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iCRAG 2019

Resources for a Sustainable Future

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Oral Presentation Abstracts

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iCRAG 2019

Resources for a Sustainable Future

Keynote Addresses

iCRAG 2019

Resources for a Sustainable Future

iCRAG - Solutions for Sustainability

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iCRAG has achieved much in the past five years, particularly in characterizing Ireland's onshore and offshore surface and subsurface, and its energy, mineral, and water resources. As we look to the future, the climate emergency, coupled with the other 16 U.N. Sustainable Development Goals, challenges iCRAG's physical and social scientists to provide sustainable solutions.

Geoscience, Earth Change and Society

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The planet on which we live is undergoing change every day due to an intricate combination of natural processes and human interactions. The natural processes initiate from deep within the Earth through to its uppermost surface and surrounding fluid envelope and span an enormous range of spatial and temporal scales - molecules to continents and seconds to eons. Human society has been sustained by Earth's abundant natural resources - including water, energy, minerals, and land - and has been fundamentally altered by the impacts of natural events such as earthquakes, volcanic eruptions, floods, fire, and drought. Human populations have also learned how to manipulate and engineer various aspects of the Earth system to make use of the natural resources, to construct and build infrastructure below and above ground, and to avoid or mitigate the impacts of geohazards. These and other human activities increasingly have had direct effects on and feedbacks with ongoing "natural" Earth processes and have influenced dramatic Earth change on timescales that matter for people. The geosciences offer a powerful set of individual disciplines and multi-disciplinary approaches to understand Earth processes, and their interactions and consequences for human society and the environment. By measuring, monitoring, analyzing, and modeling Earth processes at many scales, geoscience research contributes to understanding these processes and predicting change at timescales and in spatial dimensions that matter for decision-making; resource stewardship; environmental health; and the economic growth, health, and security of communities.

Responsible Mining for a Sustainable Future?

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Increasing global population size[1] coupled with our evolving needs and desires mean that we are going to be forced to make use of our non-renewable natural resources for centuries to come. Extraction of these natural resources through activities such as mining is therefore crucial to human survival. While these activities have been undertaken and honed for thousands of years, there is still much more we can do to ensure that we mine in the most responsible manner possible.

Mining has a terrible reputation. Images of children scratching commodities such as cobalt so urgently needed for our latest batteries from seams buried at the end of unsupported tunnels[2] rub shoulders with the catastrophic failure of waste dams ("tailings") facilities[3] and safety statistics showing that sixteen of the world's largest twenty-seven mining companies lost 50 workers through workplace fatalities in 2018[4]. This is hardly responsible or sustainable. However, it is by acknowledging, understanding and working with these threats that the true opportunities for mining to become more responsible emerge.

The opportunities for mining are numerous and start with contributing to the addressing of the United Nation's Sustainable Development Goals (SGDs). For example:

- **No poverty (SDG #1).** Some of the world's richest natural resources are located in the poorest countries[5]. By large scale mining working together with artisanal and small-scale mining, increased wealth can be retained in country and in-community.

- **Affordable and clean energy (SGD #7).** All forms of renewable energy require a cocktail of specialist minerals and metals[6]. Each of these have to be responsible extracted from the ground. Mining could be the new clean energy sector.

- **Good health and well-being (SDG #3)**. The situation and nature of the rocks we are increasingly required to mine (deeper and more complex) mean that new technologies are required to make the mining possible. These increasingly remove people from the workface, reduce dust and noise, and reduce the need for waste management – all of which improve health and well-being.

Mining therefore holds the key to a sustainable future, provided we can mine in a responsible manner.

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The Myopia of a Carbon-Only Lens

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The energy transition is being described by some through a carbon only lens: climate change is caused by human CO2 emissions; the oil industry is to blame; and the answer is wholescale government intervention in energy and economic markets. Not only is this political viewpoint myopic, it is fallacious. The real energy transition, which is different and better, will happen when every person on earth has access to secure energy and the environmental impacts of energy - atmospheric, air, land and water - are reduced. Secure energy - affordable, available, reliable, and sustainable - is vital for economic health and also to lift the world from poverty. To accomplish the real energy transition will require a public, non-partisan understanding of the science, technology, and economics of energy resources; atmospheric emissions reduction; local air emission improvement; land use, mining and landfill; and full cycle water use. Rather than propagating the divisive political dichotomies of “good and bad” and “clean and dirty” it is vital that the dialog seek compromise and convergence on workable solutions in the radical middle, that difficult and impactful overlap space between energy, the economy and the environment.

iCRAG: Research for a Sustainable Future

iCRAG Groundwater: Advances in Understanding Water Resources for both Human Supply and Ecohydrological Habitats

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An estimated four billion people worldwide rely on groundwater for their primary source of drinking water and it is a major water source for agriculture and industry. Groundwater also supplies many rivers, lakes and estuaries, forming a significant part of the overall flows, particularly during ecologically sensitive low-flow periods, as well as supporting many wetlands with unique habitats, known as Groundwater Dependent Terrestrial Ecosystems. iCRAG's groundwater research activities seek to provide innovative methodologies, measurements and models to improve our understanding of ongoing and future threats to groundwater quantity and quality. Our research focusses on the hydrogeology of fractured/fissured aquifers in order to characterise both flow and contaminant transport processes more accurately.

A summary of activities over the past 4 years is presented to cover research highlights. This includes a comparison of different methods that are being applied to model karst aquifers - distributed finite difference approaches to semi-distributed pipe and tank network models - from which the importance of different flow paths are being characterised. Other research has investigated the key parameters that influence recharge processes into such fractured aquifers, from which the impacts of climate change on water resources are being predicted. The ecohydrological dynamics of ephemeral lakes (turloughs) in karst areas and assessment of the ecosystem services that they provide is also presented.

From a water quality perspective, the pollution of karst aquifers from human wastewater (septic tanks) is being quantified using several novel fingerprinting compounds. Agrochemical pollution from veterinary drugs has also been detected for the first time in Irish aquifers and other projects have been evaluating the water quality in private wells with respect to microbiological contamination as well as geogenic sources of uranium and arsenic. Finally, the impacts of submarine groundwater discharges on the aquaculture industry in bays off the west coast of Ireland are detailed.

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iCRAG Raw Materials: Improved Models for the Origin and Discovery of Mineral and Aggregate Deposits

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A secure and efficient supply of raw materials is a major challenge in the continued development of the European economy and a prerequisite for ongoing decarbonisation. As Ireland represents a European country actively engaged in mining, iCRAG scientists are in a key position to address this research challenge by conducting fundamental and applied research on many aspects of Irish mineral and aggregate deposits. iCRAG research is focused on improved exploration methods for mineral discovery but also includes research to enhance resource production and better achieve project closure.

The principal goals of our research are facilitated by the analysis of refined models constructed from Ireland's mineral exploration archive, including borehole, geophysical and geochemical datasets. Our work is helping to extend the productive life of the world class Irish zinc-lead mineral province by developing improved models for their origin, geometry and evolution. Alongside this, iCRAG researchers are investigating ways to broaden the Irish mineral industry by examining several prospective mineral deposit types in Ireland that are not currently exploited. In addition, iCRAG is also examining deposits of critical minerals that may not be found in Ireland but are critical for a sustainable future. Our research is leading to the definition of better geological, geochemical and geophysical methods for the discovery of such mineral and aggregate deposits.

In this talk we describe some of the main advances and innovations of iCRAG's raw materials related research and briefly outline our plans for the future.

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iCRAG Geomarine: Safeguarding Marine Resources for Sustainable Development

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The United Nations Sustainable Development Goal 14 sets out to "conserve and sustainably use our oceans, seas and marine resources for sustainable development". This is central to research challenge, where we provide better information and understanding of the ocean and its seabed to provide baselines for assessing 'Good Environmental Status' offshore Ireland. Our research provides a better understanding of the environmental change in our oceans and the habitat response focussing on high protection status cold-water coral reefs. We focus on developing an understanding biochemical processes in our oceans and providing calibration for ocean remote sensing. We have also developed new remote sensing software tools for industry to support the economic development of Ireland's offshore regions and provide a new suite of decision making tools for industry and policy makers. We continue to research on the impact of marine acoustic noise and develop tools to use the natural acoustic noise in the environment as an imaging and monitoring tool. In collaboration with MaREI and SEAI, we are developing GIS-based tools to assist in the development of offshore wind energy developments and have complete research to determine the shallow sub-seabed sediment architecture, geological history and its relevance of offshore installation foundation design. Our marine research aims to make Ireland's offshore environment a test bed and natural science laboratory for innovative and novel technologies in the marine sector.

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iCRAG Energy Security: Providing Insight into Resources, Risks and Long-term Environmental Change

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With ever increasing demand, sourcing secure and reliable energy at a reasonable cost is critical to Irish economic development. iCRAG's Energy Security research is delivering improved understanding of the geological setting of critical resources across multiple scales, by studying basin evolution, reservoir modelling, unconventional hydrocarbons and sediment tracking. These approaches ultimately aid in the prediction and de-risking of these resources both in Ireland and beyond.

Understanding the provenance (or source) of sediments and sedimentary rocks is one such tool that can help in this challenge, while also providing important information on past earth environments. Such information, for example, helps to constrain previous plate-tectonic configurations, the development of ancient/modern drainage systems and the evolution of sedimentary basin infill. Irish researchers are leading the way in improving analytical techniques that allow us to track individual sediment grains back to their ultimate source such that signals and fingerprints from individual sediment grains, across a variety of mineral types, can be interrogated.

These approaches provide valuable insights into the nature and distribution of important economic resources. For example, Triassic sandstones are an important potential Irish resource as they 1) act as reservoirs for gas in offshore basins (e.g. Corrib); 2) are potential sites for storing sequestered CO_2; and 3) form important local groundwater aquifers in Northern Ireland. Recent iCRAG research has revealed intricate drainage patterns feeding through and between Triassic basins onshore/offshore Ireland - helping to constrain the nature and distribution of these rocks and aiding in the prediction of their storage potential.

Beyond resources, these techniques can be applied to a range of problems and challenges in the geosciences. Sediment dispersal is ultimately controlled by a combination of climate and tectonics, hence these types of data can be used to reconstruct dramatic changes in environments at a local or global scale. Anthropogenic impacts on large-scale sediment transport systems can also be assessed using these approaches. From a palaeoclimate perspective, provenance data can be used to track, temporally and spatially, the delivery of ice rafted debris from glaciated margins, hence offer a means of establishing records of ice sheet dynamics through time.

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Geophysics: Enabling Methodologies for a Sustainable Future

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Imaging the sub-surface and understanding how geo-systems change on short timescales draw heavily on geophysical methodologies. Whilst traditional methodologies have been very successful, they often have burdensome environmental and/or financial costs. In particular high resolution time-lapse work tends to be either prohibitively expensive or logistically challenging. A key focus in the iCRAG Geophysics Platform has been the development of environmentally low impact and financially cheaper 'passive' methodologies. The work has focused on both the terrestrial and marine environments and the coupling between ocean and land in deep water. In this presentation we will put new passive methodologies in context and look at examples of their application in a range scenarios. We will also assess pathways for their implementation as part of environmentally friendly cheap operational toolkits.

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Public Perception and Acceptance of the Extraction Industry in Ireland

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Earth's resources such as energy, water and minerals are limited. To ensure that Earth's resource are available to present and future generations changes need to be made, for example in the energy grid. These changes have significant societal impacts, for example it impacts jobs, the (local) environment, and people's wellbeing. It is important to understand how people (mis)perceives these changes and impacts, how they responds to them, and under which conditions they find these changes (un)acceptable.

Many of changes aimed at a sustainable future require the availability of minerals. However, there is often strong public resistance to the extraction industry. One key research area is to understand the public perception and acceptance of the extraction industry. We find that concerns about the environmental risks, rather than economic concerns, of the extraction industry are very important for people's acceptance of the extraction industry. This has implications for communication strategies of scientists, policy makers and the industry about projects involving the extraction of natural resources and minerals.

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Testing Negative C Emission Technology via Enhanced Chemical Weathering in an Irish Agricultural Context

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The recent Intergovernmental Panel on Climate Change (IPCC) 1.5°C Special Report suggests that CO_2 removal is required to achieve net negative emissions in the 21st century in order to limit the temperature rise below 1.5°C, in all future pathways. Plant-mediated enhanced chemical weathering offers one theoretical solution by increasing the rate at which photosynthetically assimilated CO_2 helps to weather calcium silicate rocks, which in turn increase the rate at which carbonates are deposited and stored in the ocean system. Our multiple ICRAG funded projects experimentally explore the current carbon sequestration capacity of Irish soils (Citizen Science Project 2019 - 2020) and the potential for enhanced carbon sequestration as a result of volcanic ash-fertilization of Irish grasslands under modern and future climatic conditions (Negative C Emission Project 2018 - 2020).

Towards these aims, experiments have been carried out in controlled environment growth chambers simulating current ambient and future climatic conditions over a period of 4 months. A total of 8 treatments and a split-plot experimental design have been used to test the potential for grass-mediated enhanced weathering of volcanic ash-enriched soil. Preliminary results on the degree of volcanic ash weathering and the effects of ash fertilisation on grass morphology, physiology and productivity as well as on water cycling will be presented. Our study will assess the potential of volcanic ash addition to Irish soils as a “negative” emissions technology and will optimise a protocol for future field-based trials. Furthermore, our experimental results are directly feeding into an ongoing citizen science project, which aims to map the current chemical weathering capacity of Irish soils and to explore public perception of moderate geoengineering solutions in climate action.

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iCRAG Geohazards: Engineering Offshore Solutions

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With the publication of the Offshore Renewable Energy Development Plan in 2014, the forthcoming Marine Planning and Development Management Bill, the new Renewable Electricity Support Scheme (RESS) and the future implementation of a Marine Spatial Plan for Ireland, there is current significant stimulus to invigorate the offshore wind sector. Currently consented, or considered, projects are likely to be joined by others. Given the complexity of seabed and sub-surface conditions in the Irish Sea there are geological vagaries which may never facilitate the deployment of offshore wind. In other areas inhibitors, such as sediment dynamics and overconsolidated glacial deposits, may significantly impact development. Understanding the seabed sediments and sub-surface structure with regard to siting offshore windfarms and other renewable energy infrastructure, therefore, becomes a first order need and the first stage assessment towards a sustainable, national marine energy development strategy.

The EASTWIND project at iCRAG focuses on identifying and investigating the primary geological and geotechnical challenges to developing offshore wind in the Irish Sea. Collaborating with industry partners, fellow SFI research institutions and other iCRAG projects, EASTWIND is undertaking stratigraphic and geomorphic studies that develop our understanding of the seabed in order to develop a set of geohazard and constraint maps critical to marine spatial planning and project siting. Furthermore, it is executing data collection surveys to fill data gaps and facilitate engineering feasibility studies.

This work supports UN Sustainable Goal 7 of *'...access to affordable, reliable, sustainable and modern energy'*, as well as Goal 14 to '*conserve and sustainably use the oceans, seas and marine resources'*.

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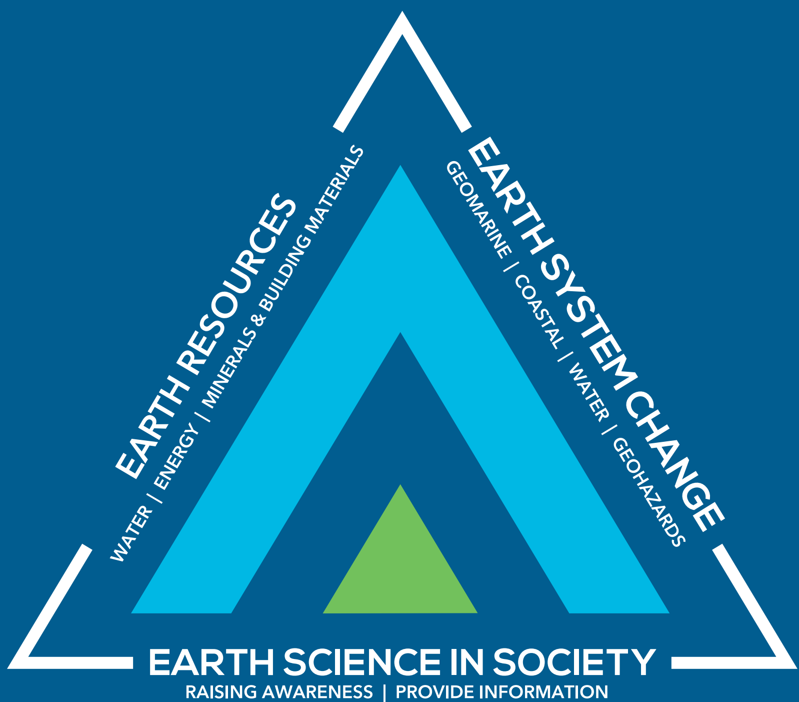
Resources for a Sustainable Future

iCRAG Technical Snapshots:
Earth Resources: Raw Materials



Enhancing the Explorer's Toolkit: Geochemistry Techniques and Applications to Mineral Deposits Studies

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As our society continues to develop while balancing our needs for low-carbon energy security and environmentally sustainable technologies, the efficient supply of raw materials are becoming more important than ever. However, mineral deposits are becoming continually harder to explore for. With falling grades and greater depths, new technologies are required to help optimise extraction. In iCRAG we are actively investigating how our in-house analytical capabilityand expertise can be applied to help explorers and miners de-risk their activities and provide maximum context and characterisation of mineral systems and mineralogy. Presented in this talk is a snapshot of the various geochemical techniques available in iCRAG and an overview of their applications. It will also highlight new developments and their role in understanding ore-formation, as well as elucidating the fingerprints of geochemical and physical processes that can be used to better unravel mineral systems. We will also introduce plans for new projects and expansion in the near future that will present new opportunities to expand our technologies and their applications to help industry tackle the problems facing raw materials supply in a changing world.

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Integrated 3D Geological Modelling and Data Analysis of the Irish Carboniferous

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Secure and sustainable supply to groundwater, raw materials, and geothermal resources in Ireland is vital for Irish society. Understanding and finding these is critically dependent on the existence of high-quality models of the subsurface. iCRAG is developing refined 3D geological models for the Irish geological subsurface which aim to underpin current and future exploration and management efforts for these resources.

This presentation will highlight how our research brings together high-quality datasets from iCRAG research, industry, academia and government sources to develop a coherent model of the economically important Carboniferous geology of Ireland. This is done using a multidisciplinary workflow, combining several state-of-the-art geomodelling and spatial analysis systems. Large datasets are combined of geological, geochemical, reflection seismic, drillhole and potential field geophysical data at a variety of scales from both open source and proprietary information.

This work produces structure and horizon models in an integrated data environment that is used to study processes, and relationships between data in space and through time. We will highlight our research into Carboniferous tectonostratigraphic basin evolution, quantifying the development of fault systems. The analysis of this structural framework, in combination with lithofacies distribution and development of bathymetry during basin formation, allows us to understand current and past fluid flow pathways, and how this relates to, for example, mineralising events. We will demonstrate how integrated 3D analysis provides a crucial background for research into the geometry and formation of mineral deposits in the world-class zinc-lead mineral province in Ireland, as well as on groundwater flow, geothermal energy potential and hydrocarbon systems.

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Structural Framework of the Irish Lower Carboniferous and the Kinematics of Associated Faulting

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Fault systems in the Irish Lower Carboniferous are important in relation to subsurface resources, including groundwater, geothermal and mineral resources. For example, major metal deposits in the world-class Irish Orefield occur in association with normal faults. Given their importance, however, the fault networks and structural framework at depth are still poorly constrained.

Several decades of mineral exploration in the Irish midlands has resulted in the generation of a high-quality drilling dataset for the Irish midlands. The past 5-10 years has seen the adoption of 2D seismic reflection profiling as a tool to explore deeper targets. The combination of these data together with high quality airborne magnetic and electromagnetic data, including the Tellus survey, and gravity data provide excellent data coverage for a large portion of the country.

These integrated datasets form the basis for a new interpretation of the structural framework of the Irish midlands and have been used to carry out detailed mapping of faults within the Midlands. The geometry of the key faults across a range of scales has been defined and the nature of the interactions between faults, including synthetic and conjugate relay zones have been studied.

The presence of Lower Carboniferous growth sequences on faults allows the timing of the fault movement during and after the Lower Carboniferous to be established. Inversion of these faults during the Variscan orogeny is also observed. Some faults show no Carboniferous growth and can be correlated to Permo-Triassic aged extension. The lateral offset of Cenozoic dykes imaged in high quality airborne magnetic data allows the mapping of major Cenozoic strike slip faults; These faults correlate well with the mapped Carboniferous faults indicating that they reactivate older faults during the Cenozoic.

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The 'Blue Book' Revamped: Towards a Tectono-stratigraphic Framework of the Tournaisian & Viséan of Ireland

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The past half-century of mineral exploration and research activity in Ireland has generated a considerable amount of lithostratigraphic data. Philcox (1984) produced an extremely valuable compilation of this work in an Irish Association for Economic Geology (IAEG) publication titled “Lower Carboniferous Stratigraphy of the Irish Midlands”. Colloquially known within the industry as ‘The Blue Book’, it focused on the Tournaisian of the Irish Midlands, which proved invaluable amongst exploration geologists.

Since 1984, exploration of Carboniferous strata has expanded both regionally and at depth, placing greater demands on our understanding of the Tournaisian and Viséan lithostratigraphy of Ireland. This GSI/iCRAG funded project will produce a revised dynamic stratigraphy of Tournaisian and Viséan strata in Ireland and will include new and unpublished lithostratigraphic data collected in the last 3 decades. Several other ongoing iCRAG projects will build upon and feed into this work, moving towards a more comprehensive understanding of the tectono-stratigraphic framework of the Tournaisian & Viséan of Ireland.

The finished product will be presented as online chapters, each covering a geologically distinct region. Each chapter will include a revised and updated stratigraphy combining detailed lithological descriptions, colour photographs with hyperspectral scanning data and correlative sections of lithofacies within the designated areas. The chapters will be digitally published sequentially as stand-alone products. PDFs of chapters and a PDF of the full book will be publically available for download online on the GSI website with information, links and examples on the iCRAG website. An online interactive viewer will also be developed which can be used in tandem with online chapters to give the reader a wealth of additional information about a particular area they are interested in.

The final product aspires to be an invaluable, dynamic and updatable resource for geoscientists in both industry and academia, for both research and teaching purposes.

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Pathfinders Towards Mineralization: The Application of Mineral Chemistry and Isotope Analysis to Exploration

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Since the 1980s Ireland has been a major contributor to world Zn-Pb production, with five Zn-Pb mines and over twenty sub-economic prospects discovered. The Navan deposit, mined by Boliden Tara Mines, is one of the larger Zn deposits in the world, employing around 580 people. However, with the 2015 closure of the Lisheen Zn-Pb mine, Navan is the only operational Zn-Pb mine in Ireland. Zinc is an important element as we transition to a more sustainable future and aim to achieve several of the UN sustainable development goals (SDG's 7, 8, 11, 12 and 13). With applications in long-term energy storage development and as a micronutrient for agriculture, making the discovery of new zinc deposits a priority.

Increasing understanding of how economic deposits, and their surrounding sub-economic geochemical haloes, form will lead to higher exploration success rates for Zn-Pb deposits in Ireland. We have approached this by trace element and isotopic analysis of hydrothermal minerals. Lisheen mine has offered an excellent testing ground for geochemical techniques, since it was operational for over 15 years and there already existed a good understanding of deposit formation from structural and earlier geochemical studies.

Initial mineral chemistry studies of the Island Pod orebody, Lisheen, have shown average orebody concentrations of Co, As, Ni, Tl in pyrite almost double those for its halo. Trace element variation on the scale of the wider Lisheen deposit is currently being investigated. Isotopic investigations (clumped O-C, S, H, Pb) are helping uncover more detail of fluid flow and mixing patterns. This helps to further our understanding of the complex interactions which led to sulphide precipitation.

These geochemical techniques have the potential to be developed into vectoring tools to search more efficiently for Zn-Pb orebodies. This will lead to more informed exploration strategies and help to de-risk exploration in Ireland.

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Lithium Pegmatites in Southeast Ireland: A Storehouse for Critical Metals

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Lithium-ion batteries dominate the market for electric vehicles, consumer electronics and renewable energy storage, making lithium supply essential to climate action through decarbonisation. In 2018, over 60% of the world's lithium was mined from pegmatites containing the mineral spodumene in Australia; the remainder was produced from subsurface brines below South American salars. Lithium compounds are made from Australian spodumene in China and then distributed for battery production around the world. Due to high emissions and energy consumption involved in resulting long transport routes, and environmental problems involved in brine production, responsible lithium consumption in Europe requires a domestic supply chain from deposit to end product. Understanding how domestic lithium deposits formed and how they may be found are therefore crucial steps towards sustainable development. Other valuable metals typically enriched in lithium pegmatites include tantalum and tin, also often deemed critical because of their requirement in modern electronics.

Our research focuses on spodumene pegmatites associated with the Leinster Granite in southeast Ireland. In drill cores, these pegmatites show high ore grades, up to 1–2 wt.% lithium. Our model for the crystallization of these pegmatites indicates that highest potential for tantalum and tin occurs in different parts of the pegmatites to the highest concentrations of lithium, with implications for mine planning to prevent valuable by-products becoming waste. Geospatial analysis of southeast Ireland Tellus stream sediment data, publicly available from Geological Survey Ireland, suggest that combined anomalies of tin and tantalum in stream sediments could be indicative of lithium pegmatites. This is supported by studies showing that the sediments in catchments with lithium pegmatites contain the tin and tantalum ore minerals cassiterite and columbite-tantalite, respectively, which were likely derived from the pegmatites. Regional geochemical data, often publicly available from geological surveys, could prove a highly efficient tool to assess EU lithium prospectivity.

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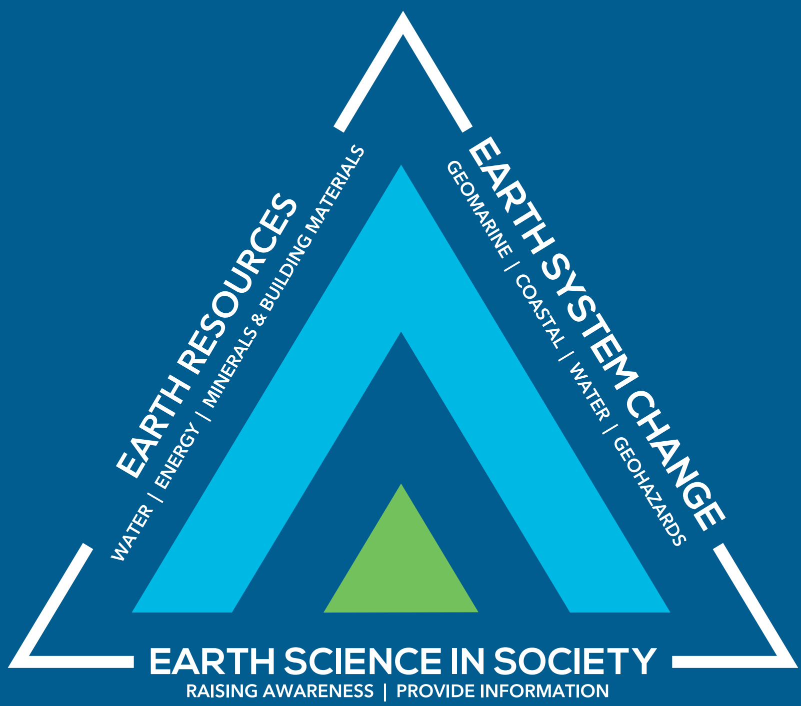

From Rifting to Hyperextension: Upper Jurassic – Cretaceous Succession of the Porcupine Basin, Irish Atlantic Margin

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Although energy systems are transitioning away from fossil fuel dependency to renewable energy, new petroleum discoveries are still necessary to meet the growing global energy demands and to sustain economic growth in the coming decades. New indigenous discoveries would help Ireland's and the EU's energy security and lessen dependence on imported energy sources.

The Porcupine Basin, an area of exploration and research interest, is one of several sedimentary basins on the Irish Atlantic margin that developed during Mesozoic rifting that preceded the south-to-north opening of the Atlantic Ocean. The V-shaped basin offers a unique opportunity to study and understand the transition from low-magnitude rifting in the north to hyperextension in the south where extreme crustal thinning potentially led to localised mantle exhumation, volcanism and incipient oceanic crust. Late Jurassic – Early Cretaceous rifting transitioned to a protracted phase of thermally-controlled subsidence that accommodated a southward-thickening Cretaceous succession up to 6 km thick, containing several reservoir intervals. The basin margins locally contain numerous unconformity-bounded 'transition' sequences that drape the fault-controlled syn-rift sequences, some of which contain proven source rock intervals. However, until now the stratigraphic and structural relationships between the margins and hyperextended parts of the basin are poorly understood.

The present tectonostratigraphic study of the Upper Jurassic – Cretaceous succession integrates extensive 2D and 3D seismic data with well information to determine the crustal and stratigraphic response to rifting. The results reveal a predominantly asymmetrical rift system comprising five major segments formed by southward-increasing strain. Early rifting involving low-magnitude extension and syn-rift deposition was strongly controlled by the influence of inherited crustal structures. As rifting evolved to hyperextension, the influence rapidly reduced as strain localised towards the rift axis, resulting in fault reorientation and younger syn-rift and 'transition' sequences in the basin centre where source rock intervals potentially developed. The results of this study reveal the timing, distribution and potential reservoir quality of sedimentary systems in Porcupine Basin and have wider implications for the hyperextended setting.

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Structural and Kinematic Analysis of the Slyne Basin: Exploring the Links Between Structural Evolution, Salt Tectonics and Trap Formation

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The Slyne Basin is an elongate and narrow series of half-grabens and grabens bounded by transfer zones, located off the north-western coast of Ireland. It belongs to a chain of rift basins extending along the NW European Atlantic margin from Morocco to Norway. The basin formed through a complex, multiphase geological evolution, with episodic extensional events in the Late Permian, Early to Middle Jurassic, and most significantly, the Late Jurassic. Kilometre-scale erosion of the Upper Jurassic strata during the Early Cretaceous created a distinct regional angular unconformity before a thin Cretaceous cover was deposited. A second phase of uplift and erosion during the Palaeocene resulted in a subtle angular unconformity between Cenozoic and Cretaceous sediments and removed the Cretaceous section south of the Central Slyne Transfer Zone, juxtaposing Cenozoic and Jurassic sediments. Localised zones of strike-slip faults likely developed during this time, related to along-strike dextral and sinistral movement on Caledonian lineaments. Eocene magmatism resulted in the emplacement of numerous sills within the Jurassic succession and extrusion of lava flows onto the Palaeocene unconformity, followed by the deposition of Oligocene to Miocene sediments. Mild reactivation of a variety of structures occurred during the Miocene with evidence of both normal and reverse movements. A final minor period of erosion during the mid-Miocene created a regional unconformity, upon which a thin cover of undeformed Miocene to Recent sediments was deposited.

Unravelling the multiphase evolution of the Slyne Basin reveals complexities not previously understood, including the role of salt tectonics in basin development, and the nature and impact of Caledonian lineaments which segment the Slyne and several other basins offshore Ireland. Understanding the interplay of these processes places the petroleum system of the Slyne basin, including the Corrib gas field, into a wider, margin-focused context, which will aid future resource discovery.

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Cenozoic Exhumation in the Celtic Sea Basins (Offshore Ireland) from a Multidisciplinary Approach

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The Mesozoic extensional basins developed along the north-western European margin were largely affected by exhumation as a combination of multiple episodes of basin uplift and intra-plate shortening during the Cenozoic. In the Celtic Sea basins, Cenozoic exhumation is evidenced by a generalised absence of Cenozoic age strata and the Mesozoic basin infill (mostly Upper Cretaceous chalk) subcropping beneath the present-day sea floor. Despite the widely recognisable effects of the exhumation, the magnitude and mechanisms of exhumation are not fully understood.

This work represents the largest exhumation study in the Celtic Sea area including a multidisciplinary approach (thermal and compaction methods) based on 102 wells covering the Fastnet, Mizen, North Celtic Sea and South Celtic Sea basins. The widespread distribution and high density of wells available have allowed the identification and quantification of the main patterns and wavelengths of exhumation. The results show a broad regional-scale pattern of exhumation with maximum values between 1.6 and 2 km distributed along the axis of the North Celtic Sea Basin and a marked westward tilting of the region. This pattern is attributed to the combined effects of epeirogenic uplift (regional scale wavelength of exhumation) and Alpine compression (medium and short wavelengths of exhumation, < 50 km) associated with basin upwarp and the localised growth of inversion structures.

The database used in this work has been facilitated by the Petroleum Affairs Division of the Department of Communications Climate Action and Environment (DCCAE).

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Sediment Supply to Irish Carboniferous Basins: Insights into Ancient Climate and Landscapes

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In sedimentary basins, sandstone composition is controlled by the nature of the original source rock and by processes such as weathering, sorting, storage and burial. These processes are ultimately controlled by tectonics and climate. Climate has a direct impact on sand composition as chemical weathering (more intense in hot humid climates) results in the removal of more unstable minerals (e.g. feldspar). The longer the sediment is exposed to these processes, the more likely the sandstones will evolve towards mature compositions. This has important implications for porosity/permeability evolution of a sandstone and its ability to act as a reservoir, aquifer or site for sequestered CO_2. In addition, investigating the sedimentary fill of ancient basins offers a means of assessing past climatic conditions. Recycling of pre-existing sedimentary or metasedimentary rocks can also produce mature compositions. It is thus critical to constrain ancient patterns of sediment routing and drainage in order to better understand these processes.

To test these ideas, this project investigates quartz arenites from the mid-Carboniferous Clare Basin, onshore western Ireland. Sandstones from other contemporaneous basins in the UK and Ireland are mineralogically immature, illustrating that climate at the time cannot be solely responsible for the composition of the Clare Basin sandstones. Zircon and apatite U-Pb geochronology, coupled with apatite trace element and heavy mineral analysis, is an ideal approach to track the sources of these sandstones. Apatite is unlikely to survive multiple sedimentary cycles as it is easily weathered at surface and resistant during burial. The data reveal a complex sedimentary routing history where poly-cyclic and first-cycle detritus can be distinguished. These results highlight the potential of using sedimentary provenance tools to better understand the links between sand delivery, landscape evolution, sandstone properties and palaeoclimate over long time periods.

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Hierarchical Compression-based Reservoir Modelling: A New Workflow for Realistic Reservoir Models

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Conventional geostatistical modelling methods (including variogram-based, object-based and pixel-based multiple-point statistics) are unable to generate models with low sand connectivity at high net:gross ratios. The connectivity of permeable sand facies in these geomodels is inevitably controlled by their sand proportion, where the models become entirely connected when a net:gross of 27% sand is exceeded. Non-random geological processes such as compensational stacking result in geological systems often having poor connectivity at high net:gross ratios and which therefore have lower sweep efficiencies than the geomodels. It is therefore important if we are to improve predictions of reservoir performance, that the correct degree of connectivity is incorporated into reservoir geomodels to realistically represent the heterogeneity present.

A new workflow has been developed allowing for the creation of low connectivity facies models conditioned to well data. The method combines a relatively new technique (the compression algorithm) with multiple-point statistics (MPS) simulation. The method works by using a low net:gross training image and geometrically transformed conditioning wells as the inputs to the MPS workflow. The inverse transformation (the compression algorithm) is subsequently applied to the final model allowing for the generation of reservoir geomodels with realistic connectivity while also honouring well data. This workflow has been further modified to include the hierarchical sedimentological framework recognised in deep marine deposits. The hierarchical fine-grained units which bound the sand-prone bodies can act as key flow barriers and baffles and may lead to complex compartmentalisation, impacting reservoir connectivity and overall recovery. The hierarchical compression-based workflow allows connectivity to be defined at each hierarchical level while also honouring the conditioning well data. The workflow has been applied using multiple conditioning wells in a producing oil-field.

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Understanding and Modelling the Shallow Plumbing System of Geological Fluids

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Whether through the extraction of societally critical fluids such as potable water or hydrocarbon, the permanent disposal of waste fluids such as carbon dioxide, or the storage of strategic gases such as methane or hydrogen, we are both constrained by, and interact with, the natural plumbing system of the upper few kilometres of the earth's crust. Understanding the geometry of the system and how it controls and is modified by flow of different fluids driven by natural or engineered pressure gradients is therefore important for the sustainable management of geological fluid resources. This presentation will highlight research from the iCRAG Geomodelling team focused on developing improved understanding and modelling capabilities of different facets of the problem, ranging from pore-scale two fluid-phase displacement processes, to predicting flow path quality in faults and fractures, to assessments of the kilometre-scale interconnectivity of porous sandstone units.

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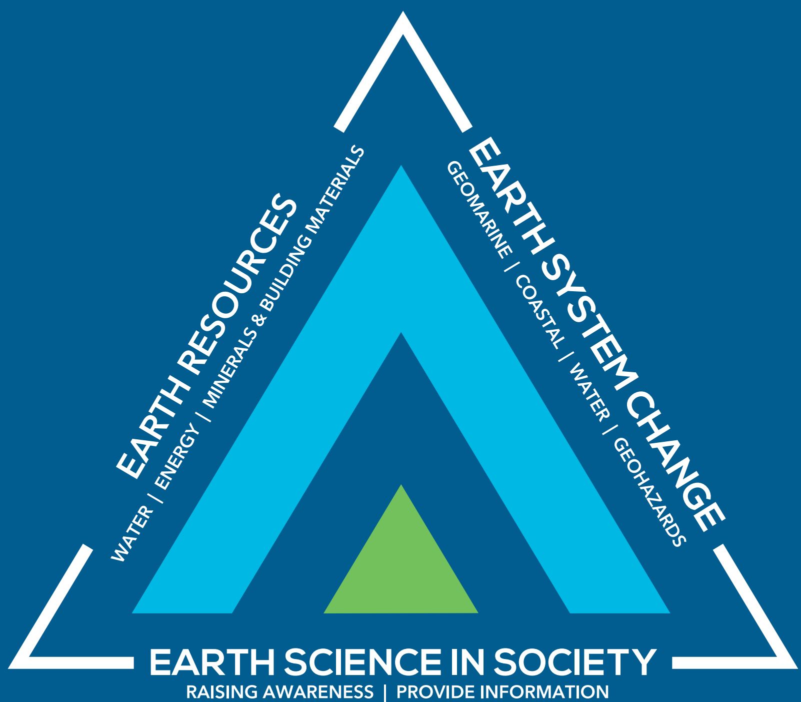

Insights on the Passive Ocean Seismic Noise Generated Offshore Ireland

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The use of the continuous background seismic noise related to ocean wave pressure fluctuations has been well-established in seismology for passive imagery and monitoring. Such noise, also called microseism noise, is the result of a strong acoustic-elastic coupling at the sea-floor associated with changes in spatial and temporal distributions of the noise sources. Therefore, the seismic wavefield characteristics need to be properly understood in order to recover reliable images of the subsurface. For instance, the radial and transverse radiated seismic wavefield respectively associated with Rayleigh and Love surface waves will exhibit different sensitivity to the underlying velocity structures. Due to its position with respect to the main North Atlantic low-pressure systems, Ireland is ideally located for the study of ocean microseisms. In fact, a broad distribution of microseism sources offshore Ireland is usually predicted by ocean wave models. However, specifically tuned land arrays in Ireland consistently point at very localized noise sources at or near the shelf edge. In order to investigate those discrepancies, we performed regional 3D numerical seismic simulations covering most of the Irish offshore hyper-extended margin. Both bathymetry and sediment morphologies associated with the continental margin are influencing both ocean-generated Rayleigh and Love wavefields recorded on land. In addition to controlling the transition from pseudo-Rayleigh to Rayleigh waves at the shelf, we discovered the structure of the margin has a substantial impact on microseism's Love wave generation and propagation. The Love wave energy observed from land is highly dependent on bathymetry and sediment gradients impacting the transverse wavefield radiation patterns. Exploring the ocean ambient seismic wavefield is significant, not only for the development of more sustainable approaches of imaging and monitoring the subsurface but also for its direct connection to the climate and sea state.

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Assessment of Ocean Noise in the Irish Offshore: Tracking Anthropogenic Influence

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Seismic surveying for hydrocarbon exploration, while operational, is one of the major sources of anthropogenic sound in the ocean surrounding Ireland. The resulting pulsed noise propagation, and associated environmental impact, depend on parameters including distance from source, water depth, slope and sub-seafloor geology. Measured and/or modelled sound values in a given area quantify the degree of potential harm or behavioural disturbance to resident or transient marine mammals and other fauna present.

Through use of a dedicated airgun/hydrophone survey, evaluation of the 3D sound space in a continental margin region, hosting a canyon, was made SW of Ireland in 2018. Initial results indicate that the variation in 2D/3D pathways from source to receiver location is highly complex and displays noise focussing, dissipation and multiple reflection pathways. When comparing canyon versus slope, the differences in noise behaviour demonstrate the influence of more severe topography and its inherent three-dimensional complexity. Additional field observations have only just been completed in the northwest Irish Sea, aimed at characterising a host of anthropogenic noise sources including ships passage, trawling and our own geophysical research survey. This most recent deployment shares multidisciplinary collaboration lead by an iCRAG postdoc investigating geohazards and offshore wind energy development. Along with assessing anthropogenic noise, acoustic measurements can be used here as baseline values of ambient sound in the region pre-development.

The overarching aim is to understand and build capacity to monitor and model Ireland's anthropogenic ocean soundscape, in order to mitigate against pollution, protect ecosystems and achieve/maintain good environmental status under structures such as the Marine Strategy Framework Directive.

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Understanding the Geotechnical and Hydrological Response of Intact Upland Blanket Bog to Wind Farm Construction: A Detailed Case Study in Co. Cork, Ireland

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Construction activity on upland blanket bog increased significantly since 2000 due to the development of on-shore wind renewables in the Republic of Ireland and Northern Ireland. Peat is an organic soil characterised by high water content, highly compressibility and low shear strength. These characteristics are difficult for civil engineering design. In addition to these geotechnical constraints, on sites where intact blanket bog occurs (Annex 1 habitat under the European NATURA Directive), there is a planning imperative to minimise adverse hydraulic and hydrochemical impacts on sensitive peatland ecology and hydrology.

This research looks at one of these wind farm sites in detail, where historically a number of innovative engineering design measures were employed to mitigate negative impacts on the intact blanket bog (Annex 1 habitat) present at the site. These design measures include: (a) Drive-Piled Foundations, (b) Coffer Dam / Sheet Pile Foundations, (c) Floating Roads and (d) Floating Compounds. It is now 10 years post construction and the objectives of this research is to evaluate how effective these measures have been in minimising adverse hydraulic and hydrochemical impacts on the intact blanket bog; to compare actual results (geotechnical, hydrological and ecological) with the predicted impacts; and improve methodologies for risk assessment and impact assessment for similar projects.

Initial findings of the research indicate that the original "analytical models" used to predict impacts arising from using piled, coffer and floating construction technologies on intact blanket bog were largely correct in predicting the radial extent of hydraulic impact arising from the construction footprint. What was not modelled or envisioned was the degree of impact arising from (a) consolidation of the peat substrate under and adjacent to the infrastructure, (b) the impact of constructed SuDs drainage on peatland hydrology, and (c) the hydrochemical impacts arising from the incursion of inorganic particulates (dust) from unpaved infrastructure on otherwise very low ionic content blanket bog habitat.

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Uncovering Karst Groundwater: A 3D Hydrogeological Modelling of an Irish Karst System

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Karstic aquifers represent 25% of the water resources worldwide, and are vulnerable to pollution, especially in regard of the high-flow velocities in the conduits. Carboniferous limestones, largely karstified, underlie up to half of Ireland; they are an important source of groundwater, they also play a key role in the extensive, recurring groundwater floods occurring in Ireland. Therefore, understanding these systems and the study of their vulnerability is of major importance with respect to the effective management of such water resources. Among the different numerical modelling approaches used to represent karst systems, coupled continuum pipe flow (CCPF) models (also called "hybrid models") enable flow and transport to be simulated in the different conduit /fracture/ matrix domains.

We modelled flow and contaminant transport on a small Irish catchment located in county Leitrim, Ireland. This karst system feeds the Manorhamilton spring through a well-developed network of conduits. We used Modflow with the UnStructured Grid (USG) and Connected Linear Networks (CLN) modules developed by USGS. We first built a 3D geological model (using MOVE, Midland Valley-Petex) to characterise precisely the aquifer, before simulating flow using Modflow, calibrating against the measured spring discharge. Signal analysis (more specifically multiresolution analysis) methods were used to further investigate the internal behaviour of the model. We then modelled punctual contaminant transport using tracer tests to calibrate relevant parameters. This fully distributed approach enables flow and conservative contaminant transport to be simulated simultaneously in a multi-porosity aquifer (with conduit nodes discretisation that can be independent of groundwater flow cells). Whilst it does require a good understanding a the system, large datasets and a relatively long calibration process, it provides a powerful tool which can be used to further understand the dynamics of the karst aquifer involved and can help inform the management of water resources both quantitatively and qualitatively.

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Geogenic Contamination of Irish Groundwater

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Groundwater is a vital source of drinking water, underpinning not just Sustainable Development Goal 6, but also the accomplishment of many of the other SDGs internationally. In Ireland, >25% of drinking water is sourced from groundwater resources, with over 170,000 private wells (exempt for quality regulations) also in use. However, with the diverse range of geological environments present in Ireland comes a risk of geogenic contamination. The most widely discussed geogenic contaminants globally are arsenic (As) and fluoride (F), but any elevated naturally-occurring element may be considered as a geogenic contaminant e.g. chromium (Cr), lead (Pb), and uranium (U). Such contaminants are often are colourless, odourless, and tasteless so can remain undetected leading to potentially toxic health consequences.

The Tellus datasets of stream sediment, stream water, and soil geochemistry have identified hotspots for a range of elements across Ireland. These datasets were used to highlight areas of groundwater arsenic and uranium contamination, within private wells, above the World Health Organisation (WHO) recommended limits of 10 µg/L and 30 µg/L respectively. Arsenic contamination (<60 µg/L) was identified across three geologically distinct areas of fractured bedrock across South-East Ireland. Sources of the arsenic include cobaltite-bearing Palaeogene basaltic dykes, arsenopyrite-bearing Palaeozoic greywackes, and mineralised quartz veins. Uranium levels in excess of WHO limits have been found in about 10% of private wells surveyed in parts of the Leinster Granite in SE Ireland. The source of the uranium and its mobilisation, in particular the possible role of recharge through carbonate-bearing glacial-tills and fluvioglacial deposits is currently being investigated to identify the areas most at risk.

These studies highlight the vulnerability even within more developed nations such as Ireland for drinking water quality issues, with potential impacts on public health. Interdisciplinary approaches are required to fully understand water systems and their wider impact on society.

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Groundwater Resources as Reservoirs for Antimicrobial Resistance

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Antimicrobial resistance is a widely recognised global public health threat, with extensive evidence of its spread in and beyond clinical settings. However, relatively little is known of the role of the natural aquatic environment in its dissemination. Of particular concern is groundwater, the world's largest reservoir of freshwater. Groundwater aquifers are the primary drinking water source for approximately 2.2 billion people worldwide and provide vital baseflow to rivers and streams during dry weather periods. Hence, identifying and understanding the sources and pathways for antimicrobial-resistant bacteria (ARB) and antimicrobial residues along subsurface pathways is critical to protect human health. Despite this, no comprehensive synthesis of the incidence of antimicrobial-resistant bacteria in groundwater environments has been carried out to date. Accordingly, the current project aims to identify the current prevalence levels of ARB in groundwater globally (via a systematic literature review) and in the Irish context, as well as the environmental determinants and mechanisms possibly mediating their occurrence. Results will provide a baseline for future research and ultimately guide policymakers when developing action plans and remediation efforts to safeguard public health.

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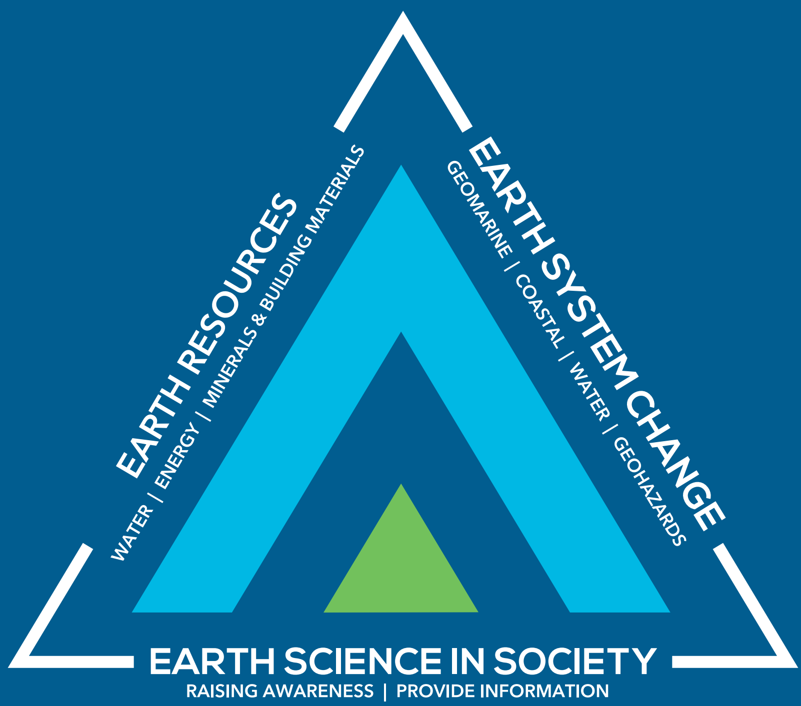

Building Materials: Expanding Potential

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Significant problems with building materials used in the construction industry in recent years have highlighted the positive role geoscience can play in the sector.

The pyrite-to-gypsum reaction leading to expansive heave in aggregate was recognised in Ireland in 2006. The lengthy legal arguments following the discovery exposed questions on quality control and traceability of aggregates, which resulted in changes in national standards and the application of new analytical methods to 'fingerprint' sources.

Further research by advanced analytical techniques, using SEM-EDX, LA-ICP-MS and sulphur isotope analysis of pyrite in aggregate, has produced much data whch is now being interpreted using advanced machine learning techniques.

Serious problems with concrete blocks in Counties Donegal and Mayo became evident following the severe winter of 2010. These defects have been attributed respectively to excess free-mica in the <63 µm fines, and framboidal pyrite-bearing aggregate. Application of a combined SEM-EDX elemental mapping and feature analysis method has provided quantification of deleterious compounds, which can be subjective or problematic using other methods.

These issues with building materials have brought geoscientists into the construction sector in Ireland to forensically diagnose failures and predict the stability and lifetime of products. To date, the focus has largely been on the legacy issues, but in the future, continued collaboration and research will provide information and guidance on: the testing, quality control and viability of recycled building materials; extending the life-cycle of existing structures with known problematic materials and; the development of new green building materials with low footprints / beneficial environmental parameters.

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Underground Space Technology: From Past to Future

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Since the second Industrial Revolution in the late 19th century, a number of large-scale underground infrastructures have been built over decades to centuries in Europe, for example, London Underground dated back to more than 150 years ago, the European Organization for Nuclear Research (CERN) tunnel network for particle collision experiments in Switzerland and France and recent London Crossrail Project.

Increasing challenges in underground construction and maintenance demand cutting-edge computational modelling and field monitoring technologies in geotechnical engineering. This presentation will introduce time-dependent soil-tunnel interaction and the associated numerical simulation, including both ageing tunnel structural deterioration and long-term ground settlement with time. Furthermore, a case study of geothermal train station foundation, which harnesses the energy stored by the ground for heating and/or cooling buildings, will also be described. Lastly, the presentation will introduce an emerging field monitoring technology: distributed fibre optic sensing (DFOS) for continuous strain measurement of civil infrastructures. The development of underground space technologies will greatly contribute to Sustainable Cities and Communities (SDG 11) and other SDGs both in Ireland and beyond for a Sustainable Future.

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Resources for a Sustainable Future

GeoPlan: A New Engagement Framework for Decision-making on Coastal Geohazards

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Coastal communities in Ireland face significant and interrelated geohazards such as coastal erosion, sea level rise and flooding. Since the early 1990s it has been recognized that 1500km of the coastline is at risk of erosion with 490km defined as 'in immediate danger'. More recently, a study by the City and County Managers' Association estimated that approximately 800 properties could be impacted by erosion over the next fifteen years. We also know that coastal erosion and land loss (as well as inappropriate responses to it), can have significant social and ecological impacts. Despite these risks, there is no national strategy for managing coastal erosion in Ireland and there is evidence that current management strategies, which involve reacting to major problems as they arise and rely heavily on building new coastal defences, will become increasingly untenable in the context of climate change. Indeed, the complexities and uncertainties surrounding planning in coastal areas is likely to be exacerbated as the impacts of climate change become more intense. This is consequent on the wide variety of demands placed on the coast and the variable risks and impacts between different people and places. Our research project responds to the challenges posed by such complexity and uncertainty by engaging relevant practitioners and community actors in a policy co-design process. This innovative approach aims to support local community members, scientists and regulators in identifying problems, generating knowledge and ultimately in making decisions regarding what management strategies are feasible and preferable for different areas.

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Fostering Sustainable Communities with Improved Public Health Through Knowledge of Radon Risk

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Radon is a naturally occurring radioactive gas, which primarily emanates from rocks and soil. Exposure to radon is associated with an elevated risk of developing lung cancer, with some 300 radon-induced lung cancer cases estimated to occur in Ireland every year. This equates to approximately 12% of the national lung cancer incidence, which is in the upper part of the range (3-14%) for countries worldwide. The population weighted average domestic indoor radon concentration for Ireland is 98 Bq/m^3, which is over twice the global indoor average. Approximately 460,000 people live in radon-prone areas in Ireland, yet only around 40,000 homes have been tested. A national legislative radon map is defined in the Building Regulations. Areas in which >10% of homes are estimated to exceed the national domestic reference level of 200 Bq/m^3 are defined as "high radon" areas. New homes in such areas are legally required to implement radon preventative measures such as a radon barrier and sub-foundation pump. Current efforts to update the national legislative radon map include the addition of geological information. This research has resulted in an improvement of the spatial resolution of the national map from 10x10 km^2 to 1x1 km^2, and a redefinition of radon priority areas.

New research supported by iCRAG seeks to develop a greater understanding of risk perception and decision-making surrounding radon testing and remediation. It investigates the role of geoscience communication as a key tool in promoting radon risk to policy makers, decision influencers and the general public. A key factor of the study is to examine how customised geoscience risk communication can support fact-based decision making in order to promote greater legislative support and increase the rate of radon testing and remediation. This in turn will lower the national health burden and improve the health of the general population.

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Engaging for our Sustainable Future

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Education and Public Engagement is central to iCRAG as a centre and is an important means for our researchers to engage in two-way communication with various external publics. The crucial role that applied geoscience plays in underpinning our society is becoming ever more apparent as we move into the 'Green Transition' and new and unprecedented demands are placed upon resources, both nationally and globally. Research undertaken by iCRAG is rising to meet these demands. By engaging with publics, we can share our research to achieve three key aims:

1. Empower the Irish publics to make informed decisions about the Earth's resources and changing climate
2. Enhance public understanding of Earth's resources and Earth system change
3. Engage with publics such that our research is influenced by, and shared with, the publics for mutual learning

These aims are achieved using our four engagement programmes: Geocareers, Earth Science Education, Earth Science in the Arts and Citizen Involvement. Each programme encompasses a variety of individual projects. Several projects are collaborations with key external stakeholders, such as teaching organisations, music and arts festivals, community groups and production companies. This talk will cover the work that the engagement programmes do, how interested parties can get involved, and reflections on the Centre's learnings on engagement activities.

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Fostering Dialogue: Comparing Geoscientists' and Non-geoscientists' Thoughts and Feelings About Geoscience

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Geoscientists and non-geoscientists often struggle to communicate with each other, especially around complex or contentious geoscience issues connected to the sustainable use of natural resources. This hinders communication processes that are essential to sustainable development. We aim to understand mental models - defined as people's representation of a phenomenon - of geoscientists and non-geoscientists regarding geological concepts and processes. To this effect, using a mixed-methods approach, we compare mental models of the subsurface, mining/quarrying, drilling, and flooding between geoscientists (n=24) and non-geoscientists (n=38). We identify four dominant themes which underlie their mental models: (1) degree of knowledge and familiarity, (2) beliefs about human interactions, (3) affective beliefs, and (4) beliefs about perceived impact of the processes. While the mental models of non-geoscientists focus more on the perceived negative environmental and economic impacts of geoscience, those of geoscientists focus more on human interactions, as well as having more familiarity and technical knowledge related to geoscience. We argue that mental models are the result of beliefs, including both cognitive (based on rational thoughts) and affective (based on feelings and emotions) components, and that both need to be acknowledged for successful dialogue between the two groups to take place around sustainable use of Earth's resources.

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