UNIVERSITY OF LEICESTER

PARTNERSHIP, SUCCESS, OPPORTUNITY

APPLIED RESEARCH FOR THE MINERALS INDUSTRY

CONTENTS

OVERVIEW OF OPPORTUNITY

APPLIED RESEARCH IN THE MINING INDUSTRY

We aim to undertake scientific research that solves problems, or aids industry by: contributing to geological models; aiding exploration targeting; increasing metallurgical understanding; reducing energy and water usage in mineral processing; and reducing costs at any stage of the minerals business. We do this by partnering with industry and other academic institutions and engage with government to tackle these issues with applied geoscience.

All partners benefit from this approach, with industry benefiting through better understanding of orebodies and exploration terranes; access to expertise, facilities and graduates; and all in a cost effective way. The academic partners benefit from gaining research impact and funding and the ability to offer unique, industry-focused experiences to students. Students themselves benefit by gaining experience of industry within their degrees, with the ability to see their work in a business context, and increase their employability.

- Focus on improving exploration models and approaches in the search for, and discovery of, mineral deposits.
- Utilisation of the Mineral Systems Approach to exploration targeting.
- Advanced mineralogical analysis for mineral processing applications.
- Novel, environmentally friendly solutions for mineral processing.
- Large variety in scope of projects, from small Masters-level research, through PhD research to large scale, multi-year consortium approaches.
- Funded by industry and UK government.

THE APPLIED RESEARCH APPROACH

1. Industry identified problem (e.g. exploration targeting, mineralogical characterisation, geological/structural controls on orebodies).
2. Identify resources (expertise of researchers, analytical facilities, scope and personnel).
3. The research project (fieldwork, data sharing, data generation).
4. Reporting (provides answers to the questions posed in Step 1).

The Centre for Sustainable Resource Extraction at the University of Leicester is a unique multidisciplinary research unit with the ambition to ensure both the security of supply of metal resources to society and a substantial reduction in environmental footprint. It brings together staff with expertise in minerals, rock mechanics, materials science, fluid mechanics & chemistry. We have published over 100 papers in in the past five years and been involved in successful grants of >£25million.

ANALYTICAL FACILITIES

The Centre for Sustainable Resource Extraction hosts one of the UK's most complete and advanced suites of analytical facilities for mineralogical and geochemical characterisation of geological materials. This includes XRF, solution and laser ablation ICP-MS, a custom-built ZEISS SEM with Mineralogic software and 3D X-ray CT scanning. In addition, we are global leaders in the application of deep eutectic solvent chemistry for ore processing.

STAFF EXPERTISE

Applied geology staff in the Centre for Sustainable Resource Extraction have a wide range of expertise in deposit types and various aspects of the minerals industry. We have experience in exploration at all stages, mining and novel extractive technologies. Our geological expertise focusses on base and precious metal deposits in magmatic and hydrothermal systems, with particular world class knowledge of magmatic Ni-Cu-PGE deposits, porphyry Cu-Au systems and orogenic gold mineralisation.

HOW TO COLLABORATE

- Masters research projects: These are undertaken as part of the fourth year of an undergraduate Masters (50% of final year). The final year is equivalent to UK MSc (similar to Honours in RSA). Student can start data collection/ fieldwork from June, return to Leicester in October for analytical work, data interpretation and write up with completion of the thesis in May. Costs are very low for a piece of applied research (~£5000) with in house analysis and supervision free to the partner company. They are a good way to tackle small, focussed questions.
- PhD research projects: There are a number of funding options from offering full funding (~£85,000), part funding (~50%) with the University making up the remainder, or UK Research Council funding. They can include supervisors/partners from industry and academia worldwide. They are 3.5 year research degrees that are good ways to tackle large scale and multiple problems. There is a large scope for state-of-the-art analytical work and they promote a sustained working relationship between the student and the industry partner.
- Large projects: These can be government Research Council and/or industry funded and are often formed of large consortia of universities in the UK, worldwide and industry. They are usually major multidisciplinary projects tackling focused objectives within a broad theme over 4-5 years.

COUNTRY CASE STUDY

ZAMBIA

The University of Leicester is committed to developing world-class global research. We have already established a strategic partnership across four countries in Sub-Saharan Africa, with universities in Kenya, South Africa Rwanda and Malawi covering a broad range of research. In addition to this, our Centre for Sustainable Resource Extraction is leading the way in forging strong partnerships in Africa within the minerals sector. Zambia is a current focus and we have a number of established and new partnerships across the industrial and academic sectors in the country that focus on Ni-Cu-PGE sulfide (including our flagship partnership with the Munali Mine), sediment hosted Cu-Co and Iron Oxide Copper Gold mineralisation.

The development of our engagement with the Zambian minerals industry can be demonstrated through the increased scope of the projects we have been involved with since 2015:

- Masters Research Projects: 2015-present. funded by UK-Zambian industry and based at the University of Leicester with additional industry partners in Zambia and the UK.
- PhD Research Scholarships: 2017-present. funded by UK-Zambian industry, the University of Leicester, and the UK government (Natural Environment Research Council).
- Strategic Research Partnership: 2020-onwards. "Applied Research for the Minerals Industry in Zambia". University of Zambia-University of Leicester collaboration.
- UK-government funded research: 2020-2024. "Cu Basin Exploration Science" (CuBES). A UK universities consortium with industry partners.

Details of these projects and partnerships can found on the following pages of this brochure.

In addition, we have presented Knowledge Exchange workshops in Lusaka and at the Munali Mine, Zambia and given presentations to the Geological Society of Zambia. Publicity of the research and Munali in general has been through presentation of the research at international conferences, such as the International Geological Congress in Cape Town, South Africa, 2016; the International Platinum Symposium, Polokwane, South Africa, 2018; the Biennial SGA conferences in Quebec City, Canada, 2017 and Glasgow, UK, 2019. In addition, University of Leicester researcher Daryl Blanks led the 2018 Munali Geological Conversation event which involved showcasing Munali to the mining industry in the region prior to its reopening in 2019, and represented Consolidated Nickel Mines at the 2019 Mining Indaba.

KEY FEATURES

- Well established links between the University of Leicester, industry and academia.
- Example of how partnerships can develop from small scale applied research projects to large government-funded consortium projects.
- Interaction of Zambian industry and academia, UK academia and industry, and UK government.
- Opportunity for further expansion into other countries.

DEVELOPMENTS IN GEOLOGICAL AND EXPLORATION MODELS

THE MUNALI NICKEL MINE, ZAMBIA

The research collaboration between the University of Leicester and the Munali Nickel Mine was initiated in 2015 when UoL graduates were hired by Consolidated Nickel Mines to help with a relogging program of historical drillcore generated during the operation of the mine by a previous company. This was followed by the identification of two key areas of applied research that would be of benefit to Mabiza Resources and CNM: deposit scale research on the geological model for the orebody; and the exploration potential of the surrounding area. These two areas of research were initiated with 10-month Masters research projects, and followed up with more in depth PhD scholarships.

DEPOSIT SCALE RESEARCH - THE MUNALI NICKEL MINE, ZAMBIA

Masters project 2015-2016 – Chloe Mitchell

- Classification of different styles of sulfide mineralisation.
- 3D modelling of the intrusive body to indicate feeder zone down dip.
- Funded by CNM.

PhD project 2017-2020 – Daryl Blanks

- Identified first order structural controls to mineralisation.
- Determined detailed metal characteristics and variability within the orebody with implications for discovering further resources.
- Updated the geological model of magmatic and sulfide emplacement.
- Implementation of new logging protocols following the identification of different sulfide styles.
- Funded by CNM and the University of Leicester.

REGIONAL EXPLORATION POTENTIAL

Masters project 2015-2016 – Grace Howe

- Geochemical and fertility comparison of the Munali mafic-ultramafic intrusions to other magmatic bodies on a camp scale in the Munali Hills area.
- Constraints on regional prospectively of intrusive bodies in the region and input into regional exploration strategy.
- Funded by CNM.

PhD project 2017-2021 – Laura Ward

- Detailed geochronological, isotopic and geochemical comparison of the mafic-ultramafic intrusions in the Zambezi Belt and Copperbelt.
- Determination of key fertility indicators for Ni mineralisation in terms of timing, source and composition.
- Application to exploration targeting.
- Funded by UK research council Natural Environment Research Council, with support from CNM, plus partnerships with First Quantum Minerals and Metorex.

Mabiza Resources Limited

CONSOLIDATED NICKEL MINES LTD

CMI CONSOLIDATED MINING & INVESTMENTS LTD

UKRI Natural Environment Research Council

KEY FEATURES

- Collaboration between University of Leicester, Consolidated Nickel Mines (UK) and Mabiza Resources (Zambia).
- Support of Masters research on the nature and genesis of the orebody, followed by PhD scholarships funded by CNM, the UoL and UK government research council.
- Integration of research to geological models and exploration approaches.
- Implications for further resource discovery and brownfields exploration.
- Research contributing to the re-opening of the mine in 2019.

DEVELOPMENTS IN EXPLORATION TECHNIQUES

MAGNETITE AS AN EXPLORATION INDICATOR FOR NI-SULFIDE DEPOSITS

Indicator mineral chemistry has been a successful early stage exploration technique for many years, especially in the search for diamonds. The key features of successful indicator minerals are:

- that they have a much higher abundance than the main commodity;
- they survive in weathering processes; and
- have distinctive chemical compositions.

In addition to diamond exploration, indicator minerals are now starting to be used in the exploration for a number of base metal deposit types, including magmatic Ni-Cu-PGE sulfide deposits. Whilst this has been suggested as being possible, we have shown that it can be an effective tool through a case study around the Munali Nickel Mine, Zambia.

Magnetite is a common accessory mineral often associated with Ni sulfides. It is robust during weathering and is very easy to separate and collect from soil samples. At Munali, magnetite is present in ultramafic rocks that are associated with sulfides, within the sulfide mineralisation itself, but also in the much more voluminous mafic rocks that are barren of sulfides. Research work undertaken through a 10-month Masters level project proved that in the bedrock, the chemical characteristics of magnetite from the different rock types was distinct. These chemical signatures were shown to be translated with fidelity into the overlying overburden. As such, magnetite in soils can be used to fingerprint the presence of mineralised sulfide bodies from surface soil samples.

In a regional survey, magnetite in soils picked out 'fertile' signatures over the Munali deposit itself, but also over one of the major magnetic anomalies in the area, which has no exposure and is yet to be drilled. This indicator of fertility added an increased level of confidence, alongside traditional soil sediment geochemical anomalies and the geophysical anomaly, to the next stage of drill target generation in the area.

FURTHER READING

Ward L.A., Holwell D.A., Barry T.L., Blanks D.E., Graham S.D. (2018) The use of magnetite as a geochemical indicator in the exploration for magmatic Ni-Cu-PGE sulfide deposits: a case study from Munali, Zambia. *Journal of Geochemical Exploration*, 188, 172–184.

KEY FEATURES

- New indicator mineral technique for use in regional soil sampling programs.
- First application to Ni-Cu-PGE sulfide systems.
- Chemical composition of magnetite in soils reflects magnetite in hidden orebodies/barren systems.
- Magnetite highly effective as an indicator mineral – withstands weathering, can be collected with magnets, and has distinct chemical compositions.
- Effective identification of new targets for drilling in Zambia.

DEVELOPMENTS IN METALLURGICAL UNDERSTANDING

THE KITUMBA COPPER DEPOSIT, ZAMBIA

This applied research collaboration involves an investigation into the metallurgical characteristics of an orebody within a project that has advanced as far as resource definition. The Kitumba copper deposit is an example of Iron Oxide Copper Gold mineralisation in central Zambia that has undergone supergene enrichment and represents a high-grade copper orebody with a mineralogy consisting of a range of secondary copper minerals.

The aim of the project, delivered through a 10-month Masters level research project, based at the University of Leicester, is to quantitatively assess the mineralogical and geochemical zonation within the deposit in order to provide critical information that can be fed into the design of mineral processing techniques.

The research involves partnering with the exploration and mining companies (CMI and Vulcan) and a specialist partner, Carl Zeiss Microscopy (ZEISS). Through the partnership with ZEISS, and the use of their state-of-the-art scanning electron microscopy facilities and automated mineralogy software, Mineralogic, the research has produced detailed and quantitative data on the metallurgical characteristics of the ore.

This style of research project is relatively cost effective (~£5k) but produces high quality research under the supervision of experienced personnel. Such projects are ideal for tackling discrete problems in a relatively short timeframe. Examples of such projects include:

- Mineralogical characterisation of exploration prospects,
- Geochemical characterisation of orebodies and alteration systems,
- 3D orebody modelling using software such as Micromine,
- Prospectivity analysis in target generation exercises,
- Specialist isotopic and geochronological investigations,
- Application of novel processing techniques to a range of ore types.

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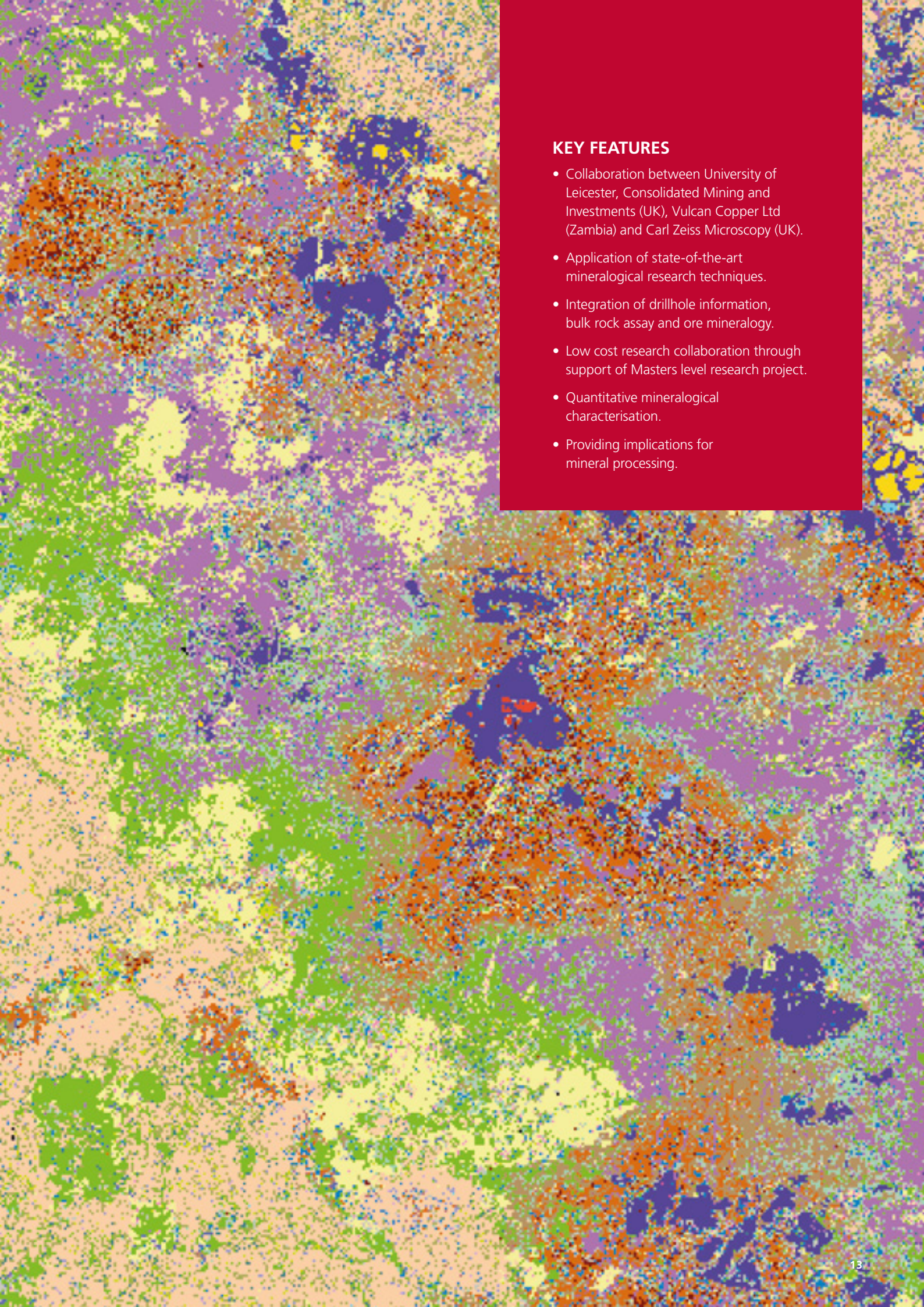
ZEISS

VULCAN COPPER LIMITED



KEY FEATURES

- Collaboration between University of Leicester, Consolidated Mining and Investments (UK), Vulcan Copper Ltd (Zambia) and Carl Zeiss Microscopy (UK).
- Application of state-of-the-art mineralogical research techniques.
- Integration of drillhole information, bulk rock assay and ore mineralogy.
- Low cost research collaboration through support of Masters level research project.
- Quantitative mineralogical characterisation.
- Providing implications for mineral processing.

UK GOVERNMENT FUNDED RESEARCH

CuBES – COPPER BASIN EXPLORATION SCIENCE

SEDIMENT-HOSTED COPPER-COBALT DEPOSITS: A MAJOR GLOBAL RESOURCE

The criticality of copper and cobalt in battery technology and electricity transmission has established them as key components of the carbon-free energy transition. A major proportion of these metals are sourced from sedimentary basin-hosted deposits. Recent work has shown that diverse basin architectures and processes were responsible for their genesis, yet we still do not understand why so few basins become highly endowed with metals. Given their paucity, the geological evolution of such basins demands the juxtaposition of unique conditions that:

- generated large volumes of metal-bearing fluid;
- provided sufficient sulfur;
- created reducing trap sites; and
- focused fluid flow into these sites.

Understanding large deposits is particularly significant because they are efficient to mine and offer the greatest societal benefits.

MINERAL SYSTEMS APPROACH

Our particular focus is to develop and integrate mineral and petroleum systems approaches to provide a disruptive innovation opportunity in the science and industrial applications in this field. Our objectives are to identify the processes, operating over a range of scales, that lead to the formation of large Cu-Co-(V) deposits and derive new and practical exploration tools. The opportunity is timely, given the current wave of academic interest in these ore systems, and the increased collaboration between industry and academia to develop sophisticated methods that can reduce exploration costs, risk and environmental impact.

PROJECT STRUCTURE AND APPROACH

To tackle these challenges, we have assembled a multi-institute academic consortium with internationally-recognised expertise across the geosciences. We have also built strategic research alliances with:

- the UK's major mining houses, Rio Tinto and Anglo American, and with BHP and First Quantum Minerals, all with global interests in sediment-hosted copper mineralisation;
- the energy sector (Scheupbach Energy); and
- international academic partners (CSIRO, Univ. Houston, GFZ Potsdam, Universidad Nacional Rio Negro).

The collaboration between the academic researchers, six PDRAs, PhD students, industry and international partners will deliver high impact scientific publications, new data and tools to support the development of lower risk mineral exploration strategies, and highlight the UK as a world-leading community for research in basin-hosted mineral systems.

KEY FEATURES

- 'Highlight topic' funded by Natural Environment Research Council.
- Consortium approach of multiple UK institutions with industry partners in Africa and across the globe.
- Focus on the Central African Copperbelt.
- Includes the first large scale seismic survey across the Copperbelt and Katangan basin in northern Zambia.

STRATEGIC RESEARCH PARTNERSHIP

UNIVERSITY OF LEICESTER – UNIVERSITY OF ZAMBIA COLLABORATION

The University of Leicester are currently in the process of setting up a Memorandum of Understanding (MoU) with UNZA to undertake collaborative research. This will be in a number of potential areas including Life Sciences and Medicine. The most advanced proposal, which will be arranged under this MoU as a Strategic Partnership, is between the School of Mines at UNZA and the School of Geography, Geology and the Environment at the UoL: "Applied Research for the Minerals Industry in Zambia."

BENEFITS TO THE ZAMBIAN MINERALS INDUSTRY

Applied research projects are a cost-effective way of tackling challenges across all aspects of the business, including exploration targeting, resource assessment, mining methods, and processing techniques. By engaging with experienced researchers, significant energy, time and ultimately financial savings can be implemented within the working operations. The student engagement in these projects trains the next generation of graduates for work in the industry, often with the partner company. The opportunity to develop staff through internationally-recognised CPD training courses increases the skillsets of personnel within the industry.

BENEFITS TO THE ZAMBIAN ECONOMY

Applied research impacts positively on the economy through the implementation of improvements in efficiency exploration and mining operations. This is key in a country where mining accounts for 12% of GDP. The training of graduates and professional staff contributes to increasing the level of skilled professionals in the industry and may lead to the improvement of the human development index (HDI) for Zambia.

BENEFITS TO THE UK UNIVERSITY PARTNER - UNIVERSITY OF LEICESTER

The partnership allows a greater opportunity to attract increased industry funding for research, including income generated through the use state of the art analytical facilities for applied research with broad scientific implications. Additional income to UoL will be generated from jointly-delivered CPD courses delivered by the partnership to the Zambian mining industry. Numbers of research outputs, including those with industrial and international co-authors, and collaborations will increase. The opportunity to generate outputs with well-defined Impact. UoL students will have increased opportunities to work with international industry and undertake research/field time in Zambia, improving their employability and internationalising their academic experience. There will capacity building for UoL academic and research staff through regular interactions with colleagues at UNZA through joint research, co-hosting of CPD training programmes and co-publishing.

BENEFITS TO THE AFRICAN UNIVERSITY PARTNER - UNZA

The partnership allows a greater opportunity to attract local and regional industry funding for research that has been historically restricted due to the lack of access to state-of-the-art research facilities. Additional income to the university will be generated from offering of jointly-delivered CPD courses. Numbers of research outputs, including those with industrial and international co-authors, and collaborations will increase. Students will have an expanded skillset through increased opportunities to work with local and regional industry and to undertake research and teaching in the UK. This will improve their employability and internationalise their academic experience. There will capacity building for UNZA academic and research staff through regular interactions with colleagues at UoL through joint research, co-hosting of CPD training programmes and co-publishing.

KEY FEATURES

- Provide relevant and supportive research to tackle challenges identified in the Zambian minerals industry that also have broad scientific implications.
- Generate collaborative high impact, high-quality scientific outputs.
- Generate research income for university partners.
- Produce highly qualified personnel (from Zambia and the UK) at Masters and PhD level.
- Deliver training courses for Zambian mining professionals.
- Improve the Zambian economy through the provision of highly skilled graduates and staff to the mining industry, and drive efficiency savings in exploration and mining.

INDUSTRY FUNDED RESEARCH

NORTHERN LIMB 4D – TARGETED RESEARCH FOR ANGLO AMERICAN'S NORTHERN BUSHVELD OPERATIONS

The NL4D consortium is a large research program on the Northern Limb of the Bushveld Complex to be undertaken over a period of five years by a consortium of UK universities in conjunction with Anglo American. The Consortium Leaders of NL4D are Dr David Holwell (Leicester), Dr Iain McDonald (Cardiff), and Dr Hannah Hughes (Exeter/Camborne School of Mines). All Consortium Leaders have a proven track record of applied research on the northern Bushveld and magmatic Ni-Cu-PGE deposits in general. The consortium aims to provide outstanding supervision for research students and access to unrivalled analytical facilities (including SEM, EMPA, ICP/ICPMS, LA-ICPMS, QEMSCAN, micro-CT radiogenic and stable isotopes, LECO analyser, plus mineral processing and geotechnical facilities) for the study of Ni-Cu-PGE ore systems in the northern Bushveld Complex to address outstanding questions on the genesis of mineralisation within the area that benefit Anglo mining and exploration operations.

The research will be delivered through a range of projects and personnel on different timescales that together will increase the geological understanding exponentially during the course of the five year project. Early returns will be delivered through short term (3-4 month) MSc projects, 9 month MGeol/MESci projects and flexible Masters level projects. These smaller projects will be used to tackle discrete problems or questions and inform more in depth work.

More in depth work will be completed through three PhD projects and two postdoctoral researcher positions that allow for detailed study on a breadth of topics across the science program. All individual research projects (students, pre-docs and the post-doc) within the program will be supervised by one of the main academic leaders, with input from at least one of the other two in supporting roles. Visits to South Africa by the UK-based researchers as part of field supervision and meetings will include guest lectures, workshops and field trips at partner South African universities.

The overarching aim of the research is to deliver a major scientific advancement in the understanding of one of the world's largest base and precious metal ore deposits and exploration provinces that will support, inform and drive more cost and energy effective exploration, mining and processing methodologies for Anglo American, and provide the basis for increasing the value of Anglo assets in the northern Bushveld.

KEY FEATURES

- Collaboration between Anglo American (South Africa/UK) and a consortium of UK universities – Leicester, Cardiff and Exeter.
- Five year, £1.2 million research project on re-evaluating geological and exploration models for polymetallic mineralisation in the northern Bushveld.
- Brings together key research experience on Bushveld and magmatic ore deposit systems.
- Supporting postdoctoral, PhD and Masters level research.
- Strategic research program aligned with value creation and exploration efficiency.

DEVELOPMENTS IN ORE CHARACTERISATION

HIGH RESOLUTION 3D X-RAY COMPUTED TOMOGRAPHY (HRXCT)

X-RAY COMPUTED TOMOGRAPHY

This procedure uses X-ray imaging to produce thousands of 2D images of a rock sample that are then processed to produce a 3D image in the same way as medical CT scanning. The X-rays are attenuated by the sample and images show density variations that relate to different minerals and their 3D textural relations. It does not identify minerals but, provided that the sample has been mineralogically characterised, a density range can be attributed to a particular mineral. It is a non-destructive technique, with a spatial resolution down to ~1 µm. A scan takes 1-4 hours depending on resolution required. Smaller samples (usually 2 cm core or less) gives the best resolution. Processing takes 10-15 minutes.

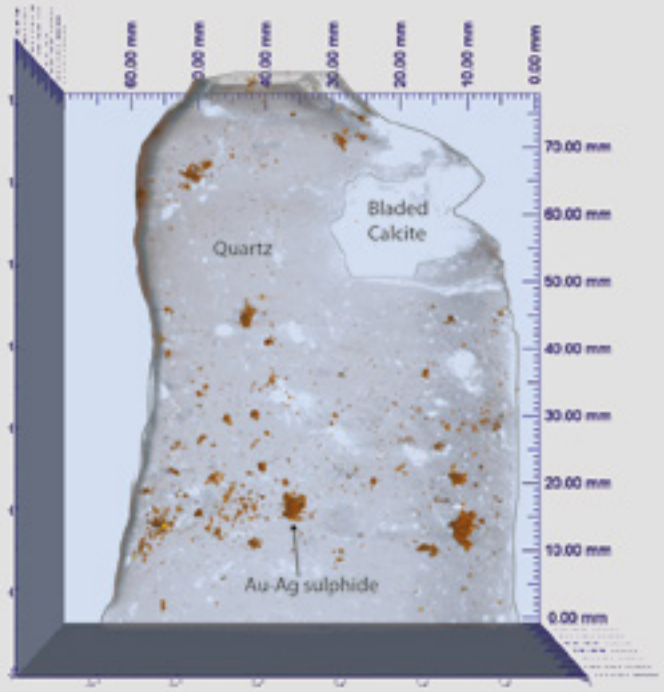
APPLICATIONS IN ORE CHARACTERISATION

There are large differences in density between ore minerals (gold, sulfides and oxides) and gangue (silicates and carbonates) so this technique is particularly appropriate for characterising base and precious metal ore textures.

- Location of areas of interest for sectioning. Before making a thin section, virtual sections can be made in any orientation through a sample in order to choose the best position to observe the mineralogy with optical and microbeam techniques.
- Textural location of ore minerals. Ore minerals can be associated with a particular texture or vein stage within a sample. Gold and gold minerals are particularly amenable because of their very high density contrast to gangue minerals.
- Quantify proportions (grade), grain sizes and mineralogical associations of mineral of interest. Once a mineral is associated with a particular density each grain can be characterised and bulk data compiled. Especially useful for nuggety and low grade ores.

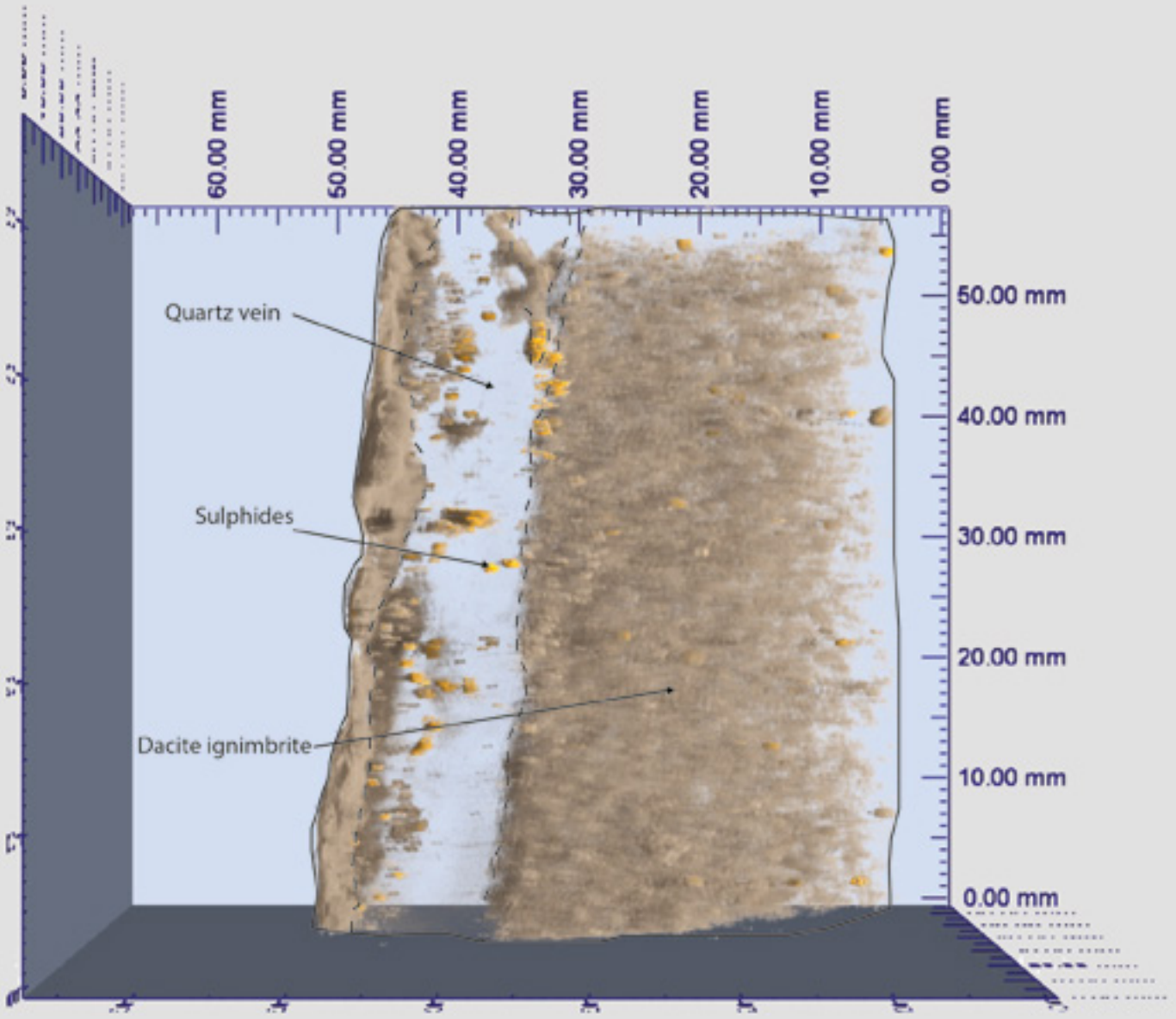
FURTHER READING

Firth et al. (2015). Constraints on the development of orogenic style gold mineralisation at Mineral de Talca, Coastal Range, central Chile: evidence from a combined structural, mineralogical, S and Pb isotope and geochronological study. *Mineralium Deposita*, 50, 675-696. DOI: 10.1007/s00126-014-0568-6



KEY FEATURES

- 3D textural analysis.
- Increased confidence over 2D analysis.
- Ideal for nuggety ores.
- Requires complimentary compositional analysis.
- Paragenetic studies – order of mineral formation.
- Metallurgical studies – mineral associations, grain size and shape, grade quantification.
- Non-destructive.



DEVELOPMENTS IN MINERAL PROCESSING

DEEP EUTECTIC SOLVENT IONIC LIQUIDS

IONIC LIQUIDS

These are salts that are liquid at low temperature, typically <100°C. These anhydrous liquids are composed of ions and, like high temperature molten salts, are electrolytes and powerful solvents. In contrast to aqueous systems, in water-free ionic liquids much higher metal concentrations can be achieved. This, together with the fact that ionic liquids can be reused in a closed circuit, means that high volume/low concentration aqueous wastes are not produced, reducing effluent treatment costs.

DEEP EUTECTIC SOLVENT IONIC LIQUIDS

To be suitable for large-scale metallurgical processing a reagent must be: low cost, readily available in large quantities, chemically stable to allow prolonged reuse, environmentally benign, and have no licensing restrictions. Most ionic liquids do not meet one or more of these criteria. This led to the development at the University of Leicester of the deep eutectic solvents (DESs). These are mixtures of salts, such as choline chloride, with hydrogenbond donors such as urea or citric acid. The solvent properties of DESs can be adjusted by changing the hydrogen-bond donor, giving 105 possible different liquids and allowing the possibility of tailoring the properties of the liquid to a specific process. DESs are environmentally benign, yet chemically stable. Their components are common, cheap chemicals: choline chloride (vitamin B4) is mainly used as an animal-feed additive (~$2/kg). Urea is a common nitrogen fertilizer (~$0.5/kg).

SELECTIVITY IN MINERAL DISSOLUTION

Silicate and carbonate gangue minerals are insoluble.

The following minerals are soluble in DES:

- Native metals (gold, silver, copper, tellurium)
- All sulfides
- Arsenides, tellurides, selenides, bismuthides, antimonides
- Sulfosalt minerals (e.g. enargite, tetrahedrite)
- Some oxides

Some of these will dissolve with a simple oxidising agent such as iodine, whereas some will only dissolve by electrolysis. Dissolution rates vary widely. Thus dissolution is highly mineral-specific and can potentially be tuned to target particular minerals and the elements they contain.

SELECTIVITY IN METAL RECOVERY

Recovery from solution can be by electrowinning, cementation, ion exchange or precipitation, allowing particular metals to be targeted and separated from others.

POTENTIAL APPLICATIONS

- Cyanide-free gold processing. Gold dissolution rates in DES are at least 80 times faster than in cyanide. Gold dissolution and electrorecovery is demonstrated above.
- Recovery of by-products. Potential by-product elements are often concentrated into minor minerals. Selective dissolution of these might allow economic recovery of by-products. E.g. hessite, Ag2Te, dissolves as rapidly as gold, so Ag and Te might be recovered from some concentrates.
- Tackling complex "dirty" ores. Increasingly companies are mining and treating ores containing enargite or tetrahedrite for copper and gold, but processing these arsenic-bearing ores is environmentally challenging. With DES there is the potential to recover a range of valuable elements from these complex minerals.

FURTHER READING

Jenkin et al. (2015). The application of deep eutectic solvent ionic liquids for environmentally-friendly dissolution and recovery of precious metals. *Minerals Engineering*, 87, 18-24, DOI: 10.1016/j.mineng.2015.09.026. (Open Access).

UKRI Natural Environment Research Council

KEY FEATURES

- Non-toxic, biodegradable, environmentally safe.
- Cheap and produced in industrial quantities.
- Low energy process.
- Powerful water-free solvents – reduced aqueous waste.
- High selectivity in dissolution and recovery from solution.
- A new set of tools for ore processing.

ONLINE AND FACE-TO-FACE SHORT COURSES

MINING AND QUARRYING CPD

These courses are designed for professionals who are currently working, or intend to work, in the mining or quarrying industries, and want to increase their professional knowledge. The courses are approved by the Geological Society of London and the Institute of Materials, Minerals and Mining.

With funding from the UK Government's Chile Prosperity Fund: 2016, the University of Leicester developed a number of short-courses specifically for the Chile/South America mining and quarrying industries. Most of these are on-line (web-based), distance-learning courses, but also include a number of face-to-face seminars in Chile, covering a variety of subjects. Since the establishment of these courses, we have expanded their scope and now train students from across the globe including Africa.

The following online short courses (ranging in cost from £125 to £195) address some of the critical issues in relation to safe and sustainable mining and quarrying:

- Tailings Facility Management
- Blasting
- Effective Surface Mine Design
- Slope and Face Stability
- Introduction to Surface Mining Methods

The study material has been drawn from leading experts in the field and will assist those wishing to broaden or deepen their professional knowledge. The courses are delivered in a way which makes them accessible if you want to study part-time and achieve a recognised number of hours of Continuing Professional Development.

Each course can be taken independently of the others, so it is possible to study one or more in any sequence. Completion of courses such as these not only contributes towards the fulfilment of CPD requirements of a number of professional bodies (e.g. Geological Society of London), but also helps to demonstrate a commitment to demonstrating and maintaining competency. As such, it should increase your opportunities within the industry.

CPD is an essential element of career development and helps to enhance job prospects. Whether you're an employee looking to get ahead or an employer keen to develop the capabilities of your workforce, studying a CPD course with us will bring the resources of a leading University to your organisation.

The Geological Society

endorsed training course

Foreign & Commonwealth Office

IOM3 PD APPROVED

IOM3 The Institute of Materials, Minerals and Mining

KEY FEATURES

- Continuing professional development (CPD) short-courses.
- Aimed at professionals entering or within the mining and quarry industries.
- Based on UK academic and consultant expertise.
- Developed initially for the Chile/ South America industries, and now implemented in Africa.
- Courses include: mine design, tailings management, face & slope stability, and environmental impacts.

CONTACT DETAILS

APPLIED RESEARCH PROJECTS

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MUNALI NICKEL MINE PROJECTS

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20-01-006-GL CARTO