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Geoscience Research
GSI
Suirbhéireacht Gheolaíochta Éireann
Geological Survey of Ireland

Geological Survey of Ireland Research Programme
- Short Call 2015, Final Report -

Name of Lead Investigator	Pat Meere/Giulio Solferino
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Organisation name	University College Cork (NUI)
Organisation type:	☒HEI ☐Public Sector (other) ☐Private Sector
Department/section	School of Biological, Earth and Environmental Science

Project Title	The Geochemistry of the Waterford Copper Coast Mineralisation
Contract No.	2015-sc-052

INFOMAR
Integrated Mapping for the Sustainable Development of Ireland's Marine Resource

Tellus
Understanding Underground

Marine Institute
Foras na Mara

2. Project information:

Title of project	The Geochemistry of the Waterford Copper Coast Mineralisation
Did you make any formal amendment to the project workplan / budget?	☒ yes ☐ no If yes, please specify: Original Lead Investigator, Dr Giulio Solferino changed institution and took up a role as Co-PI.

Project Report (*max 1500 words, excluding figures and headings*):

(i) Objectives and scientific/engineering targets beyond the state of the art

The research project has achieved its core objective of contextualising the formation conditions of the Waterford Copper Coast ores within the current framework of vein-type ore genesis.

One of the largest obstacles to overcome in this project has been the lack of previously published material. As a result of the lack of data, structural analysis of the study area has been a core component of the research given the intrinsic relationship between base metal mineralisation and large scale fault structures (*Figure 1)*.

Figure 1a. Photo showing a typical fault-hosted, mineralised lode on the Copper Coast.

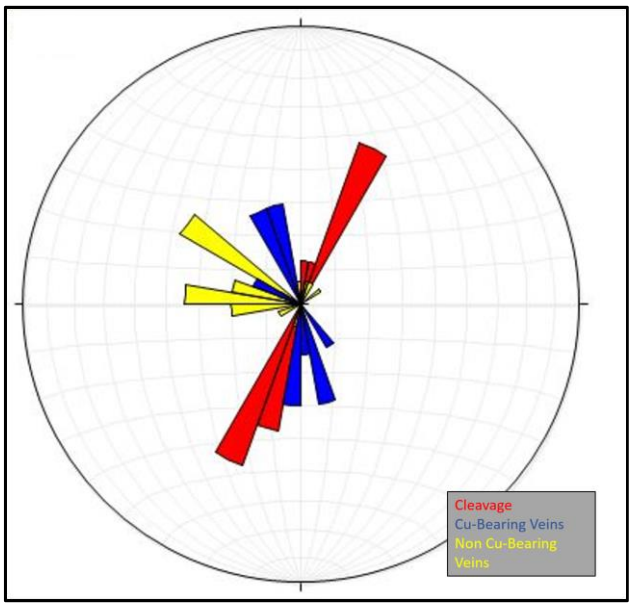


Figure 1b. Stereographic plot showing the orientations of major structures on the Copper Coast.

There are 15 mineralized lodes which have a mean strike of 340 and dip of 66° either to the east or west (*Figure 1a, 1b and 2*). The angle and morphology of the fault structures indicates they initially formed as large scale, normal faults with an extensional axis aligned NE-SW. Within the fault structures

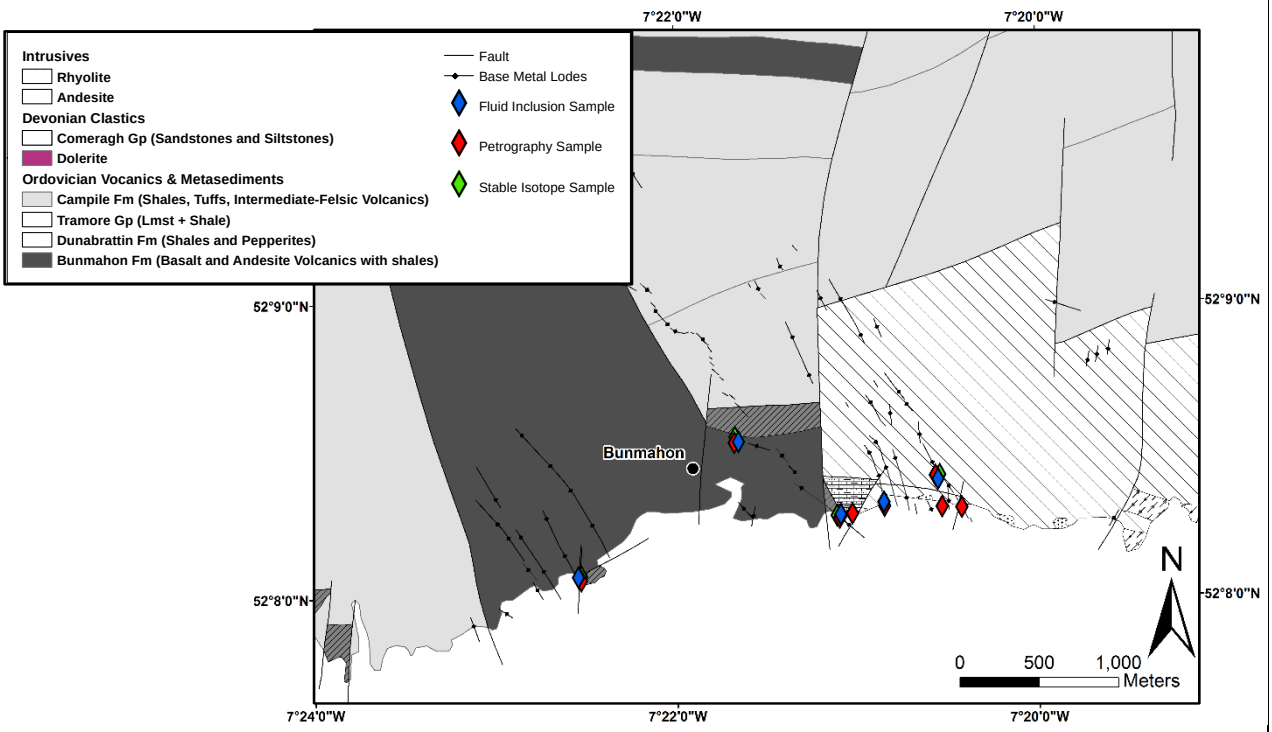


Figure 2. Geological map showing distribution of mineralised lodes and sample location on the Copper Coast.

there is also evidence for a significant component of shear strain, with large-scale corrugations seen on the Tankardstown Lode. The structural textures and orientations observed in the field suggest that the lode structures may have formed as a result of oblique-slip strain induced within a transtensional regime, most likely associated with a large-scale tectonic orogeny.

Petrographic analysis has shown that the behaviour of mineralisation within each respective lode is influenced by wall rock composition. The main lodes can be effectively divided between those that are volcanic-hosted and those that are shale-hosted. The copper mineralisation occurs principally as chalcopyrite with minor tennantite-tetrahedrite and bornite. Each lode shows a complex history of fluid flux with significant precipitation of barren quartz up to 3m thick.
Ore mineral paragenesis has shown that copper mineralisation occurred in association with distinct phases of both silica-rich and carbonate-rich hydrothermal fluids. These phases are preceded by the development of a syn-genetic pyrite-rich vein system that is associated with the original volcanic complex and proceeded by late, breccia-hosted, Pb-Zn ores consisting of galena and sphalerite (*Figure 3*).

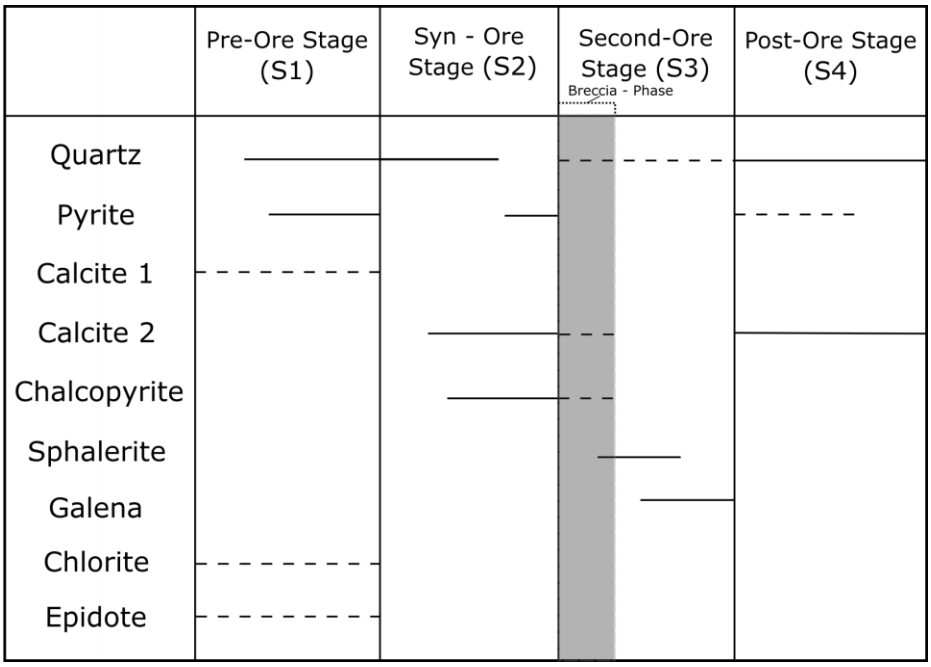


Figure 3. Paragenetic sequence of ore petrography carried out on Trawnamoe and Stage Lodes.

Fluid inclusion analysis has proved problematical during the time-frame of this study. Early samples contained extremely numerous and very small fluid inclusions (c.5 µm) which were not feasible candidates for microthermometry. Recently collected samples have yielded larger and more distinct bi-phase inclusions *(Figure 4)*. Fluid inclusion petrography, however, has shown that the primary fluid phase contains evidence of fluid "flashing" with large pockets of mono-phase vapour-rich inclusions in ore-phase quartz. In direct proximity to chalcopyrite mineralisation, co-existing vapour-rich and liquid-rich inclusions may indicate that fluid boiling was a key mechanism for copper-mineral precipitation. The relationship of mineralisation to boiling/flashing has not been fully resolved. A boiling mechanism for sulphide precipitation fits well into the interpreted structural setting of the lodes assuming tectonically-triggered fluid flux.

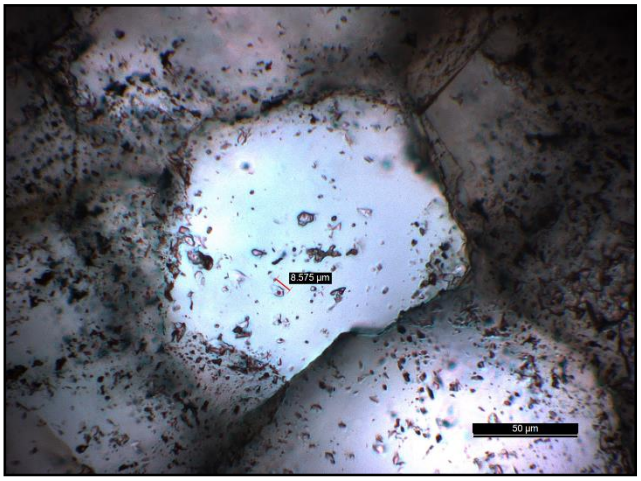
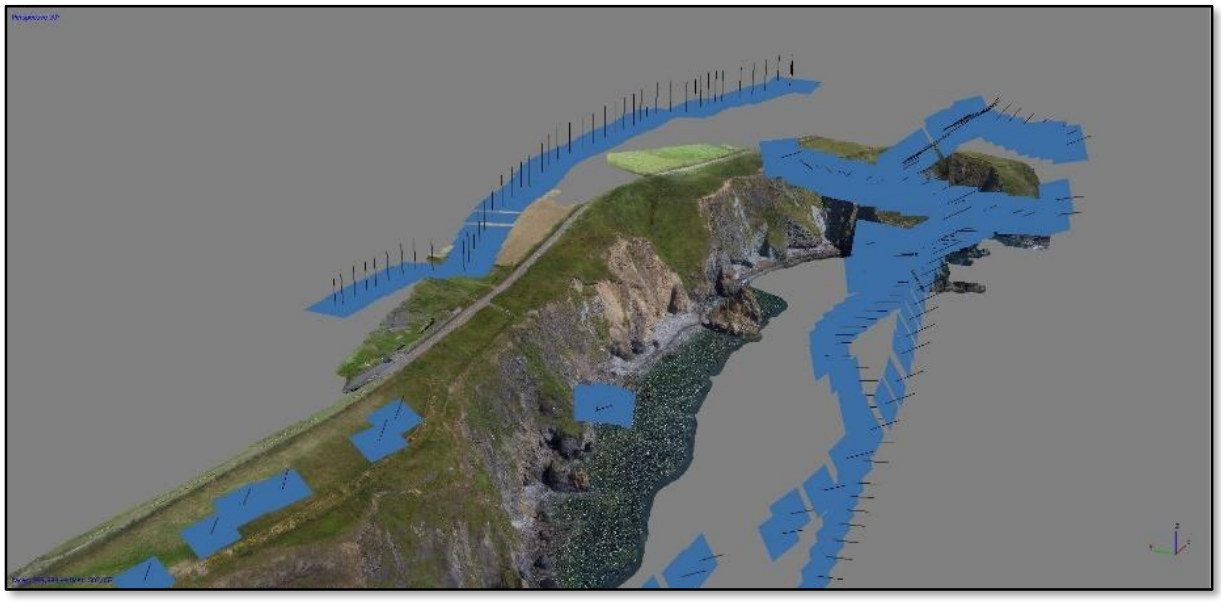


Figure 4. Photomicrograph showing the appearance of bi-phase inclusions within ore-phase quartz.

Stable isotope analysis was carried out at the University of Salamanca in their state-of-the-art facility. Using in-house protocols and established techniques, the samples were prepared for Sulphur, Oxygen and Hydrogen stable isotope analysis on chalcopyrite, quartz and respectively. The initial sample preparation and sulphur analysis was overseen by the research student. Analysis on the more complex oxygen and hydrogen is currently ongoing, with results due in the coming weeks.

In terms of work that progressed beyond the state-of-the-art, the use of aerial drones to map the Copper Coast in 3D was also implemented as a way for increasing the amount available outcrop for the study. Using a DJI Inspire Pro aerial drone, the cliff sections of the Copper Coast were extensively photographed and then processed photogrammetrically to produce a high resolution, georeferenced, 3D surface (*Figure 5*). This surface will be processed further using geological modelling software in order to aid in the structural modelling of the Copper Coast. In completing this objective, the researcher aims to improve the understanding of the structural evolution of the Copper Coast.

Figure 5. Snapshot of 3D model processing with image positions plotted in 3D space.



(ii) Implementation (including reference to timelines, milestones, management)

The majority of the project has progressed according to the original timeline. Generally, objectives have been achieved with the exception of those where technical challenges still need to be overcome.

The initial phase of the project, which started in mid-February involved a literature review and the construction of a comprehensive GIS database, compiled from previous exploration data and GSI files.

Fieldwork was conducted over the course of 2 months with some later dates used for revisiting key areas of geological significance. Samples were selected, cut and examined with key specimens chosen on the basis of contextual and geological merit. Approximately 80 samples were collected and subsequently examined.

Petrography and fluid inclusion analysis was undertaken following the completion of fieldwork and is still ongoing. 22 samples were selected for polished thin section, polished block and fluid inclusion wafer preparation. The initial batch of samples did not yield sufficient geological data to conform with the objectives of the project. This resulted in a delay whilst additional samples were prepared for analysis. SEM (Scanning Electron Microscopy), CL (Cathodoluminescence) and EDS (Energy Dispersive Spectroscopy) analysis is presently being undertaken on selected samples in Royal Holloway University, London to aid in the interpretation of the complex quartz-carbonate-sulphide relationships.

Stable isotope analysis was conducted within the projected timescale at the Stable Isotopes Laboratory in University of Salamanca, Spain. Samples were selected and prepared, in advance, using rock crushing facilities at Trinity College Dublin and were taken to Salamanca for analysis. Using in-house protocols and established techniques, the samples were prepared for Sulphur, Oxygen and Hydrogen stable isotope analysis on chalcopyrite and quartz. The initial sample preparation and sulphur analysis was overseen by the research student. Analysis on the more complex oxygen and hydrogen is currently ongoing, with results due in the coming weeks. Initial results from sulphur isotope analysis on primary, ore-phase give a mean value of +11.7 $\delta^{34}S_{CDT}$(‰). These values require further interpretation in tandem with the ongoing oxygen and hydrogen stable isotope analysis so as to infer the potential fluid source of the mineralizing fluids.

Geochemical modelling will be carried out pending the results of the stable isotope, SEM, EDS and CL analysis.

MSc thesis write up is currently underway with a projected submission date in February 2017. The thesis will be written as a series of articles which will then be used to produce an article suitable for publishing in a peer-reviewed journal in 2017.

In terms of the projected milestones of the original proposal; the specified goals are still on track for completion with the added consideration of conference dates. The aim is to present the final project at EGU in Vienna in April 2017. The submission of a manuscript on the geochemical characterisation and genetic model of the Waterford copper deposits is still on track and will be submitted once the MSc thesis is completed.

(iii) Outputs (please use bullet points)

- Final Report (To GSI)
- Finance Report (To GSI)
- Conference Poster, Geoscience 2016, Dublin Castle, Dublin, Ireland.
- Conference Poster, MDSG Winter Meeting, Bristol, UK.
- Oral Presentation, BEES Postgraduate Symposium, University College Cork, Cork.

Impact/value of the project (M*ax 500 words*):

This research project will have a significant impact on the understanding of the Copper Coast mineralisation in both general and economic terms. The completed work functions as both a standalone piece of research as well as a strong foundation for further research efforts in the area.

This is the first project to characterise the mineralisation of the Copper Coast UNESCO Geopark (CCUG) using modern, state-of-the-art techniques. Stable isotope analysis in conjunction with petrographic analysis, structural field studies and 3D modelling has allowed the completion of a broad-spectrum investigation into the Copper Coast mineralisation and its structural setting. This research product will help update the regional understanding of metallogenesis in southern Ireland and add incentive to active and potential mineral exploration companies, especially when combined with the recent TELLUS survey of this region.

With the ongoing research of iCRAG (Irish Centre for Research in Applied Geosciences) into the copper ores of Ireland this research represents the first step in developing a regional synthesis of copper ore deposits from Lower Palaeozoic rocks into the Upper Palaeozoic occurrences associated with lead and zinc in the Irish Midlands.

The outcomes of this research will also be used to prepare multiple grant applications to Science Foundation Ireland and the Irish Research Council aimed at extending this project. In the longer-term, this project will contribute to a planned application for an EU grant (H2020 ITN – European Training Networks) as a part of a European-scale consortium of experts aimed at describing, categorizing and characterising European copper resources. This study also ties into the Europe-wide efforts to discover and inventory new and existing base metal and energy critical ore deposits. This endeavour is embodied in the Horizon 2020 Challenge – Climate Action, Environment, resource Efficiency and Raw Materials.

This project will have a positive impact on the understanding of Irish economic geology by successfully characterising a significant, and understudied base metal resource. This region currently hosts some of the most active mineral exploration in the country. The publication of this project's findings will help to "de-risk" elements of the southern copper fields of Ireland, incentivising more exploration and expenditure.

In addition to the production of high-quality research, this project has enabled the training and qualification of a MSc student. The candidate has been trained in state-of-the-art laboratory and field techniques in world class facilities. In addition, the candidate has received training from world-leading researchers as part of both formal and informal instruction and has gained the experience and knowledge to positively contribute to the Irish minerals industry.

Finally, this project has helped to develop a communicable understanding of the geological heritage of the Copper Coast UNESCO Geopark, which will directly feed into the geotourism activities of the area.

Appendix 1 – Publications & Presentations:

[Upcoming] [Conference Publication] Copage, J.; Meere, P.; Solferino, G.; Unitt, R. (2016) The Geochemistry of the Waterford Copper Coast Mineralisation, Ireland. *MDSG winter Meeting 2016,* Bristol, United Kingdom, 19-Dec-16.

[Conference Poster] Copage, J.; Meere, P.; Solferino, G.; Unitt, R. (2016) The Geochemistry of the Waterford Copper Coast Mineralisation, Ireland. *Geoscience 2016,* Dublin, Ireland, 2-Nov-16.

[Oral Presentation] Copage, J.; Meere, P.; Solferino, G.; Unitt, R. (2016) The geology of the Copper Coast Cu-Pb-Zn epithermal vein system, County Waterford. *BEES Postgraduate Symposium*. University College Cork, Cork, Ireland, 7-Dec-16.