srk news
Exploration geology: strategies to discover

Unravelling geological complexity

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Geological mapping in the Kazakh steppe

Mineral exploration is being reshaped by shifting demand for critical minerals across energy, industrial, and technology sectors. These pressures are influencing where and how exploration is conducted. More effort is being directed toward deeper targets beneath significant cover, unconventional deposit types, and settings where environmental and social constraints can present greater obstacles to project development. In this context, geological understanding and technical accuracy are more important than ever for reducing risk and uncertainty.

This issue covers several approaches currently used to investigate mineral systems that are not readily exposed at the surface. Advances in subsurface imaging, structural interpretation, and data integration continue to refine how geoscientists construct geological models in greenfield and brownfield settings. Articles covering discovery at depth, dynamic structural modelling in brownfield environments, structurally controlled geological modelling and the evaluation of spatial continuity describe how updated workflows are being applied to interrogate complex terranes and assess the continuity of geological domains. Contributions addressing complementary approaches to prospectivity analysis—including use of mineral systems concepts, machine learning and absolute prospectivity—demonstrate how different methodologies can be combined for early-stage project evaluation and target ranking.

…continued

Unravelling geological complexity *(continued)*

Technological developments are increasing the range of tools available for interpreting large and diverse datasets. Applications of artificial intelligence, feature engineering, and machine learning are being used to support data-driven targeting, while maintaining the essential requirement for expert geological knowledge for interpretation. Real-time data modelling and the use of spaceborne observations illustrate how remote sensing is contributing more than ever to reconnaissance-scale assessments. These tools, when applied with appropriate geological controls, can support exploration effectiveness in settings where traditional methods may face limitations.

Several contributions in this issue address operational and market considerations. Case studies involving graphite and iron ore projects outline how data quality impacts project progression. Discussions on exploration performance, organizational approaches, and long-term investment cycles provide context for strategic decision-making.

The incorporation of sustainability factors into exploration planning reflects the growing importance of how technical, environmental, and social information is evaluated from the outset of project design.

Contributed by SRK's consulting practices worldwide, articles in this edition provide a cross-section of the current exploration practice. They document recent methodological developments, geological insights, and strategic considerations relevant to mineral exploration under changing technical and market conditions. The full set of articles offers readers perspectives on factors influencing discovery and project advancement today.

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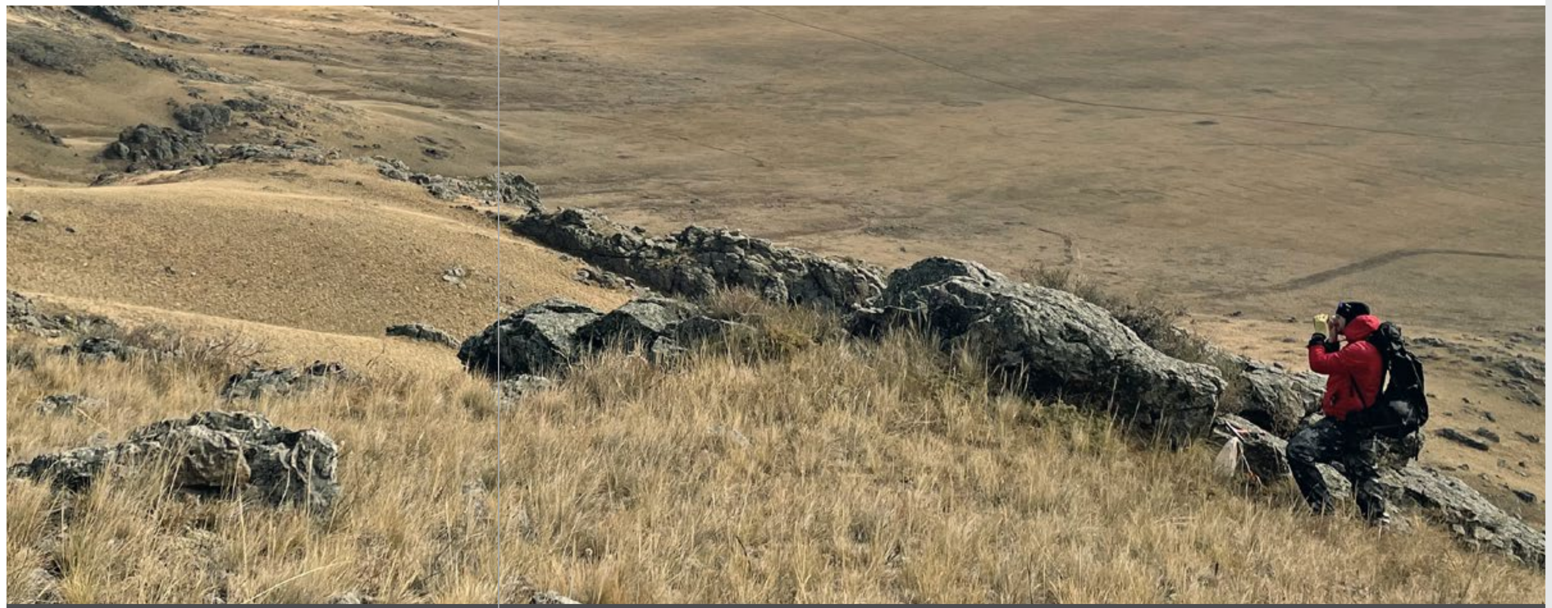
Diamond drilling an orogenic gold deposit in Saudi Arabia

Absolute prospectivity


Surface geology and structural mapping form the foundation for prospectivity modelling in greenfield and brownfield exploration

As regional prospectivity models become more common across the mineral exploration sector we need to act with caution. Although they are often commissioned with the worthy aim of optimising the probability of exploration success, when wielded incorrectly they can have the opposite effect.

The typical output of a prospectivity model is a heat map ranging from 1 (most prospective) to 0 (least prospective); the important point is that this is a relative scale. As a prospective terrane approaches full maturity, the number of deposits left for discovery becomes small, and exploration becomes progressively less viable. A relative scale fails to capture this dynamic and could be used to justify exploration where none is warranted. The solution is to develop an absolute prospectivity model, in which the scale reflects the actual estimated probability that a cell hosts undiscovered mineralisation.

Furthermore, in exploration, size matters, and it is often the case that only the small probability of a very large discovery makes exploration worthwhile. Maturity tends to disproportionately diminish the probability of large discoveries as these are easier to find; consequently, the probability on any discovery diminishes with maturity and that any new discovery is small increases with maturity. This effect should be captured, so that an optimal absolute prospectivity model encapsulates a probability distribution of undiscovered mineralisation of varying size within each cell.

A related problem is the misidentification of prospectivity as a sensitivity issue. There is often an expectation that prospectivity models, particularly those invoking "AI", can identify novel targets that traditional targeting cannot, by being more sensitive to subtle signals in the data. This may be true in some cases, but it is worth asking what kind of targets are revealed only through a prospectivity model; the answer is often second- or third-tier targets with weak expressions. To the extent that a prospectivity model prioritises novel, weak targets over stronger, recognised ones is likely the extent to which it diverts exploration capital toward poorer targets. Rather, the focus of a prospectivity model should be on noise and false-positive reduction.

To address these challenges, SRK have developed M-VAP, a Bayesian-based absolute prospectivity model. The model balances a predictive, mineral-systems-based prior model against an evidential model derived from known mineralisation and previous exploration activity. Because the model is also size-segmented, the output is a map in which each cell contains a probability distribution representing the estimated probability of undiscovered deposits of different sizes. These probabilities can be summed across an area of interest to assess the overall likelihood that a project will yield different discovery outcomes. This approach enables better exploration decision-making and more effective capital allocation across a portfolio.

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Dan is a Senior Geologist with more than 16 years' experience in mineral exploration, specialising in the application of geophysics to locate and characterise mineral deposits. He has conducted mineral prospectivity mapping and target-generation studies across a range of commodities and deposit types, covering everything from transcontinental metallogenic belts to individual exploration licences. Dan is an advocate of integrating geological, geochemical, geophysical, and remote sensing data to provide clients with robust, decision-ready interpretations.

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Niall has 20 years of experience in mineral exploration, ranging from establishing remote field camps to the valuation of exploration properties and CP technical reporting. His experience spans projects from reconnaissance through to bankable feasibility, with a particular focus on early-stage exploration. Niall conducts valuations and evaluations of exploration properties from greenfield to brownfield, acts as CP/QP for technical reporting of early-stage exploration, and specialises in applying statistical methods to value and manage exploration projects.

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Discovery at depth: modern workflow for mineral exploration beneath surface cover

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Oliver, a Principal Geologist, is a mineral exploration specialist with over 20 years' experience in diverse commodities on projects from generative area-selection, greenfield exploration through to mine development and production. He specialises in audit and due diligence of exploration projects, project management, remote sensing for mineral exploration, prospectivity analysis and target generation, and exploration programme development. This is based on extensive experience in the design, management, and implementation of mineral exploration projects globally.

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Alejandro has led the implementation of machine learning and deep learning models for mineral exploration and resource estimation at SRK Peru. He has developed and deployed web applications to support data analysis and automated workflows, improving processing efficiency. As a data science consultant, his expertise directly contributed to advancing mineral prospectivity projects.

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Thick cover sequences of the Al Farafra Basin, Egypt

Exploration under cover is the new frontier of discovery in maturing mining districts as outcropping deposits dwindle. Success in these challenging environments depends on integrating geological, geochemical, hydrogeochemical, and geophysical techniques, with approaches tailored to deposit style, host rocks, and cover type.

A robust understanding of the fundamental geology and deposit mineral systems is key to discovery in any terrain. Building geological models under cover is particularly challenging. At SRK, geophysical data (principally magnetics and gravity) are interpreted within a geological framework, assisted by machine learning (ML) classifications. ML models are trained on mapped outcrop areas and then applied under cover.

The mineral systems approach provides a conceptual framework that translates ore-forming processes into practical exploration criteria, emphasising indirect proxies at regional scales and direct detection methods at prospect scales. At depth or under cover, indirect proxies are often more evident; however, surface geochemistry and geophysical parameters such as chargeability and conductivity can directly detect mineralisation.

Exploration, including in areas under cover, is most effective when conducted through a phased, risk-managed approach, each phase narrows the search area and increases the intensity and cost of investigation. Recent approaches to regional scale/initial phases combine mineral systems models, structural geology, and broad geophysical and hydrogeochemical surveys. For example, regional airborne magnetics and gravity are used to map major structures and lithological domains, while hydrogeochemical assays of ground and surface waters help detect dispersion halos from concealed mineralisation.

As target areas are refined, exploration shifts to local scale where direct detection methods are prevalent. Here, detailed drone or ground geophysics (magnetic, electromagnetic, induced polarisation) are combined with high-resolution geochemical sampling—such as partial-leach soils (ionic) and, more rarely, vegetation geochemistry—to define drill targets. The exact combination of methods is adapted to the target deposit type, depth of cover, and weathering environment.

It is important that exploration remains an iterative process. Geological models inferred from geophysics, and mineralisation targets defined by direct detection methods, are ultimately validated by drilling. Updating models is key to ultimate success, and an ongoing cycle of mapping, modelling, predicting, and validating ensures that interpretations remain grounded in reality—even as exploration pushes into deeper terranes.

Mineral exploration under cover is a multidisciplinary, phased endeavour. Exploration programs build an understanding of the fundamental geology through field mapping, remote sensing, and geophysics—inferring continuity beneath cover through geological experience supported by machine learning and modelling—and validating predictions with drilling. By integrating mineral systems thinking, structural geology, geophysics, and geochemistry at every stage, and by adapting methods to the specific geological and weathering context, explorers can reduce risk, focus resources, and achieve real discovery success in challenging terranes.

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Porphyry–skarn copper prospectivity mapping with machine learning models

A study conducted by SRK Peru evaluated the application of several machine learning models for mineral prospectivity mapping of copper porphyry–skarn deposits in the Andahuaylas–Yauri metallogenic belt of southern Peru. Public geoscientific datasets, such as those from the Instituto Geológico Minero y Metalúrgico (INGEMMET), were integrated to construct evidential maps representing lithogeochemical, lithological, and structural factors relevant to the formation of the target deposit types. Four models — Random Forest (RF), Multilayer Perceptron (MLP), Convolutional Neural Network (CNN), and Graph Convolutional Network (GCN) — were compared to benchmark their performance in identifying areas with higher probabilities of mineral occurrence.

All models were assessed using spatial cross-validation based on geographic clustering to mitigate bias, given the limited and imbalanced number of positive mineral occurrence data points. The primary metric was the area under the ROC curve (AUC), with average results of 0.89 (RF), 0.912 (MLP), 0.901 (CNN), and 0.907 (GCN). Although the Multilayer Perceptron achieved the highest Area Under the Curve, the Graph Convolutional Network produced results with greater spatial and geological coherence, assigning high probabilities to geologically favorable areas and delineating new zones of potential interest consistent with known mineralizing processes.

Furthermore, the prospectivity maps generated by the GCN showed a spatial logic more consistent with mineral systems models through their ability to incorporate spatial relationships within the data using graph structures. Unlike alternative approaches, which tended to overfit or failed to reflect significant geological variations, graph-based models offer distinct advantages for integrating complex spatial information in mineral exploration scenarios.

In conclusion, geological data quality and processing remain critical to the success of MPM, but artificial intelligence algorithms such as GCNs represent a significant advance in delineating and prioritizing exploration areas. These methods can effectively integrate both public and private data sources for mineral targeting.

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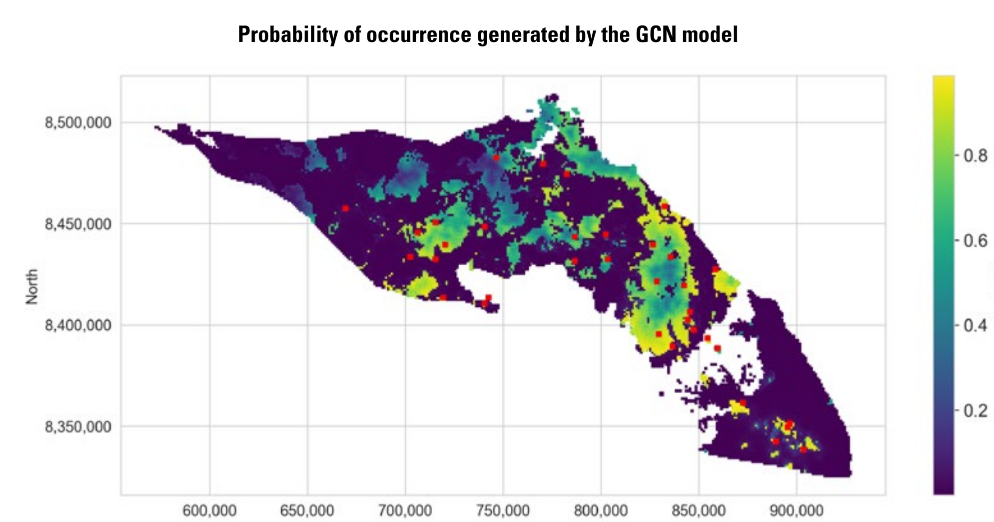
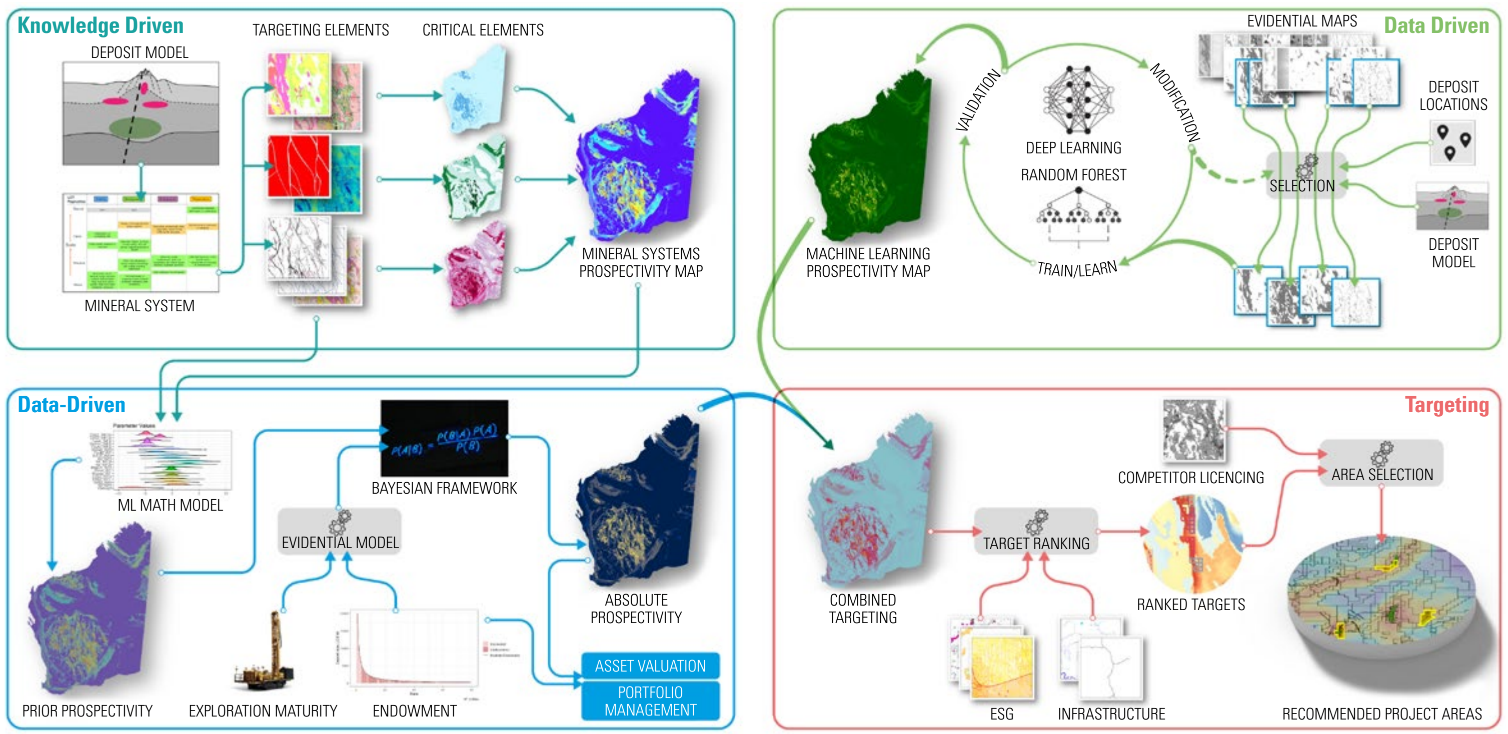


Complimentary approaches to mineral prospectivity mapping



Combining knowledge-led and data-driven models for absolute prospectivity mapping and mineral property ranking

Prospectivity mapping synthesises geoscience datasets to infer the likelihood of discovering mineral deposits within a given area. Commonly displayed as a heatmap, such maps help explorers focus their efforts on the most promising targets. By understanding the strengths and limitations of how prospectivity maps are constructed, geologists can gain new insights into mineral systems and the most valuable exploration vectors.

Prospectivity mapping approaches can be broadly categorised as knowledge-led or data-driven. Knowledge-led methods rely on experienced geologists recognising features in key spatial datasets that indicate deposit-forming geological processes occurred at favourable times in Earth's history—the foundation of the mineral-systems concept. These models are particularly useful in data-poor regions where little or no exploration has been conducted. Known deposits are used only to validate the model, not to produce it.

Data-driven models integrate extensive datasets, known deposit locations, and machine-learning algorithms to identify patterns and correlations that predict where similar deposits may occur. These methods—and hybrid approaches that combine them with expert knowledge input—are generally more objective than purely knowledge-led ones but depend on high data density and a sufficient number of known deposits for model training.

For prospectivity analysis, SRK typically uses a hybrid approach or develops both model types for comparison. The approaches are considered complementary, as demonstrated in a recent prospectivity- mapping project across Western Australia (WA).

A mineral-system model was developed from first principles for lithium-caesium-tantalum (LCT) pegmatites, which occur widely in Archaean greenstone belts across the Yilgarn and Pilbara cratons. Using a focused set of key datasets to map the critical elements and constituent processes of the mineral system, SRK produced a knowledge-led prospectivity map.

The extensive, high-quality geoscience coverage for WA also enabled development of a data-driven model. Both models, covering more than 2.5 million km², showed strong correlation with a bespoke database of LCT-pegmatite occurrences—and with each other.

Both models highlighted geologically favourable sections of greenstone belts where historical exploration had targeted gold or nickel, potentially not considering lithium prospects.

Comparing the outputs of the two approaches helped identify the effects of sparse data and gaps in deposit-model knowledge. In this way, the relative confidence or reliability of each model could be assessed.

Incorporating exploration-maturity and endowment analysis enabled SRK to estimate absolute prospectivity—the statistical probability of discovering a deposit of a specified size within a given area.

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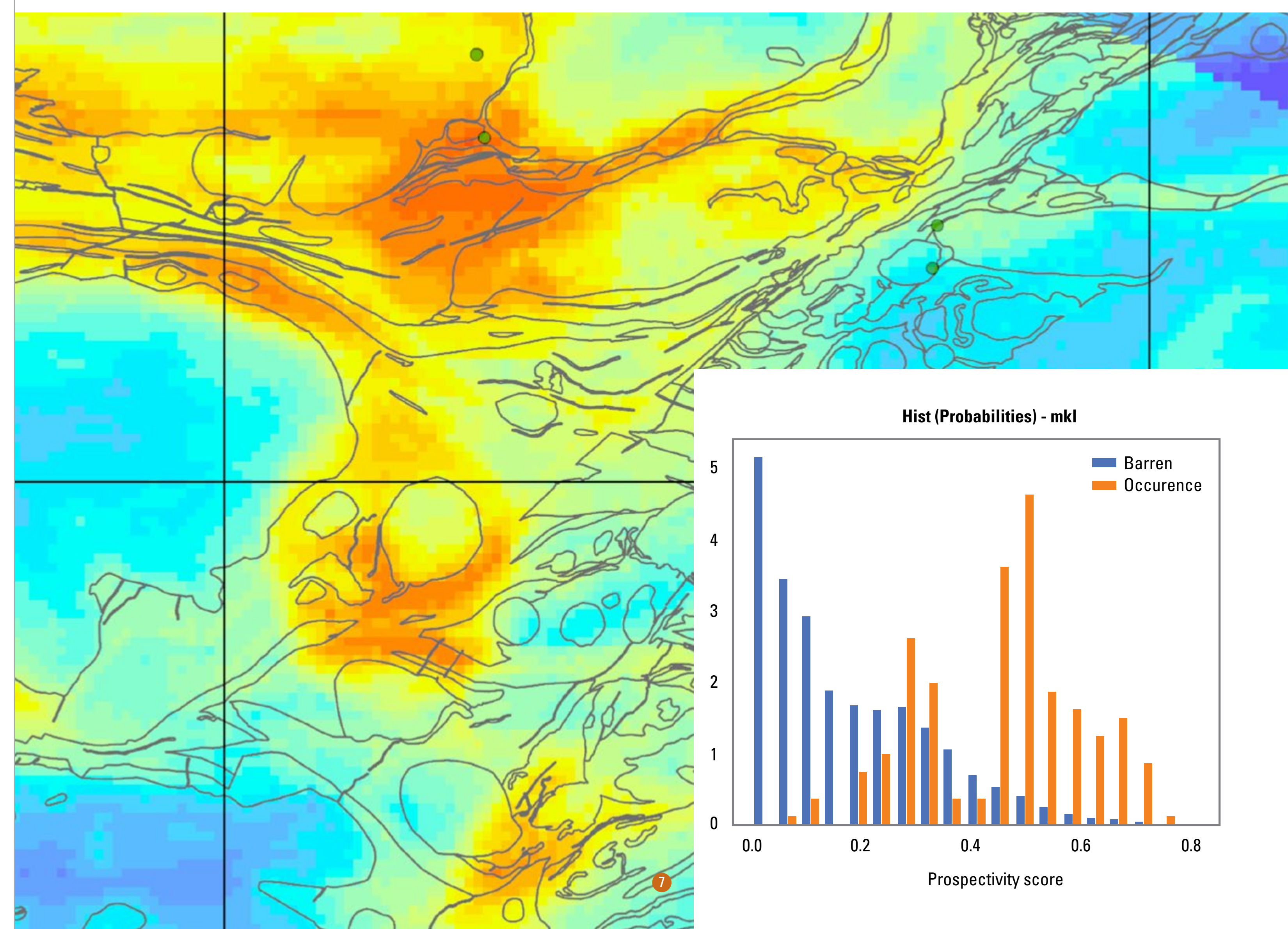
Evaluating prospectivity model performance against known mineral occurrences



Integrating feature engineering with mineral systems for data-driven targeting

A representative mineral systems framework for orogenic gold deposits in Southern India

Orogenic Gold (SCALE)	Age	Lithology	Fertility	Geodynamics	Pathway	Mineralogy	Geochemistry	Alteration	Preservation
Global	***Archean (>2.5 Ga)***	Enriched felsic crust	Au-enriched source crust	Plume-arc transitions; supercontinent cycles	Crustal thickening; transcrustal conduits	Dispersed Au, pyrite arsenopyrite	Elevated Au, As, Cu; MgO, MnO enrichment	Regional metamorphism; minor metasomatism	Preserved in stable Archean nuclei
Province	-3.0–2.5 Ga	***• TTG, • Greenstones, ultramafic-mafic, • Younger Granites, • BIFs***	Hydrated mantle lithosphere	Subduction-accretion; plume underplating	BSZ–CSZ deep-rooted shears	Pyrite, Fe-carbonates, magnetite, minor sulphides	MgO, MnO, LOI, Cr, Cu enrichment	Carbonate-sericite zones	Exhumation of mid-crust; limited erosion
Deposit		Metamafic volcanics, BIFs	***Metasomatism in greenstones, allow gold to precipitate***	***• Convergent margins; • Crustal reworking; • Shear zones***	***• Shear zones, • Close to fault conduits, • Axial planal cleavage, • Fracture network***	***Quartz-carbonate-sulphide veins***	***POSITIVE: Mafic Index, Alkalinity Ratio, Alteration Indices NEGATIVE: TiO_2, SiO_2, Rb LREE/HREE Ratio, Eu Enrichments***	***• Proximal sericitization ± chlorite ± carbonate; • Silicification***	***Preserved in uplifted fault blocks, structural culminations, quartz veins***

- Major Fault provide fluid pathway
- Second order structure create trap for gold precipitation
- Structural lineaments control localization of the deposits

** The green boxes highlight the characteristics observed in the region across various scales, ranging from global to deposit level

Feature engineering guided by geology is a key step in applying machine learning to mineral exploration. Combined with mineral systems, it strengthens mineral prospectivity analysis by linking geological knowledge with data-driven methods. Traditional prospectivity studies often rely on a single dataset—such as geophysical or geochemical data—and manual interpretation, which limits their ability to capture the complex processes controlling ore formation.

The newer approach begins with feature engineering, where raw geological data from remote sensing, geophysics, geochemistry, and geology are transformed into quantified meaningful variables. For instance, remote sensing data are used to derive alteration indices. Geophysical datasets highlight structural features such as lineament density and orientation, while geochemical data define anomaly contrasts and multi-element patterns. Geological information contributes distances to faults, intrusions, or favourable rock units. Each feature is linked to a specific mineral system component—fertility, fluid pathways, traps—ensuring geological relevance and statistical robustness. Instead of raw datasets, these engineered features become inputs for mineral prospectivity models, maintaining alignment with ore-forming processes and improving predictive reliability.

The next step is the feature importance analysis, which ranks variables by their contribution to prediction. Several methods are used: Mutual information captures non-linear relationships with mineralisation; Random Forest and XGBoost rank features by their influence on model gain and decision splits; and permutation importance measures accuracy loss when a feature is shuffled. These techniques identify the most influential variables and enable comparison with mineral system concepts. In orogenic gold deposits, for instance, alteration indices or structural corridors usually rank highest, confirming consistency with mineral systems framework.

The final step, feature selection, retains only the most informative variables while removing redundancy. Variance and correlation thresholding exclude static or highly similar variables, while univariate tests, such as ANOVA and Chi-square assess relationships with mineralisation. Advanced techniques like Lasso (L1 regularisation) suppress weak predictors, and recursive feature elimination iteratively selects the optimal subset. Geological reasoning remains central throughout this process.

In a recent orogenic gold prospectivity project in Southern India, SRK applied this approach and found it geologically reproducible, and efficient. The method successfully identified gold-prospective zones controlled by sericite alteration and structural conduits, which were validated against known deposits, active mines, and documented occurrences.

In summary, once features are prepared, advanced machine learning models can be applied in an automated, reproducible workflow that scales from regional to local studies. The outputs include not only prospectivity maps but also interpretable layers, where each prediction can be traced to a mineral system component—enhancing accuracy, transparency, and confidence while reducing exploration risk.

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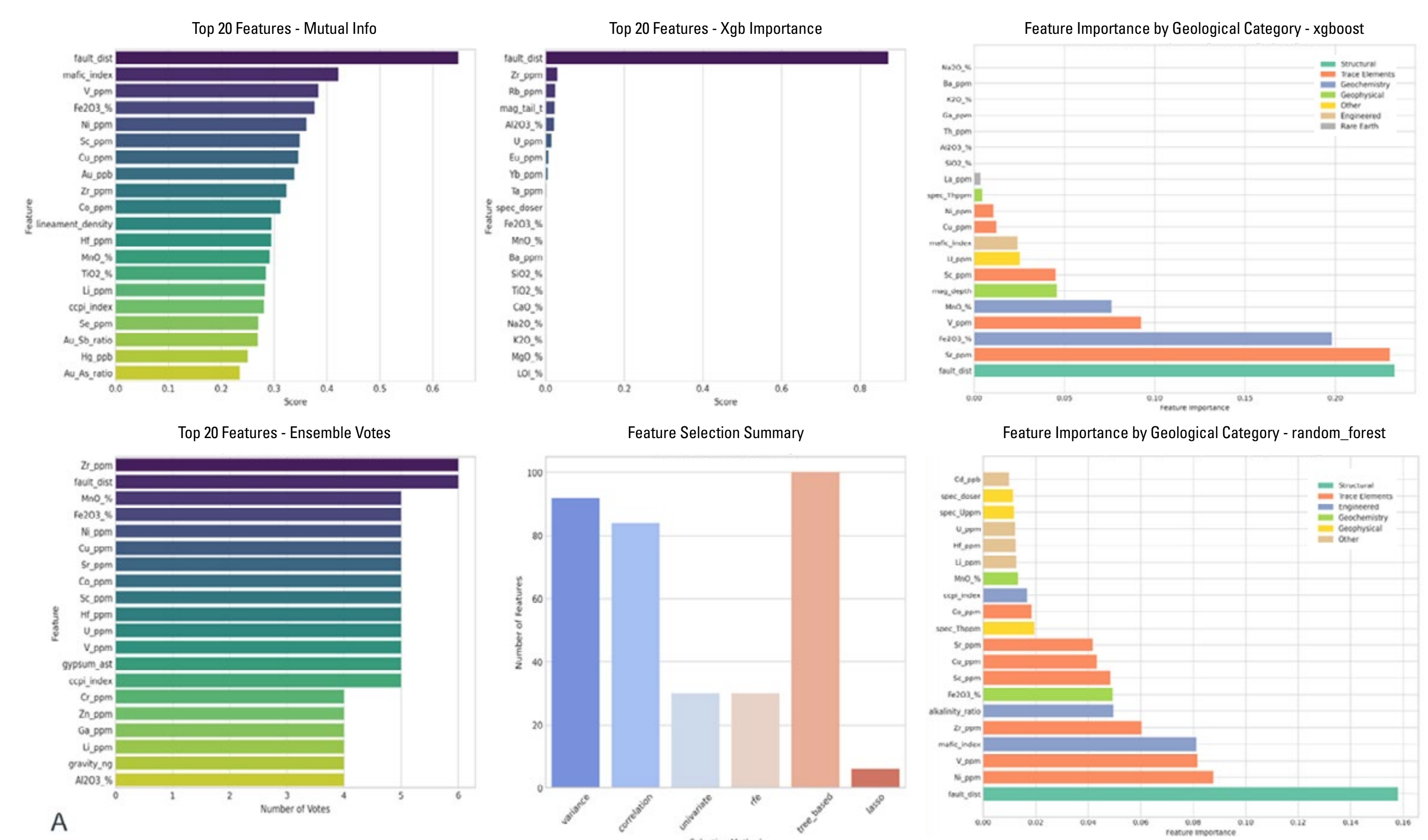
Representative feature selection and feature importance results for orogenic gold deposits in Southern India



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Atree is a Project Geologist specialized in integrating data-driven methodologies with geological expertise for mineral exploration. With a strong background in feature engineering, mineral systems analysis, and machine learning, he enhances mineral prospectivity studies by linking geological knowledge with advanced data analytics. Atree has extensive experience in geological modeling, resource estimation, and exploration planning across diverse commodities. His innovative approach, combining geology and technology, reduces exploration risks while improving accuracy and confidence in identifying mineral targets.

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An updated appraisal of the mineral prospectivity of the Arabian Shield

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James is a Senior Geologist with 10 years of experience. He specialises in exploration and mineral resource geology, the delivery of multidisciplinary studies and audits, and technical advisory services. James is an experienced and effective technical lead and project manager for multidisciplinary mineral-systems and prospectivity studies across a range of critical, precious, and base-metal commodities. His PhD research focused on hydrothermal fluid chemistry and fertility indicators in sediment-hosted copper districts, including the Central African and Kalahari Copperbelts.

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Mineral prospectivity mapping has become a key tool in generative exploration, helping reduce search spaces and prioritise areas for resource-intensive follow-up. A key challenge, however, is optimising value from data coverage across a given search space. One solution is adopting a systems-based approach that defines specific spatial proxies for key targeting criteria linked to the critical components of a given mineral system, at a range of spatial scales. In 2023, SRK was commissioned by the Saudi Arabian Mining Company (Ma'aden) to undertake a mineral systems-based prospectivity study covering a broad range of precious, base, and critical metals in the Arabian Shield.

The Arabian-Nubian Shield (ANS) records a protracted history of terrane accretion throughout the Neoproterozoic, including juvenile volcanic arcs, continental arcs, and fragments of thicker, evolved Rodinian crust. The Arabian Shield Prospectivity Study builds upon a revised geodynamic framework developed by SRK for the Arabian sector of the ANS. This framework underpins a reassessment of prospectivity for diverse deposit styles, including arc-related porphyry-epithermal and volcanogenic massive sulphide deposits, younger orogenic gold, post-collisional rare-metal granites, lithium-caesium-tantalum pegmatites, and comparatively underexplored systems such as magmatic Ni-Cu-PGE sulphides and podiform chromite.

Field validation of mineral system spatial proxies in the Arabian Shield

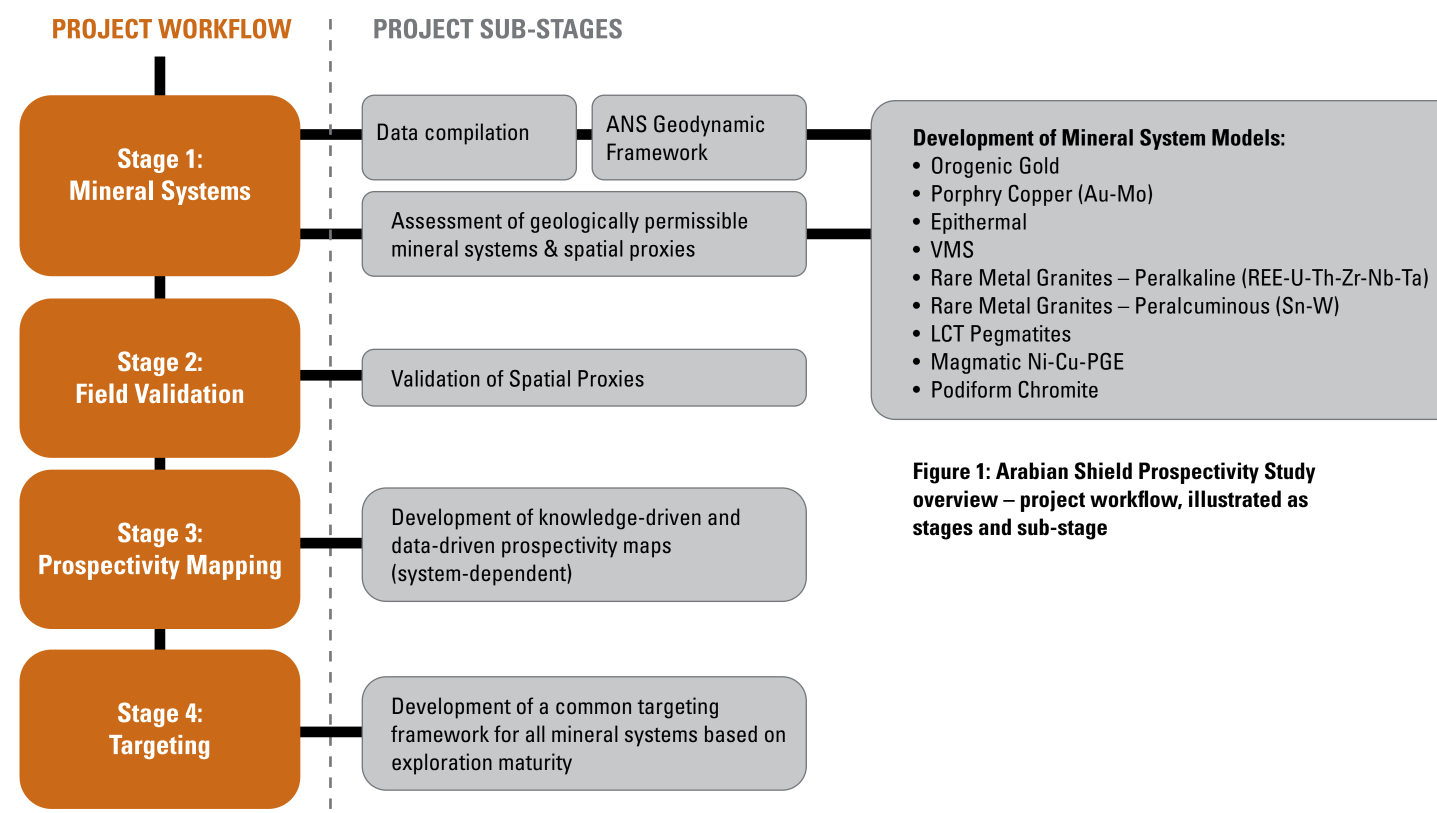

Figure 1: Arabian Shield Prospectivity Study overview – project workflow, illustrated as stages and sub-stage

Conducted over a two-year period, the study drew on expertise in structural and field geology, geochemistry, geophysical data processing and interpretation, data science and machine learning, geochronology, and palaeo-plate reconstruction. Moreover, subject matter experts contributed detailed knowledge of critical, base, and precious metal systems. The SRK team, comprising specialists from the UK, North America, Australia, South Africa, and Exploration practices, adopted a four-stage workflow, as outlined in Figure 1 and summarised as follows:

Stage 1 – Mineral Systems: development of an integrated geodynamic model and mineral system frameworks, identifying critical parameters that control mineralisation and preservation.

Stage 2 – Field Validation: verification of key spatial proxies by SRK and Ma'aden geologists, refining evidential layers for modelling.

Stage 3 – Prospectivity Mapping: application of knowledge-driven (Fuzzy Logic) and data-driven (machine learning) approaches to both exposed and undercover areas of the Shield, chosen according to data coverage and suitability.

Stage 4 – Targeting: generation of targets at multiple scales, ranked within a common framework that enables comparison across mineral systems based on exploration maturity rather than size/area.

The study provided a revised interpretation of the Arabian Shield's geological history, integrating multidisciplinary datasets and expert knowledge. The updated geodynamic framework, combined with mineral system models for eight deposit styles, forms the basis of the most comprehensive suite of prospectivity maps and exploration targets produced to date in Saudi Arabia. These outcomes underpin diversification of exploration in the ANS, demonstrating strong inherent prospectivity for a wide spectrum of commodities, from critical minerals to base and precious metals.

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No element left behind: getting the most out of multi-element geochemistry

The use of multi-element geochemistry is becoming increasingly prevalent in exploration. With tools such as portable X-ray fluorescence (pXRF) now a staple in many geologists' toolkits, multi-element geochemistry is more accessible than ever. As inductively coupled plasma mass spectrometry (ICP-MS) is available at most laboratories, reliable low-level multi-element geochemical analyses are routinely conducted on samples ranging from early-stage soil surveys to diamond drill core. However, in many cases, only one or two of the dozens of reported elements are used for targeting, leaving a wealth of potentially informative data overlooked. This unused data can provide critical insight into key aspects of a mineral deposits, from fingerprinting to lithological and alteration discrimination.

Interpreting geochemical data is a methodical process, and developing a clear understanding of the dataset is the essential first step. Exploratory Data Analysis (EDA) involves extracting as much as possible from the complete dataset. This step helps determine which pre-processing methods, such as using central log ratios among others, are required before further manipulation and presentation for interpretation.

Understanding how elements interact with one another is the next major step. Correlations between elements can be identified using tools such as correlation matrices and principal component analysis (PCA). By recognising these relationships, geologists can perform deposit fingerprinting. A simple example is the well-established correlation between arsenic and silver with gold in orogenic deposits.

Geochemistry can be used to vector exploration targets effectively. Common trace-element ratios such as vanadium to scandium (V/Sc) and strontium to yttrium (Sr/Y) can help identify potentially favourable magmas associated with porphyry copper deposits. Additionally, scatter plots of immobile elements such as thorium, scandium and titanium enable lithological discrimination, providing a quick and effective means of validating core logging. Alteration minerals and their interrelationships can also be characterised through geochemical data, including proportions of sericite to chlorite and biotite, feldspar composition, and the degree of sulfidation. Geochemistry has also been a vital tool in identifying lithium pegmatites. By using various elemental signatures, their fertility and classification can be determined without requiring lithium assays, which are often absent from historical datasets.

Additionally, by using advance tools such as Uniform Manifold Approximation and Projection for Dimension Reduction (UMAP) and ternary PCA maps, geochemistry can be integrated with other datasets, such as remote sensing and airborne geophysics, to produce desktop-based geological maps for field validation. These techniques can also be applied to historical soil-sample data, even when only a limited number of elements have been assayed.

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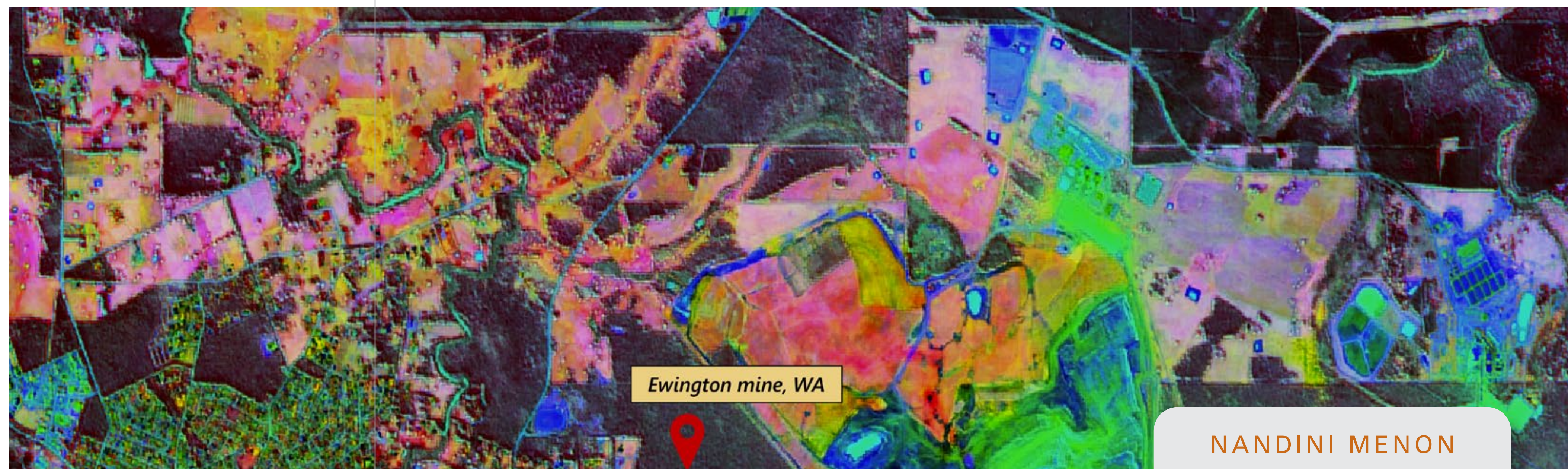
Deep learning meets spaceborne data in mineral exploration



Spaceborne data

The application of machine learning in mineral exploration has gained considerable momentum over the past decade; however, its effectiveness is often constrained by the need for high-quality data, particularly in regions where comprehensive datasets are unavailable or difficult to acquire. The recent expansion of the space race and advances in earth-observation technologies have generated a wealth of remotely sensed datasets capable of capturing regional conditions at ever increasing spatial, spectral, and temporal resolutions. While high-resolution airborne multispectral datasets provide limited spectral detail and airborne hyperspectral data remain cost-prohibitive, open-source spaceborne datasets offer significant advantages despite their coarser resolution. Sentinel constellations, the Landsat series, EMIT hyperspectral imagery, and ASTER are among the most widely used spaceborne datasets, providing medium- to high-resolution imagery at commercially viable price points.

Although conventional machine-learning models such as random forests and support vector machines are widely used in remote-sensing applications for mineral exploration, the complex, noisy, and high-dimensional nature of these datasets often requires more sophisticated techniques to produce actionable results. This is where deep learning becomes indispensable. Deep-learning models—particularly convolutional neural networks (CNNs)—are uniquely suited to handle large-scale, multidimensional remote-sensing data. Specialized architectures such as UNET (U-shaped encoder-decoder network), LSTMs (Long Short-Term Memory networks), and GANs (Generative Adversarial Networks) facilitate automated feature extraction for mineral mapping, object detection to identify mine workings, and advanced time-series analysis, among other applications.

At SRK, we have developed an innovative variation of the UNET architecture—SCAR-UNET (Spatial Channel Attention Optimized Recurrent UNET Model). This advanced recurrent UNET is specifically designed to capture both spatial and channel features, enabling accurate identification of mine workings on a global scale. The training dataset for this model was assembled by sourcing, validating, and integrating information from the Global Mining Footprint dataset (https://doi.org/10.1038/s43247-023-00805-6) along with corresponding Sentinel-2 satellite imagery.

The integration of spaceborne data with advanced deep-learning models such as SCAR-UNET represents a transformative leap in mineral exploration. Harnessing these tools enables faster, more accurate, and cost-effective exploration, unlocking new opportunities in regions once considered inaccessible.

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Nandini is an Environmental Scientist specializing in data science integration with remote sensing and mineral exploration. With three years' experience, she has contributed to projects like spectral mapping, ESG analytics, and mineral prospectivity. She has published multiple articles in Scopus-indexed journals and led research on flood mitigation, crater detection, and pollution analysis. Nandini works in AI model design, GIS products, and web applications, including SCAR-UNET and EXSAT.

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Intelligence amplified: how AI and expertise solve exploration challenges

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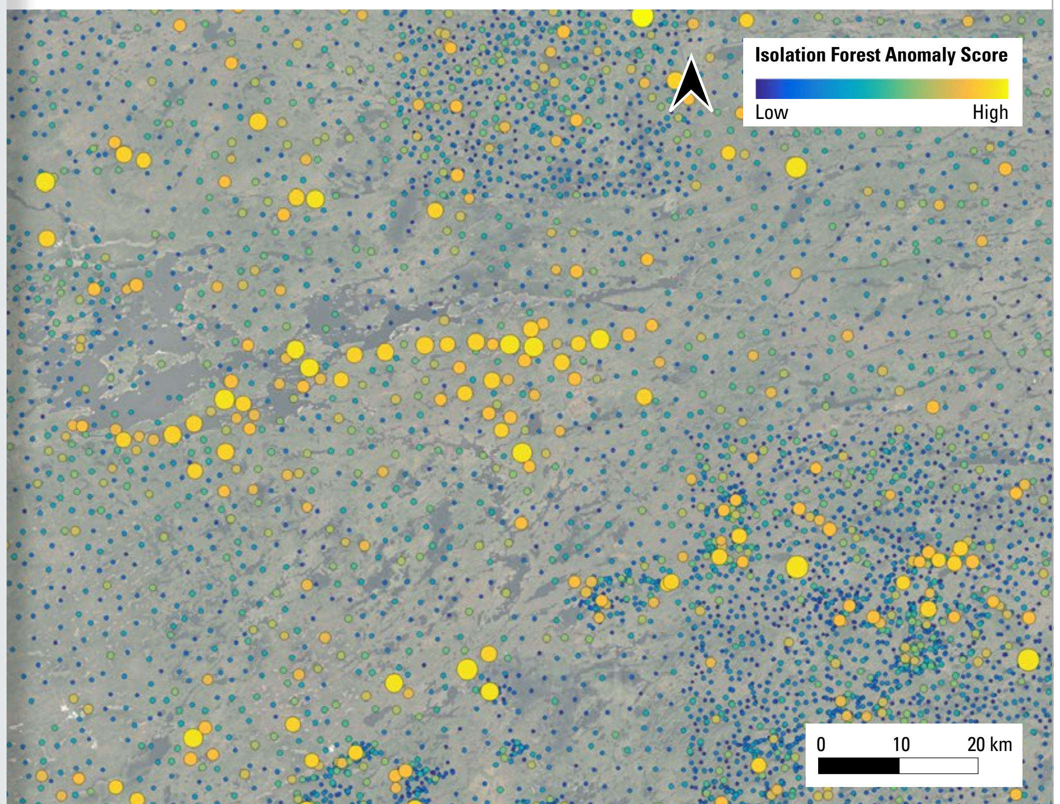

Multi-element Isolation Forest anomaly score from lake sediment geochemistry for gold mineralization in the James Bay region, Quebec

In mineral exploration, the debate often centers on whether human intelligence or artificial intelligence (AI) offers the best solutions to complex challenges. While these opposing viewpoints are intriguing, the most powerful results often come from combining both. When human expertise and machine learning work together, they deepen understanding, accelerate discovery, and enable breakthroughs that were once out of reach.

SRK has pioneered the integration of domain knowledge with advanced AI tools to address exploration challenges. The examples below show how this combined approach is improving our clients' exploration workflows.

First, SRK has merged exploration geochemistry expertise with data science and machine learning to extract geological insights from complex datasets. By analyzing stream sediment, soil, and whole-rock data—from national to deposit scales—we identify lithologies, alteration zones, and multi-element metal anomalies. Data science tools reveal patterns, while geochemists interpret and integrate them into exploration models. This approach surpasses traditional geochemical methods, efficiently handling large datasets and reducing data noise. The outcome is a sharper, more actionable understanding of geochemical patterns that guide exploration success.

Geological mapping has also advanced through the integration of deep learning with satellite imagery. SRK has developed AI models trained to recognize geological features such as alteration signatures of known deposits, gossans, and artisanal workings. Informed by field observations, these algorithms can be applied over vast areas, enabling country-scale exploration campaigns. The method saves time and ensures that key geological features are detected accurately, even in remote regions.

The interpretation of structural features in drill core has long been challenging and subjective. SRK addresses this by combining core photography, deep learning computer vision, and structural geology expertise to map features such as veins, rubble, gouge, foliation, and breccias. The labeling approach produces reproducible, descriptive outputs rather than interpretations. Structural geologists can then use these data to model the 3D architecture of faults and shear zones controlling mineralization. Automating this step generates consistent, detailed data that strengthen expert interpretations.

These examples show that human expertise and AI can be more effective together than apart. By combining the strengths of both, SRK is applying approaches that help address complex exploration challenges. This partnership between human and artificial intelligence is not only influencing the future of exploration—it is defining its present.

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Decision-making as a cornerstone of sustainable exploration

In today's sustainability driven landscape, recognising when a project has reached its limit is key. The discovery push recently has largely been driven by the need to supply raw materials to sustainable technologies. As the first stage of the discovery process, exploration should aim to also be as sustainable as possible.

Exploring more efficiently, not just more intensively, should be on the minds of exploration geologists. The recent increase in exploration budgets and aggressive programmes by some major mining companies has not correlated with discoveries. The data output related to these types of programmes can be massive and requires effective management allowing for on-the-fly interpretation to assist decision making. Recently, SRK has assisted clients in Egypt and Saudi Arabia by interpreting large volumes of data using advanced software. Prior to this, the geologist should have a good understanding of the geological context, and drafting cross-sections at the rig based on what comes out the ground will always have its place. Continuous updates to interpretations assist target prioritisation.

Exploration is dynamic. The ability to be flexible during programmes can prepare the company for changes in geological interpretation, budget, timescales and ESG commitments, each affecting target priority. Blanket drilling programmes are less effective, and for the most part should be avoided in early-stage projects. SRK has recently been in Cameroon assisting with drill programme development and reinforcing the importance for the geologist to be at the rig, maximising the drill programme and being prepared to stop holes in full consideration of the geological interpretation.

Persisting with low-probability projects drains the motivation and budget that should be allocated to explore in other potentially more prospective areas. The phrase 'keeping the rigs turning' is often unsustainable in an exploration context. Targets should be managed using clear decision points at the end of each exploration stage e.g., 1) continue to next phase of exploration, 2) conduct more exploration at that stage for further understanding, and 3) drop and move to another target. Dropping a target or project is not negative, it opens up the chance to focus efforts elsewhere.

In present exploration environments, efficiency, flexibility, and clear decision-making are essential. By integrating decision points and adapting to what we see on the ground, explorers can focus resources where they matter most. Sustainability in exploration lies not just in discovery, but in knowing when to move on.

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On the fly interpretation

Integrating sustainability into exploration decision-making

The mining industry faces growing pressure from regulators, investors, downstream supply chains, and host communities to meet sustainability requirements — expectations that extend to their trusted consultants. During the exploration phase, early understanding of sustainability considerations enables risk-based decisions that benefits exploration planning, enhances financing opportunities, and supports long-term project development.

SRK implements a structured workflow to systematically integrate sustainability considerations into exploration-stage projects. At its core, the process builds on an understanding of each project's unique environmental, social, and governance context to identify material issues and risks that inform decision-making.

In a recent province-wide prospectivity assessment, sustainability-linked 'modifiers' were used to inform the selection of prospective areas and to rank exploration targets. The sustainability modifiers included spatial features or landscape constraints that could influence the ability to explore or construct a possible future mining operation at the identified locations. Examples included areas where exploration or mining is legally prohibited, such as environmentally or culturally sensitive areas, and areas subject to specific land-use or access restrictions. The modifiers influenced decision-making by highlighting permitting-related risks to future mine development. In effect, the modifiers aimed to answer the question: "Can a future mine be built here?"

Once identified, the modifiers were sorted into priority categories based on the anticipated complexity associated with permitting future exploration or mining projects areas. The modifiers within each priority category were scored and integrated with geological information to build the overall prospectivity model. Site-specific analyses were then performed to validate the model outputs and interpret the findings. Jurisdictional legal requirements had a strong influence on the prioritisation and scoring of modifiers. For example, understanding why access to an area was restricted, or how site-specific management plans could affect project objectives, allowed scores to be refined to better reflect sustainability considerations in prospectivity.

Through effective collaboration between exploration geologists and sustainability professionals, the team delivered integrated insights into geological and sustainability-related complexities, enabling the client to identify, prioritise, and assess potential targets early in the process.

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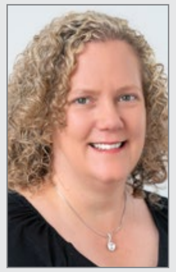

Teresa is an ESG practitioner with over 20 years' experience integrating environmental, social and governance considerations into mining developments and technical studies in line with international reporting codes. Originally trained as a geologist, she later specialized in environmental science, law and policy, and now applies this combined expertise to assess, manage and review ESG risks across the mining lifecycle. Her experience includes implementing environmental management systems, overseeing legal compliance and permitting, and contributing ESG components to feasibility studies, mineral reports and due diligence reviews at mine site, business-unit and corporate levels.

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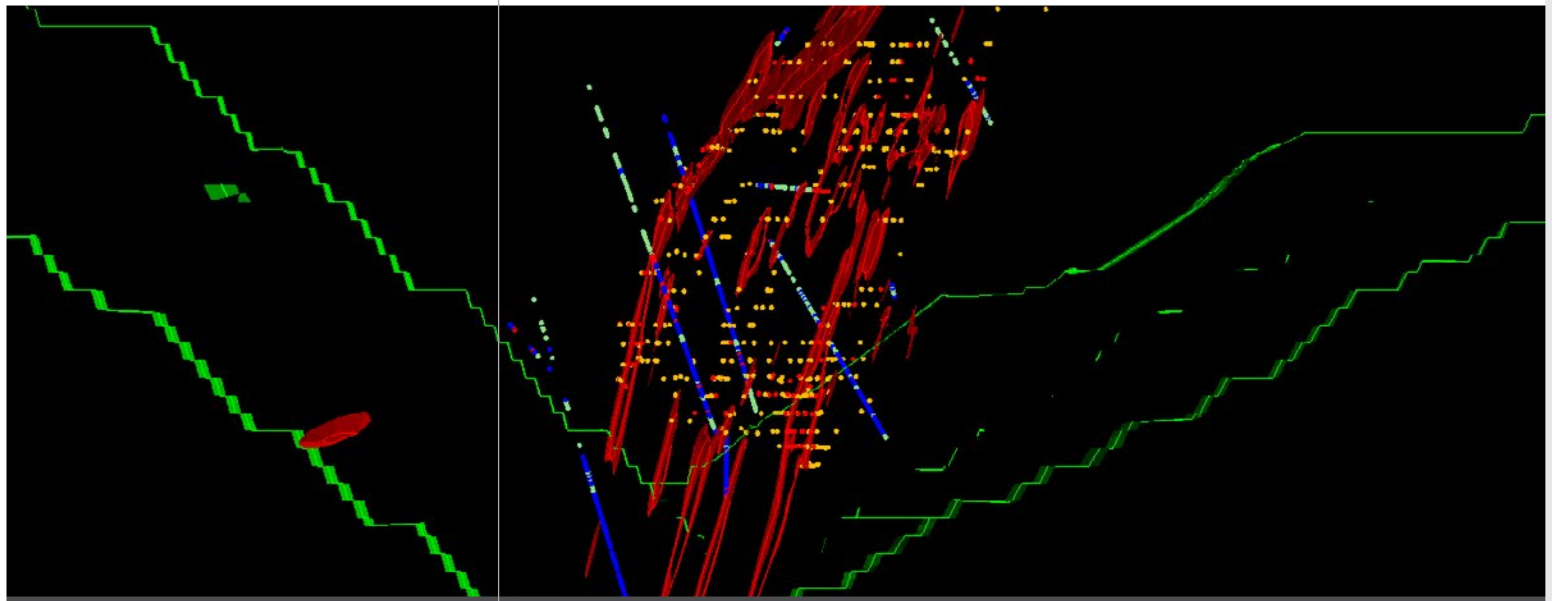
Evaluation of spatial continuity for structurally controlled geological modelling



Visual breccia validation with geological data

Spatial continuity of geological models must be controlled rigorously because they have a direct impact on the mineral resource estimate. These models typically integrate drillhole assay and geological information—such as lithology, alteration, and mineralization along with some structural data; however, the spatial trends used are often scarce or inaccurate, especially between different structural domains. In addition, modelling databases may have suboptimal codification, and drillhole and blasthole data may not be integrated when available. These issues can lead to simplified models that tend to show under- or over-projection of geological units.

To generate geological models and evaluate their spatial continuity, SRK uses implicit modelling software combined with integrated Python workflows. Leveraging its established geological modelling expertise, SRK has developed a methodology that addresses most of the issues described above.

Modelling databases can benefit from post-processing scripts that apply multielement thresholds or ratios to refine geological codification. For example, clay spectrometry or arsenic grades may help improve alteration coding. For validation, Python workflows can evaluate geological codification by generating clusters using algorithms such as k-means, hierarchical clustering or DBSCAN, and by assessing spatial continuity when coordinates are included as features.

Geological units may exhibit different spatial continuity across structural domains, so these domains must be modelled beforehand to identify the boundaries where local trends control continuity and orientation. Also, implicit modelling relies on parameters such as ranges and ellipsoid shapes, which are often defined based on geological knowledge rather than quantitative methods. These parameters should be validated using indicator variograms to assess continuity ranges and directional anisotropy, thereby determining appropriate ellipsoid shapes.

For post-processing, sample support should be evaluated for each orebody to assess the spatial continuity of geological units. Using Python workflows, mesh diameters along their major, intermediate, and minor axes can be measured while accounting for anisotropy. Sample support can then be flagged per mesh and expressed as a diameter ratio to quantitatively evaluate whether the geological units exhibit under- or over-projection.

Implementing this methodology across different mineral deposits has allowed SRK to assess the spatial continuity of structurally controlled geological models more accurately. Whether the objective is geological modelling or due diligence, this approach provides mining companies with robust feedback and recommendations, helping reduce risk within the mineral resource estimate.

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FERNANDO STOCKER

Fernando is a Resource Geologist based in SRK Chile and has over five years of academic and industry experience focused on geological modelling and geostatistics. He applies Python-based workflows for technical services and audits, using data analysis and machine-learning algorithms to integrate structural, geochemical, and metallurgical information into resource models. His MSc research developed an integrated geometallurgical characterization methodology for comminution in iron oxide copper-gold deposits. Fernando has worked on copper, iron, gold, and cobalt projects across Chile.

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EMILY HARRIS

Emily is a Chartered Environmental Professional with 20 years in the mining industry experience across multiple commodities and global jurisdictions. Emily collaborates with geology and engineering colleagues to embed sustainability considerations throughout the mine life cycle, including exploration. Through her work, Emily understands the importance of focussing on key issues and effective collaboration and integration with technical studies and decision-making to enhance value for a project and its stakeholders.

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Artisanal mining for gold and greenfield exploration programs

Grete Vanstaden, examining coarse heavy mineral concentrate recovered by an artisanal miner in Sierra Leone

CASEY HETMAN

Casey Hetman is a Professional Geologist with over 30 years of experience on primary diamond deposits, Archean lode gold systems, epithermal gold–silver projects, and critical mineral deposits worldwide. A registered Professional Geoscientist in multiple Canadian jurisdictions and a NI 43-101 Qualified Person, he has conducted field investigations across 50+ mining operations in 20+ countries. Casey integrates detailed geological observations with petrographic, geophysical, and grade data to develop 3D models that support exploration, evaluation, mine planning, and technical reporting from scoping to feasibility studies.

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Integrating artisanal mining data can greatly assist exploration teams in greenfield programs by helping identify and locate primary gold deposits. Artisanal mining activities are often encountered in greenfield programs and in areas of large-scale mechanized mining. Artisanal miners in many countries are often involved in informal, small-scale gold recovery throughout their lives, representing multi-generational mining traditions within local communities. Over time, these miners have developed a wealth of knowledge about the distribution of gold within various systems from which it is recovered.

Historically, geologists have been cautious or have avoided engagement with artisanal miners due to concerns, including: security risks and operational safety; informal land access and ownership complexities; environmental and social risks; lack of formal production records; and potential conflict with mining permits and regulatory framework.

However, when managed responsibly, engagement with artisanal mining communities can yield valuable geological insights that significantly enhance exploration targeting and interpretation in the search for a primary gold deposit.

Artisanal miners primarily exploit secondary gold deposits with hand tools, gold pans, sieves and crude washing tables. These miners focus on modern active drainage systems, ancient river channels, and terrace deposits. It is less common for them to work on primary deposits, and where they do, the focus is often within laterite and saprolite. Gold distribution within the secondary environments is inherently complex and highly variable. In some systems, gold concentrations may remain static where the primary source has been completely eroded. In contrast, other systems may experience seasonal or flood-driven recharge, during which gold continues to be liberated from an active primary source or sources into the secondary environment.

It is important to appreciate that drainage systems hosting the gold are dynamic environments and that gold is often redistributed over time. Drainage dynamics and flow directions can change multiple times and even reverse, resulting in a complex distribution of gold, and therefore, locating a proximal primary source may be very challenging. The most important factors supporting exploration targeting in artisanal mining environments include:

1. Confirmed recovery of gold within the area of interest; 2. Sustained artisanal mining activity over multiple years; 3. Gold grain morphology indicating minimal transport; 4. Preservation of associated minerals providing insight into primary source lithologies; 5. Artisanal mining occurring directly within or adjacent to primary mineralized zones

Review of artisanal mining activities using Google Earth, satellite imagery, and historical aerial photography allows for exploration geologists to evaluate the spatial evolution of artisanal mining activity over time. The rapid relocation behaviour of artisanal miners when the ground becomes unproductive creates discernible spatial patterns that can effectively guide exploration targeting strategies. In addition, LIDAR surveys allow exploration teams to identify drainage features and historic mining areas obscured by vegetation.

The examination of gold grains recovered by artisanal miners provides essential information to exploration teams. Parameters such as the volume of gold recovered, grain-size distribution, and gold-grain morphology provide strong indications of source proximity and potential source-rock characteristics. Investigation of gold grains using a Scanning Electron Microscope (SEM) and Backscattered Electrons (BSE) imaging enables detailed morphological analysis, aiding in the classification and interpretation of textures preserved on recovered grains.

Angular, irregular grains with jagged morphology and the preservation of associated host minerals (quartz, carbonate, sulphides) typically indicate limited transport (< 3km) and proximity to the primary mineralization. In rare cases, delicate primary growth features and even sponge-like structures can be partially preserved.

Gold grains that have experienced significant transport (> 3km to 10s of km) from the primary source display very different morphology, characterized often by smooth, flattened disc-shaped grains, and they lack any associated gauge minerals. It is important to appreciate that although the size of gold grains can reflect transport distance, welding of grains can occur (up to 30mm – see photo on this page).

Artisanal mining activities and the investigation of gold grains recovered from small-scale mining operations may provide important data that can significantly inform early-stage greenfield exploration programs. Integration of artisanal mining data with geological mapping, geochemical surveys, structural interpretations, remote sensing and geophysics enhances the probability of identifying primary gold sources and refining exploration models.

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GRETE VAN STADEN

Grete is a Senior Geologist specialising in geological development for primary and alluvial diamond projects, Archean lode gold systems, emerald deposits, and other critical minerals. She conducts detailed field investigations on outcrops, drill cores, and mining exposures in both open-pit and underground settings. Grete has extensive experience in 3D geological modelling for exploration, evaluation, and mine planning, prepares NI 43-101 technical reports, audits geological and mining datasets, and provides on-site training in mapping, data collection, and 3D modelling.

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Coarse gold recovered from an artisanal mine in Honduras

Gibi project: advanced stage iron ore exploration

Exploration drill site at Zezia Hills

ALAN PAGE

Alan is a Principal Geologist with SRK South Africa. He holds degrees in geology from the Universities of Cape Town and KwaZulu-Natal and has more than 30 years' experience in exploration, geological modelling, mineral resource estimation, and mining geology. Alan has worked extensively across Africa on gold, platinum, chrome, and base-metal projects, with a focus on iron ore and PGE-chromitite deposits of the Bushveld Complex. He is a Competent Person for Mineral Resources.

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The Gibi Project is an advanced-stage iron ore exploration project in Bong County, Liberia, about 89km east-northeast of Monrovia. The deposit is a magnetite-dominated Banded Iron Formation (BIF), referred to as itabirite, likely formed in a restricted marine basin setting. The client's strategy is to fast-track production by initially focusing on a smaller target area within the larger 448km² exploration licence. The Ridge 1–4 iron ore deposits at Zezia Hills extend ± 4km north–south within a 1.7 km-wide zone and average ± 40m in depth.

SRK South Africa undertook the following:

- Reviewed and provided Standard Operating Procedures (SOPs) for exploration work, including drilling, core orientation, recovery, and handling, storage, cutting, sampling, QA/QC, pXRF, and Archimedes density determination.
- Assisted and monitored drilling and sampling programmes.
- Examined the nature and extents of the iron formation outcrops and designed an independent QA/QC programme, which was implemented and reported.
- Conducted two site visits to the project (Phases 1 & 2) to monitor SOP implementation and assess geological and structural controls on the distribution of iron ore mineralisation.

Phase 1 exploration (2023 period) included geological mapping, rock-chip sampling, and diamond drilling (DD) by Cestos Drilling Company. Fifty-two holes (3,030m) were drilled mainly along strike at ± 200m spacing, with limited dip drilling. A total of 490 density measurements were collected. Three ore types were identified: BIF, Supergene BIF, and Massive Magnetite Iron Formation.

Phase 2 exploration (2024) involved mapping and airborne magnetic and radiometric surveys by New Resolution Geophysics, processed and modelled by Southern Geoscience Consultants to identify targets. Subsequent DD and sampling, conducted by drilling companies, Energold and Cestos, tested the Zezia Ridge 1–4 target areas. Drill holes were spaced 50m along strike and 40m down dip to define mineralisation continuity. A total of 153 holes (4,295 m) were drilled, with 841 density measurements collected. Drilling confirmed canga, haematite, and magnetite mineralisation. A drone LiDAR topographic survey covered Ridges 1–4 target areas.

Phase 3 exploration is currently in progress with a total of 4,000m drilling and sampling planned. SRK is assisting with drillhole planning and daily monitoring as West 26 advances resource expansion.

SRK estimated grade and tonnage ranges for the Zezia Hills target area and issued a JORC compliant Exploration Target in November 2023. Subsequently, SRK completed a NI 43-101 compliant Mineral Resource Estimate for the Ridge 1–4 deposits iron ore deposits, effective in 2025.

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Building better graphite projects with credible data

Graphite exploration differs from other mineral commodities, requiring a nuanced approach beyond the traditional focus on grade. The quality and economic potential of a graphite deposit are not solely determined by grade but rather by a combination of critical factors, including flake size, distribution, shape, and purity. These factors are essential for the marketability and value of the deposit, yet they are often overlooked in early-stage exploration.

Many graphite projects advance far into development focused on grade, yet lack credible data on flake size distribution and other mineralogical properties. This oversight can lead to significant challenges in project valuation, feasibility studies, and ultimately, market competitiveness.

Flake size plays a particularly pivotal role in determining the end-use applications and market value of graphite. Larger flakes, such as jumbo (0.3-0.5mm) and super jumbo (>0.5mm), command premium prices due to their suitability for high-value applications such as expandable graphite products and high-performance batteries. Smaller flakes, while less valuable, serve critical markets such as anodes for electric vehicles (EVs), lubricants, and refractory materials.

Understanding these distinctions requires a multidisciplinary team of geologists, mineralogists, and metallurgists equipped to conduct detailed mineralogical studies and flake size analysis, which are both time-consuming and technically demanding.

Laboratory floatation procedures are essential for separating graphite flakes from gangue minerals, assessing their recovery potential, and preserving their size during processing. Liberation studies further evaluate the degree to which graphite flakes can be freed from the host rock. These steps are critical for generating credible data that can inform project decisions and market strategies.

As graphite drives energy transitions and industrial advances, understanding its market dynamics and mineralogical properties is essential to unlocking a project's potential. With growing demand fuelled by its critical role in energy storage and industrial applications, companies must adopt a comprehensive exploration approach to remain competitive in this rapidly evolving sector.

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SARA TURNBULL

Sara is a Senior Exploration Geologist with over 12 years of professional experience in exploration and mining. She has had exposure to diverse geological terrains and a variety of commodities across the whole of Africa. Sara began her career as an expatriate exploration geologist with a multi-commodity, Australian-listed junior company. She has contributed to multi-disciplinary teams, successfully advancing numerous projects from greenfields through feasibility and into production.

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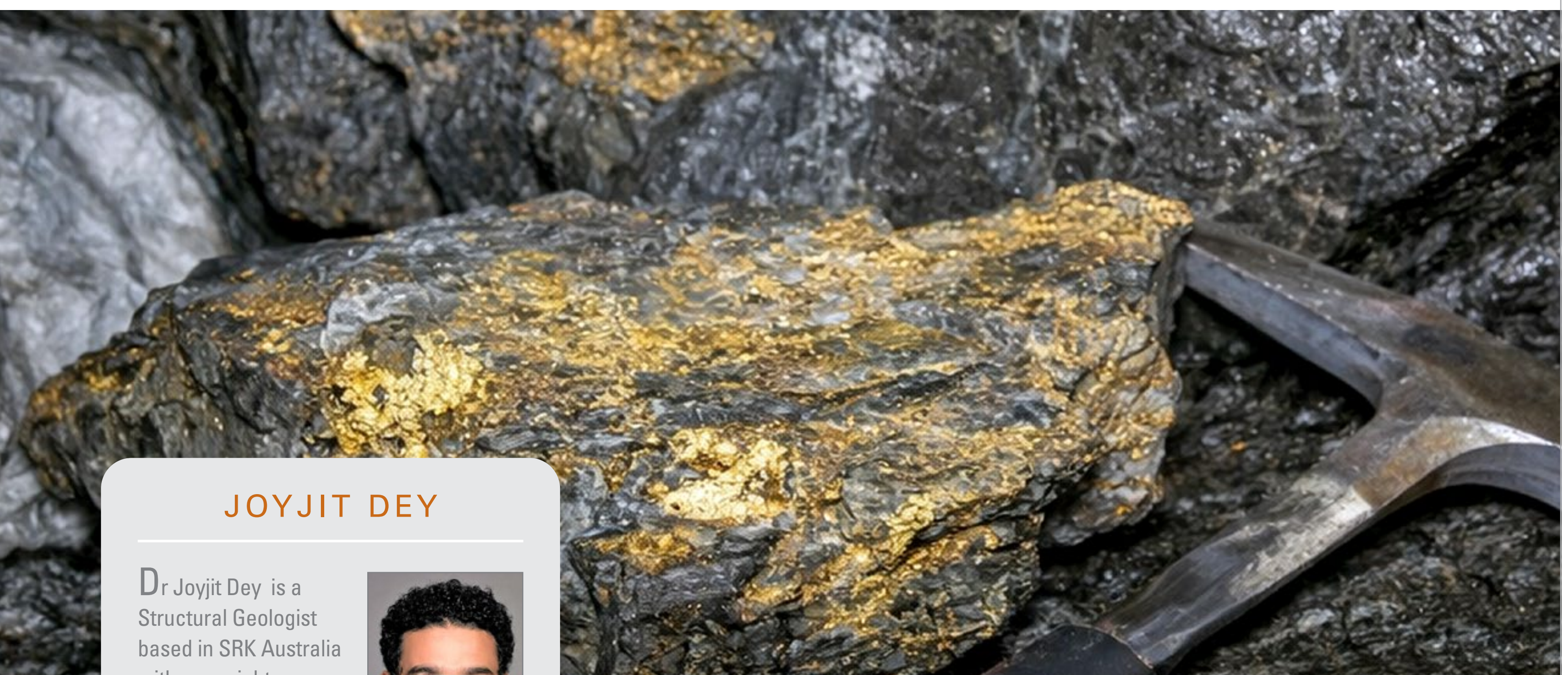
Logging diamond core in Mozambique for graphite-vanadium project

Dynamic structural modelling in brownfield exploration: beyond structurally controlled systems



Rock sample with visible mineralization

JOYJIT DEY

Dr Joyjit Dey is a Structural Geologist based in SRK Australia with over eight years of academic research and industry field experience. His current work focuses on exploration targeting and geotechnical operations. Joyjit integrates structural geology, geophysics, and geochemistry with surface and underground mapping and applied 3D modelling. He uses a multi-scale approach—from regional litho-structural mapping to microstructures, core logging, and geophysical/geochemical analysis—to identify mineralisation controls and support geotechnical work. He has worked on iron, zinc, lead, gold, copper, coal, and lithium projects across Australia, India, Saudi Arabia, Africa, the UK, and Europe.

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Dynamic structural modelling can be a powerful and adaptive tool in brownfield mineral exploration, offering a framework to integrate diverse, multi-scale geological datasets into evolving 3D models. While dynamic structural modelling is often used for strongly deformed systems such as orogenic gold or volcanogenic massive sulphide deposits, it is equally valuable for banded iron fomation (BIF)-hosted deposits such a those found in the Pilbara region of Western Australia. In these deposits, faults, folds, and shear zones can upgrade and redistribute mineralization, shaping ore geometry and continuity.

In brownfield contexts, exploration must reconcile legacy data with new inputs from active mining. Dynamic modelling facilitates this by fusing data streams such as Unmanned Aerial Vehicle (UAV) photogrammetry for structural mapping of continuously exposed benches, blasthole geochemistry, Reverse Circulation (RC) drilling with downhole geophysical logs (e.g., gamma), and targeted diamond drillholes with Acoustic Televiewer (ATV)/Optical Televiewer (OTV) datasets for fracture/fault characterization. These are integrated within a multi-user geodatabase (e.g., Leapfrog, Vulcan) that supports iterative, version-controlled updates as interpretations evolve. This dynamic environment enables geoscientists to test hypotheses, quantify uncertainty, and prioritize targets with greater precision and confidence.

Even though BIFs are stratiform in origin, structural processes play a major role in concentrating high-grade zones of iron ore mineralization—so understanding deformation is critical. When applied effectively, structural modelling enhances understanding of fault offsets, fold amplitudes and wavelengths, and brittle-ductile regimes that influence ore distribution, mineral hydration states, and grade variability.

SRK has applied dynamic modelling techniques to numerous iron ore operating pits in the Western Australian in Pilbara region. Using UAV imagery and Vulcan software, high-confidence structural data were extracted from continuously exposed benches and integrated with crest and pit mapping, blasthole geochemistry, and drillhole datasets. This composite dataset validated geological conformance. Discrepancies triggered immediate model updates, refining understanding of how faulting and folding localize high-grade, hydrated ore. This data-driven approach guided infill drilling campaigns, optimizing resource definition within active pit shells.

Importantly, dynamic structural modelling aligns with the principle that geological models must evolve alongside exploration and mining.

As resource extraction progresses—through new exploration zones, pit extensions and cutbacks, and continuous mining—new data such as point cloud mapping, in situ assays, and production drilling results need to be fed back into the structural framework, capturing incremental morphological changes in the ore body. The modelling workflow proceeds hierarchically, from regional-scale geometry to deposit-scale deformation features and from well-constrained to poorly known domains, progressively reducing uncertainty through targeted data acquisition and model calibration.

Overall, dynamic structural modelling is a powerful tool for brownfield exploration. It supports adaptive decision-making, integrates evolving datasets, and enhances geological understanding, especially in mineral systems where stratigraphy and structure interact to control mineralization. Geotechnical risk assessment for pit design and optimization, as well as hydrogeological analyses, also benefit from this approach.

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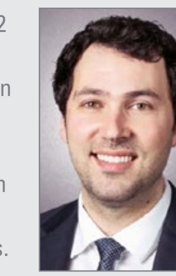

Stephen has over 12 years of experience in mineral exploration and ore deposit geology, working across porphyry, iron oxide copper-gold, and iron ore systems. As an experienced geologist, he has held exploration roles in regional, near-mine and generative teams throughout South America, Southeast Asia and Australia. Stephen brings strong 3D modelling capability and is proficient in Vulcan, Leapfrog, Micromine, MapInfo, QGIS, ioGAS and TSG. He is recognised for effective communication, problem-solving and organisational skills within multidisciplinary exploration teams.

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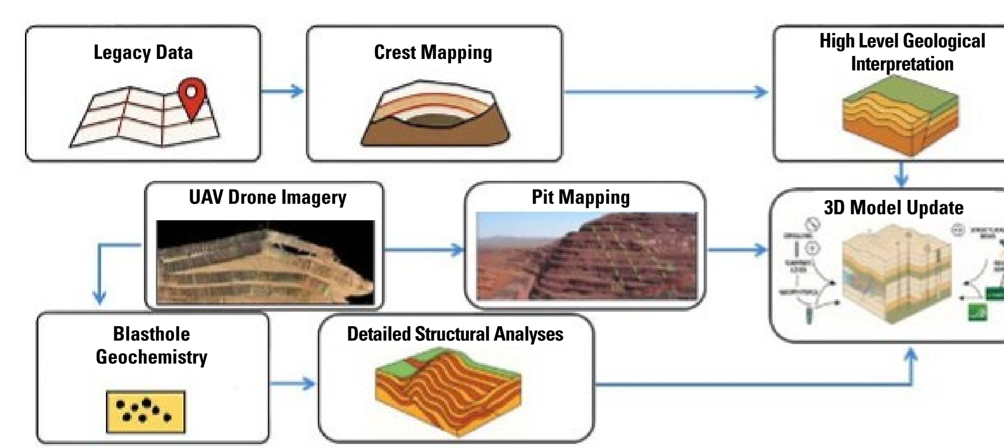
Dynamic structural modelling in brownfield exploration



Exploration decision-making through real-time data review and modeling

Exploration drilling is crucial to safeguard shareholders' interests and maintain economic viability. The real value of drilling lies not only in data collection but also in the review and analysis of results.

Concurrently, updating geologic models, refining mineralization domains, estimating preliminary mineral inventories, upgrading resource classifications, and optimizing pits and mineable stopes can greatly enhance the success of a drill program, maximizing the value of each drillhole. Therefore, leveraging updated models to plan metallurgical drillholes also ensures accurate representation of grade and mineralization styles—crucial for informed decision-making in processing strategies.

Exploration geologists, equipped with advanced implicit modeling software, have powerful tools to update geologic models quickly and seamlessly. This minimizes the time needed to integrate new drillhole data and dynamically adjust downstream models. With up-to-date models, geologists can better understand subsurface geology, structural controls, and mineralization trends, enabling more precise targeting and efficient use of exploration resources.

Furthermore, the ability to update mineralization domains, estimate mineral inventories, and apply economic parameters to pit and stope optimizations enhances a project's economic assessment. Integrating fresh drilling data into updated models helps identify open high-grade areas and avoid zones of low economic potential, improving resource delineation and mine planning. Upgrading the resource classification throughout a drill program not only improves conversion efficiency but also helps to design targeted infill programs to meet project objectives.

In addition, the strategic planning of metallurgical drillholes based on updated models ensures representative sampling of grade and mineralization styles—essential for accurate metallurgical testing and process optimization. By properly placing these drillholes, the exploration team can obtain samples that reflect the deposit variability, improving orebody understanding and reducing project risk. Ensuring representative sampling early in the exploration phase can shorten project timelines by reducing the need for later infill drilling. In regions with short field seasons, this efficiency can materially impact project delivery.

The benefits of reviewing drilling results in real time and using implicit modeling software for dynamic model updates cannot be overstated. This approach enables teams to maximize value from each drillhole, optimize resource delineation, refine exploration and processing strategies, and make informed decisions throughout active programs. In an environment where efficiency and value creation are paramount, embracing advanced technology and data-driven methodologies is key to unlocking the full potential of mineral exploration projects.

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SCOTT BURKETT

Scott is a Principal Geologist with executive-level mining and exploration expertise offering more than 18 years of mining and exploration experience, specializes in resource development, project management, geologic modeling, and resource estimates. Scott has worked globally on diverse mineralized systems, including sediment-hosted gold, epithermal precious metals, carbonate replacement base metals, and sedimentary exhalative zinc, spanning greenfields exploration to production in open pit and underground operations.

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An exploration transformation process study for Indonesia's MIND ID company

In 2024, SRK undertook an Exploration Transformation Process study on behalf of the large Indonesian mining company PT Mineral Industri Indonesia (MIND ID). MIND ID is a state-owned holding enterprise comprising the member organisations PT Aneka Tambang Tbk, PT Bukit Asam Tbk, PT Freeport Indonesia, PT Indonesia Asahan Aluminium, PT Timah Tbk, and PT Vale Indonesia Tbk.

The key objective of the study was to provide MIND ID with a maturity assessment at the strategic, tactical, and operational levels of its exploration capability, departmental processes, and performance. The study also evaluated how these elements align with MIND ID's strategic roadmap and its goal of becoming a world-class mining company with assets and investments in Indonesia and internationally.

The study focused on the geology and exploration departments of PT Aneka Tambang, PT Bukit Asam, and PT Timah (covering nickel, gold, bauxite, coal, and tin), as well as the overarching MIND ID support framework.

Prior to MIND ID embarking on its Exploration Transformation Process and the study led by SRK, the Member organisations focused on near-mine and resource conversion/replenishment activities (including conversion to higher confidence categories) to support short-term ore replacement and operational ore feed.

To meet the study objective, SRK was tasked with the following: first, conducting a maturity assessment at the MIND ID Group levels mentioned above. From an initial assessment perspective, the relevant teams were evaluated based on SRK's observations, discussions, and document reviews across four key areas: strategy, capability (people), capability (technology), and process and performance management. This included visits to various operational facilities, presentations from teams, and follow-up discussions with senior team members.

Drill core facilities, Pongkor Gold Mine – Mark Rieuwers liaising with PT Aneka Tambang Tbk exploration geologists on core logging, structural observations and sampling procedures

Second, benchmarking this baseline information against global industry best practices, including those of major mining company exploration teams and relevant industry or regulatory standards. MIND ID's existing effective processes, approaches, and practices were leveraged wherever possible during the transformation process.

Finally, presenting and seeking feedback on findings, and preparing supporting documentation including a) summary of findings and maturity scorecards, b) outline recommendations and refinements to the MIND ID exploration roadmap, and c) a suitable operating structure for MIND ID's planned exploration strategy. A second, shorter phase provided initial training to support the implementation of key findings that could be achieved in the short to medium term.

A range of findings and recommendations were made, including guidance on how to focus efforts and structure activities to achieve medium- to long-term exploration objectives.

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MARK RIEUWERS

Mark has 20 years of experience in the mining and exploration industry with a track record of orebody discovery and project delivery – predominantly in nickel, gold, iron oxide copper-gold, porphyry copper, iron ore and lithium systems. During his years in the industry, Mark has focused on integrating mineral systems geoscience, structural geology, geochemistry and geophysics along with data-driven and knowledge-driven geoscience in building effective exploration targeting and generative strategies.

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Boom-bust cycles in exploration – are they a thing of the past?

JON RUSSILL

Jon is a Principal Exploration Geologist and Director of SRK Exploration where he has worked for 18 years. He works on the management and reporting of exploration projects around the world for a wide range of commodities but has a special interest in critical raw materials and high latitude areas. Jon has worked on several research projects into social factors in mineral project development, the role of government policy and opportunities for mining to meet sustainability goals.

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Exploration has always felt commodity swings first. From 2010 onward, exploration for rare earth elements (REEs) surged as supply concerns grew—until that bubble burst. Lithium then dominated, driving record exploration expenditure in 2023 before cooling again. These fluctuations have long defined exploration consulting: exciting, but unpredictable.

Although, this time feels different. Despite gold's extraordinary rise—exceeding US$4,000/oz in October 2025 when topping US$3,000 seemed incredible a year earlier—exploration activity has not followed. A decade ago, such prices would have triggered a rush of market enthusiasm and drilling. Similar booms lifted REE resources—excluding China—fivefold between 2010 and 2015, and lithium resources by 44% from 2020 to 2025. Yet today, the surging gold price is not translating into grassroots exploration.

For many junior explorers, especially those listed on growth stock markets such as the London Stock Exchange Alternative Investment Market (AIM), access to capital has become severely constrained. Once central to global discovery pipelines, many are simply staying afloat. Conversely, activity has intensified around more advanced projects in stable jurisdictions, where environmental, social, and governance risks are better understood and managed. SRK teams supporting such projects are engaged in continuous due diligence for mergers and acquisitions, feasibility assessments, and resource updates. In essence, the market has de-risked: shifting focus from speculative discovery toward disciplined, risk-managed investment.

This evolution reflects both caution and maturity. After years of volatility and increased scrutiny, investors now prioritise capital preservation and transparency. SRK is adapting in turn by pursuing specialised generative work for major mining companies with leaner geological teams, developing new analytical approaches, and integrating digital and data-driven capabilities. SRK's growing expertise in data analytics and generative exploration work illustrates how innovation is replacing reactivity.

At the same time, governments are taking a more active role in securing critical raw materials.

- Canada has committed CAD 3.8 billion to critical minerals.
- The EU supports 47 strategic projects requiring EUR 22.5 billion.
- The US and Australia have launched an US$8.5 billion partnership.

These initiatives explicitly recognise exploration as a vital link in the supply chain. The US Government, for instance, has even taken direct stakes in domestic and foreign base metals, lithium and REE ventures. While state involvement remains unusual in Western mining, attitudes are shifting. There is growing discussion of price-support mechanisms to reduce boom-and-bust cycles in exploration that have long stifled discovery.

This orientation suggests a broader understanding that sustained mineral project development requires more than market cycles—it needs long-term commitment and confidence in exploration. If this new environment holds, the sector could be entering a more stable, strategically guided phase—one where cyclical volatility gives way to sustained, purpose-driven growth. For SRK, this is not only an opportunity to apply deep technical insight, but to help shape a more resilient future for mineral exploration globally.

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Exploration for REEs in Greenland

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