

AI in the Geosciences Abstract Book

ORAL PRESENTATIONS

Wednesday 04 June 2026

KEYNOTE

At the Axis: Orienting AI in the Geosciences Toward the Public Good

David Leslie^{1,2}

¹Turing Institute

²Queen Mary, University of London

Many geoscience processes are governed by nonlinear, multiscale flow dynamics that remain computationally expensive to simulate using conventional numerical models. In particular, variably saturated flow in heterogeneous subsurface systems poses significant challenges due to strong nonlinearities and complex spatial structure. While operator-learning approaches such as Fourier Neural Operators (FNOs) offer a promising data-driven alternative, purely statistical formulations often suffer from limited physical consistency and poor generalisation beyond training conditions. We present a modified FNO framework that embeds governing physical constraints directly into the training process through physics-informed loss functions. The approach is applied to variably saturated flow governed by the Richards equation in unsaturated karst systems and fractured carbonate rocks, where strong heterogeneity, preferential flow pathways, and nonlinear saturation–pressure relationships challenge traditional modelling approaches.

The physics-informed FNO improves model stability, interpretability, and extrapolation performance relative to standard FNO formulations. The proposed model accurately reproduces key flow behaviours predicted by the Richards equation while significantly reducing computational cost, enabling efficient surrogate modelling for high-resolution unsaturated flow simulations.

This work demonstrates how hybrid physics–AI approaches can bridge data-driven learning and process-based understanding in subsurface hydrology. By embedding physical knowledge into operator-learning frameworks, the proposed methodology supports more reliable and responsible use of AI for modelling unsaturated flow, with potential applications in scenario analysis, uncertainty quantification, and digital-twin development for subsurface systems.

SESSION ONE: MACHINE LEARNING

Physics-Informed Fourier Neural Operators for Variably Saturated Flow in Unsaturated Subsurface Systems

Amin Nadimy¹, Liang Wang¹, Daqian Shi¹, Chales Danquigny², Gérard Massonnat²}, Jean-Louis Lesueur², Cédric John³

¹Research Associate

²TotalEnergies

³Professor and Head of Data Science for the Environment and Sustainability

Many geoscience processes are governed by nonlinear, multiscale flow dynamics that remain computationally expensive to simulate using conventional numerical models. In particular, variably saturated flow in heterogeneous subsurface systems poses significant challenges due to strong nonlinearities and complex spatial structure. While operator-learning approaches such as Fourier Neural Operators (FNOs) offer a promising data-driven alternative, purely statistical formulations often suffer from limited physical consistency and poor generalisation beyond training conditions. We present a modified FNO framework that embeds governing physical constraints directly into the training process through physics-informed loss functions. The approach is applied to variably saturated flow governed by the Richards equation in unsaturated karst systems and fractured carbonate rocks, where strong heterogeneity, preferential flow pathways, and nonlinear saturation–pressure relationships challenge traditional modelling approaches.

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Multimodal Log-Guided Generation of High-Fidelity Synthetic Core Images from FMS Data

Daqian shi¹, Cedric John¹

¹Queen Mary, University of London

High-resolution core images play a critical role in carbonate facies analysis and sedimentological interpretation, yet coring remains expensive and often suffers from incomplete recovery. Formation Micro Scanner (FMS) logs provide continuous borehole-scale imaging, but their reliance on non-unique resistivity values and lower-resolution limits their lithological expressiveness and can impair geological interpretation.

A previous study (Baharuddin and John, 2025) has shown that generative AI can translate FMS images into realistic synthetic core images with good textural fidelity and lithological consistency. But some issues existed in the previous work, with textures sometimes misrepresenting the rock, and a general smoothing of the grains, leading geologists to interpret the rocks as finer-grained than actual. Here, we go one step further and propose a novel multi-modal generative architecture to solve this issue. Unlike prior approaches that rely on off-the-shelf image-to-image translation models, our method explicitly integrates multiple well-log modalities as complementary geological context to FMS data. We design a dual-tower neural architecture, where FMS images and auxiliary log signals are encoded separately to extract modality-specific representations, which are then fused to guide the generation of high-quality core images. This design enables the model to suppress FMS-specific noise while enhancing textures informed by subsurface physical measurements.

Experiments conducted on paired FMS–core datasets from carbonate successions demonstrate that the proposed multimodal framework consistently outperforms single-modality baselines in both visual realism and facies discriminability. The generated images exhibit clearer textural patterns, reduced noise artifacts, and closer resemblance to real core photographs, leading to improved geological interpretability.

Our results indicate that multimodal log fusion combined with tailored generative architectures offers a robust pathway to bridge the gap between borehole imaging logs and core-scale geological characterization, providing a scalable alternative for subsurface analysis in data-limited coring scenarios.

Deep Learning for Sediment Core Analysis: An Explainable AI Framework for Facies Segmentation

*Andrea Di Martino*¹, *Carlini Gianluca*², *Alessandro Amorosi*³

¹University of Bologna, Italy

²CINECA, Italy

³University of Bologna, Italy

Subsurface stratigraphic modeling is crucial for addressing a wide range of environmental, societal, and economic challenges; however, the need for specialized sedimentological expertise in core analysis may constitute a significant limitation. Recent advances in artificial intelligence are transforming geosciences by enabling deep-learning-based approaches that automate time-consuming workflows and support increasingly complex analytical tasks.

In this study, we present a deep learning framework for the automatic semantic segmentation of sedimentary facies from high-resolution digital core images, coupled with a comprehensive Explainable AI (XAI) pipeline. The model is trained and tested on a robust dataset of Holocene-age continuous sediment cores representing a broad spectrum of continental to shallow-marine depositional environments.

To maximize geological relevance, six sedimentary facies associations, rather than traditional lithology-based classes, are used as target labels. We systematically compare convolutional neural networks and Transformer-based backbones to evaluate predictive performance, generalization capability, and model behavior. In addition, a patch-size ablation study is conducted to assess the influence of the field of view on model performance, aiming to mimic human sedimentological reasoning, which inherently relies on stratigraphic context across multiple scales.

Model interpretability, uncertainty, and error patterns are investigated through Grad-CAM saliency mapping and predictive entropy resulting from a Montecarlo dropout prediction pipeline, highlighting geologically meaningful image regions and enabling class-specific assessments of model behavior. This integrated approach provides insights into the decision-making strategies of the network, alleviating the intrinsic black-box nature of deep learning models. To ensure reproducibility, the full computational workflow is released as open-source code, and the high-resolution dataset is made publicly available. Although developed for sediment core analysis, the proposed framework is scalable and readily transferable to a wide range of geological and computer-vision applications.

SESSION TWO: MACHINE LEARNING

Reconstructing historic coastal and mining landscapes with AI, digitised maps, and LiDAR

*Iris Kramer*¹

1ArchAI

Artificial intelligence now makes it feasible to digitise historic cartography at national scale, creating time slices of past landscapes that inform today's geoscience and risk. We present an AI pipeline that converts scanned historic maps into structured geospatial layers, and fuses these with modern LiDAR to recover features that were never mapped. Our focus is coastal substrates, sand, shingle, mud, rock, and legacy mining infrastructure, shafts, spoil heaps, quarries, across map epochs centred on 1850, 1900, and 1950.

The workflow applies semantic segmentation across all map rasters to detect coastal substrates, mining symbols, and hachures. Hachure segmentation supports identification of infilled land, for example cuttings from abandoned railways that were later levelled, which can signal ground instability or altered drainage. We pair these map derived layers with LiDAR processed to accentuate local relief from small earthworks, providing a present day time slice of surviving forms. The fusion step stacks knowledge across epochs and LiDAR, closing gaps where cartography was incomplete, and clarifying evolution where development has been limited and relief persists.

Beyond individual features, this capability creates a shared, provenance-rich evidence base for the sector. It turns static maps into queryable, interoperable data that shortens desk studies and targets field survey, strengthens due diligence and environmental assessments, and supports climate adaptation by revealing long-term trajectories of change. It provides uncertainty estimates that are explainable to non-specialists, and will be made available free for academic research, with commercial licensing for operational use. Pairing historic map epochs with LiDAR offers a framework linking past land use to present-day ground conditions, ready for integration into planning, risk screening, and research.

A multi-modal semi-supervised model for ocean sediment lithology

John Aiken^{1,2}, *Dunyu Liu*³, *William Gilpin*⁴, *Thorsten Becker*^{3,5,6}

¹University of Oslo, Norway

²Expert Analytics

³Institute for Geophysics, Jackson School for Geosciences The University of Texas at Austin, Texas, USA

⁴Department of Physics, The University of Texas at Austin, Austin, Texas, USA

⁵Department of Earth and Planetary Sciences, Jackson School for Geosciences, The University of Texas at Austin, Austin, Texas, USA

⁶Oden Institute for Computational Engineering & Sciences, The University of Texas at Austin, Austin, Texas, USA

Earth science data are typically highly heterogeneous which leads to mixed determined inverse problems and poses challenges to extract process-level information. For example, ocean sediment cores from the International Ocean Discovery Program (IODP) contain hundreds of millions of measurements across multiple geophysical properties, but usable datasets are only 5-10% complete due to missing data. We present a semi-supervised variational autoencoder with masked encoding that simultaneously imputes missing measurements and predicts lithology, enabling more complete utilization of legacy IODP archives. We train a masked variational autoencoder on the LILY database (89 km of core, 34 million observations, 42 IODP missions) to learn joint distributions across bulk density, magnetic susceptibility, RGB reflectance, and natural gamma ray attenuation. The model uses selective masking during training to learn imputation strategies for missing modalities. Crucially, the learned latent representations are constrained to recover lithological labels from unseen cores without retraining. We demonstrate that the model both captures the nonlinearities contained in the training data and is able to reconstruct the test data ($R2_{avg}=0.86$) and that data lithology ($AUC_{avg}=0.9$), while also providing descriptive embedding vectors ($ARI=0.2$). Additionally, the underlying data contains strong non-linear relationships that are not captured by simpler models on reconstruction (e.g., a typical LASSO-based regression ($R2=0.24$)). Our work represents a step towards scalable cross-modal assimilation and representation of existing earth datasets.

Enriched clustering methodology with relaxation labeling for automated electrofacies interpretation from wireline data

Francesco Saverio Patacchini¹, Alina-Berenice Christ¹, Abdelaziz Faraj¹, Christophe Cornet¹, Nina Khvoenkova¹, Luca Mattioni¹, Antoine Bouziat¹

1IFP Energies nouvelles

We present a unified theoretical and applied framework for automated electrofacies and lithology classification from borehole petrophysical logs. The approach addresses a long-standing challenge in geosciences: inferring rock types from multimodal well-log data, a task traditionally performed manually by experts and increasingly supported by machine-learning methods.

On the applied side, we propose a fully unsupervised workflow that combines data preprocessing (rescaling and PCA-based dimensionality reduction) and probabilistic clustering via Gaussian mixture models, as well as silhouette analysis to determine automatically the optimal number of clusters. Unlike standard clustering approaches, the method explicitly incorporates spatial autocorrelation along depth through relaxation labeling (a classical tool for picture processing by computer), which smooths cluster affiliations while preserving meaningful heterogeneities. The workflow is validated on a public well-log dataset (Lauda-1, Northern Carnarvon Basin) using expert lithological interpretations as ground truth, showing improved purity and Rand scores compared to nonrelaxed clustering.

On the theoretical side, we provide an interpretation of relaxation labeling as a replicator-type dynamical system on label probabilities. Probabilities are updated using contextual scores, known as supports, that combine data with spatial coupling, favoring labels that are consistent with both measurements and neighboring locations; consistency is then defined as a pairing between probabilities and supports. Ambiguity is quantified through a convex function involving weights aligned with the replicator geometry. These choices yield clean variational results: under mild conditions, consistency increases and ambiguity decreases along the dynamics.

Overall, the framework bridges probabilistic clustering, spatial regularization and evolutionary dynamics, offering a theoretically grounded and practically effective tool for AI-assisted geological interpretation, hopefully scalable to large well databases and generalizable to multiple wells.

From Source to Runout: A Scalable Machine Learning Framework for Regional Landslide Risk Assessment in New Zealand

Alex Stokes¹

¹Tetra Tech

Traditional landslide hazard assessments are often limited by the scale of data and the complexity of non-linear environmental interactions. This project presents a coupled, scalable machine learning (ML) framework for mapping both the likelihood of a landslide occurring and its potential travel path, demonstrated through case studies in Gisborne and Hawke's Bay, New Zealand.

The framework consists of two integrated ML models. The first identifies source susceptibility—where a landslide is likely to start—while the second maps the potential runout—where the debris is likely to go. Both models were trained on extensive regional datasets containing thousands of landslide examples recorded after major storm events.

A key strength of this approach is its flexibility. The results can be tailored to meet specific project needs, such as simple "low, medium, and high" risk categories, detailed probability distributions, or predictions based on the intensity of future weather events.

However, these machine learning methods should not be viewed as a "silver bullet" that provides a single perfect answer. The quality of the results depends on carefully selected data and rigorous expert review. For these tools to be effective, their limitations must be clearly understood and the outputs interpreted with professional engineering judgment.

SESSION THREE: ANALYTICAL APPLICATIONS

Assessment of formation integrity and rock strength to improve wellbore stability in overpressured sequences by using AI (Central North Sea)

*Peter Evans*¹

¹NEO NEXT

Background: Since the launch of ChatGPT at the end of 2022, there has been an exponential increase in AI computer intelligence with many experts projecting an annual ten-fold increase in computer power over the coming years. Huge amounts of efficient low cost energy will be required to power the build out and operations of datacentres for AI, which includes the operation of autonomous vehicles, robots and appliances. With the backdrop of an AI race being led by the USA and China, it is critical scientists and engineers in the UK adopt and maximise the benefits of AI to improve efficiency, lower costs and thence maximise value in a safe and sustainable manner.

Energy Industry: The energy sector is filled with geoscientists, technologists and engineers. The oil and gas sector invented 3D seismic, horizontal/multi-lateral drilling and offshore development technologies. These employees and contractors embraced the Internet, workstations, mobile communications and new ways of working. AI is the next key breakthrough technology and its advancement is inevitable. Workers will soon have access to PhD level input in seconds. Like a geophysicist refusing to use a 3D seismic workstation, those that do not embrace AI risk becoming obsolete.

Geoscience AI Work Practices and Tools: As an operations geologist responsible for pore pressure prediction and geomechanics, within a UK Central North Sea portfolio, the concept was to develop AI tools as Assistants or Agents to test how these can maximise productivity by delivering high-quality output.

AI was used to assess 1200 leak off test values against theoretical fracture pressures for sixteen geological formations across the Central North Sea. The theoretical values were compared to the measured data with the finding that homogeneous chalk/shale formation showed a good match, whereas heterolithic/permeable formations gave a poorer match. This assessment was then expanded to look at how fracture pressures increase with increasing shale overpressures. Geomechanical strength averages were also calculated to allow better drilling bit selection. Such assessments help reduce mud losses and influx risks whilst improving wellbore stability. Through the application of AI, average rock strength data was calculated in 10% of the normal time and rate of penetration was assessed to support the drillers in developing time / cost estimates. In

addition, a simple model was created to predict which fields/wells were most exposed to Naturally Occurring Radioactive Minerals – mainly found within tubing scale. The aim was to efficiently utilize, sort and analyse well data collected over the last 55 years to improve operational safety within NEO NEXT's assets and also share across the industry as a demonstration of how AI can assist with the analysis of large data sets.

The impact of AI in the next five years is also described for context with scenarios on how this might impact Geoscientists and Engineers in the work place through to 2030.

Beyond classified geological maps: the case for AI-enabled mapping of geological properties

*Charlie Kirkwood*¹

¹University of Exeter

Geological maps represent our knowledge of Earth's geology, and have traditionally been — and continue to be — constructed through a process of classification, so that the map is a collection of polygons (or volumes) that together provide a summary of the geology of the region. The map shows which class (or unit, formation) the geology at any location belongs to, and may be accompanied by a summary description of the geological conditions within each class.

Can such a map tell us everything we would like to know? By its very nature, a classified geological map does not provide location-specific information but unit-wide summaries. This prevents us from realising geology at its full natural fidelity: i.e., with properties free to vary continuously and at all scales, abruptly and gradationally.

But traditional classified geological maps don't just lack fidelity, they lack verifiability: they cannot be objectively verified since there is no cleanly defined way to measure the discrepancy between a subjectively classified map and reality. This means that it's not possible to objectively say whether one traditional classified geological map is better than another, or ultimately therefore whether making changes to a classified map makes it better or worse. This is a huge barrier to progress.

One fundamental change in approach can overcome all these issues: we should construct our geological maps first as continuous (regression based) predictions of measurable geological properties – including, but not limited to, the properties on which our traditional classified geological maps are already based (i.e. age, composition, texture). Since the geological properties themselves are objectively measurable, it then becomes straightforward to measure the discrepancy between the map and reality, therefore providing a clear route forward for the continuous improvement of our geological maps.

Here we discuss how techniques from AI can support us in achieving this goal.

Agent-Based Reinforcement Learning for Geochemical Control in Geothermal Energy Systems

FUSUN TUT-HAKLIDIR¹, Mehmet HAKLIDIR²

¹Istanbul Bilgi University

²TUBITAK BILGEM

Geothermal resources represent a significant, uninterrupted, and largely sustainable energy source for the future, both through conventional methods and the adaptation of innovative technologies for electricity and heat production.

Geothermal energy production and reinjection processes create interconnected feedback loops that are difficult to manage with static rule sets or periodically updated models, as they continuously change pressure, temperature, and fluid chemistry. In many high-enthalpy areas, suboptimal control of mineral scaling and corrosion has been associated with early production losses and increased chemical consumption. While ‘smart field’ concepts have brought real-time monitoring and optimisation, most artificial intelligence components in this field are still used as passive predictors rather than active decision-makers.

In this study, inspired by previous fuzzy logic control studies conducted in the Kizildere geothermal field in western Türkiye, we present a proof-of-concept agent-based AI controller for geochemical process management. A simplified geothermal brine flow, combined with the PHREEQC-3 geochemical simulator, has created a reusable control environment where temperature, pH, flow rate, separator pressure, and major ion concentrations are determined at each time step, inhibitor dosage is applied, and the amorphous silica saturation index is calculated. Two basic strategies are applied: (i) a conservative fixed-dose strategy and (ii) a fuzzy rule-based controller that adapts the inhibitor dosage according to silica levels. On top of the latter, a lightweight table Q-learning agent, operating under a composite reward that balances net power proxy, chemical usage, and saturation index safety margins, has been added as an agency layer. This agent learns small, situation-dependent adjustments around human-designed rules.

The simulation results in this PHREEQC-integrated environment demonstrate that the agency controller can recover most of the cumulative performance of the conservative fixed-dose baseline by using less than half the inhibitor dosage and with zero saturation index violations. The framework demonstrates how physics-based geochemical simulators and reinforcement learning can be combined to prototype AI-driven, closed-loop control strategies for geothermal systems and, more broadly, other geoscience applications where chemical risks must be managed under uncertainty.

Integrating Geochemistry and Geodynamics into Machine Learning–Based Mineral Prospectivity along the Andean Margin

Juan Bello¹, Nicole Krumm¹, Nicolas Molina¹, Sebastian Seguel¹, Alonso Cancino¹, Francisco Plana¹

¹Geolnova

The increasing global demand for critical minerals requires exploration strategies capable of integrating geological processes, spatial uncertainty, and long-term tectonic evolution within a unified predictive framework. This study presents a regional-scale mineral prospectivity approach that integrates tectonic reconstructions, geochemical and geophysical indicators, and machine learning to evaluate mineral potential along the Andean margin throughout the Cenozoic.

A spatiotemporal geodynamic grid is constructed using plate kinematic reconstructions, hotspot track predictions, convergence velocity vectors, distances to the magmatic arc and continental margin, and key geochemical proxies related to magmatic fertility. The framework incorporates more than 2,000 geochemical samples including major and trace elements, which provide quantitative constraints on magmatic composition and metallogenic potential. These variables are integrated with geological and structural information to train a binary classification model based on XGBoost, aimed at discriminating conditions favorable for the formation of large mineral deposits. Model training incorporates robust data preparation, feature normalization, and stratified cross-validation to assess predictive performance and reduce bias associated with heterogeneous datasets.

The trained model is applied across the full space–time grid to estimate probabilities of mineral occurrence, which are subsequently integrated through time to obtain cumulative prospectivity values for each spatial location. The resulting probability maps reveal continuous prospective corridors from southern Peru to central Chile, showing strong spatial coherence with major porphyry and epithermal districts such as Chuquicamata, Escondida, El Teniente, Antamina, and Las Bambas.

High-probability areas are closely associated with key geodynamic features, including reconstructed hotspot tracks and variations in convergence velocity, highlighting the role of large-scale tectonic controls on magmatic fertility. Elevated Sr/Y and Sm/Yb ratios emerge as influential factors, consistent with hydrated, high-pressure magmatic systems typical of compressional subduction settings. This first-order framework demonstrates how geodynamically informed features and machine learning can be combined to identify prospective regions and support strategic decision-making in large-scale mineral exploration.

Mapping essential ocean variables with machine learning: Needs, challenges and opportunities

Arianna Olivelli¹, Alizée Roobaert¹, Maurie Keppens^{1,2}, Andrea van Langen Roson^{1,2}, Daniel J. Burt¹, Peter Landschützer¹

¹Flanders Marine Institute (VLIZ), Belgium

² Department of Biology, Ghent University, Belgium

The ocean plays a fundamental role in regulating Earth's climate. It absorbs 90% of the excess heat and 25% of the atmospheric CO₂ generated from human activities. However, this oceanic uptake has severe implications on the health of marine ecosystems through ocean warming, acidification, and deoxygenation, with both environmental and socioeconomic consequences. Therefore, it is crucial to ensure that the state of the ocean is adequately monitored and changes are detected promptly.

Despite the unprecedented amount of in situ observations of essential ocean variables (EOVs), these remain extremely sparse in space and time. Consequently, in situ measurements alone are insufficient to monitor warming, acidification and deoxygenation systematically on a global scale.

In the last decade, machine learning applications in ocean sciences have allowed to fill observational gaps and develop global maps of EOVs at various spatial and temporal resolutions. These maps include temperature, partial pressure of CO₂ (pCO₂), dissolved inorganic carbon (DIC), and O₂ concentrations. The gap-filling process relies on identifying relationships between the variable of interest and a suite of oceanographic or atmospheric predictors that are known to influence it. Thus, the ability to map EOVs depends not only on the availability of in situ observations, but also on the coverage and quality of fully mapped predictors.

Here, we present a suite of machine learning-derived, reconstructed products of pCO₂, temperature, DIC, and O₂ concentrations at the global and regional scale. We discuss the most pressing needs and challenges associated with their development, including data scarcity, imbalance in sampling efforts, uncertainty quantification, and improved representation of driving processes through the inclusion of novel predictors. Lastly, we highlight opportunities for future development and applications to monitor the state of the ocean from surface to depth, and better constrain the biogeochemical cycles of carbon and oxygen in a changing climate.

Thursday 05 June 2026

KEYNOTE

Can AI discover a new oil field? Practical applications of AI for subsurface evaluation

Karen Heyburn¹, Andrew Davies, Marc Servais, James Scotchman, Graham Baines, Thomas Butt, Matt Booker, Fan Jiang

¹Halliburton

This presentation explores the practical application of artificial intelligence (AI) to subsurface evaluation, addressing the central question: can AI help discover new oil fields? Drawing on real-world workflows and case studies, we demonstrate how AI augments—not replaces—geoscientists by accelerating interpretation, improving consistency, and reducing exploration risk through data-driven insights.

We outline how AI integrates across the exploration lifecycle, from regional geological screening to prospect definition. At the basin scale, machine learning supports fairway identification by combining tectonic, stratigraphic, and geodynamic inputs into predictive palaeo-environmental models, enhanced through human-guided optimisation. At the prospect scale, AI-assisted workflows enable rapid seismic and well interpretation, including lithology prediction, petrophysical modelling, sequence stratigraphy, and fault and horizon identification.

Key examples highlight scalable cloud-based solutions capable of processing large datasets in minutes, the use of probabilistic models for seismic facies classification, and workflows that propagate well-derived properties into seismic volumes to refine lead definition. We also examine the role of AI in generating training data, standardising well failure analysis, and embedding geological context into automated interpretations.

While significant challenges remain, AI is already transforming subsurface workflows. The concept of a “geological copilot” illustrates a future in which AI enhances expert interpretation, enabling faster, more informed decision-making and ultimately increasing the probability of exploration success.

SESSION FIVE: ETHICAL CONSIDERATIONS AND USE CASES

The Intelligent Geoscientist: Harnessing AI for Discovery, Decision-Making, and the Next Generation

Keith Richard Holdaway¹, Kevin Scott¹

¹Society of Petroleum Engineers and Society of Exploration Geophysicists

The geosciences stand at the precipice of a profound transformation, driven by the rapid ascent of artificial intelligence (AI) and machine learning (ML). This abstract outlines a critical pathway for the community not only to adopt but also to shape these powerful technologies, focusing on four interconnected pillars essential for future progress.

First, we explore the frontier developments and opportunities within AI and ML, moving beyond conventional applications to highlight emerging capabilities in deep learning for pattern recognition in complex datasets, physics-informed neural networks that integrate domain knowledge, and generative AI for creating realistic subsurface models. These advancements are revolutionizing our ability to decipher Earth's systems.

Central to this revolution is the paradigm of data integration, interpretation, and automation using AI tools. We demonstrate how AI acts as a force multiplier, enabling the seamless fusion of disparate, multiscale data, from satellite imagery and geophysical surveys to geochemical analyses and historical core logs. This facilitates the automated interpretation of vast datasets, uncovering subtle, previously indiscernible signals and accelerating the journey from raw data to geological insight, thereby freeing expert time for high-level synthesis and hypothesis testing.

However, the integration of AI demands a proactive and ethical framework. We critically examine the importance of considering ethics, bias, and transparency in the implementation of AI. The "black box" nature of some complex models poses risks for high-stakes decision-making in resource exploration and hazard assessment. We advocate for the development of explainable AI (XAI) and rigorous bias auditing of training data to ensure that AI-driven conclusions are robust, trustworthy, and equitable.

Finally, to secure this future, we emphasize the paramount importance of AI in geoscience education. The next generation of geoscientists must be equipped as digitally fluent professionals. We propose integrating AI and data science fundamentals into core curricula, thereby fostering a new breed of geoscientists who are capable of

developing, critiquing, and applying AI tools with both technical proficiency and a deep understanding of geology.

We contend that by strategically embracing these themes—harnessing new AI capabilities, automating data workflows, embedding ethical principles, and modernizing education—the geological community can unlock unprecedented discoveries and ensure its continued leadership in addressing the world’s most pressing environmental and resource challenges. We urge the Geological Society of London to champion this integrated vision.

Who Builds the Ground Model? Ethics and Fostering Engineering Judgement in AI-Enabled Ground Engineering Practice

Thomas Perriment¹, Vick Kumaran¹

¹Mott MacDonald

AI-enabled ground engineering presents a paradox: tools that can accelerate insight may inadvertently bypass the learning that helps develop critical thinking, engineering judgement, and communication skills.

Machine learning and generative AI offer new opportunities for data analysis, interpretation, and workflow efficiency, but their use raises critical ethical and professional questions about how ground engineering professionals develop and exercise their expertise. Early-career professionals are particularly at risk of missing formative experiences if AI tools and workflows are applied without appropriate steering and support.

This presentation proposes that responsible integration of AI into ground engineering practice requires AI to be used as a learning partner, progressive use that scales with experience and competence, and the active fostering of critical thinking and judgement. Using the conceptual ground model and the communication of geotechnical risk as a guiding framework, the talk explores where AI can enhance understanding, highlight uncertainty, and challenge assumptions, while emphasising the enduring role of human-led interpretation, assurance, and communication.

Practical, discipline-specific principles are proposed as a framework for the ethical and responsible use of AI in ground engineering practice, positioning AI as a constructive partner in developing competent, critically minded early-career professionals.

Ethical impacts of AI upon the science of a national geological survey

*Andrew Kingdon*¹

¹British Geological Survey

AI is rapidly changing how geoscientific research is undertaken. AI allows multiple data streams to be captured, processed and integrated so it can be analysed using newly available techniques all at unprecedented speed and scale. Like all scientific institutes National Geological Survey Organisations (GSO) wish to take advantage of such new capabilities. However, the role of GSO in providing data and research outcomes to support national government policy, in often controversial situations, means prioritising research that can be accurately reproduced and defended through peer-review. GSO research must be undertaken ethically in ways that respects the rights and responsibilities of the data owners and stakeholders, direct and indirect, affected by that research.

The software houses that have built many widely available AI tools, especially Large Language Models (LLM) have often not obeyed such ethical constraints, misusing private intellectual property, and prioritising generating an answer to the detriment of delivering accurate outputs. The difficulties in using generative AI to deliver reproducible science outputs that are traceable to source data are the consequence of choices around AI techniques, rather than features of these techniques. Such approaches are unacceptable to GSO.

This paper describes efforts by the British Geological Survey, the UK GSO, to define an ethical framework in which geological science can be conducted using AI capabilities. Examples include how a GSO can operate in ways that respect the rights of IPR holders and handling of privileged information that is held confidentially. Also how scientific data can be used to support policy advice for national governments, and in forecasting of implicitly uncertain geohazards where the requirement to highlight potential hazards conflicts with the desire not to cause needless alarm.

Fair and Responsible AI for Earth Science: Benchmarking Deep Learning and Generative Methods for Rare Class Detection in Geological and Environmental Data

*Masoud Rostami*¹

¹University of Texas at Arlington

AI is rapidly transforming geoscience research, including the study of ancient environments, fossil biodiversity, and long-term ecosystem change. Many geological and paleoecological datasets contain very few samples for key taxa or environmental indicators. These rare classes often hold the greatest scientific value because they correspond to ecological transitions, climate events, or biotic turnovers. However, deep learning models trained on imbalanced datasets tend to overlook these minority classes, which creates fairness concerns and limits the reliability of automated tools used in paleoenvironmental reconstruction. This study presents a benchmark of deep learning strategies designed to improve rare class detection under data scarcity, a condition common in both modern ecology and deep time records. We evaluate transfer learning, class reweighting, metric and few-shot learning, and generative augmentation. Accuracy-focused models perform well on abundant classes but consistently fail to detect rare taxa. In contrast, metric learning and biologically informed generative augmentation provide more balanced predictions and reduce bias against underrepresented classes. By viewing imbalance as an intrinsic property of both modern ecosystems and paleoecological archives, this work underscores the importance of fairness aware and responsible AI methods in geoscience. The framework supports more reliable identification of rare fossils, ancient pollen types, and other geological indicators that form the basis of past climate and environmental reconstructions. These approaches contribute to the development of AI systems that are more equitable, transparent, and scientifically meaningful for Earth history research and modern environmental monitoring.

Architecting Synergy: Reframing AI as a Traceable Digital Junior to Drive Positive Disruption in the Geosciences

*Bernique de Kock*¹

¹Terra Mineral Solutions (pty) Ltd

The greatest threat to the modern geoscientist is not artificial intelligence, but the inability to utilise it. Despite an abundance of sophisticated tools, the geosciences remain trapped in “Pilot Purgatory,” largely because current workflows fail to address the fundamental human need for traceability. This presentation argues that to escape this stagnation, the industry must rebrand AI from an autonomous replacement to a “Digital Junior”—a tireless coworker that extends, rather than extinguishes, the geologist’s cognitive reach. We explore the economic and psychological architecture required to build Human-in-the-Loop (HITL) protocols. Evidence suggests that AI-integrated exploration companies achieve a 28% higher discovery rate by structurally relocating capital toward data-rich environments. However, these gains are unsustainable if the AI remains a “black box.” We demonstrate how utilizing Explainable AI (XAI) tools, such as SHAP values and heatmaps, provides the auditability required for supervisors to fact-check outputs against physical data, thereby mitigating the industry-wide fear of obsolescence. Finally, we address the necessity of “positive disruption.” Successful adoption requires workflows so efficient that reverting to manual processes becomes unthinkable. By grounding AI methodologies in deep domain knowledge, we propose an educational shift from dependency to synergy, ensuring technology serves as the bedrock for innovation and frees geoscientists to focus on high-level interpretation.

The relation of students with AI in geosciences.

Mario Sarasa Navarro¹, *Lorién Crespo Gracia*²

1Universidad de Barcelona

2TU Bergakademie Freiberg

As recent graduates in geosciences, we observed first-hand how generative AI tools have become embedded in everyday student workflows, including coding, data processing, report drafting, and the exploration of complex geological concepts. In practice, these tools are primarily used to save time, increase productivity, or improve the perceived quality of academic outputs, often in the absence of clear institutional guidance or ethical instruction. This has led to informal and unregulated patterns of use, where students rely on AI-generated results without a systematic understanding of model limitations, data bias, uncertainty, or the risk of misleading outputs. Rather than attempting to prohibit AI use, geoscience educators are therefore challenged to integrate these tools transparently and responsibly into curricula. This integration should prioritize the development of AI literacy as a core geoscientific competency, emphasizing critical interpretation, explainability, and the validation of AI-generated insights through classical geoscience reasoning, physical principles, and domain expertise. Assessment strategies must evolve accordingly, shifting from AI-avoidant tasks toward formats that require explicit disclosure, justification, and reflection on AI use. By embedding ethical frameworks, transparency, and critical evaluation into teaching practices, geoscience education can harness AI as a supportive tool while preserving scientific rigor, geoscientific intuition, and academic integrity.

SESSION SIX: LLM

Promises and challenges in geoscience information retrieval with Large Language Models: examples with technical reports and basin simulation results

Antoine BOUZIAT¹, Ilyas TIBARI¹, Mehdi DEBIANE², Abir EL FEKI¹, Alina-Berenice CHRIST¹, Vanessa TELES¹, Renaud DIVIES¹, Thomas CRABIE¹, Christophe CORNET¹, Romain GIBOREAU³, Sanjay Kamath RAMACHANDRA RAO⁴, Olivier SICCARDI⁴

1IFP Energies nouvelles (IFPEN)

2TECH'advantage

3Beicip-Franlab

4TotalEnergies

Delving into large collections of files and documents to extract useful data and key insights is a routine task for many geoscientists both in academia and subsurface industries. For long, this has been identified as a fruitful area for digital innovation, as enormous gains of operational efficiency can be unlocked through automation. Recently, the rise of Large Language Models and Retrieval Augmented Generation (RAG) techniques has completed the existing Natural Language Processing toolbox to provide geoscientists with powerful information-retrieval systems. However, these technologies are not magic wands and much remains to be done to finely appraise their relevance in niche technical domains such as geoscience disciplines, and to identify their optimal settings in the corresponding operational contexts.

Thus, in this presentation, we will share some lessons learned in using Large Language Models to retrieve geoscience information from three different types of sources: (1) a set of 10 subsurface characterization reports issued to evaluate the carbon storage potential in several European locations, (2) a larger pool of 781 license relinquishment reports from the Norwegian North Sea, and (3) output files from a commercial software for basin simulation.

From these three practical case studies, we will highlight the promising capabilities shown by the AI integration, as well as the technical challenges to be faced. Notably, we will discuss topics such as the need for a rigorous multi-criteria evaluation of the LLM configurations, the added value of Graph-RAG approaches to enrich the understanding of geoscientific concepts in advanced queries, or the difficult handling of complex and non-standardized data tables within the documents. More generally, we advocate that experience sharing within the digital geoscience community is critical to ensure LLMs are integrated in our daily tasks with efficiency, reliability and responsibility.

Guiding Generative AI With Subsurface Reasoning for Scalable Play

Innovation in Oil and Gas Exploration

*Nicholas Edward Holgate*¹, Paul Cleverly^{2,3}, Nate Suurmeyer⁴, Kira Dickey⁴, Wenwen Kong⁴

1Shell

2Infoscience Technologies Ltd

3Robert Gordon University, UK

4ThinkOnward

Play-Based Exploration is a structured approach to hydrocarbon discovery that focusses on identifying and evaluating a viable combination of component play elements within sedimentary basins. Generating new play ideas is typically conducted through analogical and counterfactual reasoning, but these are inherently biased by practitioners' knowledge and experience, as well as the data available to them.

This presentation outlines a methodology that applies Large Language Models to enhance play ideation through analogue and counterfactual reasoning. Basin reports, containing stratigraphic, tectonic, and petroleum system information, from all prospective basins globally are generated using public data and LLMs. The reports are transformed into embeddings to capture relationships between basins and their component geological and petroleum system features, which in turn creates a global, basin-scale similarity index.

LLMs are then further utilised to formulate geological queries, simulate plausible subsurface scenarios, and generate novel play concepts using the basin similarity index and global repository of descriptive basin reports. This includes reasoning across analogous basins to infer missing petroleum system elements, proposing counterfactual configurations, and identifying underexplored basin segments. The generative process is guided by domain-specific prompts and constrained by geological plausibility rules embedded in the basin similarity index.

The approach enables scalable, data-driven play ideation expanding the range of conceptual possibilities and reducing bias. It supports exploration strategy by providing a reproducible framework for identifying overlooked opportunities and enhancing portfolio development.

AI for mineral exploration: What are areas of promise and challenges of AI-assisted subsurface imaging of ore deposits?

Thomas Samuel Hudson^{1,2}, Martin Gal¹, Jack Muir¹, Gerrit Olivier¹

1Fleet Space Technologies Ltd

2ETH Zurich

Given the unprecedented demand for minerals required to drive the green energy transition, it is essential that as a society we find more minerals as fast and efficiently as possible. AI has proven beneficial for empirical analysis of large datasets across various industrial sectors. The challenge of exploring for minerals in the subsurface using dense complementary geophysical and geological datasets collaboratively naturally leads to the question: can AI be harnessed to accelerate and derisk mineral exploration by enhancing geophysical subsurface imaging? Here, we first present an example of where AI shows promise for accelerating the generation of ensembles of forward models that are essential for producing probabilistic images of the subsurface, while also reducing computational cost. We then touch on how the nuts and bolts behind general AI algorithms are having an impact even for conventional multiphysics inversion approaches. Finally, we briefly highlight some challenges for the mineral exploration sector, such as establishing trust in AI-driven results. While AI promises a great revolution across sectors, our findings suggest that the contributions to subsurface mineral exploration may be more subtle, with the biggest challenges to adoption in the mining industry may lie in trust and acceptance of the results rather than technical challenges.

Knowledge Graph–Augmented Reasoning for Accurate and Transparent Geological Inference with Small Language Models

*Maryam Alakkas*¹

¹Freelancer

The energy sector’s adoption of Generative AI presents growing challenges in balancing accuracy with cost. Large Language Models (LLMs) provide strong reasoning capabilities but remain expensive and difficult to interpret, while smaller cost-efficient models are prone to hallucinations, especially when answering numerical or factual geological queries from unstructured text. Retrieval-Augmented Generation (RAG), relying on text-only retrieval, can yield acceptable results, it largely operates as a black box, providing limited visibility into how answers are synthesized, often leading to unverifiable interpretations and inaccuracies.

To isolate the impact of reasoning structure rather than model capacity, both pipelines in this study were evaluated using the same small language model (GPT-4o-mini). This ensures that performance differences arise solely from the data representation and reasoning framework, not from parameter scale differences.

We present a domain-specific Knowledge Graph (KG) framework that enables small models to achieve high-fidelity reasoning with full transparency.

A dual-pipeline evaluation was conducted comparing a Text-Only RAG workflow against a KG-Augmented workflow on a set of geological queries.

In the KG-Augmented approach, unstructured geological reports were transformed into structured triples (Subject–Predicate–Object), forcing the model to traverse explicit logical relationships e.g., (Poolowanna Formation) → [gas_peak_depth] → (2421 m) rather than relying on probabilistic token prediction alone.

Results show that the KG-Augmented approach outperforms the Text-Only baseline. It reduces hallucinations by grounding answers in verified relationships and demonstrates superior precision and stratigraphic consistency. Also, achieved a modest latency improvement of approximately 5% (1.25 s vs. 1.32 s).

Importantly, the proposed architecture introduces reasoning transparency by logging the exact knowledge-graph traversal path used to derive each answer, allowing geoscientists to audit and validate the reasoning process. These findings confirm that high reliability does not require large-scale models. Instead, structured knowledge integration enables small, cost-efficient models to deliver explainable, expert-level performance in high-risk geoscience applications.

Geoscience and AI: A Collaborative Approach to Trustworthy Literature Synthesis

Jesse Lord¹

¹FabrigAI

GeoScienceWorld, a nonprofit collaborative platform that offers journals, eBooks, and GeoRef records from 40+ global societies and publishers, has been exploring how to better support geoscience researchers and professionals by delivering trustworthy answers and insights from generative AI.

Geoscientists need accurate and transparent responses based on trusted information sources. They do not want confidently presented incorrect responses to questions that have no clear answers, nor conclusions based on incorrect or fictitious references – both of which remain common challenges with general-purpose generative AI tools.

To address these needs, a Retrieval-Augmented Generation (RAG) application was developed, designed specifically for geoscientists. Articles from Economic Geology, GeoArabia, Lithosphere, PALAIOS and the Journal of Sedimentary Research were combined with cutting edge AI models and search technology to create an interactive portal that allows natural language interrogation of the literature corpus.

Images and associated captions were extracted and surfaced alongside AI responses for quick visual scanning, helping end users quickly assess the relevance and value of the cited content. Hyperlinks to the source articles cited in the AI responses were provided for transparency, and to facilitate verification and further analysis of source data and information.

The collaboration model was key to the success of this initiative. Subject Matter Experts selected the corpus and framed the domain problems, while AI and search engineers designed the systems to satisfy these challenges. Results were validated first by an internal team of geoscience domain specialists, and then with geoscientists from over fifteen different institutions.

To evaluate the system, geoscientists were given freedom to explore their own research questions and then interviewed about their experience using a structured survey and online meetings. We tested different AI configurations to understand which approaches produced the most useful and trustworthy results. Responses from these interviews and the survey data formed the basis of our evaluation framework.

Our findings challenged the assumption that geoscientists want a standalone, general-purpose chatbot. Participants expressed clear preferences for AI that is integrated into existing research workflows, including guided, multi-step literature search and review

support; contextual assistance when reading individual articles; and AI-enhanced exploration of spatial data.

Rather than representing an either/or choice between augmenting search or interpretation, the results indicate that geoscientists value both: AI that accelerates search by surfacing more relevant results more quickly, and AI that extends beyond search to support literature review, synthesis, and deeper integration with interpretive tools. This suggests that generative AI can deliver the greatest value in geoscience when it supports multiple stages of the research lifecycle.

SESSION SEVEN: IMPLEMENTATION FOR DATASETS

GebPy, a Python-based open source tool for the synthetic generation of geophysical and compositional data of minerals, rocks and whole rock sequences

Maximilian Alexander Beeskow¹, Christoph von Hagke²

¹RWTH Aachen University

²Paris-Lodron-Universität Salzburg

GebPy is an open-source, Python-based framework designed to generate synthetic, internally consistent data of geophysical properties and chemical composition of minerals, rocks, and entire rock sequences. It is built on the concept that the bulk properties of a rock are fundamentally determined by its mineralogical composition and its interaction with fluids like water. The framework addresses a fundamental limitation in geoscientific machine learning: the scarcity of controlled, reproducible, and physically interpretable training data.

GebPy follows a bottom-up modeling strategy in which bulk rock properties result from mineralogical composition and fluid properties. At the mineral scale, properties such as density, seismic velocities, and gamma-ray response are calculated based on chemical composition, crystallographic and elastic parameters which are taken from literature or carefully constrained estimates. These mineral-scale properties are then combined to simulate the bulk properties of a rock, accounting for the proportional contributions of individual minerals, including the influence of pore fluids such as water or hydrocarbons.

Importantly, GebPy focuses exclusively on the generation of synthetic geophysical and compositional data and does not perform subsurface interpretation or machine learning itself. Instead, it provides idealized, internally consistent datasets that can be used as training and testing data to improve the performance, robustness, and interpretability of machine learning models applied to real subsurface observations.

One of the key strengths of GebPy is its scalability. Beyond individual minerals (currently more than 150 minerals) and rocks, the tool enables the simulation of entire rock sequences, generating idealized datasets, free from measurement artifacts and uncontrolled natural variability, that are highly valuable for geophysical applications.

These data allow controlled simulations for algorithm benchmarking, sensitivity analysis, and uncertainty quantification, thereby supporting the development of more reliable AI-assisted subsurface interpretation workflows.

Unlocking Geological Archives with AI: Multimodal Retrieval and UI Design applied to Critical Mineral Intelligence

Rachel Heaven¹, Bharat Bedi², Tim Donovan², Mohab Elkaref², Pierre Josso¹, Andrew Kingdon¹, Vishnudev Kuruvanthodi², Angela Suriyakumaran², Shinnosuke Tanaka², Janice Tjeng³, Isaac Watkins¹

1UKRI – BGS

2IBM

3UKRI – STFC

The Hartree National Centre for Digital Innovation (HNCDI) is a funded collaboration between IBM and UKRI STFC to support companies in learning how AI and machine learning can address their real-world data and challenges. British Geological Survey (UKRI BGS) benefited from a HNCDI project to develop an AI-driven pipeline for extracting critical mineral intelligence from a legacy archive of approximately 40,000 pages of UK mineral exploration reports dating from the 1970s-80s. These documents combine typewritten and handwritten text, maps, sketches, and tables. The size, age and multi-modality make manual exploration or traditional information extraction infeasible. Unlocking this data is valuable to identify UK occurrences of minerals needed for green technologies and the energy transition such as lithium, graphite, and rare earth elements.

Two complementary approaches were implemented:

1. OCR + Ontology Pipeline leveraging IBM's Knowledge Hub for document ingestion, entity recognition, and structured retrieval, grounding answers using a domain ontology, and using state of the art open source OCR (OlmoOCR) for text detection.
2. Multimodal Vision-Language Model (VLM) approach that bypasses OCR entirely, enabling unified representation across text, tables, and images. This approach explores emerging techniques for scalable retrieval, including vector databases (Milvus), OCR-free vision RAG (ColPali), and multimodal embeddings (Nomic).

The prototype integrates a user-centric interface for query formulation, filtering of source pages, relevance visualization via attention heatmaps, and geospatial mapping of extracted entities. Responses include source citations to mitigate hallucination and support provenance—a critical requirement for verifiable geological decision-making. Evaluation remains challenging due to the absence of comprehensive ground truth in an otherwise unexplored archive.

This work demonstrates how advanced AI architectures can transform pre-digital archives into actionable knowledge, addressing scalability, hallucination mitigation,

and multimodal fusion. Beyond critical minerals, the methodology generalizes to other archives, offering a blueprint for applying AI to knowledge extraction from complex geoscience archives at scale.

Optimizing Deep Learning Workflows for Seismic Catalog Building

Rossella Fonzetti¹, Bailo D.¹, Münchmeyer J.²

¹Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy

²Helmholtz Centre for Geosciences, GFZ, Potsdam, Germany

Deep learning models are increasingly adopted in geoscientific applications for detecting and classifying continuous signals. In seismology, these methods are employed to construct seismic catalogs, which are structured databases of earthquake parameters (such as time, location, and magnitude). These catalogs are essential for understanding fault structures. However, the effectiveness of these models depends on decision thresholds that strike a balance between true detections and false positives. Despite their importance, threshold selection remains underexplored and often relies on fixed values.

We tested different threshold values in the P- and S-wave arrival times detection phase (phase picking), attempting to extract statistical information that would enable this choice to be made automatically.

We use the PhaseNet CNN to analyze continuous three-component seismic waveforms and provide three probability time series for the P-wave, S-wave, and noise (Zhu and Beroza, 2019). The arrival times are determined based on the confidence level (threshold) of these functions. The chosen threshold value controls the number of extracted picks and influences the number of final events in the catalog.

We propose a Python workflow that integrates phase picking, event association, and high-precision localization, enabling a visual evaluation of how thresholds impact the seismic catalog quality. We apply the workflow to the Amatrice–Visso–Norcia 2016–2017 seismic sequence in Central Italy. The neural network was trained on the AQ2009 dataset (Bagagli et al., 2023) via the SeisBench platform (Wollam et al., 2022). After exploring thresholds from 0.1 to 0.9, our results show that the optimal value is strongly context-dependent—influenced by seismicity, station distribution, and Signal-to-Noise ratio (SNR)—and cannot be defined a priori.

We discuss data-driven and statistical strategies for automated threshold calibration based on quality metrics from downstream processing. These strategies are applicable both in seismology and other scientific domains requiring optimized signal detection.

AI-Powered Understanding of Geological Uncertainty in Fractured Caprocks

Sarah Perez¹, Florian Doster¹, Hannah P. Menke¹, Ahmed ElSheikh¹, Andreas Busch¹

¹Heriot-Watt University, Edinburgh, UK

Faults and fractures are central to many subsurface systems, controlling fluid migration, storage integrity, and long-term behaviour of CO₂ storage sites. Yet the geological characteristics of these fractures, from roughness at the scale of mineral grains to damage-zone complexity spanning tens of metres, remains difficult to fully resolve. Even when high-resolution images are available, turning geometry into meaningful predictions of conductivity is challenging. As a result, leakage risk and storage performance are often assessed using simplified hydraulic laws that neglect uncertainty and can misrepresent how these systems behave.

Here, we explore how AI can help geoscientists bridge this gap by converting uncertain geological observations into quantitative flow outcomes. We develop a workflow that takes natural fracture images and produces not just a single hydraulic response, but a range of possible behaviours reflecting geological variability.

Rather than evaluating permeability from idealised aperture relationships, we also learn the relationship between fracture geometry and flow using deep-learning surrogates trained on physically grounded datasets. This allows us to understand how the behaviour of rough-walled fractures translates into probabilistic conductivity distributions relevant for reservoir-scale scenarios, while preserving uncertainty related to local features.

We demonstrate the approach using natural sheared fractures from a caprock formation in a natural CO₂ reservoir in Utah, showing how small-scale roughness and uncertainties can propagate into different hydraulic responses. By generating probabilistic rather than deterministic forecasts, this method supports more transparent risk assessment and informed decision-making for geological storage.

More broadly, this work highlights the growing role of AI as a bridge between geological observation and predictive modelling, particularly where uncertainty, heterogeneity and scale interact to control subsurface behaviour.

Ensemble Data Assimilation for Parameter Calibration of Stratigraphic Forward Models Using Well-Log–Derived Thickness Observations

Liang Wang¹, Amin Nadimy¹, Daqian Shi¹, Charles Danquigny², Gerard Massonnat², Jean-Louis Lesueur², Cedric John¹

¹Digital Environment Research Institute (DERI), Queen Mary University of London

²TotalEnergies

Stratigraphic forward models (SFM) are widely used to simulate sedimentary architecture, but uncertain input parameters often limit their predictive skill. Manual tuning of parameters is time-consuming and rarely quantifies uncertainty, which hampers the wider application of SFMs. We present an AI-enabled, uncertainty-aware workflow that couples an SFM with ensemble data assimilation (DA) to calibrate model parameters using observations available from well logs. As an initial target, we focus on thickness-related measurements, with optional extensions to facies proportion metrics. To enable robust DA in high-dimensional settings, we first perform global sensitivity analysis (GSA) using Sobol indices to identify the parameters that most strongly control thickness and related outputs. High-dimensional inputs such as time-dependent forcings and functional relationships defined by response curves (e.g., production–depth functions) are reduced to a small set of assimilable controls (e.g., multipliers and axis shifts) that preserve physical structure while remaining identifiable. The forward model is executed as a black-box native simulator, and scalar metrics are extracted from volumetric outputs to form the data–model mismatch. The resulting parameter set provides a principled pathway from sensitivity screening to ensemble-based calibration (e.g., ES-MDA), producing posterior parameter distributions and uncertainty-bounded predictions. This work demonstrates how probabilistic inference can be integrated with process-based stratigraphic simulation to support uncertainty-aware forecasting and digital-twin–style model updating in geoscience applications.

Transformer-Based Geotechnical Classification of Borehole Logs with Benchmarking of Uncertainty Quantification Methods: an Italian case study.

Roberto Cilli^{1,2}, Guillaume Caumon¹, Marianne Clausel², Federica Cotecchia³, Nunzio Losacco³, Nicola Amoroso⁴, Ester Pantaleo⁴

¹GeoRessources

²Université de Lorraine

³Polytechnic University of Bari

⁴University of Bari

Geological borehole descriptions are a fundamental resource for subsurface modeling, yet they are often stored as unstructured text, limiting their usability for automated analysis. While a growing number of studies have applied natural language processing to geological texts, most approaches disregard the semantic continuity between adjacent lithological descriptions and overlook the structured nature of stratigraphic successions within borehole logs. In this study, we introduce a context-aware sequence labeling framework that applies natural language processing and positional encoding to classify lithological units from borehole log descriptions modeled as structured sequences by combining a pre-trained Sentence-BERT model for semantic encoding with a single-layer Transformer encoder that captures contextual and positional relationships. We evaluate our approach on a dataset of manually labeled boreholes from the Pianello hillslope, located in Southern Italy, focusing on five lithological classes relevant to slope stability analysis. The proposed method achieves an accuracy gain of approximately 15% compared to a baseline random forest classifier fed with Sentence-BERT embeddings, revealing that the context of a lithological description can significantly improve the classification performance of NLP algorithms. Furthermore, we show that the proposed architecture is lightweight and scalable, enabling rapid processing and confirming its practical applicability in real-world scenarios especially in low-resource computing environments.

Finally, a comparison between benchmark uncertainty quantification (UQ) algorithms, including Bayesian NN (Blundell et al. 2015), Deep Ensemble (Lakshminarayanan et al. 2016) MAPIE Conformal Learning (Taquet et al. 2023, Paris Saclay) and Gaussian Processes (Rasmussen and Williams, 2005) has been conducted. Preliminary results highlight that, while Deep Ensembles are among the most computationally viable UQ methods in low-resource settings, their reliability remains limited: uncertainty estimates are often poorly calibrated, epistemic and aleatoric components are not clearly separable, and unexpected behaviors when synthetic inputs are considered.

POSTER PRESENTATIONS

Responsible resource ownership: Operationalising AI in ore movement

Michelle Keegan¹, Cael Gniel¹, Brice Gower¹

¹Augmented Technologies

Across the operational mining environment, there are significant benefits to be had through the adoption of AI and machine learning. None more so than in ore movement, the golden thread connecting the investment in building geologic knowledge in the resource models, to the investment in recovery of ore at the plant. If this thread breaks, all other investments under deliver.

While investors seek certainty in mining investments, and the underlying performance to plan on tonnes and metal recovery, communities and stakeholders expect miners to maximise the life of an orebody through responsible mining practices.

In order to preserve the knowledge in the underpinning block model, through the chaos of blasting and so track ore movement, is at the heart, responsible resource ownership. In the absence of more advanced AI solutions, it is a challenge only answered sub-optimally in the past through physical measurement systems. Never have these systems either provided the accuracy needed or confidence across an entire blast.

The development of AI-driven 3D blast movement solutions, now makes the accurate tracking of ore after blasting possible by relocating each 1m³ block from an insitu position to the muckpile. It has become a necessary part of the grade control workflow with mining companies across the globe. Applicable across hard rock metalliferous surface operations, the geologist, mining engineer and metallurgist are presented with a practical solution to inform the dig plan, the stockpile plan and processing plan.

Combining domain knowledge and data science and taking advantage of advancements in compute power and AI, the everyday geoscience problem of understanding ore movement in mines is possible. And more importantly the value of reduced dilution, one of the highest leverage improvements in mining can be realised.

Using machine learning for seabed sediment mapping

Ben Marchant¹, Dayton Dove¹, Mary Mowat¹ and Andrew Finlayson¹

¹British Geological Survey

The British Geological Survey has a long history of utilising its earth science expertise to produce maps of subsurface properties. Domain experts integrate their understanding of the processes driving spatial variation with available measurements to draw contours which reflect the variability of properties such as the thickness of superficial deposits or the composition of seabed sediments. Machine learning methods could be used to rapidly integrate different types of continuous sensor data and point observations of the subsurface to produce high resolution maps of that property. However, a workflow wholly based on machine learning neglects the experience and expertise of earth scientists. Although the resultant maps are likely to closely reflect the training data, it is also likely to be difficult to interpret the causes of variation and local unrealistic artefacts might occur where the training data is insufficient to reflect the earth science context.

We discuss how machine learning can supplement expert knowledge with particular reference to the BGS Predictive Seabed Sediments (UK) digital maps which were released in 2025. These maps were produced by using multivariate distributional random forests to integrate almost 40,000 point measurements of the proportions of sand, gravel and mud with covariate data such as bathymetry data, morphometric derivatives (at multiple spatial scales), as well as hydrodynamic data layers (currents and tidal). Experts were closely involved in the data selection, data cleaning, interpretation and validation of the results leading to high resolution maps which not only accurately reflected the observed data according to statistical validation metrics but were also consistent with the expectations of these experts. More generally, we seek to design iterative workflows, where expert opinion informs the application of machine learning methodologies and the results from these methodologies suggests new hypotheses to experts regarding the drivers of variation in subsurface properties.

Groundwater model emulation with Recursive Neural Networks

Matthew Arran¹, Kirsty Upton, Chris Jackson, Setareh Nagheli, Ben Marchant¹

¹British Geological Survey

With changes in climate and water demand placing increasing pressure on UK groundwater resources, water companies need to be able to rapidly and reliably simulate a wide range of scenarios for precipitation, evapotranspiration, and borehole abstraction. But models derived purely from historical data are unreliable in changing conditions, while physics-based groundwater models require time and expertise to run. Here, we show that a Recursive-Neural-Network-based emulator of a physics-based model can make predictions that are both rapid and reliable, giving water companies a tool for both operational decision-making and long-term planning. We discuss the practical importance of representative training data, user-friendly interfaces, and clear uncertainty communication. Finally, we indicate the broader applicability of our work.

Distribution-agnostic graph transformers for landslide modelling

Itahisa Gonzalez Alvarez¹, Alessandro Novellino¹, Kathryn Leeming¹, Holly Hourston¹, Erin Mills¹, Rahul Chahel¹

¹British Geological Survey

Natural hazards such as landslides, floods, and earthquakes pose significant risks to communities worldwide, with climate change amplifying the frequency and severity of extreme events. Artificial intelligence approaches are opening new pathways to improve hazard modelling, improving our understanding of their effects and enabling more accurate predictions. Graph Transformer neural networks (GTNNs) represent a recent development in deep learning. They are designed to capture complex relationships in data structured as connected graphs which, thanks to the attention mechanism, can explore and preserve spatial and temporal relationships present in the data. These characteristics make GTNNs particularly well-suited to study natural hazards, for which complex interactions between the local geography, geology, hydrology, and climate play key roles in the severity and extent of their effects.

In this study, we model landslide areas (LAs) in the Emilia-Romagna region of Italy after two extreme rainfall events. These unprecedented events took place within days of each other in May 2023, causing over 80,000 landslides, widespread flooding, nearly 40,000 evacuations and 17 casualties. For this purpose, we pair a GTNN with a custom loss function that allows us to assign relevance values to landslides depending on their area, therefore making it possible to better model larger but less frequent landslides that might have a bigger impact on local populations. This approach helps us tackle the issue of LAs generally presenting very skewed distributions, with most landslides covering small areas and only a small minority of them spreading over larger areas. To optimize the quality of our predictions, we apply a range of relevance functions to our target variable and test several network architectures and hyperparameter choices. Our results suggest this approach can predict the location and extent of landslides triggered by extreme rainfall events, which might help support mitigation strategies that protect lives and infrastructure.

AI-Powered Extraction and Visualization of Historic Well Logs for CCUS Projects

*Usman Ayobami*¹, *Autumn Haagsma*²

¹CoreExtract

²Michigan Geological Survey

Historic geophysical well logs are essential for subsurface energy projects, including Carbon Capture, Utilization, and Storage (CCUS), but they are often scanned, inconsistent, and unstructured, making manual digitization slow, costly, and error-prone.

We developed Core Extract, an AI-powered extraction engine, to automatically convert scanned well logs into clean, structured digital data. Our workflow combines AI-driven recognition with human verification to ensure high accuracy, scalability, and reliability. The extracted data are delivered in formats suitable for analysis, including JSON and Excel, and can be visualized through wellbore diagrams linked to geologic formations.

In collaboration with the Michigan Geological Survey, we applied this approach to thousands of legacy well logs across Michigan, directly supporting a DOE-funded project aimed at de-risking CCUS. Our method enables rapid, cost-effective creation of a searchable digital database and visualization tools, saving significant staff time and improving data accessibility.

This work demonstrates the potential of AI to accelerate geoscience workflows, improve data integration, and enhance subsurface energy project planning. We highlight lessons learned on combining automated extraction with domain expertise and discuss how this approach can scale to other energy and environmental datasets.

GEOLAB+: An AI-Enhanced LINE Chatbot and Virtual Mineral–Rock Laboratory for Improving Geoscience Learning Performance

*Vimoltip Singtuen*¹

¹Khon Kaen University

Hands-on learning in mineralogy and petrology often faces structural limitations, including restricted laboratory hours, variable access to thin-section collections, and limited instructor availability for real-time support. To overcome these barriers, we developed GEOLAB+, an AI-enhanced instructional ecosystem integrating a Virtual Mineral–Rock Laboratory with a LINE-based AI Chatbot that functions as a Teaching Assistant (TA) for geoscience students. The system utilizes high-resolution mineral and thin-section images stored in a virtual repository, which is connected to the Chatbot through MAKE (Integromat) workflows and the Gemini LLM, enabling automated retrieval of specimen information. The Chatbot assists students in identifying minerals, locating specimen numbers, interpreting petrographic textures, and answering conceptual questions—mimicking the responsiveness and clarity of a human TA. Importantly, the AI's responses are strictly constrained to a curated dataset consisting of instructor-authored laboratory manuals, mineral identification guides, and reference images. This closed-domain design ensures accuracy, prevents hallucination, and guarantees that students receive reliable and curriculum-aligned explanations. From 2021–2024, the system was implemented in mineralogy and petrology courses (n = 268). Students demonstrated substantial improvements: confidence in mineral identification increased by 35–48%, mean self-evaluation scores improved from 2.84 → 4.12/5, identification test accuracy increased by 27%, and ability to interpret thin-section textures improved by 52%. Satisfaction scores averaged 4.63/5, with 94.7% agreeing that the Chatbot enhanced learning efficiency, and 91.3% reporting reduced anxiety during laboratory practice. GEOLAB+ demonstrates how AI-driven, closed-domain chatbots can transform geoscience education by providing continuous, personalized, and curriculum-accurate learning support. Future directions include AR/VR integration, dataset expansion, and adaptive learning analytics for tracking student progress.

AI-Driven Optimization of Reservoir Management and Production Forecasting

Mohammed Abubakar Mohammed¹,

¹Federal University of Lafia

The optimization of reservoir management and production forecasting is crucial for maximizing hydrocarbon recovery and minimizing costs in the oil and gas industry. This presentation presents an approach to the AI-driven to optimize reservoir management and production forecasting by leveraging machine learning and deep learning techniques. Reservoir management is a critical aspect of maximizing oil and gas recovery while minimizing operational costs. Artificial Intelligence (AI) and Machine Learning (ML) have the potential to transform how reservoirs are managed, providing more accurate predictions and automated optimization.

Therefore, my approach integrates data-driven modeling, predictive analytics, and optimization algorithms to predict hydrocarbon production rates, identify optimal production strategies, and optimize well placement. The proposed framework is applied to a real-world reservoir dataset, demonstrating significant improvements in prediction accuracy and optimization outcomes. The results show that AI-driven optimization can lead to increased hydrocarbon recovery, reduced costs, and improved decision-making. This study highlights the potential of AI in transforming reservoir management and production forecasting, enabling more efficient and sustainable operations in the oil and gas industry.

This presentation focuses on how AI-driven tools are utilized for optimizing reservoir management and enhancing production forecasting, why reservoir management matters, traditional reservoir management vs AI driven management.

Finally, a case studies and industry application of AI driven optimization of reservoir management and production forecasting will be discussion. While concluding on future prospects and a closing thoughts.

Deep Learning for Seismic Facies Classification in the Sergipe-Alagoas Basin

Robson Wants¹, Carolina Danielski Aquino¹; Rodrigo Brunetta¹

¹Federal University of Parana

Seismic facies characterization is a method used to investigate subsurface depositional components, contributing to the development of depositional models in sedimentary basins. Traditionally, the process of interpreting seismic data for seismic facies identification is predominantly manual and interpretative, demanding considerable time to detail areas of interest. Given the increasing volume of seismic data, manual processing becomes inefficient and hinders the quantification of associated uncertainties, overloading the processing capacity of a human interpreter in a timely manner. From the perspective of optimizing the recognition of these seismic structures, this work proposes the implementation of a deep learning technique to automate the recognition of features of interest, allowing the interpreter to focus on those most pertinent to their study. To perform this research, a conventional seismic survey from the Sergipe-Alagoas Basin, located in the offshore portion of northeastern Brazil, was used. In this work, a convolutional neural network and semantic segmentation through a U-Net type classification techniques within the scope of artificial intelligence and computer vision were developed to perform the task of classifying and recognizing channel erosion and infill patterns in seismic images, which are recurrent features in the studied basin. The code was written using Python, and the seismic analysis was performed using free software such as OpendTect. Statistical metrics such as Dice Loss were adopted in the evaluation of the deep neural network during the training and validation phases. The results using different seismic lines were satisfactory, with the U-Net algorithm successfully identifying and differentiating erosion and infill regions along the extent of the sedimentary basin. These results indicate the effectiveness of the algorithm for seismic facies classification.

iGeologist: The Connected Ecosystem of Rocks, Sensors, AI, and Geologists

James Cleverley¹, Dave Lawie¹

1IMDEX

Artificial intelligence is rapidly reshaping the minerals industry, influencing everything from predictive maintenance to discovery targeting. As exploration becomes more data rich, geologists are increasingly responsible for building robust Earth Knowledge to support confident decision making throughout the life of a project. With the growth of rapid sensing technologies, such as geochemistry, imagery and petrophysics, AI is becoming an essential partner, helping geologists interpret complex datasets, and deciphering the language of rocks.

Rather than viewing AI systems as separate technical tools, they should be seen as collaborators that enhance geological expertise. These technologies improve productivity and uncover subtle patterns that traditional methods may miss. By integrating AI into their workflows, geologists can make more accurate, timely decisions that advance Ore Body Knowledge, improve discovery outcomes, and support more sustainable mining practices.

A clear example is the use of rapid driller collected natural gamma data, which can immediately influence sampling and logging decisions. This information can also serve as a foundational dataset for modelling and visualising the 3D subsurface. Delivering real time insights directly to logging geologists allows them to focus on interpretation while reducing the burden of data management and engineering.

This talk will showcase real-world applications of driller-acquired natural gamma data in core-yard logging workflows and demonstrate how integrating this data with geochemistry improves geological understanding. It will outline practical examples, highlight workflow efficiencies, and show how analytics and AI can be embedded seamlessly into daily decision-making. Bringing meaning to information.

The integration of AI and advanced data ecosystems marks not just a technological step forward but a shift in how geologists work. Embracing these tools strengthens expertise, supports informed decisions, and ultimately leads to more successful discoveries. The future of mineral exploration lies in the partnership between human insight and artificial intelligence.

AI assisted drought monitoring with open CHIRPS rainfall data: a reproducible notebook workflow for geoscience education

Nimatallahi Masuud¹, Ahmed Adeyekun(West Chester University of Pennsylvania)

¹INFINION Technology

²West Chester University of Pennsylvania

Drought monitoring is a core geoscience task with clear value for risk awareness, agriculture, and water management, yet many classroom and practitioner workflows remain manual or difficult to reproduce. This presentation introduces a simple, open data, AI assisted pipeline for drought monitoring using CHIRPS v2.0 monthly rainfall data. The workflow follows six steps designed for transparency and teaching. First, we define an area of interest using an openly available national boundary (Nigeria as the default example). Second, we download CHIRPS monthly GeoTIFF rainfall data for a user selected period and automate preprocessing, including clipping to the area of interest and computing area mean monthly rainfall. Third, we calculate drought relevant indicators by deriving a monthly climatology and standardized rainfall anomalies (z-scores) by month of year. Fourth, we create an interpretable drought label using a threshold on the anomaly time series. Fifth, we train a lightweight machine learning classifier (logistic regression) using simple features, including one month lag anomalies, three month aggregated anomalies, recent rainfall sums, and seasonality (month index). Sixth, we evaluate performance using time aware cross validation and report accuracy focused metrics (precision, recall, F1, ROC-AUC), alongside clear visualizations of rainfall, anomalies, and predicted drought probability.

The main contribution is a fully reproducible notebook that demonstrates data integration, interpretation, and automation with AI tools while supporting open, collaborative educational reuse in geoscience courses.

Seamount detection using a convolutional neural network

Zhenyu Wang^{1,2}, *Anthony Brian Watts*²

1Institute of Earthquake Forecasting, China Earthquake Administration

2 University of Oxford

The seafloor is littered by seamounts, most of which are volcanic in origin. The development of new technologies such as the single beam echo sounder and the multibeam (swath) bathymetry systems since the mid-20th century radically altered our views of the nature of the ocean floor. Recent developments in the construction of high-resolution seafloor topography models derived from shipboard bathymetry data, combined with target recognition technology based on machine learning may further transform our knowledge. Here we use a convolutional neural network within the Pytorch framework, together with the along-track echo-sounder data labeled seamounts of Hillier & Watts (2007) as a ground truth data set, to train a seamount recognition model. The input data include the high resolution SRTM15+V2.7 (GEBCO 2025) bathymetry model, and its derivatives such as normalized topography, gradients along four directions (North, Northeast, East, and Southeast), and curvature. Given that the ground truth data cannot identify all seamounts, we assign different weights to positive and negative samples when calculating the loss. Besides, we divide unknown regions by distance from labeled seamounts. For regions distant from labeled seamounts, we assign higher suppression weights to make heat values at these background zones keep low. Conversely, as for regions close to labeled seamounts, we systematically lower the suppression weights to make unlabeled yet genuinely existing seamounts to be found. Preliminary results in two pilot study areas on old and young oceanic seafloor in the Pacific Ocean indicate that machine learning yields up to a factor of 2 more seamounts than were identified in the training data set. This research demonstrates the feasibility of using AI to detect volcanoes not only on Earth but the terrestrial planets.

Hillier, J.K., Watts, A.B., 2007. doi:10.1029/2007GL029874.

Tozer, B., Sandwell, D.T., Smith, W.H.F., et al. 2019. doi:10.1029/2019EA000658

RockGPT, a Researcher-Curated, Self-Hosted Large Language Models for Trusted Knowledge Management in the Geosciences

Daniele Bailo¹, Valentino Lauciani¹, Raffaele di Stefano¹), Fabrizio Bernardi¹

¹Istituto Nazionale di Geofisica e Vulcanologia - INGV

The increasing adoption of Large Language Models (LLMs) in geoscientific research has raised several challenges, including epistemic and ethical questions concerning the origin, reliability, and governance of the scientific knowledge used by these systems. Most contemporary LLMs are trained on large-scale web-derived corpora, where peer-reviewed scientific information is interwoven with heterogeneous, non-validated content. While such models may perform well in general contexts, this knowledge mixture poses serious issues when applied to specialized scientific domains requiring accuracy, traceability, and methodological rigor.

We present RockGPT, a fully self-hosted, open-source Large Language Model system for trusted knowledge management in geoscience, grounded in researcher-curated, peer-reviewed literature. RockGPT is based on the premise that researchers are not merely end-users of AI systems, but custodians of validated domain knowledge, responsible for selecting and governing the corpora used for AI-assisted reasoning. To operationalize this principle, RockGPT employs Retrieval-Augmented Generation (RAG) to anchor model outputs to controlled, and continuously updatable scientific sources managed within institutional infrastructure.

The system is implemented using a modular three-tier architecture combining local LLM inference, a web-based user interface, and a vector-based retrieval pipeline. RockGPT was evaluated on a curated corpus of peer-reviewed geoscience publications focused on Italian tectonics and seismology. Multiple open LLMs were tested in baseline and RAG-enhanced configurations on tasks of knowledge retrieval and scientific reasoning and synthesis.

Expert qualitative evaluation shows that RAG-enabled configurations significantly outperform baseline models in terms of content correctness, contextual relevance, and reasoning coherence. Statistical analysis confirms that these improvements are primarily driven by the quality and governance of the underlying knowledge rather than by model scale alone.

Future development will focus on expanding and structuring the curated knowledge base to support context-specific reasoning across geological domains, and on integrating institutional earthquake reports to support and partially automate scientific and technical reporting in disaster monitoring scenarios.

A Deep Learning-based Workflow for the Automated Focal Mechanism Determination in Italy

Flavia Tavani¹, P. Artale Harris¹ (INGV), L. Scognamiglio¹ (INGV), M.-A. Meier² (Department of Earth and Planetary Sciences, Institut für Geophysik, ETH)

¹Instituto Nazionale di Geofisica e Vulcanologia - INGV

² Department of Earth and Planetary Sciences, Institut für Geophysik, ETH

In modern seismology, the rapid and accurate characterization of seismic sources following an earthquake is a fundamental task. Most observatories currently compute moment tensor solutions for events exceeding specific magnitude thresholds to ensure reliability. For instance, the National Institute of Geophysics and Volcanology (INGV) provides routine solutions for moderate to large events ($M_w \geq 3.5$) using established methods (Scognamiglio et al., 2009). However, characterizing smaller events remains challenging due to low signal-to-noise ratios and limited station coverage.

Machine learning (ML) techniques have emerged as powerful tools to address these limitations, particularly in improving the prediction of first-arrival seismic wave polarities. These ML-derived polarities can be effectively integrated into traditional frameworks to compute robust focal mechanisms. In this study, we implement a workflow that bridges deep learning polarity predictions with standard focal mechanism estimation techniques, focusing on the tectonic setting of the Italian Peninsula.

Our methodology consists of two primary stages. First, we trained a Convolutional Neural Network (CNN) for polarity prediction using the INSTANCE catalog (Michellini et al., 2021), which provides the high-quality, manually reviewed data essential for supervised learning. Second, we validated the model's performance by analyzing approximately 4,700 earthquakes that occurred in Italy between January 1 2021, and January 1 2025, with magnitudes below 4.5.

To benchmark our results, we selected a subset of earthquakes with existing Time Domain Moment Tensor (TDMT) solutions (Scognamiglio et al., 2006). Using the polarities predicted by the CNN, we computed focal mechanisms using the SKHASH code (Skoumal et al., 2024). The accuracy of these solutions was then evaluated against the TDMT catalog using Kagan angle analysis (Kagan, 1991) to quantify the rotation between double-couple sources. Our ultimate objective is to apply this automated procedure to the seismic catalog of the L'Aquila sequence (Fonzetti et al., 2025), enhancing our understanding of its high-resolution kinematic evolution.

From limited scenarios to robust subsurface insights: A practical autonomous workflow for asset management

Mathieu Ducros¹, Kognitus team

¹Kognitus

This work presents a systematic autonomous workflow for uncertainty quantification and the construction of proxy models for instantaneous predictions, tailored for broad geosciences applications. The tool connects to existing physics-based simulators, ingests user-defined uncertain inputs and quantities of interest, and automatically orchestrates simulation campaigns to build multi-fidelity machine-learning surrogates capable of representing multi-dimensional outputs, all under strict, rule-based control. Starting from an execution-graph description of the workflow, the system generates and runs batches of simulations, adaptively refines the design of experiments, and terminates when a user-specified prediction-accuracy criterion is satisfied.

The resulting validated surrogates provide instantaneous predictions for new parameter sets and serve as a foundation for robust statistical analyses, including global sensitivity analysis, efficient model calibration, and comprehensive uncertainty propagation. All decisions within the workflow are governed by transparent, rule-based heuristics, which reduce manual expert effort, shorten study turnaround time, and lower computational cost while ensuring the rigor and transparency required in decision-making and regulatory-driven contexts.

For operational teams, this approach functions like a “direct flight” to decision-ready insight: instead of managing a fragmented process with multiple manual stops to run scenarios, reconcile outputs, and iterate analyses, users specify their objectives and uncertainty ranges once, and the workflow delivers an integrated set of metrics that robustly explores the full uncertainty space, clarifies system behavior through fully multidimensional sensitivity analysis, and quantifies consistent probabilities of desired outcomes (probability of success) or potential issues (probability of failure) while explicitly accounting for dependencies between coupled physical mechanisms.

The methodology finds direct application in sweet-spot identification, reservoir delineation, and forecasting of CO₂ and pressure plume fate, among others. We showcase selected practical cases to demonstrate how the workflow moves beyond simplistic scenario-based analyses to provide rigorous probability assessments, paving the way for agent-oriented automation of subsurface decision processes.

Spectro-Temporal Characterisation of Urban Traffic: A Deep Learning Approach to Estimating Vehicles from Seismic Data

Luke Potts¹,

¹Manchester Metropolitan University

With the increasing pressure to optimise urban mobility and traffic management to move towards smart cities within the scope of industry 4.0, the monitoring and mitigation of traffic levels has become an increasingly important task. Current monitoring methods such as Automatic Number Plate Recognition (ANPR) and Inductive Loops either lack the granularity required for in-depth vehicle characterisation, bring extreme operational expenditure or face stringent data protection regulations such as GDPR. They also present a difficult trade off between data quality and operational viability, with the capturing and storage of Personally Identifiable Information (PII) creating increasing legal and ethical overheads.

This research proposes a cost effective and “privacy-by-design” approach to vehicle aggregation by leveraging urban seismology. By utilising Data Science and Computer Vision techniques, this research uses the seismic footprint left behind by vehicles as distinctive visual patterns. This involves using a low cost Raspberry Shake seismometer to collect 1D raw ground vibration signals that can be transformed into time-series spectrograms. These visual representations allow for the application of complex Deep Learning (DL) architectures such as Convolutional Neural Networks (CNN’s), Vision transformers (ViT’s) and unsupervised approaches such as Deep Convolutional Embedded Clustering (DCEC) to detect vehicle aggregations based on their distinct seismic footprint.

Results from this research demonstrated that frequency analysis can be effectively used to correlate seismic activity with traffic flow by uniquely identifying traffic events based on specific vehicle characteristics, thereby offering a computationally inexpensive and non-invasive alternative to video surveillance. CNN’s demonstrated consistent performance across varying traffic densities, this establishes a robust foundation for using seismic signals as proxies for vehicle classification and smart city traffic analysis.

Deep Learning for Geothermal Frontier Exploration: Identifying Hydrothermal Alteration in Puga Valley, Ladakh, Using PRISMA Hyperspectral Data and CNNs

Mohammad Taqi Daqiq¹, Ravi Sharma¹, Harshinee R¹

¹Indian Institute of Technology Roorkee²Université de Lorraine

Geothermal energy represents a cornerstone for sustainable development in high-altitude regions, yet mapping its surface manifestations remains a logistical and technical challenge. The Puga Valley in Ladakh, India's most promising geothermal field, provides a complex geological backdrop where traditional mapping is often hindered by extreme terrain and subtle mineralogical variations. This proposed study aims to bridge the gap between advanced spaceborne hyperspectral imaging and deep learning to automate the detection of hydrothermal minerals.

This study utilizes PRISMA hyperspectral data, leveraging its high spectral resolution across the short-wave infrared (SWIR) range, a region critical for identifying diagnostic absorption features of alteration minerals, such as kaolinite, chlorite, and silica. To address the limitations of traditional spectral angle mappers, this research will implement a Convolutional Neural Network (CNN) framework. Unlike conventional pixel-based classifiers, the CNN will be designed to account for spatial context and textural patterns, which are essential for discriminating hydrothermal assemblages in the heterogeneous wetland and weathered environments of Puga.

The methodology involves rigorous atmospheric correction using the FLAASH algorithm, followed by dimensionality reduction via Principal Component Analysis (PCA) to isolate key variance. We will train the model using a curated dataset of spectral signatures validated by the USGS spectral library. By comparing CNN performance with standard machine learning models, such as SVM and MLP, we expect to demonstrate that deep learning can significantly increase mapping accuracy, even in the lower signal-to-noise ratios inherent in spaceborne sensors. The final output will be a high-resolution mineral evidential map, providing a low-cost, scalable tool for targeting geothermal resources in remote Himalayan regions.

Integrating Multisource Geodata Using AI Tools for Enhanced Mineral Mapping in Algeria

Hamida Diab¹,

¹University chikh Larbi tebessi Tebessa Algeria

The increasing availability of geological, geophysical, and remote sensing datasets presents both an opportunity and a challenge for mineral exploration, particularly in data-rich but underexplored regions such as Algeria. This study aims to develop an integrated framework for the processing, interpretation, and automation of multisource geodata using Artificial Intelligence (AI) tools to improve mineral mapping accuracy and efficiency. The proposed approach combines geological maps, geochemical data, and satellite imagery (Landsat 8, Sentinel-2, and ASTER) within a Geographic Information System (GIS) environment. Machine learning algorithms—such as Random Forest, Support Vector Machines, and Convolutional Neural Networks—are applied to extract, classify, and predict mineralized zones based on spectral and structural features. Data fusion techniques are employed to merge spatial layers and enhance the detection of lithological units and alteration zones associated with ore deposits. Preliminary results indicate that AI-assisted data integration significantly improves the identification of prospective mineral zones compared to traditional methods. The study also demonstrates how automated workflows can reduce interpretation time and human subjectivity in geological analysis. This research contributes to the modernization of mineral exploration practices in Algeria, offering a replicable model for other regions with similar geological contexts. Ultimately, integrating AI-driven data analytics supports decision-making for sustainable resource management and promotes innovation in the geoscience sector.

Development of an Intelligent Chatbot DAISY for Natural Disaster Information Dissemination

Amanda He¹, Alice Zou², Dominick Pelaia³, Nathan He⁴, Sadie Jones³, Flora Zhu⁵

1Valley Christian High School

2California Institute of Technology

3L&N STEM Academy

4Ocean Lakes High School

5Great Neck South High School

Natural disasters pose a great threat to communities worldwide, creating a pressing need for tools that rapidly disseminate accurate information. We present DAISY (Disaster Awareness and Information Serving You), a conversational AI chatbot that enhances public access to real-time disaster information. DAISY integrates Large Language Models (LLMs), GPT-3.5 Turbo and Zephyr-7B Alpha, with Retrieval-Augmented Generation (RAG) to deliver accurate, context-specific responses on environmental disasters such as hurricanes, volcanic eruptions, wildfires, tornadoes, earthquakes, subsidence, and floods. Real-time data is fetched from the Global Disaster Alert and Coordination System (GDACS).

We evaluated the two models (GPT-3.5 Turbo and Zephyr-7B Alpha with RAG) on three metrics: answer length (word count), answer depth (human evaluation), and answer accuracy (verified using ChatGPT-4o with human supervision), with a score of 2 out of 3 metrics constituting a win. The Zephyr-RAG system outperformed the fine-tuned GPT model in six of seven disaster categories, providing longer, more detailed, and more accurate responses. By leveraging RAG, the Zephyr-based chatbot was able to retrieve up-to-date external information and provide direct source citations in its responses. Utilizing relevant real-world information improved the accuracy and relevance of the responses, as reflected in higher accuracy and depth scores.

Using earlier, simpler models allows for a clearer attribution of performance improvements to the implementation of RAG. Nonetheless, future work includes replicating this analysis using newer-generation large language models (ChatGPT-5.2 and Zephyr-7B Beta) to assess whether the advantages of RAG persist as base model capabilities continue to evolve.