Tharalson, E.R., Monecke, T., Cattalani, S., Nicholls, O., and Skewes, W., 2018, Volcanic facies architecture of the Castle Mountain low-sulfidation epithermal deposit, San Bernardino County, California: Society of Economic Geologists 2018 Conference. Keystone, Colorado (September 22-25, 2018). Electronic Conference Proceedings, P216.

The Castle Mountain (CM) project hosts a 7+ Moz Miocene-aged low sulfidation epithermal gold deposit and is currently being explored by Equinox Gold. The deposit occurs adjacent to the Colorado River Extensional Corridor (CREC) and is largely flat lying in comparison to the rocks of the CREC that can be vertically dipping (e.g., Faulds, 1995). The CM project is an atypical low sulfidation epithermal deposit because the ore is disseminated in nature and the alteration related to the hydrothermal system extends over 4.5 km^2.

The gold is hosted by felsic and intermediate epiclastic, volcaniclastic, and coherent rocks. The intermediate lavas are mildly alkaline and overlain by an immature epiclastic succession composed of clasts of the underlying lavas. Calc-alkaline felsic volcanism resulted in a variety of rhyolite domes/flows, tuffs, and tuff breccias that are cut by vertically continuous diatreme breccia bodies. The majority of the oxidized ore is hosted by the felsic volcanism.

The extreme contrasts associated with different coherent and volcaniclastic rocks appears to have locally influenced the distribution of grade as has been suggested by Rowland and Simmons (2012). Detailed graphical core logging has aided in reconstructing the volcanic environments of the numerous felsic lavas and partially explain the control of Au distribution. Faulting that occurred prior to the emplacement of the calc-alkaline succession is also shown to focus hydrothermal upflow and created extremely high grade (e.g., >30 ppm Au) pods.

Meuzelaar, T., Warren, M., Monecke, T., and Tharalson, E., 2018, Mine life cycle optimization using machine learning: Society of Economic Geologists 2018 Conference. Keystone, Colorado (September 22-25, 2018). Electronic Conference Proceedings, P119.

The digital transformation of the mining industry is expected by many to be driven by disruptive innovation that relies heavily on artificial intelligence. Machine learning is an application of artificial intelligence that involves construction of computer algorithms to facilitate exploration of large, complex datasets and to make predictions and decisions. Machine learning offers considerable potential to enable process optimization and automation throughout the project life cycle by way of rapid and intelligent decision making, in many cases using data that operators are already collecting. In this presentation, we explore several machine learning use cases for life cycle-based mine materials management using both structured (i.e. assay) and unstructured (i.e. hyperspectral imagery) drillhole data from the Castle Mountain low-sulfidation epithermal gold project and the Bear Lodge rare earth element project. A typical machine learning model relies on a set of predictor variables such as bulk assay or hyperspectral mineralogy to estimate one or more target variables. As they relate to mine materials management, target variables are those that are difficult to quantify in the field or core shack due to high uncertainty, operator subjectivity or the need for expensive and time-consuming laboratory testing. Examples exist across the project life cycle and include alteration, oxidation, lithology (exploration), material type, refractory properties, leachable content (beneficiation) and ARD potential, metals leaching properties and waste type (environmental). A typical machine learning process is highly iterative, requiring close collaboration between site geoscientists and data scientists, with long-term aim of optimizing predictive accuracy. Machine learning models presented herein were constructed using R Studio and the Microsoft Azure platform using a variety of algorithms for both structured data (e.g. ensemble decision trees and random forest) and unstructured data (artificial neural networks).

Tharalson, E.R., Kelly, N.M., Monecke, T., Pfaff, K., Reynolds, T.J., and Zeeck, L., 2020 Distribution of ore minerals in banded epithermal veins: Results of micro-X-ray fluorescence mapping. Goldschmidt Virtual 2020 (June 21- 26, 2020), Goldschmidt Abstracts, 2020, 2585.

Low-sulfidation epithermal deposits are significant sources of Au and Ag. The deposits are formed in the shallow subsurface by near-neutral chloride waters that are of low salinity (<3-4 wt.% NaCl). However, the distribution of precious metals is not uniform, with only discrete quartz bands containing ore minerals. Understanding the distribution of ore minerals and their associations with quartz textures is key to understanding the processes associated with precious metal formation in low-sulfidation epithermal deposits.

Micro–X-ray fluorescence (μXRF) mapping was conducted on a number of representative ore samples from deposits worldwide to characterize the distribution of ore minerals and to study metal associations within the bands. The μXRF maps (e.g., Fig 1) show that Au and Ag commonly occur together in light grey quartz bands, which are widely referred to as ginguro bands. However, Au also occurs in separate discrete white quartz bands (referred to as gankin bands) that lack Ag-rich phases. Focused investigation of the ore-bearing ginguro and gankin bands show they are characterized by the presence of fine-grained mosaic quartz with subtle textures of preexisting microspheres, which is interpreted to have formed as a result of flashing of the ore-forming fluids.

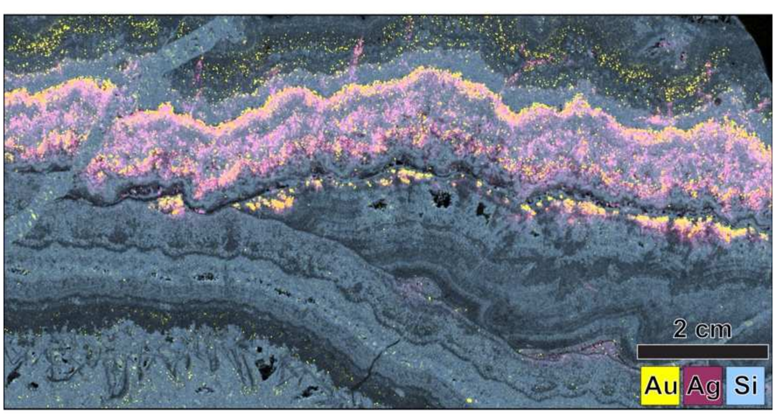

Figure 1: Composite Au-Ag-Si element map of a banded vein sample from the Sado deposit, Japan.

Taksavasu, T., Monecke, T., Tharalson, E.R., 2020, Distribution and textural characteristics of ore minerals in bonanza-type quartz veins at the Buckskin National and Fire Creek deposits, Humboldt and Lander Counties, northern Nevada: Geological Society of Nevada 2020 Symposium: Vision for Discovery. Sparks, Nevada (May 17-20, 2020), Technical Proceedings Volume, A101.

Bonanza-type quartz veins in low-sulfidation epithermal deposits such as the Buckskin National and Fire Creek deposits, which are located along the Northern Nevada Rift, are typically crustiform and consist of quartz bands that have distinct quartz textures in thin section. Studying on textural characteristics of ore and gangue minerals in these deposits may provoke us to better understand the ore-forming process, which led to the formation of high-grade bonanza-type ore minerals. At the Buckskin National deposit, quartz showing mosaic, comb, plumose, and pseudobladed textures is the most common. Adularia is rare and calcite has not been observed. At the Fire Creek deposit, bonanza-type quartz veins include mosaic and comb quartz. Rhombic adularia and late stage calcite are present. Careful microscopic investigations show that ore minerals in both deposits occur primarily in colloform quartz bands that consists of mosaic quartz or small interlocking euhedral quartz grains. Relict silica microspheres (2-5 µm) were recognized in some of the ore-bearing colloform bands. Ore minerals were never observed in colloform bands consisting of chalcedonic quartz or bands characterized by the presence of large euhedral comb quartz.

To study the shape of the ore minerals in three dimensions, several vein samples from both deposits were treated in concentrated hydrofluoric acid. After several days, all quartz was dissolved and the fragile grayish brown to dark gray dendritic ore minerals could be recovered. Scanning electron microscopy showed that naumannite and sulfur-rich naumannite are the most common ore minerals in the obtained concentrates. The dendritic grains range from 0.5 to 1 mm by 1 to 5 mm in size. They show multi-branching tree-like forms that have a fractal pattern. The surfaces of the dendrites are characterized by the presence of small pits that have negative crystal shapes that are up to 10 µm in size, resembling the small quartz crystals identified in thin section.

The dendritic ore minerals with colloform banding in the bonanza-style veins from the Buckskin National and Fire Creek deposits are interpreted to have formed during short periods of intense boiling or flashing of the hydrothermal fluids. Violent vaporization of the liquid may have resulted in the formation of colloidal particles of precious metals and silica allowing the growth of the ore dendrites. The occurrence of silica microspheres, which originally may have been composed of opal-A, is consistent with rapid deposition of silica during phase separation that were probably recrystallized to quartz and microspherical shapes are still preserved. Thus, the textural observations of this study may possibly be focused as exploration strategy for other epithermal mineral deposits elsewhere.

Tharalson, E.R., Monecke, T., Nicholls, O., and Skewes, W., 2020, The geology of the Castle Mountain low-sulfidation epithermal gold deposit, San Bernardino County, California: Geological Society of Nevada 2020 Symposium: Vision for Discovery. Sparks, Nevada (May 17-20), Technical Proceedings Volume, A123.

The Castle Mountain gold deposit is a Miocene low-sulfidation epithermal deposit in southern California. Currently, the deposit contains a resource of ~6.5 Moz gold. Past production at Castle Mountain between 1991 and 2004 mined ~1.5 Moz gold. The volcanic host-rock succession of the Castle Mountain deposit consists of three distinct formations. The Jacks Well formation comprises trachyandesite lava flows and associated autoclastic deposits. Volcanism resulting in the deposition of the trachyandesite lavas was followed by a period of relative volcanic quiescence. During this period, the trachyandesite was reworked in a fluvial-lacustrine environment resulting in the deposition of a laterally discontinuous succession of epiclastic conglomerates, sandstones, and mudstones. The conformably overlying Linder Peak formation is dominated by felsic volcanic rocks including rhyolite flows and domes as well as primary pyroclastic rocks. The highly permeable pyroclastic rocks represent the main host to gold mineralization. A second phase of felsic volcanism emplaced the Hart Peak formation. Rhyolite plugs and dacite dikes assigned to this formation occur throughout the Castle Mountain range but are unaltered and postdate the gold mineralization.

The volcanic host rock succession of the Castle Mountain deposit was formed contemporaneously with the Colorado River Extensional Corridor. Map and drill- based three-dimensional modeling of the volcanic host rocks and the zones of mineralization show that two dominant styles of faulting occur at Castle Mountain, an early set of dominantly northeast-striking conjugate faults and a more diffuse set of broadly east-striking faults. Lava domes and plugs of the Linder Peak and Hart Peak formations occur along synvolcanic northeast-striking faults while intersections of the two fault sets appear to have controlled the location of ore chutes. Ore chutes at Castle Mountain have variable orientations with an average trend of 043° and plunge of 63°. Despite the average grade of reserves and resources being <0.6

ppm Au, some of these ore chutes have bonanza-type gold grades exceeding 30 ppm Au.

Gold dominantly occurs as free grains disseminated through the silicified volcanic rocks. Fluid inclusions hosted in quartz indicate that the fluids responsible for the low-grade mineralization at Castle Mountain were highly dilute and largely of low temperature (i.e., < 250°C). Boiling fluid inclusion assemblages were not observed. This suggests that the pervasive silicification at Castle Mountain was solely related to cooling of the upwelling hydrothermal fluids. At higher temperatures, silicification occurred through quartz precipitation. At cooler temperatures, likely below ~180oC, silicification occurred through chalcedony precipitation and is recognized in thin section in many of the silicified volcanic rocks. High-grade silica veins are rare in the deposit area but were exploited and largely exhausted by miners at the beginning of the 20th century. The silica veins contain colloform quartz bands and bands with abundant adularia. Textural evidence suggests that the silica veins formed as a result of fluid boiling or flashing. This suggests that different processes of gold precipitation are responsible for the different grades encountered at Castle Mountain.

Pfaff, K., Rotem, A., Vidal, A., Tharalson, E.R., Monecke, T., Tenorio, L., 2020 Increasing the value of hyperspectral data using advanced machine learning techniques. Geological Society of America Annual Meeting. Online (October 26–30, 2020), Electronic Abstracts, paper 164-8. doi: 10.1130/abs/2020AM-357749

Knowledge of the deposit mineralogy and physical and mechanical properties of rock units is critical at many stages of project development from early exploration to mining and remediation. Hyperspectral core scanning is currently the method of choice to determine the mineralogy of ore deposits and their host rocks. Common hyperspectral sensors cover the visible to near-infrared (VNIR) and short-wave infrared (SWIR) regions of the electromagnetic spectrum. However, within the SWIR wavelength range, traditional methods of spectrum matching are inefficient to correctly identify and quantify common minerals such as feldspar, quartz, oxides, and sulfides. The aim of this project is to automate mineral identification in a fast, accurate, and efficient way by finding functional relations between hyperspectral and quantitative automated mineralogy data using advanced machine learning techniques.

We have successfully applied deep learning (CNN), support vector machines and lasso/total variation methods to predict the most abundant mineral and individual proportions of each mineral. The obtained accuracies were found to be between 70% and 90%. The confusion matrix, which compares the true mineral assignment to the predicted mineral assignment, was predominantly diagonal, indicating correct predictions of individual mineral assignments. Predictions of the modal abundances of minerals were around 95% and their spatial distribution was close to the original.

Initial upscaling tests and masking applied to drill core have shown very promising results. Thus, supervised machine learning seems to be an efficient and accurate tool in mineral identification and classification.

Taksavasu, T., Monecke, T., and Tharalson, E.R., 2019, Dendritic ore minerals in the Buckskin National and Fire Creek bonanza-style low-sulfidation epithermal deposits, Nevada: Geological Society of America Annual Meeting. Phoenix, Arizona (September 22-25, 2019), Electronic Abstracts, paper 242-5. doi: 10.1130/abs/2019AM-333673

Bonanza-style vein ores from low-sulfidation epithermal deposits such as the Buckskin National and Fire Creek deposits in northern Nevada contain ore minerals that show dendritic habits. Thin section inspection revealed that the dendritic ore minerals only occur in specific colloform bands within the veins. Most commonly, the ore minerals are intergrown with mosaic quartz or quartz forming small euhedral grains. Relict 2-5 µm large silica microspheres can be recognized in some of the ore-bearing colloform bands. The ore minerals were never observed to occur in colloform bands comprised of chalcedonic quartz.

To study the shape of the ore minerals in three dimensions, several vein samples from both deposits were treated in concentrated hydrofluoric acid. After several days, all quartz was dissolved and the fragile grayish brown to dark gray dendritic ore minerals could be recovered. Scanning electron microscopy showed that naumannite and sulfur-rich naumannite are the most common ore minerals in the obtained concentrates. The dendritic grains range from 0.5 to 1 mm by 1 to 5 mm in size. They show multi-branching tree-like forms that have a fractal pattern. The surfaces of the dendrites are characterized by the presence of small pits that have negative crystal shapes that are up to 10 µm in size, resembling the small quartz crystals identified in thin section.

The dendritic ore minerals in the bonanza-style veins from the Buckskin National and Fire Creek deposits are interpreted to have formed during brief periods of intense boiling or flashing of the hydrothermal fluids. Violent vaporization of the liquid may have resulted in the formation of colloidal particles allowing the growth of the dendrites. The occurrence of silica microspheres, which originally may have been composed of opal-A, is consistent with rapid deposition of silica during phase separation.