ESGI195 Challenge: Absolute mineral prospectivity mapping under complex exploration biases

This ESGI195 challenge is presented by

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Overview

Metals and minerals are essential for almost all modern technology and infrastructure. However, many shallow, "easy" deposits have already been found. Therefore, future discoveries will be deeper, more concealed and in more complex geology. Exploration is expensive and risky, and decisions about acquiring, exploring or dropping licences are still often made on qualitative judgement rather than on transparent quantitative analysis, especially in junior companies that conduct much of the world's exploration. What is missing is a tool that can quantify how prospective different areas are in absolute terms, and thereby help mitigate exploration risk and guide capital towards projects with the best balance of probability and reward.

Current prospectivity analysis falls into two main camps: knowledge-driven models (expert geological opinion) and data-driven machine-learning models based on known deposits. Both produce relative rankings ("this area looks better than that"), but neither provides absolute probabilities of finding deposits. They also fail to integrate geological knowledge and exploration data in a unified, dynamically updated framework.

Moreover, exploration itself is staged, highly selective and biased: we see positive examples (discovered deposits) but almost no true negatives. Most locations without known deposits are simply unexplored or only lightly tested. Standard supervised machine-learning methods, however, require both positives and negatives to train a classifier, and in practice they often treat the locations with less chance of deposit occurrence as arbitrary negative examples. As a result, such models learn patterns of where exploration has been successful, rather than the underlying geological controls, and are fundamentally unsuited to estimating absolute prospectivity.

Challenge focus

The core mathematical problem is to estimate, for each grid cell (typically 1 km × 1 km), a probability distribution over deposit size classes (none, small, medium, large, world-class), accounting for:

- Structured geology via mineral systems (fertility, geodynamics, architecture, preservation).

- Endowment and maturity: how many deposits of each size plausibly exist in total, how many are already discovered, and what fraction is realistically discoverable in 5–10 years.
- Exploration bias and imperfect detection: exploration is targeted, sparse and expensive, so absence of discovery does not imply absence of deposits.

The deposits we observe are only a biased subset of all mineral deposits that actually exist. Many cells without known deposits may still host undiscovered deposits and therefore have non-zero probabilities of containing deposits of various sizes. At the same time, exploration maturity (reports, geochemistry, geophysics, drilling) strongly affects the likelihood that a deposit would have been detected, but exploration effort is itself preferentially allocated to geologically favourable or strategically attractive areas. We need a modelling approach that explicitly accounts for this biased, incomplete and preferential sampling, and that estimates absolute prospectivity while incorporating detection probabilities and exploration maturity.

Our prototype framework, MVAP (Management and Valuation through Absolute Prospectivity), tackles this via a hierarchical Bayesian model that combines a mineral-systems prior, Evidence layers (e.g., occurrence maps, exploration maturity) and endowment constraints. For ESGI195, participants are invited either to refine and improve MVAP (better hierarchical structures, priors, likelihoods, treatment of preferential sampling, inference methods) or to propose alternative probabilistic formulations that solve the same problem of absolute prospectivity under complex exploration biases.

Outcome

The aim is to obtain a more rigorous, transparent and robust framework for absolute mineral prospectivity mapping that can:

- Provide cell-level probability mass functions over deposit size classes consistent with both mineral systems geology and province-scale endowment.
- Correct for exploration bias and imperfect detection.
- Aggregate cell-level probabilities into licence- and portfolio-level metrics for valuation and risk analysis.

Practically, we hope ESGI teams will:

- Formulate a clear generative or hierarchical model linking covariates (mineral systems), known deposits, exploration effort, detection and observed deposits.
- Show how endowment and discovery time series can be incorporated as constraints on cell-level probabilities.
- Recommend feasible inference strategies and diagnostic checks to ensure outputs are driven by geology, not artefacts of exploration bias.

Gridded mineral systems covariates, deposit and occurrence data, exploration maturity and drilling density, and endowment/discovery history for parts of the Yilgarn Craton will be provided. Using this data, ESGI participants can either enhance MVAP into a more principled hierarchical Bayesian framework or propose a new modelling approach that could underpin the next generation of absolute prospectivity and Unified Exploration Models, directly informing exploration strategy and investment decisions.

1. Industrial context and motivation

Metals and minerals underpin almost all modern technology and infrastructure, and the energy transition (batteries, renewables, electrification) is driving rapid growth in demand for commodities such as lithium, nickel, copper and rare earths, alongside continued demand for gold and base metals. Many of the "easy" deposits at surface have already been found; future discoveries will increasingly be deeper, more concealed and in geologically complex regions. This makes exploration more difficult, more expensive, and more dependent on making good decisions about where and how to explore.

For any project, explorers need to make a series of decisions, starting with initial licence or project selection, and later 'explore / drop / deal' type decisions at regular stages as exploration proceeds. Decisions also need to be taken by other interested parties such as investors and governments when offering land for licencing or tender. But how do we make such decisions in an informed way?

Such decisions should require an assessment of prospectivity weighed against the cost of acquiring, investing in and/or exploring the project. The best explorers carefully weigh such considerations and conduct detailed analysis. However, all too often critical decisions such as whether to acquire a project, or whether to explore or drop a project, are made on the basis of subjective judgement and personal networks that influence whether a project is funded or not, this problem is particularly aa problem for junior exploration companies through which much of the global exploration is conducted. Even where detailed analysis is undertaken, it is invariably qualitative in nature and highly dependent on individual geologists' judgement. These problems are particularly acute for grass-roots exploration projects with little exploration data and are one factor that may lead investors to unduly favour brownfields projects over greenfields exploration. This in turn results in the rate of discovery of large new deposits being supressed.

Prospectivity analysis attempts to deploy a more rigorous approach to the assessment necessary for such decisions, and can be done with traditional GIS-based techniques. Increasingly, machine learning is also deployed to make sense of the vast amounts of geoscientific data now available. In broad terms, current practice falls into two camps:

- **Knowledge-driven models**, which use geological understanding (mineral systems, expert rules, conceptual models) to score or rank areas. These can be applied in data-poor regions where few deposits have been discovered and exploration datasets are sparse.
- **Data-driven models**, which rely on statistical or machine-learning relationships between known deposits and predictor variables. These are most effective in data-rich regions with extensive exploration histories and large numbers of known deposits and occurrences.

Both approaches provide useful information about which projects appear better than others, but neither is entirely satisfying. First, they remain firmly in the realm of relative prospectivity: they answer “which areas look better than which others?” but not “what is the actual probability of finding a deposit of a given size here within a realistic time frame?”. They therefore do not inform how much a project is worth in dollar terms, or how much should reasonably be spent, beyond making relative comparisons between projects on similar terranes.

Second, the separation between knowledge-driven and data-driven methods is artificial. In practice, explorers must use all available information: expert knowledge, mineral systems understanding, limited early data in frontier regions, and rich exploration histories in mature provinces. As exploration proceeds, new data (geochemical anomalies, geophysical surveys, drilling results, discoveries and failures) should update our view of prospectivity in a consistent way. Existing methods rarely provide a formal mechanism for this kind of dynamic updating across both data-poor and data-rich regimes.

Furthermore, current approaches do not provide information regarding which projects have high potential to become exploration “traps” – projects that uncover enough “smoke” to attract large expenditure, but with little prospect of an economic discovery. These are the projects with the lowest value, which can in fact be highly negative. Similarly, they are poor at quantifying the effect of ultra-rare world-class discoveries. This is critical, because the sector-wide payoff of exploration is highly skewed towards these world-class deposits; they are, in essence, what makes mineral exploration economically viable.

In the following sections we describe the problem in more detail and offer a look inside our attempt to address it. MVAP (Management and Valuation through Absolute Prospectivity) is a framework developed by SRK Exploration in partnership with the University of Exeter (College of Engineering, Mathematics and Physical Sciences) specifically to estimate absolute prospectivity under complex exploration biases. MVAP represents a substantial step beyond traditional relative prospectivity mapping, but it still has important limitations and several modelling choices that are ad hoc or overly simplified. For the ESGI challenge, participants are invited either to improve and refine the MVAP framework (for example by proposing better hierarchical structures, priors, likelihoods or computational strategies), or to propose alternative mathematical formulations that address the same core problem: estimating the probabilities of deposits of different sizes, in each cell, while correctly accounting for geological structure, exploration bias and endowment constraints.

2. Geological and exploration concepts

Mineral deposits do not occur randomly in space or time. Each commodity (gold, lithium, copper, etc.) has a particular genesis: a specific combination of physical, chemical and tectonic processes that must operate for an economically viable deposit to form, and then be preserved close enough to the surface to be discovered and mined. These processes act over a wide range of scales – from whole-lithosphere geodynamics (plate motions, crustal thickening, magmatism) down to local structures and fluid pathways – and leave recognisable signatures in rocks, structures and geophysical and geochemical data. As a result, the distribution of deposits is highly structured, controlled by these underlying processes, rather than being a simple random sprinkling of points. In what follows we briefly outline three key concepts that underpin our approach and that are important for the ESGI problem.

2.1. Mineral systems model

A mineral systems model is, first and foremost, a geological conceptual model, not a mathematical one. It is built by geologists to describe the chain of processes that must occur, at multiple scales, for a particular type of mineral deposit to form and be preserved. In our work, this model is later translated into mathematical form, but its origin is expert geological understanding rather than statistical fitting.

The concept of applying mineral systems has become an accepted way of understanding mineral deposits and their formation over the last few decades. This approach recognises that mineral deposits are the result of the actions of much larger geological processes, and that only when enough of these processes have occurred, can a deposit form. These processes are often related to a wide variety of deposit types and commodities. By moving thinking away from classical deposit models that describe the physical and chemical characteristics of the deposit itself (and are rarely found in their "textbook" form in nature), a mineral systems approach opens the possibility of identifying new deposit types, rather than just analogues of known occurrences.

A widely used way to organise this thinking is to break each it down into four critical elements:

1. **Fertility**
   Is the lithosphere enriched in the relevant elements (gold, lithium, etc.) or their carriers (magmas, fluids)? This depends on secular Earth evolution, lithospheric enrichment, and other large-scale controls.

2. **Favourable transient geodynamics**
   Short-lived tectonic events (orogenies, rifting, magmatic pulses) that provide heat, fluid flow and deformation conducive to mineralisation, often over very limited time intervals.

3. **Whole-lithosphere architecture**
   Structures that act as pathways for mass and energy transfer (faults, shear zones, crust-mantle boundaries), focusing magmas and fluids into specific parts of the crust where deposits can form.

4. **Preservation**
   The balance of uplift, erosion, burial and destruction that leaves deposits near the present-day surface and not eroded away or buried too deeply to be explored.

For this challenge, the mineral systems model is treated as defining covariate layers on a spatial grid: for each cell s, a vector of geological predictor variables $G_s$is computed, derived from the targeting elements and mineral systems scores.

2.2. Endowment and exploration maturity

For absolute prospectivity we care not only about *where* deposits might occur, but also *how many* deposits of different sizes plausibly exist in total within a region, how many have already been found, and how many could realistically be discovered in a given time frame. This is the role of endowment modelling.

- **Total endowment** is the estimated total number and size distribution of economically viable deposits within a geologically coherent area (e.g. a craton or province).
- **Residual endowment** is obtained by subtracting known deposits from the total endowment; it represents the deposits that still exist but are currently undiscovered.

- **Discoverable endowment** is the portion of the residual endowment that is realistically discoverable within a specified time frame (typically 5–10 years), given the inefficiency and pace of exploration.

Where long discovery histories are lacking, we estimate endowment using power-law (Zipf-law) models of deposit sizes. Empirically, when deposits in a province are ranked by size, their sizes often follow an approximately power-law relationship. Fitting such a curve to the known deposits allows the “missing” points along the curve to be interpreted as likely undiscovered deposits, providing a quantitative estimate of residual endowment when time-series discovery data are sparse.

For mature provinces like the Yilgarn, time-series analysis shows that discovery rates fall over successive decades, that early discoveries tend to be larger while later discoveries are smaller and fewer, and that even in prolific provinces large undiscovered deposits are now very rare, with residual endowment concentrated in small deposits in the “long tail”. This temporal behaviour is a crucial constraint on absolute prospectivity: future discoveries cannot simply be assumed to resemble past ones in number or size.

For the ESGI challenge, endowment and exploration maturity enter the problem as constraints on our cell-scale absolute prospectivity: the sum of expected deposits over all cells, by size class and time horizon, should be consistent with independent endowment estimates and with the observed temporal pattern of discoveries.

2.3. Exploration process and biases

Mineral exploration is a staged, selective and expensive process. It does not sample the crust uniformly, and this has profound implications for how data can be used in modelling.

A typical exploration workflow begins with desktop data analysis: compiling geological maps, geophysical data, geochemistry and prior exploration reports, and applying knowledge-based techniques such as mineral systems modelling to identify regions that are conceptually favourable.

Field work involves a range of activities that may be carried out sequentially or concurrently, depending on the project and strategy. These include:

- **Geological mapping and reconnaissance**: understanding outcrop, structures, lithologies and surface features.
- **Geochemical sampling** and analysis (soil, rock, stream sediment): In favourable settings, subtle geochemical anomalies at the surface can reflect mineralisation at depth, providing an indirect signal of concealed deposits. However, some deposit types and some minerals produce weak, discontinuous or very localised geochemical footprints, so the absence of a strong anomaly does not reliably indicate the absence of a deposit.
- **Geophysics**: ground or airborne methods (magnetics, gravity, radar, ambient noise tomography, deep ground-penetrating radar) provide indirect images of structures and, in some cases, mineralisation. Their effectiveness varies by deposit type; for example, some minerals are weak geophysical responders, limiting targeting power.
- **Remote sensing**: satellite multispectral and hyperspectral imagery provides information only about the surface (exposed rocks, soils, vegetation). It is valuable for regional

geological mapping and for detecting surface expressions of mineralisation, but it cannot "see" through cover; any deposits concealed beneath younger rocks or regolith will not be directly visible, and must be inferred indirectly or via other methods.

- **Drilling**: reverse circulation (RC), diamond drilling (DD), sonic drilling, etc. Drilling is the only way to directly sample the subsurface and confirm a deposit, but it is extremely expensive. Drillholes are therefore placed very selectively, and the density of drilling is often too low to guarantee detection of all deposits present.

Although these stages do not necessarily occur in a fixed order and can overlap, drilling almost always requires at least one of the preceding methods to have identified a target, because it is too costly to deploy without prior evidence or anomalies.

At each stage, companies make economic decisions: if results are unpromising, they scale back or stop work; only the most encouraging targets are drilled. As a result, vast areas of the crust are never explored at depth, many areas are only lightly tested (e.g. a few reconnaissance samples), and even where drilling occurs there is no guarantee that a deposit is not present—it may simply have been missed by limited drill coverage. This creates a crucial problem for standard data-driven modelling: we observe positive examples (locations where deposits or mineral occurrences have been discovered), but we very rarely observe true negative examples (locations where we can confidently say "no deposit exists" because thorough exploration has ruled them out). Nonetheless, most conventional machine-learning prospectivity methods require deposits and "non-deposits" as labels; in practice they use known deposit locations as positives and construct pseudo-negatives by sampling random locations that are not known deposits, or by selecting areas judged geologically unfavourable.

This is problematic for two main reasons. First, absence of evidence is not evidence of absence: a cell with no known deposit is not necessarily a non-deposit; it may simply be unexplored or inadequately tested. Treating such cells as negative examples implicitly assumes that exploration has been exhaustive, which is almost never true. Second, there is strong preferential sampling and spatial bias. Exploration is concentrated where companies already believe the geology is favourable (near major structures, in certain terranes, close to existing mines), so positive examples (deposits) lie in areas of high exploration intensity, while pseudo-negative examples, if sampled randomly over the map, are drawn mostly from lightly explored or unexplored areas, many of which may be geologically prospective but have simply not yet been drilled. The model therefore tends to learn that "high prospectivity" means "close to known deposits and existing exploration corridors", rather than capturing the true underlying geological controls. Even more sophisticated approaches that attempt to use "sterilised" ground (areas with extensive drilling but no deposits) as negatives are limited: such areas are rare and highly clustered, and still reflect the same targeting biases.

Therefore, this is unacceptable for calculating absolute prospectivity: we want the probability that a deposit exists in a cell accounting for the fact that exploration effort is biased, incomplete and imperfect at detecting deposits. Simply fitting a classifier to deposits versus pseudo-non-deposits will conflate geology with exploration strategy and cost, and will systematically under-estimate prospectivity in under-explored regions.

The mathematical task is to develop models that treat deposits as partially observed outcomes of a biased sampling process, rather than as direct labels of presence/absence, and to infer absolute prospectivity while correctly accounting for these exploration biases. Therefore in ESGI challenge, the exploration process and its biases must therefore be modelled explicitly:

- The likelihood that a deposit in cell s would have been explored and detected depends on exploration intensity, methods used, and deposit size.
- Cells with no known deposit are still characterised, for each size class, by a probability between 0 and 1 of hosting a deposit of that size.
- The observed pattern of deposits is thus a biased and censored sample of the underlying deposit field, not a clean training set.

3. Our current MVAP framework

MVAP (Management and Valuation through Absolute Prospectivity) is our R&D framework, developed by SRK Exploration in partnership with the University of Exeter, to overcome the limitations of traditional prospectivity mapping methods by working explicitly in terms of absolute prospectivity. Here, absolute prospectivity means estimating, for each grid cell, the probabilities of different exploration outcomes – from no discovery, through small and medium deposits, up to a world-class find – rather than just ranking areas qualitatively. In parallel, MVAP seeks to build an Exploration Model that describes how staged exploration projects unfold in practice: how decisions to continue, defer, sell or drop are made over time, and how discovery or non-discovery emerges along different exploration paths. By combining absolute prospectivity with this Exploration Model, we aim to construct a Unified Exploration Model capable of assessing both the probabilities of different outcomes and their dynamic evolution through time, supporting quantitative project valuation, uncertainty profiling, and decision-tree or real-options analysis of whether exploration expenditure is warranted and at what level.

With the odds of a prospect becoming a mine often estimated at 1 in 1000 or less, MVAP is aimed at answering the question: “How can we better direct our resources towards the 1, and walk away from the 999 sooner?”.

The Yilgarn Craton in Western Australia, with its rich data and high exploration maturity, has been used as the main test case. The MVAP roadmap (Figure 1), shows that the desired Unified Exploration Model consists of two main streams: Absolute Prospectivity and The Exploration Model.

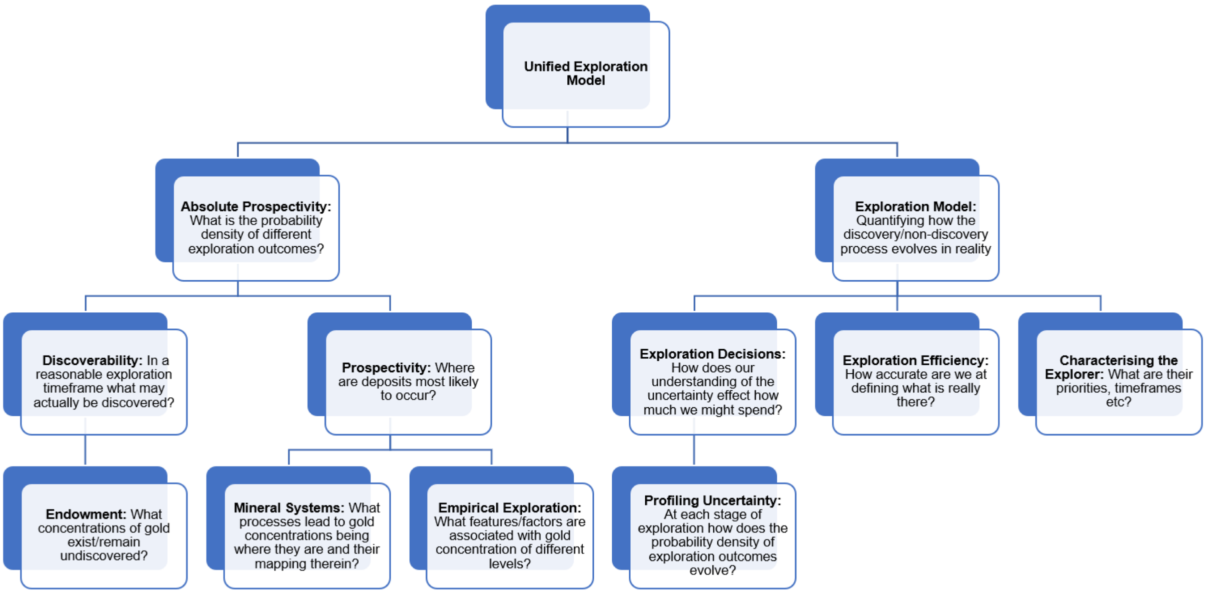

Figure 1) Roadmap towards a Unified Exploration Model for estimating absolute prospectivity.

The mineral systems model is first processed into predictor layers that can be used quantitatively in MVAP. Targeting elements derived from the MSM (e.g. mapped structures, proximity and density of structures and lithology) are converted into spatial evidential maps, and for each grid cell s these are assembled into a vector of geological covariates G_s.

Alongside these MSM-derived covariates, MVAP incorporates additional data layers: exploration maturity and intensity (from WAMEX exploration reports in Western Australia), endowment data (total and residual deposit counts and sizes), and exploration history. A terrane such as the Yilgarn Craton is discretised into a grid of cells, typically 1 km × 1 km, chosen so that each cell is small enough to reasonably contain at most one deposit. For each cell, the combined set of covariates then forms the input to the hierarchical Bayesian inference of absolute prospectivity. The overall structure of this workflow is illustrated schematically in Figure 2.

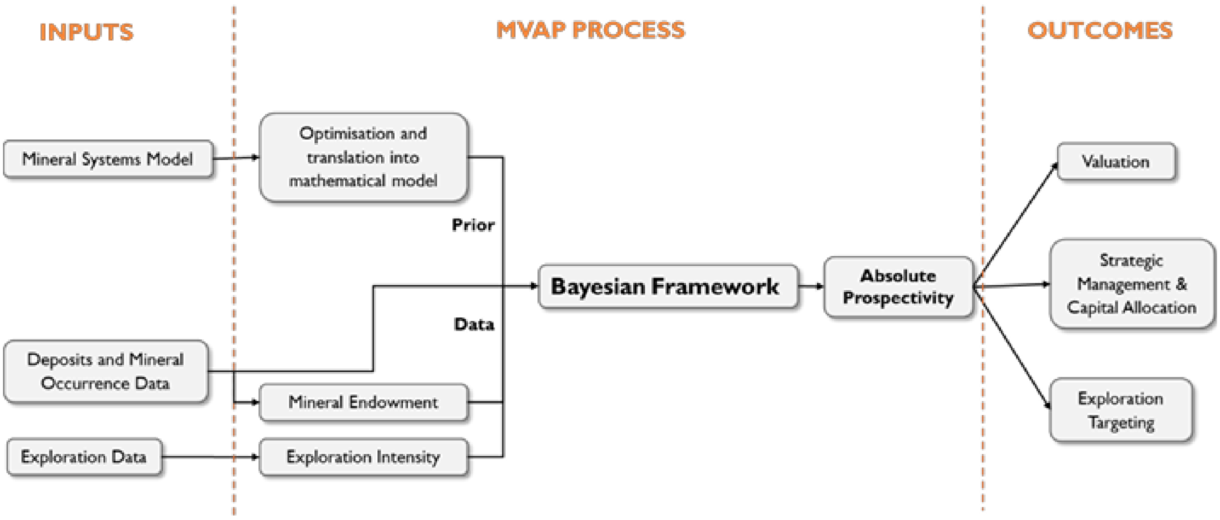

Figure 2) MVAP framework.

MVAP is implemented as a hierarchical Bayesian model in which an initial, geology-based prior is updated by multiple evidence layers to produce a posterior probability of deposits of different sizes in each grid cell.

At the top level, MVAP uses the mineral systems model as a knowledge-led input. The MSM scores for each cell (derived from targeting elements and evidential maps) are translated into a mathematical prior using a logistic regression model. Because the original MSM was built using fuzzy logic and cannot be expressed directly as a simple formula, we approximate it with logistic regression whose parameters are fitted via Simultaneous Perturbation Stochastic Approximation (SPSA). SPSA is run on a subsample of cells to minimise the difference between the MSM scores and the logistic model outputs. Once calibrated, this provides, for each cell s, a prior probability (or density) of mineral inventory M_s– effectively a prior probability distribution over deposit size classes in that cell.

This prior is then updated using several evidence layers:

- A mineral occurrence map, constructed from known deposit locations and rasterised to the grid.
- Exploration maturity and intensity layers, derived from WAMEX annual exploration reports (filtered by commodity and report size) and from the spatial distribution and depth of DD/RC drillholes. For each cell, we count exploration reports and deep drillholes, reflecting how thoroughly that cell has been tested. Using the spatial overlap between these exploration layers and the occurrence polygons, MVAP infers parameters for exploration efficiency (probability that exploration in a cell would reveal existing deposits) and drilling efficiency (probability that given drilling would intersect the deposit), with efficiency depending on deposit size (larger deposits are easier to detect).
- Endowment constraints, from province-scale endowment modelling, which specify the total and residual number of deposits per size class and inform what fraction of these is likely discoverable within the relevant time horizon.

The overall MVAP mechanism above can be summarised in the schematic shown in Figure 3, a hierarchical Bayesian framework that has the objective of updating the posterior probability of mineral occurrences: Xs.

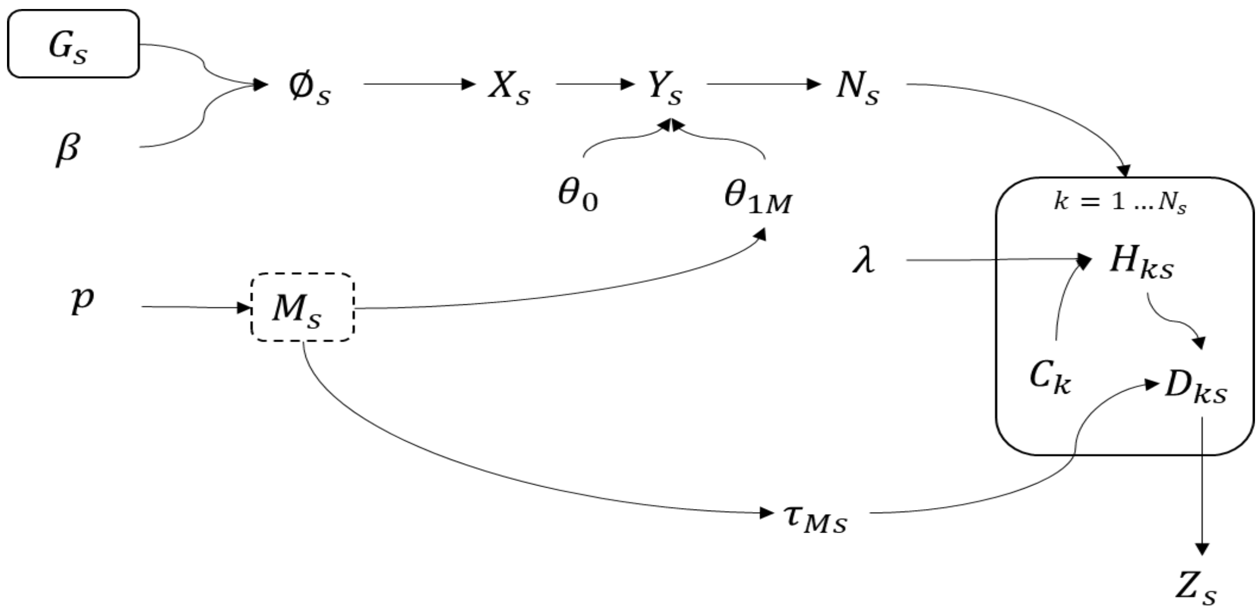

Figure 3) Overall MVAP mechanism.

This approach allowed us to incorporate multiple sources of information, including the presence of discovered deposits and the performance metrics of exploration projects, such as hit rate and false positive rate. The flexibility of the approach also means that other more advanced factors such as the evidence of mineralisation that may arise from 'evidential' (i.e. non-MSM) type data such as geochemical or geophysical anomalism can be incorporated. Upstream of X_s is the mineral system model (G_s) with covariates (β), optimised as described earlier. Furthest downstream is our evidence of deposits (Z_s) that passes through intermediate levels of our model representing the quantity and location of exploration and our understanding of province endowment. These parameters were treated as random variables following certain probability distributions, which were informed by the available geological knowledge and expert knowledge of the exploration process. The exploration and drilling efficiency $\theta_1^{M_s}$ & τ^{M_s} is calculated separately depending on mineralisation quantum, reflecting the reality that, when present, larger deposits are more easily discovered than smaller ones.

Through Bayesian inference, the posterior probability distribution of mineral occurrences is iteratively updated by integrating the prior information with the observed exploration outcomes. In this way, estimates of mineral potential are refined while uncertainties in the data and model assumptions are explicitly accounted for. This provides a flexible and principled framework for updating our understanding of mineral occurrences and informing decision-making in mineral exploration and resource management. Estimates of undiscovered or discoverable endowment are used to constrain a probability mass function in each cell of the map; where larger and smaller deposits are known to have different mineralisation controls, each size class can be modelled separately to reflect this.

The hierarchical structure of MVAP, and the conditional relationships between the mineral systems prior, exploration process and observed deposits, are expressed by the following formulas.

$$P(Z_s, M_s, Y_s | Z_s, p_m, \theta_s, \tau_s, \theta_0, \theta_{1m})$$

$$\prod_{s=1}^{S} P(Z_s|Y_s, X_s, M_s, \tau_s) P(Y_s|M_s, \theta_0, \theta_{1m}, X_s) P(M_s|X_s, p_m)$$

$$= \prod_{s\in m} P(Z_s|Y_s, M_s, \tau_s) P(Y_s|M_s, \theta) P(M|p_m) \prod_{s\notin m} P(Z_s|Y_s, \tau_s) P(Y_s|\theta)$$

$$= \prod_{s\in m} Ber(Z_s; \mathcal{J}_s[1 - \prod_{i=1}^{N_s}(1 - Y_s \kappa^i_{M_s})]\phi_s).\, Ber(Y_s; \theta_1^M).\, Cat(M_s, p)$$

$$\prod_{s\notin m} Ber(Z_s; \sum_{j=1}^{Mclass} p_j[1 - \prod_{i=1}^{N_s}(1 - Y_s \kappa^j_{M_s})]\phi_s]).\, Ber(Y_s; \sum_{j=1}^{Mclass} p_i \theta_1^{M_i} \phi_s + \theta_0(1 - \phi_s))$$

$$\phi_s = logit^{-1}(X_s \beta)$$

$$\theta_1^{M_s} \sim Beta(\dots)$$

$$\beta \sim \mathcal{N}(\dots) - - > (MSM)$$

$$p = (.,.,.,.,.,.)$$

$$\tau^{M_s} \sim Beta(\dots)$$

$$\theta_0 \sim Beta(\dots) - - > (E(\theta_0) = 0.2)$$

$$\kappa^k_{M_s} = \tau^{M_s}(1 - e^{-\lambda/C_k})$$

$$\mathcal{J}_s = \mathbf{1}(N_s > 0)$$

$$\lambda \sim \mathcal{G}(.,.)$$

G_s= Mineral system model variables
$Ø_s$= Prior map
X_s= Probability of mineral occurrence or deposit
Y = Exploration (Y=1, exploration with diamond drillhole and Y=0 exploration with cheaper methods)
Z_s = Known mineral occurrences and deposits
M_s = Mineralisation quantum
$\theta_1^{M_s}$=Exploration efficiency
p = Terrane endowment
β = Covariates extracted from mineral system model
τ^{M_s} = Drilling efficiency (chance of hitting the deposit with a drillhole)
N_s = Number of exploration projects in cells
C_k = Number of grid cell in project k
H_{ks} = Number of drillholes that project k drills at grid box s
D_{ks} = Probability project k finds a deposit in cell s if a deposit is present
λ = Rate of drilling

4. Data

For ESGI195, the key inputs used in MVAP will be provided for selected test areas (e.g. parts of the Yilgarn Craton), already prepared on a common grid (typically 1 km × 1 km cells):

- **Mineral systems covariates**
  - Gridded predictor layers G_S derived from the mineral systems model (geological, geophysical and geochemical targeting elements and scores).
- **Mineralisation evidence**
  - Locations and sizes of known deposits and mineral occurrences.
- **Exploration maturity and intensity**
  - Counts and spatial footprints of WAMEX exploration reports (by commodity, type, and era).
  - Gridded DD/RC drilling density (number of deep drillholes per cell), with basic metadata (depth filters, hole types).
- **Endowment and discovery history**

Exact data availability and format can be discussed with the organisers and tailored to the working group's preferred level of detail. The data and further documentation can be accessed via:

ESGI195 - SRK Exploration

5. Glossary

Absolute Prospectivity
A quantified measure of the probability of a discoverable mineral deposit occurring within an area.

Craton
An old (>1000Ma) and stable part of continental lithosphere, often forming the nucleus of a continental area.

Cover
Rocks of a younger age than the mineralising event that can act to conceal mineralisation underneath. The term 'exploring under cover' relates to trying to conduct exploration for such concealed deposits through the younger cover.

Discovery
The realisation that a specific area has the potential to host a Mineral Deposit, typically through the drilling of Discovery Drillhole(s). The exact time of Discovery may only be determined in retrospect. A poorly defined term within the industry, other usages of the word may mean only Mineral Deposits that can be economically mined with certainty or conversely any mineralisation including sub-economic Mineral Occurrences.

Endowment Modelling
Endowment Modelling (Mineral Endowment Modelling/Metal Endowment Modelling) is the process of estimating the number of deposits of varying sizes that may exist within a geological coherent area. Unless otherwise specified, will generally refer to entire an entire Craton or Mineral Province i.e. entire Yilgarn craton or Murchison Province.

Exploration Inefficiency
The phenomenon of exploration not being an efficient process. Exploration programmes can often miss or otherwise mischaracterise Mineral Deposits within the area of study and exploration effort is often wasted unproductively on areas that will not produce economic deposits.

Exploration Model
A process and methodology to characterise the process of mineral exploration that encompasses Exploration Inefficiency, the nature of discovery, the staged nature of exploration and cost.

Geological Province
An area with common *geological* attributes and history. Most commonly used to refer areas at the largest scale, for example the Yilgarn. However, in Australia the term is also used to define sub-areas within.

Maturity (Exploration Maturity)
The extent to which an area has been previously explored. A mature area has had a lot of exploration conducted in the past and it is therefore thought that the many of the existing deposit have been already discovered.

Mineral Deposit
A natural accretion of a commodity of interest that is of sufficient tonnage and grade that it has a reasonable prospect of being economically mined in the future, is currently being mined or has been mined in the past.

Mineral Occurrence
A natural accretion of a commodity of interest that is significantly above background levels but is not known to contain the commodity in high enough quantities or grade that there are reasonable prospects that it may be economically mined and thereby be classed a Mineral Deposit. Note that exploration work on a Mineral Occurrence may reveal a larger extent of mineralisation and causing it to be upgraded to a Mineral Deposit. In some usages the term can be used to encompass both Mineral Occurrences and Mineral Deposits.

Mineral Province
A geologically coherent area that is also characterized by a particular assemblage of mineral deposits, or by a distinctive style of mineralization. Note: that it is not defined by commodity as 2 adjacent areas may host deposits of the same commodity but that were formed from different genesis and therefore have different styles.

Mineral Systems Approach or Mineral Systems Model ("MSA" or "MSM")
The mineral systems approach provides a framework for the consideration of all geological processes that control the formation and preservation of mineral deposits. Various authors have offered interpretations of what are the fundamental processes, with one of the more popular being 'The 5 Questions Approach' developed by the predictive mineral deposits Cooperative Research Centre in Australia.

Prospectivity Analysis
Prospectivity Analysis (Prospectivity Mapping) is the process, often subjective, of analysis of how likely an area is to host a discoverable Mineral Deposit. Prospectivity is the magnitude of the likelihood a certain area has to host a Mineral Deposit, prospective may be used as a verb in this sense. Traditionally prospectivity is a relative measure of if one area is more likely to contain a deposit than another. Project Murchison aims to quantify Prospectivity in absolute terms to estimate Absolute Prospectivity.

Real Option
A right, but not obligation, to take an action (e.g. progress to the next stage of exploration, build a mine) at a predetermined price, for a predetermined period of time. They are derived from their financial cousins and if a project is modelled as a Real Option the same pricing mechanisms (e.g. Black Scholes, Risk Neutral Probabilities) can be used to price them. This can be used in a decision making context to compare the predicted expenditure required against the 'option price'.

Unified Exploration Model
A model that incorporates Absolute Prospectivity and other factors pertinent to exploration such as Exploration Inefficiency to profile the range of different potential exploration outcomes. The model will utilise this as the basis of project valuations and decision-making frameworks based on Decision Trees and/or Real Options. The Unified Exploration Model is the final objective of Project Murchison.

Yilgarn Craton
A large craton that covers much of Western Australia that assembled 2.94 to 2.63 Ga through the accretion of smaller blocks, with gold mineralisation occurring in the final stages of this accretion period. The Yilgarn is made up of a number of 'Geological Terranes/Provinces': Western Gneiss Terrane, Murchison Province, Southern Cross Province, Eastern Goldfields Province.