

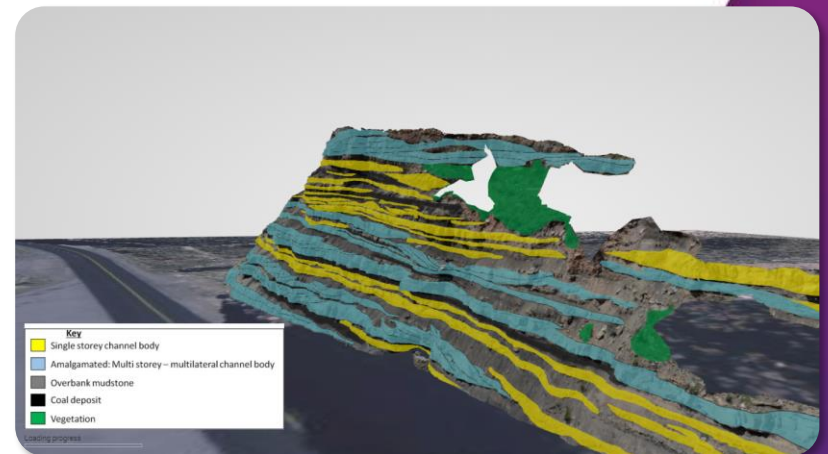
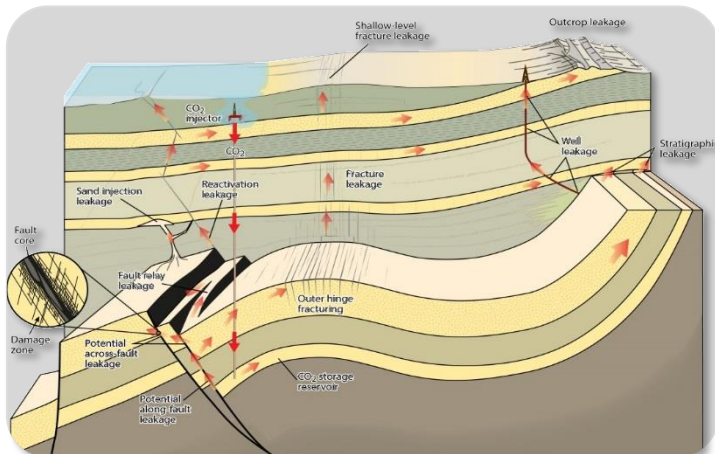
Uni Research CIPR

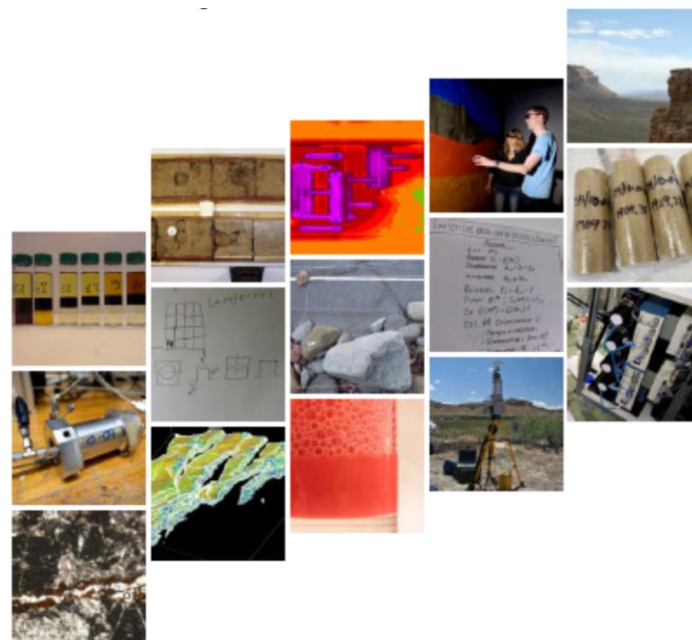
Geoscience & Virtual Outcrop Geology

Simon Buckley, Anita Torabi

Uni Research AS, P.O. Box 7810, N-5020 Bergen

Contact: simon.buckley@uni.no, anita.torabi@uni.no





Geoscience & Virtual Outcrop Geology

Uni Research CIPR overview

Uni Research AS

- Research institute owned 85% by University of Bergen, 15% Unifob Foundation
- Seven departments, eight themes
- **Merging 2018** into new institute (with IRIS, CMR, Teknova, Agder Forskning)
 - NORCE



ENERGY



ENVIRONMENT



CLIMATE



BIOTECHNOLOGY



HEALTH



SOCIETY



BIG DATA



OCEAN AND COAST

Uni Research CIPR (est. 2003)

- Enhanced oil recovery
- Reservoir simulation
- Microbiology and SCAL
- Geoscience & Virtual Outcrop Geology (VOG)

CIPR Geoscience: core expertise

Geoscience

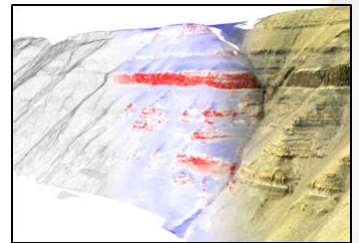
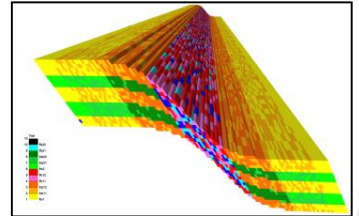
- Structural geology
- Sedimentology
- Reservoir characterisation
- Fracture networks
- Geomodelling
- Deep weathering
- Environmental geoscience
- Renewable energy
- Geothermal
- Geophysics
- Geomechanics

Virtual outcrop geology

- Geospatial science/geomatics
- Remote sensing
- Hyperspectral imaging
- Photogrammetry/lidar
- UAV/drones
- Databases & data sharing
- Graphics & visualisation
- Software development
- *Digitalisation...*

Geoscience

Themes & initiatives



Geothermal reservoirs

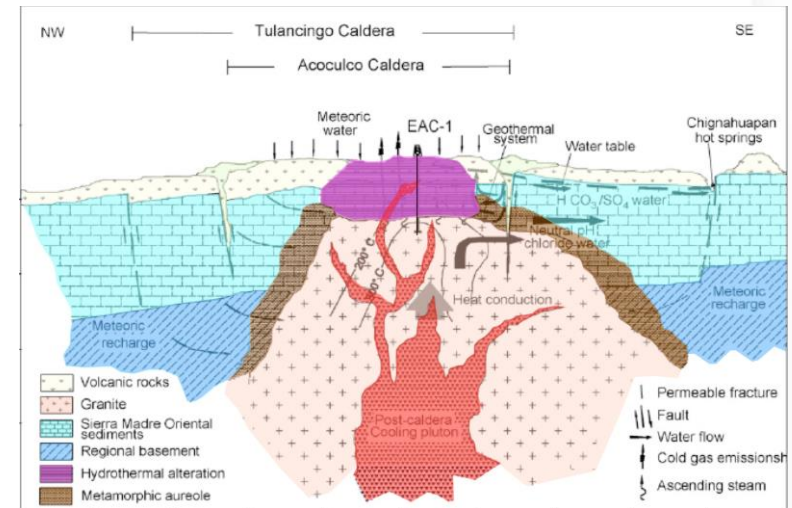
GEMex EU Horizon2020 Project

Contact: walter.wheeler@uni.no

- Horizon2020 funding 2016-2019
- Budget ~€10M to Europe
- 22 EU & 5 Mexican institutes
- Led by GFZ, Germany, WPs led by CIPR
- Superhot & Hot Dry Rock
- 300-450°C at 2km depth

Main contributions:

- Fracture frequency (flow proxy)
- Scan-lines & 3D outcrop models
- Age / Timing / Strain / Stress
- Mineralization (hyperspectral)
- Relation to larger structures
- Core analysis



GEMex: Cross section of Acoculco field, Mexico. Reservoir temperatures at Los Humeros field are >400°C at 2000m depth.

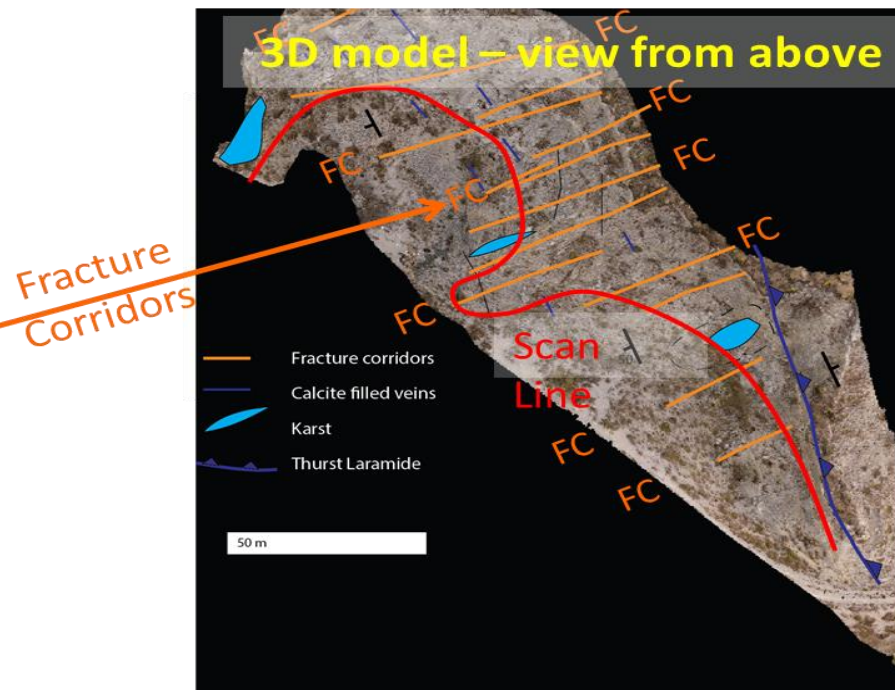
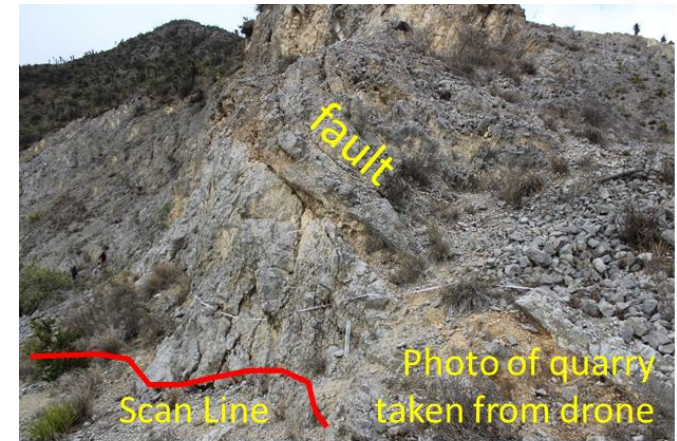
Geothermal reservoirs



Fractured Limestone Reservoir Analog

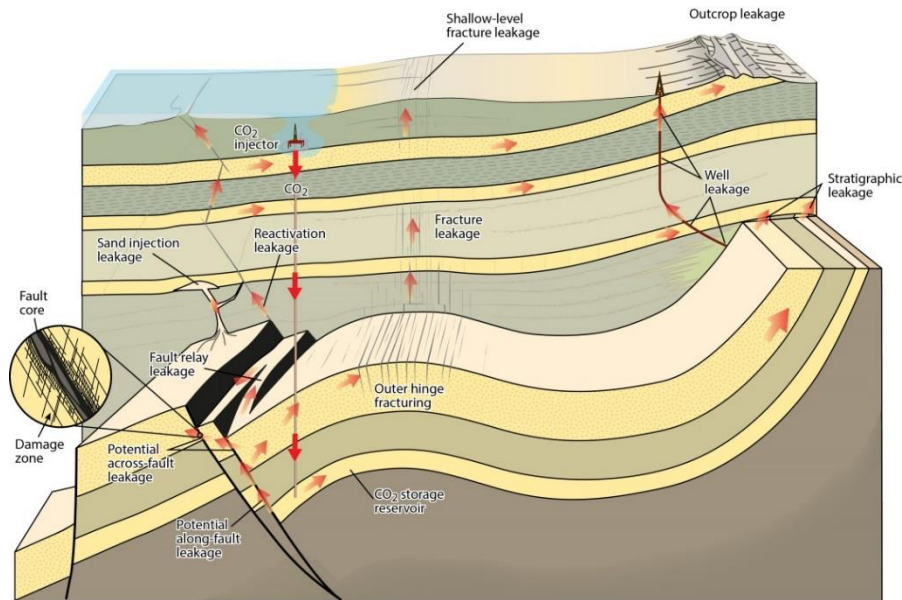
Spatial fracture data at the interwell scale

- Middle Cretaceous, thick-bedded, macrofossils
- Laramide fold and thrust structures, Mexico



Impact of fault rock properties on CO₂ storage

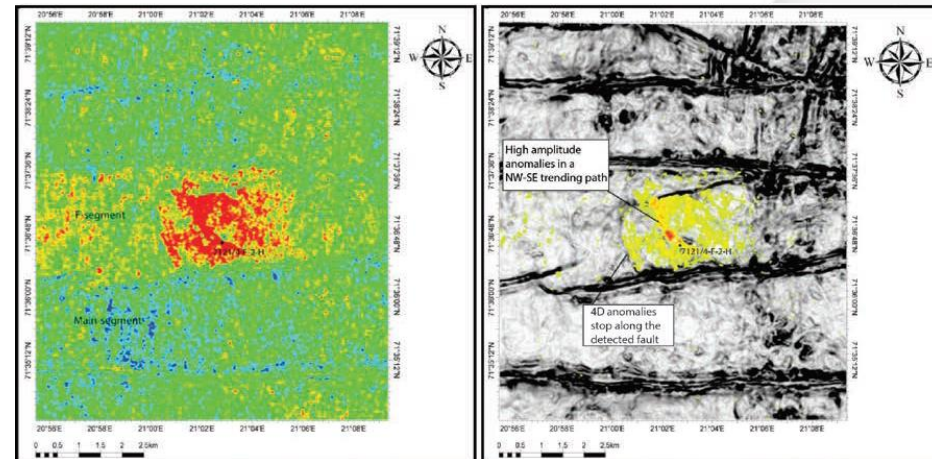
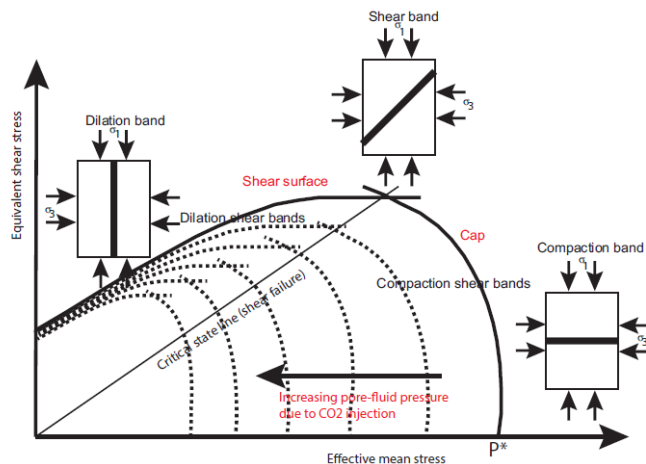
CLIMIT, Statoil funded, 10 MNOK, led by Anita Torabi, with NGI, UiO, Univ. Grenoble, Northwestern University (US)



- Outcrop studies
- Triaxial experiments
- Numerical modelling
- Seismic studies for Snøhvit

Contact: anita.torabi@uni.no

For a summary, see Torabi et al., 2015, *First Break*

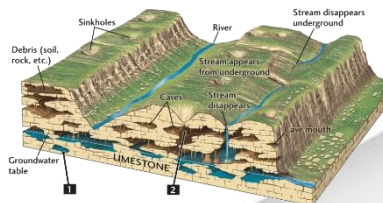
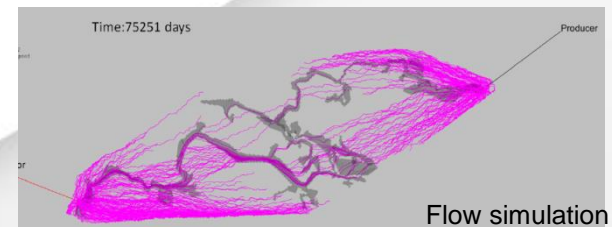
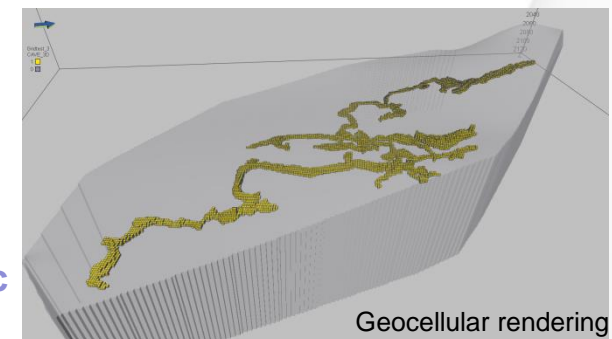
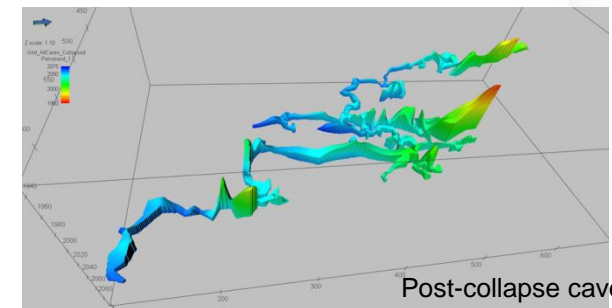
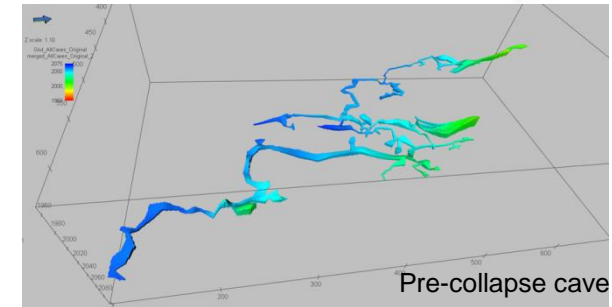


FOPAK

Petromaks2 project with NORSAR, UiB

- **Processes** controlling karst formation and the transformation of karst to paleokarst (PK) **are well understood**
- Allows **forward modelling** of mapped cave systems originating from different tectonic, stratigraphic and climatic settings
 - Build karst and **paleokarst reservoir models** and establish guidelines/tools for implementation of PK features
 - Investigate **flow performance** of different PK systems
 - Investigate seismic characteristics of PK systems using **seismic forward modelling** of PK systems

Contact: jan.tveranger@uni.no



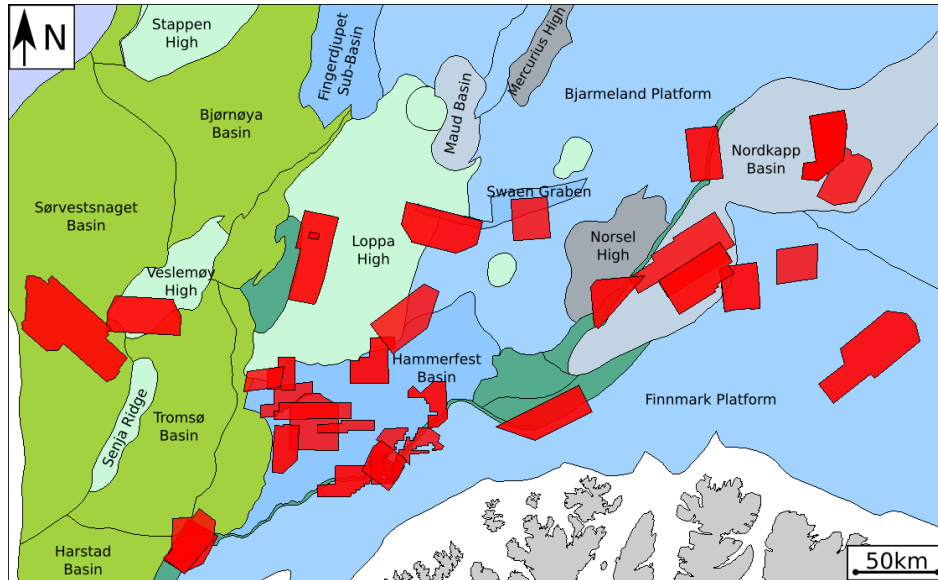
https://cetologydotorg.files.wordpress.com/2015/01/karst_topography.jpg

Barents Sea Fault Project

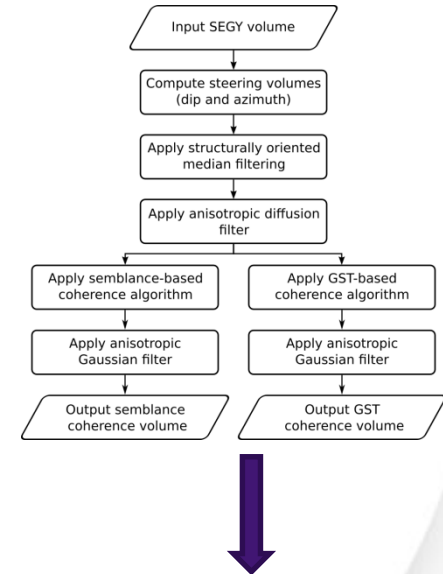
Contact: anita.torabi@uni.no

NORRUSS, Petromaks2, 5 MNOK, 2015-2018

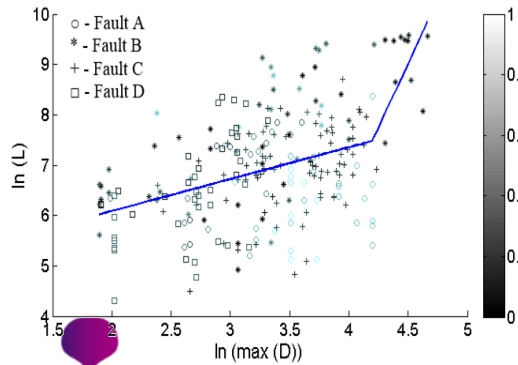
Barents Sea 3D seismic database



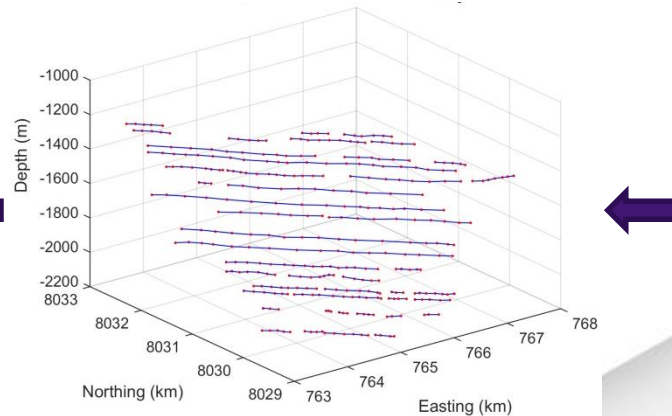
Fault imaging workflow



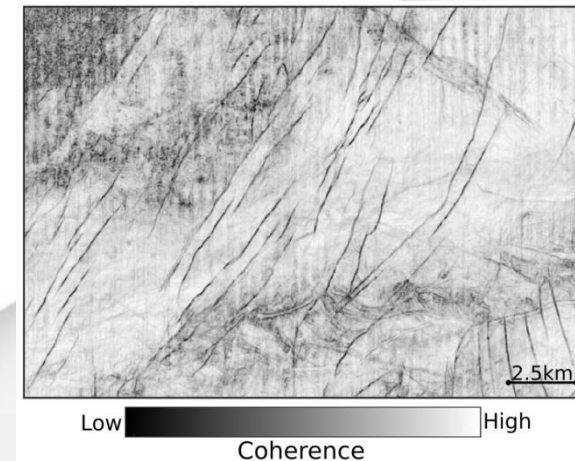
Statistical analysis of fault attributes



Fault geometric attributes

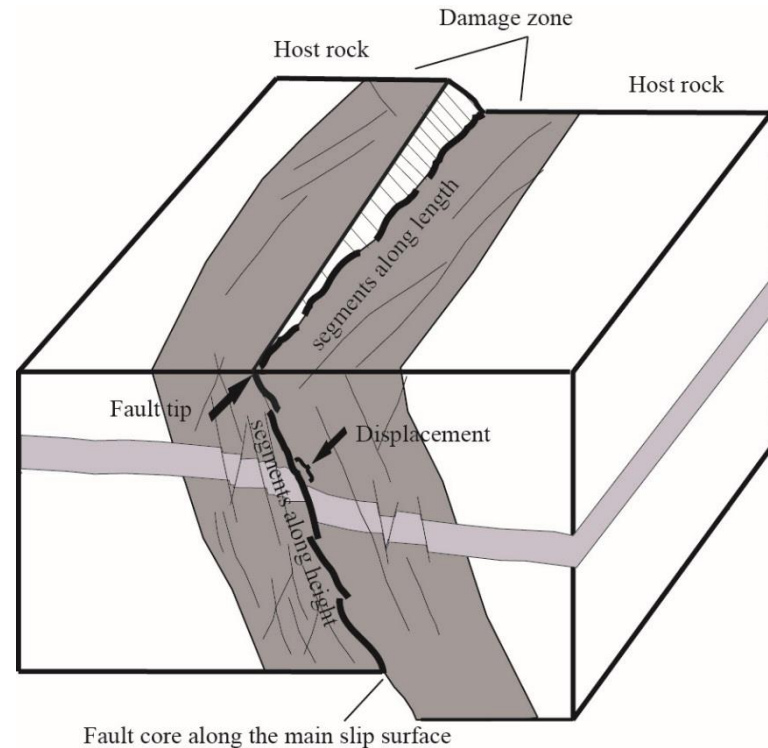


Fault seismic attribute volumes



Fault data bank

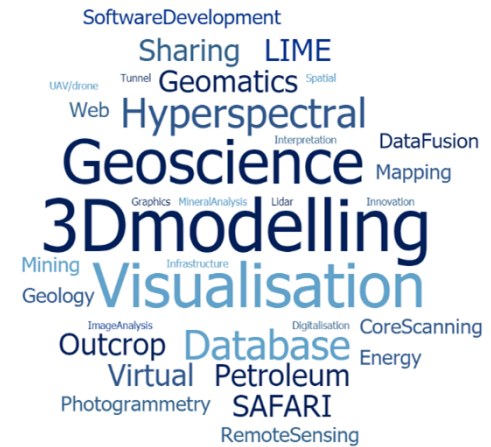
For more information, contact: anita.torabi@uni.no



- Digitised structured fault database
- Geometry, petrophysical and mechanical properties

Data from a wide range of lithology and tectonic settings, both outcrops and NCS

- Aim: reduce uncertainties in understanding
- Hydrocarbon migration pathway
- Trapping mechanism
- Sealing capacity

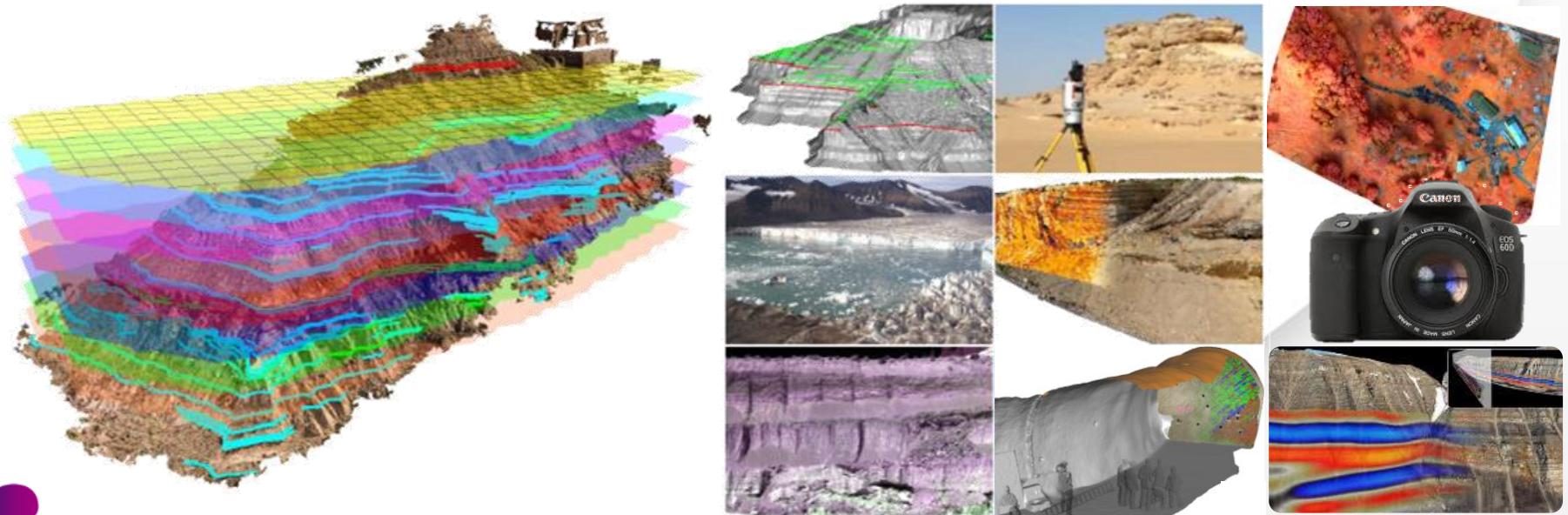


Virtual Outcrop Geology

Themes & initiatives

Virtual Outcrop Geology (VOG)

- Long-standing expertise in geospatial innovations in geoscience
 - Established for outcrop characterisation in petroleum industry in 2005
 - Remote sensing methods (e.g. laser scanning, photogrammetry, hyperspectral)
- Projects in outcrop geology, oil & gas, mining, subsurface repositories, cultural heritage, tunnelling & infrastructure



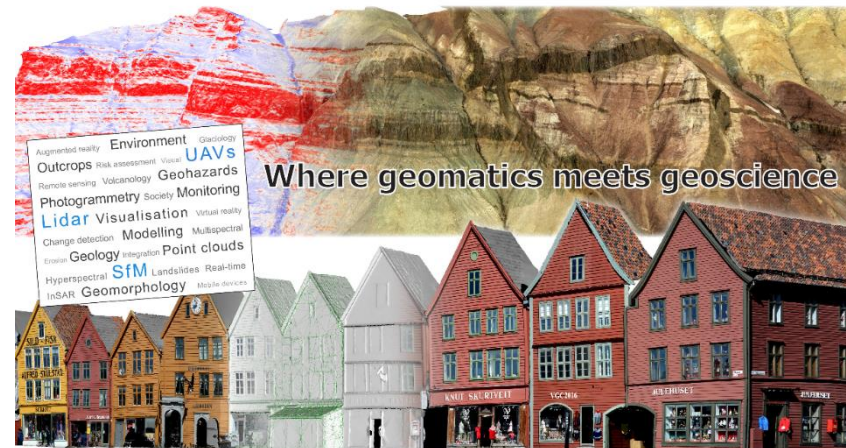
Virtual Outcrop Geology (VOG)

- Cross-disciplinary competence in geomatics, remote sensing, spectroscopy, geology, visualisation/graphics, software development
 - 7 full-time staff members
- Focus on innovations and software directed towards digital geology
 - Digital outcrop mapping
 - Data fusion & visualisation
 - Hyperspectral data analysis
 - Serving and sharing spatial data
- Convenors, 2nd Virtual Geoscience Conference, Sept 2016

2nd Virtual Geoscience Conference

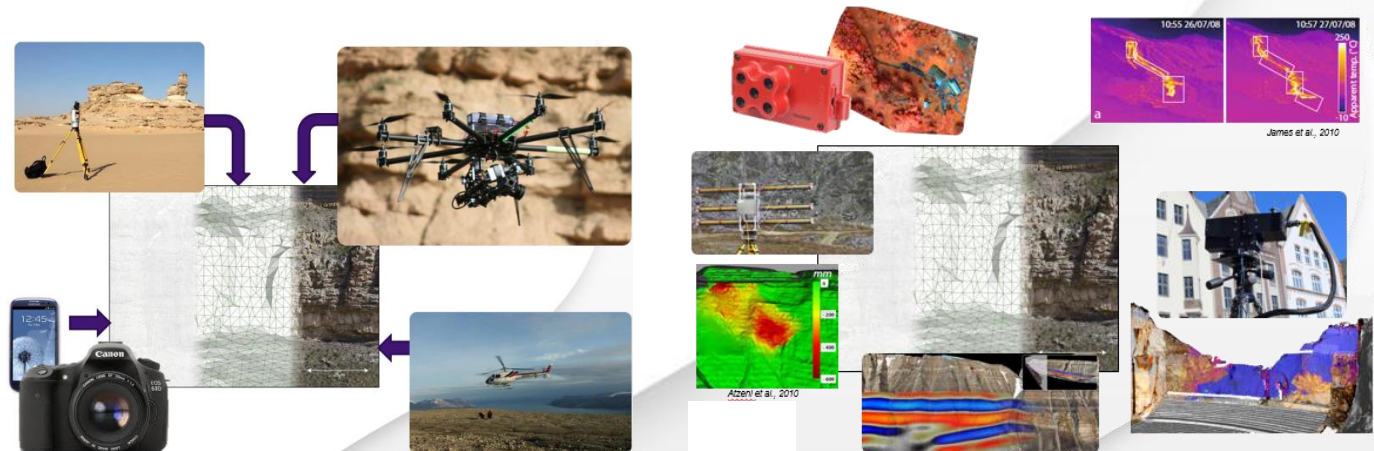


22-23 September 2016, Bergen, Norway

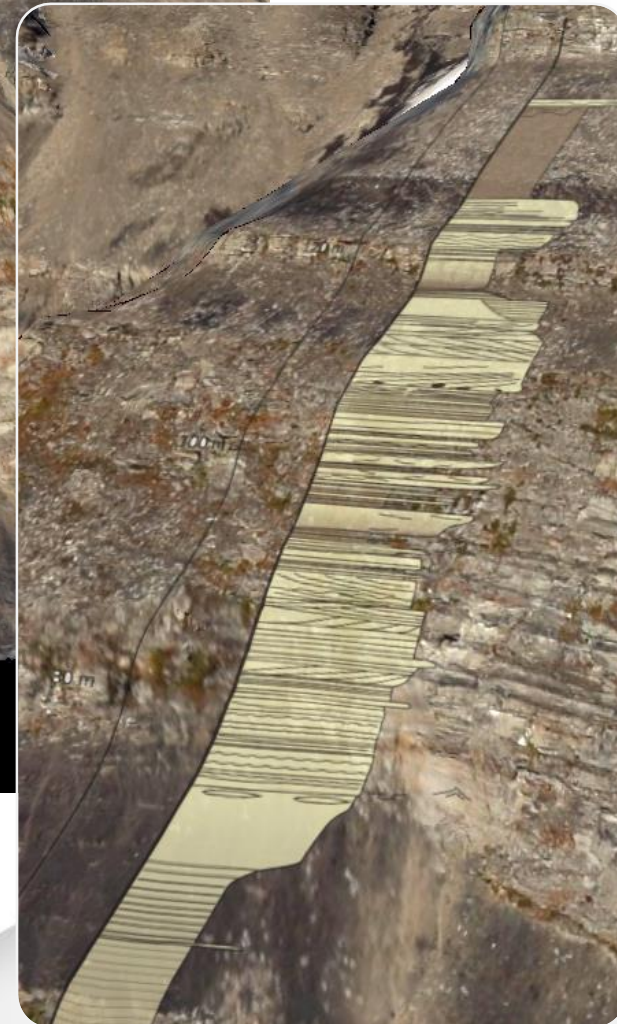
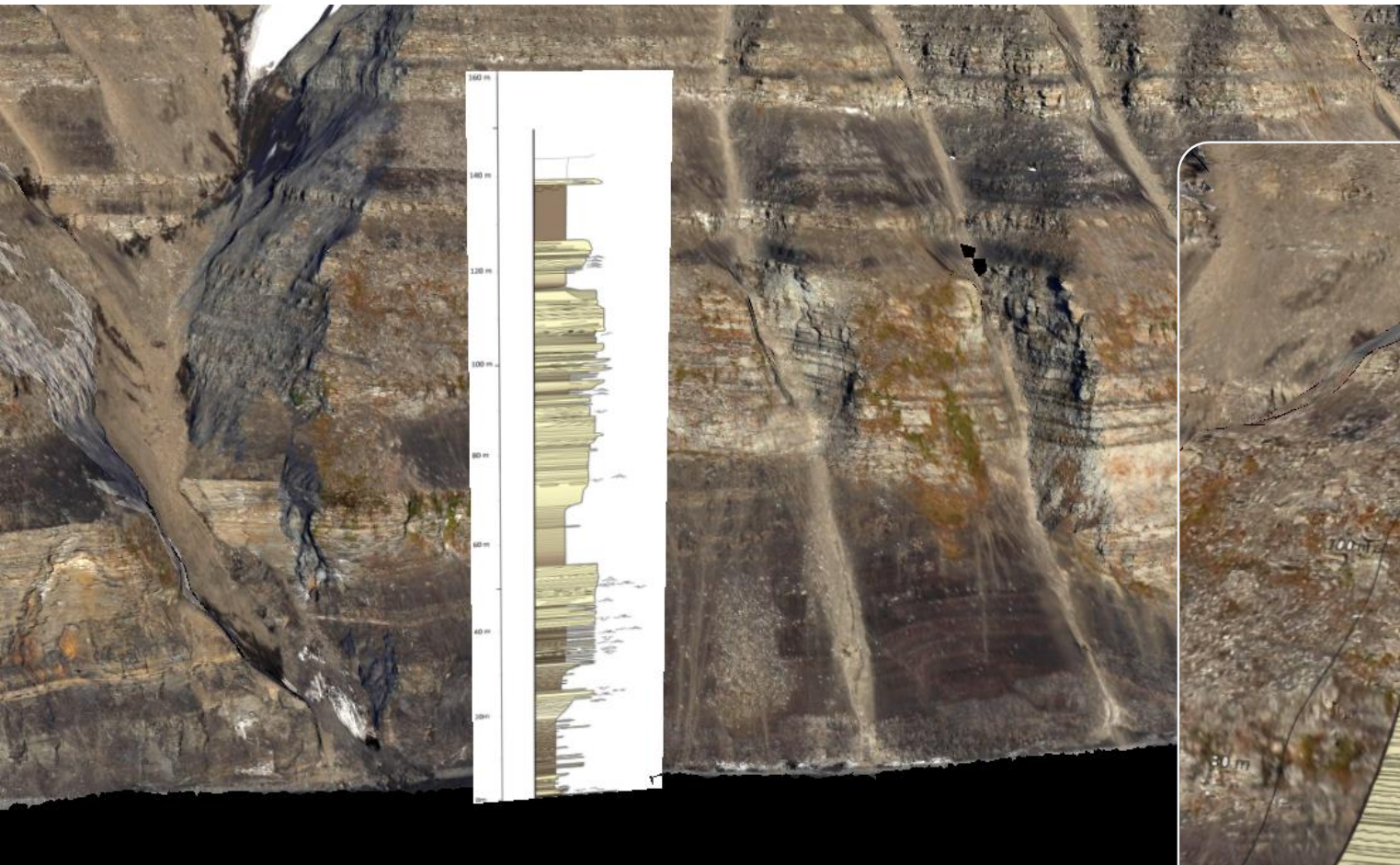


LIME software

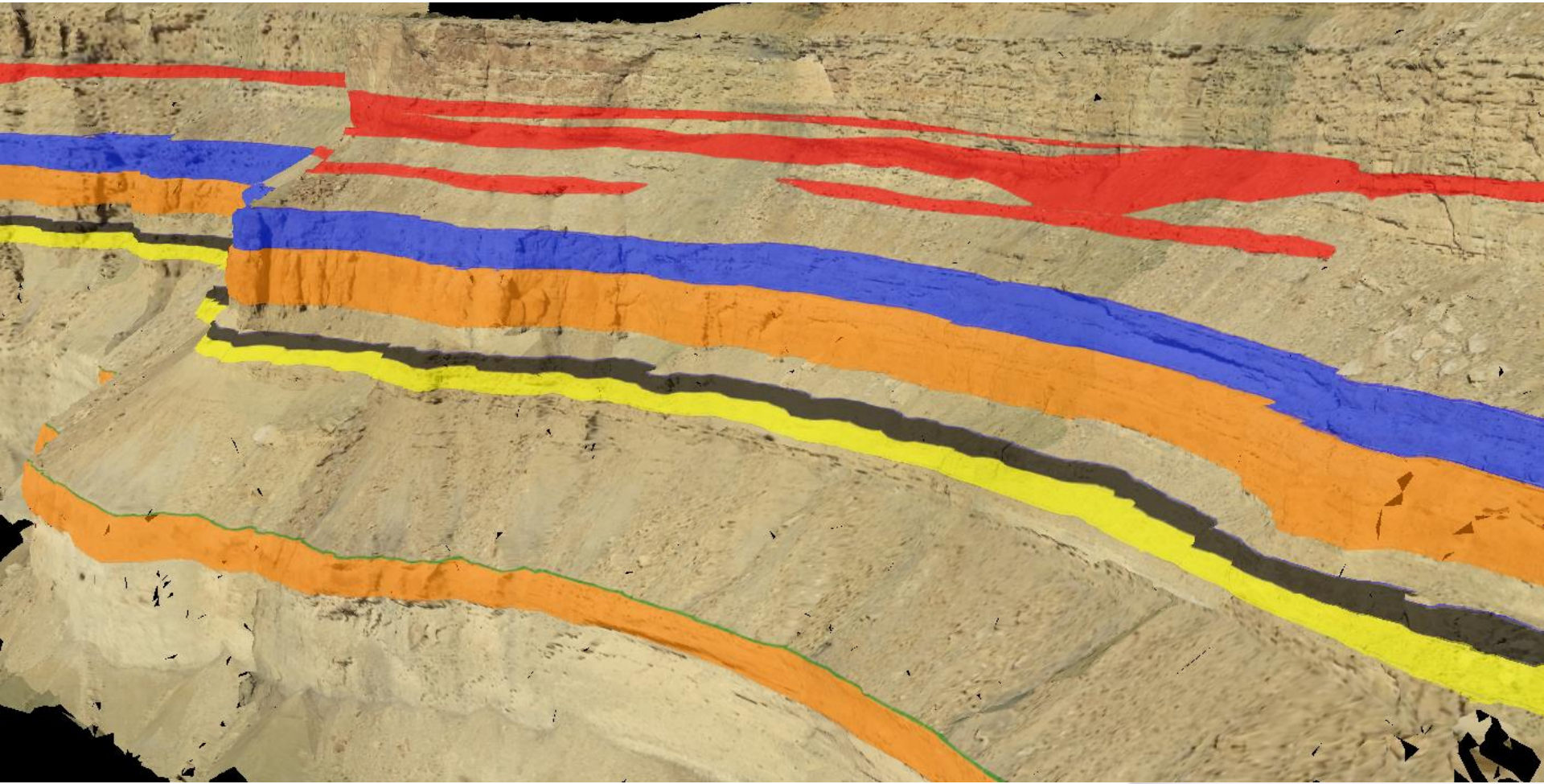
- Digital outcrops increasingly used over last 15 years
 - For quantitative, qualitative and educational purposes
 - Early barriers to adoption: hardware, data, analysis & integration software
- LIME developed as simple tool for students & collaborators to work with digital outcrop models providing:
 - Interpretation and measurement tools
 - Co-visualisation of different sources of spatial/non-spatial data
 - Use in education, sharing and dissemination – virtual field trips



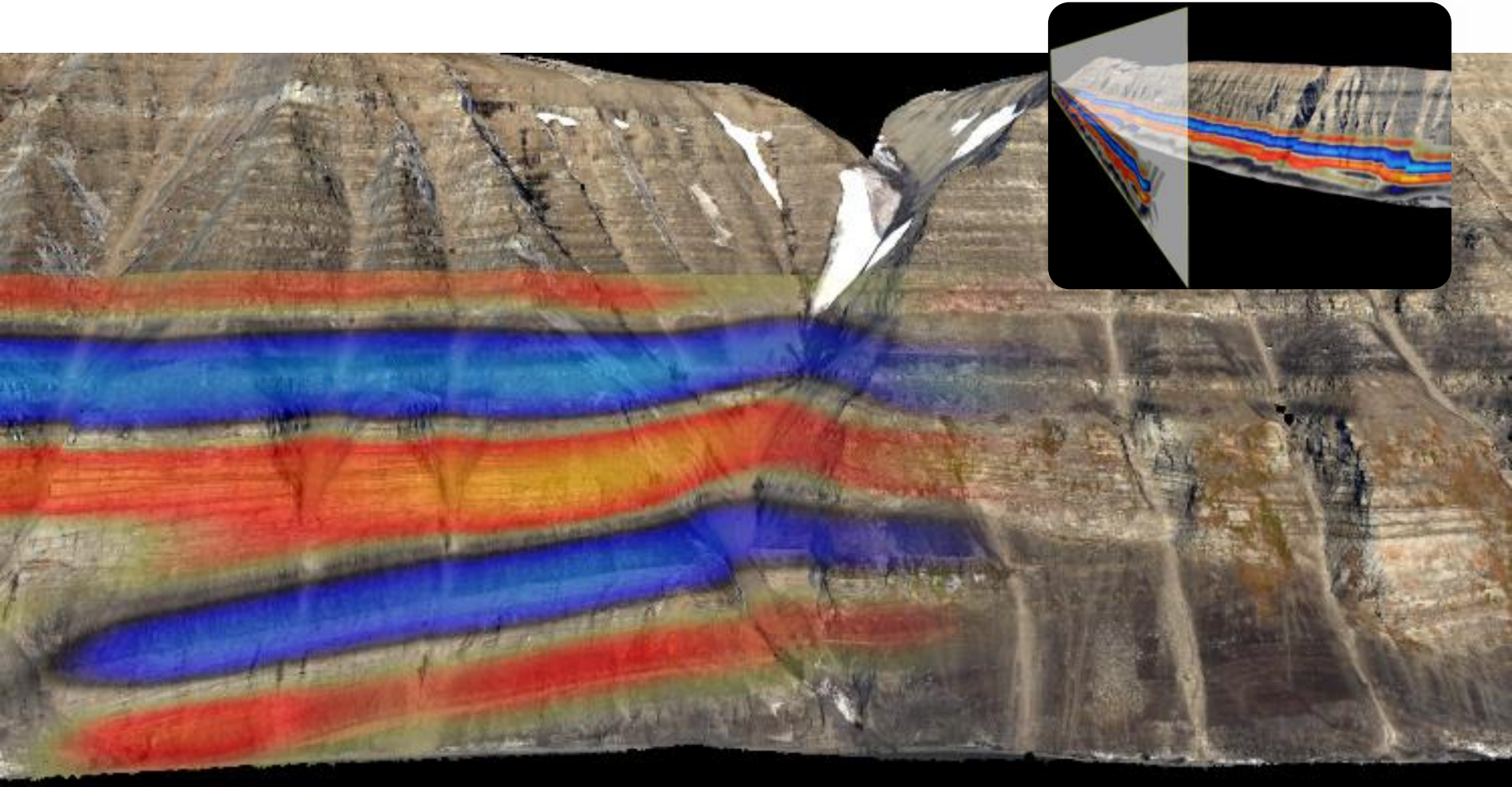
Log integration



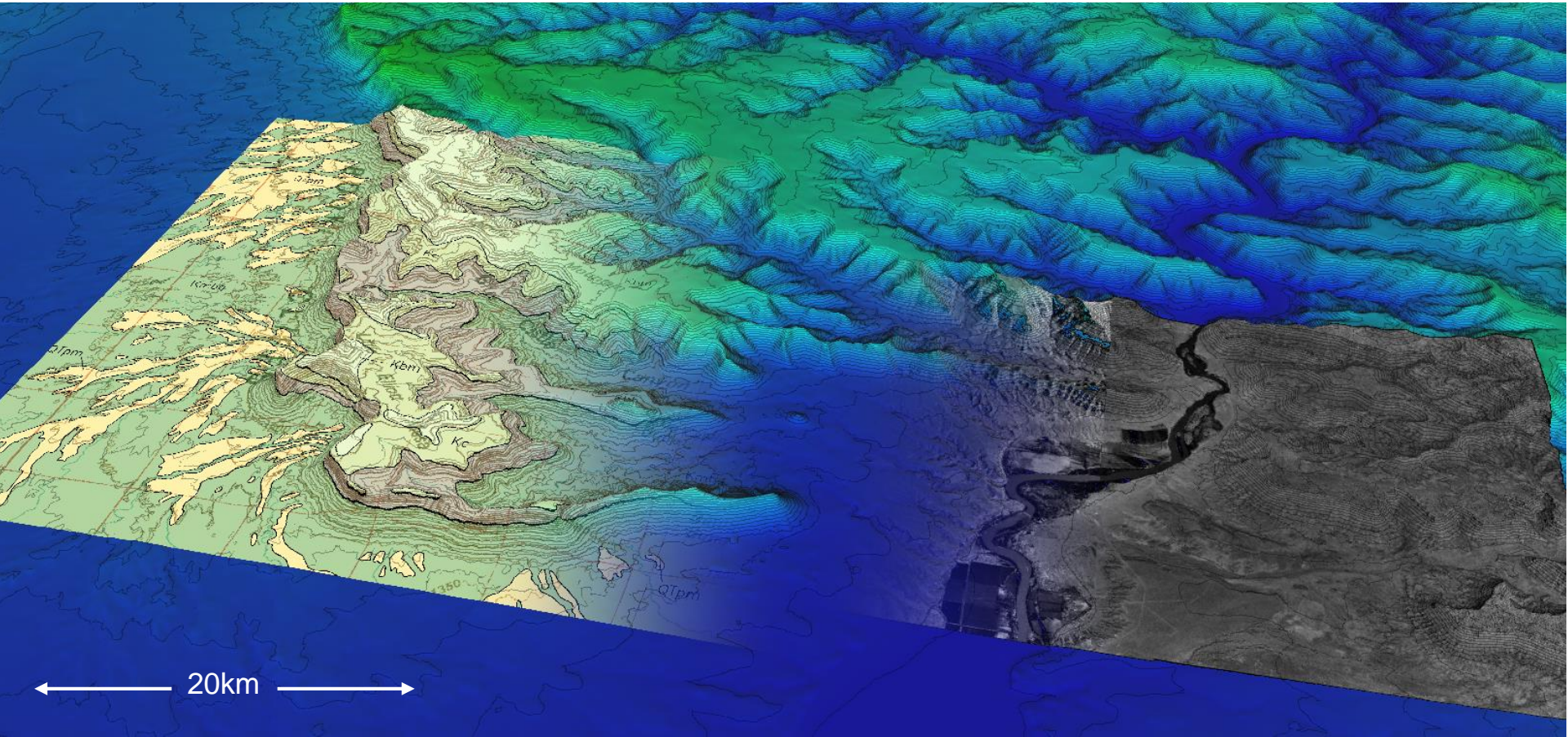
Interpretation



Seismic modelling overlay



DEM/GIS data integration



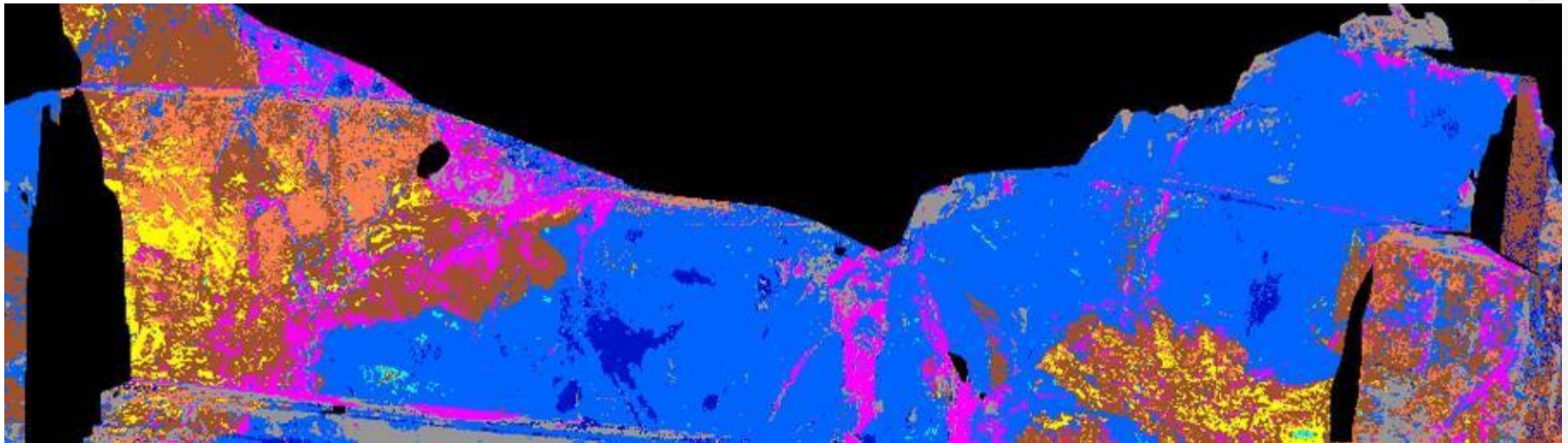
Book Cliffs, Utah @10m, with aerial imagery and geological map










Hyperspectral imaging (HSI)

- Remote sensing method for analysing surface material properties
 - Geology, tunnelling, mining, civil engineering, ++
 - Fluid flow properties controlled by mineralogy and lithology
- Multi-scale analysis
 - Laboratory (sample-core - μm to mm)
 - Field, tunnel face and site-scale (mm-dm)
 - Airborne (UAV – dm-m)
 - Satellite ($\sim 10\text{m}$)



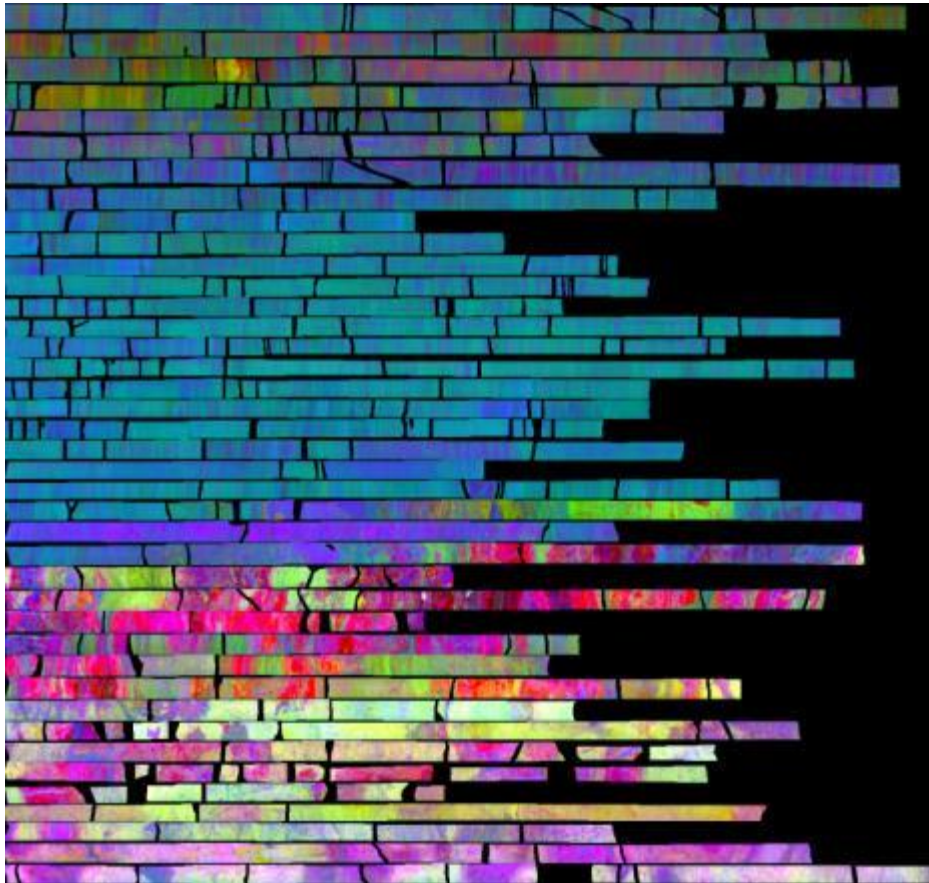
Outcrop mapping using HSI



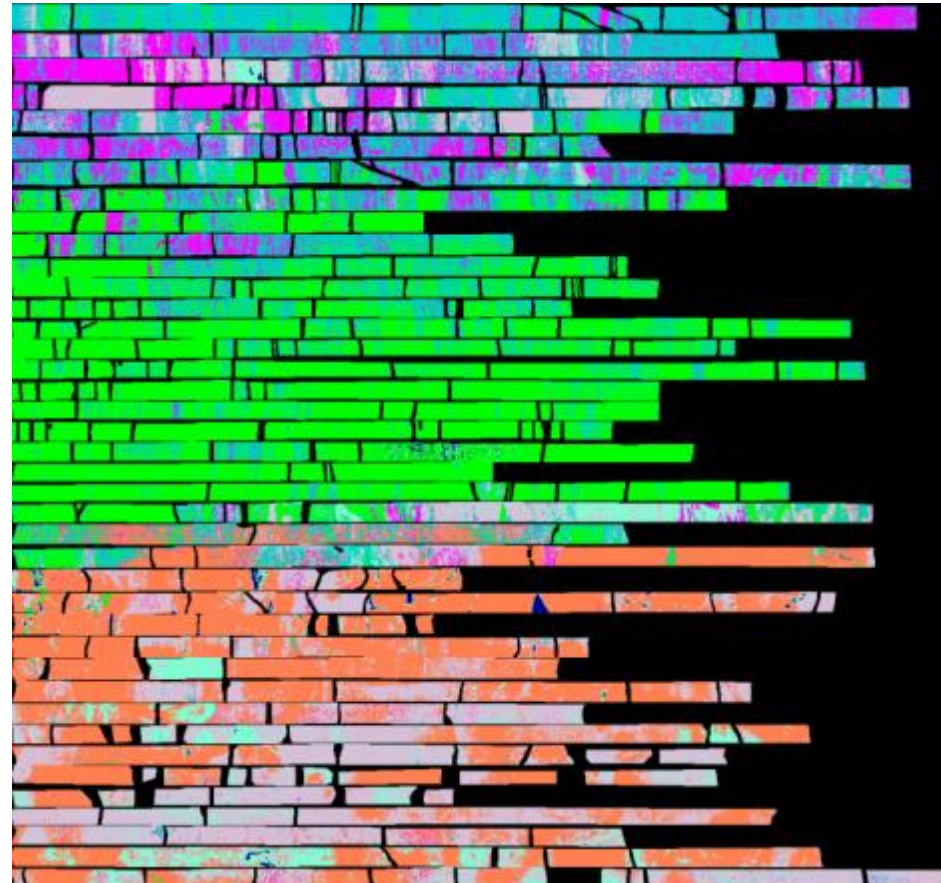
 host limestone, 438.9 m ²	 coarse crystalline dolomite, 37.3 m ²	 recent karst, 83.9 m ²
 pure calcite, 3.4 m ²	 zebra dolomite, 75.8 m ²	 not classified, 54.3 m ²
 organic rich limestone, 23.4 m ²	 dolomite (not differentiated), 195.4 m ²	 masked pixels

Lab & drill core analysis

- Lab HSI setup
- Sample & core analysis (non-destructive)
- Novel integration of HSI in industry workflows



1 m



1 m

SafariDB.com – The Geological Outcrop Database

A new way of data sharing & publication

SafariDB
The Geological Outcrop Database

Learn More

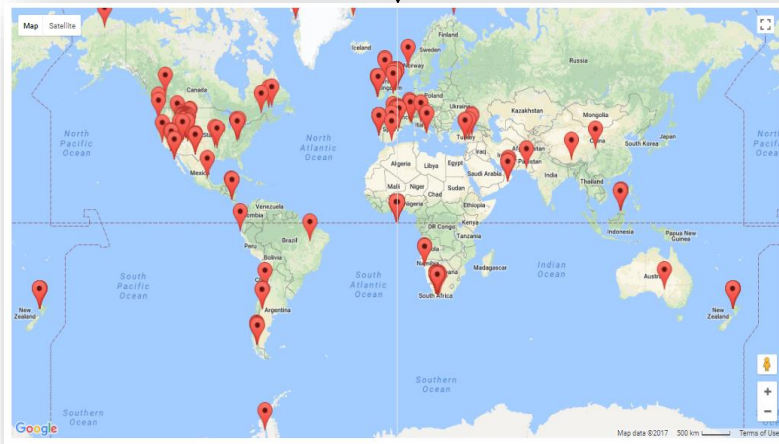
Browse Outcrops
Search for information on over 300 geological localities.

Contribute Outcrop Data
Increase the visibility of your research - join the community and add outcrop data.

Sponsor Dashboard
Log in here to access numerical data, the modern analogue finder, the knowledge base, and over 200 virtual outcrops.

Fully searchable cloud-based repository for outcrop analogues:

- Detailed location descriptions
- Individual studies with maps, interpretations, photos, cross-sections, figures, publications, etc.
- Web-based 3D virtual outcrop model viewer



Castlegate road cut - Blackhawk Fm. Book Cliffs

The Castlegate Road Cut outcrop provides an excellent exposure of Upper Cretaceous (Campanian) coastal plain fluvial deposits within the Aberdeen and Kenilworth members of the Blackhawk Formation (Mesa Verde Group).

Overview **Map** Palaeogeography Pictures Cross Sections Sedimentary Log Facies Virtual Outcrop Reservoir Model

Panoramas

Introduction

This study forms part of an MSc project thesis submitted by Saad Bhatti, University of Aberdeen (link to thesis provided). As part of this evaluation, six virtual outcrops were studied from several global regions, including the Castlegate road virtual outcrop of the Book Cliffs region.

The study focuses on the sub-seismic scale heterogeneities that are associated with fluvial avulsion, crustal movement variations, sea-level fluctuations and sediment input. The objective is to interpret and model four of the six outcrops, using object-based stochastic and pixel-based Sequential Indicator Simulation modelling (SIS).

The focus of this study is to interpret a variety of fluvial systems in the form of 3D rendered virtual outcrops (VO) and use them to extract geometric data to incorporate into reservoir models. The two types of stochastic models (Object & SIS), along with outcrop-based interpretations, will help record the distribution of heterogeneity in fluvial systems and improve the predictability of fluvial reservoirs.

Six analogue outcrops were used to represent braided, meandering and ephemeral fluvial systems. The geometries measured from the outcrops will help bridge the gap between the scales of resolution in seen in the subsurface.

The aims of this study are threefold: interpret virtual outcrops, extract geometric data and reservoir model construction.

Lithology and Depositional Environment

The Castlegate road cut virtual outcrop exposes the Aberdeen and Kenilworth members of the Upper Cretaceous (Campanian) Blackhawk Formation, Mesa Verde Group. The Mesa Verde Group is characterised by eastward thinning silticlastic wedges of non-marine to marginal-marine deposits that built out into the north-south trending foreland



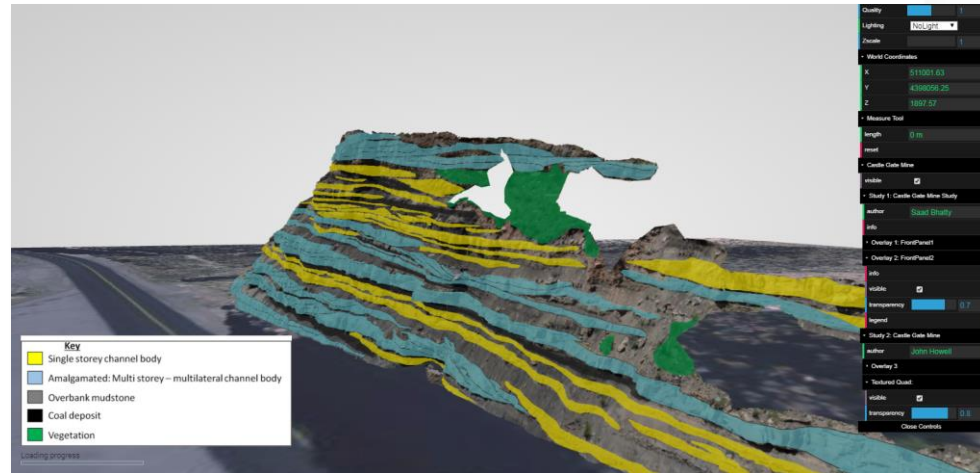
Work carried out by: Saad Bhatti (University of Aberdeen)

Key Parameters

GDE:	Paralic and Shallow marine
DE:	Fluvial influenced shoreface (WF)
SE:	Coastal plain

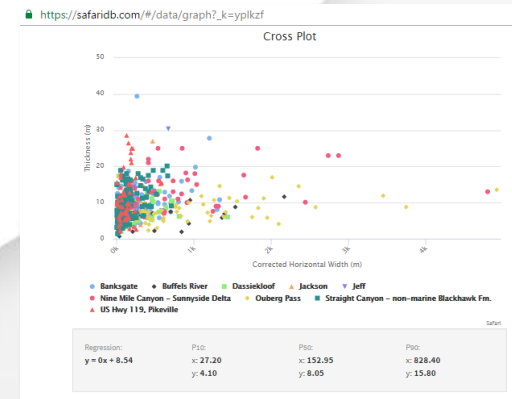
SAFARI today

- Integrated source of analogue information for exploration and production, linked through common data standard
- Database includes:
 - 200+ outcrops
 - 100+ virtual outcrop models
 - 5000+ measurements
 - Modern analogue finder GIS tool
 - Knowledge base (wiki)
 - PhD & MSc theses and data



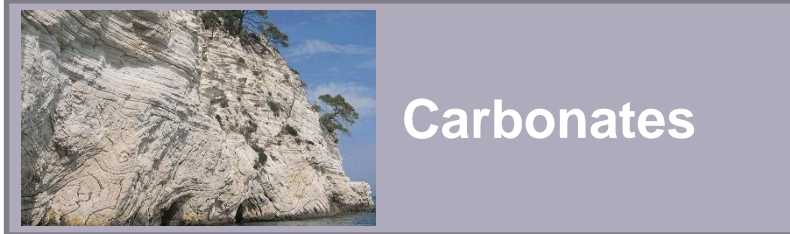
SAFARI virtual outcrop web viewer v2.0

- User authentication & access levels:
 - SAFARI sponsors
 - Proprietary data upload
 - **Public upload** and access to parts of DB



SAFARI Phase 4 - “Beyond Clastics”

Core Research Work Packages

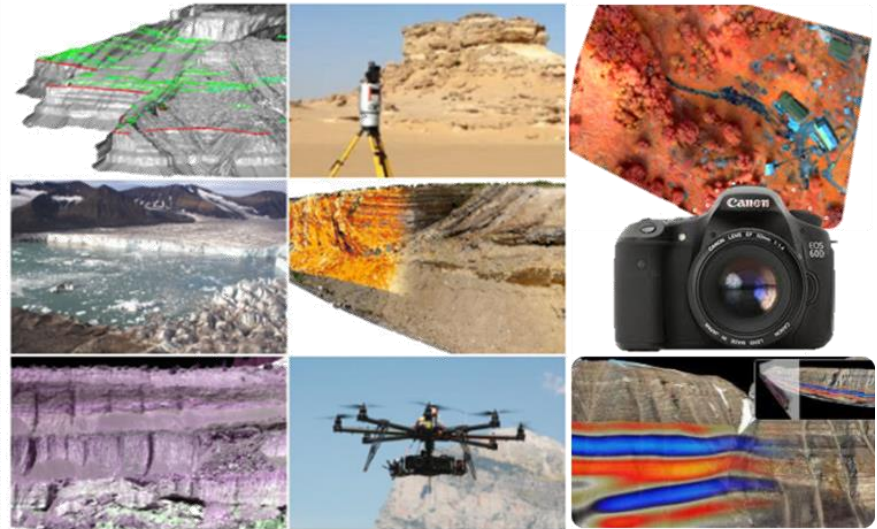


- Extend standard and database structure for carbonates and structural geology
- Add 100 virtual outcrops for each WP to the database
- Globally relevant with special reference on NCS
- Sponsors are invited to propose outcrops to be included

Planned start in summer/autumn 2018

New companies are welcome to join the consortium

For proposal contact: Nicole.Naumann@uni.no or John.Howell@abdn.ac.uk



Centre for Spatial Innovation in Earth Science

SFI Initiative 2018

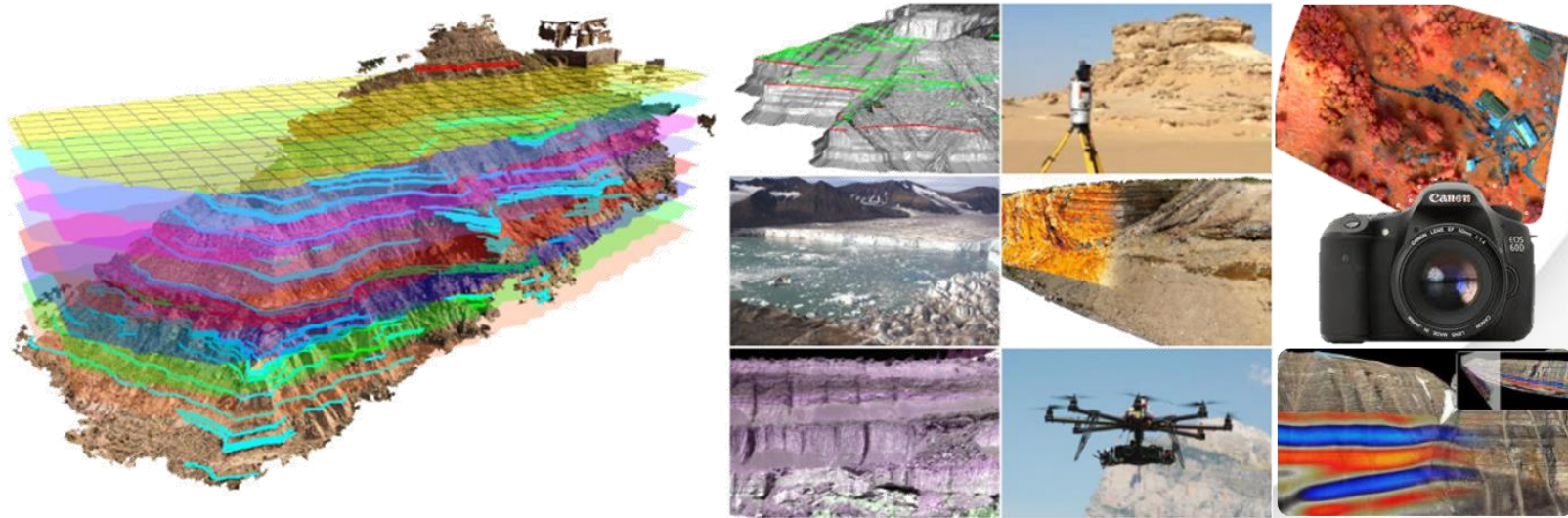
Background to SFI scheme



- NFR's Sentre for forskningsdrevet innovasjon (SFI) initiative establishes long-term research programmes between leading research groups in collaboration with partners from industry and public bodies
- Aims to promote innovation, technology transfer, internationalisation and researcher training
 - Minimising distance between cutting edge *research, education* and *implementation in operations*
 - Encourage companies to innovate through long-term research
- Funding for up to 8 years
 - NFR (50%), host institute and research/user partners (50%), of which $\geq 25\%$ must be from company partners
- Uni Research & UiB GEO intend to apply on geomatics in 2018

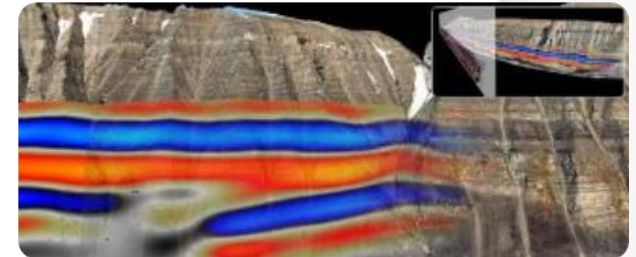
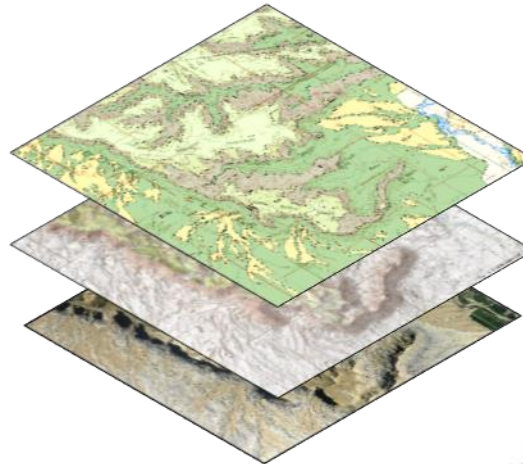
Background to SFI application

- Spatial data fundamental across critical sectors of society related to earth science:
 - Energy, resources, infrastructure, environment, geohazards and more
 - Multi-scale, multi-sensor, multi-temporal solutions
 - *Keywords: mapping, monitoring, visualization, sharing, spatial analysis, communication, digitalisation...*



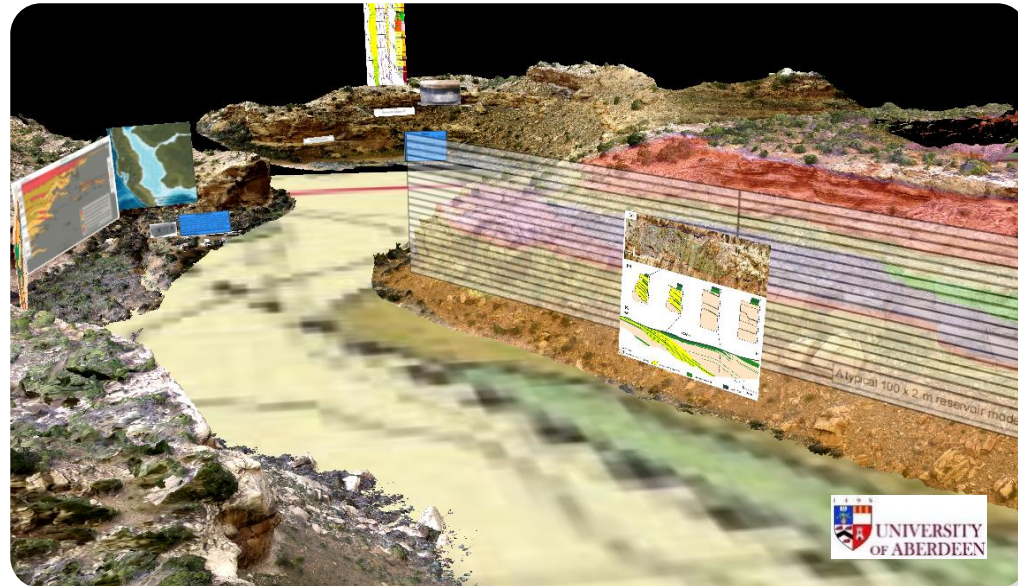
Background to SFI application

- Challenges relate to efficient exploitation of spatial data for specific problems, characterised by:
 - Rapid technology development cycle
 - Lack of software and standards
 - High expertise levels from multiple disciplines (e.g. geomatics, computer science/vision, geoscience domains)
 - Ad-hoc and bespoke solutions developed at high cost for individual applications



SFI vision/goal

- Vision is to be at the forefront of the digital geoscience revolution
 - Novel methods and developments transferable between domains
 - Advancing state-of-the-art through R&D, industry interaction and knowledge transfer
 - *Keywords: 3D mapping, geovisualisation, virtual/augmented reality, machine learning, spectral imaging, data fusion, drones, databases and open data standards*

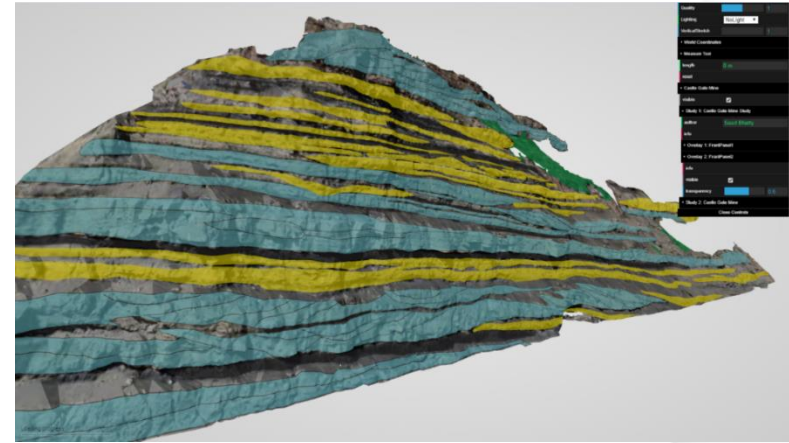


Centre for Spatial Innovation in Earth Science
CSI-EARTH

Industry Partners

Centre for Spatial Innovation in Earth Science
CSI-EARTH

- We are currently seeking industry partners to engage in SFI
 - Energy companies
 - Mining & resources
 - Public sector administration & government
 - Infrastructure actors
 - Hardware/service providers



- Companies and public sector with leading roles in geoscience
 - Where core operations require inherent need for spatial innovations
 - Where future staff expertise is important for maintaining leading position
 - Where technological developments can improve current operations
 - Where efficiency and planning are improved by geospatial methods
 - Who desire guiding role in navigating the complex geospatial–geoscience landscape