

iCRAG

IRISH CENTRE FOR RESEARCH
IN APPLIED GEOSCIENCES

A World
Leading SFI
Research
Centre



IMPACT REPORT 2015-2020

HOST INSTITUTION



PARTNER INSTITUTIONS



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SECTION 1 FOREWORD



iCRAG, the Science Foundation Ireland Research Centre in Applied Geosciences was established in 2015 with a €17.9 million investment from SFI and a vision to be a world leader in applied geosciences research, securing maximum benefits from our natural resources while protecting the environment.

research impact, we have used the SFI impact classification across 7 key impact types:

- ECONOMIC
- HUMAN CAPACITY
- SOCIETAL
- ENVIRONMENTAL
- HEALTH & WELLBEING
- INTERNATIONAL ENGAGEMENT
- POLICY & PUBLIC SERVICES

In the six years since establishment, iCRAG has grown its world class research activity, expanded into multiple new research fields, welcomed a large number of new industry and state policy partners and developed significant global recognition across the geoscience community. During that time period, over 200 academics and researchers have directly worked on the iCRAG research programme, with many more national and international collaborators contributing to the impact that iCRAG has made.

As we move into the second phase of iCRAG funding with an additional investment of €28m from SFI, our goal is to *deliver integrated research on the earth system, to facilitate environmentally sustainable development of earth resources, and to promote understanding of how people react to and manage our relationship with the earth.*

This impact report outlines the excellent research, top talent development and tangible benefits and impacts that iCRAG has made to Ireland's economy, society, environment and beyond. Alongside our scientific excellence and

The evolution of iCRAG into a world leading research centre is an inspiring story of hard work, determination, community and scientific excellence. Long may it continue.

Prof. Murray Hitzman
iCRAG Director



economic & commercial



human capacity



societal



environmental



health & wellbeing



international engagement



policy & public service

iCRAG AT A GLANCE: 2015 - 2020



SECTION 2 SCIENTIFIC EXCELLENCE AND RESEARCH IMPACT

Central to all iCRAG activities is a dedication to excellence in research. The commitment and endeavour of our researchers is evident in the quality of research outputs produced. Across our three research challenges and five platform technologies which are guided by the United Nations Sustainable Development Goals, iCRAG researchers have delivered impactful academic outputs to help us better understand the Earth's past, present and future, and how people are connected to the Earth.

Through extensive collaboration across our eight institutions and beyond, iCRAG has had a significant impact on the scholarly output of Ireland in the area of geoscience research. In the period 2015-2020 iCRAG-affiliated members have published over 1,100 papers, generating over 11,800 citations (Figure 1). A number of our publications have been in high impact journals, with 23 in *Nature* journals, 4 in *Science* journals, 12 in *Geology* and 8 in *Economic Geology*.

Field Weighted Citation Impact

The Field-Weighted Citation Impact (FWCI) measures the number of citations received by a Research Centre's publications compared with the average number of citations received by all other similar publications indexed. iCRAG's FWCI of 1.39 is consistent with similar research institutions, including the Colorado School of Mines (CSM), the Department of Geology and Geophysics at the University of Aberdeen (G&PG), the Centre for Ore Deposit and Earth Science (CODES) at the University of Tasmania and the Geosolutions Centre at the University of Leeds (Figure 2).

iCRAG researchers have delivered over 660 oral presentations at both national and international conferences and published 90 technical reports.



- 660+**
ORAL PRESENTATIONS
- 250+**
INVITED SPEAKERS & KEYNOTES
- 30+**
CONFERENCE EXHIBITS
- 865+**
POSTER PRESENTATIONS
- 100+**
WORKSHOPS/ CONFERENCES ORGANISED

iCRAG AT A GLANCE: 2015 - 2020

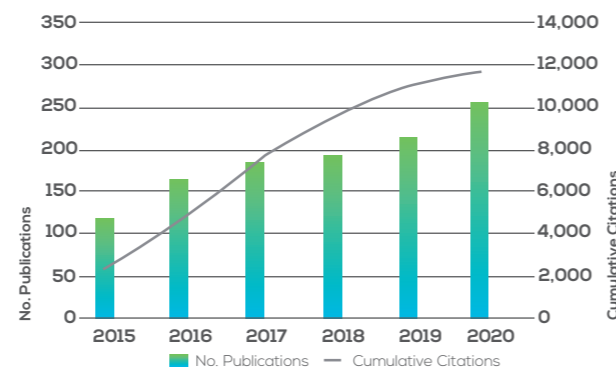


Figure 1: iCRAG publications and citations, 2015 - 2020. Source: Elsevier SciVal, using all types of publications from 2015 to 2020 authored by iCRAG membership in each year. Data encompass all iCRAG researchers' publications between 2015-2020 and includes publications that may not have been attributed to iCRAG funding but are thematically related.

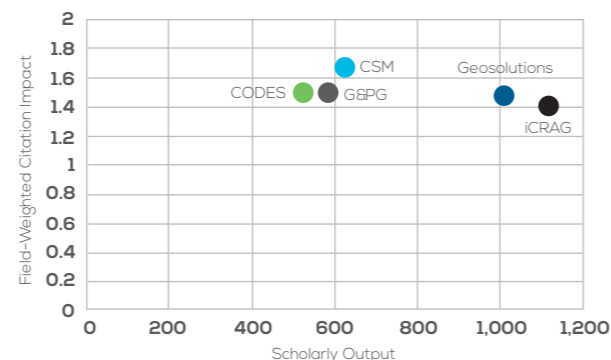


Figure 2: iCRAG FWCI and Scholarly Output, 2015 - 2020. Source: Elsevier SciVal, journal articles only from 2015 to 2020 authored by the current members of each institute/centre as of March 2021.



EARTH SYSTEM CHANGE

Our high impact publications have included:

EARTH SYSTEM CHANGE

Engineered silver nanoparticle (Ag-NP) behaviour in domestic on-site wastewater treatment plants and in sewage sludge amended-soils.

Science of Total Environment Bolaños-Benitez V., McDermott F., Gill L., Knappe J. (2020).

The Bolaños-Benitez et al. paper focussed on engineered Ag-NPs that are increasingly used as biocides on textile fabrics and in other consumer products and are released to the environment via domestic wastewater. This was the first study of their behaviour in domestic scale septic tanks in which releases to groundwater could potentially occur. Ag-NPs in the 60 to 100 nm range were found to be strongly sulphidised by excess sulphur within domestic sewage sludge and are consequently strongly bound as silver sulphide within the particulate phase in the tanks. Important risks to groundwater were identified as a consequence of the common practice of land-spreading of sewage sludge due to sulphide oxidation.



EARTH RESOURCES

EARTH RESOURCES

3D Modelling of the Lisheen and Silvermines deposits, Co. Tipperary, Ireland: Insights into structural controls on the formation of Irish Zn-Pb deposits.

Economic Geology Kyne, R., Torremans, K., Guven, J., Doyle, R., Walsh, J.J. (2019).

The Kyne et al. paper elegantly presented two stellar examples of the role of normal faults on the formation of the zinc-lead deposits of Ireland. Though this control has been recognized for some time, the huge drill hole datasets utilized in this study allowed clear evidence to be presented of this control and provided very distinct parameters for mineral explorers to utilise during exploration.



EARTH SCIENCE IN SOCIETY

EARTH SCIENCE IN SOCIETY

Risk perceptions towards drinking water quality among private well owners in Ireland: the illusion of control.

Risk Analysis Hooks, T., Schuitema, G., McDermott, F. (2019).

The Hooks et al. paper presented a study of attitudes toward risk in an important, largely rural population in Ireland, highlighting significant potential health hazards. The authors proposed a theoretical model arguing that perceived control is central in the perceived contamination risks of well water. The paper also represented iCRAG's first collaboration between science and social science to be published in a top journal in business school rankings (ABS4), demonstrating the interdisciplinary impact the Centre is making.



PLATFORM TECHNOLOGIES

PLATFORM TECHNOLOGIES

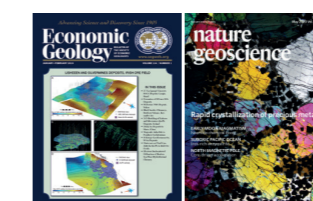
1. Sourcing the sand: Accessory mineral fertility, analytical and other biases in detrital U-Pb provenance analysis

Earth-Science Reviews Chew, D., O'Sullivan, G., Caracciolo, L., Mark, C., and Tyrrell, S. (2020).

2. The trace element composition of apatite and its application to detrital provenance studies.

Earth-Science Reviews O'Sullivan, G., Chew, D., Henrichs, I., Kenny, G., Mulligan, D. (2020).

The linked Chew and O'Sullivan *et al.* papers presented new methods for combined geochronological and trace element fingerprinting to characterise mineral grains in sediments. Sediment provenance models combine geochronological and radiogenic isotope tracers to determine where the minerals making up sand-bearing sedimentary rocks originated. These data are utilised by industry to reconstruct paleo-environments and ancient drainage systems from scales of a reservoir to the breadth of a continent.



Selected journal covers

Dr Roisin Kyne's 3D model images of Irish deposits featured on the front cover of *Economic Geology* in 2019 (left). Prof. Stephen Daly's article on the crystallization of precious-metal-mineralized layers in mafic magmatic systems was showcased on the May 2020 front cover of *Nature Geoscience* (right).

SECTION 3 ECONOMIC IMPACT



economic & commercial

The economic impact of iCrag since its establishment has been wide and varying. This can be seen in its direct impact in terms of teaching and research but also in its indirect impact in terms of attracting money into the economy, both for research funding and student expenditure.

The economic impact of iCrag between 2015 – 2020 is estimated to be €123 million¹.

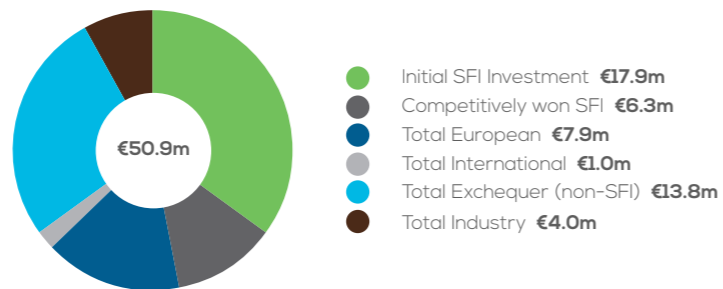
This was broken down by a direct impact of €50.9 million in research funding secured from both domestic and international sources including:

- €17.9 million of initial SFI investment in iCrag
- €13.8 million in exchequer funding from sources other than SFI
- €6.3 million of competitively won SFI grants
- €4.0 million in industry cash investment
- €7.9 million in European funding
- over €1 million in international funding.

A further economic impact of €42.3 million was related to the multiplier effect of iCrag expenditure, i.e., €14.7 million was from indirect purchases by iCrag suppliers and €27.6 million from the salaries of iCrag staff and researchers subsequently spent in the economy.



FUNDING WON BY iCrag RESEARCHERS



Along with Induced effect of an estimated €3.4 million² spend by post graduate students in the economy (Indecon 2019:39) it is estimated that the Exchequer receives a net benefit for every Masters and PhD student graduating through iCrag due to higher incomes associated with graduates and their taxation. For a Masters student this is estimated to be €46,000 and for PhD graduates €126,000 over the premium associated with an undergraduate degree (Indecon 2019:35). On this basis iCrag will also provide a net benefit to the Exchequer of €7.3 million from the cohort of students between 2015-2020.

A final impact from this funding is classified as a “spillover”, which Indecon (2019:11) describe as benefits flowing from iCrag to the private sector from direct R&D collaboration, dissemination and publication of research findings and through iCrag graduates entering the work force. Using Indecon’s analysis this is estimated to be a further €29.8 million over this period and the spillover to the private sector can be seen in the fact that 22% of iCrag researchers have moved into the private sector directly from iCrag.

¹ Using Indecon’s Independent Assessment of the Economic and Social Impact of Irish Universities, April 2019 <https://www.iaa.ie/ouruniversities/universities-impact/>
² iCrag-affiliated Investigators enrolled 76 PhD students over the period with the average timeframe of 5 years to complete their studies, and 8 Master students who completed their studies with the year. This is multiplied by the estimated €8,235 annual spend by post graduates students in the economy.



An essential source of iCrag’s funding is competitively won from national research programmes. Since 2015, iCrag has won over €5.5 million funding from the Department of Environment, Climate and Communications through our key partner Geological Survey Ireland, and over €2.9 million in funding from the Environmental Protection Agency.

In the period 2015-2020, iCrag researchers have had 34 European funding wins, 27 International funding wins and 117 Exchequer wins. The bulk of iCrag’s European funding wins have come from H2020’s Pillar 1 “Excellent Science” and Pillar 3 “Societal Challenges”.

Examples of successfully won European funding include:

- **GREENPEG:** iCrag is among a team of thirteen international partners working on the €8.3 million GREENPEG project launched in 2020. Funded by the European Union’s Horizon 2020 research and innovation programme, GREENPEG is focussed on the development of new techniques to explore for battery and other green technology metals. Dr Julian Menuge of iCrag at UCD leads GREENPEG’s prospect-scale methodology research, focussed on pegmatite ore deposits that carry lithium-caesium-tantalum (LCT) and niobium-yttrium-fluorine (NYF).

- **EU H2020 Marie Curie Skłodowska Individual Fellowships:** ARCTICO – won by Dr Audrey Morley of iCrag at NUIG focussed on the provision of informed constraints on the magnitude of future climate change; MODIO – won by Dr Koen Torremans of iCrag at UCD, investigated the structural controls on mineralisation in the world class Irish Lower Carboniferous base metal deposits; PALEOCARBON – won by Dr Weimu Xu of iCrag at UCD investigated the effect of basalt weathering on carbon sequestration; FINSEIS – won by Dr Nicholas Roche of iCrag at UCD focused on the quantitative analysis of the structural controls of faults on induced seismicity magnitude.

- **MetalIntelligence:** a European Industrial Doctorate focused on future efficient mineral analysis, processing and training led by former Deputy Director Prof. Balz Kamber of iCrag at TCD.

As the Centre enters its new phase of funding, iCrag will continue to build partnerships nationally and internationally, successfully capture competitive funding and expand our research agenda and economic impact.

iCrag’s EUROPEAN, INTERNATIONAL AND EXCHEQUER FUNDING SUCCESSES 2015-2020

	AMOUNT	WINS
EUROPEAN		
Excellent Science	€3,434,292	8
Societal Challenges	€2,252,127	6
Other – COST; EIT; Interreg; ERANET; general	€2,234,089	20
Total	€7,920,508	34
INTERNATIONAL		
International Interest organisation; International Government Source; Other Source	€831,407	26
National Science Foundation	€171,097	1
Total	€1,002,504	27
EXCHEQUER		
Department of Agriculture, Food and the Marine	€1,122,193	2
DECC/GSI	€5,569,439	27
Enterprise Ireland	€119,762	4
EPA	€2,973,516	11
HEA	€11,916	4
IRC	€1,430,267	15
Marine Institute	€1,492,591	22
SEAI	€619,488	5
University Sector	€174,569	16
Other OSI, Smartbay, NPWS, RIA)	€253,557	11
Total	€13,767,298	117



SECTION 4 INDUSTRY CASE STUDIES

iCrag's industry partners are central to our applied research mission and actively collaborate across a range of research and Centre activities. To date iCrag has worked with over 64 industry partners across all fields of our research.

Selected industry and state policy partners that have worked with iCrag include:



Transport Infrastructure Ireland

Transport Infrastructure Ireland (TII) was established through a merger of the National Roads Authority and the Railway Procurement Agency in 2015. TII provides sustainable transport infrastructure and services, delivering a better quality of life, supporting Irish economic growth and respecting the environment. TII has partnered with iCrag since 2015 across a range of projects including groundwater and geohazards.

"iCrag has the requisite expertise and skills required by TII to support infrastructure planning, development and management in Ireland, especially in relation to landslide and flooding risk related to road and rail infrastructure. The collaboration with iCrag has highlighted the breadth of knowledge available in Ireland in subsurface imaging, understanding karst features and the potential impact of geological hazards on transport infrastructure."

The collaboration has provided a conduit to engage with the research community. The robust research outputs have also provided evidence-based research for certainty on infrastructure planning and provided a platform for future continued collaboration."

Dr Billy O'Keefe, Senior Geologist/Hydrogeologist, TII



EARTH SYSTEM CHANGE



EARTH RESOURCES



PIPCO RSG

The Petroleum Infrastructure Programme (PIP) was set up by the Petroleum Affairs Division of the Department of Environment, Climate and Communications in 1997. PIP has been an industry partner of iCrag since 2015 and has supported the Centre across multiple research projects in the fields of the energy transition, marine environmental monitoring, groundwater management and raw materials.

"The societal challenge of climate change is critical to the energy industry. Coordinated land, coastal, and marine-based research projects in the Irish testbed will create world-class models for understanding climate change by elucidating and modelling the movement of carbon through the environment."

Collaboration with iCrag has reduced exploration risk offshore Ireland and stimulated investment in exploration efforts. PIP member companies have invested directly in follow-on research based on iCrag projects and now access Irish research infrastructure such as iMARL and LIR. iCrag's unique research infrastructure is attracting world class geoscientists to Ireland making Ireland a leader in applied geoscience research addressing global societal issues. PIP continues to fund iCrag projects relevant to the energy transition, in particular innovative approaches to CO² storage offshore Ireland and the associated risks."

Nick O'Neill, Project Manager, Irish Shelf Petroleum Studies Group

New Boliden

For more than 90 years, Boliden has been exploring, extracting and processing base metals and precious metals. Boliden's production is based on experience, innovation and modern technology, developed in collaboration with technology and engineering companies. Tara mine, which is one of the largest zinc mines in the world, accounts for half of Boliden's production of zinc concentrate and employs 550 staff. New Boliden has partnered with iCrag since 2015.

"Boliden is interested in research engagements where the abilities of the research team offer unique, world-class solutions to our needs and the iCrag Research Centre offers this. iCrag's focus matches our focus in terms of both production at Navan and mineral exploration in Ireland. There has been a long history of current iCrag researchers being involved with Boliden Tara Mine's work in Ireland and in Sweden and Boliden scientists aided in planning the original iCrag proposal."

The Tara Deep deposit was discovered by Boliden using seismic techniques in 2012. iCrag researchers have been involved in Boliden's initiatives to discover more Zn-Pb reserves at the Tara mine (Navan). This includes work with the Boliden team utilizing seismic geophysical data to improve our understanding of the deposit and help with the ongoing delineation of the Tara Deep orebody."

Ian Farrelly, Head of Section, Exploration Department, Boliden Tara Mines



EARTH SCIENCE IN SOCIETY



Gavin & Doherty Geosolutions Ltd

Gavin & Doherty Geosolutions Ltd (GDG) is a specialist geotechnical engineering consultancy, providing innovative geotechnical solutions across a broad range of civil engineering sectors. GDG's geotechnical engineers provide services to both the domestic and international markets including concept design, detailed design, in-situ monitoring and general geotechnical advice. GDG joined iCrag in 2017 as part of iCrag's new geohazards spoke on a targeted project focussing on de-risking of the Irish offshore environment for wind energy development through geological assessment and mapping.

"GDG recognised the emerging talent being developed within iCrag as well as the mature research expertise in geology and geosciences which are fundamental areas for GDG's ongoing development. GDG sees iCrag as a collaborator that facilitates the company exploring new and innovative business streams through novel technology and processes. Our collaboration with iCrag has grown since joining as an industry partner. GDG has a number of projects on-going with iCrag and we have identified a number of new geotechnical projects to progress in the same areas and along new research topics."

Dr Paul Doherty, Managing Director, GDG

SECTION 5

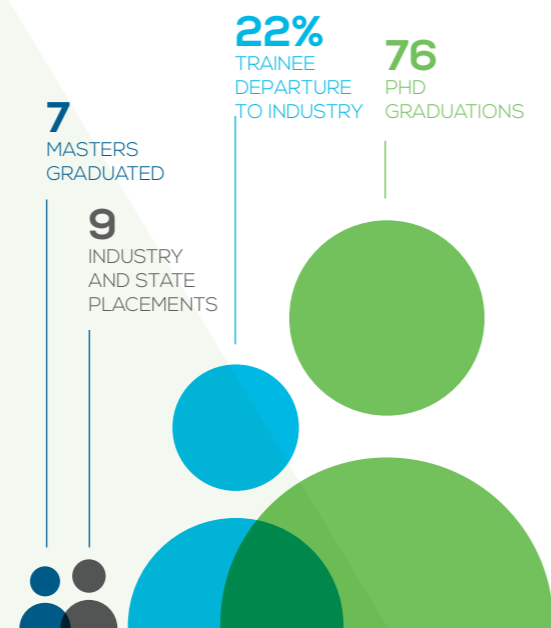
HUMAN CAPACITY IMPACT



human capacity

iCrag researchers have a wide skillset that is in demand across industry, academia and beyond. Over the last six years, our postgraduate and postdoctoral researchers have successfully moved to a variety of positions in numerous employment sectors and countries. During this period, one in five iCrag-affiliated researchers have moved to industry as a first destination following their training in iCrag. Our researchers have also undertaken placements in industry and within the state sector including the Department of Environment, Climate and Communications, and the Houses of the Oireachtas Library and Research Service.

iCrag TALENT PIPELINE 2015 - 2020



OUR PEOPLE – A SELECTION:

DR. EMMA MORRIS

Then: Emma Morris was a postdoctoral researcher in iCrag at UCD working on reservoir significance of thin-bedded successions in deep-water settings.

Now: Postdoctoral Research Associate at University of Utah, Salt Lake City.

“My favourite part of being a member of iCrag was my fieldwork in West Clare; not only are the outcrops world class but this fieldwork also gave me the opportunity to engage with the local community on Loop Head, from co-leading geology walks to visiting the local schools. It meant that I was able to share the significance of the geology of this area with the people who lived there.”

DR. PHILIP SCHULER

Then: Philip Schuler was a PhD student in iCrag at TCD working on the characterisation of diffuse recharge into karst aquifers.

Now: Hydrogeologist at CDM Smith, Dublin.

“In iCrag I carried out exciting groundwater fieldwork on the surface, below ground and even in the sea. My career goal was to transition to industry and these experiences helped me make the move to industry after my PhD.”

DR. LÉA DURAN

Then: Léa Duran was a postdoctoral researcher in iCrag at TCD working on the visualization of flow and contaminant transport through karst aquifers.

Now: Data Scientist at Atos in Montpellier, France.

“I really appreciated how iCrag fostered a dynamic geosciences community in Ireland, I got a chance to discuss and collaborate with researchers from very different fields and expertise, which prepared me for my current interdisciplinary environment.”



DR. MUDASAR SAQAB

Then: Mudasar Saqab was a postdoctoral researcher in iCrag at UCD working on the kinematics of fault systems offshore Ireland.

Now: Geologist at Norwegian Geotechnical Institute based in Perth, Australia.

“During my time in iCrag I learned a number of valuable skills that I use in my current role and hope to be able to pass along to the people I work with.”



DR. ROISIN KYNE

Then: Roisin Kyne was a postdoctoral researcher in iCrag at UCD working on 3D modelling of Irish Carboniferous Basins

Now: Project Geologist with Teck Resources in Vancouver, Canada.

“My time at iCrag was instrumental in shaping my career path. From the research, I gained valuable skills in state-of-the-art technologies and theory, which I use daily to ensure project success and that my company is at the forefront of innovation.”



DR. OAKLEY TURNER

Then: Oakley Turner was a PhD researcher in iCrag at TCD who worked on the geochemical vectoring of Irish-type Zn-Pb mineralization along the Rathdowney Trend.

Now: Senior Project Geologist at Anglo American based in Zambia.

“The support network in iCrag helped me in my journey through academia, allowing me to enter industry with both the technical and soft skills required to excel.”



DR. TERESA HOOKS

Then: Teresa Hooks was a postdoctoral researcher in iCrag at UCD working on the public perception groundwater and geological activities in Ireland.

Now: European Research Project Manager at Teagasc.

“My time in iCrag gave me, as a social scientist, the opportunity to experience true multidisciplinary research by engaging with geologists and the complex social issues this research area faces.”



DR. STEVE HOLLIS

Then: Steve Hollis was a postdoctoral researcher in iCrag at UCD funded by our state policy partner Geological Survey Ireland. Steve’s research focused on the origin and discovery of Irish-type orebodies using new isotopic methods.

Now: Lecturer in Ore Systems at The University of Edinburgh, UK

“Being part of the raw materials team and wider iCrag community provided fantastic opportunities for collaborating with a large number of researchers on different projects and establishing new industry contacts. iCrag helped my career advance to the next stage through opportunities in project supervision, lecturing, career training and grant procurement.”



SECTION 6

SOCIETAL IMPACT



Modern societies and economies are underpinned by applied geosciences. The provision of secure sources of clean water, raw materials, and energy, all of which are crucial for economic and societal functioning, are directly reliant on applied geosciences.

During 2015-2020, the iCrag Public Engagement programme has engaged with a wide range of publics including school students, teachers, artists, citizen scientists and the media with the aim of creating scientifically-informed publics on iCrag's research on the Earth's system, the sustainable development of natural resources and our relationship with our planet.



2015

The **Switch movie screening** took place in the Irish Film Institute in November 2015 as part of an iCrag collaboration with the Science Expressions Film Festival. Dovetailing with iCrag's Earth Resources research activities, *Switch* takes the viewer on a journey through the world's energy mix, asking important questions on how we currently power our society and what a sustainable future energy mix looks like. Following the movie screening, Prof. John Walsh of UCD and Prof. Iain Stewart of the University of Plymouth, took part in a public Q&A attended by over 200 people.

2016

In collaboration with UCD, iCrag launched the **Science Apprentice – Energy and Resources book** which was co-created with primary school children from across Ireland. Pupils from the school were directly involved in the content development, character design and "try at home" activities that feature in the book. iCrag researchers led the students on a field trip to the Arigna Mining Experience where a tour and community debate by the schoolchildren on windfarm development took place. 15,000 copies of the book were distributed across the country with the Irish Independent.

TEACHER COMMENTS:

"I ASKED THEM AT THE START OF THE YEAR WHAT THEY WANT TO BE WHEN THEY GROW UP, AND IT WAS POP-STAR, HAIRDRESSER, WORKING IN A BEAUTY SALON, ONE VET AND ONE ARTIST. I DID IT AGAIN AT THE END OF THE YEAR AND A GOOD FEW OF THEM SAID SCIENTIST, SO THEY'VE TAKEN THAT ON, THEY SEE THEMSELVES AS THE SCIENCE CLASS OF THE SCHOOL AND MOST OF THEM PLAN TO DO SCIENCE IN SECONDARY SCHOOL."



2017

2017 saw the launch of iCrag's Earth Science in the Arts programme which aims to use the arts as a STEM engagement medium to cross boundaries in collaboration with artists. In collaboration with the National Museum of Ireland – Archaeology, iCrag ran **The Bone Vault** event which examined earth science and palaeontology through the poetry of Seamus Heaney and Ted Hughes. Since 2017, iCrag has gone on to collaborate with Féile na Bealtaine (Dingle Arts Festival) to run a series of landscape poetry and geology walks and workshops attended by over 300 festivalgoers.

ATTENDEE COMMENTS:

"I LIKED THE MERGE BETWEEN THE ARTS AND SCIENCE AND THAT COMPLEX SCIENTIFIC PROCESSES CAN BE EXPLAINED THROUGH A MEDIUM THAT IS MORE UNDERSTANDABLE AND RELATABLE TO A NON-SCIENTIST SUCH AS MYSELF."

2018

In 2018 iCrag launched **Girls into Geoscience (GIG) – Ireland**, a public engagement programme designed to introduce Senior Cycle female identifying people to the geosciences. With an emphasis on hands on geoscience, role modelling and the opportunity to meet females currently working in geoscience the event has run yearly in Ireland in collaboration with the Irish Association for Women in Geosciences, and has joined forces with GIG chapters in England, Scotland and Wales, to run virtual events, engaging with over 270 participants.

PARTICIPANT COMMENTS:

"I HAD NEVER REALLY HEARD OF GEOSCIENCE BEFORE SO IT WAS GREAT TO GET AN INSIGHT INTO THE VAST RANGE OF CAREER PATHS/SUBJECTS AVAILABLE FROM LIKE-MINDED PEOPLE WHO ARE REALLY PASSIONATE ABOUT WHAT THEY DO."

"THE LEVEL OF INSPIRATION I FELT FROM HEARING WOMEN'S CAREERS, ADVICE, STORIES AND ENCOURAGEMENT ALL RELATING TO GEOSCIENCE AS AN EXCITING SCIENCE TO STUDY."

2019

iCrag, in collaboration with Geological Survey Ireland, partnered with Junior Cycle for Teacher STE(A)M to create an interactive **teacher CPD workshop**. The 1.5 hour sessions were created with teachers for teachers to raise awareness of earth system change, and how our society can sustainably tackle the problems presented by management of earth's finite resources. To date, iCrag teacher CPD sessions have reached over 30 teachers across Ireland.

TEACHER COMMENTS:

"THIS EVENT WAS SO HELPFUL IN SEEING THE CONNECTIONS BETWEEN SUBJECTS AND JC (JUNIOR CYCLE) OVERALL."

2020

iCrag curated **Inception Horizon: a celebration of subterranean karst systems** which transformed Trinity College Dublin's museum building with its unique take on art, science and sound. iCrag partnered with composer Norah Constance Walsh, sculptor Helen O'Connell and the Mellow Tonics choir to create an immersive concert experience that took over 170 attendees on a journey into Ireland's karst systems.

ATTENDEE COMMENTS:

"I LIKED EVERYTHING. THE SETTING. THE NARRATION OF KARST FORMATION FROM ALL THE PRESENTERS. IT WAS SPLENDID. OH AND THE SONG, WOW! THIS WAS AMAZING. ... I DEFINITELY GOT A CLEAR EXPLANATION FROM THE EVENT, EVERY WORD WAS MADE EASY EVEN TO THOSE WHO HAVEN'T SEEN THE FORMATIONS BEFORE."

In 2020 iCrag's **Purls of Wisdom Climate Crafting** won European Geosciences Union Public Engagement Grant funding. The programme works with local fibre-crafting communities to create climate crafts which visualise Ireland's local climate and earth science data.

SECTION 7

ENVIRONMENTAL IMPACT AND HEALTH & WELLBEING IMPACT



health & wellbeing



environmental

Changes in the earth system are leading to a cascade of environmental impacts that are having significant effects throughout Irish and global society. As a strategically located, North Atlantic European island country, Ireland provides iCrag researchers with an ideal location to observe and understand these changes and develop successful mitigation and adaptation strategies that can have both national and global impacts.

Marine Noise Pollution

PhD researcher Eoghan Daly and Dr Martin White of iCrag at NUIG revealed in 2020 that the noise of bottom trawling in or near underwater canyons can “echo” and disturb protected mammals such as fin whales and beaked whales in important feeding grounds and along migratory paths. Published in the Marine Pollution Bulletin the team modelled how the noise generated by bottom trawling travelled through the water column, along the seabed and through a 20km long submarine canyon in the Porcupine Basin on the continental margin, off the south-west coast of Ireland. Their analysis showed that the noise is focussed through underwater canyons and is carried to deeper waters, having a potentially harmful effect on the marine environment and protected mammals found in these areas.



Groundwater Quality

Anthelmintics are an emerging organic contaminant in rural catchments due to their use in animal husbandry. PhD researcher Damien Mooney, Dr Catherine Coxon and Prof. Laurence Gill of iCrag at TCD, in collaboration with Dr Karl Richards of iCrag at Teagasc, developed an analytical method, published in *Molecules* in 2019, for testing for these anti-parasitic drugs which are found in karst and fractured aquifers across Ireland. With over one fifth of investigated sites across Ireland having some level of anthelmintics present, this research lays the foundation for ensuring that local drinking water supplies in rural areas are tested to maintain high drinking water quality.

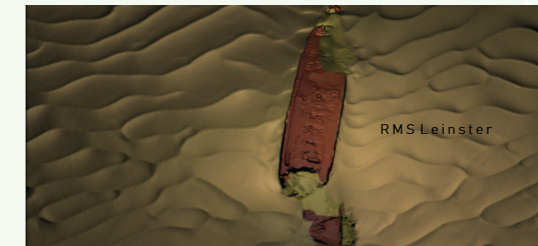
Antimicrobial resistance represents a significant global health threat, with increasing incidences noted in both clinical and environmental settings. PhD researcher Luisa Andrade, Dr Jean O'Dwyer and Dr John Weatherill of iCrag at UCC, with funding support from GSI, presented the first systematic review and pooled analysis of antimicrobial resistant bacteria in groundwater supplies in *Water Research* (2020). With over 2.2 billion people worldwide dependent on groundwater for their primary drinking water supply, this paper highlighted the high occurrence of resistant bacteria in worldwide supplies, and that groundwater represents a major global reservoir for antimicrobial resistant bacteria.

Passive Seismics in Raw Materials Exploration

PhD researcher Senad Subasic and Prof. Chris Bean of iCrag at DIAS published in *Geophysical Prospecting* in 2020 on the potential of passive seismic receiver functions for ore body exploration. Working in collaboration with iCrag industry partner Boliden at the Tara Mines site in Co. Meath, the team worked to image the shallow subsurface using phase conversions at discontinuities in seismic impedance with teleseismic earthquakes acting as a source. Compared to active seismic studies, the cost and logistic effort of this passive seismic approach is minimal and the environmental impact negligible.

Offshore Wind and Shipwrecks

Central to achieving Ireland's target of 5GW of offshore wind energy by 2030 is the identification of suitable sites for the construction of wind turbines. Published in *Geoarchaeology*, Dr Mark Coughlan of iCrag at UCD, along with colleagues in Ulster University, examined the use of shipwrecks in the Irish Sea as analogues for wind turbine structures. Shipwrecks perturb near-seabed currents, causing certain types of sediments to be washed away or scoured. Scour holes developed in this way, near shipwrecks, can ultimately lead to their collapse with the same principles applying to engineering structures on the seabed including wind turbines. With funding from Science Foundation Ireland and Geological Survey Ireland, and support from the Marine Institute, the research team mapped an area of 650 km² in the north Irish Sea and their findings helped characterise the suitability of the area for wind turbine foundations.



Deep Sea Marine Environment

Dr Aaron Lim and Prof. Andy Wheeler of iCrag at UCC revealed the stunning details of a submarine canyon on the edge of Ireland's continental shelf, 320 km west of Dingle, in 2018. The team used remotely operated vehicles and state-of-the-art mapping technologies to examine the Porcupine Bank Canyon which is up to 3,000m deep in places. Funded by Science Foundation Ireland and Geological Survey Ireland, and supported from the Marine Institute, the mapping revealed stunning cold water coral reefs and mounds and provided insight into potential changes due to changing marine currents and climate change.



Critical Raw Materials for Decarbonisation

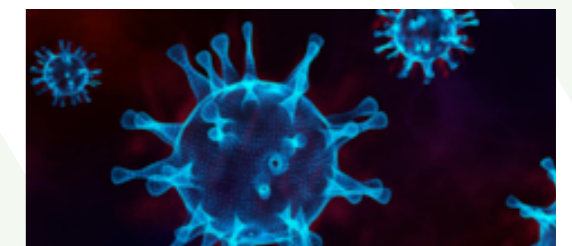
A shift in the global energy sector towards low carbon technologies will result in an increased demand of critical metals such as lithium and tantalum. PhD researcher David Kaeter and Dr Julian Menuge of iCrag at UCD, along with Prof. David Chew of iCrag at TCD, presented in their 2018 paper in *Geochimica et Cosmochimica Acta* a three-stage model for the magmatic-hydrothermal transition of critical metals including lithium. Understanding these mineralisation processes is essential for the exploration of critical metals that are central to the green transition.

In late 2020 Silicon Valley startup KoBold Metals partnered with iCrag to collaborate on exploration for the critical metals cobalt, nickel and copper that are needed for the green transition. Using advanced machine learning and data analytics, in combination with advanced lab techniques at the iCrag Labs at TCD, the partnership focusses on examining mineral samples from one of the world's highest grade cobalt-copper deposits to better understand how high-grade deposits form and how they may be discovered.



Mapping COVID-19

Dr Jean O'Dwyer's SFI funded CO/SMID project between UCC and TU Dublin to track COVID-19 clusters based on geo-referenced data has enabled more accurate prediction of outbreaks. The research techniques use advanced modelling and geospatial analysis together with traditional epidemiology to understand how COVID-19 responds to the easing of restrictions and has formed a new tool used by policy makers for prompt real-time emergency management and communication.



SECTION 8

INTERNATIONAL ENGAGEMENT



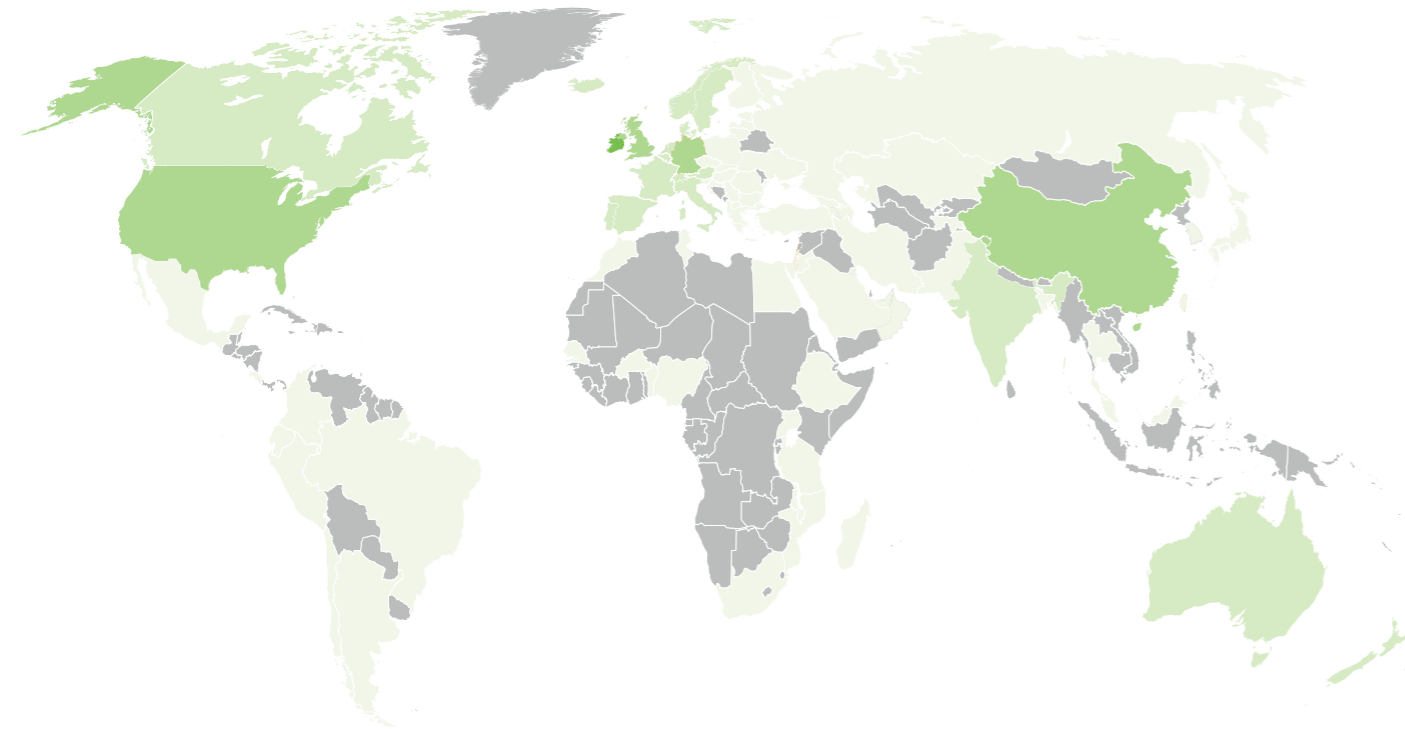
international engagement

iCRAG's researchers come from all corners of the globe, with members from over 30 countries, representing a highly integrated international community within iCRAG. Our researchers are globally networked, and during the period 2015 – 2020, iCRAG members co-authored publications with researchers based in 90 countries, participated in 32 EU projects and co-organised twelve international conferences across six continents.

TOP 20 COLLABORATING COUNTRIES

TOP 20 COLLABORATING COUNTRIES	NO. PUBLICATIONS
Ireland	1,024
United Kingdom	319
Germany	172
United States	138
China	105
France	100
Australia	88
Canada	85
Italy	65
Spain	62
New Zealand	61
Norway	60
Austria	48
India	44
Sweden	41
Netherlands	39
Switzerland	39
Denmark	31
Belgium	26
Portugal	23

COLLABORATING COUNTRIES



Source: Elsevier SciVal, using all types of publications from 2015 to 2020 authored by the iCRAG historic membership in each year.



Equality, Diversity, and Inclusion in Geosciences (EDIG) project

To help address prejudice, inequity, sexism, bias, exclusion, and discrimination in geoscience, researchers at iCRAG, in collaboration with geoscientists from partner organisations, launched the Equality, Diversity, and Inclusion in Geosciences project (EDIG). In 2020, across 2 days, over 200 attendees from across the globe joined the first EDIG conference to hear international perspectives on challenges faced by the geosciences and how to promote effective, long-term change to help the geoscience community become more inclusive and equitable. The EDIG project has grown in size and scope, and has created significant international momentum to address these issues.

US-Ireland Centre-to-Centre Partnership

The US-Ireland Research and Development Partnership is a unique initiative involving funding agencies across three jurisdictions: the National Science Foundation (USA), Science Foundation Ireland, and the Department for the Environment (NI). iCRAG at UCD is the Irish lead on the US-Ireland Centre-to-Centre partnership entitled "Multi-scale Investigation of Bio-Based Mineral Precipitation in Carbonate Bearing Granular Soils and Construction Related Waste". The award, valued at over €500,000 to iCRAG, began in 2020. The partnership collaborates with several Irish and international industrial partners as part of programme including the NSF-funded Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) and Queen's University Belfast Energy Efficient Materials Research Center (EEM). The focus of the research is on the use of microbes and enzymes to enhance methods of bio-based mineral precipitation which can be used to cement granular soils, encapsulate problematic waste such as asbestos, and stabilise soil slopes in areas of high landslide risk.



EXPANDING iCRAG'S GLOBAL REACH

Researching Social Theories, Resources, and Environment (ReStoRE)

The Researching Social Theories, Resources, and Environment (ReStoRE) International Summer School hosted led by Dr Geertje Schuitema of iCRAG at UCD in 2019, and run under the patronage of UNESCO, brought together a group of 42 early-career scientists and practitioners from geoscience and social science backgrounds who set out to tackle the question of how society can sustainably supply future generations with earth resources, such as minerals, energy, and water.

The week-long intensive programme of workshops and talks by leading experts united participants from 28 different nationalities, the majority of which were developing countries, representing institutions from 9 developing and 12 developed countries. The summer school created a stimulating interdisciplinary setting for collaboration, and knowledge sharing and building networks.



Cutting-edge tunnel monitoring system in CERN

The European Centre for Nuclear Research (CERN) is one of the world's largest research centres operating the most powerful particle accelerator within a large-scale underground tunnel network of over 70 km. However, the continuous development of cracks, water infiltration and structural deformation over time in CERN tunnels is of major concern to one of science's great experiments.

Dr Zili Li and MSc researcher Darragh O'Brien of iCRAG at UCC, in collaboration with colleagues from CERN, have developed a technique for automatic crack detection in CERN's tunnels. Using distributed fibre optic sensing (DFOS), artificial intelligence and convolutional neural networks, the team are able to monitor strain levels in the tunnel and gain a better understanding of long term tunnel lining deformation.

SECTION 9

POLICY AND PUBLIC SERVICE IMPACTS



policy & public service

Ensuring that iCRAG's research informs the development of policy both at a national and European level is crucial. During 2015–2020, iCRAG researchers have undertaken numerous activities on the pathway to policy and public service impact.

Domestic Waste Water Treatment Systems

With over one third of the population of Ireland living in rural areas, the management of on-site domestic waste water treatment systems is central to ensuring high quality groundwater and surface water. Prof. Laurence Gill's work of iCRAG at TCD has been central to the technical development of the Environmental Protection Agency's Code of Practice for Domestic Waste Water Treatment Systems (Population Equivalent ≤ 10) which provides guidance on installation and maintenance of such systems to ensure adequate environmental and human health protection.

Road Construction

The discovery of an unusually deep sediment-filled karst feature near Coolough Quarry during the ground investigation for the proposed Galway City Ring Road led to a geotechnical research project carried out by Megan Dolan and Dr Bryan McCabe of iCRAG at NUIG, in collaboration with ARUP, and funded by Geological Survey Ireland, that utilised a multidisciplinary approach across geophysics, structural geology, and geological engineering to understand its formation and

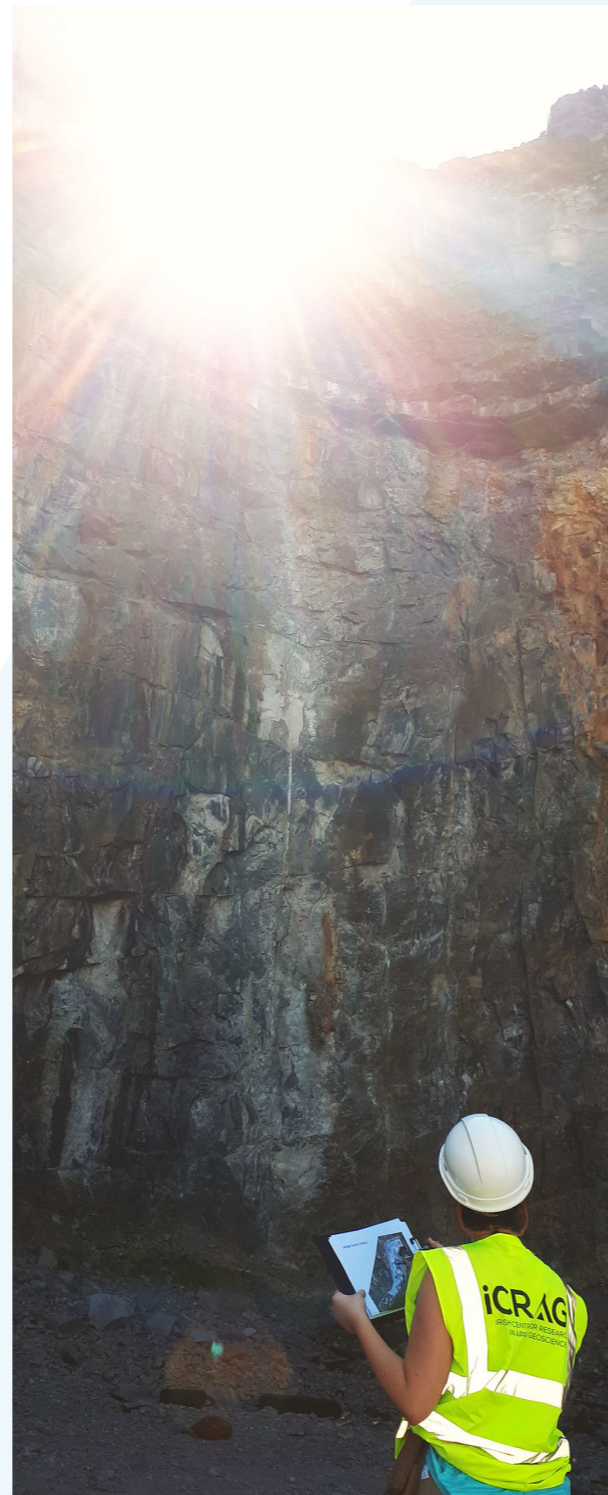
the implications for construction of the ring road. The research is providing progress along a pathway to impact by informing Galway City and County Councils about options for safe and more economical construction.

Road Aggregates

Aggregates are a key building block of the built environment, across roads, buildings and infrastructure. Dr Richard Unitt and Dr Pat Meere of iCRAG at UCC published in *Wear* in 2018 on the mineralogical and microstructural controls on the surface texture of high polished stone value aggregates. This work has been integrated by Transport Infrastructure Ireland into a nationwide study to determine risk parameters for all parts of the national road network, and will be incorporated into Irish Standards.

Pyrite Damage to Housing

The presence of pyrite in Irish rock aggregates used during the building boom of the early 2000's has led to the expansion and damage of up to 12,500 homes across Ireland with associated costs of in excess of €500M. PhD researcher Tadhg Dornan and Dr Robbie Goodhue's 2020 paper, published in *Computers and Geoscience*, explored the application of machine learning methods to aggregate geochemistry aid in quarry source location. Data from this study has been used to develop a sophisticated quarry identification technique called the Aggregate Quarry Classification Model which will be of use to the Department of Housing, Local Government and Heritage in light of the expanded demand for housing and infrastructure, and the significant legacy issues of defective concrete blocks used in home construction across Ireland.



CONCLUDING REMARKS

As we look forward to the next number of years of iCRAG research our ambition is to expand our research areas, grow our international networks and play our part in assisting Ireland reach net carbon neutrality by 2050.

With a focus on sustainability and diversity, iCRAG's vision furthers the Centre's activity as a world leader in applied geoscience research, discovery, and public understanding of earth's critical resources and environment for a sustainable society.

iCRAG has fostered an unprecedented level of integration and collaboration across the Irish geoscience community, creating research clusters, developing cross-disciplinary collaboration, and growing strong connections

between researchers, government agencies, and industry dedicated to solving questions of societal and economic importance.

Building on what has been a successful foundation, iCRAG will continue to deliver economic and societal impacts, train the next generation of earth scientists, engineers and social scientists, and provide a pipeline of highly skilled talent for both industry, state policy partners and academia.

Working with existing industry partners, and welcoming new industry partners as our fields of activity expand, our focus on research excellence will ensure that iCRAG remains a world-leading research centre for applied geoscience research.



iCRAG
IRISH CENTRE FOR RESEARCH
IN APPLIED GEOSCIENCES

Resources for a
Sustainable Society