Synergetic Utilisation of CO_2 storage Coupled with geothermal EnErgy Deployment – SUCCEED

"ACT – Accelerating CCS Technologies" Project No: 294766

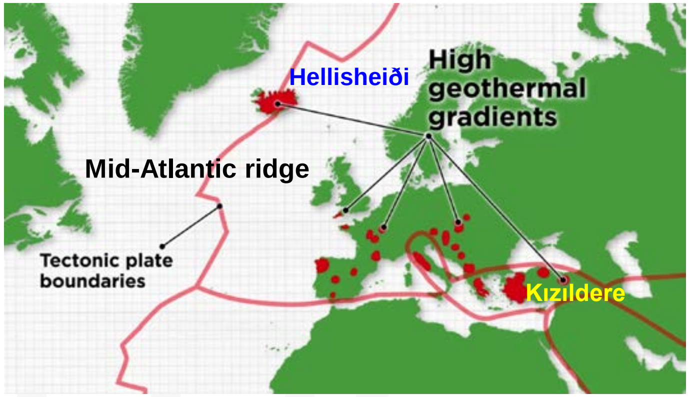
01 September 2019 – 31 August 2022

Middle East Technical University

The Project

An industrial CO_2 storage project utilising the existing wells and infrastructure at producing geothermal fields in Kızıldere (Turkey) and the CarbFix technology site Hellisheiði (Iceland).

The objectives of the project include:



i) to research and demonstrate the feasibility of utilising produced CO_2 for re-injection into a carbonate reservoir to maintain reservoir pressure and improve geothermal performance, while also storing the CO_2,

ii) to develop further, test and demonstrate innovative monitoring technologies applicable in all CO_2 storage field sites:
   a. the new higher signal-to-noise ratio Distributed fibre-optic Acoustic Sensing systems iDAS and Carina®
   b. the new permanent and highly repeatable and environmentally friendly seismic monitoring EM-vibrators

to provide semi-continuous seismic monitoring capability at HPHT environments,

iii) to investigate rock-fluid interactions under simulated HPHT conditions in the laboratory and determine geochemical, geomechanical and geophysical response of the reservoir rocks to supercritical CO_2,

iv) to model and investigate performance of injected CO_2 in the reservoir

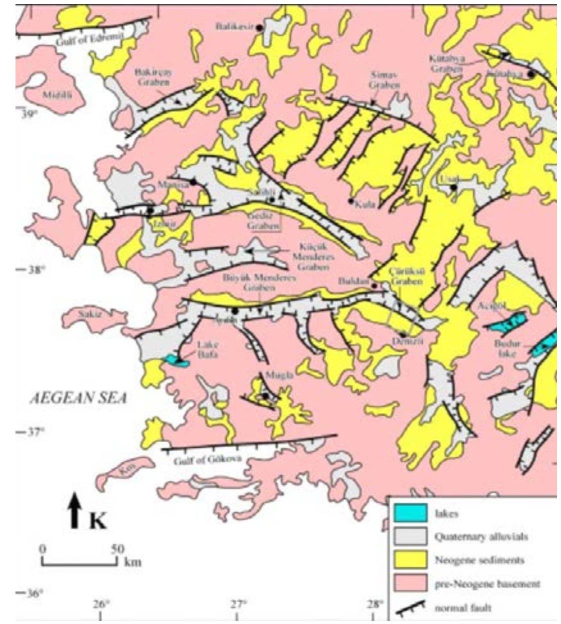
v) to develop reliable technoeconomic and life cycle environmental impact assessment methodologies for CO_2 storage in geothermal projects

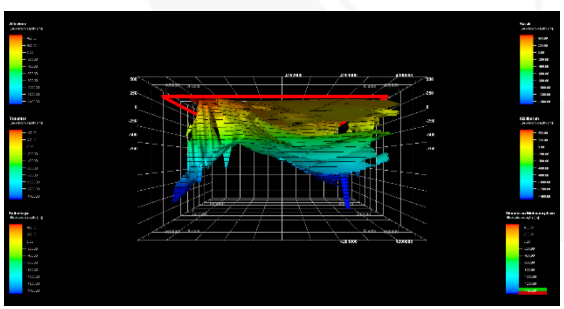
SUCCEED

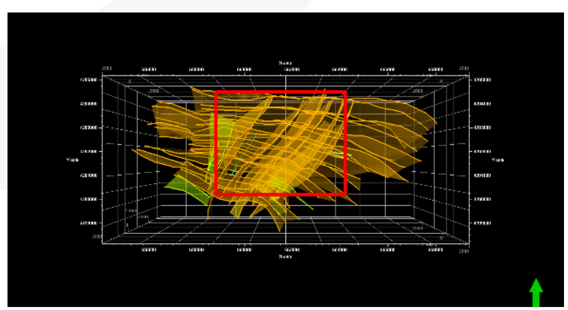
Two Geothermal Field Sites

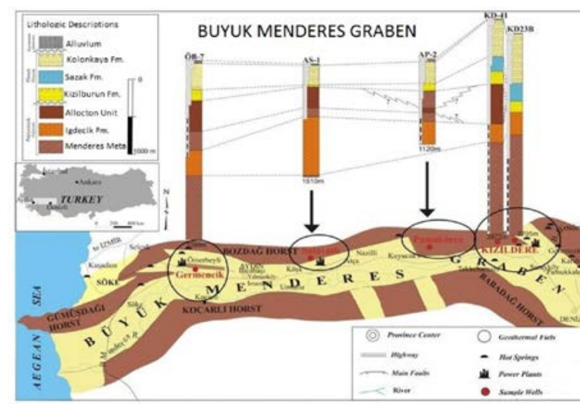
Kızıldere site operated by Zorlu Energy:

- 260 MWe installed capacity
- 2,000 – 3,500 m reservoir depth, 220 – 245 ^{o}C temperature in the carbonate reservoir
- Currently producing approximately 7,000 tonnes/hr geothermal fluid from 41 wells and reinjecting 5,300 tonnes/hour spent fluid back into the reservoir from 27 wells.
- Aimed at reducing CO_2 emissions while at the same time enhancing geothermal performance and storing CO_2









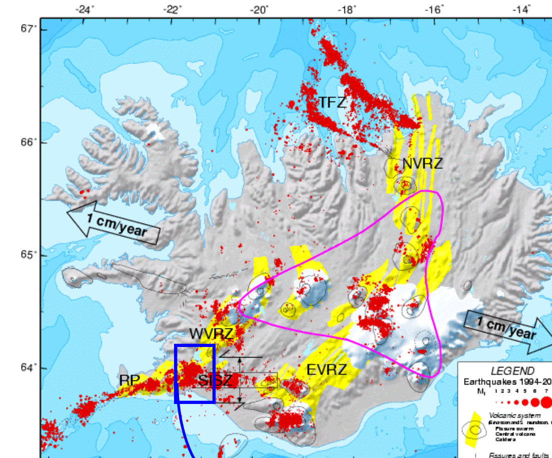
Buyuk Menderes Graben

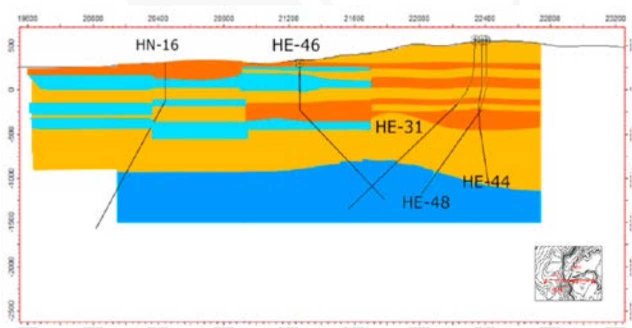
Two Geothermal Field Sites

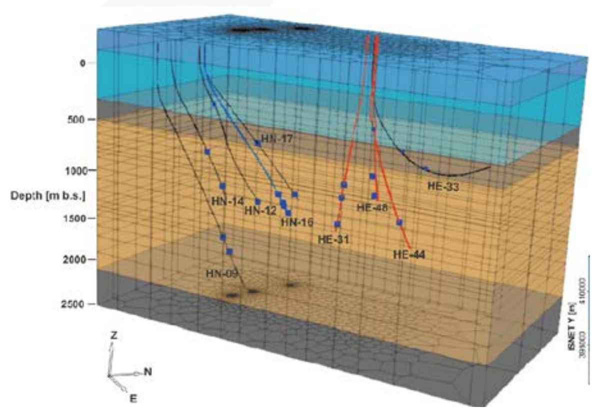
Hellisheiði site operated by Reykjavik Energy:

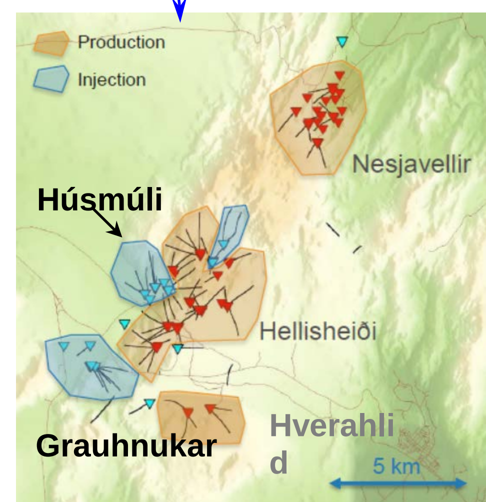
- 303 MWe installed capacity
- 700 – 2,500 m reservoir depth, 270 – 320 ^{o}C temperature in the fractured basalt reservoir
- Currently producing approximately 4,500 tonnes/hr geothermal fluid and reinjecting 3,800 tonnes/hour of the spent fluid back into the reservoir.
- CarbFix site re-injecting CO_2 dissolved in spent geothermal fluid since 2014. Planned CO_2 injection rate 12,000 tonnes per annum. Also has a seismic monitoring network

Hengil volcanic system



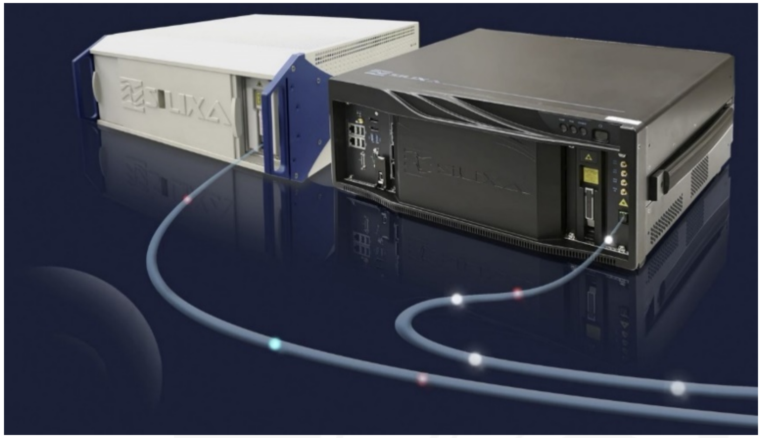






SUCCEED

DAS Technology and Carina Innovation



- Simultaneous measurement of acoustic amplitude, phase and frequency at every metre along fibre
- No cross talk
- 120 dB dynamic range

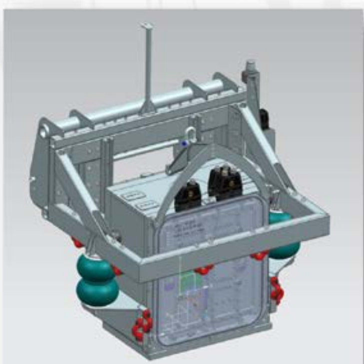
- Engineered fibre without introducing significant excess loss in the forward propagating light (Constellation fibre)
- The new iDASv3 interrogator provides enhanced measurement with standard fibre, but gives a step change improvement (more than x100) with new engineered fibre
- The SNR improvements are transformative for DAS applications

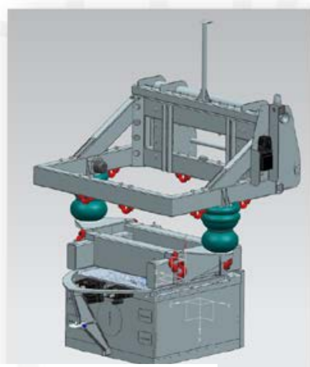
+

The Repeatable EM-Vibrator

Design

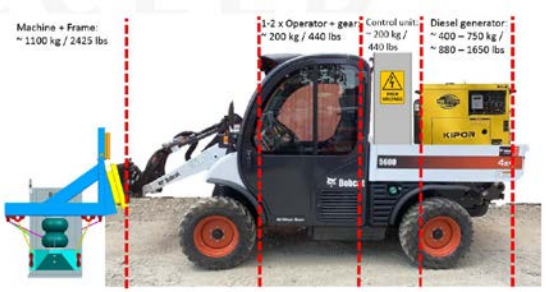
- Designs completed
- 95% of materials ordered, some delays in deliveries
- Currently testing drives, poser supply and software
- Manufacturing to start in December 2020 and complete in February 2021





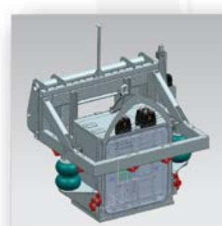
Specifications

- Total force 10kN
- P + S wave source
- Weight - 1,000kg
- Operating temperature - -32 to + 50^{o}C
- Power - 15kW generator

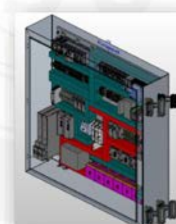


Extra weight put on vehicle = ~ 1900 kg / ~ 4188 lbs or ~ 2250 kg / ~4960 lbs (depends on gene

Field operation



80x80x40cm

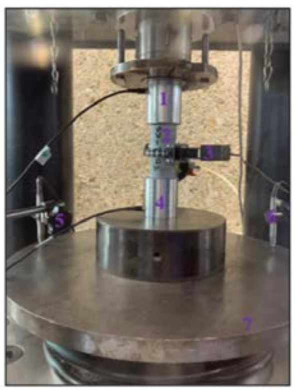


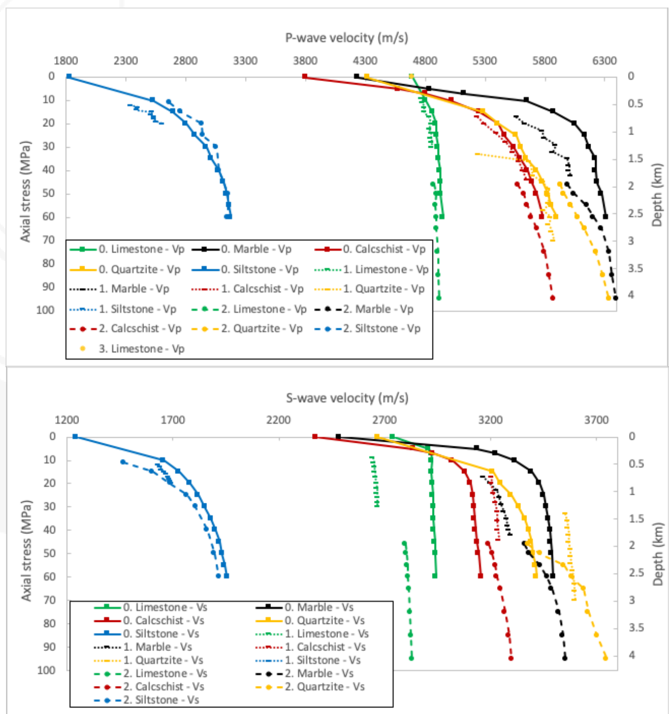
120x120x30cm

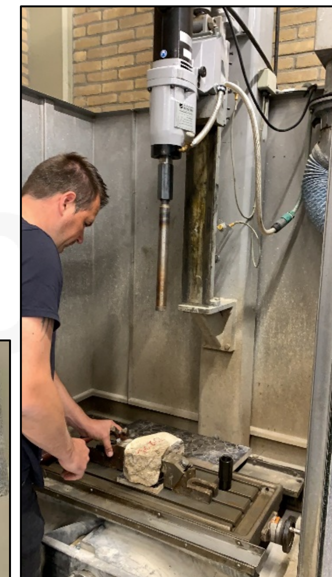
Reservoir Characterisation Studies

Seismic response characterisation at field-representative conditions

	Calcschist	Marble	Limestone	Quartzite	Siltstone
Length (mm)	61.5 ± 0.1	62.5 ± 0.1	60.8 ± 0.1	62.8 ± 0.1	62.8 ± 0.1
Diameter (mm)	29.8 ± 0.1	29.8 ± 0.1	29.8 ± 0.1	29.8 ± 0.1	29.8 ± 0.1
Porosity (%)	2.42 ± 0.03	2.15 ± 0.09	10.48 ± 0.24	2.77 ± 0.16	22.55 ± 0.01
Bulk density (g/cm³)	2.68 ± 0.01	2.69 ± 0.01	2.47 ± 0.01	2.81 ± 0.01	2.15 ± 0.01





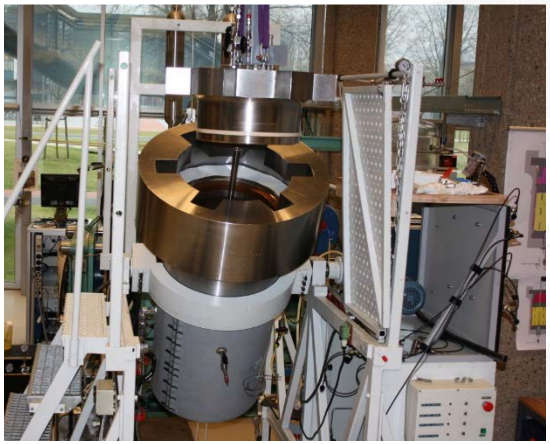


- Vp/Vs ratios
  - Limestone 1.80-1.82
  - Marble 1.76-1.83
  - Calcschist 1.63-1.74
  - Quartzite 1.48-1.63
  - Siltstone 1.43-1.54

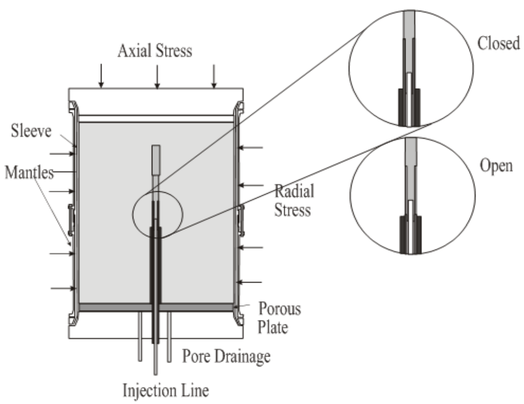
SUCCEED

Large-scale HPHT Laboratory Experiments

HPHT borehole simulator experiments on the seismic response to CO_2/brine-saturated flow



	Range	
Temperature	0-150	°C
Confining pressure	0-57 (routine pressure 40 bar)	MPa
Fluid pore pressure	0-40	MPa
Borehole fluid pressure	0-70	MPa
Axial displacement	~30	mm
Specimen diameter	400	mm
Specimen length	800	mm



400 x 800 mm

Peripherals, i.e. DAS, various transducers, etc.:

- Partly ordered, delivered and used for the uniaxial acoustic stress experiments.
- Partly not delivered/delayed or not ordered yet.

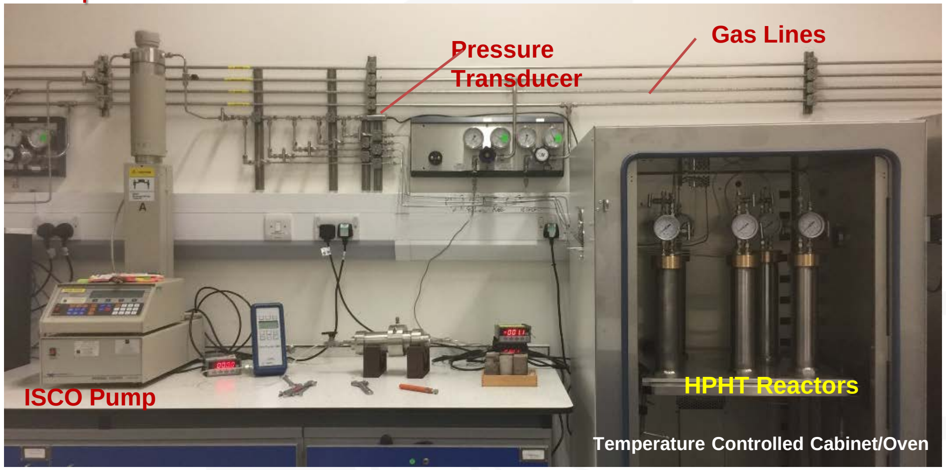
End caps with transducer configurations:

- A new P,T-resistant cap plate is under development in the laboratory.
- Manufacturing and assembly after the drawings and specs are approved (HSE).

Large-scale HPHT Laboratory Experiments

Long-term HPHT Treatment of Reservoir Rocks from Kızıldere and Hellisheiði Sites

Multiple reactor connection



HPHT Reactors

Experimental set-up

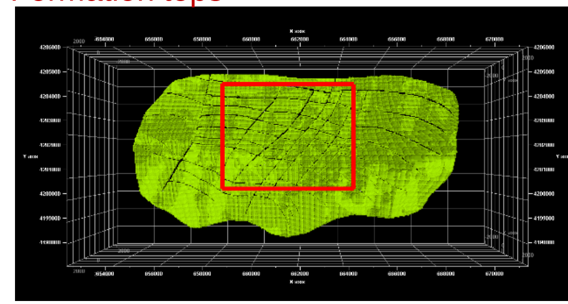
- All parts ordered and received
- Experimental set-up for the Kızıldere reservoir rocks constructed
- Being duplicated for the Hellisheiði reservoir rocks on the left hand side of the laboratory

Kızıldere Static Model Development

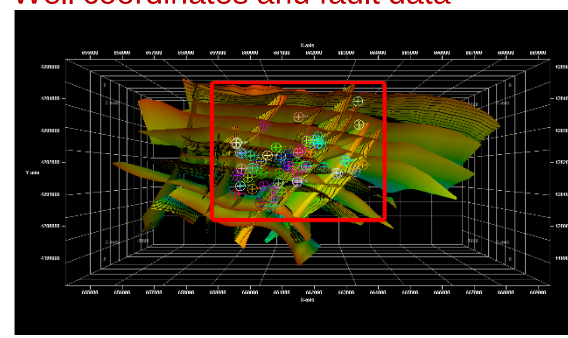
Site data available from Zorlu Energy

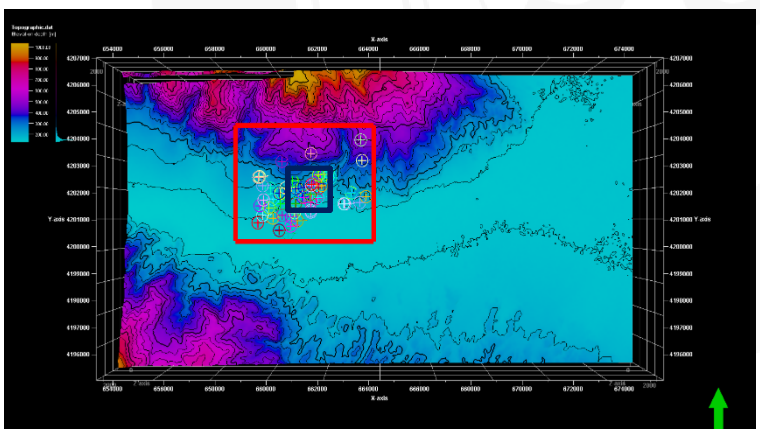
- Well Coordinates
- Stratigraphic Succession of Wells
- Fault Maps from Interpreted Seismic Surveys
- Topographical Maps
- Well Drilling Surveys
- Geochemistry of Well Fluids
- Well Tests
  - Static and Dynamic Pressure and Temperature Surveys
  - Drawdown and Build-Up Tests
  - Results of Tracer Testing
- Mud Losses

Formation tops



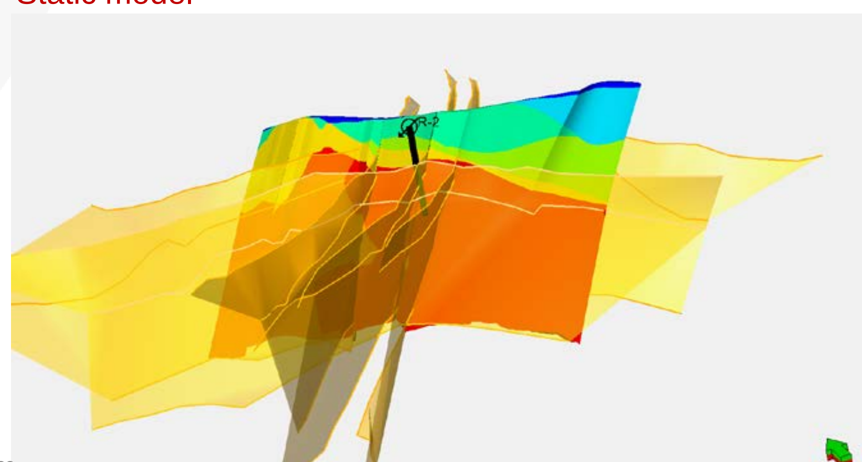
Well coordinates and fault data





Static model area – Red Rectangle
Dynamic model area – Blue Rectangle

Static model

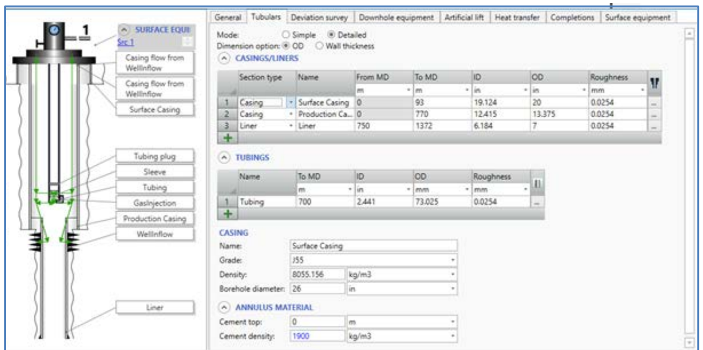


SUCCEED

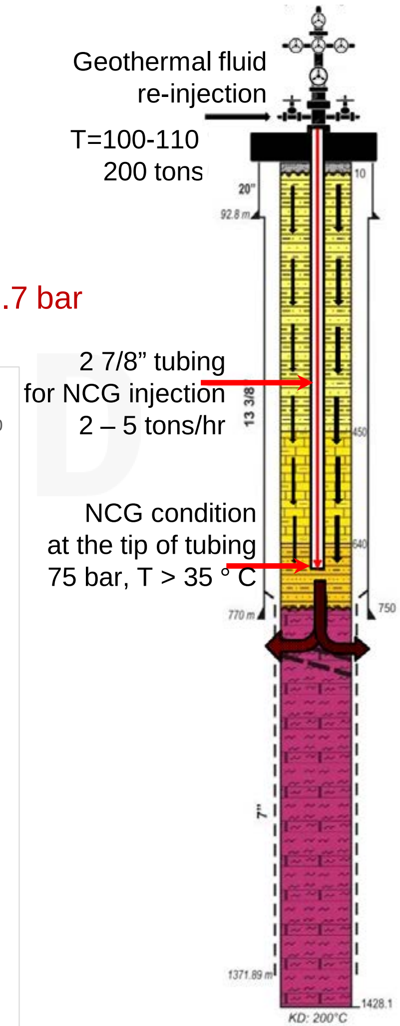
Injection Infrastructure Planning at Kızıldere

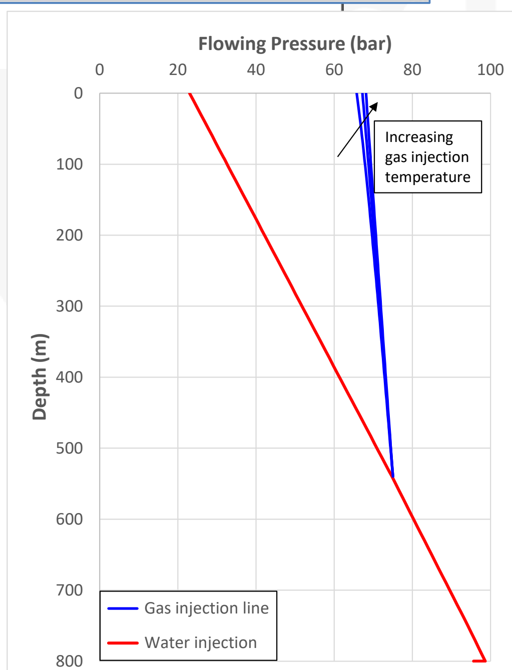
Assessment of gas injection conditions at Kızıldere

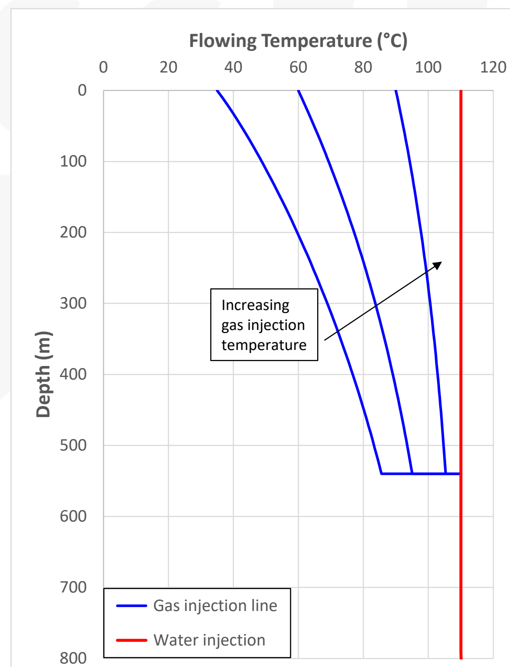
PipeSim simulations of the injection well



- Wellhead pressure: 23 - 27 bar
- Water injection rate: 200 tonnes/hr
- Gas injection rate: 2 - 5 tonnes/hr
- Tubing length required: 500-540m
- Compressor pressure required: 66.3 – 68.7 bar

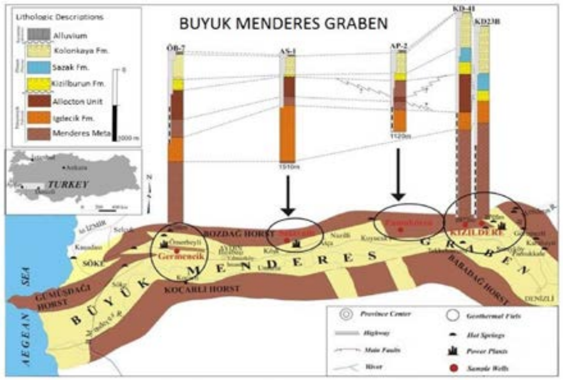






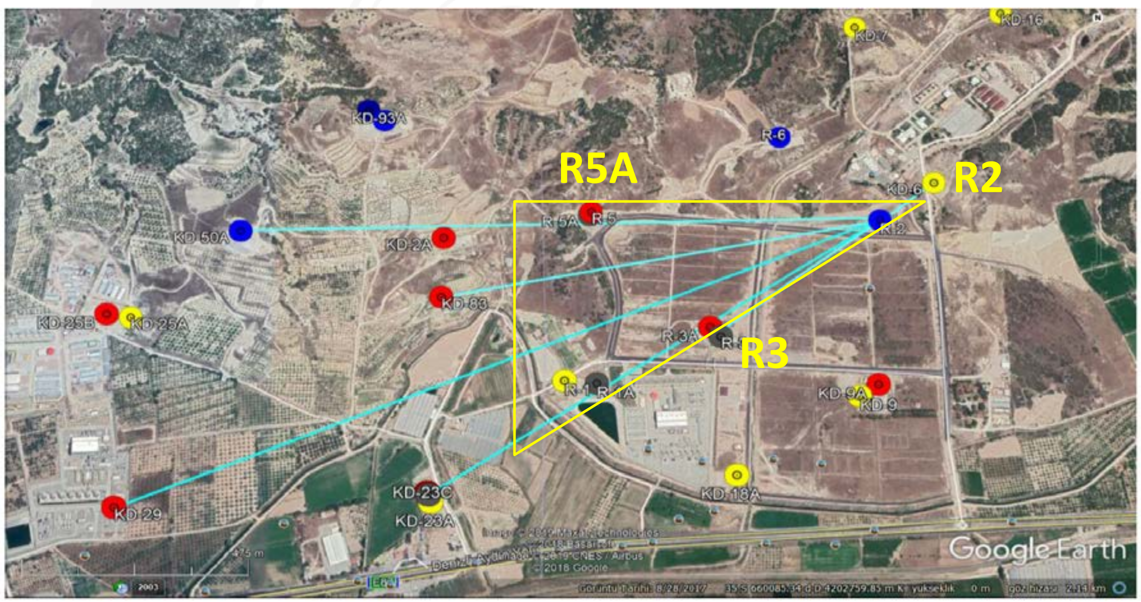
SUCCEED

Selection of Injection and Monitoring Wells at Kızıldere



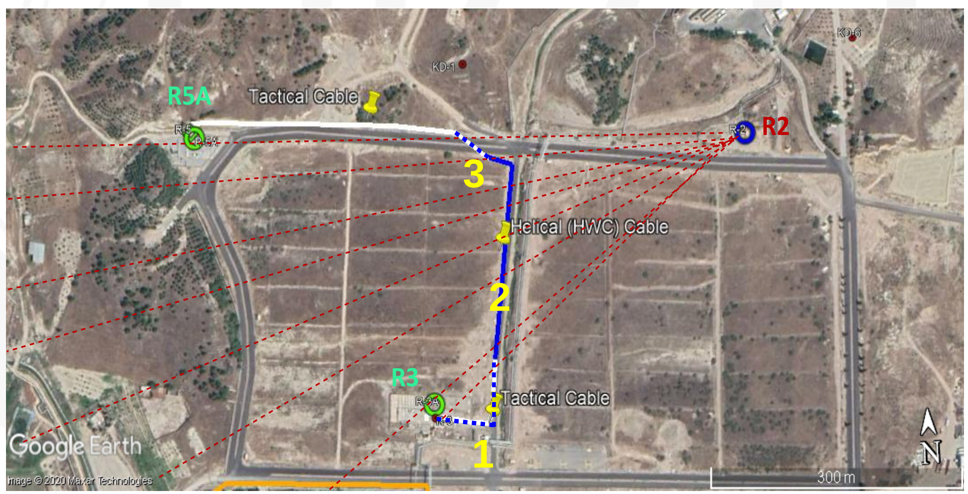
Buyuk Menderes Graben

- Work towards the selection of injection and monitoring wells at Kızıldere were completed in February 2020
- R2 was selected as the injection well and wells R3 and R5A were selected as the monitoring wells



Surface Fibre-optic Cable Route at Kızıldere

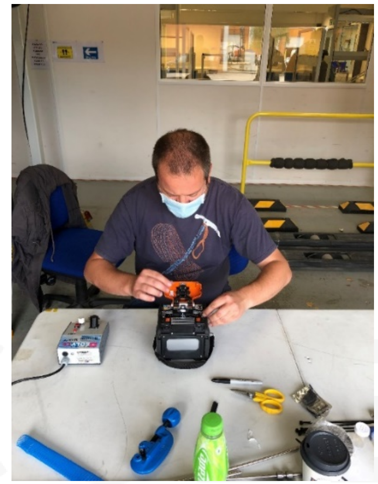
- Planning and design of FO cable installations at Kızıldere were completed in February 2020
- Downhole fibres are designed for both temperature and seismic profiling in wells R3 and R5A (260°C rating)
- Both the surface Helically Wound (HWC) and the Tactical Cable, and the engineered cables for the wells have recently arrived at Kızıldere

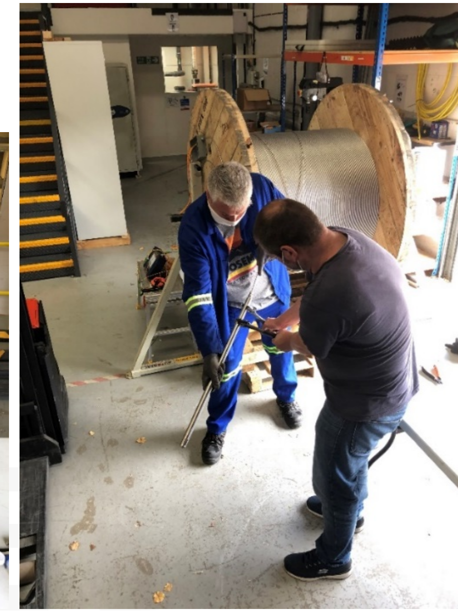


SUCCEED

Hellisheiði and Kızıldere Surface and Downhole Cables

Cable Designs and In-house Termination





Hellisheiði

- 1,500m of HWC and 350m of Tactical cable
- Junction boxes
- iDAS v2
- 54TB Data storage RAID
- GPS antenna

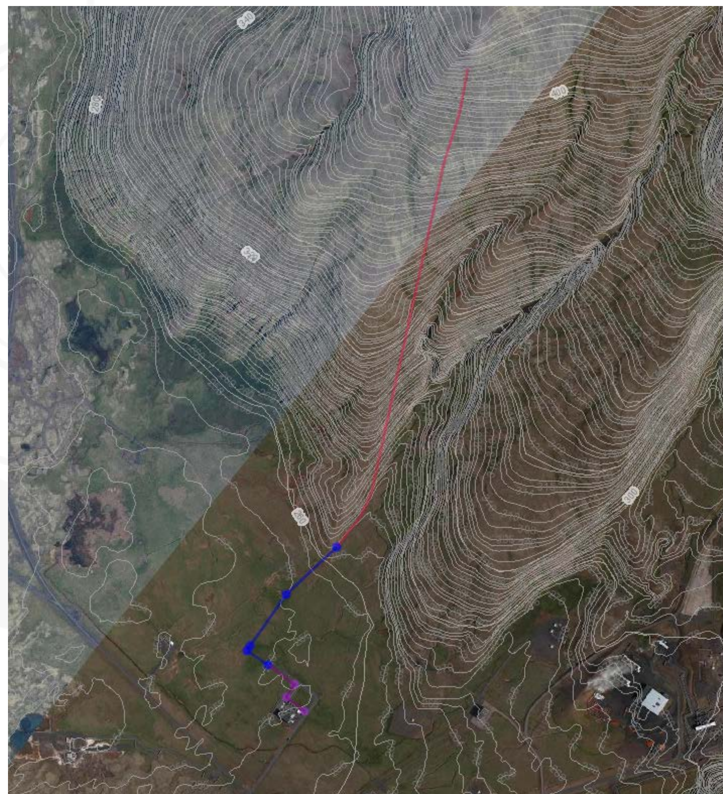
Kızıldere

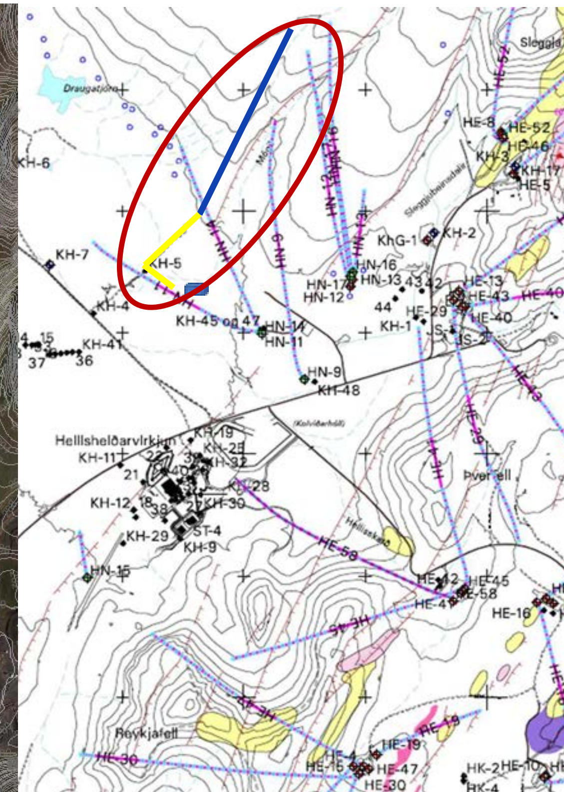
- 500m of HWC and 600m of Tactical cable
- 1,700 + 1,100m Constellation fibre
- iDAS v2 and Carina
- Junction boxes
- Data storage RAID
- GPS antenna

Planning and Design of Installations at Hellisheiði

Fibre-optic Cable Route at Hellisheiði

- Planning and design of FO cable installations at Hellisheiði started in late November 2019, revised several times, and finalised in June 2020
- Surface Helically Wound Cable (HWC) and the Tactical Cable were shipped in June for installation in July 2020



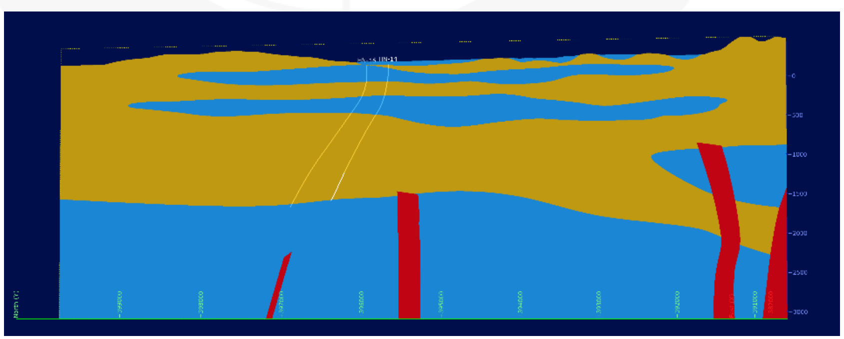


Planning and Design of Installations at Hellisheiði

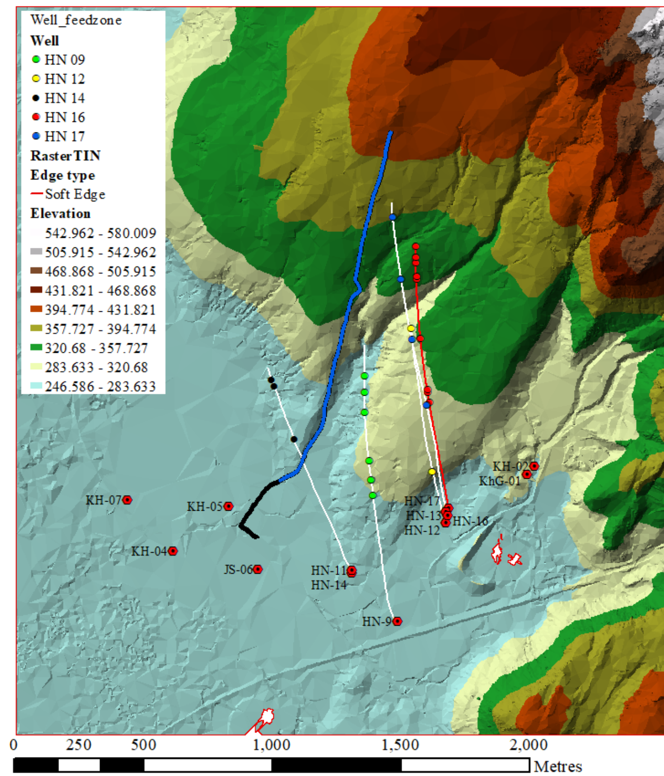
Fibre-optic cable installation at Hellisheiði

- The HWC and Tactical Cables were installed at Hellisheiði during week 20-24 July 2020 the first passive seismic survey conducted during the following 6 weeks

Final FO cable route



Section along the FO cable route



Tactical cable (FO)

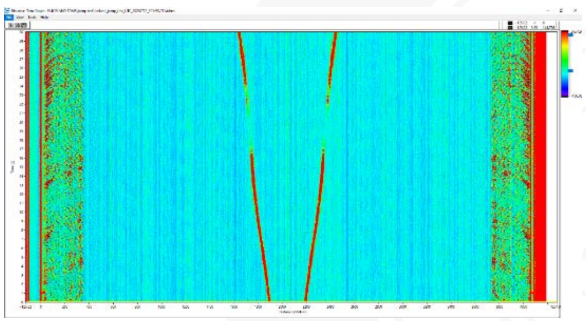
Helically Wound Fibre Optic Cable

Hellisheiði HWC Cable Installation

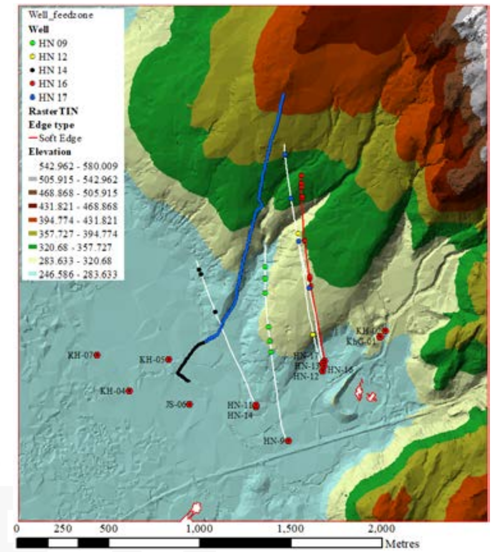
Hellisheiði – First Passive Survey

DAS Data Collection – HWC + iDAS

- 40 days recording
  - 22/07/20 - 30/08/20
- ~50 TB recorded

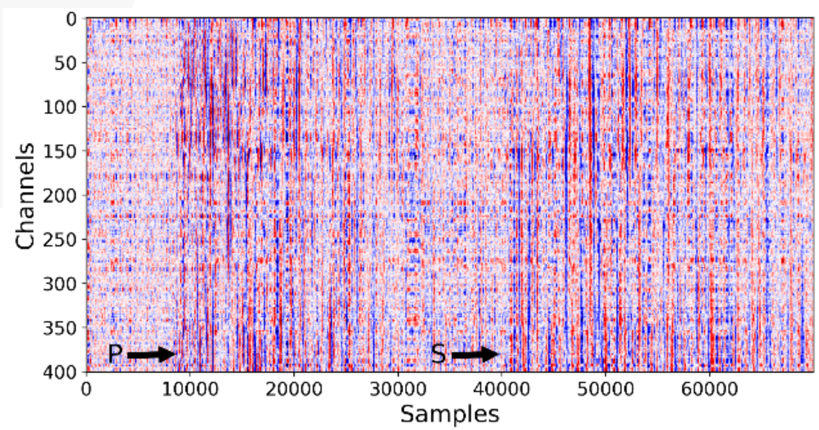


4X4 driving along cable track



Recording M3.3 Earthquake

- 23 July 2020
- Apprx 100km from site
- P- and S-waves

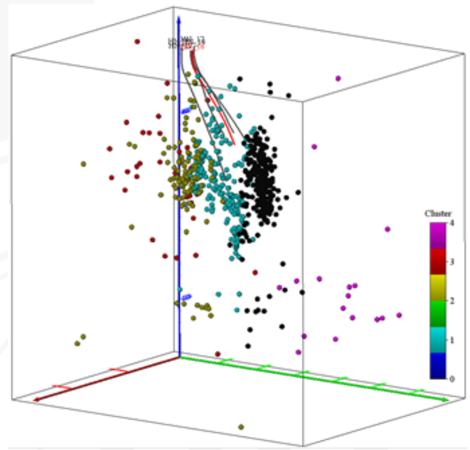


Jumping/walking over cable 1850m from the iDAS interrogator

Hellisheiði Seismic Monitoring and Interpretation

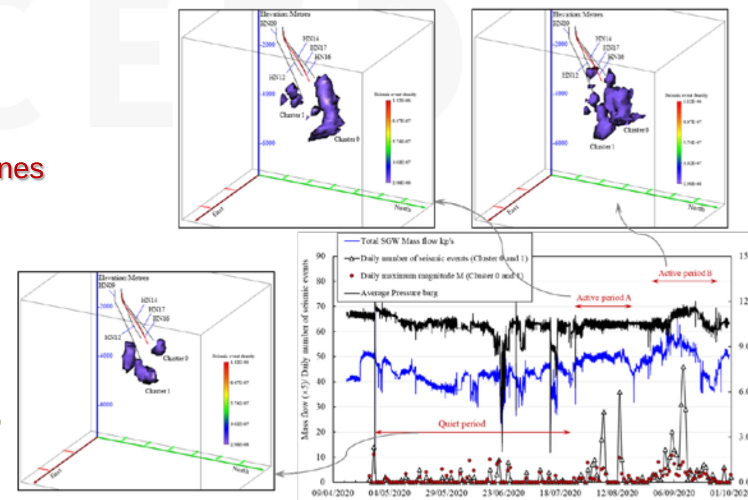
Seismic events in the Húsmúli injection region (April -October 2020)

- 4D spatial-temporal seismic information was used as input
- 5 seismic clusters were identified in the Húsmúli region
- Clusters 0 and 1 are closely related with this Injection Area



Induced Seismicity and Injection Activities

- Quiet period: HN09, HN14, HN16 and HN17
- Active period B: HN09, HN12, HN14, HN16 and HN17
- Active period A: HN16



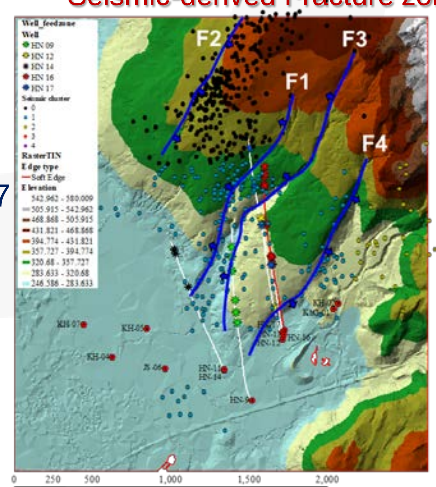
Correlating Seismicity with Fracture Zones

- Cluster 0: Fracture zones F1 and F2
- Cluster 1: Fracture zones F3 and F4

Injection Activities and Fractures

- Cluster 0: Injection wells HN16 and HN17
- Cluster 1: Injection wells HN9, HN12 and HN14

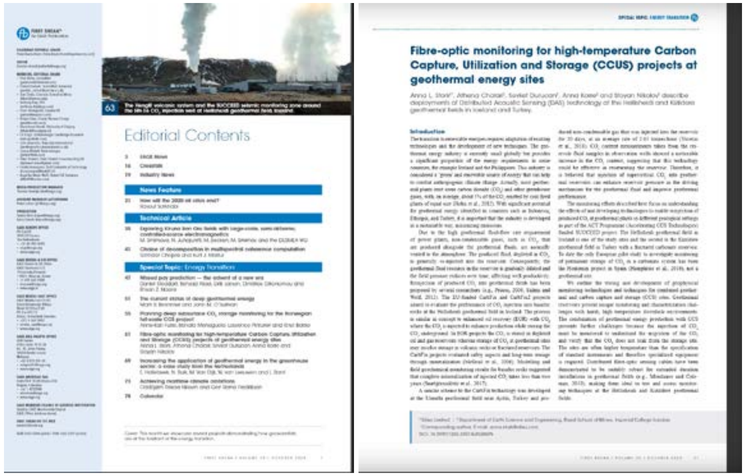
Seismic-derived Fracture zones



SUCCEED

Dissemination

- K-H Wolf, SUCCEED - CATO-3 meeting, "ACT - RVO presentations to the CATO-3 Consortium", 26 November 2019
- A.L. Stork, A. Chalari, .S Durucan, A. Korre, S. Nikolov, "Fibre-optic monitoring for high-temperature Carbon Capture, Utilisation and Storage (CCUS) projects at geothermal energy sites", First Break Energy – Energy Transition, October 2020, P.61 https://www.firstbreak.org/
- M. Janssen, J. Russel, A. Barnhoorn, D. Draganov, K-H. Wolf, S. Durucan, "Seismic Velocity Characterisation and Modelling for Synergetic Utilisation of CO_2 Storage Coupled with Geothermal Energy Extraction", 1st Geoscience & Engineering in Energy Transition Conference, 16 – 18 November 2020, Strasbourg, France
- S. Durucan , A. Korre, M. Parlaktuna, et.al., "SUCCEED: A CO_2 storage and utilisation project aimed at mitigating against greenhouse gas emissions from geothermal power production", 15th International Conference on Greenhouse Gas Control Technologies GHGT-15, 15-18 March 2021, Abu Dhabi, UAE



Editorial Contents

Fibre-optic monitoring for high-temperature Carbon Capture, Utilization and Storage (CCUS) projects at geothermal energy sites

Acknowledgements

Department for Business, Energy & Industrial Strategy

Netherlands Enterprise Agency

TÜBİTAK

Accelerating CCS Technologies

SUCCEED is funded through the ACT programme (Accelerating CCS Technologies, Horizon 2020 Project No 294766). Financial contributions made by the Department for Business, Energy & Industrial Strategy UK (BEIS), the Rijksdienst voor Ondernemend Nederland (RVO), the Scientific and Technological Research Council of Turkey (TUBITAK), and our research partners Orkuveita Reykjavíkur/Reykjavik Energy Iceland (OR) and Istituto Nazionale di Oceanografia e di Geofisica Sperimentale Italy (OGS) are gratefully acknowledged.

ZORLUENERJi

OR Reykjavík Energy

Imperial College London

Middle East Technical University

TUDelft

OGS

SILIXA

seismic mechatronics