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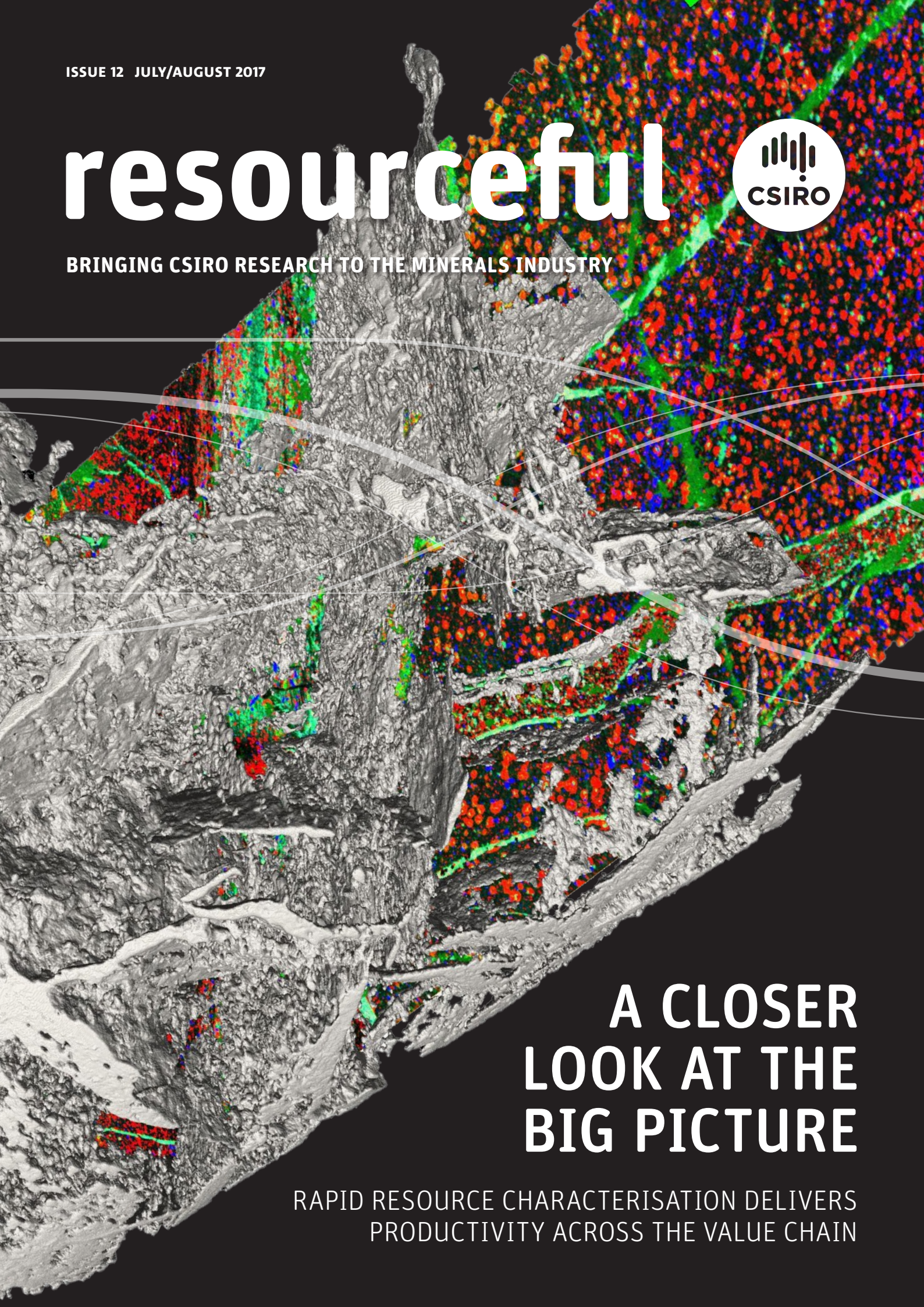
resourceful

BRINGING CSIRO RESEARCH TO THE MINERALS INDUSTRY

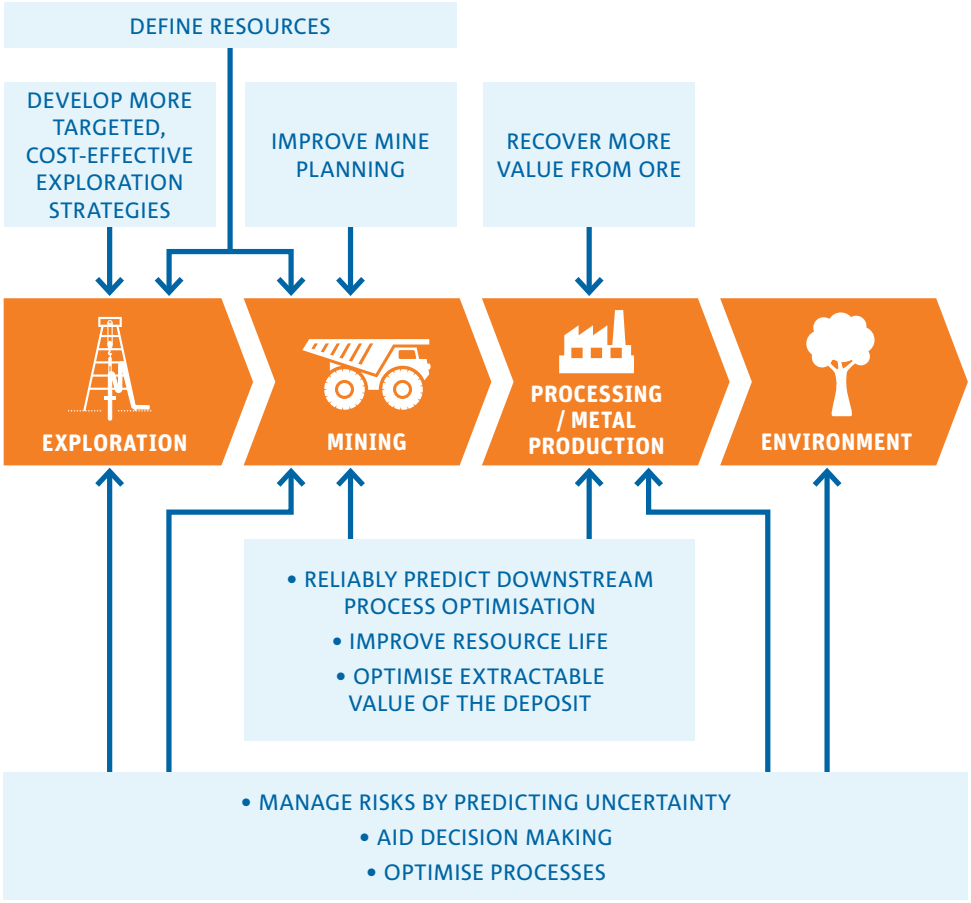


A CLOSER LOOK AT THE BIG PICTURE

RAPID RESOURCE CHARACTERISATION DELIVERS PRODUCTIVITY ACROSS THE VALUE CHAIN

WHY CHARACTERISE RESOURCES?

Characterisation or mineral analysis improves our understanding of the geological features of a resource.



CHARACTERISATION EXPERTISE

ELEMENT DEPORTMENT

MINERALOGY

PROCESS SIMULATION

GEOMETALLURGY

BULK AND ONSITE ANALYSIS

THE CHALLENGE

QUANTIFYING RESOURCES AT ALL SCALES + OPTIONS UPSTREAM AND DOWNSTREAM = PRODUCTIVITY IMPROVEMENT + SCENARIO MANAGEMENT

INSIDE THIS

ISSUE

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Jonathan Law

LEADER'S COMMENT

THE DATA SCALE REVOLUTION

Sensor and data analysis tools are driving advances in resource characterisation at every scale, a key opportunity for the mining industry and their suppliers to increase their productivity, writes CSIRO Mineral Resources director, JONATHAN LAW.

Resource characterisation has always been at the heart of profitable mining. Understanding the nature of the ore and waste – its texture, chemistry and mineralogy – defines the mine plan and process performance, as well as the nature of the remnant waste. So it's no surprise that many performance, productivity and commercial failures have their origins in characterisation problems.

Geoscientists are very familiar with drawing informed inferences based on sub-optimal characterisation datasets – if they didn't, practical mining operations would be untenable.

But, the characterisation landscape is changing rapidly in line with the broader momentum of the digital revolution. Greater data is providing opportunities to fundamentally rethink our approach to the mining value chain.

Driving advances are the range of new sensors that can measure both chemistry and mineralogy at a range of scales and provide unprecedented detail and volumes of data that capture the ore variability. It's enabling what I like to think of as the "pixel" effect; as the resolution of the characterisation tools increases, so does our understanding of the underlying complexity of geological systems and orebodies and the impact on decision making.

This new data leads to two important opportunities at different scales. First, the detail provides a tool to optimise performance of small-scale processes like comminution, flotation and chemical processing. Second, the ability to link zones of similar type in ore, provides the option to build orebody models that may open up fundamentally new approaches to mining.

In this edition of *resourceful*, we cover a suite of new tools that focus on mineralogy, chemistry and 3D architecture in rock samples (p.14) to illustrate these characterisation opportunities.

Of course, more data does not necessarily mean better outcomes. That's why, the ability to manage and process disparate data streams with a focus on identifying the variables and proxies that have the greatest impact on downstream performance, is a key driver and major focus of our current research.

Used in combination, sensor and data analysis tools are having a major impact on decision making from exploration through to processing. This edition focuses on new mineral systems approaches in exploration, graphite characterisation and new processing options for low grade uranium, as examples of how the industry is reaping rewards from applying these technologies.

It's not just the mining industry, but also its suppliers, who will benefit from advances in characterisation. As highlighted in CSIRO's recently released Mining Equipment Technology and Services (METS) Roadmap, technology that enables data driven mining decisions is a key growth opportunity for the future.

Rapidly evolving characterisation tools have the ability to disrupt the mining industry and open up new business opportunities for the METS sector. As we have seen happen in other industries, disruption is changing the way companies do business – it will not necessarily be the current large companies that dominate the future world of mining.

The METS Roadmap is a valuable tool for companies seeking to take advantage of new technology opportunities, like characterisation, to secure a competitive advantage in future. Copies of the report are available at: www.csiro.au/METSRoadmap.

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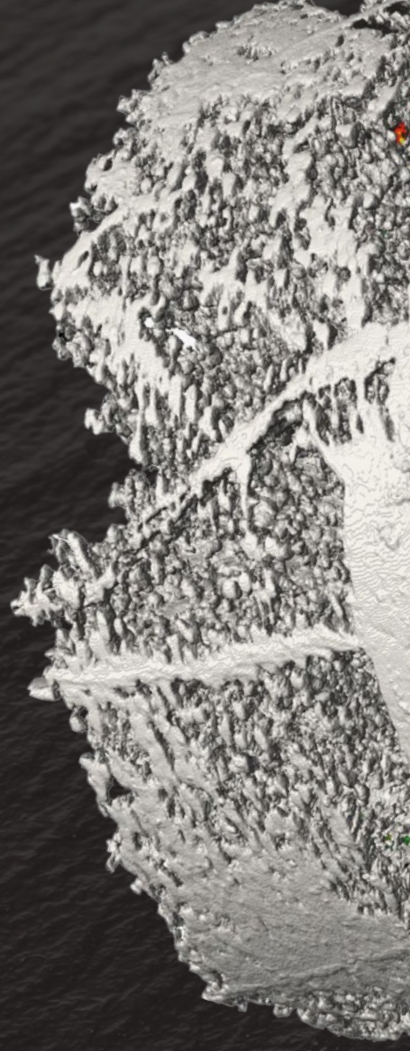
INDUSTRY ENGAGEMENT

WHAT TO KNOW ABOUT GRAPHITE



With the rise of electric vehicles, graphite is poised to be hot on the commodity market to meet the demand for lithium ion batteries. Two companies seeking to establish a competitive edge in the market have gained crucial understanding of their deposits and how to make the most of them.

LOUIS WHITE reports

The word graphite derives from the Greek word 'grephein', which means to write or draw. Graphite's uses extend beyond creative paints and pencils to batteries, crucibles, refractory bricks, car brakes and for printing electrotypes.

It's a metamorphic mineral, with approximately one million tonnes sold annually in the form of tiny graphite flakes ranging from 1-300 microns, mostly sourced from China and Brazil.

"A lot of work is going into diversifying the sources of graphite, as it's expected to be in increasingly high demand for lithium-ion batteries," Dr Mark Pearce, CSIRO research scientist, says.

"Many graphite deposits around the world are in ancient rocks whose geology is poorly understood. These rocks have been metamorphosed – heated and put under pressure – numerous times with the potential for fluids to move minerals, including graphite, around to produce rich zones."

Dr Pearce says the crystallinity of graphite grows with increasing temperature, as the organic matter (dead bacteria or plants in younger rocks) is "cooked up" and converted to graphite.

"The geological history of the rocks is important in determining the quality of the graphite present, since the market price for graphite is determined in part by the flake size," Dr Pearce says.

"Our characterisation work helps to determine the history of these rocks. It also allows us to look at the variability in the minerals that accompany the graphite so that it can be taken into account for processing."

Kibaran Resources is an ASX-listed exploration company focused on unlocking the graphite potential of the mineral-rich landscapes of Tanzania in east Africa.

The company's primary focus is on their Epanko Deposit – a key graphite target that has been identified to host large flake graphite.

"CSIRO studied the metamorphic gradient and process of the Epanko deposit," Andrew Spinks, Kibaran Resources managing director, says.

"This study supported the recently completed bankable feasibility study, which shows that Epanko holds world-class graphite.

"The results have been incorporated into the downstream processing of Epanko graphite for the production of battery grade graphite. Understanding why Epanko has such high grade, combined with large flake, has been critical to position the resource for the enormous graphite growth forecast."

This research and similar work will increase the geological knowledge around Kibaran's several graphite prospects throughout Tanzania, making them more feasible as mines.

Another company seeking to become a global leader in bulk graphene and graphite supply, Talga Resources, owns five graphite projects in northern Sweden which cover the full range of market flake size specifications.

This includes the largest deposits defined in Europe and the highest grade graphite mineral resource in the world. The company has its own unique low cost process to liberate graphite, as well as bulk quantities of graphene.

"Talga's graphite has a long geological history of approximately 1.8 billion years and what we are doing is exploring the properties of this ore to make the world's lowest cost bulk graphene," Mark Thompson, Talga Resources managing director, says.

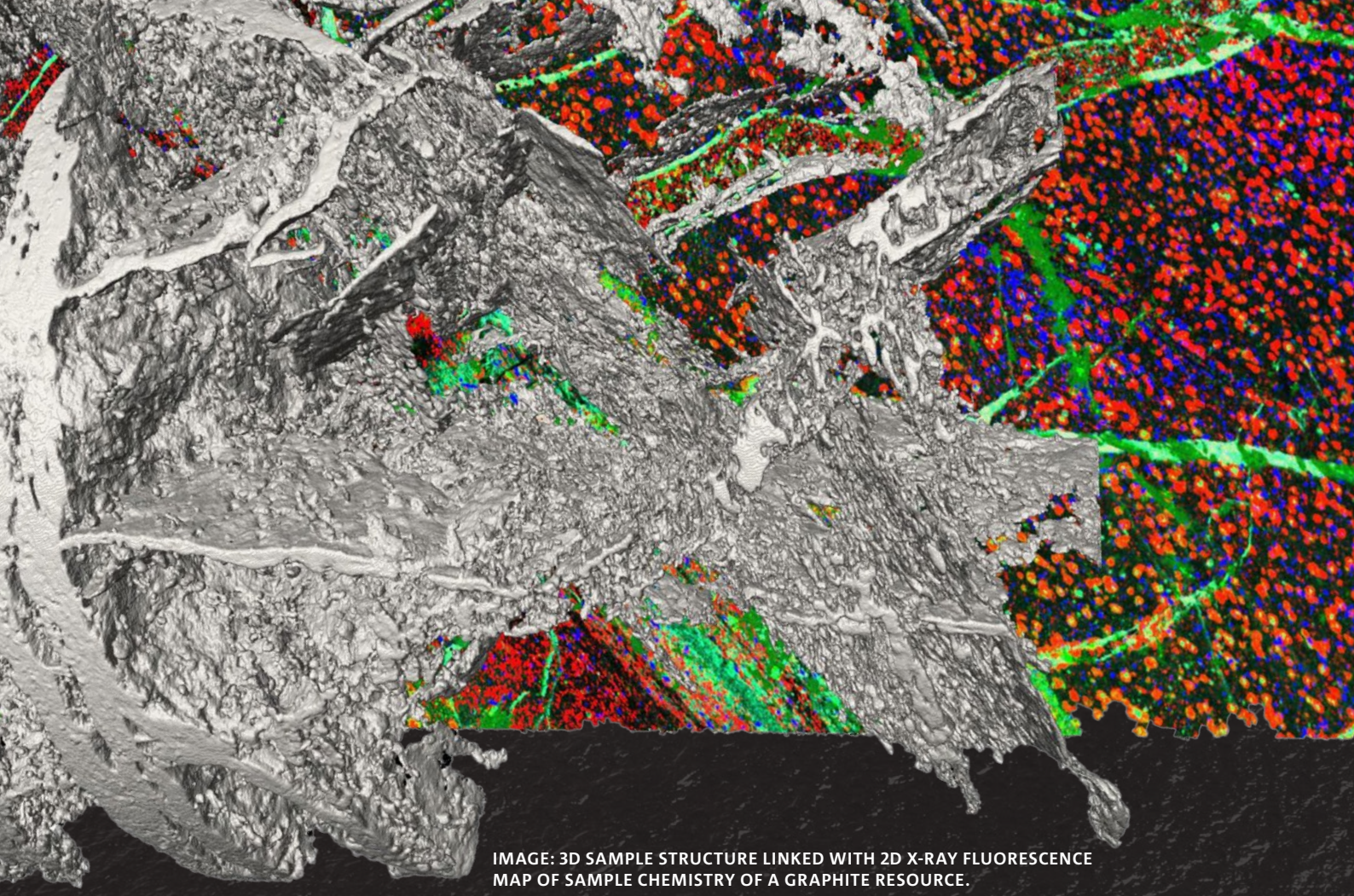


IMAGE: 3D SAMPLE STRUCTURE LINKED WITH 2D X-RAY FLUORESCENCE MAP OF SAMPLE CHEMISTRY OF A GRAPHITE RESOURCE.

"We worked with CSIRO to obtain a greater understanding of our most unique graphite deposit via mineralogical characterisation at a larger scale than provided by our nanotechnology research programs."

Dr Pearce adds that Talga Resources own a large graphite deposit in northern Sweden that contains so much graphite that the rocks actually conduct enough electricity to complete a circuit with a battery and a light bulb.

"Talga was developing a novel processing method using electrolysis and wanted to understand what minerals the rocks contained that could impede or improve it. They were also interested in how the graphite flakes were aligned to enable the extreme conductivity and new processing method to work," Dr Pearce says.

CSIRO analysed the microstructures of four ore samples from the Nunasvaara graphite deposit using a variety of techniques to quantify variations in chemistry, mineralogy and graphite grain size.

Core-scale chemical maps were made using an x-ray fluorescence mapper and areas of interest were selected for more in-depth analysis, based on their microstructures.

"The final stage of the project was to do detailed analysis of the graphite and the other minerals present using scanning electron microscopes to image the rocks at the micro-scale," Dr Pearce says.

"We produced maps of the graphite flakes and other minerals that Talga could then use to understand how the ore was so conductive and how the graphite may break up during processing.

"We also deduced the geological history of these ancient rocks and measurements of carbon isotope ratios showed that the graphite was in the rocks when they were initially laid down as sediments."

Mr Thompson says it was vitally important to be able exfoliate the rock into individual one-atom-thick sheets of graphene, which fetches much higher prices than graphite.

GRAPHENE'S ADVANTAGES ARE THAT IT IS 300 TIMES STRONGER THAN STEEL, ITS ELECTRICAL CURRENT DENSITY IS AT LEAST 10 TIMES HIGHER THAN COPPER AND DUE TO ITS USE IN SUPER BATTERIES, CONDUCTIVE CONCRETE, FLEXIBLE SEMICONDUCTORS AND WATER FILTRATION, IT HAS THE POTENTIAL TO BE A KEY PLAYER IN THE DEVELOPMENT AND CHANGE OF MULTIPLE INDUSTRIES.

"It's very expensive and hard to make graphene," Mr Thompson says. "Working with CSIRO helped us to optimise exploration for the right style of deposit while also maximising graphene production capability."

Both projects with Talga and Kibaran were supported by the Australian Government's Innovation Connections program for small- to medium-sized businesses.

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FEATURE

MATTERS OF SCALE

Australia's pre-eminent analytical facility for mineral resources is expanding with a new suite of technologies that will enable the world-first ability to characterise ore samples from kilometre to atomic scales. The benefit will be increased knowledge on rock systems and new data workflows for industry. **ADAM COURTENAY reports**

So much of geoscience is about concentrating on a "global" all-encompassing picture. There are stories about breakthroughs in airborne electromagnetics, the coordination of large-scale state geoscientific maps and new stratigraphic drilling methods that improve our ability to look deeper into the architecture of the Earth.

Over the past few years Australian geoscience has been able to delve deeper into the world of nano- and micro-characterisation (or analysis) of mineral ore, as the technology around it has advanced. This analytical data provides insight into the chemical composition of orebodies and how it relates to the geological structure, texture and mineralogy of the rock.

It is an area with the potential to disrupt some previously held truths on geological formations, while benefiting industry with more informed decision making on whether to mine or not, as well as information that can make recovery and processing more efficient and productive.

At the very cutting edge of this science is the Australian Resource Characterisation Facility (ARCF), the infrastructure component of the National Resource Sciences Precinct headquartered in Perth, Western Australia. It has been funded by the Science and Industry Endowment Fund (SIEF) to the tune of $12.4 million over five years. The total project investment including partner contributions is $38 million.

Supported by its three founding partners CSIRO, Curtin University and the University of Western Australia (UWA), the ARCF acquired three advanced characterisation technologies, each separately managed and run by the partner institutes. In their own respective ways, each piece forms a key part of the workflow to analyse drill cores, rock and mineral specimens and was selected to address gaps in the sample scales used for data analysis. With this new offering, scientists can map samples from lengths of metres down to the atomic scale with unprecedented precision.

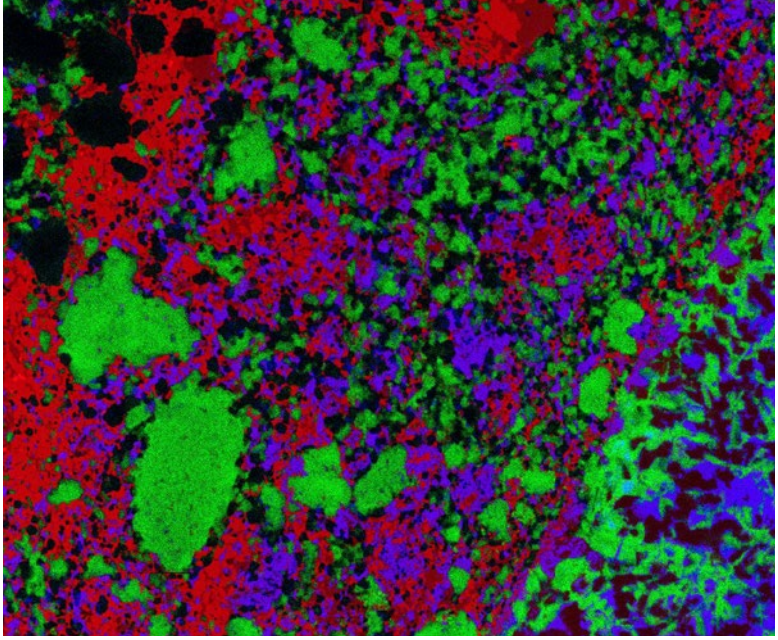
Analysing samples at the largest scale is the CSIRO-developed Maia Mapper. With the world-first prototype now up and running, it can produce a detailed picture of a drill core of up to half a metre, looking at the sample's texture and chemical composition using an intense, focused x-ray beam.

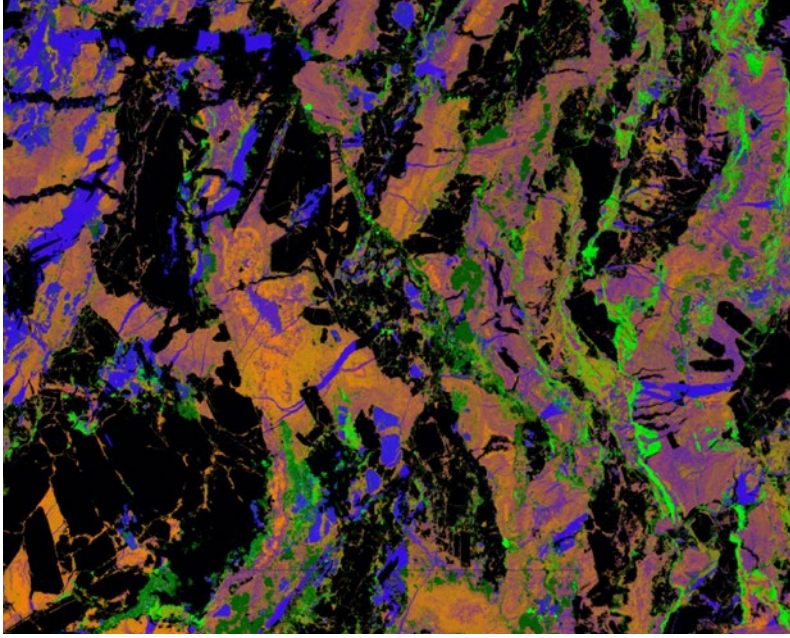
A thousand times further down the scale, is the University of Western Australia's NanoSIMS (secondary ion mass spectrometer) for sub-micron scale imaging. It works by projecting a highly intense ion beam onto a sample less than the thickness of a human hair, releasing secondary ions that are carried into a mass spectrometer. A magnetic field is then able to sort the ions by their atomic mass to create a chemical profile of the sample.

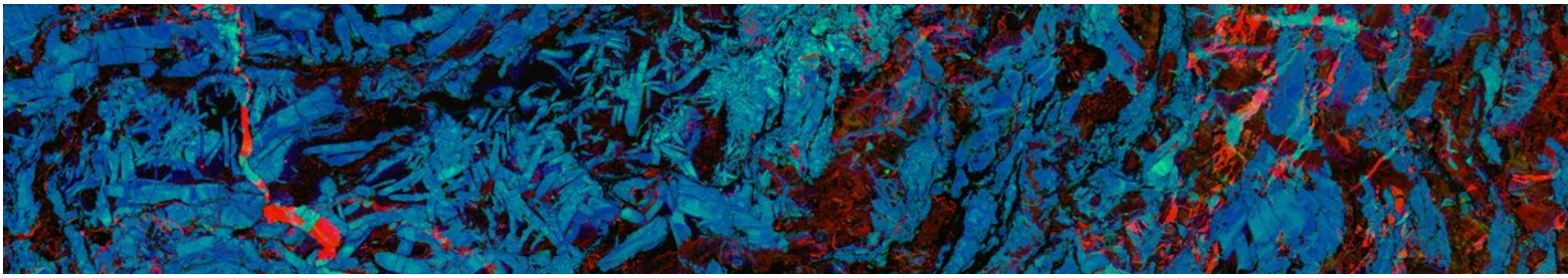
Zooming in another thousand times smaller is Curtin University's Geoscience Atom Probe, the first in the world to be focused on geoscience applications. This technology uses high electric fields and rapid laser bursts to "evaporate" individual atoms from a tiny sample of rock. The time it takes for a particular atom to move from specimen to position-sensitive detector, indicates the type of atom present – and the order they hit the detector – allows an accurate 3D geochemical model of atom positions to be constructed.

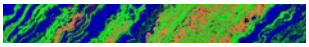
The three partner organisations take a collaborative approach to sharing the equipment and building greater intelligence.

"Everything is available to everyone," Dr Louise Fisher, CSIRO's head of mineral characterisation research, says.









"Researchers at each institution can request access to the instruments at any time. We meet quarterly to discuss issues and results which are important to all of us. We want students to be able to come in and be part of the entire process."

In a bid to be at the forefront of mineral characterisation and to fully understand the context of the samples, the ARCF is undergoing a further technological expansion to create a new drill core laboratory.

The expansion so far has seen CSIRO sign a research agreement with Swedish company Minalyse, to bring its line scanning x-ray fluorescence scanner into the picture, providing geologists with real-time measurements of element concentrations in drill core. The Minalyse XRF line scanning system allows data to be collected down the middle of the entire core sample, offering the chemistry of the core in increments.

The Hylogger infrared technology, initially developed by CSIRO and now licensed to mineral services company Corescan, is another key piece of equipment to form the new laboratory. It provides an objective, semi-quantified means of identifying minerals using infrared spectroscopy.

Corescan managing director, Neil Goodey, says the latest version of HyLogger is now able to detect a much wider range of wavelengths. It can now detect "more species" of minerals, such as quartz and feldspar.

"What we often see are changes in the chemistry of rocks that would be impossible for geologists to see with the core sample in hand," Mr Goodey says.

"Suddenly we will see mineral changes that are a proxy for giving you a distance to the hot part of the deposit. It will tell us whether the actual deposits are under pressure and their formation temperature. We can often get to the guts of an event."

Dr Fisher says the technology will provide "greater context" about what samples are selected for more detailed analysis by the ARCF – creating a more complete workflow for data collection and representative sampling at different scales.

IMAGES: THREE ELEMENT RGB (RED, GREEN, BLUE) COMPOSITE CHEMICAL MAPS OF DRILL CORE SAMPLES COLLECTED ON THE ARCF MAIA MAPPER PROTOTYPE. EACH ORIGINAL SAMPLE WAS BETWEEN 235-240 MILLIMETRES (MM) LENGTH, BOTTOM BLUE IMAGE SHOWS FULL 236MM OF CORE SAMPLE TO SCALE.

"The end goal is having a full geological understanding of rock systems. We want to increase the base knowledge for industry and provide workflows which they can adopt.

Dr Louise Fisher

The work is challenging and Dr Fisher says that getting an elemental and contextual understanding of rock formation at a smaller scale often changes the assumptions made about how rocks are formed or what processes have occurred. If the ARCF can support more informed interpretation of regional geochemical datasets, companies will be enticed.

"It will help to weigh the relative importance of exploration targets and will also add a lot of value for those processing refractory ores," Dr Fisher says.

This message is echoed by Matt Kilburn UWA Associate Professor of the ion probe facility. What you see in the rock in hand isn't necessarily the case when you get to the micro-scale, he says.

"Even the most skilled geologists can only see so much. You might identify that you have gold in a sample, but you might not be sure what mineral it's in or what it's associated with," A/Prof Kilburn says.

The university's ARCF-funded NanoSIMS is proving to be one of the best available means to detect lithium, which is essential to the growing battery industry. The instrument can see what mineral the lithium is locked up in and what other elements are present.

Curtin University's atom probe is the final piece in the ARCF collaboration. Facility manager, Dr David Saxey, agrees that even at the atomic scale, larger "macro" puzzles can be solved. The atom probe's analysis of gold ores in West Africa has influenced the understanding of the formation of the ores and how best to process them.

Science leader for the geoscience atom probe, Professor Steve Reddy, emphasises the versatility of the technology in geoscience.

"As well as looking at ore deposits, we've been able to look at the composition of refractory metal nuggets in meteorites," Prof Reddy says.

"These are only a few 10s of nanometres in diameter and the atom probe data show that they must have rapidly migrated around the protoplanetary disk before they were trapped in the meteorite. Such results have major implications for the formation and migration of the first materials in the early solar system."

Greater resolution will lead to old assumptions being questioned and new opportunities to use natural variability to advantage.

"You may have cutting edge instruments but you still have to sell the concept to various communities," A/Prof Kilburn says.

Prof Reddy realises that potentially interested third parties need proof of value before they jump on the bandwagon.

"First we have to develop a track record and publish some high quality science that highlights the potential applications of these techniques.

"Our role is to develop the scientific potential and then convince industry that such analyses are a worthwhile investment," Prof Reddy says.

They are already taking on clients from both the research and industry sectors, and agree that as the science improves and the mining and extraction industries comes to accept the processes, samples could easily move through all three technologies from the large-scale Maia mapping, down to the atomic probe.

Dr Fisher believes it will be intrinsic to solving some of the bigger geoscience problems, including the study of fluid-rock reactions and the geological processes which are driving metal deposition.

"The end goal is having a full geological understanding of rock systems. We want to increase the base knowledge for industry and provide workflows which they can adopt," Dr Fisher says.

In the interim, Dr Fisher says the ARCF has to build an infrastructure that will get maximum value from data collection that can then be fed back into "a bigger picture".

"We already have individual projects where we have demonstrated that multi-scale approach and have been able to wrap data analytics and machine learning around it. Demonstrating that kind of capability and applying it to industry requirements is what will drive uptake," she says.

Dr Fisher wants to see a migration of drill core logging and subsequent sample selection go from being a largely subjective skill, once determined by the keenness of a geologist's eyes, to following more objective workflows, ruled by more scientific processes and underpinned by robust data analysis.

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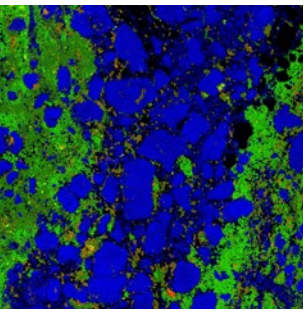
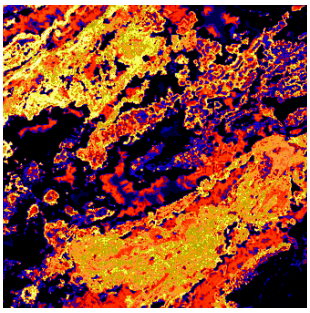
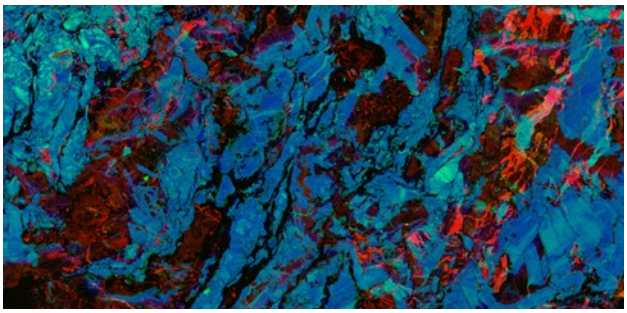
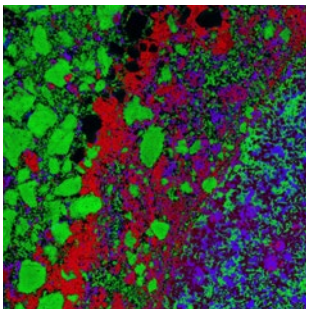

RESEARCH PERSPECTIVE

A COMPLETE PICTURE

Head of CSIRO's mineral characterisation research, DR LOUISE FISHER, explains why analysing data at every scale is essential to inform better decision making across the mining value chain.

DR LOUISE FISHER

It's hard to make the most of an economic resource when you only know part of the picture.

For instance, you might be making decisions without knowing the answer to critical questions on mineral relationships, such as whether or not the gold is refractory, what minerals host key elements and what mineral phases will impact on processing steps.

Now, advances in mineral analysis and characterisation technology are deepening our knowledge and understanding so that it's possible to paint a more complete picture of a resource to feed into decision making across the value chain.

We can process big datasets – with a wealth of information – faster and more cost-effectively than ever before. It means that the chemical makeup or characteristics of a resource can now be analysed and understood at a fundamental, even atomic, level.

Only with data from every sample scale (from kilometre to atomic), can we fully understand the true value of a resource and how it will behave during processing to maximise extraction and recovery.

We know that because when we review large-scale data – such as regional geochemistry – with understanding from micro-scale data, we often find that the "bigger picture" model doesn't hold up. This calls for a reinterpretation of large-scale datasets.

Micro-characterisation is also valuable for validating an exploration tool or confirming process understanding for increasing confidence in the application of a method.

Bias can be introduced in sampling and data collection in a multitude of ways. For example, drill core logging on an exploration camp or minesite may be undertaken by numerous geologists over time, each of whom may have slightly different interpretations of the logging codes.

Using a data driven approach to create objective logging methods improves correlation and supports more informed sub-sampling. Objectively analysing characterisation data at every scale underpins the collection of representative samples.

Machine learning provides a tool for integration of micro-scale data back into the larger models. Such approaches allow micro-scale data to be used to support the prediction of chemistry or other ore characteristics from bulk datasets, allowing for earlier and more informed decision making. For example, in helping to determine the optimal process pathway to take to maximise recovery and increase productivity.

With the development of a new drill core laboratory, as part of CSIRO's Advanced Resource Characterisation Facility expansion, we envisage creating a new workflow where data is collected on whole drill cores, and the subsequent categorising (or domaining) of that data, drives an informed and representative approach to progressive sub-sampling. This creates a framework for integrating the data from micro-scale analysis back into mine models.

In the same way that geochemical data has become routine in minesite data collection; the use of micro-characterisation data is poised to become standard practice and fundamental to decision making at any mine operation. As a result, value will be created for industry at every stage – from exploration to processing.

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INDUSTRY PERSPECTIVE

DATA MINING

DR ESMÉ RYAN

Principal advisor in mineralogy at Rio Tinto, DR ESMÉ RYAN, shares her perspective on the importance of mineral characterisation data and the value it can deliver – from informing investments and development decisions to improving productivity for resource companies.

Interview by KEIRISSA LAWSON

Exploration, mining and processing companies require reliable data about the character and composition of mineral resources. What value do you think mineral characterisation delivers for these operations?

The value of mineral characterisation for the resources industry is undeniable, particularly when it is linked directly to metallurgical data (geometallurgy). It translates the traditional definition of mining blocks from grade and tonnes to value, such as the expected mineral recovery against operating costs.

A value-based mine model allows optimal mine scheduling to maximise profit as early as possible, optimises extraction efficiency and pro-actively manages problematic ore types in the processing plant.

Different processes require data that are fit for purpose with appropriate confidence levels. Sometimes this means that data with a high degree of analytical accuracy and precision is very important, such as indicator-mineral chemistry for exploration. Other times we need technologies that provide fast throughput and high volumes of data at an analytical accuracy that only need to provide reliable "estimates".

How does quality characterisation contribute to the bottom line for resource companies at various stages of the value chain?

The earlier the data are available the more value it adds.

In the exploration phase, if quality indicator-mineral data – which is relatively cheap to collect – can confidently suggest that a target is substandard, companies can walk away before spending millions on drilling, or billions on plant and infrastructure building for a project that doesn't deliver value.

> **The value of mineral characterisation for the resources industry is undeniable, particularly when it is linked directly to metallurgical data.**

In the development phase, quality orebody knowledge acquired before and during flowsheet design will inform the most appropriate processing options and highlight costly fatal flaws in design.

Once the plant is operational, mineral characterisation plays a more reactive role and the value becomes more incremental.

Think of it as the length of a spanner. The longer the handle the more torque you can apply to the bolt. The earlier mineral characterisation is done the bigger the monetary return.

Mineral characterisation covers a range of different techniques and technologies that provide an array of data and information. In the era of big data, what role does the expert play in translating this information into valuable, profitable decisions?

Experts play a crucial role in translating the data for decision-makers and need to take accountability for that translation process. The mineral characterisation expert is one step further removed from the decision-related pressure faced by the resource geologist, the mining engineer or processing plant superintendent. They are the ones that have more time and space to step outside the boundaries of pure mineral characterisation and understand the issue and how the data inform the issue.

For example, handing over a report to a flotation plant manager with a comment like "*yesterday you lost 10 per cent recoverable copper and it looks like it was most likely a problem in the grinding circuit*" is a lot more useful than "*here are your chalcopyrite liberation plots from yesterday*".

The resources sector invests significantly in innovation to increase productivity and ensure the industry is sustainable. Do you think innovation in mineral characterisation and analysis will help achieve these objectives?

Yes definitely, provided the data are available early enough. From a characterisation perspective, the more proactively (rather than reactively) you respond to an ore-related issue, the greater the productivity gains will be.

What technologies are exciting you most in the world of mineral characterisation?

Real-time online technologies with fast integration with other data from multiple sources and informative visualisation capability that allow a timely and confident response.

Do Australian suppliers of characterisation services adequately respond to the needs of the industry?

Some do, some don't. The most useful collaboration with suppliers of characterisation services is when there is a fundamental understanding of, and focus on, the ultimate business value and/or commercial pain points. This seems obvious but in my experience has not always been the case. Commercial focus and fundamental research are not mutually exclusive.

What are some future challenges for mineral characterisation?

Characterisation technologies are developing faster than we can solve the challenge of sample representivity.

How do we translate the interesting data we have for a teaspoon worth of dirt from a particular ore type, in to useful information for the truckloads of variably mixed ore we will mine?

This brings us back to big data again. The only solution I see to this issue is the integration and interpretation of multiple data sources at different scales in a multi-disciplinary collaborative environment. From the scale of the remote sensing fly-over right down to the forensic mineralogist sitting behind the scanning electron microscope.

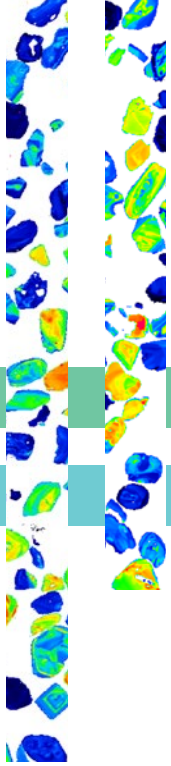
What would be the growth opportunities for characterisation to support Australia's resource sector?

Data fusion and data analytics technologies that allow an informed and timely response to ore properties and ore variability.

Lip service is often paid to the value of mineral characterisation in the resources sector, but in my opinion it is still not being used to full potential. This is because making a change in response to new information to an established model or process can be viewed as too daunting or too risky, no matter how convincing the data in that report on your desk.

RESEARCH NEWS

X-RAY VISION



World-leading soft x-ray mineral characterisation developments are providing information for more profitable processing decision making.

DAVID SIMPSON reports

The demand for high quality commodities is placing pressure on companies to optimise their processes to compete globally.

Iluka Resources, for example, mine heavy mineral sands, processing them in Western Australia to produce zircon, rutile and ilmenite.

Synthetic rutile, or titanium dioxide (TiO2), is used in the manufacture of pigments, ceramics, sunscreens and the production of the metal titanium.

Zircon crystals or "zircons" are used in various forms in applications including ceramics, precision casting, refractories, catalysts, fuel cells, fibre optics, nuclear power generation, water treatment and medical prosthetics.

The commercial value of both synthetic rutile and zircons is directly related to their purity, which in turn, is determined by the processing parameters. The parameters can be optimised by having a detailed understanding of the nature of the feedstock and its transformative states during the process. It's a continuous process that can typically take several days.

CSIRO – through its microbeam laboratory – is working with Iluka to apply micro-characterisation methods to better understand this feedstock. They use an electron microprobe-based technique that uses x-rays to characterise both ilmenite and the processing materials during the various steps through the production of synthetic rutile and zircons.

"By combining the chemical information that CSIRO's x-ray analysis provides us, together with structural information from x-ray diffraction, we can set the parameters of the process to ensure we optimise the quality and hence the value of the minerals we produce," Nick Bernard, Iluka Resource's technical development manager, says.

Iluka has worked with CSIRO for more than 40 years on mineral characterisation and development, as well as processes for upgrading titanium minerals. As a major producer of synthetic rutile, this relationship has been pivotal to Iluka's ability to commercialise new resource discoveries.

CSIRO's characterisation work has contributed to Iluka's development of new upgrading technologies and the production of feedstock for their Metalysis titanium metal process.

The micro-characterisation performed by the CSIRO research team uses a custom electron microprobe. This technology was acquired by a consortium comprising CSIRO, Monash University, RMIT University, Swinburne University and The University of Melbourne, together with a Linkage Infrastructure, Equipment and Facilities (LIEF) grant from the Australian Research Council.

"Collaborating with CSIRO to develop this world-leading capability is simultaneously improving our working relationship with the organisation, our ability to conduct research that nobody else can and build upon the strength of having the Australian Synchrotron, the various Monash University and analytical platforms and CSIRO all in one precinct at Clayton, Melbourne," Dr Andy Tomkins, Monash University, says.

CSIRO research group leader, Colin MacRae, says that in the past soft x-ray analysis has generally been the province of synchrotrons, which cannot match the spatial resolution of the probe and require long lead times.

"WHAT WE'VE DONE, AND I BELIEVE WE ARE WORLD LEADERS IN DOING SO, IS MODIFIED THE HARDWARE AND SOFTWARE OF AN ELECTRON MICROSCOPE AND ASSOCIATED EQUIPMENT TO ENABLE IT TO PERFORM A WIDER RANGE OF FUNCTIONS.

By incorporating detectors sensitive to soft x-rays, Mr MacRae's team is able to improve the spatial resolution of their data analyses or maps, enabling features smaller than 100 nanometres to be analysed.

"The soft x-rays carry with them both chemical and structural information and we are developing new analysis strategies to utilise this new information," Mr MacRae says.

"Our characterisation technique takes a small sample – only milligrams to grams of material – we then mount it and polish it to an optical flat. The surface is then examined using the electron microprobe."

The microprobe is a medium to high vacuum instrument that produces a highly focused beam of electrons.

When these electrons impact the specimen they can produce x-rays, light and electrons. All are collected in parallel with the light and x-rays, primarily being used to characterise the sample both through mapping and point analysis.

Mr MacRae's team are continuing to develop the technology to enable high resolution micro-characterisation and mapping in the electron microprobe to provide better solutions to production and analytical problems in the mineral industry.

Mr MacRae also predicted an increasing wide range of applications for the consortium's world-leading technology.

"We're already looking at using it to investigate gold deportment in sulphide deposits and we anticipate many more mineral applications as we continue to develop and refine the capability and identify our markets.

"Soft x-ray analysis is applicable to materials as well as minerals, and there's exciting potential in intermetallics and materials like aluminium lithium aerospace alloys," Mr MacRae says.

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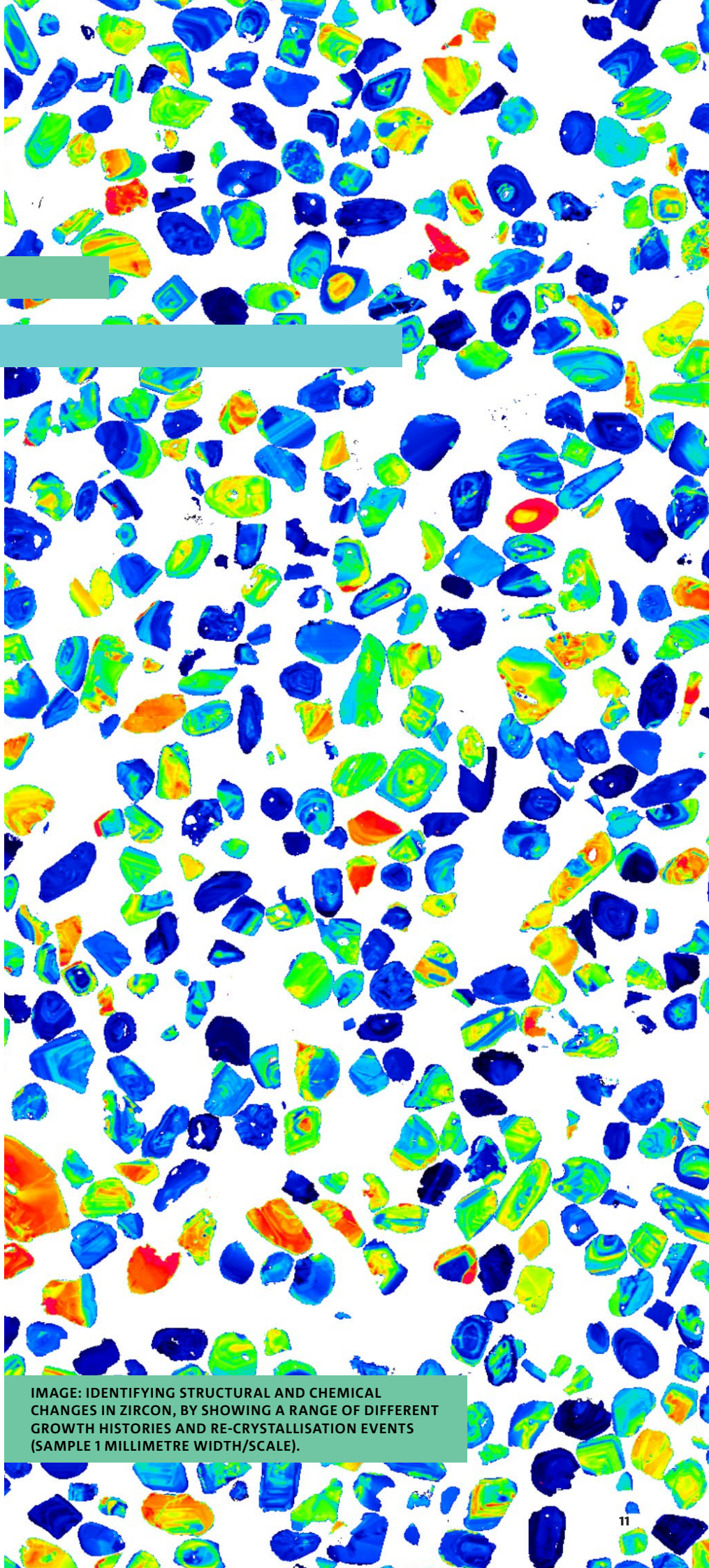
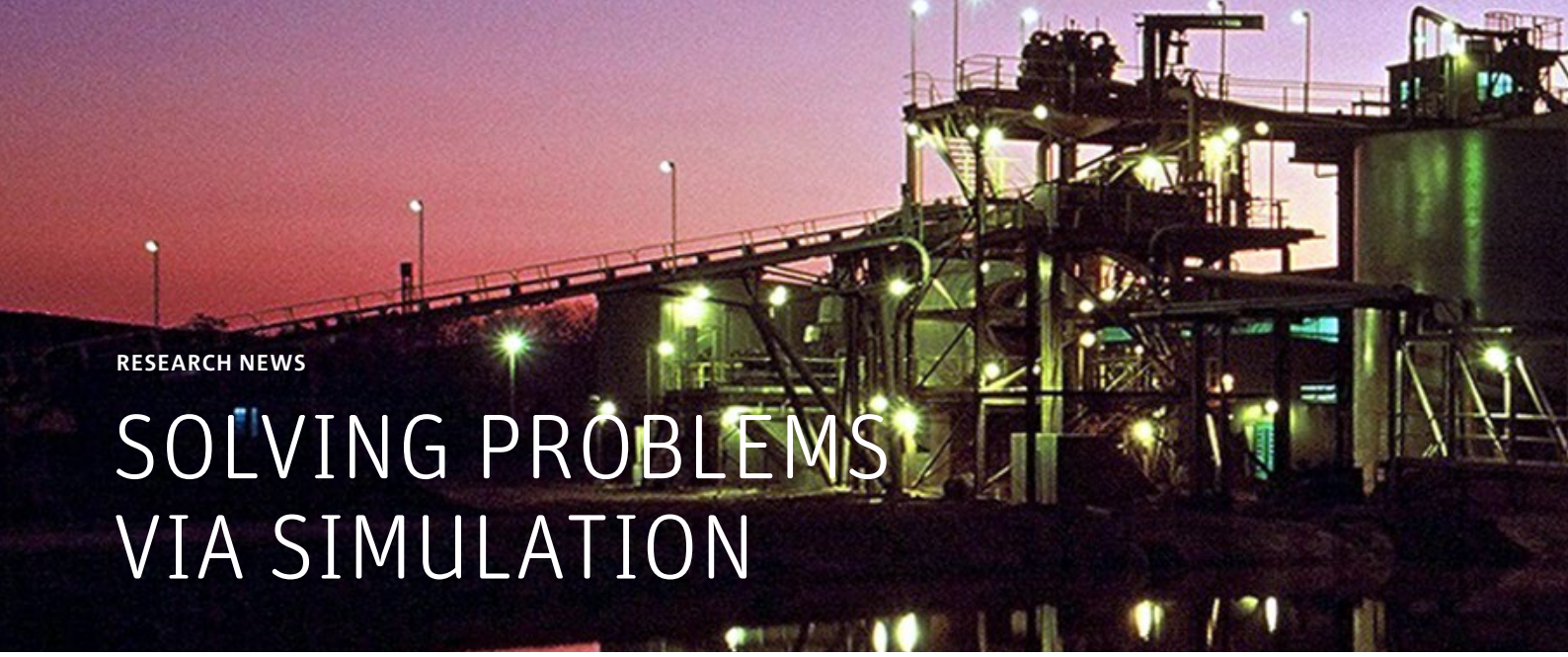


IMAGE: IDENTIFYING STRUCTURAL AND CHEMICAL CHANGES IN ZIRCON, BY SHOWING A RANGE OF DIFFERENT GROWTH HISTORIES AND RE-CRYSTALLISATION EVENTS (SAMPLE 1 MILLIMETRE WIDTH/SCALE).



RESEARCH NEWS

SOLVING PROBLEMS VIA SIMULATION

The ability to simulate mineral processes and the industrial conditions they operate under such as heat, gas and pressure, is providing an accurate insight into how material behaves during processing and the impact on the end product. **EMILY LEHMANN reports**

As ore quality declines around the world, it's more important than ever before for mining companies to be able to optimise their processes for greater efficiency and productivity.

Understanding the properties of complex ores and how they behave during mineral or metal processing at a fundamental level is essential for accurately assessing the viability and impact of making any process modification.

CSIRO team leader, Dr Nathan Webster, says the ability to "see" into a dynamic process and understand how it works takes niche expertise and can't be accurately achieved in traditional post-mortem style analyses.

"Our ability to truly understand an industrial process is hampered when a product sample is taken from the operation into the laboratory for analysis," says Dr Webster.

"Whether it's a hydro- or pyro-metallurgical process, an electrochemical process or a materials synthesis reaction – when a sample is removed from operating conditions its characteristics will naturally change due to different environmental conditions.

"For example, mineral phases (mineral species) that are stable at high temperature, and under highly reducing conditions, may react during cooling or when exposed to air."

CSIRO has the unique ability to simulate the industrial process using x-ray technology, overcoming the limitations of traditional lab-based analyses, ensuring accurate results. They are able to recreate process conditions such as extremes of temperature, pressure and gas atmosphere.

Dr Webster's team worked recently to drive process efficiencies in the electrowinning process.

"Replacing the industry standard lead-based alloy used in copper electrowinning with an alternative material could lower energy and material consumption, as well as reduce downtime and maintenance costs," Dr Webster says.

"It's important to understand what the impacts different lead alloys would have on the process. We did this by simulating the process with our x-ray diffraction techniques.

"We carried out both electrochemical and diffraction measurements simultaneously on each of the alloys, assessing not only their electrochemical performance but their characteristics that could affect the end product's mechanical integrity.

In another example, a top-tier mining company sought to get a better understanding of the effect of particular gangue minerals on iron ore sintering operations.

"We simulated the iron ore sintering process and tracked the mineral phase evolution throughout the process, revealing the mineralogical changes as a function of temperature and time for each ore type," Dr Webster says.

"We were able to improve the company's understanding of the influence of the various gangue minerals on the final product, and the desirable ore properties for processing."

CSIRO has a range of advanced diffraction-based characterisation technologies in their toolkit, including some of the most advanced equipment in Australia.

Dr Webster likened the team's approach to a "high-throughput" one.

"We acquire a large amount of information in only a few hours. This would have taken days or weeks using traditional laboratory analysis methods.

"By rapidly handling large amounts of data, our customers get more insight in a quicker timeframe, which helps them to save costs."

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INDUSTRY ENGAGEMENT

FINDING THE RIGHT PATHWAY

An investigation into processing options for a complex, low grade uranium deposit has resulted in an unexpected new pathway for an Australian miner turned technology supply business. **LOUIS WHITE reports**

Mining complex or low grade ore often doesn't make economic sense using traditional processes.

The challenge of determining how to improve a process or develop an entirely new one to make a resource viable, often requires two or more parties coming together.

Marenica Energy Limited (Marenica) approached CSIRO to better understand their calcrete-hosted carnotite deposit and investigate the best processing options.

"CSIRO applied their minds and equipment to understand the Marenica ore and establish solutions to specific mineral separations," Murray Hill, Marenica chief executive officer, says.

"I was not aware of the work that CSIRO did and the benefit they could bring to small companies like Marenica, and for that matter, the wider mining industry."

CSIRO's micro-characterisation team leader, Dr Peter Austin, says they have been working together since early 2012.

"The initial enquiry was for the characterisation of some ore samples, but it soon became apparent that the project would hinge on the combination of mineral characterisation and mineral processing expertise," Dr Austin says.

The Marenica orebody is extremely large, but relatively low grade. The cost of conventional processing would exceed the value of the ore based on the uranium prices of the day.

Marenica needed a low cost process to upgrade their ore to reduce capital and operating costs.

"Our mineral characterisation work identified key properties of the ore that we used to develop a new process," Dr Austin says.

"This process generates a significant upgrade of the uranium bearing mineral carnotite and removes other minerals that would otherwise create processing problems."

CSIRO then analysed the various steps utilising QEMSCAN and x-ray diffraction technologies to better understand how the ore behaved during processing. Marenica was able to use the mineralogical analysis to determine the most appropriate beneficiation techniques and optimise the process.

"When things didn't go as expected, they were also able to analyse the processed materials to understand the issues and make the required changes. This is not always the case with resource development," Dr Austin says.

As a result of the engagement with CSIRO, Marenica has developed its aptly named *U-pgrade* process. This process is the subject of several patent applications and Marenica are marketing the process as a solution for other uranium miners around the world. They are now a resource developer and a technology supply company.

"*U-pgrade* is a beneficiation process for upgrading secondary uranium ore by up to 50 times, halving capital and operating costs when compared to conventional processing," Mr Hill says.

"The process is applicable to secondary uranium ores that are located in semi-arid to arid environments around the world."

A pilot plant is now needed to further demonstrate the *U-pgrade* process. CSIRO's Waterford site in Perth has a process bay facility that is licensed for a substantial quantity of unsealed radioactive sources, suitable and purpose built for radioactive pilot plants.

"We are in the process of commissioning that facility as a registered radioisotope laboratory," Dr Austin says.

"By piloting the process, Marenica will be able to demonstrate its efficiency on a larger scale.

"If processing problems do occur, we have the tools to rapidly analyse samples and identify the root cause of the problems and assist Marenica to adjust the process to deal with them." ●

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RESEARCH NEWS

SEEING ON THE INSIDE

Pioneering work to 3D image the inside of rocks will transform the mining industry by removing the guesswork from mineral exploration and processing.

JOHN MILLER reports

Almost as good as rocks having the ability to talk and tell us whether or not they host valuable minerals, could be x-ray-like vision to see what's inside.

A 3D imaging project, known as "digital rock", led by CSIRO senior research scientist, Belinda Godel, aims to do just that and is gaining the attention of mining companies and universities in Australia and abroad.

Dr Godel says digital rock technology has been used in oil and gas for 20 years, but its use in minerals is limited due mostly to the variability and complexity of the mineral systems involved, with each commodity presenting unique challenges.

Dr Godel's team is developing a world-leading methodology that uses high-resolution x-ray computed tomography (MicroCT) combined with image analysis to create a 3D image from the inside of rocks and compute characteristics without the need for extensive sample preparation or slicing of the rock.

MicroCT works similarly to medical CT (Cat) scans, but more powerful x-rays are used to better penetrate complex and dense materials containing valuable resources. For the past five years, CSIRO has been developing its application for the minerals industry across the value chain.

"The MicroCT technology forms an important component of the work, but the strength in the CSIRO methodology relies on its integration with other technologies to provide an accurate 3D characterisation," Dr Godel says.

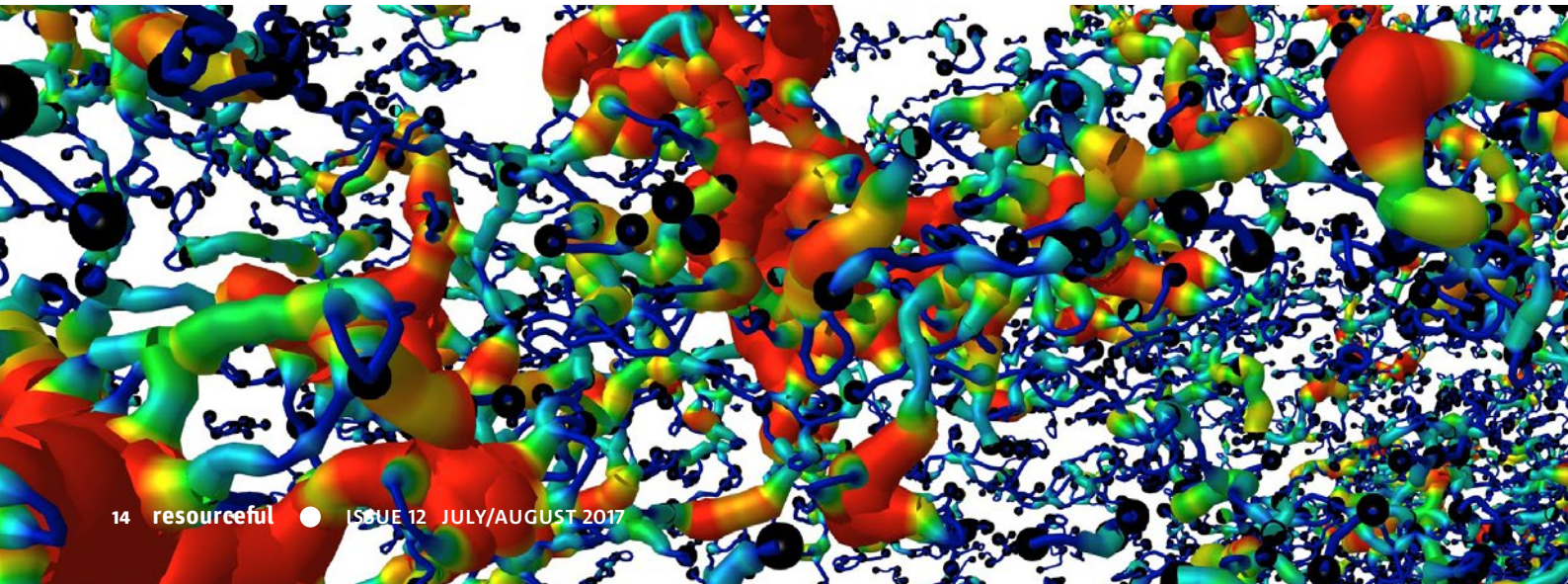
These technologies include optical microscopy, scanning electron microscopy, x-ray fluorescence mapping, laser-ablation inductively couple mass spectrometry (LA-ICP-MS) and electron back-scattered diffraction analysis.

"With many variables, one of the challenges is setting up the instruments to obtain the required data and another is processing the data so that the numerical results provided can be used by customers to address their problems. Our development philosophy is whatever the parameters required; we will find a way to calculate them," Dr Godel says.

Traditionally, mineral characterisation has been two-dimensional – the geologist would gather the sample, slice it, put it under the microscope or another technique to observe it in 2D and sometimes quantify it.

"MicroCT introduces the third dimension, eliminating the assumptions made looking at 2D by producing "real" statistics. It provides the entire picture – such as shape, size, real association of minerals or pores and their degree of connectivity," Dr Godel says.

IMAGE: 3D MINERAL PHASES AND POROSITY DISTRIBUTION IN NATURAL IRON ORE (1 MICROMETRE RESOLUTION).



> **We can understand what products are doing in processing and get a feel for what a product's value is to the consumer.**
>
> **Dr Keith Vining**

3D data of mineral relationships is a significant improvement over traditional 2D microscopic analysis.

CSIRO's digital rocks program initially focused on nickel and platinum group metals.

"With platinum group metals the technology was developed to determine where the platinum was in the rocks, how much was there, how small it was, was it associated with particular mineral sulphide, silicate minerals, or chromium oxide. The results had implications for ore genesis but also for mineral processing.

"Then, we looked at using MicroCT to infer physical processes leading to the formation of nickel sulphide deposits looking at sulphide distribution, size and morphology, and their degree of connectivity in the rock.

"Knowing the sulphide characteristics, we then analysed the palladium content using LA-ICP-MS and merged all datasets to help us understand how the deposit formed. This methodology can potentially be used to target high grade ores.

"We have since applied the concept to other commodities such as graphite, copper and gold, and owing to iron ore industry interest, are now focusing mainly on this area. We are looking at a range of iron ore products across a range of scales – full exploration cores, lumps, fines, pellets or sinters."

CSIRO research group leader, Keith Vining, says that for the first time porosity can be measured with some degree of accuracy, with benefits for iron ore processing and metal production.

"Understanding porosity is important for predicting downstream processing behaviour – from crushing and handling to blast furnace performance, and the strength and reactivity of agglomerates put into the furnace," Dr Vining says.

"Previously we could only look at things in 2D. Essentially, you had to cut the rock or sinter and try to measure porosity looking at one face, which is time-consuming and doesn't provide an accurate picture. Now we can identify the open pores from the closed pores, which is important to iron ore's behaviour in the iron making process.

"We can understand what products are doing in processing and get a feel for what a product's value is to the consumer.

"For iron ore we are trying to understand how quickly is it melting; which parts aren't melting; which parts are remaining stable; how quickly is the pore structure developing; and how it is behaving in the blast furnace."

Dr Godel says the mining industry is becoming interested in the work because it has to find new and better ways of doing things to improve productivity, as deposits get harder to find and more complicated to process.

"Our work is trying to put new context into exploration and processing – the 'Holy Grail' would be the ability to use data obtained during exploration to predict how the ore will behave downstream during processing. It is where geology meets data analytics and large-scale simulation.

"The speed of MicroCT processing has improved drastically over the past few years, but the most important aspect is the quality of the data. Even if we can access the fastest computer and the smartest algorithms on Earth, if we feed in poor-quality data, we will most probably end up with a poor prediction."

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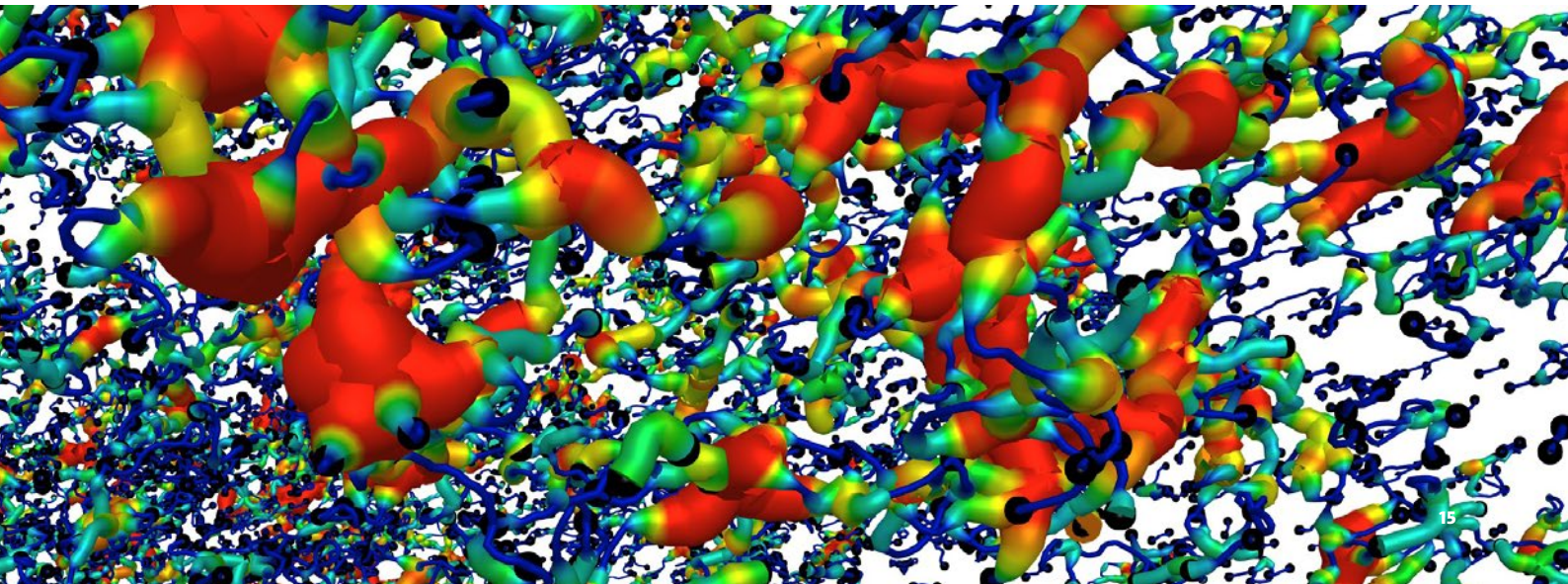

COLLABORATION

EXPLORATION BREAKTHROUGHS

Collaborative research is breaking down barriers to cutting edge analytical technologies and data for junior explorers, while building our fundamental understanding of mineral systems.

TIM TREADGOLD reports

Recent developments in mineral characterisation and analysis technologies have been some of the most significant advances for decades in exploration – opening up entirely new approaches and a wealth of valuable new data.

An example of such innovation is the ability to rapidly analyse mineralogy and texture of rock chips generated from low cost work such as rotary air blast (RAB) drilling.

Rock chips do not necessarily contain the mineral being sought by an explorer, but can contain indicator minerals associated with the formation of mineral systems. These help narrow down the area to be searched.

The TESCAN integrated mineral analyser (TIMA) has this ability – it analyses rock chips, and then stores the data, to form the basis of an increasingly valuable "library" to help identify potential mineralised systems.

Importantly, the information extracted from minerals in the chip samples can assist in significantly expanding the footprint of a potential system. It can also reveal the timing of a geological event, which helps with understanding geological structures by integrating the data with geochemical and geophysical information.

CSIRO, through its Advanced Resource Characterisation Facility, plays a critical role in providing the industry with access and expertise to use TIMA and other cutting edge technologies.

Fortunately for small- to medium-sized companies – who make a significant proportion of Australia's exploration industry – access is also made much easier and affordable through federal government programs.

Initiatives like Innovation Connections support collaboration between industry and research organisations, by providing funding and access to technology, as well as the geoscience experts who can provide enormous value to the data analysis.

Australian company, Sipa Resources, recently engaged CSIRO through this program to apply the latest mineral analysis technologies, including TIMA. The company found the work to be particularly useful in narrowing down its search for copper and other minerals in the remote Paterson region of north-west Western Australia. Paterson is home of the giant Telfer goldmine and a number of other substantial deposits of gold, copper and tungsten.

Sipa chief executive, Lynda Burnett, says thanks to the collaboration, the team was able to collect a vast amount of data that an exploration company would not normally acquire because of the cost.

"The analyses gave us quantitative petrology (the composition, texture and structure of rocks) from all our fresh rock drill chip samples. It tells us exactly what minerals are there, and what percentage in every sample," Ms Burnett says.

"As you interpret the data you build a strong picture of the regional geology and the paragenetic history (the sequence of rock formation and subsequent alteration and deformation). It's a real breakthrough for working under surficial cover.

"In particular, the alteration paragenesis and its spatial zonation is helping us to make decisions about where exploration should focus, whether we're looking at a mineral system capable of hosting a large deposit and what type of mineral system it is."

A core focus of CSIRO's integrated research programs using a range of analytical characterisation capabilities, is to extend the detectable "distal" footprint (mineral signature) for a range of different deposits under cover.

CSIRO group leader in mineral system science, John Miller, says mineral analysis and characterisation also helps to answer basic questions about the type of mineralised system being explored – an early but important question to determine the best exploration techniques.

"By analysing the chips, you can tell what type of system you're in," Dr Miller says.

"That's huge for a mineral explorer, because it answers a question of whether it's something that's worth pursuing. It means an early decision in the exploration process because it can be tuned to different deposit types."

Dr Miller says a lot of analysis had been conducted on core produced from diamond drilling, but the ability to analyse chip samples enables engagement during the first pass stage of drilling favoured by the exploration sector (e.g. air core, RAB or reverse circulation drilling).

"It's those chips which give an explorer a good look at what is underneath surface cover."

THE CSIRO TEAM IS CURRENTLY WORKING WITH NINE OTHER COMPANIES ON MINERAL SYSTEMS ANALYSIS PROJECTS THROUGH GOVERNMENT SUPPORTED INDUSTRY RESEARCH COLLABORATIONS. THESE PROJECTS ENABLE SMALLER COMPANIES TO DOUBLE THE VALUE OF THEIR RESEARCH DOLLARS.

The benefits go both ways, with the CSIRO researchers getting access to real data that helps build their knowledge base on mineral systems around Australia.

CSIRO research scientist, Adam Bath, says the team discovered the importance of more alkaline fluids in the formation of some ore deposits where slightly acidic and near neutral fluids have previously been favoured.

"This has implications for gold deposit formation, because gold nanoparticles are known to be more stable in alkaline fluids and these types of fluids may be more efficient at transporting the gold," Dr Bath says.

In addition to gold, the team is gaining insight into polymetallic, copper and tungsten systems.

"A lot of the work we've done is based on the understanding of mineral systems," Dr Bath says.

"We learn a lot about those systems, we learn about their patterns and we apply that knowledge to greenfield exploration."

Dr Bath says that in the case of using TIMA, the data being generated often comes from rocks that are not actually mineralised.

"Those non-mineralised rocks still show hydrothermal alteration that's part of the broader mineralised system, because the fluids at the heart of the system don't just stay where the metals are deposited, they move into outlying rocks.

"Often when you get further away from a deposit, the alteration assemblage that's related to the mineralisation is very subtle. Having bulk rock mineralogy doesn't always help.

"It's important to see the textures, and say, that's the alteration event because I can see it over-printing another event. You get a timing relationship that you won't see in other datasets."

Peering deeply into the mineralogy and texture of a chip sample is a microscopic version of one of the oldest forms of exploration, looking for indicator minerals in stream samples such as the garnets used as pointers to potential diamond deposits.

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CSIRO blog

THE CONVERSATION

MAGNETIC MYSTERY ON THE NULLARBOR

The Nullarbor in South Australia is a strange, geological marvel. In the 1970s, survey planes detected mysterious magnetic signals emanating from beneath the barren plains.

Stretching across the south-western corner of South Australia, this vast expanse where the Earth's magnetic field is unexpectedly weak became known as the Coompana Anomaly. The Coompana Anomaly has intrigued geologists for decades, sparking speculation on the source of these unique signals.

One explanation for this phenomena may be that the rock was actually formed in the Northern Hemisphere and moved south on its tectonic travels. Another explanation suggests the rock formed at a time when the Earth's magnetic poles were reversed. A third theory suggests its strange crater-like shape could be the result of an ancient meteorite impact. An interesting hypothesis considering this region is a favourite fossicking ground for meteorite hunters searching for more recent falls.

What these magnetic signals do suggest is the existence of a deep body of unusual magnetisation beneath the surface limestone and sand. But why would these rocks emit different magnetic signals from the surroundings?

Remember the iron filings and magnet experiment at school? Well, just like those traces of iron filings lining up along the magnetic field coming from the magnet, iron particles within rocks are similarly affected by the Earth's magnetic field.

When new igneous rock forms and cools, iron particle within the rock lock in the magnetic field present when it was first formed. This magnetic record is called remanent magnetism.

The Coompana Anomaly, one the largest remanent magnetic anomalies in the world, is due to the remanent magnetism of the deep igneous basement rock, which was formed at a different time to the surrounding rock.

Further investigating the phenomenon, the South Australian Geological Survey recently completed a more detailed airborne survey of the area using remote sensing from a magnetometer just 80 metres above ground level on lines only 200 metres apart.

For the full story, visit: blog.csiro.au

DATA VISUALISATION ISN'T JUST FOR COMMUNICATION, IT'S ALSO A RESEARCH TOOL

At the heart of the scientific method lies the ability to make sense from data.

However, this is a challenge in the fast-moving field of biotechnology, where new experimental methods are creating huge amounts of complex data. These data promise to revolutionise healthcare, food and agriculture, but it can be difficult to extract answers to specific research questions from these sets of numbers.

Data visualisation can help. Our eyes deliver information very rapidly to our brains, and then sophisticated pattern recognition abilities take over. Well-designed visualisation tools can reveal discoveries that would otherwise remain buried.

There are three data visualisation tools we have developed to help life scientists find relevant and useful information amongst the noise. The visualisation principles used in these tools are general and help in many complex data challenges.

For the full story, visit: theconversation.com

FIND OUT MORE ABOUT

PROCESS PRODUCTIVITY

READ OUR EXPERT TIPS ON HOW MINERAL AND METAL PRODUCTION COMPANIES CAN IMPROVE THEIR PROCESS PRODUCTIVITY AT: research.csiro.au/resourcesandsustainability

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