes, rather than basin forming faults at regional scale.

A national scale structural framework may be too coarse a tool for subsurface planning applications. At a national level, the structural framework will pose and answer questions about the geology, and some coarse trends in geomanifestations will be apparent. To answer a question related to sub-surface planning, a series of small scale structural frameworks made using a variety of different decision trees would give a fuller picture to answer specific questions.

Managing subsurface planning may include competing interests for the same volume of rock (e.g. storage in a reservoir used for drinking water abstraction). On the other hand, these activities can be managed if occurring at different depths below the surface. Therefore, subsurface management needs to consider the 3D volume of rock. A single structural framework, even if optimised to the structural features relevant for the management required, may not be sufficient to effectively do that as it is essentially a 2D view.