Drilling Applications

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QUARRY
ACADEMY

Improving Processes. Instilling Expertise.

Drilling Management

Agenda

- well planned operations and correctly selected rigs yields low cost drilling
- technically good drilling and correctly selected drill steel yields low cost drilling operations
- straight hole drilling yields safe and low cost D&B operations

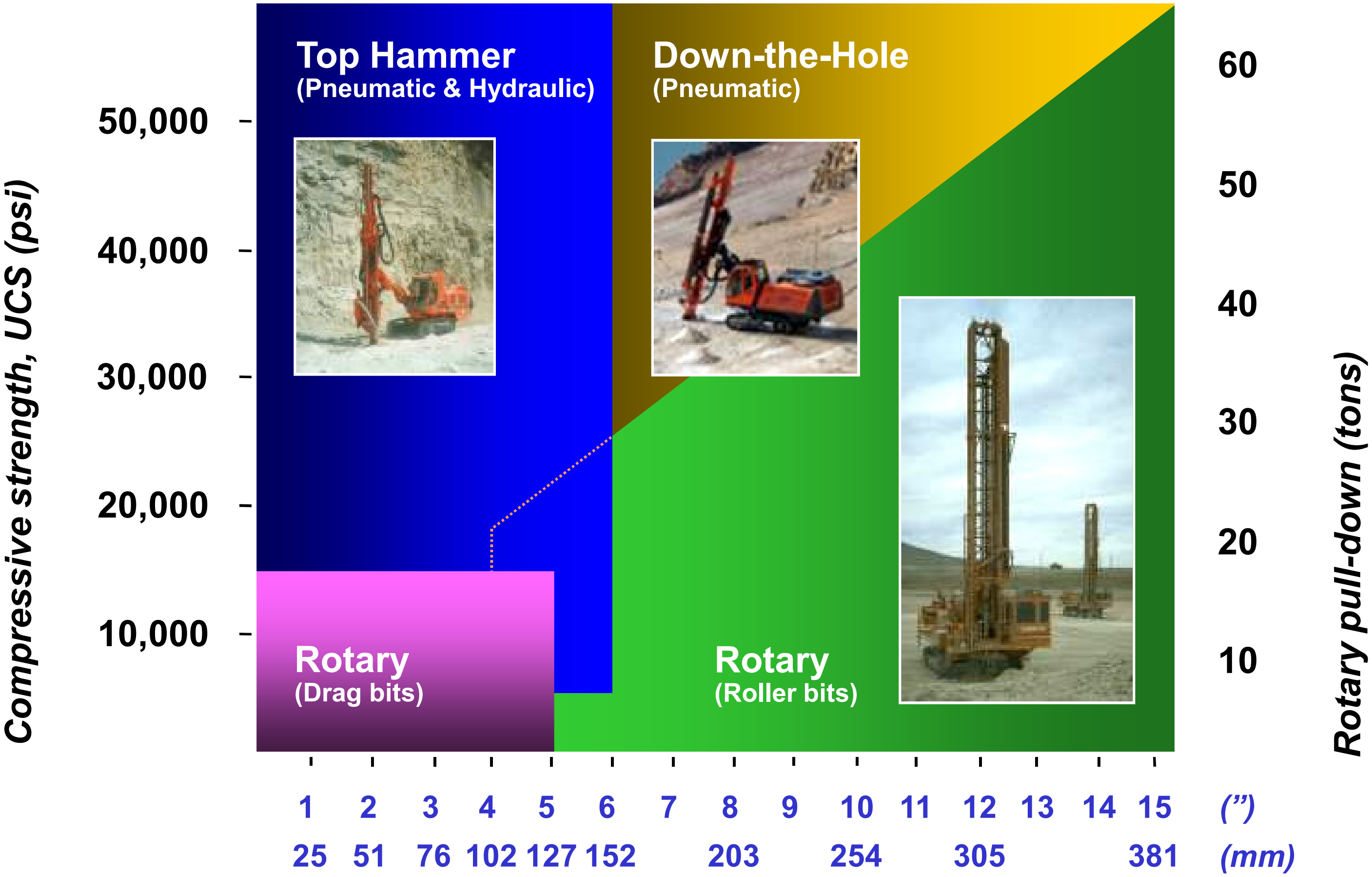
Drilling Management

Drilling consists of a working system of:

- *bit*
- *drill string*
- *boom or mast mounted feed*
- *TH or DTH - hammer*
  Rotary - thrust
- *drill string rotation and stabilising systems*
- *drilling control system(s)*
- *collaring position and feed alignment systems*
- *flushing (air, water or foam)*
- *dedusting equipment*

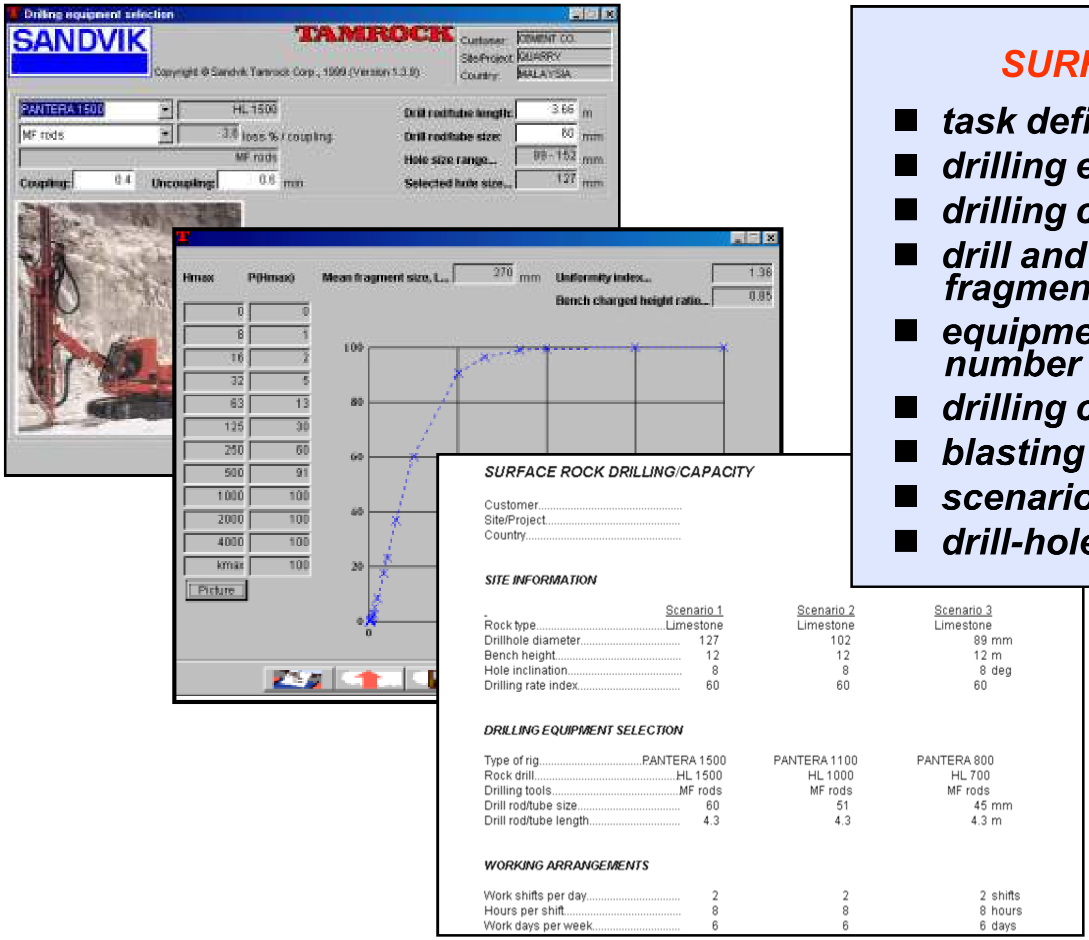
Drilling Management

The most common drilling methods in use



Drilling Management

Simulation tools - Study programs



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Customer: CEMENT CO.
Site/Project: QUARRY
Country: MALAYSIA

PANTERA 1500 — HL 1500
MF rods — 3.8 loss % / coupling
MF rods
Coupling: 0.4 Uncoupling: 0.6 min

Drill rod/tube length: 3.66 m
Drill rod/tube size: 60 mm
Hole size range... 89 - 152 mm
Selected hole size... 127 mm

Mean fragment size, L... 270 mm
Uniformity index... 1.36
Bench charged height ratio... 0.85

Hmax	P(Hmax)
0	0
8	1
16	2
32	5
63	13
125	30
250	60
500	91
1000	100
2000	100
4000	100
kmax	100

SURFACE ROCK DRILLING/CAPACITY

Customer..
Site/Project..
Country..

SITE INFORMATION

	Scenario 1	Scenario 2	Scenario 3
Rock type	Limestone	Limestone	Limestone
Drillhole diameter	127	102	89 mm
Bench height	12	12	12 m
Hole inclination	8	8	8 deg
Drilling rate index	60	60	60

DRILLING EQUIPMENT SELECTION

Type of rig	PANTERA 1500	PANTERA 1100	PANTERA 800
Rock drill	HL 1500	HL 1000	HL 700
Drilling tools	MF rods	MF rods	MF rods
Drill rod/tube size	60	51	45 mm
Drill rod/tube length	4.3	4.3	4.3 m

WORKING ARRANGEMENTS

Work shifts per day	2	2	2 shifts
Hours per shift	8	8	8 hours
Work days per week	6	6	6 days

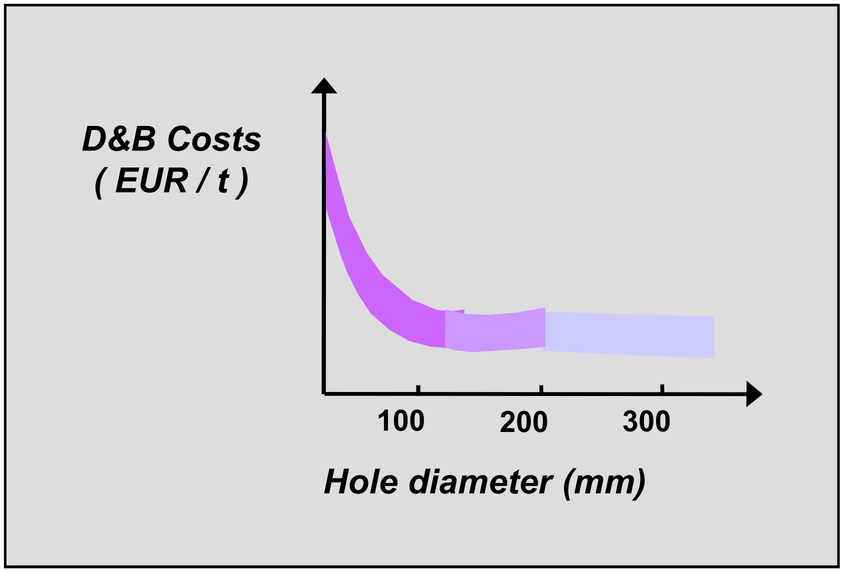
SURFACE STUDY PROGRAM

- task definition / site information
- drilling equipment / tools selection
- drilling capacities
- drill and charge patterns versus shotrock fragmentation and boulder count
- equipment performance and required number of units
- drilling costs
- blasting costs
- scenarios (optimisation)
- drill-hole deviation

Drilling Management

Criteria for selecting drills

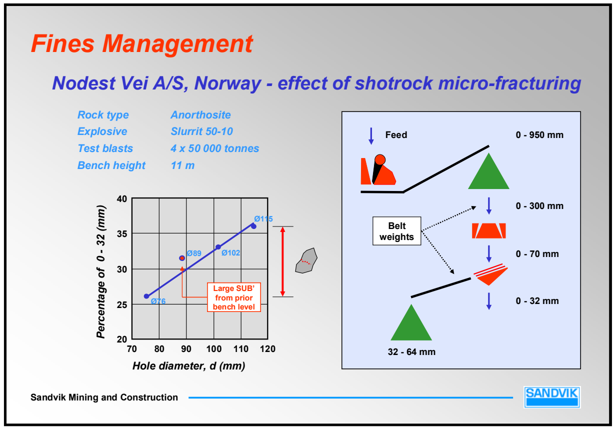
- *annual production requirements in bm^3 or t* => *number of drills*
- *critical diameter of explosive* => *hole size big enough?*
- *flexibility in usage* => *different types of work?*
- *application costing* => *D&B costs per bm^3 or t*
- *level of automation*
- *operator startup training*
- *operator comfort and safety*
- *ease of transport between pits*



Drilling Management

Quarries and D&B Contractors

- *equipment flexibility and reliability*
- *blast to aggregate production requirements*
- *ability to handle difficult ground conditions*
- *availability of local / on-call field service*



Fines Management

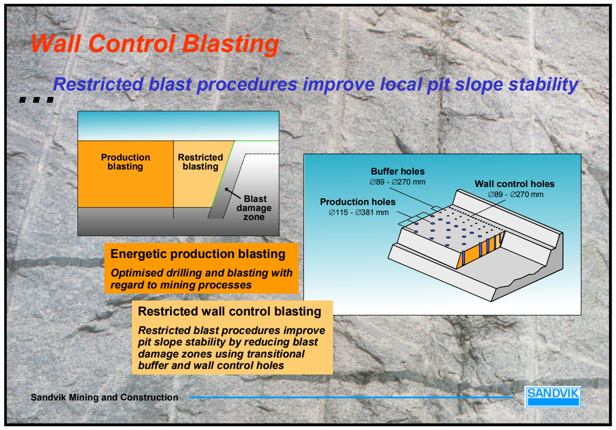
Nodest Vei A/S, Norway - effect of shotrock micro-fracturing

Rock type	*Anorthosite*
Explosive	*Slurrit 50-10*
Test blasts	*4 x 50 000 tonnes*
Bench height	*11 m*

Sandvik Mining and Construction

Mines and Mining Contractors

- *wall control blasting (plus dewatering, depressurisation and bolting holes)*
- *grade control (sampling, MWD, …)*
- *system for tracking consumables, engine hours, …*
- *inpit remote controlled / automated drills*
- *availability of service contracts*



Wall Control Blasting

Restricted blast procedures improve local pit slope stability

Energetic production blasting

Optimised drilling and blasting with regard to mining processes

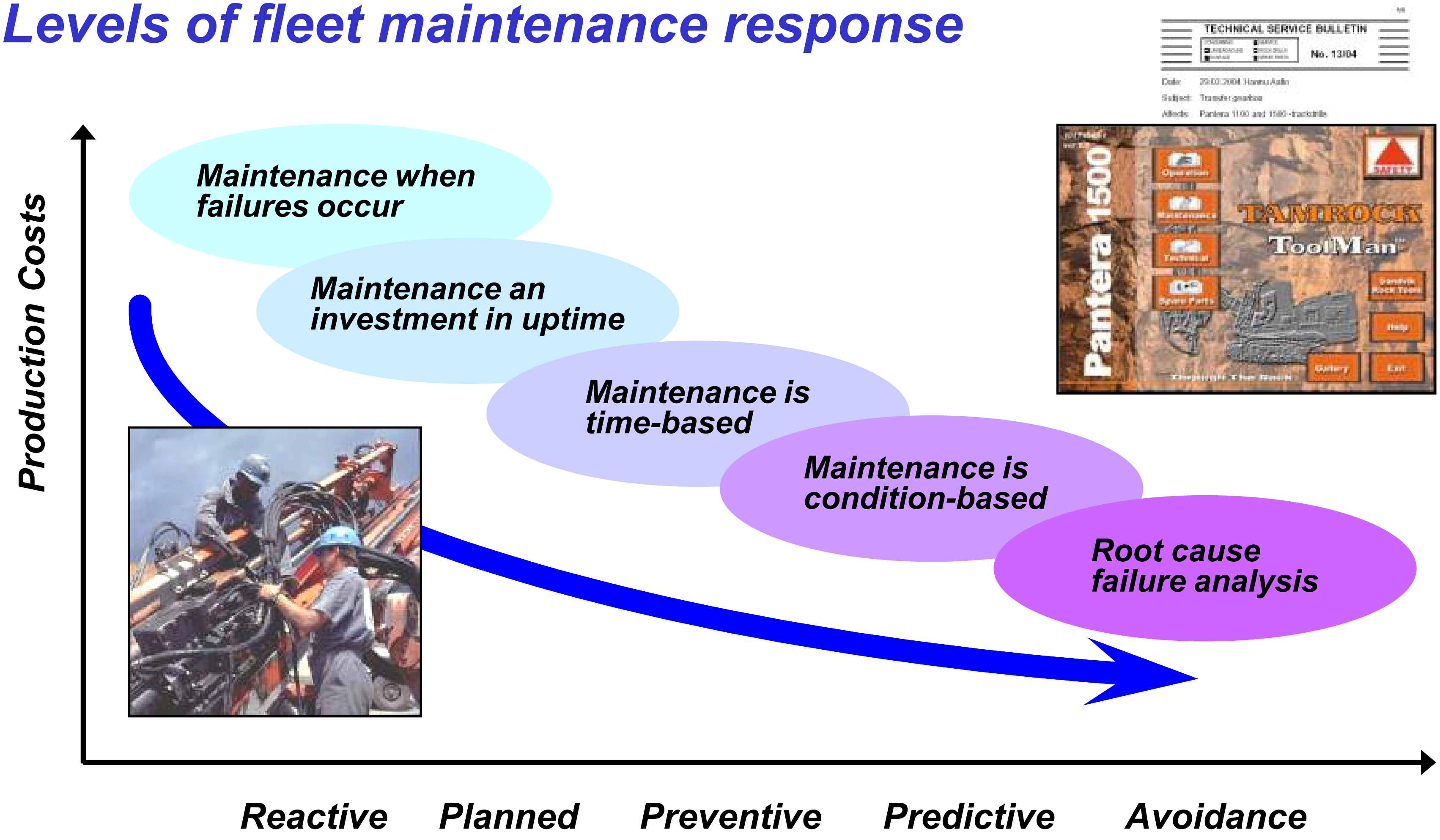
Restricted wall control blasting

Restricted blast procedures improve pit slope stability by reducing blast damage zones using transitional buffer and wall control holes

Sandvik Mining and Construction

Fleet Management

Levels of fleet maintenance response



Production Costs

Maintenance when failures occur

Maintenance an investment in uptime

Maintenance is time-based

Maintenance is condition-based

Root cause failure analysis

Reactive Planned Preventive Predictive Avoidance

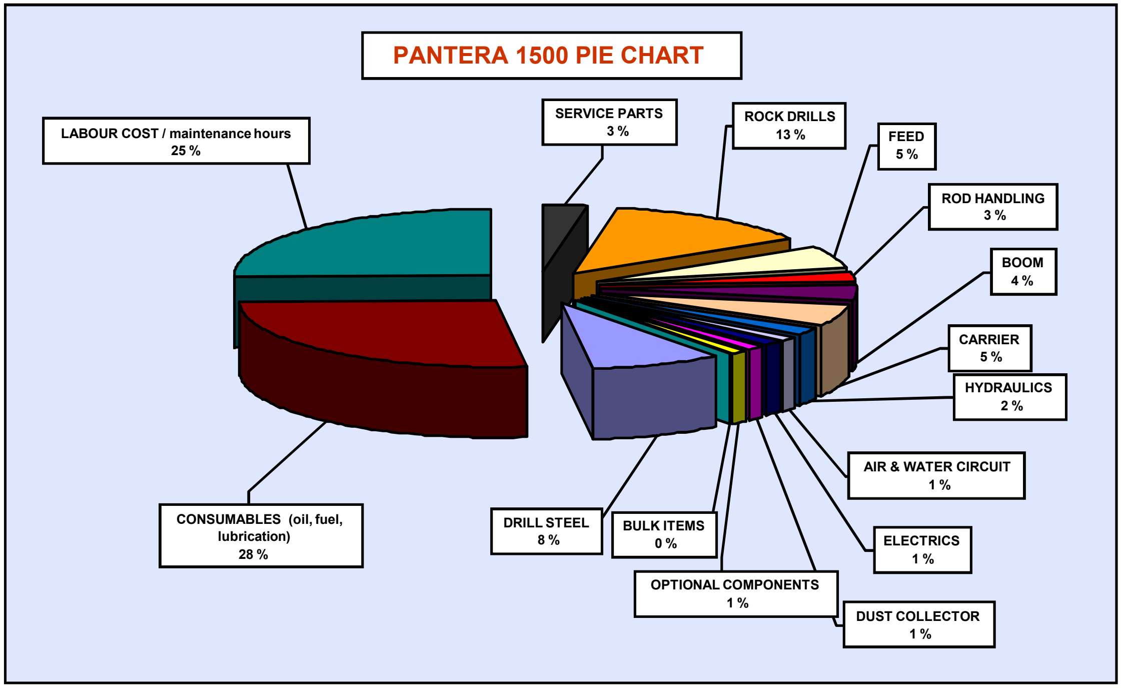
Fleet Management

Machine Lifecycle Operating Costs, MLOC

Fleet Management

Machine Lifecycle Operating Costs, MLOC

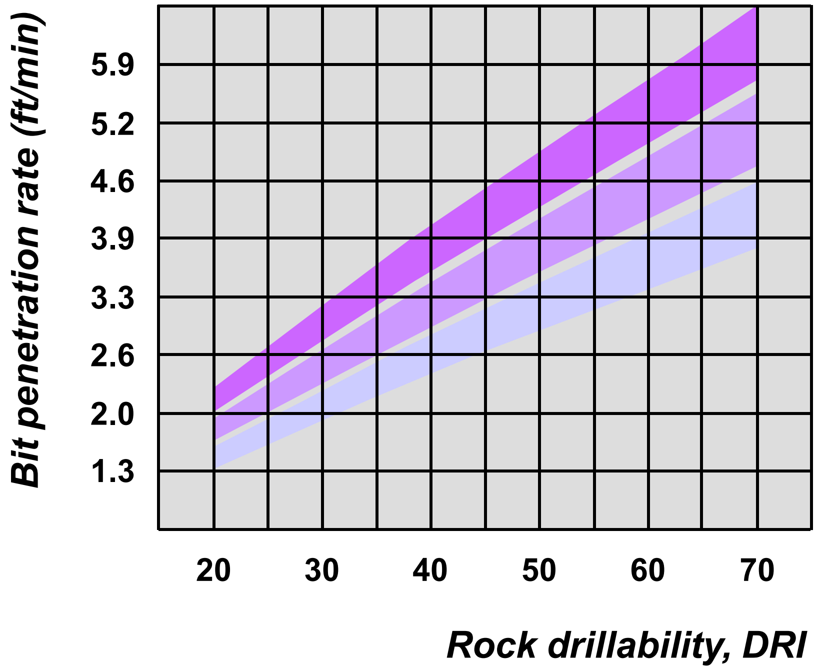
MLOC provides a tool which will guide a person without intimate knowledge of conditions and maintenance procedures to generate realistic estimates of operational costs for equipment in specific conditions



Drilling Management

TH - predicting bit penetration rates (ft/min)

- *rock mass drillability, DRI*
- *percussion power level in rod(s)*
- *bit diameter*
  - ✓ *hole wall confinement of gauge buttons*
- *goodness of hole-bottom chipping*
  - ✓ *bit face design and insert types*
  - ✓ *drilling parameter settings (RPM, feed)*
- *flushing medium and return flow velocity*



HL510/HLX5T	51 mm	2”
HL600	64 mm	2.5”
HL710/800T	76 mm	3”
HL1500/1560T	102 mm	4”

HL510/HLX5T	64 mm	2.5”
HL600	76 mm	3”
HL710/800T	89 mm	3.5”
HL1000	89 mm	3.5”
HL1500/1560T	115 mm	4.5”

HL510/HLX5T	76 mm	3”
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HL710/800T	102 mm	4”
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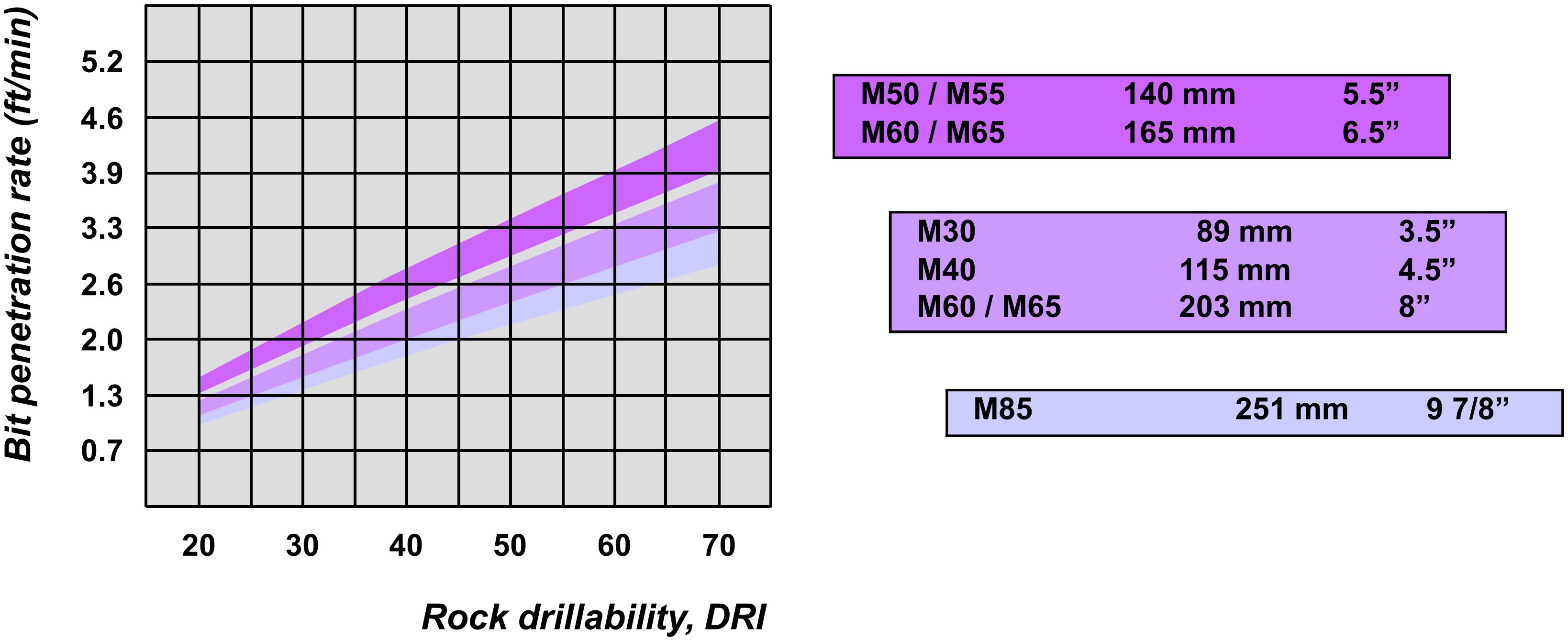
HL1500/1560T	127 mm	5”

Drilling Management

DTH - predicting bit penetration rates (ft/min)

- *rock mass drillability, DRI*
- *percussion power of hammer*
- *bit diameter*
  - ✓ *hole wall confinement of gauge buttons*
- *goodness of hole-bottom chipping*
  - ✓ *bit face design and insert types*
  - ✓ *drilling parameter settings (RPM, feed)*
- *flushing and return flow velocity*



M50 / M55	140 mm	5.5”
M60 / M65	165 mm	6.5”

M30	89 mm	3.5”
M40	115 mm	4.5”
M60 / M65	203 mm	8”

M85	251 mm	9 7/8”

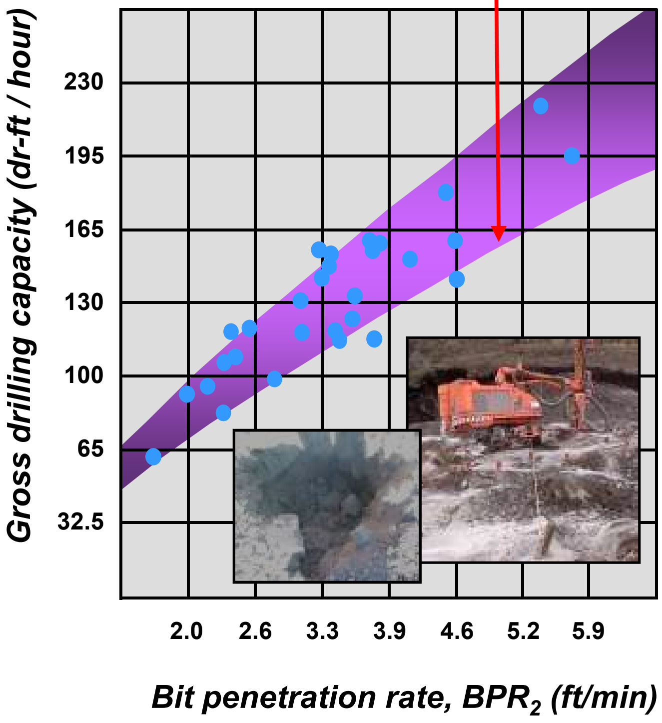
Drilling Management

Gross drilling capacities (dr-ft/shift)

- ***rig setup and feed alignment time per drill-hole***
- ***collaring time through overburden or sub-drill zone***
- ***drill-hole wall stabilisation time (if required)***
- ***rod handling times (unit time and rod count)***
- ***bit penetration rate loss percentage i.e.***
  - ✓ *rods and couplings* — *6.1 % per rod*
  - ✓ *MF rods* — *3.6 % per rod*
  - ✓ *tubes* — *2.6 % per tube*
- ***effect of percussion power levels on:***
  - ✓ *bit penetration rates*
  - ✓ *drill steel service life*
  - ✓ *drill-hole straightness*
- ***rig tramming times between benches, refueling, etc.***
- ***effect of operator work environment on effective work hours per shift***
- ***rig availability, service availability, service and maintenance intervals***

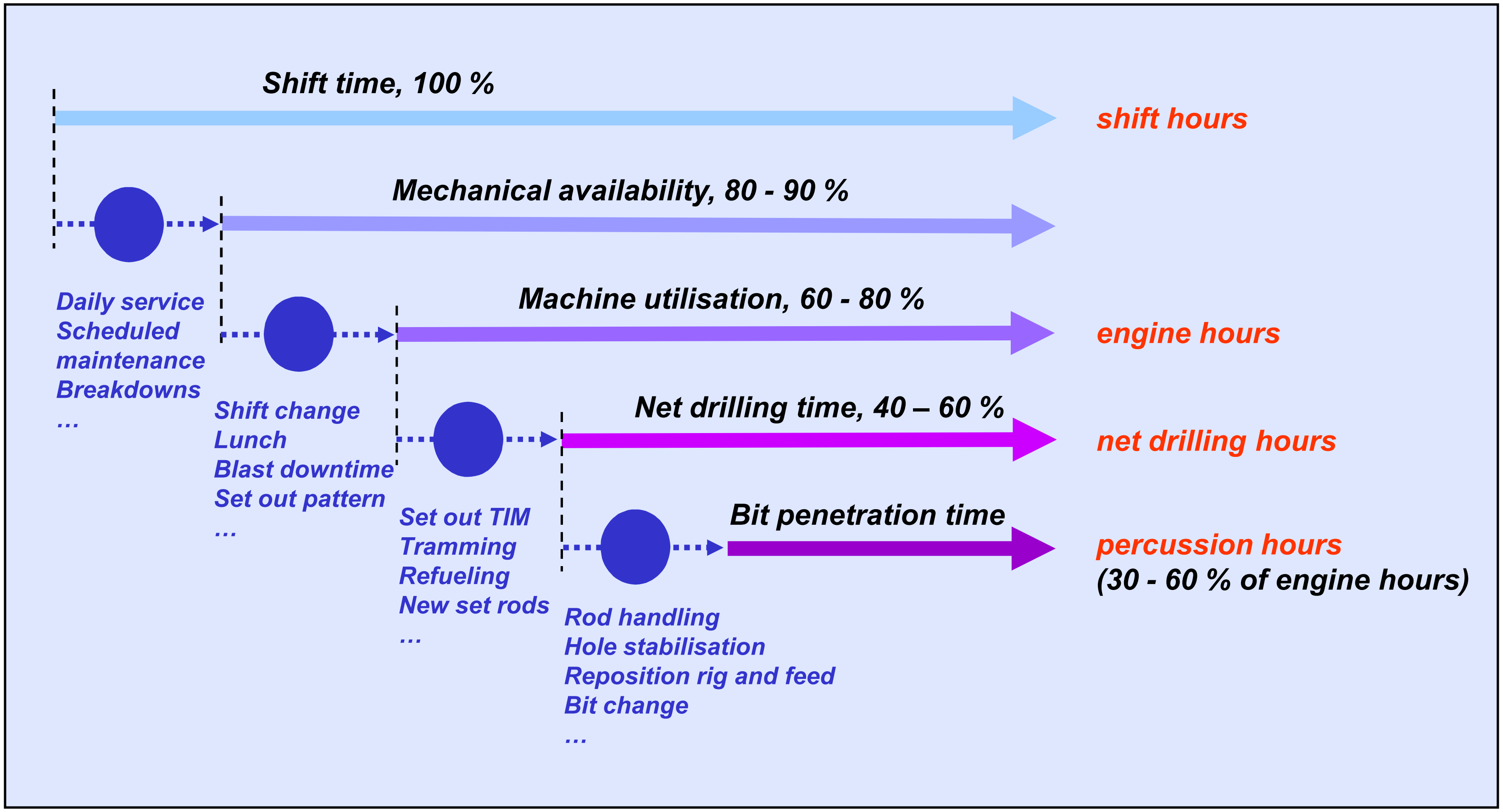
Poor net drilling capacities for:

- ✓ **very broken rock**
- ✓ **terrain benches - winching**
- ✓ **very low or very high benches**
- ✓ **very poor collaring conditions**



Drilling Management

Typical breakdown of long term rig usage and capacities



Shift time, 100 % — shift hours

Mechanical availability, 80 - 90 %

Daily service
Scheduled maintenance
Breakdowns
…

Machine utilisation, 60 - 80 % — engine hours

Shift change
Lunch
Blast downtime
Set out pattern
…

Net drilling time, 40 – 60 % — net drilling hours

Set out TIM
Tramming
Refueling
New set rods
…

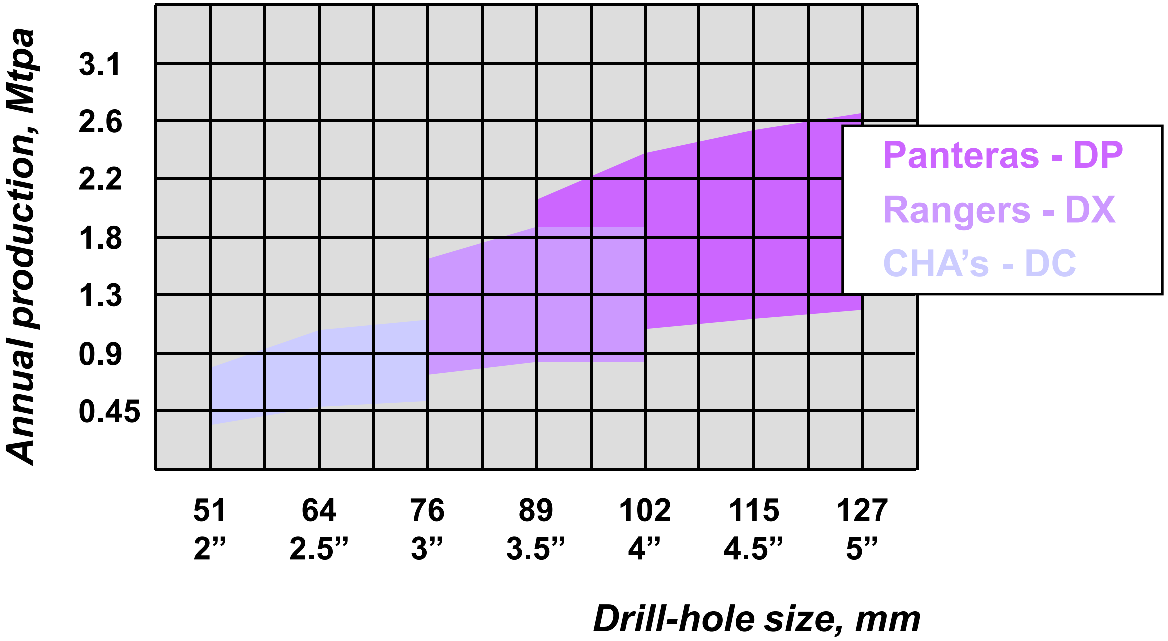
Bit penetration time — percussion hours (30 - 60 % of engine hours)

Rod handling
Hole stabilisation
Reposition rig and feed
Bit change
…

Drilling Management

TH - annual drill rig production capacities

- *shifts per year* *225* = *5 d/w · 45 w/a*
- *shift hours per year* *1800* = *8 h/d · 5 d/w · 45 w/a*
- *engine hours per year* *1224* = *1800 · 68 % utilisation*
- *rock density, g/cm^3* *2.7*



Drilling Management

DTH - annual drill rig production capacities

- *shifts per year* *225* *= 5 d/w · 45 w/a*
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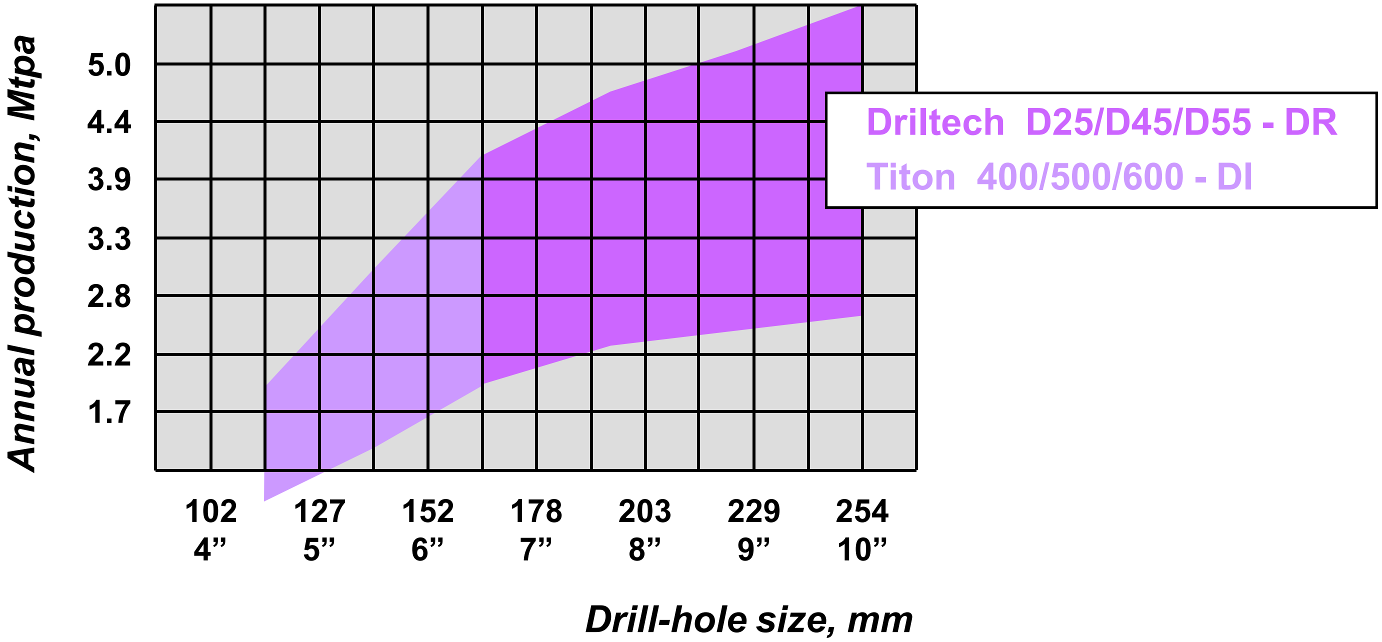

Drilling Management

Drilling operational items and objectives

- drill patterns as per blasting supervisors specs
- site preparation and procedures for:
  - ✓ removal or drilling through prior sub-drill zone
  - ✓ marking of collaring positions
  - ✓ drill-hole alignment
  - ✓ minimising drill-hole deflection
  - ✓ drill-hole depth control
- selection of percussion power level and other drilling parameters
- selection of drill steel, bit regrinding procedures and consumption followup
- scheduled equipment service and maintenance
- production reporting and work documentation for Quality Assurance
  - ✓ shift, weekly reports, …
  - ✓ drilling deviation reports
- for contractors - rapid rig relocation to new jobsites

Prior bench level sub-drill zone removed

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Drilling Management

Site preparation

Drill-hole positioning, alignment and levelling

Drilling through overburden with foam flushing

Drilling after removing overburden

Drill-hole monitoring & documentation

Water tank for special drilling conditions

Bit regrinding

Field service

Refueling

Utility wagon

Transport to new jobsite

Drilling Management

Good drilling practices

Setup & Collaring

- ✓ lock oscillation cylinders, use rear jack (not lift rig), firmly push feed-pin into ground and keep retaining centralizer closed while drilling
- ✓ if the marked collaring point is in a bad spot (sloping surface, sinkholes, etc.) - it is then better to collar on the side and adjust feed alignment to correspond to the targeted drill-hole bottom
- ✓ have a plentiful supply and use shothole plugs to avoid rocks falling into shotholes

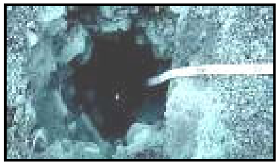
Drilling

- ✓ avoid drilling with hot couplings - adjust feed pressure or bit RPMs or change bit model
- ✓ change drill rods before threads are totally worn out - use thread wear gauges
- ✓ ensure that sufficient flushing is available - especially when drilling with large bits
- ✓ check that drilling is carried out with optimum bit RPMs with regard to button wear rates
- ✓ if the drill string bends while drilling - align feed to drill string so as to reduce the adverse effects of excessive drill string bending on hole straightness
- ✓ avoid excessive rattling against the hole-bottom and retaining centralizer when loosening threads (typically only 10 - 20 seconds)

Drill steel selection

- ✓ select bit type according to rock mass conditions e.g. retrac in broken ground, big front flushing hole(s) in weathered rock/mud seams, spherical buttons in hard and abrasive rock types, etc.
- ✓ select bits, drill rods/guide tubes according to service life or hole straightness requirements
- ✓ avoid excessive loss of bit diameter when regrinding - especially when using hand held grinders
- ✓ in non-abrasive rocks such as limestone, dolomite, etc. it can be advantageous to adopt frequent “touch-up” regrinds at the rig in stead of traditional regrinding procedures to remove snakeskin on button wearflats and wearflat edges

Drill-hole deviation



- ✓ excessive drill-hole deviation reduces drill steel life - typically caused by bit deflection when drilling through shears and mud seams
- ✓ rod breakage is reduced when using rods with loose couplings when compared to MF rods
- ✓ lower a flashlight to check drill-hole deflection depth as a rough rating of hole straightness

Drilling Management

Drilling in difficult (rock mass) conditions

Prior sub-drill zone

- ✓ stabilize drill-hole walls in the prior sub-drill zone with water added to the flushing air
- ✓ drill through the prior sub-drill zone with reduced percussion power and feed force. Adjust the flushing flow to a minimum so as to reduce return-air erosion around the collaring point
- ✓ if drill-hole walls tend to collapse - stabilise walls with additives such as Quik-Trol, EZ-Mud, ...

Very jointed rock

- ✓ use straight hole drill steel selection guidelines to minimise drill string deflection
- ✓ use retrac type bits and back-hammering to ease drill string extraction
- ✓ use power extractor if required to retrieve drill string
- ✓ adjust drilling parameter settings frequently to match drilling in varying geological conditions

Soft or weathered rock

- ✓ increase bit RPMs or use X-bits to increase bit resistance to indentation. This improves the percussion energy transfer efficiency ratio and reduces the feed force requirement - and reduces the problem of opening tight threads

Mud seams and shears

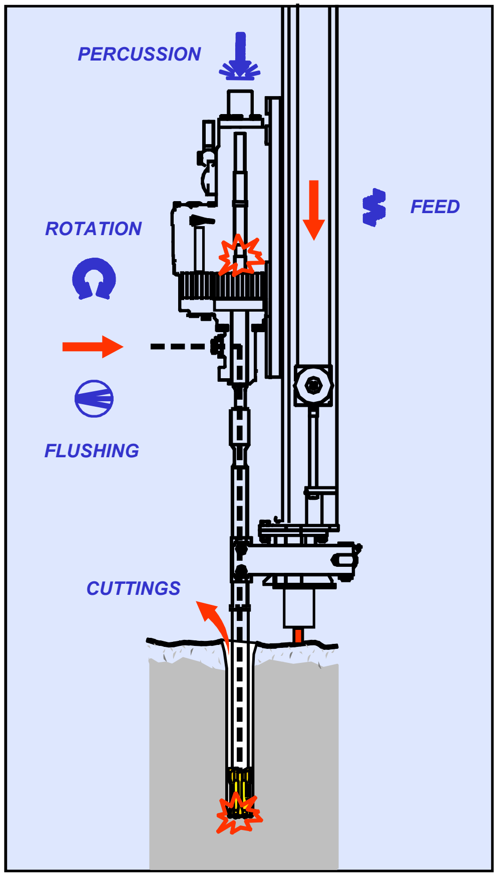
- ✓ use bits with big front flushing hole(s) to reduce the occurrence of bits getting stuck and the anti-jamming mechanism triggering in too often
- ✓ flushing control automatics recommended - it retracts the drill string when the flush flow is close to zero (adjustable set-point)
- ✓ do not retract the drill string too fast when drilling in mud so as to avoid the collapse of holes by this "vacuum" effect
- ✓ avoid high return-air velocities by reducing the flushing flow when drilling in water filled holes so as to avoid the added water erosion effect on drill-hole walls and the collaring point

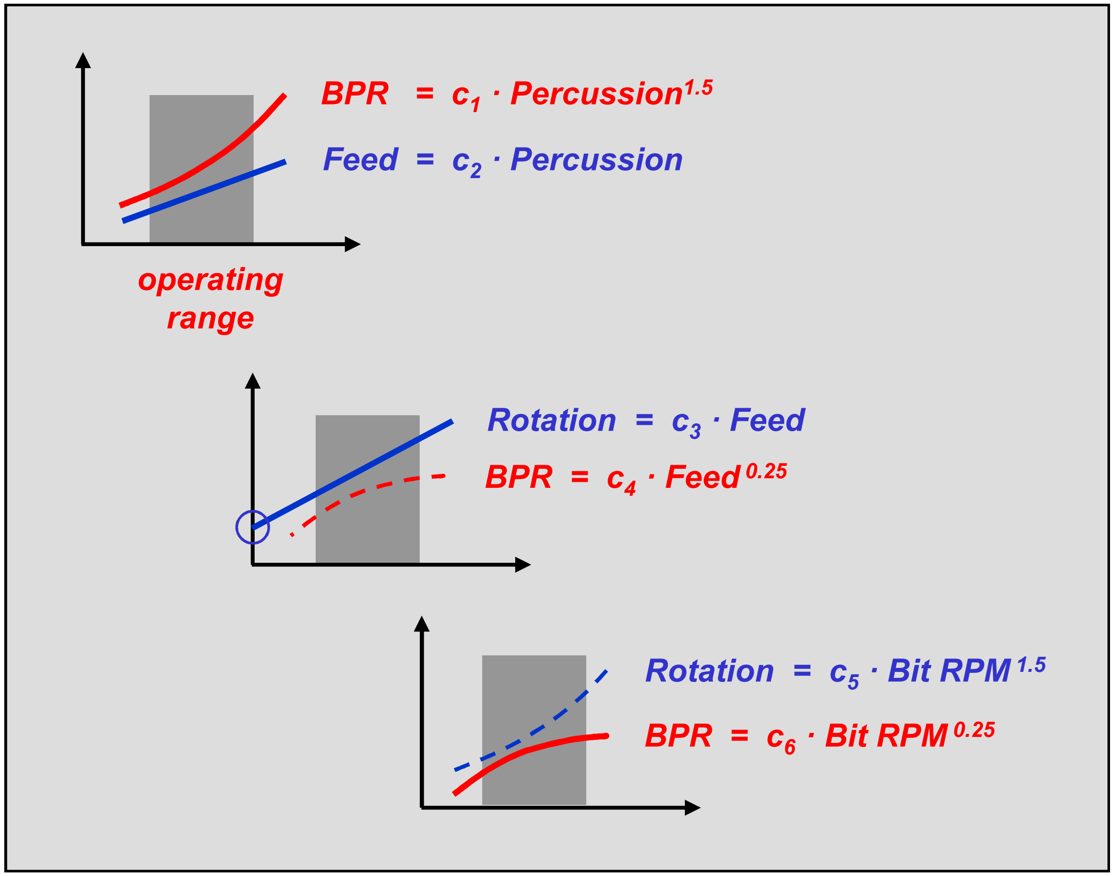
Dust prevention

- ✓ use "ZeroDust™" to avoid releasing dust into the air when the dust collector empties. "ZeroDust™" also reduces the amount of airborne dust after blasting.

Drilling Management

Relationships bwtween BPR and drill settings - TH





$\text{BPR} = c_1 \cdot \text{Percussion}^{1.5}$

$\text{Feed} = c_2 \cdot \text{Percussion}$

$\text{Rotation} = c_3 \cdot \text{Feed}$

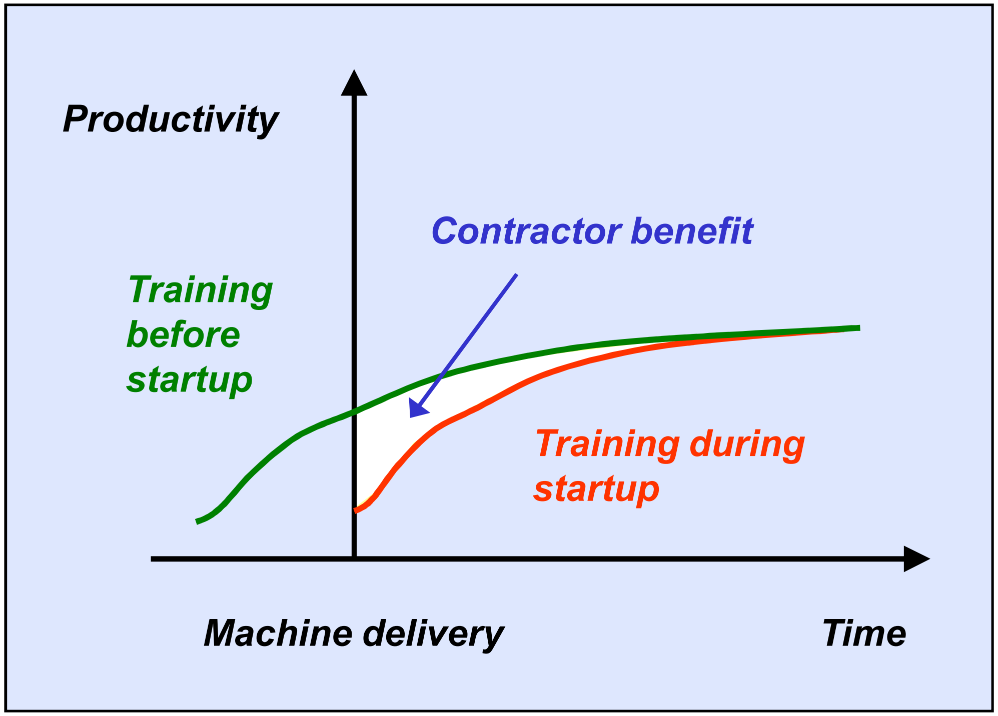
$\text{BPR} = c_4 \cdot \text{Feed}^{0.25}$

$\text{Rotation} = c_5 \cdot \text{Bit RPM}^{1.5}$

$\text{BPR} = c_6 \cdot \text{Bit RPM}^{0.25}$

Drilling Management

Simulation tools – Operator training for DPi



Drilling Management

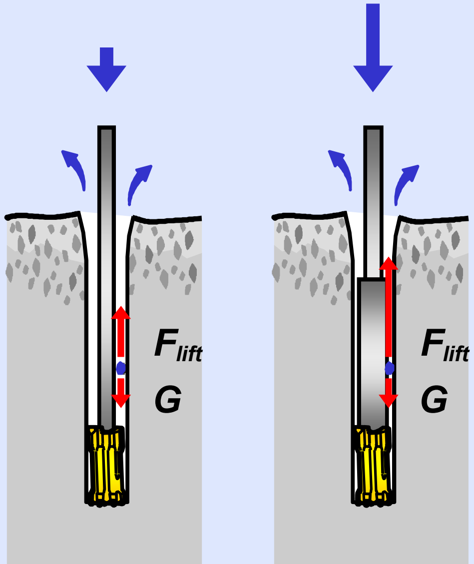
Flushing of drill-cuttings

Insufficient air < 50 ft/s

- *low bit penetration rates*
- *poor percussion dynamics*
- *interupt drilling to clean holes*
- *plugged bit flushing holes*
- *stuck drill steel*
- *"circulating" big chip wear*

Too much air > 100 ft/s

- *excessive drill steel wear*
- *erosion of hole collaring point*
- *extra dust emissions*
- *increased fuel consumption*



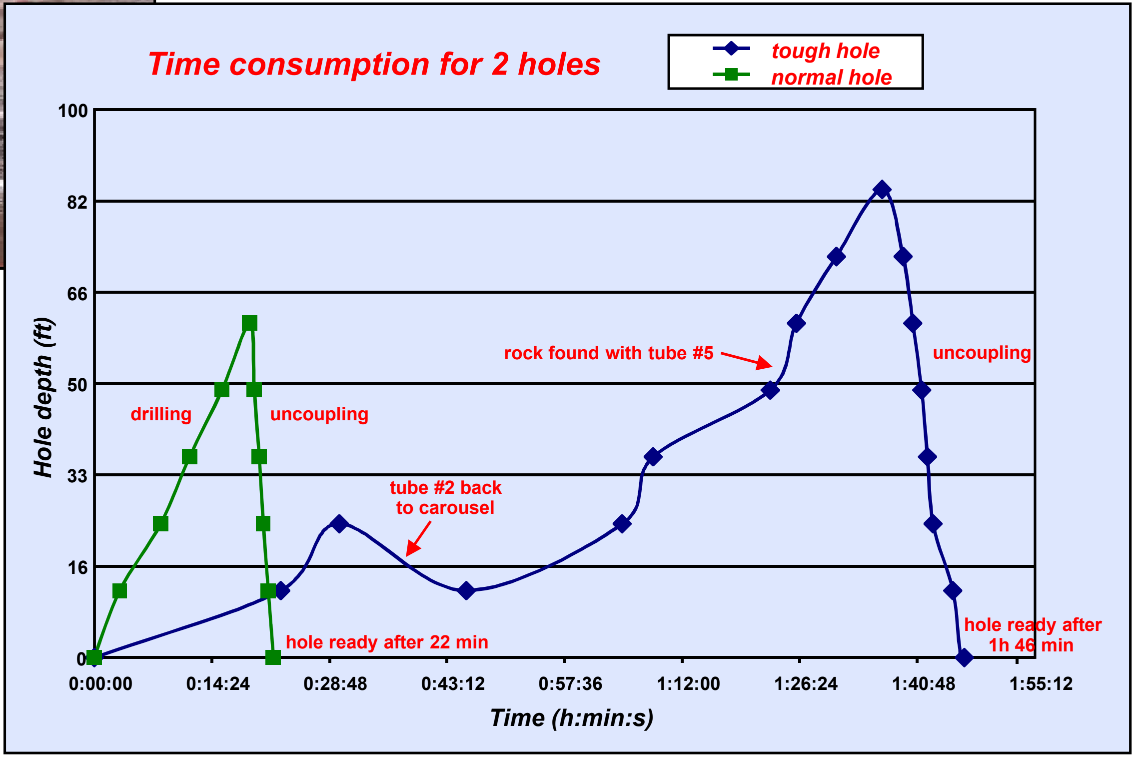
Correction factors

- *high density rock*
- *badly fractured rock*
  (air lost in fractures - use water or foam to mud up hole walls)
- *high altitude*
  (low density air)
- *large chips*

Drilling Management

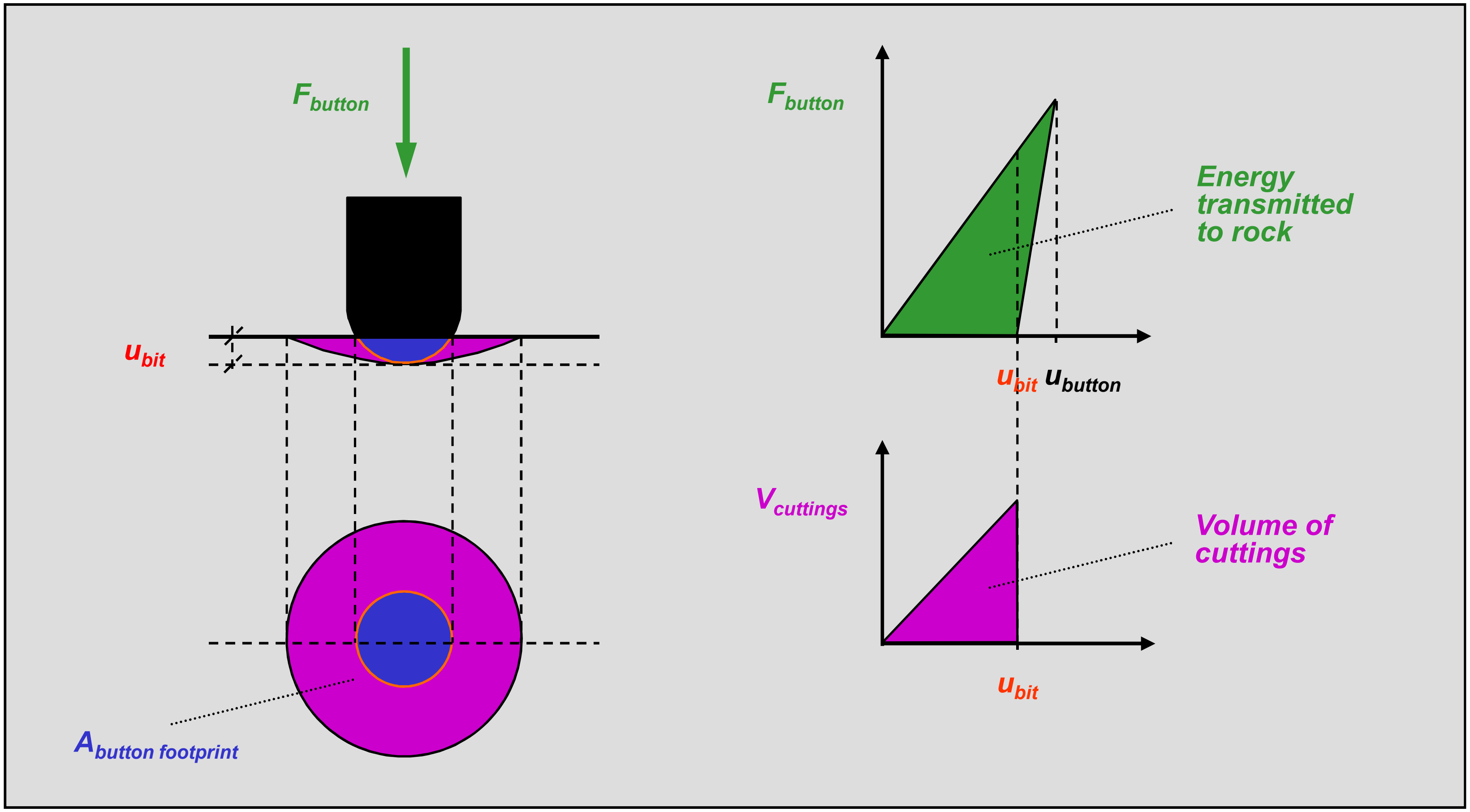
Foam flushing – an aid for drilling in caving material

Burst of inhole water



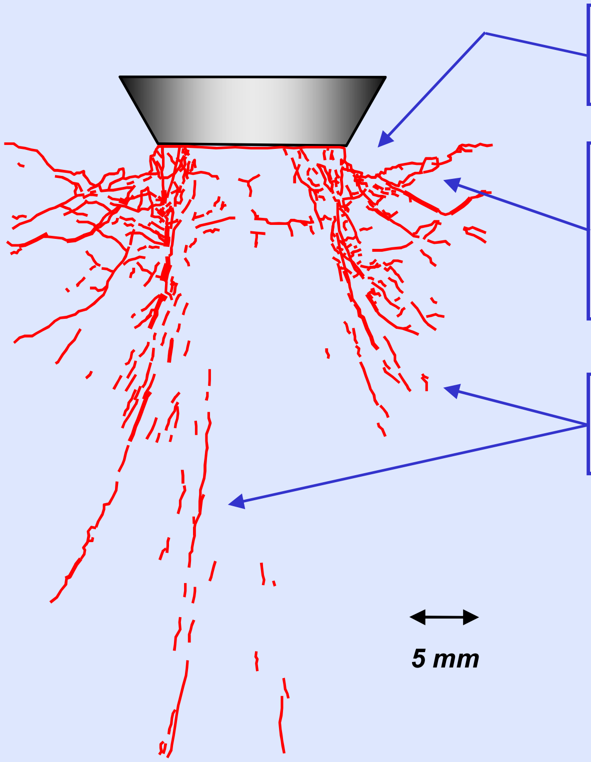
Drilling Management

How rocks break in drilling



Drilling Management

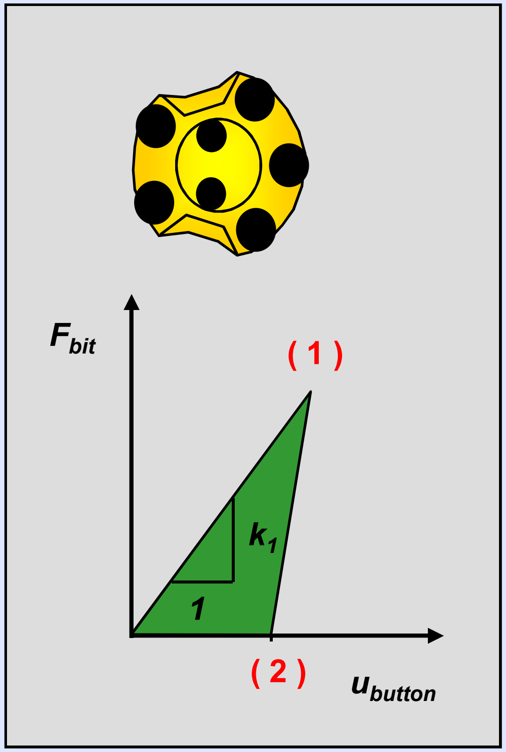
Button indentation, chip formation and bit force



Chipping around the button footprint area

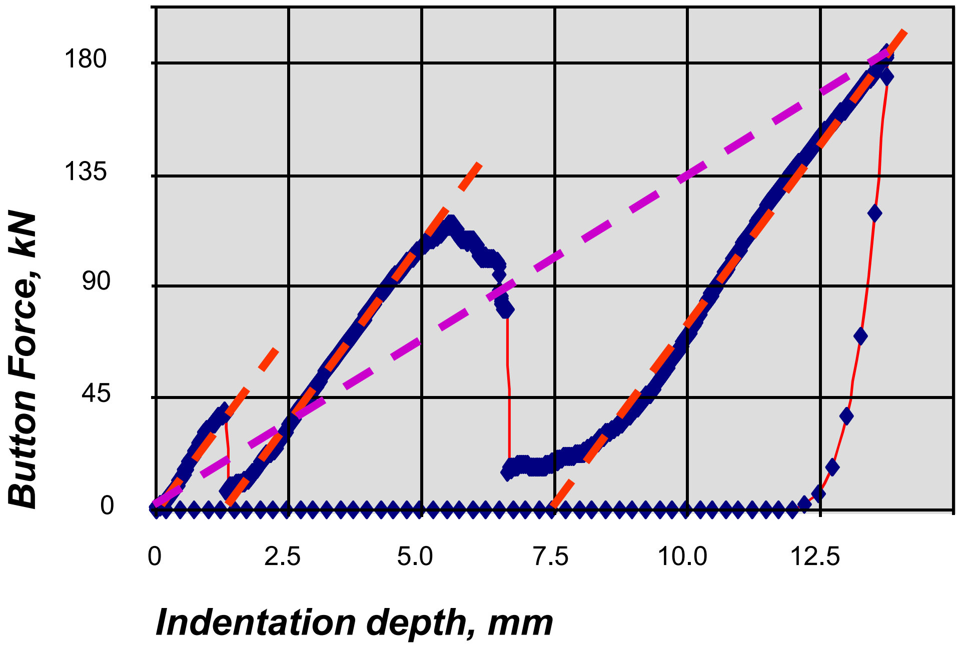
Off-loading fractures at (2) which create cuttings by chip spalling

On-loading fractures created at (1)



Drilling Management

Full depth button indentation and chipping frequency



— — — k_1 = 30 kN/mm for individual chip formations

— — — k_1 = 13 kN/mm for full depth indentation

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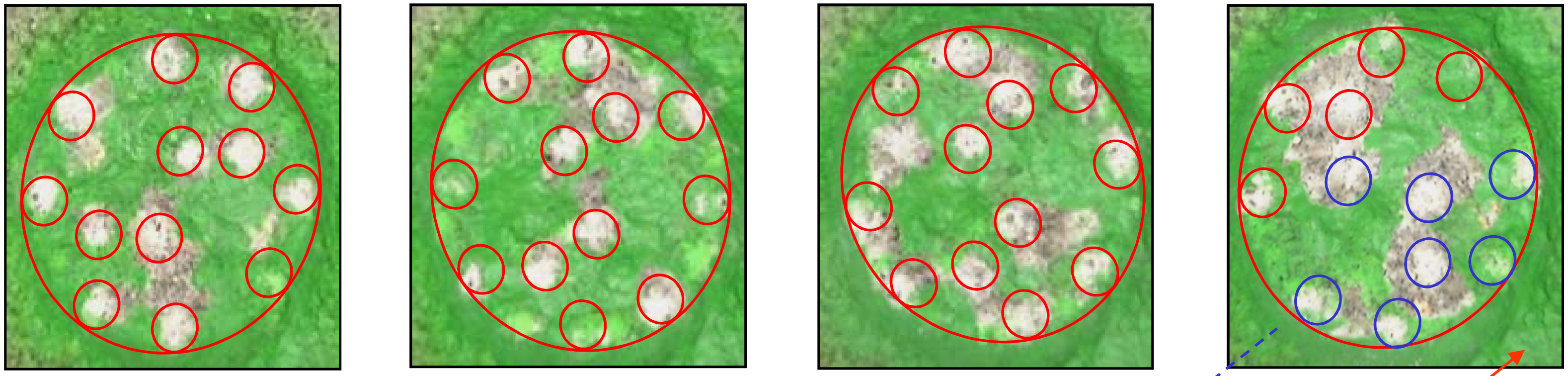
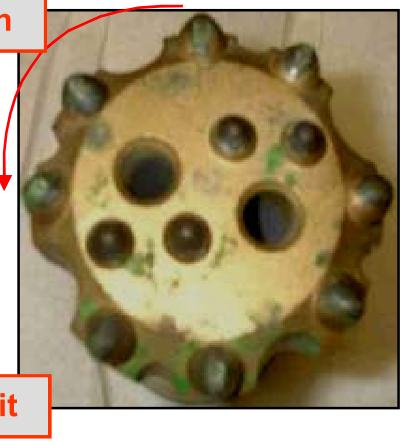
Drilling Management

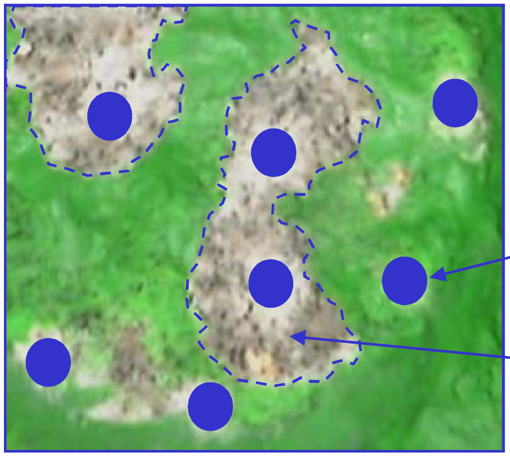
Chip formation by bit indentation and indexing



Direction of bit rotation



Ø3” bit



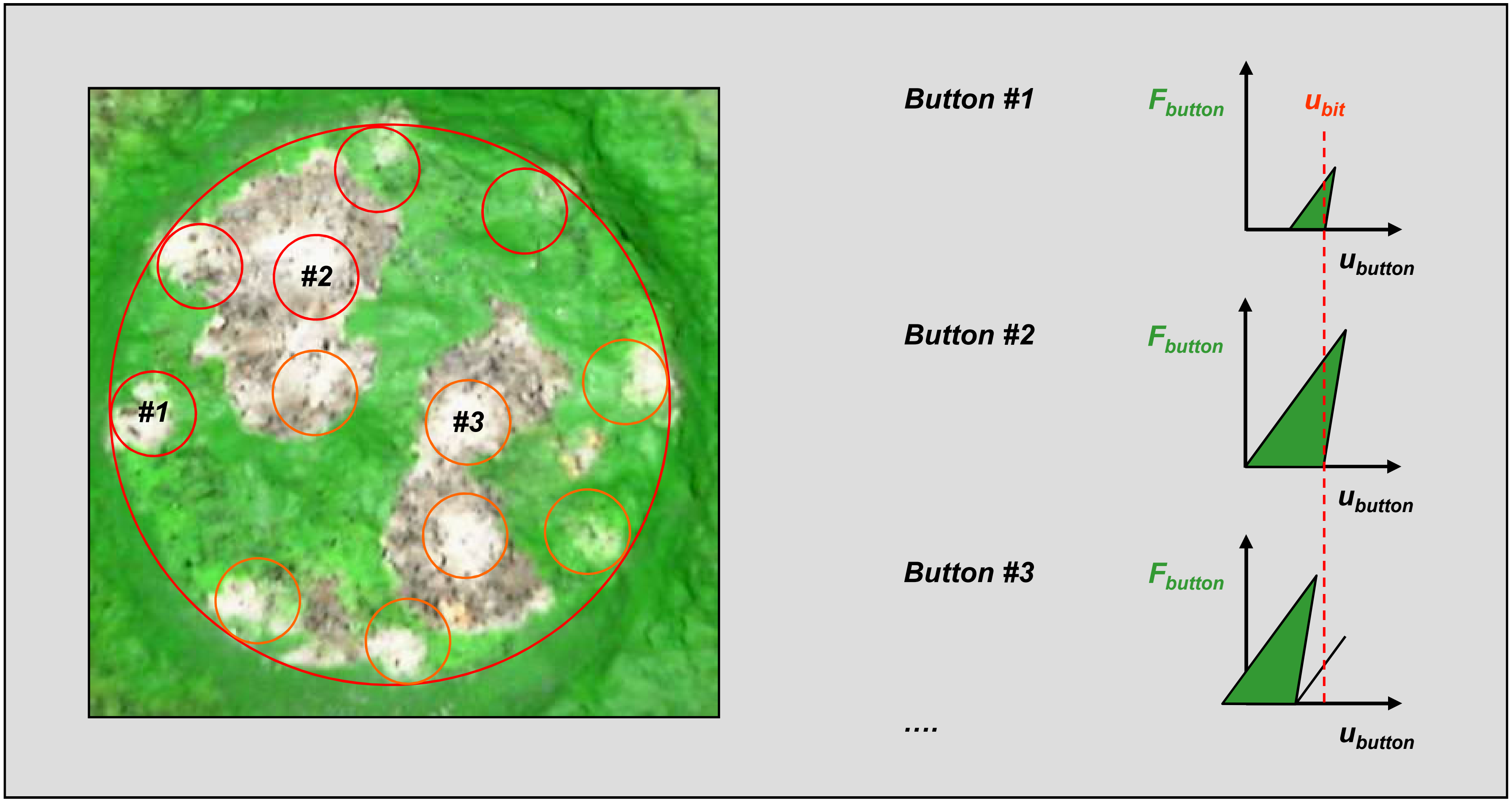
Spray paint applied between bit impacts

Button footprint area

Chipping around the button footprint areas

Drilling Management

Hole bottom breakage / button and bit indentation forces



Button #1

Button #2

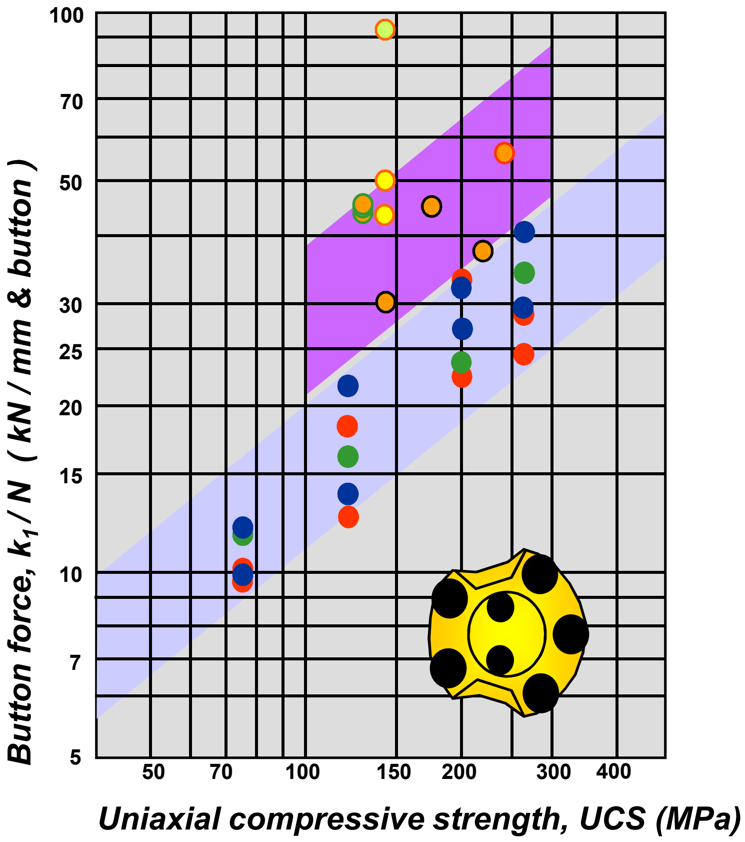
Button #3

….

Drilling Management

Button force versus rock strength, UCS

- ● *dynamic, Ø11mm spherical buttons*
- ● *dynamic, Ø10mm spherical buttons*
- ● *dynamic, Ø9mm spherical buttons*
- ● *static, Ø9mm spherical buttons*
- ● *static, Ø11mm spherical buttons*
- ● *static, Ø12mm spherical buttons*



Geologic Considerations in Quarrying

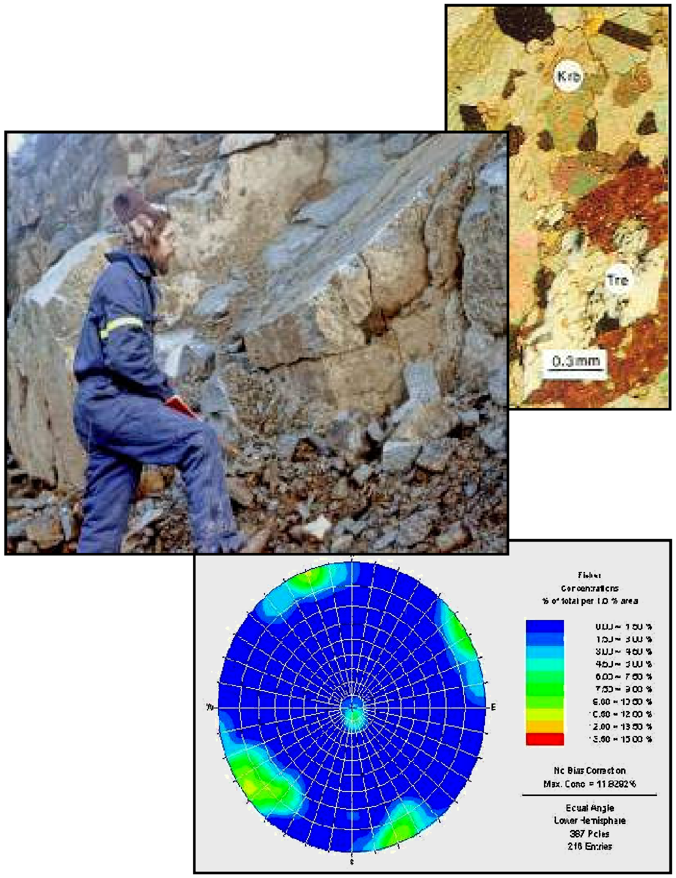
Components of rock mass workability

- bit penetration rates (BPR ratio 1:10)
  - ✓ precussive drilling – rock drillability related to specific energy
  - ✓ rotary drilling – rock drillability related to the axial tool force required for a unit depth of cut (or specific energy)
- rock abrasivity and tool service life (bit service life ratio 1:200)
  - ✓ related to interaction between wear materials, rock surface hardness and tool usage
- magnitude of drill-hole deviation (ratio 1:10)
  - ✓ related to interaction between bit, drill string and rock mass while drilling
- rock mass blastability (ratio 1:5)
  - ✓ drill patterns and powder factors related to mean fragment size k_{50}
  - ✓ wall stability, backbreak, …
- rock crushability (ratio 1:4)
  - ✓ crushability related to specific energy

Geologic Considerations in Quarrying

Traditional testing of rock mass properties

- ***atomic scale***
  - ✓ *chemical analysis and XRF for element and molecular content determination*
- ***microscopic scale***
  - ✓ *thin section and XRD for mineral content*
- ***macroscopic scale***
  - ✓ *laboratory testing of intact rock specimens:*
    - *strength properties, drillability, blastability, abrasivity, crushability, …*
- ***rock mass scale***
  - ✓ *representability of selected intact rock specimens for laboratory testing*
  - ✓ *mapping of rock mass discontinuities:*
    - *fracture set orientation and properties (strike, dip, frequency, aperature, …)*



QUARRY ACADEMY

Geologic Considerations in Quarrying

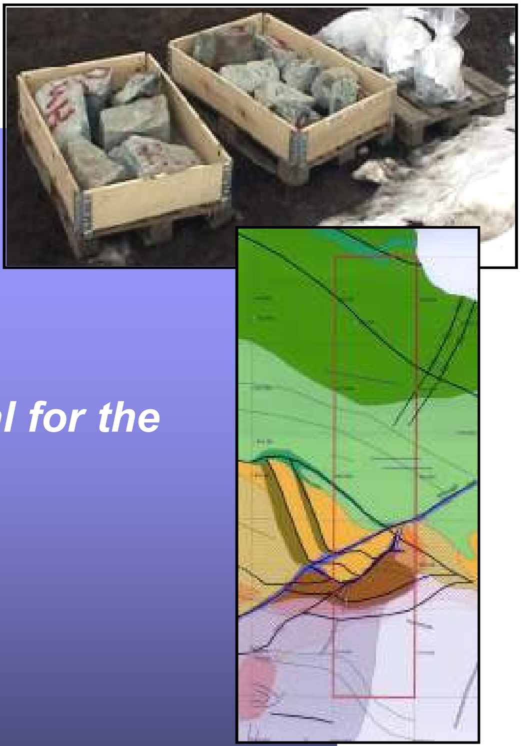
Use of production followup data

- brown field projects (ongoing sites)
  - ✓ predict NPR from current equipment performance
  - ✓ predict drill steel service life from current performance
- green field projects (virgin sites)
  - ✓ predict NPR from rock drillability
  - ✓ predict drill steel service life from rock abrasivity
- benchmarking of new products

What is the average drillability and blastability for this bench ?

Geologic Considerations in Quarrying

Practical rock sampling for drillability

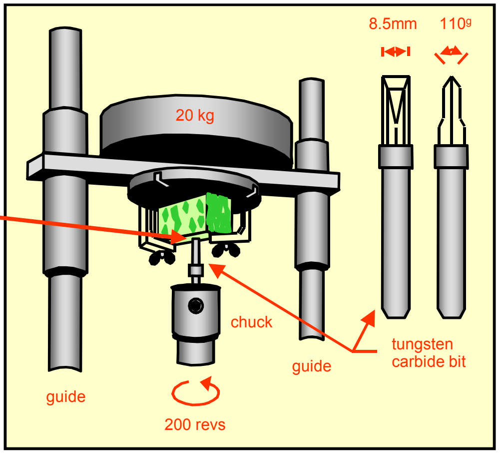


Sample weight	20 - 30 lbs
Min. thickness	5”
Note	Rock samples should be typical for the drilling site with regard to: - colour - texture - density
Additional info	Worksite, mine level, nearest town, province, country (Relevant drilling parameters and results)

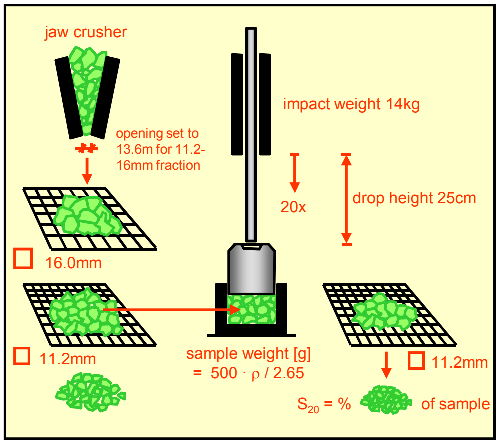
Geologic Considerations in Quarrying

Drilling Rate Index, DRI

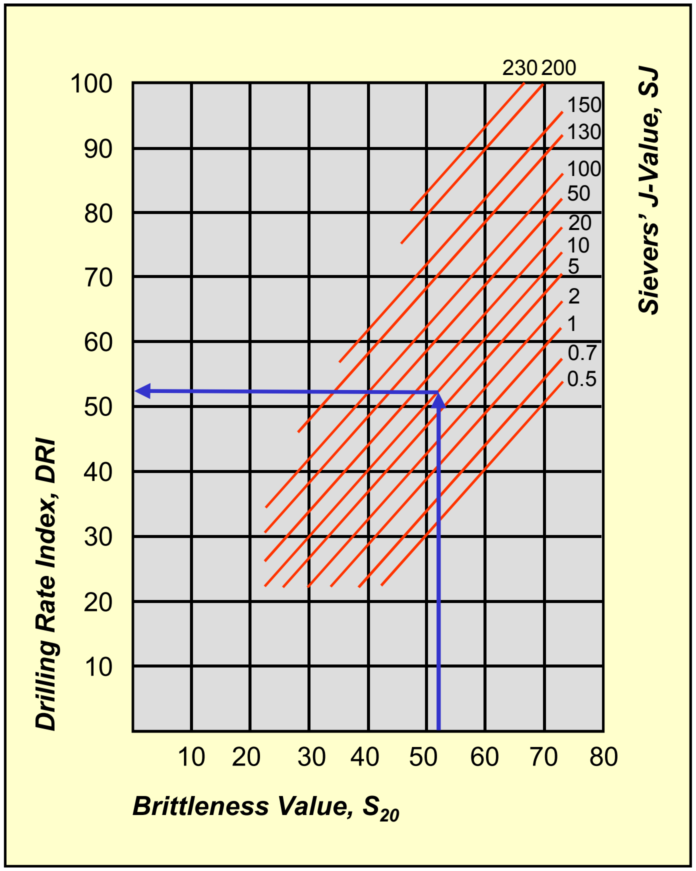
Rock surface hardness, SJ



Rock toughness, S_{20}



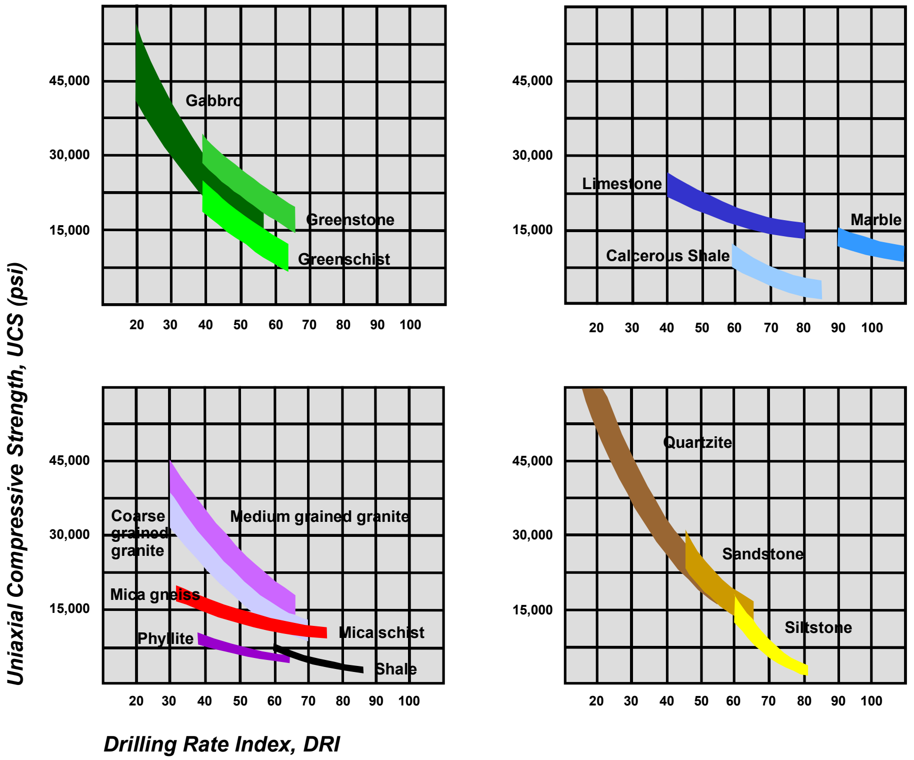
Rock drillability, DRI

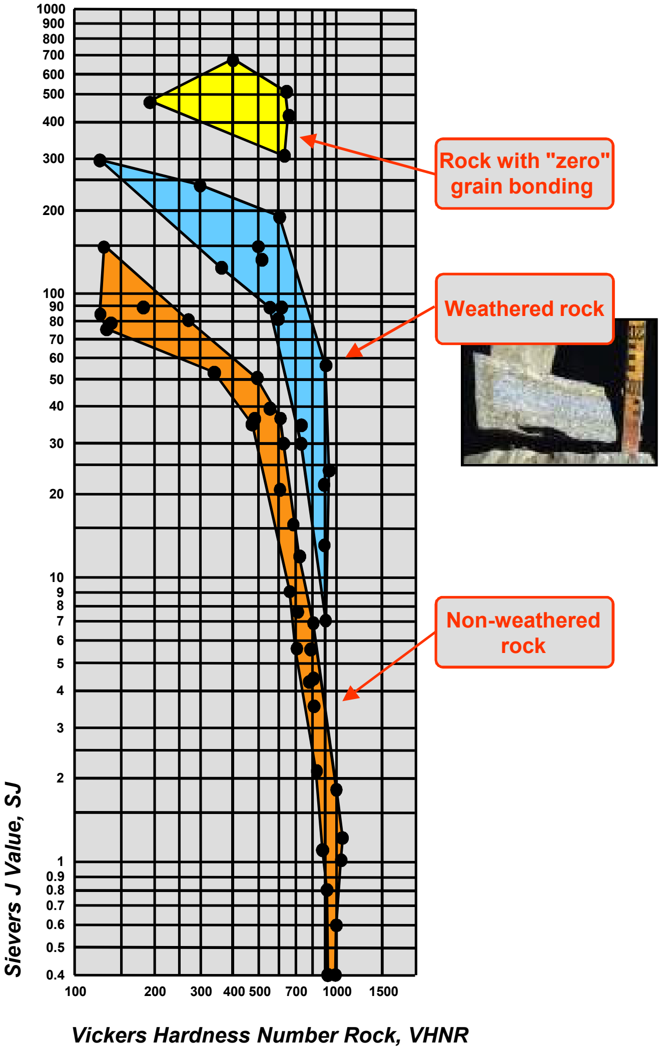


Geologic Considerations in Quarrying

DRI drillability test result evaluation

- *Drilling Rate Index versus UCS*
- *detect weathered samples (SJ / VHNR chart)*





Rock with "zero" grain bonding

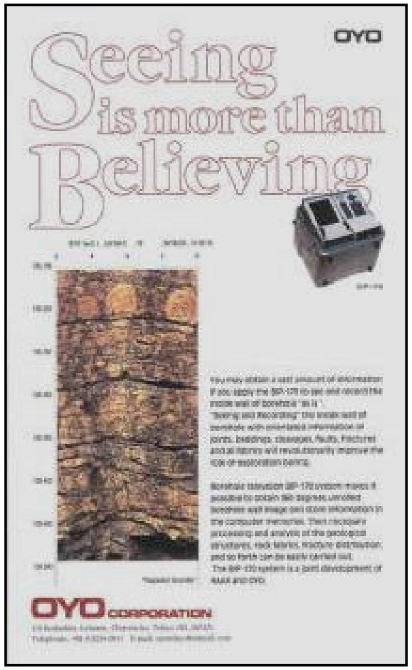
Weathered rock

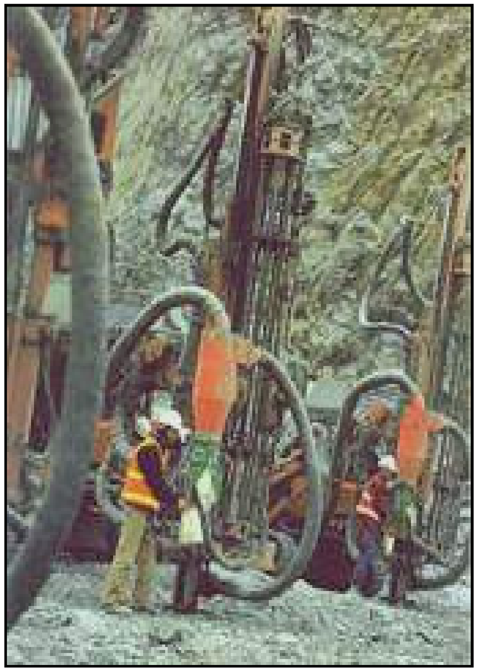
Non-weathered rock

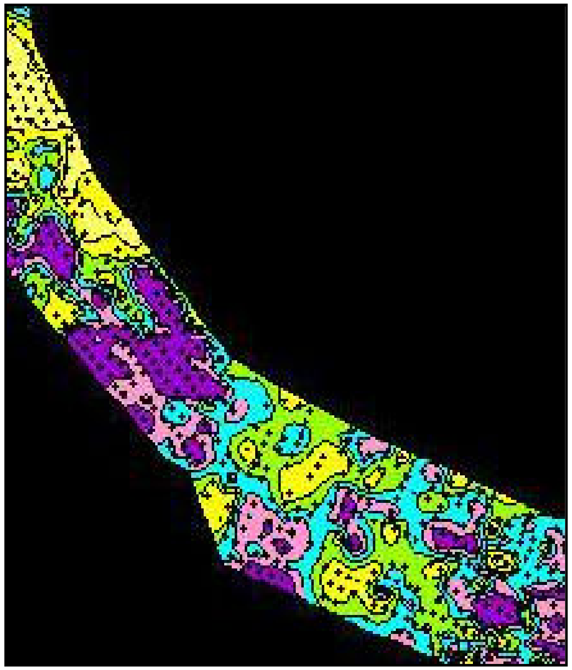
Geologic Considerations in Quarrying

In situ testing of rock mass properties

- *inhole video surveys of shotholes*
- *sampling of cuttings for chemical analysis*
- *measurement-while-drilling or MWD basis for digital pit mapping*

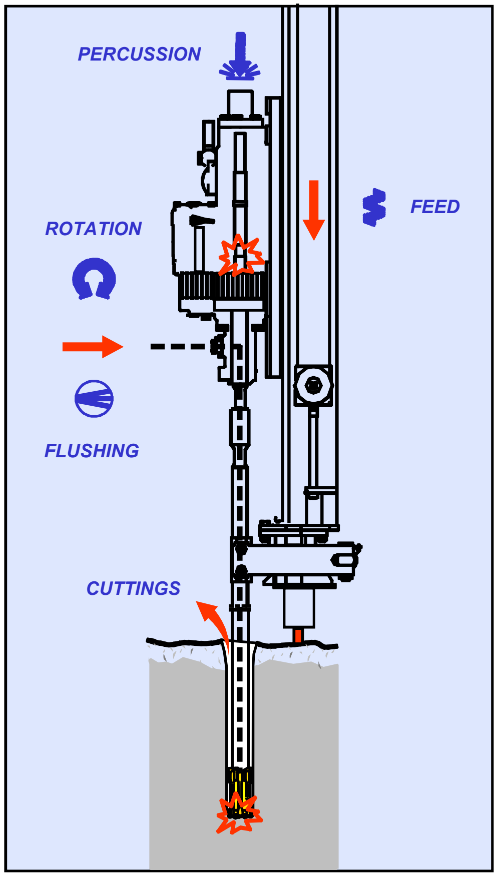






Drilling Management

Mechanics of percussive drilling



Percussive drilling

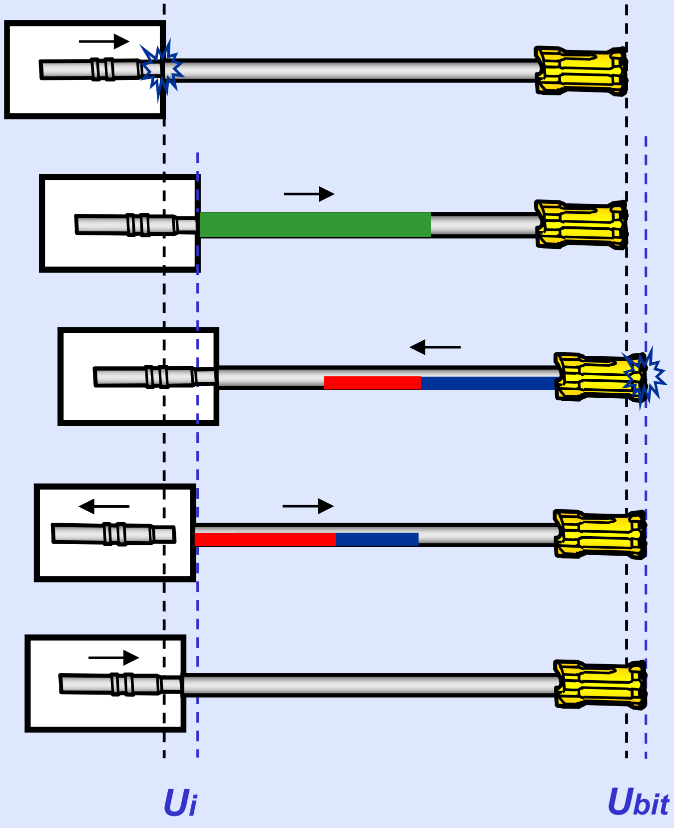
- ✓ **Down-the-hole, DTH**
  Stress waves transmitted directly through bit into rock
- ✓ **Tophammer**
  Stress wave energy transmitted through shank, rods, bit and then into rock

Basic functions

- ✓ percussion - reciprocating piston used to produce stress waves to power rock indentation
- ✓ feed - provide bit-rock contact during impacts
- ✓ rotation - provide bit indexing
- ✓ flushing - cuttings removal from hole bottom
- ✓ foam flushing - drill-hole wall stabilisation

Drilling Management

Percussive impact cycle in TH drilling



Piston accelerates forwards and strikes shank

Incident stress wave travels down drill string to bit. Rod compression u_i

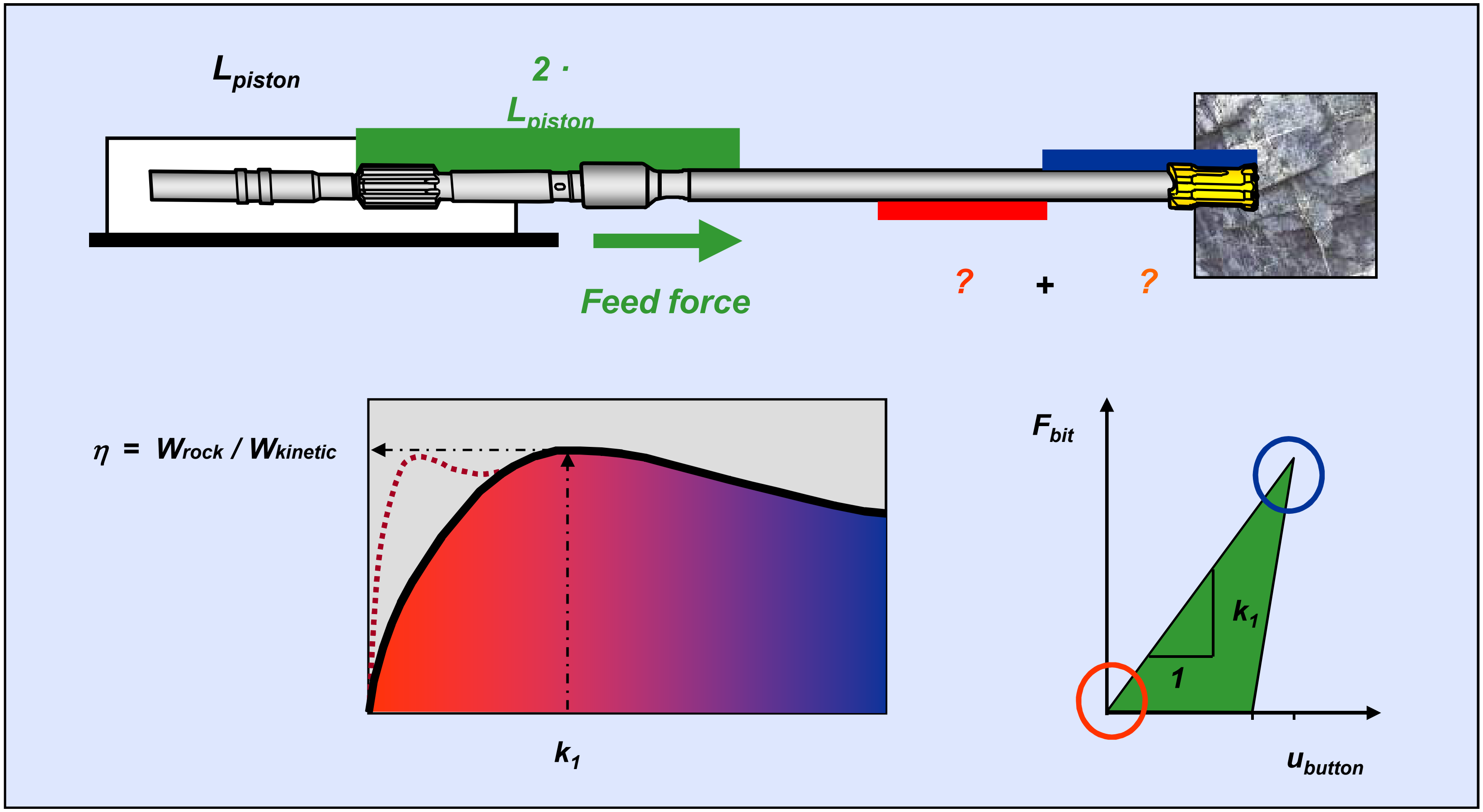
Incident stress wave powers bit indentation u_{bit} – and reflections travel back to shank-end

Re-reflected stress waves travel to bit again – etc. Piston accelerates backwards - starting a new cycle

Rock drill now moved forwards by u_{bit} – and drill string ready for next piston strike

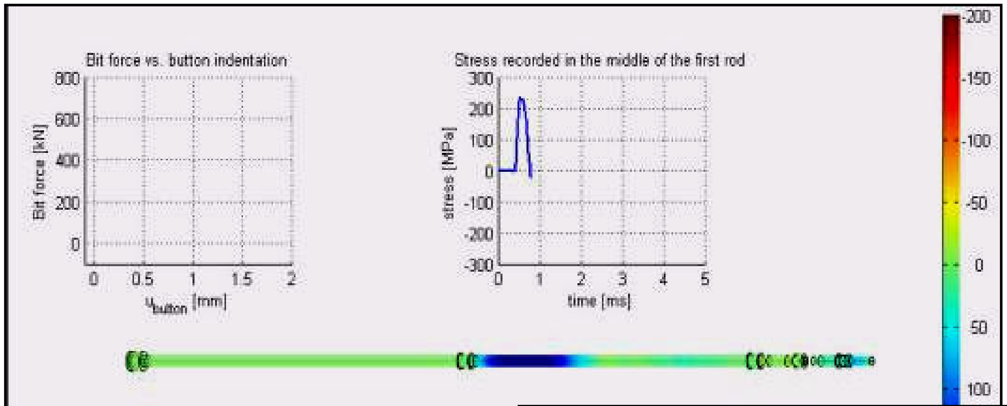
Drilling Management

Energy transfer efficiency in TH drilling

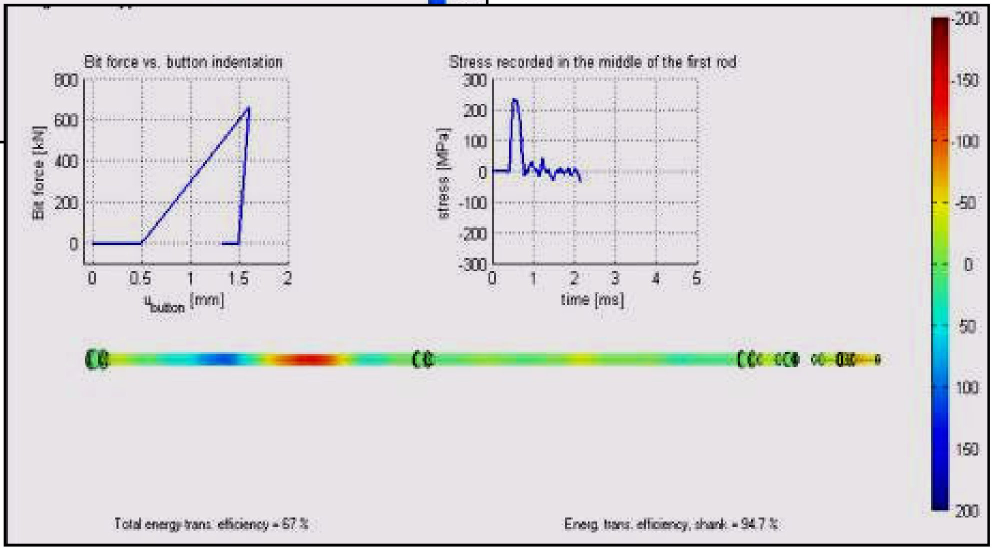


Drilling Management

The energy transfer chain in TH drilling



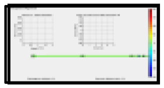
Total energy trans. efficiency = 0 %



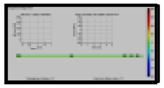
Total energy trans. efficiency = 67 %

Energ. trans. efficiency, shank = 94.7 %

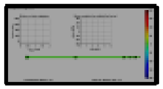
HL700_2xT51_Retrac89_Cavity_Rscale2.avi



HL700_2xT51_Retrac89_k600_Rscale2.avi

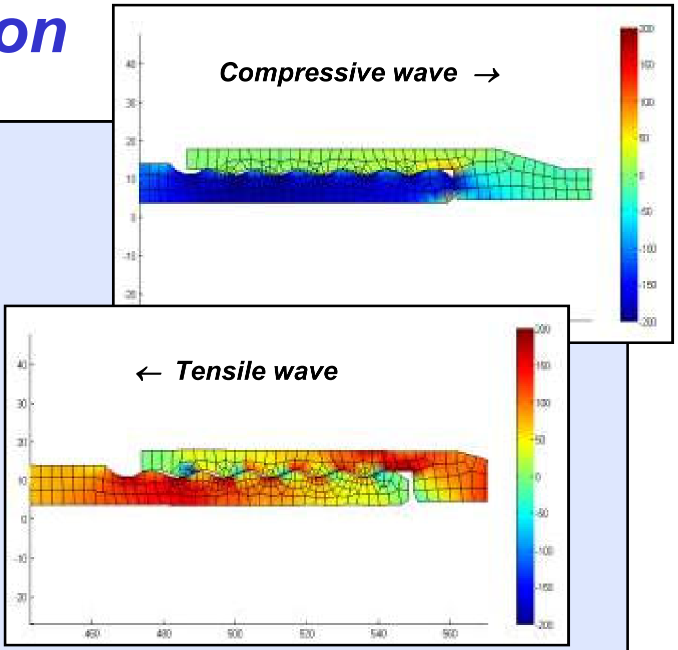


HL700_2xT51_Retrac89_k600gap05_Rscale2.avi



Drilling Management

About stress wave energy transmission



Energy transfer efficiencies can be divided into:

- *energy transmission through the drill string*
  - *optimum when the cross section throughout the drill string is constant*
  - *length of stress wave*
  - *weight of bit*
- *energy transmission to rock*
  - *bit indentation resistance – k_1*
  - *bit-rock contact*

The most critical issue in controlling stress waves is to avoid high tensile reflection waves.

Tensile stresses are transmitted through couplings by the thread surfaces - not through the bottom or shoulder contact as in the case for compressive waves.

High surface stresses combined with micro-sliding result in high coupling temperatures and heavy wear of threads.

Drilling Management

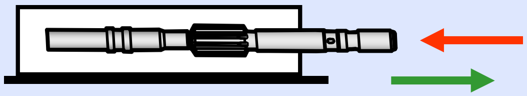
Feed force requirements

From a drilling point of view

- *to provide bit-rock contact*
- *to provide rotation resistance so as to keep threads tight*

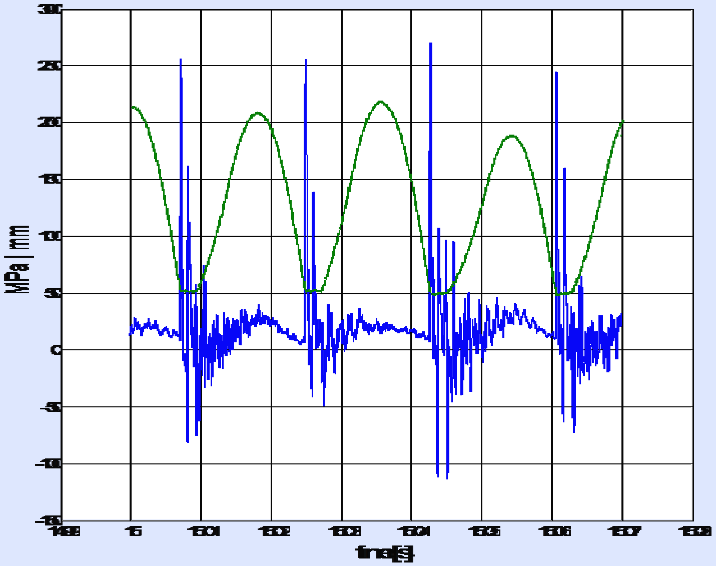
From a mechanical point of view

- *compensate piston motion*
- *compensate linear momentum of stress waves in rods*



Rod force
Feed force

— *Stress waves in rod (MPa)*
— *Piston movement (mm)*



Drilling Management

Feed force level characterisation - TH

Underfeed

Rereflected tensile waves pull shank forwards – creating first a gap and thereby moving piston strike point forwards – resulting in:

- high tensile stresses	=> low drill steel life
- low rotation pressure	=> threads run open and wear out rapidly

Optimum feed

Optimum feed is a given force level high enough to avoid underfeed.
Feed over this limit is considered as overfeed.

Overfeed

Rereflected compressive waves push shank and rock drill backwards – creating jerky rock drill movements – resulting in:

- drill steel bending	=> drill-hole deviation
- high rotation pressure	=> threads very hard to open
- high friction at bit face	=> increased button wear

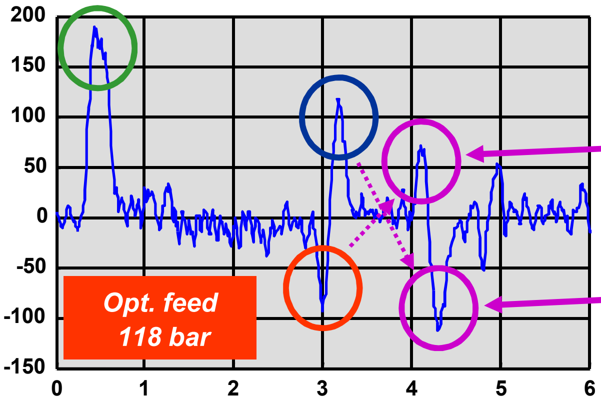
Drilling Management

Reflected stress wave response in rods to feed force levels

HL700 / CF145
2 x MF-T45-14'
∅76mm @ 120RPM

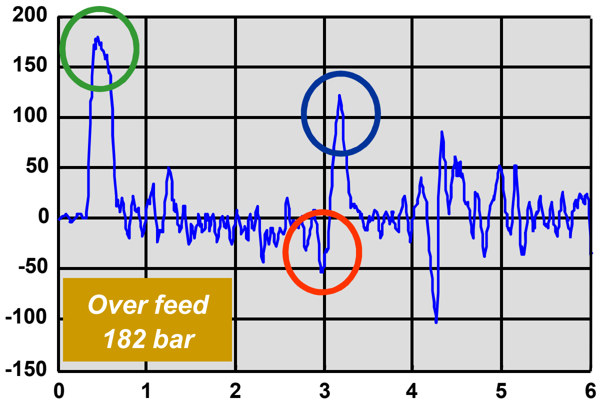
Stress axis in MPa

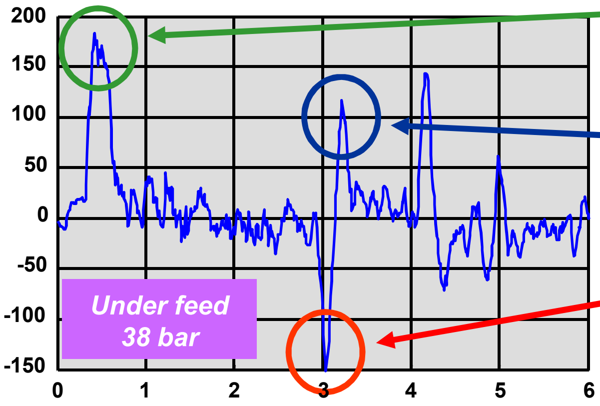
Time axis in milliseconds



incoming re-reflected tensile wave from backend of shank

incoming re-reflected compressive wave from backend of shank





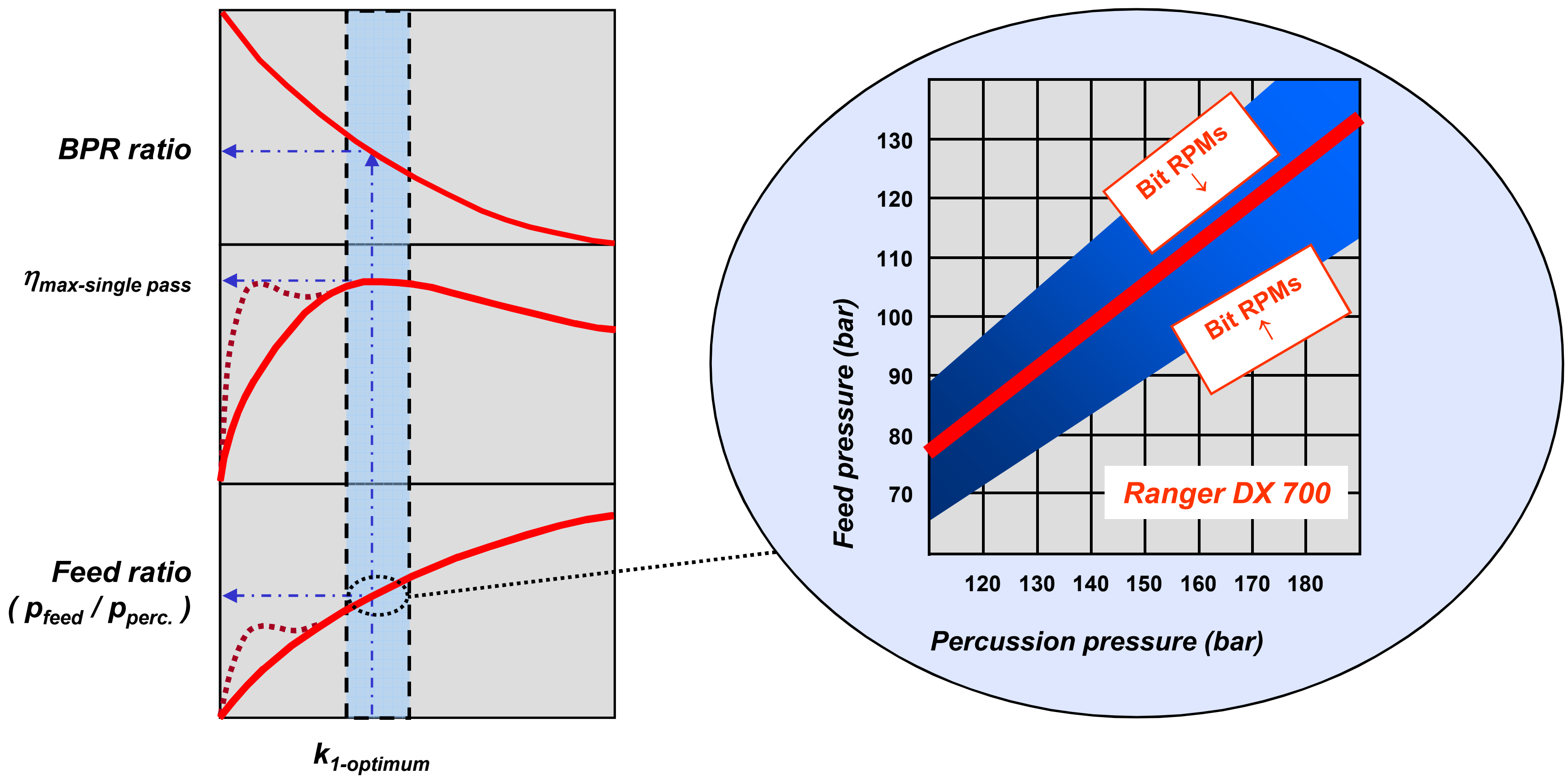
incident (incoming) compressive stress wave from the piston

too small primary reflected compressive wave from bit-rock interface

too big primary reflected tensile wave from bit-rock interface

Drilling Management

Energy transfer efficiencies and feed force requirements - TH

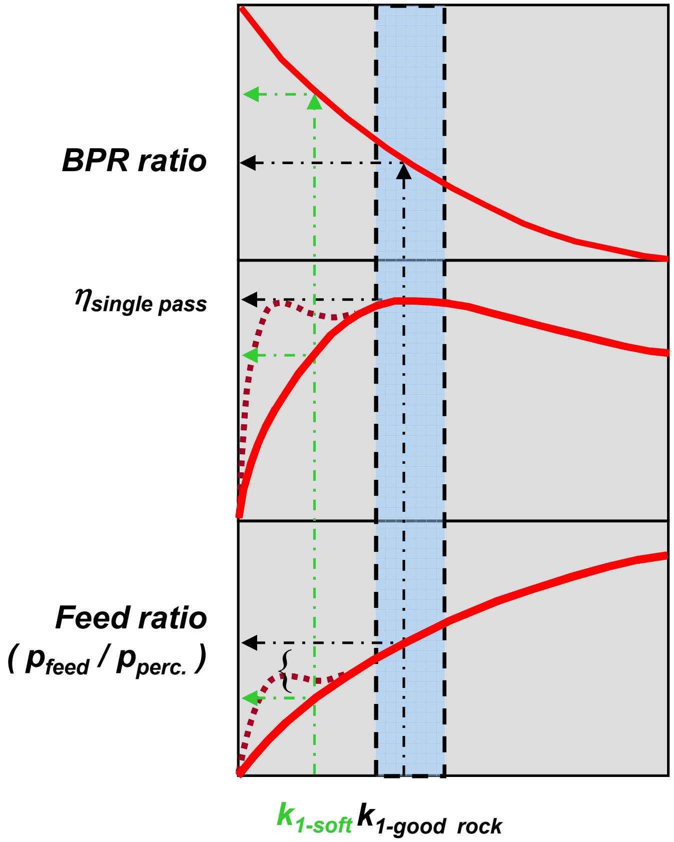


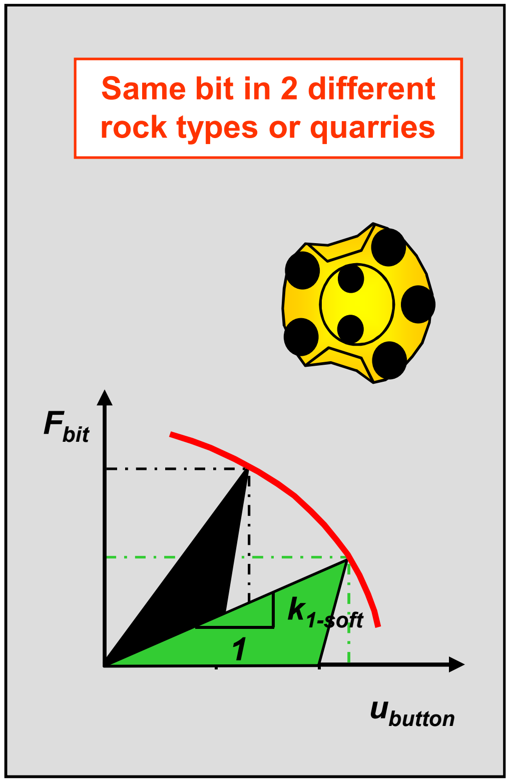
Shorter piston, L ‑·‑·▸ ◂·‑·‑ *Thinner rod, A_{rod}*

The basic parameters (L, A_{rod}) + bit mass determine the transfer efficiency curve and the $k_{1\text{-optimum}}$ value for a given percussive system

Drilling Management

Matching site drilling to transfer efficiency curve - TH



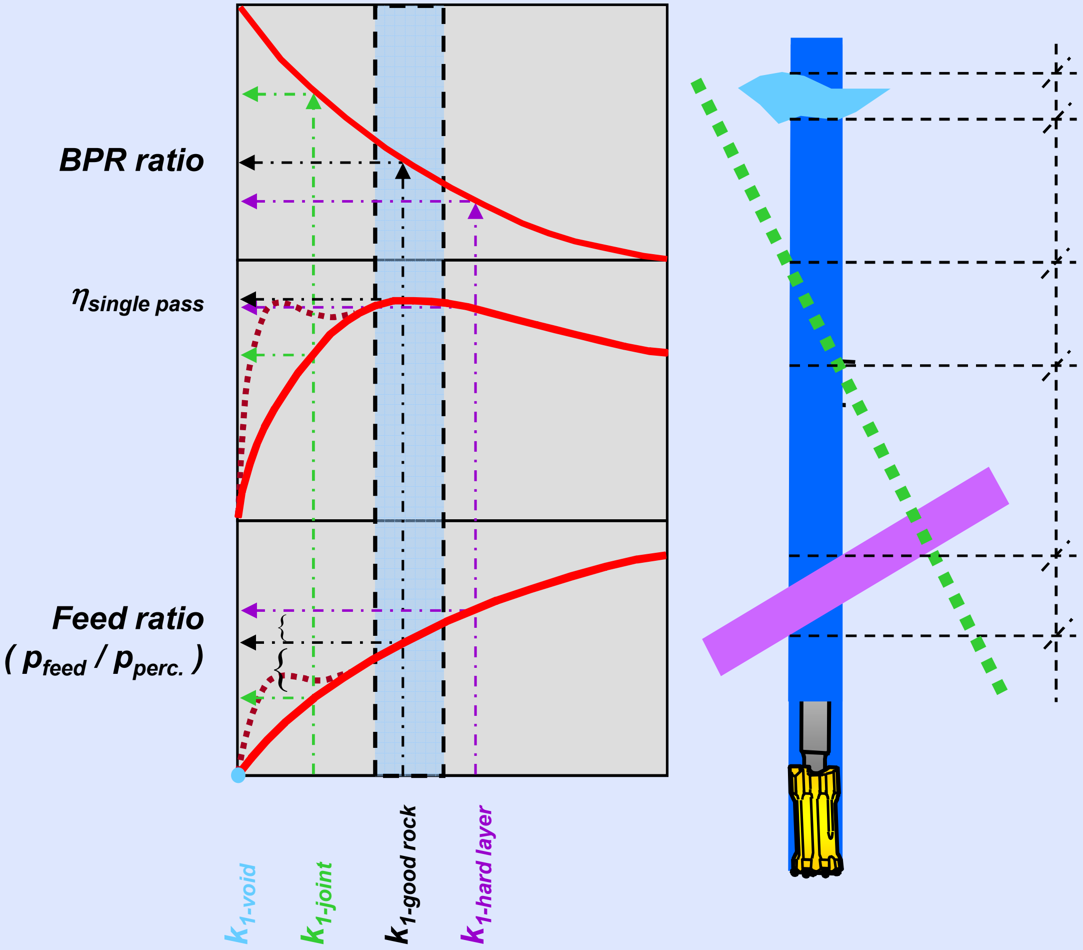

Same bit in 2 different rock types or quarries

Rock hardness -·-·-► ◄-·-·- *Chipping frequency*

Button count and size -·-·-►
(and bit size)

Drilling Management

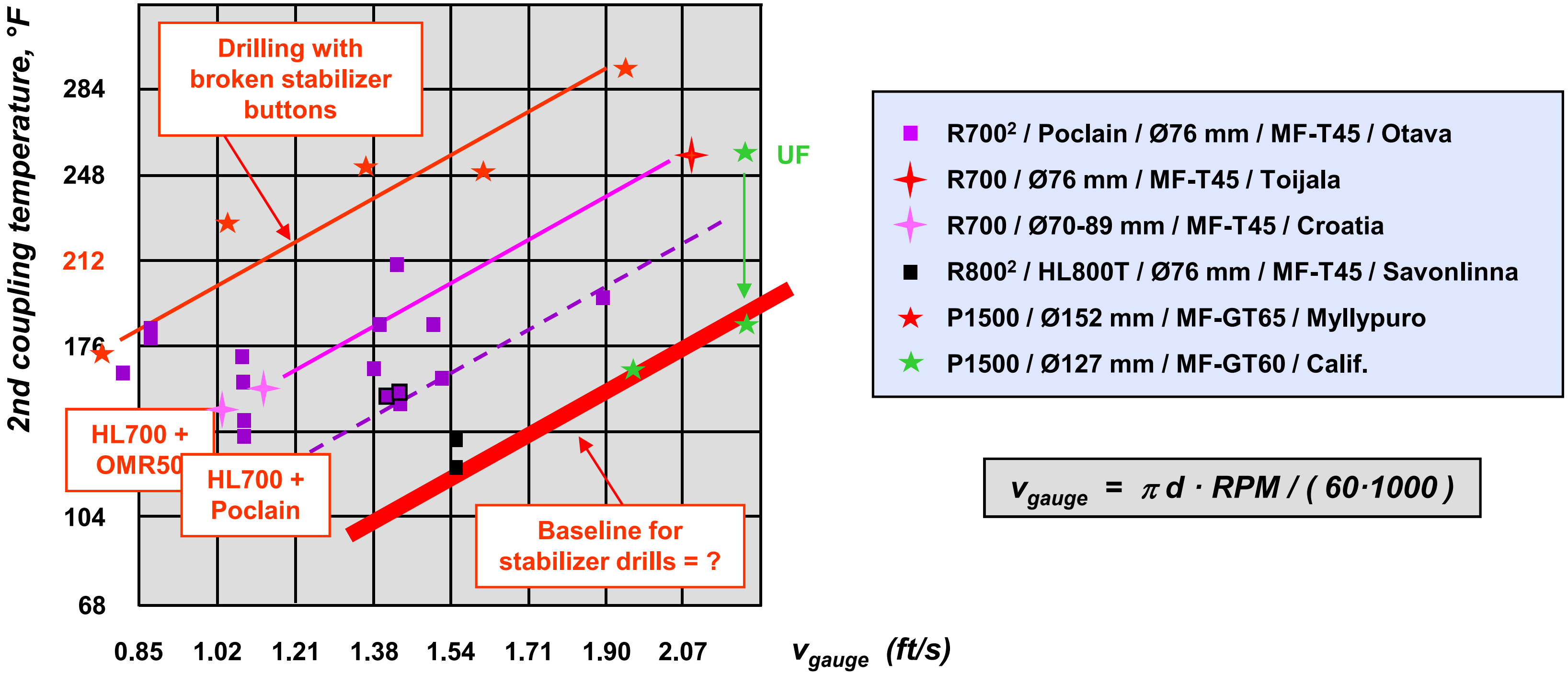
Drilling in variable rock mass



Situation =>	Actual feed conditions
$k_{1\text{-void}} \approx 0$	Total overfeed (feed speed control)
$k_{1\text{-good rock}}$	OK (feed ratio set here)
$k_{1\text{-joint}} < k_{1\text{-good rock}}$	Overfeed
$k_{1\text{-good rock}}$	OK
$k_{1\text{-hard layer}} > k_{1\text{-good rock}}$	Underfeed

Drilling Management

Ranger DX 700 and 800 / Pantera DP1500

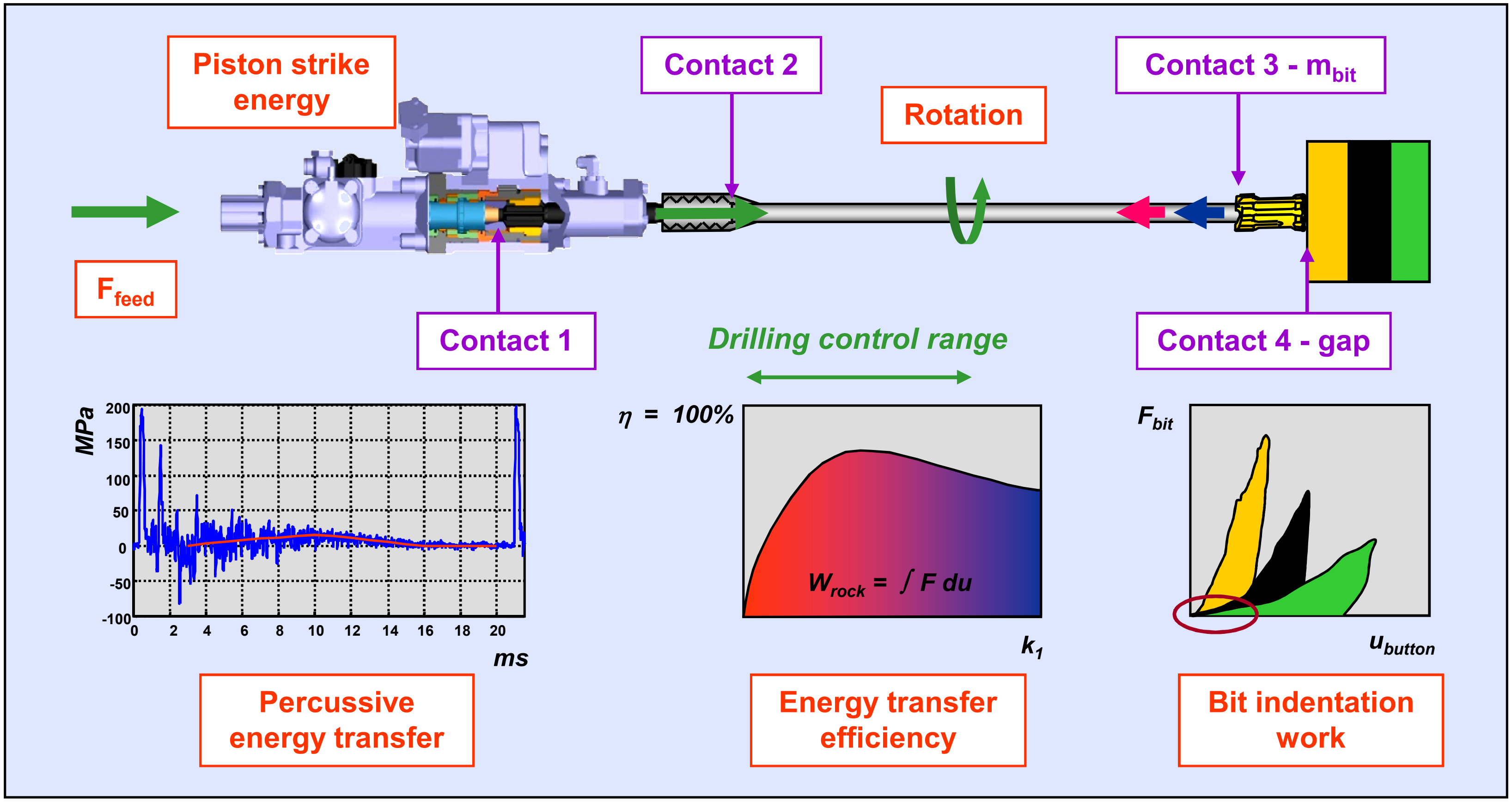


$$v_{gauge} = \pi d \cdot RPM / (60 \cdot 1000)$$

66	79	92	105	118	132	145	158	*RPM for Ø76 mm / 3”*
56	67	79	90	101	112	125	135	*RPM for Ø89 mm / 3½”*
49	59	69	78	88	98	108	118	*RPM for Ø102 mm /4”*
39	47	55	63	71	79	87	95	*RPM for Ø127 mm / 5”*
33	39	46	53	59	66	72	79	*RPM for Ø152 mm / 6”*

Drilling Management

Summary of percussion dynamics - TH



Piston strike energy

Contact 2

Rotation

Contact 3 - m_{bit}

F_{feed}

Contact 1

Drilling control range

Contact 4 - gap

Percussive energy transfer

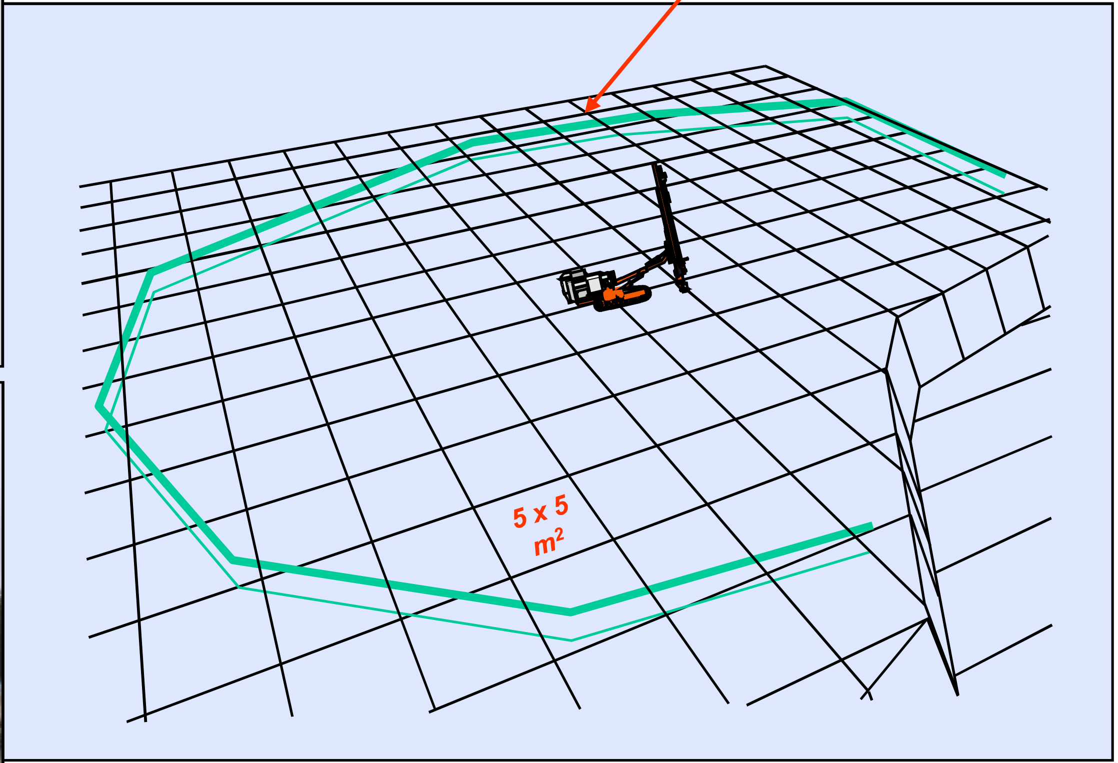
Energy transfer efficiency

Bit indentation work

Drilling Management

Drilling noise levels - TH

Standard	*ISO 4872*
Pressure	*L_{WA} dB(A)*
Commando 100	*125.7*
Commando 300	*123.8*
CHA 660	*124.2*
Ranger 700	*126*
Pantera 1500	*127*



85 dB(A) boundary for CHA 660

Feed casing reduces noise levels by approx. 10 dB(A)

Drilling Management

Safety issues of inpit operations

- *pit planning and operations supervision*
- *safety consciousness of workforce*
- *operator hazard training*

=> minimum occurrence of accidents

Rollover from terrain bench - 35m drop

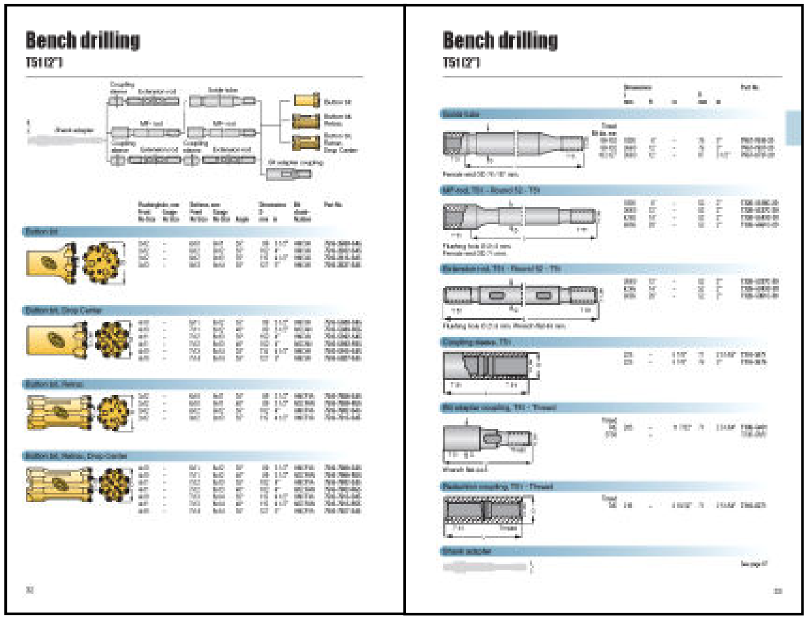
Premature ignition of electric detonators and blast due to lightning

Pit wall failure burying 3 drill rigs in rubble

Drilling Management

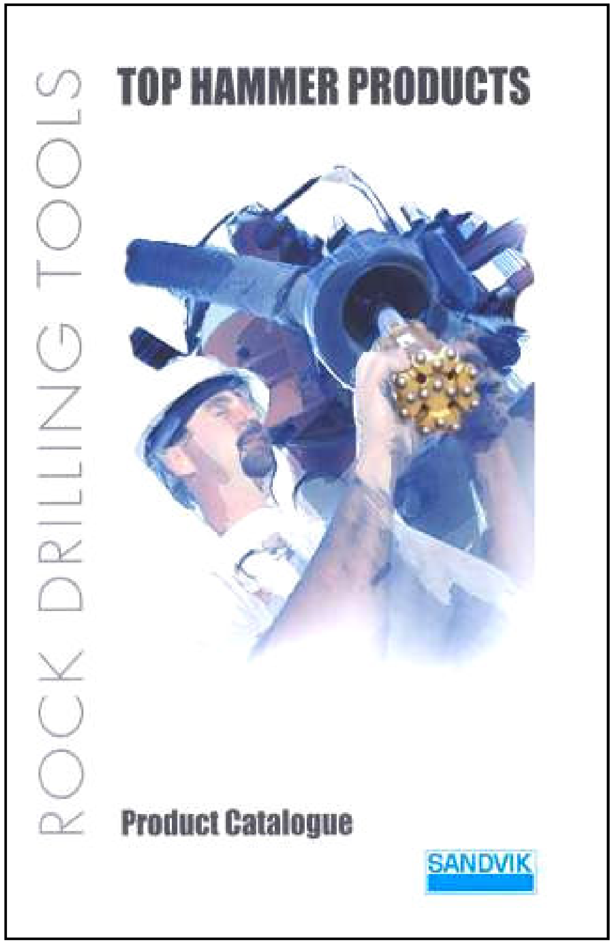
Selecting drilling tools - TH

- *bit face and skirt design*
- *button shape, size and cemented carbide grade*
- *drill string components*
- *grinding equipment and its location at jobsite*



Bench drilling
T51 (2")

Bench drilling
T51 (2")



TOP HAMMER PRODUCTS

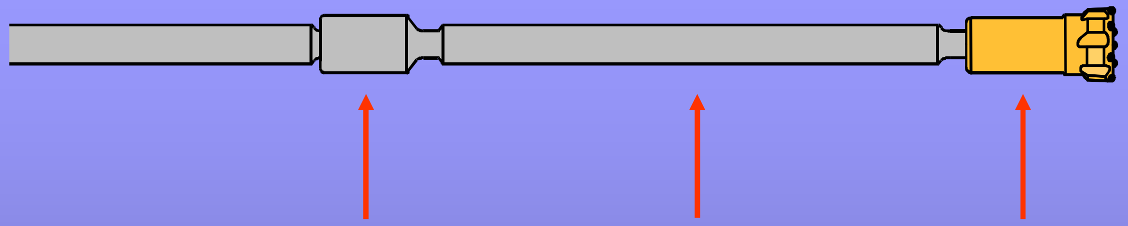
ROCK DRILLING TOOLS

Product Catalogue

SANDVIK

Drilling Management

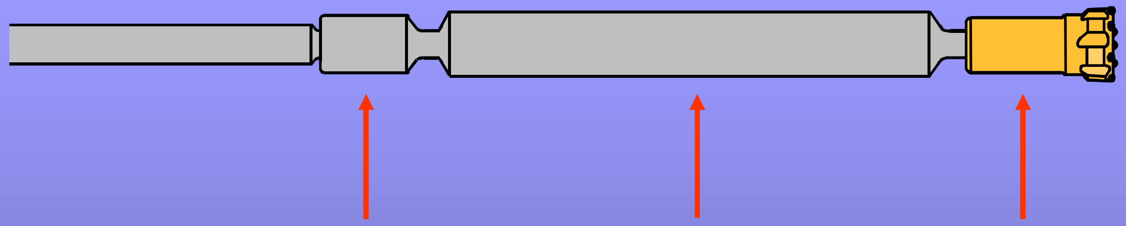
Optimum bit / rod diameter relationship - TH



Thread	Cross section coupling	Cross section	Optimum bit size
R32	∅44	∅32	∅51
T35	∅48	∅39	∅57
T38	∅55	∅39	∅64
T45	∅63	∅46	∅76
T51	∅71	∅52	∅89
GT60	∅82	∅60	∅92
GT60	∅85	∅60/64	∅102

Drilling Management

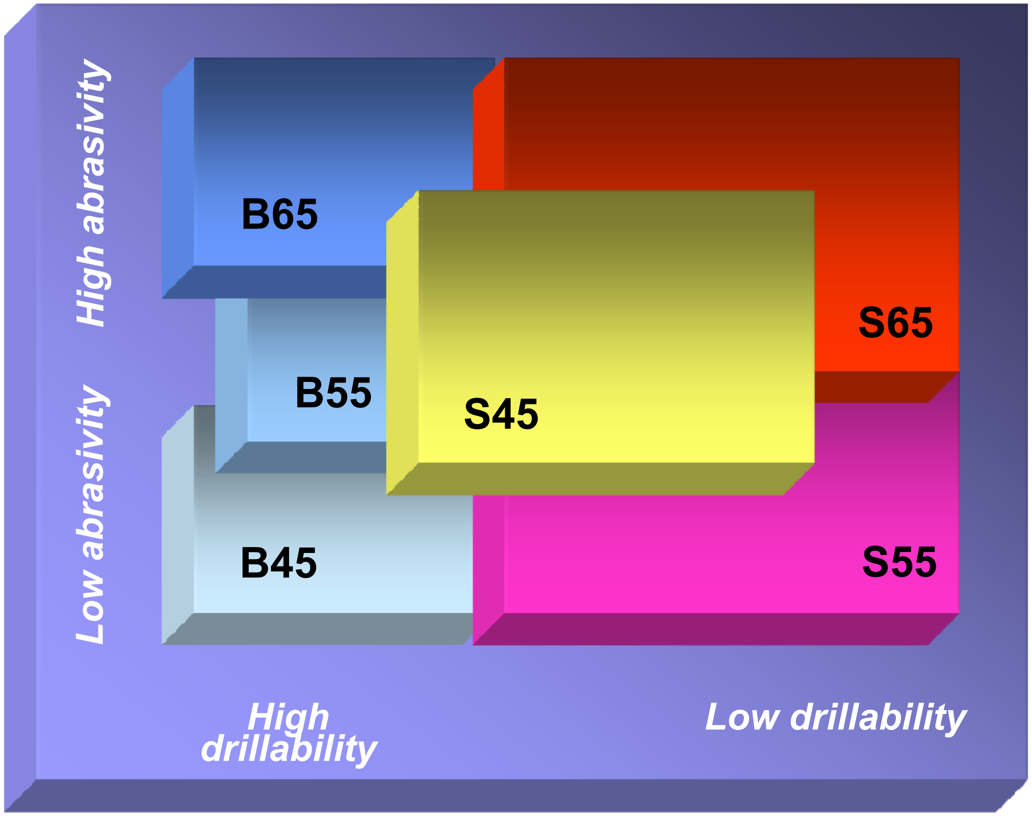
Optimum bit / guide or pilot (lead) tube relationship - TH



Thread	Cross section coupling	Cross section	Optimum bit size
T38	∅55	∅56	∅64
T45	∅63	∅65	∅76
T51	∅71	∅76	∅89
GT60	∅85	∅87	∅102
GT60	∅85	∅102	∅115

Drilling Management

Selecting button shapes and cemented carbide grades



Spherical buttons
MP45

S45

Ballistic buttons
DP55

B55

R ← **Robust ballistic**

Drilling Management

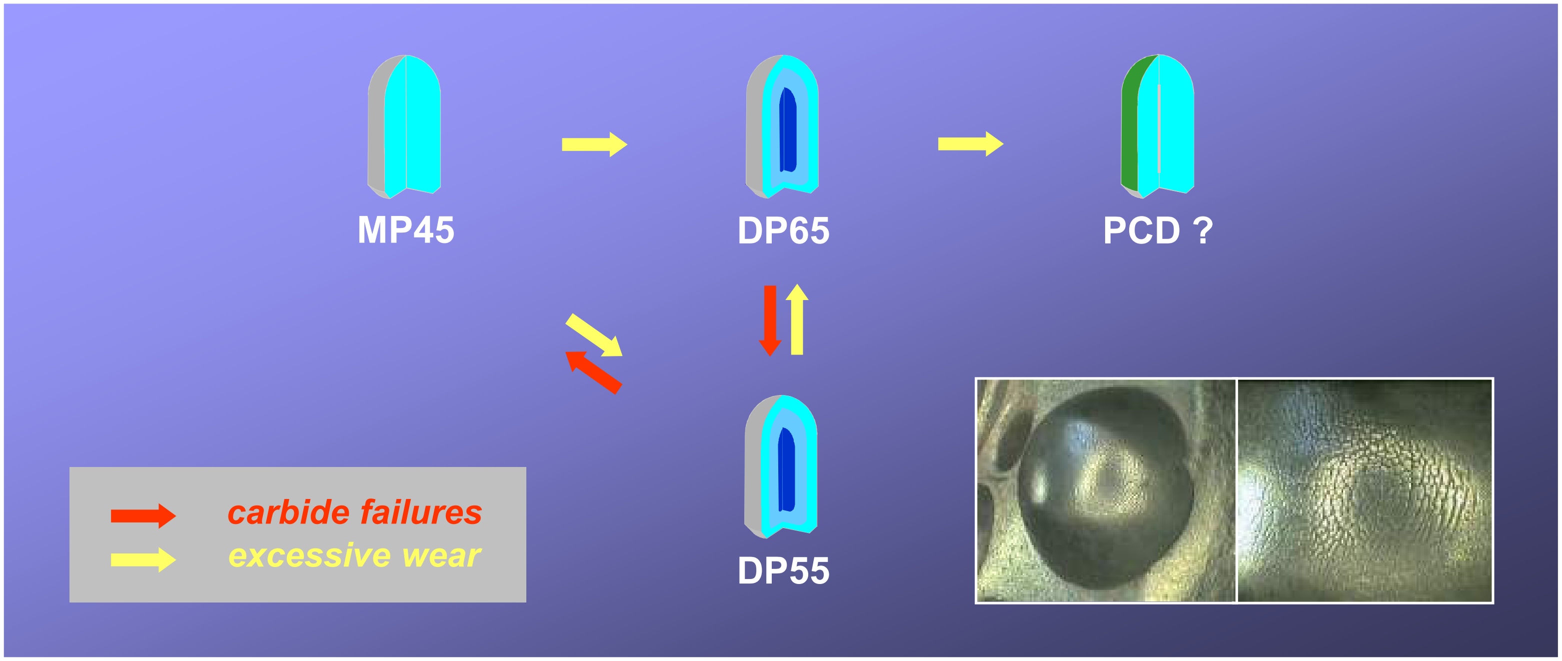
Guidelines for selecting cemented carbide grades

- ***avoid excessive button wear (rapid wearflat development)***

  => select a more wear resistant carbide grade

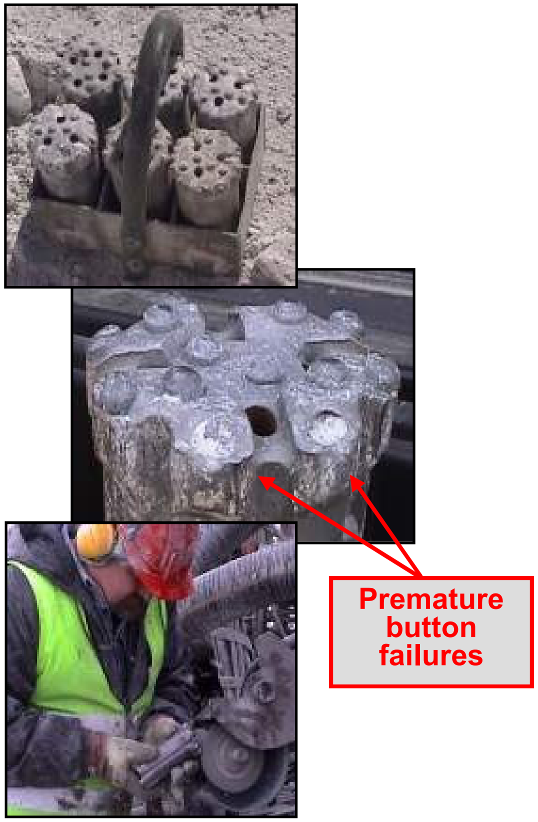
- ***avoid button failures (due to snakeskin development or too aggressive button shapes)***

  => select a less wear resistant or tougher carbide grade or spherical buttons

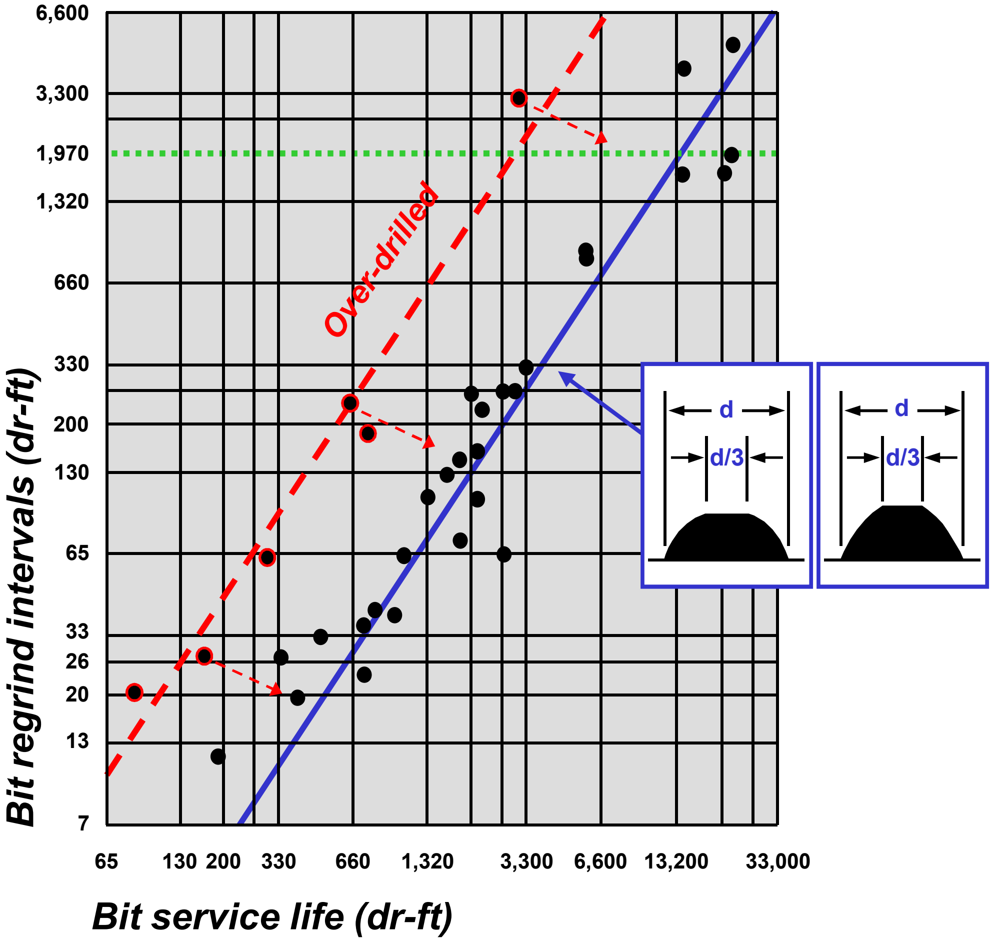


Drilling Management

Bit regrind intervals, bit service life and over-drilling

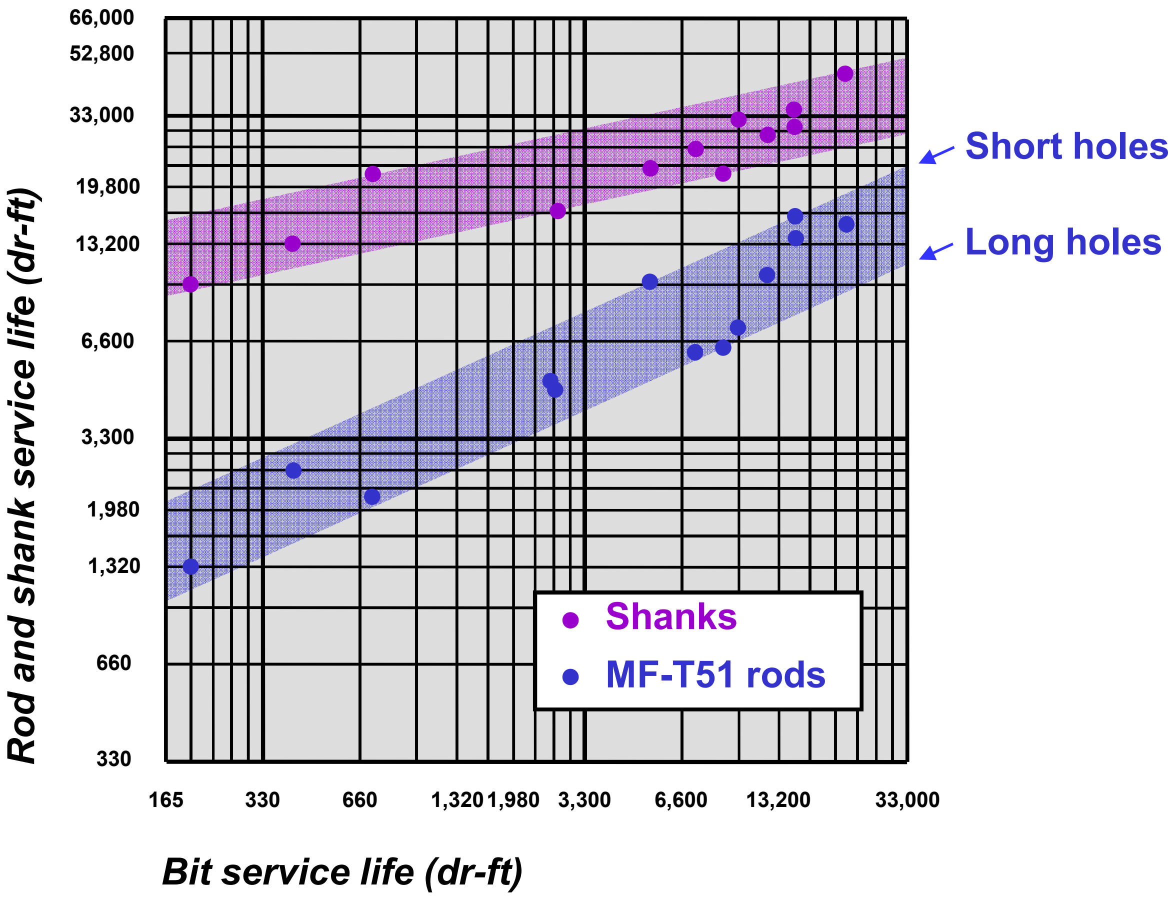


Premature button failures



Drilling Management

Example of drill steel followup for MF-T51

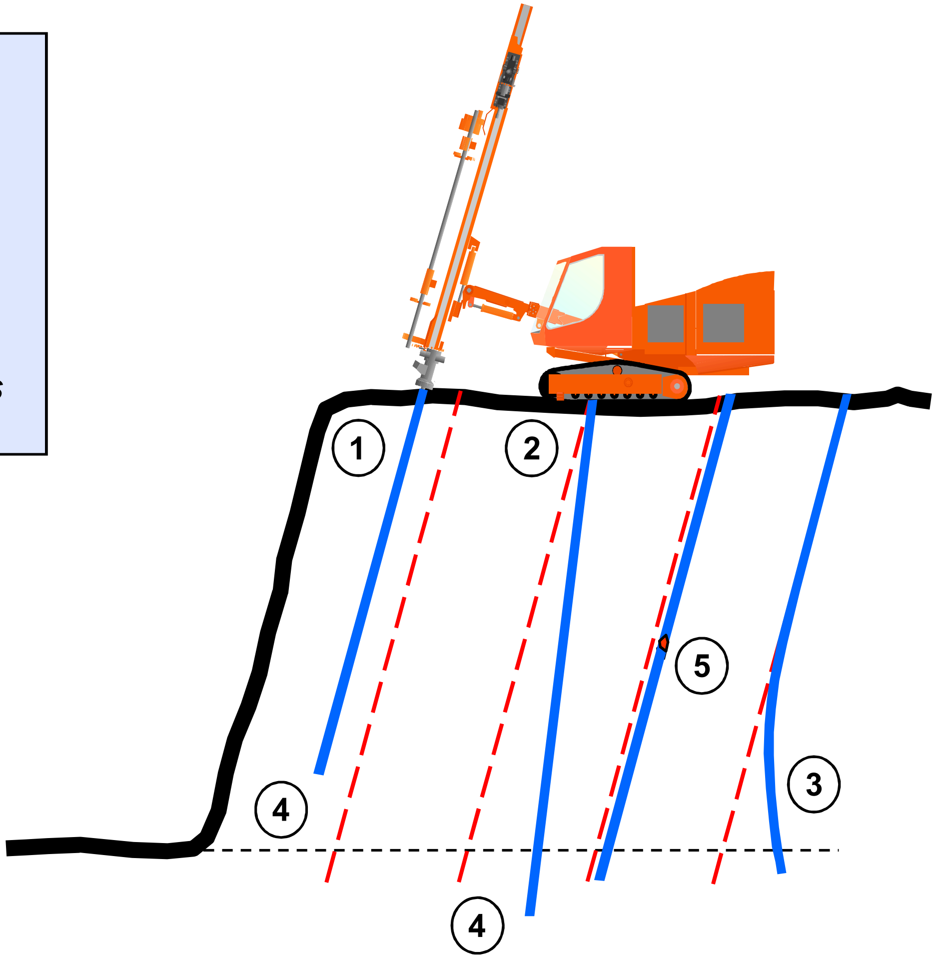


Drilling Management

Accurate drilling gives effective blasting

Sources of drilling error

1. Marking and collaring errors
2. Inclination and directional errors
3. Deflection errors
4. Hole depth errors
5. Undergauge, omitted or lost holes



Drilling Management

Examples of drill-hole deviation

Directional error Ø3½" retrac bit / T45 in granite

Deflection caused by gravitational sagging of drill steel in inclined holes in syenite

Deflection with and without pilot tube for Ø3½" DC retrac bit / T51 in micaschist

Drilling Management

I-26 Mars Hill Highway Project, North Carolina

D & B excavation volume	*13.7 mill. m^3*
Contractor for presplitting	*Gilbert Southern Corp.*
Equipment for presplitting	*3 x Ranger 700 with PS feeds*
Bench height	*7.6 m with 40° inclined walls*
Drill steel	*Ø3" retrac / T45*
Target accuracy at hole bottom	*152 mm at 10.0 m or 15.2 mm/m*
Rock type	*biotite-granite gneiss*

Drilling Management

Lafarge Bath Operations, Ontario

Annual production	1.6 mill. tonnes
Rock type	limestone

Current program - Pantera 1500

Bench height	32 m
Bit	Ø115 mm guide XDC
Drill steel	Sandvik 60 + pilot tube
Hole-bottom deflection	< 1.5 %
Gross drilling capacity	67 drm/h
Drill pattern	4.5 x 4.8 m^2 (staggered)
Sub-drill	0 m (blast to fault line)
Stemming	2.8 m
No. of decks	3
Stem between decks	1.8 m
Deck delays	25 milliseconds
Charge per shothole	236 kg
Explosives	ANFO (0.95 & 0.85 g/cm^3)
Powder factor	0.34 kg/bm^3

Drilling Management

Marking and collaring position error control

Marking collaring positions

1a. Use tape, optical squares or alignment lasers for measuring out drill-hole collaring positions.

1b. Use GPS or theodolites to determine collaring positions - an advantage when drilling from undulating terrain.

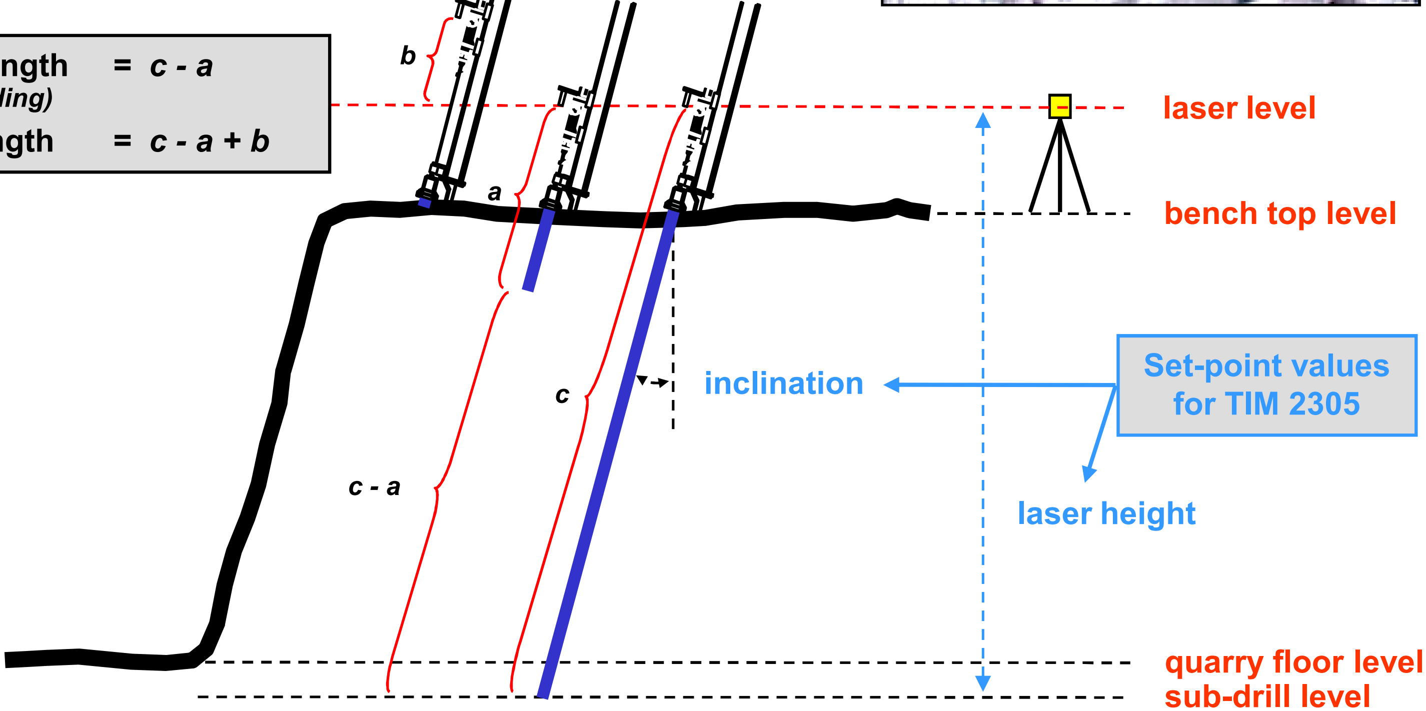
2. Collaring positions should be marked using painted lines - not movable objects such as rocks, shothole plugs, etc.

3. Use GPS guided feed collar positioning device.

Drilling Management

Hole depth error control

Remaining drill length = *c - a*
(at 1st laser level reading)
Total drill hole length = *c - a + b*



laser level

bench top level

inclination

Set-point values for TIM 2305

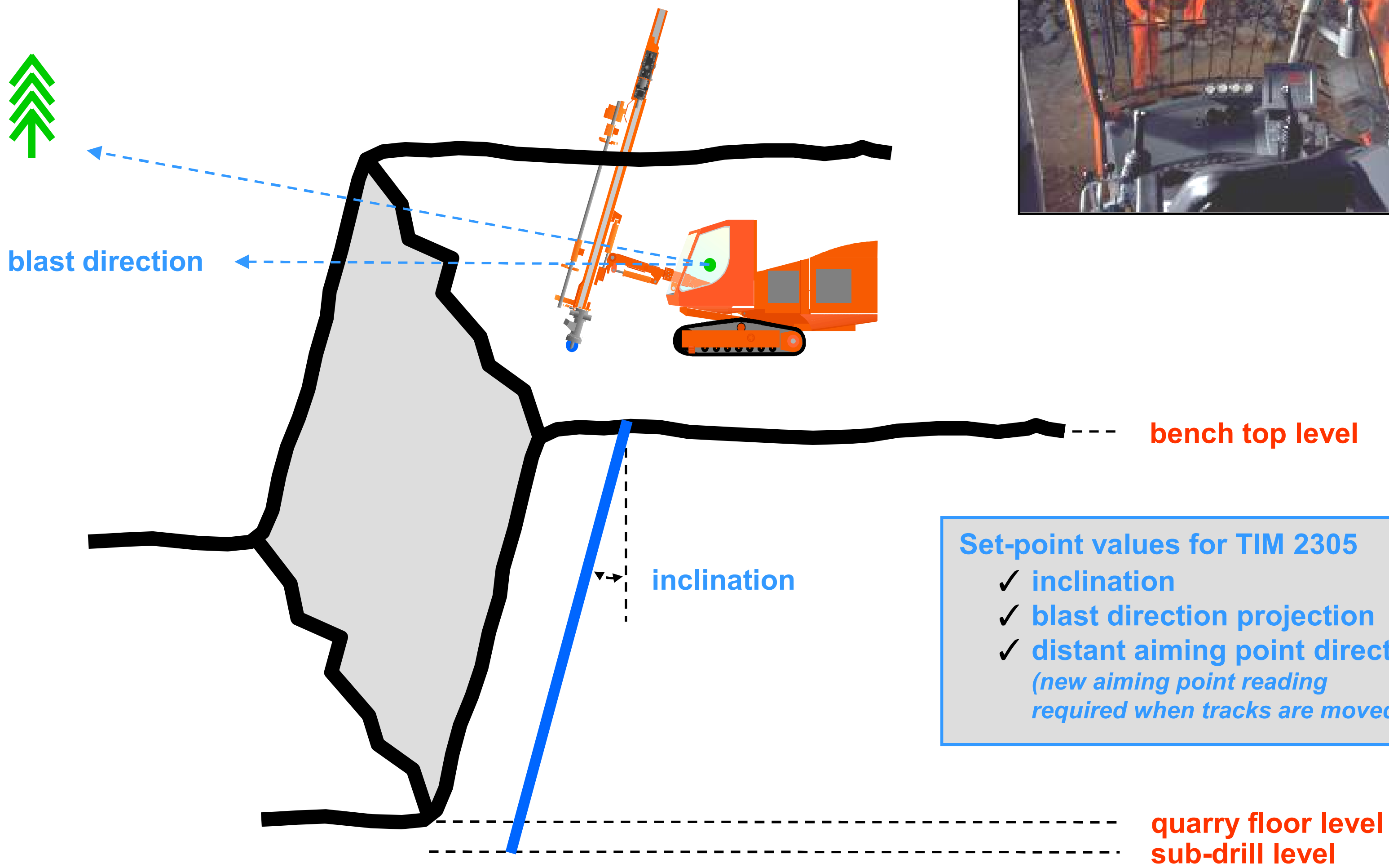
laser height

quarry floor level

sub-drill level

Drilling Management

Inclination and directional error control



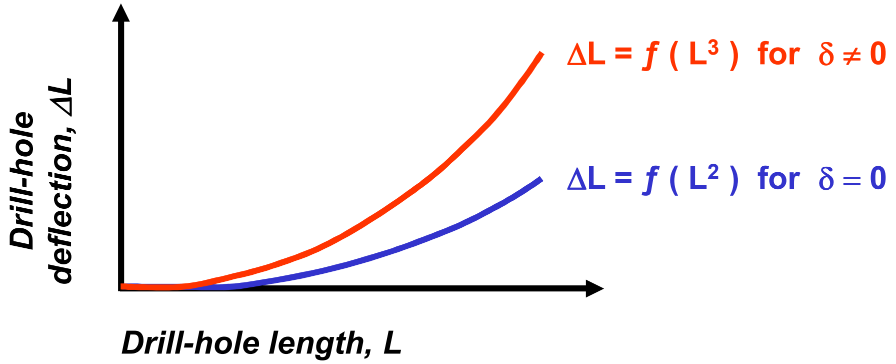
Set-point values for TIM 2305

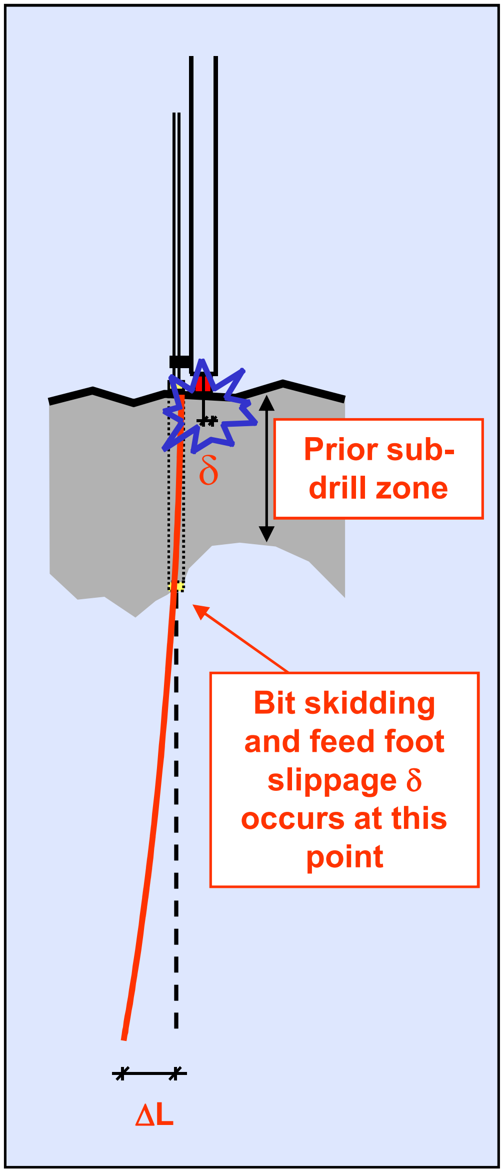
- ✓ inclination
- ✓ blast direction projection
- ✓ distant aiming point direction
  (new aiming point reading required when tracks are moved)

Drilling Management

Drill-hole deflection error control

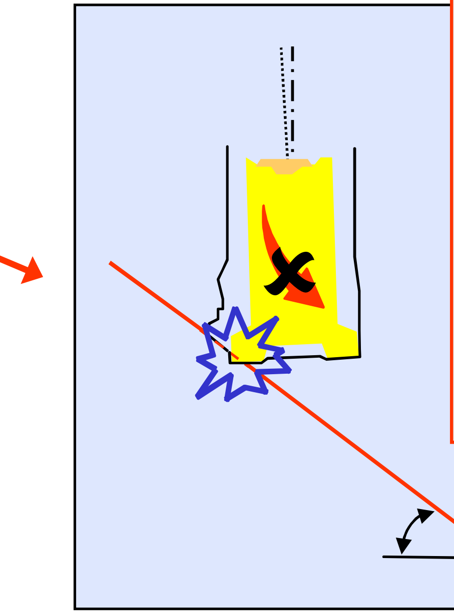
- *select bits less influenced by rock mass discontinuities*
- *reduce drill string deflection by using guide tubes, etc.*
- *reduce drill string bending by using less feed force*
- *reduce feed foot slippage while drilling - since this will cause a misalignment of the feed and lead to excessive drill string bending (occurs typically when drilling through sub-drill zones from prior bench levels)*
- *avoid gravitational effects which lead to drill string sagging when drilling inclined shot-holes (> 15°)*
- *avoid inpit operations with excessive bench heights*





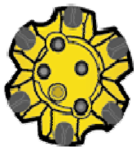
Drilling Management

How bit face designs enhance drill-hole straightness



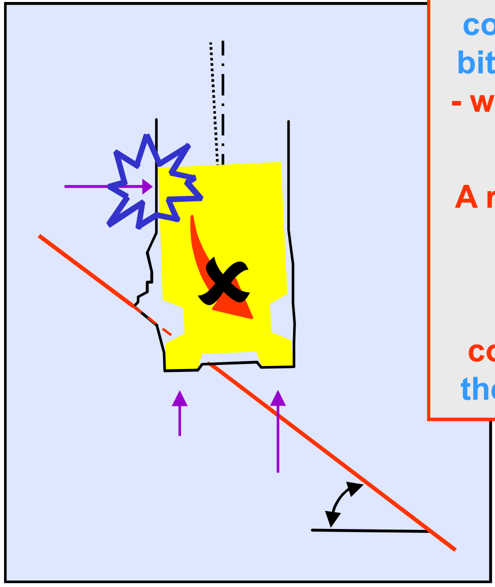
When the bit starts to drill through the fracture surface on the hole bottom - the gauge buttons tend to skid off this surface and thus deflect the bit.

More aggressively shaped gauge inserts (ballistic / chisel inserts) and bit face profiles (drop center) reduce this skidding by allowing the gauge buttons to "cut" through the fracture surface - thus resulting in less overall bit and drill string deflection.



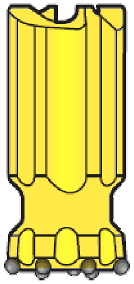
Drilling Management

How bit skirt designs enhance drill-hole straightness



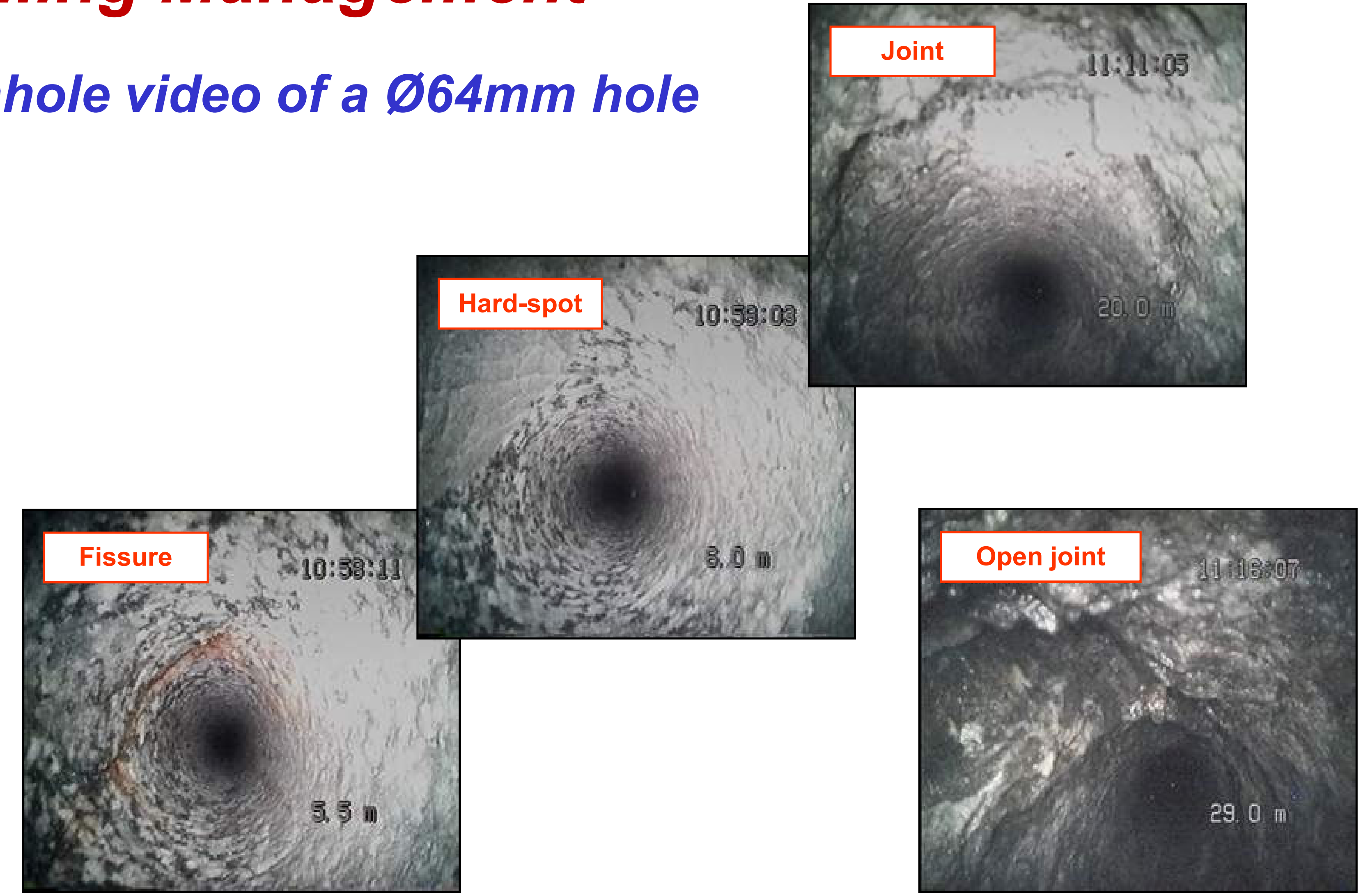
When the bit is drilling through the fracture surface - uneven bit face loading conditions arise; resulting in bit and drill string deflections - which are proportional to the bit impact force.

A rear bit skirt support (retrac type bits) reduces bit deflection caused by the uneven bit face loading conditions by "centralizing" the bit with this rear support.



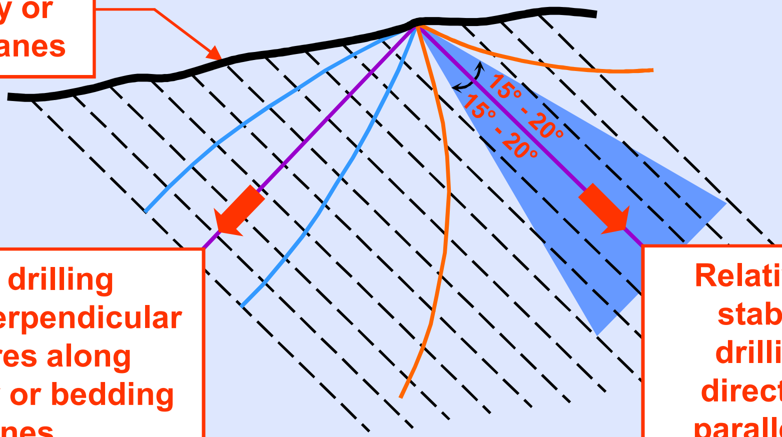
Drilling Management

Inhole video of a Ø64mm hole



Drilling Management

Drill-hole deflection trendlines in schistose rock



Fissures along schistosity or bedding planes

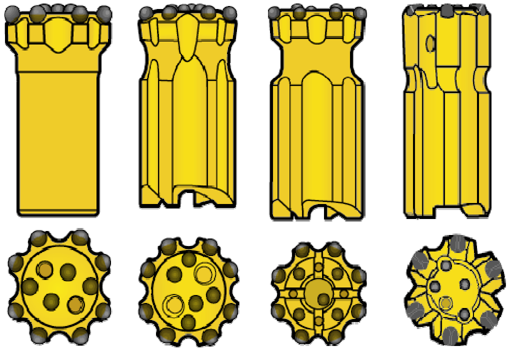
Stabile drilling direction perpendicular to fissures along schistosity or bedding planes

Relatively stabile drilling direction parallel to fissures along schistosity

Drilling Management

Selecting straight-hole drilling tools - TH

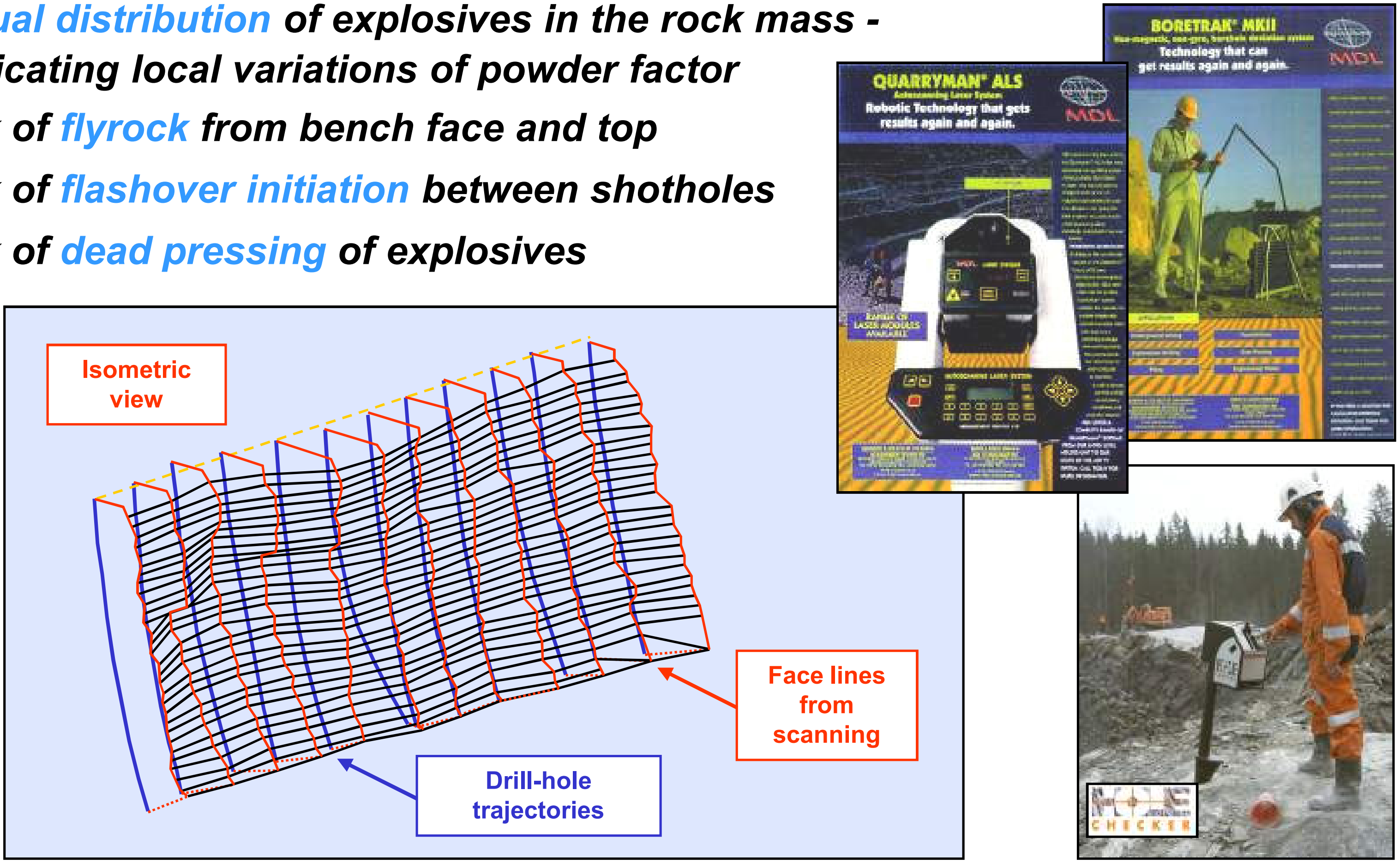
- *optimum bit / rod diameter relationship*
- *insert types / bit face and skirt*
  - ✓ *spherical / ballistic / chisel inserts*
  - ✓ *normal bits*
  - ✓ *retrac bits*
  - ✓ *drop center bits*
  - ✓ *guide bits*
- *additional drill string components*
  - ✓ *guide tubes / pilot (lead) tubes*



Drilling Management

Documention of drilling and charging prior to blasting

- actual distribution of explosives in the rock mass - indicating local variations of powder factor
- risk of flyrock from bench face and top
- risk of flashover initiation between shotholes
- risk of dead pressing of explosives



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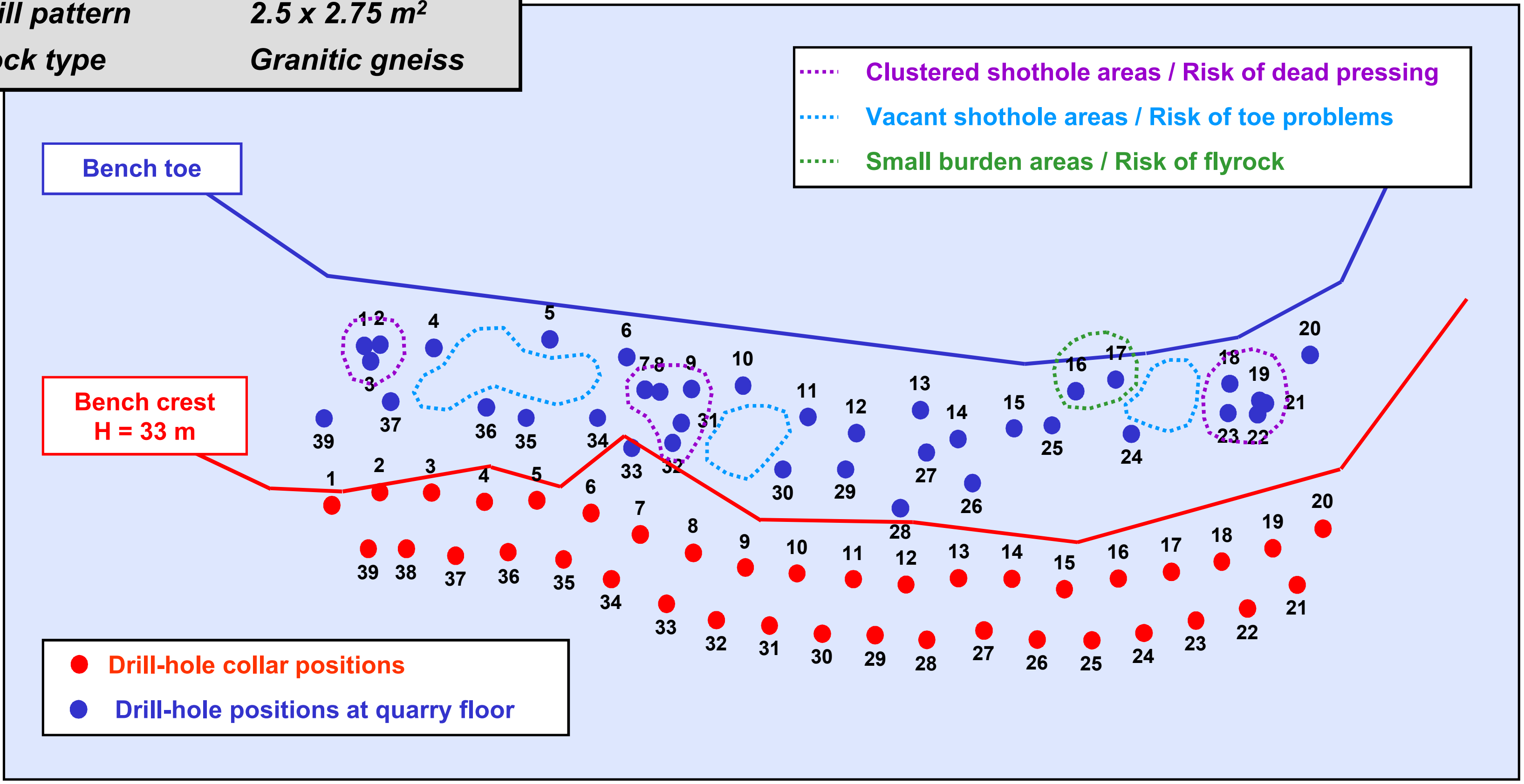
Drilling Management

Drill pattern at quarry floor

Bench height	*33 m*
Hole inclination	*14°*
Drill steel	*Ø3" retrac / T45*
Drill pattern	*2.5 x 2.75 m^2*
Rock type	*Granitic gneiss*



······ Clustered shothole areas / Risk of dead pressing

······ Vacant shothole areas / Risk of toe problems

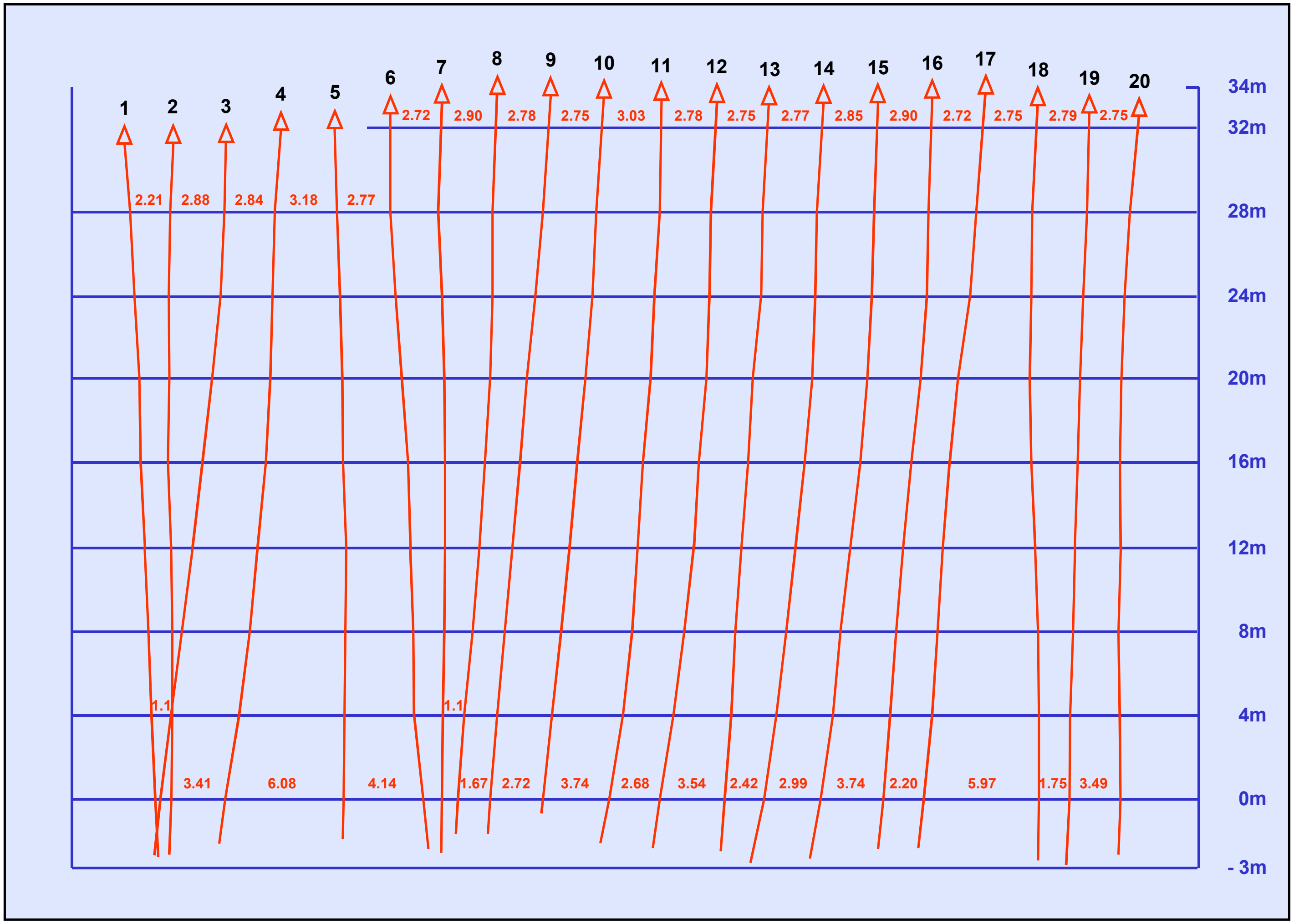
······ Small burden areas / Risk of flyrock

● Drill-hole collar positions

● Drill-hole positions at quarry floor

Drilling Management

Vertical projection of Row 1



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Drilling Management

Summary of H = 33m bench drill-hole deviation errors

Target inclination	14.0°
Average inclination	14.4°
Standard deviation	1.4°

Target azimuth	0.0°
Average azimuth	-7.6°
Standard deviation	7.7°

Bench height, H (m)	Drill-hole length, L (m)	Inclin. and directional errors, ΔL_{I+D} (mm)	Deflection errors, ΔL_{def} (mm)	Total deviation errors, ΔL_{total} (mm)	Deviation $\Delta L_{total} / L$ (%)
9	9.3	440 (140)	120	420	4.5
13	13.4	640 (210)	240	650	4.9
17	17.6	840 (275)	400	900	5.1
21	21.7	1040 (340)	610	1190	5.5
33	34.1	1630 (530)	1470	2270	6.7

(…) values where the systematic azimuth error has been excluded

Drilling Management

Summary of drill-hole deviation prediction

Prediction of overall drill-hole deviation magnitude

- *collaring errors* $\Delta L_C \sim d$
- *inclination + direction errors* $\Delta L_{I+D} = k_{I+D} \cdot L$
  $k_{I+D} = 20 - 60 \ (mm/m) \ \text{or} \ 1.1° - 3.5°$
- *deflection errors* $\Delta L_{def} = k_{def} \cdot L^2$
- *total errors* $\Delta L_{total} = (\Delta L_{I+D}^2 + \Delta L_{def}^2)^{1/2}$

Straight-hole drilling components

- ***driller*** - *marking, collaring position and feed foot slippage adjustment and feed control*
- ***drill rig*** - *inclination and directional control, hole depth, drilling control systems, collaring procedures*
- ***drill steel*** - *bit skidding while collaring, sagging and deflection control*
- ***management*** - *quality and cost of shotrock production, blasting safety and documentation*

Drilling Management

Prediction of deviation errors

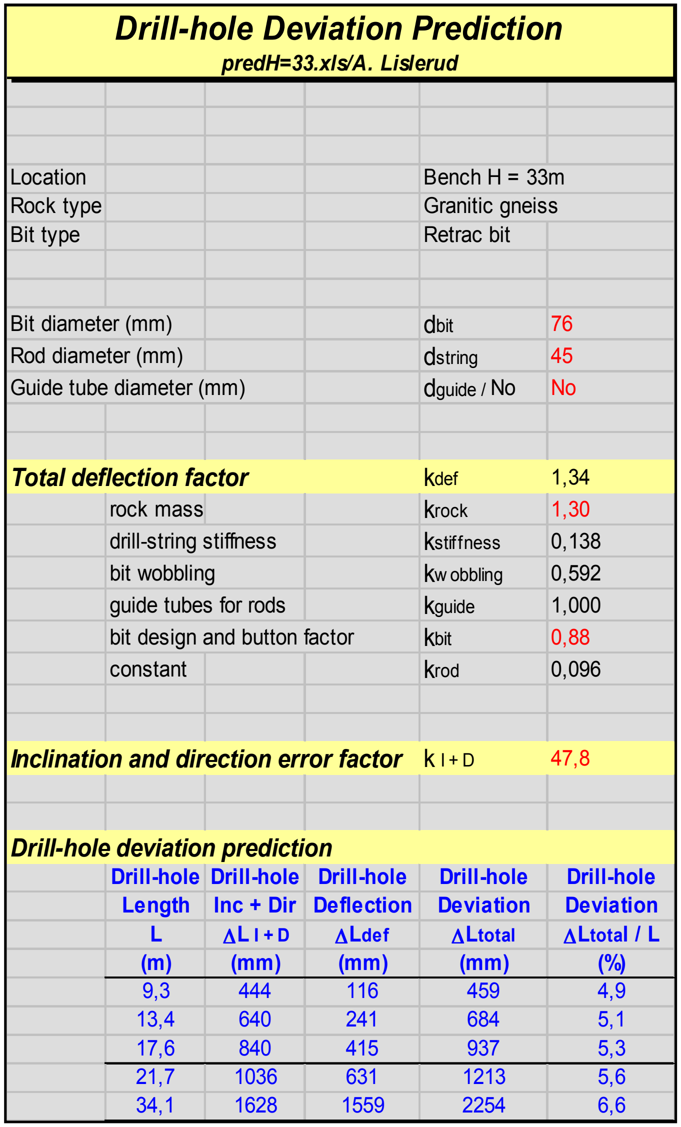
- direction of deviation can not be "predicted"
- magnitude of deviation can be predicted

Rock mass factor, k_{rock}

massive rock mass	0.33
moderately fractured	1.0
fractured	2.0
mixed strata conditions	3.0

Bit design and button factor, k_{bit}

normal bits & sph. buttons	1.0
normal bits & ball. buttons	0.70
normal X-bits	0.70
retrac bits & sph. buttons	0.88
retrac bits & ball. buttons	0.62
retrac X-bits	0.62
guide bits	0.38



Drill-hole Deviation Prediction

predH=33.xls/A. Lislerud

Location	Bench H = 33m	
Rock type	Granitic gneiss	
Bit type	Retrac bit	
Bit diameter (mm)	d_{bit}	76
Rod diameter (mm)	d_{string}	45
Guide tube diameter (mm)	d_{guide} / No	No
Total deflection factor	k_{def}	1,34
rock mass	k_{rock}	1,30
drill-string stiffness	$k_{stiffness}$	0,138
bit wobbling	$k_{wobbling}$	0,592
guide tubes for rods	k_{guide}	1,000
bit design and button factor	k_{bit}	0,88
constant	k_{rod}	0,096
Inclination and direction error factor	k_{I+D}	47,8

Drill-hole deviation prediction

Drill-hole Length L (m)	Drill-hole Inc + Dir ΔL_{I+D} (mm)	Drill-hole Deflection ΔL_{def} (mm)	Drill-hole Deviation ΔL_{total} (mm)	Drill-hole Deviation ΔL_{total} / L (%)
9,3	444	116	459	4,9
13,4	640	241	684	5,1
17,6	840	415	937	5,3
21,7	1036	631	1213	5,6
34,1	1628	1559	2254	6,6

Drilling Management

How drilling errors affect down-stream operations

Drilling	■ reduced drill steel life
Blasting	■ danger of poor explosives performance in neighbouring shotholes due to deflagration or deadpressing ■ danger of flyrock due to poor control of front row burden
Load and Haul	■ poor loading conditions on "new floors" with reduced loading capacities due to toes and quarry floor humps and locally choked (tight) blasts
Good practice	■ max. drill-hole deviation up to 2-3 %

Drilling Management

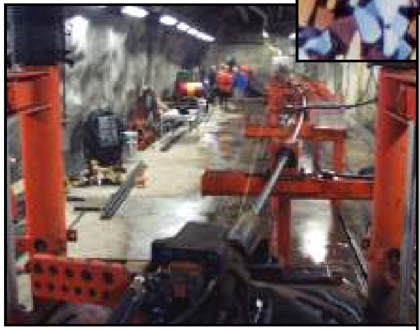
Summary of some topics in percussive drilling

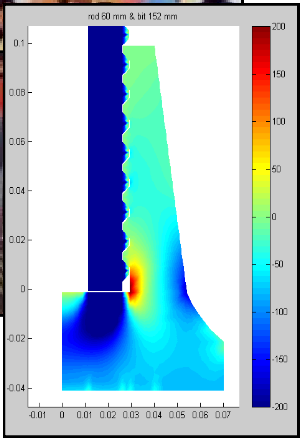
Drill bits

- ✓ *induce rock chipping*
- ✓ *sets conditions for impact energy transfer efficiency in TH drilling*
- ✓ *clean hole bottoms - flushing*
- ✓ *self stabilising bit bodies - enhance straight hole drilling*

Bit regrinding – extended bit life

- ✓ *remove snakeskin - avoid premature button breakage*
- ✓ *reshape topworn buttons - reduce bit forces and button breakage*
- ✓ *avoid flat buttons, low protrusion and bit bottoming*





Drill steel

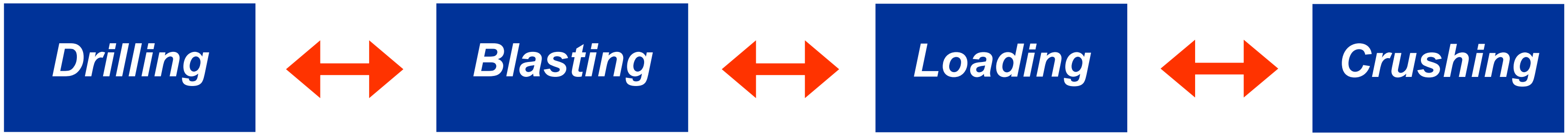
- ✓ *impact energy transfer efficiency in TH drilling*
- ✓ *flushing - return air velocity*
- ✓ *tubes or pilot tube/rods - straight hole drilling*

Drilling control systems

- ✓ *bit feed speed control*
- ✓ *flushing flow control*
- ✓ *drill string anti-jamming*
- ✓ *feed force and impact power control*
- ✓ *feed alignment, hole length and rig positioning systems*
- ✓ *input source for condition monitoring and MWD*

Quarry Management

How drilling and blasting affect down-stream operations



Drilling ↔ **Blasting** ↔ **Loading** ↔ **Crushing**

Drilling

- *sizing drill patterns*
- *drilling accuracy*

Blasting

- *field performance of explosives*
- *shotrock fragmentation*
  - ✓ *boulders*
  - ✓ *floor humps*
  - ✓ *fines and fragment microcracks*
- *muckpile profiles & swell*

Loading

- *loadability and loading capacities*
- *selectivity in mining & industrial mineral operations*

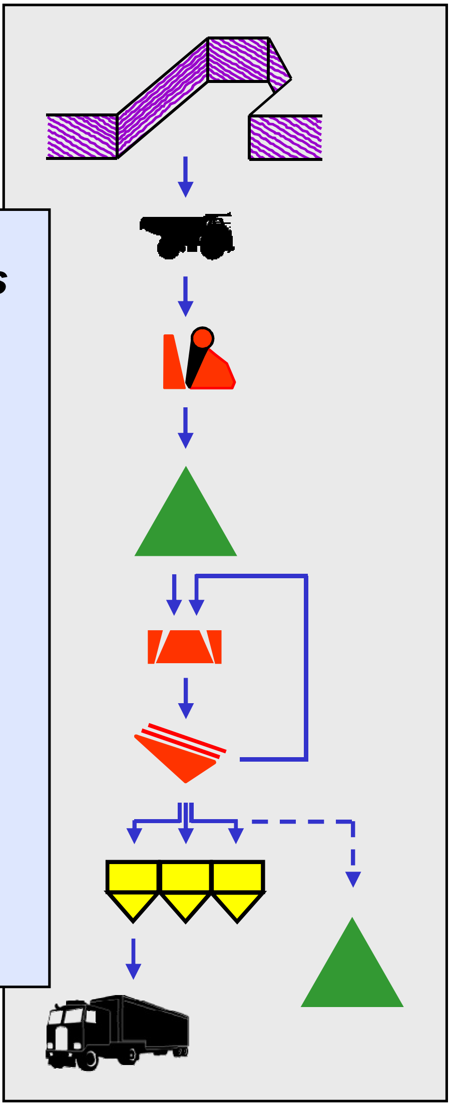
Crushing

- *boulder downtime*
- *crushing capacities*
- *power consumption*
- *production of fines and waste*

Quarry Management

Quarry Process Mapping

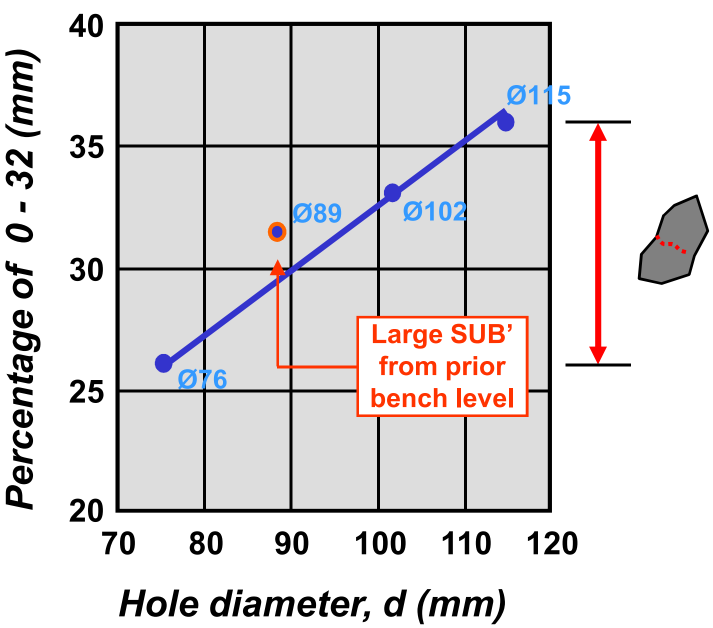
- create a baseline for existing quarrying operations and sales
- determine end-product fraction quantities as to market oppurtunities and fraction profitability
- review alternative quarry layouts - especially hauling
- adjust drill, charge and firing patterns for shotrock that:
  - ✓ enables production of desired end-product fraction quality and quantities from crushing plant
  - ✓ reduces equipment downtime
  - ✓ minimises waste
- systems in place for tracking consumables, machine hours, work-hours and production for costing and KPI input

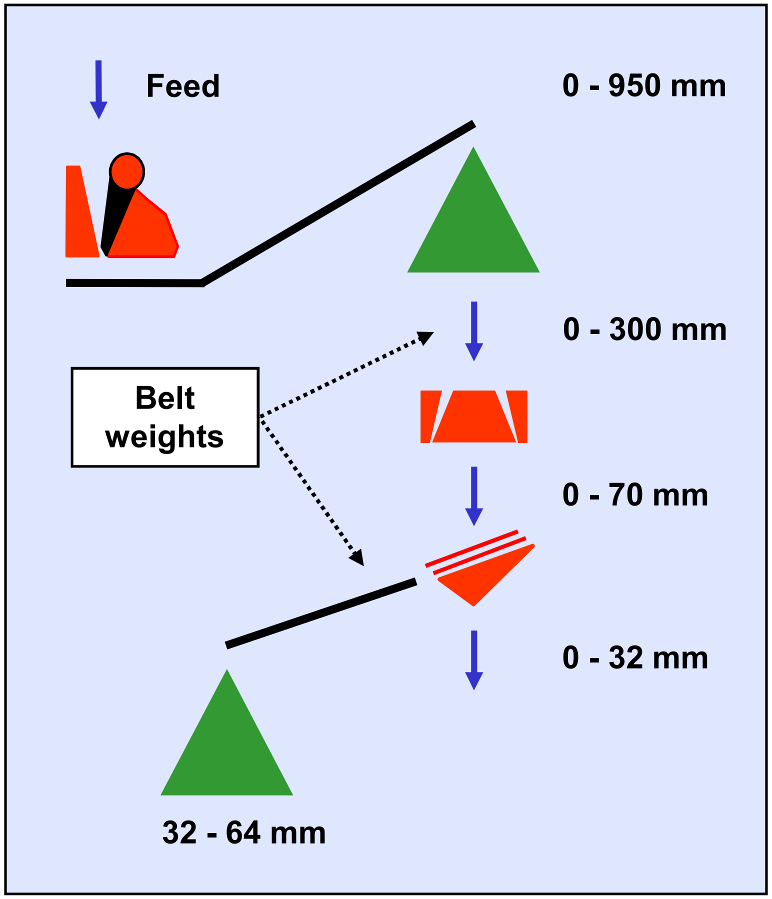


Fines Management

Nodest Vei A/S, Norway - shotrock micro-fracturing

Rock type	*Anorthosite*
Explosive	*Slurrit 50-10*
Test blasts	*4 x 50 000 tonnes*
Bench height	*11 m*




Feed
0 - 950 mm
0 - 300 mm
Belt weights
0 - 70 mm
0 - 32 mm
32 - 64 mm

Quarry Management

Lafarge Exshaw Cement Quarry

Annual production	1.6 mill. tonnes
Rock types	limestone / dolomite
Density	2.6 g/cm^3
Primary gyratory crusher	54" / 1370 mm - opening 150 mm

Base Line

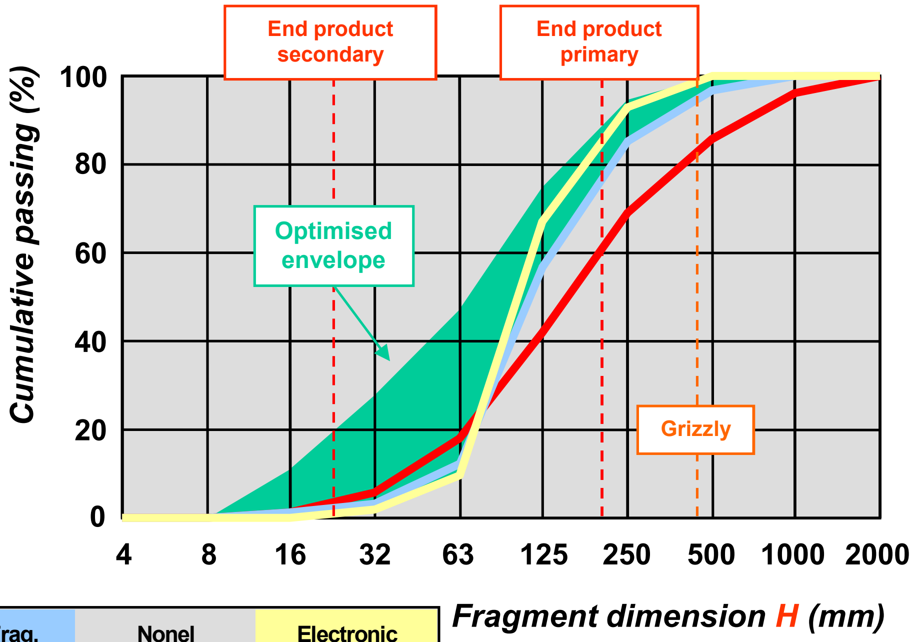
Bench height	11 m
Drill-hole diameter	Ø200 mm
Drill pattern	6 x 7 m^2 (rectangular)
Sub-drill	1.5 m
Stemming	6.0 m (0 - 19 mm matr.)
Burden delay	25 ms/m
Spacing delay	6.0 ms/m
Explosive	ANFO (1.05 g/cm^3)
Charge per shothole	215 kg
Powder factor	0.47 kg/bm^3
Back-break	up to 11 m
Shotrock fragmentation	d_{90} = 630 mm
Secondary crusher	995 tph

Finer Fragmentation

Bench height	11 m
Drill-hole diameter	Ø102 mm
Drill pattern	3 x 3.5 m^2 (staggered)
Sub-drill	1.0 m
Stemming	2.0 m (with stem plugs)
Burden delay	31 ms/m
Spacing delay	7.1 ms/m
Explosive	ANFO (0.95 g/cm^3)
Charge per shothole	78 kg
Powder factor	0.67 kg/bm^3
Back-break	avg. 2.9 m
Shotrock fragmentation	d_{90} = 300 mm
Secondary crusher	1150 tph
Crushing plant	30% power reduction

Quarry Management

Lafarge Exshaw Cont.



		Base Line	Finer Frag.	Nonel	Electronic
Drill & Blast	Shothole diameter, mm	200	102	102	102
	Drill pattern, m2	6 x 7	3 x 3,5	3,5 x 3,5	3,5 x 3,5
	ANFO density, g/cm3	1,05	0,95	1,05	1,05
	Powder factor, kg/bm3	0,47	0,67	0,63	0,63
Firing	Initiation system	NONEL	NONEL	NONEL	Daveytronic
	Downhole delay, ms		500	500	None
	Inter-hole delay, ms	42	25	17	17
	Inter-row delay, ms	150	92	92	92
Shotrock Fragmentation	90% passing - d90, mm	630	300	351	220
	Grizzly retain (> 480 mm), %	18	5	5	0
Ground Vibrations	Distance, m	375	375	280	270
	Peak particle velocity, mm/s	> 8	4,75	6,97	4,51
	Main frequencies, Hz	9 - 21	14 - 21	10 - 21	11 - 39
Plant Production	Peak - 1 hour average, tph	834	980	980	1050
	Power consumption, kW	2259	1808	1979	1858
	Specific energy, kWh/t	2,71	1,84	2,02	1,77
	3 day average, tph	625	725	676	722
	Power consumption, kW	1645	1342	1370	1283
	Specific energy, kWh/t	2,63	1,85	2,03	1,78

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