ABSTRACT BOOK

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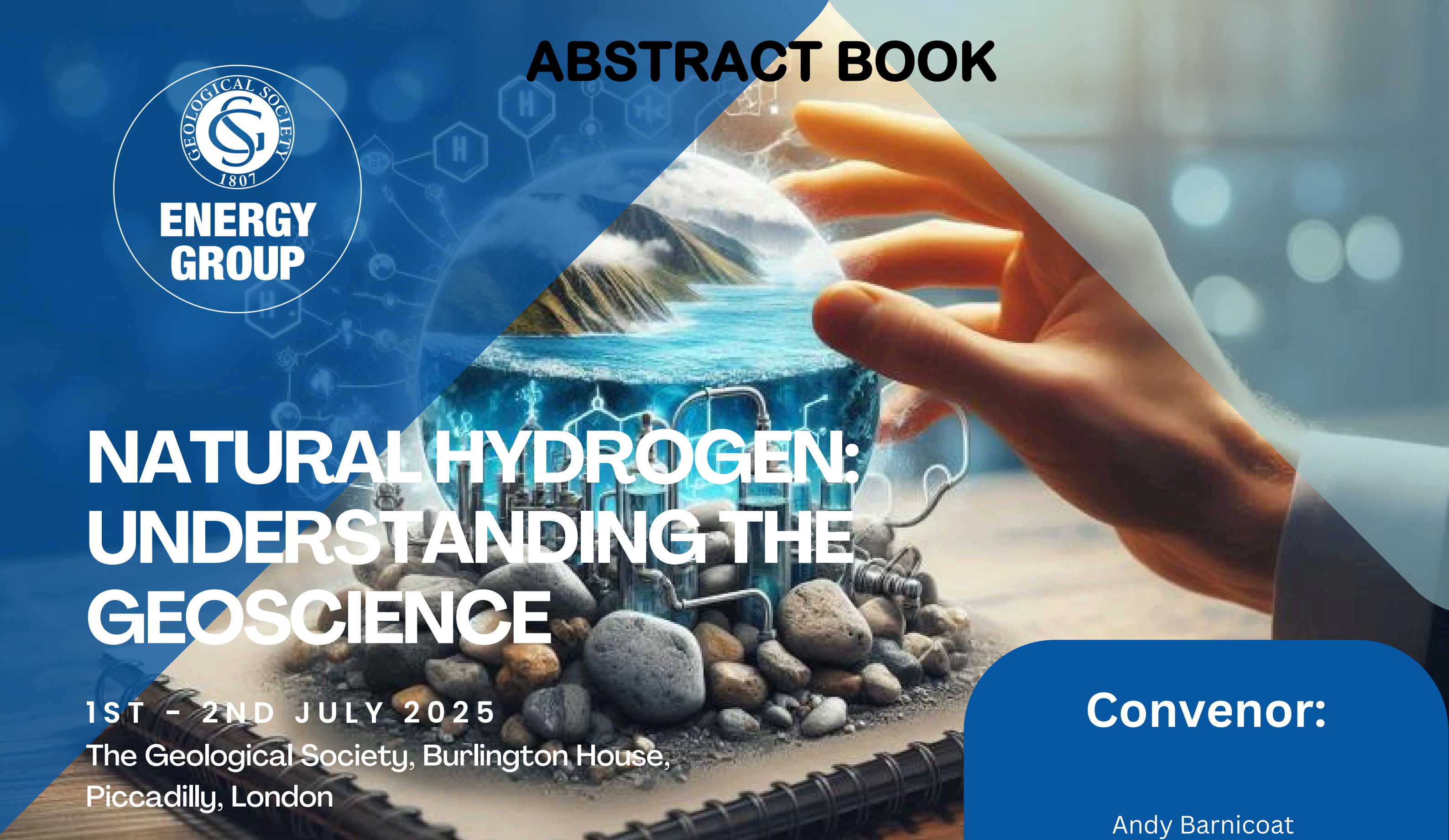

NATURAL HYDROGEN: UNDERSTANDING THE GEOSCIENCE

1ST - 2ND JULY 2025

The Geological Society, Burlington House, Piccadilly, London

An AI rendition of natural hydrogen

Natural hydrogen exploration has officially begun, with over 40 companies focussed on natural hydrogen exploration, and a dozen or more wells drilled in the search for hydrogen reserves. Additionally concerted research has begun into how geological hydrogen generation can be stimulated artificially. But what have we learned about the geology of hydrogen and how to exploit it? Following on from the successful Energy Group natural hydrogen conference in 2023, this conference will focus on the developments in natural hydrogen geoscience, review the potential realised so far, and assess what uncertainties remain.

- **Natural Hydrogen Systems** – Source: potential yields, quantification, ideal protoliths; Migration: gas-phase v. solution, concentration v. dispersal; Sealing & Entrapment: Loss mechanisms (organic & non-organic), mixing & dilution, reservoir deliverability and energy, static vs dynamic.
- **Geological Hydrogen Stimulation** – ongoing research, cross overs between stimulated and natural hydrogen, sub surface vs above ground stimulation, catalysts and low temperature activity
- **Technology & Data in Hydrogen Exploration** – new vs repurposed technology and data related to natural hydrogen, cross over between Mining, Storage and Oil & Gas datasets and techniques, new interpretation and processing approaches, remote sensing and hydrogen detection, application of AI.
- **Geotectonic Settings & Exploration Plays**: Geological make-up of natural hydrogen systems in different geotectonic settings from deep crystalline rocks to sedimentary basins, building play models and fairway analysis, screening, risking and ranking natural hydrogen targets, synergies with other transition geoscience subjects.
- **Exploration and Discoveries Case Studies**: Ongoing exploration projects, data and methodologies, results & forward plans, discoveries and plans for development.

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Natural Hydrogen - Understanding the Geoscience
1 - 2 July 2025

Hybrid Conference, Burlington House, and Zoom, BST

Final Programme

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09.35	**The character and habitat of natural hydrogen resources** Chris Ballentine, *University of Oxford*
10.00	**Hydrogen systems analysis and play based exploration – A global perspective** Michael Lawson, *Snowfox Discovery*
10.25	**Modelling hydrogen-generation potential of water-rock reaction** Andy Barnicoat, *NHSG*
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11.50	**Iron redox state of serpentinized mantle rocks through a Wilson cycle: implications for serpentinization-sourced hydrogen systems** Francesca Dimasi, *Université de Strasbourg*
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Posters
Understanding hydrogen production in continental lithosphere: effect of spinel on olivine serpentinization Emanuele Fanesi, *University of Bristol*
Assessment of natural hydrogen potential in Iberia from serpentinization of shallow lithospheric mantle rocks Jesús García Senz, *CN IGME-CSIC; Geological and Mining Institute of Spain*
Pathfinder Modelling of H2 solubility and migration in sedimentary basins Alexander Hartwig, *Geos4 GmbH*
Assessing Finland's Natural Hydrogen Potential and Key Influencing Factors Timo Jaakko Olavi Hietava, *Geological Survey of Finland*
Investigation of the geological-hydrogen potential of the MCR in Northeastern Minnesota Valentine Combaudon, *University of Colorado Boulder*
Enhancing Low-Temperature Serpentinisation for Hydrogen Production: Catalytic Role of Awaruite and Chromite Jeffrey Akuoko, *University of Manchester*
Hidden Energy Streams: Evaluating Serpentinization-driven Hydrogen Generation in the Ronda Peridotite (S. Spain) Inés Membrado-Royo, *University of Granada*
Natural Hydrogen Exploration Workflow - a pragmatic evaluation matrix from Regional to Play to Prospect scales Dominique Pourtoy, *Pole Avenia – earth2*
The Global Search for Commercial Natural Hydrogen – An Update Alan Driscole, *NVentures*
The role of organic matter in the H2 system of the western Pyrenees, A missing player? Nicolas Lefeuvre, *Université de Pau et des Pays de l'Adour*
Unlocking the evaluation and scalability of Natural Hydrogen Exploration: the HOREX Techno Pilot. Part 1: Play-based strategy Emmanuel Masini, *Mantle8*
Natural hydrogen prospect assessment and the difference with traditional oil and gas workflows Martin Neumaier, *ArianeLogiX*
Natural Hydrogen Occurrences in the Western Portion of Northern Apennines, Italy Vivian Azor de Freitas, *University of Parma*
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ORAL ABSTRACTS
(In Programme Order)

Day one

Session One: Natural Hydrogen Systems

The migration of hydrogen from planetary to basin scale

Bhavik Harish Lodhia, Geological Survey of Western Australia, Luk Peeters, CSIRO, Ema Frery, CSIRO

The occurrence of natural hydrogen and its sources have been reviewed extensively in the literature over the last few years, with current research across both academia and industry focused on assessing the feasibility of utilising natural hydrogen as an energy resource. However, gaps remain in our understanding of the mechanisms responsible for the large-scale transport of hydrogen and migration through the deep and shallow Earth and within geological basins. Due to the unique chemical and physical properties of hydrogen, the timescales of migration within different areas of Earth vary from billions to thousands of years. Within the shallow Earth, diffusive and advective transport mechanisms are dependent on a wide range of parameters including geological structure, microbial activity, and subsurface environmental factors. Hydrogen migration through different media may occur from geological timescales to days and hours. We review the nature and timescale of hydrogen migration from the planetary to basin-scale, and within both the deep and shallow Earth. We explore the role of planetary accretion in setting the hydrogen budget of the lower mantle, discuss conceptual frameworks for primordial or deep mantle hydrogen migration to the Earth's surface and evaluate the literature on the lower mantle's potential role in setting the hydrogen budget of rocks delivered from the deep Earth. We also review the mechanisms and timescales of hydrogen within diffusive and advective, fossil versus generative and within biologically moderated systems within the shallow Earth. Finally, we summarise timescales of hydrogen migration through different regions within sedimentary basins.

The character and habitat of natural hydrogen resources

Chris Ballentine, University of Oxford, R Karolytė, Snowfox Discovery Ltd, A Cheng Snowfox Discovery Ltd, B Sherwood Lollar, University of Toronto, J Gluyas, Durham University, M Daly, University of Oxford

Hydrogen is produced naturally in the continental crust through water-rock reactions with mafic or ultramafic rocks and the radiolysis of water from the radioactive decay of U and Th. The mass of H2 generated, little associated with carbon, has the potential to be a significant clean societal H2 resource. Other putative terrestrial sources of H2, such as the deep Earth's mantle, are not substantiated. The timescales and environments that enable significant hydrogen generation occur in different continental terrane. These vary from dominantly Phanerozoic ophiolite/mantle wedge complexes, Proterozoic-Phanerozoic alkaline granite complexes, Mesoproterozoic-Phanerozoic large igneous provinces, to dominantly Archean TTG and greenstone belts. The capacity to form traps in all systems is required alongside the porosity and permeability history that exposes the rock to water. Both will be associated with the tectonic evolution in each setting. To form a commercial reserve, an environment that produces and preserves a free gas phase from the ubiquitous water over the timescale of the system is essential. Helium (4He) provides an important analogue for natural hydrogen behaviour. This includes the processes that control both deep-seated flux to the near surface and gas phase formation. Loss due to microbial utilisation remains a high preservation risk. Accumulations have to be both geologically accessible and close to markets to form a commercially viable natural resource.

C Ballentine, R Karolytė, A Cheng, B Sherwood Lollar, J Gluyas, M Daly. Natural hydrogen resource accumulation in the continental crust, Nature Reviews Earth & Environment, In Press

Hydrogen systems analysis and play based exploration – A global perspective

Michael Lawson, Snowfox Discovery, Anran Cheng, Ruta Karolytė, Euan Macaulay

With an increasing focus on the need for a range of renewable and green energy solutions to meet societal environmental ambitions, hydrogen has attracted attention as a potential low cost, low carbon energy source. However, the projected future growth in hydrogen supply is likely to meet only 50% of net zero demand by 2050 (IEA, 2022). Natural hydrogen has the potential to radically change this outlook, providing cost competitive supply at a fraction of the carbon footprint of alternative hydrogen sources.

Natural hydrogen has been encountered in a range of tectonic settings, associated exclusively with radiolysis or serpentinsation, and produced from source rocks that span the geologic record. However, not all hydrogen systems will be equally prospective. Successful exploration will first require identifying hydrogen source rocks globally in space and time, and the ability to differentiate between robust and delicate hydrogen systems through evaluation of the generative potential of different source rock types. Understanding the genetic characteristics of all hydrogen systems elements, and specifically the key controls that govern hydrogen release, migration, trapping, and preservation, will be fundamental to exploration success.

In this talk, we will describe how Snowfox Discovery applies its significant experience in hydrogen systems analysis to identify natural hydrogen opportunities. We will emphasise the importance of understanding the key role that the tectonic setting plays in the development of robust hydrogen systems. Finally, we will provide an overview of the hydrogen specific quantitative models, workflows, and technologies required to successfully explore for and discover natural hydrogen accumulations.

Modelling hydrogen-generation potential of water-rock reaction

Andy Barnicoat, NHSG; Allan Leal, ETH Zürich

Hydrogen generation by water-rock reaction is geologically rapid and yields predicted from published studies show it to be capable of forming a 'point' source, meaning that it is likely to be critical for play-based exploration for natural hydrogen.
Existing studies of hydrogen generation by water reaction, in particular serpentinisation (e.g. McCollom & Bach, 2009, Klein et al., 2013, McCollom, 2022, Leong et al., 2021, Ely yet al., 2022) used the modelling software EQ3/6. This has a major drawback in that it can't simulate the formation of a gas phase: formation of a gas phase or the development of one during migration to reservoir conditions is likely to be essential for the development of economically viable accumulations of hydrogen in nature. In this study, we have used the Gibbs-energy minimisation software Reaktoro (Leal, 2015) which does allow form the formation of a gas phase during water-rock reaction.
Here we explore the effects of PT conditions and protolith chemistry on hydrogen generation from a range of rock types.

Iron redox state of serpentinized mantle rocks through a Wilson cycle: implications for serpentinization-sourced hydrogen systems

Francesca Dimasi, Université de Strasbourg, Marc Ulrich, Manuel Muñoz, Flora Hochscheid, Gianreto Manatschal

Serpentinization-driven native hydrogen (H_2), resulting from iron-bearing mantle rocks oxidation upon water interaction, is a promising low-carbon and economic energy source [1]. This process can occur during ocean formation and their recycling in rift-inverted orogens (Wilson cycle). While extensively studied at mid-ocean ridges and subduction zones [2], serpentinization systems in rift-inverted orogens (e.g., Alps or Pyrenees) remain poorly constrained. However, such settings offer better H_2 exploration potential due to enhanced accessibility and cost-effective extraction. Successful exploration requires understanding the "kitchen" (H_2 production site) and material fertility (remaining oxidizable iron), as well as linking iron oxidation states to geodynamic evolution. H_2 production depends on kitchen conditions (water/rock ratio, pressure, temperature, oxygen fugacity, reaction kinetics) and rock fertility, both changing throughout the Wilson cycle [3]. Thus, predicting and quantifying H_2 production requires samples recording different mantle states within the cycle. Such material is rare, and is so far only described, based on decades of research, from the Grischun/Malenco area (SE-Swiss/N-Italian Alps). The study area is one of the few locations worldwide exposing a rift-inverted kitchen with a well-documented tectonic history [4], and extensively characterized material [5]. Previous studies on > 50 serpentinite samples from this area allowed to identify 6 serpentine generations with variable Fe-concentrations (and thus H_2 production potential). Fe K-edge µ-XANES analysis will directly quantify Fe oxidation states, addressing the open question of redox evolution and H_2 fertility in rift-inverted orogens, with key implications for H_2 exploration.

[1] Osselin, et al. (2022), Nature Geoscience, https://doi.org/10.1038/s41561-022-01043-9
[2] Andreani, et al. (2013); Lithos, https://doi.org/10.1016/j.lithos.2013.04.008
[3] Zwaan, et al. (2025) Science Advances, https://doi.org/10.1126/sciadv.adr3418.
[4] Manatschal., Müntener (2009); Tectonophysics, https://doi.org/10.1016/j.tecto.2008.07.021
[5] Hochscheid, et al., (2024), J. of Petrology, https://doi.org/10.1093/petrology/egae063

Full-physics numerical models for hydrogen migration: One step closer to model natural hydrogen plays in sedimentary basins

Javier García-Pintado, MARUM - Center for Marine Environmental Sciences, University of Bremen, Tiago Abreu Cunha, IGI Ltd., Marta Pérez-Gussinyé, MARUM, Marianne Nuzzo, IGI Ltd.

Understanding the mechanisms that control basin-scale hydrogen migration and integrating them into numerical models capable of predicting realistic scenarios is key to the exploration of natural hydrogen. However, this is a complex task, due to the unique properties of hydrogen, the paucity of known accumulations to ground-truth the concepts, the large variety of potential hydrogen sources and sinks in the shallow upper mantle, crust and sedimentary basins, and the range of timescales over which different processes operate.
In this study, we use high-resolution box-size numerical models of miscible multiphase flow to improve the current understanding of the main factors controlling the migration and trapping of hydrogen in sedimentary basins. This is arguably an ideal approach for carrying out such analyses, allowing efficient multi-parameter model testing and sufficiently short time steps to resolve the different processes and associated feedbacks. The models resolve the equations of state for density, viscosity and specific enthalpy, and the equilibrium between the gas and dissolved mass fractions as a function of T-P conditions.
Initial model tests, assuming near steady-state high flux conditions, broadly reproduce the setting of the Mali (Bourakébougou) discovery. The models presented here use realistic generation rates from the hydrothermal alteration of iron-rich ultramafic rocks, and evaluate the migration and trapping conditions for a range of porosity-permeability and diffusivity contrasts characteristic of sedimentary basin layering. The models also constrain the threshold conditions that define the dominant migration mechanism (advection versus diffusion), and allow us to speculate on the longevity of hydrogen accumulations.

A Systems Approach to Hydrogen Migration, Migration Efficiency, and Preservation

Jay Huang, Northlight Resource Analytics

The growing potential of geologic hydrogen resources has spurred recent advancements in the analysis of natural hydrogen systems. However, the role of hydrogen migration in exploration and resource assessment frameworks may still be insufficiently recognized. Several mechanisms of hydrogen migration within sedimentary basins have been identified, including: 1) diffusion driven by concentration gradients, 2) pervasive upward flow in porous media due to buoyancy and pressure, and 3) focused migration along pathways such as faults, fractures, and seal leak points, driven by pressure gradients.

This study highlights significant differences in the effectiveness and efficiency of various hydrogen migration mechanisms. Hydrogen (H_2) can be particularly reactive during migration. While data remains under-constrained, available evidence suggests that the vertical velocity of hydrogen diffusion and pervasive hydrogen flow in porous media (Type 1 & 2) is 2-3 orders of magnitude slower than hydrogen migration along focused pathways such as faults and fracture networks. Consequently, the abiotic/biotic conversion of hydrogen to methane during Type 1 and Type 2 migration may consume significantly more hydrogen than previously appreciated. Furthermore, methane generated during these migration processes would compete for available trap space in potential hydrogen accumulations, thereby reducing both hydrogen resource density and commercial viability. Notably, the only known high-concentration hydrogen accumulation and production at the Bourabougou field in Mali is attributed to dynamic recharge at the production timescale via large-scale faults and fracture networks.

Based on these observations, identifying focused hydrogen migration pathways should be a critical component of an integrated hydrogen exploration strategy. Key enabling technologies for this effort include play-based analysis, fairway delineation, and seismic and geochemical detection methods.

Keynote - Challenges and opportunities related to geologic hydrogen prospectivity mapping

Geoffrey S. Ellis, US Geological Survey, Jane S. Hearon, US Geological Survey, Sarah E. Gelman, US Geological Survey

The US Geological Survey has developed a methodology for mapping geologic hydrogen prospectivity based on a 'hydrogen system' conceptual model. The methodology has been applied to the lower-48 states of the US (Gelman et al., 2025) and is currently being used for prospectivity mapping of the state of Alaska. The workflow involves the identification of proxy datasets for the individual components of the hydrogen system, the assignment of a range of weighting values – referred to as 'chance of sufficiency' (COS), and the combination of the weighted inputs to calculate a probability of net prospectivity for geologic hydrogen resources. Uncertainty in the model and inputs is accounted for by the range of assigned COS values, as well as spatial buffers on certain inputs. The method also accounts for potential hydrogen migration away from source rocks in sedimentary basins.

Mapping geologic hydrogen prospectivity at the regional scale (as opposed to the play- or prospect-scale) presents unique challenges. The need for representative datasets with sufficient spatial resolution can be difficult to satisfy for all components of the model. Additionally, the two-dimensional nature of maps restricts the ability to represent some three-dimensional aspects of natural systems. Some important natural features (e.g., fracture patterns and density) cannot be represented at the regional scale. This presentation will discuss some limitations of current prospectivity mapping approaches, the implications of these deficiencies on the resultant maps, and the activities (e.g., data acquisition, research, etc.) that could be undertaken to improve the accuracy of regional geologic hydrogen prospectivity maps.

Gelman, S.E., Hearon, J.S., and Ellis, G.S., 2025, Prospectivity mapping for geologic hydrogen (ver. 1.1, January 17,
2025): U.S. Geological Survey Professional Paper 1900, 43 p., https://doi.org/ 10.3133/ pp1900.

Session Two: Geological Hydrogen Stimulation

Electrical Reservoir Stimulation: Lab-Scale Hydrogen Generation Experiments of Fractured Peridotite Cores and Upcoming Field Pilot in Oman

Mark Hansford, Eden GeoPower, Jonas Toupal, Eden GeoPower, Jacob Newmark, Eden GeoPower, Alexis Templeton, Eden GeoPower, University of Colorado, Boulder, Eric Ellison, University of Colorado, Boulder, Lucas Meija, Eden GeoPower, Ali Tarokh, Eden GeoPower, Chase Nau-Hix, Eden GeoPower, Spencer Aertker, Eden GeoPower, Rafael Villamor-Lora, Eden GeoPower

Geologic H2 is formed via serpentinization and while this process occurs naturally over geologic timescales, it can also be enhanced to occur at industrial rates. For stimulated geologic H2 to become economic, the permeability and reactive surface area must be increased by several orders of magnitude. In this presentation, we will share the results of our lab experiments and discuss our upcoming field pilot.

In the lab, Eden has conducted H2 generation experiments on cores fractured with pulsed power as well as baseline (unfractured cores), single-fracture cores, and powdered peridotite. We will share the results of electrical fracturing of impermeable cores from the Oman Ophiolite under in-situ conditions of 400 m depth (~7 MPa confining pressure, ~4 MPa pore pressure, 40-100°C). In core flooding cells, fluids representative of observed Oman Ophiolite fluids, were injected into the cores and H2 was generated. We observed substantial increases in pore pressure within 24 hours and found that H2 generation rates increased throughout the first two months of the experimental duration. Early results suggest increased reaction progress and H2 production rates due to higher fracturing degree and faster flow rates.

Eden is partnering with 44.01 and currently planning a pilot test in the field in Oman. This project aims to demonstrate the ability increase permeability in the subsurface using electrical stimulation in an environment representative of stimulated hydrogen production. This test will demonstrate that our technology is capable of creating the right conditions to produce stimulated hydrogen commercially in the Samail Ophiolite.

Turning Subsurface Gambles into a Factory of Hydrogen Certainty

Alexei Tcherniak, GeoKiln Energy Innovation, Lorna Ortiz, GeoKiln Energy Innovation

Despite growing global interest in natural hydrogen, the field continues to face two primary challenges: subsurface uncertainty and the inability to achieve sustained, commercially viable production rates. While exploration efforts have intensified, evidence of continuous hydrogen generation at usable commercial scales remains limited.

This work presents an engineering-led approach that seeks to reduce geological uncertainty by applying controlled thermal stimulation to accelerate hydrogen-generating reactions in suitable lithologies, such as ultramafic rocks. Drawing on decades of oil and gas field experience, we repurpose established techniques—horizontal drilling, zonal heating, and thermal reservoir modeling—to evaluate and activate in situ hydrogen production potential.

Rather than relying on the discovery of naturally trapped hydrogen accumulations, this approach focuses on inducing and accelerating subsurface hydrogen reactions like serpentinization under controlled conditions. Our method allows for modular scalability while providing a framework to better quantify subsurface responses, fluid pathways, and energy efficiencies in diverse geologic settings.

Initial modeling and early screening suggest that thermally stimulated hydrogen generation can achieve technically and economically relevant rates (estimated at \$1.5–\$2.0/kg H_2), depending on formation characteristics and thermal responsiveness. This contribution will present the foundational principles, modular engineering design, and scalability potential of the approach. Rather than competing with conventional geologic hydrogen exploration, this method serves as an enabling pathway—designed to reduce subsurface uncertainty, produce early-stage hydrogen, and accelerate commercial production rates. It represents a shift from passive exploration toward active subsurface activation, offering a practical framework for accelerating the development of natural hydrogen resources.

Hydrogen Stimulation in Ultramafic Systems: Reactive Reservoirs and Their Associated Challenges

Owen Edward Sutcliffe, Halliburton

Hydrogen generation by the stimulation of ultramafic rocks is a technology-led concept for lower cost hydrogen. Central to this concept is that a target formation will be a “reactive reservoir” rather than a passive storage vessel. Existing research is used to characterize the impact of serpentinization on rock properties, whilst experiments deliver insight into the rates of these processes. Collectively these works will define the geological risks. Key aspects in the development of a reactive reservoir are the injection, flow and accumulation of hot, reactive water into a stiff crystalline formation. As serpentinization advances, the potential for declining permeabilities and pore-clogging is a significant risk to production if flow rates to reaction sites cannot be managed. Gaseous hydrogen will also need to be separated from non-economic phases. During the sanction of projects, there will be a requirement to prove our ability to initiate serpentinization and expand the scale of hydrogen generation at economic rates. This is envisaged as a four-stage appraisal process. Development of a reactive reservoir will be accelerated by the blending of technologies from other forms of energy production. These include enhanced geothermal systems, steam-assisted gravity drainage and the production of hydrocarbons from tight plays. Given the low porosities of ultramafic rocks, hydraulic fracturing, multi-zone completion and multi-lateral horizontal drilling will be fundamental to any production strategy. In conclusion, the advancement of stimulated hydrogen will be solved by the seamless blend of a new breed of geoscientist and innovative reservoir engineers. Does a cleaner energy future await?

Scientific challenges for Stimulated Geologic Hydrogen

Florian Osselin, Vema Hydrogen

Stimulated Geologic Hydrogen has gained incredible momentum in the last few years due to its immense potential for the energy transition. Different estimates suggest that there could be thousands of years of hydrogen to be extracted from the subsurface, even when entirely replacing fossil fuel usage. Stimulated Geologic Hydrogen has the potential to decarbonize hard-to-abate sectors, such as heavy chemistry, transportation, steel industry, and fully disrupt a $1.4Tn market.
The technology harnesses naturally occurring reactions that produce hydrogen underground. These are the same chemical reactions that are generating natural (or white) hydrogen. A brine solution containing catalysts is injected into shallow geological formations, where it reacts with iron bearing minerals to produce hydrogen. The hydrogen is then collected, purified, compressed or liquefied before being sold to offtakters.
However, for this technology to achieve its full potential, an important scientific effort is necessary. In this presentation, we highlight several technical and scientific challenges which need to be addressed before deploying safely the technology in the field. Some of which are already being researched by different academic and private teams around the world. These scientific challenges range across all lengthscales --from nanometric molecular mechanisms to large scale multiphase flow is reactive fracture media – and all disciplines, including geochemistry, geophysics, geomechanics, reservoir engineering, fluid mechanics, biogeochemistry and many others.
Stimulated Geologic Hydrogen is not only a promise for a cleaner and better source of decarbonized hydrogen, it is also a beautiful, stimulating and challenging scientific journey.

Day two

Keynote - Natural Hydrogen Development-Potential and Challenges

Arnout Everts, AEGeo Sdn Bhd

Natural hydrogen has recently been identified as a potential source for future energy systems. This paper investigates the technical development potential of natural hydrogen by estimating, for some recent finds and identified prospects, in-place and recoverable hydrogen, well productivity, water production and other byproducts that a future development would have to cater for. Finds and prospects are in three broad play types: 1) focused-seepage plays where predominantly aqueous hydrogen migrates with minimal trapping; 2) coalbed plays where hydrogen is adsorbed molecularly in coals; 3) reservoir-trap-seal plays with gaseous hydrogen trapped underneath an impermeable seal. Focused-seepage plays have a low to modest hydrogen resource-density, low well-productivity and developments may co-produce large volumes of water. Coalbed hydrogen plays may have higher resource density but again, low well-productivity and in addition, coals may have other gases such as CH_4 and CO_2 adsorbed alongside hydrogen. Only developments of reservoir-trap-seal plays with material columns of hydrogen gas trapped in porous and permeable reservoir could potentially achieve industrial offtake; low hydrogen content and short gas columns are the main downside risks of this play. To date, no accumulations of this type have unambiguously been discovered.

Session Three: Settings, Plays & Case Studies

Keynote - Following the Yellow Brick Road to Natural Hydrogen: Early Exploration Insights from Kansas

Benjamin Mee, HyTerra Ltd, Avon McIntyre, Jeff Goodall, Josh Whitcombe, Paul Kralert, HyTerra

Natural hydrogen, as a promising alternative energy source, has garnered significant interest in recent years due to its potential role in the transition to cleaner energy. Our company has started a 12-month exploration program in Kansas, USA, with the aim of advancing the understanding of natural hydrogen resources and starting to assess commercial viability. This abstract presents preliminary findings from the Stage 1 exploration drilling operations, focusing on the objectives of the well to demonstrate a working hydrogen and helium system, ascertain gas compositions, and characteristics of the reservoir zones for further appraisal.

The lessons learned from the Stage 1 drilling campaign will contribute to refining the geological models for natural hydrogen and helium and inform the Stage 2 exploration program.

The HyTerra Exploration campaign represents an important step in bridging the gap between theoretical models of natural hydrogen accumulation and real-world exploration, offering new insights into the potential of this energy resource.

Could rift-inversion orogens host large-scale natural H2 accumulations?

Frank Zwaan, University of Lausanne, Switzerland - GFZ Helmholtz Centre for Geosciences, Potsdam, Germany - University of Fribourg, Switzerland

Serpentinization of mantle rocks is a highly promising mechanism for large-scale natural hydrogen gas (H2) generation. To undergo serpentinization, mantle rocks that are normally situated at great depth need to be brought closer to the surface by plate tectonics and other geodynamic processes. Here, they may react with water to be efficiently serpentinized and generate natural H2, which can accumulate in reservoirs as it migrates to the surface (as part of a natural H2 system).

Exploring natural H2 systems requires a solid understanding of their geodynamic history, which can be informed by numerical geodynamic modelling. Through such modelling we can trace how, when, and where mantle material enters the serpentinization window, as well as when active, large-scale faults penetrate exhumed mantle bodies allowing for water circulation that facilitates serpentinization and H2 generation.

Our recent modelling of rifting and subsequent rift inversion (Zwaan et al., 2025) shows that volumes of natural H2 generated during inversion may be up to 20 times higher than during rifting, due to the colder thermal regime in rift-inversion orogenic environments. Moreover, suitable reservoir rocks and seals required for natural H2 accumulations to form are readily available in rift-inversion orogens, whereas they may not be present when serpentinization occurs in deep marine continental rift or oceanic spreading settings.

Our model results thus provide a first-order motivation to turn to rift-inversion orogens for natural H2 exploration and are supported by indications of natural H2 generation in for example the European Alps, Pyrenees and Balkans.

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Natural hydrogen occurrences in Mpumalanga, South Africa, and their relationship with underlying geology

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Over 4000 recorded shallow depressions (locally known as 'pans') in Mpumalanga, South Africa are morphologically similar to other shallow depressions found internationally, that are linked to natural hydrogen flux from surface soils into the atmosphere. We mapped the occurrence of pans and measured for the presence of hydrogen seeps in the field. Geological mapping and geophysical modelling helped determine subsurface geology. In-situ soil gas sampling of the hydrogen at shallow depths revealed a considerable concentration of hydrogen (max. 45000 ppm using a Varitoec hydrogen meter) around the perimeter of pans. Mapping suggests that pans in the Mpumalanga region are developed almost exclusively on Ecca Group strata (coal, shale and sandstone) of the lower Karoo Supergroup. These Karoo strata are preserved only at shallow depths (<500m) and unconformably overlie a variety of Archaean and Palaeoproterozoic lithologies, that include Archaean greenstones and granitic gneiss, mafic to ultramafic volcanic supracrustal rocks, and mafic-ultramafic intrusive rocks. It seems likely, that hydrogen is produced by serpentinisation or radiolysis in these various Precambrian rocks at greater depth in the crust, and the Ecca strata act as a partial trap for the hydrogen. The striking preferred orientation of pans, and sub-parallel relationship with geophysical lineaments suggests that the Ecca Group trap leaks along faults. Although the precise controls over hydrogen production, storage and surface occurrences are still not fully understood, a workflow of appropriate geomorphological and geological factors was developed, based on case studies from across the world to aid with future exploration programs. This research was conducted within the scope of the HyAfrica project, under the auspices of LEAP-RE, and has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530. The South African portion of this project is funded by the South African National Energy Development Institute (SANEDI).

A Top Down Approach to Natural Hydrogen Exploration in the Semail Ophiolite, Ras Al Khaimah, United Arab Emirates

Daniel Holloway, RAK Gas; Giacomo Firpo, Paul Swire, Thibaut Burckhart, RAK Gas; Gabriel Pasquet, Keanu Loiseau, Mohamed Diatta, Isabelle Moretti, Université de Pau et des Pays de l'Adour

Ophiolites, consisting of obducted oceanic crust and upper mantle, are a target for natural hydrogen exploration in the Semail Ophiolite, Ras al Khaimah, UAE. Olivine rich facies in peridotites facilitate oxidation-reduction processes and serpentinization of peridotites results in hydrogen generation. Analysis of surface gas, soil, regolith and rock samples was conducted to evaluate hydrogen concentration and determine the potential of the Semail ophiolite for hydrogen generation.

Gases from bubbling pools were analysed by gas chromatography and mass spectrometry to determine gas composition. A BIOGAS 5000 tool was used to measure gas composition within the soil/regolith. Rock samples were converted to thin sections and powders to determine mineralogy by microprobe, inductively coupled plasma optical emission spectrometry and mass spectrometry. X-ray diffraction determined the rock's paragenesis and variation.

Serpentinites near a bubbling pool (87.75 mol% hydrogen) bordering the Masafi-Ismah metamorphic window exhibit serpentinization without late meteoric carbonation. Soil in the metavolcanics contained up to 171 ppm of hydrogen. Soil/regolith along the central lineament of RAK South between gabbros and peridotites contained up to 121 ppm of hydrogen. Aluminum oxide at the edges of serpentine in fractures are a catalyst for serpentinization. Aluminum enhances the solubility of olivine, accelerating serpentinization and generating serpentine at lower temperatures without forming magnetite. Ferrobrucite, an intermediary in the formation of magnetite, was identified in the texture of serpentinites. Ferrobrucite is a mineral produced from low temperature hydrogen generation (Klein et al. 2013). Peridotites are sparse in magnetite, showing hydrogen generation potential still remains.

Surface hydrogen in the Semail ophiolite is interpreted to be formed from low temperature serpentinization (below 100°C) and not from high temperature serpentinization. Hydrogen exploration should be focused on deeper peridotites (>3km depth) that have undergone high temperature serpentinization (above 200°C) where basal crustal layered gabbros overlay peridotites at and near to structural lineaments.

Prospect of Natural Hydrogen in Himalayan region, India

Annapurna Boruah, UPES Dehradun

The Himalayas, formed by the collision of the Indian and Eurasian plates, offer unique geological conditions for natural hydrogen production. Several processes contribute to hydrogen formation, the most significant being serpentinization, where ultramafic rocks react with water to release hydrogen gas. The presence of ophiolitic sequences in Ladakh, Arunachal Pradesh, and Sikkim suggests strong potential for this process. Additionally, radiolysis of water in uranium- and thorium-rich basement rocks can generate hydrogen over long timescales.

Another key factor is the geothermal activity and fault-associated degassing in the Himalayas. Numerous geothermal springs and active fault systems, especially along the Main Central Thrust (MCT) and Main Boundary Thrust (MBT), serve as natural pathways for hydrogen migration from deep sources to the surface, increasing the chances of subsurface accumulation.

Several Himalayan regions show promise for hydrogen exploration. Arunachal Pradesh and Sikkim have geothermal springs and ophiolitic formations, Ladakh and Jammu & Kashmir contain ultramafic rocks and active faulting, while Uttarakhand and Himachal Pradesh have geothermal activity and fractured basement rocks, making them potential targets for future studies.

Overview of the natural hydrogen potential of Senegal and Republic of the Congo (Congo-Brazzaville)

Richard Cooke, HydroGenesis

HydroGenesis have conducted an initial ‘bottom-up’ review of the natural hydrogen potential onshore Senegal and Republic of the Congo. Evidence has been established throughout each, with highlights described below, and more detail to be presented.

In eastern Senegal, the Kédougou-Kéniéba Inlier contains volcanic belts and sedimentary basins with intrusions of TTG and calc-alkaline granite. Airborne surveys and fieldwork have allowed mapping of ultramafic rocks, where lherzolites, wehrlites and pyroxenites have been sampled within a greenstone belt. Thick sedimentary sequences and intrusions complete the ‘natural hydrogen system’.

To the west within the extensive Mesozoic to Cenozoic sedimentary basin, source potential includes Precambrian crust, granitic intrusions identified in wells, layered mafic intrusions at the Cape Verde Peninsula, or hypothesised deep sources. Onshore exploration wells and 2D seismic profiles have established reservoirs and seals, and traps including igneous sills, horst and graben structures, and stratigraphic traps overlying basement.

A portion of the Central Basin within the Precambrian Congo Craton extends into north-east Republic of the Congo. Potential source material includes mafic intrusions linked to a suspected failed Proterozoic rift, Precambrian crust, or hypothesised deep sources. 2D seismic profiles along the eastern border of the country, combined with well and potential field data, confirm structural highs flanked by deep basins (~5 km) that could provide trap, reservoir and seal.

Elsewhere in Congo, Archean blocks contain Precambrian greenstone belts, TTG, calc-alkaline granite, and Banded Iron Formations throughout. A ~15 km2 ultramafic ‘lopolith’ complex resides within the northernmost block, with olivine, peridotites, and serpentinised dunite recorded.

A potential H_2-He-N_2 gas province in southern Denmark: insights from legacy well data

Kasper H Blinkenberg, Geological Survey of Denmark and Greenland, Kresten Anderskouv, University of Copenhagen, Mohamed El-Shemy, University of Copenhagen, Henrik I. Petersen, Geological Survey of Denmark and Greenland

The deep Danish subsurface has historically been explored for hydrocarbons, and today production takes place in the offshore North Sea region, where hydrocarbons were first discovered in the late 1960s. The first deep subsurface exploration activities took place in the onshore Danish area, and numerous hydrocarbon exploration wells were drilled during the late 1940s and early 1950s, with a later phase of exploration during the 1970s and 1980s. From the early exploration phases during the 1950s, a potential natural hydrogen (H_2) occurrence reported in a legacy completion report was initially described by Howell et al. (1993) and later presented by Smith (2002) and Zgonnik (2020). This finding highlights the need to re-evaluate legacy well data from the region for overlooked H_2 shows and other economically important gases such as helium (He). Based on an evaluation of open-access completion reports from legacy well data, we show that several H_2 occurrences are present in the subsurface of the Danish onshore region. The most prolific H_2 occurrences are recorded in Zechstein carbonates and evaporites in southern Denmark, where a potential H_2-He-N_2 gas province is recognized, and shares similarities with legacy natural H_2 shows from Germany. However, potential generation mechanisms are poorly understood at this time due to limited data from the deepest segments of the onshore Danish subsurface. Overall, this study highlights the need to re-evaluate the onshore Danish subsurface for its H_2 and He gas potential.

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The role of fractures in the genesis and migration of natural hydrogen in ophiolites

Keith Rawnsley, SubsurfaceLabs, Lingli Wei, SubsurfaceLabs

Ophiolites, remnants of ancient oceanic lithosphere, are composed of ultramafic rocks (peridotites), mafic rocks (gabbros and basalts), and sedimentary rocks. Ophiolites occur in many locations, including Oman, Cyprus, Turkey, eastern Adriatic, Canada, Philippines, New Caledonia and the United States. Hydrogen seepage is observed in these ophiolites, often associated with deep-rooted faults that facilitate the migration of hydrogen from depth to the surface. Hydrogen was detected across a fracture system in the peridotites of the Oman Samail ophiolite, and no traces of hydrogen in unfractured peridotites (Zgonnik et al. 2019 and Leong et al. 2023). While hydrogen seepages can manifest in shallow boreholes and as gas bubbles in spring water, the vertical extent of the associated fractures-faults is typically uncertain, raising questions about the depth at which hydrogen is generated and the mechanisms governing its migration to the surface. Furthermore, as groundwater circulation in an ophiolite aquifer is controlled by conductive fracture systems, and as hydrogen generation relies on water reactions with Fe^{2+} rich minerals such as olivine, fractures also influence the generation of hydrogen.
This work aims to provide a better understanding of the role of faults-fractures in both the generation and migration of hydrogen by integrating field observations and numerical simulations. The models take into account hydrogen generation and migration within fracture-fault configurations and factors such as hydrogen diffusion, solubility in water and groundwater flow dynamics. Implications for improved estimation of hydrogen resources, potentially underestimated, are discussed together with applications for natural hydrogen exploration and development.

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Mafic sheet intrusions in sedimentary basins: insights from field and subsurface data implications for hydrogen exploration

Simon Holford, University of Adelaide, Nick Schofield, University of Aberdeen

Mafic intrusive complexes are commonly found in basins across a range of tectonic environments, often comprising networks of interconnected sheet intrusions (e.g. sills and dykes). There is growing interest in the role of mafic intrusions in relation to natural hydrogen systems within Phanerozoic and Proterozoic sedimentary rock sequences, in terms of their potential ability to act as seals for hydrogen accumulations, and also as potential source rocks for natural hydrogen generation through the hydration of mafic minerals. Here we present recent advances in the understanding of intrusive systems achieved through the analysis of hydrocarbon exploration datasets (e.g. seismic and geophysical log data), supported by field-based observations. Both subsurface and outcrop datasets indicate that, whilst mafic intrusions in sedimentary rock sequences are generally considered to be barriers to subsurface fluid flow, the development of fractures at the margins of intrusions (developed where host rocks accommodate magma emplacement through brittle deformation) can lead to preferential, intrusion-parallel migration. In some instances, deep (i.e. present-day depths of >3 km) intrusions can retain intra-intrusion fracture systems, as evidenced by unanticipated influxes or flosses of gases or fluids when drilling through intrusions. The long-lived development of fracture systems within networks of stacked, interconnected intrusions may enable them to vertically transfer fluids and pressures through sedimentary rock sequences. In the context of natural hydrogen systems, the presence of intra-intrusion fracture systems may facilitate water-rock interactions that could lead to hydrogen generation. Evidence from an array of subsurface datasets indicates that the presence of intrusions is likely to complicate fluid and gas migration pathways in sedimentary rock sequences, though the question of the timescales (e.g. production-to-geological) over which intrusions are likely to act as barriers to migration (and hence potential seals) is unresolved and needs to be considered and evaluated on a basin-specific basis.

Session Four: Technology & Data in Hydrogen Exploration

Keynote - Rock physics for quantitative geophysical interpretation of natural hydrogen resources

Yashee Mathur, Stanford University, Tapan Mukerji, Stanford University

Natural hydrogen systems formed through subsurface serpentinization of ultramafic rocks is an emerging focus area for low carbon hydrogen production. Serpentinization, involving hydrolysis of ferromagnesian minerals, alters rock properties, including density, elastic moduli, seismic velocities, and magnetic susceptibility, making it pivotal for geophysical exploration and characterization of subsurface hydrogen reservoirs. While geochemical insights into serpentinization are extensive, the geophysical interpretation using rock physics remains underexplored.
This study compiles over 1,000 samples from the literature from diverse geological environments to analyze physical property changes during serpentinization, such as density and velocity reduction, and moduli variations. Regression models and cross-property relationships are developed to quantify these changes and link them to the degree of serpentinization. The findings reveal a predictable density decline (~3.3 g/cc for peridotites to ~2.6 g/cc for serpentinites), a significant velocity reduction (~40% for P-wave and ~60% for S-wave velocities), and distinct trends in moduli. These relationships are validated using Differential Effective Medium (DEM) models, highlighting their utility in geophysical monitoring and exploration. Furthermore, cross-property plots like density vs. magnetic susceptibility and velocity vs. porosity elucidate the interplay of rock composition, fluid presence and porosity changes.

This comprehensive dataset and analysis enable the application of gravity, seismic, and electromagnetic methods to image hydrogen source rocks and reservoirs, advancing exploration strategies. The study also underscores the importance of integrating multi-physics approaches to mitigate interpretation pitfalls, offering a robust framework for natural hydrogen prospecting and real-time monitoring of stimulated hydrogen systems.

Using Potential Fields Data to Model Potential Natural Hydrogen Production from Ultramafic Bodies: Assorted Case Studies from Around the World

David Tierney, Getech Group plc, Max Brouwers, Sam Cheyney, Howard Golden, Bill Heins, Simon Campbell, Getech Group plc

Natural hydrogen has recently gained prominence as a very promising alternative to fossil fuels when considering the need to decarbonise energy sources. Many potential sources for natural hydrogen (e.g. iron-water reactions, radiolysis, coal pyrolysis) are hypothesised but one geological pathway is generally seen as the prevalent one: serpentinisation of ultramafic rocks. This is due to its relatively rapid and efficient geochemical hydrogen generation potential and is believed to be primarily responsible for the natural hydrogen manifestations at locations such as the Semail Ophiolite, the Mid-Continent Rift, the Vardar Zone ophiolites of the Balkans and numerous others.

These ultramafic rocks generate strong gravity and magnetic anomalies which greatly enhance their ability to be mapped (e.g. bounding faults and internal fractures) with potential fields data. Furthermore, when placed within the regional stress field a model of fault dilatancy can be generated, providing a powerful method for predicting primary fluid flow conduits through the relatively ‘open’ fractures. This flow is key for both H2O reaching the rock surface for the geochemical reaction to occur and the subsequent migration of H2 out of the rock into a potential trap.

Alongside the powerful option of mapping their lateral extent within the subsurface, careful inversions of these magnetic and/or gravity data allow a 3D distribution model of the width, depth and thickness of these bodies. These can be further refined by modelling the internal variation of density and susceptibility to indicate how much serpentinisation may have occurred at depth. These can then be converted to a modelled source rock volume which, when geo-located within the local geothermal gradient, can allow estimates of natural hydrogen generation. Knowing these will: 1) greatly enhance any subsequent predictions of the potential volume of generated natural hydrogen and 2) de-risk any further detailed exploration involving seismic and/or the drilling of wells.

Mössbauer spectroscopy to characterize Fe in H2-generating rocks

Ugo Geymond, VEMA HYDROGEN, K. Loiseau, LFCR-UPPA, V. Roche, Université du Mans, G. Pasquet, LFCR-UPPA, S. Revillon, SEDISOR, M. Sougrati, Université de Montpellier, I. Moretti, LFCR-UPPA, J. Fort, VEMA HYDROGEN, F. Osselin, VEMA HYDROGEN

The oxidation of Fe^{2+} by anoxic water in the subsurface is a key geochemical process that contributes to the formation of geological dihydrogen (H_2). Accurately characterizing the content, speciation, and distribution of iron (i.e. its mineralogical) is therefore critical for resource exploration and subsequent production. Traditionally, Fe analysis has been conducted either through time-intensive, high-resolution methods at the micrometer scale or through faster, bulk-scale analyses. Each approach presents trade-offs in terms of accuracy and representativeness. Furthermore, most conventional techniques are limited to determining either Fe speciation or distribution, necessitating multiple analyses to achieve a comprehensive understanding. This approach is not well-suited to the industry's demand for rapid, high-quality, and cost-effective characterization.
To overcome these limitations, the potential of Mössbauer Spectroscopy (MS) was investigated as a single-step technique to simultaneously characterize both Fe speciation and distribution in relevant samples. Analyses were performed on both simple (i.e. single phase) and complex (i.e. several phase) mineral assemblages to assess the versatility of the technique. The results demonstrate a strong correlation between MS and conventional titration measurements, validating the reliability of MS when appropriately applied. Unlike titration, which only provides the bulk $Fe^{2+}/\Sigma Fe$ ratio, MS offers detailed insight into both the oxidation state and mineralogy of iron.
Based on these findings, Mössbauer Spectroscopy can now be adopted as a routine analytical tool across various workflows, spanning from prospect potential evaluation to experimental material characterization.

Regional 4He Basement Flux Assessment in South Australia: implications for H2 Transport

Zak Milner, Durham University

‘Natural hydrogen (H_2) is often found in subsurface gas systems and, if harnessed, could play a significant role in the energy transition [1]. In crustal environments, H_2 is primarily generated through water radiolysis—alongside the production of helium-4 (^4He)—and iron reduction.

Understanding the processes governing H_2 generation, migration, accumulation, and preservation is crucial for exploration efforts. South Australia presents a particularly promising setting for studying these principles, with recorded gas occurrences reaching up to 95.8% H_2 [2].

This study investigates noble gas isotopes (He to Xe) in groundwater samples from 19 locations across the Yorke Peninsula and Adelaide Superbasin. Radiocarbon dating enables the residence time of the groundwater to be derived and the basement ^4He flux into it determined.

We compare ^4He basement flux with modelled ^4He production from uranium (U) and thorium (Th) decay to evaluate how crustal ^4He migrates into regional groundwater aquifers. Given the similar migration behaviour of ^4He and H_2 [3], this approach serves as a valuable proxy for subsurface H_2 transport and can be applied to other geological settings with high natural H_2 potential.

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Numerical Simulation of Stimulated Hydrogen Generation at Varying Serpentinization Rates: Impacts and Benefits of Code Comparisons

Mark White, Kansas Geological Survey, Brendan Bream, Kansas Geological Survey

Numerical modeling of coupled thermal, hydrological, geomechanical, and geochemical processes in the subsurface are well established in several application areas, such as groundwater, hydrothermal, carbon sequestration, oil and gas recovery. Even more niche application areas, such as enhanced oil recovery, enhanced geothermal systems, natural gas hydrates, have well established modeling approaches and solution schemes. Code comparison studies have proven beneficial in gaining acceptance and building confidence in subsurface simulators, eliminating coding bugs, demonstrating capabilities, and developing benchmark problems for future development activities. In the realm of geologic storage of carbon dioxide, the GeoSeq and Stuttgart international code comparison studies were foundational in establishing modeling approaches for carbon sequestration in deep saline reservoirs. These studies helped to transform carbon sequestration modeling from the status of research to commercial over a relatively short period of time. Whereas recent modeling approaches in other application areas are applicable to modeling geologic hydrogen systems (e.g., storage, production via stimulation, preservation), there are differences associated with hydrogen that make its modeling a nascent technology. A reservoir simulator has been developed at the Kansas Geological Survey for investigating coupled processes associated with geologic hydrogen, based on the established STOMP suite of computer codes. This simulator has been applied to the generation of hydrogen from a hydraulic fracture stimulated in ultramafic rock to investigate the impacts of serpentinization rates on hydrogen generation and secondary mineral formation. In the interest of establishing confidence in simulation of geologic hydrogen systems, we encourage the assembly of an international code comparison study.

POSTER ABSTRACTS

Understanding hydrogen production in continental lithosphere: effect of spinel on olivine serpentinization

Emanuele Fanesi, University of Bristol, Oliver Lord University of Bristol, Richard Brooker, University of Bristol, Simon Clark, Macquarie University

As the global transition toward net-zero emissions accelerates, an increasing number of countries are investing heavily in hydrogen production. However, conventional methods such as steam methane reforming (grey hydrogen) and water electrolysis (green hydrogen) remain highly energy-intensive and contribute to significant CO_2 emissions, even when powered by renewable energy. In contrast, natural hydrogen (white hydrogen) offers an inherently low-carbon alternative. Understanding the geological contexts and conditions which lead to optimal hydrogen production and accumulation is fundamental to enhance exploration, but the conditions at which hydrogen-producing reactions occur are poorly explored. Specifically, serpentinization reactions, which produce hydrogen and magnetite through the hydration and decomposition of olivine, have almost exclusively been studied at conditions relevant to the oceanic lithosphere. However, field evidence suggests that hydrogen is also being produced within the continental lithosphere, which extends to much greater depths. Additionally, the kinetics of serpentinization are highly sensitive to the mineral composition of the host rock. Notably, it has been shown that the presence of silica-free, Al- and Cr-bearing minerals (e.g., spinel) accelerates reaction rates up to several orders of magnitude. Here we explore the kinetics of serpentinization under conditions relevant to the continental lithosphere, examining the influence of varying spinel concentrations along the geotherm of the Kalahari craton (2.4 GPa, 700 °C). Experiments were performed using a piston cylinder apparatus. Hydrogen production was calculated using magnetite modal abundance as a proxy. Comprehensive chemical and petrological characterizations were performed using scanning electron microscopy (SEM), electron probe microanalysis (EPMA), and Mössbauer spectroscopy.

Assessment of natural hydrogen potential in Iberia from serpentinization of shallow lithospheric mantle rocks

Jesús García Senz, CN IGME-CSIC; Geological and Mining Institute of Spain, Antonio Pedrera, CN IGME-CSIC, Károly Hidas, CN IGME-CSIC

We present a preliminary prospectivity map for natural hydrogen associated with serpentinization processes across the Iberian Peninsula. This region is characterized by hyperextended continental margins formed during Mesozoic rifting, which facilitated the exhumation of mantle peridotites along the West-Iberian, North-Iberian, and South-Iberian margins. Subsequent Alpine convergence led to the incorporation of some of these shallow mantle rocks into the Pyrenean and Betic collisional orogens (Pedrera et al., 2017, 2020). Our analysis integrates geological cross-sections and geophysical data to evaluate the crustal architecture of these domains, with emphasis on the geometry and distribution of hydrogen source peridotitic bodies. We also assess the potential for hydrogen leakage to the surface along fault zones and identify sedimentary covers that could act as reservoirs. To evaluate the conditions for active serpentinization and hydrogen generation, we developed a regional geothermal model that incorporates measured heat flow data and lateral variations in crustal composition and thickness. This allows us to delineate zones where temperature conditions favors ongoing serpentinization reactions. We highlight the critical role of orogenic architecture and tectonic evolution—particularly the compressional reactivation of hyperextended margins—in the natural hydrogen system. Finally, we explore multiple hydrogen prospectivity scenarios based on alternative structural interpretations of the Iberian orogens, providing a framework for future exploration.

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Pathfinder Modelling of H_2 solubility and migration in sedimentary basins

Alexander Hartwig, Geos4 GmbH, Brian Horsfield

Predicting natural hydrogen (H_2) migration paths at the basin scale requires a straightforward and adaptable modelling approach using global parameters such as depth, pressure-temperature conditions, and water salinity. This method can be applied to any hydrogen generation setting. The goal is to distinguish between zones of H_2 aqueous and free-gas phase migration ("bubble-point") and to calibrate to known occurrences of natural hydrogen in the subsurface. This approach is referred to as Pathfinder Modelling, serving as a rapid screening tool before more complex transport and reaction modelling.
The Cooper Basin in central Australia serves as a pilot-study case due to its fully calibrated published basin model, hydrogeologic atlas, and documented occurrences of natural hydrogen. This study demonstrates how modelling H_2 generation from organic matter in Patchawarra coals and its solubility in formation waters can predict free-phase hydrogen gas occurrence at a regional scale. Locations with H_2 gas shows align with areas where the models predict the transition from aqueous to gaseous hydrogen in the aquifer. A comparison is made between organically sourced and basement sourced H_2 scenarios. This basin modelling approach provides a framework to investigate how regional geologic events impact the generation and expulsion of H_2 into the aquifer system.
The presented modelling workflow has been adapted for natural H_2 exploration on a regional scale, allowing migration pathways and gas-shows to be studied within a combined geologic context.

Assessing Finland's Natural Hydrogen Potential and Key Influencing Factors

Timo Jaakko Olavi Hietava, Geological Survey of Finland, J Konnunaho, M Hagström,
T Arola, Geological Survey of Finland

The natural hydrogen (H2) potential of Finland's Archean and Proterozoic crystalline bedrock has been studied only to a limited extent so far. Initial measurements from drillholes have demonstrated that hydrogen does exist in groundwater associated with various geological environments. These measurements have not been specifically performed for H2 exploration but have been conducted in the context of bedrock research, mineral exploration and nuclear waste management projects. Exploration for H2 resources have not yet been made at a sufficient level to determine the potential concerning Finnish bedrock.
This poster presents the current knowledge of measured H2 concentrations in drillholes, as well as the most promising areas from the perspective of known H2 formation processes. Several areas across Finland are theoretically prospective for hydrogen due to favorable lithologies. These include, for example, greenstone belts with various ultramafic rocks, ophiolitic rocks, and various mafic-ultramafic layered intrusions that contain strongly serpentinized rocks. Additionally, rapakivi granites and other igneous rocks can be inducive to radiolysis processes. Other interesting potential rock associations include carbonatites, kimberlites and specific ore deposits such as IOCG deposits known for hydrothermal alteration processes. All of these can generate H2 via water-rock interaction.
The comprehensive data sets of Geological Survey of Finland (GTK), including lineament interpretation data and low altitude aerogeophysical data, and bedrock drilling data can be a major factor in delineating areas with H2 potential. Case examples will be presented using these existing data. Existing measurement equipment and research capabilities will be part of the presentation.

Investigation of the geological-hydrogen potential of the MCR in Northeastern Minnesota

Valentine Combaudon, University of Colorado, Boulder, Eric T Ellison, University of Colorado, Boulder, Alexis S Templeton, University of Colorado, Boulder

The Mid-Continent Rift (MCR) extends from Kansas to the Lake Superior region and has been targeted for geological hydrogen exploration. In Northeastern Minnesota, highly alkaline and reducing waters, usually known as markers for geological hydrogen production, are associated with Fe-rich igneous rocks belonging to the MCR. During a recent fieldwork in Northwestern Minnesota, gas was found bubbling from these groundwaters. The inorganic chemistry and dissolved gas species were quantified, including hydrogen, and the carbon isotopic signatures of methane and dissolved inorganic carbon were characterized to help determine gas origin. The abundance of several small molecular weight fatty acids was also quantified. In addition, DNA was extracted from the H2-bearing groundwaters and sequenced to identify possibly hydrogen-consuming organisms. Separately, we collected subsamples of drill cores from several source rocks associated with these gas-rich groundwaters and characterized their mineralogy and Fe-speciation before conducting low-temperature H2-generation experiments (50-150C). Here, we will present the results of this geochemical study and propose a first comprehensive picture of geological hydrogen production and cycling in the subsurface rocks where the MCR outcrops in Northeastern Minnesota.

Enhancing Low-Temperature Serpentinisation for Hydrogen Production: Catalytic Role of Awaruite and Chromite

Jeffery Akuoko, University of Manchester, Lin Ma, University of Manchester

Serpentinisation, the hydration of ultramafic rocks to produce hydrogen gas, offers a potential clean energy resource. While optimal hydrogen production is known to occur at 250–350°C, serpentinisation at lower temperatures—typical of Earth's surface and potentially relevant to Mars—remains limited by sluggish kinetics.
This study investigates the catalytic potential of awaruite ($Ni3Fe$) and chromite in accelerating low-temperature serpentinisation. Modified rate laws from the literature are implemented in PHREEQC to model the catalytic effects, with results benchmarked against experimental hydrogen production data. The findings would reveal how these minerals enhance reaction kinetics, providing insights into the role of catalysis in hydrogen generation.
By focusing on the catalytic behavior of awaruite and chromite, this research contributes to understanding the key factors controlling hydrogen yield in serpentinisation at low temperatures. These results have implications for sustainable energy production on Earth and potential applications in planetary geochemistry.

Hidden Energy Streams: Evaluating Serpentinization-driven Hydrogen Generation in the Ronda Peridotite (S. Spain)

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Growing interest in hydrogen as a clean energy source has prompted renewed attention towards low-temperature serpentinization processes in ultramafic settings. The Ronda Peridotite, within the Betics-Rif orogen, offers one of the world's largest mantle exposures, uniquely suited to investigating hydrogen generation linked to serpentinization. Faults intersecting this massif potentially facilitate fluid circulation, promoting the emergence of hyperalkaline springs variably enriched in hydrogen and methane, with those with higher concentrations being located along active fault planes.
A detailed morphotectonic survey combined with petrographic and geochemical analyses is being conducted to clarify relationships between fault structures and serpentinization. Preliminary observations suggest that serpentinization occurs over a broad temperature range and involves diverse iron partitioning pathways, revealing its influence in hydrogen fluxes. By mapping spring distributions and analyzing the tectonically rejuvenated basins of the area, this research aims to elucidate geodynamic controls on serpentinization processes. This integrated approach will offer new insights into tectonic modulation of serpentinization-driven hydrogen seeps, establishing a robust basis for future exploration and resource strategies. Findings from this study will refine existing hydrogen-generation models, enhancing our understanding of hydrogen generation in orogenic contexts and its implications as a potential sustainable energy resource.

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Natural Hydrogen Exploration Workflow - a pragmatic evaluation matrix from Regional to Play to Prospect scales

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The ambition is to provide an update of the evolutive workflow for natural hydrogen exploration, towards evaluation of subsurface hydrogen resources, resulting from a collaborative work from earth2 program.

A workflow matrix is proposed as an extensive tool box, following a pragmatic, methodological approach :
• from Regional to Play to Prospect scales
• inspired from O&G and mining industry
• but adequated to natural H2 specificities

The consequent benefits consist in:
• understanding key stakes & risks
• proposing data acquisition plan
• reducing uncertainties
• ranking and selecting prospects to help for decision and strategy
• promoting natural hydrogen network

The Global Search for Commercial Natural Hydrogen – an update

Alan Driscole, NVentures

The search for commercial natural (geological) hydrogen around the world is currently expanding at a rapid pace. This is shown by increases in acreage under licence, in surface and subsurface exploration activity and by an acceleration in exploration and appraisal drilling. New areas are also becoming accessible as countries, recognising the potential, set the legal groundwork for exploration and development.

A large and growing number of hydrogen exploration start-ups, as well as existing hydrocarbon and helium exploration companies, are implementing a wide range of exploration and development strategies. This in turn reflects recent developments in our understanding of natural hydrogen generative systems and in hydrogen exploration methodologies, as well as the issues and risks associated with a sustainable, commercial natural hydrogen project.

Here, we provide an update on the status of global hydrogen exploration activity. We will summarise the various geological hydrogen systems and where and how they are being played around the world, the main philosophies driving this exploration effort and document recent activity. This includes reviews of recently drilled, dedicated hydrogen wells (and those planned), including in Kansas, South Australia, Western Australia, France, Spain and Morocco.

The role of organic matter in the H2 system of the western Pyrenees, A missing player?

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The Pyrenees, formed by tectonic inversion of a former rift system, offer a geological setting favorable for natural hydrogen (H_2) generation. While shallow mantle bodies beneath the western North Pyrenean Zone are considered a primary H_2 source, distant occurrences such as at Monzón suggest additional generation mechanisms and long-range migration. One such mechanism could be the overmaturation of organic matter in formations subjected to temperatures above 200 °C.
This study investigates organic-rich Paleozoic formations (Silurian–Devonian) in the Aquitaine and Ebro basins, where these units may lie at depths >10 km. Samples were obtained from surface outcrops (Ossau Valley) and deep wells (up to 6000 m) in the Aquitaine Basin. These formations include thick clay-rich layers containing organic matter with hydrogen generation potential.
A multi-analytical approach combining RockEval, H_2Eval, and Raman spectroscopy was used to assess organic and mineral carbon contents, H_2 potential, and thermal maturity. Results reveal heterogeneous thermal histories across the region. While parts of the Aquitaine Basin may retain conditions favorable to H_2 production, many samples show low total organic carbon (TOC), limiting the potential for active generation. Moreover, in some areas of the Aquitaine Basin, H_2Eval results suggest that hydrogen production is not solely driven by organic matter, but also involves siderite alteration, pointing to a possible abiotic contribution.
These findings highlight the combined role of organic and mineral processes in H_2 generation. They underscore the need for further exploration to better constrain the extent and mechanisms of natural hydrogen systems in the Pyrenees for energy resource assessment.

Unlocking the evaluation and scalability of Natural Hydrogen Exploration: the HOREX Techno Pilot. Part 1: Play-based strategy

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If it is widely accepted that hydrogen will play a key role in decarbonizing the economy, yet the promises of the clean hydrogen revolution remain unfulfilled. Progress is stalled by the cost gap between hydrocarbon-based hydrogen and clean hydrogen, the so-called “green premium”. This cost remains high, driving growing interest in natural hydrogen which could compete with hydrocarbons but only if significant reservoirs are discovered and produced near point of use. So far, natural hydrogen discoveries have been mostly accidental. However, the emerging industry is shifting towards a programmatic, scalable, play-based exploration strategy requiring subsurface imaging hydrogen-specific technologies to assess and evaluate prospects in a probabilistic and realistic manner.

In this presentation, we will introduce the “HOREX” technological pilot, the most ambitious multiphysics imaging initiative for natural hydrogen exploration to date. First deployed in the French Pyrenees in 2025, HOREX features a geology-driven design to de-risk the key elements of the hydrogen system, from source generation to surface leakage. It integrates an all-in-one acquisition campaign optimized for impact and cost efficiency. Using 1000 new-generation SERCEL seismic sensors alongside gravimeters and other various non-seismic methods, HOREX champion passive seismological surveying and imaging techniques. The collected geophysical and geochemical data are jointly processed into 4D multiphysics images, enabling estimates of kitchen volume, plumbing networks, as well as characterization of reservoirs and traps. While early exploration started years ago, HOREX could unlock the next stages of exploration by providing data-driven, probabilistic evaluations to guide drilling decisions within a portfolio strategy.

Natural hydrogen occurrences in the western portion of Northern Apennines, Italy

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The western sector of Northern Apennines in Italy exhibits favourable conditions for natural hydrogen (H2) occurrence, being characterized by the presence of ophiolitic bodies, hyperalkaline waters and deep-seated faults. To evaluate the potential for natural H2 exploration in this region, a comprehensive geochemical and geological investigations was conducted, including compositional and isotopic analyses of gas in spring water, bubbling gas and soil-gas measurements, along with petrographic studies of ultramafic rocks. H2 was observed in multiple springs in both foothill (Taro valley ophiolites) and hinterland (Bobbio Tectonic Window). In the Taro valley, H2 occurrences are primarily associated with hyperalkaline springs linked to peridotites with high degree of serpentinization, which is likely the main source of the observed H2. Conversely, in the Bobbio Tectonic Window, the neutral pH springs, located away from exposed ultramafic bodies, the H2 origin is still uncertain. However, the potential presence of ultramafic bodies within the sedimentary sequence may generate H2 through serpentinization at depth. Notably, all H2 occurrences are associated with methane (CH4) which exhibits isotopic signatures indicative of a predominantly thermogenic origin. This suggests that H2 and CH4 may derive from different rock systems. The presence of hydrocarbon reservoirs in the region point to the potential for subsurface H2 accumulation, particularly in the Bobbio area.

Time-resolved 2D and 3D Imaging of Two-Phase Hydrogen and Brine Injection into Porous Clashach Sandstone

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Extracting natural hydrogen (H_2) from underground porous media could support the energy transition by providing economic H_2. Important unknowns to natural H_2 exploration include the H_2 fluid flow through the porous medium which affects the volume of extractable H_2. We used time-resolved X-ray micro-computed tomography to image unsteady and steady-state injections of H_2 and brine (2 M KI) into a Clashach sandstone core at 5 MPa and ambient temperature (Clashach composition: ~96 wt.% quartz, 2% K-feldspar, 1% calcite, 1% ankerite).

During steady-state injections, entry of H_2 into the brine-saturated rock was within seconds, with H_2 entering into several pores in bursts while, at other locations, snap-off occurred. Over time, despite low capillary numbers of 10^{-9}, some H_2 ganglia connected, disconnected and then reconnected (intermittent flow), indicating that the current presumption of a constant connected flow pathway during multiphase fluid flow is an oversimplification. Pressure oscillations at the core outlet during steady-state experiments were characterized as red noise, confirming observations of intermittent pore-filling. At higher H_2 fractional flow the H_2 saturation in the pore space increased from 20-22% to 28%. Average Euler characteristics were generally positive over time, indicating poorly connected H_2 clusters and little control of connectivity on the pore space H_2 saturation. In unsteady-state injections, H_2 displacement of brine was as Haines jumps. Our results suggest low volumes of extractable H_2, especially in aquifers with high hydrodynamic flow. For more accurate predictions of the potential for geological H_2 extraction, geological models should incorporate energy-dissipating processes such as Haines jump.

Geological Society
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