FOGAP
Seismic Risk Assessment

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MINERALS COUNCIL SOUTH AFRICA

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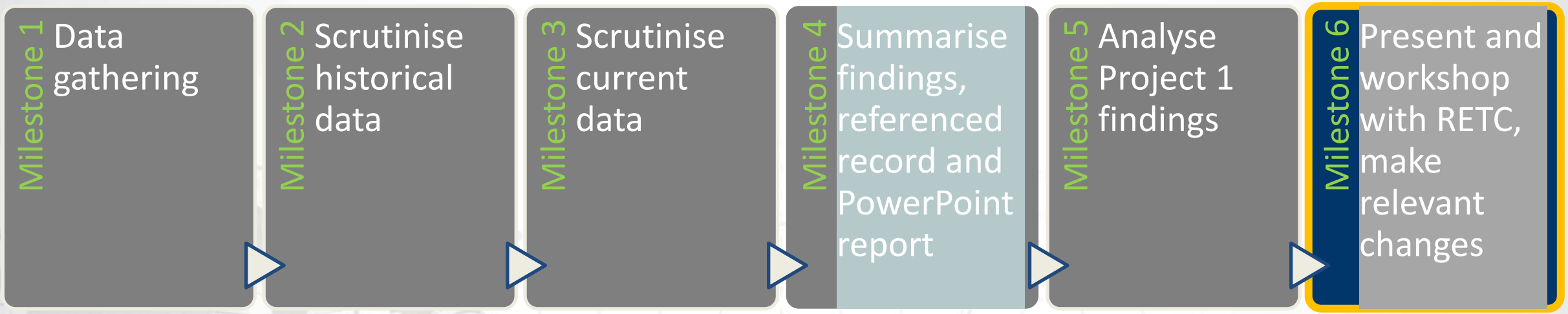
SiM FROM DATA TO KNOWLEDGE

Scope

CSIR scope of work

- ✓ Item C: Review of local seismic risk management practice for platinum and gold mines in South Africa.
- ✓ Item D: Gap analysis conducted within findings provided by all contributors to the overall Project 1 scope of work, on Items A through C.
- ✓ Item E: Workshop to present overall findings of Project 1.

Milestones



•Summarise current seismic risk management practice (local and international), including seismic hazard assessment, ground motion, source mechanisms, damage mechanisms, geotechnical data used, modelling, mine design, support systems, re-entry protocols, TARP systems, etc. Short-, medium-, and long-term risk management strategies should also be examined.

•The review should include the education level, skills, and experience of personnel responsible for seismically active operations.

Milestone 4 results

Rock Engineering Actions in the Code of Practice

- How are the seismic hazards identified on South African mines?
  - Before mining commences
  - During mining operations
- What influences the seismic risk of the identified hazards?
- Which Rock Engineering actions take place to manage seismic risk?
  - Before mining commences
  - During mining operations
- What seismic control procedures are implemented on operations.
- Seismology and Rock Engineering Survey Results

Rock Engineering Actions Implemented on South African AU and PGM Mines

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Science and Innovation
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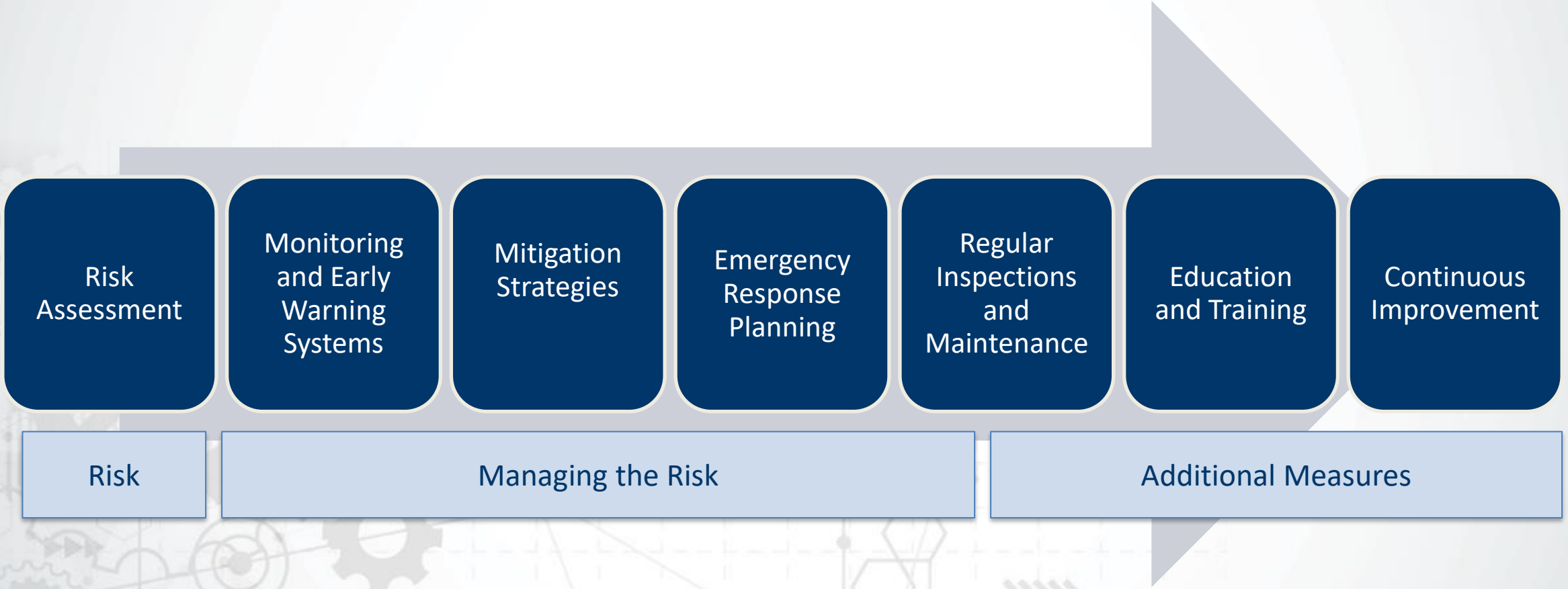
Systems and Procedures for Seismic Risk Management



Rock Engineering Actions

Seismic Hazards Identified

Actions Prior to Mining

Factors Influencing Seismicity

Actions During Mining

Rock Engineering Actions

Sibanye Rustenburg Operations

Seismic Hazards:

- Geological Structures (Faults and Dykes)
- Mining Faces
- Stabilizing Pillars
- Abutments
- Isolated Blocks
- Rock Mass Properties

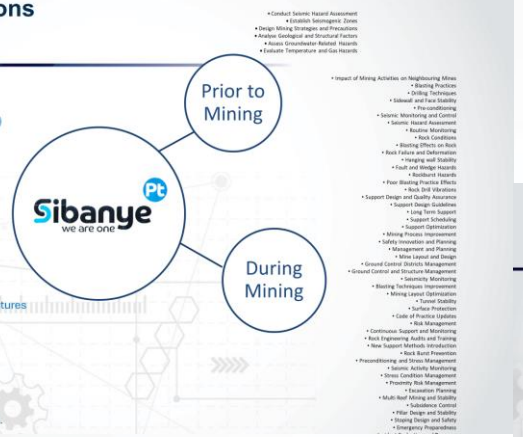
Factors Influencing Seismic Activity:

- Evaluation of frequency of geological features
- Angle of approach
- Mining span
- Rate of mining
- Extraction sequence
- Regional support system characteristics.

- Conduct Seismic Hazard Assessment
- Establish Seismogenic Zones
- Design Mining Strategies and Precautions
- Analyse Geological and Structural Factors
- Assess Groundwater-Related Hazards
- Evaluate Temperature and Gas Hazards

- Impact of Mining Activities on Neighbouring Mines
- Blasting Practices
- Drilling Techniques
- Sidewall and Face Stability
- Pre-conditioning
- Seismic Monitoring and Control
- Seismic Hazard Assessment
- Routine Monitoring
- Rock Conditions
- Blasting Effects on Rock
- Rock Failure and Deformation
- Hanging wall Stability
- Fault and Wedge Hazards
- Rockburst Hazards
- Poor Blasting Practice Effects
- Rock Drill Vibrations
- Support Design and Quality Assurance
- Support Design Guidelines
- Long Term Support
- Support Scheduling
- Support Optimization
- Mining Process Improvement
- Safety Innovation and Planning
- Management and Planning
- Mine Layout and Design
- Ground Control Districts Management
- Ground Control and Structure Management
- Seismicity Monitoring
- Blasting Techniques Improvement
- Mining Layout Optimization
- Tunnel Stability
- Surface Protection
- Code of Practice Updates
- Risk Management
- Continuous Support and Monitoring
- Rock Engineering Audits and Training
- New Support Methods Introduction
- Rock Burst Prevention
- Preconditioning and Stress Management
- Seismic Activity Monitoring
- Stress Condition Management
- Proximity Risk Management
- Excavation Planning
- Multi Reef Mining and Stability
- Subsidence Control
- Pillar Design and Stability
- Stoping Design and Safety
- Emergency Preparedness

Rock Engineering Actions
Sibanye Rustenburg Operations



Seismic Hazards:
- Geological Structures (Faults and Dykes)
- Mining Faces
- Stabilizing Pillars
- Abutments
- Isolated Blocks
- Rock Mass Properties

Factors Influencing Seismic Activity:
- Evaluation of frequency of geological features
- Angle of approach
- Mining span
- Rate of mining
- Extraction sequence
- Regional support system characteristics.

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Rock Engineering Actions
Target – Harmony

Seismic Hazards:
- Geological Structures (Faults and Dykes)
- Mining Faces
- Stabilizing Pillars
- Abutments
- Isolated Blocks
- Rock Mass Properties

Factors Influencing Seismic Activity:
- Evaluation of frequency of geological features
- Angle of approach
- Mining span or Panel Length
- Rate of mining
- Extraction sequence
- Regional support system characteristics.

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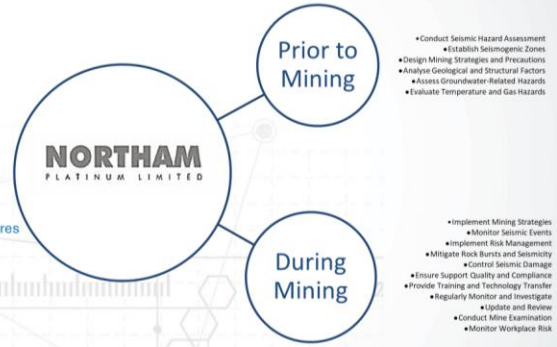
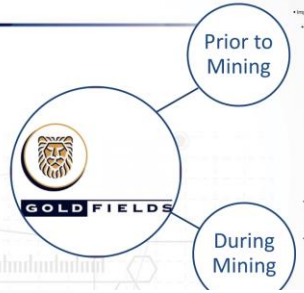
Seismic Hazards:
- Geological Structures (Faults and Dykes)
- Mining Faces
- Stabilizing Pillars
- Abutments

Influencing Seismic Activity:
- uation of frequency of geological features
- e of approach
- ng span
- of mining
- action sequence
- onal support system characteristics.



Rock Engineering Actions
Goldfields – South Deep



Seismic Hazards:
- Geological Structures (Faults and Dykes)
- Mining Faces
- Stabilizing Pillars
- Abutments

Factors Influencing Seismic Activity:
- Evaluation of frequency of geological features
- Angle of approach
- Mining span
- Rate of mining
- Extra
- Regi

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Rock Engineering Actions
Driefontein - Sibanye

Seismic Hazards:
- Geological Structures (Faults and Dykes)
- Mining Faces
- Stabilizing Pillars
- Abutments
- Isolated Blocks
- Rock Mass Properties

Factors Influencing Seismic Activity:
- Evaluation of frequency of geological features
- Angle of approach
- Mining span
- Rate of mining
- Extraction sequence
- Regional support system characteristics.

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Seismic Hazards:
- Geological Structures (Faults and Dykes)
- Mining Faces
- Stabilizing Pillars
- Abutments

Factors Influencing Seismic Activity:
- Evaluation of frequency of geological features
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- Rate of mining
- Extraction sequence
- Regional support system characteristics.

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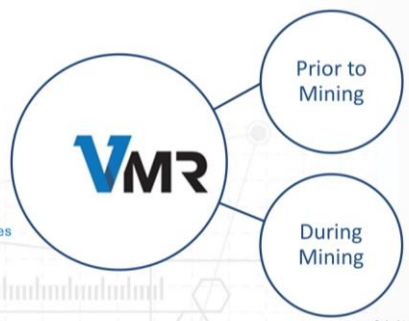

Seismic Hazards:
- Geological Structures (Faults and Dykes)
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- Abutments
- Rock Mass Properties

Factors Influencing Seismic Activity:
- Evaluation of frequency of geological features
- Angle of approach
- Mining span
- Rate of mining
- Extraction sequence
- Regional support system characteristics.

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What influences the seismic risk of the identified hazards?

Seismic Hazards:

- Geological Structures (Faults and Dykes)
- Mining Faces
- Pillars
- Abutments
- Isolated Blocks
- Rock Mass Properties

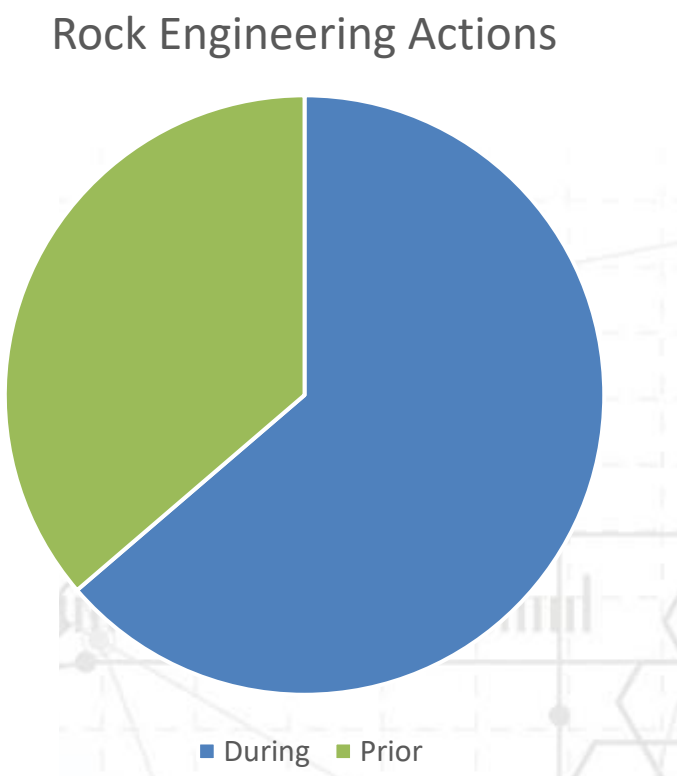
Factors Influencing Seismic Activity:

- Evaluation of frequency of geological features
- Angle of approach
- Mining span or panel length
- Rate of mining
- Extraction sequence
- Regional support system characteristics – Energy absorption calculations

Rock Engineering Actions

Rock Engineering Actions Prior to Mining

- Seismological Setting of the Mine
- Impact of Mining Activities on Neighbouring Mines
- Identify Seismic Hazards
- Understand Factors Influencing Seismic Activity
- Seismic Monitoring and Data
- Historical Rock-Related Accidents
- Ground Control Districts
- Geological Setting Considerations
- Specific Faults and Dykes
- Risk Assessments
- Fracture Zones and Rock Conditions
- Rock Engineering Strategies
- Ground Control Strategies
- Geological Considerations
- Management and Qualifications
- Mine Layout and Support Design
- Safety Measures
- Mining Processes
- Specific Challenges
- Support Systems
- Identification of Geological Discontinuities
- Geotechnical Stress Assessment
- Preliminary Seismic Risk Assessment
- Pre-emptive Seismic Monitoring System
- Conduct Seismic Hazard Assessment
- Establish Seismogenic Zones
- Design Mining Strategies and Precautions
- Analyze Geological and Structural Factors
- Assess Groundwater-Related Hazards



There are a substantial number of rock engineering related actions taken during mining.

Rock Engineering Actions During Mining Operations

- Impact of Mining Activities on Neighbouring Mines
- Blasting Practices and Effects
- Drilling Techniques and Accuracy
- Sidewall and Face Stability
- Pre-conditioning and Controlled Strain Release
- Seismic Monitoring, Hazard Assessment, and Control
- Monitoring and Analysis of Seismic Events
- Historical Rock-Related Accidents
- Ground Control Districts Management
- Geological and Seismological Considerations
- Risk Assessments and Mitigation
- Fracture Zones, Faults, and Rock Conditions
- Rock Engineering and Support Strategies
- Mine Layout, Support Design, and Multi-Reef Mining
- Safety Measures and Emergency Preparedness
- Mining Processes and Challenges
- Support Systems and Optimization
- Identification of Geological Discontinuities
- Geotechnical Stress and Preliminary Seismic Risk Assessment
- Pre-emptive Seismic Monitoring System
- Designing Mining Strategies and Precautions
- Analyzing Geological, Structural Factors, and Groundwater-Related Hazards
- Evaluating Temperature and Gas Hazards
- Rehabilitation and Continuous Improvement
- Rock Fall, Burst Hazards, and Damage Control
- Backfill, Stability Monitoring, and Control of Support
- Orebody Extraction Guidelines and Hazard Ratings
- Participation in Planning, Continuous Assessment, and Technical Support
- Modification of Mining Methods and Ongoing Monitoring
- Rock Engineering Audits, Reviews, Training, and Competence
- Introduction of New Support Products and Methods
- Face Perpendicular Preconditioning, Stress Management, and Seismic Activity
- Management, Qualifications, and Integrated Mine Process Design
- Ground Control Districts (GCD) Management and Mining Direction
- Groundwater-Related Hazards and Geological Discontinuities Management
- Mining-Induced Seismicity Monitoring and Stress-Related Damage Prevention
- Continuous Blasting Techniques Improvement and Optimization
- Effective Pillar Design, Support Systems, and Tunnel Stability Measures
- Surface and Mine Access Protection, Code of Practice Updates, and Rock-related Risks Management
- Tunnel Support Types, Design Optimization, and Support Prioritization
- Control of Rock-related Hazards in Tunnels and Continuous Innovation for Safety Improvement

How are the seismic hazards identified on South African mines?

- Seismological Setting of the Mine, Seismogenic Zones, Identify Seismic Hazards
- Impact of Mining Activities on Neighbouring Mines
- Ground Control Districts, Geotechnical Stress Assessment
- Historical Data, Pre-emptive Seismic Monitoring
- Geological Considerations, Specific Geological Structures

PRIOR TO MINING

How are the seismic hazards identified on South African mines?

- Response to Mining Activities
- Monitoring and Analysis of Seismic Data
- Geological and Rock Conditions
- Support Systems and Design Layout
- Planning and Management – Empirical Anticipation

DURING MINING

Operational Review – Shallow vs Deep Summary

Items and processes that were repeated in each of the COPs regardless of mining depth and/or commodity:

Similarities:

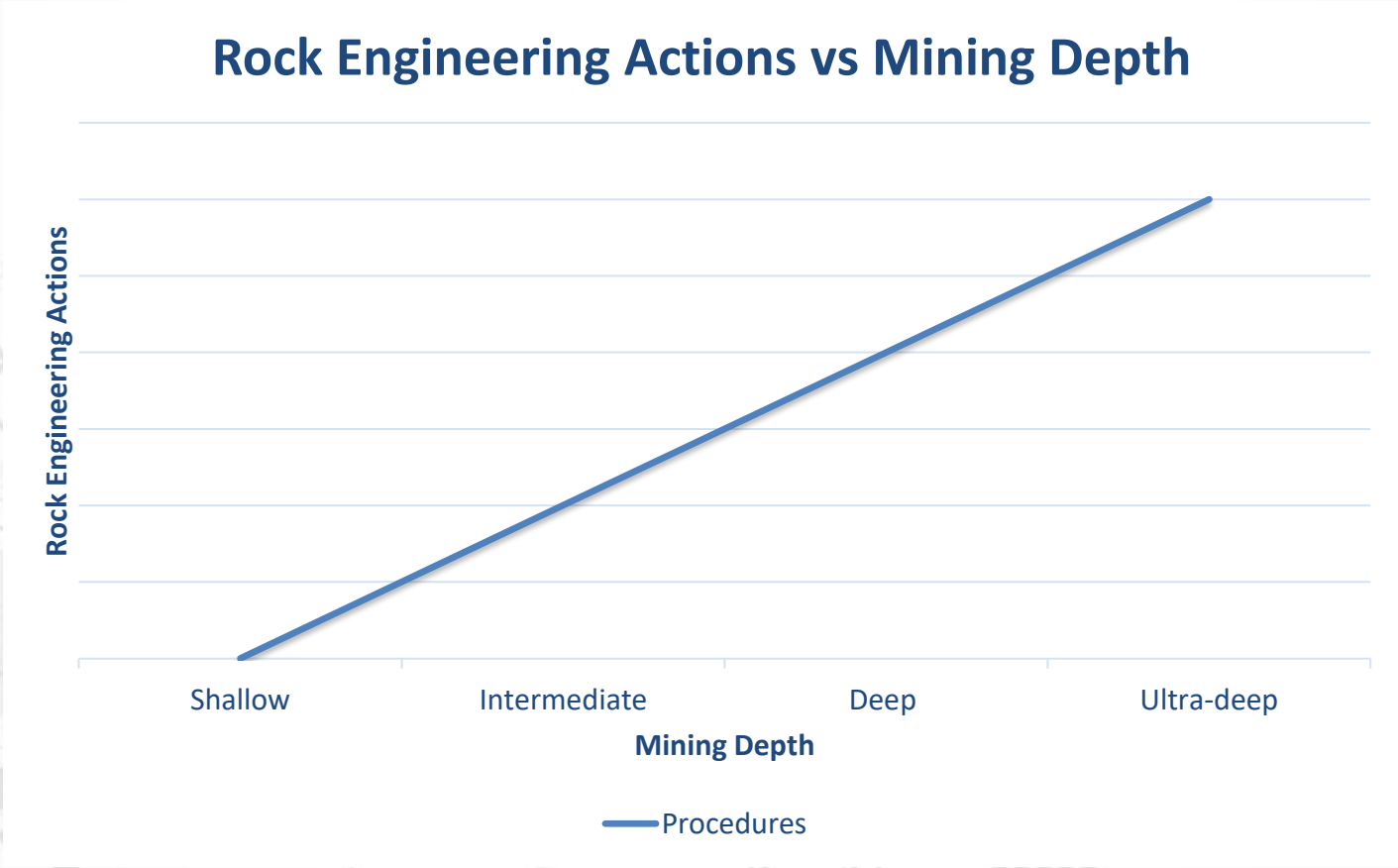
Seismic Hazard Identification
Seismic Risk Management
Induced Seismicity
Fault-slip
Influence of Geology

Items and processes that were different between COPs with depth of mining and commodity being major factors:

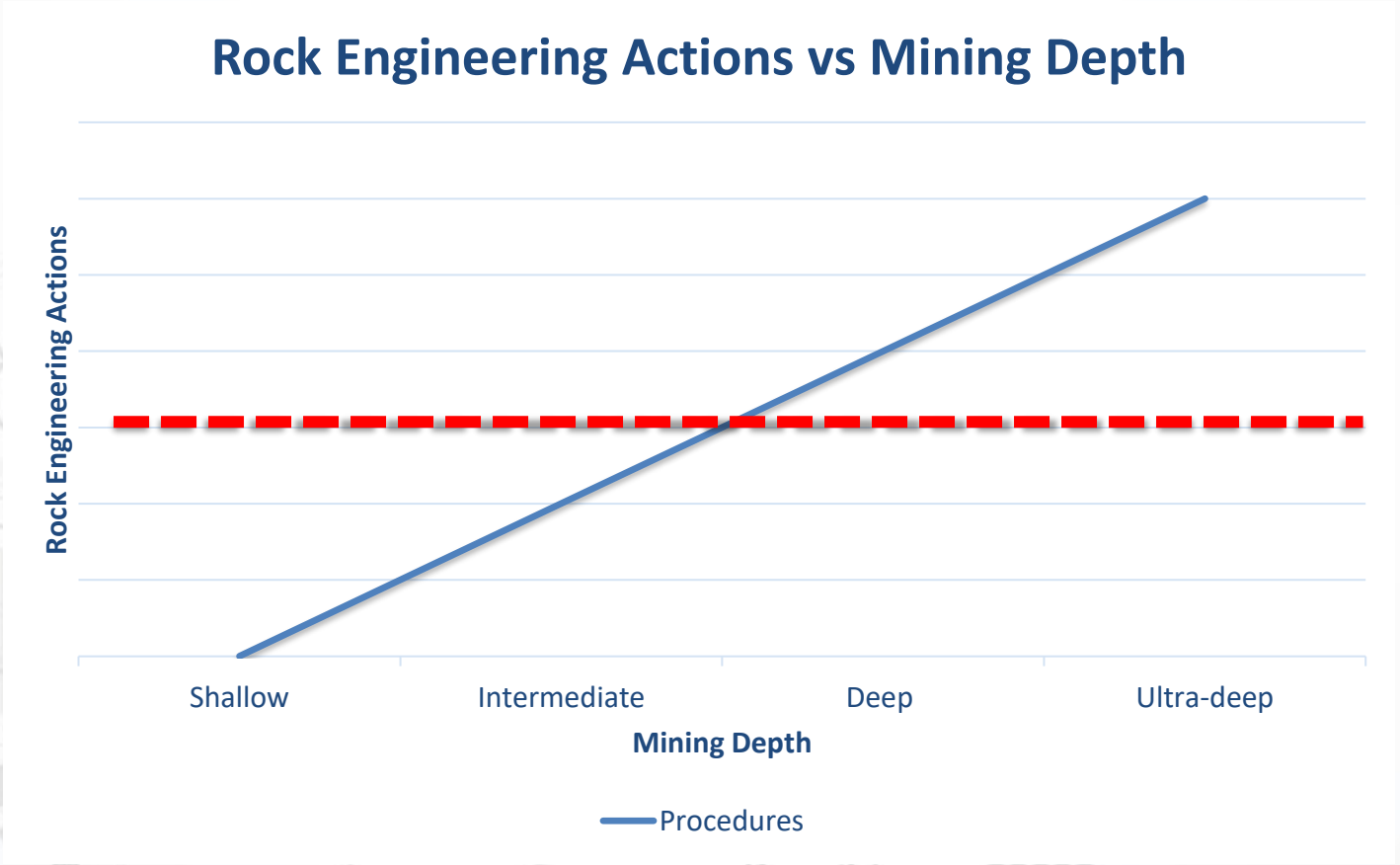
Differences:

Depth and Stress
Rock Mass Properties
Seismic Sources
Impact and Consequences

Operational Review – Shallow vs Deep Summary



Operational Review – Shallow vs Deep Summary



Best Practice

Surveys

Rock Engineering and Seismic Risk Management

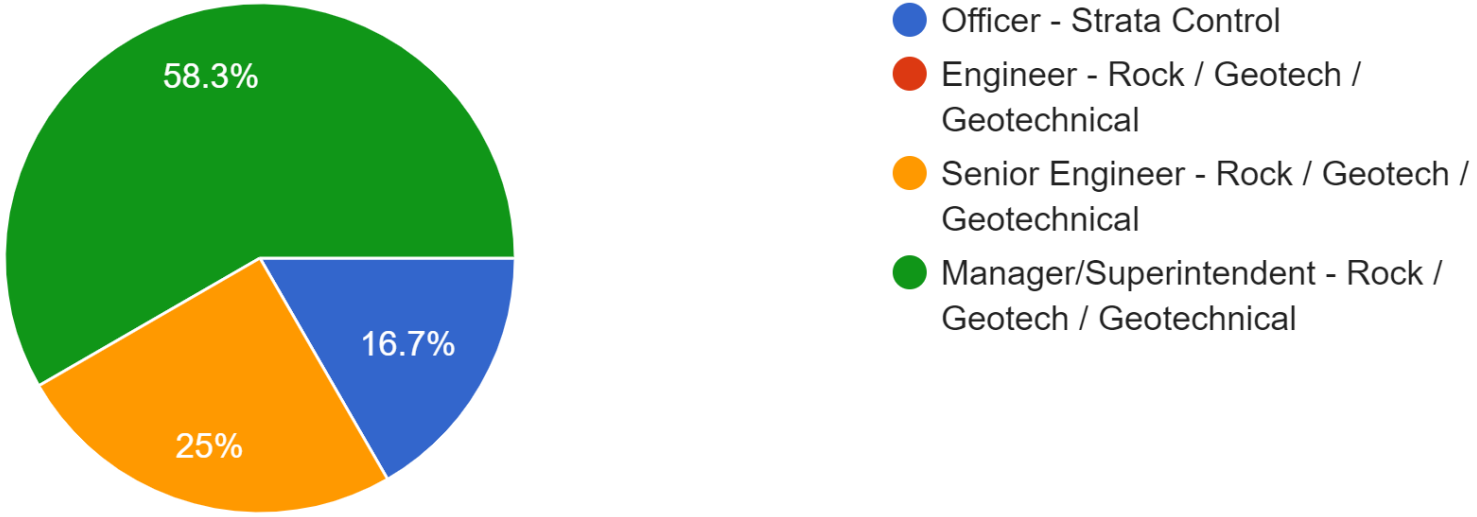
- Rock Engineering survey
  - A number of leading mines were selected to receive a survey evaluating Rock Engineering and Seismic Risk Management at the mine level.
  - The survey was distributed to all members of the Rock Engineering department involved in Seismic Risk Management.
  - The questions were designed to gauge experience levels and to test individual opinions and comfort levels when dealing with seismic terminology.
  - The answers to the questions are presented without filtering.

Rock Engineering Survey

Respondent seniority level

Which best describes your Rock / Geotechnical Engineering Level in your Department:

24 responses

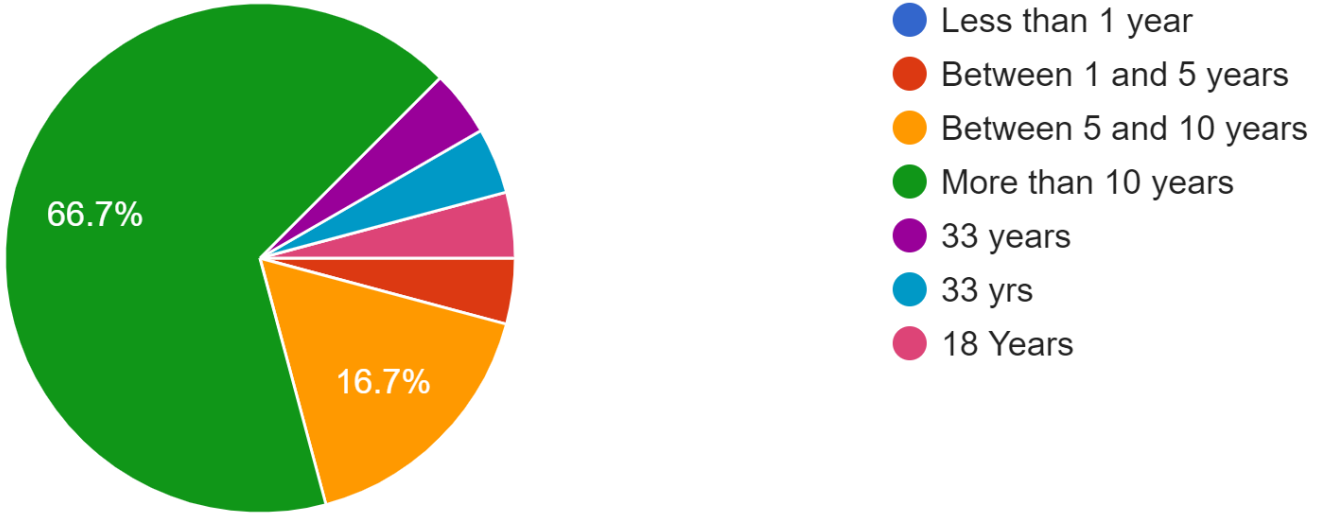


Rock Engineering Survey

Respondent experience in rock engineering

How many years of Rock / Geotechnical Engineering experience do you have:

24 responses



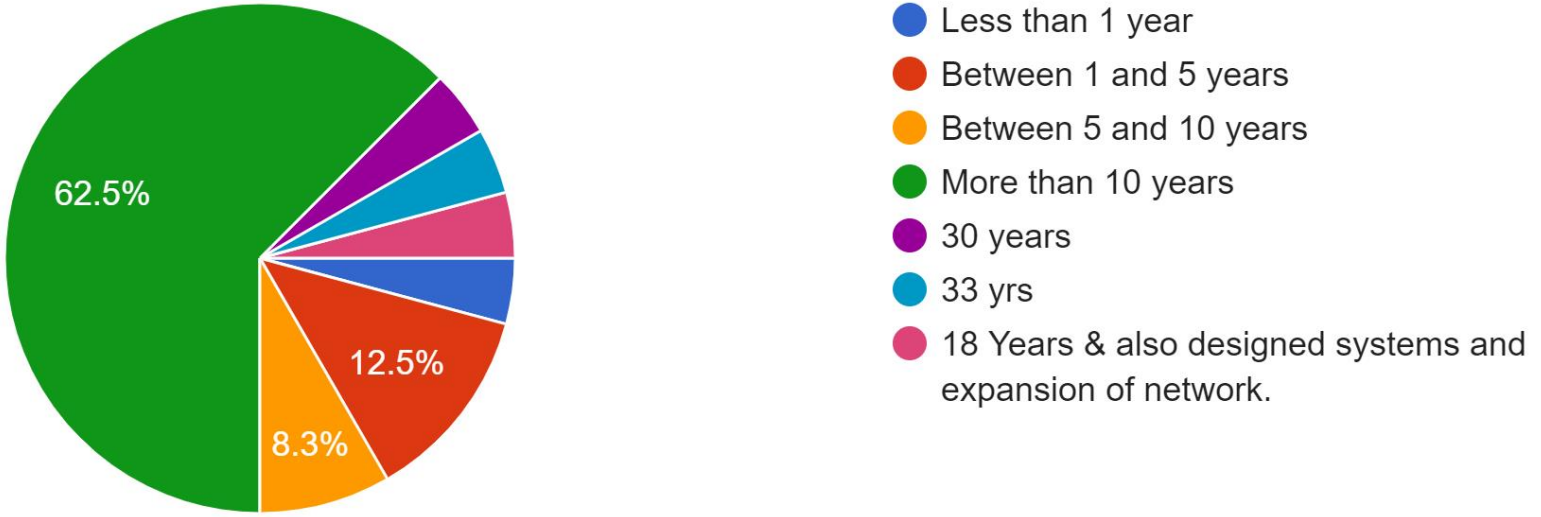
76% has more than 10 years Rock Engineering experience.

Rock Engineering Survey

Respondent experience with mine seismology

How many years of seismic exposure do you have (i.e. working on a mine with seismicity):

24 responses



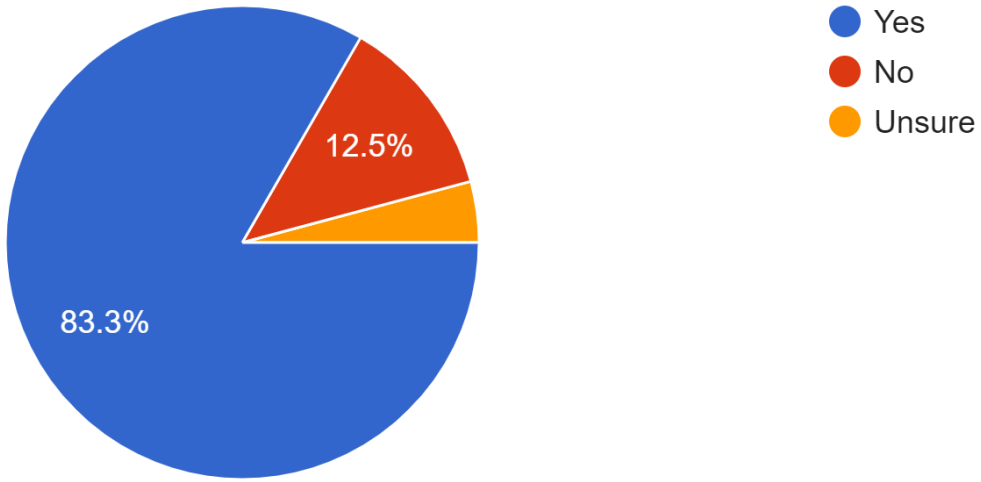
76% has more than 10 years Rock Engineering experience.

Rock Engineering Survey

Respondent knowledge of mine seismology

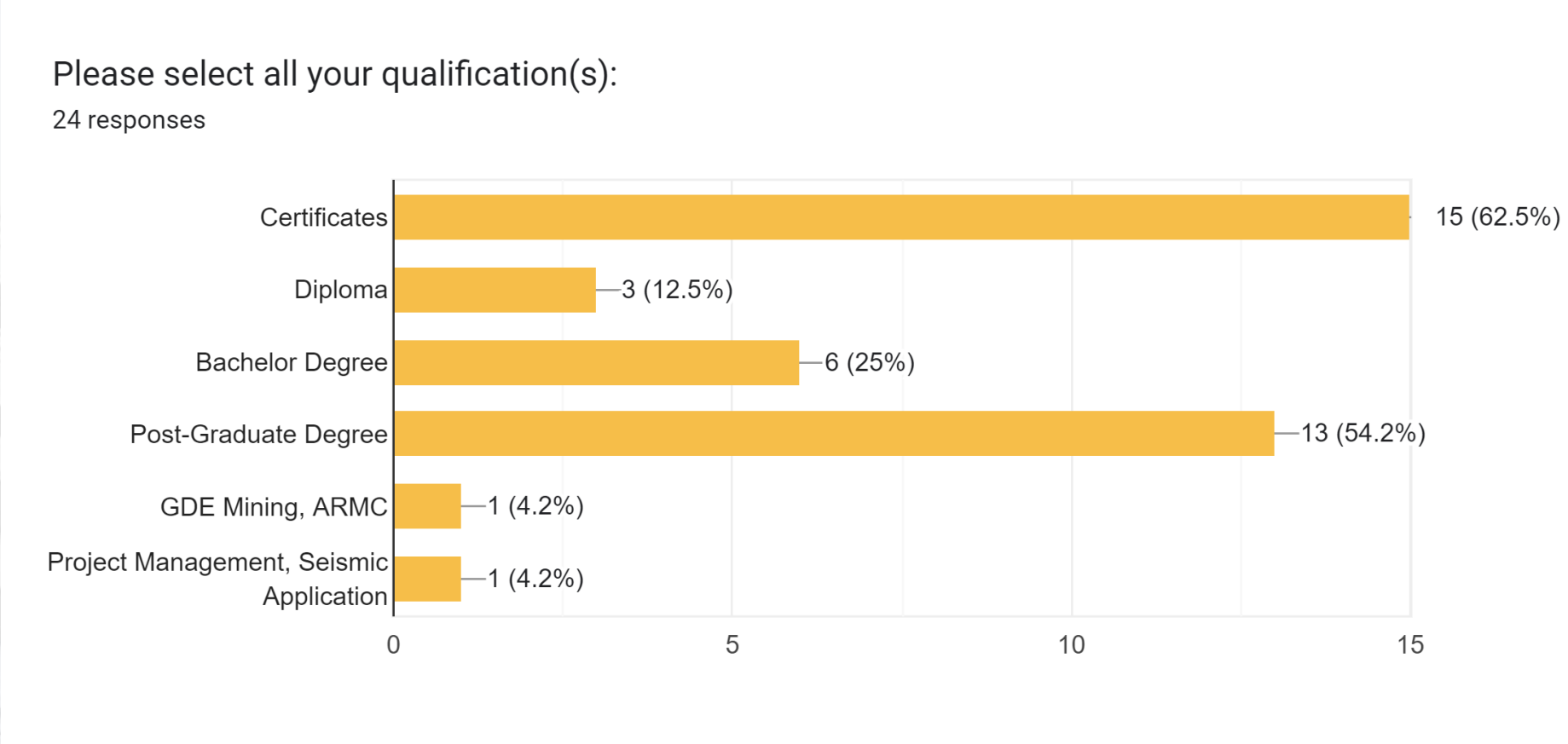
Do you feel that your knowledge of seismic systems and seismic data analysis is adequate to make a good call on implementing protocols to keep your production crews safe?

24 responses



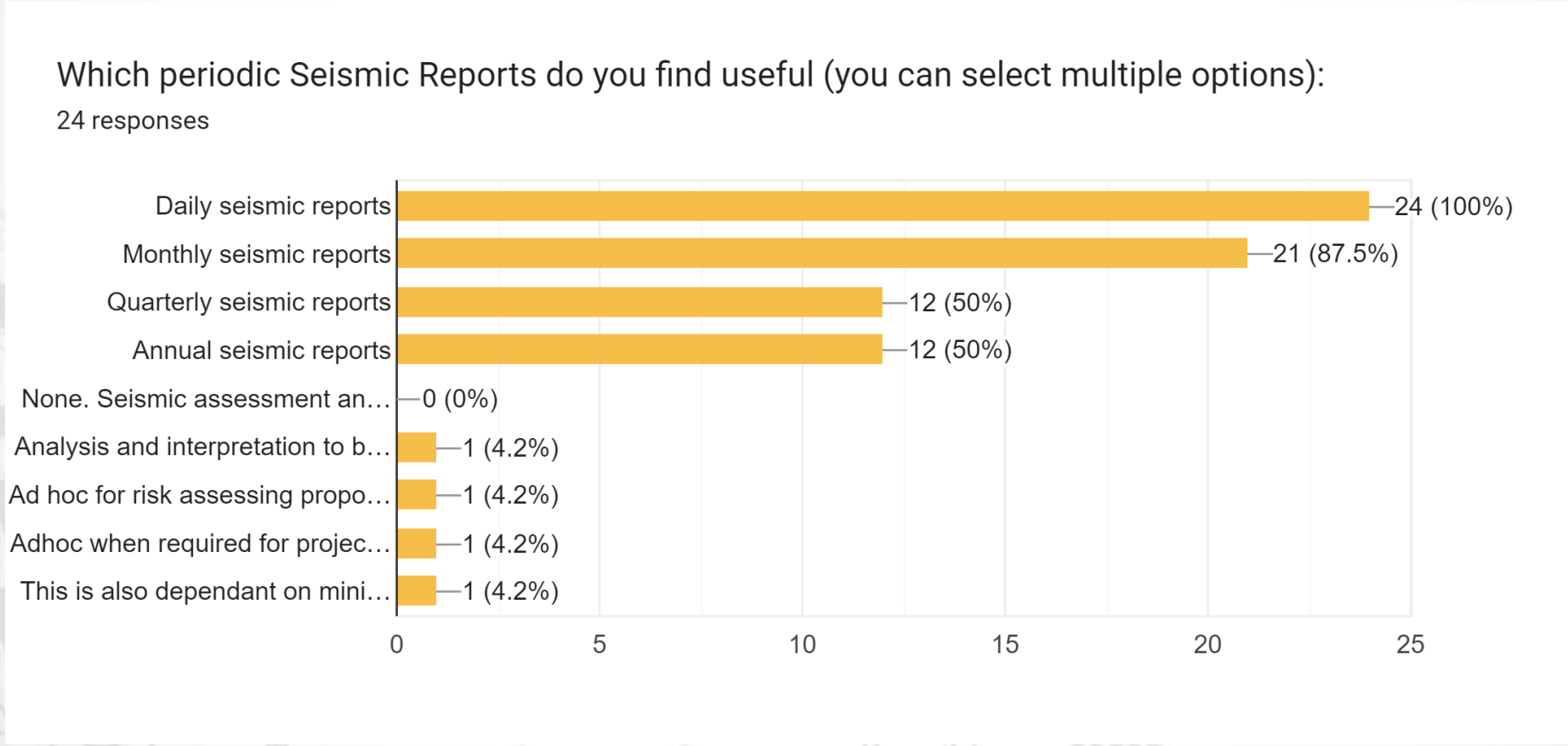
Rock Engineering Survey

Respondent Qualifications



Rock Engineering Survey

Seismic reports used by Rock Engineers

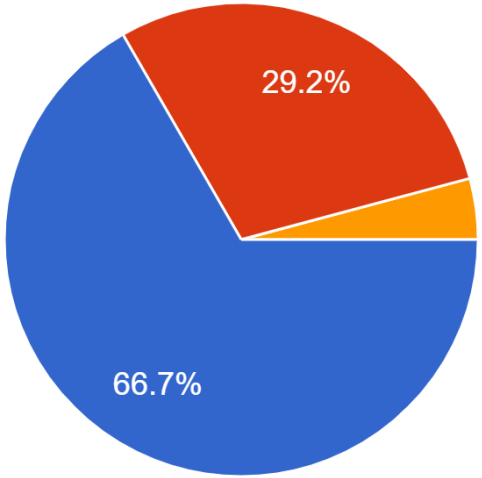


Rock Engineering Survey

Role of Rock Engineer ito seismic data

What do you believe the role of the Rock / Geotechnical engineer is in assessing and addressing seismic activity on the mine:

24 responses



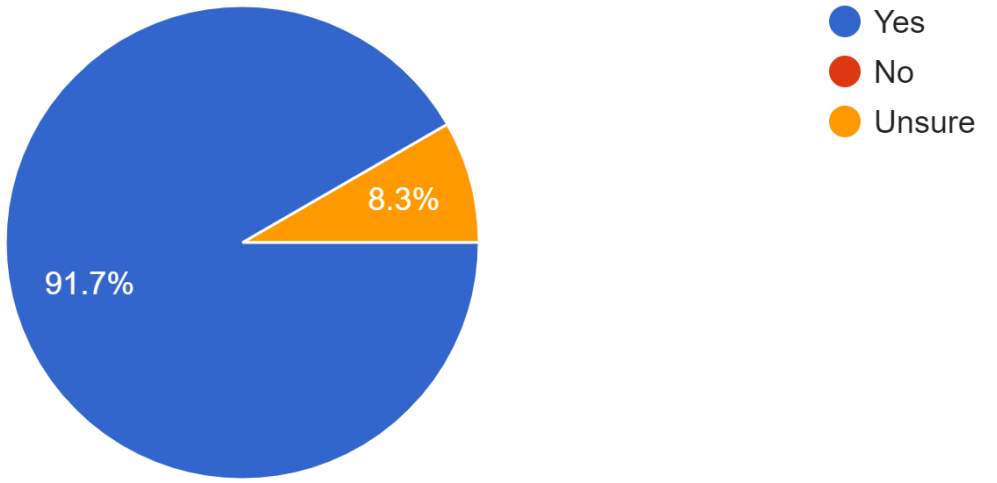
- The Rock / Geotechnical engineering department will review the seismic data analysis done by seismologists and use the seismologist recommendations in planning and recommendations to production personnel. The Rock / Geotechnical engineering department does not have to be experts in seismology as they contract seismic service providers to interpret seismic responses to mining.
- The Rock / Geotechnical engineering department must plan their seismic system layout, conduct seismic data analyses, and have a deep understanding of how to read and control seismic activity. The Rock / Geotechnical engineering department must be absolute experts in seismology and should not rely solely on the input from seismologists.
- Seismic activity and the study of seismology should not be a Rock / Geotechnical engineering function. The seismic experts should be a separate function on the mine that consults directly with production personnel.

Rock Engineering Survey

Respondent ability to affect protocols

On your mine, are you able to identify the shortfalls or improve on the predefined protocols for adjusting mining operations based on seismic activity?

24 responses

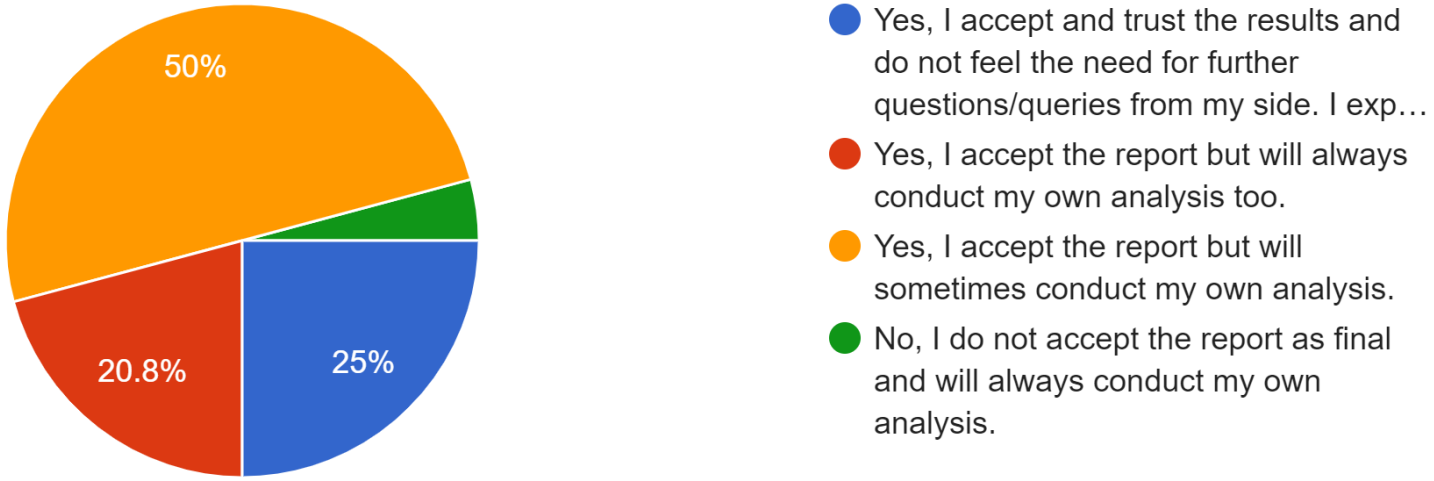


Rock Engineering Survey

Confidence placed on received ‘Alerts’

If a periodic report is “GREEN” or there are “NO ALERTS” in the report, do you accept the report or conduct your own review and analysis of the period represented by the report?

24 responses



Rock Engineering Survey

Well-understood seismic parameters

Which seismic parameter(s) are you most comfortable with?
Name the seismic parameters you use and understand (from the top of your head):

- Event rate and distribution.
- Large indicator, Activity rate, Potency
- Lead/lags and Face shape
- Location, activity rate, potency, Local Magnitude, Moment, Energy
- Moment, time, energy, XYZ, mechanism
- X Y Z, time, energy moment
- Seismic moment, time, location
- Activity rate
- Event Magnitude, b-value, P-wave, S-wave, slip or crush event, seismic moment, peak particle velocity
- magnitude
- Magnitude, Seismic Moment
- Magnitude
- Magnitude, Sensetivity,Clusturing, Activity rate, Source failure mechanism, after shock
- local magnitude, potency, ERR, ESS
- seismic activity
- Cum Apparent Volume, Schmidt number, Energy Index, Activity rate
- Time, location, energy, moment, hazard magnitude, Schmidt number, activity rate, clustering, source parameters potency, cumulative apparent volume,
- Potency
- Knowledge of different parameters are difficult to understandt.
- Moment-tensor decomposition, potency, local magnitude, ToD distribution, location accuracy (cloud), off-shift/on-shift percentage, mMax, Gutenberg-Richter anaylsis, clustering
- Potency / Production, Cumulative displacement, ERR
- Magnitude of potential damaging seismic events, location (clustering), number of events in a given period, potency, source mechanism, probability of reoccurrence
- Seismic Potency
- NONE

Rock Engineering Survey

Confusing seismic parameters

Which seismic parameter(s) confuse you?
Name (up to three) parameters you stay away from using because they are confusing to you.

- Schmidt number, seismic latency
- Schmidt, EI index
- Not applicable
- Debora's number, Schmid number,
- Time, energy, location
- Potency, EI Index, Activity, Schmidt, Events
- None
- Schmidt number
- seismic moment
- focal mechanism plots
- Debora number, Energy Index, Seismic Schmidt number
- None
- Potency, Moment Tensor,
- Moment tensor
- Schmidt number
- Any analysis in time domain without including the driver like volume mined.
- None
- None
- Knowledge of different parameters are difficult to understand
- Moment magnitude
- Schmidt Index, Sum of Moment & Energy, Normalized activity Rate
- Moment tensor, PGV, Total energy

Rock Engineering Survey

Preferred and important seismic parameters

Are there specific parameters you prefer to use when planning and sequencing mining operations? Name the top parameter(s) that you consider vital to your planning.

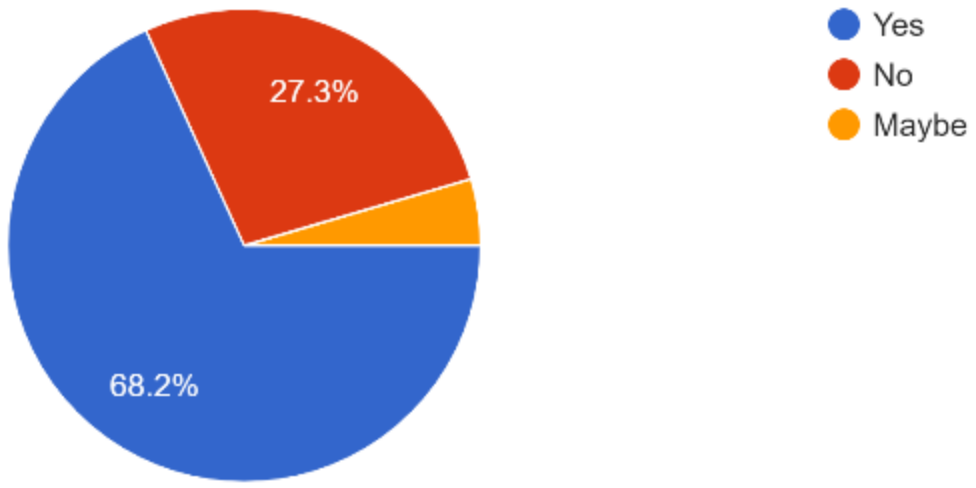
- Using the SRP graphs and potency
- Lead/Lags and Face shape
- Cumulative Potency normalized to cumulative production
- Mechanism, location
- Monthly seismic Rating, Magnitude, Mechanism, Hazard Map
- Local magnitude, frequency of occurrences, mining geometry and presence of adverse geology
- Numerical modeling incorporating seismic history
- Energy release rate
- ESS; Lead and Lags
- Magnitude, Energy Release Rates
- No
- Probability of reoccurrence, magnitudes,
- ERR, ESS
- Seismic activity rate
- Activity rate
- Clustering, source parameters, activity rate, location, potency, production rates.
- Stress, ERR, ride/potency, RCF
- Knowledge of different parameters are difficult to understand
- Time-of-day distribution, cumulative potency/production, damaging or large event frequency, event location, raise line seismic hazard ranking
- ERR's, Sigma 1
- Probability of reoccurrence, expected magnitudes and related damages, clustering of events

Rock Engineering Survey

Implementation of seismic data

Are there instances where you have adjusted monthly planning and sequencing proposed by the production personnel (monthly planning meeting), based on findings from seismic reports?

22 responses



Rock Engineering Survey

Most used re-entry protocols

When you receive a seismic report which is “RED” or there are “CRITICAL ALERTS” which according to protocol, stops a working place and withdraws t...re-entry procedure you are most comfortable with:

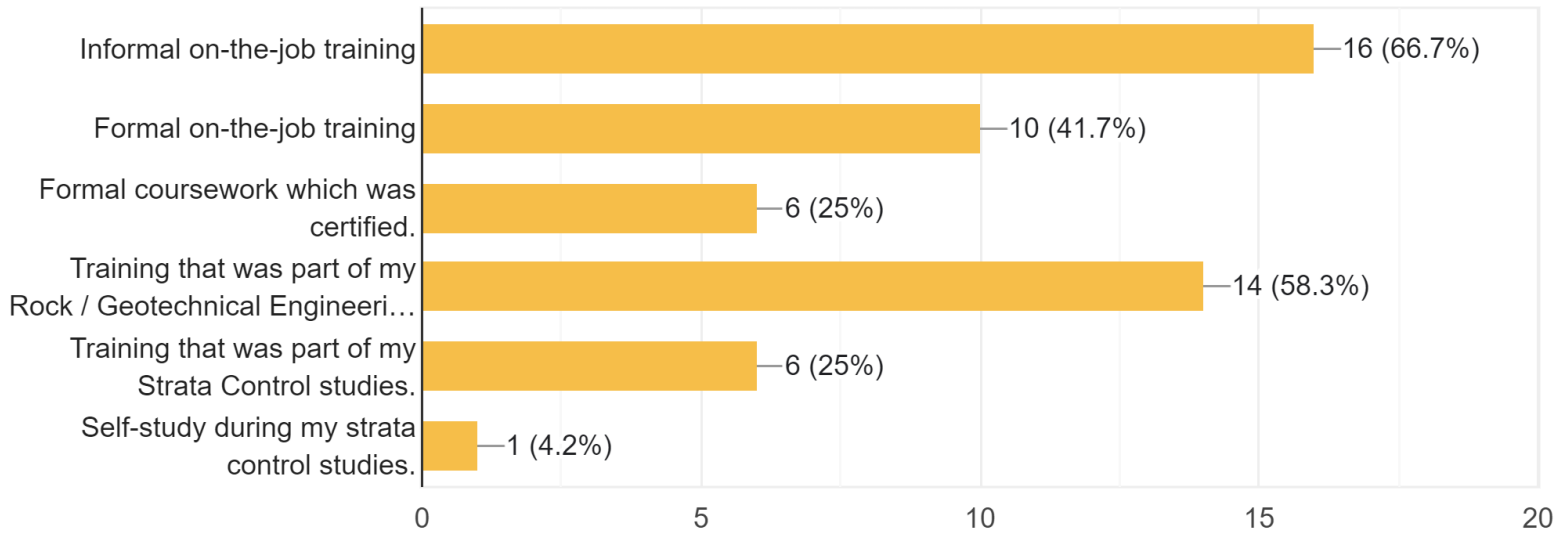
24 responses

Rock Engineering Survey

Mine seismology training to date

Have you received training on seismic systems and seismic data analysis (you can select more than one answer)?

24 responses



Rock Engineering Survey

Mine seismology training needs

Do you feel you need more seismic training to (effectively) do what is expected of you as a Rock / Geotechnical engineering representative?

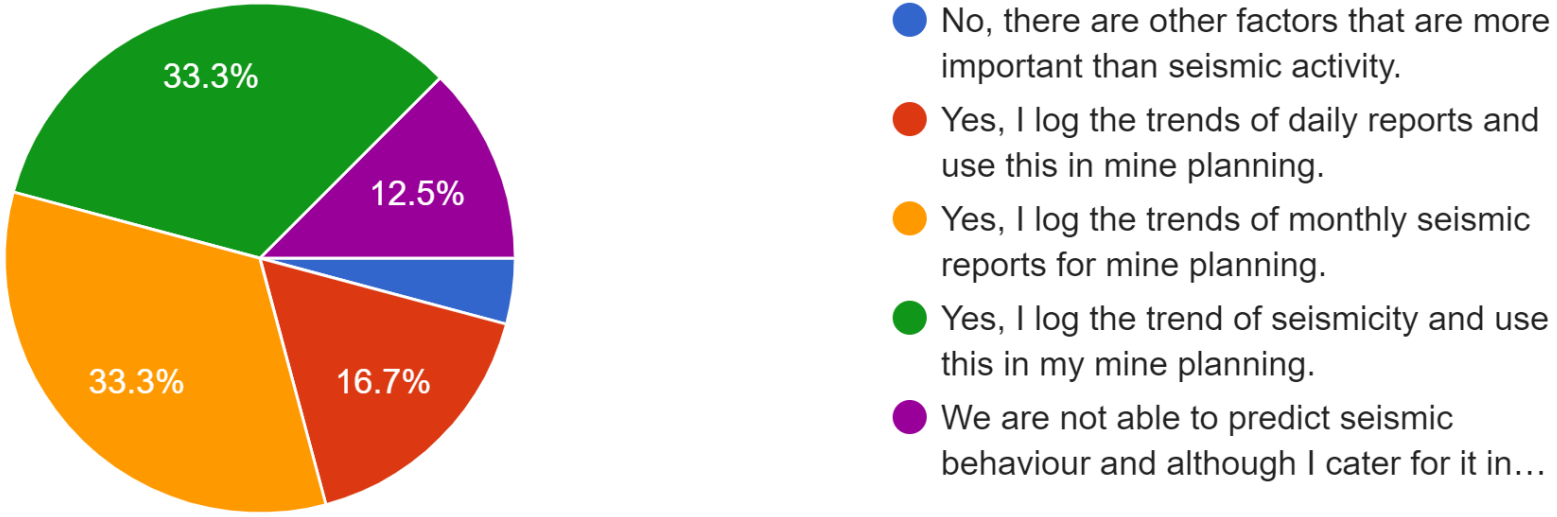
24 responses

Rock Engineering Survey

Impact of mine seismology reports on planning

Do periodic seismic reports govern your mine planning? Select the best option from the list below.

24 responses



Rock Engineering Survey

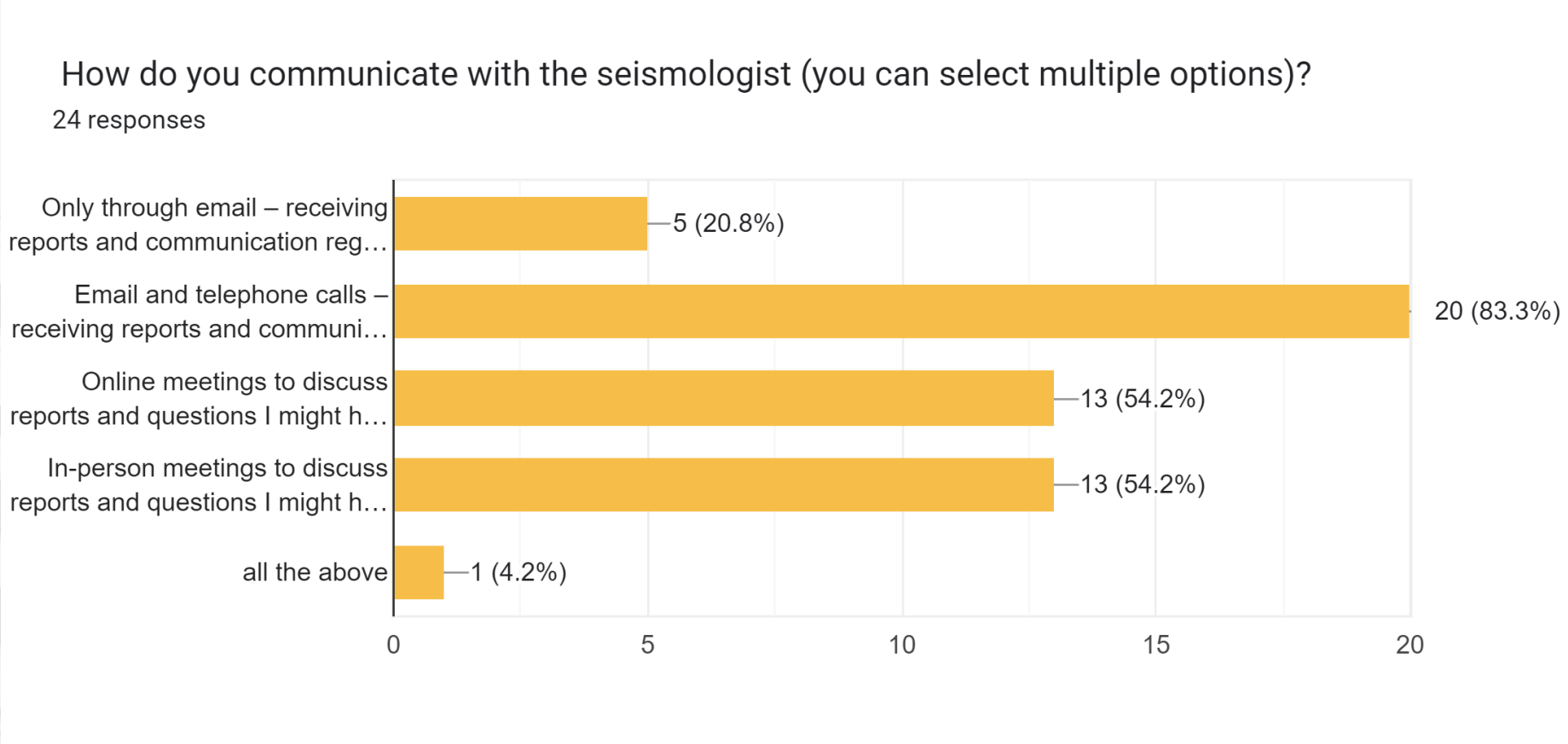
Mine seismology reports as ‘critical’ information

When you arrive at the office in the morning, do you consider seismic reports a critical report to review daily or only when there are seismic alerts?

24 responses

Rock Engineering Survey

Communication method with seismologists

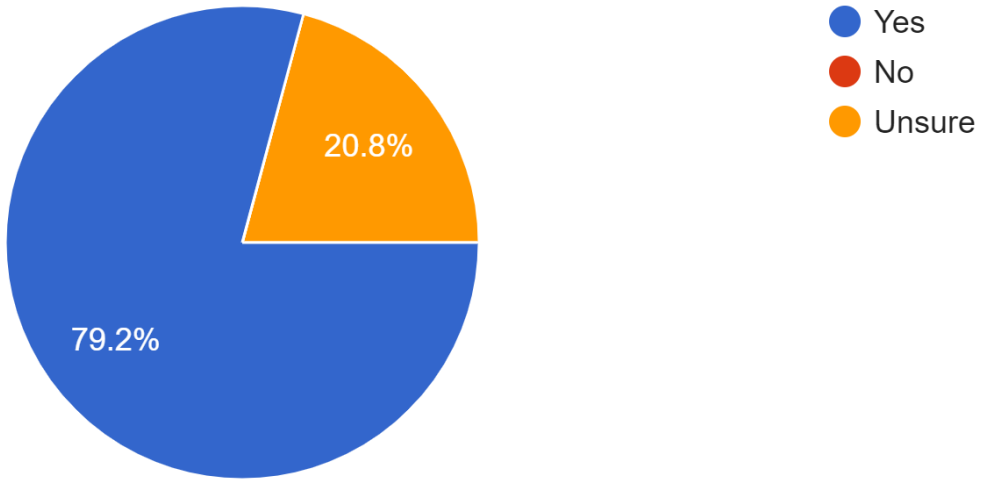


Rock Engineering Survey

Mine seismologist communication impact

Do you feel the communication and service from your seismologist is satisfactory and empowers you to make confident decisions?

24 responses



Rock Engineering Survey

Mine seismology software packages

Are you able to operate software packages that display and analyze seismic data?

24 responses

Operational Review – Shallow vs Deep Summary