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A Framework for Modelling Groundwater Flow in Deep Heterolithic Sedimentary Sequences for Radionuclide Transport

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Background

- Public opinion regarding the safe disposal of nuclear waste is a pressing concern to secure **government investment** into the nuclear industry
- A **GDF** (Geological Disposal Facility) is the internationally recognised long-term preferred solution for the safe isolation of radionuclides from the biosphere
- **MMG** (Mercia Mudstone Group) in the **EISB** (East Irish Sea Basin) [Fig 1a & 1b] is one of the host rock candidates due to its low hydraulic conductivity, self-sealing and good radionuclide retardation properties[a]
- However, MMG is a **highly heterogenous** and **anisotropic** material, which evokes **complex groundwater flow** patterns potentially impacting radionuclide transport
- Understanding groundwater flow will improve radionuclide transport and migration modelling in the MMG

Aim: Develop conceptual hydrogeological and radionuclide models to enhance understanding of groundwater flow and radionuclide transport in the MMG within the EISB.

Objectives

1. Create a comprehensive 3D **Geological Model** of the EISB
2. Identify potential **groundwater flow pathways** through the MMG, EISB
3. Construct **numerical models** to simulate groundwater flow
4. Conduct **Radionuclide transport simulations** to identify which MMG characteristics affect radionuclide migration and associated uncertainties

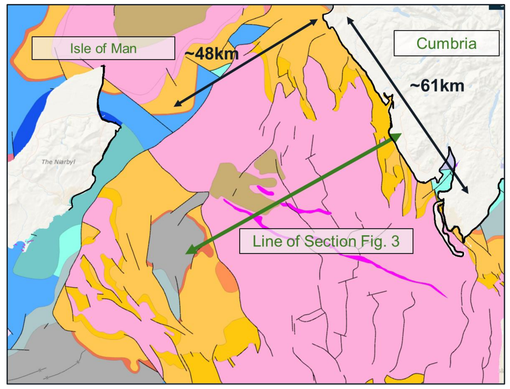


Figure 1a: Study area with MMG in pink[b]

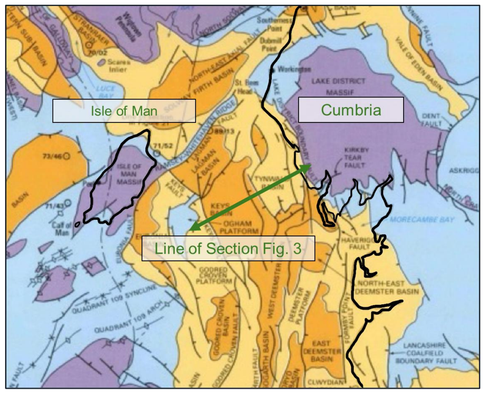


Figure 2: Structural geometry of the EISB[c]

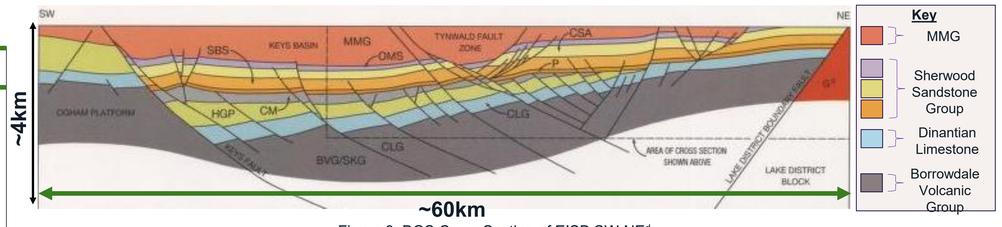


Figure 3: BGS Cross Section of EISB SW-NE[d]

Methods

- Database collation and processing including, borehole data processing [Fig 6], seismic data[e], publications & Cross Sections [Fig 2]
- Software identification for geological modelling including PETREL & GemPy
- Define/constrain the study area with an initial conceptual model
- Initialise ICFERST using WSL (Windows sub-system for Linux) and run experiemntal simulations

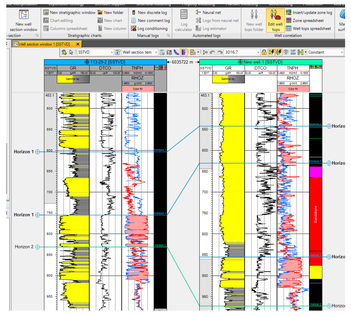
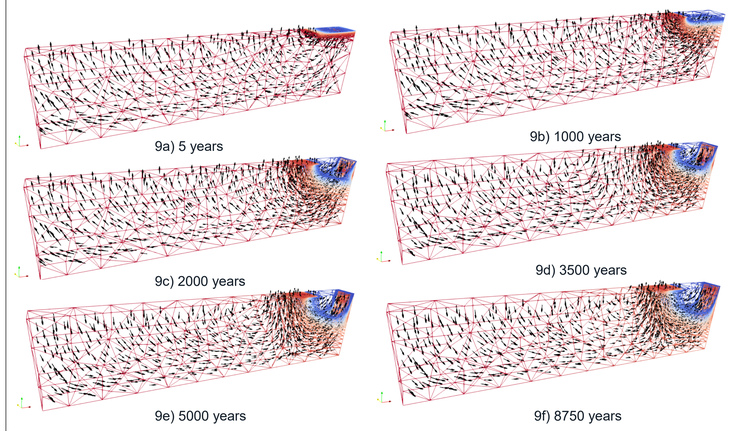


Figure 5: Petrel Well data processing

Results



This simulation with around 10,000 elements ran for 10,000 years with .vtu dumping every 5 years, with adaptive temporal and meshing. Total simulation time took 6 hours.

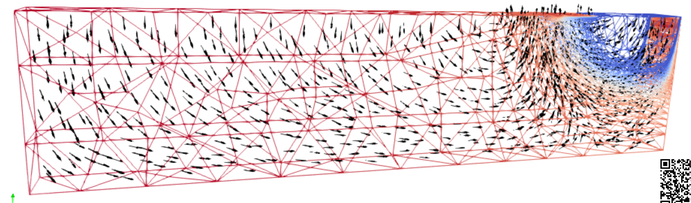


Figure 9: Pseudo 3D ICFERST Model Simulation Final Timestep 10,000 years

Scan to view Video

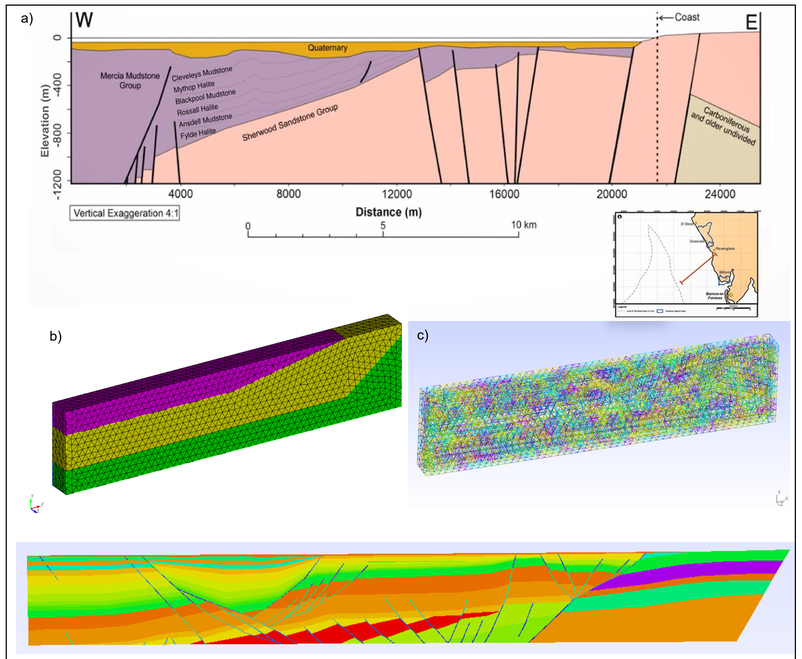


Figure 4a) Cross Section across EISB[f] [4b) Simplified Numerical Model in Cubit 4c) GMSH Visualisation 4d) Hipkins (2018)[h] mesh in GMSH

Numerical Modelling

- The study area is around 60km x 60km x 4km for the EISB however for preliminary numerical experimentations a smaller 'slice' of 30km x 7km x 2km was used [Figure 4b]
- Numerical modelling is done in Coreform **Cubit** [Fig 4], a CAD modelling software package, the approach is 2D to 3D with GMSH as supplementary software for visualisation [Figure 4c]
- **ICFERST** (Imperial College Finite Element Reservoir Simulator)[g] is used to simulate groundwater flow and radionuclide transport

Link to ICFERST

- Open-source code based on the **Double-Control Volume Finite Element** (**DCVFE**) Method, with dynamic unstructured mesh optimisation [Fig 6] and temporal adaptivity
- Darcy's Law:

$$Q = -\frac{kA}{\mu}\frac{dp}{dx}$$

- Advantages of **adaptive meshing** include faster run times and can handle high aspect ratios in basin scale modelling and density driven saline fronts [Figure 5] below

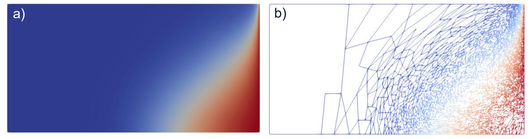


Figure 6a) 2D Henry Saline Intrusion Boussinesq approximation Simulation example in ICFERST with 6b) adaptive meshing

Initial Conceptual Model

- The initial conceptual model assumes three lithological units heading offshore from the coast where there's recharge of freshwater at -1.095e-3 m/day. The sea is modelled as a hydrostatic pressure boundary condition.

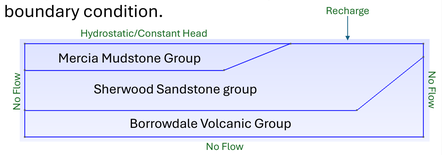


Figure 7: Conceptual model of the Pseudo 3D Model

- The pseudo 3D model assumes 6 velocity boundary conditions and one pressure boundary condition, with one recharge velocity boundary and the rest is no flow
- Previous 2D models with similar boundary conditions saw the development of a coastal saline front with excess water being driven upwards to the sea. It would be interesting to see if the same results occur in the pseudo 3D case.

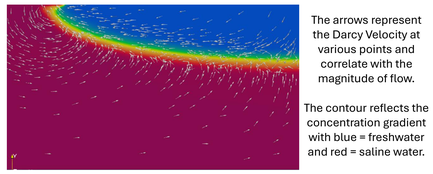


Figure 8: 2D Saline Intrusion Example in ICFERST

Discussion

- Recharge flowing into the model filled with denser hypersaline water creates this inverse Henry Saline problem but still establishes this saline front
- Upwelling of water back towards surface as expected with data processing to follow

Conclusions

- Complex geometry and multi scale of the EISB requires gradual increase in the simulation model
- Gradually increase formations and structural geology, faults and intrusions
- Refine conceptual and hydrogeological models with more data from published literature
- Explore implications of major faulting in the area using numerical modelling and doing sensitivity tests

References:

[a] Hobbs et al. (2002) https://nora.nerc.ac.uk/id/eprint/3664/1/RR01002.pdf
[b] BGS Geoindex Offshore https://mapapps2.bgs.ac.uk/geoindex_offshore/home.html
[c] DI Jackson et al (1995) https://webapps.bgs.ac.uk/Memoirs/docs/B01847.html
[d] BGS Bootle Map Sheet 47, 1997 https://largeimages.bgs.ac.uk/iip/mapsportal.html?id=1001526Ents
[e] NDR https://ndr.nstauthority.co.uk/
[f] NWS https://midcopeland.workinginpartnership.org.uk/progress-in-understanding-mid-copelands-geology-video/
[g] ICFERST https://multifluids.github.io
[h] Hipkins (2018) https://orca.cardiff.ac.uk/items/2121e319-0964-40a0-8c5a-103fffe9ddfb

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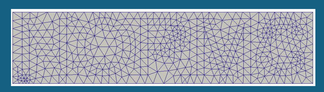

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