ORAL ABSTRACTS

TUESDAY 28TH OCTOBER 2025

SESSION ONE: AI AND MACHINE LEARNING

KEYNOTE: In the with the old, in with the new: Integrating analog and digital methods for outcrop and borehole characterization

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Sedimentary geology is oftentimes considered to be a qualitative science, particularly when dealing with descriptions of depositional environments from outcrop and borehole (e.g., core) data. However, much of what we measure is quantifiable (e.g., bed thickness, grain size, stacking patterns, geobody dimensions), and technology seems to have finally caught up with our aspirations. Modern hardware (e.g., drones, core scanners) and software allow for the collection of large, quantitative datasets from outcrops and cores. Synthesis of these at-times disparate datasets has also become straight-forward due to advances in data-science methods. Blending these 'old' and 'new' methodologies results in better predictive frameworks for parameterizing reservoir models for water-resources, critical minerals, hydrocarbons, sequestered carbon, and hydrogen storage. Perhaps the most exciting advances in the last five years have come from software that enables (1) creation of 3D digital outcrop models and 2D georectified orthomosaics (i.e., the photo from the perspective that you've always wanted but could never hike to), and (2) geologic interpretation of those 3D outcrop models. Crucially, this software also facilitates the export of those interpretations as tabular data that can be interrogated quantitatively (e.g., using python). Examples of geologic features that can be quantified are bedding orientation, erosional surface orientations, bed thickness and depositional-element thickness and spatial changes in thickness (i.e., thinning rate), and fracture orientations and dimensions. I will showcase a few examples of how these tools have helped to interpret and quantify mechanical stratigraphy in siliciclastic and carbonate slope settings. Core scanning robots, developed mainly be mining-industry service companies, are also extremely useful for quantifying core data that is inherently analog in nature. Core scanners collect photography, multi/hyperspectral imagery, lidar, XRF, magnetic susceptibility, hardness (among others) that is all depth-registered in a tabular export framework. I will showcase examples of how these data and methods can augment traditional core descriptions and result in predictive frameworks using machine learning, particularly when combined with outcrop data.

SynSection2: Adaptive Synthetic Data Augmentation with Unified Domain Transfer and Segmentation in Carbonates Petrography

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Petrographic analysis of carbonate rocks faces limitations due to time-intensive manual grain identification and scarcity of properly labeled training datasets for deep learning applications. While synthetic data generation through SynSection has shown promise for training segmentation models (Ransinangue et al., 2025), a persistent domain shift between synthetic and real petrographic images compromises training efficiency and validation accuracy. This study introduces SynSection2, a unified framework that simultaneously performs adaptive image-to-image translation and semantic segmentation to bridge the synthetic-real domain gap while maintaining geological consistency. Inspired by CycleGAN approaches (Hoffman et al., 2017; Zhu et al., 2017), the proposed method integrates a shared encoder-decoder architecture with domain-specific decoders, adversarial training, and Adaptive Instance Normalization for style transfer (Huang & Belongie, 2017). The framework employs masked cycle consistency loss applied exclusively to grain-containing regions, enabling enhanced textural variation in backgrounds while preserving fine-grained details within objects. A segmentation constraint prevents artifact generation while directly training a target-domain segmentation model within the same network. The method demonstrates substantial improvements over the previously established synthetic data training and real data fine-tuning approach. Domain adaptation achieved a 67-point reduction in Fréchet Inception Distance (from 86.12 to 18.69), indicating enhanced image quality and distributional alignment. Segmentation performance improved consistently: accuracy (+4%), Dice coefficient (+5%), and IoU (+4%). Most notably, derived petrographic regression tasks showed marked enhancement, with mean grain size estimation improving by +12% (R^2 = 0.78) and grain sorting analysis by +6% (R^2 = 0.72) (Folk, 1954, 1974). The study introduces local thickness measurements as a robust alternative to traditional grain diameter calculations, demonstrating superior resilience to segmentation noise while aligning with visual petrographic interpretations (Dahl & Dahl, 2023). Full thin section characterization examples showcase the framework's practical utility for quantitative geological analysis, enabling objective compositional assessment and grain size distribution analysis that complement traditional interpretation.

Unsupervised Geological Core Image Classification: Extracting Rich Features for Consistent Analysis

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Traditional geological core analysis relies on qualitative visual descriptions that often yield subjective interpretations due to overlapping patterns, structures, and geological features. Combined with supplementary sources (well logs and thin sections), there exists significant potential for extracting more comprehensive geological information through advanced analytical approaches. This study presents a novel multi-stage analytical framework leveraging unsupervised deep learning techniques to determine the extent of extractable information from geological core imagery. The methodology comprises three key components: (1) semantic decomposition of core images into hierarchical levels including textural backgrounds, structural patterns (both regular and irregular formations), and discrete geological objects, enabling independent analysis of each semantic level; (2) mean-shift unsupervised clustering for systematic feature extraction from image patches; and (3) comprehensive correlation analysis between extracted visual features and independent qualitative and quantitative geological measurements to validate the learned representations. The unsupervised algorithm identified latent geological features that demonstrate statistically significant correlations with quantitative measurements not directly observable in core imagery alone. Results demonstrate that the proposed framework can reveal previously unrecognized patterns and relationships in geological cores while eliminating subjective interpretation bias. The semantic decomposition strategy effectively separates overlapping geological information, while the unsupervised feature extraction identifies meaningful geological characteristics without predetermined classification constraints. These discovered feature relationships provide insights for developing comprehensive classification systems that integrate multiple information sources and geological aspects present in core samples. This research contributes to automated geological interpretation by providing an objective, reproducible methodology for core analysis. We aim to maintain geological relevance while improving consistency across different interpreters and geological contexts. The framework offers significant potential for enhancing geological characterization accuracy and supporting more reliable subsurface geological modeling.

Deep Edge Detection for Fracture Characterization in Outcrop

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The advent of low-cost, powerful sensory platforms, such as camera drones, smartphone cameras and more recently, iOS lidar have catalysed geospatial data collection from rock exposures within the geosciences, leading to a renaissance in discontinuity analysis studies. Despite this progress, fracture detection and mapping from outcrop images, remains challenging due to the inherent complexity and variability of natural discontinuity networks exposed in outcrop, presenting a considerable bottleneck within digital fracture analysis studies. Conventional edge detection techniques, though widely used, struggle in complex geological environments, with many workers resorting to manual digitization, which is generally prohibitive for large fracture arrays. The advent of deep learning has introduced more robust methodologies for edge detection. However, benchmark segmentation models still encounter difficulties when applied to geological outcrops, with the unique challenges posed by these images, such as intricate branching fractures, occlusions by physical objects like roots and rocks, and varying contrast levels between fractures and host rock, making automated segmentation a non-trivial task. To overcome these challenges, a bespoke U-Net-based model (GeoFracNet), equipped with gated edge aware skip connections is proposed, delineated convolutions and custom gradient-based loss, representing a significant step forward in addressing the challenge of fracture detection from outcrop images. By specifically tailoring the architecture to the unique demands of fracture segmentation, GeoFracNet achieves notable improvements in both accuracy and reliability. Moreover, a dedicated open access benchmark dataset of annotated fracture edges (GeoCrack) is introduced in order to cultivate reproducibility and further model development. This work sets the stage for further exploration of deep learning models in geological fracture detection, with the potential for extending the approach to instance segmentation / multi-class panoptic segmentation tasks and/or to 3D mesh-based reconstructions of outcrops captured in the digital field.

Augmenting Digital Fieldwork: LLM-Enhanced Interpretation of Digital Outcrop Models

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By integrating Large Language Models (LLMs) with Digital Outcrop Models (DOMs) through the Model Context Protocol (MCP), we demonstrate how LLMs can augment digital fieldwork. DOMs already capture complex geological exposures in high-resolution, but their utility is often constrained by the difficulty of querying and interpreting heterogeneous data. This integration with LLMs enables more natural and powerful interaction with digital geology. Our framework enables natural language interaction with two complementary knowledge streams. First, an internal interpretation database stores annotations, measurements, and contextual information linked directly to outcrop geometry. Using MCP, LLMs can access this database, returning context-aware responses that remain grounded in site-specific data. Second, a retrieval-augmented generation (RAG) pipeline, built on a separate dedicated database, integrates external resources such as peer-reviewed literature, technical reports, and project documentation. Together, these streams allow geoscientists to move between outcrop-specific interpretation and broader conceptual understanding, enhancing the analytical value of DOMs in industrial, research and teaching applications. The main challenge lies not in implementation of MCP or RAG, but in context engineering: designing data structures and workflows that provide LLMs with the right level of geological context. Digital Outcrop Model data spans multiple forms (for example: triangular meshes, point clouds, photographs, cross sections, interpretations, and textual knowledge) that must be aligned to avoid ambiguity and ensure scientific validity. Strategies such as linking geometric primitives to ontological tags, filtering retrieval for subject relevance, and prompt design to minimise hallucination are therefore central to this work. The resulting system supports workflows such as comparing outcrop-scale observations with published analogues, guiding field-based teaching through interactive queries, and accelerating interpretation in research contexts. This work demonstrates how LLMs, MCP, and RAG pipelines can enhance the utility of digital outcrop models, moving toward interactive, knowledge-rich digital fieldwork. Crucially, it shows that the success of LLM's in geoscience depends heavily on the thoughtful engineering of geological context.

Multi-Scale Reservoir Characterization Using Machine Learning, Digital Core Integration, and 3D Outcrop analogues: Insights from the Volve Field

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This talk presents a multi-scale workflow for reservoir characterization in the Middle to Late Jurassic Hugin Formation of the Volve Field, Norwegian North Sea, focusing on wells 15/9-19A and 15/9-19BT2. The approach integrates automated core data analysis, and interpretation of 3D photogrammetry models of tidal outcrop analogues, using the Stratbox Core Explorer and Stratbox Analytics. High-resolution core imagery was processed using a random forest classifier for automated lithological description, refined through thin-section petrography. Facies were correlated with petrophysical properties and pore network characteristics, enabling robust reservoir zonation. This workflow identified three reservoir zones in well 15/9-19A and two in well 15/9-19BT2, each exhibiting distinct facies assemblages and reservoir quality variations influenced by lithological and diagenetic heterogeneities. Automated lithological description significantly reduces interpretation time while maintaining consistency and quality. Core analysis delivers high-resolution vertical profiles of lithofacies and reservoir quality; however, its narrow lateral reach constrains broader interpretation. Outcrop analogues address this limitation by offering a wider context to better understand subsurface variability. Integrating core and outcrop observations facilitates the scaling of petrophysical and facies trends, leading to more reliable reservoir models.

Can combining geochemical and geophysical measurements from Geological Survey Ireland's Tellus surveys improve a machine learning algorithm's ability to predict the bedrock lithology below?

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We here introduce the GeoPhyChem Combined dataset, Ireland's first country-wide combined geochemical and geophysical property inclusive dataset. We further show that a random forest bedrock classifier trained on this combined dataset demonstrates an improvement over using geochemical data alone. Combining geochemical and geophysical datasets provided by Geological Survey Ireland's Tellus Programme is a non-trivial task, requiring resolution alignment, feature selection, log-ratio transformations and data layer spatial joins. We discuss here how this was achieved, the difficulties encountered and the advantages of using the resulting dataset as an input for machine learning tasks. We ran the model using only the geochemical properties from the GeoPhyC Combined dataset and subsequently with the whole dataset, which includes both geochemical and geophysical properties. We demonstrate here the benefits and improvements of combining the two to predict lithology labels at three scales of map detail for a 4km squared point grid across Ireland. Improvements of up to 7% in accuracy scores were observed. Lithological label data used to train and test the model were obtained from the Geological Survey Ireland 1:1 Million Bedrock Map, the Geological Survey Ireland 1:500k Bedrock Map and a 3-class set of labels (sedimentary, metamorphic & igneous). The 1:1 Million scale map resulted in 63 labels of classification and the 1:500k scale map resulted in 28 labels. Analysis of the experimental results yields interesting insights into the types of rocks which cannot be accurately predicted, suggesting avenues for future research. The findings we present here are a precursor to using the GeoPhyC Combined dataset, along with known mineral occurrence data across Ireland, in order to predict new areas of mineral prospectivity in Ireland. These Critical Raw Materials, such as copper, lithium and zinc, are vital to the production of renewable energy and Ireland reaching its 2030 Climate Goals.

SESSION TWO: APPLICATIONS OF DIGITAL OUTCROP GEOSCIENCE

KEYNOTE: Recovering the Past: Tips and Workflows for 2D and 3D Models from Vintage Media

William Hawkins[1]

1Pix4D

A web-based geological mapping tool

Keith Milne

A web-based geological mapping tool has been developed to enable geological features to be interpreted and placed on Earth terrain. Features added by one person can be shared with others and can be accessed by anyone through a web browser. This is achieved with a shared database. The tool is most useful in remote and inaccessible areas. Of course, some geological knowledge on the ground is required, this could be from field work, a geological map, road sections or a publication. The visualisation of the terrain from any angle can enhance the interpretation of structural features such as folds and faults. A unique function is the ability to add the dip and strike of a sedimentary layer or other feature. For example a curved thrust surface can be generated from dip data, further enhancing the understanding of the geology in 3D. The tool can be used to build a virtual field trip to familiarise geologists with a particular area. The website has been developed using a combination of html, javascript and php with an sql database. Functions available in the webpage: * create a list of geological units and location names * add labels and pins * digitise geological polygons (draped on the terrain or flat) * create lines such as faults * add dip and strike points (from actual readings or estimated from the terrain) * create geological surfaces from a set of dip and strike readings (the surface is displayed above and below the terrain) Three examples will be illustrated: • Thrusting and folding in the Assynt area (integrated with detailed field work carried out by the author in Glen Oykell) • Mount Everest tectonics • Glacial features of upper Deeside.

Synthetic Well Logs from Virtual Outcrops: a Database-Driven Approach

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Depositional facies (architectural elements) are the most significant control on the distribution of petrophysical properties in subsurface reservoirs and repositories. Data on then typically comes from wells in the form of wireline logs and more rarely cores. Wells are often spaced hundreds of m's to km's apart and interpretation of the interwell sedimentary architecture is a key component of reservoir modelling. Outcrop analogues provide dimensional information on architectural elements and their constituent facies and are routinely used to predict the distribution of those properties in subsurface systems. However, outcrop observations typically differ to those made in subsurface datasets, especially in well logs. Selecting appropriate analogues and matching them to subsurface reservoirs remains a challenge. Behind outcrop boreholes are one way to bridge the gap between the outcrop and the subsurface but these are typically expensive and rarely collected. Creating synthetic well logs from the outcrop is a lower cost solution which can potentially generate large volumes of data. This study uses a novel empirical approach to generating synthetic well logs from outcrop data. The challenge is addressed by building a relational database of petrophysical responses for key architectural elements in a series of cored wells. Using publicly available data from the UK and Norwegian sectors of the North Sea, the database was populated with gamma ray, sonic, deep resistivity, density, and neutron measurements, assigned to a variety of architectural elements, classified within the SAFARI data standards. Intra-body, property trends were also recorded. Synthetic wireline logs are generated by extracting vertical architectural elements profiles from virtual outcrops. Properties from the petrophysical database are then stochastically assigned to the different elements, honouring the observed vertical trends. The resulting synthetic well logs have been validated through direct comparison with drilled wells located behind outcrops, demonstrating a high degree of similarity. Overall, this approach allows direct comparison between subsurface reservoir data and their outcrop analogues providing better interpretation and analogue selection.

A statistical approach for building comparable reservoir models from virtual outcrops

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Outcrop analogues have long been used to improve the understanding of subsurface systems, including building reservoir models of cliff sections to examine the impact of heterogeneities on fluid flow. Such models are typically built by deterministically mapping key surfaces and architectural elements from outcrops. These deterministic models replicate observed outcrop structures using a spatially referenced grid. Here, we present an alternative statistical approach that employs a coordinate-free 3D grid populated with statistical data, object dimensions, and spatial trends derived from the outcrop. The workflow includes: (1) Data collection from an outcrop and geostatistical analysis: geostatistics can be obtained using the Panel Analyser tool, which examines interpreted virtual outcrop panels and extracts the relevant statistics. These statistics are required to populate the reservoir model. (2) Creation of the statistical box grid: a coordinate-free 3D grid, independent of the original outcrop geometry, is defined. (3) Reservoir modelling and simulation: the statistical descriptors are applied to populate the box with facies distributions through stochastic modelling. Facies are subsequently assigned petrophysical properties, either from standard templates or derived from a specific field. Flow simulations are performed under consistent conditions and well placements. Multiple fluid simulation scenarios can be used depending on the purpose of the research (e.g. oil production or CO_2 injection). By applying geostatistics, we are not limited by individual outcrop dimensions and can select a grid size that captures geological heterogeneity across various depositional environments, while remaining computationally efficient for flow simulation. This method enables faster and more optimized reservoir model construction. More importantly, it allows geomodellers to compare multiple reservoir models from different outcrops, while the deterministic approach is limited to parameter alteration within a single outcrop.

Multi-Scale 3D Outcrop Models for Digital Mapping and Reservoir Characterization of the Tumey Giant Injection Complex, California

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Digital outcrop mapping is reshaping geological workflows by providing reproducible, georeferenced datasets that overcome many limitations of traditional field methods. Drone-based photogrammetry is central to this transformation, enabling scalable acquisition of 3D models from outcrop to regional scale. We applied a multi-scale workflow to the Tumey Giant Injection Complex (TGIC), San Joaquin Basin, California, combining satellite imagery, drone photogrammetry, and field data. Careful pre-fieldwork planning of flight paths ensured consistent coverage, efficient acquisition, and optimal resolution. Large-scale models (5 km^2, 2 cm/pixel) were built from automated drone acquisition with grid-based flight plans, ensuring uniform image overlap, minimizing operator bias, and generating continuous models across the area. Higher-resolution models (~0.3 cm/pixel) of selected outcrops were generated through combined automated and manual flights. Digital mapping was supported by 45 sedimentological logs (3.26 km cumulative), bridging the gap between regional-scale features and outcrop observations. In the study area, the TGIC architecture comprises a 150 m lower succession of remobilized slope channel complexes (parent units) overlain by ~300 m of mudstone-dominated strata intruded by sandstones. The intrusive network (ca. 850 intrusions mapped) is defined by connected sills and dykes forming multiple staked wings, verging northwest to northeast, composing a large (2 km wide) saucer-shaped intrusion system. Individual wings reach 23 m in thickness, extend laterally for tens to hundreds of metres, and penetrate vertically ca. 150 m into host mudstones. The network is highly interconnected, with an average N/G of 22%. Injection breccia zones enhance connectivity and present N/G between 40-50%. This study demonstrates the value of systematic multi-scale digital workflows for geological mapping of complex geological systems. The approach enhances resolution, reproducibility, and scalability, offering tools to map and understand the architecture and reservoir characteristics of sand injection complexes and associated sedimentary successions.

Virtual Outcrop Model at the gate of prehistory: structural geology of the backbone of Romanelli Cave, Southern Italy

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Romanelli Cave, a key Palaeolithic site on the Adriatic coast of southern Italy, provides a unique opportunity to integrate digital technologies with structural geology and speleogenesis research. While the Quaternary infill of the cave has long been studied for its archaeological and palaeoentological insights, comparatively little attention has been paid to the structural and mechanical frameworks of the Cretaceous carbonates hosting the cave. To address these points, we generated a high-resolution 3D Virtual Outcrop Model (VOM) of both the Romanelli Bay area, and the cave interior, by combining UAV-based photogrammetry with DSLR imagery. This hybrid approach enables the seamless reconstruction of complex geometries, from regional folds to overhanging cave vaults, and supports accurate structural mapping, stratigraphic analysis, and digital extraction of fractures, bedding planes, and fault surface orientations, overcoming accessibility limitations in the field. Mesoscale structural data and rock property measurements were integrated within the digital framework to assess the mechanical contrasts among the various carbonate facies intersected by the cave. Our results indicate that the cave geometry is largely controlled by extensional tectonic structures, which are subtle and difficult to recognize in the field but clearly imaged in the VOM. Furthermore, the analysis reveals that cave stability decreases where weaker lithologies occur within the vault.

Digital Outcrops Project, Solitario Dome, West Texas, USA

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A series of high-resolution, 3D digital outcrop models of classic exposures of the Paleozoic sedimentary succession in Far West Texas, USA is being created using camera drones, structure-from-motion photogrammetry, and digital interpretation applications, with a focus on interpreting and increasing the understanding of stratigraphic, sedimentologic and structural features. The project area is located in the Solitario Dome of Big Bend Ranch State Park, within a region where four major geological features of North America come together: the Appalachian/Ouachita/Marathon orogenic belt, the Rocky Mountain orogenic belt, the Trans-Pecos Volcanic Field, and the Basin and Range Trend. The Solitario also contains the westernmost exposure of sedimentary rocks that were deposited along the southern margin of Laurentia during the early Paleozoic Era, as well as the westernmost known exposure of structures related to the late Paleozoic Appalachian/Ouachita/Marathon orogenic belt. Many of the outcrops in the Solitario are difficult to access in a safe manner because of their remote location and/or being high cliffs that can only be physically examined by using climbing equipment. Thus, digital twins of these classic outcrops will enable anyone to safely become familiar with many important aspects of the geology of the area.

DFN Modelling Utilising Photogrammetry Data Acquisition in Digital Geoscience

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Accurate characterisation of fracture networks is essential for predicting fluid flow, mechanical behavior, and stability within rock masses. This paper describes a scalable workflow that integrates high-resolution photogrammetry with Discrete Fracture Network (DFN) modelling, enhancing subsurface predictions through comprehensive fracture analysis and stochastic simulation. The workflow begins with multi-scale data acquisition using UAVs and terrestrial cameras. Rigorous camera calibration, placement of ground control points, and quality protocols ensure robust spatial accuracy across complex outcrop geometries. Consistent image overlap, controlled lighting conditions, and redundancy checks yield reliable datasets for processing. Captured imagery is transformed into dense point clouds, digital elevation models, and textured surface meshes. Semi-automated routines delineate fracture traces, while manual validation refines measurements of discontinuity length, orientation, and intensity. This reproducible approach captures geometric parameters across varied structural domains with high fidelity. Extracted fracture attributes undergo statistical analysis. Orientation data are fitted to directional distributions, while intensity metrics quantify both linear and areal fracture densities. Spatial correlations in discontinuity size are also assessed. Statistical descriptors inform the generation of DFN realisations, with fracture sets stratified by structural domain to reflect anisotropy and scale-dependent heterogeneity. Within a defined modelling domain, hundreds of DFN realisations are generated and conditioned using borehole data, mapped photogrammetric traces, and hydraulic welltest data. Conditioning refines network topology and leads to calibrated hydro-mechanical properties, ensuring each DFN honours field-based observations. A case study of a limestone rock slope illustrates the methodology. Photogrammetry-conditioned DFNs support kinematic stability assessments and also enables three-dimensional hydrogeological simulations. Compared to conventional two-dimensional mapping, this approach is considered rapid, it helps reduces uncertainty in discontinuity description, and significantly improves forecasting, which is critical for evaluating development optimisation. This replicable and scalable workflow offers substantial advantages for rapid decision-making in geological and engineering contexts by delivering robust, high-resolution rock mass models.

WEDNESDAY 29th OCTOBER 2025

SESSION THREE: TEACHING AND LEARNING

KEYNOTE: Perceptions on virtual outcrops for structural geology teaching and research

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SeeOutcrop: A realtime collaborative, Multi User Virtual Fieldtrip and Outcrop Interpreter Web App

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SeeOutcrop, a real-time, collaborative, multi-user virtual fieldtrip, outcrop interpretation, and database web application developed to enhance geoscience education and research. The platform allows multiple participants to explore and analyze digital outcrop models directly within a browser-based environment, eliminating the need for specialized software. Key features include: Digital Outcrop Browser – Users can upload their own digital outcrops and browse publicly shared datasets. Virtual Fieldtrip Mode – A designated fieldtrip leader guides the session while participants' camera views are synchronized to match the leader's perspective. Collaborative Interpretation Tools – Real-time annotation, measurement (length, height, strike, and dip), and geological structure interpretation with instant synchronization across all connected devices. Seismic Visualization Simulation – Generate pseudo-seismic images from outcrop imagery for advanced interpretation exercises. The system is built with Python Flask as the core web framework, MongoDB for robust and flexible data storage, Socket.IO for collaborative communication, and Three.js for 3D visualization within the browser. This architecture delivers a lightweight and cross-platform experience accessible on various devices without installation overhead. By integrating data hosting, real-time collaboration, and interactive visualization, SeeOutcrop bridges the gap between traditional fieldwork and digital collaboration. It provides an effective solution for remote teaching, interdisciplinary research, and global geological teamwork—empowering users to share and interpret field data anytime, anywhere.

Virtual Field Trips five years on from the pandemic: What have we learnt and where are we going?

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Virtual field trips (VFTs) rapidly became a foundation of geoscience education during the COVID-19 pandemic, providing an essential alternative to physical field trips (PFTs) during periods of widespread travel and social restrictions. Their design and delivery varied considerably depending on data availability, software platforms, and staff expertise. The pandemic also created a unique opportunity to directly compare VFTs and PFTs in terms of pedagogy, learning outcomes, and student engagement. The Virtual Outcrop Geology (VOG) Group fortuitously collected extensive photogrammetry and LiDAR-based models of field localities pre-pandemic, largely for research purposes. These datasets enabled the development of VFTs at the University of Aberdeen, delivered through LIME, and using V3Geo, both developed by the VOG group. Building on pre-pandemic VFT experience, these field trips integrated a wide range of datasets, including virtual outcrops, photographs, regional DEMS, well and sedimentary logs, core data, seismic, and reservoir models. Findings from these like-for-like comparisons, highlight both the advantages and negatives of VFTs. Negatives of VFTs include reduced opportunities for embodied learning, spatial awareness, social cohesion, and informal peer-to-peer interaction, alongside issues such as increased cognitive load, technological barriers, and limited opportunities for new data collection. Conversely, VFTs offer significant benefits: they improve accessibility, enable repeatability and flexible delivery, are geographically independent, and can enhance 3D spatial understanding. They are also environmentally conscious, time-efficient, and provide opportunities to integrate diverse datasets at multiple scales. In this contribution, we argue that the most effective workflow is not treating VFTs as replacements for PFTs, but in using their strengths to improve field-based learning experiences. We reflect on five years of practice and research, highlighting the challenges encountered, the solutions developed, and the best practices established for embedding VFTs into geoscience curricula. We also discuss how lessons from the pandemic are shaping the future of digitally enhanced fieldwork.

Enhancing Geoscience Fieldwork Through Virtual Outcrop Technologies: Applications and Impacts in Subsurface Education

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Outcrops are essential for Geosciences Education as they promote making direct empirical observations from hand lens to interwell scale. Nowadays, widely available digital technologies, especially drones, have revolutionized access and teaching methods via virtual outcrops. Virtual outcrops (i.e., a digital, 3D representation of an outcrop) enable geoscience professionals to visually explore, measure, and interpret geological features within an interactive environment. Shell has actively incorporated virtual outcrops into subsurface training, complementing a robust program of in-person field seminars with digital modules accessible via online, virtual, and hybrid courses. The integration of virtual outcrops offers several scientific and educational benefits: • Repeatable, exposure-free learning: Learners can revisit key sites as often as needed, zooming in on features and practicing interpretation techniques independent of temporal, climatic, or geographic constraints. Hazardous or remote sites can be viewed in a safe environment. • Enhanced accessibility and inclusivity: Virtual outcrops lower barriers for individuals who may face physical, financial, or logistical challenges. • Educational value: While they cannot fully replicate empirical and spatial fieldwork experiences, virtual outcrops serve as powerful preparatory and supplementary tools. When deployed alongside traditional field trips, they foster observational skill development, critical thinking, and spatial reasoning. Their integration with annotation and collaborative interpretation tools supports active and group-based learning. • Subsurface evaluation: Outcrop models serve as analogues for subsurface scenarios across many depositional environments. Their integration into reservoir evaluation software enhances interpretation of static and dynamic behaviors, strengthening hydrocarbon recovery, geothermal and/or Carbon Capture efficiency prediction and decision-making during exploration and development, with a focus on the interwell scale. Virtual outcrops represent a transformative asset in geoscience education, enriching traditional field experiences with flexible, inclusive, and scientifically robust digital tools. Within Shell Learning, virtual outcrops are leveraged to complement—not replace—physical field seminars, ultimately broadening access and deepening conceptual understanding for future generations of geoscientists.

Five years of V3Geo: Experiences from building a global virtual outcrop repository

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V3Geo is a purpose-built repository for accessing and sharing high quality virtual 3D geoscience models, with a particular focus on virtual outcrops. It was released in March 2020, as the COVID-19 pandemic triggered a major impact on physical fieldwork and excursions worldwide. During this period, V3Geo provided continuity for many organisations as field activities were moved online, from introducing basic geology to fully recreating physical field trips in digital form. Beyond the pandemic, V3Geo has continued to be a community resource to support publication, collaboration and for complementing traditional field activities. Initially seeded with c. 150 virtual outcrops, V3Geo now includes around 400 publicly available contributions from the geoscience community. Features of the platform are its dedicated geoscience remit, Creative Commons licenses for model authors, handling of large datasets and multiple model scales in a 3D web viewer, and technical quality control for added reliability in the scientific and professional community. Since its inception, V3Geo has been utilised and integrated by universities, professional organisations and companies around the world, from undergraduate education to virtual field trips and excursions. This has included bachelor-level introductions to sedimentary, igneous, metamorphic and structural geology, supplementing master-level courses in geology and virtual geoscience, as well as being a crucial spatial data source supporting research projects. In this contribution, we share experiences from five years of the V3Geo platform, charting its evolution from concept to a widely used resource. We will cover V3Geo's development with community input, features and content, applications, usage statistics, interactions with contributors, common pitfalls affecting model submissions, and challenges with maintaining quality. Finally, we will explore the potential roadmap for V3Geo as a sustainable initiative within the geoscience community.

SESSION FOUR: ADVANCES IN DIGITAL GEOSCIENCE METHODS

Digital Geological Outcrop model as a tool for structural analysis of North-West Mount Sharp region (Gale crater, Mars)

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Digital outcrop models (DOMs) have become a powerful tool for structural and geological investigations, both on Earth and on other planetary bodies. Their importance is particularly evident in planetary science, where direct fieldwork is not possible and digital tools provide the only possibility of analyzing complex terrains. Mars represents a prime case for such studies, as it offers an abundance of orbital and rover datasets. Within Mars, Gale Crater—and particularly its central mound, Mount Sharp—has been investigated since the Curiosity rover landed in 2012. The wealth of available imagery and digital elevation models now enables detailed structural analysis of this region using virtual outcrop software such as VRGS. In this work, we used a DEM and an orthophoto mosaic (Calef & Calef, 2016) as inputs for mesh and texture with resolutions of 1 m and 0.25 m. The in-built tensor analysis tool in VRGS confirmed the general NW dipping trend of strata along the rover path identified in the previous research (Turner & Lewis, 2023). Meanwhile, manual dip measurements (polylines, n-point, and 3-point methods) revealed additional variability at smaller scales. Structurally, the region exhibits a low average dip of ~5° toward the northwest, with local variations likely related to gentle folding both before and after two observed unconformities. The origin of this folding remains uncertain, but DOM-based mapping highlights subtle stratigraphic and structural nuances that refine our understanding of Gale Crater's geological history References: Calef III F. J. and P. T. (2016) PDS Annex, U.S.G.S; Turner M., Lewis K. (2023) JGR:P 128(9). https://doi.org/10.1029/2022JE007237.

Multi-Scale Geological Mapping: From Space to Outcrop

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High-resolution satellite imagery and 3D digital outcrop models are increasingly used to complement traditional field-based geological mapping, improving both data capture and analytical scope. Platforms such as Google Earth provide accessible, broad-scale coverage of the earth from satellite and aerial imagery sources. These data are useful for remote identification and interpretation of geological features that are valuable for pre-fieldwork planning and regional mapping. Satellite or aerial based imagery, however, is constrained by resolution, with ground sample distances that typically range from 0.5 - 0.3 m. Digital outcrop models, in contrast, are higher resolution and facilitate smaller-scale observations. Integrating satellite or aerial derived interpretations with digital outcrop data and ground-based observations permits detail capture at resolutions unattainable through a single acquisition method, while retaining regional context. Importantly, this multi-scale integration reduces interpretation uncertainty and enables analysis across broader spatial scales. The availability of historical satellite and aerial imagery, as well as repeated photogrammetric surveys across multiple field seasons, enables temporal cross-referencing of observed features. This facilitates assessment of seasonal vegetation changes, variations in exposure, and differing light conditions, all of which can influence data resolution and the resultant geological interpretation. An applied case study demonstrates this workflow by combining satellite imagery, digital outcrop models, and targeted field observations, to regionally map geological features at scales greater than what digital outcrop models can provide, and below that of the satellite imagery. This method facilitated greater mapping coverage and interpretation accuracy beyond what any single remotely sensed dataset could provide alone. The approach underscores the value of integrated digital fieldwork methods to enhance geological mapping to provide robust and spatially extensive outputs that can be adapted to diverse geological settings.

KEYNOTE: Open source software for digital field data collection at the BGS

John Stevenson

Reproducible outcrop mapping and interpretation

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We present an open-source extension to the GeoJSON standard designed to embed geological interpretation metadata directly within geospatial features. This extension introduces structured blocks for capturing surface boundary definitions, stratigraphic hierarchy, sedimentary log intervals, structural measurements, lithology descriptors, and interpretation provenance. Validation against the schema ensures that geometry and interpretative context remain permanently linked, whilst remaining both human- and machine-readable. Digital Outcrop Models (DOMs) already facilitate capture of three-dimensional exposures at scales that conventional field methods cannot achieve, and they increasingly serve as primary datasets for sedimentological and structural analysis when outcrops become inaccessible. Yet, the utility of DOMs is not matched by structured, reproducible records of the observations and reasoning used to derive geological interpretations. Too often, interpreted features remain buried in field notebooks, locked inside proprietary formats, or in disparate attribute tables that lack a shared schema. Without a machine-readable audit trail, such interpretations risk becoming irreproducible, severing the critical link between geological reasoning and outcrop geometry. Although calls for open access to DOMs and metadata are growing, no existing standard adequately encodes key stratigraphic and structural data in a form compatible with the lightweight, JSON-centric workflows common in open-source geoscience. By extending GeoJSON, our approach provides a portable, open, and reproducible framework for encoding interpretation data, serving as a foundation for a community-driven standard. We invite the geoscience community to contribute, refine, and expand this extension to advance transparent and reproducible digital fieldwork.

Applied GIS and Systems Development for Engineering Geological Practices: Hong Kong case studies

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Hong Kong's annual ground investigation (GI) expenditure, estimated at HK$3.6 billion, constitutes only a small portion of the city's construction market. Despite an extensive geotechnical data repository through GInfo—a comprehensive web portal—project-specific investigations remain essential to develop more precise ground models for diverse engineering works. This paper presents case studies illustrating the local industry's preparation for digital transformation and resilience to technological change. A key innovation is the GEO-commissioned SmartLog system, developed by Arup, which signals a shift away from proprietary and traditional geotechnical data management. Designed to align with established AGS and GEOGuide standards, SmartLog supports certified logging geologists and geotechnical field technicians through an intuitive, streamlined workflow. Its compatibility with open-source relational databases and hybrid cloud/on-premises deployments ensures scalability and flexibility for future needs. Digital advancements also extend to GI field practices, exemplified by the transition from manual boulder survey field notebooks to GIS-based digital forms. Boulder surveys are labour intensive, and data driven. By leveraging ArcGIS Enterprise, teams of Gammon Construction Limited's field geologists now seamlessly connect with office staff, enhancing data integrity, operational efficiency, and safety of the geologists. In addition, automated report generation and tailored training have further empowered staff, increasing both technical capabilities and competitiveness in securing projects. Additionally, GI monitoring dashboards has been implemented widely to help multiple layers of users to understand site conditions. The input of data is still manual, but the workflows that have been identified have high potential for further innovation. The adoption of AI and large language models may greatly revolutionize data analysis and management, building upon existing digital frameworks. These case studies aim to highlight the progress and limitations in advancing digital methods of GI data capture, transformation and visualisation. However, maintaining a "single source of truth" remains fundamental to ensuring data reliability and sustainability.

Smarter Marine Operations: From Spreadsheets to Digital Survey Management

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Despite significant investment in subsurface technology and AI-driven interpretation, most offshore survey operations still rely on spreadsheets and email chains. We have more technology to track a pizza delivery than manage multi-million-Euro offshore campaigns. This innovation deficit presents real opportunities to tackle inefficiencies that limit technical focus and inflate project costs. This paper examines digital transformation in marine geoscience operations on the Berwick Bank project, where SSE Renewables implemented an integrated operations platform following successful 2024 trials and subsequent enterprise deployment. The experience demonstrates how standardised digital workflows address coordination and management challenges in complex offshore data collection campaigns. The implementation provided real-time situational awareness, automated progress reporting, integrated budget tracking, and carbon emissions monitoring within a single web-based framework. This approach democratised data access, breaking down traditional silos between operational, technical, and project management teams whilst reducing administrative overhead. Teams could focus on technical and operational analyses rather than information management, while standardised protocols created consistent datasets for performance benchmarking. The key innovation is consolidating these disparate operational and technical management elements into a single digital environment, enabling stakeholders to quickly access KPI dashboards, automated Daily Progress Report visualisations, QHSE data, and systematic carbon footprint tracking. The carbon assessment capability addresses a significant gap in renewable energy project environmental accounting, where pre-construction activities are often excluded from sustainability metrics. The standardised data model enables performance benchmarking across SSE's offshore portfolio. This creates opportunities for evidence-based optimisation of survey planning and resource allocation, as well as strategic opportunities such as refining contract terms and optimising specifications. Results demonstrate that integrated digital platforms can transform marine operations management from reactive operational coordination to proactive tactical and strategic optimisation. The approach represents a scalable methodology for enhancing efficiency while supporting environmental accountability in offshore fieldwork.

Digital geological mapping: integrating digital and traditional data capture methods for multi-scale geological assessment, a case study of the Strathmore Basin

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Digital mapping techniques enable integrated analysis of geological data across a range of scales. Traditional 'paper' field mapping at the British Geological Survey (BGS) was time and labour intensive, and adjacent sheets were often mis-matched at sheet boundaries creating problems with fault patterns and stratigraphy. These legacy problems were translated into the current 1:50 000 scale BGS digital geological map through digitisation in the late 2000's. Addressing these legacy issues is critical to ensure geological maps are fit for 21st Century applications including geothermal resource assessments and groundwater modelling. Using a case study for the Strathmore Basin in central Scotland, we demonstrate how digital capture, visualisation, and analysis tools are being combined to improve the consistency of BGS digital geological maps and the geological understanding that underpins them. The Strathmore Basin is a structurally controlled NE-SW trending Silurian-Devonian sedimentary basin spanning over 200 km. Geological mapping dates from the 1880's to1990's, mostly prior to plate tectonic theory and the advent of digital terrain datasets. An integrated digital desk-to-field methodology was developed to inform map revision within the context of a holistic, tectonostratigraphic understanding of basin development and deformation. Initial basin-scale analysis was undertaken though compilation and review of lithological information from multiple digital BGS datasets, along with c.4000 basin-wide structural observation points digitised from legacy paper maps and fieldslips. Structural data were analysed alongside a basin-scale lineament analysis from a 5 m resolution DTM. The results indicate a more complex fold geometry than previously mapped and localised inconsistencies in stratigraphy and mapped fault patterns, enabling areas of uncertainty to be targeted for fieldwork. New field observations were captured using a digital data-capture system, which allows reference to the digital datasets in the field. This integrated method ensures that centuries of geological data are accessible to new generation of geologists.

Extracting Geometric Data from Virtual Outcrops for improved Sedimentological Understanding

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The geometry and architecture of sedimentary bodies are the fundamental control on fluid flow in subsurface reservoirs and repositories. In the subsurface, data are typically taken from wells or boreholes which provide limited insight to the critical geometry away from the well bore. Outcrop analogues provide information on the sedimentary architecture that is a key part of building geostatistical models of the subsurface to predict fluid flow and storage capacity. Virtual outcrops are now routinely used to capture key analogue sections and can be source of geobody dimensions and spatial relationships. In this presentation we illustrate new methods for extracting such data from virtual outcrops. Interpretation layers are generated on the virtual outcrops in Lime. Panels extracted from these layers, oriented orthogonal and normal to depositional dip, are taken into the Panel Tool. This tool automatically extracts, object dimensions, proportions, transition statistics and variograms for all of the architectural elements. These statistics are then used as the inputs for a variety of different, industry standard reservoir modelling tools. This approach increases the utility of virtual outcrop analogues which until now have more typically been used for improving conceptual understanding of depositional systems. The ability to rapidly extract geostatistics from virtual outcrops provides a framework for significantly improving the numerical inputs for subsurface models making more robust scenarios which ultimately improve prediction of fluid flow in reservoirs and repositories.

Application of drone technology to improve geometric fault characterization and refine fault global scaling laws

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The main geometric attributes involved in fault characterization are length, throw, core thickness and damage zone width. The cross-correlation between these attributes define the statistical scaling laws, used for prediction of geometrical attributes and to understand fault growth mechanisms at different scales. However, current challenges are related to (i) inaccessibility to fault 3D structures; (ii) datasets resolution limits; (iii) uncertainties of methodologies used to study faults and (iv) existence of specific-scale gaps in the fault global dataset. Our contribution aims at reducing the global information gaps to refine the fault-scaling equations by using drone technology on inaccessible outcrops of faults. Drone imagery offered a bridge between two scales of fault studies in outcrops and reflection seismic data. We modelled 17 digital outcrops along the Baza, Galera, and Padul active fault zones, southern Spain. These three structures extend along tens of kilometers with recurrent exposure. Throw, length, fault core thickness and damage zone width were measured on the digital models using the Virtual Reality Geological software and calibrated with outcrop manual measurements. We applied advanced statistical methods (piecewise truncated power laws) to refine the fault global scaling laws. Our results show that maximum values of geometrical attributes such as fault throw, length and core thickness are localized in the narrower sections of fault zones. Furthermore, we observed that the studied syn-sedimentary active faults have a larger displacement and a thicker fault core, compared to the global dataset. Finally, we present refined global scaling laws, introducing confidence boundaries to predict missing geometrical attributes. Supporting our hypothesis, the drone technology allowed extending the study coverage, while preserving a high resolution, which reduced the existing information gaps. This is essential to understand the behavior and complexity of fault arrays at specific scales and to comprehend the limitations of comparing different datasets.

POSTER ABSTRACTS

Alteration Zone Mapping in Pacitan Regency, East Java, Using Spatial Data Analysis Through Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Landsat 8 Imagery

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Remote sensing offers an efficient method for mapping alteration zones over large and remote areas, providing preliminary insights before detailed field investigations. This study focuses on identifying areas of change in the Pacetan district, East Java, using satellite images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Landsat 8 OLI/TIRS. The satellite data were processed using digital image processing, spectral analysis, change detection, and multitemporal analysis to clarify change features and delineate lithological boundaries. ASTER, with six shortwave infrared (SWIR) bands and five thermal infrared (TIR) bands, has excellent mineral change detection capabilities, allowing for more detailed differentiation compared to Landsat 8. In contrast, Landsat 8 offers broader coverage and higher visit frequency, making it easier to track temporary changes in the surface. The interpretation results show clear spatial patterns of hydrothermal changes and lithological variations, with potential indications of Fe–Mn skarn mineralization in certain areas. These findings provide a preliminary basis for further geological and geochemical investigation in the field. The combination of multisensor satellite data and advanced image processing techniques presents an effective and cost-efficient approach to preliminary investigation in complex geological areas.

Rapid Flood Assessment in Jakarta Through Sentinel-1 SAR and Automated Otsu Thresholding

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The rapid development of remote sensing technology has opened up innovative opportunities to improve accuracy, speed, and efficiency in environmental monitoring and disaster mitigation. One strategic implementation is multispectral data analysis using Sentinel-1 imagery combined with the Otsu algorithm to quickly and accurately detect and monitor floods. In this study, Sentinel-1 Level-1 GRD data was processed through several pre-processing stages, including radiometric calibration, speckle filtering to reduce noise in radar images, and terrain correction to eliminate geometric distortions caused by topography. Subsequently, the Otsu algorithm was applied to automatically separate flooded and non-flooded areas based on the optimal intensity threshold value. This study focuses on the Jakarta Special Capital Region, which is known to have a high vulnerability to flooding due to a combination of hydrological factors, rapid urbanization, land subsidence, and the impact of climate change. The segmentation results were then validated using flood event reference data obtained from official institutions, showing that this method can produce flood maps with good spatial coverage.

Fracture architecture of carbonate anticlines revealed by Virtual Outcrop Models in the Umbria–Marche Apennines

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This study examines the fracture pattern of a representative carbonate anticline (i.e. the Gubbio anticline), located in the Umbria-Marche Apennines, central Italy, through the integration of structural geology field data, 3D modelling and fracture network simulations. The Gubbio Anticline exhibits a NE-verging forelimb, exposing a Cretaceous multilayer of pelagic carbonate rocks (Umbria-Marche succession), whilst its backlimb is downthrown by a SW-dipping, high angle normal fault (the Gubbio fault). The excellent exposure of both compressional and extensional elements makes this structure a natural laboratory for studying fractured anticlines. Fracture characterization was primarily conducted using UAV-based surveys, producing high-resolution Virtual Outcrop Models (VOMs). Fracture orientation and geometry were extracted using commercial (e.g., VRGS) and open-source (e.g., CloudCompare) software. Selected outcrops were additionally surveyed with conventional field mapping methods (i.e., scanlines), to evaluate the accuracy and reliability of VOM-derived datasets. The postprocessing workflow focused on estimating the contribution of individual fracture sets and assessing their implications for subsurface fractured reservoir analogues. Discrete Fracture Network models were generated from the acquired datasets to evaluate the role of fractures in enhancing permeability and controlling fluid flow in carbonate formations with low primary porosity, such as those exposed in the Gubbio anticline. Results show that the observed fracture pattern is mainly related to anticline development and plays a fundamental primary control on fluid flow. The majority of segments formed during compression were subsequently reactivated under extensional tectonics, with pervasive calcite infilling marking this later deformation stage. Numerical simulations reveal that the rock mass permeability is strongly dependent on fracture orientation, geometry and connectivity. These findings improve our understanding of carbonate reservoir behaviour by revealing structural controls on fracture development and connectivity. They also highlight the value of field-analogue characterization for reducing uncertainty in reservoir modelling and improving predictions of fluid flow in structurally complex carbonate settings.

Multi-Scale 3D Outcrop Models for Digital Mapping and Reservoir Characterization of the Tumey Giant Injection Complex, California

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Digital outcrop mapping is reshaping geological workflows by providing reproducible, georeferenced datasets that overcome many limitations of traditional field methods. Drone-based photogrammetry is central to this transformation, enabling scalable acquisition of 3D models from outcrop to regional scale. We applied a multi-scale workflow to the Tumey Giant Injection Complex (TGIC), San Joaquin Basin, California, combining satellite imagery, drone photogrammetry, and field data. Careful pre-fieldwork planning of flight paths ensured consistent coverage, efficient acquisition, and optimal resolution. Large-scale models (5 km^2, 2 cm/pixel) were built from automated drone acquisition with grid-based flight plans, ensuring uniform image overlap, minimizing operator bias, and generating continuous models across the area. Higher-resolution models (~0.3 cm/pixel) of selected outcrops were generated through combined automated and manual flights. Digital mapping was supported by 45 sedimentological logs (3.26 km cumulative), bridging the gap between regional-scale features and outcrop observations. In the study area, the TGIC architecture comprises a 150 m lower succession of remobilized slope channel complexes (parent units) overlain by ~300 m of mudstone-dominated strata intruded by sandstones. The intrusive network (ca. 850 intrusions mapped) is defined by connected sills and dykes forming multiple staked wings, verging northwest to northeast, composing a large (2 km wide) saucer-shaped intrusion system. Individual wings reach 23 m in thickness, extend laterally for tens to hundreds of metres, and penetrate vertically ca. 150 m into host mudstones. The network is highly interconnected, with an average N/G of 22%. Injection breccia zones enhance connectivity and present N/G between 40-50%. This study demonstrates the value of systematic multi-scale digital workflows for geological mapping of complex geological systems. The approach enhances resolution, reproducibility, and scalability, offering tools to map and understand the architecture and reservoir characteristics of sand injection complexes and associated sedimentary successions.

Forecasting Subseasonal Wildfire Intensity Using Novel TabNet-GPR and GNN-LSTM Architectures

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Wildfires are escalating in severity, with 8.9 million acres burned in the U.S. in 2024 alone. To combat this, two pipelines were developed and compared for predicting subseasonal Fire Radiative Power (FRP): a spatio-temporal Graph Neural Network (GNN) + Long Short-Term Memory (LSTM) model and a data-driven TabNet Neural Network + Gaussian Process Regressor (GPR). FRP quantifies fire power output, acting as a key marker for estimating wildfire output. The data consisted of 2-day lags from satellite, weather, and historical fire data, centered on pixel-neighbor FRP values. Bayesian Optimization tuned both pipelines. GNN-LSTM modeled patterns via graph embeddings and recursive rollout, where nodes represented GCS coordinates. TabNet-GPR used residual learning to refine predictions. Models were evaluated through recursive predictions with MAE, RMSE, and R^2 against three baselines: Persistence, Climatology, and Linear Regression. In next-day predictions, GNN-LSTM reduced MAE by 9.2% compared to Linear Regression and achieved the highest R^2 (0.3169), above TabNet-GPR (0.059) and Linear Regression (0.078), and MAE was below all baselines. During forecasting, TabNet-GPR had spikes and negative values, showing how small or high-variance datasets impact the pipeline. GNN-LSTM had few spikes from spatio-temporal awareness, as shown by higher R^2. For subseasonal forecasting, GNN-LSTM outperformed TabNet-GPR. Temporal modeling with LSTM captured sequential patterns, while GNN accounted for spatial information. TabNet alone achieved an R^2 of 0.099, 67.8% better than with GPR. Though GPR improves short-term predictions, its lack of memory led to amplified noise in recursive rollout, leading to error drift and spikes. GNN-LSTM's errors stemmed from node sparsity and static graph construction, while TabNet-GPR's error rates were from micro-sampling necessitated by GPR. Computational constraints limited outcomes significantly, requiring 10% sampling. Next steps include dataset expansion to improve R^2, quantile regression for uncertainty, and replacing GPR with LightGBM to boost efficiency.

Digital Transformation of Ground Data Group

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Earlier this summer, representatives from AtkinsRéalis, Arcadis, Arup, GCG, Mott MacDonald, Tony Gee & Partners, COWI, Aecom, GB Card & Partners, A-squared Studio Engineers, Equipe Group, and Jacobs formed the ‘Digital Transformation of Ground Data’ group. The group envisions a future where ground data is seamlessly shared and connected to collaborative, interoperable, and digitally mature connected data ecosystems that empower all stakeholders with timely, reliable, and context-rich subsurface data and information. The group aims to: • Promote standardisation of data formats to ensure consistency, quality, and interoperability across platforms and organisations. • Support open, secure, and scalable data sharing that respects commercial sensitivities while unlocking collective value for the industry. • Champion creation of the ‘golden thread’ linking factual data, ground models, and geotechnical designs, ensuring clarity, traceability, and appropriate use of data and information at every stage. • Drive industry-wide education and upskilling, enabling companies of all sizes to adopt best practices in digital ground engineering. • Influence policy and software development to align with the real-world needs of ground engineering professionals and clients. • Advance data stewardship and ownership clarity, ensuring that data is treated as a long-term asset for the industry, not a organisations project by-product. Together, the group aims to raise the baseline of digital capability across the ground engineering sector, reduce duplication, and improve decision-making, to ensure that we can all deliver safer, more sustainable, and more efficient infrastructure. The group would like to present at this conference to raise awareness and ask the audience questions which will inform a future publication. Example questions could include: • Who do you believe owns the data? (GI Contractor, client, designer, no one?, the BGS on behalf of the crown (some central authority) (e.g. Netherlands?)) • Should we be sharing interpreted data with the BGS?