srk news
Gold focus

Gold perspective: from exploration to closure

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Gold, quartz, and arsenopyrite from the Rosia Montana deposit, Romania

Gold mining presents a unique set of technical and environmental challenges, requiring an interdisciplinary approach from exploration through to mine closure and defining the critical practices that shape modern gold mining. This SRK News issue highlights these challenges.

In gold exploration targeting, it is critical that early-stage geological assessments are done correctly to evaluate the impacts on mine design and resource estimation. There are many gold projects that have failed due to a lack of geological understanding. This can be a challenge when dealing with legacy mining data, such as in the Central Asian region, for example, the integration and validation of historical Soviet-era information. Several articles explore how to move beyond data-driven exploration by addressing legacy data issues and integrating structural interpretations of aeromagnetic data to improve mineral targeting.

Always a challenge in gold mining is the extraction of gold from narrow veins in underground operations. How to manage dilution and control costs in mining methods are reviewed, illustrating how meticulous planning and innovative solutions can support viable operations despite difficult ore conditions. In tandem, the best practices for geotechnical and hydrogeological (e.g., pore pressure) evaluations for open-pit gold mines are discussed — benefiting from pore pressure assessments and drawing on valuable geotechnical experience from the Maricunga gold belt deposits in Chile.

…continued

Gold perspective: from exploration to closure *(continued)*

There are several intricacies of processing free-gold and refractory gold in a wide range of gold deposit types. Through case studies, we see how local mineralogical conditions demand tailored extraction techniques and technical adaptations. Environmental geochemistry studies explore the effects of gold's "unwanted neighbours" — deleterious elements that must be carefully managed to minimize environmental impact. The issue also reexamines the myth that rinsing in gold cyanide heap leaching is essential to remove cyanide and to stabilize geochemically a heap.

Practical solutions address challenges in data scarcity for waste design, particularly in Brazil, where limited geochemical data affects waste management and long-term closure planning. Enhanced seepage management in tailings facilities is highlighted by a case study from a Northern Mexico mine that extracts gold and base metals.

Environmental, social, and governance (ESG) principles in gold mining are increasingly important to both stakeholders and investors. An analysis of responsible tailings storage options highlights approaches from Latin American projects, where risk management, economic viability, and reduced environmental footprint are central.

Together, these articles provide a comprehensive overview of the technical, environmental, and social considerations shaping responsible gold mining, offering insights into the innovations and strategies that define this sector's evolving landscape.

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James has over 25 years of experience in structural analysis of mineral deposits. He specializes in deciphering deposit-scale controls on ore plunge in precious and base metal deposits, district-scale geophysical interpretation for exploration, and 3D geological modeling. He provides technical reviews and operational support for global exploration and mining projects, working across Europe, North, South, and Central America, Asia, and Africa. James has also taught over 50 Applied Structural Geology courses to more than 1,500 geologists and engineers.

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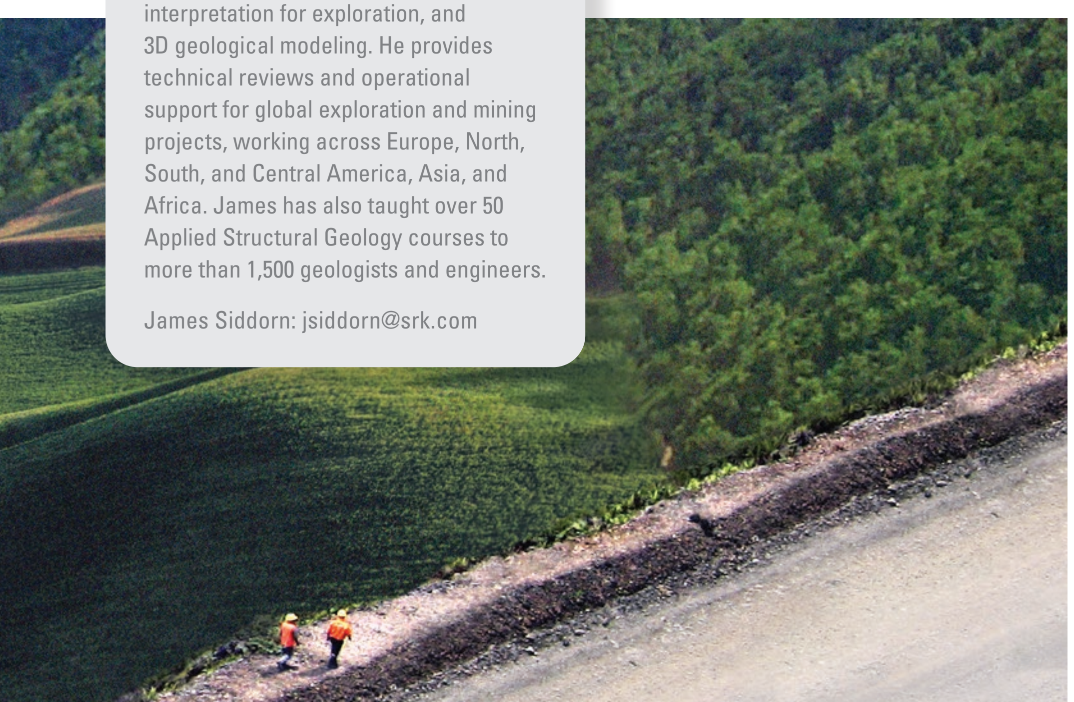

Land restoration adjacent to an operating mine

The Khotgor gold project

Khotgor gold project (looking south)

As exploration steadily moves into more complex geological terranes, geologists require a range of tools and methods. Comprehensive understanding of mineral systems, including regional geotectonic and metallogenic context, is key. System elements include mineralisation fluid sources/drivers (e.g., fertile granites, volcanic or metamorphic sources). Fluid pathways enable the migration of mineralisation fluids to near-surface depositional sites. Deposition controls can include favourable lithologies with chemical or rheological contrast or structural trap sites. These elements can be used to predict where mineralisation may be and help narrow the exploration search window.

The Khotgor Gold project is an early-stage exploration project that exemplifies how applying mineral system analysis can improve understanding of the mineral potential of a project and assist exploration targeting. The project lies in the Khovd Province, approximately 1,400 km southwest of Ulaanbaatar, Mongolia, and hosted in the Trans-Altai Zone, Dulate Arc subzone, part of the Edrengiin metallogenic belt. This region is prospective for a range of island-arc-magmatic–related mineral systems, including volcanogenic Au-Cu, porphyry Cu-Mo (±Au, Ag) and granite-related Au-vein type systems. Several high-K calc-alkaline–related Au-Ag quartz vein targets have been identified in the project.

SRK undertook an independent technical review of the exploration results and identified target areas and recommendations for ongoing exploration. The review encompassed available datasets, including mapping, geophysics (aeromagnetics, induced polarity), satellite (ASTER, Landsat) and geochemistry (rock chips, soils). These were used to assess the project's defined mineralisation and broader mineral potential, with porphyry-style mineralisation identified as an additional target. Geophysical and satellite interpretations were integrated with all geological datasets to refine the structural and lithologic architecture and alteration patterns potentially associated with mineralisation. Evaluation of the defined Au-Ag vein mineralisation was also undertaken to define the local controls to assist with exploration targeting.

For exploration targeting, a mineral system framework was developed for Au-Ag vein and porphyry mineral systems. These included fluid sources/drivers (arc-related calc-alkaline rocks from mapping and geophysical interpretations), fluid pathways (long strike-length structures, interpreted structural dilational sites) and fluid trap sites (favourable lithologies or structural traps, phyllic or argillic alteration, soil/rock chip anomalies).

Targeting was conducted in ArcGIS, a popular geographic information system (GIS) software, applying a fuzzy logic method, integrating ranked mineral system inputs developed from exploration and interpretive inputs. Targets were defined from areas with a higher number of highly ranked overlapping elements. By applying integrated data analysis to develop the structural, lithological, alteration interpretations and mineral system framework, SRK was able to provide an improved understanding of the project for effective future exploration.

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BEN JUPP

Ben has 20 years' experience specialising in geology and 3D geological modelling. He has worked in many commodities within Australia and internationally, including gold. His experience includes multi-scale mineral prospectivity and targeting studies, structural mapping, and 3D geological modelling at both deposit and regional scales. Ben has strong technical knowledge inclusive of structural geology, geophysical analysis, seismic interpretation, structural mapping, geochemistry, GIS, and geophysical modelling. Ben has expertise in several 3D modelling software packages, including GOCAD-SKUA and LeapFrog.

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PETR OSVALD

Petr has some 30 years' experience in geology, exploration, resource estimation, mining engineering, mine management, and project evaluation. He has extensive international experience – he has evaluated mining projects in eight countries across three continents, as well as conducted early stage exploration, resource estimates, and mine to mill reconciliation.

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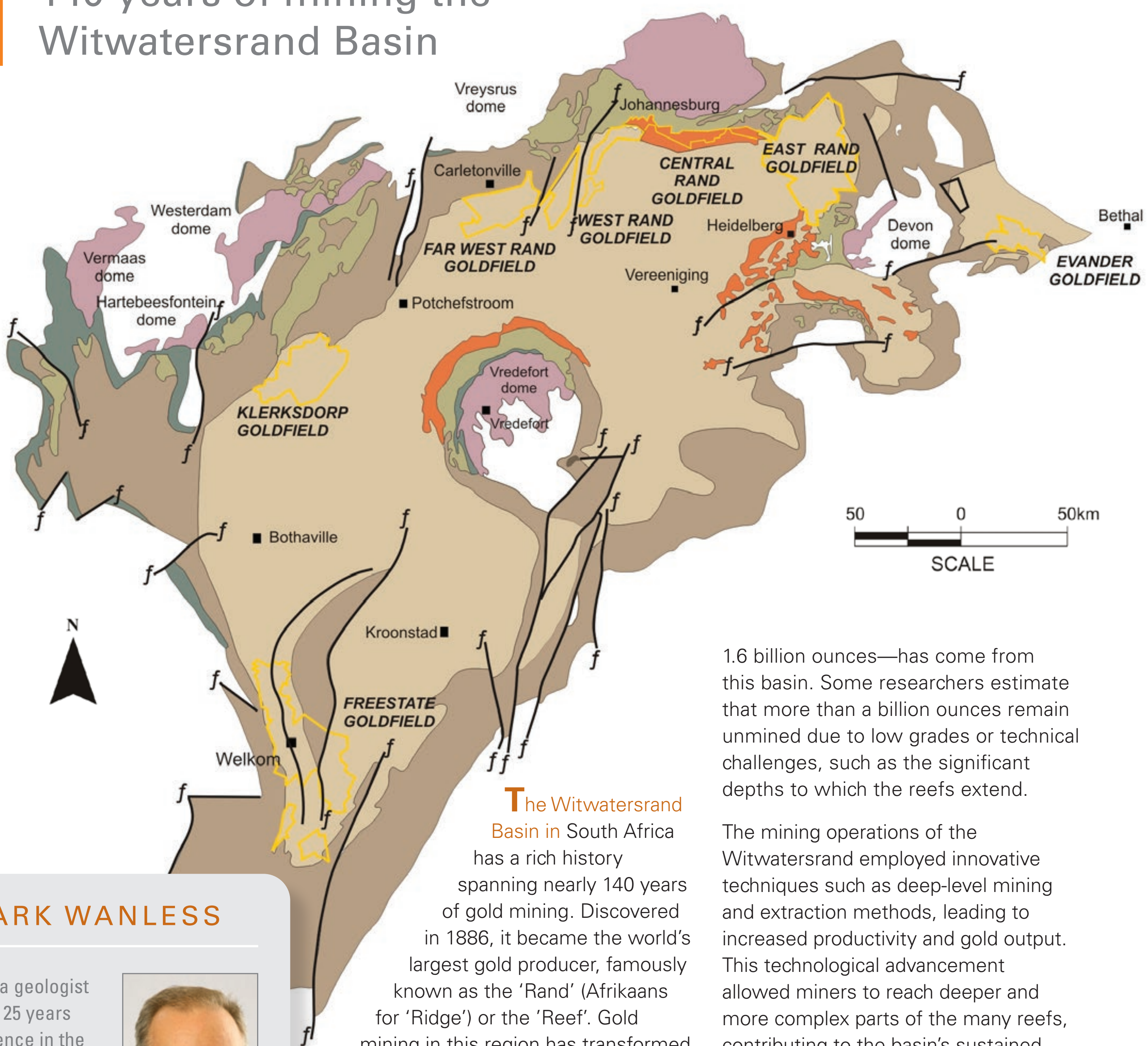
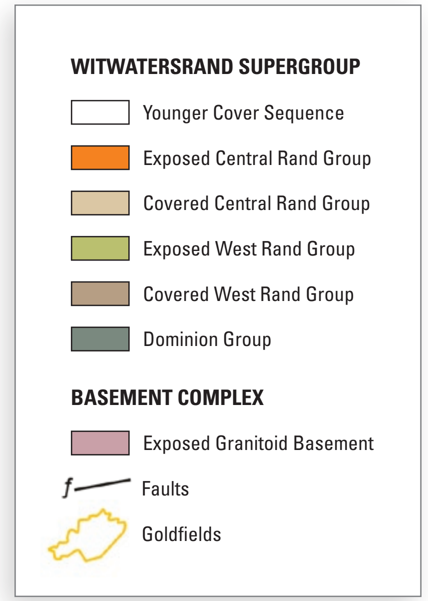
140 years of mining the Witwatersrand Basin





MARK WANLESS

Mark is a geologist with over 25 years of experience in the mining industry. He has a special interest in the Witwatersrand Goldfields, where he started his career. He has worked on projects and mines in all basins of the Witwatersrand Goldfields. Mark has also worked in exploration and mines around the world, specialising in Mineral Resource estimation covering commodities including gold, PGEs, base metals, iron, manganese, nickel, lithium, fluorspar, and mineral sands.

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The Witwatersrand Basin in South Africa has a rich history spanning nearly 140 years of gold mining. Discovered in 1886, it became the world's largest gold producer, famously known as the 'Rand' (Afrikaans for 'Ridge') or the 'Reef'. Gold mining in this region has transformed South Africa's economy and shaped its history significantly.

The discovery of gold by George Harrison, a prospector who is credited with discovering the Witwatersrand gold reef in 1886 near Johannesburg, and the subsequent developments attracted an influx of fortune seekers and prospectors to the area. The rapid growth of Johannesburg was fuelled by this gold rush, transforming it from a tented camp into a bustling city. The Witwatersrand Basin has been an extraordinarily prolific gold-producing region. It is estimated that 30–40% of all the world's gold ever mined—over 1.6 billion ounces—has come from this basin. Some researchers estimate that more than a billion ounces remain unmined due to low grades or technical challenges, such as the significant depths to which the reefs extend.

The mining operations of the Witwatersrand employed innovative techniques such as deep-level mining and extraction methods, leading to increased productivity and gold output. This technological advancement allowed miners to reach deeper and more complex parts of the many reefs, contributing to the basin's sustained production over the years.

The Mponeng gold mine, previously known as Western Deep Levels #1 Shaft, holds the title of being the world's deepest mine. At its deepest point, it reaches around 2.5–4 kilometres (approximately 1.6–2.5 miles) below the Earth's surface. This mine represents the extreme depths that mining operations in the Witwatersrand Basin have reached in their quest to extract gold from deep-seated ore bodies. SRK has been part of many of the technological advancements, and its consultants continue to contribute to the successful operation of the many mines across the basin.

The gold extracted from the Witwatersrand Basin played a pivotal role in the global economy, influencing international gold markets and driving South Africa's economic development. However, the mining industry also faced a variety of challenges, including labour disputes, demanding working conditions and environmental concerns arising from extraction processes and mine tailings.

In recent years, the focus has shifted towards addressing environmental impacts, reclaiming abandoned mines and finding sustainable ways to extract remaining gold resources while mitigating ecological consequences. SRK's multidisciplinary expertise in geology, mining engineering, ESG, tailings stability management and contamination are integral to supporting successful and sustainable mining practices within the Witwatersrand Basin. Their contributions have helped mining companies navigate the complexities of mining in this historically rich but challenging gold-producing region.

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Solving the scale paradox in gold exploration

In all mineral exploration, the 'Scale Paradox' is the fundamental factor that exploration professionals must overcome. The paradox is how to go from a global/country/terrane scale down to targeting an individual drillhole. One would think that when moving from a larger area to a smaller one, exploration would become easier, but it doesn't; it becomes more difficult and more expensive. This is the Scale Paradox.

Historically, geological mapping was key to bridging this paradox. This allows for the definition of areas of anomalous mineralization or key lithological/alteration/structural associations on the surfaces. However, as exploration continues to look deeper, geological mapping is no longer reliable. Explorers look for other techniques, like geophysical or geochemical targeting, all focused on reducing the Search Space and solving the paradox.

Exploration is now being driven by more and more diverse datasets, with the hope that a combination of data types can help define exploration targets.

Geologists love data and hate interpretation. We love absolutes, values, and numbers, and so explorers try to acquire more and more data. Machine learning approaches are being used to assimilate and cogitate these diverse datasets in the hopes that the computer can do much of the interpretation. There is a consistent drive to define a geochemical anomaly before critically understanding the geological history of a region. However, fundamental geological understanding and interpretation must always underpin any element of exploration, and geologists must push themselves to interpret continuously and not rely on absolutes.

A great example is in orogenic gold deposits, where exploration can be extremely difficult. These deposits have limited to no geophysical signature, limited geochemical anomalies, and are associated with tight alteration halos. This means methods that can be applied to other deposit types, like electrical geophysical surveys in massive sulphide deposits or alteration vectoring in porphyry copper deposits, do not work in orogenic gold. Luckily, these deposits form in major mountain-building events and are strongly controlled by structures therein. Using geological knowledge about how structures moved and created dilatancy illuminates exploration targets never seen and solves the Scale Paradox. This cannot be achieved simply with more and more data; fundamental geological skills remain the most important factor.

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Geological mapping for orogenic gold, Saudi Arabia

Interpretation of aeromagnetic data for mineral exploration targeting

Understanding the structural framework of a region is critical in identifying areas of potential mineralization; consequently, the structural and lithological interpretation of 2D and 3D geophysical data is a powerful tool in mineral exploration targeting. Aeromagnetic data are particularly useful, since they display a wider range of geological attributes than radiometric, gravity, and electromagnetic data. They can be applied at any scale or depth, in all terranes, with high resolution. SRK is an expert in the interpretation of aeromagnetic data and has completed projects worldwide for a wide range of commodities at scales ranging from deposit- to district- and country scale, with proven results leading directly the discovery of new deposits.

The interpretation of aeromagnetic data is based on three fundamental processes: interpreting geophysical data, applying geological models that must include an understanding of the geological history, and mapping mineral system concepts.

SRK's process involves a systematic approach that involves recording form lines from derivative imagery, cross-referencing aeromagnetic observations with surface geological data, integrating additional data sets, interpreting fault locations, scales, ages, and kinematics, and forming a working solid geology interpretation map. This approach helps generate a structural and lithological framework that combines geophysical data with mapped geology, which can be interrogated by mineralization models over a wider area than traditional methods. Interpretations of aeromagnetic data can provide information on paleo-stress orientations and fault kinematics at the time of mineralization. Zones of enhanced structural complexity and/or dilation commonly promote mineralization. These zones can be defined by the analysis of fault kinematics, fault and intersection density calculations, and by fault segment orientation analysis. When combined with knowledge of the geological history and its relationship to mineralisation, this can provide accurate targets and help design drill programs. High-quality interpretations provide a broad view of geological processes and features, making it a cost-effective solution for guiding exploration strategy.

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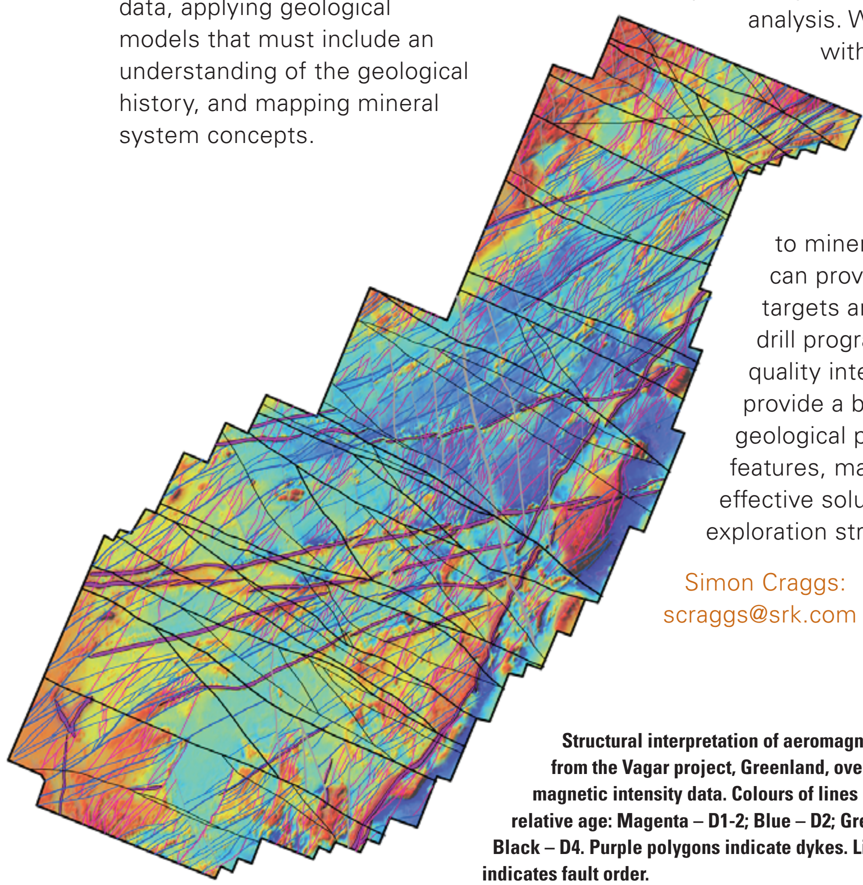

Structural interpretation of aeromagnetic data from the Vagar project, Greenland, overlaid on total magnetic intensity data. Colours of lines indicate relative age: Magenta – D1-2; Blue – D2; Grey – D3; Black – D4. Purple polygons indicate dykes. Line thickness indicates fault order.

Central Asian gold projects

Gold Production Sites of Central Asia (left), Almalyk Mine, Uzbekistan (right)

According to the most recent USGS publication, Kazakhstan and Uzbekistan were the 6th and 10th largest gold-producing countries in the world in 2023, producing 130 and 100 tonnes per annum ("tpa") respectively[1]. SRK has worked with most of the large gold producers in Kazakhstan, Kyrgyzstan and Uzbekistan. The map above shows all notable operating gold mines in the region, many of which are porphyry copper mines and orogenic gold vein systems.

AGMK is one of the largest industrial enterprises in Uzbekistan, operating for more than 70 years. During this time, the enterprise has not only become the country's leader in copper production and a flagship of the Uzbekistan mining industry but has also become strategically important for the country's economy.

In 2021, SRK collaborated with AGMK to estimate mineral resources and ore reserves for copper and gold projects in Central Asia, following the JORC Code. This included a feasibility study for the Kalmakyr and Yoshlik I deposits, which together form the Oliy Ziyo deposit. SRK also conducted resource and reserve estimates for AGMK's underground gold mines, in accordance with the JORC Code.

Altynalmas owns over 15 orogenic gold deposits throughout Kazakhstan at various stages of development; the mines collectively produce 16 tpa of gold. For several years, SRK has assisted in the transformation of datasets, geological models, geotechnical studies and mine plans and prepared the first estimates and technical reports in accordance with the JORC and KAZRC reporting codes.

AltynEx owns the Yubileinoye gold mine in Kazakhstan. In 2022, SRK authored a feasibility study for the mine, the concept being to expand production to achieve 5 tpa through transforming the mine from underground to open pit mining.

Kumtor in Kyrgyzstan is one of the highest altitude mines in the world; it has produced some 15 tpa gold for the last 25 years, contributing over 10% of the country's GDP. SRK has supported the operation through studies on structural geology and waste dump design.

NGMK in western Uzbekistan is the fourth-largest gold mining company in the world. Its assets include Muruntau, which produces 50 tpa gold from the largest open-pit gold mine in the world. SRK has undertaken a number of technical studies for NGMK, assisting in the preparation of Mineral Resources and Ore Reserves in accordance with the JORC Code, the evaluation of slope stability and the development of strategic options. SRK has also been assisting NGMK with its journey towards alignment with international standards for responsible mining.

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1. NASDAQ (10 Largest Producers of Gold by Country)- accessed on 16 April 2024.

MARTIN PITTUCK

Martin has some 30 years of international experience specializing in mineral resource estimation, mining geology, mine project evaluation, and reporting of mineral resources and ore reserves according to international reporting codes. Martin works closely with SRK's team in Almaty and chairs the SRK Kazakhstan board.

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SIMON CRAGGS

Simon has over 10 years of experience in geological mapping and structural analysis of complex terranes. He has contributed to exploration, mining, and hydrocarbon projects, specializing in fault/fracture mechanics and fluid flow in upper crustal settings. An expert in structural interpretation, Simon holds a PhD from the University of New Brunswick.

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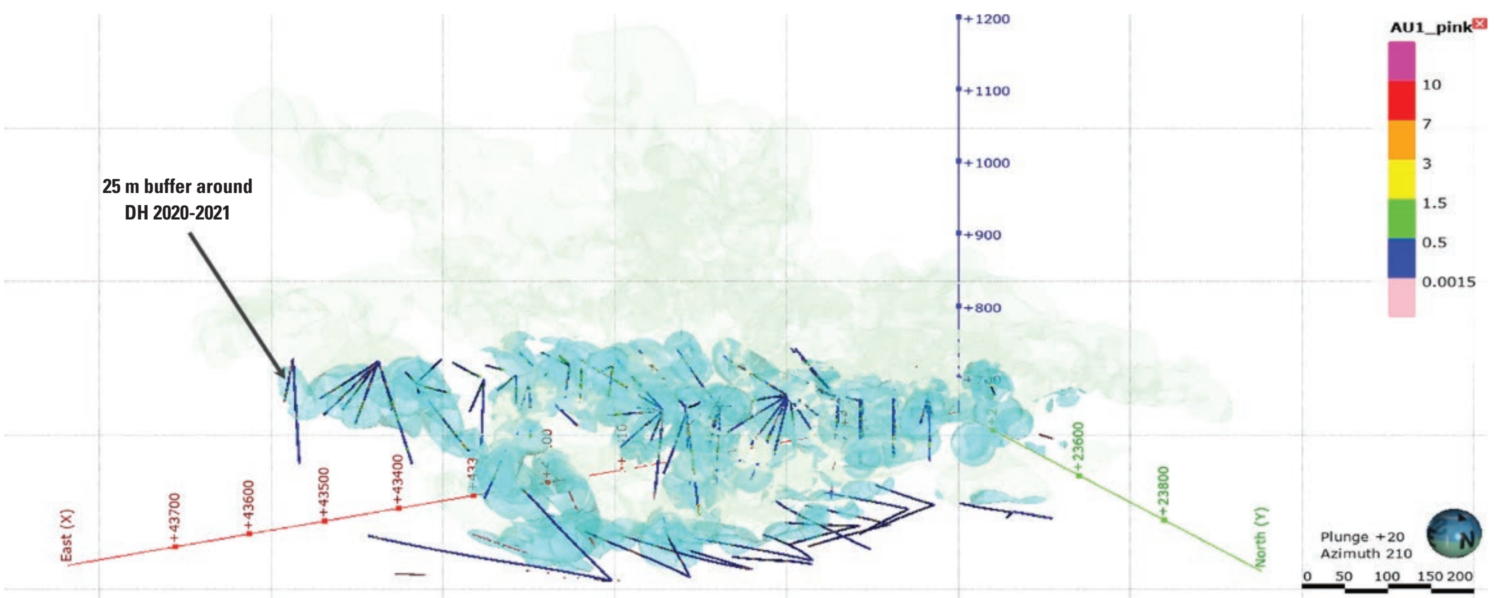
Accounting for biases in historical data, Kyzyl-Alma gold underground mine



Common volume comparison within 25 m distance buffer around 2020-2021 holes and inside 1 g/t AuEq grade shell

SAMAT KOISHIBAYEV

Samat Koishibayev (MAusIMM, FGS) is a Consultant Geologist with six years' experience in mining and resource geology. He worked on various projects within Central Asia, Europe and Russia for commodities such as precious, base metals, coal and industrial minerals. He is responsible for the design and supervision of exploration and resource drilling programmes, QAQC protocols and various sampling designs for metallurgical studies. Experienced in 3D geological modelling and Mineral Resource Estimation as well as preparing technical reports on MRE and other technical studies.

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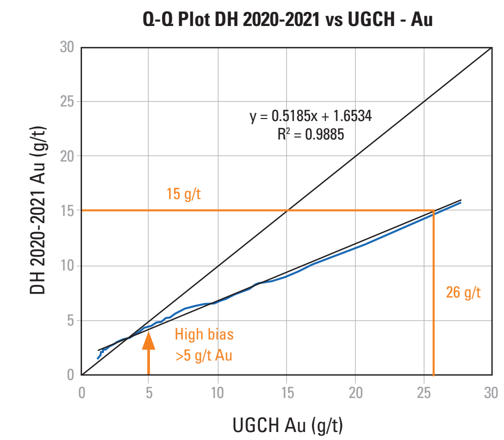
Resource estimates prepared for projects in former Soviet Union countries often rely on historical data that is several decades old. This historical data can have a high risk of bias due to the limitations of sample collection, sample preparation and analytical methods and tools used at the time. A challenge for resource estimation is to identify and account for such biases so that the maximum benefit can be extracted from historical databases.

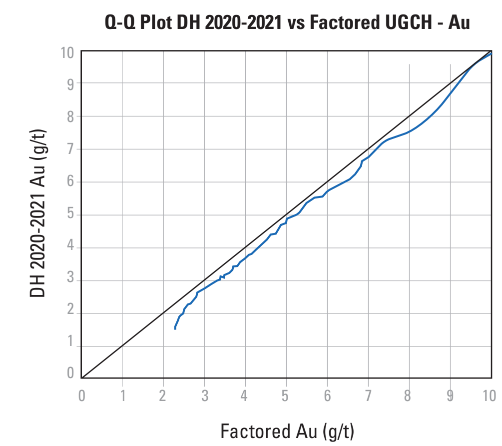
In 2019–2022, SRK Kazakhstan completed the first Mineral Resource Estimate (MRE) reported according to the JORC Code for the Kyzyl-Alma epithermal gold mine in Uzbekistan. Kyzyl-Alma is an operating underground mine which commenced production in 1976. Mining is carried out by sublevel caving.

The information available to support the MRE included detailed verification drilling of historical underground channel sampling and historical diamond drilling.

SRK investigated the difference in Au grade between the 2020–2021 diamond core samples and the historical underground channel samples, inside a common volume to remove any locational bias from the comparison. A 25 m buffer was created around the channels within this volume. The statistical properties of the composite grades from core and channel samples were assessed. Separate block grade estimates were undertaken, first using only drillhole data and second using only channel data. Adjustment factors derived from the common volume block model for Au were applied to the Au and Ag values of all underground channels and historical surface and underground drillholes.

Q-Q plots illustrating the relationship between the 2020–2021 drilling and original underground channels (top right image) and channel grades after application of the adjustment equation obtained from the linear regression factor (bottom right image). Factored grades also showed strong reconciliation to the plant in both grades and contained metal, which was within 10% difference.





Q-Q plots illustrating the linear regression between the 2020-2021 drilling and underground channels. Top figure shows original channel's grades, bottom figure - channel's grades after application of the linear regression factor in the common volume block model.

This bias (historical data high relative to verification sampling) is considered to be the result of a combination of historical laboratory bias and sampling bias, leading to samples not being satisfactorily representative. The results of the production reconciliation allowed for a confident application of an adjustment to the historical grades. As a result, SRK was able to quantify the bias in raw data and use both historical and recent sampling data to support Indicated and Inferred Mineral Resources.

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Gold's unwanted (and forgotten) neighbours

A gold mine is a desirable asset, representing wealth and success. For the prospectors of gold, the lure of shiny yellow metal in streams promised richness; however, barring a few rare examples, gold is no longer so easily acquired. Gold today more commonly occurs in complex metal sulphide ores that require mineral separation and chemical or thermal treatment to render the metal amenable to collection and concentration. Along the way, it must be separated from its metal neighbours. Due to a change in the world's focus on metals, many of these neighbours are now considered valuable, some even more than gold itself. Understanding the geometallurgy of a gold ore is essential in discerning wanted from unwanted neighbours.

Gold is associated with pyrite in almost all ore types. Pyrite may encompass more chemicals than its parts of iron and sulphur. Indeed, gold itself can be part of the pyrite if sufficient arsenic is present, such as in the Carlin belt of Nevada. Here, arsenian pyrite is the main gold mineral, and separation requires intense processing and waste management. Due to the presence of mercury, even atmospheric discharges need treatment. To quote the motto "forewarned is forearmed," understanding this can improve process design to ensure gold's neighbours do not poison the product or the environment.

Another motto, "all that glitters is not gold," can be inversed: not all gold glitters. Gold forms chemical compounds not only as a trace of sulphides, but also as rare minerals containing critical metals such as tellurium, selenium, antimony, and bismuth. Identifying such minerals allows the metallurgist to collect these forgotten metals, produce a value critical need and benefit from an unexpected bounty. Once again, good mineralogical knowledge and geological insight into a deposit improve geometallurgical knowledge and allow the benefit of a gold ore to be maximised.

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ROB BOWELL

Dr. Rob Bowell is SRK's Corporate Consultant in Geochemistry & Geometallurgy with internationally recognised expertise in the geochemistry and geometallurgy of complex ores. For over 30 years, he has specialised in applying geochemistry and mineralogy to diverse mining and engineering projects related to all stages of the mine's life cycle. Rob has coauthored books on arsenic, gold, vanadium and uranium geochemistry as well as mine waste hydrogeochemistry. In 2018, Rob was appointed adjunct professor at Queen's University in Kingston, Ontario, where he continues to do research and teach.

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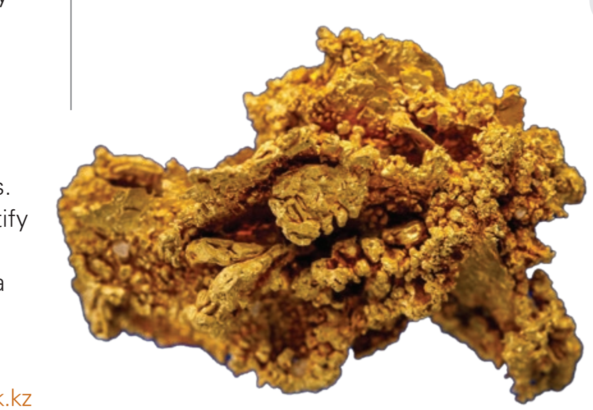

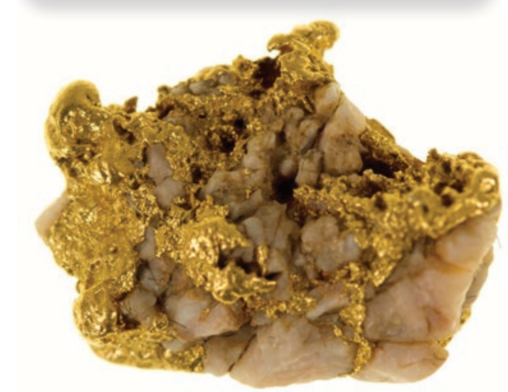

Not all gold shines

Gold, with its shimmering allure and enduring value, has captivated humanity for millennia. Beyond its beauty, gold holds significant economic, cultural and historical importance. Most gold deposits originate from hydrothermal fluids that percolate through cracks in the Earth's crust, precipitating gold-bearing quartz veins. Placer deposits, formed by the erosion of primary deposits, yield nuggets and flakes in riverbeds and alluvial plains. We assume that gold occurs as a shiny yellow metal in veins or streams, but the majority of gold mined today does not shine. This presents challenges in its exploitation.

Placer gold on quartz, California, 7 cm in length (top), Gold associated with Arsenopyrite, California, 5 cm in length

Gold occurs in naturally forming minerals. Native gold and electrum (an alloy of gold and silver) make up more than 90% of gold mineral occurrences, but there are over 40 known minerals that contain gold, mainly alloys with elements like mercury, copper, tellurium and platinum group metals, but also some sulphosalt and a sulphide mineral. Historically, gold was largely mined as a native metal, but in most current deposits, gold occurs as a trace component of pyrite or arsenopyrite or their oxidized equivalents.

The growing complexity of gold ores influences the extraction and recovery processes. Gold as fine particles, often called micron gold, can be recovered by intense milling and leaching by cyanide. Gold that occurs in sulphides or telluride minerals requires pretreatment through chemical, biological, or thermal oxidation prior to leaching and recovery of the metal. This adds cost to the mining project, so it is critical to use geometallurgical and mineralogical tools early in the development of a mine to identify potential host phases to inform the evaluation of any consequence. SRK works with various universities and laboratories worldwide on many complex gold ores using such tools and can not only characterize but also advise on the implications of such results for a mining study.

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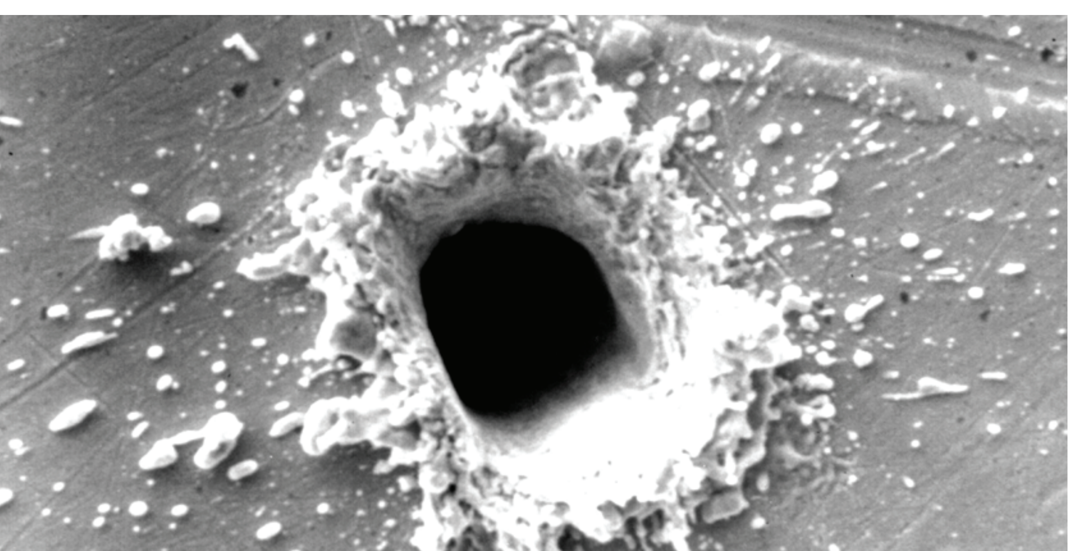
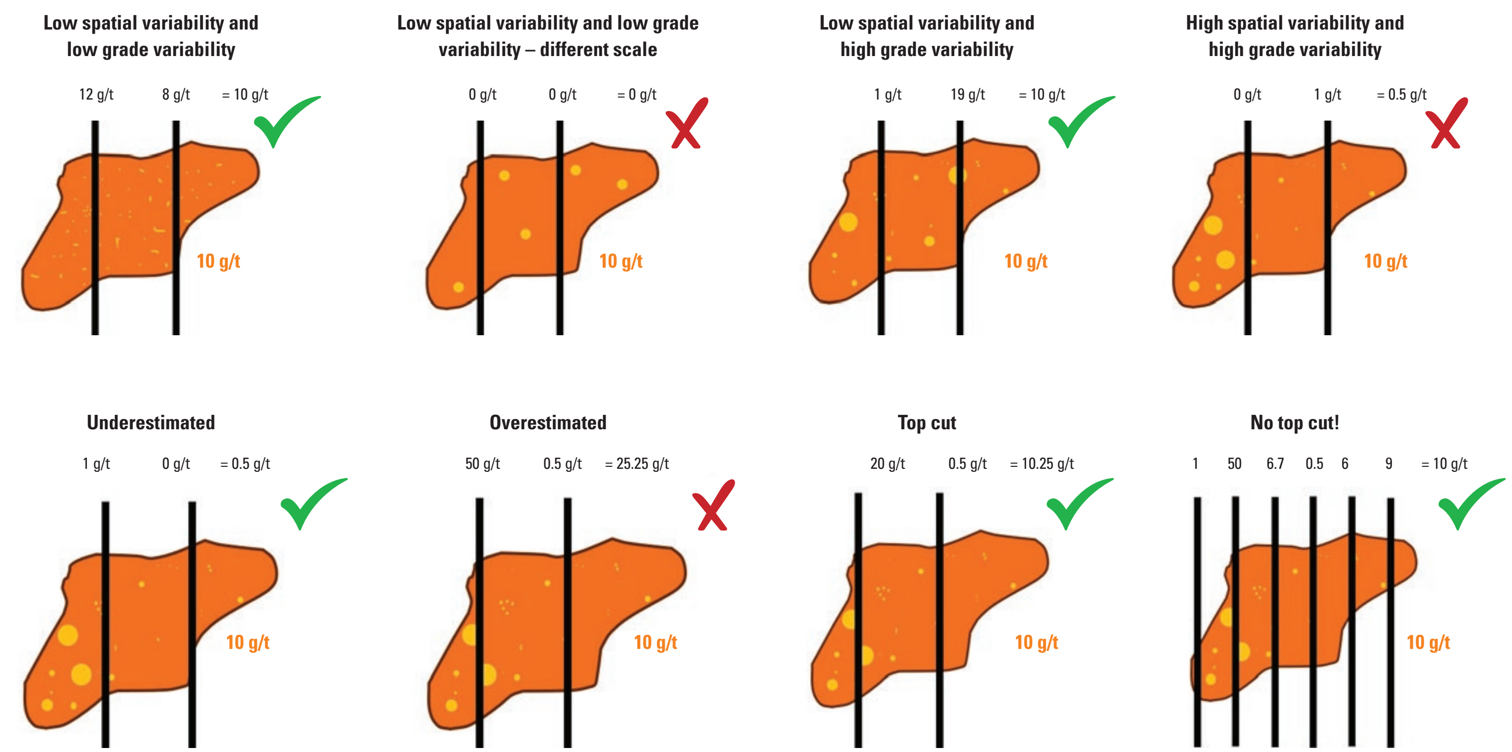


Hole drilled by laser for chemical analysis of gold in pyrite from Getchell mine, Nevada

Navigating high nugget situations: the scary nugget effect

THE SCARY NUGGET EFFECT

'Oh no! It's a high nugget deposit! I won't be able to estimate it with any confidence at all…Arghhhhhh…I give up…'



The illustration above, originally presented at the 2024 Victorian Gold Forum in Melbourne, Australia, highlights some typical mineralisation distribution scenarios and conceptual "high geological nugget" issues, together with ways to resolve them and arrive at a better estimate of the global mean grade.

The top left two images show the differences the scale can make. The top right two images show how spatial as well as grade variability make a difference. The bottom left two images show what can happen when there is insufficient drilling. The bottom right two images demonstrate how sparse drilling with top cuts or dense drilling without top cuts might produce a better average.

In high nugget situations, reasonably accurate global grade-tonnage curve estimation at the selective mining unit scale is usually achievable by using low sample number searches to increase variability while maintaining the correct average grade through ordinary kriging.

Globally accurate and locally precise local block estimation, however, is almost impossible at the resource definition and feasibility stages in high nugget situations. Only when multiple holes are available within each block can estimates be locally accurate.

Depending on the situation, locally precise block estimation may not be necessary if reconciliations based on large volumes and large time scales are acceptable.

If you have low confidence in the variogram model you are using because of difficulties interpreting the experimental variogram, then estimates with several variogram models with different nuggets and ranges can be run to examine the sensitivity of your estimate to the variogram model itself.

In summary, the nugget effect isn't that challenging; we just need to understand the purpose of the model we are creating and how to express the expected local selection variability and or global accuracy correctly for that stage of the project life cycle.

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Danny Kentwell is an Empirical Geostatistician with a background as a surveyor, several years' experience as an open cut and underground design engineer and who often masquerades as a resource geologist. He has been with SRK for over 25 years and has numerous Mineral Resource estimates, reviews, practical papers and presentations to his name.

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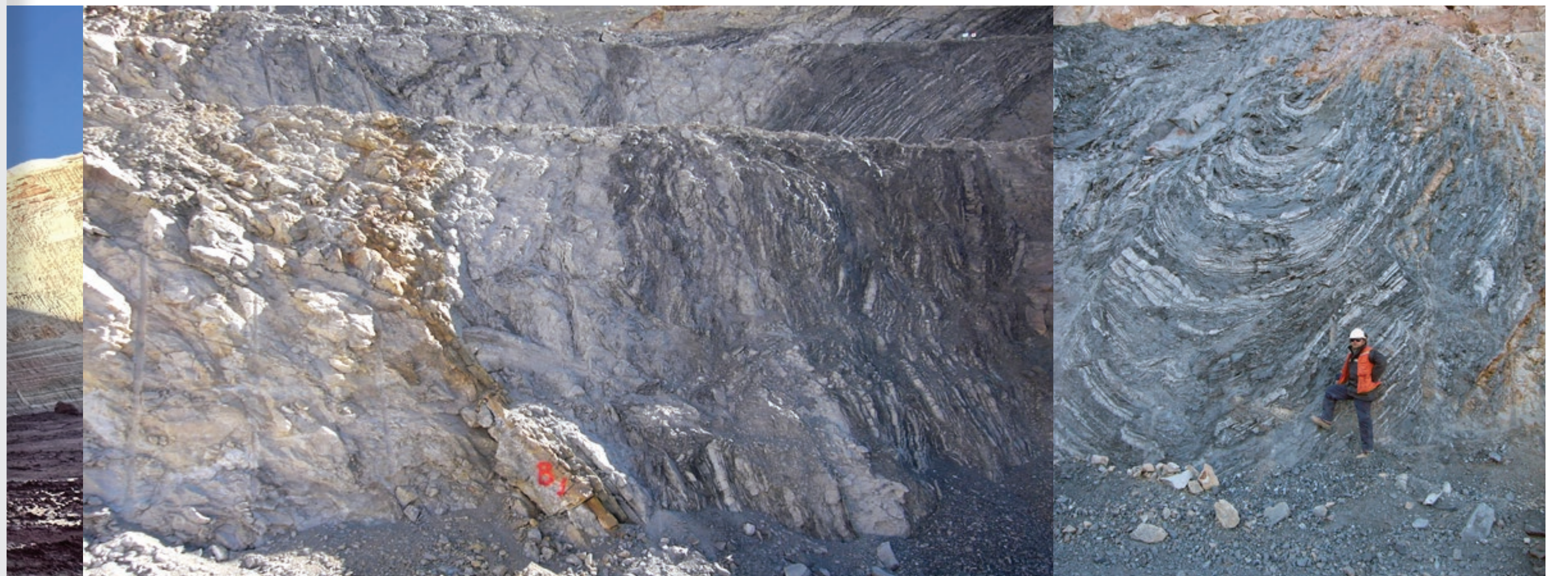
Geotechnical experience at the Maricunga gold belt deposits, Chile



Typical sedimentary rock encountered at the Maricunga gold belt deposits

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Esteban, a mining engineer with over 30 years of experience, specializes in geomechanical analysis and design for underground mining and surface excavations. Holding a Master of Science in Geophysics with a focus on applied hydrogeology, he excels in 2D and 3D numerical modeling, stability analysis, and slope design. Esteban has led major mining projects worldwide and authored over 40 technical publications. Currently, he serves as Vice-President of Latin America at the International Society of Rock Mechanics (ISRM).

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EDGAR MONTIEL

Edgar is a geotechnical engineer with vast experience in mining and civil engineering. He has led key projects in Chile, including Chuquicamata Underground and Los Pelambres mines, and assessed tunnel risks for the Santiago Metro. In Mexico, he worked on dam stability at CFE and major projects, such as La Yesca and Santiago. A former UNAM professor and CAMIMEX Scholar, he supervised theses and developed field manuals. Edgar, an “Alfonso Caso” Medal recipient, has published 28 papers on geotechnical stability and numerical modeling.

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SRK Chile’s Rock Mechanics team has more than 25 years of experience working in several geotechnical and hydrogeological studies at the Maricunga gold belt deposits. The Maricunga District is elongated to a north-south orientation between latitudes 26° to 28°S. It extends for approximately 200 km in length and 50 km in width. Regional geology is dominated by the Miocene to Pliocene volcanic rocks and portions of an exposed Paleozoic-Triassic basement. The older basement of Paleozoic and Mesozoic igneous and sedimentary rocks is unconformably overlain by the Miocene volcanic rocks (see Gamonal 2015). The main rock types associated with mineralization are breccias, usually under a very complex structural pattern. On the other hand, host rocks are mainly volcanic sedimentary rocks, mudstones, sandstone and shale (top image).

To develop comprehensive geological, geotechnical and structural characterization, geotechnical units, three-dimensional structural models and a geotechnical block model need to be defined. Thanks to previous experience at several gold deposits located in the same area, the slope design can be carried out with considerable confidence. Back analyses play an important part in the confidence of design. As part of the slope design process and slope optimization, the past performance of the pit slopes needs to be assessed for the future pit pushbacks.

The main challenge for slope stability analyses is to incorporate the anisotropy associated with the sedimentary folded rock with a practical approach. To incorporate the strength anisotropy, a novel constitutive model was defined for three-dimensional numerical models (bottom right image). A sophisticated mesh using griddle software was used to incorporate anisotropy based on the ubiquitous approach. For anisotropy, the use of constitutive models accounting for the effects of discontinuities in nonlinear strength curves is required. A proposed approach relied on the “Subiquitous Joint Model” (see Montiel et al., 2024) aligning the bilinear envelope with the strength properties to observe the impact of the discontinuity sets.

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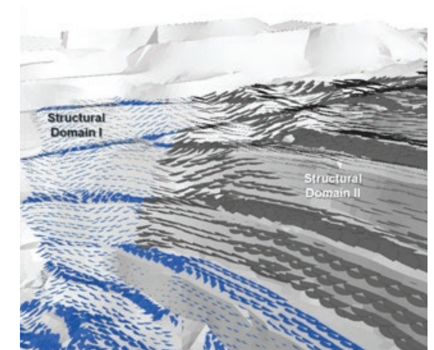
A three-dimensional numerical model incorporating the sub-ubiquitous anisotropy to model sedimentary folded rocks. Disks with different colours represent ubiquitous joints of different structural domains.



The 1964 closure of Wright Hargreaves after a mine scale seismic event

The term “mine scale event” describes very large mining- related seismic events that are generally greater than Nuttli Magnitude (MN) 3.0. These events are influenced by or part of rock mass failure processes that exist on a similar scale to a significant part of the mine. The consequences of these events have been among the most catastrophic in mining, having the potential to cause multiple fatalities and immense loss of resources.

Undoubtedly, the worst period of rock bursting in the history of Canadian mining was the 1930s to 1960s in the deep Kirkland Lake gold mines. The Kirkland Lake main break held a rich gold-bearing ore body, which was extracted from seven mining operations. As the mines matured and extraction took place at great depths, rock bursting became a serious problem, resulting in many large seismic events and numerous fatalities.

The Wright-Hargreaves mine, opened in 1923, was the deepest of the Kirkland Lake gold mines, reaching 2,500 metres below the surface. After a day shift on August 14, 1964, a shrinkage stope in the central shaft pillar was blasted. The ground response immediately after the blast was not considered to be unusual, and two miners reentered the area to resume work. Soon afterwards, a MN 3.1 took place in the shaft pillar, causing the stope to collapse and the death of both miners. After the mine was evacuated, an even larger event (MN 4.2) occurred. Damage from the MN 4.2 was even greater than the first event, cutting off access to 11 levels and damaging the shaft. The decision was made to close the mine permanently on August 27, two weeks after the events.

Wright-Hargreaves did not have a significant rock bursting problem until late in the mine’s life at high extraction, suggesting that mining-induced rock mass failure processes likely played a significant role in the generation of these large events. The physical damage to the Wright-Hargreaves mine existed over 11 levels (365 vertical metres), suggesting the physical scale of the seismic source was comparable to a large part of the mine, and the event could truly be called a “mine scale event.” The tragic closure of the Wright-Hargreaves mine underscores the critical importance of understanding and mitigating seismic risk in deep mining operations. These historical lessons continue to inform modern mining practices, emphasizing the need for rigorous safety protocols and advanced monitoring technologies to protect miners and resources alike.

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REFERENCES:

Blake, W. and Hedley, D.G.F. (2001) Rockburst Case Histories for North American Hardrock mines. Report for CAMIRO Mining Division. 73 p.

BEN OLLILA

Ben Ollila has spent a large part of his career in high stress rock mechanics at Kidd Creek mine. Ben has expertise in the management of mine seismicity, using seismic monitoring and data analysis techniques (mXrap) as well as numerical methods (FLAC3D). He has hands-on expertise in designing, implementing, and assessing ground support strategies for a wide range of mining applications. He is skilled in the geotechnical aspects of mine design, including optimizing stope designs and sequencing.

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Pore pressure assessment for slope stability in gold and base metals

The mining industry increasingly requires robust and accurate pore pressure representation in slope stability evaluations. This need is evident in the growing number of operations employing pore pressure monitoring systems and numerical groundwater models. These real-world datasets create opportunities to verify the reliability and applicability of groundwater numerical model results against site-specific data.

A methodology for assessing the reliability of pore pressure models in slope stability evaluations was tested at two mine sites: Compañía Minera Antapaccay (CMA) copper mine in Peru, and the Pueblo Viejo Dominicana Corp (PVDC) gold mine in the Dominican Republic. Both sites presented have mature pore pressure models, with extensive hydrogeological and monitoring data in FEFLOW and MINEDW software, respectively.

The proposed methodology involves a three-step approach: evaluating groundwater construction and architecture, categorizing calibration behavior and residuals, and assessing geotechnical sensitivity to pore pressure. Finally, the methodology assigns pore pressure reliability scores to modeling outputs that are based on hydraulic head and trend categories and weighted by local-scale geomechanical importance. These scores guide the use and understanding of pore pressure outputs in geomechanical models.

For case studies at CMA and PVDC, results showed that both models had questionable elements but were not invalid. CMA exhibited larger residuals and error percentages than PVDC, highlighting the importance of site-specific geotechnical requirements. The methodology's advantage lies in its project-specific approach, enabling rapid quantification and adjustment of pore pressure reliability volumes as guidance for slope stability analyses.

The final product includes reliability volumes and maps, intended for use alongside other spatial analyses to ensure accurate slope stability assessments. This approach provides a systematic tool for evaluating pore pressure outputs, aiding in the identification of necessary corrections before geomechanical modeling.

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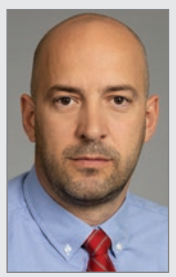

Göktug is a principal hydrogeologist with over 20 years of experience in groundwater flow modeling, aquifer characterization, and mine hydrogeology. He has worked on international projects concerning environmental and feasibility studies related to mine dewatering, water supply, and other elements of mine hydrogeology.

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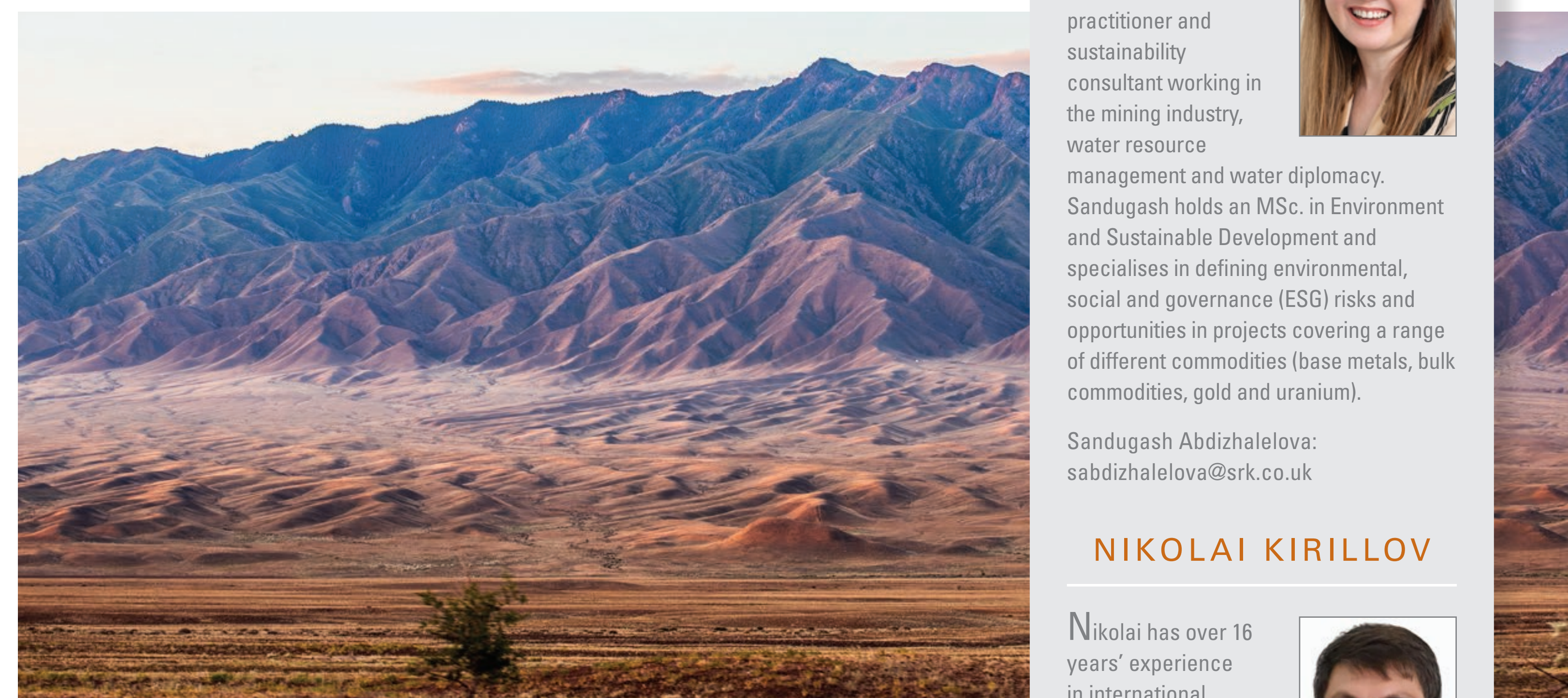
Gold opportunities in Central Asia: technology and innovation in Kazakhstan

The Central Asian region, encompassing Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, is known for its rich geological endowment and hosts various types of gold deposits. These countries are emerging global mining hubs, and their governments are on a journey to liberalise national mining laws, opening prospects for global players. Kazakhstan, Uzbekistan and Kyrgyzstan are the most advanced in this respect. To meet their ambitions, these countries are applying novel technologies.

According to the Kazakhstan government, exploration is promising in the country. Kazakhstan seeks foreign direct investment and aims to align its mining legislation with advanced jurisdictions like Australia. One of its innovations is the digitalisation of geological information through a unified mining platform[1]. The platform is currently in its pilot phase and is designed to provide easy access to historical geological data, with the aim of facilitating exploration investment. It also aims to contribute to industry transparency: the e-government platform, one of the arms of the digitalisation initiative, is being developed to encourage disclosure and ease the communication process between the regulator and the public and private sector.

Another example of innovation is a "digital mine" programme of Altynalmas, one of the gold-producing companies in Kazakhstan. The pinnacle objectives of the digital mine are to enhance safety and operational efficiency, minimize production costs, and optimize staff performance through the use of cutting-edge methods and the latest information technologies.



Tian Shan mountain range, Central Asia

Innovative new technologies are also being used to improve sustainability performance in Kazakhstan. Major emitters of pollutants are now required to install automated monitoring systems, ensuring real-time data supply to the regulator. This is expected to improve enforcement of compliance and will allow the regulator to respond to accidents immediately. The infrastructure is being commissioned throughout the country. Public access to environmental data is provided via "ecoportal"[2], an online platform that discloses information from ongoing impact assessment processes and associated public consultations, as well as monitoring results and waste management data.

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1. https://minerals.gov.kz/
2. https://ecoportal.kz/

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Sandugash has more than 10 years' experience as an environmental practitioner and sustainability consultant working in the mining industry, water resource management and water diplomacy. Sandugash holds an MSc. in Environment and Sustainable Development and specialises in defining environmental, social and governance (ESG) risks and opportunities in projects covering a range of different commodities (base metals, bulk commodities, gold and uranium).

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NIKOLAI KIRILLOV

Nikolai has over 16 years' experience in international mining and mining consultancy. Specialising in mine closure planning and costing, including LoM and ARO liability estimates, Nikolai's experience includes Environmental and Social Impact Assessments (ESIA), leading project studies in accordance with national legal requirements, as well as international standards, such as IFC Performance Standards, Equator Principles, EBRD and ICMM. He has also been responsible for the environmental sections of comprehensive due diligence audits and Competent Person's Reports (including for IPO), scientific and technical projects, and other project studies.

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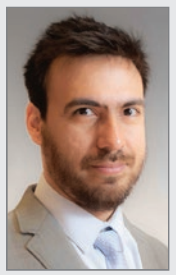
Addressing seepage challenges in a gold mine's tailings facilities

General view of the TSF3

ALEJANDRO ORTIZ



Alejandro is a Senior Consultant based in the Mexico City office, with experience as Deputy EoR, tailings facilities design, dam safety inspections and dam safety reviews, in the design and management of geotechnical site investigations, and soil mechanics projects. Alejandro's projects include foundations, embankments, excavations, retaining structures and tunnels.

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HUGO RIBEIRO DE ANDRADE FILHO

Hugo is a professional with over 24 years of experience in mining planning, mine operations, and contract management. He had worked for 10 years in underground gold mines, including eight years in narrow veins. He has worked in a range of roles, including the management of technical services teams. He has relevant experience in highly mechanized mining methods, such as sublevel stoping, room and pillar, sublevel retreat, narrow vein mining methods, retreat mining -VRM with paste fill, and open-pit mines.

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A mine located in northern Mexico extracts gold, silver, zinc, and lead, processing 3,850 tons of dry tailings daily, transported via pipelines with a water-to-solid ratio of 35% to 65%. The site has three tailings storage facilities (TSFs), with TSF-3 under construction and partially operational during a seepage incident in early 2021. In 2020, SRK contributed to the design of the TSF-3 buttress and raise, carrying out preliminary geotechnical investigations to better understand the dam's current conditions.

The incident summary begins on February 11, 2021, a seepage issue was observed in Basin 2, a sub-basin within TSF-3. The client promptly reported it to SRK. Over the next five days, the seepage worsened, leading to the discovery of a second-affected zone on the main embankment. SRK's initial investigation suggested that the cause might be piping, characterized by the erosion of materials due to water flowing through or beneath the structure.

The TSF-3 structure has a mid-level barrier, mainly made up of natural terrain, dividing it into two sections: one active (Basin 1) and another in development (Basin 2). Additionally, the urgent release options for TSF-1 and TSF-2 further contributed to the operational complexity.

In terms of prompt action taken to address the seepage issue, the mine's team implemented a Trigger Action Response Plan (TARP) designed by SRK. This included a series of coordinated steps aimed at stabilizing the situation.

SRK recommended several measures, including temporarily suspending the disposal of tailings and water into Basin 1 to relieve pressure on TSF-3. Simultaneously, excavation work on Basin 2 stopped, and a buttress was built, changing the affected area's shape. This modification prevented construction delays and expanded the mine's storage capacity.

Reclaimed water was rerouted to TSF-1, while TSF-2 underwent emergency cyclonic releases. To prevent water pressure spikes that could endanger the dam's structural integrity, water was withdrawn from TSF-3.

Alerts were immediately issued to downstream areas near TSF-3 regarding potential risks. Alternative emergency water discharge solutions were explored to ensure operational continuity and safety.

Among key observations during the event, continuous monitoring revealed expanding wet zones on the downstream side of the main embankment, along with altered water flow patterns.

Furthermore, enhanced field inspections identified these changes, as well as an increased expansion of wet zones, indicating infiltration. SRK consultants from various offices supported this finding.

In the process of stabilizing the situation after stopping waste and water discharges on February 21, 2021, no further seepage or wet zone expansion was detected.

Following stabilization, a comprehensive inspection of the basin and geosynthetics was conducted. This led to enhanced quality control measures for geosynthetic placement in future operations.

Finally, lessons learned, proactive monitoring, contingency planning, and quality control are essential for tailings management. Swift TARP activation and coordination prevented escalation, protecting operations and communities. Collaboration among SRK's multidisciplinary teams was crucial.

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Managing dilution and costs in underground gold mines with narrow veins: challenges and solutions

Controlling dilution and costs in narrow-vein underground gold mines is essential to ensure the economic viability of the projects. Dilution, meaning the entry of unwanted material during ore extraction, has a significant impact on the operational costs, which must be managed to secure long-term profitability and sustainability of operations throughout the life of the mine.

Common underground mining methods in narrow vein mines include cut and fill, room and pillars, and sublevel stoping. The choice of the mining method depends on deposit characteristics, such as the competence of the ore and wall rocks, thickness and ore dip, aiming to optimize mining recovery and minimize dilution. Veins where the dip is shown at intermediate values bring greater complexity to the choice of mining method. Methods based on stopes tend to be more productive but depend on a minimum ore dip that enables flow through the side walls of the stopes. Often, the presence of material not mucked from the stopes leads to a mistaken understanding of underbreak. In these cases, it is appropriate to use auxiliary equipment that allows fine material cleaning.

The selection of mining equipment is also critical for dilution. Standard equipment, offering higher productivity, requires larger drift sections, leading to significant dilutions ranging from 100% to up to 400% depending on the ore thickness, making the operation uneconomical in many cases. An alternative to reducing dilution in wide sections of development is the practice of split blasting, where the waste rock at the base of the face is blasted and mucked first, followed by ore blasting and mucking. Conversely, low-profile equipment favors dilution reduction but may negatively impact operational productivity. Striking a balance between equipment efficiency, productivity, and dilution minimization is essential to ensure the profitability and sustainability of underground mining operations.

During mine development, geological-structural mapping and sampling play a crucial role in ensuring the correct positioning of the auriferous vein on the heading faces to prevent unplanned dilutions and excavation instability, which may arise from inaccuracies in ore vein positioning during excavation. Workforce quality for production drilling and effective excavation monitoring is also fundamental to guaranteeing efficient and safe operations in adherence to mine design standards.

Precise and comprehensive management is required for dilution and cost control in narrow vein underground gold mines. From mining methods and equipment selection to geological and structural control and workforce quality, the industry can improve efficiency, reduce dilution, and enhance economic sustainability in underground gold mining.

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Underground narrow vein gold mine in the Midwest of Brazil

The myth of gold cyanide heap leach "rinsing"

In 1989, the first modern gold heap leach closure regulations were introduced in Nevada, USA. These regulations were based on limited information and assumptions, offering several ways to demonstrate geochemical stability, the first of which was the option to "rinse" a heap. This led some mine operators and regulators to believe that "rinsing" was essential to remove cyanide and to stabilize geochemically a heap. Although the recirculation of process solutions commonly occurred after cyanide addition ceased, this was not done to reduce cyanide, but rather to recover residual gold, a phase known as *residual gold recovery*[1]. After residual gold recovery, additional recirculation of process solutions continued, not to reduce weak acid dissociable (WAD) cyanide, but to reduce the quantity of process fluids from the circuit rather than cyanide, referred to as the "inventory reduction" phase of heap closure[2].

As more heap leach facilities were closed in the 1990s and early 2000s, data continued to show that rinsing was unnecessary to reduce WAD and free cyanide concentrations in heap drainage. In fact, some research studies of heap closure during this period revealed that not only was rinsing not required to reduce WAD and free cyanide but could even release stable constituents from the heap[3].

The belief that "rinsing" was required was largely influenced by a 1992 study by Cellan et al.[4]. That study was based on data from a small diameter laboratory column used for metallurgical testing, with solutions confined to a closed circuit. Using fresh water, the setup lacked the exposure to air and ultraviolet radiation that occurs during the recirculation in residual gold recovery and inventory reduction. Consequently, the study results misrepresented the necessity of rinsing to reduce WAD cyanide in heap solutions during closure.

Although data from all closed heaps in Nevada and other western U.S. states — along with the removal of rinsing from regulations — suggest otherwise, the belief that rinsing is required to reduce WAD and free cyanide still persists in some jurisdictions. Although there has never been a heap leach pad closed in North America using rinsing.

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1. Parshley et al. (2012), Mine Closure 2012.
2. Ibid.
3. Bowell et al. (2009), Minerals Engineering, 22(4), 477–489.
4. Cellan et al. (1996), Comparison of Laboratory and Commercial Neutralization Rinse Data.

JEFF PARSHLEY

With over 45 years in mining, Jeff is a leading expert in environmental and closure planning, specializing in cost estimation and regulatory compliance. He has managed abandoned mines, contributed to World Bank and IFC projects, and developed corporate standards. Jeff served as SRK's global group chairman from 2016 to 2021.

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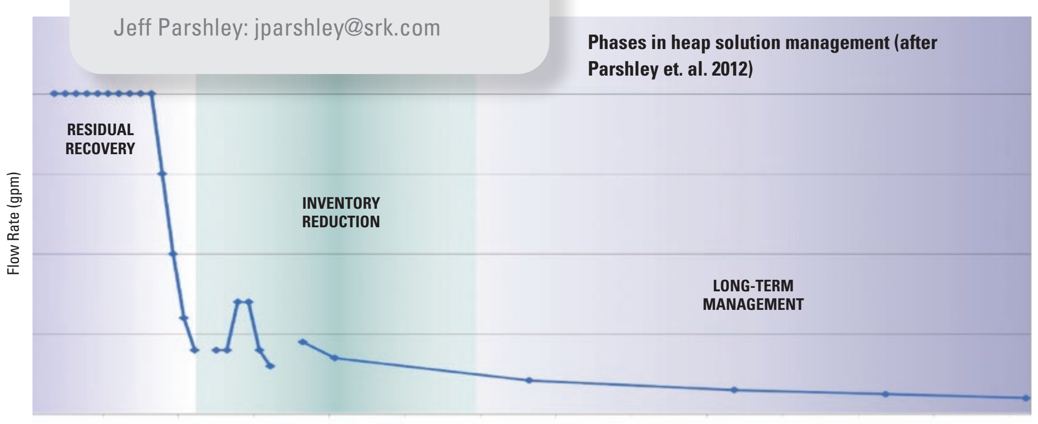

Phases in heap solution management (after Parshley et. al. 2012)

Impact of scarce geochemical data on mine waste, design, management, and closure

Mineralogical features resulting from acid mine drainage

The absence of robust and reliable geochemical characterization can indicate a high potential for environmental and social impact during the life of the mine and post-mine closure, and can impact the development of a mining project in its different stages.

"Know your enemy and know yourself…" - Sun Tzu, *The Art of War*

It is fundamental for the mining entrepreneur to know as much as possible about the characteristics of both the mineral ore of the commodity and the geological materials that host it. Logically, this applies to gold mining, especially from sulphide ores. Over the course of the mining operations, geological materials will be removed from the natural environment, modified, and later disposed of as waste rock or tailings, disturbing a presumably balanced environment.

From a geochemical point of view, the mine operator should know characteristics like grain size, chemical and mineralogical compositions, and short- and long-term chemical stability prediction. The operator should also simulate geochemical conditions of the tailing storage facilities (TSFs) that, in place of their original environment, will store the materials from mining operations. Special attention should be given to gold mining TSFs containing cyanide residues, among other commonly found contaminants, such as arsenic.

It is precisely this knowledge that serves as the primary guideline to allow for the planning, design, and construction of environmentally safe TSFs and, therefore, good practices in mining waste management.

If the mining entrepreneur, including gold mining, understands the geochemical characteristics of their waste rock and tailings, there will be significant opportunities to utilize these 'allies' to better design and understand the mine, thereby emerging 'victorious in the war.' Otherwise, the tailings and waste rock will be their 'enemies,' and so the 'war could be lost' through major socio-environmental and financial impacts, even post-closure.

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CLAUDINA GONZÁLEZ

Claudina has six years of experience. During these years she has specialized in the geochemical characterization of waste materials in mining operations. During this period, she has developed expertise in designing sampling plans, executing campaigns, and interpreting results to predict ARD/ML potential. In addition, she has experience in the hydrochemical characterization of surface and groundwater, assisting in the implementation of water quality monitoring.

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Fernando has 30 years of experience. He worked for 11 years in projects related to industrial water quality. He also worked as a technical manager in an environmental laboratory for two and a half years. He has worked as an environmental consultant for 15 years, acting as a manager and technical consultant in several projects in environmental geochemistry and related areas.

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Tailings storage alternatives assessment in a mine in Latin America

Inspection of the current TSF of the mine site

SANTIAGO PASTINE

Santiago is Senior Consultant in SRK's Salta office. He has over seven years of experience in design, analysis and operational assistance for tailings storage facilities, heap leach pads, and waste rock dumps. He has been involved in several mining projects, from scoping to detailed design, construction and operation, with extensive experience in site selection, field investigation and geotechnical characterization, design support, operational assistance, and audits to confirm compliance with the GISTM and the prescribed international standards.

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IGNACIO EZAMA

Ignacio Ezama is a Principal Consultant and Practice Leader in SRK's Salta office. He has extensive experience in developing geotechnical solutions, in site-based and desktop applications. Ignacio has worked on projects involving a broad scope of tailing management, including thickened, dry stacks, cyclones, co-disposal and conventional tailings covering a variety of commodities in both tropical and arid climates around the world. Ignacio has extensive experience in brine evaporation projects, including undertaking the site exploration and design of several extensive evaporation systems for lithium and potash projects in South America and Australia.

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A gold–silver mine in Latin America that has been operational for over 20 years with a single tailing storage facility (TSF) has recently expanded its life of mine (LOM) above the current TSF storage capacity. With the objective of guaranteeing continuous tailing deposition, a storage alternative assessment was conducted to determine the preferred alternative to store the additional tailings during the LOM once the current TSF capacity is achieved.

The following options were assessed:

- Downstream, centreline or upstream raise of the current TSF.
- Central thickened disposal (CTD) in the current TSF.
- Construction of a new TSF.
- In-pit tailings deposition.

To determine the preferred alternative, a series of workshops with the mine and corporate personnel were held. A pre-screening assessment was conducted and conceptual-level designs for the pre-selected alternatives were developed.

A comparative analysis was finally conducted, in which the upstream raise of the current TSF was identified as the preferred alternative for the following reasons:

1. Site-specific and facility conditions are adequate for the implementation of an upstream raise. The RoR is ~0.7 m. per annum, and current TSF conditions allow for a controlled beach and prevent water ponding against the embankment. Evaporation is considerably higher than precipitation throughout the year, and the site is in a stable seismic area.
2. Upstream raising complies with tailings and water storage requirements throughout the LOM.
3. Only one additional pump is needed, preventing the need to move ancillary infrastructure located at the toe of the current embankment.
4. Total cost per tonnage of tailings is lower than the other alternatives, except the in-pit TSF.
5. Closure of only one facility is needed.

The CTD alternative was ruled out for not complying with tailings and water storage requirements. However, creating the tailings land-forming near the end of the LOM was identified as an option, minimizing earthworks and preventing water ponding through the embankment.

The in-pit TSF alternative might be a competitive alternative, since it minimizes risks associated with dam failure and capital and operational expenditure requirements (particularly if no lining or sealing is required). However, for the relatively short LOM, the benefit could not be fully realized. Should LOM be expanded, an integration between operation and closure should be studied, leading to minimizing the closure of earthworks and reducing environmental passives. Eventually, a reduction in environmental passives, in comparison with the closure of the pit itself, could be achieved (though this requires further study).

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Improving gold processing plant throughput

Every mine strives to achieve the highest possible throughput using existing equipment whilst also maximising the profit. SRK consultants have been engaged in increasing gold processing plant throughput with minimal capital investment.

Assessment of the operating parameters for crushing and grinding sections at selected plants allowed for improvements that increased throughput by 4–12%, which significantly improved the revenue of the operations. Key processes in each project were also monitored to avoid metal losses with plant tailings.

SRK's approach includes the following steps:

- Reviewing performance statistics and identification of dependencies.
- Analysing mineralogical data, deposit characteristics and determination of the influence of variability of physical and mechanical properties on plant performance.
- Collecting samples of the plant feed for strength testing.
- Auditing the process flow sheet and collection of process samples.
- Estimating the capacity for each piece of equipment in the process line and comparison of estimated and actual performance.
- Process modelling using specialist software.
- Developing different upgrade options and estimating potential throughput.
- Estimating capital investment and expected return from proposed modifications.

The solution to increase the plant's throughput often lies on the surface. It may be the mill liner design, crushing size, solid-to-liquid ratio in the mill feed, ball load, unstable thickener performance, etc. If good quality and accurate raw data are available, the required estimates and changes in the plant process parameters can be completed relatively quickly, providing benefits without significant capital investment.

The importance of exploring plant feed hardness variability as part of geometallurgical mapping deserves special recognition, as it is a powerful tool for ensuring the reliability of planned production and financial performance. Different methods are used for hardness determination; mines often use a simple bench-scale grinding test using a laboratory mill with preset time and controlled product size. Each method has its own benefits and drawbacks. SRK helps to optimise the cost of geometallurgical mapping programmes while collecting relevant information.

In one case study, the mandate was to increase throughput at one of the operations with minimal capital investment. Following an audit and assessment of the equipment condition, the maximum theoretical equipment capacity was estimated, taking plant feed strength properties into account, and a plan to increase throughput by 13% was developed. The project was implemented successfully: with less than US$1.2M invested, the plant's throughput increased from 1.69 to 1.9 Mtpa.

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DMITRY ERMAKOV

Dmitry's experience in precious metals mining and metallurgy includes operational management, engineering, capital equipment supplies, and consulting roles. During his career Dmitry worked his way from a mill operator to a Processing Director at a large holding company. Dmitry specialises in auditing and evaluating designing and existing mining and processing operations, rebuilding production facilities and commissioning new plants.

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Assuring responsible gold mining

There has been an intense focus on environmental, social and governance (ESG) matters in recent years. Investors, purchasers and the public want confidence that ESG performance is assured by independent external providers. However, there is a danger that generalist sustainability assurance providers, who undertake assurance for a wide range of industries, may not appropriately identify the complex set of site-specific risks associated with mining operations. So how are gold mining companies rising to this challenge, and will their actions satisfy these stakeholders?

Many major gold mining companies have made clear commitments to align with either the World Gold Council's Responsible Gold Mining Principles (RGMPs) or the International Council of Mining and Metals (ICMM) Performance Expectations, or both. These organisations have set performance expectations that define responsible mining. They require independent assurance or validation processes and a commitment to disclose the outcomes.

To assess conformance with the RGMPs, external assurance must be in accordance with the International Standard on Assurance Engagements 3000 (or equivalent). Similarly, ICMM requires its members to have their sustainability reports independently assured against the Global Reporting Indicator Standards. Since 2020, ICMM's members have had to validate that they meet performance expectations; this includes self-assessment and external validation of key sites. Selected gold company websites and sustainability reports show this is happening and, in some cases, has been extended to cover the RGMPs.

These onerous assurance requirements have been carried through to the draft Consolidated Mining Standard that is currently out for consultation. This much-sought-after initiative will consolidate performance expectations from the RGMPs, ICMM, Copper Mark and Towards Sustainable Mining, reducing confusion and responding to society's demands.

It can take years of experience, access to an extensive network of technical specialists and a detailed understanding of how mines can potentially impact the human and biophysical environment to comprehensively recognise gaps in ESG performance and identify meaningful opportunities for improvement. Not all assurance providers (such as accountancy, management consulting or specialist assurance firms) have this. Recognising this, SRK has helped incorporate the requirements of various ESG performance standards (including from ICMM and the RGMP) into our clients' capital project standards, with the aim of ensuring integration of ESG through the entire project development process, from initial scoping to project implementation. By setting the groundwork for future sustainability reporting and associated disclosure, technical specialists can work together with assurance providers to meet our client needs and address stakeholder concerns.

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FIONA CESSFORD

Using over 30 years' experience, Fiona helps clients navigate the challenges and opportunities posed by ESG issues. Fiona provides ESG support to capital projects with the aim of integrating ESG into business decision making. She contributes to mineral reporting and advises on ESG management and closure planning. She has consulted on several loan agreements and contributed expert opinions to international arbitration. She communicates ESG threats and opportunities to mine managers, investors, corporate decision makers and other stakeholders.

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Changes in catchment conditions means infrastructure designed in the 60s now fail to deliver

Attenuation dams and 1m pipeline that discharges over the dolomitic area (left), Pipeline over the dolomitic area (right)

Gold mining on the Witwatersrand started in the late nineteenth century as sporadic open-cast mining and ceased in the late twentieth century, leaving a complex network of haulage, tunnels and ultra-deep vertical shafts/sub-vertical shafts. At least three ore bodies (conglomeritic horizons) were mined down to a depth in excess of 3,000 m from the surface. Three large mining basins resulted from the mining methodology applied, namely the Western, Central and Eastern (Rand) Basins (van Wyk, 2013). This gold ore body was one of the largest in the world. The mines needed to be dewatered to safely mine and due to the geology of the area sinkholes formed, including the Wonderfonteinspruit stream.

In the 1960s, a pipeline was constructed to control the flow of the Wonderfonteinspruit stream across a dolomitic area in the West Wits mining region west of Johannesburg. The pipeline managed the water inundation and recharge into the underground mine workings, maintaining safe working conditions.

Recently, however, significant urbanization of the Upper Wonderfonteinspruit has increased the rate and volume of runoff into the stream, particularly during storms. These problems have been exacerbated by significant leaks from water systems, as well as the discharge of partially treated sewage from the Flip Human wastewater treatment plant, which previously transferred water into the Vaal River catchment but is no longer operational.

During the rainy seasons, flow into the pipeline has exceeded its capacity, and water overtops the attenuation dams. This not only expands the number and extent of sinkholes along the Wonderfonteinspruit watercourse, but also contributes to excessive ingress of water into the underlying mine workings, requiring expensive dewatering activities. Seepage from the attenuation dams poses further potential risks of sinkhole formation and system failure over time.

The Sibanye-Stillwater mine in the area has been actively investigating options to minimize the amount of discharge from the dams. Together with SRK, the mining company has conducted an option analysis of the ways to accommodate the additional flow so that it does not exceed the capacity of the attenuation dams.

SRK is undertaking a feasibility study to install a temporary pump station at the attenuation dams. This would increase the velocity of flow through the pipeline and control the water level accumulation in these dams during the rainy season.

Part of this study is the lining and engineering of the attenuation ponds to minimise discharge into the dolomitic areas.

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PETER SHEPHERD

Peter is a principal hydrologist and partner of SRK Johannesburg. He has over 28 years of experience in specialisations such as flood lines, dam hydrology, mine water management, river hydrology, water supply and flood management. Peter has worked on mining projects in various African countries, focusing on stormwater management and water management plans, including the impact of variable climatic conditions.

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ANDREW WOOD

Dr. Andrew Wood obtained a PhD in Pollution Control from Manchester University in 1983. After five years at the Council for Scientific and Industrial Research (CSIR) in Pretoria, Andrew joined the Water and Environmental Technology (WET) group of SRK SA in 1989. Over the subsequent 31 years, Andrew and his team have specialised in mining and industrial water, wastewater and waste management focused on sustainable water resource protection and utilization, informing water conservation and demand management. Environmental protection, water, mine water and process wastewater and sewage treatment plant process design and contaminated land risk mitigation, management and remediation.

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