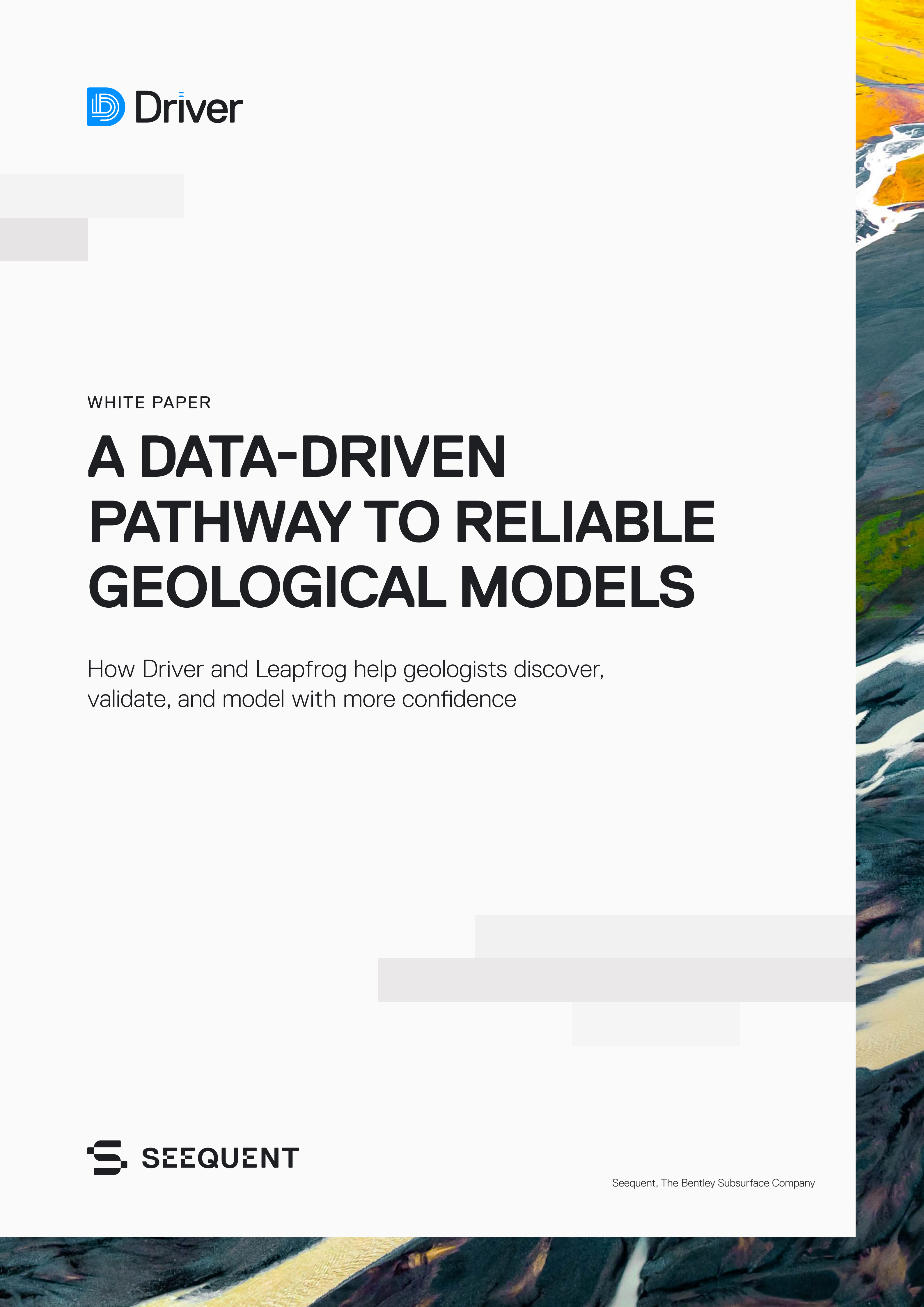
Driver

WHITE PAPER

A DATA-DRIVEN PATHWAY TO RELIABLE GEOLOGICAL MODELS

How Driver and Leapfrog help geologists discover, validate, and model with more confidence



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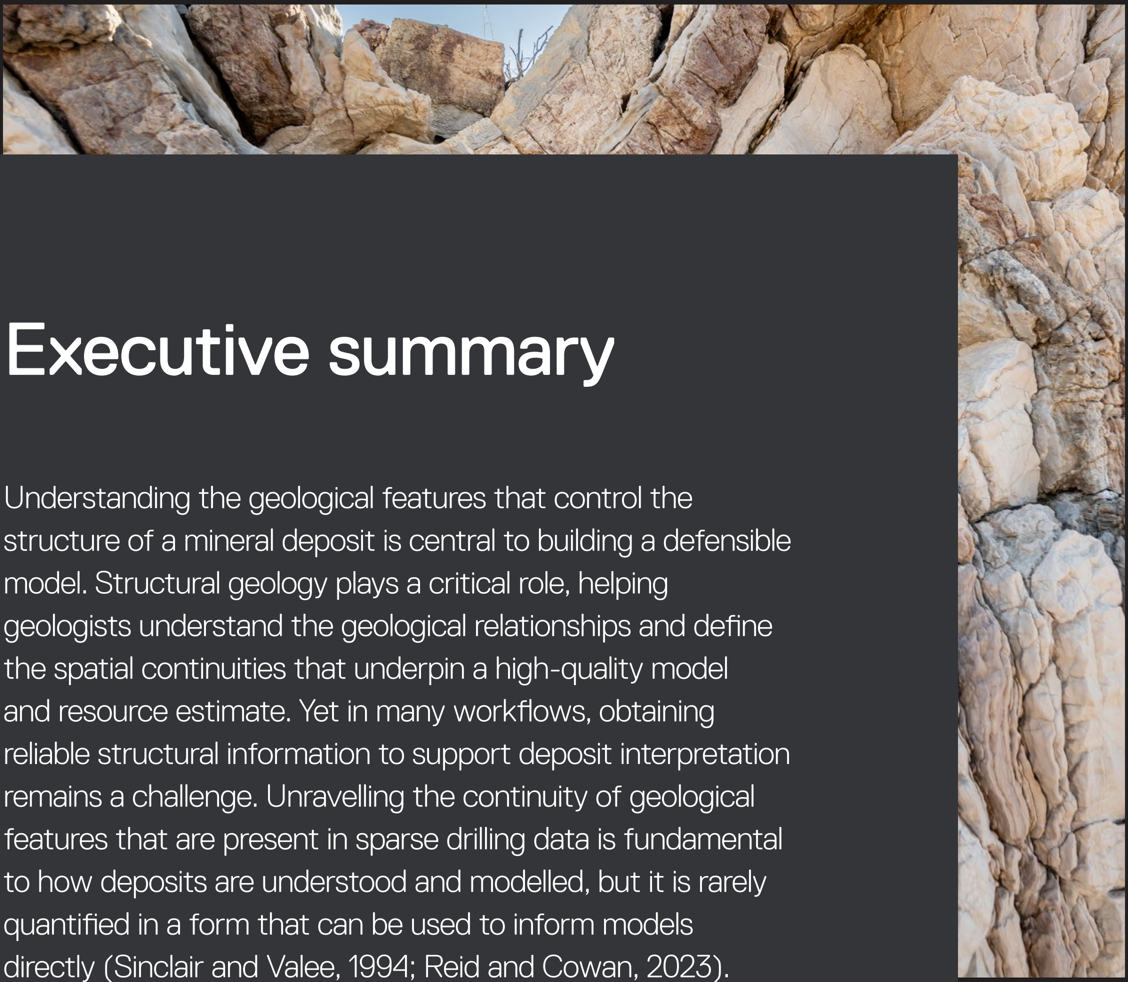


Executive summary

Understanding the geological features that control the structure of a mineral deposit is central to building a defensible model. Structural geology plays a critical role, helping geologists understand the geological relationships and define the spatial continuities that underpin a high-quality model and resource estimate. Yet in many workflows, obtaining reliable structural information to support deposit interpretation remains a challenge. Unravelling the continuity of geological features that are present in sparse drilling data is fundamental to how deposits are understood and modelled, but it is rarely quantified in a form that can be used to inform models directly (Sinclair and Valee, 1994; Reid and Cowan, 2023).

Driver, through a connected workflow with Leapfrog, addresses this gap by quantifying local geological continuity directly from drilling data. Using machine learning, it identifies structural trends embedded in the spatial configuration of the assays and logged lithology and alteration, turning them into practical outputs that geologists can inspect, interpret, and apply. In doing so, Driver provides a data-driven, quantitative workflow for structural deposit interpretation, generating outputs that reduce the manual effort required to build structurally-informed models and update them as new data becomes available.

This paper explains why structural deposit interpretation requires a data-driven approach, how Driver quantifies geological continuity, and how those insights can be used across discovery, modelling, and estimation workflows. Drawing on real-world examples and case studies, it shows how Driver generates more geologically realistic models and helps geologists identify, test, and apply structural patterns that would otherwise remain difficult to use.

CHAPTER 1

Why structural interpretation needs a more data-driven approach

Geological modelling has always relied on expert interpretation. That remains essential, but it also creates constraints. In most workflows, geologists must make a long series of decisions that translate geological data observations, interpretations, and deposit understanding into software inputs that ultimately transform the data into a usable digital model (Kentwell, 2019). Leapfrog has made surface and volume generation much faster, but the interpretation of the data and features still depends heavily on the user. As datasets grow larger, denser, and more complex, that dependence becomes increasingly difficult to manage.

More data has not automatically made modelling more data-driven

More drilling data should create an opportunity to build models that are more responsive to the data itself (Sinclair and Blackwell, 2002). In practice, however, structural interpretations are sometimes established early and then carried forward without regular revision or updates. As the model becomes more data-rich, challenging the original interpretation often becomes less practical rather than more so.

This risk creates a workflow in which early biases may persist, manual adjustments increase decision fatigue, and the model becomes harder to scale and defend quantitatively. The result is a significant dependency on the initial human interpretation, even when new data should support a more detailed and objective digital representation.

Continuity is foundational, but difficult to capture well

One of the biggest challenges in building quantitative geological models is the realistic representation of geological continuity.

Continuity describes how the features intersected by individual drillholes are actually connected in 3D space. It governs the geometry of geological units and the way grade is distributed throughout the deposit (Sinclair and Valee 1994). A robust understanding of continuity is therefore central to both model quality and resource confidence.

Continuity itself is difficult to quantify directly. It may be inferred from downhole structural observations such as vein orientations, bedding, or foliation, but these datasets are often inconsistent and may not represent continuity at a scale that is meaningful for building a representative model.

To complicate matters further, geology is rarely uniform across a deposit (Stoch et al., 2022). Most geological features show strong directional dependence (anisotropy), with changes in primary orientation often occurring at a local scale (e.g., folded and deformed stratigraphy, complex vein networks, and irregular orebody shapes). Models that acknowledge and incorporate local continuity tend to better reflect geological reality (Martin et al., 2019).

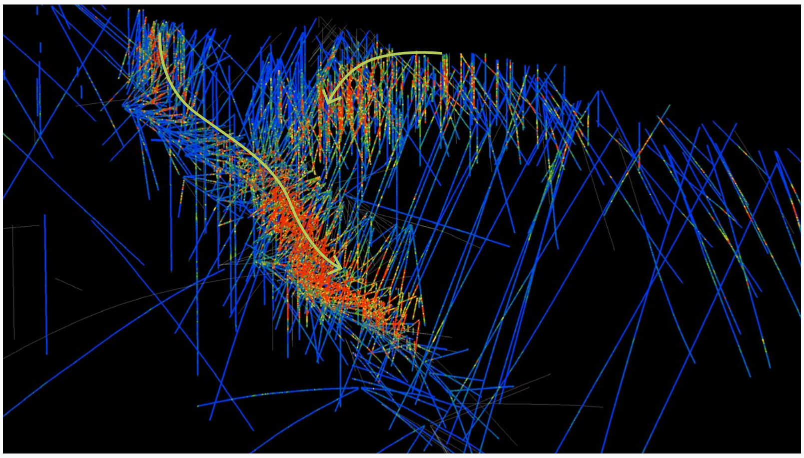
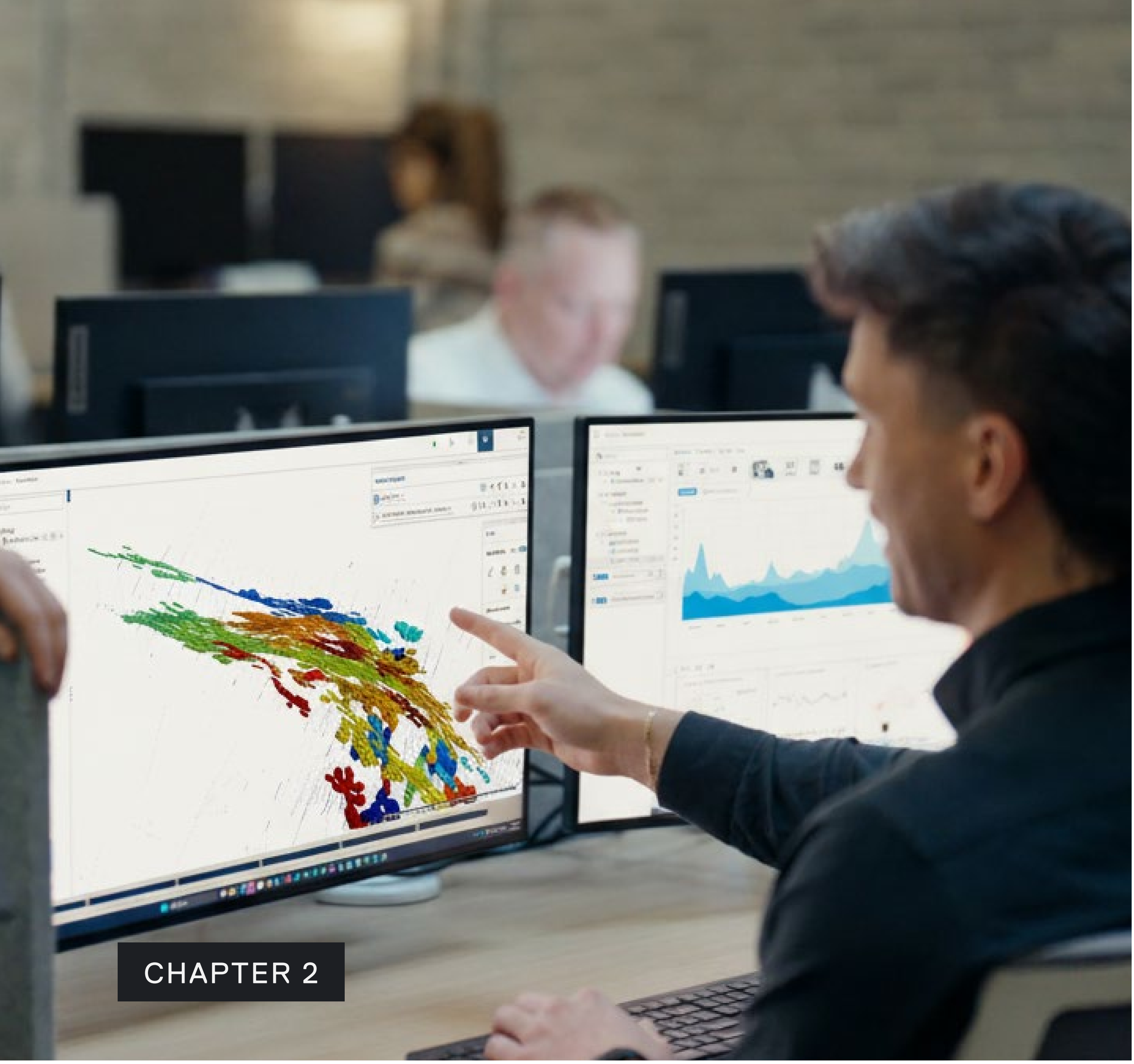


FIGURE 1: Local continuity expressed in grade assay data from drilling. Deposit-scale patterns (green arrows) visible in this data can provide important insight into the structural features controlling the deposit distribution.



CHAPTER 2

How Driver quantifies local geological continuity

Driver is designed to help geologists quantify local geological continuity directly from drilling data. Its core method, Spatial Continuity Mapping (SCM), is an unsupervised machine learning algorithm that detects and measures continuity within 3D geological datasets. SCM selects strategic analysis locations from the drilling data and, at each location, measures and models the spatial geological continuity of similar samples within the surrounding area.

The results are expressed as a series of local ellipsoids, each representing the predominant orientation and extent of continuity at a given point. Taken together across a deposit, these ellipsoids represent a locally varying anisotropy (LVA) field that geologists can inspect, interpret, and use in downstream workflows (e.g., Stoch et al., 2022).

Driver's spatial continuity mapping can be applied to both scalar numeric attributes, such as assays, and categorical information, such as logged lithology or alteration codes. When applied to mineralisation-related data, it reveals local structural controls on grade continuity. When applied to categorical data, it highlights features such as stratigraphic layering, intrusive geometry, vein orientations, and fault offsets. In each case, the goal is the same: to extract structural patterns directly from the data rather than defining them manually.

How Spatial Continuity Mapping works

SCM ingests attributed 3D point or downhole interval data. In geological analysis, these data typically represent subsurface drill samples logged with information such as stratigraphic units, vein lithologies, or geochemical assays. Samples representing the feature of interest, such as a specific lithology or a grade above a chosen cut-off threshold, are assigned a value of 1, while all other samples are assigned 0. Before analysis, the data is usually composited downhole to a regular interval length to reduce high-frequency noise while preserving the essential geological features relevant to interpretation and modelling.

The SCM workflow occurs in three key steps: i) centre selection, ii) continuity mapping, and iii) anisotropy learning.

First, a subset of samples is selected as analysis centres to distribute the points semi-evenly across the area of interest. At each centre, SCM aggregates nearby samples above the user-defined cut-off to map the local continuity present in the surrounding data. This generates a representative anisotropy ellipsoid that delineates the extent and orientation of continuity surrounding the analysis center.

Each ellipsoid captures the principal axes (expressed as dip, dip direction, and pitch), and limits (ranges) of local continuity, and includes quality metrics such as model confidence and data support.

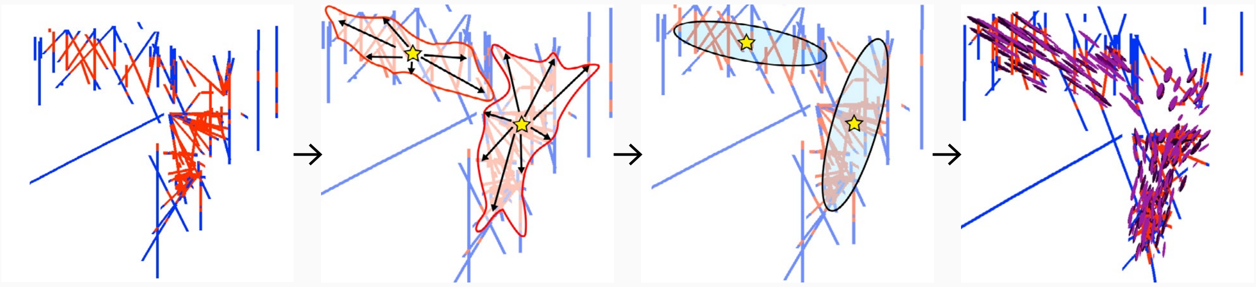


FIGURE 2: The SCM algorithm for modelling local continuity as a function of attributed drilling data.

Confidence is calculated as the proportion of angular space around the centre that contains 3D information, while data support records the number of unique samples contributing to the analysis at that location. Together, these outputs give geologists quantified metrics for assessing the reliability of each local result.

Rather than using traditional variography to interpret spatial continuity over a larger domain, SCM learns the local geometry of continuity directly from the spatial arrangement of the attributed data.

Driver represents continuity as local ellipsoids because they offer a flexible way to describe geological features with complex spatial signatures. Under a single, unified framework, ellipsoids can represent most common geological geometries, such as planar features (e.g., stratigraphic layers or veins), and linear features (e.g., ore shoots or plunging fold axes), and quantify geometric continuity in a form that can be visually inspected and carried into downstream workflows.

A related extension of SCM is the automated classification of ellipsoids based on their spatial proximity and anisotropic properties, including orientation, size, and shape. Integrated directly with SCM, this clustering capability uses a semi-supervised machine learning propagation technique to identify groups of samples that are spatially and anisotropically consistent. The algorithm relies on iterative propagation to produce groupings that follow curvilinear geometries such as folds and position decision boundaries in areas where continuity changes rapidly. The algorithm is largely non-parametric, meaning users do not need to define the number of clusters in advance. Instead, it will learn associations directly from the spatial configuration of the data and the continuity field generated by SCM, while allowing users to adjust the angular tolerance on nearby ellipsoid-to-ellipsoid connections.

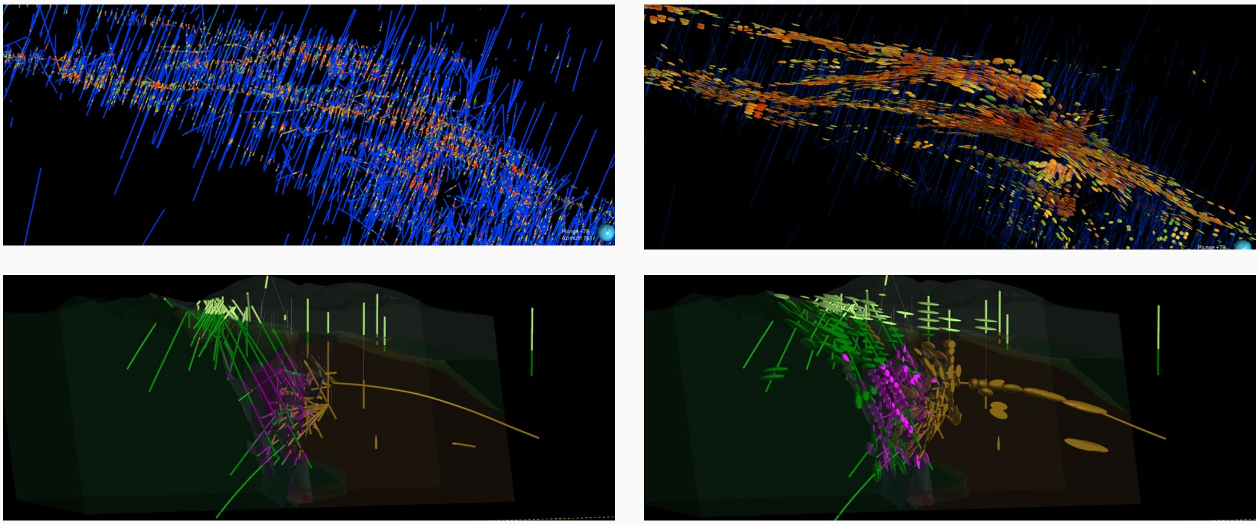


FIGURE 3: Example outputs of SCM analysing local continuity of Gold (Au)-bearing veins (upper) and lithology units captured in drilling data (lower).

Applying Driver in geological modelling workflows

Driver's value lies in how its outputs are used: to validate or uncover geological features, build improved implicit models, and support estimation workflows that depend on data-driven anisotropy.

01

Structural data for geological validation and discovery

The continuity data generated by Driver is a form of structural information that represents the primary geological trends embedded in drilling information. It can help geologists identify features they may not have recognised previously or confirm that an existing interpretation is genuinely supported by the data that is available. This makes Driver useful not only for finding new opportunities, but also for testing structural ideas and domaining decisions explicitly and with greater confidence.

Geological validation at Golden Cross, Coromandel, New Zealand

One example of Driver supporting structural interpretation validation comes from the Golden Cross gold-silver deposit in Coromandel, New Zealand. The deposit contains two primary mineralisation zones: the steeply dipping Empire Zone and a shallower-dipping western Stockwork Zone (Begbie et al., 2007).

Driver was applied directly to the gold grade data, where it generated a set of local ellipsoids that revealed complexity, including a series of grade-bearing vein offshoots in the Empire Vein footwall zone. While these offshoots were noted in some of the original cross-section interpretations, their independent reproduction through continuity derived directly from the assays provides an important validation of that geological interpretation, strengthening geological domaining decisions and providing a powerful link between the conceptual model and the empirical patterns present in the grade assays.

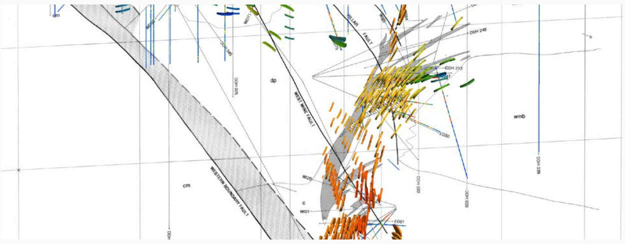


FIGURE 4: Geological features delineated by Spatial Continuity Mapping at the Golden Cross Mine, Coromandel, New Zealand.

Geological discovery at OceanaGold's Waihi operation

Driver's structural outputs can also support the discovery of economically significant features within deposit datasets. At OceanaGold's Waihi underground operation, Driver helped the geology team identify a previously unmodelled vein splay.

Working in a geologically complex epithermal system with multiple mine areas and historic workings, the team used Driver to analyse the resource drilling dataset and generate ellipsoids that captured the orientation and distribution of local continuity in grade-bearing structures. When reviewed against known geology and underground ore control data, Driver's interpretation aligned closely with the observed vein architecture, giving the team confidence to investigate further.

The key insight came when Driver highlighted a group of ellipsoids in an area where no vein had yet been modelled. This suggested the presence of a mineralised structure branching from the main deposit. The team then validated that interpretation against an existing mine drive, reviewing underground information to confirm that the structural pattern identified by Driver was real and actionable. Once confirmed, the splay was wireframed, estimated, and incorporated into the mine planning workflow. From initial review to a fully estimated block model ready for planning took about one hour.

The outcome was immediate and measurable. OceanaGold identified a previously overlooked source of value, pointing to more than 2,000 additional ounces of gold, with more than 100 ounces already recovered. In this case, Driver helped reveal a subtle but economically meaningful structural trend and supported a more complete model that was more closely linked to the features inherent in the data.

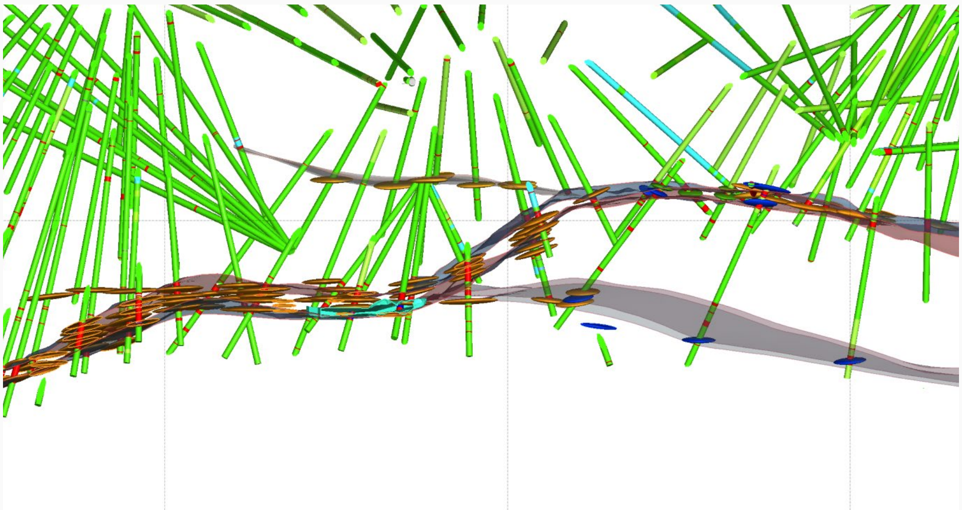


FIGURE 5: Driver ellipsoids highlighting primary vein and splay orientations derived from resource drillhole dataset.

Read the full case study →

02

Categorical continuity analysis and geological validation

SCM can be applied directly to categorical data, offering a powerful avenue for quantifying spatial geometric relationships within logged downhole information such as lithology and hydrothermal alteration groupings. By dividing the data into indicator classes representing each category, the algorithm can map the local extent of continuity, generating sets of coded ellipsoids that can be evaluated or used to inform downstream models.

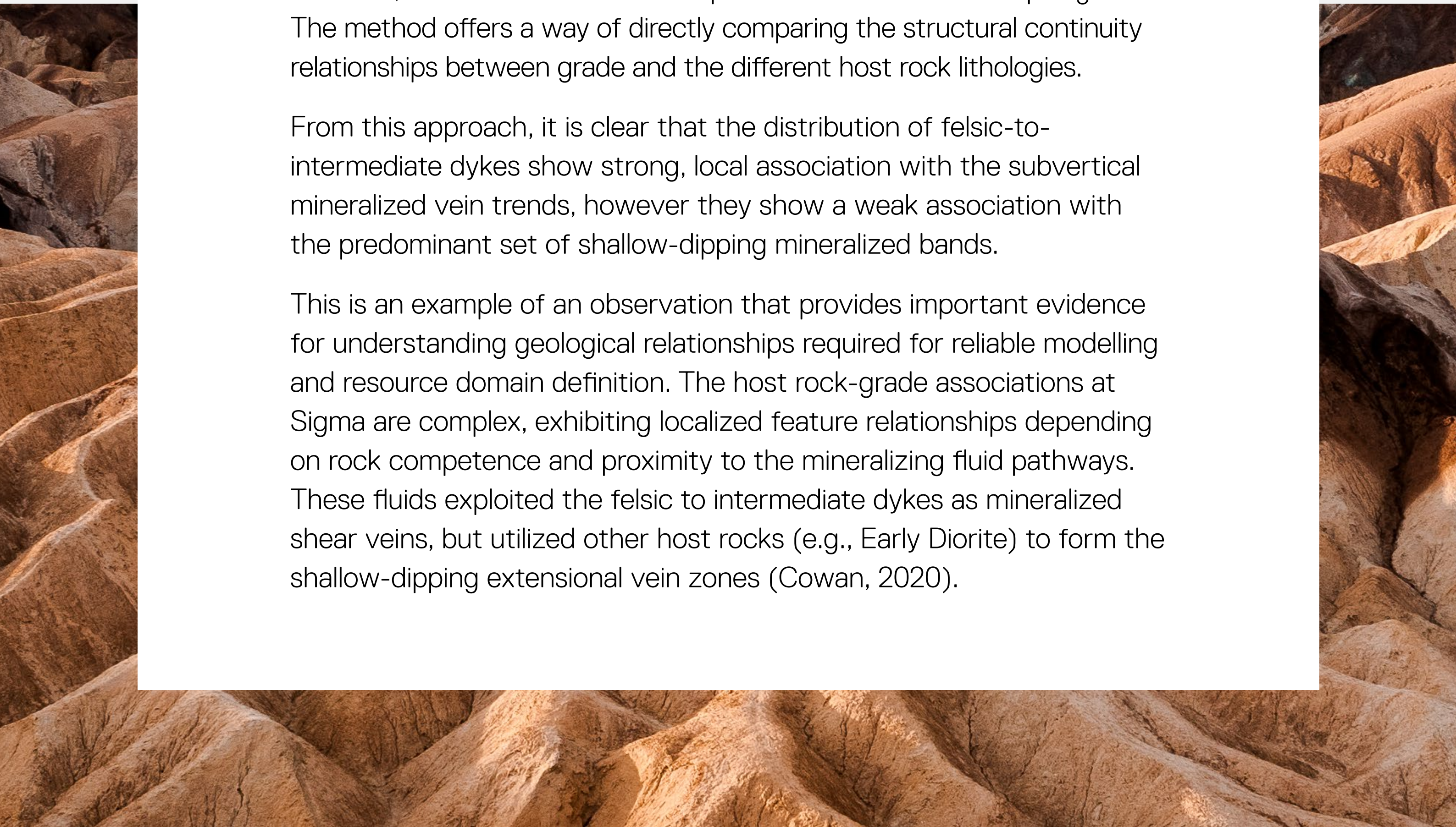
Untangling grade-lithological relationships in an orogenic deposit dataset

In the Sigma-Lamaque orogenic gold deposit, Canada, categorical SCM analysis was used to unravel host rock-grade associations between mineralized gold veins and felsic-to-intermediate dykes.

First, an analysis of gold continuity was conducted to establish a representative baseline of the local distribution of samples yielding elevated grades. Next, a set of ellipsoids were generated for each logged rock unit, and the results were compared in visual slices in Leapfrog. The method offers a way of directly comparing the structural continuity relationships between grade and the different host rock lithologies.

From this approach, it is clear that the distribution of felsic-to-intermediate dykes show strong, local association with the subvertical mineralized vein trends, however they show a weak association with the predominant set of shallow-dipping mineralized bands.

This is an example of an observation that provides important evidence for understanding geological relationships required for reliable modelling and resource domain definition. The host rock-grade associations at Sigma are complex, exhibiting localized feature relationships depending on rock competence and proximity to the mineralizing fluid pathways. These fluids exploited the felsic to intermediate dykes as mineralized shear veins, but utilized other host rocks (e.g., Early Diorite) to form the shallow-dipping extensional vein zones (Cowan, 2020).



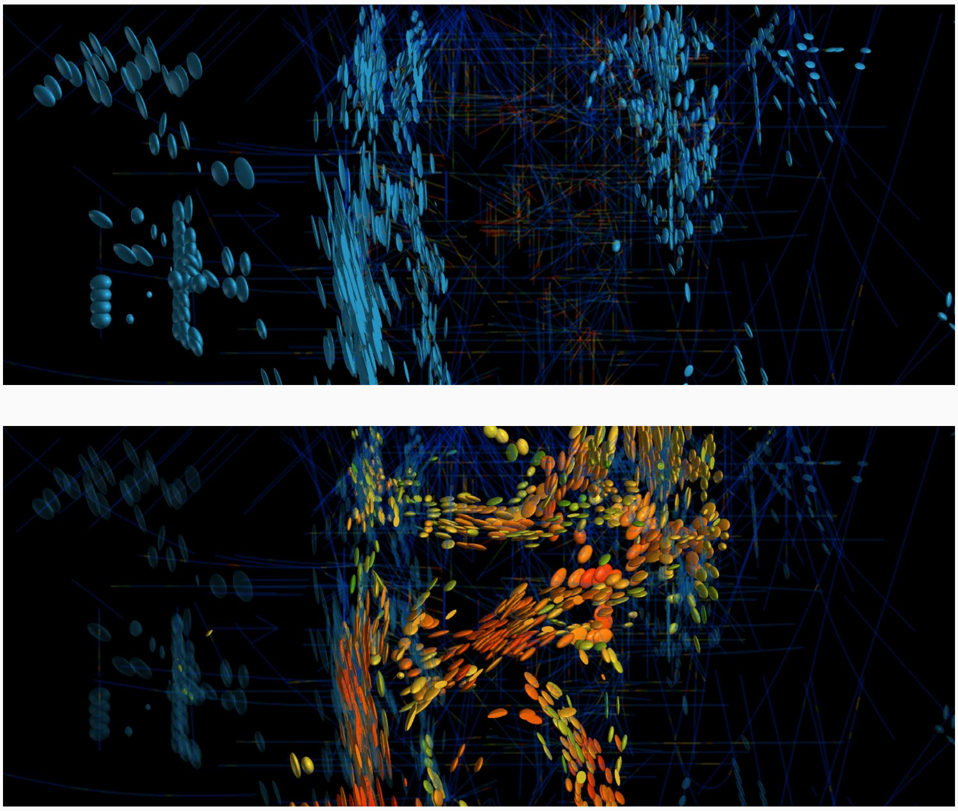


FIGURE 6: Category continuity analysis using Driver used to interpret lithology relationships with elevated gold grade. Structural discs coloured pale blue represent local orientations of felsic to intermediate dykes. Multicoloured ellipsoids represent elevated gold grades, coloured by analysis confidence.

03

Improved implicit modelling

Geology is rarely simple, and global trends often fail to capture the complex, local continuity of real deposits (Stoch et al., 2022). While Leapfrog offers tools to influence local anisotropy, these controls must still be constructed manually and reviewed as the data and model evolve.

Driver automates this by using SCM to generate objective, locally adaptive continuity constraints directly from drillhole data. It produces a fully auditable ellipsoid field that captures the local triaxial state of continuity, which geologists can review, filter, and refine before incorporating it as constraints into their implicit model.

This workflow is enabled through Leapfrog's triaxial blending structural trend tool. This trend preserves Driver's full 3D output, including planar and linear geometries, and is used to influence the output generated by Leapfrog's RBF interpolation engine. The result is a direct pathway from quantified continuity to geologically plausible, highly responsive implicit models.

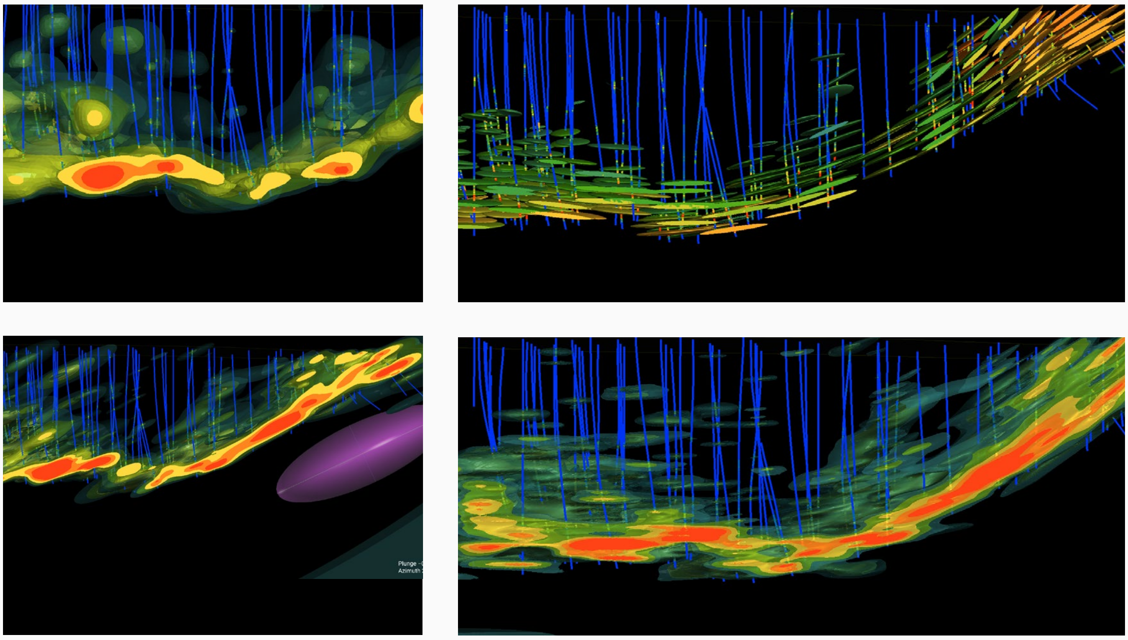
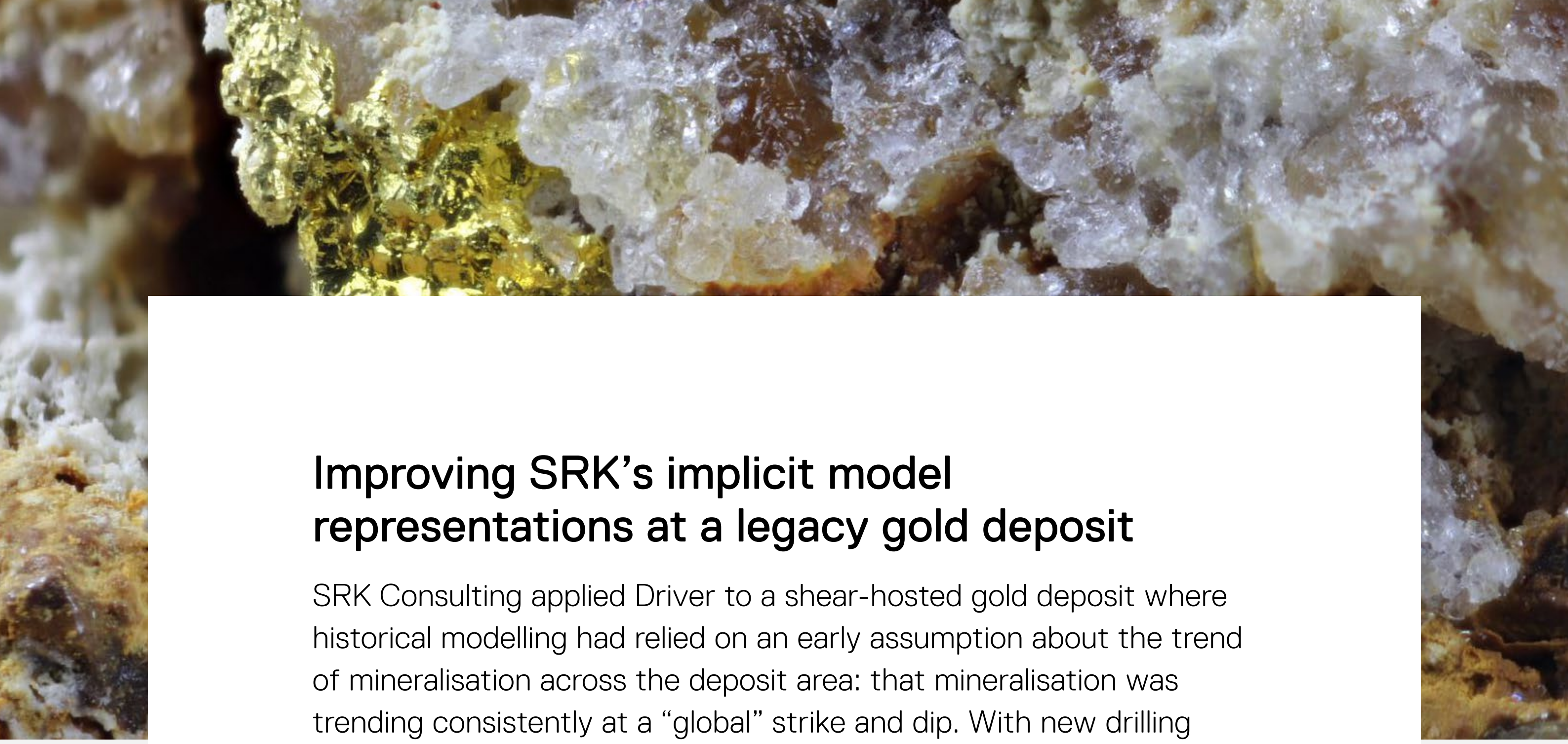


FIGURE 7: Driver-Leapfrog workflow showing how Driver-generated local ellipsoids can be used to inform implicit numeric models in Leapfog. Left) numeric models in Leapfrog with isotropic and global trend, Right) Driver-generated local ellipsoids and triaxial-blending structral trend informed model



Improving SRK’s implicit model representations at a legacy gold deposit

SRK Consulting applied Driver to a shear-hosted gold deposit where historical modelling had relied on an early assumption about the trend of mineralisation across the deposit area: that mineralisation was trending consistently at a “global” strike and dip. With new drilling data available, SRK wanted to review this structural interpretation and update the models in Leapfrog to support a new resource estimate. A first review of the data showed that while the legacy interpretation was acceptable as an initial approximation, it did not adequately reflect the deposit’s more intricate local structural features, including several major local changes in dip, abrupt grade discontinuities, and broad fold-like structures.

Driver was used to test the legacy structural hypothesis and determine whether a more locally representative continuity model could be used to support a new generation of fit-for-purpose grade-based domain models. SRK generated several SCM analyses to examine continuity at various grade cut-offs, then selected a representative local ellipsoid object to pass to Leapfrog for interpretation and inclusion in the updated model.

The Driver analysis broadly validated the legacy interpretation but also revealed structural complexity that was not represented in the original estimate. The local ellipsoids indicated a broad open syncline in the northern part of the deposit, multiple areas where local shear-zone dips deviated by more than 10–15 degrees from the primary trend, and, most critically, a pronounced steepening of continuity in the proposed expansion mining area. In the original model, none of this local variation had been captured.

After filtering ellipsoids with low confidence and poor data-support metrics, SRK used the local ellipsoids and Leapfrog's triaxial blending structural trend to generate a series of grade-based indicator volumes, which showed a clear improvement over the legacy interpretation. The Driver-informed surfaces were more structurally coherent, more flexible locally, and more faithful to the geometry suggested by the drilling data, clearly delineating both the steep continuity structure in the proposed mining area and the broad syncline observed in the north. Importantly, this was achieved within minutes and with substantially less manual intervention than a conventional approach.

Read the full case study →

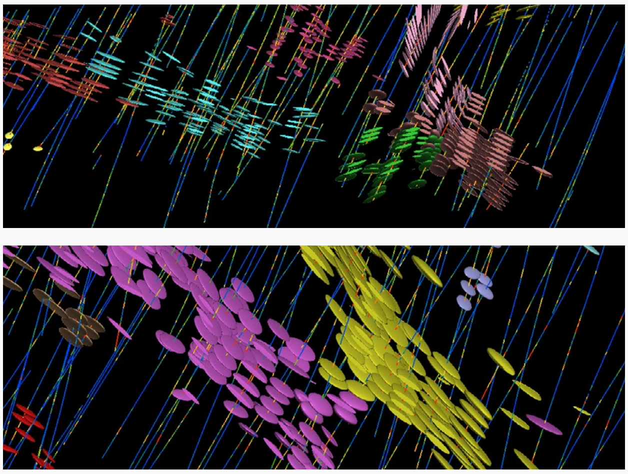
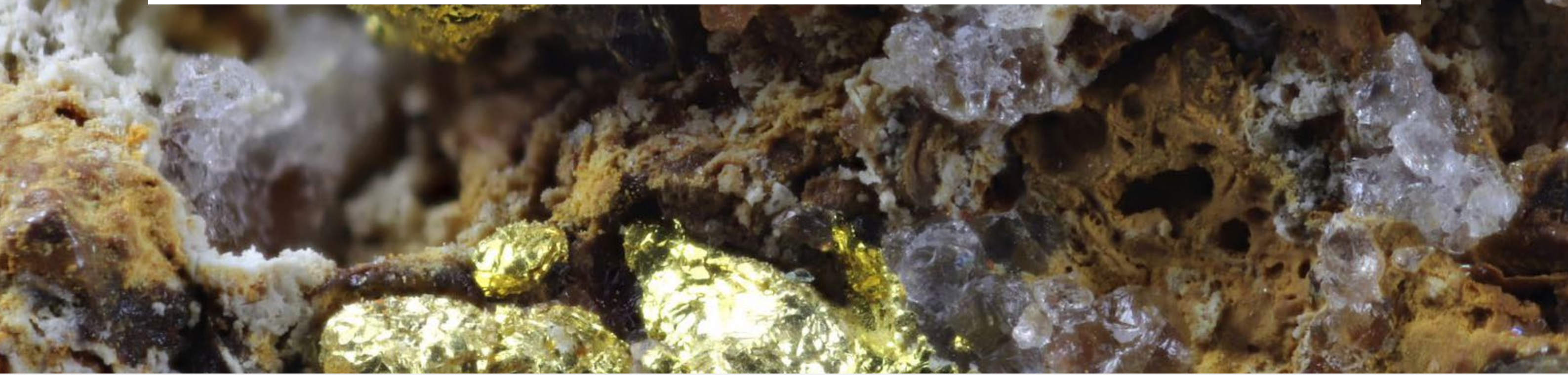


FIGURE 8: SCM results colored by automatic cluster groupings showing steep continuity structure in the proposed expansion pit (top) and dipping shears in the western deposit region (bottom).



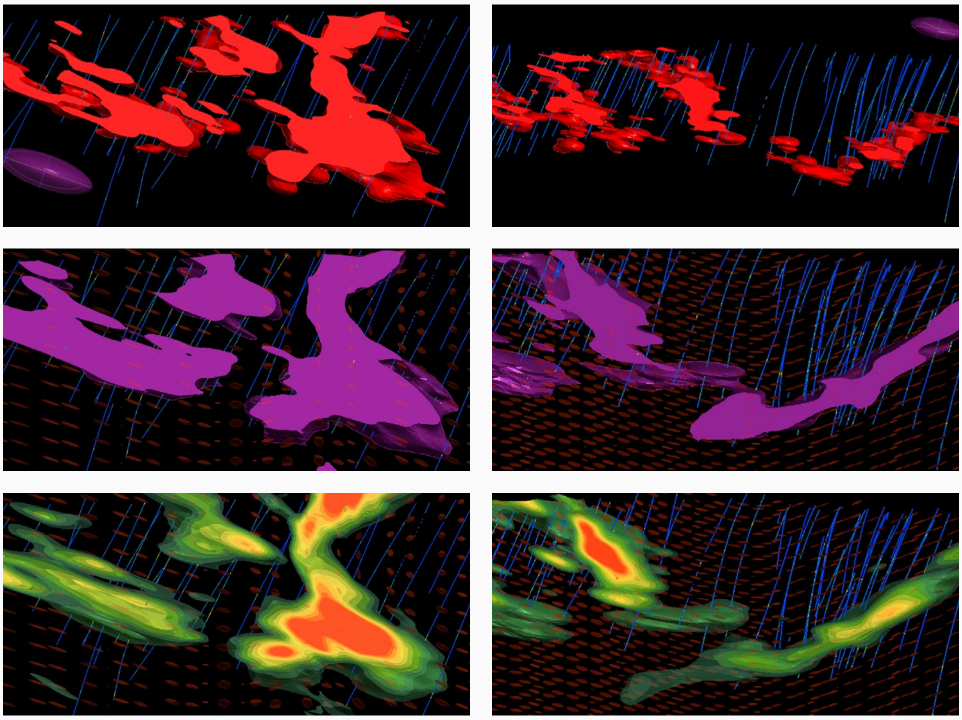


FIGURE 9: Comparison of Leapfrog implicit domain and numeric models constructed using the triaxial blending structural trend informed by Driver (purple and hot colours), compared with the legacy global dip model (red). Results delineate a steeply dipping local continuity structure in the proposed mining area (left) and a broad open syncline structure (right).

04

Automated clustering of SCM ellipsoids for structural domain delineation

The clustering feature in Driver transforms continuity analysis into a rapid, quantitative starting point for data-driven domain interpretation, model data preparation, and exploratory analysis.

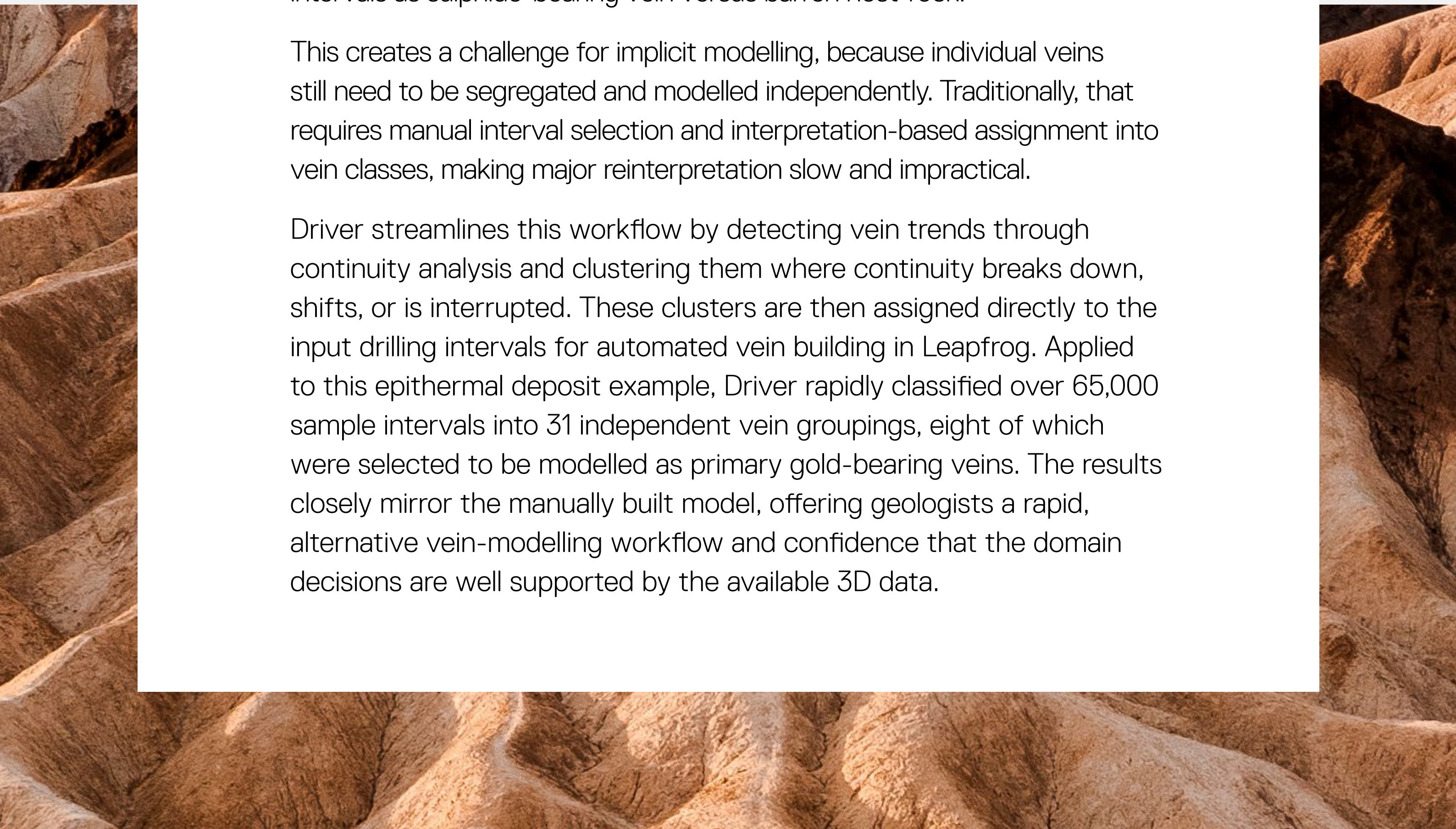
It uses a semi-supervised machine learning propagation technique to identify groups of samples that are spatially and anisotropically consistent. Clusters of SCM-generated ellipsoids may be interrogated directly or evaluated back onto the source drilling data, allowing geologists to quickly select intervals that correspond to the individual veins and structural domains needed for subsequent modelling in Leapfrog.

Generating automatic vein associations for an epithermal gold

Epithermal gold deposits often display geometrically complex quartz vein configurations such as bifurcations, splays, and vein intersections. It is challenging to capture this complexity directly within downhole lithological logging, which usually only captures the basic details, tagging certain intervals as sulphide-bearing vein versus barren host-rock.

This creates a challenge for implicit modelling, because individual veins still need to be segregated and modelled independently. Traditionally, that requires manual interval selection and interpretation-based assignment into vein classes, making major reinterpretation slow and impractical.

Driver streamlines this workflow by detecting vein trends through continuity analysis and clustering them where continuity breaks down, shifts, or is interrupted. These clusters are then assigned directly to the input drilling intervals for automated vein building in Leapfrog. Applied to this epithermal deposit example, Driver rapidly classified over 65,000 sample intervals into 31 independent vein groupings, eight of which were selected to be modelled as primary gold-bearing veins. The results closely mirror the manually built model, offering geologists a rapid, alternative vein-modelling workflow and confidence that the domain decisions are well supported by the available 3D data.



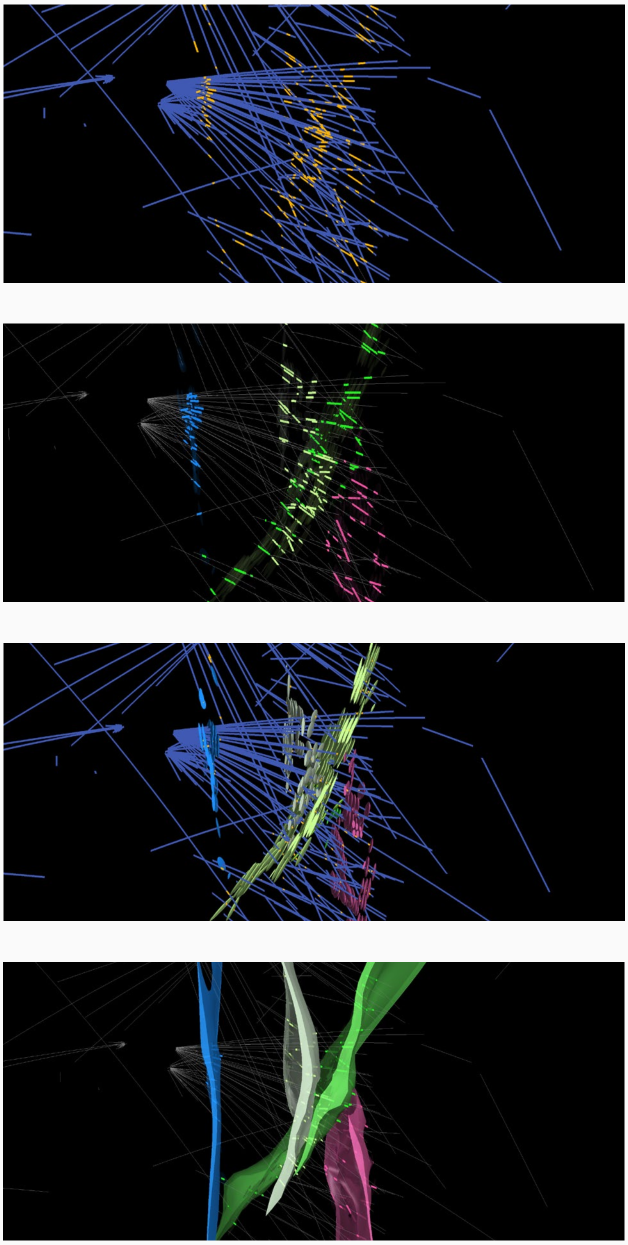


FIGURE 10: Continuity clustering used to delineate veins in an epithermal gold deposit. The first panel shows the raw data as logged sulphide-bearing veins. The second and third show ellipsoids clustered and evaluated onto the input drilling intervals. The final panel shows a Leapfrog vein model constructed from 8 of the chosen clusters generated by Driver.

05

Locally varying anisotropy supporting advanced geostatistics

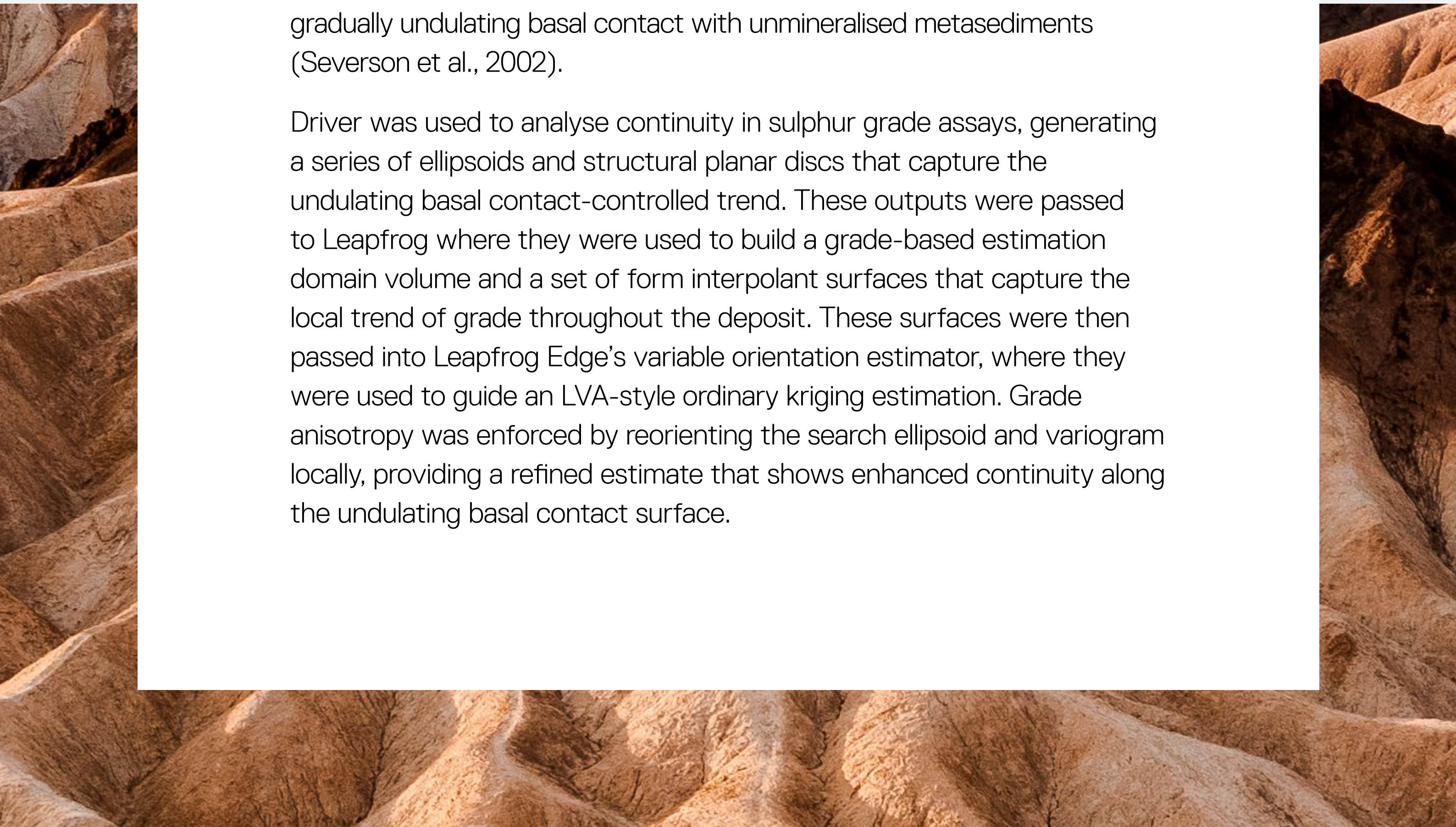
Driver's continuity outputs can also support advanced geostatistics, particularly where estimation depends on locally varying anisotropy (LVA). Locally-changing grade trends are not impossible to model manually, but they are time-consuming to build and difficult to maintain, especially when geologists are digitising mesh surfaces and visually estimating geometry by hand.

Driver provides a fast, data-driven foundation for LVA estimation by generating ellipsoids and structural information directly from drillhole continuity. The outputs can be used to streamline domain modelling, as an independent test for geometric stationarity, and as local orientation controls influencing Leapfrog's implicit mesh and form interpolant construction, which can be used to control variable orientation estimation of grade.

Rapid locally varying anisotropy (LVA) estimation of sulphur within the Babbitt deposit

The Babbitt deposit is a large, low-grade Cu-Ni deposit in Minnesota, United States. Sulphide mineralisation is hosted within gabbroic rocks at the base of the sequence, primarily along a narrow band following a gradually undulating basal contact with unmineralised metasediments (Severson et al., 2002).

Driver was used to analyse continuity in sulphur grade assays, generating a series of ellipsoids and structural planar discs that capture the undulating basal contact-controlled trend. These outputs were passed to Leapfrog where they were used to build a grade-based estimation domain volume and a set of form interpolant surfaces that capture the local trend of grade throughout the deposit. These surfaces were then passed into Leapfrog Edge's variable orientation estimator, where they were used to guide an LVA-style ordinary kriging estimation. Grade anisotropy was enforced by reorienting the search ellipsoid and variogram locally, providing a refined estimate that shows enhanced continuity along the undulating basal contact surface.



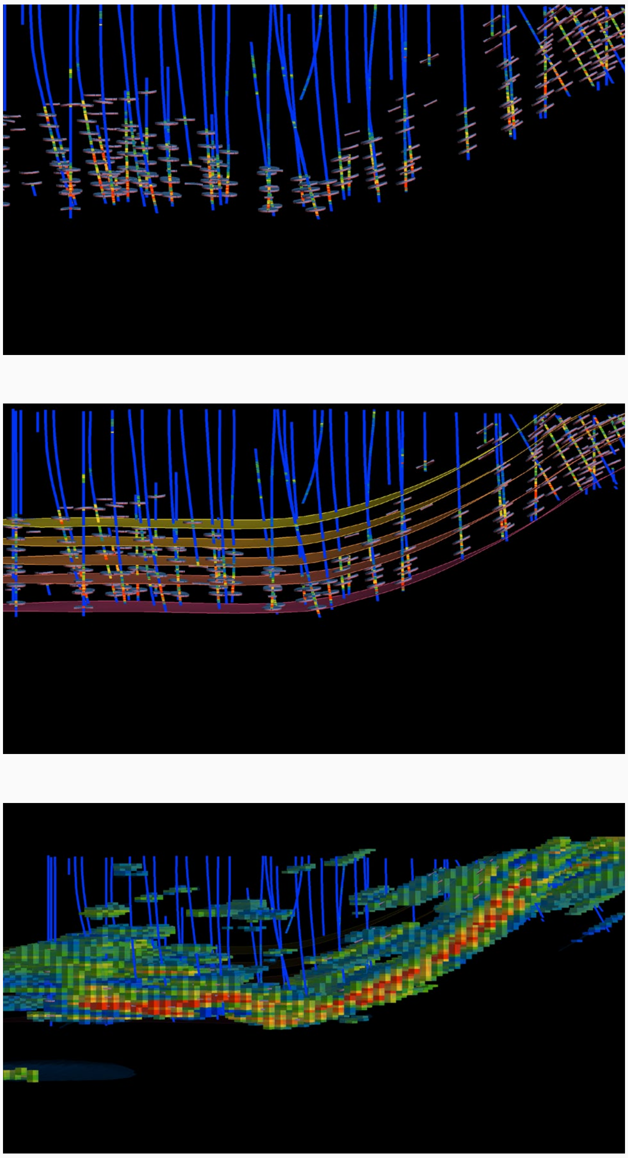
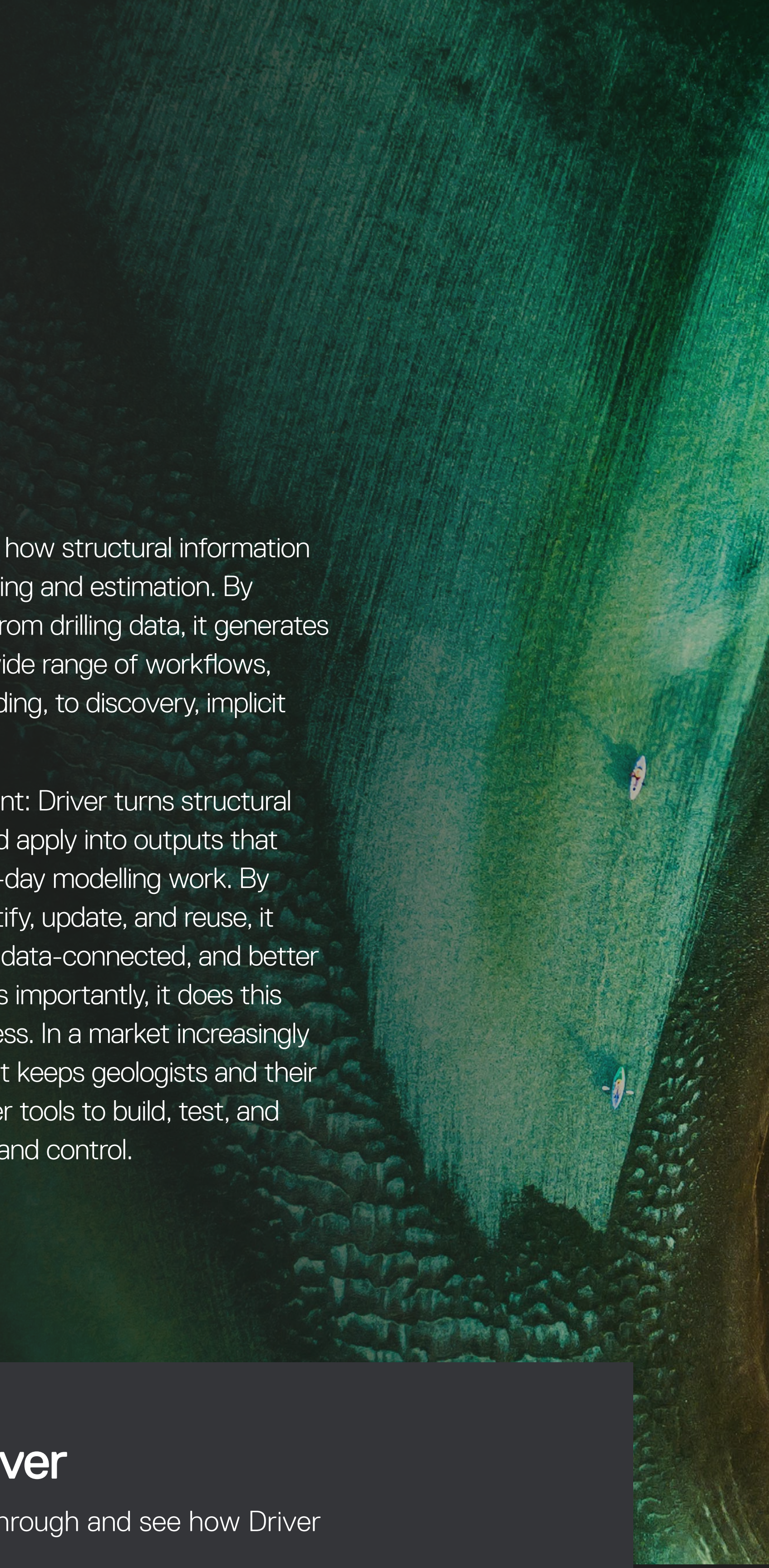


FIGURE 11: LVA-style estimation of sulphur within the Babbitt deposit. Driver-derived trends are used as data-driven inputs for Leapfrog form interpolants, grade-based domain volumes, and variable orientation estimates.



Conclusion

Driver represents a significant advancement in how structural information can be extracted and used in geological modelling and estimation. By quantifying local geological continuity directly from drilling data, it generates meaningful structural insights that support a wide range of workflows, from exploratory data analysis and domain building, to discovery, implicit modelling and estimation.

Across these applications, the value is consistent: Driver turns structural information that is often difficult to capture and apply into outputs that are transparent, auditable, and useful in day-to-day modelling work. By making structural interpretation easier to quantify, update, and reuse, it supports models that are more dynamic, more data-connected, and better aligned with the local nature of geology. Just as importantly, it does this without removing the geologist from the process. In a market increasingly shaped by automation, Driver offers a path that keeps geologists and their expertise at the centre while giving them better tools to build, test, and refine models with greater speed, confidence, and control.

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