Empowering Geologists. Maximizing Data Use. Enabling Scanning Technologies.

Our joint paper on the benefits of Core Scanning
with Newmont Chief Geoscientist, Anthony Harris.

MINALYZE | TruScan™

Executive Summary

Veracio are extremely proud to announce this groundbreaking moment in our industry's history.

The paper, "**Empowering Geologists in the Exploration Process—Maximizing Data Use from Enabling Scanning Technologies**" published by SEG in their January/February 2024 edition, is led by the esteemed Chief Geoscientist of Newcrest Ltd (now Newmont), Anthony C. Harris, and is co-authored by three distinguished members of the Veracio team.

The content of the paper delves into how semiautomated XRF scanning (in this case, TruScan) can redefine the process of drill core analysis.

CORE SCANNING, A KEY DRIVER OF VALUE

This publication invites those who read it to consider how the XRF scanning of driller derived materials (Chips and Core) can be integrated into operations.

A unique demonstration of how Veracio's expertise and technological solutions can be leveraged for enhanced exploration outcomes and operational efficiencies.

PRACTICAL CASE STUDIES

The paper features two case studies, one in Canada, the other in Australia; both demonstrating the application of scanning XRF technology.

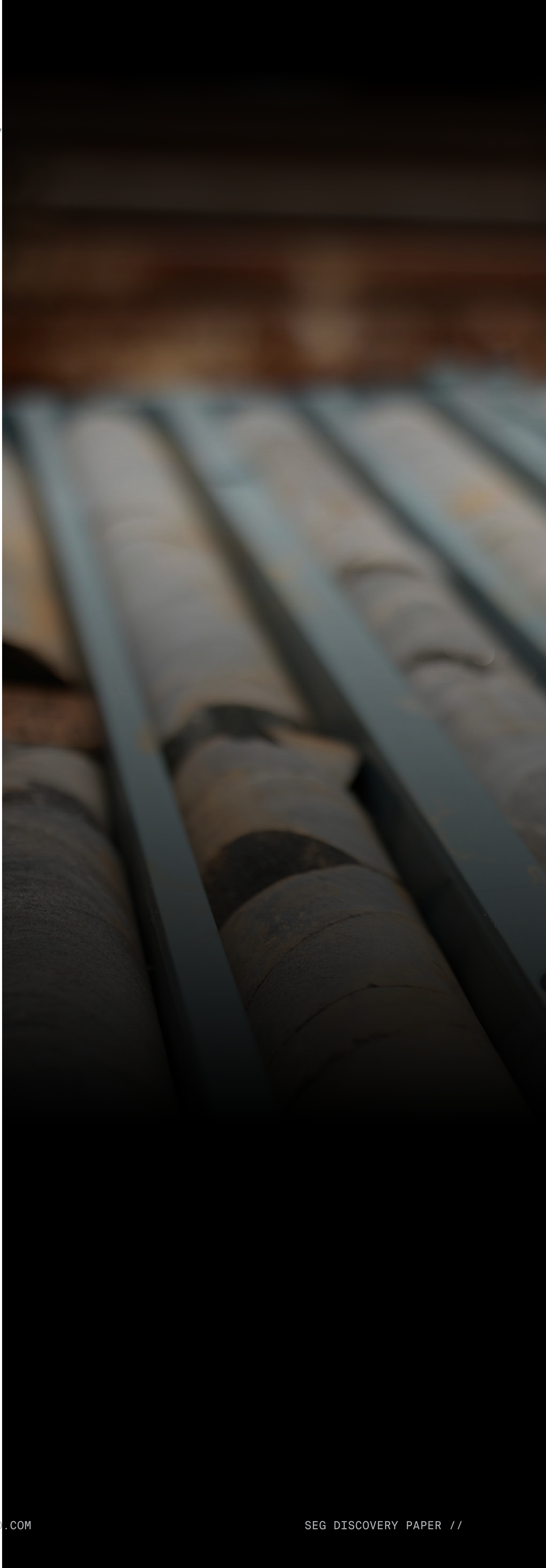
The case studies highlight the integration of algorithms and visualization tools aids geologists in interpreting complex data sets, fostering a more informed approach to exploration and discovery. Eliminating subjective observations and observational biases, ensuring more consistent and robust data.

EMPOWERING GEOLOGISTS GLOBALLY

The technologies and methodologies discussed in this paper, especially the use of TruScan, are not just academic exercises but practical solutions that can be applied in real-world scenarios.

By providing a near-real-time delivery of sensor-derived metal values, it plays a critical role in decision-making around drill hole planning and can significantly transform core-shed workflow.

For those looking to stay at the forefront of innovation in the mining industry, understanding and implementing the insights from this paper could be a game changer.



FEATURE ARTICLE

Empowering Geologists in the Exploration Process—Maximizing Data Use from Enabling Scanning Technologies

Anthony C. Harris *(SEG Lindgren Fellow)*,[1,†] **David J. Finn,**[1] **Fraser T.A. MacCorquodale** *(SEG Member)*,[1] **Michael Ravella,**[2] **William J. Clarke,**[1] **Sasha Krneta,**[2] **Eric Battig,**[1] **and Shauna Maguire**[2]

[1]*Newcrest Mining Limited (now Newmont), 600 St. Kilda Road, Melbourne, Victoria 3004, Australia*
[2]*Veracio, 2455 South 3600 West, West Valley City, Utah 84119, USA*

Abstract

Semiautomated X-ray fluorescence (XRF) scanning of drill core can inform downhole lithology, mineralization, and alteration domains that can objectively guide core logging and provide new insights for deposit formation and, more importantly, provide new exploration guides through to deposit extraction and recovery. When completed systematically and continuously at a deposit scale, near-real-time data delivery of sensor-derived metal values not only helps in decision-making around drill hole planning but also can be transformational in core-shed workflow modification. Scanning core at centimeter-scale resolution helps minimize ambiguity in the geology and reduce observation-related slowdowns in the process of core logging.

Two case studies are presented here that demonstrate the practical application of scanning XRF technology to provide for more consistent and robust physical and chemical data that eliminates subjective observations and observational biases. Algorithms, combined with interconnected visualization tools, help the field geologist in interpreting complex and large multiparameter data sets, extracting the essential information and knowledge important to new discoveries. We believe that scanning technology can augment the exploration geologist, providing focused data sets that support geology-led knowledge generation, rather than an accepted environment of small-scale data collection that is so commonly engrained in the core logging process.

The routine application of in-field scanning XRF, while itself has an added field cost, delivered operational improvements in the process of logging and data collection to inform geologic models that impact the mining value chain. The value of the derived data and knowledge coming from the systematic scanning of core far exceeded the financial outlay of the scanning.

Confidence in XRF scanning technology and its output can be lost without fully understanding the importance of a comprehensive calibration. A fully optimized calibration may require large volumes of sample material, including whole-rock samples combined with kilometers of core, depending on rock complexity and textural heterogeneity. Several iterations may be needed in the early stages of scanner deployment to a new project site. Furthermore, the agility to effectively deploy field-based scanning technology relies on people and their ability to recognize how the outputs impact their work.

Introduction

Mineral exploration remains an observational science that searches for patterns in the physical and chemical footprint of mineral systems. The process of scale reduction, from thousands of kilometers down to tens of meters, requires information important to focusing geologists' attention to higher-probability metal-bearing rock to expedite the lead time to discovery. In a data-rich world, exploration geologists are increasingly utilizing technology and tools to quantify mineral system geology to define and test targets (e.g., Wood and Hedenquist, 2019).

[†]Corresponding author: e-mail, anthony.harris@newcrest.com.au
doi: 10.5382/SEGnews.2024-136.fea-01

Semiautomated X-ray fluorescence (XRF) scanning of drill-derived material is becoming progressively utilized across the exploration value chain, from analysis of rock chips collected in early-stage exploration through to high-volume scanning of drill core completed as part of a deposit drill out. We outline here examples of the practical use of in-field scanners, including high-resolution XRF and hyperspectral scanners, to aid in the logging of geologic material. The routine scanning of core limits the need for production-style logging, liberating geologists to focus on the targeted work of extracting and interpreting essential information and knowledge important to the mining value chain.

Although single-point portable XRF technologies (e.g., ThermoFisher Scientific Niton, Olympus Vanta, SciAps X-Series) have been operationally deployed since the early 1980s (see Potts et al., 1995; Hall et al., 2014; Lemière, 2018), it is only in the past 10 years that robotic laboratory-grade microbeam XRF scanners have become available for in-field geologic logging of mineral deposits (e.g., AvaaTech, GeologicAI, GeoTek MSCL-XRF, Minalyze CS, TruScan). These scanners house more powerful and complex X-ray tubes that, when combined with larger detector heads, have resulted in improved detection limits and data precision for a greater suite of elements (e.g., Sjöqvist et al., 2015). Documented here are the learnings from the deployment of robotic XRF scanners at two Newcrest Mining Limited operated sites: Red Chris (Canada) and Havieron (Australia). Newcrest geologists, together with Veracio technical specialists, worked to embed the TruScan XRF technology into operating core sheds (Fig. 1). We overview machine-enabled core logging workflows and the impact of near-real-time chemical analyses of core delivered to geologists well ahead of the final laboratory assays.

Scanning technology is a tool that is conceptually no different than a hand lens—it helps the geologist better recognize what they are seeing—and its

Fig. 1. In-field, trailer-based X-ray fluorescence scanning units operating in the core shed at Red Chris, British Columbia.

systematic use can transform the process of core logging. We emphasize that the increased use of in-field scanning technology and associated machine-derived outputs is not now, nor likely ever will be, a substitute for field-based geologists. Nor does it eliminate the need for specialized core technicians. Rather, it permits the rapid collection and assemblage of larger and more robust quantified data sets available for critical analysis by exploration and resource geologists, geotechnical engineers, and metallurgists. We also reiterate here the importance of real-time data to inform geologic analysis and interpretation of core at the time of drilling. Future discoveries or the unlocking of our future metal deposits remain with the creative opportunities recognized by geologists in assessing these drilling-derived data sets.

Importance of Drill Core Logging

Drilling is critical to the mining value chain and, as such, is important in the testing of an exploration concept, advancing a metal deposit discovery, through to defining a metal volume (Arndt et al., 2017; Wood and Hedenquist, 2019; Orpen and Orpen, 2020). Drill-derived geologic material has an inherent value that goes well beyond the up-front time and money spent collecting the sample. Geologists capture systematic geologic observations and data from drill samples that inform physical models of the size, shape, and mineral composition of a metal volume. These models can inform decisions about the viability of a mining project and the best methods for extraction. Such studies can be developed long after the completion of drilling, which in cases may be even decades after the cessation of drilling.

Through the sequential description and measurement of mineralized and altered rock from a zone of mineralization, it is possible to separate true geologic observation from interpretation that best describes geologic domains. Core-based observations logged by geology teams can inform the following:

1. Geologic domains: Accurate mapping of a rock volume, including its size and shape, is fundamental to constraining the spatial distribution of ore-forming metals. Resultant metal volumes models are tied to the variability and continuity of associated mineralization. Lithology, alteration, mineralization, and structure is typically defined using cross sections, plan maps, and three-dimensional volumes that are constructed from the start of drilling and continually updated as drilling proceeds (Arndt et al., 2017).
2. Mineral distribution and quantification: Identification of key minerals (ore, gangue, and alteration) and determination of their relative proportions is an important aspect of core logging. The texture and size of minerals can be important visual guides that help vector to mineralization (e.g., Lypaczewski et al., 2019). Mineralogical variations and zonation can also underpin mining models, reflecting a rock mass hardness/strength or potential recovery (e.g., Johnson et al., 2019).
3. Structural analysis: Identification and description of the orientation and relationships of minerals and rock structures help build the structural and geotechnical properties of a rock volume that are used in resource modeling to mine design (Hoek et al., 2000).

Semiautomated scanning of drill core provides for consistent and robust physical and chemical data that can be used by a geology team to complete more fact-based discussions and eliminate subjective observations and observational biases (e.g., Huntington et al., 2006; Tappert et al., 2011; Fresia et al., 2017; De La Rosa et al., 2022). When it is completed systematically and continuously at a deposit scale, it is possible to derive new geologic insights that can be used to inform the decision-making process across the mining value chain.

Newcrest's Early Adoption of Machine-Enabled Logging

Over the past 30-plus years, Newcrest has successfully explored for and discovered multiple Au-Cu deposits, from those that crop out to those beneath hundreds of meters of barren rock. Newcrest core logging practices have evolved through the drilling of multiple deep deposits, specifically porphyry Au-Cu deposits with kilometer-scale vertical extents (e.g., Cadia Hill, Cadia Quarry, Ridgeway, and Cadia East all in the Cadia district, New South Wales).

Standard core logging practice at Cadia during the 1990s exploration stage transitioned from preprinted graphical logging sheets to more efficient digital means of capturing lithology, alteration, mineralization, and structural (including geotechnical) observations. The volume of data being generated during the drill out of the Cadia district required a more efficient logging system and one that provided the data in an electronically available form (see Malone, 2011). Geologists entered observations systematically using Datcol, a computerized barcode core logging system. The observed geology was documented by selecting descriptors and qualifiers selected as appropriate from compiled bar code sheets (Malone, 2011). Newcrest's core logging evolved in the early 2000s to entering observations into a series of templates synchronized routinely to the project database (e.g., Seequent MX Deposit or acQuire GIM). Guidelines and procedures outlined codes, definitions, descriptions, and representative photographs of all potential geologic features.

Newcrest first trialed geologist-led, machine-enabled logging in 2011, deploying a high-resolution hyperspectral core scanner (Corescan) to the Namosi porphyry Cu (Au) project (Fiji) (Martini et al., 2017). Here, scanning data from core provided consistent, accurate mapping and quantifiable mineralogical outputs that confirmed traditional observations made regarding the zonal arrangement of alteration in this Cu (Au) porphyry deposit. Both early- and main-stage mineralization events were captured via associated alteration assemblages, as were subsequent overprints and peripheral/distal alteration suites. Alteration mineral correlations not previously recognized were identified, including the strong correlation between Cu grade and the Fe-rich chlorite that overprints the primary biotite (phlogopite)-bearing potassic core of the porphyry. The insight permitted improved three-dimensional modeling of alteration proxies associated with metal volumes and the development of more precise resource domains.

Systematic high-resolution hyperspectral core scanning of the Golpu porphyry Cu-Au deposit (Papua New Guinea) helped to build a robust alteration model that was not possible with traditional hand lens-based observations. Here, high- and intermediate-sulfidation epithermal veins and alteration overprint and conceal the uppermost parts of the Golpu porphyry Cu-Au deposit (Rinne et al., 2018). Earlier metallurgical domaining separated two basic lithology-based ore types (i.e., porphyry versus wall rock) that oversimplified the orebody complexity and resulted in a high potential for mixing of metallurgical recovery responses. New metallurgical domains required a step change in ore deposit knowledge (outlined by Moorhead, 2015). Robotic hyperspectral mapping of drill core was used to help geologists build key indicator mineral maps that could be directly correlated to recovery.

The high-spatial-resolution nature of systems like Corescan helps amass billions of hyperspectral data points across several tens of kilometers of scanned core (Deyell-Wurst and Harraden, 2021). Although it may be perceived as oversampling, the ability to use precision robotic, high-resolution spectrometers scanning across a large volume of drill core helped to precisely differentiate clay and sericite minerals at Golpu. Fundamentally, individual SWIR spectral signatures, built by hundreds of narrow bands, quantitatively identify and spatially resolve white mineral species that were near impossible to visually differentiate. Field geologists found the technology mapped knife-sharp single mineral domains, rather than diffuse gradients of complex mineral mixtures as defined using handheld spectrometers. High-resolution core scanning also had a better success in the recognition of very fine grained dark actinolite that could be overlooked visually by even the most experienced geologist. Metallurgists embraced scanner outputs and subsequently built mineralogical domains that spatially separated contrasting epithermal domains (dickite versus alunite) from porphyry-related domains (sericite- and actinolite-bearing) and therefore allowed for a well-informed recovery/value model for Golpu (see Newcrest Mining Ltd., 2020a).

High-resolution semiautomated hyperspectral mineral logging has also been applied to the Ladolam gold deposit (Lihir, Papua New Guinea). Gold at Ladolam is complex and refractory, associated mainly with pyrite and marcasite occurring as veinlets, disseminations, replacements, and breccia fillings. Higher-grade epithermal mineralization formed in the brecciated core of a volcano and itself overprints multiple, early formed porphyry systems. Texturally destructive hydrothermal alteration and mineralization obscured the wall rocks that are cut by multiple diatremes and subvolcanic intrusions. This complexity has made basic observations and interpretations difficult. Despite this, integration of a long history (30-plus years) of mineral observations with automated drill core hyperspectral scanning and multielement geochemistry across Ladolam resulted in a new geologic model (see Newcrest Mining Ltd., 2020d).

With a spatial resolution down to 0.5 mm, application of Corescan technology has made it possible to complete a deposit-scale mineralogical study using visible to near infrared-short-wave infrared (VNIR-SWIR) spectra. This knowledge, gathered in the context of a well-established paragenetic framework (from multiple research projects in collaboration with university-based researchers), challenged accepted thinking on the nature of the Ladolam ore types. Over 20 km of drill core scanning helped inform a new detailed spatial model that further subdivided the adularia-pyrite (upper) epithermal from an anhydrite-dominant (lower) epithermal domain. Detailed subdivision of the advanced argillic domain was also possible. Drill core scanning provided a greatly enhanced way of identifying important minerals and alteration boundaries compared to using conventional logging data. It can be shown that moderately dipping adularia-rich epithermal domains overprint multiple upright, zoned porphyry centers.

Deposit-scale scanning, using a hyperspectral scanner, can unlock large-scale physiochemical patterns that constrain the geologic model and help geologists precisely define features that correlate to grade in three dimensions. The submillimeter data, with fine intervals that demonstrate small-scale mineralogical characteristics and paragenetic relationships, can be scaled up to the full drill hole or deposit to demonstrate larger mineralogical patterns. High-resolution hyperspectral core scanning, when coupled with in-field XRF scanner technology, can help inform deposit-scale mineral models and calculated mineralogy models. When used simultaneously, geologists can more precisely log to inform comprehensive geometallurgical models at the time of deposit drilling.

In-Field XRF Scanner Technology

When geologic material is exposed to short-wavelength (high-energy) X-rays, the atoms of the material can be ionized, exciting or “shooting out” an electron from an inner shell (see Jenkins and De Vries, 1970). This hole in the inner shell is filled when higher-energy electrons drop down and emit energy in the form of a photon that can be detected. Without touching or damaging the sample, XRF is a robust means of geochemical analysis where elements exhibit a contrasting X-ray fluorescence (Fig. 2). The intensity of each characteristic fluorescence spectra is directly proportional to the amount of each element in the material, which is what makes XRF spectroscopy ideal for qualitative and quantitative analysis of

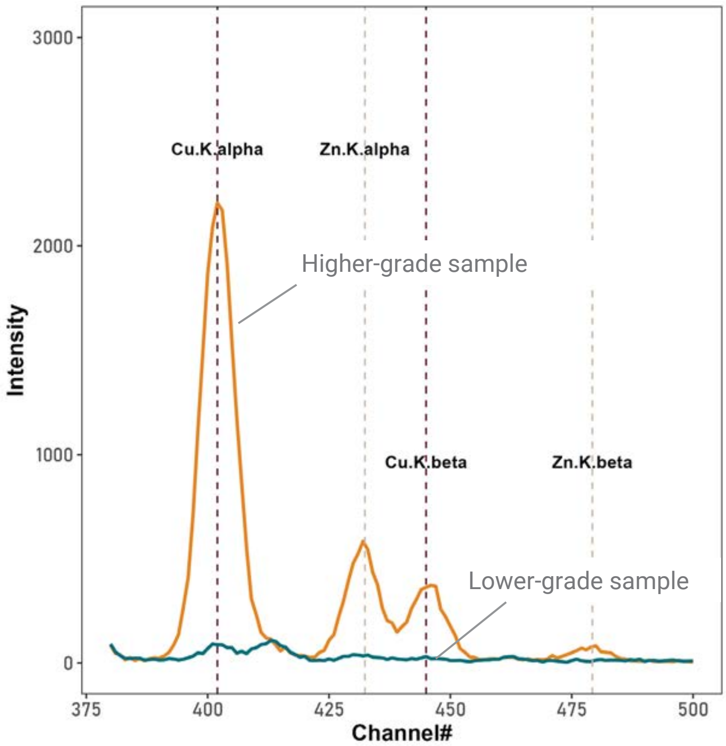


Fig. 2. Contrast between copper and zinc fluorescence spectra. The intensity of each characteristic radiation is directly proportional to the amount of each element in the material, ideal for qualitative and quantitative analysis of major, minor, and even trace elements in geologic samples. Orange line = copper, green line = zinc.

major, minor, and even trace elements in geologic samples.

X-ray fluorescence scanning technologies, like TruScan, have introduced in-field, high-density line scan chemical analyses of core well ahead of the final laboratory assays. It is now possible to routinely report up to 40 elements, from sodium to uranium on the periodic table, to the core shed in near real time (within 24 h) (Fig. 3). These technologies are continuing to become more lab-like (with geochemical outputs being more precise and accurate) and without the need for the extensive sample preparation required for lab sample analysis.

The TruScan XRF unit comprises a rhodium-target X-ray tube that is optimized for light elements (Na-K) through the application of low 15-kilovolt (kV) and 30-microamp (µA) tube current parameters, whereas intermediate elements (Ca-Fe) and heavy elements (Fe-U) are optimized with a 50-kV/30-µA energy. Helium purge of the gap between the sample and the X-ray tube helps in the detection of lighter elements and extends the elemental range. Trailer-based X-ray spectrometers take advantage of higher power and variable kilovolt excitation microbeams coupled to larger active area high-resolution electronically cooled silicon detectors important for the simultaneous analyses of a greater number of elements. The footprint of a single scanning spot is millimeter scale (8- × 3-mm ellipse) and can continuously operate as a drag scan along the core—this represents a high-density, core-based profiling system for XRF analysis (Fig. 4).

Robotic scanners offer an expandable multisensor platform capable of geospatially linking high-resolution photography to microbeam XRF. Increasingly, XRF spectrometers are being coupled with high-resolution hyperspectral imaging cameras. Integrated sensors combined with seamless data delivery platforms and advanced data processing tools (like specialized image analysis) helps reduce interoperability issues. Cloud-based storage of scanner output tied to a well-designed database architecture ensures data flow from field scanner to remote analyses, back to field-based geologists and core technicians.

Newcrest has completed multiple field-based programs using robotic XRF technology that has included codevelopment of new in-field workflows. Working together with Veracio, we have applied this scanning technology to a variety of Cu-Au deposit styles (porphyry, epithermal, intrusion-related, and iron oxide) and contrasting drilling-derived samples (drill core versus drill chips) and at sites in Australia and North and South America.

Calibration of in-field microbeam XRF systems

Traditional lab-based XRF spectroscopy involves laborious, time-consuming sample preparation, with geologic material being crushed and pulverized to be fused into a homogenized disk prior to analysis. Determination of element concentration requires a calibration that uses a library of different element concentrations and intensities of known geologic matrix (Jones et al., 2005; Brand and Brand, 2014; Gazley and Fisher, 2014). Portable XRF systems can be quasi-matrix-matched, calibrated for particular use cases in exploration including the analysis of soils, rocks and rock chips, and core (Le Vaillant et al., 2014). In-field microbeam XRF scanning, when completed at the centimeter scale or finer, requires a fit-for-purpose calibration that accounts for variability of rock types with contrasting matrix and textural variability (e.g., Potts and West, 2008). Our site-based calibrations suites include 200 to 500 pressed disks of rock pulp, combined with in situ core, with known elemental concentrations from all known rock types.

Systematic centimeter-scale XRF analyses of drill core requires calibrations with sufficient range of elemental concentrations to account for sample heterogeneity (e.g., Jones et al., 2005). Disseminated sulfides, mineral fracture fill, or coarsely crystalline silicates can introduce element spikes (Fig. 4) that are not commonly encountered on geochemical samples that are pulverized and homogenized (e.g., Potts and West, 2008). An increase in range (or end-member variability), caused by dramatic elemental variations coming from mineral heterogeneity, can result in poor fitting of the calibrations. Similarly, detector blinding (too many photons) caused by elemental bombardment from geologic features like metal-rich disseminations, veins, and breccias can cause issues in concentration determination. Furthermore, element deportment in minerals (e.g., Cu in chalcopyrite, chalcocite, or malachite) and/or coexisting

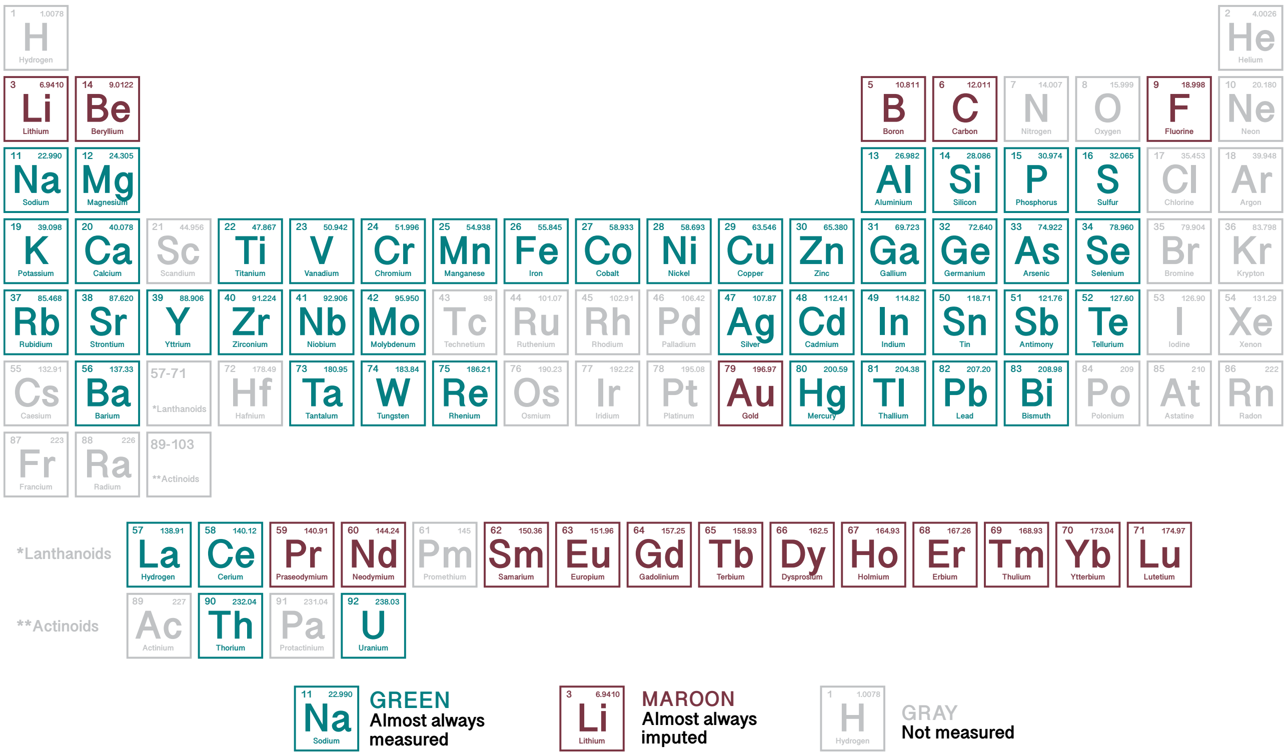


Fig. 3. Elements available to field geologists using TruScan technology as applied to the two case studies described below.

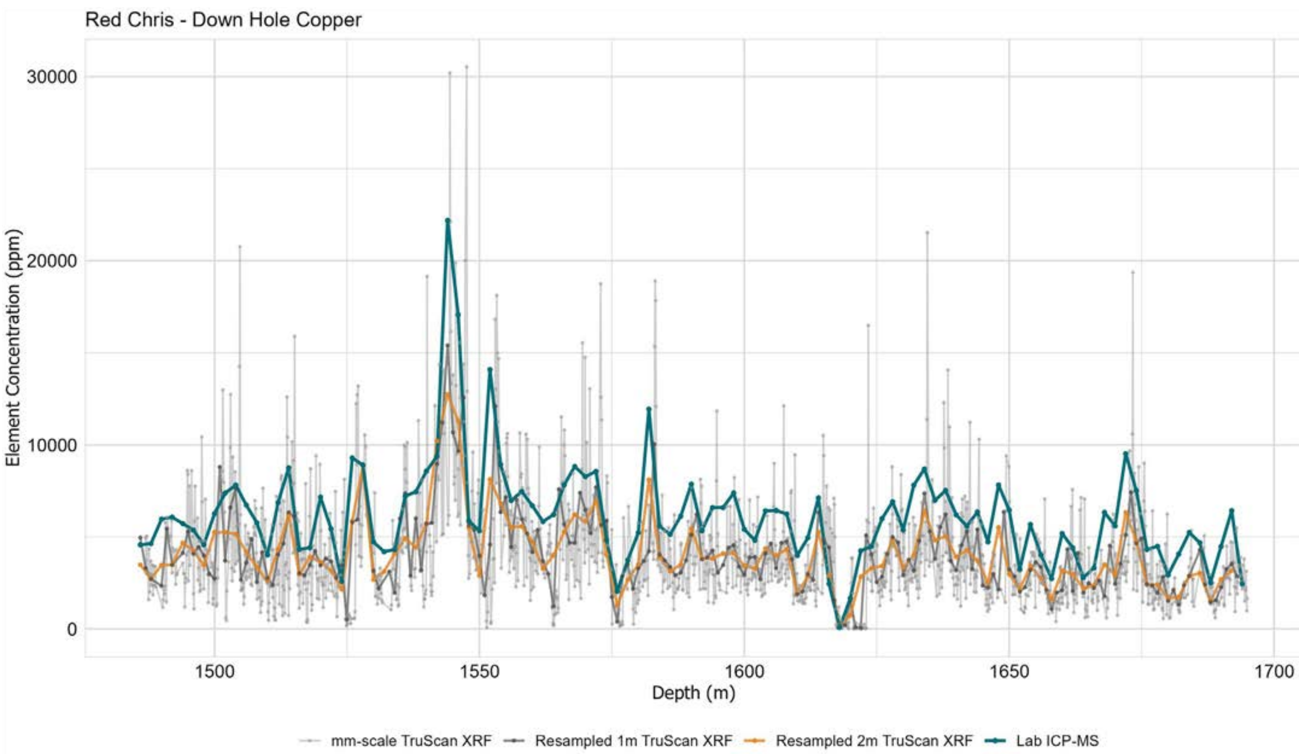


Fig. 4. Example of downhole X-ray fluorescence (XRF) scanner Cu versus lab-based Cu values (Red Chris). Shown here is a comparison between different subsets of the line scan XRF data (millimeter versus meter sample intervals); this highlights the sensitivity of the XRF scanner to heterogeneity within the sample when the millimeter-scale XRF Cu values are compared to meter-scale intervals. The narrow sampling window, combined with the dense sampling, results in spikes of Cu when the beam scans sulfide-bearing veins versus disseminations and/or silicate minerals in the groundmass. ICP-MS = inductively coupled plasma-mass spectrometry.

minerals assemblages (e.g., chalcopyrite-pyrrhotite) can also introduce result variability through X-ray fluorescence peak overlap (e.g., Fe, Bi, and Au). High-resolution XRF scanning therefore needs more complex calibrations that better account for true elemental distribution of in situ rock texture.

Ore-forming elements like Cu, Mo, and Zn and lithogeochemical elements such as K, Ca, Sr, and Rb are best measured using linear calibrations, incorporating slope and matrix corrections that account for any interferences. This ultimately results in calibrations that perform well not only inside a volume of mineralization but also in least altered, unmineralized wall rock. Machine learning algorithms, including extreme gradient boosting combined with neural networks, can be used in establishing a fit-for-purpose calibration for lower-concentration elements. Such calibrations generally perform well but are inherently prone to manifesting nonlinear error when new rock types and elemental associations are encountered outside of the calibration data set.

Field trials completed on a variety of deposit styles have found that the best calibrations are created from geologic material that captures the variety of lithology, alteration, and mineralization from the immediate area of the exploration target or deposit. Samples used for calibration must be prepared as a uniform pulp and have high-quality multiacid laboratory geochemistry to ensure that the element concentrations are known. A multiacid digest may have some residual mineral phases that will result in the underreporting of Zr, Cr, Al, and to a lesser extent K, which will inherently impact the calibration and the resultant output from the XRF scanner. Attempts to apply a universal calibration to new scanning projects has been largely unsuccessful, as they fail to account for the strong matrix effects, including element attenuation because of matrix variability within the rock volume and local density variations within the scanned samples.

The single most important factor in determining the success of a scanning XRF project is the quality of the calibration. Several iterations may be needed in the early stages of scanner deployment to a new project site. A fully optimized calibration may require large volumes of sample material, i.e., 500 to 1,000 pulps and hundreds to thousands of meters of core, depending on deposit complexity. Collation of a representative sample suite will ensure that a fully optimized calibration is achieved quickly. Confidence in the technology and its output can be lost without fully understanding the importance of a comprehensive calibration. Once a robust calibration, capturing all representative rock types and a full range of mineralization, is in place, rock volumes can be understood and defined in near real time as drilling occurs, driving efficiency in orebody definition and moving resource drillouts much faster.

Deposit-scale XRF scanning

Near-real-time data delivery of XRF sensor-derived metal values not only helps in decision-making around drill hole planning, but it can also be transformational in core shed workflow modification. Newcrest's exploration team, working with technology partner Veracio, has developed new ways of logging that have come from the application of XRF scanning technology to multiple sites and integrated them into large-scale drilling programs. Two case studies are presented to highlight the deployment and integration of XRF scanning to a porphyry Cu-Au deposit (Red Chris) and a complex breccia-hosted Cu-Au deposit (Havieron).

Case Study 1—Red Chris, British Columbia, Canada

Porphyry-related fracture-controlled and disseminated chalcopyrite ± bornite at Red Chris is centered on a composite swarm of at least three porphyry phases (P1-P3) that are subdivided based on subtle compositional and textural differences and truncated veins (Rees et al., 2015). The bulk of Cu-Au was introduced during emplacement of the P2 set of porphyry dikes. Higher-grade Cu-Au is centered on early potassic (K-feldspar-biotite-albite-quartz ± magnetite) and calc-potassic (actinolite-biotite-K-feldspar-magnetite) assemblages that have been overprinted by phyllic and pervasive intermediate argillic (quartz-illite-chlorite-carbonate) rocks. Propylitic (epidote-chlorite) alteration occurs as a distal footprint to the potassic alteration and a late-stage overprint to postmineral porphyry intrusions.

At Red Chris, Newcrest has completed 310,685 m of drilling from 301 drill holes since August 2019 (after Newcrest acquisition of its 70% interest in the Red Christ joint venture) (Newcrest Mining Ltd., 2021a). Systematic step-out and deep drilling of this multiple-center porphyry Cu-Au district has resulted in the discovery of multiple higher-grade porphyry pods, including East Ridge. X-ray fluorescence scanner technology was initially deployed to Red Chris in November 2019 to enable geologists to make faster and better-informed decisions at the time of drilling. Two parallel TruScan units were in operation by late 2020 to meet the core production from six to eight surface rigs drilling a variety of deep targets at Red Chris (Fig. 1). A single unit, when running 24 h, processed between 150 and 200 m per day. Over 192,750 m of drilling has been scanned as of May 2023. Geochemical results are delivered to the core shed immediately after the completion of a day of scanning.

Matrix-matched calibrations evolved through multiple iterations to ensure representation of all Red Chris rock units, alteration, and associated mineralization. Site-based calibrations come from an accumulated analysis of a large number of pressed pulp material (n = 668) and core material (7,000 m). Early pulp-based calibrations successfully reported Cu (max values of 1.5% Cu) together with S, As, Fe, K, Al, Ca, and Mo. Successive updating of the calibration was completed using core to include higher-grade domains (of >2% Cu and then >5% Cu) and textural variations in the rock hosting this grade. Red Chris geologists have an extended 36-element suite for all scanned core that can be scaled from 0.1, 1.0, 5.0, to 20.0 m, depending on the geologist's requirement.

Scanned XRF Cu interval data was used initially to track the progress of Newcrest's earliest drilling at Red Chris, including Newcrest's East Zone Resource Definition Program. On December 17, 2019, management was informed of an infield XRF scanner-derived interval for RC595 of approximately 702 m at an expected grade of 0.51% Cu from 399 m. Not only were metal values available for spatial modeling weeks in advance of final laboratory assays, but the data also helped prioritize intervals (in this case from 342 to 1,062 m) to be rushed to the lab. Subsequent public release (see Newcrest Mining Ltd., 2020b) of RC595 returned 720 m at 0.56% Cu and 0.59 g/t Au from 394 m based on lab-based chemistry. Over time, scanned Cu values helped focus core sampling and the sequence of lab dispatch, prioritizing the Cu-bearing material over weakly anomalous wall rock. Near-real-time Cu also helped Red Chris core logging of sulfide abundance due to the fine-grained (0.1–1.0 mm) nature of the disseminated Cu-Fe sulfides. Bornite can be so very finely disseminated that it can easily be mistaken for dark-red or blue-black specular hematite and/or missed where it occurs inside dark minerals (see Rees et al., 2015). Consistent logging of chalcopyrite versus bornite across the entire deposit was made easier using this XRF technology.

Immobile trace elements (Sc, Al, P, Ti, V, Y, Zr, Nb, La, and Th) are available to geologists to differentiate rock types at Red Chris. Texturally destructive alteration can obscure subtle visual cues (phenocrysts + texture) used by geologists to differentiate the multi-phase ore-related porphyries, so-called P2 porphyries, from premineral P1 and postmineral P3 (Fig. 5). At least three phases of P2 porphyry are present and are variably mineralized (Rees et al., 2015). Quartz stockworks occur along porphyry contacts and as dense (up to 80 vol %) domains that make porphyry subdivision problematic and intrusive contacts difficult to define. Core loggers observe the core in parallel with downhole plots of XRF scanner-derived Mo and Cu values, compared to Cu/Mo and Ti/Nb ratios, to assist with discrimination of intrusive phases. Sharp and consistent step changes in Mo values demarcate intrusive phase changes, with the Mo values themselves used to define the intrusive type (Fig. 5).

Red Chris geologists use a variety of ratios to map alteration mineralogy, including K/Al and Na/Al, to map distribution of K-feldspar, sericite, and albite, together with Fe/S to map the distribution of sulfides. Overprinted sericite-clay-pyrite and later low-sulfide carbonate-clay-hematite occur in the upper parts of the porphyry columns. The latter also occurs in fault zones that cut through the porphyry-style mineralization. Geologists use As and Sb values to precisely pick out discrete fault arrays that can be visually cryptic inside broad clay-altered damage zones. Near-real-time geochemistry enables logging geologists to pinpoint, confirm, and document important grade boundaries in Red Chris accurately and consistently. Scanning core at centimeter-scale

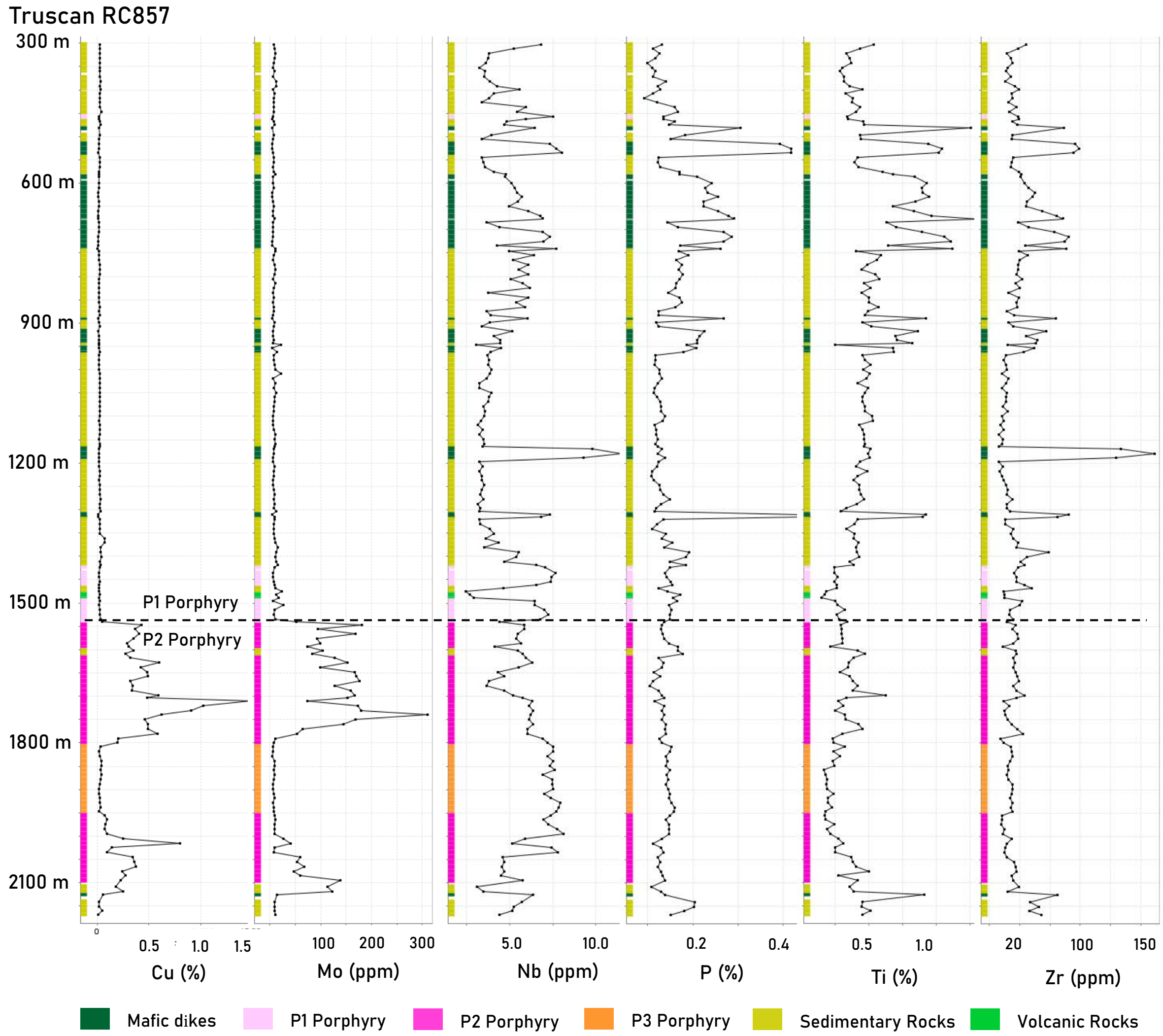


Fig. 5. Example of downhole scatter plot of elements used at Red Chris to help geologists differentiate rock types. The high resolution of the scanning helps geology teams pick the contacts of the porphyry phases (e.g., P1 and P2 contact at 1,520 m). Note the subtle chemical differences in the mafic and felsic dikes in the deposit, which can be differentiated using variations in the concentration of Cu and Mo and Nb, Ti, and Zr.

Empowering Geologists in the Exploration Process *(cont.)*

resolution has helped minimize ambiguity in the geology and reduce observation-related slowdowns, including core-shed debates, in the process of core logging. At Red Chris, this time saving alone is between 2 to 3 h in a core shed processing 300 to 350 m of core production per day.

The discovery of East Ridge at Red Chris was a significant postacquisition milestone for Newcrest (see Newcrest Mining Ltd., 2021b) and was the first internal use of whole-of-deposit, XRF-scanned Cu values to build an initial East Ridge metal volume (Fig. 6). Copper exhibits a strong positive relationship (correlation coefficient $R^2 = 0.90$) between nondestructive, in situ scanner-derived Cu compared to crushed, pulverized, and homogenized laboratory assays (n = 94,592) (Fig. 7). Given this data confidence, scanned Cu was used to manage drilling and drill results, including the live update of the metal volume on a hole-by-hole basis in three-dimensional modeling software. Near-real-time data reduced the time to decision imposed by the physical core-processing workflows that include off-site laboratory analysis.

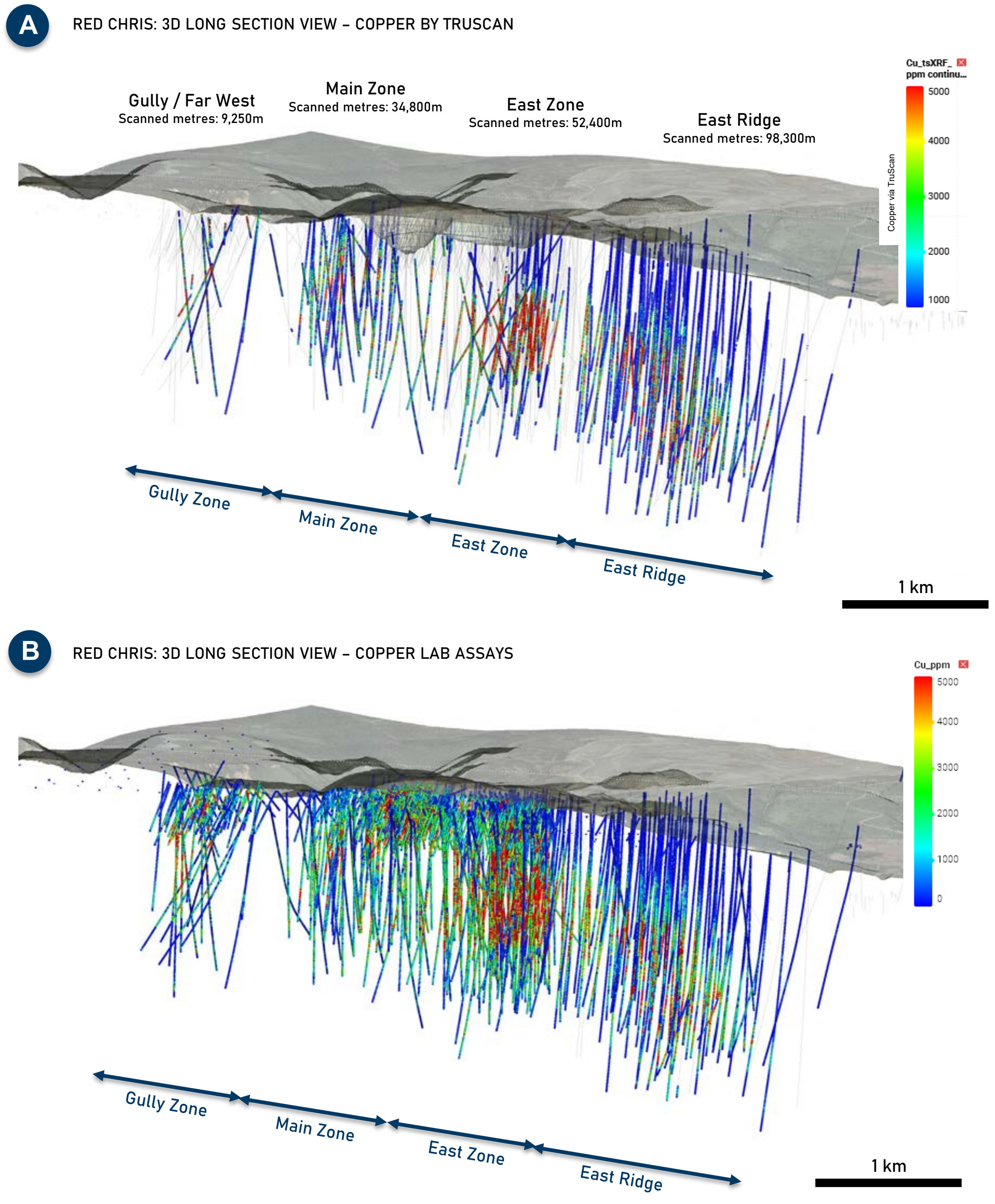


Fig. 6. Distribution of in-field X-ray fluorescence (XRF) scanned drill holes completed at Red Chris (as of May 2023). A. Copper as determined via an in-field XRF scanner is shown on drill traces (gray lines). The determined values are via a process of site-based matrix matching to available multiacid geochemistry. B. Copper determined via lab-based process as has been reported by Newcrest (Newcrest Mining Ltd., 2023).

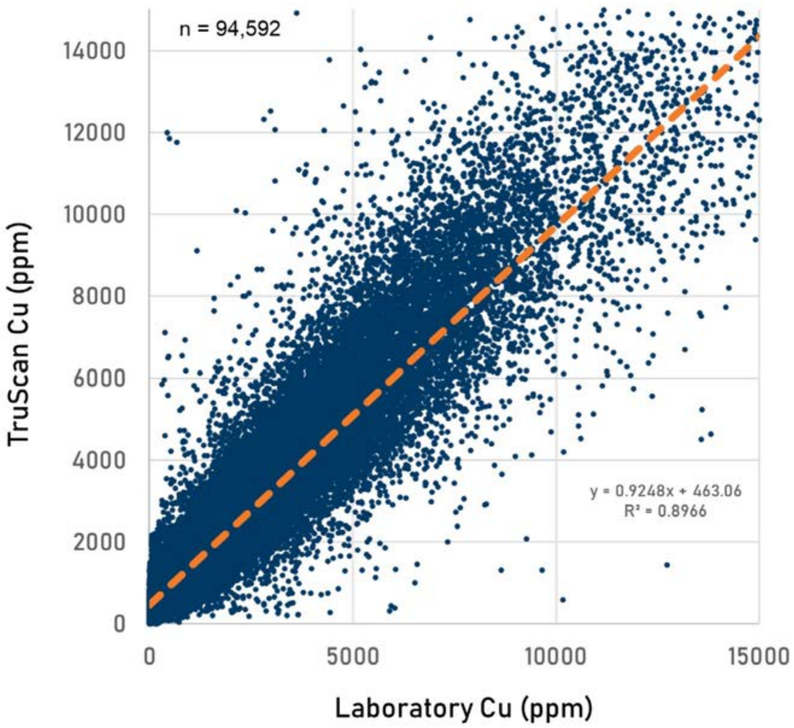


Fig. 7. Correlation between Cu concentrations from laboratory and Cu values from in-field X-ray fluorescence (XRF) scanner.

Depending on cutting backlog, combined with lab availability, conventional lab assay turnaround time can be as much as six weeks (up to 12 weeks at the peak of COVID). Knowledge of the metal volume in advance of the final assays meant that the accompanying geologic models could be built (see Newcrest Mining Ltd., 2023).

Case Study 2—Havieron, Western Australia

The Havieron Au-Cu deposit comprises a series of nested breccia columns that cut up along the contacts of a multiphase diorite dike intrusive complex emplaced into a metasedimentary rock package (Ackerman et al., 2021). The most volumetrically significant concentrations of these breccia columns coalesce to define the SE Crescent zone—this zone occurs along the southeast edge of an ovoid zone (700 × 400 m) of calc-silicate alteration that comprises varying proportions of hydrothermal carbonate-quartz-sulfide-actinolite-biotite as breccia, veins, and replacements. A postmineralization dolerite dike truncates the deposit.

Multiphase hydrothermal breccias at Havieron have pre-, syn-, to postmineralization timing relationships. Breccia facies are separated on the nature of matrix infill, including variable proportions of actinolite, calcite, and sulfide cement. Quartz-rich variants of the actinolite-cemented breccias also occur. Higher gold (>2 g/t Au) and copper (>0.2% Cu) grades are typically associated with sulfide-bearing actinolite-calcite–cemented breccia that in parts of the system transitions into the more massive Fe-Cu sulfide mineralization. Still higher gold (>5 g/t Au) grades can be found associated with the quartz-rich variant where the distribution of Au can be difficult for a geologist to define. Even the most experienced logging geologist is challenged by the systematic documentation of the fine Au, Bi, and Bi-Te minerals that occur interstitial to pyrrhotite, chalcopyrite, and lesser pyrite. A real need to confidently identify the extent of this subtle but high-grade mineralization drove the initial deploy of the TruScan to site.

Havieron geologic logging records descriptions of lithology, alteration, and mineralization for all core drilled, including structural orientation of key geologic features. Geotechnical measurements are manually recorded, including rock quality designation (RQD), fracture frequency, solid core recovery, and qualitative rock strength measurements. Magnetic susceptibility measurements are recorded every meter down the core, with bulk density measurements selectively taken using whole core. All geologic and geotechnical logging is completed at Havieron by teams that comprise geologists and core technicians in a field camp approximately 40 km from the Telfer mine site. Observations and derived physical data underpin metal volume estimates that have been published for Havieron (Newcrest Mining Ltd., 2020c).

Initial deployment of an XRF scanner to Havieron sought to assist site-based geologists in their end-of-hole decisions (i.e., the early hole termination or hole continuation) combined with future drill hole planning, including rapid-follow-up drill holes. Although the earliest scanning results were acceptable in the bulk of the system, the earliest calibration struggled in the more massive pyrrhotite parts of Havieron, including zones of higher grade. Detector blinding caused by Fe fluorescence saturation imposed by the volume of pyrrhotite caused issues in the determination of Au, Bi, and to a lesser extent Cu. Confidence in the outputs began to suffer principally due to an incomplete understanding of the technology limitations imposed by a calibration that did not account for extreme elemental end members. An improved and considerably larger calibration suite restored confidence.

Using a known Bi-Au correlation (30:1) derived from laboratory geochemistry made it possible to infer Au grades using systematic Bi values (above 20 ppm), and this was more reliable than using scanned Au values (>1.5–>2.0 g/t Au) that remain affected by Fe fluorescence saturation. Geologists now begin their shift by reviewing stacked profiles of Cu, Bi, S, Co, Ni, W, and Te (Fig. 8) to determine the physical limits of the mineralized breccias, including a machine-enabled means to log breccia geology to Cu-Au and Au-only domains (Fig. 9). In a complex orebody like Havieron, this simple process change has resulted in 2 to 4 h of time savings in a core shed processing 300 to 350 m of core production per day.

Automated workflows developed at Havieron included the seamless delivery of chemical data from the X-ray scanner to an acQuire database via cloud-based storage. Site-specific significant intercept

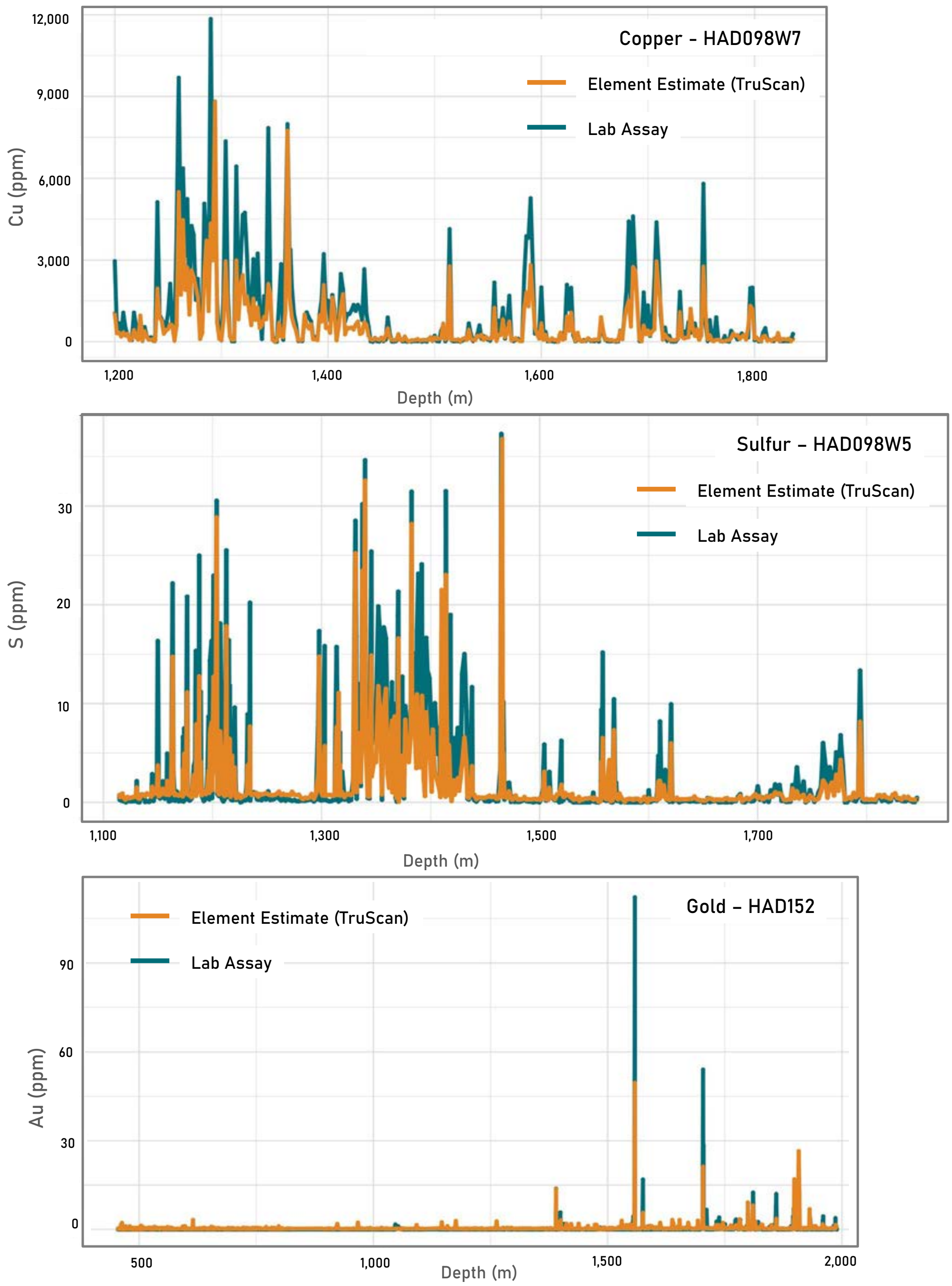


Fig. 8. Example of downhole scatter plots of Cu, S, and Au that compare laboratory assays to values from X-ray fluorescence (XRF) scanning technology (from Havieron, Western Australia). Results presented here are elements used by Havieron geologists to log mineralization zones. Although considered a problematic analysis via in-field XRF technology, a single downhole plot of Au is shown.

alerts coming from the in-field XRF results were set to inform the logging team when a particular threshold (e.g., >10 m at 0.3% Cu, >10 m at >2 g/t Au, and/or >10 m at >30 ppm Bi from TruScan) had been intersected in a particular drill hole. Downhole plots of Ti, Nb, V, Zr, and Al (Fig. 10) assisted in differentiating fine-grained feldspathic sandstone (plagioclase, quartz, zircon) from fine-grained plagioclase-phyric intrusive rock. Complex and often subtle variations in mineral proportions caused inconsistent logging of the concentrically zoned core of calc-silicate alteration that comprises zones of calc-sodic (actinolite-albite ± calcite and albite-rutile ± actinolite)

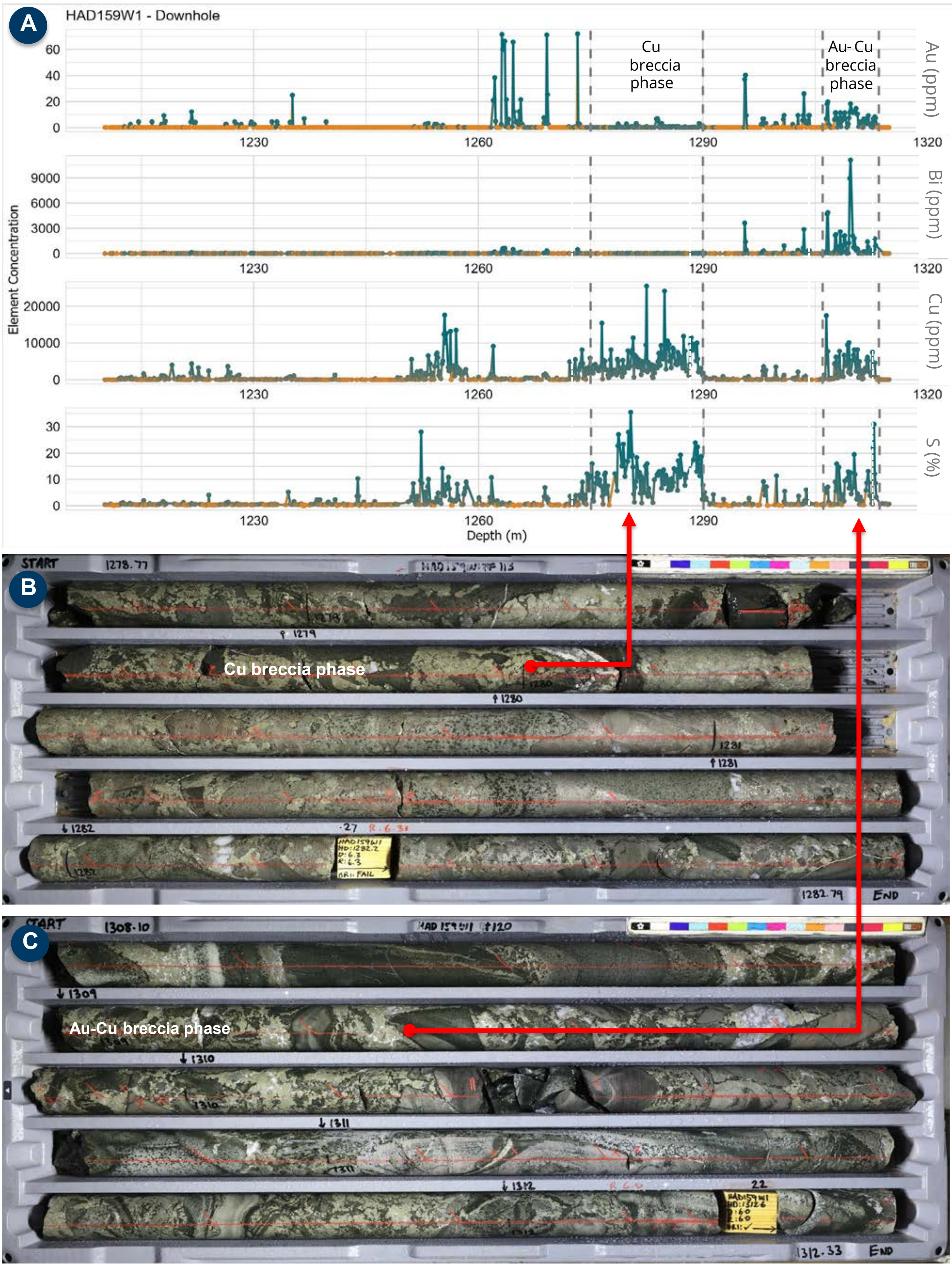


Fig. 9. Example of real-time dashboard used by logging geologists to differentiate near-equivalent metal-bearing breccias (Havieron). A. Two phases of breccia phases can be easily separated using the downhole strip logs. B. Example of the sulfide-bearing breccia with high Cu values compared to C., which is a similar-looking breccia that is more Au rich (inferred from the detectable Au and higher Bi values).

Empowering Geologists in the Exploration Process *(cont.)*

and calc-potassic (biotite-actinolite ± carbonate-albite) alteration, out to distal albite-biotite ± carbonate-actinolite alteration assemblages. Hand lens observations were made more confidently on the core using Ca, Na, Mg, K, and Al scatter plots delivered via an easy-to-access dashboard to the core shed (e.g., Fig. 9). Geologists of all experience levels are now able to confidently observe and log the outermost cryptic albitic halo to the Havieron deposit (often overlooked in the wall-rock feldspathic sandstones). Using geochemistry at the time of logging reduces the need for future relogging exercises that validate original observations made from hundreds of kilometers of core.

Core photography outputs coming from the TruScan scanner have been modified to mimic the standard Newcrest procedure (including optimized lighting, high resolution of raw photograph, imprinted metadata, and coincident low-resolution photographic thumbnails). At Havieron, it has been possible to eliminate the laborious process of manual core photography and in doing so reduce unnecessary manual handling of core and remove a step in the core-processing workflow. While it appears simple, the routine acquisition of scanner-based photography and its automated delivery to final storage locations provide for a significant time and cost savings (i.e., between 2 and 3 h per day of a dedicated core technician). This environment is contained and seamless with respect to data, with images moving from the scanner to a cloud-based platform capable of detailed image analysis via computer vision algorithms, combined with machine learning, that offer the opportunity to rapidly collect large volumes of geotechnical data not possible via manual logging of drill core.

Techniques for calculating the orientation of structural features from high-resolution drill core photography (Berry and Nguyen, 2016) have evolved to incorporate automated means for identifying and orienting drill core features (e.g., Cadia East, Harraden et al., 2019). Machine learning algorithms are used to complete systematic core measurements (e.g., RQD), identify fractures, fracture frequency, and orientation, and calculate vein volumes. At Havieron, Newcrest adopted a new way of working that involved presenting labeled imagery back to the geotechnical logger

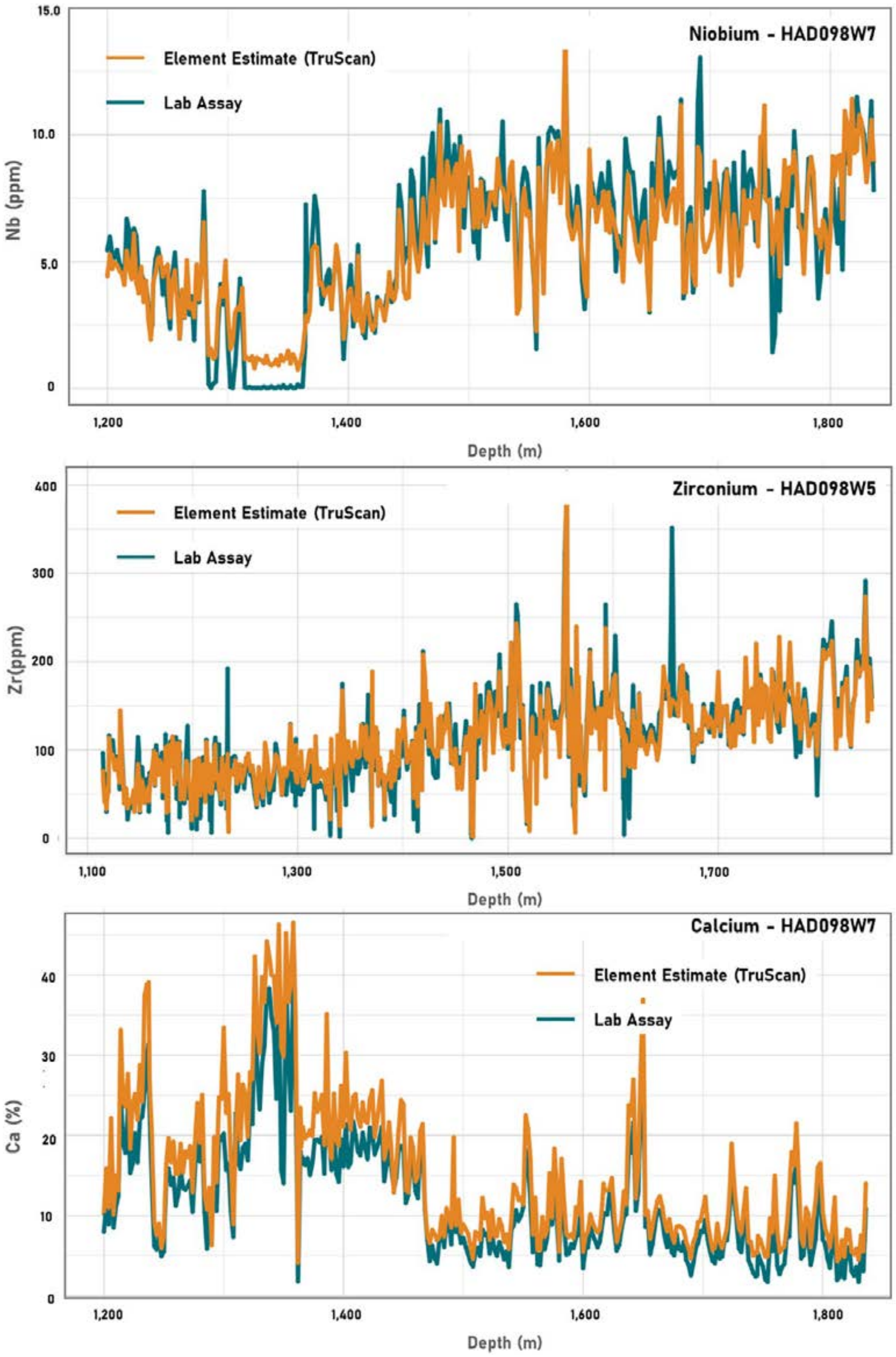


Fig. 10. Example of downhole scatter plots of Nb, Zr, and Ca that compare laboratory assays to values from X-ray fluorescence (XRF) scanning technology (from Havieron, Western Australia). These are elements used by Havieron geologists to log lithology and alteration domains.

observing the core. This has meant larger, more systematic field-validated basic geotechnical data on all drill holes (e.g., geotechnical logging of a 1,500-m hole via manual means will commonly capture >200 features, compared to >2,000 features via machine-assisted geotechnical logging). It has improved the productivity of core technicians through increased logging speeds and reduced physical handling of core and core trays (Fig. 11). Removal of inconsistencies in manual core logging techniques, including variable experience

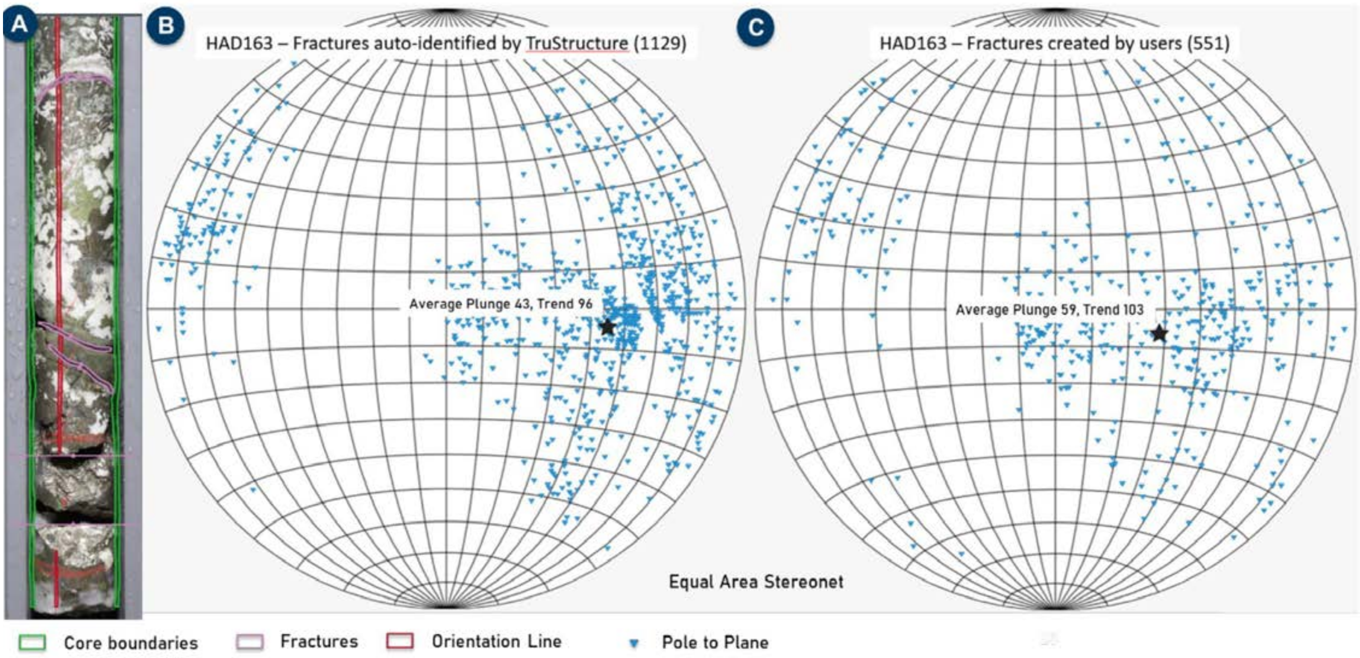


Fig. 11. Machine-driven logging of basic structural data (Havieron). A. Example of automated pickup structural data—both planes and lines—in oriented core photography, with only minor loss in precision of measurement compared to the physical measurement of orientation data. B and C. Geologist/technician-validated automated mapping of structural data can result in larger volumes of robust data compared to fractures mapped via traditional logging. Removal of inconsistencies in manual core logging techniques (including variable experience and training and personal observation bias) means that data collected from all drill core within a deposit can be used in a geotechnical model.

and training and personal observation bias, means that data collected from all drill core in a deposit can be used in a whole-of-deposit geotechnical model.

Future Developments

Petrophysics provides the link between subsurface geology and geophysical measurements, which requires particular attention as exploration teams seek deeper exploration targets and extend reliance on geophysical data. In contrast with the oil and gas industry, where large quantities of petrophysical data are routinely collected downhole to characterize subsurface hydrocarbon potential, in mineral exploration it is impractical to collect sufficient petrophysical measurements to adequately characterize the complex geologic processes. As such, mineral systems are inevitably poorly characterized in the petrophysical domain.

Using an abundance of XRF data from Red Chris, photon responses of rock being scanned can be used to predict petrophysical properties. Machine learning models that incorporate 2,048 raw channels from the X-ray spectra acquired on a single scanning point of TruScan can been used to predict downhole resistivity, chargeability, and p-wave slowness with reasonably low error rates. It is possible to increase the size of the training set and refine the machine learning model with the addition of magnetic susceptibility and conductivity measured directly from the core.

With a future pathway for petrophysical properties to be derived from X-ray fluorescence scanned core, it will become possible to report petrophysical properties for all scanned drill holes in and around a deposit, and as such there is the potential to optimize decision-making at all stages of the exploration pipeline: drill hole reconciliation, geophysical survey design, and vectoring to mineralization or impacting orebody knowledge such as rock quality characterization.

The narrow sampling window combined with the dense sampling enabled by X-ray fluorescence scanners means there is now the potential to derive near-end-member mineral chemistry compositions where mineral crystals are either coarse (e.g., calcite or pyrite veins) or from simple mixed assemblages (e.g., quartz-illite-pyrite). This means that the abundance of particular trace elements (e.g., Mn in calcite, chlorite or epidote, or As in pyrite) can now be predicted. If coupled with an understanding of element deportment established through three decades of research of laser ablation-inductively coupled plasma-mass spectrometry on mineral chemistry in hydrothermal systems (e.g., Cooke et al., 2014), this knowledge and its potential exploration value can now be imputed from continuous high-spatial-resolution XRF scanner data.

Lessons Learned

Newcrest's long history of applying hyperspectral and subsequently XRF scanning technology has shown that it is possible to transform how traditional geologic observation and core logging is completed. In using this technology, geologists have realized new ways of working that can include near-real-time fact-based discussions. When scanning is completed across an entire deposit, like at East Ridge Red Chris, it is possible to remove inconsistent manual core logging. It is possible to rapidly upskill geologists, irrespective of their experience and training, and to reduce personal observation bias. Integration of human observations with machine-acquired data creates a more dynamic environment of analysis and interpretation and improves productivity and the experience of geologists and field technicians.

We emphasize that in-field, semi-automated scanning technology and associated machine-derived outputs are not a future substitute for field-based geologists. Future discoveries remain with the creative opportunities recognized by geologists. Machine-driven products facilitate the distillation and integration of complex data that geologic teams need to combine with their mineral systems knowledge to increase the probability of discovery. We highlight the opportunity that lies in unlocking more accurate and quantified field-based geologic observations derived from high-resolution sensor technology. In the process, it is possible to augment the exploration geologist providing focused and objective data sets that support geology-led knowledge generation rather than an accepted environment of small-scale data collection.

Field deployment of XRF scanning units for sustained periods affords the opportunity to develop new core shed workflows. An estimated 8 to 10 h/day of operational improvements to the core logging process are estimated to come from faster and consistent observations by site-based geologists, combined with smarter and consistent acquisition of data and logged data products from core technicians. Field-based scanners come at an additional cost to laboratory assays and conventional means of core-based logging; however, it can be shown that far greater value and time/cost savings comes from the early creation of data sets that can impact geology, geotechnical, geometallurgy, and geoenvironmental aspects of a mineral resource project.

Unlocking the knowledge from geologic data, irrespective of data source, requires better interoperability between systems and platforms and algorithms that combine increasingly complex multidimensional data with the vast amounts of exploration data that has been collected over the past decades. While the volume of data derived from scanning technology can be perceived to be overwhelming, successful deployment of any such technologies must ensure that site-based geologists are provided with only simple data distillations to help inform their core-based decisions.

Acknowledgments

This work was not possible without the support of Newcrest and its geology teams. The authors acknowledge the valuable contributions of technical specialists from Newcrest's technology partners who have helped deploy scanning technology to Newcrest sites, including Neil Goodey. John Holliday, supported by Dan Wood and Colin Moorhead, scoped the original vision for Newcrest's early adoption of this technology. This article was reviewed by Scott Halley, Cassady Harraden, and Shaun Barker, whose comments and edits are greatly appreciated.

REFERENCES

Ackerman, B., Finn, D., Baxter, C., Harris, A., Switzer, C., MacCorquodale, F., Wilson, A., Lizowiec, N., and Williams, J., 2021, Haverion gold-copper deposit: Next generation of undercover discoveries: Newgen Gold, Perth, Western Australia, 2021, Conference Proceedings, p. 145–159.

Arndt, N.T., Fontbote, L., Hedenquist, J.W., Kesler, S.E., Thompson, J.F.H., and Wood, D.G., 2017, Future global mineral resources: Geochemical Perspectives, v. 6, no. 1, 171 p.

Berry, R., and Nguyen, K., 2016, Structure from photographs of oriented core: STORC: Economic Geology, v. 111, p. 1525–1527.

Brand, N., and Brand, C.J., 2014, Performance comparison of portable XRF instruments: Geochemistry: Exploration, Environment, Analysis, v. 14, p. 125–138.

Cooke, D.R., Baker, M., Hollings, P., Sweet, G., Chang, Z., Danyushevsky, L.D., Gilbert, S., Zhou, T., White, N.C., Gemmell, J.B., and Inglis, S.I., 2014, New advances in detecting the distal geochemical footprints of porphyry systems: Epidote mineral chemistry as a tool for vectoring and fertility assessments: Society of Economic Geologists, Special Publication 16, p. 147–166.

De La Rosa, R., Tolosana-Delgado, R., Kirsch, M., and Gloaguen, R., 2022, Automated multi-scale and multivariate geologic logging from drill-core hyperspectral data: Remote Sensing, v. 14, article 2676.

Deyell-Wurst, C., and Harraden, C., 2021, The future of core logging: Applications for hyperspectral core imaging: Corescan Presentation, November 29, 2021, https://corescan.com.au/resources/.

Fresia, B., Ross, P.-S., Gloaguen, E., and Bourke, A., 2017, Lithological discrimination based on statistical analysis of multi-sensor drill core logging data in the Matagami VMS district, Quebec, Canada: Ore Geology Reviews, v. 80, p. 552–563.

Gazley, M.F., and Fisher, L.A., 2014, A review of the reliability and validity of portable X-ray fluorescence spectrometry (pXRF) data, *in* Mineral resource and ore reserve estimation—the AusIMM guide to good practice, 2nd ed.: Melbourne, The Australasian Institute of Mining and Metallurgy p. 69–82.

Hall, G.E.M., Bonham-Carter, G.F., and Buchar, A., 2014, Evaluation of portable X-ray fluorescence (pXRF) in exploration and mining: Phase 1, control reference materials: Geochemistry: Exploration, Environment, Analysis, v. 14, p. 99–123.

Harraden, C.L., Cracknell, M.J., Lett, J., Berry, R.F., Carey, R., and Harris, A.C., 2019, Automated core logging technology for geotechnical assessment: A study on core from the Cadia East porphyry deposit: Economic Geology, v. 114, p. 1495–1511.

Hoek, E., Kaiser, P.K., and Bawden, W.F., 2000, Support of underground excavations in hard rock: Netherlands, CRC Press, 225 p.

Huntington, J.F., Mauger, A.J., Skirrow, R.G., Bastrakov, E.N., Connor, P., Mason, P., Keeling, J.L., Coward, D.A., Berman, M., and Phillips, R., 2006, Automated mineralogical core logging at the Emmie Bluff iron oxide-copper-gold prospect: Mines and Energy South Australia, MESA Journal, v. 41, p. 38–44.

Jenkins, R., and De Vries, J.L., 1970, Practical X-ray spectrometry: London, MacMillan, 190 p.

Johnson, C.L., Browning, D.A., and Pendock, N.E., 2019, Hyperspectral imaging applications to geometallurgy: Utilizing blast hole mineralogy to predict Au-Cu recovery and throughput at the Phoenix mine, Nevada: Economic Geology, v. 114, p. 1481–1494.

Jones, M.C., Williams-Thorpe, O., Potts, P.J., and Webb, P.C., 2005, Using field-portable XRF to assess geochemical variations within and between dolerite outcrops of Preseli, South Wales: Geostandards and Geoanalytical Research, v. 29, p. 251–269.

Lemière, B., 2018, A review of pXRF (field portable X-ray fluorescence) applications for applied geochemistry: Journal of Geochemical Exploration, v. 188, p. 350–363.

Le Vaillant, M., Barnes, S.J., Fisher, L., Fiorentini, M.L., and Caruso, S., 2014, Use and calibration of portable X-ray fluorescence analysers: Application to lithogeochemical exploration for komatiite-hosted nickel sulphide deposits: Geochemistry Exploration Environment Analysis, v. 14, p. 199–209.

Lypaczewski, P., Rivard, B., Gaillard, N., Perrouty, S., Piette-Lauzière, N., Bérubé, C.L., and Linnen, R.L., 2019, Using hyperspectral imaging to vector towards mineralization at the Canadian Malartic gold deposit, Québec, Canada: Ore Geology Reviews, v. 111, article 102945.

Malone, E., 2011, The Cadia Valley mines: A mining success story: Australasian Institute of Mining and Metallurgy (AusIMM) Spectrum Series, v. 19, 268 p.

Martini, B.A., Harris, A.C., Carey, R., Coodey, N., Honey, F., and Tufilli, N., 2017, Automated hyperspectral core imaging—a revolutionary new tool for exploration, mining and research: Exploration 17, Toronto, Canada, October 22–25, 2017, Proceedings, Paper 83.

Moorhead, C., 2015, Bottom-up innovation: Successful research adoption: Australian Minerals Industries Research Association (AMIRA) International Exploration Managers Conference, Barossa Valley, Australia, March 17–20, 2015, Proceedings, p. 135.

Newcrest Mining Ltd., 2020a, Wafi-Golpu project, Morobe province, Papua New

Guinea: NI 43-101 Technical Report, www.newcrest.com.
——2020b, Newcrest quarterly exploration report: www.newcrest.com, dated January 30, 2020.
——2020c, Initial inferred mineral resource estimate for Havieron of 3.4 Moz of gold and 160 Kt of copper: Market release, December 10, 2020, www.newcrest.com.
——2020d, Lihir operations Niolam Island, Papua New Guinea: NI 43-101 Technical Report, www.newcrest.com.
——2021a, Red Chris operations, British Columbia, Canada: NI 43-101 Technical Report, www.newcrest.com.
——2021b, Newcrest exploration update: www.newcrest.com, dated March 11, 2021.
——2023, Red Chris exploration success expands East Ridge exploration target delivering additional mining potential: Newcrest Exploration Update, www.newcrest.com, dated March 14, 2023.
Orpen, J., and Orpen, D., 2020, Error-proofing diamond drilling and drill core measurements: SEG Discovery, no. 123, p. 23–34.
Potts, P.J., and West, M., 2008, Portable X-ray fluorescence spectrometry: Capabilities for in situ analysis: Cambridge, The Royal Society of Chemistry, 291 p.
Potts, P.J., Webb, P.C., Williams-Thorpe, O., and Kilworth, R., 1995, Analysis of silicate rocks using field-portable X-ray fluorescence instrumentation incorporating a mercury (II) iodide detector: A preliminary assessment of analytical performance: Analyst, v. 120, p. 1273–1278.
Rees, C., Riedell, K.B., Proffett, J.M., Macpherson, J., and Robertson, S., 2015, The Red Chris porphyry copper-gold deposit, northern British Columbia, Canada: Igneous phases, alteration, and controls of mineralization: Economic Geology, v. 110, p. 857–888.
Rinne, M.L., Cooke, D.R., Harris, A.C., Finn, D.J., Allen, C.M., Heizler, M.T., and Creaser, R.A., 2018, Geology and geochronology of the Golpu porphyry and Wafi epithermal deposit, Morobe province, Papua New Guinea: Economic Geology, v. 113, p. 271–294.
Sjöqvist, A.S.L., Arthursson, M., Lundström, A., Calderón Estrada, E., Inerfeldt, A., and Lorenz, H., 2015, An innovative optical and chemical drill core scanner: Scientific Drilling v. 19, p. 13–16.
Tappert, M., Rivard, B., Giles, D., Tappert, R., and Mauger, A., 2011, Automated drill core logging using visible and near-infrared reflectance spectroscopy: A case study from the Olympic Dam IOCG deposit, South Australia: Economic Geology, v. 106, p. 289–296.
Wood, D., and Hedenquist, J., 2019, Mineral exploration: Discovering and defining ore deposits: SEG Discovery, no. 116, p. 1–22.

Anthony Harris was awarded his B.Sc. (Hons) and Ph.D. degrees from the University of Queensland. After working at the Center for Ore Deposit and Earth Sciences (CODES; University of Tasmania), including as a Newcrest embedded researcher, he joined Newcrest (now Newmont) where he is involved in technical guidance from exploration targeting to project assessment, from early-stage projects to mines. Anthony is technical lead responsible for the advancement, application, and integration of new exploration technologies in Newcrest. He has worked on a variety of Au-Cu deposit types found in the circum-Pacific, focusing on porphyry Cu-Au and epithermal Au deposits.

This paper was published in the January-February 2024 edition of

SEG Discovery

The Society of Economic Geologists (SEG) is an international organization comprising individual members with a keen interest in economic geology. Founded in 1920, SEG's membership spans industry professionals, academics, and government officials. The society focuses on advancing geological science, particularly in mineral deposits and resources, and aims to disseminate scientific knowledge through conferences, field trips, courses, and publications. SEG plays a crucial role in enhancing the status and ethical standards of the economic geology profession. The society is governed by a Council and Executive Committee, and offers various membership categories including Fellows, Members, and Student Members.

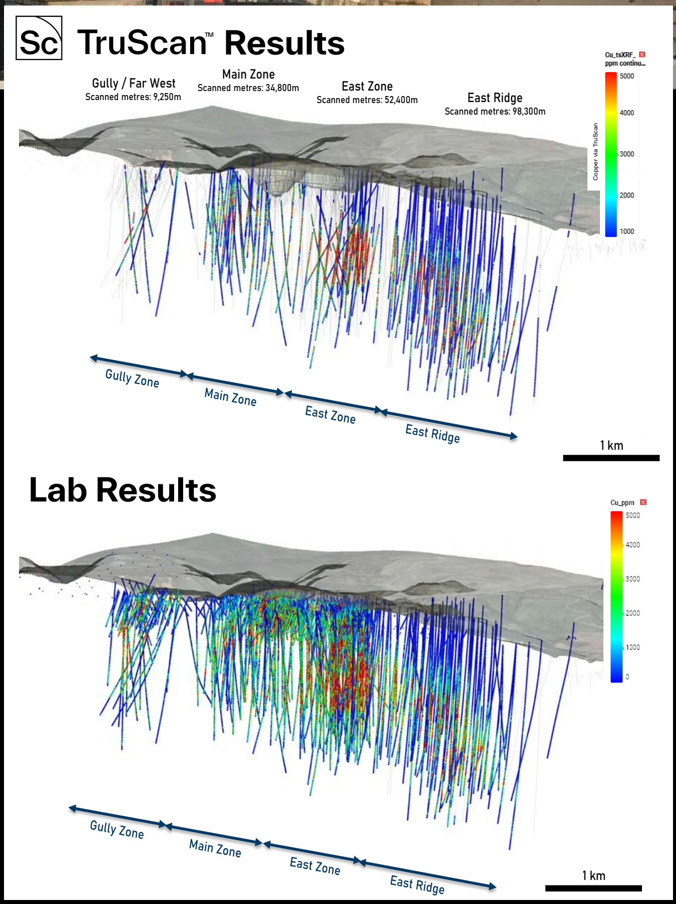
Case Studies

A defined resource ahead of lab results

Newcrest's Red Chris mine in British Columbia required real-time data to guide core-based observations and overcome lab assay delays, especially during the COVID pandemic.

This innovation empowered geologists with timely insights, enabling them to make proactive decisions based on near-real-time Cu values and advanced geological models. TruScan's sensor technology provided real-time insights into spatial modeling of core samples, offering crucial information weeks ahead of final laboratory assays.

TruScan's cutting-edge technology set a precedent for applying similar solutions across the mining site. Demonstrating the ability to provide real-time, accurate data can lead to improved operational efficiency and informed decision-making in the mining industry.



RESOURCE DATA AHEAD OF THE LAB

The data not only aided in prioritizing core intervals for expedited lab processing but also allowed for the creation of geological models that incorporated metal volume information well before assay results were available.

LAB PRIORITISATION

Scanned copper (Cu) values were particularly instrumental in refining core sampling and lab dispatch sequences, focusing on Cu-bearing material while minimizing processing of weakly anomalous wall-rock.

Sampling to public release in 6 weeks

Red Chris Mine, 2019-2023
British Columbia, CA

TruScan capabilities became a critical tool that Newcrest could use to effectively communicate the value and potential of the RedChris Project; enhancing transparency and confidence with investors and stakeholders.

Newcreast wanted to accelerate the public reporting of key grade discoveries. Utilizing TruScan's in-field assays, the Project was able to prioritise assays that would ensure effective communication that maximized investor confidence in the project.

> "
>
> Not only were metal values available for spatial modeling weeks in advance of final laboratory assays, but the data also helped prioritize intervals (in this case from 342 to 1,062 m) to be rushed to the lab.
>
> Excerpt from Case Study 1 - Red Chris, BC Canada.

RAPID ANALYSIS

TruScan's in-field assays provided rapid and accurate analysis of key grade discoveries. This allowed for prioritisation of assay results and the timely release of important information to the market.

ACCELERATED TIMELINE

Using the rapid analysis, the Project achieved a remarkable reduction in taking on-site scanning through to public release in only six weeks. Ensuring that the market received timely updates on key a grade discovery between December 2019 and January 2020.

MAXIMIZING PROJECT SUCCESS

This efficient information dissemination played a crucial role in maximizing the project's success and attracting continued support.

TruScan capabilities became a critical tool that Newcrest could use to effectively communicate the value and potential of the RedChris Project; enhancing transparency and confidence with investors and stakeholders.

//

VERACIO™ | Case Study

Red Chris Mine, 2019-2023
British Columbia, CA

Enhancing Geology Workflows at Red Chris Mine

Newcrest's Red Chris mine is leveraging Strata, Veracio's assistive logging tools to deliver tangible benefits, including rapid data processing, streamlined workflows, and empowered geologists.

Enhancing Geology Workflows at Red Chris Mine

The integration with TruScan's advanced technology showcases innovation in the mining industry, where data-driven insights pave the way for operational excellence.

The Red Chris geology team needed faster data and had identified opportunities to streamline their workflows. By vertically integrating TruScan with Strata's assistive logging software, the mine achieved remarkable efficiency gains.

Anthony Harris,
Newcrest's chief geologist said:

"This environment is contained and seamless with respect to data, with images moving from Scanner to a cloud-based platform capable of detailed image analysis via computer vision algorithms."

RAPID TURNAROUNDS

Substantial reductions in core logging time. One core technician at Red Chris noted that scanner-based photography they already had available would eliminate an entire step of unnecessary work in their logging workflow throughout the day. An improvement that allowed for an additional 8 hours of capacity in a core shed, daily.

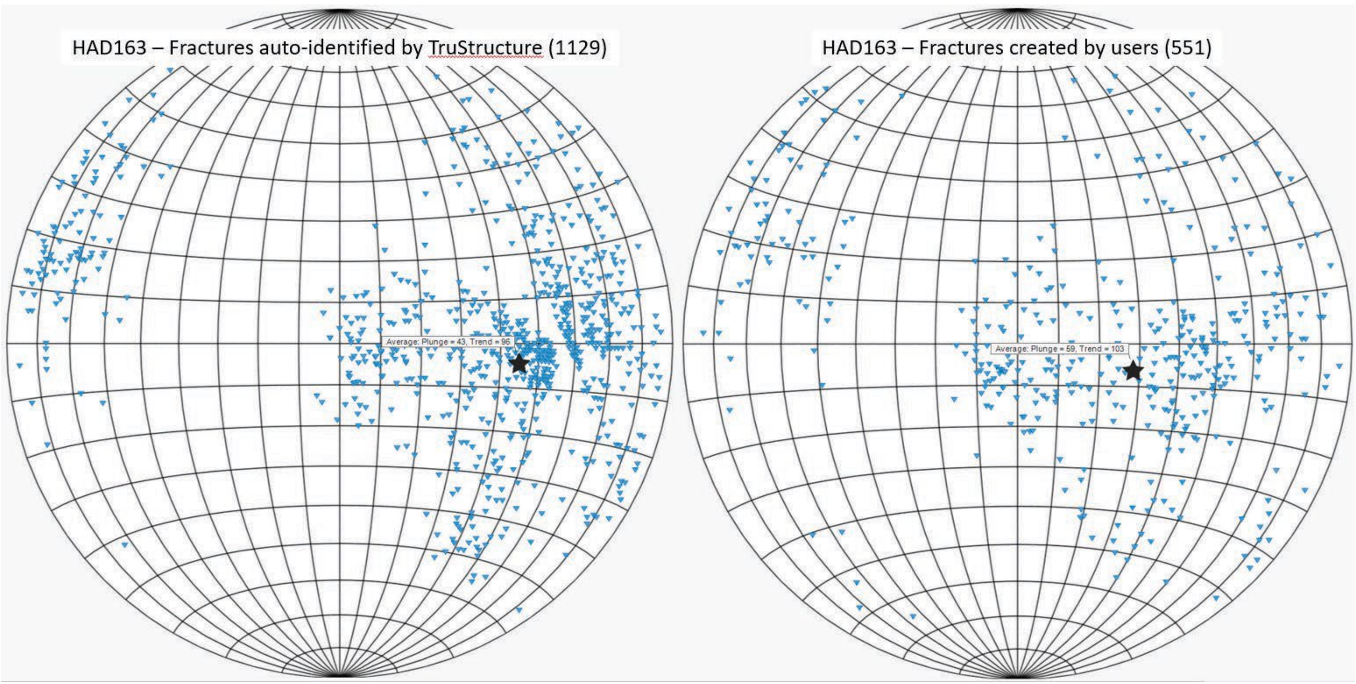
INTEGRATED EFFICIENCY

Strata's suite, comprising TruAccess, TruStructure, and Autologger, seamlessly integrates with TruScan, ensuring enhanced efficiency across the workflow.

RAPID TURNAROUNDS

Strata's tools empowered geologists by providing more time for thoughtful analysis, enabling them to make well-informed decisions.

8 extra hours per day in the core shed



St TruStructure™

Manual Logging

Geotechnical logging of a 1,500 m hole via manual means will commnoly capture +200 features. This is compared to +2000 features via machine-assisted geotechnical logging.

Anthony Harris,
Chief Geoscientist

Images courtesy of:

NEWCREST MINING LIMITED

Empowering Geologists in the Exploration Process – Maximizing Data Use from Enabling Scanning Technologies

TEAM VERACIO

Veracio are privelaged to have co-authored this paper alongside Anthony Harris, David Finn, Fraser MacCorquodale and William Clarke. These individuals are leaders in their own right and work every day to help Veracio drive the next generation of orebody knowledge to mining companies and assets all over the world.

Mike Ravella is both a Geologist and the innovative mind behind Veracio's early genesis (formerly Boart Longyear's Geological Data Services division). Since 2014 Mike has developed award-winning technologies and a global business that is focused on providing geological information through a fusion of science, technology and data. Mike holds a Master of Science in Earth Science from Boston University, Summa Cum Laude and a Bachelor of Science in Geology from Keene State College, Summa Cum Laude.

Sasha Krneta is a Principal Geologist renowned for his leadership in the development of TruScan. His pioneering work in core scanning technologies has yielded solutions that simultaneously optimize economic and environmental outcomes. His academic journey includes a Bachelor of Science in Geology, with Honors, and a research-driven PhD from the University of Adelaide.

Shauna Maguire is a Lead Geoscientist at Veracio. With expertise in the practical application of geology technologies in operating environments; including proof of concepts for short-interval grade control, her skillful delivery of project scope across various sites are exemplified in her work featured in this paper. Shauna's holds an Bachelors Degree (Honours) in Geology/Earth Science from the University of Adelaide.


#30

VERACIO™

The global leader in core scanning

Data + AI

Strata™

AI-assisted structural logging

TruStructure™

AI-assisted lithological logging

AutoLogger™

Secure data access in the cloud

TruAccess™

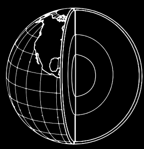
3D Core Analysis

MINALOGGER

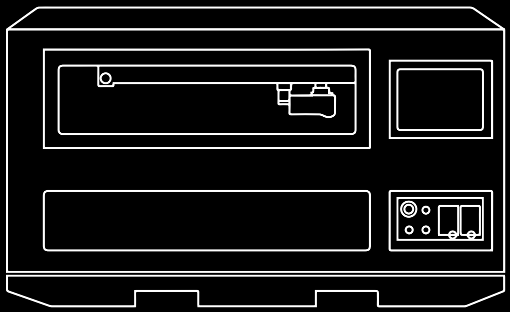
Geotech + Geochem Analytics

TruVision™

Specifications



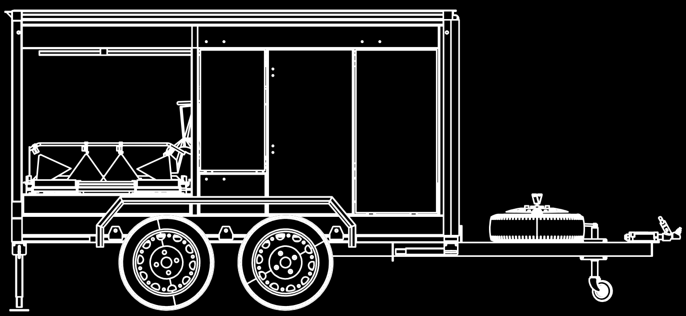
MINALYZER CS



Power	400v
Peak Power	16 amps
Water	N/A
Requirements	Flat, level ground is required for operation

Width	1100mm
Length	1800mm
Height	1200mm
Maximum Tray Dimensions	530W 1100L 100H

TruScan™



Power	110v - 220v
Peak Power	<15 amps
Water	20litres/1000m of core
Requirements	Flat, level ground is required for operation

Length	3,400mm
Length (w/ hitch)	4,980mm
Width	2,310mm
Requirements	1220mm additional width for loading / unloading core boxes