srk news

Exploration Geology: Keys to success

Geological foundation

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Exploring under cover – New South Wales, Australia

World-class deposits are becoming increasingly hard to discover, even with exploration expenditures having reached all-time highs in 2012. Industry performance has declined, fewer discoveries are turning into mines and their conversion is taking longer, and over the past decade the average cost of discovery has tripled (Schodde, 2017).

There is also recently a trend towards exploring deeper and under cover. As a result, numerous conferences and courses have focused on techniques for exploring better—including at depth and under cover—which largely incorporate the use of geochemistry and geophysics to see through cover (DMEC-PDAC, 2015).

The reason for their use lies in the fact that modern exploration is predominantly data-driven and focused on the direct detection of mineralisation. In greenfields exploration this may include defining geochemical or geophysical anomalies, whereas brownfields exploration often concentrates on data integration and geophysical testing, especially in sulphide systems. This is technically challenging when exploring at depth or in areas of cover, with overburden sometimes masking or diluting results or generating false-positive anomalies. For example, the Iberian Pyrite Belt in southern Spain is covered by a thick marl sequence that limits the application and depth penetration of airborne electromagnetic techniques to explore for massive sulphides.

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Geological foundation *(continued)*

With the challenges of discovering deposits under cover and at depth, exploration success today depends on developing a strong understanding of a target area's geology, structural architecture, geodynamics, and potential deposit preservation from factual observations, rather than relying solely on data and direct detection. This may include field observations of controlling structures and using fault geometry and kinematics to define the geometry of mineralisation (both in outcrop and drill core) or the geological interpretation of geophysical data based on geological principles. Even when using modern techniques for exploring, such as machine learning, the fundamental foundation remains geological understanding, and companies focusing heavily on this benefit from higher discovery rates.

Sadly, many exploration companies pay little attention to understanding the geology of their deposit or exploration area, which is one of the fundamental reasons for the overall decline in discovery. Instead, these companies often only pursue understanding of the geological controls on metal distribution once things go wrong. The repercussions of this include:

- Drilling more metres than required due to not understanding mineralisation distribution/ore plunge,
- Truncation of an orebody by a fault that was not predicted, and
- Significant changes in resource estimation (tonnage and/or grade) due to not understanding the geological controls on metal distribution.

Every exploration project should focus on understanding the geological controls on grade distribution—whether primary controls, such as structures controlling the formation of vein systems, or secondary/overprinting disruption of a mineral system, for example overprinting by a late stage, barren, low-temperature hydrothermal system. Controls should then be defined, for instance the distribution of auriferous veining related to the movement on a fault system controlling dilation, and directly applied to exploration targeting, reconnaissance mapping, and drill planning.

Taking the time to develop this in-depth understanding will always reduce exploration risk, increase discovery rates, save money, and accelerate projects into production.

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JAMES SIDDORN

Dr James Siddorn, PGeo, Principal Consultant (Structural Geology), has over 20 years of experience in the structural analysis of mineral deposits. He is an expert in deciphering deposit-scale controls on ore plunge in precious and base metal deposits, the structural inputs to geotechnical/hydrogeological studies and mine seismicity and applied 3D geological modelling. James also assists clients with strategy and technical reviews for exploration and mining projects worldwide, and has undertaken projects in Europe; North, South and Central America; Asia; and Africa. He has taught more than 50 Applied Structural Geology courses to over 2000 exploration and mining geologists and engineers.

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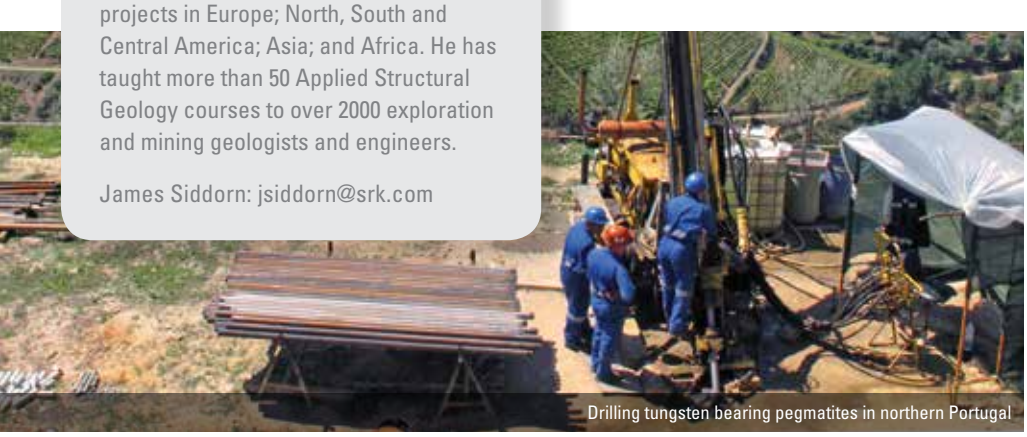

Drilling tungsten bearing pegmatites in northern Portugal

Geochemical exploration has seen major advances, mainly driven by technological breakthroughs as laboratory and field equipment have improved -- but has our ability to interpret the results kept up? I have my doubts.

The biggest advances in the laboratory have been the maturing of ICP linked techniques for optical emission and mass spectrometry. This produced significantly lowered detection limits and simultaneous accurate multi-element analyses. Advances in x-ray fluorescence (XRF) spectrometry took place mainly in developing greatly improved algorithms for matrix corrections.

The biggest advances in field equipment came about through continuing improvements in the portable XRF, Infra-red and near Infra-red spectrometry, and x-ray diffraction tools. Although the latter method is used for mineral identification, it is ideal in detecting the alteration envelopes surrounding some mineral deposits. The biggest challenge with these tools lies with the advertisers that depict them as a revolver in the hands of today's cowboy. However, if used responsibly, where the analyses are based on representative, appropriately prepared samples, such instruments can dramatically reduce turn-around time on sample analyses, rapid redirection of sampling programmes, target selection, and follow-up exploration.

The huge advances in robust portable computing facilities, gridding software and the linked geographic location technology all contribute to bringing geochemical exploration into real-time.

Geochemical exploration: what is truly new?

Exploring for chromite in the Hidu Kush mountains, Asia

However, this is where the new has stopped. The greatest challenge facing the modern explorer is inadequate training and experience in processing and interpreting ever increasing sets of data and the operator's limited understanding of sampling theory, geochemical associations and the chemical processes in the primary ore forming and secondary weathering environments.

For example, the plunge into multi-variate statistics as new methods provide us with multi-element analyses at no additional cost without considering:

- Differences in the nature of the distributions of underlying populations;
- More than one population sampled;
- Auto correlation;
- The effect of closure; and
- That the software packages used do not indicate the error or weakness in the results.

It seems like the same cowboys are now using sophisticated statistical operations and come to conclusions without considering the error or relevance of the underlying assumptions. The fact is that exploration for new discoveries becomes more challenging since the targets are no longer so easy to find.

I believe that the new advances discussed here are of huge significance if coupled with advanced sampling, sample preparation and data processing methods. Some of the historical methods used need to be re-discovered.

A few examples include:

- Considering the ease with which major element analyses now become available, it is advocated to return to the traditional normative mineral calculations developed for major element geochemistry;
- Conduct alteration studies using the isocon diagram, the boxplot and various alteration index formulas developed in the past;
- Introduce methods to separate out different underlying populations in the data at the earliest stage, if not, at the onset of the interpretation, using tools such as the Probability Plot procedure of Sinclair; and
- Calculate residuals for stream and soil samples to eliminate the effect of scavenger processes in the weathering environment.

Exploration geochemistry is at the dawn of a new day of discovery, and the role of the well-qualified, experienced geochemist is becoming even more important.

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HENNIE THEART

Hennie, a Corporate Consultant and Partner with SRK Consulting (SA) since 2009, is a Geologist with more than 35 years of experience in exploration geology, economic geology, mineral valuation, exploration methodology and mining geology. His expertise includes metamorphosed and deformed base-metal sulphide deposits, and exploring for base-, precious-, and ferrous-metals and industrial minerals, using advanced geochemical tools for detection. As a professor (2000–2008) Hennie taught Economic Geology and Mineral Evaluation and supervised post graduate studies and published in both the scientific and technical press. He acts as an advisor to governments and private companies.

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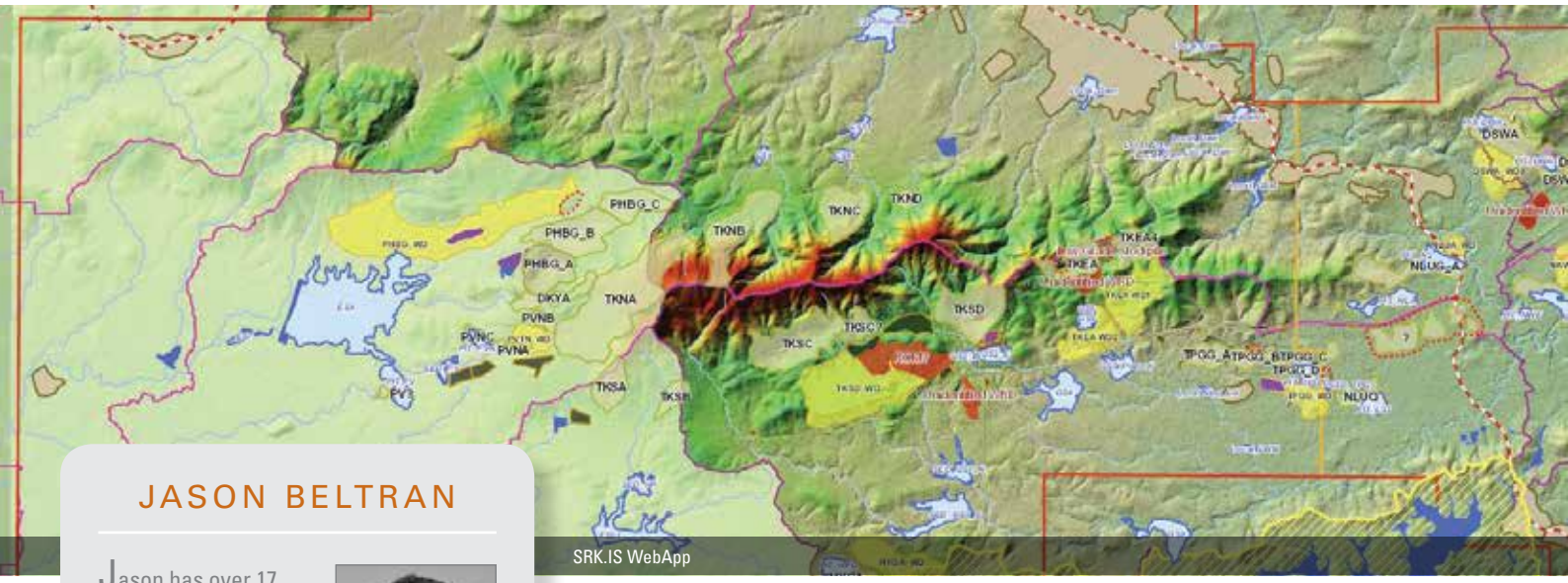
Mapping in a connected world



SRK.IS WebApp

JASON BELTRAN

Jason has over 17 years of experience in the GIS industry. His expertise in GIS project management includes implementing procedures for digital map creation and best practices in GPS field mapping. Jason currently manages all GIS data within SRK Australia, developing systems using ESRI's ArcGIS Server technology to publish and share digital mapping data across the organisation. He has experience in the design of maps for publicly released reports, and provides technical GIS support and database administration for junior miners. Jason also specialises in closure cost estimations and has experience in designing geological maps using analytical GIS.

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Traditional paper maps are static and limited to the size of the paper on which they are printed. There is also the difficulty in viewing the detail when maps portray a lot of information. The solution is either to split the map into separate sheets, or to remove some of the features, which lessens the map's value or usefulness.

But in a digitally connected world, we can use smart devices – mobile phones and tablets – for collecting and sharing mapping data. Doing so means we can produce accurate digital maps collaboratively more quickly, and without the limitations of size and scale. SRK has leveraged a customised in-house mapping portal using ArcGIS technology initially developed by ESRI – using 'IS' for 'information system', it's called SRK.IS (pronounced 'circus'). SRK.IS works with web apps that are customised for a particular client or project. Essentially, SRK.IS integrates digital data collection in the field with a centralised database, making it possible to access maps and other geographical information in real time and viewed by a variety of users simultaneously.

The advantage of SRK.IS is that it provides different connection options, whether the data is collected in the field, or viewed and/or edited in a client's office. Using ESRI's ArcMap or ArcPro, the data is transferred to maps in the SRK.IS web app and published as a map service to SRK.IS, so users can interact with the map service. The level of accessibility is subject to the map service requirements and user permission settings.

For collecting data, SRK.IS connects to a dedicated ESRI application called Collector for ArcGIS, which works on Android, iOS and Windows mobile devices. The data is customised according to the requirements of the mapping task, and data pre-filling options can be activated to save time and reduce exposure to human error in data entry. Digital photos can be attached to a datapoint to automatically georeference the location of each photo.

Users can download maps beforehand, so data can be collected in remote locations with no internet or mobile connection. Later, when internet connection is available, the offline data can be synced to SRK.IS and integrated with existing data.

The data on SRK.IS is accessed via a portal, https://gis.srk.com.au, using a web browser, or by a direct WebApp URL. The web browser interface works like the Google Earth application – by toggling between different map layer options, users can control the geospatial information to view.

Office-based ArcGIS administrators can log in to the SRK.IS portal to view mapping progress in real time. The data can be edited, and synced back to the SRK.IS user in the field – reducing the time lag involved in waiting until the map is produced before processing any edits, enabling faster map creation than previously possible.

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Machine learning

Machine learning is a trending buzzword in all industries, including mineral exploration. Complex models have been successfully implemented by large multinationals and small start-ups to sell targeted advertising, implement self-driving cars, or perform automatic trading.

In mineral exploration, machine learning models are mainly used for 2D mineral prospectivity analysis and borehole data interpretation. The value of machine learning in these fields is recognised, and both mining and service companies are adding machine learning to their toolbox.

Other promising uses for 3D modelling, ore characterisation or automatic geological mapping from remote sensing data are being developed. Machine learning models have the potential to radically change the way exploration is being conducted from greenfield targeting to resource estimation.

However, algorithms are only as strong as the data that is fed to them. A successful prospectivity map requires extensive expert knowledge to select the right geological, geochemical or geophysical variables that will be used by the algorithm to predict the mineral potential for a specific deposit type. This critical step is often overlooked, but when poor data is fed to an algorithm the predictive model will not provide a satisfying prediction, or worse, mislead the targeting exercise.

Machine learning should be considered a new tool for mineral exploration rather than a replacement for the standard exploration procedure. A state of the art implementation of a prospectivity algorithm on an exploration dataset, backed-up by strong field knowledge and deep deposit expertise can only lead to successful decision making. Similarly, integrating borehole data to automatically interpret lithologies, alteration and structures in boreholes should not replace the logging geologist, but be a support tool for quicker, more accurate and reproducible drill core description and analysis.

Using machine learning improves decision making in exploration and accelerates the data integration and interpretation process. However, algorithms and models should not be used blindly as black boxes. They require upstream and downstream supervision by exploration experts who can critically assess predictions and make the right decision based on them.

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ANTOINE CATE

Dr Antoine Caté is a structural geology consultant at SRK Toronto. He has 7 years of both academia and industry field experience, working on gold and base metal deposits. Antoine is an expert in the applications of data science and machine learning in geosciences, including applications for prospectivity analysis. He was the leader of the team that was awarded the second place at the Integra Gold Rush challenge in 2016 and was involved in founding two companies involved in machine learning and the mining industry. Antoine's current work at SRK includes structural field investigation, 3D modelling, and the development of innovative tools applied to structural geology, and mineral exploration.

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Using the Mineral Systems Approach to increase exploration success

In an attempt to reduce the inherent risk in mineral exploration, SRK, with their clients, continues to use innovative and new technology, approaches and concepts that assess the increasing amounts of geological data in the most time efficient manner. One approach that has become increasingly accepted is the Mineral Systems Approach to assessing prospectivity.

The Mineral Systems Approach considers the origin of deposits in the framework of lithospheric-scale processes from the time-honoured perspective of source, fluids, transport and traps. Applied to exploration strategy, this approach allows for more predictive models. Rather than matching patterns, knowledge of the underlying geological processes and tectonic setting can be used to identify prospectivity.

Furthermore, a Mineral Systems Approach can broaden the scope of prospectivity indicators and therefore allows for earlier, more efficient fertility assessments.

The five questions of mineral system theory are geodynamic history and setting, architecture, fluid reservoirs, fluid pathways, and driving forces for transport and deposition. The questions were formulated for hydrothermal mineral systems but are equally applicable to magmatic ores. Translating this theory into a useful tool for exploration involves understanding how critical processes of the mineral system are reflected in the geology, and using them to define targeting criteria to detect elements directly or by proxy.

A good example is that of porphyry Cu-Au-Mo deposits. Both the well-known tectonic environment proximal to subduction zones within magmatic arcs, and the classic Lowell-Gilbert model of propylitic-phyllic-potassic alteration are widely used to identify areas of mineralisation. Thus, exploration focuses on identifying areas indicating alteration at the surface, on a scale of hundreds to thousands of metres. However, using a Mineral Systems Approach considers the range of geological processes that occur to produce a porphyry deposit. The source-fluid-transport-sink pathway in this case includes mantle melting, magma transport, lower and upper crustal magma chambers, sulfide saturation and volatile exsolution. By understanding the signatures that these processes leave in the common and widespread magmatic and volcanic rocks in arcs can mean a much broader range of rocks can indicate a fertile system. These processes leave signatures in minerals like zircons and apatites, which are common in most magmatic rocks, mineralised or not. Thus, any magmatic rock in a district can help identify fertile or barren systems as a proxy to the essential elements of the mineral system – and not just direct evidence of mineralisation or alteration.

At SRK, we are active in the continued research of mineral systems and are currently involved in a large research project focused on these deposits (FAMOS: From Arc Magmas to Ore Systems); the project aims to make exploration for porphyry deposits cheaper, quicker and more efficient. Applying the Mineral Systems Approach is now becoming an increasingly advantageous tool for exploration across all deposit types.

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DAVID HOLWELL

Dave is an Associate Exploration Geologist with 15 years of experience in applying economic research to exploration approaches. He specialises in using multi-scale datasets to assess the genesis of magmatic and hydrothermal ore deposits, with a focus on magmatic Ni-Cu-PGE, IOCG and orogenic gold systems. He is currently involved in several projects that apply Mineral Systems philosophy to identifying fertility indicators for base and precious metal deposits.

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Navigating and meeting the listing requirements for an Initial Public Offering (IPO) can prove a daunting task. This is particularly true for explorers considering a listing on stock-exchanges such as the SGX (Singapore) and HKEX (Hong Kong). To consider a listing, both the SGX and the HKEX require at least an Indicated Mineral Resource Estimate under international reporting standards – JORC, NI 43-101 or SAMREC – substantiated in a Competent Person's Report.

SRK recently assisted two clients, exploring for vein-type tungsten mineralisation in Mongolia and focusing on a magnetite skarn in Malaysia. SRK helped the clients develop an exploration strategy for their assets in view of a smooth listing process. Both companies hold mining rights over known deposits with past or current artisanal to small-scale mining, supported by historic, non-compliant resource estimates.

Optimising exploration strategies: fast-tracked listing for SE Asian exchanges

Working with the local exploration team at Ulaan Uul, Mongolia

SRK's first task was to conduct a review of available data, supported by a site visit, to assess whether historical drilling data and samples could form the basis of a Mineral Resource Estimate. At the magnetite skarn project, core samples had been preserved, and recommended measures included re-logging the core with selective re-sampling and twinning of key holes where samples were not available. This review also allowed SRK to identify possible by-product mineralisation that had not been considered by previous explorers of the skarn. At the tungsten project, historical Russian surface mapping and underground sampling data were compiled, interpreted and compared with SRK field observations to ascertain exact location of the veins and associated exploration work.

SRK then prepared drilling programs that would support an indicated classification. 3D geological models were developed for each project from existing surface and drilling data to better constrain the mineralised bodies. The tungsten deposits featured narrow or discontinuous mineralisation in 0.5 to 1.5 m wide quartz-wolframite veins. The magnetite skarn consisted of hectometre-sized magnetite lenses. 3D modelling allowed SRK to delineate the most prospective areas and formed the basis for drill planning. In a longer-term strategy, a broader regional exploration program was developed to identify additional potential.

An important aspect of SRK's assistance consisted in ensuring that best industry practices were implemented, starting from the initial procurement of drilling and sampling equipment to ongoing monitoring of data quality. Tailored standard operating procedures were prepared and on-site training provided for the rig and supervising geologists that focused on appropriate sampling and QA/QC. This particularly held true for the tungsten project, as deep drilling (400-500 m) targeted coarse-grained tungsten mineralisation characterised by a strong nugget effect.

On both projects, SRK's experts in exploration, resource geology and project evaluation contributed to training on-site staff, and the elaboration of tailored and effective exploration strategies with a fast-tracked IPO in mind.

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BERT DE WAELE

Bert has over 25 years of structural mapping experience, including undertaking significant projects in Laos, Indonesia, Malaysia, Mongolia, and the Philippines. He has consulted on base metal and gold prospects, setting up and running exploration programs and interpreting regional geological data. Bert has conducted Independent Technical Assessments on various mineral assets and he has developed both expert and data-driven exploration targeting systems. Much of his work has included on-the-job training of sampling teams and mapping geologists using cutting-edge paperless mapping technologies.

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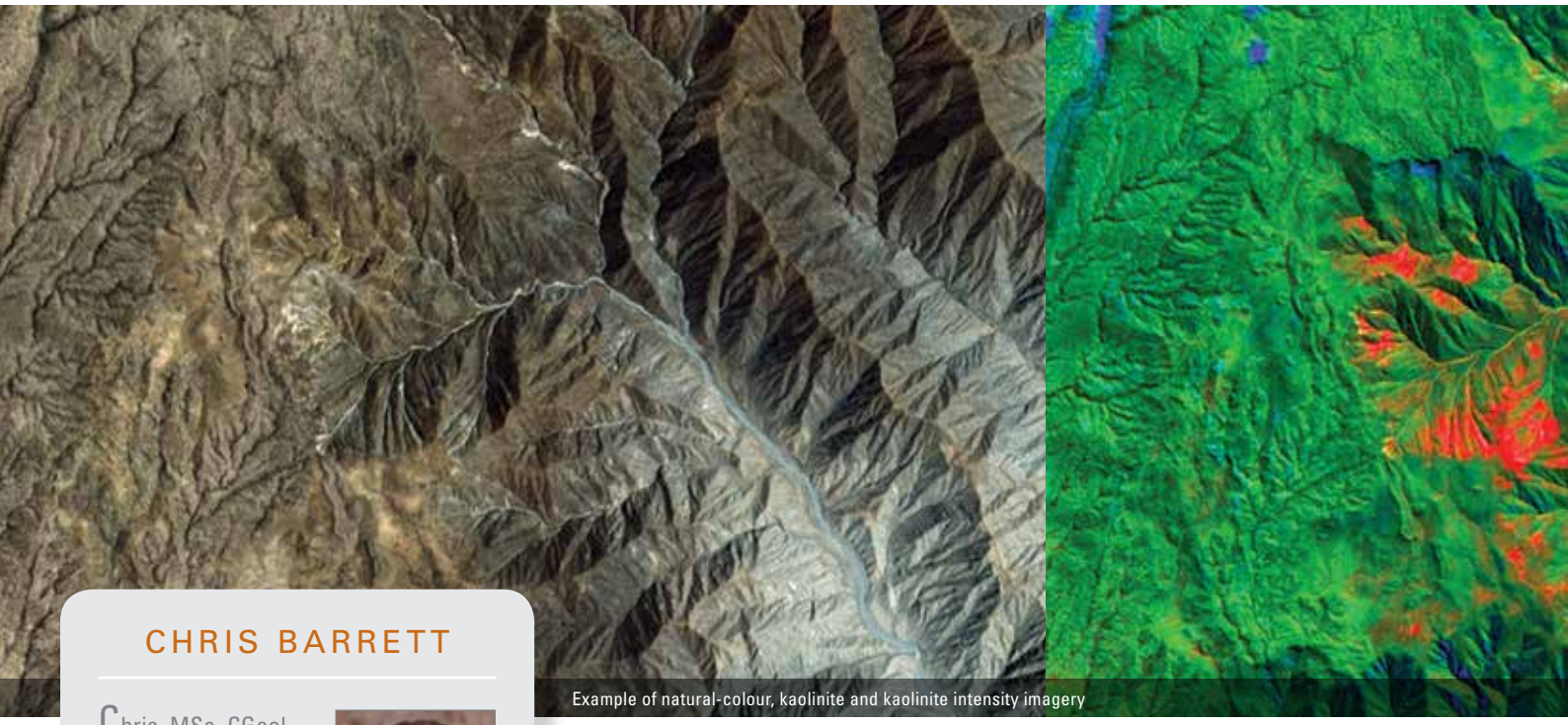
The power of spectral remote sensing



Example of natural-colour, kaolinite and kaolinite intensity imagery

CHRIS BARRETT

Chris, MSc, CGeol, is a Principal Exploration Geologist with SRK Exploration and has 20 years of international experience. He has worked on geologically and geographically diverse projects located in more than 40 countries and targeted a wide variety of mineral commodities. His proficiencies include the design, implementation and management of exploration programmes, project evaluation, the application of GIS and spectral remote sensing to mineral exploration, prospectivity assessment and technical reporting.

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Spectral remote sensing involves the collection, processing, and interpretation of electromagnetic energy that is reflected or emitted from features on the Earth's surface. The fundamental premise is that different materials reflect and emit energy at different wavelengths and can be discerned accordingly.

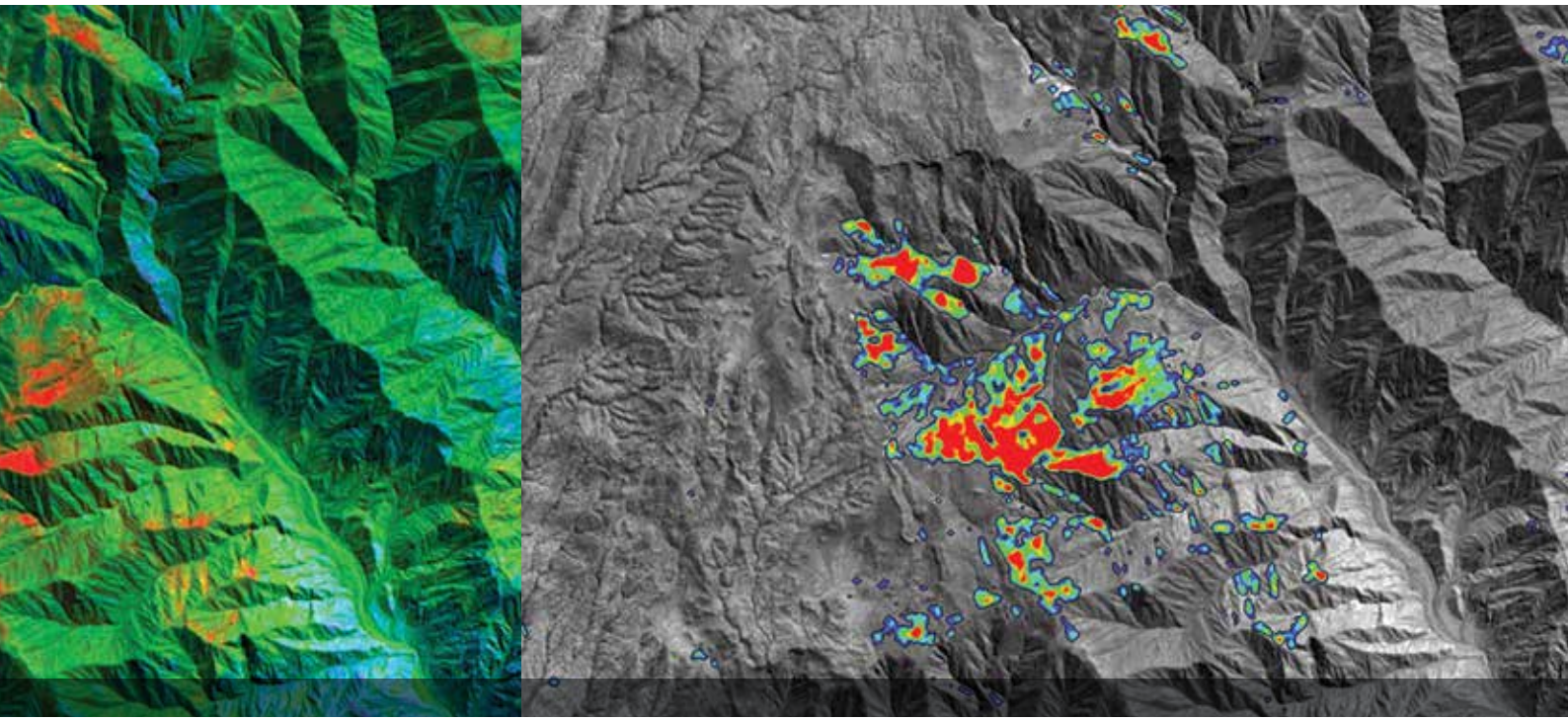
In mineral exploration, spectral imagery can be used for a variety of applications that include:

- Outcrop identification
- Lithological mapping
- Mineral/alteration mapping
- Structural mapping
- Geomorphological mapping
- Indicator mapping
- Logistical planning

Related applications include mine planning and environmental monitoring. Some sensors also collect stereo imagery that enables the creation of elevation models.

Outcrop identification spectral data can be particularly effective where the type of mineralisation being sought is associated with geological characteristics that are spectrally distinct, such as a specific host rock or alteration type. Major deposit types with associated alteration features that can be identified using spectral imagery include porphyry copper-gold, epithermal gold, orogenic gold, and volcanogenic massive sulphides.

Using spectral imagery in mineral exploration is associated with numerous advantages that include:



- Being able to consider large areas cost-effectively;
- Providing an elevated vantage to identify features less visible at ground level;
- Being able to identify features not visible to the human eye;
- Using data and imagery that is often readily available "off-the-shelf";
- Being able to acquire some types of data for free;
- Using a discrete and confidential means of exploration;
- Not requiring permitting, and
- Having a very low environmental impact.

Like other exploration methods, spectral remote sensing is associated with some limitations. Fundamentally, it can only detect what is exposed at the surface and, consequently, anything obscuring the features of interest (for example, cloud, snow/ice, vegetation, shadow, urbanisation) can hinder its effectiveness.

SRK is experienced in all forms of spectral analysis and retain the most modern and up-to-date remote sensing approaches. SRK routinely acquires, processes and interprets spectral imagery to facilitate mineral exploration, particularly for remote geological and alteration mapping, assessing regional prospectivity, area selection, and target generation.

SRK recently completed a project in Saudi Arabia, targeting volcanogenic massive sulphide (VMS) mineralisation, involving the selection, acquisition, processing and interpretation of Landsat 8 and Sentinel 2 multispectral data. The derived spectral data and imagery were used to facilitate remote lithological, structural, and mineral (iron oxide and clay) mapping, and in identifying targets. These targets were subsequently verified on the ground and resulted in identifying new mineralised zones.

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The continuity challenge: old gold in West African deformed terranes

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Wayne is a Principal Consultant with 20 years of experience. He has been employed over 8 years as a mining operations-based geotechnical engineer and applied structural geologist. Subsequently, Wayne performed as consulting structural geology specialist in mining and exploration in Africa, North America, South America and Asia. He specialises in defining the structural geology of mining projects to properly characterise the rock mass for geotechnical engineering applications from scoping to pre-feasibility studies, as well as problem-solving in active mining operations.

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SIMON CRAGGS

Simon is a Senior Structural Geology Consultant with over 10 years of experience in geological mapping and structural analysis of deformed terranes around the world. He has collaborated on exploration and mining projects for numerous deposit types, geotechnical studies for underground and open pit mines, and research projects for the nuclear waste management and hydrocarbon sectors. He specialises in detailed analysis of fault/fracture and fluid flow mechanics in upper crustal settings. Simon is currently completing a PhD on the structural and geochronologic controls on Ag-Pb-Zn vein development in the Keno Hill mining district, Yukon.

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Example of typical deformed quartz veins systems spatially associated with "old gold" mineralisation in West Africa

Exploration in highly deformed orogenic environments is challenging because of the potential for extensive deformation of the mineralised target zone. One of the key factors impacting the continuity of economic mineralisation is timing of mineralisation relative to deformation. If gold mineralisation is relatively old with respect to the deformation, then the structural deformation patterns overprinting the gold distribution need to be well understood for greenfield or brownfields exploration, and resource characterisation and exploitation on the mines.

Project experience by SRK in Liberia and the Paleoproterozoic Birimian terranes of Burkina Faso between 2010 and 2018 included at least 5 projects with gold mineralisation that clearly predates at least two phases of penetrative, ductile or brittle-ductile deformation. The gold mineralisation on all these projects is closely associated with quartz vein systems and sulphides (such as pyrite, pyrrhotite, chalcopyrite, arsenopyrite), and typically associated with magnetite, sericite alteration and sometimes more general silicification. These systems were most likely originally formed as orogenic gold deposits.

The distribution of gold mineralisation on these projects has been structurally investigated on all scales, from (i) regional airborne and ground magnetics, and soil sampling, to (ii) mine and outcrop scale mapping and grade control, and through (iii) drill core assay, mineralogical and textural observations.

The early rock structural fabrics, the gold mineralisation and the associated minerals including quartz veins, are isoclinally deformed (transposed) by an early deformation phase associated with a penetrative foliation. The patterns observed at all scales include zones of isoclinal folding, pinching and swelling, and stretching along high strain zones and fold axes. These deposits have then subsequently been folded by a second and often third phase of deformation, creating a complex interference pattern.

Only when the control on mineralisation is identified can the deformed and often simplified structural geometry be used for further targeting. Lineament-type interpretation is useless. Rather, structural investigations based on geophysics, mapping and core logging should be applied without exception to define the deformation patterns and gold trends. Understanding the structural patterns in combination with soil sampling allows exploration targets to be accurately defined.

In contrast to the "old gold", in at least one of these West African projects, there is also a later phase of gold mineralisation associated with more typical structural targets, such as dilation zones and complex fault intersection areas favourable for fluid permeability. Such "late gold" is well documented at other locations, notably along the Birimian fault systems in Ghana at Obuasi Mine.

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Keno-Lightning project, Yukon

In November 2016, Metallic Minerals Corp. commissioned SRK to conduct a desktop and field structural geology analysis of the Keno-Lightning project. This work aimed to define targets for exploration drilling. It included an initial structural interpretation of airborne geophysical data with the aim of developing a litho-tectonic framework for the region, and was followed up by a short program of mapping to ground truth -interpreted structures.

The Keno-Lightning project is located in the underexplored eastern portion of the historic Keno Hill silver-lead-zinc mining district, within the Selwyn Basin, Yukon. Silver-lead-zinc mineralisation is preferentially hosted in thick, competent quartzite units within the Mississippian Keno Hill Quartzite, and to a lesser extent, in deformed Triassic greenstone units where they occur within broad packages of relatively ductile schist. Three discrete episodes of deformation have been defined in the Keno Hill area: pre-mineralisation fold and thrust belt development (D_1); syn-mineralisation sinistral strike-slip to sinistral-normal oblique-slip brittle fault development (D_2); and post-mineralisation, Cordillera-parallel, dextral-normal oblique-slip fault development (D_3). Silver-lead-zinc mineralisation in the district is controlled by the complex interplay of fault geometry and orientation, secondary thickening of host rocks as a result of early folding and thrusting (D_1), and variations in the mechanical properties of the various lithological units.

Understanding the variation in orientation and geometry of D_2 faults is critical for exploration targeting within the Keno Hill district. First-order D_2 faults occur as laterally extensive east-northeast-trending structures that may be associated with discrete, narrow (less than 0.2 metre wide) mineralised veins. However, thicker, higher grade silver-lead-zinc veins are typically associated with second- and third-order, northeast to north-northeast-trending, D_2 faults that splay off, or link between the more laterally extensive first order faults. Veins associated with the second- and third-order structures can reach thicknesses of over 5 metres, and can carry grades well in excess of 1000 gpt silver.

The initial interpretation of airborne magnetic data identified numerous structurally complex zones, where dense networks of second- and third-order D_2 faults were present, and where they intersected first-order faults. This interpretation was compared with historic lithological mapping data to refine the targets based on the presence of coexisting structurally complex zones and favourable lithology.

Metallic Minerals used this interpretation, combined with their own mapping efforts, to drive their exploration drilling and trenching program over the summer of 2017. Preliminary results from the defined targets are promising with numerous boreholes intersecting wide (greater than one metre), high-grade mineralisation in two of the primary targets outlined by SRK.

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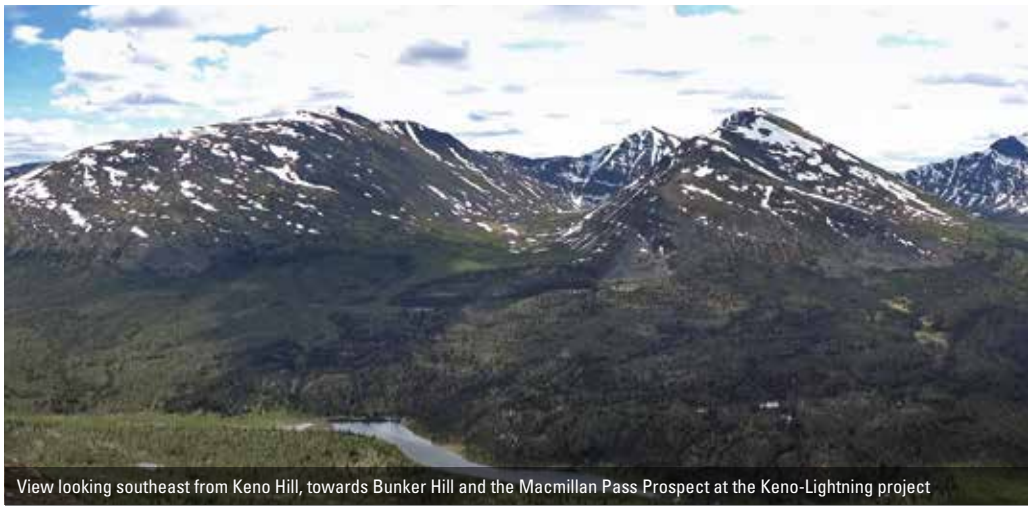

View looking southeast from Keno Hill, towards Bunker Hill and the Macmillan Pass Prospect at the Keno-Lightning project

Peridot gemstone exploration

Exploring for coloured gemstones is different from exploring for other metals or coal; the key to successful exploration is collaboration between gemologist and geologist. In 2017, SRK was commissioned by Yanbian FULI Peridot Mining Industry Co., Ltd to undertake a technical assessment of its Yiqisong Nanshan peridot project in northeast China.

Globally, there are two main types of peridot deposits that are distinguishable on the basis of the host rock: basaltic eruptive and ultramafic intrusive. Most peridot gemstones are the basalt type, while the smaller, ultramafic intrusive type deposits often supply the largest and finest gemstones.

The geological history of the Yiqisong Nanshan deposit includes volcanic eruptive activity and an associated peridot mineralisation event. The peridot is predominantly hosted in ultramafic inclusions within a basalt layer. In rare cases, peridot deposits are found in isolation in the basalt formation. The relationship between the percentage of ultramafic inclusions and the grade of gemstone peridot is well defined at the global scale but is less precise in specific drill core or bulk samples.

Between 2014 and 2016 exploration activities at the site involved drilling, trenching, and underground bulk sampling. The drilling led to delineating the mineralised zones, which were shown to be relatively shallow-dipping within basaltic layering. The percentage of ultramafic inclusions was calculated from each section of drill core samples.

While the acquisition of drill data is an important component, due to the nature of exploration for coloured gemstones, it also must be correlated with other production data. There may be sections without intercepts of gemstone mineralisation, while other sections have grades in the hundreds of carats. Another reason for exercising caution is the fact that most peridot gemstones are hosted in the ultramafic inclusions, for which drill recovery is poor. After reviewing past exploration and resource evaluation work, SRK's geologist and associate gemologist proposed a revised program for sample verification and additional exploration.

The revised exploration program focused on gathering additional data for verification, integrating data from the two exploration campaigns to build a database. More importantly, the new exploration program employed additional underground bulk sampling and logging the underground workings for the percentage of ultramafic inclusions. The samples were screened, while over 600 pieces of peridot gemstones were handpicked by skilled technicians. These raw gemstone samples were weighed, classified, polished and certified. The data in each process of statistical significance was recorded.

A preliminary resource evaluation of the Yiqisong Nanshan project indicated that the project, as well as the region, has potential to be an important peridot-producing area.

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Large peridot and ultramafic inclusions in basalt ore


Conglomerate rock within the Hardey Formation

Conglomerate-hosted gold and alluvial gold draining conglomerate sequences have been discovered by multiple explorers over an extensive area of the Pilbara region of Western Australia. Most of the conglomerate-hosted gold in the region has been recognised in the conglomerates of the Hardey Formation at the base of the Mount Roe Basalt in the lower part of the Fortescue Group.

Like the Witwatersrand gold deposit to which they have been compared, the conglomerate contained in the Pilbara was deposited prior to the Great Oxygenation Event, where low levels of oxygen in the atmosphere allowed detrital gold to be co-deposited with pyrite, graphitic carbon and uraninite.

Understanding sedimentary features and controls on gold distribution are key tools for exploration. Numerous researchers and explorers have suggested a sedimentary or paleoplacer deposition model for the Pilbara conglomerate-hosted

Exploring for conglomerate gold in the Pilbara

gold deposits, a different style of gold mineralisation than traditionally mined in Australia. The paleoplacer model refers to gold deposited within coarse sediments, where distribution and grade can be directly related to sedimentary controls.

Gold discovered in the Pilbara appears to have a relatively high nugget. 'High nugget' refers to the large statistical differences between closely spaced samples of the same material in the mineral system, making a resource difficult to estimate.

High nugget is a common problem in gold deposits and may be exacerbated in the Pilbara deposits by the relative immaturity of the host conglomerates, but this has not been extensively tested. Early indications are that the Pilbara conglomerate-hosted gold is typically coarse, producing watermelon seed-sized gold grains. How these gold nuggets are formed remains a contentious topic, and a lot more work is needed to fully understand this phenomenon and the implications for sample assay statistics.

Results from conglomerate-hosted gold at the similarly challenging Pardo deposit in Ontario highlight the variability in sample grade in this style of mineralisation. A recent 985 tonne bulk sample of exposed pyritic conglomerate returned a head grade of 4.2 g/t gold in a pilot plant program. The volume of rock excavated had an estimated average grade of 1.3 g/t gold from 11 diamond drill holes. The variability in grade from drill core to bulk sample is typical of high nugget gold deposits and creates a challenge when estimating a Measured or Indicated Resource required for preliminary economic assessment.

Because high-nugget mineralisation requires customised sampling to address the statistical variance, more work is required to determine exactly how the nugget effect will influence the accuracy of resource estimation of Pilbara conglomerate-hosted gold deposits.

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Stuart is a Structural Geologist with 25 years of experience. He has consulted on a wide range of geological projects for mining and exploration companies, including management of exploration projects and pre-development studies with a gold focus and he's provided technical advice at a corporate level. In addition, Stuart has been involved in growth through acquisition, involving due diligence and identification of the potential upside. As a structural geologist, he was involved in detailed studies of controls on mineralisation, resource model assessment, technical due diligence, independent expert's reporting and strategic planning.

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Pengfei, Geologist/Geophysicist, joined SRK China in 2008. He specialises in geological exploration design and quality assurance and quality control. In geophysical exploration on metal mineral deposits, he applies geoelectric and electromagnetic methods, 3D geological modelling and resource estimation. Pengfei's experience extends to due diligence reviews, including geology, exploration and resource reviews, and exploration design. He has worked on geological modelling and resource estimation/reconciliation projects in China, Mongolia, Africa, South America, and other parts of Asia.

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Exploring for graphite: opportunities and challenges

Graphite is a form of pure carbon that normally occurs as black crystal flakes and masses. Its unique physical and chemical properties make it well-suited to many industrial applications, including electronics, lubricants, metallurgy, and steelmaking. Global demand for natural graphite doubled between 2006 and 2012. Although Chinese industrial activity has slowed and led to prices falling from the high levels seen in 2011, consumption of smart electronic devices has caused a growth in demand and this may continue to grow as sales of electric and hybrid vehicles require larger batteries. China and India are the largest graphite producers, with over 80% of global production. Chinese graphite, however, is declining in quality while production costs are increasing. China has a 20% export duty on graphite, a 17% value added tax, and has instituted an export licensing system to ensure supply to its domestic economy, creating supply concerns for the rest of the world.

Graphite generally forms from high-grade metamorphism of organic matter in sediments. The three main types of commercially significant natural graphite are crystalline or disseminated flake, crystalline vein or lump, and microcrystalline or amorphous graphite. The largest flake graphite deposits are often relatively low grade. In contrast, vein graphite deposits are smaller and higher grade. Amorphous deposits can range in size but generally produce lower quality graphite with restricted uses. Recent exploration has focused on flake graphite in East Africa, Canada and Australia. The largest deposits are in Mozambique and Tanzania, an area noted for large, high purity flake graphite. This increased exploration activity has resulted in global inferred resources exceeding 800 Mt (USGS, 2015).

The value of graphite deposits depends on grade, purity, size and range of flakes or needles, and the presence of impurities that may have a negative effect on extraction. Pricing is complex and depends on total graphitic carbon (TGC) content; deposits with grades of over 80% TGC are economically viable.

The two main assay methods for measuring TGC are: LECO analysis and Double Loss of Ignition (DLOI). DLOI is normally used as a graphitic indicator, while the LECO method provides a more detailed assessment. DLOI may not always accurately represent the actual TGC values in the rock as the measurements can be affected by the presence of sulphides and calcite (carbonate). Processing flake graphite aims to optimise the liberation of flakes by size (Large: +180µm; Jumbo: +300µm; and Super Jumbo: +500µm flakes) and to maximise grade and recovery. Evaluating the economic potential of graphite samples requires an understanding of the extraction process. Over 80% of graphite demand is still driven by industrial applications. Predictions see the battery sector increasing market share over the next few years with a rebound in the steel industry having potential to also fuel demand.

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Mike has over 15 years of experience as a Geologist and has consulted on projects in Australia, Asia and Africa, on a variety of commodities. His expertise covers 3D modelling of vein, epithermal and BIF styles of mineralisation, drill targeting, modelling, and mineral resource estimation. Mike has also been involved in preparation of Independent Geologist's and Competent Person's Reports for ASX (JORC Code, 2012, VALMIN 2015) and TSX (Canadian National Instrument 43-101) listings.

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Late northeast-trending quartz-tourmaline-pyrite veins at

SRK applies rigorous geological and structural interpretations to provide insight for exploration targeting, constraints on resource modelling, and support for geotechnical evaluations. Interpreting the structural setting during mineralisation is critical for understanding the geometry of the system. Fault-fill (i.e. shear) veins in orogenic gold deposits are often associated with active reverse slip fault systems (Robert and Poulsen 2001; and their references) but this is not universally the case. SRK has been involved in analysing two Paleozoic orogenic gold deposits in Ireland and Canada where gold bearing fault-fill veins developed within normal fault systems.

The Curraghinalt gold deposit (Dalradian Resources Inc.) in Northern Ireland, hosted in Paleoproterozoic metasedimentary rocks, is cut by a series of moderately northeast-

Gold mineralisation during orogenic extension

Valentine represent a later phase overprint on the dominant thrust parallel, northeast-trending fault-fill veins

dipping, quartz-pyrite-carbonate fault-fill veins. Previous workers recognised that these post-date the main Ordovician Grampian orogeny compressional deformation events and movement on the regional Omagh Thrust Fault, but the tectonic setting during vein formation has been debated. Vein formation and gold mineralisation was a multi-staged process with evidence for an early compressional component. However, several observations suggest the gold mineralisation associated with the fault-fill veins was primarily emplaced during oblique dextral-normal transtensional deformation during later orogen-oblique extension. These include the geometry of a pervasive set of steeply dipping, northwest-striking extension veins associated with the fault-fill veins, mineralised extension veins inflating the fault fill veins, combined with dextral-normal kinematic indicators in the faults and a compatible northeast plunging mineral lineation.

The Valentine Lake gold property (Marathon Gold Corp.) in central Newfoundland comprises four deposits occurring along the boundary between the Neoproterozoic Valentine Lake intrusive complex and the Silurian Rogerson Lake conglomerate. These are juxtaposed along the Valentine Lake Thrust Fault, a major tectonic feature formed during the Silurian Salinic Orogeny (Appalachian Orogeny). Gold mineralisation is hosted in quartz-tourmaline-pyrite veins, veinlets and stock-works forming a stacked, shallow-dipping set of extension veins associated with more extensive fault-fill veins parallel to the Valentine Lake thrust fault. The bulk of gold mineralisation is associated with the main compressional orogeny. One of the deposits, however, contains a significant set of fault-fill veins with normal movement kinematic indicators oriented perpendicular to and cutting the main shear veins, suggesting formation during a later, orogen-parallel extensional event.

BLAIR HRABI

Blair, MSc, PGeo, is a Principal Consultant with SRK. He is a Structural Geologist with over 22 years of experience with the exploration industry, government geological surveys and in academic settings mapping and modelling the lithology, structure and mineral deposits in deformed Archean to Paleozoic terranes. Blair is an expert in structural controls on ore deposits. He applies his expertise to integrating field, open pit and underground mapping to build geologically sound 3D structural and lithological models to support exploration targeting, resource estimation, and geotechnical studies, and to GIS-based structural interpretations of aeromagnetic data for exploration targeting.

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Gold mineralisation in these two orogenic systems was at least partly emplaced during later extensional deformation phases, post-dating the main compression, and possibly representing effects of an extensional collapse of each orogen. Orogenic gold systems are typically complex and long-lived, and careful mapping and interpretation of the entire set of structural features present is needed to understand these systems. Evaluating the geometry and movement sense of all structural features present allows for the accurate prediction of the mineralised system for both efficient exploration and confident resource estimation.

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Reference: Robert, F., and Poulsen, K.H. 2001. Vein formation and deformation in greenstone gold deposits. SEG Reviews, v.14, p.111–155.

Exploring Greenland's gold districts

JON RUSSILL

Jon, BSc, FGS, Principal Exploration Geologist, has 11 years of experience in mineral exploration and geophysics. He joined SRK in 2008; his role includes data compilation and analysis, exploration targeting and programme design, project reviews, technical reporting and project management, all for various commodities and worldwide locations. Recently, Jon's work has focused on West Africa in Sierra Leone, and high latitude areas, particularly Greenland. In both regions he worked with regional mineral prospect reviews interpreting results and producing relevant documents and CPRs. Jon's exploration work has ranged from grassroots reconnaissance to drilling programmes for resource definition.

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WILLIAM KELLAWAY

Bill is a Geologist with 37 years of experience, working in 40 countries, within the petroleum, mining, exploration and educational sectors. Joining SRK in 2010, he was appointed a Director in 2012 and Practice Leader of SRK Exploration Services in Cardiff. Bill's leadership and management roles include mentoring, recruitment, marketing and business development. Technically, Bill conducts field audits of exploration properties new and old. He advises clients strategically then designs and costs tailored exploration programmes. Returning from a successful secondment as a VP of Exploration, Bill re-joined the Board and was appointed Chairman in June 2018.

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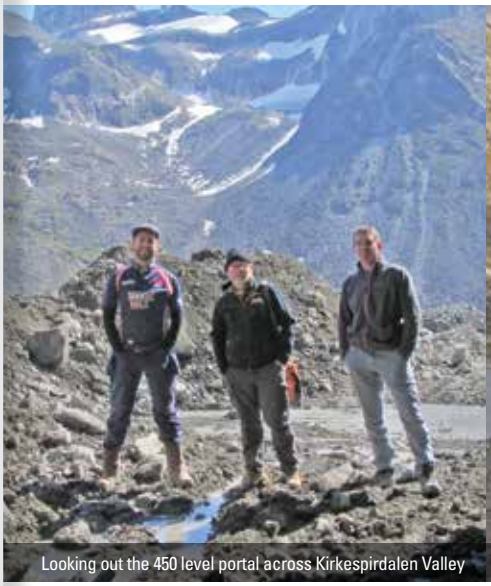

Looking out the 450 level portal across Kirkespirdalen Valley

Bidding farewell to Nalunaq at the end of the season

Greenland has numerous gold showings, but only one has ever been mined. The Nalunaq Gold Mine in South Greenland opened in 2004 following the discovery of a gold-quartz vein in the Kirkespirdalen Valley 12 years earlier. The Nalunaq discovery, like all good exploration tales, was made at the very end of a field season when a geologist stumbled upon an outcrop that glittered with visible gold. Nalunaq means "the place that is hard to find" and this alludes to the challenges of exploration in this area.

Nalunaq is an orogenic gold deposit, hosted in a quartz vein that averages 0.7 m wide (the 'Main Vein') within a highly continuous shear structure in Palaeoproterozoic metavolcanic rocks, part of the Ketilidian Mobile Belt. The Main Vein is a classic example of its type: grade distribution is very erratic, the gold is coarse and free, and resource estimation challenging; grades can be extreme: 5,240 g/t gold has been reported. Due to this extreme nugget, an approach of drilling for known structure first, with grade second, was employed in the late 1990s and early 2000s by Crew Gold.

Underground mining, using longhole open-stoping methods, took place between 2004 and 2013, first by Crew Gold and later by Angel Mining PLC, who installed a CIP plant within the mine. By 2013, about 367,000 oz of gold was estimated to have been recovered from 700,000 t of ore. Mining ceased, the site was remediated and closed in 2014, leaving a common perception that the deposit had been exhausted.

Arctic-Resources (now AEX Gold Inc.) challenged this view and acquired the mining licence in 2015. SRK's task was to make the case for Nalunaq's exploration potential and test these ideas in the field.

An SRK team of geologists, mining engineers and geotechnical engineers visited Nalunaq during the 2015 and 2016 field seasons, approaching the project from all angles. Underground conditions and infrastructure were assessed, along with a study of the pillars, remnants and

sweepings (gold-bearing fines) that remain. The relationship between gold grade continuity in the Main Vein and faulting was closely examined. Metallurgical check sampling was also conducted. On the surface, a team of specialist mountaineers worked on the upper parts of the mountain to locate and sample the Main Vein.

Surface sampling produced exciting results, confirming that the Main Vein structure is still auriferous up-dip and across the mountain. Underground findings were equally significant, discovering frequent structural offsets to the Main Vein resulting in lost reefs and implying a continuity of mineralisation that may not have been recognised by previous miners. Based on these results, unexplored potential at Nalunaq has been highlighted and targeted for further investigation.

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Rapid exploration in remote terrains

Exploration, particularly field access, is challenging in many remote environments due to lack of infrastructure. A major challenge for exploration is decision making in the field, particularly in identifying field anomalies. Recognising the need for reliable analytical field methods with quick turnaround times, SRK has utilised various field portable instruments in exploration programmes. These instruments vary from portable x-ray fluorescence (XRF) for element analysis, where elements have a mass number higher than sodium, to laser induced breakdown spectrometry (for lithium, boron, beryllium, gold and REE analysis), Terraspec FTIR spectrometry (for mineralogy), Gamma Spectrometry and Radiation Scintillometers.

In addition, SRK has invested in magnetic, resistivity and ground penetrating radar (GPR) geophysical methods to provide a reliable integrated approach to the collection of geophysical and geological observation data in the field.

A reconnaissance level exploration programme in a remote part of Namibia was recently completed by SRK to determine the geological extent and controls on uranium mineralisation, and their potential economic viability. Historic data, combined with geophysical data, were used to identify potential areas of interest for confirmation. In addition, several lower grade anomalies were also discovered by geochemical and radiometric analysis in the field.

Bedrock geology in the area includes high thorium granites with highly variable but generally low concentrations of uranium. Detailed investigation of the identified uranium anomalies found that mineralisation was confined to the regolith, with higher grade uranium (VI) mineralisation within ferric oxide-rich aeolian sand and black weathered biotite schist horizons, indicating the mineralisation was likely of secondary origin. In addition to initial anomalies, several more were identified by using XRF and Radiation Scintillometers and a drilling program was designed from the field data.

The use of portable analytical equipment contributed to a rapid and economical geochemical mapping programme in an extremely remote area where access was difficult and infrastructure undeveloped. The equipment greatly improved the efficiency of the reconnaissance programme, allowing for quick-decision making and providing near-real time sampling guidance in the field by removing the long delays associated with laboratory analysis.

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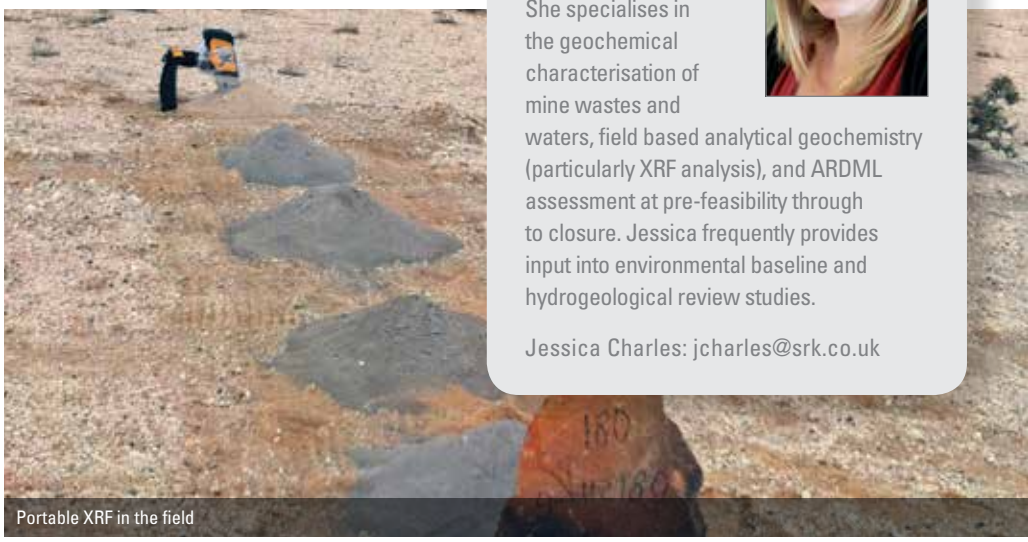
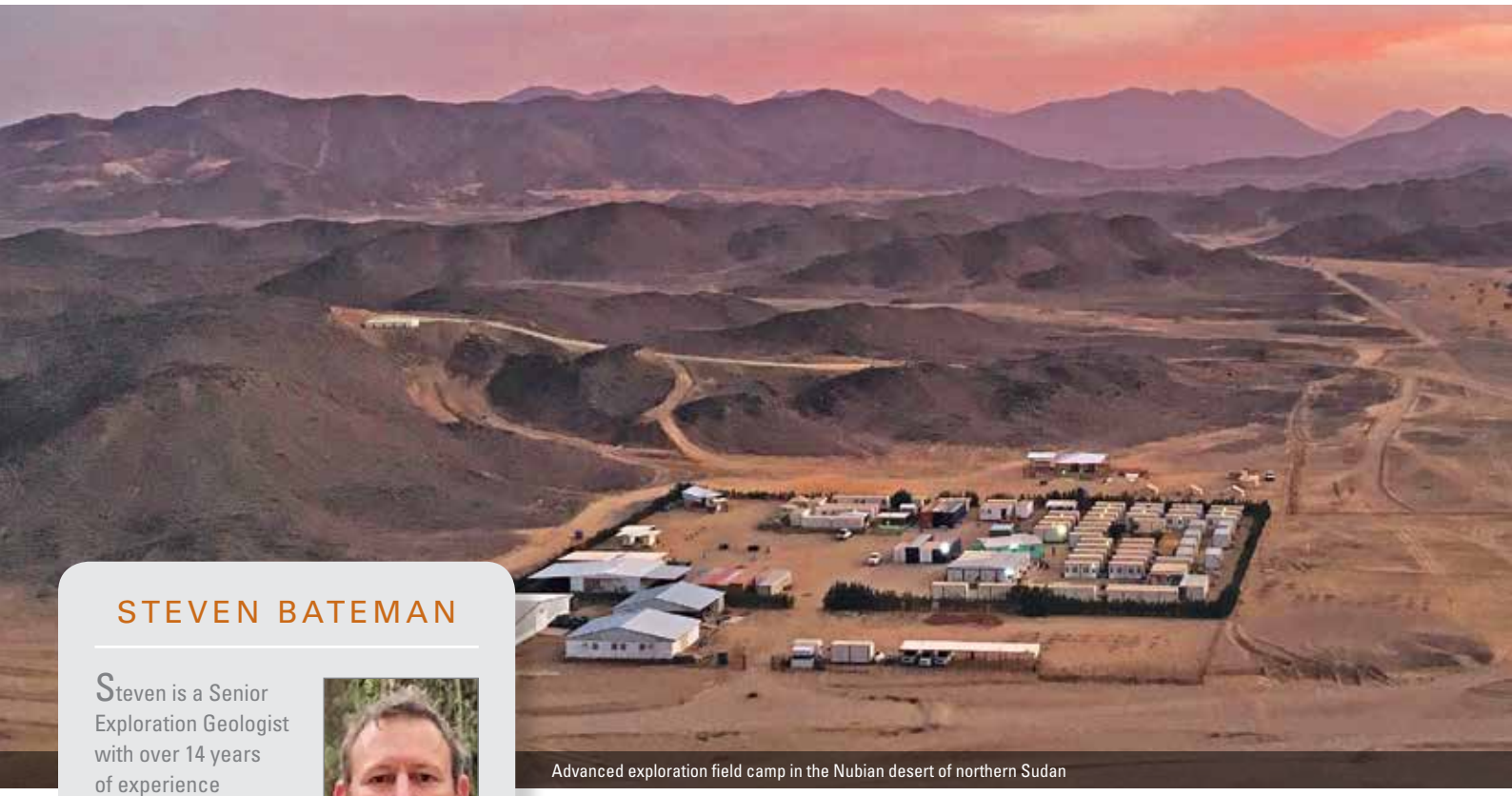


Portable XRF in the field

Exploration programme design and implementation: more than just geology



Advanced exploration field camp in the Nubian desert of northern Sudan

STEVEN BATEMAN

Steven is a Senior Exploration Geologist with over 14 years of experience in assessing exploration targets and establishing exploration and drill programs. His specialties include the design, budgeting, implementation and management of exploration projects from grassroots to mineral resource definition, as well as leading multi-disciplinary field teams, project logistics and implementing and maintaining drilling, logging and sampling QA/QC protocols in accordance with international best practices. Steven has managed projects within a wide variety of terrains across Africa, Central Asia, South America and the Russian Federation and commodities including base and precious metals, diamonds and industrial minerals.

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Running an effective and efficient exploration programme, be it in a well established jurisdiction or a remote location, not only requires a firm grasp of the geological and metallogenic processes and a competent geological team, but also robust field management and logistics. Where technical teams are not tailored or correctly selected and not adequately targeted or supported, exploration programmes can quickly go off schedule with spiralling costs. Full programme practicalities and minimum requirements must be understood including social and environmental responsibilities and risks. Regular technical decision points should be set with corresponding budgets, aims, and a clear process of measuring and reporting exploration success.

If companies do not have the resources to manage this in-house or want to concentrate limited resources elsewhere, SRK can provide tailored contract services. These field services range from the provision of personnel to supplement onsite teams through to full turnkey solutions involving technical staffing, contractor and drill programme management, camp management, official and internal reporting, logistics and health, safety and security (HSS).

Recent commissions have included drill contract tendering assistance and management services across the Balkans region, exploration management providing technical staff during summer field seasons on project locations across Greenland and full turnkey operations including

Core drilling of detrital iron ore formations in southern Gabon

camp design, construction and management on remote sites in Gabon.

Among growing requirements for all exploration companies is meeting their corporate social responsibilities and accurately assessing and providing health, safety and security training for all staff both expatriate and local. This is particularly true for remote sites and regions with high or fluctuating political risk. SRK employs HSS specialists to make these assessments, advise of requirements, and conduct a series of training programmes tailored to the mining and exploration industry. SRK manages their service provision sector through a team of experienced field explorationists. They are well versed in the practical aspects of designing, budgeting and managing field programmes from short reconnaissance projects to full multi-year phased exploration programmes. This team can be supplemented by specific skilled geologists, geophysicists, and geochemists from across the SRK group, as well as by associate field geologists and logistics experts. In this way successful exploration programmes can be delivered on time and on budget in a safe and responsible manner, all with the confidence that comes with continual SRK quality control and oversight. The results of these programmes have the advantage of being filtered directly to multiple discipline teams across the SRK group to feed directly into exploration, resource estimation, geotechnical and mining technical studies in a seamless manner, providing a true one-stop shop.

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JOE FIFIELD

Joe has 22 years of commercial experience providing safety and security support to the minerals industry. His operational experience in over 50 countries includes many with high political risks. Joe provides health, safety, security and social responsibility advice to the mining sector. In his role as Principal Safety & Security Manager with SRK Exploration Services, he runs a series of mineral industry-specific training courses.

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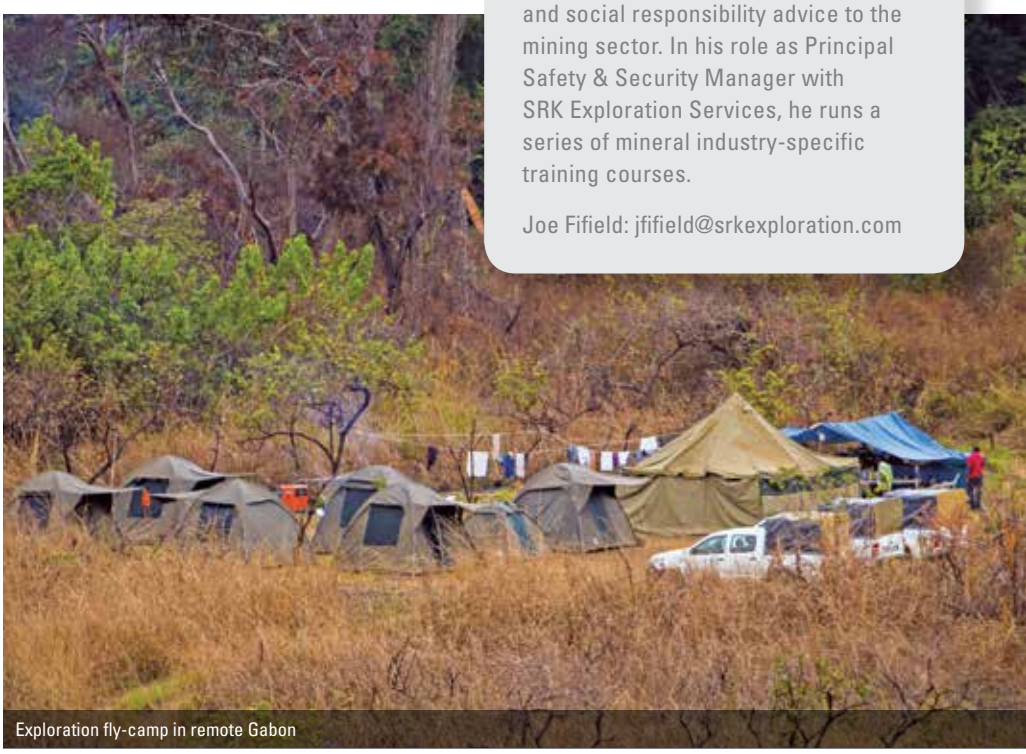

Exploration fly-camp in remote Gabon

Sonic drilling: where does it fit?

Mineral sands reveal excellent recoveries of loose sands below permafrost, 2017

OLIVER BAYLEY

Oliver, Senior Exploration Geologist, has 15 years of international experience in mining, working on projects from grassroots exploration to mine development and production across Africa, Australia and the Middle East. He specialises in exploration project reviews and audits; the design, management and implementation of mineral exploration programmes to the highest international standards for independent technical reporting such as JORC and NI 43-101. Oliver manages multi-rig complex drilling campaigns; geochemical survey and structural geological mapping programmes; and carries out structural and lithological interpretation and in-field validation of remote sensing data.

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SRK realised the full potential of sonic drilling in 2010 when they recommended the technique for an alluvial platinum project that was struggling to reconcile drilling results and mine production. Sonic drilling was ideal for this project, returning excellent recoveries in soft material while still being able to drill through large boulders in the alluvial profile. Sonic drilling enabled all the holes to reach the base of the alluvial profile. The results returned grades three times higher than the previous shell and auger drill sampling, and allowed the company to realise the full value from its exploration results. Since then, SRK has used sonic drilling across a wide variety of projects and developed extensive experience and understanding of the advantages and drawbacks of this technique.

Sonic drilling is primarily used to sample cover sequences, but unlike auger, aircore, RAB or RC drilling, it can recover a continuous core of intact sample. Returning high quality samples from near-surface unconsolidated or mixed materials is sonic drillings' main niche. Coupling this sample quality with the ability to drill through hard capping

rocks such as silcretes, basalt flows, or large boulders, and return excellent recoveries from underlying loose sediments, makes it ideal for many placer deposits and also mixed tailings or rock dumps.

Sonic drilling uses vibration of the drill string and drill bit for penetration, with the driller aiming to achieve maximum vibration (resonance) at the bit where surrounding particles are either fluidised (in loose materials) or fractured (in hard rock).

High penetration rates reduce with depth, meaning RC or RAB may become more economic with depths over ~30 m. Sonic holes can be drilled dry but drilling fluids are required through significant hard rock units and in deeper holes. The main drawback of the technique is the high relative cost, being approximately three times the cost of RAB, or one and a half that of RC. This said, sonic drilling can be ideal for remote areas where fixed logistics costs are already high, exploration seasons may be short, and excellent recovery and penetration rates are demanded.

The sonic drilling method is not the answer for every project but it holds the potential of achieving results that prove the feasibility of projects previously unsampled or considered unviable.

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Drilling platinum alluvial deposit in 2010

A dynamic approach to drill programme design

HARRI REES

Harri is an Exploration Geologist with a background in resource estimation with 7 years of industry experience. He applies his acquired knowledge of 3D geological modelling and geostatistics to his work in exploration programme design, drilling management and field mapping. Harri has worked on a variety of precious, industrial, and base metal projects at various stages of development in Africa, Australia, Europe, Greenland, North America and the Middle East.

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DAN MARSH

Dan, MSc, FGS, is an Exploration Geologist. He holds a Master's degree in Geophysics from the University of Southampton and has 8 years of experience in exploration geophysics, with Rio Tinto and now SRK. Dan provides geophysical survey design, on-site data acquisition, data processing, and geophysical interpretation for various mineral deposit types and structural settings. He is continually developing the geophysical capabilities and range of services SRK offers clients and strongly advocates for integrating geophysical and geological data to provide informed interpretation and well-founded decision making.

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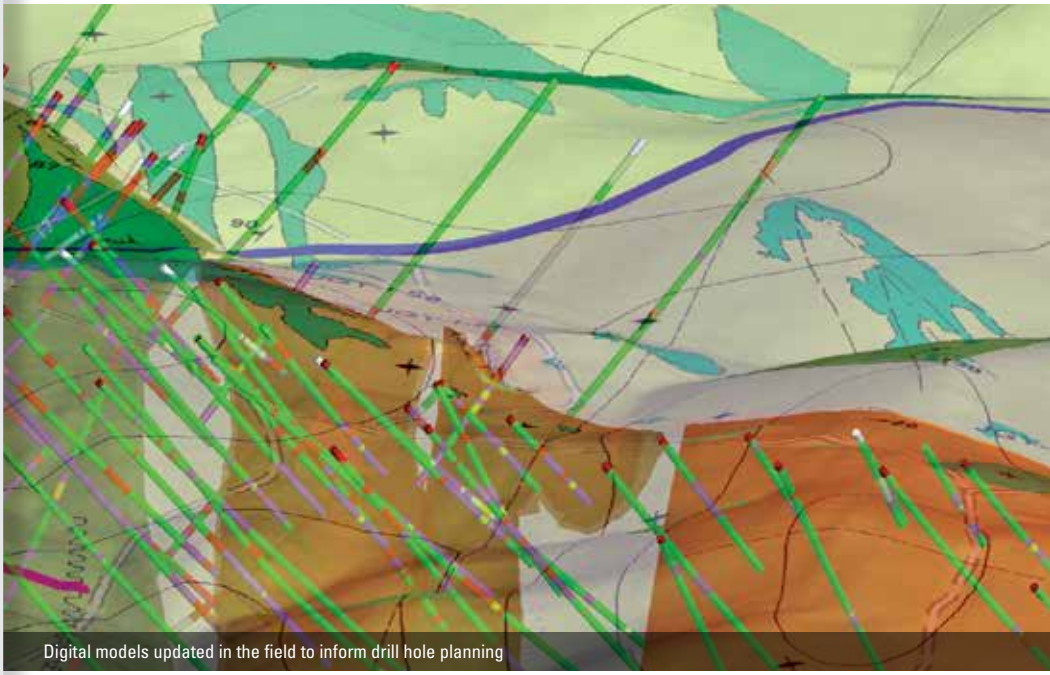


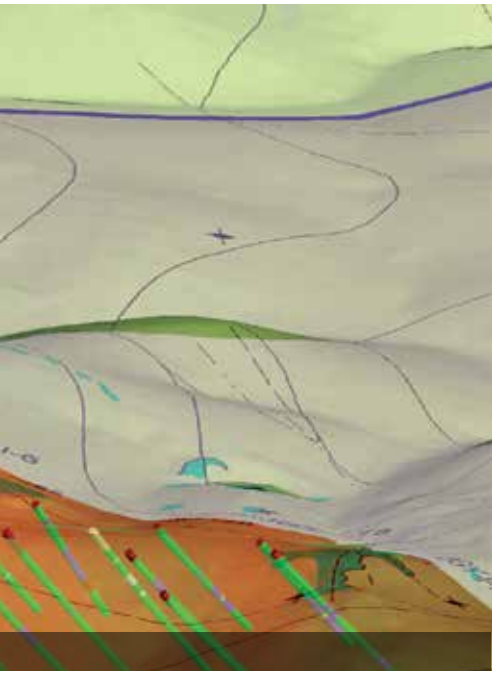
Digital models updated in the field to inform drill hole planning

With clients' exploration budgets being squeezed, long gone are the days of planning collar locations and orientations for a whole drilling programme at the outset of a campaign. It is now imperative that the modern exploration geologist can plan holes on the fly, modify drilling locations to achieve successful drilling intercepts, and maximise time and budgets. Although it has detractors, the introduction of implicit modelling software programs has revolutionised geological modelling. This allows geologists to visualise data effectively, identify crucial trends and structures, and rapidly create multiple interpretations of geological and mineralisation models, compared to CAD-based methods of 10 years ago. SRK has embraced implicit modelling software, like Leapfrog Geo, and uses them as a valuable tool in dynamic exploration programme design.

SRK recently used Leapfrog Geo this way to great effect during a long-term drilling programme for a client in Saudi Arabia. SRK was brought in to design and supervise a surface mapping and diamond drilling programme which hosts discrete, discontinuous, gold-bearing quartz veins. The data collected and interpretations made were then used to build the Mineral Resource Estimation completed by SRK.

SRK recognised this opportunity to create a dynamic programme design with implicit modelling. Data collected in the field could immediately be used to update a working 3D geological model, then used to direct drill-targeting in real-time. Informed decisions regarding collar positioning, borehole density, drilling orientations, and end of hole could be made swiftly based on evolving data. The dynamic quality control of drilling data meant assessing issues and bias as they arise. In this approach the targets were drilled and the drilling budgets optimised.

With the gradual addition of mapping and logging data, a dynamic but more



holistic model could be produced. Also, regular programme updates could be distributed through 3D visualisations.

While the usefulness of implicit modelling has been well established, quality technical, geological, and structural data must be collected and interpreted in a traditional manner. Drafting scaled cross sections showing drillhole fences with annotated interpretations should continue in drill programme management. This ensures that the geologist understands and interprets the geology rather than rely on a "black-box" approach using software. The project geologists can then scan these cross sections and reference them within the software to assist with 3D digital interpretation.

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Integrating geotechnical and hydrogeological data gathering

The Ministry of Mines is seeking to grow the mineral sector in India through a new mineral exploration policy. This policy has encouraged the mineral exploration sector in India. However, developing a greenfield mineral property and acquiring the new land required is a complex undertaking. This fact has prompted an increase in brownfield exploration of existing operations where drilling programs are usually only planned to capture the extent of the mineralisation and its grade variability. This approach often forgoes the opportunity to gather additional data, such as geotechnical or hydrogeological data, which form the basis of mine expansion planning.

In isolation, the datasets required for geotechnical or hydrogeological studies are costly to obtain but integrating geotechnical and hydrogeological data collection in brownfield exploration drilling can substantially reduce the cost.

An integrated data gathering program can easily be adopted during mineral exploration. Before routine geological logging, sampling and assaying, a geotechnical and structural logging program may produce a robust geotechnical dataset, which is key to defining the rock mass characteristics. These results can be combined with geological data to map the geotechnical domains and determine geotechnical design criteria for each of these domains that can be applied to evaluate slope design in open pits or underground mine design.

Exploration drill holes can also support hydrogeological investigations that typically include a range of tests, which not only supports quantifying aquifer parameters, but also identify faults that are frequently the principal conduit for water flows into the mine.

SRK assists clients in India to gather quality geotechnical and hydrogeological data during mineral exploration using many of these techniques. The study outcomes not only ensure compliance with regulatory frameworks, but also help achieve an optimal mine design based on geotechnical and hydrogeological data modelling.

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SUJIT ROY

Sujit, PhD, is a Senior Engineering Geologist who specialises in the geotechnics and hydrogeology of open pit and underground operations. With over 14 years of academic and mining consulting experience, Sujit has worked on mining projects in India and abroad, in Indonesia, Malaysia, Somaliland, Sudan, Tanzania, Kenya and Oman, including operating and greenfield projects. His background includes designing and managing mining site investigations, gathering geological, structural and rockmass data, and field hydrogeological data. His expertise includes 3D geological and structural modelling, and numerical geotechnical and hydrogeological modelling.

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Casing installation in an exploration borehole for aquifer pumping tests

Examples of typical errors detected in geotechnical core logging

In the first stages of a mining project, it is a cost saving advantage to collect the geotechnical basic parameters required for the geotechnical rock mass assessment during exploration. The most used geotechnical classification systems are: Q system (Grimstad & Barton, 1993), RMR (Bieniawski, 1989), RMR (Laubscher, 1990), IRMR (Laubscher & Jakubec, 2001), and GSI (Hoek et al., 2013).

ANDREA RUSSO

Andrea has 25 years of experience in the mining industry. He has worked in porphyry copper deposits, acquiring strong experience in geological, structural and geotechnical mapping for underground mining, defining and characterising structural domains, geotechnical domains and fragmentation assessment. He specialises in rock mass geotechnical characterisation, geomechanical laboratory tests analysis, defining the caving sequence and caving front orientation and defining ground support through empirical methods. Andrea worked on various open pit projects analysing slope stability in Canada and South Africa. He worked on an environmental project acquiring experience in rock mass grouting using the GIN method.

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The empirical classification systems still represent valid tools, especially during exploration as a first approach for mining and geotechnical design, to define ground support, fragmentation, cavability, stope and pillar stability.

For many projects in which SRK has been involved, one of the first tasks is to review the geotechnical database proceeding from exploration-stage geotechnical core logging, and check for errors in data collection. Typical errors in core logging relate to the rock quality designation estimation for example. This includes core pieces less than 10 cm, non-intact rock, or the length of core piece from a mechanical break to a natural joint. In calculating fracture frequency, typical errors are unexplained mechanical breaks and natural joints, and discovering that the angular correction is not applied to calculate the real spacing between discontinuities. Also, we often recognise an incorrect description of the joint condition, especially affecting the roughness condition, as loggers are not considering the scale of core logging.

These errors may be due to using the wrong core logging procedure or an inexperienced worker new to exploration core logging.

The described errors can lead to an erroneous geotechnical rock mass assessment that could impact all aspects of a mining project, from the mine design to the economic evaluation.

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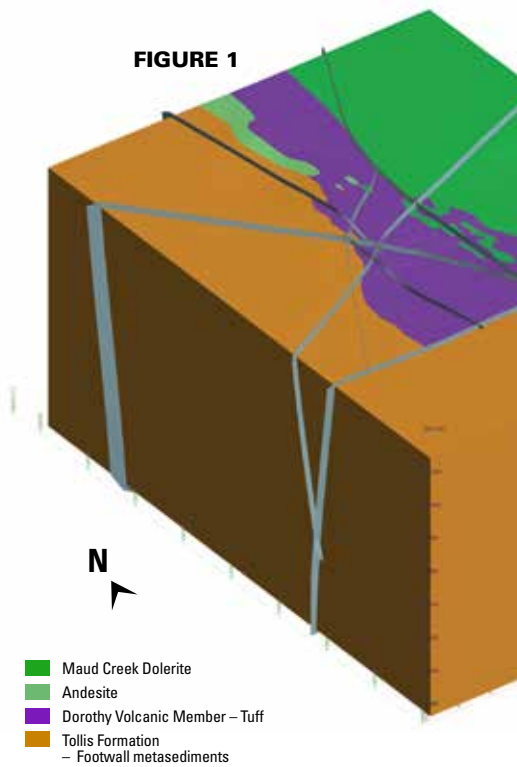
Examples of natural joints logged as mechanical breaks

FIGURE 1



Under the JORC Code, reporting a Mineral Resource requires sufficient confidence in the continuity of mineralisation to enable correlation between the sample points that form the basis of the resource. Achieving this confidence relies on understanding and interpreting the deposit's mineral system, geological and structural framework, mineralisation timing, and controls. Understanding the underlying framework is critical for defining the position and geometry of mineralisation. Geological modelling is a powerful tool that helps geologists to better investigate and define a deposit's mineral system and structure thereby improving confidence in interpretations, helping to reduce exploration risk, and improving the quality of resource domains for resource estimation.

Implicit modelling (Cowan et al., 2003) enables the integration and modelling of a diverse range of

Geological and structural modelling for better mineral resource estimation

FIGURE 2

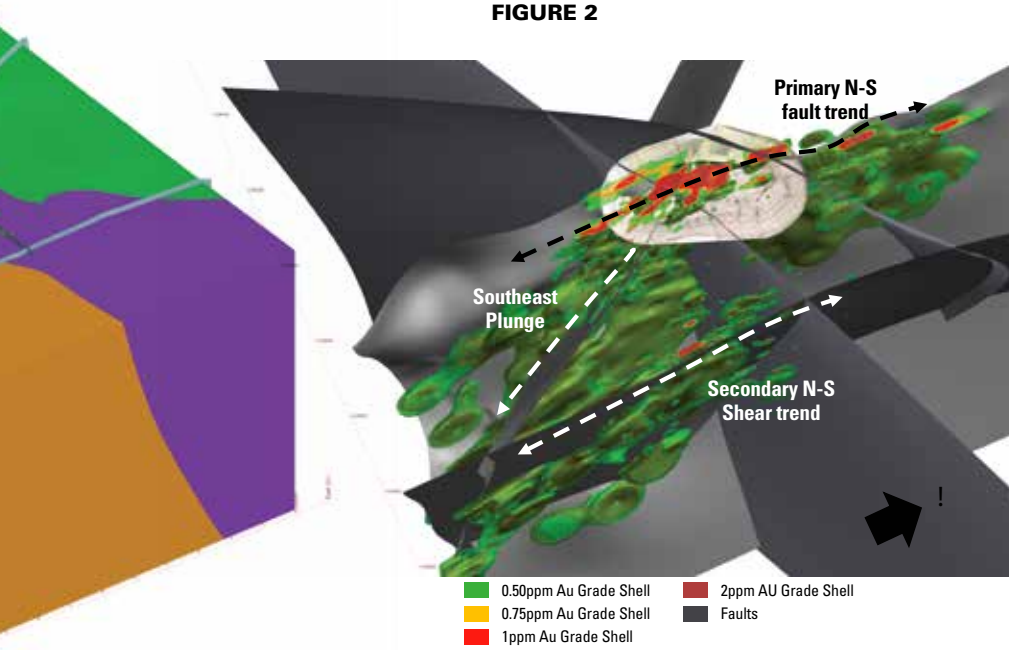


FIGURE 1: Maud Creek Deposit's primary modelled lithologies (cover units not shown)
FIGURE 2: Preliminary modelled gold grade shells and fault architecture (blue), illustrating southeast plunge of gold mineralisation along intersecting fault structure

datasets in a more streamlined and versatile workflow than conventional wireframing methodologies (e.g., CAD-based approaches). Advanced visualisation and structural modelling toolsets allow geologists to better analyse and interrogate the datasets to explore the deposit structure, timing relationships, and mineralisation controls. By applying this methodology, improved confidence in the outputs are achieved, providing models and resource domains that honour the geology and the structure, not just link grade distribution.

The Maud Creek gold deposit in the Northern Territory is an example that highlights the importance of employing 3D structural modelling to underpin the resource domaining process (Figure 1).

The deposit is understood to be structurally controlled with mineralisation hosted within the north–south striking Maud Creek fault and lithological association with the mafic tuff sequences of the Dorothy Volcanic Member.

To fully understand the mineralisation controls of the deposit, all available drilling, historic pit mapping, regional geological mapping and geophysical datasets were integrated in Leapfrog's 3D modelling system. Preliminary modelling of the gold grade using Leapfrog's implicit modelling system (Figure 2) demonstrated a strong fault control on the gold distributions, with gold dipping along the main Maud Creek fault. It also illustrated a previously unrecognised south-east plunge associated with a cross-cutting fault linking it with a structure identified within pit mapping. Additionally, a north-south structure to the east of the main gold lode was interpreted to control steeply dipping mineralisation in this area and corresponding with regional mapping and geophysical interpretations in the area.

This modelling provided a better understanding of structure, lithological controls, and grade distributions. This additional knowledge was used to develop detailed wireframes of the host vein bodies. Vein geometries were constrained within host horizons, in alignment with geological and structural observations. Grade halos were developed to observe the same controls. This process ensured resource wireframes integrated the underlying geological understanding, which provided greater confidence in the final resource domains. We find 3D geological modelling is a powerful method for integrating and analysing datasets. Improving understanding of the structure and mineral systems of a deposit during the modelling process ensures geology is honoured and ultimately improves confidence in models developed for resource estimation.

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BEN JUPP

Ben has over 10 years of international experience specialising in geology and 3D geological modelling. His experience includes multi-scale mineral and oil and gas prospectivity studies, mineral targeting studies, structural mapping in Africa and Australia, and 3D geological modelling at deposit and regional scales. Ben has strong technical knowledge, which includes structural geology, geophysical analysis, seismic interpretation, structural mapping, geochemistry, GIS and geophysical modelling. He has expertise in several 3D modelling software packages, including GOCAD-SKUA, Leapfrog, and Geomodeller.

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Valuing exploration assets: a way of keeping score

But is it fair to keep score when the size of the goalpost keeps changing?

JAMES GILBERTSON

James has over 18 years of experience in the minerals industry both as an exploration and resource mine geologist. He has conducted and managed numerous exploration programmes globally and specialises in their design, assessment, and target generation. He also directs metallogenic framework studies, technical due diligence, valuation studies and exploration strategies at a state level as well as for mining companies. James is a Principal Exploration Geologist and Managing Director of SRK Exploration Services.

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MATHEW DAVIES

Mathew is a Senior Geologist with 8 years combined industry and consulting experience in the Australian mining industry, predominantly in the Hunter Valley of New South Wales. Since joining SRK in 2011, he has been involved in a range of coal and mineral work, including coal and mineral exploration programmes, both mapping and drilling; development of 3D geological models for coal and mineral resource evaluations, and coal and mineral asset valuations.

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Exploration valuation is considered somewhat of a dark art. Unlike income or market based valuations, probabilistic based approaches (such as SRK's Exploration Risk, Kilburn, and Bayesian) rely to some degree on subjective interpretation of geological aspects. However, these aspects provide a true geological context for valuation and as such these results can be used beyond simple monetary values. Relative valuations can be used as effective tools during exploration ranking and target generation.

SRK recently used relative valuations as a key to ranking a series of early-stage exploration targets and licences across the Nubian Shield. Careful assessment of the probabilities of each target to develop through to the next exploration stage, (through the systematic assessment of source, fluid, pathway and trap descriptions), allowed clear investment priorities to be defined. This sort of valuation-based ranking limits subjectivity when assessing where a company's resources can most effectively be targeted.

Further, relative valuation through a project's or target's exploration history can be used as a tool to illustrate exploration success. There are many techniques for assessing exploration success, be it dollars spent per ounce discovered or share value growth. However, relative valuation, using the same probabilistic approach at particular exploration stage gates gives us a graphical picture of success through the project's development that is grounded in geology (Figure 1).

Careful continued geological ranking of targets within a company's portfolio can aid in directing limited investment while reducing exploration risk and aid in communicating an exploration strategy to upper management and investors.

Understanding Comparative Transactions

A 100,000 troy-ounce gold project in one of Western Australia's prime gold fields can double or halve in value from one year to the next. This is because, despite the technical value of that project remaining the same, it is only worth what someone will pay for it. The market value is driven by external factors including investor sentiment, political situation, tax incentives, commodity price, and availability of infrastructure.

FIGURE 1: Schematic example of exploration success estimates through progressive relative valuation

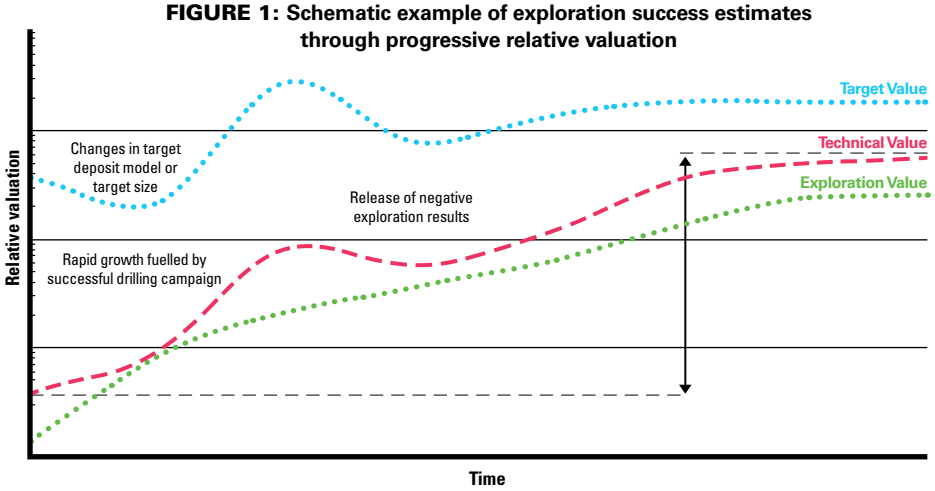


FIGURE 2: Gold transactions in Western Australia during 2016

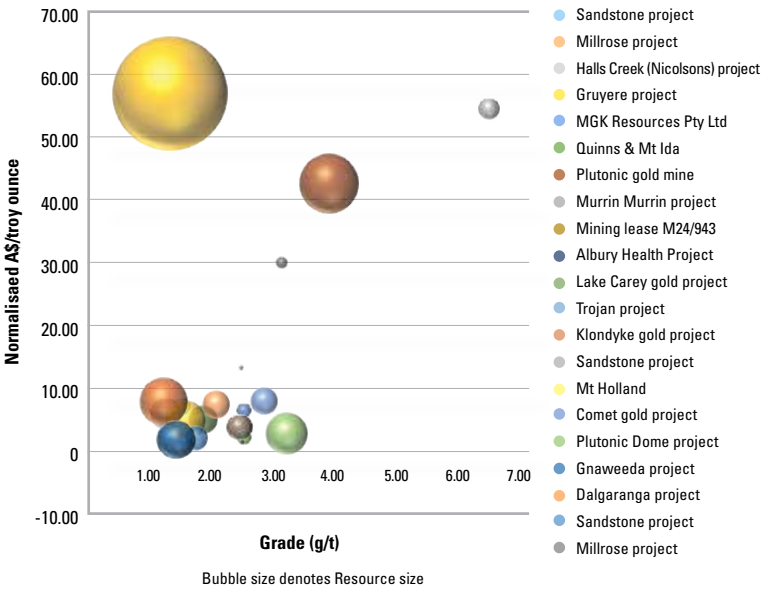
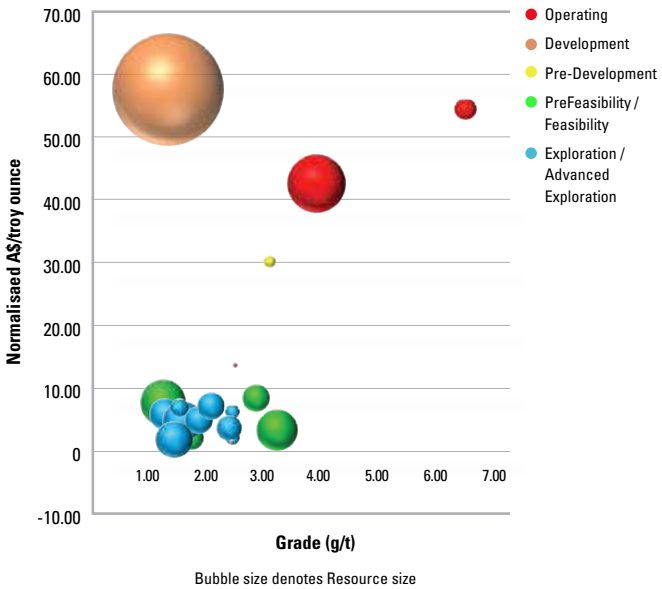


FIGURE 3: Gold transactions in Western Australia during 2016 categorised using development stage



The comparative transactions method of valuing projects is well understood and very simple. Like selling a house, look for houses on the same street, with the same number of bedrooms and bathrooms, that have sold recently. The same concept applies to mining and exploration projects, yet it isn't always adhered to. For example, there are valuations where gold projects are the basis being used to value copper, lead or zinc projects, or where operational mines are used to value early exploration stage projects. That's like using an apartment block to value a detached home.

In reality, applying a consistent and rigorous methodology to every valuation provides the most accurate valuations. Transactions should be researched and identified every time with shared commodity type, development stage, mineralisation style, and mining type. The transaction details should also be vetted to ensure the dollars paid and the implied dollar per tonne are not inflated by royalties, offtake agreements, or contingent options. Then, normalise these datasets to market conditions at the valuation date for comparison. Where a transaction is not transparent enough it should be excluded. These logical steps are clearly delineated in the real estate markets but commonly not applied in the mining sector.

Graphical and statistical analysis of these transactions can spot outliers or explain anomalous values. Figures 2 and 3 graph transactions involving gold projects with Resources in Western Australia during 2016. Initially, without context (Figure 2), we see examples of how large tonnage, low grade projects can be acquired at a similar cost, on a dollar per troy-ounce basis, to small tonnage, high grade projects. The remaining clustered data points are less enlightening. However, with context (Figure 3), by categorising using development stage, the picture is clearer. Disparities can be highlighted, despite similarities in total ounces and grade.

More interestingly, the feasibility stage and exploration projects do not show an obvious change in value although this would normally be expected. This suggests that in 2016 the market was only paying well for projects that had been de-risked through proven production or had well-demonstrated economics. Alternatively, the transaction dataset for 2016 may be too small to sufficiently differentiate these categories.

Ultimately, determining the valuation range of a project depends on researching the most appropriate transactions and applying appropriate modifying factors. Correctly categorising those transactions, in context, is crucial to determining ranges for deriving market value.

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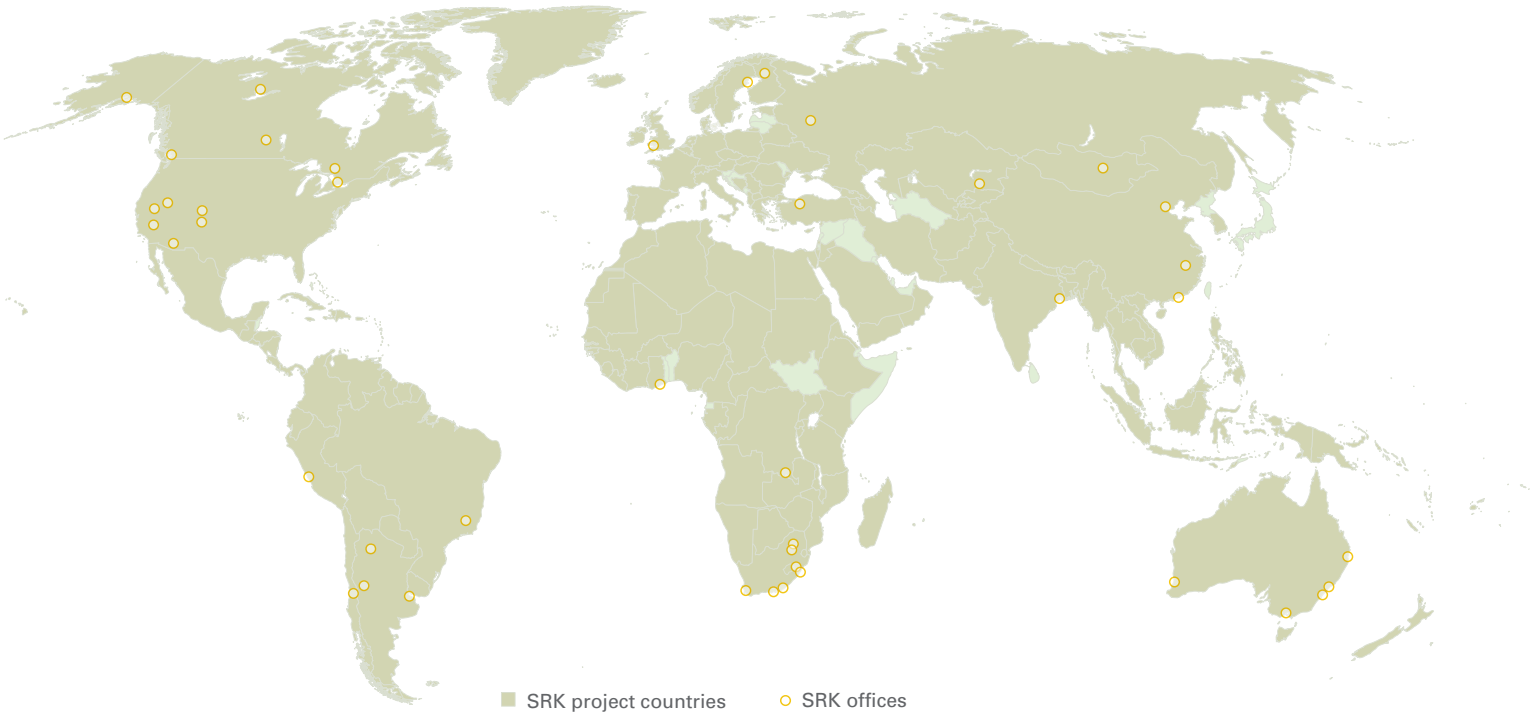

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