UNDERGROUND MINE ACCESS

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SENIOR VICE PRESIDENT

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RESPEC **BY THE NUMBERS**

COMPANY EMPLOYEE GROWTH

500+

Our staff is over 500 employees throughout the US and Canada

28+

We are in 28+ offices throughout 13 US states and 2 Canadian provinces.

50+ YEARS

Founded in 1969 in Rapid City, South Dakota, our company has withstood the test of time. We have 50 years of experience in customizing our capabilities to meet client needs.

94 PROFESSIONAL ENGINEERS

14 PROFESSIONAL GEOLOGISTS

15 DOCTORATE DEGREES

MARKETS WE SERVE

COMMUNITY DESIGN SOLUTIONS | DATA & TECHNOLOGY | ENERGY | FACILITIES | MINING | TRANSPORTATION | WATER & ENVIRONMENT

$100M+

In April 2020, RESPEC acquired PDC Engineers, an Alaska-based engineering firm of over 100 employees. Together we have 110 years of combined industry experience and a combined revenue of $100+M.

FIFTY COUNTRIES

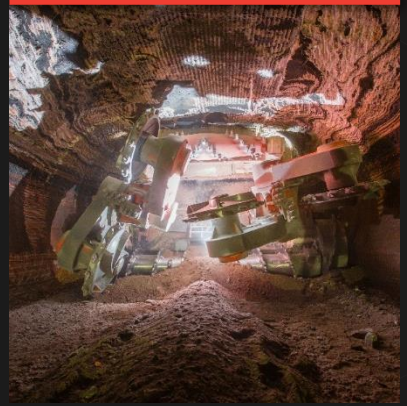
We've worked in more than 50 countries globally.

RESPEC is 100% employee-owned.

CREATING OPPORTUNITIES: BUSINESS UNITS

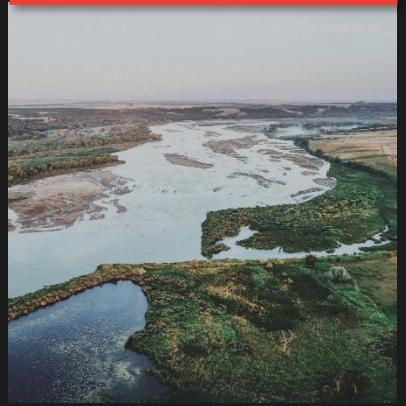
RESPEC

MINING & ENERGY



DATA & TECHNOLOGY SOLUTIONS

WATER & NATURAL RESOURCES



INFRASTRUCTURE

MINING & ENERGY

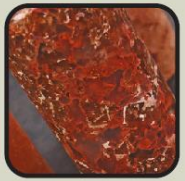
FULL MINE LIFE CYCLE

- EXPLORATION
- MINE DEVELOPMENT
- OPERATIONS
- CLOSURE & RECLAMATION

FIVE MARKETS

RESPEC TOUCHES EVERY AREA OF THE MINING SPACE.

Construction Materials



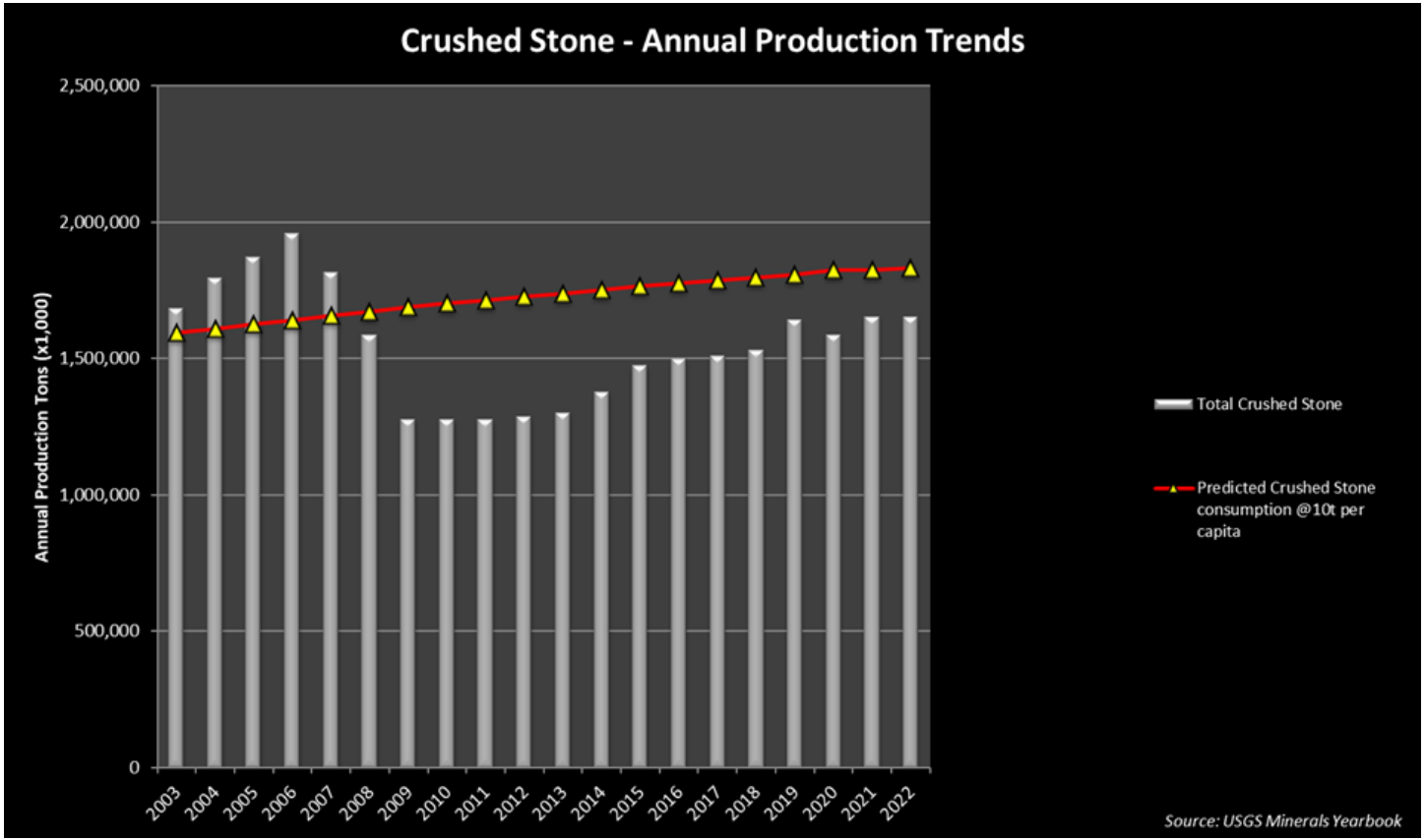
Industrial Minerals

Metals

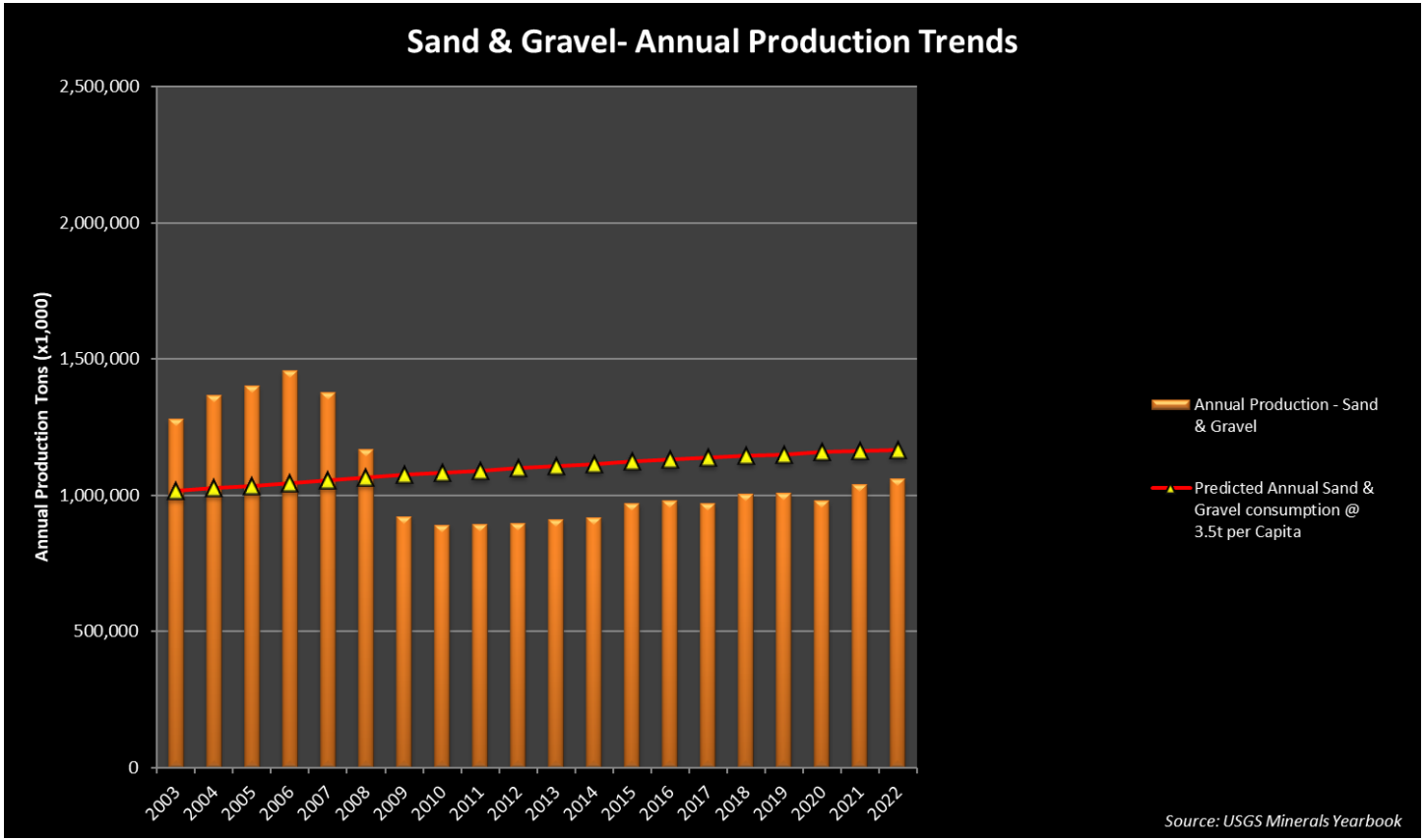
Energy

Mine Reclamation

PRODUCTION TRENDS

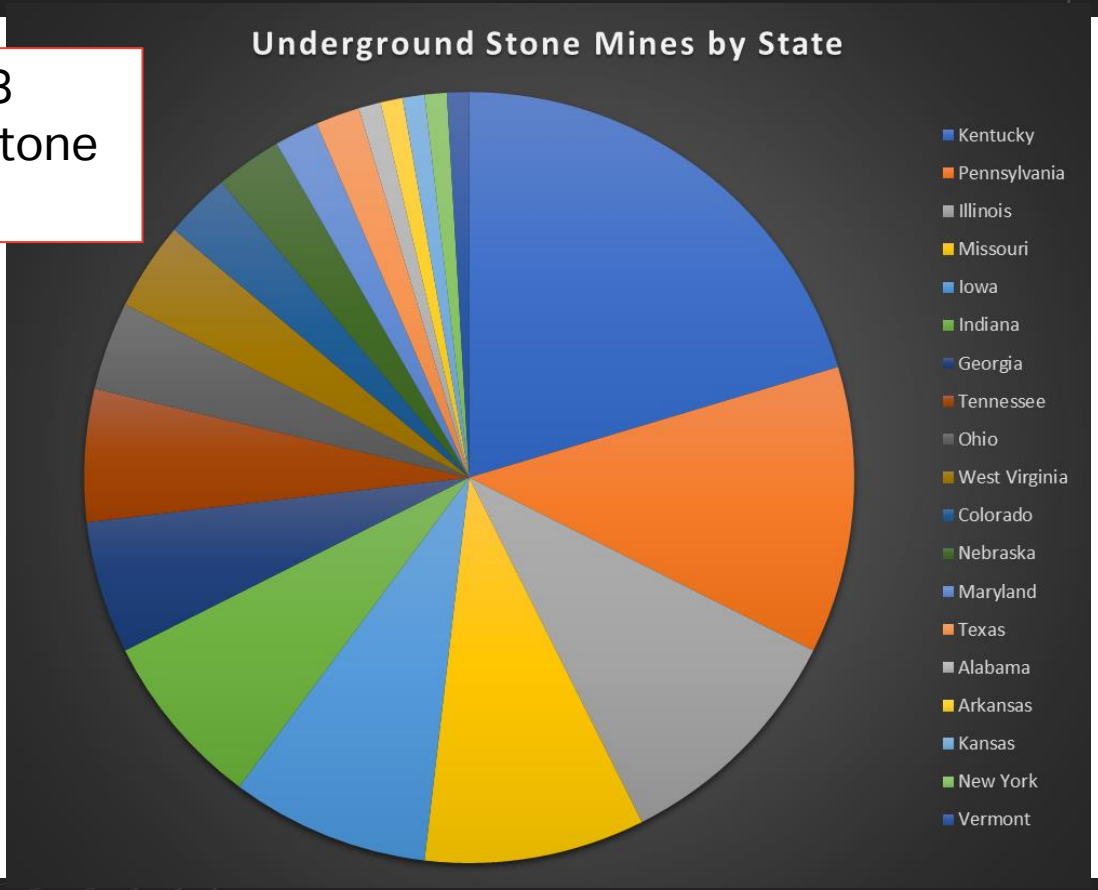


PRODUCTION TRENDS

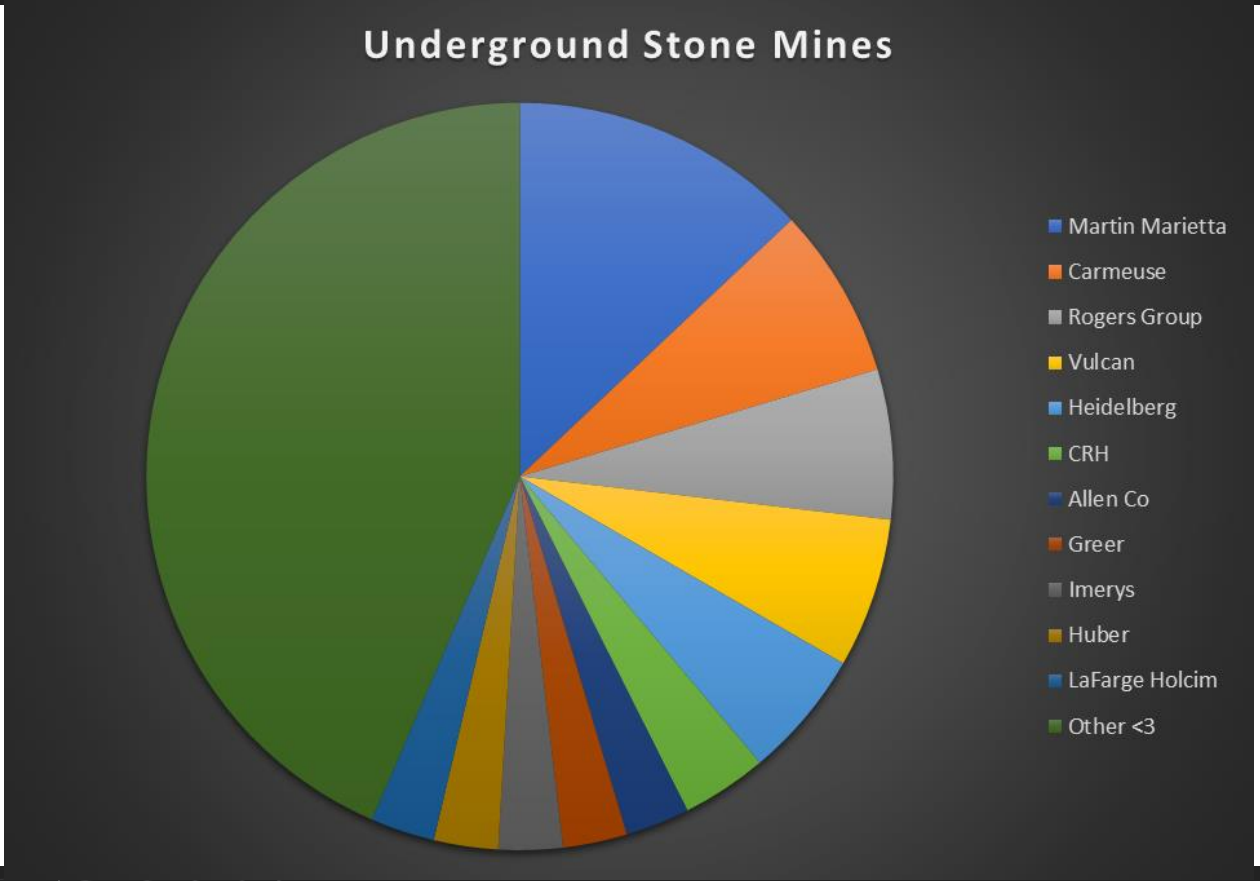


UNDERGROUND MINES BY STATE

Total of 108 Underground Stone Mines



UNDERGROUND MINES BY COMPANY



TRENDS

- INCREASING INTEREST IN UNDERGROUND MINES
- UNDERGROUND OPERATIONS USED TO EXTEND MINE LIFE, AFTER DEPLETION OF SURFACE RESERVES
- UNDERGROUND MINERAL LEASES CAN BE EASIER TO OBTAIN THAN SURFACE LEASE
- UNDERGROUND MINE DEVELOPMENT AT EXISTING OPERATION OPTIMIZES VALUE OF IN PLACE INFRASTRUCTURE
- UNDERGROUND MINES ARE MORE ATTRACTIVE AS STRIPPING RATIOS INCREASE

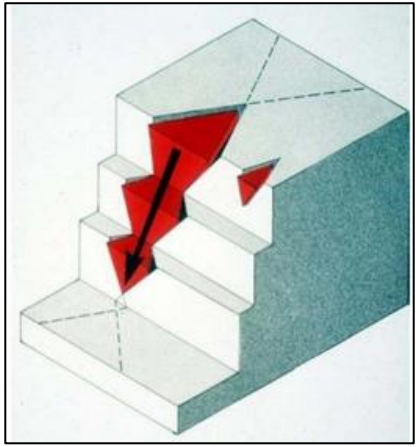
SURFACE TO UNDERGROUND TRANSITION

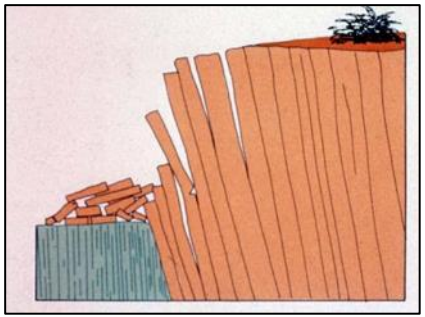
TOPICS

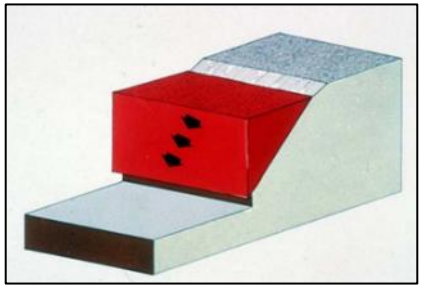
- HIGHWALL HAZARDS
- LOCATION PLANNING FOR FINAL HIGHWALL AND PORTALS
- DATA COLLECTION AND ANALYSIS FOR DESIGN
- HIGHWALL STABILIZATION SOLUTIONS
- PORTAL REINFORCEMENT

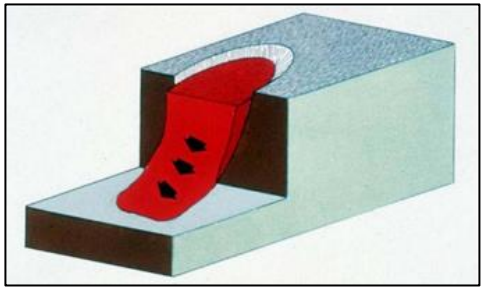
HIGHWALL HAZARDS

- **JOINT SETS**
  - Discontinuity intersections can control pillar strength and highwall wedge instability; potential for toppling failure
- **BEDDING PLANES**
  - Planar failure, roof control issues
- **UNCONSOLIDATED MATERIAL**
  - Circular failure of waste or overburden
- **MUD OR CLAY SEAMS**
  - Weak bands impact face and pillars
- **WATER / ICE**
  - Increased weight to face; freeze-thaw impacts to portals and final highwall; falling ice chunks









FINAL HIGHWALL AND PORTAL LOCATION PLANNING

- **ACCESS**
  - Adit
  - Single Decline / Shaft
  - Twin Decline
  - Twin Shaft
- **LAYOUTS ARE HIGHLY VARIABLE**
  - Fit to site topography, infrastructure, and geology

FINAL HIGHWALL AND PORTAL LOCATION PLANNING

- **MINING INTERVAL DEFINED BY CHEMISTRY OR STRATA?**
  - Multi-level mining; heading only; benching
- **WHAT DOES THE GEOLOGY ALLOW?**
  - Roof and floor selection to minimize ground control costs
  - Pillar sizing and orientation
  - Bench Face Angle
- **EQUIPMENT TO BE USED?**
  - Maneuvering room and reach
  - Ease of access and maintenance
- **IS THE UNDERGROUND MINE VIABLE/PROFITABLE?**
  - Life of the mine, any post-mine use
  - Expected production rate

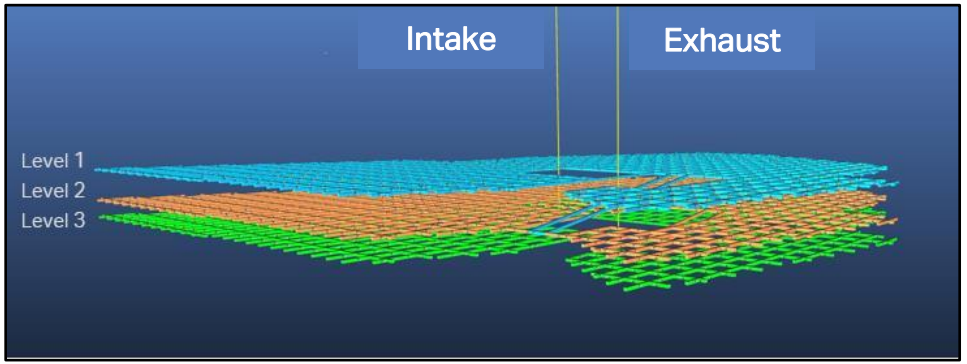
FINAL HIGHWALL AND PORTAL LOCATION PLANNING

PLANNING FOR A GOOD PRE-SPLIT AND WIDE BENCHES SAVES MONEY

- Easy to inspect and maintain
- Easy to work from to install support
- Avoid higher cost stabilization measures (rockfall fences, face grouting and bolting, additional layback)

SAVE ON OPERATING COSTS

- Ventilation simulation to determine appropriate sizing of shafts and entries
- Water management design



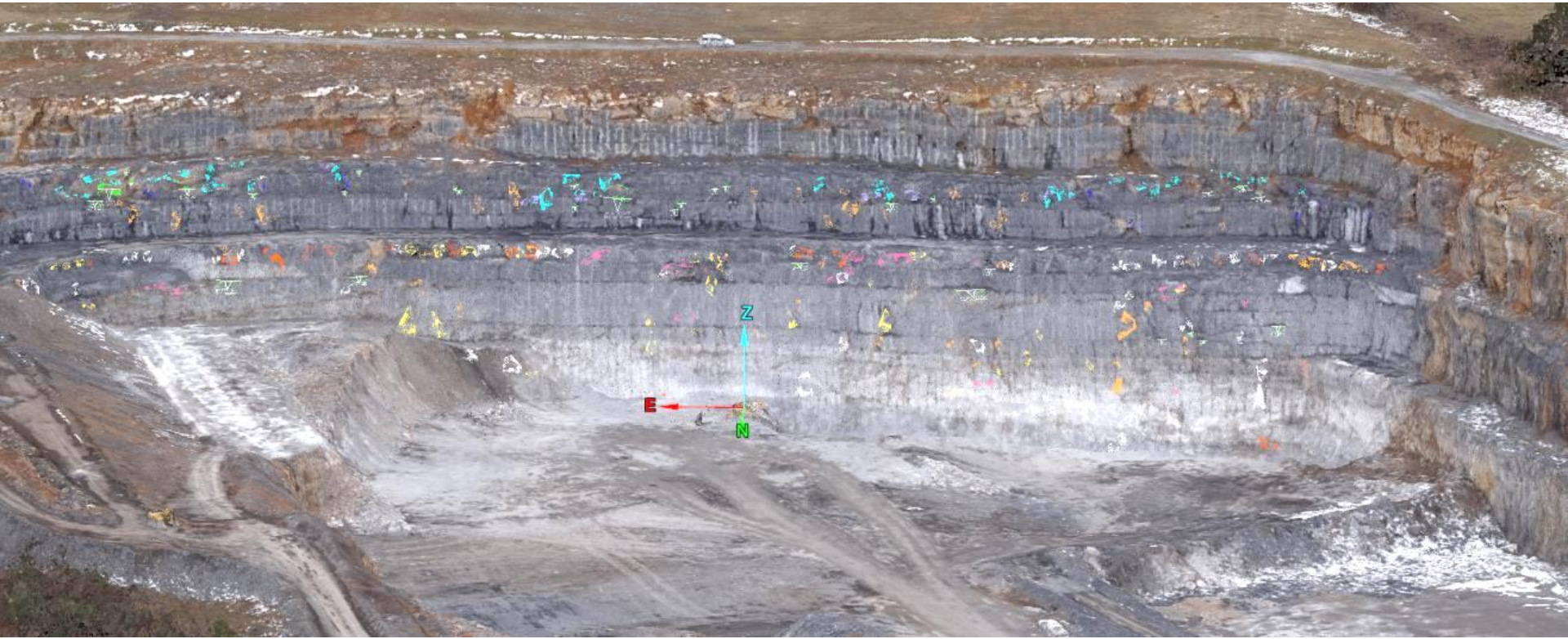
DATA COLLECTION AND ANALYSIS FOR DESIGN

DATA COLLECTION

- Existing mine infrastructure (utilities, material transport)
- Geology: corehole drilling to characterize the rock mass
  - Lithology, Rock strength testing, Geotechnical logging, Chemistry / attribute analysis
- Topography
  - Drone point clouds can be used for joint mapping, 3D modeling
- Equipment fleet and Production targets
- Site-specific needs
  - Water, Neighbors, Permit limits, State and MSHA regulations

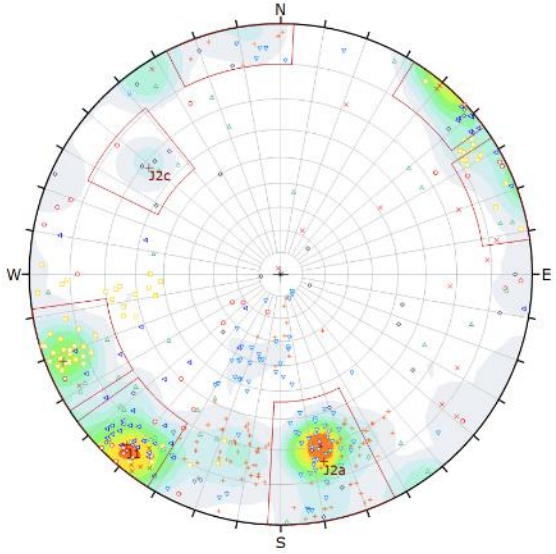
THIS INFORMATION IS ALSO USED FOR UNDERGROUND MINE LAYOUT AND PILLAR SIZING/DESIGN

DATA COLLECTION AND ANALYSIS – POINT CLOUD JOINT MAPPING



DATA COLLECTION AND ANALYSIS FOR DESIGN

- **EXPERIENCE**
  - Rules of thumb can be overly conservative / misleading
- **GEOLOGIC INVESTIGATION AND 3D MODELING**
- **ROCK MASS CLASSIFICATION**
  - Itasca models
    - FLAC - 2D and 3D geotechnical analysis
    - 3DEC – 2D and 3D jointed rock masses
  - Rocscience Models
    - RS2 – 2D geotechnical analysis
    - SWedge and UnWedge – ground support design of wedge structure
    - DIPS – slope orientation analysis
    - Slope stability and bench design for open pits



Stereonet Plot Example

UNDERGROUND LAYOUT / PILLAR DESIGN

ROCK PROPERTIES

- Discontinuities dipping between 30 and 70 deg have the greatest impact on strength
- Joint mapping more than just one wall prevents data bias

BENCHING

- More vertical height, more risk of continuous discontinuities being exposed

HIGHWALL STABILIZATION SOLUTIONS

ROCKFALL PROTECTION BARRIERS

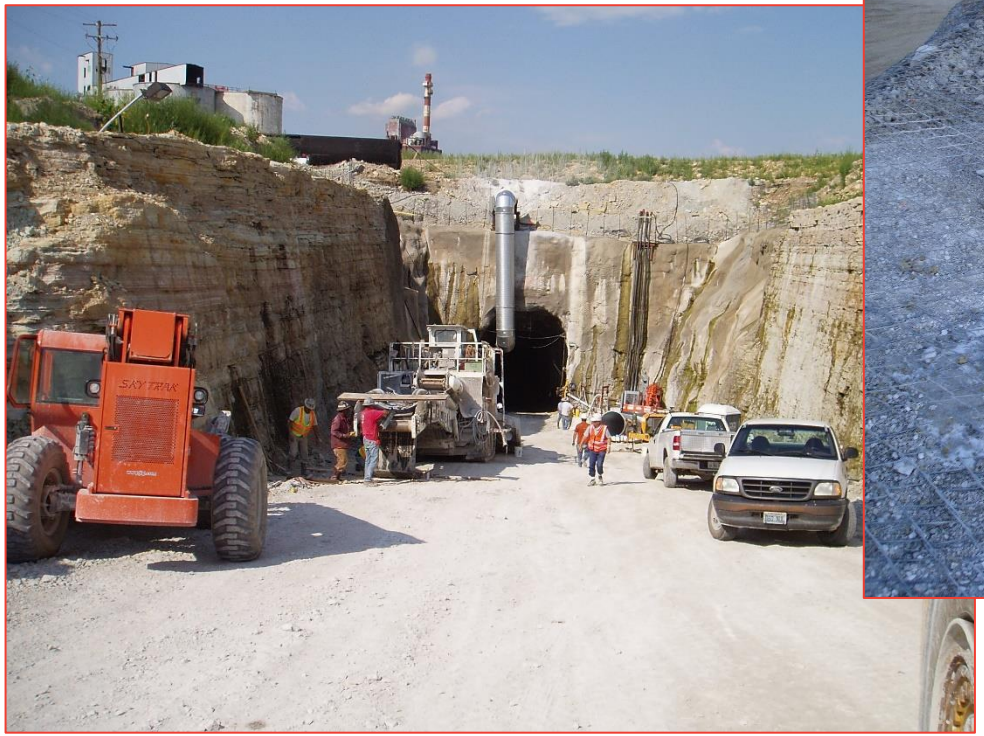
- Protection from falling rock or debris
- When space is limited and a runout zone for falling rocks is not feasible

HIGHWALL STABILIZATION SOLUTIONS

WIRE MESH DRAPE

- Chain link difficult to work with and limited strength
- Wire mesh rolls with no vertical stretch (Geobrugg, Maccaferri, etc.)
  - Efficient installation
  - Conforms to highwall shape
  - Corrosion protection (galvanized)
  - Can be shotcreted over

HIGHWALL STABILIZATION SOLUTIONS



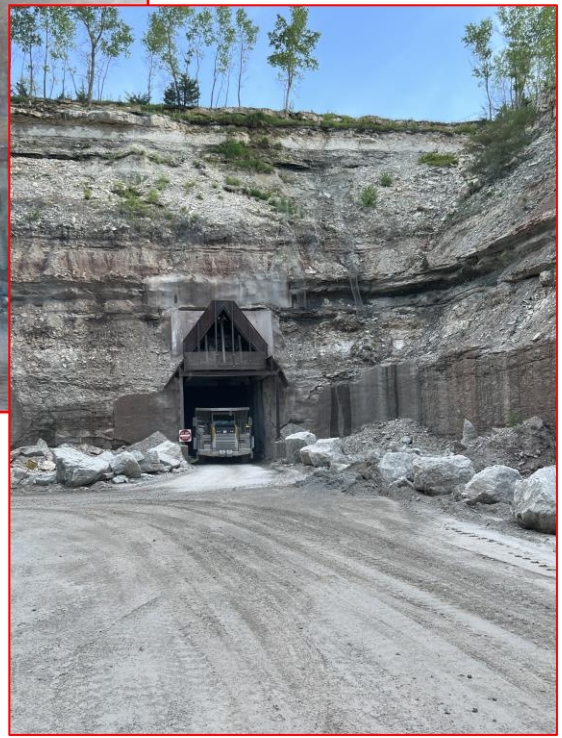
PORTAL REINFORCEMENT

- Generally, portals require more reinforcement than the rest of the underground mine
- High risk of instability (>80%) if first roof beam less than 10% of span
- Welded wire mesh panels and bolting
  - Galvanized corrosion protection
- Shotcrete
- Brow and rib straps/support
- Portal canopies

PORTAL REINFORCEMENT

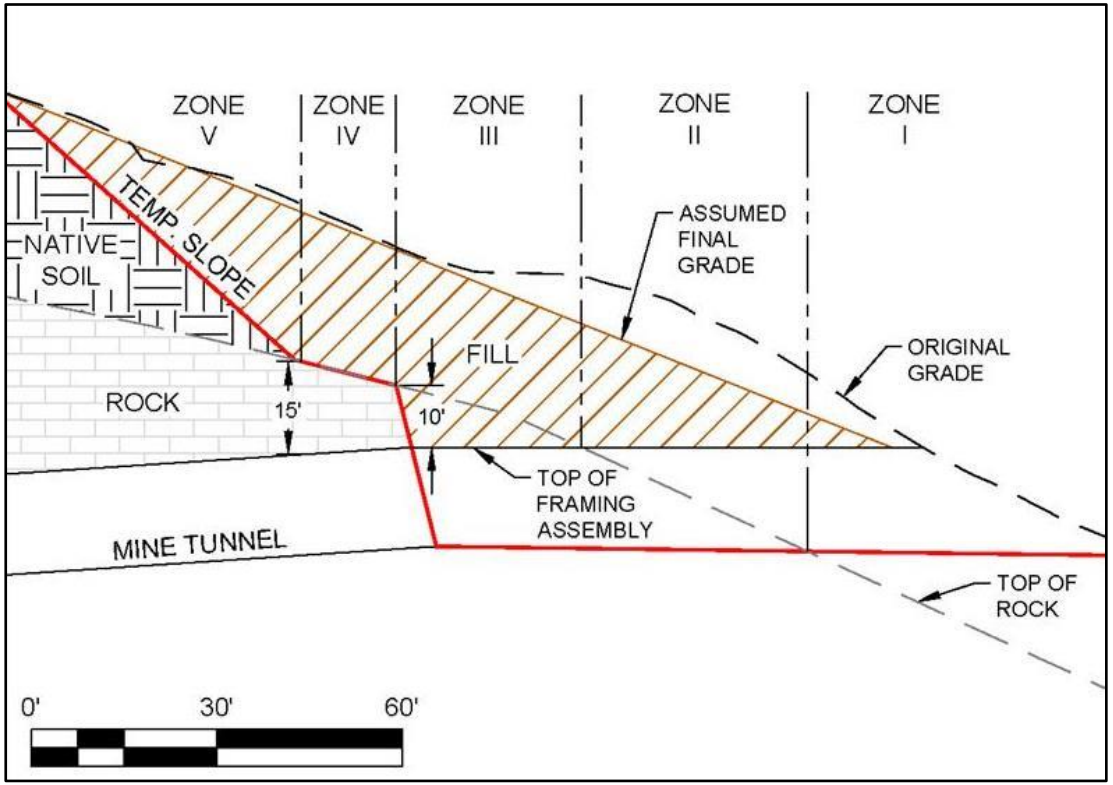
PORTAL CANOPIES

- Installed at mine openings after initial development
- Impact resistance for falling ice or rock



PORTAL REINFORCEMENT

- SOIL LOAD CALCULATIONS
- CONCEPTUAL MODEL
- DATA-BACKED ANALYSIS TO JUSTIFY APPROPRIATE GROUND CONTROL



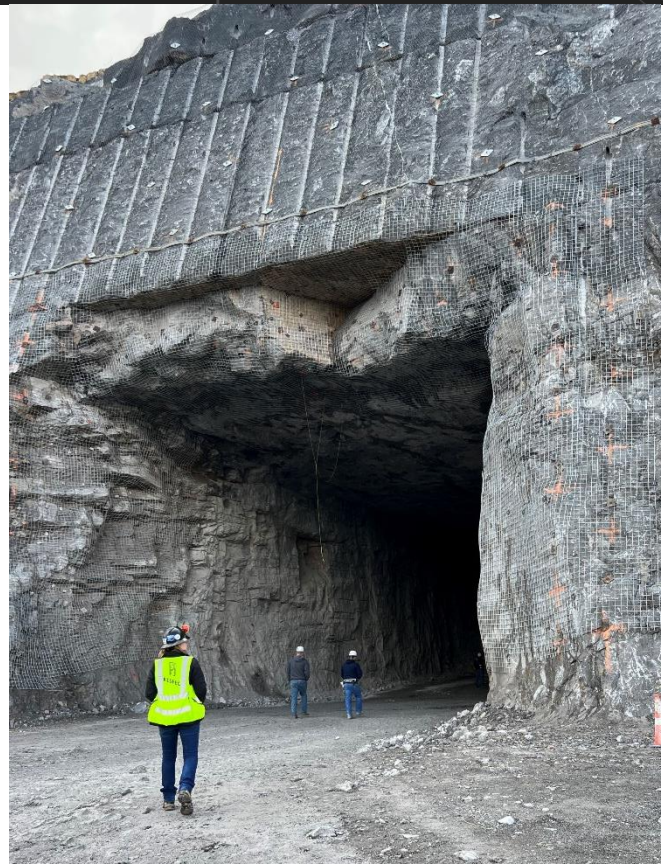
PORTAL REINFORCEMENT

- WEAK GROUND: MORE STABILIZATION NEEDED TO PREVENT COLLAPSE OR CONVERGENCE
- GEOTECH AND CIVIL / TUNNELING EXAMPLES MORE APPLICABLE


SOURCE: JENNMAR

IN CONCLUSION

- **PLANNING AND INVOLVING MULTIPLE DISCIPLINES IS USEFUL**
  - Engineers, Operators, Geologists
- **DATA COLLECTION AND ANALYSIS USEFUL TO JUSTIFY GROUND CONTROL NEEDS**
  - Problem areas can be identified in advance
  - Planning leads to Capital & Operating cost savings
- **SUPPORT METHODOLOGY MUST BE COMPATIBLE WITH GEOLOGIC CONDITIONS**
  - Monitor and verify support
- **NUMEROUS SUPPORT OPTIONS ARE AVAILABLE**
  - Not all are cost effective



QUESTIONS?

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