

Rare earth elements (REEs) are indispensable for a sustainable future, powering green energy technologies and electronic devices. Meeting the growing demand for REEs requires efficient utilisation of natural deposits and REE-bearing waste materials. However, current extraction and separation methods are environmentally and economically inefficient. To address this impending REE crisis, we are committed to advancing exploration and separation techniques.

Our research seeks to shed light on the biogeochemical behaviour of individual REEs across the lithosphere, hydrosphere, and biosphere. While these elements exhibit similar behaviour under identical conditions, discerning the nuances that set them apart remains a challenge.

In contrast to the conventional approach of studying naturally formed rocks, our methodology mimics nature itself. By replicating natural processes, we can pinpoint the specific parameters that influence REE behaviour.

Our research is primarily focused on bastnasite-bearing deposits, which are a significant source of REEs and provide over 60% of the global REE supply. We synthesize bastnasite by interacting common carbonate minerals like calcite and dolomite with single REE-bearing aqueous solutions.

This approach provides us with essential insights into the role of REEs, crystallization mechanisms, and the environmental conditions during the formation of REE-carbonate deposits. This newfound knowledge is the cornerstone upon which we are building more efficient REE extraction, exploitation, and separation methods, fundamentally altering the landscape of sustainable resource utilization.

The major findings are summarised below:

- Bastnasite forms through a multi-step crystallization sequence influenced by the involved REE. The ionic radii of the REEs significantly affect the transition between phases, contributing fundamental knowledge in geochemistry.
- The reaction is also impacted by the solubility of the host mineral and temperature, governing the rate of transformation. This allows us to produce materials with tailored compositions and structures, providing essential insights and advancing the field of material science and geochemistry.
- Our exploration has elucidated the crystallisation mechanisms of bastnasite, the role of single REEs, host carbonates, and temperature in interactions with REE-bearing fluids. Importantly, this knowledge is not limited to REEs alone; it serves as a transferable process that can be applied to investigate and enhance the understanding of various mineral resources, unlocking the potential for more sustainable and efficient resource utilization across different sectors.
- We have developed protocols for synthesizing lanthanite, tengerite, kozoite, bastnasite, and cerianite with customizable crystal sizes and structures for various applications.
- Our research represents a significant step forward in understanding the complex biogeochemical behaviour of rare earth elements (REEs) and their interactions with host minerals. By focusing on bastnasite-bearing deposits and employing a methodology that mimics natural processes, we have uncovered crucial insights into REE crystallization mechanisms and

environmental factors influencing their formation.

Moving forward, our focus will be to further investigate the behaviour of individual or combined rare earth elements (REEs) under various conditions, including factors like pH, while also introducing additional elements to the system. By better mimicking nature, we aim to understand these complexities more deeply. Additionally, we intend to identify more areas and to further investigate the application of the synthesized materials.

Adrienn was part of Dr Juan Diego Rodriguez-Blanco's team through her graduate studies at Trinity College Dublin. The last five years, the group's findings were disseminated through peer-reviewed scientific journals and popular science medial platforms; for example in the [Irish Times](#) or [ScienceDaily](#). You can find further information on the team's research and publications here: <https://jrodriguezblanco.wordpress.com> and more about Adrienn's research interest here: <https://adriennmariaszucs.wordpress.com>.

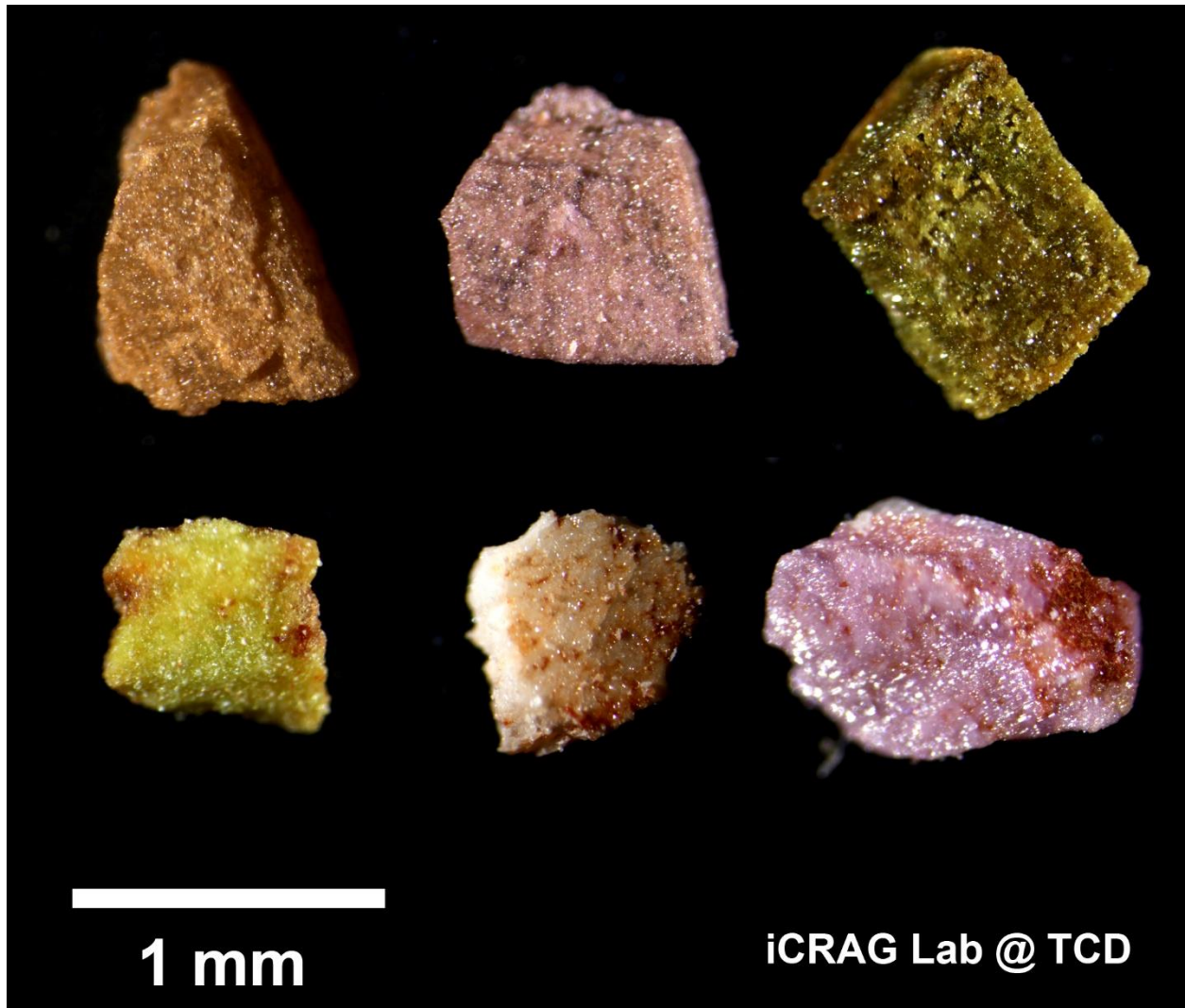
List of Publications:

Luca Terribili, Remi Rateau, Adrienn M. Szucs, Melanie Maddin, and Juan Diego Rodriguez-Blanco (2024) *Crystal Growth & Design*, 24 (2), 632-645. DOI: 10.1021/acs.cgd.3c00858

Adrienn Maria Szucs; Melanie Maddin; Daniel Brien; Remi Rateau; Juan Diego Rodriguez-Blanco (2023): The role of nanocerianite (CeO<sub>2</sub>) in the stability of Ce carbonates at low-hydrothermal conditions. *RSC Advances*. Royal Society of Chemistry (RSC). DOI:10.1039/d3ra00519d.

Adrienn Maria Szucs, Melanie Maddin, Daniel Brien, Paul Christopher Guyett, Juan Diego Rodriguez-Blanco (2022) 'Targeted Crystallization of Rare Earth Carbonate Polymorphs at Hydrothermal Conditions via Mineral Replacement Reactions', *Global Challenges* 2200085  
DOI: <https://doi.org/10.1002/gch2.202200085>

Adrienn Maria Szucs, Alexandra Stavropoulou, Claire O'Donnell, Seana Davis, and Juan Diego Rodriguez-Blanco (2021) 'Reaction Pathways toward the Formation of Bastnäs site: Replacement of Calcite by Rare Earth Carbonates', *Crystal Growth & Design*, 21(1), 512-527 DOI: 10.1021/acs.cgd.0c01313



A selection of some of the rare earth artificial rocks produced by the team. Picture taken at the iCRAG Lab at Trinity College Dublin.