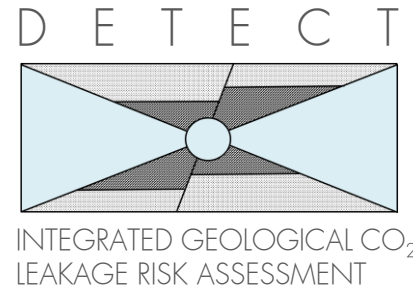




DETECT

Determining the risk of CO₂ leakage along fractures of the primary caprock using an integrated monitoring and hydro-mechanical-chemical approach



ACT Knowledge Sharing Workshop Bucharest, Rumania 2017

Project Overview

Shell Global Solutions International BV: **Marcella Dean**, Project Manager & WP4 Lead, **Jeroen Snippe**, WP3 Lead



Heriot Watt University: **Andreas Busch**, WP2 Lead



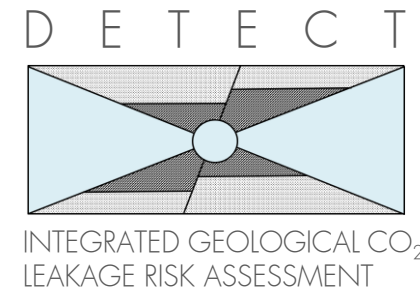
RWTH Aachen University: **Pieter Bertier**



Risktec Solutions B.V.: **Sheryl Hurst**, WP5 Lead



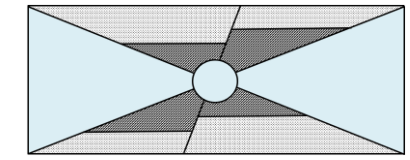
The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.



DETECT Project

Overview, Objectives, Collaboration Partners, Key Targets, Project Structure

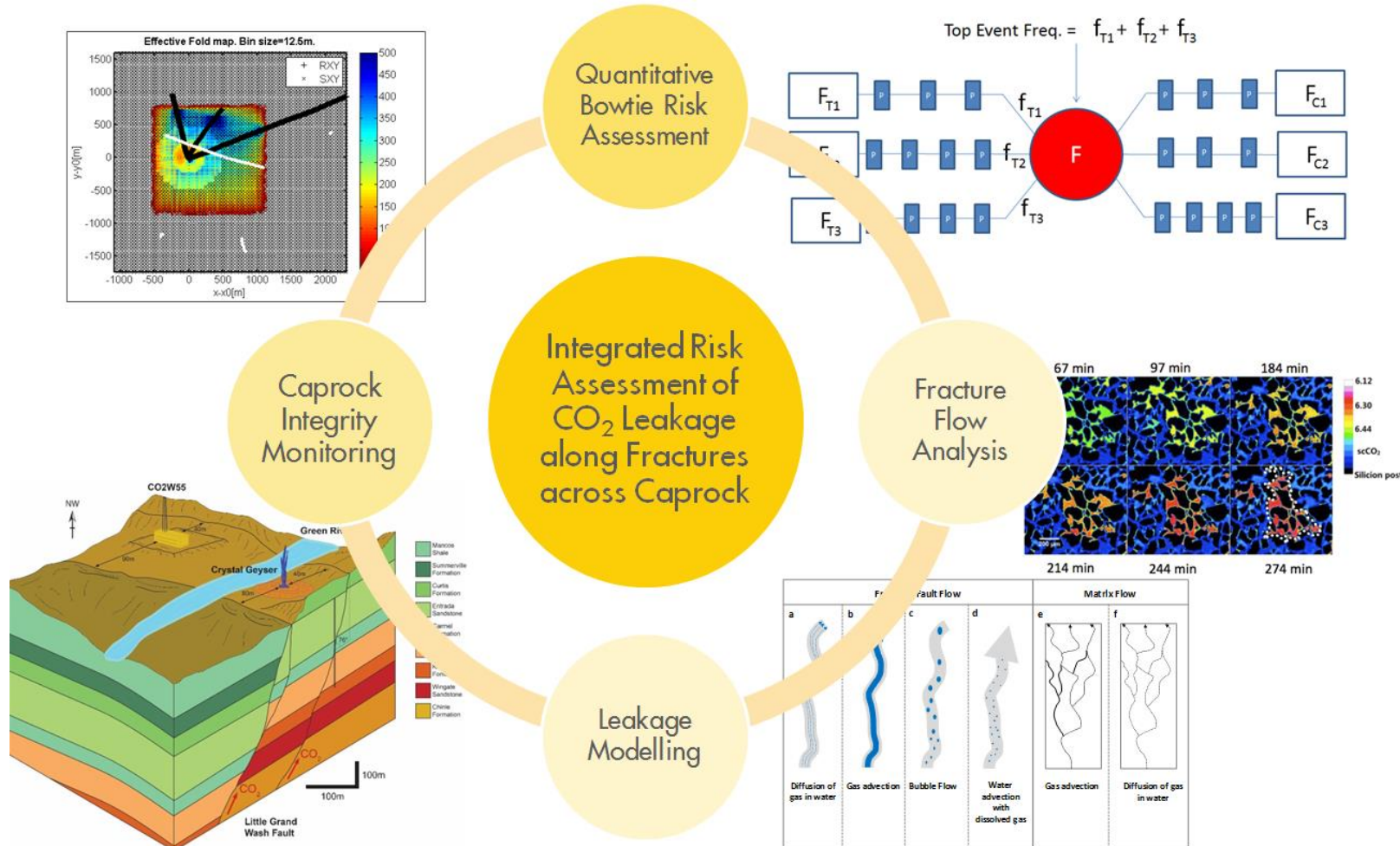




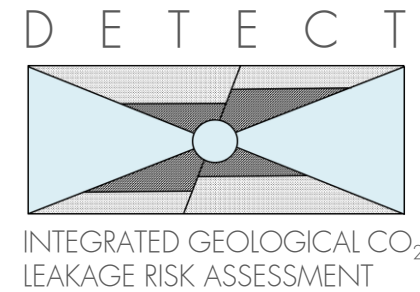
DETECT

Determining the risk of CO₂ leakage along fractures of the primary caprock using an integrated monitoring and hydro-mechanical-chemical approach

Overview



DETECT Determining the risk of CO₂ leakage along fractures of the primary caprock using an integrated monitoring and hydro-mechanical-chemical approach



Objectives

- Shell-led consortium will generate CCS industry leading guidance for managing geological CO₂ storage risks allowing stakeholders to:
 - Perform effective caprock and seal integrity risk assessment
 - Communicate clearly and logically assessed caprock risks
 - Understand realistic leakage rates and related implications
 - Select realistic and efficient leakage rate modelling approaches
 - Select cost effective and innovative containment monitoring technologies



Collaboration

- Focused consortium with recognized technology experts
 - **Shell Global Solutions International BV (Shell)** (project lead, modelling, monitoring): Leveraging key experience from the Peterhead and Quest CCS projects
 - **Heriot-Watt** (modelling): Sebastian Geiger's group is widely recognised for modelling fractured media for hydrocarbon production and CO₂ storage
 - **RWTH Aachen University** (laboratory work): Has a world-class laboratory for petrophysical, geochemical and mineralogical testing of low permeability rocks
 - **Risktec Solutions** (SME subsurface risk assessment): Since early 1990s is at the forefront of using and developing the bowtie method for risk assessment

DETECT Determining the risk of CO₂ leakage along fractures of the primary caprock using an integrated monitoring and hydro-mechanical-chemical approach

Key Targets

- **Laboratory experiments**
 - **Determine** the impact of reservoir stress changes, chemical reactions and swelling clays on fracture flow properties
- **Field studies**
 - **Characterise** fault and fracture network geometries
- **Hydro-mechanical-chemical modelling**
 - **Determine** flow in a single fracture and connected matrix, potential for upscaling of flow in fault damage zones
 - **Perform** fault zone leak path modelling of storage complexes
- **Monitoring feasibility studies**
 - **Identify** monitoring technologies to detect leakage across caprock
 - **Determine** expected monitoring performance based on fracture flow rates modelled
- **Integrated qualitative and quantitative risk assessment**
 - **Determine** passive safeguards (from lab and modelling) and active safeguards (from monitoring) for bowties and risk models
 - **Generate** guidance bowties for efficient risk assessment
- **Dissemination**
 - **Ensure** long-term relevance of outputs

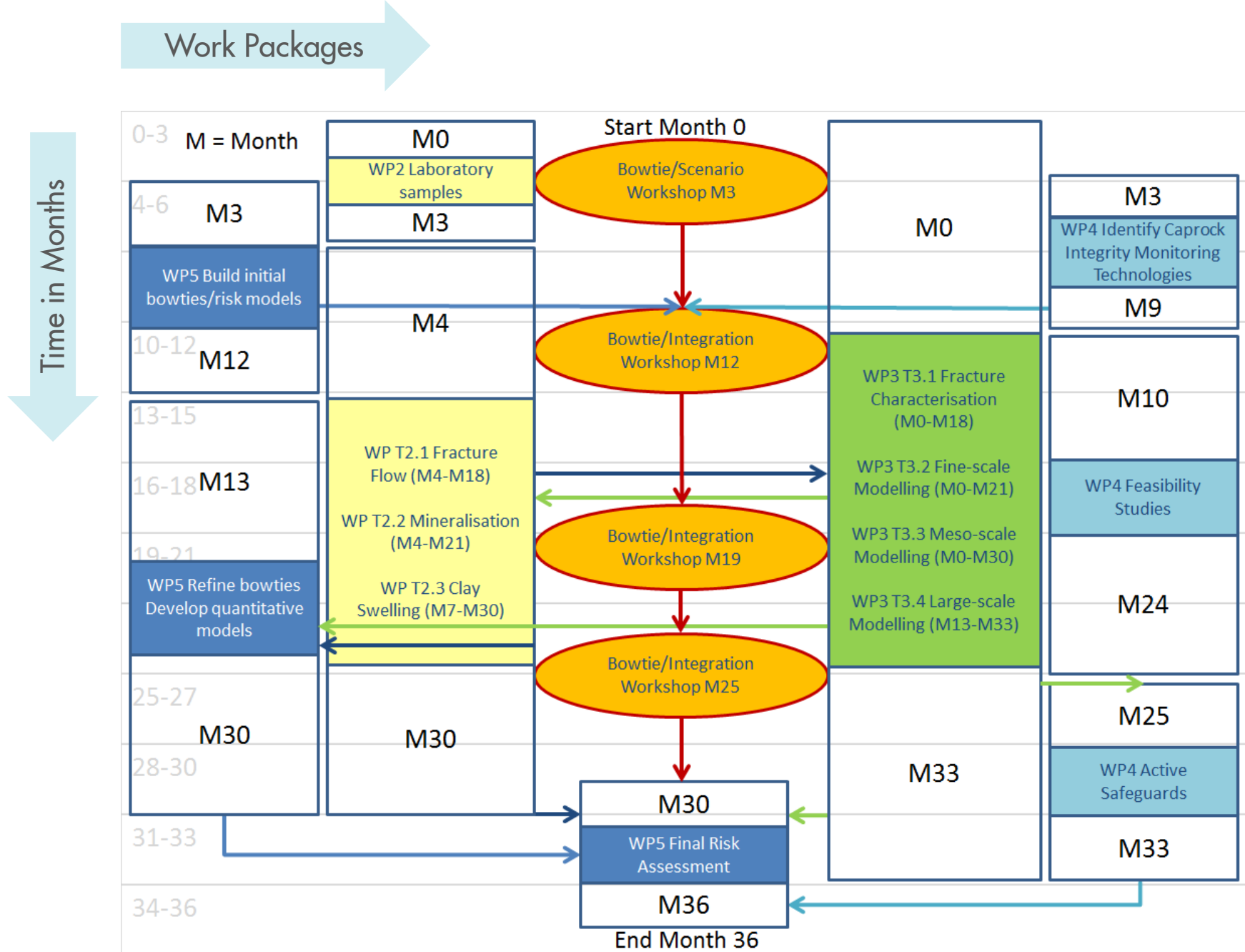


Monitoring well at the Quest CO₂ Storage site.

DETECT

Project Structure

- WP1 Project Management
 - Shell
- WP2 Fracture Characterisation
 - Heriot-Watts University
 - RWTH Aachen University
- WP3 Hydro-mechanical and hydro-chemical modelling
 - Heriot-Watts University
- WP4 Containment Monitoring
 - Shell
- WP5: Risk Assessment
 - Risktec Solutions



Work Packages

Overview, Objectives, Collaboration Partners, Tasks

WP1: Project Management

WP2: Fracture Flow, Mineralisation, Clay Swelling

WP3: Fracture Characterisation and Modelling

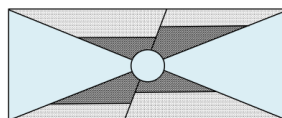
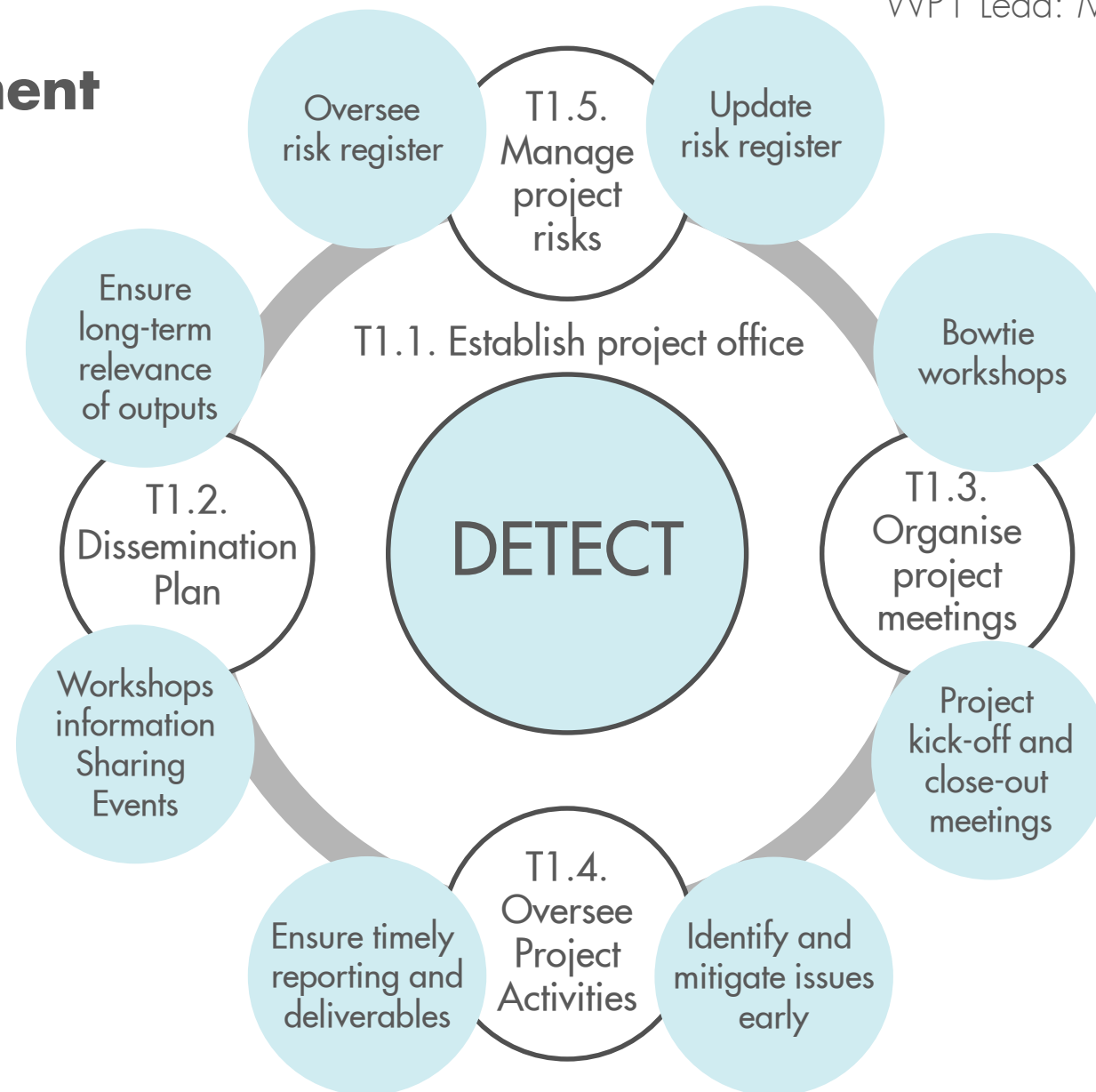
WP4: Containment Monitoring for Caprock Integrity

WP5: Qualitative and Quantitative Risk Assessment



WP1 – Project Management

- **Project Coordinator (PC):**
 - Shell, Marcella Dean
- **Supervisory Board (SB):**
 - One member from each partner
- **Project Management Support:**
 - Shell IRD Subsidy Desk, Shell External Relations and Communications team
- **Stakeholder Advisory Board (SAB):**
 - Professor Claus Otto (Curtin University), Professor Quentin Fisher (Leeds University), others TBD



WP2 – Fracture Flow, Mineralisation, Clay Swelling

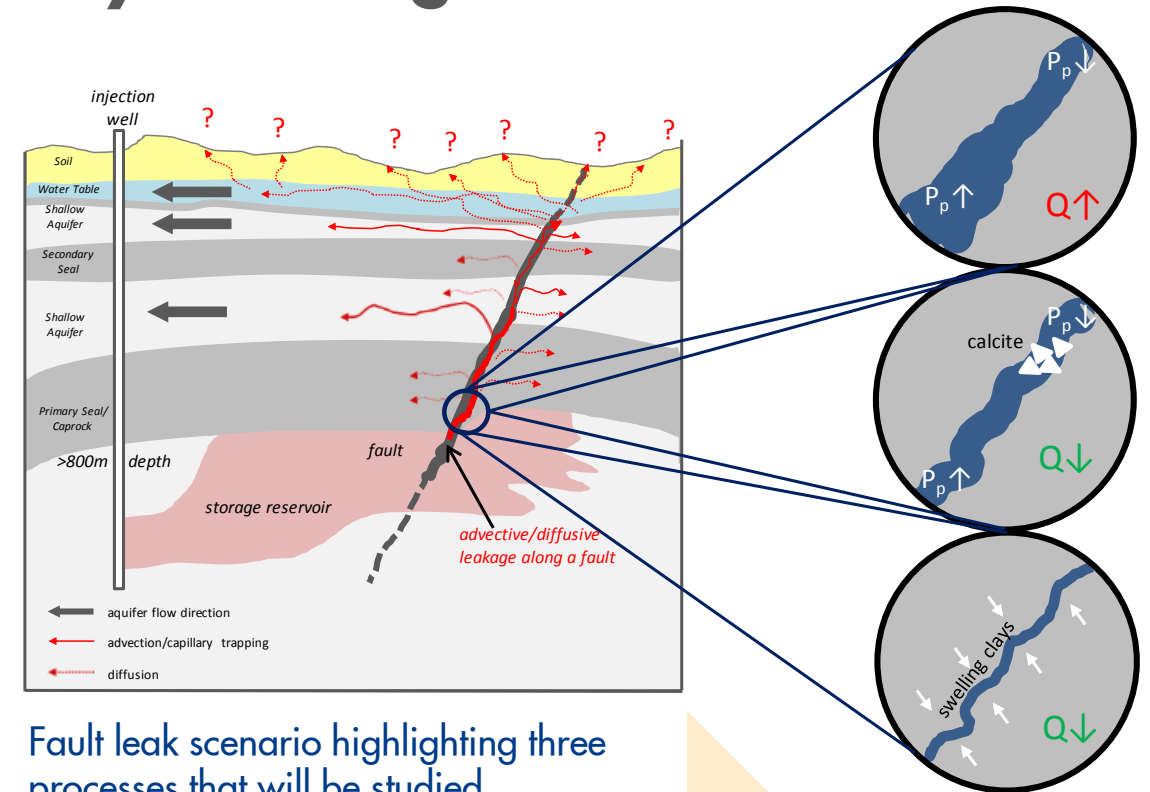
WP2 will test sensitivities of leakage rates along fracture networks or fault damage zones to fluid pressure, chemistry, mineral reaction rates, saturation changes and effective stress changes to generate the necessary input parameter for leakage modelling in WP3.

Objectives

- Identify and analyse factors controlling fracture flow as a function of temperature, pore pressure, confining stress, mineralogy or strength parameters
- Significantly improve fundamental understanding of the impact of CO₂ induced expansion of swelling clays in fractures
- Determine effects of CO₂-induced water-rock interactions on transport through fractures

Collaboration

- Heriot-Watt University, RWTH Aachen University, Shell IRD

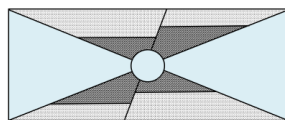


Fault leak scenario highlighting three processes that will be studied.

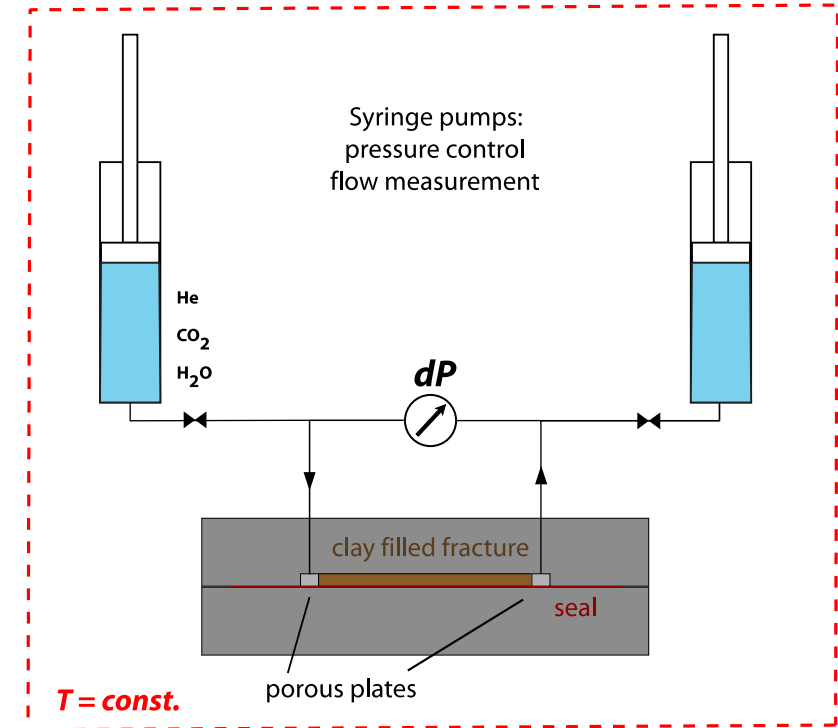
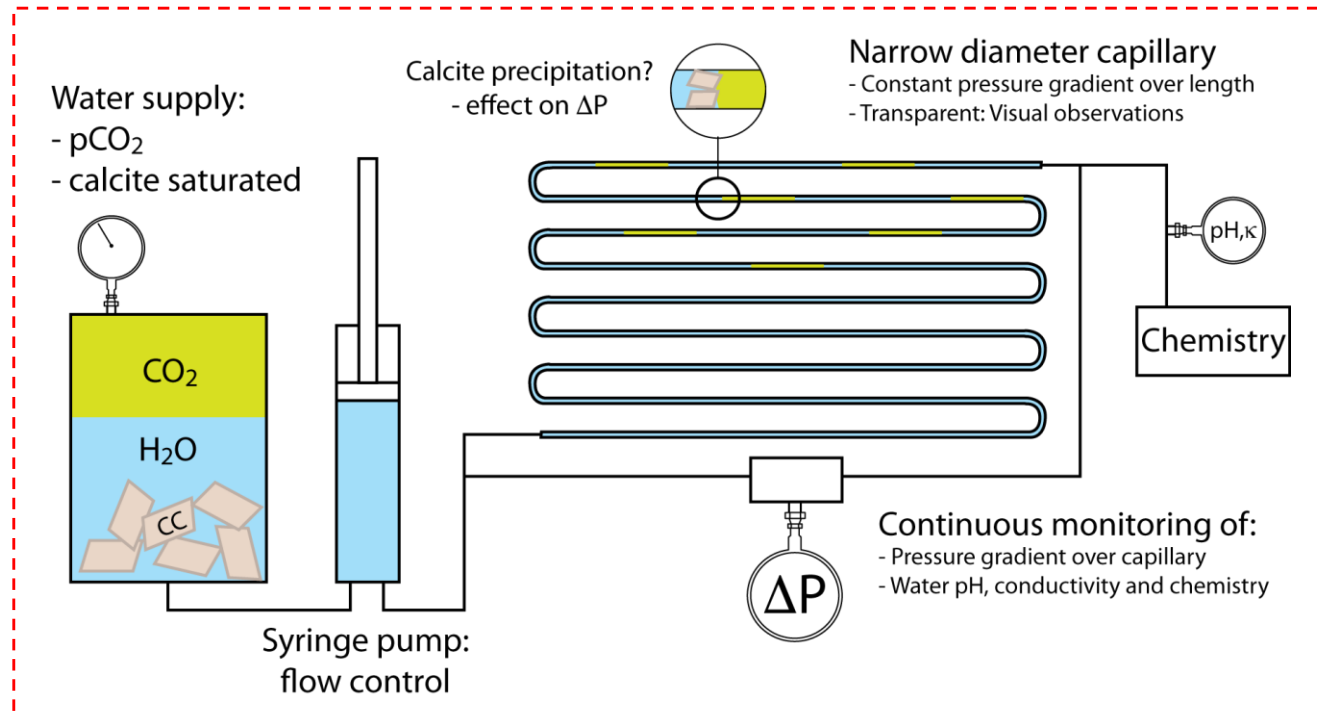
WP2.T1. Fracture Flow: stress-permeability relations

WP2.T2. Mineralisation: mineralisation in fractures

WP2.T3. Clay Swelling: clay swelling affecting fracture apertures



WP2 – Fracture Flow, Mineralisation, Clay Swelling

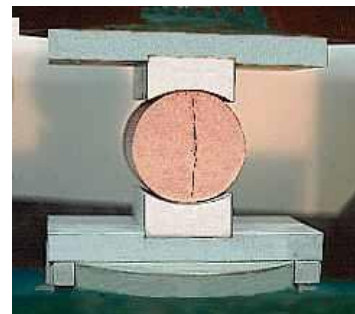


T2.2. Mineralisation Experiments

Study reactive transport in fractures under CO₂ storage conditions

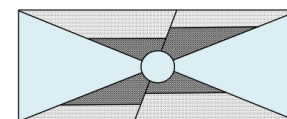
T2.1. Fracture Flow Experiments

Isotropic or triaxial cells to perform flow experiments on fractured samples



T2.3. Clay Swelling Experiments

Permeability measurements on clay filled slits to study effect of clay swelling on fluid transport



WP3 – Fracture Characterisation and Modelling

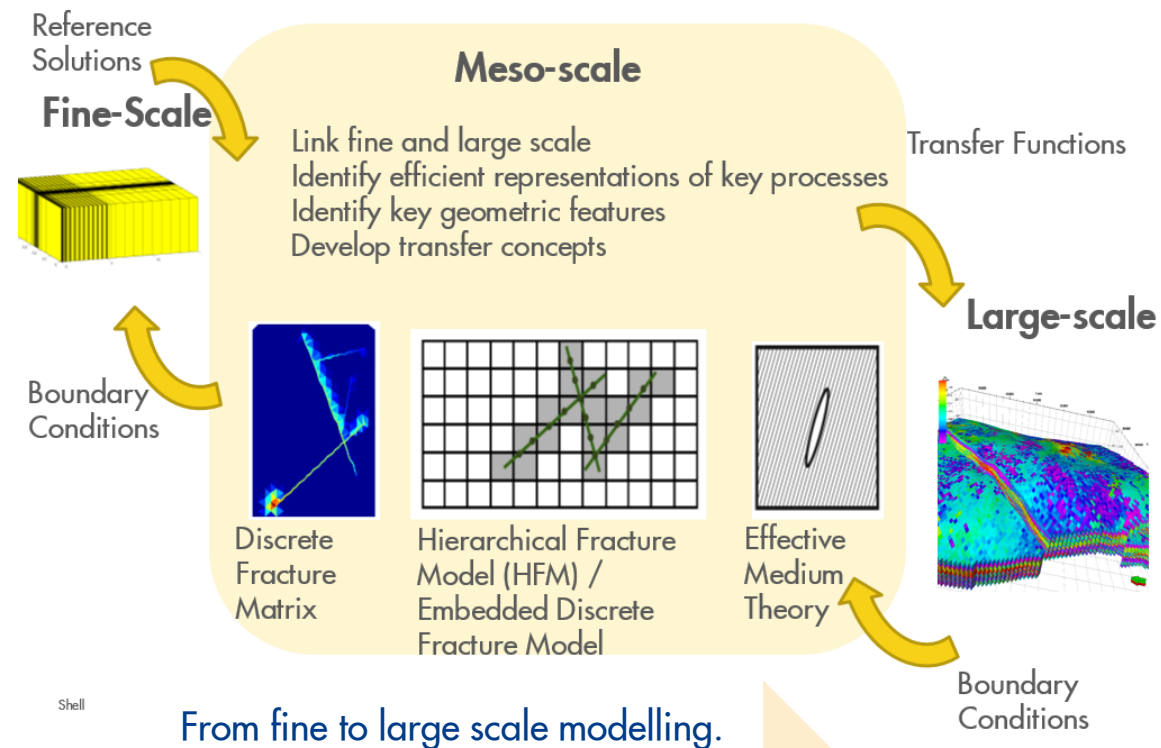
WP3 will characterise 2D/3D fracture network pattern for flow modelling. It will also perform innovative hydro-mechanical-chemical CO₂ and brine leakage modelling at fine-scale, meso-scale and large-scale. Results inform WP4 and WP5.

Objectives

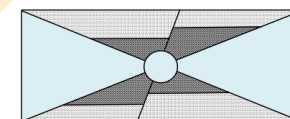
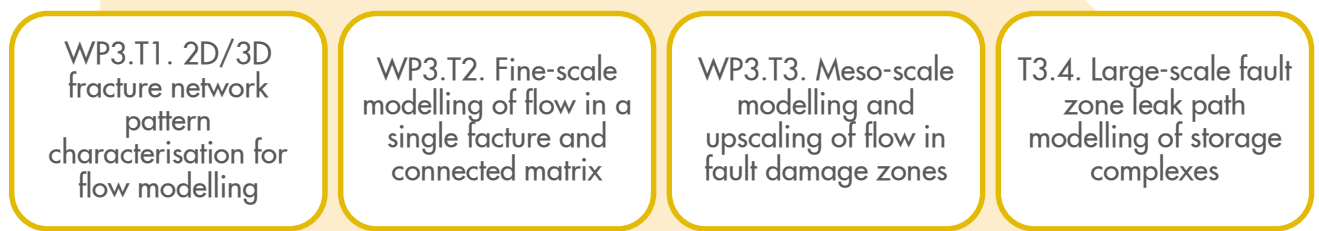
1. Develop and apply a predictive modelling workflow for realistic CO₂ and brine leakage rates along realistic fault/fracture damage zones through the primary caprock and continuing into shallower formations
2. Incorporating effects on fracture aperture of mineral dissolution/precipitation and clay swelling

Collaboration

- Shell IRD, Heriot-Watt University, University of Cambridge



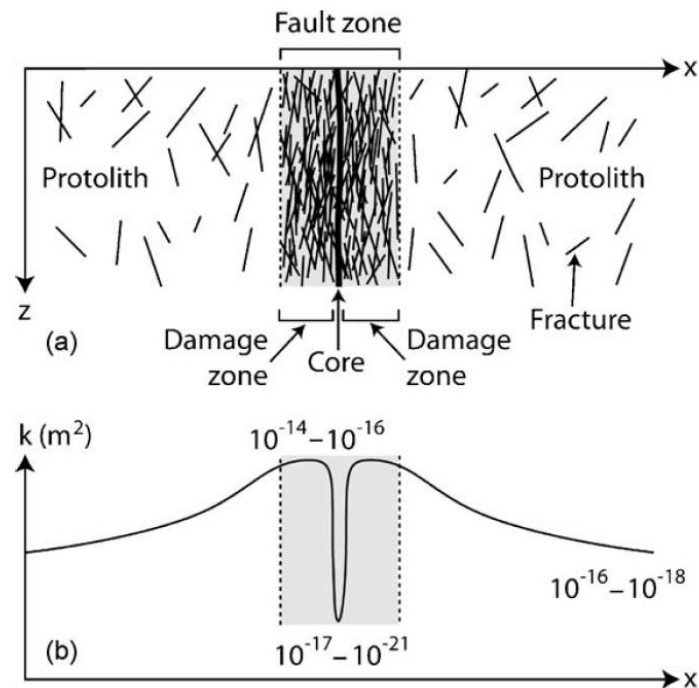
From fine to large scale modelling.



WP3 – Fracture Characterisation and Modelling

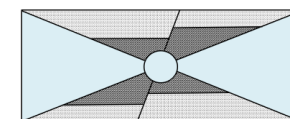
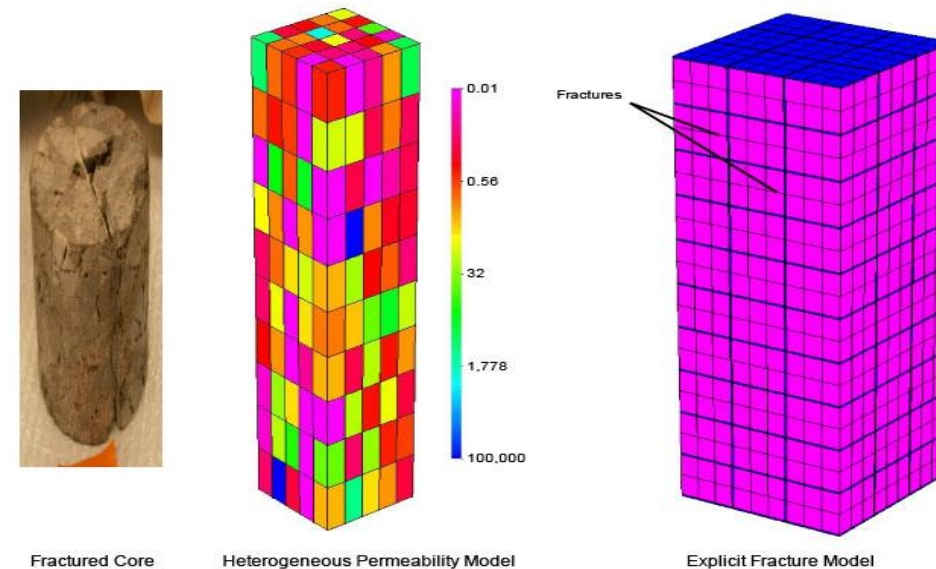
T3.1. 2D/3D fracture network pattern characterisation (HWU)

Establish database for fault attributes and map fault damage zones for flow modelling



T3.2. Fine-scale modelling of flow in a single fracture and connected matrix (HWU)

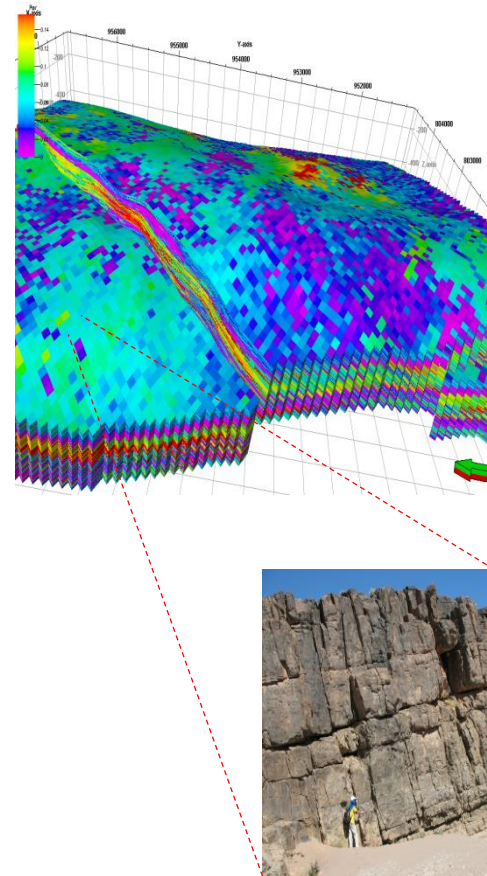
Implementation of the constitutive stress-fracture permeability relations derived from laboratory experiments into fine-scale hydro-mechanical model for single fractures considering RTM and clay swelling



WP3 – Fracture Characterisation and Modelling

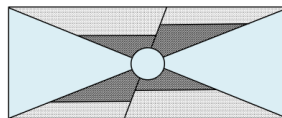
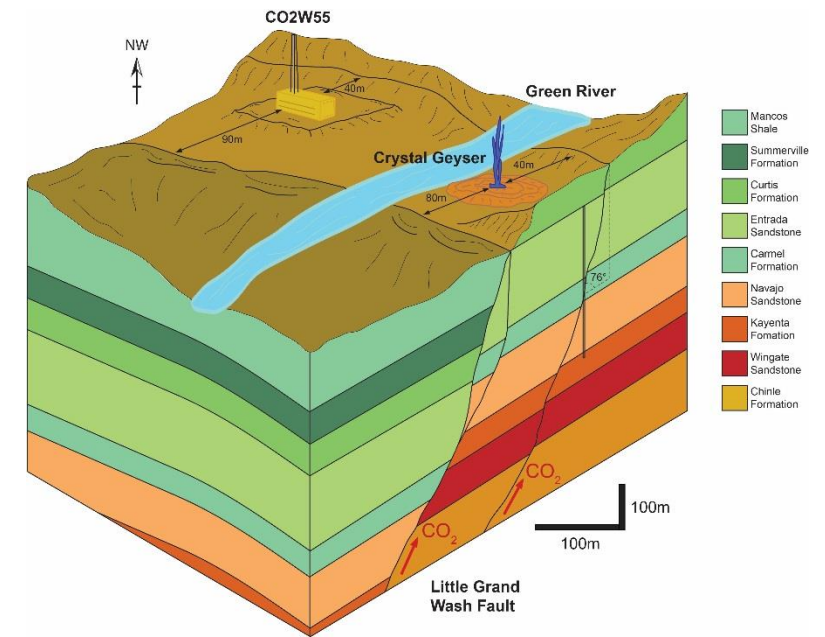
T3.3. Meso-scale modelling and upscaling of flow in fault damage zones (HWU)

Meshing and modelling of fault damage zones and fracture networks to simulate flow of CO₂ through fractured and faulted caprock



T3.4. Large-scale fault zone leak path modelling of storage complexes (Shell)

Modelling of CO₂ and brine flow in fault/fracture systems in storage complexes



WP4 – Containment Monitoring for Caprock Integrity

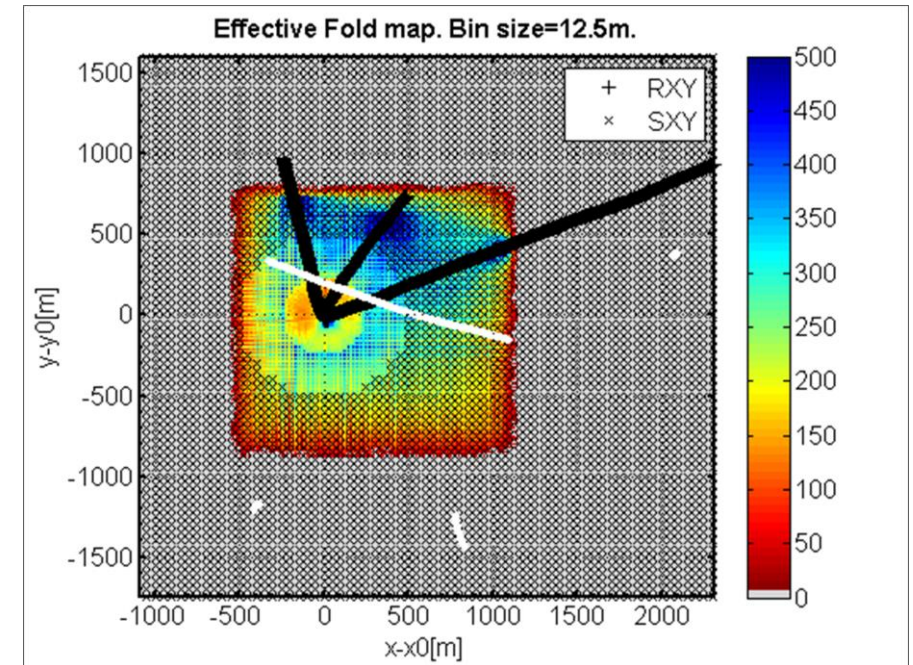
WP4 will select cost-efficient and effective caprock monitoring technologies which will be incorporated as active safeguards in bowties and quantitative risk assessment models (WP5).

Objectives

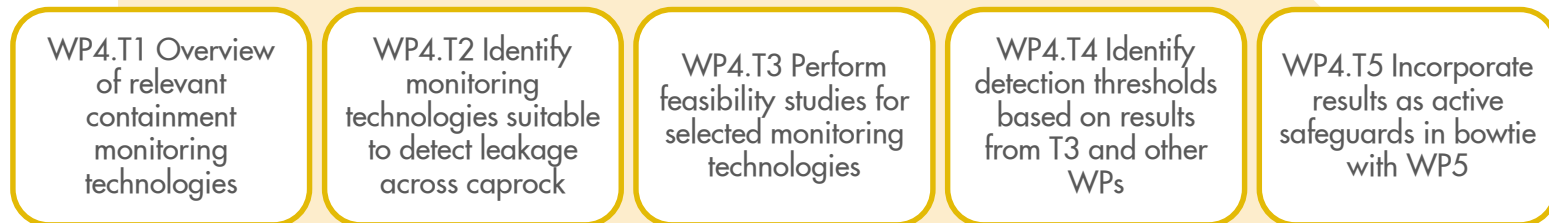
1. Identify which containment monitoring technologies can act as effective and efficient barriers to the risks posed by CO₂ leakage along fractures of the caprock
2. Give a comprehensive overview of selected containment monitoring technologies with their respective detection threshold ranges for a number of investigated leakage path scenarios

Collaboration

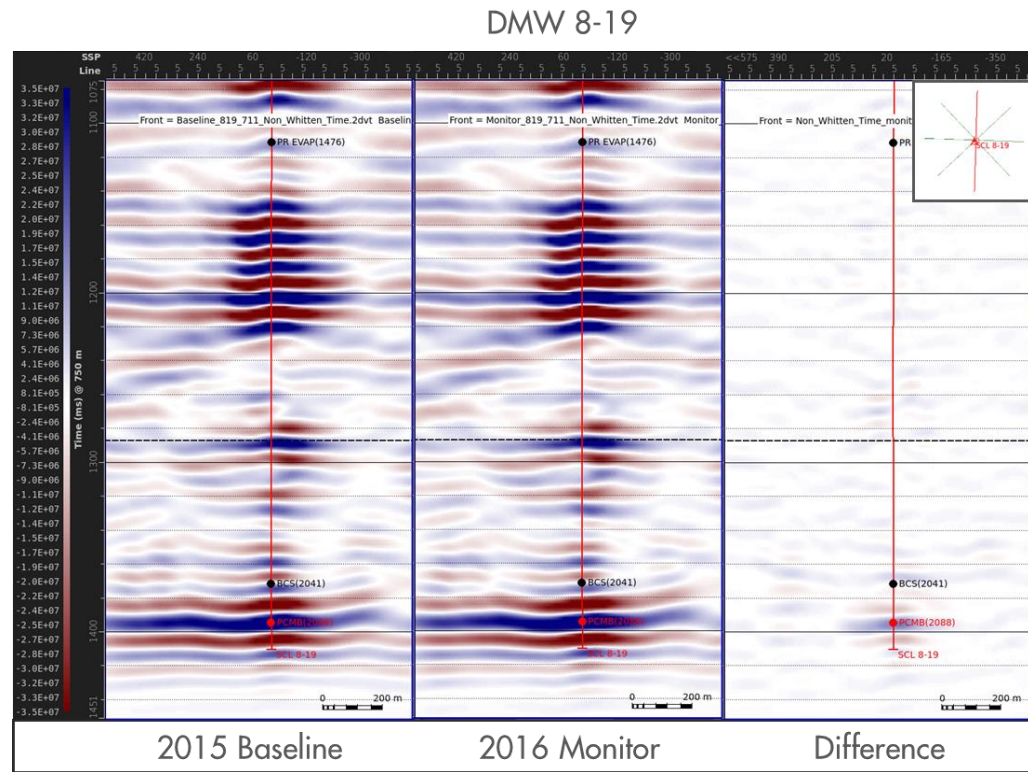
- Shell IRD, Risktec, CaMI.FRS, Otway Project



Goldeneye DAS VSP feasibility study.



WP4 – Containment Monitoring for Caprock Integrity



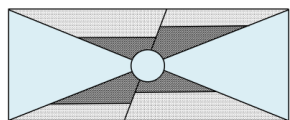
Example of a lower cost containment monitoring technology: In well Distributed Acoustic Sensing (DAS) Vertical Seismic Profiling (VSP). Baseline, Monitor and difference for well IW 8-19 at the Quest CO₂ Storage site.



CaMI.FRS (Containment and Monitoring Institute Field Research Station) showing injection and monitoring wells.

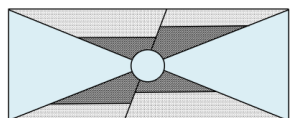


CaMI.FRS Program Director Don Lawton showing control panel for CO₂ injection.



Tasks

- **T4.1: Overview of relevant containment monitoring technologies**
 - Draw on literature and the internal experience from the MMV of the Quest and Peterhead CCS projects. Overview ready for bowtie workshop
- **T4.2: Identify monitoring technologies suitable to detect leakage across caprock**
 - Reduce the list of potential technologies based on leakage scenarios, the potential to perform the required monitoring tasks (resolution, space, time), technology readiness, innovation, cost
- **T4.3. Perform feasibility studies for selected monitoring technologies**
 - Shortlisted CMTs will then undergo individual feasibility studies considering a number of different leakage scenarios across the caprock
- **T4.4. Compare Modelled Fracture Flow Rates and Expected Monitoring Performance**
 - Compare realistic leakage rates from WP2&3 with monitoring sensitivities to determine detection threshold ranges
- **T4.5. Incorporate results as active safeguards in bowtie with WP5**
 - Incorporate safeguards in project risk assessment



WP5 – Qualitative and Quantitative Risk Assessment

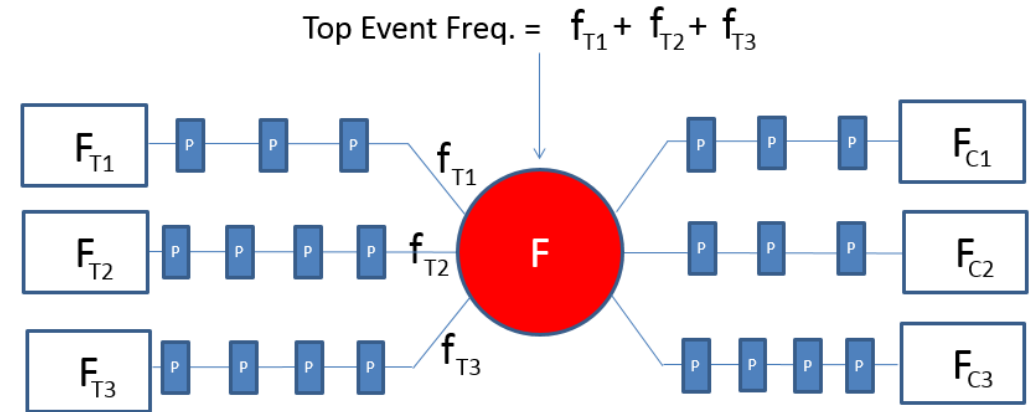
WP5 will integrate learnings from DETECT into qualitative and quantitative bowties to serve as an industry guideline for risk assessment of CO₂ leakage across fractures in the caprock.

Objectives

1. To develop bowtie diagrams depicting the natural pathways for CO₂ release from subsurface storage and the measures in place to prevent/mitigate the risk
2. To develop a quantitative risk assessment model aligned to the bowtie, using output from the other WPs to determine prevention/mitigation measure effectiveness
3. To calculate relative risks of CO₂ leaking through caprock, enabling the model to be used for future site comparison/screening purposes

Collaboration

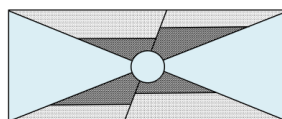
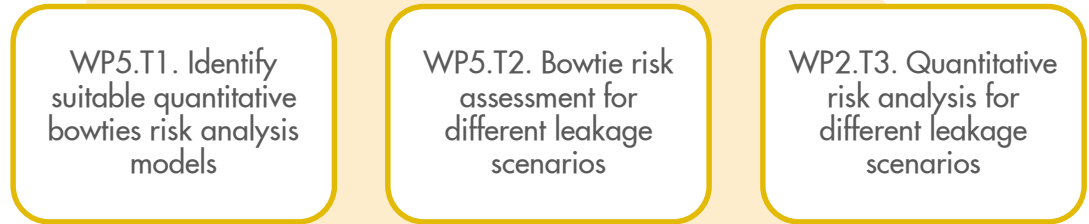
- Risktec (TÜV Rheinland Group), Shell IRD (build on learnings from Peterhead and Quest CCS projects)



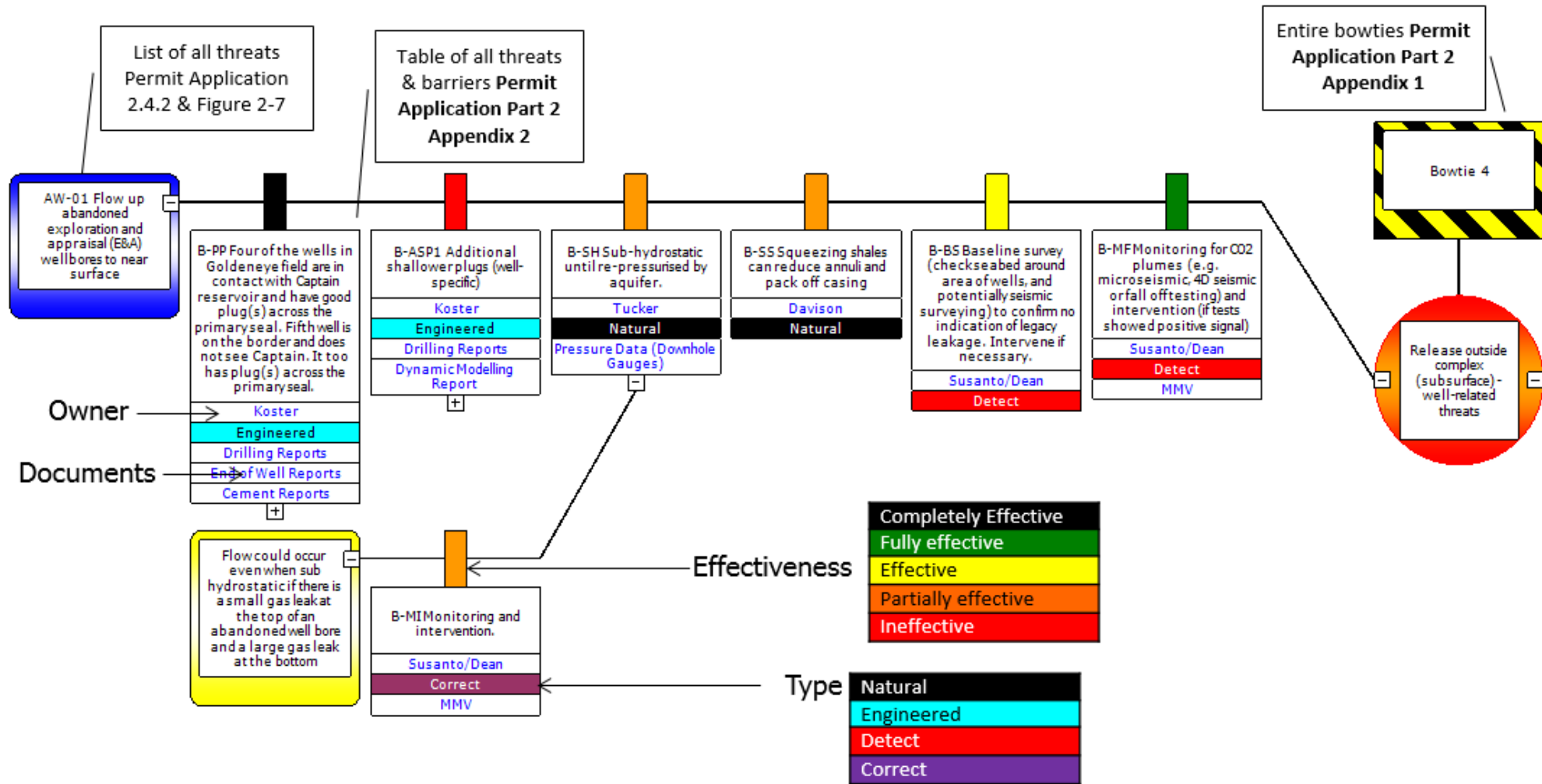
F_{T1}, F_{T2}, F_{T3} – Threat Frequency
 f_{T1}, f_{T2}, f_{T3} – Threat Branch Frequency
 F_{C1}, F_{C2}, F_{C3} – Consequence Branch Frequency
 P – Probability of Failure



An example of a semi-quantitative risk analysis model.



WP5 – Qualitative and Quantitative Risk Assessment



Example subset of the bowtie done for the Peterhead CCS project. In DETECT, we will develop new quantitative methods based on the bowtie framework to assess risks related to leakage along fractures/faults in the caprock.

