The coal mine roof rating (CMRR) was developed by NIOSH to bridge the gap between geological variation in underground coal mines and engineering design. The CMRR has been widely used and validated in Eastern US coal mines, but has seen limited application in the Western US. This study focuses on roof behavior at two Western coal mines. The first mine presents laterally continuous roof stratigraphy, yet the roof stability is not uniform even though the geology is. The second mine shows significant lateral geological variation, along with localized faulting and a laterally extensive sandstone channel network. It is hypothesized that there are other factors that are correlated with roof instability in underground coal mines that could also be included in the CMRR. This hypothesis was tested by collecting 30-50 CMRR measurements at the aforementioned mines. At each measurement location, a binary record of the roof condition (stable or unstable) was made along with parameters such as depth of cover thought to also correlate with roof stability. A statistical analysis of the data was performed to determine the parameters above and beyond the CMRR which can be correlated to roof stability.

2:45 PM | 711
What Factors Over and Above Those Included in the Existing Coal Mine Roof Rating (CMRR) Could Also Be Predictive of Roof Instability in Underground Coal Mines?
M. Young, E. Holley and G. Walter; Colorado School of Mines, Golden, CO
The entire grade control process is of utmost importance at operating open pit mines. Misclassifying ore as waste, or waste as ore, due to suboptimal polygon design can have a drastic affect and can lead to leaving revenue on the table. Recent innovations in optimized polygon design have created opportunities for increasing profits, improving reconciliation, reducing mistakes, and facilitating sensitivity studies in open pit grade control. In this talk we will share the challenges and benefits of implementing this technology across some of Newmont's operating mines.

3:05 PM | 504
Implementing Optimal Grade Control Polygons at Newmont’s Mines
M. Deutsch1, N. Kusuma2, L. Allen2 and M. Godoy2; 1Maptek, Lakewood, CO and 2Newmont, Greenwood Village, CO

DENVER, COLORADO, FEBRUARY, 2018
is vital for formulating mineral separation schemes to concentrate REE and P-containing materials for downstream extraction of these critical elements.

9:25 AM | 506
Comparative Analysis of Open Pit Gold Mine Project NPV’s Under Price Uncertainty Using Real Options and Dynamic Mine Plans
M. Visnjic and K. Dagdelen; Mining Engineering, Colorado School of Mines, Golden, CO
Open Pit Mine Production scheduling under commodity price uncertainty suffers from an exponentially increasing problem size as simulations and real options flexibility are used to generate and evaluate production schedules. Robustness evaluation techniques attempt to evaluate a production schedule that is generated on a single set of economic parameters against several varying prices and sources of uncertainty. This approach is invalid as the corresponding optimum price is different for each set of economic parameters. Using commodity market futures and treasury bonds as production schedule economic input parameters provides fully price and time-value-of-money risked scheduling parameters that maintain a deterministic problem size. This paper will provide a comparative analysis of project NPV’s coming from traditional price uncertainty evaluation based on a single fixed LOM mine plan using varying prices versus evaluation based on varying LOM plans that are both generated and evaluated using varying prices.

9:25 AM | 703
Sodium Stannate Preparation from Cassiterite Concentrates and Na₂CO₃ Roasted in CO-CO₂ Atmosphere: Effect of SiO₂
C. Anderson; Colorado School of Mines, Golden, CO
Sodium stannate (Na₂SnO₃) has been successfully prepared by a novel process of roasting cassiterite concentrates and sodium carbonate under CO-CO₂ atmosphere, namely soda roasting-leaching process. However, more than 22 wt% tin of the cassiterite was not converted into Na₂SnO₃ and the leaching residues. Quartz (SiO₂) is the predominant gangue in the cassiterite, and phase transformation of SnO₂–SiO₂-Na₂CO₃ system roasted under CO-CO₂ atmosphere was still uncertain. In this study, the effect of SiO₂ in cassiterite concentrates on preparation of Na₂SnO₃ was clarified. The results indicated that Na₂SnSi₁₈O₃₃ was inevitably formed when cassiterite and Na₂CO₃ were roasted above 775°C under CO-CO₂ atmosphere via the reaction of SnO₂ + 3SiO₂ + 4Na₂CO₃ = Na₂SnSi₁₈O₃₃ + 4CO₂, and formation of Na₂SnSi₁₈O₃₃ would be accelerated with increasing roasting temperature and Si/ Sn mole fraction. In addition, it was found that Na₂SnSi₁₈O₃₃ was insoluble in the leachate at pH value range of 1-14, which, therefore, was enriched in the leaching residues. The silicon content of the cassiterite concentrates should be controlled as lower as possible to obtain a higher conversion ratio of Na₂SnO₃.

9:45 AM | 504
Evaluating the Feasibility of Using New Epiroc Vein Miner At Hecla Lucky Friday Mine, Through Full Scale Rock Cutting Tests on Ore Samples
M. Thayagarajan1, M. Board2 and J. Rostami3; 1PhD Student in Mining Engineering, 2Earth Mechanics Institute, Colorado School of Mines, Golden, CO; 3President – Technical Services, Hecla Mining Company, Coeur d’Alene, ID and 3Associate Professor in Mining Engineering; 1Director of Earth Mechanics Institute, Colorado School of Mines, Golden, CO
To study the feasibility of rock cutting, using the new Epiroc vein miner, at the Hecla Lucky Friday mine, full scale linear cutting tests were performed at the Earth Mechanics Institute (EMI) of Colorado School of Mines (CSM). This was a part of the implementation of new vein mining design concept for fully automated underground cut and fill operation at the site. These tests were performed on a Linear Cutting Machine (LCM), using similar disc cutters employed on the mobile miner, on rock samples obtained from the vein, namely the ore. LCM measure the cutting forces on a cutter, to develop the trend of force penetration curve. This information can be used in simulation models to estimate production rate of the various rock excavation units. This paper will explain the project and its objectives, as well as, the result of full scale cutting tests and related analysis for estimation of production rate of the new vein mining machine under development by Epiroc.

9:45 AM | 703
On the Fundamentals of Arsenic Removal from Lead Bullion via Vacuum Distillation
E. Tshijk Karumb; Metallurgical and Materials Engineering, Colorado School of Mines, Lakewood, CO
Impurities present in lead bullion are commonly removed using a lengthy, energy consuming, and complex oxidation process. Consequently, great effort has been invested in the investigation of impurities removal using vacuum distillation; in this case, the focus is given to the removal of arsenic. Arsenic metal sublimes at atmospheric pressure; consequently, data on liquid arsenic has been available only recently; as such, a thorough survey has been conducted to harvest physical properties of arsenic solid and liquid. In order to predict the equilibrium partial pressure above the melt, the activity coefficient (T, P) is needed. Three different thermodynamic models which are the Molecular Interaction volume Model (MIVM), the Wilson equation model, and the Non-Random Two Liquid (NRTL) model have been to that purpose. Using these data, vapor liquid equilibrium (VLE) for the binary Pb-Ag system has been derived. The equilibrium distribution to distillate and remaining alloy has been calculated for arsenic and lead. These predictions have shown that there exists a considerable thermodynamic driving force for the separation of arsenic from lead bullion.

10:05 AM | 711
The Impact of Rock Pike Location, Length and Depth on the Propagation of Methane Flashes in Simulated and Experimental Flame Reactors
M. Fig1, C. Strebinger1, G. Bogn1 and J. Brun2; Mechanical Engineering, Colorado School Of Mines, Littleton, CO and 2Mining, Colorado School of Mines, Golden, CO
A knowledge of flame propagation characteristics through and around obstacles is needed to accurately model methane-air longwall coal mine explosive originating or propagating in the gob. Experimental investigations of methane flames in horizontal reactors with simulated gob (rock piles) were carried out alongside coupled CFD and combustion simulations. Stoichiometric methane-air mixtures were ignited in semi-open reactor vessels of 5cm, 9.5cm and 71cm diameter, all with a fixed length to diameter ratio of 8.8. Experimental results indicate that the magnitude of flame acceleration depends on pile location and geometry, and scaling trends are presented. The model captures several of these features.

10:25 AM | 110
Star Regulus and the Triumphal Chariot of Antimony
C. Anderson; Colorado School of Mines, Golden, CO
Antimony is a silvery, white, brittle, crystalline solid classified as a metalloid that exhibits poor conductivity of electricity and heat. Alchemists were fascinated by a property of antimony to form a crystalline star (i.e. the Star Regulus) under certain conditions. For alchemists, of course, that symbolized the quintessence of matter. In the Western world, it was first isolated by Yannoccio Birunguccio and he first described this in 1540. In 1604 Basillus Valenti (1605-1624) wrote a monograph on Antimony entitled Triumph-Wagen des Antimonis (Triumph Chariot of Antimony). This is regarded as the first monograph devoted to the chemistry of a single metal. Currently, the primary production of antimony is now isolated to a few countries and continues to be dominated by China. As such, a factory is currently under construction as a critical and strategic material for modern society. This presentation will outline the occurrence, production and critical aspects of this fascinating element.

10:25 AM | 504
The Characterization of Waterjet Shotcrete Removal during LINER REPAIR AND MAINTENANCE
E. Charrier, H. Miller, J. Steele, B. Asbury and J. Bourgeois; Colorado School of Mines, Golden, CO
The repair of shotcrete liners that have been structurally compromised or damaged is a common activity associated with the maintenance and rehabilitation of underground workings. Age, in-situ stresses, geology, chemical/physical decomposition, accidental impacts, and water are but a few of the many factors that necessitate the repair of these structural systems. In many cases, repair activities utilizing conventional tools inflict unintended damage to the underlying rock substrate and surrounding liner. The primary objective of this research is to compare and analyze the structural damage caused by conventional impact hammers versus a novel waterjet excavation system relative to instrumented concrete panels.

10:45 AM | 610
Visualization of AI Results for Big Data of Underground Mines in Virtual Reality
E. Ileyen and S. Duzgun; Mining Engineering, Colorado School of Mines, Golden, CO
Underground mines are complex environments in terms of data collection, analysis and visualization of analytics results for making decisions. Artificial intelligence (AI) methods used for big data from a large number of different sensors provide opportunities of understanding hidden patterns. Three-dimensional self-organizing maps (3-D SOM) are one of the effective AI methods for revealing patterns in the data sets. This study presents a framework to visualize 3-D SOM results in virtual reality (VR) for underground mines. A set of sensor data from an underground mine, is analyzed using SOM and the resultant topological map for data points is visualized in the virtual underground mine. The results indicate that visualization of AI outputs in virtual reality serves as effective tool for building situational awareness.
Pit Mines Using Direct Block Mine Production Scheduling Algorithm
C. Aras, K. Dagdelen and T. Johnson, Mining Engineering, Colorado School of Mines, Golden, CO

Traditional mine production scheduling relies on generating pushbacks with price parametrization and aggregating the blocks inside these pushbacks into benches to generate long term annual production schedules. However, the incremental fashion of obtaining pushbacks fails to incorporate the operational requirements such as multi capacity, multi destinations, blending requirements, truck hours and stockpiles. Since many production schedule outcomes depend highly on the design of pushbacks, poor designs will prevent the schedules from achieving a maximum NPV or even obtaining a feasible solution. In this paper, block by block yearly schedules will be generated by solving the mine production scheduling problem under the operational requirements and the resulting yearly schedules will be grouped into phases for the pit design with haul roads. This approach will guarantee that the phases used to take into account operating requirements will honor the production and blending requirements. Then, comparison will be made between the traditionally generated phases versus the phases obtained by using the block by block mine production scheduling algorithm.

11:05 AM | 506
A New Cone Generation Technique to Honor Complex Pit Slope Angles in Production Scheduling of Open Pit Mines
C. Aras, K. Dagdelen and T. Johnson, Mining Engineering, Colorado School of Mines, Golden, CO

Block by block open pit mine production scheduling solution algorithms require the dependencies between the blocks based on the required pit slope angles to be preprocessed. This is accomplished by generating arcs between the blocks and storing them in map containers when programmed with a C++ coding language. Then the arcs between the blocks are transformed to sequencing constraints. Hence, there is a strong-correlation between the number of arcs generated versus the processing time of the sequencing constraints and the memory allocated to store these arcs. In order to achieve fast computing times, the number of arcs generated per block should be optimized. Therefore, a new cone pattern generation scheme is developed with the aim of reducing the number of arcs generated for sequencing of the blocks in the production scheduling algorithm. This paper will discuss how this new technique represents the required pit slopes with the minimum number of arcs. This is accomplished while also minimizing the deviation from the required pit slope angles for block models with any size block dimensions.

2:00 PM-5:00 PM | 615
My First Five Years of Experience in Industry/Academia
Heather Lammons, PhD Student, Colorado School of Mines
Ali Naeimipoor, Sr. Staff Engineer, McMillen Jacobs Associates
Benjamin Teschner, PhD Student, Colorado School of Mines
Vasu Gangrade, Research Fellow, NIOSH

This session will feature presentations from junior and mid-level industry professionals about their first five years of work experience. Young professionals always face various challenges when they first join the industry. Different perspectives will be shared by young professionals with the early stages of their careers. This technical session will cover a broad range of topics concerning how to better prepare young professionals to meet the various challenges of the mining industry.

2:05 PM | 501
Identifying Key Processes on Mineralization at Khoemacau’s Cu-Ag Deposit, Kalahari Copper Belt, North West District, Botswana
C. Knight1, O. Disang1, B. Muyoba1 and M. Enders2; 1Ex. Khoemacau Copper Mining, Gaborone, Botswana and 2Mining, Colorado School of Mines, Golden, CO

The Khoemacau and Boseto Copper Projects are sedimentary rock-hosted stratiform copper-silver deposits located in North West Botswana, within the Kalahari Copper Belt (KCB). The KCB is host to a number of copper-silver deposits and mining operations in Southern Africa. The lower D’Kar Formation is host to the majority of the high-grade copper showings (>1% Cu). Exploration and targeting efforts have led to the discovery of additional, under cover high-grade copper-silver deposits in the belt including Khoemacau’s Zone 5 deposit. Recent geochemical analyses, structural modeling and stratigraphic reconstruction have highlighted how understanding the depositional environment and architectural basin evolution provide important insights on the location and distribution of economic mineralization including the following major ore controls: 1) present day starved, organic rich, shallow water environments; 2) underlying oxidized and altered sandstones, bimodal volcanic and paleo-basement; 3) magnetic and gravity highs indicative of basement faulting, major structures and metal enrichment; and 4) regional litho-stratigraphic lineaments as copper-bearing fluid traps.

2:05 PM | 210
The Role of Commodity Futures Markets in Mine Planning and Valuation
G. Davis1 and F. Dorobantu2; 1Economics and Business, Colorado School of Mines, Golden, CO and 2The Brattle Group, New York, NY

Mine planning and valuation often require the projection of metal prices decades into the future while no projection will be accurate, it should at least be unbiased, meaning that on average it is correct. In some cases the projected price is taken to be the same as the current price. This is called naïve forecasting. A similar approach is to use the average price over some prior period. Such approaches suggest that analyst forecasts are the best predictor of metal prices. The firm Consensus Economics surveys these analysts and sells their forecasts to subscribers. Economists tend to prefer the use of futures prices, which are the result of current trades on regulated exchanges for the purchase and sale of metal at some future date. In this presentation we review the theoretical and empirical support for these types of forecasts. We suggest that practitioners consider the use of futures prices in mine planning and valuation exercises since these may be the least biased measure of prices over the short term. We show how projections based on futures prices can be extended beyond the relatively short horizon for which futures trade by using empirically calibrated price models.

2:25 PM | 107
Beyond Philanthropy: Key Areas of Social Responsibility Practice for Engineers
J. Smith; Colorado School of Mines, Golden, CO

Based on interviews with over 70 industry professionals, this chapter identifies four key ways in which engineers can use their everyday work to support social responsibility, beyond philanthropy and volunteering. Engineers can use their knowledge and skills to encompass the professional practice of engineering itself. First is design for community acceptance, in which community concerns and desires are integrated into the design of mines infrastructure and processes. This area of practice is predicated on a second: listening-centered community engagement. This approach should also underly the third key area of education and outreach, which is often grounded in a deficit model of the public and one-way information flow. Finally, engineers working in the Global South, with support from organizations such as Engineers Without Borders – Canada, engage in local procurement to foster sustainable economic development in the communities closest to them.

2:45 PM | 107
Incorporating Social Conflict Risk into Project Valuation: A Stochastic Modeling Approach
B. Teschner2 and E. Holley1; 1Mining Engineering, Colorado School of Mines, Golden, CO and 2Mining Engineering, Colorado School of Mines, Golden, CO

Company-community conflict at mining properties negatively affects stakeholders and companies. Stakeholders risk fractionalization of their communities, loss of cultural identity, and physical harm when they resist mining activities. Companies risk physical harm to employees and equipment, reputational costs, delays, or complete suspension of their projects. Yet, the lead times that contribute to conflicts can be difficult to anticipate and even more difficult to quantify. This presentation will showcase a stochastic modeling method which incorporates the risk of project suspension from company-community conflict into project valuation. Our approach combines qualitative risk indicators from the project with the project’s cash flow model to determine a social-risk-adjusted NPV. Using this method, an investor can determine a project-specific ‘risk cost’ and how the risk is distributed over the life of the project. This approach can enable companies, investors, communities, and host governments to better assess social conflict risks, how and if a site should be developed, and how the project might be managed to reduce the chances of company-community conflict.

2:45 PM | 507
Predicting TBM Utilization Factor Using Simulation Approach
A. Khetwal, O. Frough and J. Rostami; Mining Engineering, Colorado School of Mines, Golden, CO

Estimation of TBM performance in terms of rate of penetration (ROP) and utilization factor (U) is one of the challenges in mechanized tunneling. Utilization factor is determined by combined effect of tunnel geology, unexpected breakdown, maintenance, utility extension, transportation. set up work, equipment breakdowns, among others, and other unforeseen downtimes. In this study, several tunneling activities and downtimes are modelled using Arena, a discrete event simulation software, to predict the TBM utilization factor. The model was developed using data from selected recent tunnelling projects that represented the range of tunnelling projects currently undertaken by tunneling contractors. The model was validated and used to predict TBM performance, which was then compared to the actual TBM performance. The comparison allowed to evaluate the model’s accuracy and reliability. The model predictions showed good correlation among themselves. This paper will discuss the background of challenges in estimation of utilization factor rate for TBM and explains the advantages of the proposed approach, along with the development of the model by the authors.
Uncertainty in rock mass quality exists due to the inherently heterogeneous nature of rock mass itself. Traditional deterministic assessment lacks a complete understanding of significant uncertainty involved and may have an adverse impact on the overall design performance. To address this problem, a probability-based uncertainty analysis approach was proposed to quantify the uncertainty in the rock mass quality Q-system. The proposed probabilistic approach can be useful in characterizing the uncertainty in rock mass quality before construction and providing insightful information for assessment of ground response and support performance of underground structures.

Diesel equipment and auto compression are two leading factors that result in the high cost to break up and move large volumes of rock during blasting, therefore, understanding mechanical behaviors of lunar soil, comprising grains characterized by highly irregular shapes. This paper uses a Particle Flow Code and describes a procedure for simulating lunar soil grains with specific size distributions and shapes. We adopt data from soil 64501 retrieved in Apollo 16 and simulate lunar soil samples as assemblies of different shapes of grains consisting of elastic spheres connected through bonds. We classify grains into four categories based on their shape: agglutinate, breccia type A, breccia type B, and plagioclase. We perform angle of repose and triaxial compression tests to investigate behaviors of samples, respectively. The largest angle of repose and the highest strength values are found to correspond to the sample with 100% agglutinate content. Results show the significance of simulating irregularly shaped grains for understanding mechanical behaviors of lunar soil. The modeling procedure demonstrates a robust means of approximating soil mechanics across a range of potential lunar soil mixtures and particle sizes.
Underground coal mines apply finely powdered limestone rock dust to inhibit explosive coal dust deposits created during the mining process. Rock dusting creates a cloud of nuisance dust downwind, preventing other work in the area. Applying a wet or foam mix of rock dust eliminates the nuisance dust, but may impact the dispersion and explosion prevention capability and thus not confer the rock dust ineffective. Dispensibility tests were conducted in a full-size mine explosion test drift at the Colorado School of Mines. Tests include dry, wet, dry-misted, and foam applications using three types of rock dust: conventional, hydrophobic, and rock dust meeting stricter German specifications. Results show that dry dust yields large, agglomerated particles that may not be effective in suppressing coal dust explosions. Hydrophobic rock dust maintains better dispersibility even when applied wet or applied dry then misted. German specification dust disperses better than U.S. conventional rock dust.

**10:45 AM | 603**

**Artisanal and Small-Scale Gold Mining in the Puno Region of Peru: A Comparison of Formalized ASGM Operations**

G. Martinez, M. Schwartz2 and N. Smith; 1Colorado School of Mines, Golden, CO and 2University of Texas at Arlington, Arlington, TX

Formalizing artisanal and small-scale gold miners to become formalized, such as complicated procedures and fluctuating policies. Peru has made considerable efforts to formalize the sector, and in the Puno Region of southeastern Peru, there are several companies that have undergone the formalization process. Although, this study examines two ASGM companies and demonstrates that even though both of these companies are working within a legal framework, there are significant differences in the mining operations, the mineral processing methods, and the organization of labor. We argue that there can be significant variation among ASGM companies that operate formally, and we highlight the need for further investigations that explore the nuances in formal ASGM operations.

**10:45 AM | 501**

**Characterization of Rock Microcracks Using Thin Section Petrography, SEM Automated Mineralogy, and MicroCT**


Understanding how rocks fracture is important for numerous fields, including structural geology to civil and mining engineering. This study describes a novel approach for examining how rock microfractures form and propagate, using a combination of destructive (optical and Scanning Electron Microscopy) and non-destructive (Micro Computed Tomography) microanalytical techniques. The results from each technique are incorporated in a global method resulting in the statistical characterization of the mineralogy of the hosting minerals and the location (intra or inter-grain). The method is presented using data from a case study on the generation of micro-fractures in granite rocks from the Pike’s Peak complex in Colorado. The micro-fractures were generated using microwave heating (3kW for 60 to 300 seconds), which is a potential method of pre-treatment in mineral processing of ores. A similar microanalytical approach could be applied to studies on the micromechanics of fractures in civil engineering (foundation, building failures etc.) and investigations of geological processes such as fluid migration during mineralizing events.

**11:05 AM | 104**

**Best Practices in Acid Rock Drainage (ARD) Characterization and Management for Reduction of Long-term Environmental Risks and Liabilities**

M. Raghav1 and S. Doyle2; 1Environmental Technology - Oro Valley, Freepoint-McMoRan, Tucson, AZ and 2Department of Civil & Environmental Engineering, Colorado School of Mines, Golden, CO

Acid rock drainage (ARD) is estimated to contribute over $100 billion in total worldwide liability associated with current and future remediation. A robust ARD characterization program can provide benefits far beyond regulatory compliance. It can provide an early understanding of potential environmental risks and guide the planning and implementation of effective ARD control/management strategies for long-term liability reduction. Best practices for ARD characterization and management include: early and ongoing ARD characterization and revision of ARD block models to match changing mine plans; refinement of scaling-level water quality using field analog data; scale-up of lab elemental release rates using field-scale testing (barrels or test ponds); and establishment and use of site-specific ARD models that evalu-ate operational materials management. This paper presents recommended best practices for ARD characterization and management through examples from the authors’ experiences in the mining industry, as well as from case studies available in literature.
11:05 AM | 605

**Nanometer-Sized Particles Generated from Drilling Activity**

C. Tsart, D. Theisen1, J. Brune2 and M. Schreiner2; 1Colorado State University, Fort Collins, CO and 2Colorado School of Mines, Golden, CO

Traditional gravimetric methods for exposure assessment may not effectively characterize the respiratory insult experienced by miners due to exposed small particles. An on-site evaluation of particle emissions from the feed-leg drilling activity was conducted to characterize particle size and elemental composition. Air quality was monitored using direct reading instruments for sizes of 10nm to 10μm and particles were collected using a novel nanoparticle sampler and side with a respirable cyclone sampler. The nanoparticles and respirable particles were directly collected onto a transmission electron microscope (TEM) grid and polycarbonate filter for microscopic analysis. The filter and TEM grid were discovered to have a multitude of particles in the nanometer to micrometer size range, and were consistent with instrument measurements. They were mostly silica rich stone, spherical iron oxide, and carbon rich soot particles according to elemental composition analysis. This study demonstrates the need for nanoparticle exposure assessment in a mining workplace.

11:05 AM | 506

**Open Pit Mine Optimization with Maximum Satisfiability**

Matthew Deutsch, Maptek, Lakewood, CO

A common casualty of modern open pit mine optimization is the assurance that the resulting design is actually achievable. Optimized mine plans that consider value and a bare minimum of precedence constraints do not, in general, translate into practical, operational mine designs that can really be used in the field. Ultimate pits may come to a sharp point at the bottom. Schedules may require taking small parcels of material from many disparate areas of the pit in a single period. And grade control polygons may be ragged, narrow, and not minable with realistic equipment. In this paper all of these problems are addressed by encoding these three fundamental open pit mine optimization problems as maximum satisfiability problems. Maximum satisfiability provides a useful framework for problems that are non-linear, and may guarantee the optimality that metaheuristics cannot.

2:00 PM-5:00 PM | 615

**My Internship Experience**

Marie Hetherington, Mining Engineering, Colorado School of Mines

Josh Holt, Mining and Minerals Engineering, Missouri S & T

Nestor Santa, Mining Engineering, Universidad Nacional De Colombia Juanita Parkerson, Mining Engineering, University of Arizona

Jarom Gleed, Mining Engineering, University of Utah

Shannon Seitz, Mining and Engineering and Geology, West Virginia University

Kegan Patrick, Mining Engineering and Civil Engineering, West Virginia University

Erica McCauley, Mining Engineering and Geology, West Virginia University

Ricky Shipe, Mining Engineering and Civil Engineering, West Virginia University

Jeremy Diehmann, Mining Engineering, West Virginia University

Industry students will share internship experiences.

2:05 PM | 703

**Experimental Methods of Flowsheet Development for Hard Drive Recycling by Preferential Degradation and Physical Separation**

B. Ott, P. Taylor and E. Spiller; Metallurgical and Materials Engineering, Colorado School of Mines, Golden, CO

Neodymium recycling from computer hard drives by the mineral processing practice of liberation and separation is envisioned and evaluated. Magnetic material is liberated from the hard drive, constructed mostly of malleable metals, by preferential degradation of the brittle magnet material. The process developed is shown to recover greater than ninety-five percent of the magnet material with a product grade of over eighty percent magnet material by mass. The process is designed to co-produce stainless steel, aluminum, nickel alloy, carbon steel, and printed circuit board concentrates as contributors to the recycle value of hard drives. The evaluation of hard drive encased value and processing costs shows the economic viability of the recycling process.

2:25 PM | 507

**Experiences and Future Challenges of the Artisanal and Small Scale Mining in Colombia**

I. Casasuebas Cabezas2, N. Smith2 and O. Restrepo Baena1; 1Universidad Nacional de Colombia, Medellín, Antioquia, Colombia and 2Mining Engineering, Colorado School of Mines, Golden, CO

This article identifies the current status of the research on artisanal and small-scale mining (ASM) in Colombia. The main goal is to present a review of the literature in order to create a baseline that can be used in future research. ASM in Colombia is an economic activity engaged in by different groups of people, such as individuals, families, and associations. There are many problems in the ASM sector, and most of them are related to economic, social, legal, and environmental challenges. In the past several years, the Colombian government has attempted to address some of these problems by creating different development-focused projects. The Universidad Nacional de Colombia in Medellin has also led some projects in collaboration with the Energy and Mining Planning Unit and the Ministry of Energy and Mining. These projects include improving the working conditions in the ASM sector and increasing the percentage of ore recuperation. While the current research shows that there have been some positive results, it also demonstrates that the Colombian government needs to continue investing in and supporting research on ASM.

2:45 PM | 503

**The Industrial Internet of Things (IIoT) and Autonomous Vehicles in Underground Mining in the US**

K. Costner1, F. Günther2, H. Misch2 and J. Brune1; 1Mining Engineering, Colorado School of Mines, Golden, CO and 2TU Bergakademie Freiberg, Freiberg, Sachsen, Germany

Underground autonomy has been explored for the past 50 years to improve safety and productivity in mines. Since then, mining equipment has been able to improve productivity while also separating and distancing workers from hazards. While remote operation and automation improves the safety of the mine, more recent trends go towards autonomous, robotic operation of certain mining equipment. Equipment that usually follows a simple pattern of movement, such as haultrucks or track-bound vehicles lend themselves more easily to autonomous operation than equipment that required more complex controls. This presentation looks at the applications for robotic equipment and the role of the Industrial Internet of Things (IoT) role in autonomy.

3:25 PM | 106

**PhD Fellowship Program Academic and Research Progress Update**

H. Lammers; Mining Engineering, Colorado School of Mines, Golden, CO

Requirements for a Ph.D. in mining engineering at the Colorado School of Mines include successful completion of course and research credit hours, a comprehensive exam, and thesis defense. I completed the course credit hour requirement during the 2017-2018 academic year, my first year as a Ph.D. student. I am currently preparing for the comprehensive exam and proposal defense, both scheduled for the 2018-2019 academic year. My third year in the Ph.D. program, 2019-2020 academic year, will include completion of the research credit hour requirement and thesis defense. I will present a brief degree progress update, including outcomes of major milestones, and summarize teaching and research activities to date. My defined research topic is in development, with my research proposal defense scheduled for the 2018-2019 academic year. My ongoing research efforts include a review of geotechnical, geochemical and climate criteria for tailings facility design, operation, and closure.

3:25 PM | 507

**Traditional and Small Scale Mining in Marmato, a Case Study of Mercury-Free Processing in Colombia**

M. Salgado Cabeza1, E. Holley2 and O. Restrepo Baena1; 1Universidad Nacional de Colombia, Medellín, Antioquia, Colombia and 2Mining Engineering, Colorado School of Mines, Golden, CO

Traditional and small scale mining in Colombia accounts for approximately 80% of gold production in the country. The government has recently outlawed the use of mercury in mineral processing but has provided little guidance for alternative technologies. This presentation offers potential solutions from the historic mining district of Marmato in the Department of Caldas, where small scale miners have significant experience with relatively sophisticated mercury-free processing technologies. Small scale mining at Marmato exploits epithermal veins by underground methods. Cooperatives and small companies operate mills and cyanidation plants to process the gold-silver ore. Case study mill flow sheets are presented, and the implications for recovery and environmental impacts are discussed.

3:25 PM | 703

**A Novel Utilization of Blast Furnace Slags (BFS): Preparing High-Temperature Composite Phase Change Materials (C-PCMs)**

C. Anderson and Y. Zhang; Colorado School of Mines, Golden, CO

Blast furnace slag (BFS) is the main hazardous solid waste during the iron production process, which has huge output and low comprehensive utilization rate. In this study, a novel utilization method for BFS to prepare high-temperature composite phase change materials (C-PCMs) was proposed. The porous structure and thermostability of BFS were first characterized. Then, three typical PCMs (NaNO3, Al and Na2SO4, with different operating temperature) were used to fabricate BFS-based C-PCMs by means of mixed sintering process, among them, NaNO3 had excellent chemical compatibility with BFS and the prepared C-PCMs had perfect phase change
performance. Furthermore, the NaN$_3$/BFS PCMs could retain good thermal reliability after 100 thermal cycles, which presented the potential application in the thermal energy storage system. In addition, the morphological structure, thermal reliability and heat transfer property of the NaN$_3$/BFS C-PCMs were characterized by using SEM, TG-DSC, etc.

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Mining in the Coffee Lands: Lessons of Coexistence in Andes, Colombia

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The municipality of Andes is located in the southwest region of the department of Antioquia in Colombia. Its main economic activities are related to agriculture, where coffee has been the dominant commodity in the last four decades. Artisanal and small-scale gold mining (ASGM) has occurred in Andes for more than 150 years and is still both culturally and economically significant in some areas of the municipality. This presentation provides some reflections on the coexistence of mining and coffee in Andes based on the analysis of two fundamental factors: coffee activity and mining communities and their practices. Additionally, we propose some opportunities for strengthening ASGM as a livelihood, based on socio-technical innovations that support cleaner, safer and more sustainable activities. This study is the result of fieldwork conducted in 2018 within the framework of the multidisciplinary, multinational NSF PIRE project – Sustainable Communities & Gold Supply Chains: Integrating Responsible Engineering & Local Knowledge.

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Microwave-Enhanced Comminution: Which Rock Types Are Suitable?

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Understanding how the mineralogy influences the efficiency of microwave irradiation could subsequently enhance comminution by facilitating the extraction of valuable minerals before processing the ore. Microwaves have been considered as a potential tool for weakening the rock before comminution, but they do not affect all rock types in the same way. This study aims to understand the mineralogical controls underlying rock mass weakening during microwave irradiation. Previous work showed that moderate irradiation time leads to a consequent reduction in rock strength via the propagation of an intra- and inter-granular fracture network with preferential mineralogical associations. This study examines the mineralogical associations of microwave-induced fracture networks in order to determine the causative mechanisms and thus the appropriate rock types for the application of this technique. Three types of granitic rocks with varying composition of hydrated minerals were exposed to 3kW microwave irradiation for 60 to 300 seconds. An integrated approach of micro computing tomography, optical and scanning electron microscopy was used to analyze the nature of the induced fractures.

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Factors Affecting the Electrochemical Recovery of Metals from Mining-Impacted Waters

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Electrochemical methods have potential to treat waters impacted by abandoned mines, while simultaneously producing a recoverable metal product to off-set treatment costs. However, current knowledge of the types of metal solids formed is limited. This paper will present results of bench-scale testing of electrochemical metals recovery from mining-impacted waters. Results will include the effects of operating conditions and water composition on the metal solids formed during treatment. Potential benefits and challenges of applying electrochemical metals recovery to mining-impacted waters will also be presented.