Drilling

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QUARRY ACADEMY

Improving Processes. Instilling Expertise.

ORICA

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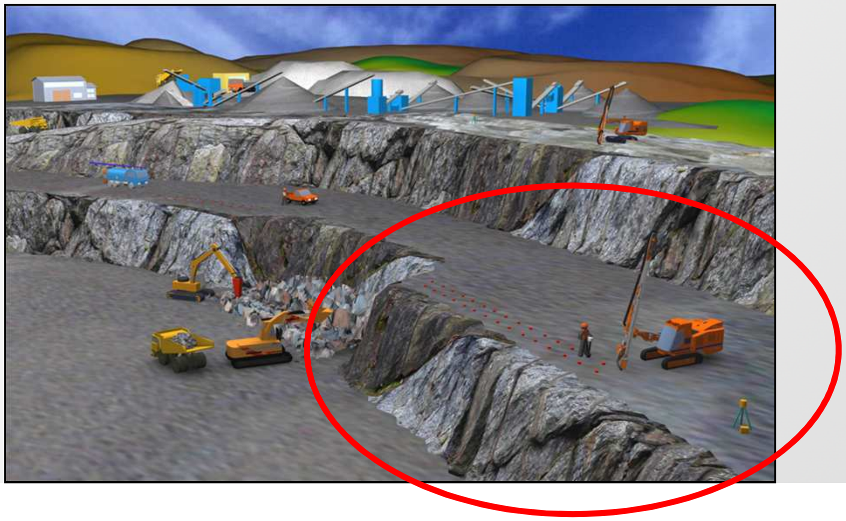
Agenda for drilling operations

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



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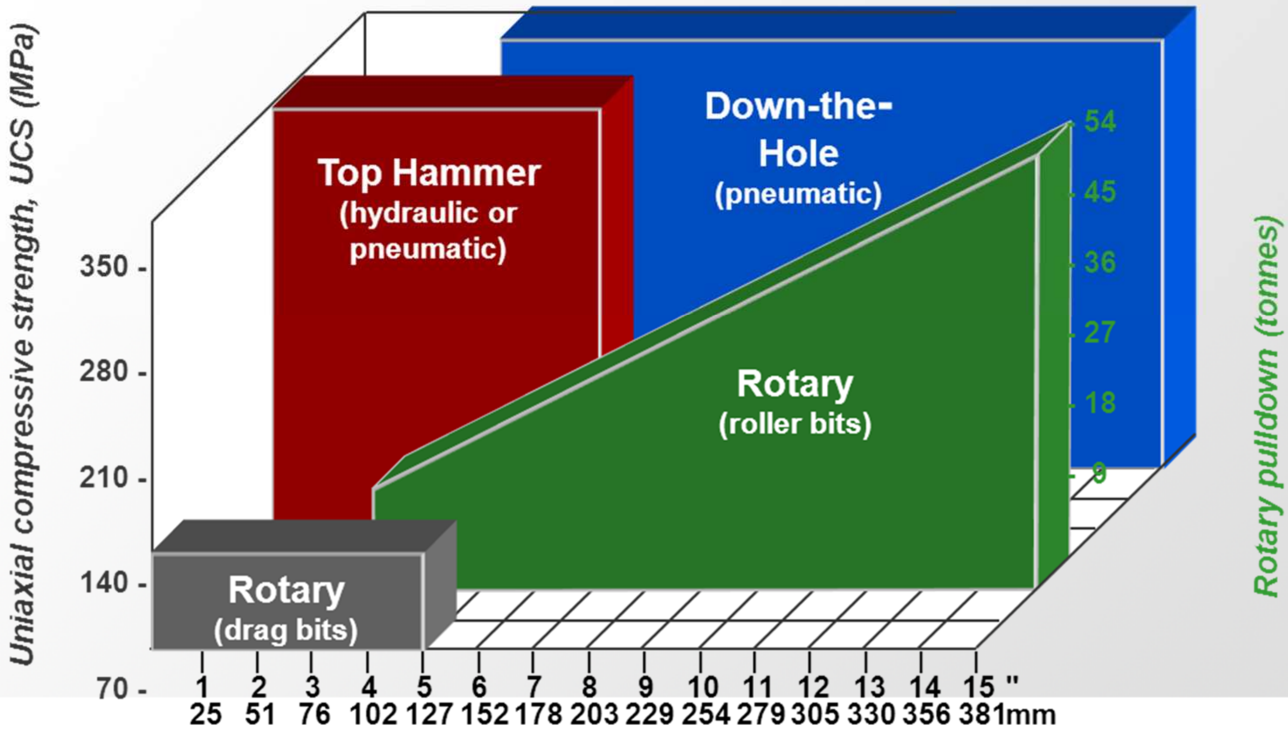
The most common drilling methods in use



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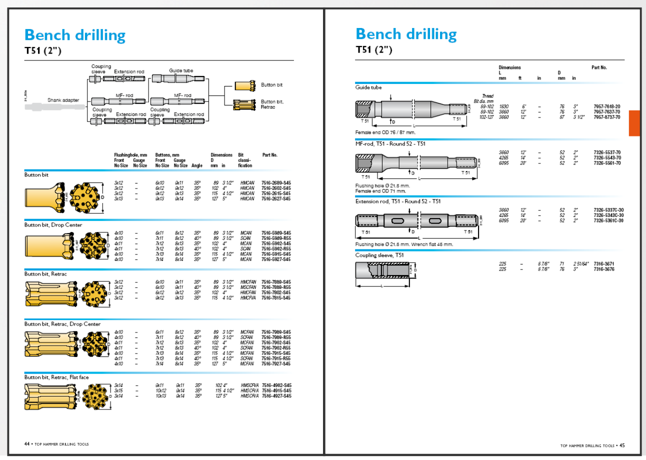
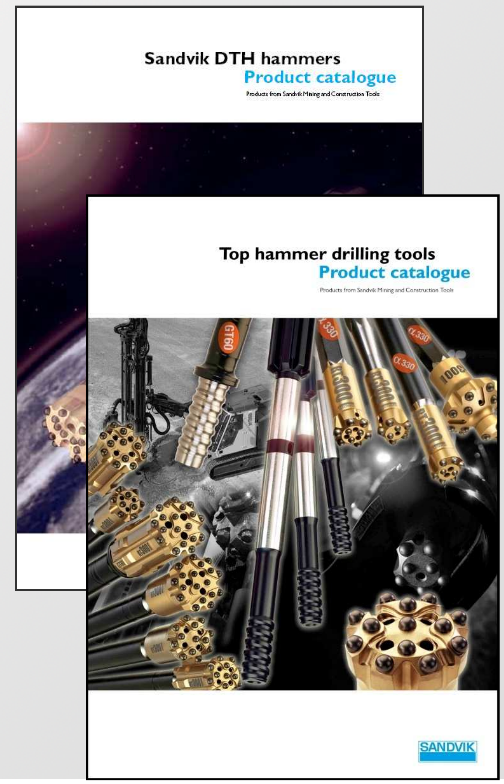
Drilling consists of a working system of:

- bits
- drill string
- boom or mast mounted feed
- TH or DTH hammer / Rotary - thrust
- drill string rotation and stabilising systems
- powerpack
- automation package
- drilling control system(s)
- collaring position and feed alignment systems
- flushing (air, water or foam)
- dedusting equipment
- sampling device(s)

Selecting drilling tools

- bit face and skirt design
- button shape, size and carbide grade
- shanks, rods, tubes, …
- grinding equipment and its location





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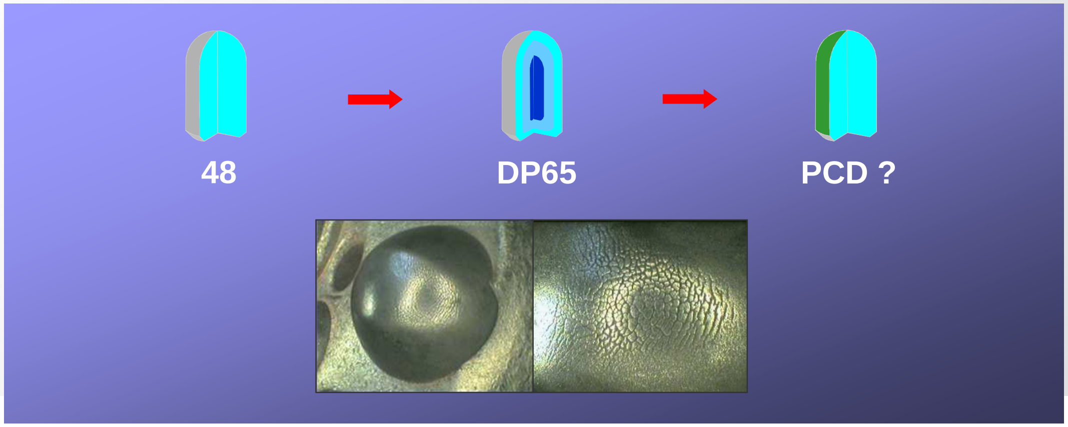
Guidelines for selecting cemented carbide grades

- avoid excessive button wear (rapid wearflat development)
  - => select a more wear resistant carbide grade or drop bit RPM
- avoid button failures (due to snakeskin development or too aggressive button shapes)
  - => select a less wear resistant or tougher carbide grade or spherical buttons
  - => use shorter regrind intervals



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Selecting button shapes and cemented carbide grades

Spherical buttons
DP65
S65

Robust ballistic buttons
48
R48

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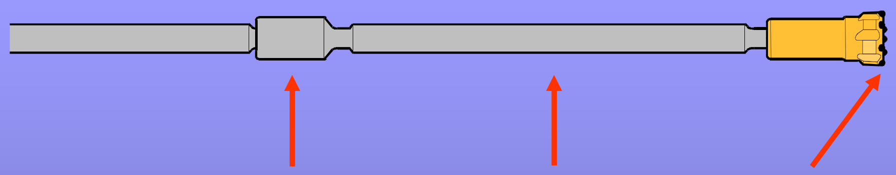
Optimum bit/rod diameter relationship for TH



Thread	Diameter coupling	Diameter	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

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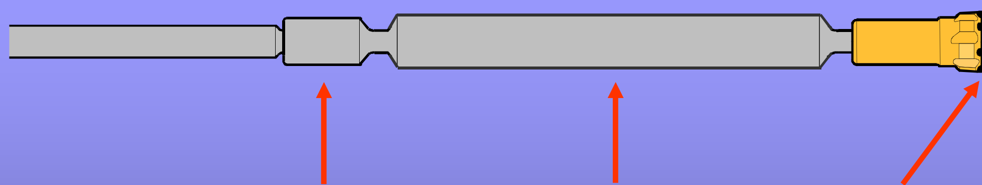
Optimum bit/guide or pilot (lead) tube relationship for TH

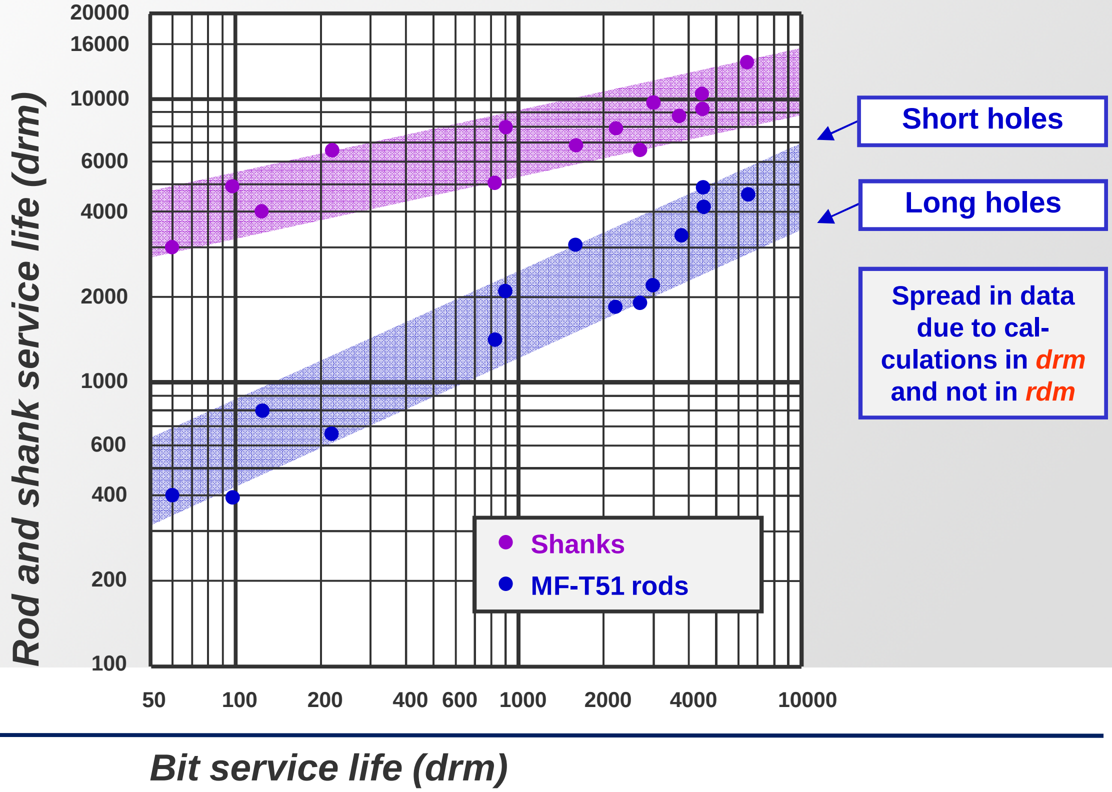


Thread	Diameter coupling	Diameter	Optimum bit size
T38	∅55	∅56	∅64
T45	∅63	∅65	∅76
T51	∅71	∅76	∅89
GT60	∅85	∅87	∅102
GT60	∅85	∅102	∅115

Jobsite KPI's for drill steel

- drill steel component life
- bit regrind intervals
- bit replacement diameter
- component discard analysis
- costs in € per drm or m^3

Example of drill steel followup for MF-T51



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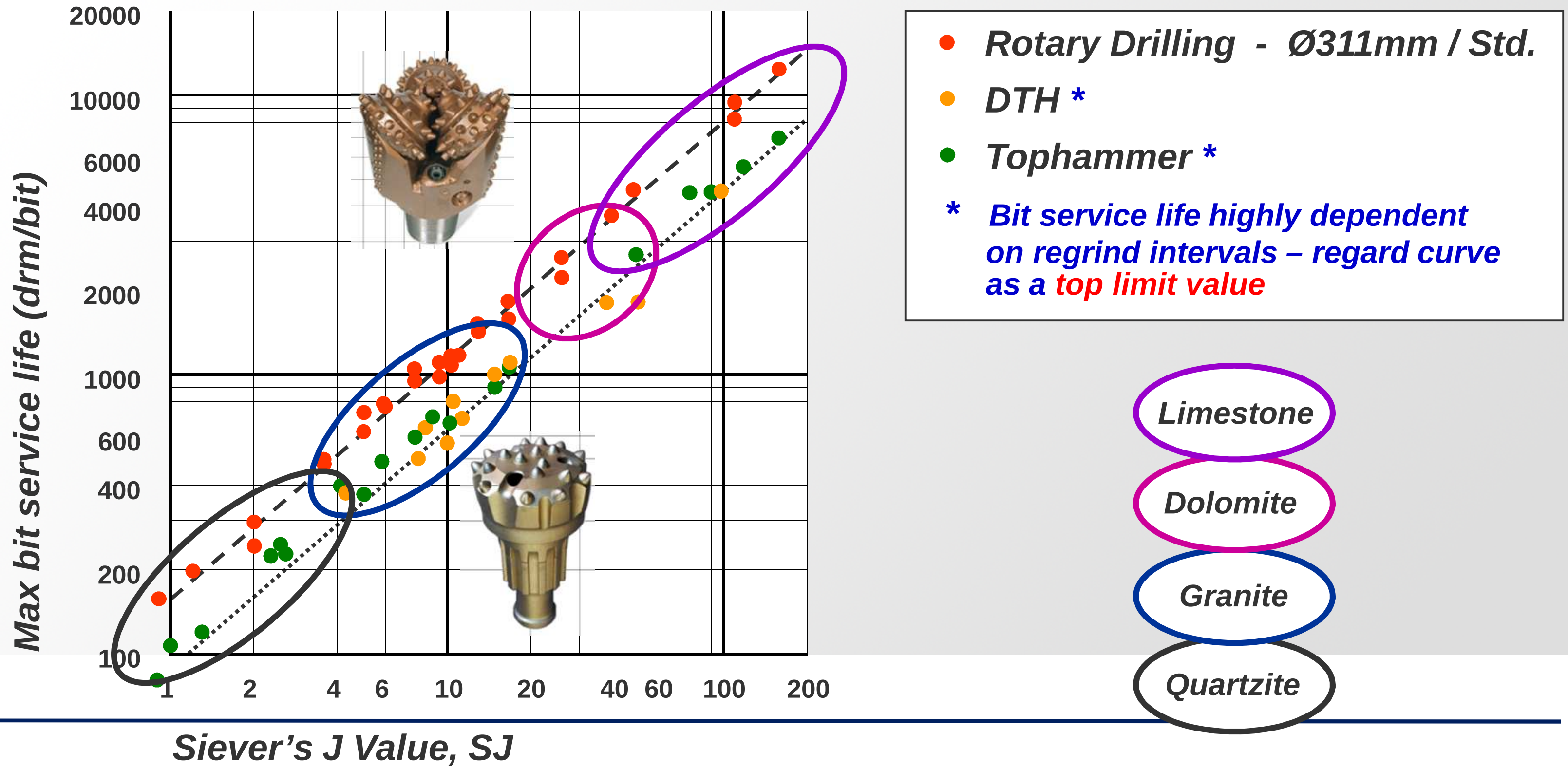
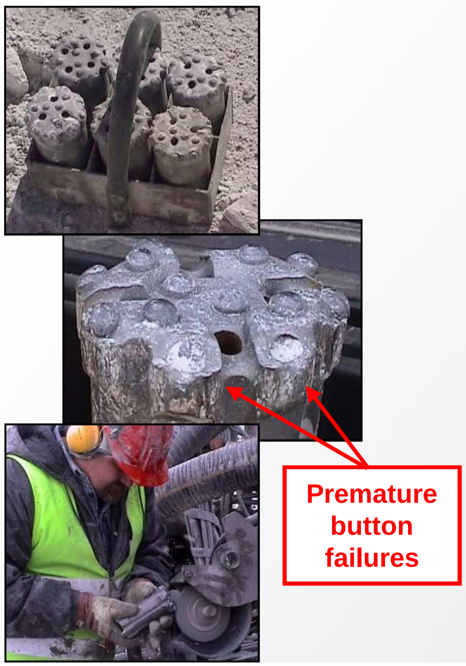
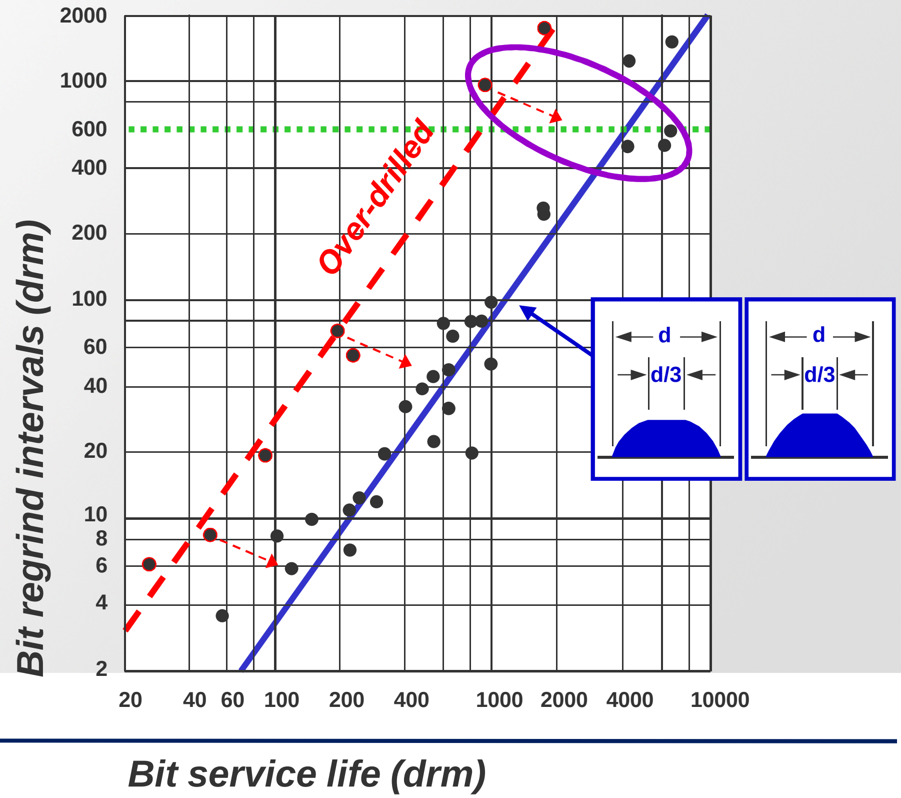
Trendlines for bit service life



Bit regrind intervals, bit service life and over-drilling





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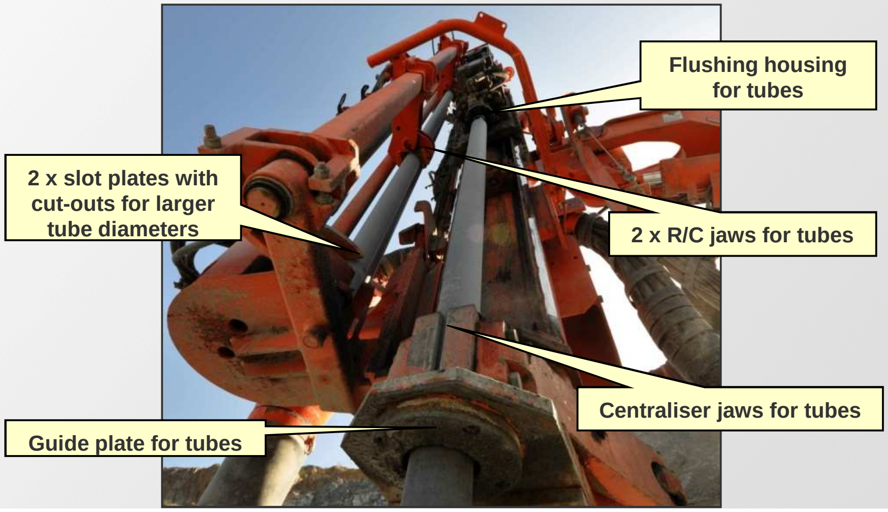
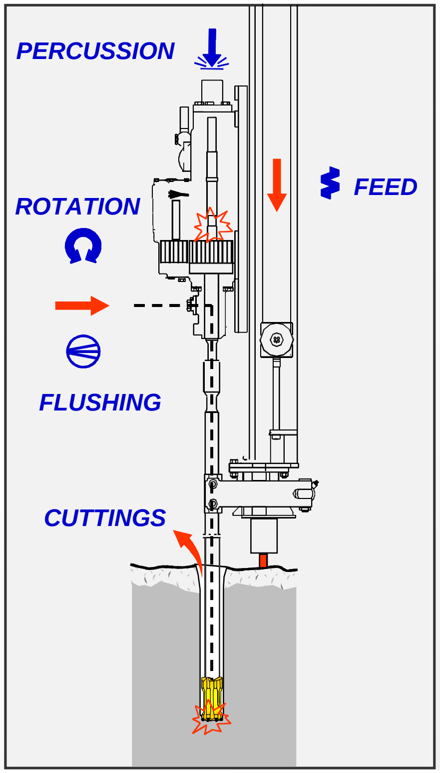
Tube drilling for TH – avoid:

- bending of drill string - leads to premature tube failure
- hardrock drilling or bit service life < 1750 drm - leads to poor tube life
- jerky drill string rotation - leads to an unstable bit which initiates drill-hole deviation



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 at impact*
- ✓ ***rotation*** - *provide bit impact indexing*
- ✓ ***flushing*** - *cuttings removal from hole bottom*
- ✓ ***foam flushing*** - *drill-hole wall stabilisation*

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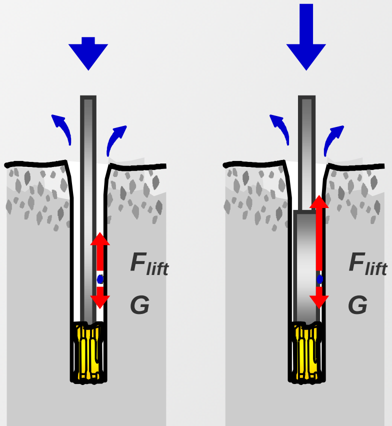
Flushing of drill-cuttings

Insufficient air < 15 m/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 > 30 m/s

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

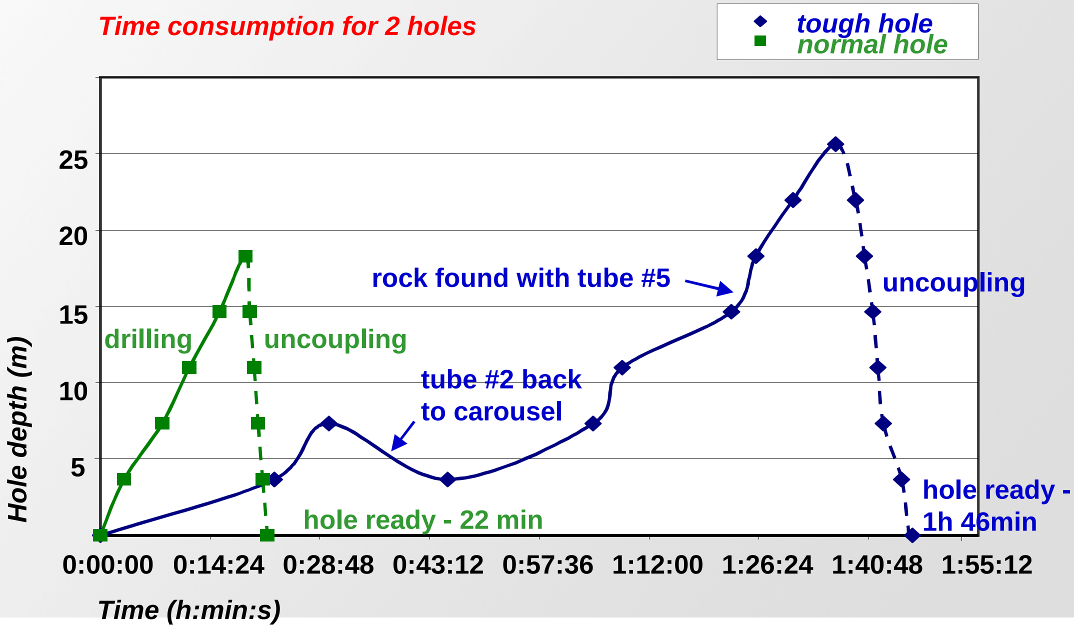


Correction factors

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

Foam flushing – an aid for drilling in caving material

Burst of inhole water



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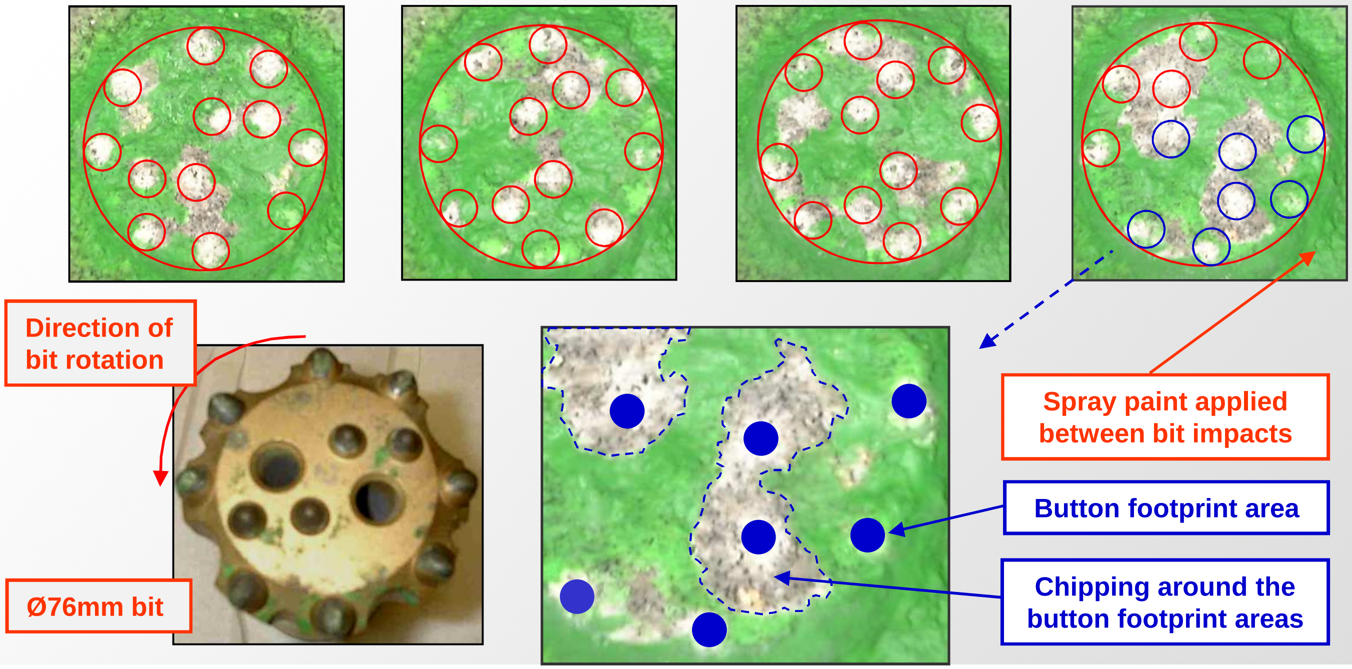
Chip formation by bit indentation and indexing



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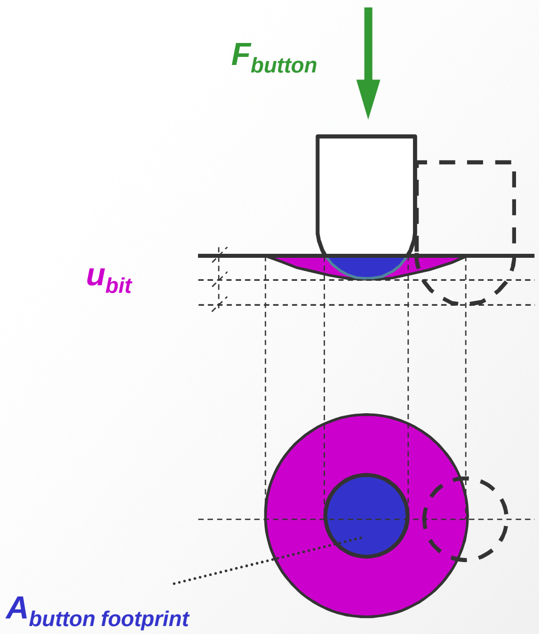
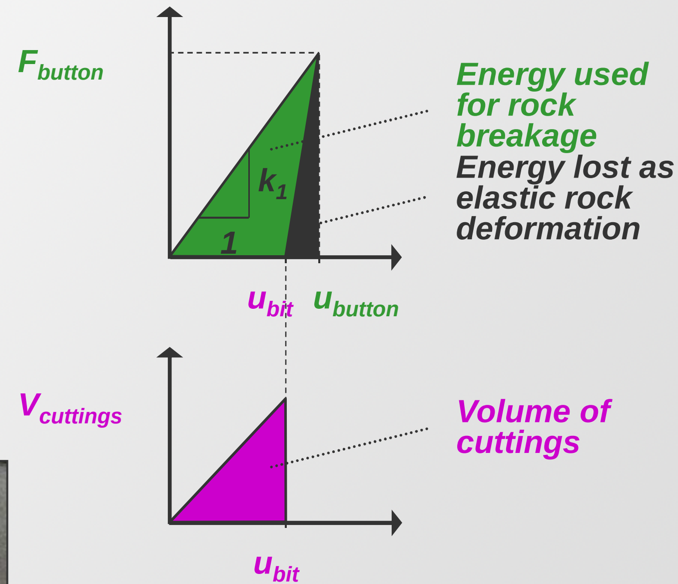
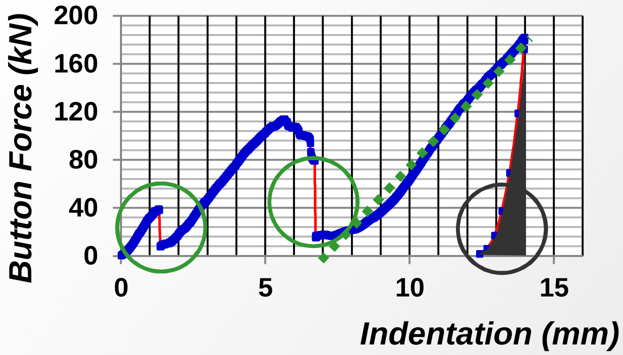
How rock breaks by indentation





Indentation with multiple chipping

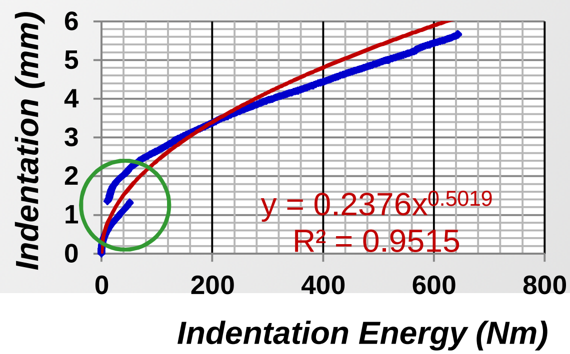


- - - k_1 = 30 kN/mm for on-loading
— k_2 = 112.5 kN/mm for off-loading
$\gamma = k_1 / k_2 = 0.267$

Drop in button force indicates elastically stored energy in rock released by chipping

chipping while on-loading

chipping after off-loading



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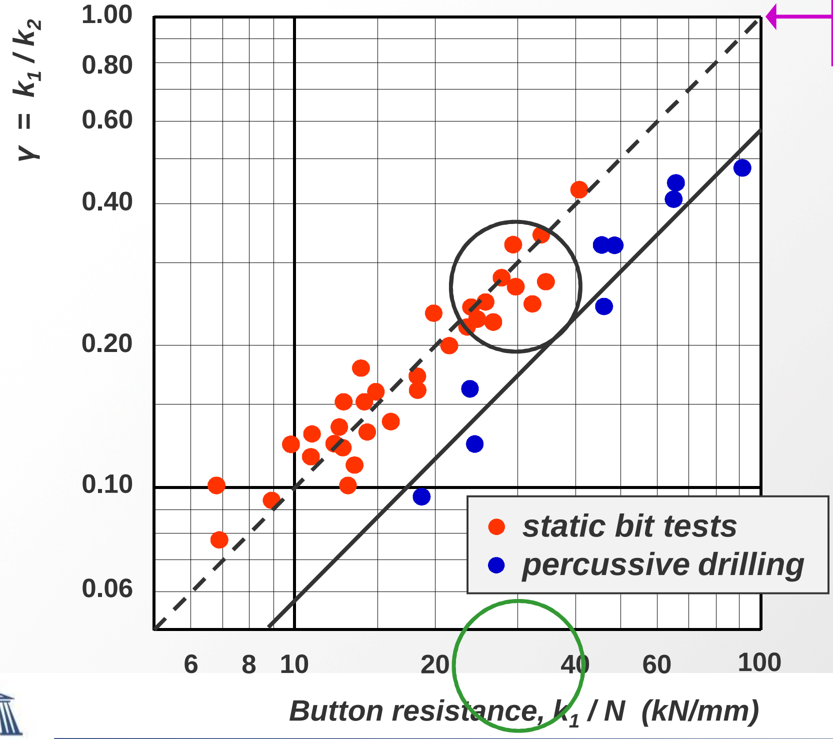
Energy transfer efficiency η related to rock chipping



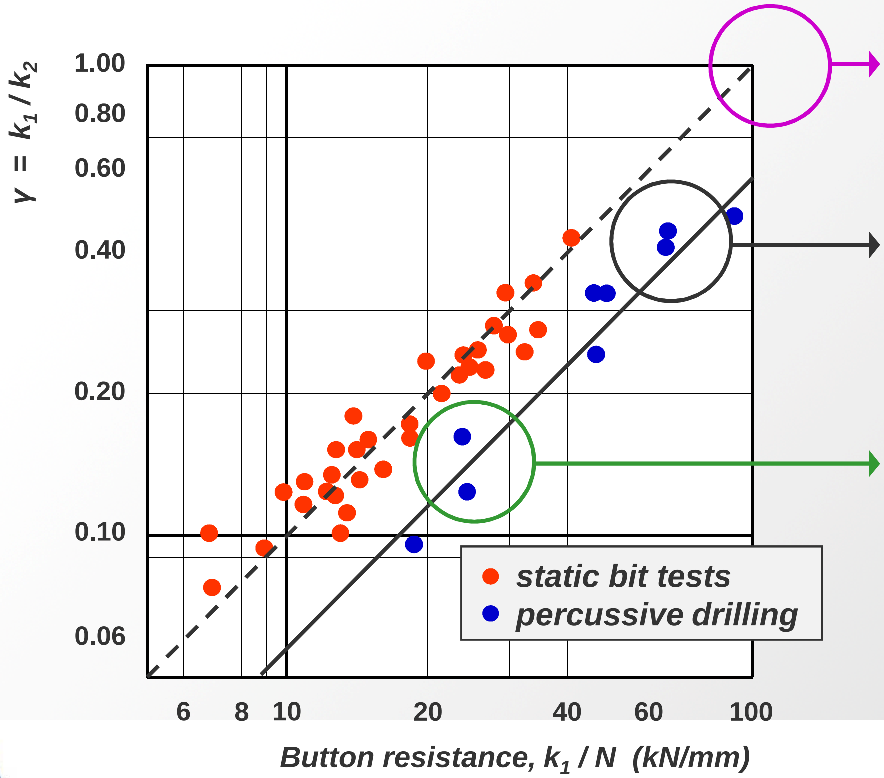
No energy retained in rock after off-loading for γ = 1.0
(all elastic energy in rock returned to drill string)

$$\eta = W_{rock} / W_{incident}$$

$$= \eta_{impedance} \cdot (1 - \gamma)$$

$$\eta_{impedance\text{-}max} \approx 0.90$$

How does this apply to practical drilling?



"Hopeless" drilling situation
- no bit advance rate for γ = 1.0

"Poor" drilling situation
- chipping after off-loading
- potential for severely reduced drill steel life
- correct choice of bit design and size?
- sufficient bit regrinding (resharpening)?

"Good" drilling situation
- chipping during on-loading
- potential to achieve max drill steel service life

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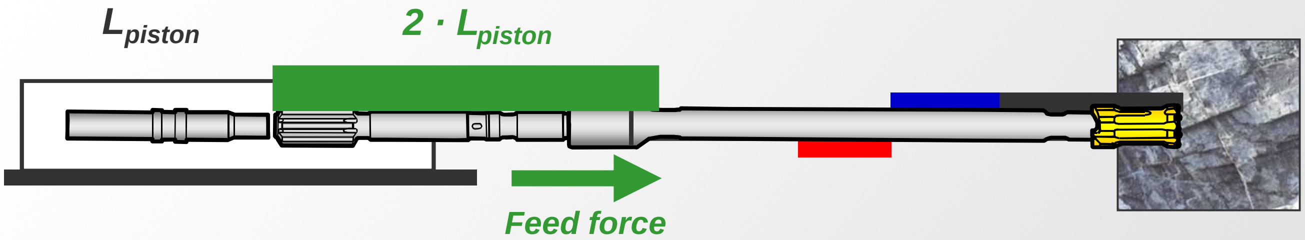
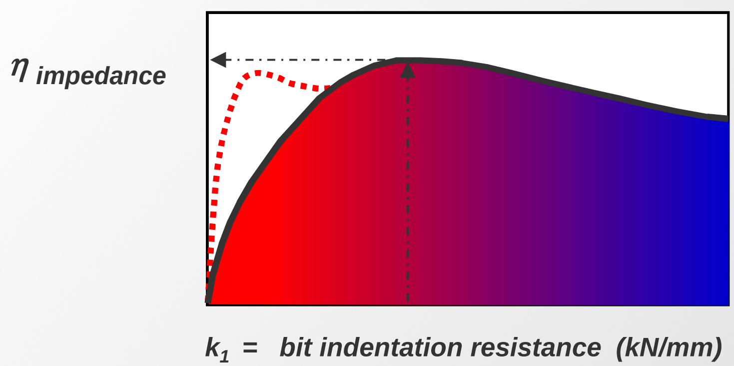
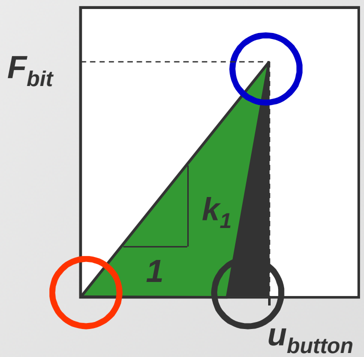
Energy transfer efficiency η related to impedance matching







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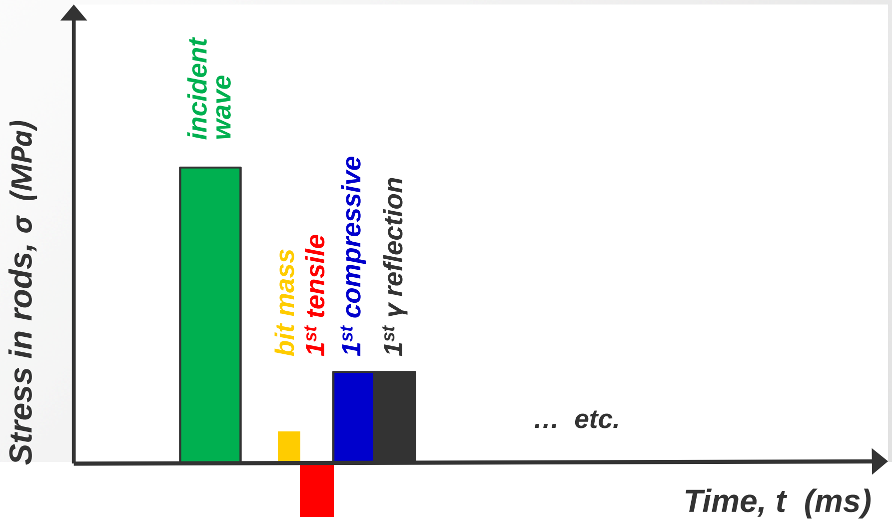
How do we study drill string energy transfer issues?

- strain gauge measurements on rods/tubes while drilling
- numerical modelling

=> the tell-tale items we are looking for:



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Energy transfer chain – video clip cases

cavity

"perfect" bit / rock match

bit / rock gap – i.e. underfeed

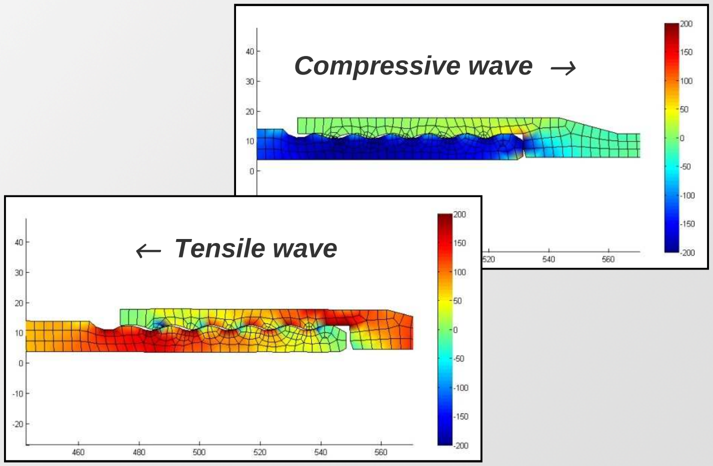
bit face bottoming – caused by:

- *drilling with too high impact energy*
- *drilling with worn bits i.e. too low button protrusion*

Energy transmission through threads

Energy transfer 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.

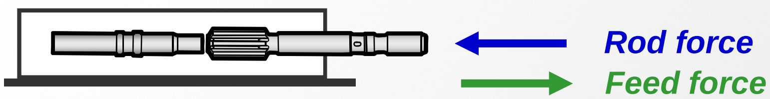
Tensile stresses are transmitted through couplings by the thread surfaces - not through the bottom or shoulder contact as in the case for compressive waves.

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

Feed force rquirements

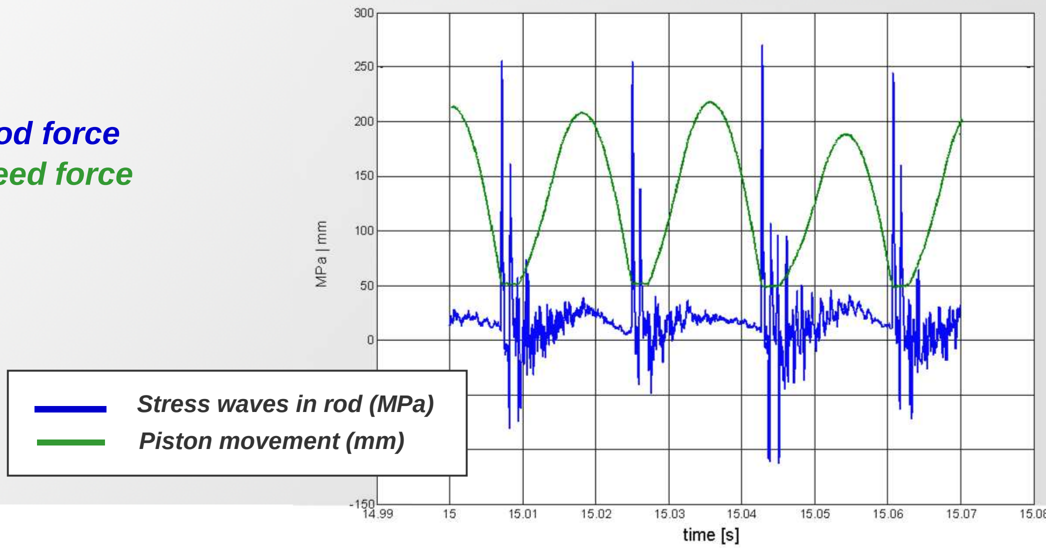
From a drilling point of view

- *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*



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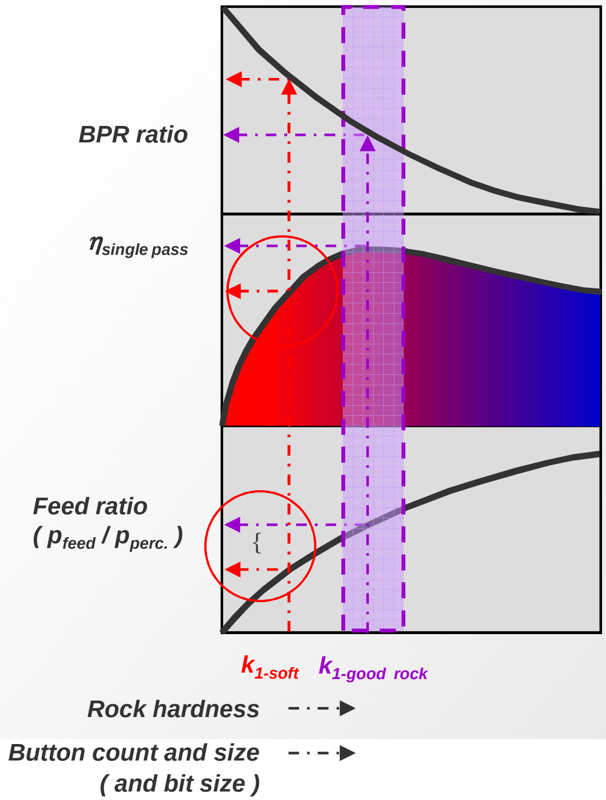
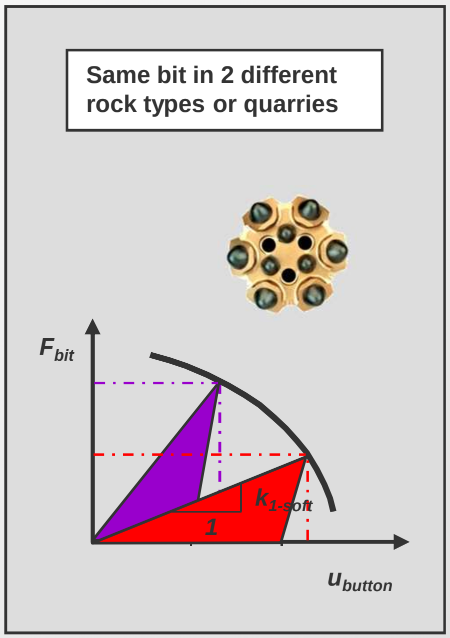
Matching drill settings to site conditions





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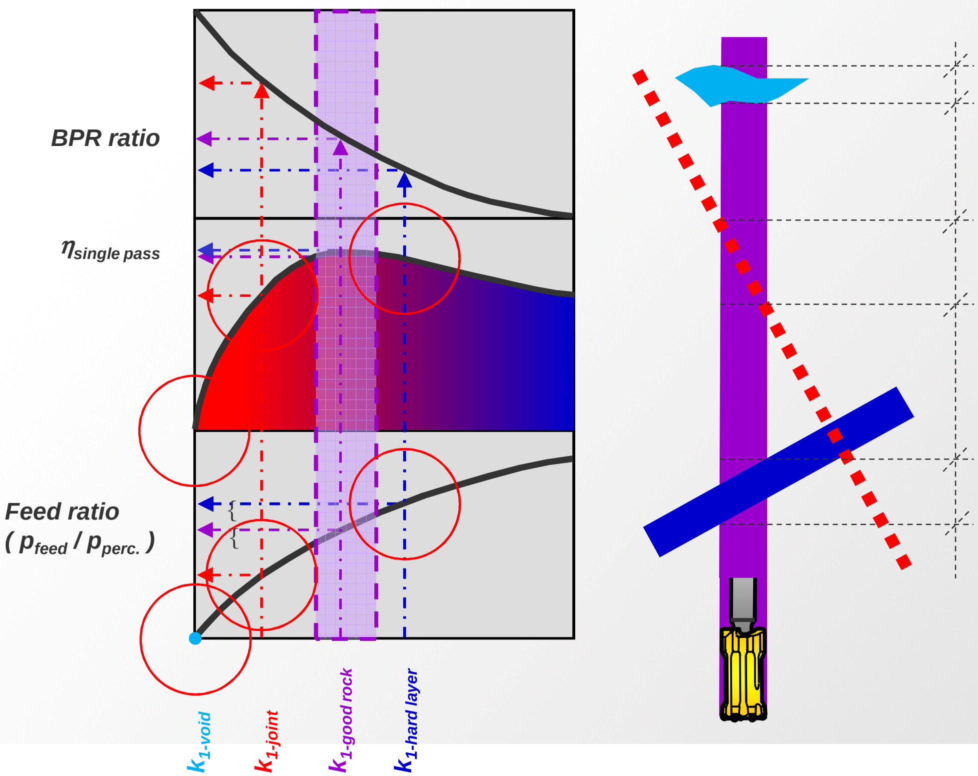
Drilling in variable rock mass conditions



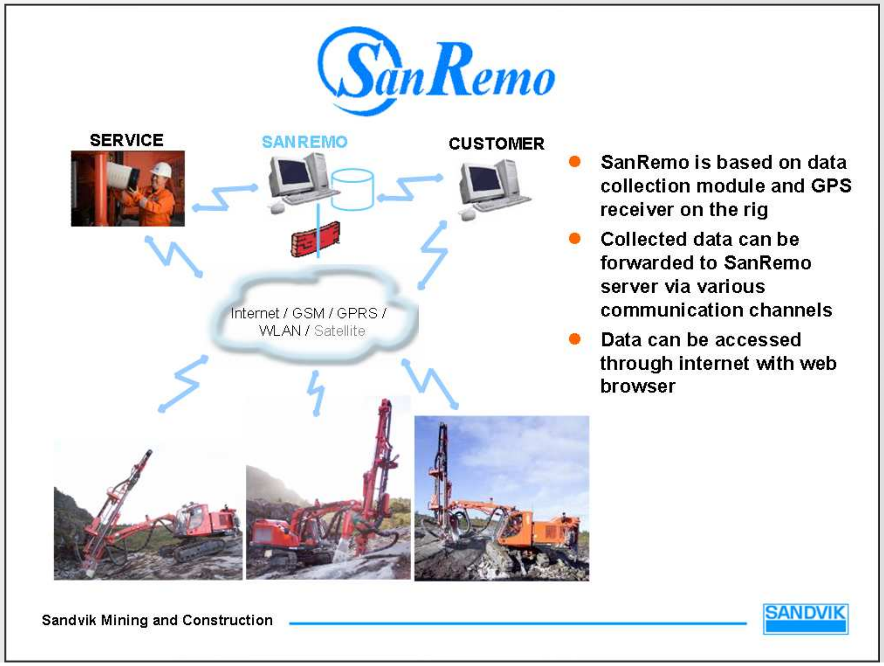
Situation =>	Actual feed conditions
$k_{1\text{-void}} \approx 0$	Total overfeed (feed speed control)
$k_{1\text{-good rock}}$	OK (ratio set here)
$k_{1\text{-joint}} < k_{1\text{-good rock}}$	Overfeed
$k_{1\text{-good rock}}$	OK
$k_{1\text{-hard layer}} > k_{1\text{-good rock}}$	Underfeed

Jobsite KPI's for drilling operations

- drilling capacities in drm/ph or drm/eh
- production capacity in drm/shift
- avg. percussion pressure
- fuel consumption l/eh
- drill steel consumption & costs

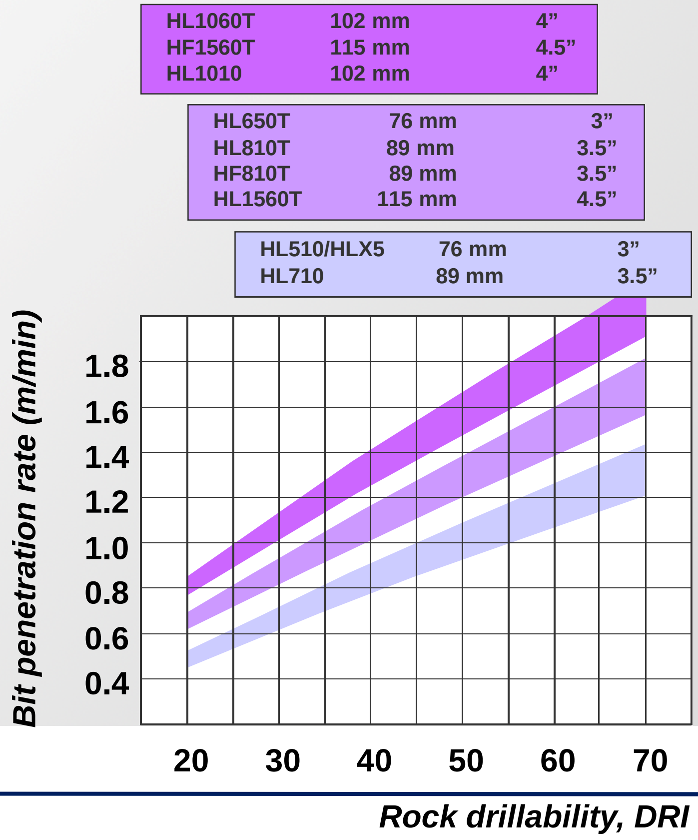
- drill-hole straightness
- geological conditions

- costs in € per drm or m^3



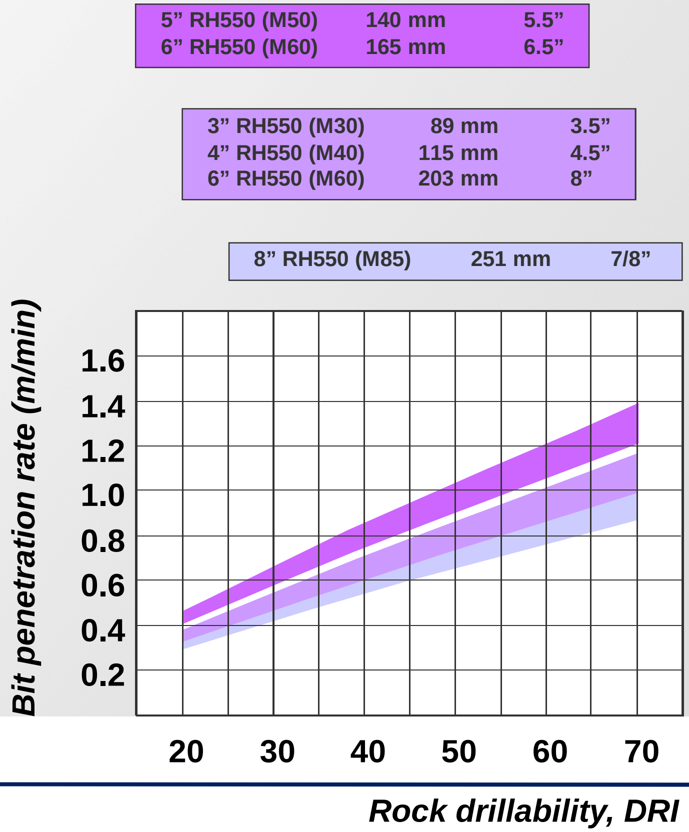
Predicting bit penetration rates - TH

- *rock mass drillability, DRI*
- *percussion power level in rods (tubes)*
- *bit diameter and type*
  - ✓ ***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*



Predicting bit penetration rates - DTH

- *rock mass drillability, DRI*
- *percussion power of hammer*
- *bit diameter and type*
  - ✓ *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*



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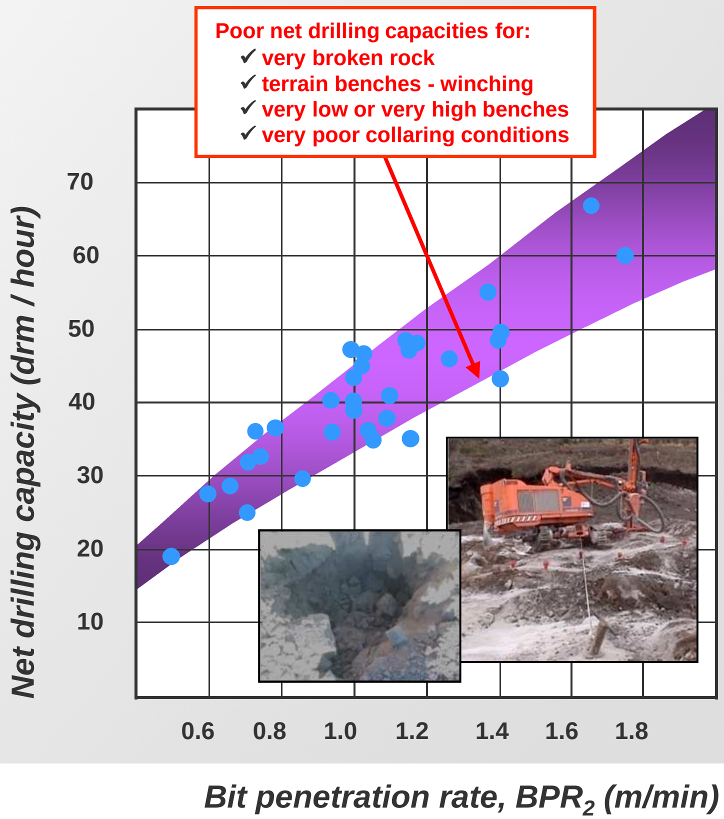
Gross drilling capacities (drm/h)

- *time for rig setup and feed alignment 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 loss rate 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*
- *time for tramming between benches, refueling, etc.*
- *effect of operator work environment on effective work hours per shift*
- *rig availability, service availability, service and maintenance intervals*



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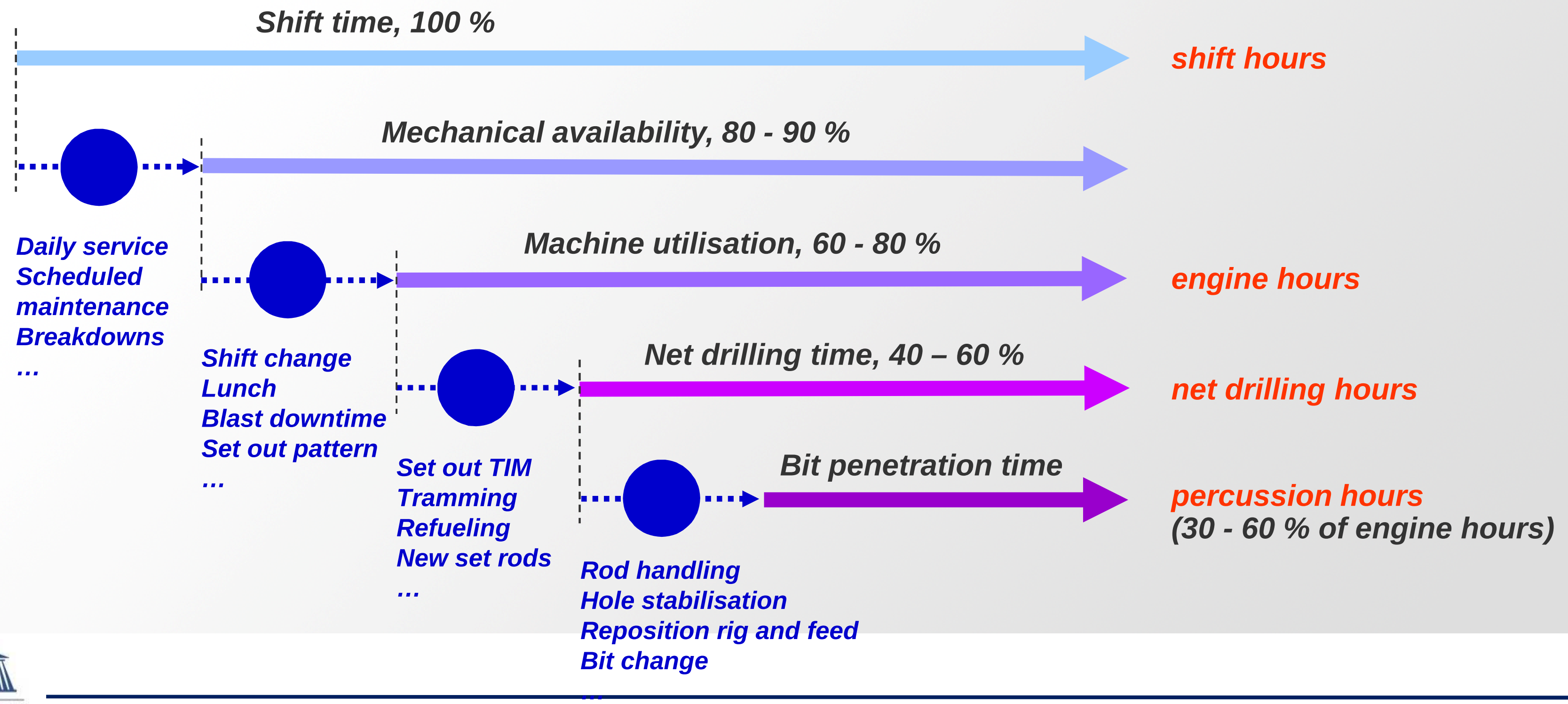
Typical breakdown of longterm rig usage and capacities



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Limestone Quarry – Drilling Report DI550 / Ø140mm

Company: xxxx		**Drillmaster:**	xxxx			
1. Net drilling time	43,0 --->	39,5	**Net drilling time (drm/ph)**		- percussion hours	
2. Moving :	10,7					
3. Total 1+2	53,7 --->	31,6	**Gross drilling time (drm/h)**		- incl. time for moving on bench	
4. No-productive time	**6,1h**	Waiting:	**h**			
		Re-dress:	**h**	Maintenance:	**4,1h**	
		Re-fuel:	**h**	Repair:	**2,0h**	
		Total:	**h**	Total:	**6,1h**	
5. Driving time	**4,3h**					
6. Shift time 3-5 (wihout breaks)	**70,50 --->**	**24,1**	**drm/shift hour**			
	Efficiency (NG) :	**76%**		Availability:	**89%**	
	Oper. ratio (eh/sh) :	**80%**				
7. Fuel consumption						
Total consumption:	**3131,0 L --->**	**1,84**	**l/drill meter**			
	--->	**53,98**	**l/engine hour**			

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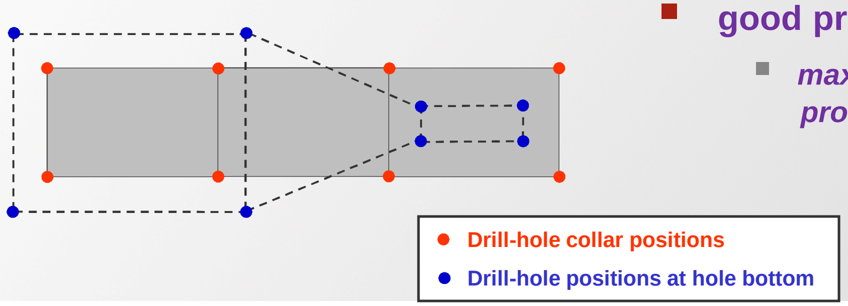
Can we drill straight holes?

Ventilation Shaft, Olkiluoto Nuclear Power Plant

Shaft diameter, Section I	Ø6.5 m
Shaft length	15 m
Rock type	Quartz Diorite
Contour hole size	Ø60 mm
Contour hole charging	80 g/m det. cord
Contour hole spacing	0.4 m
Contour row burden	0.7 m

What happens when we shoot holes that look like spaghetti?

- floor humps
  - *poor loading conditions, uneven floors*
- poor walls
  - *unstable walls*
  - *difficult 1st row drilling*
- flyrock
  - *safety issue*



- blowout of stemming
  - *safety, dust, toes, …*
- blast direction
  - *quality of floors and walls*
- shothole deflagration / misfires
  - *safety*
  - *locally choked muckpiles (poor diggability)*
- good practise
  - *max. drill-hole deviation up to 2 – 3 % for production drilling*

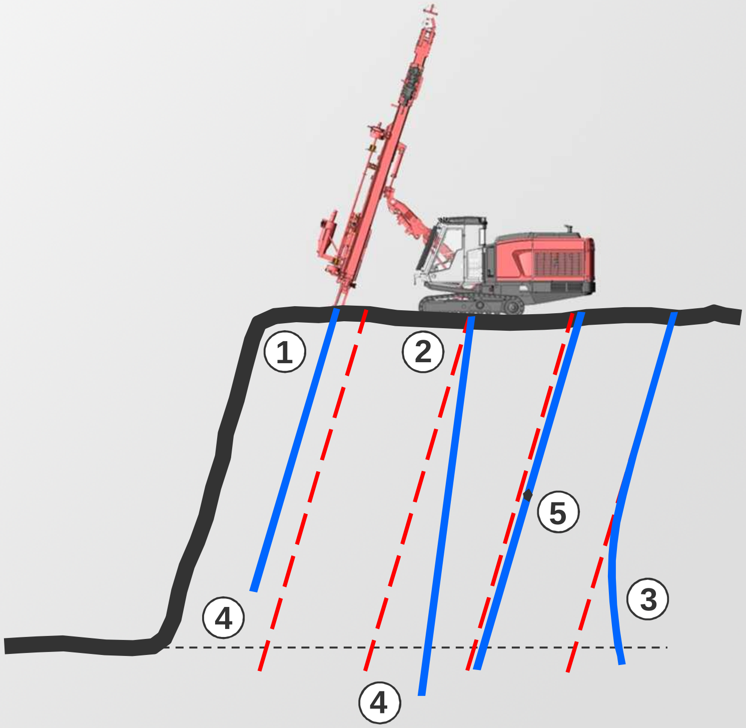
How do we go about drilling straighter holes?

- understand the many issues leading to drill-hole deviation
- technically good drill string
- technically good drill rig, instrumentation, …
- motivate the drillers!

Accurate drilling gives effective blasting

Sources of drilling error

1. Collar position
2. Hole inclination and direction
3. Deflection (bending)
4. Hole depth
5. Omitted or lost holes
6. Shothole diameter (worn out bits)



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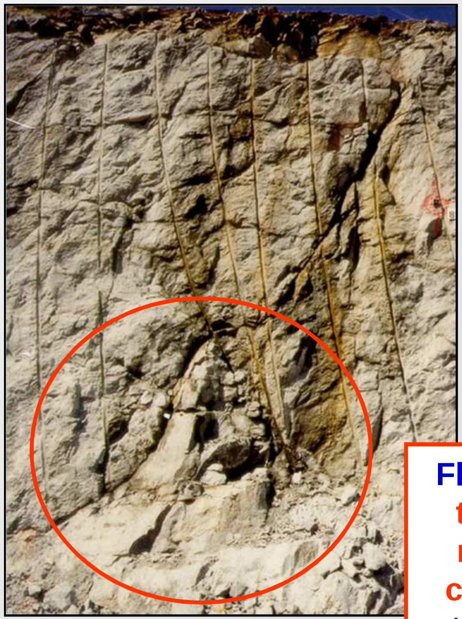
Examples of drill-hole deviation

Directional error for Ø89 mm retrac bit / T45 in granite

Drill string deflection caused by gravitational pull or sagging of drill steel in inclined holes in syenite

Examples of drill-hole deviation

Deflection with and without pilot tube for Ø89 mm DC retrac bit / T51 in micaschist

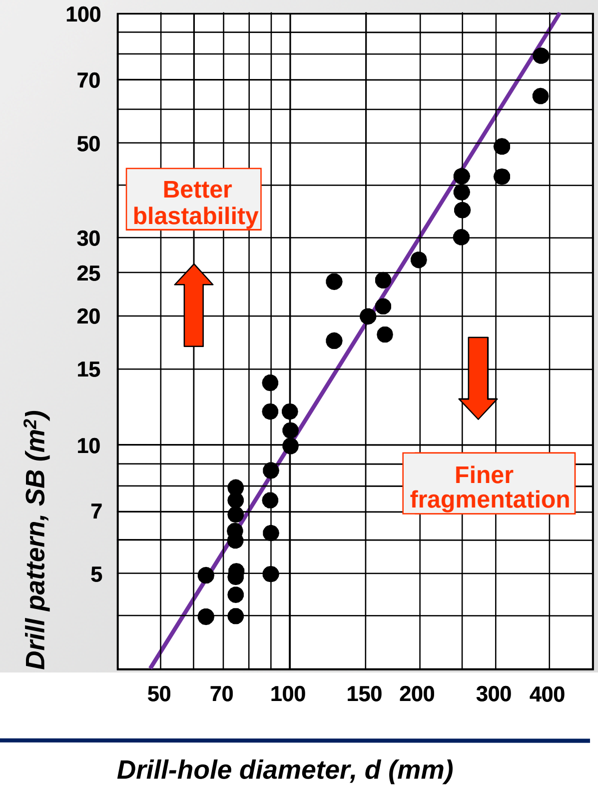


Floor hump due to explosives malfunction - caused by drill string deflection

Shothole diameter error control

- bits loose diameter due to gauge button wear
- typical diameter loss for worn out bits is ~ 10%
- diameter loss effect on drill patterns

	Diameter new bit	*Ø102mm*
	Diameter worn out bit	*Ø89mm*
	Diameter loss	*(102 – 89) / 102 = 12.8%*
=>	*Drill pattern too big*	*$(102 / 89)^{1.6}$ = 24%*



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Collar position error control

- use tape, optical squares or alignment lasers for measuring in collar positions
- use GPS or total stations to measure in collar positions
- collar positions should be marked using painted lines – not movable objects such as rocks etc.
- completed drillholes should be protected by shothole plugs etc. to prevent holes from caving in (and filling up)
- *use GPS guided collar positioning devices e.g. TIM-3D*

Difficult 1st row drilling

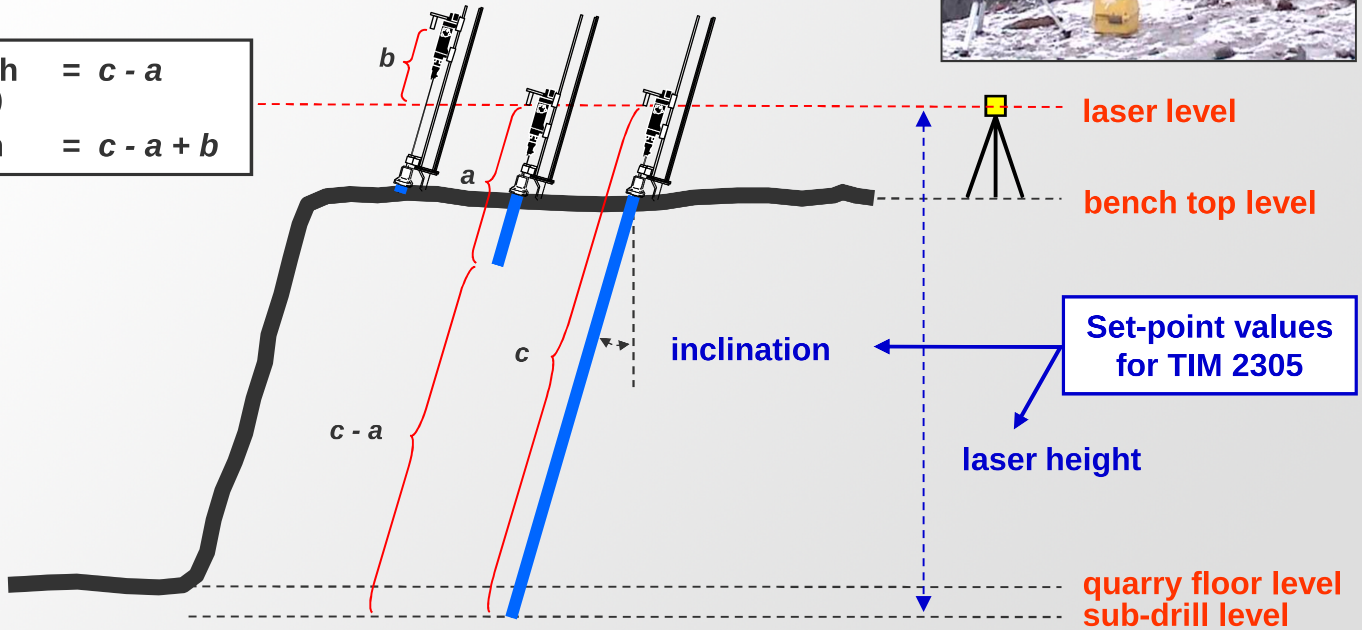
Lafarge Bath Operations, Ontario

- Rock type: limestone, 1.6 Mtpa
- Bench height: 32 m
- Bit: Ø115 mm guide XDC
- Drill steel: Sandvik 60 + pilot tube
- Hole-bottom deflection: < 1.5 % or 0.5 m
- Gross drilling capacity: 67 drm/h
- Drill pattern: 4.5 x 4.8 m^2 (staggered)
- Sub-drill: 0 m (blasted 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

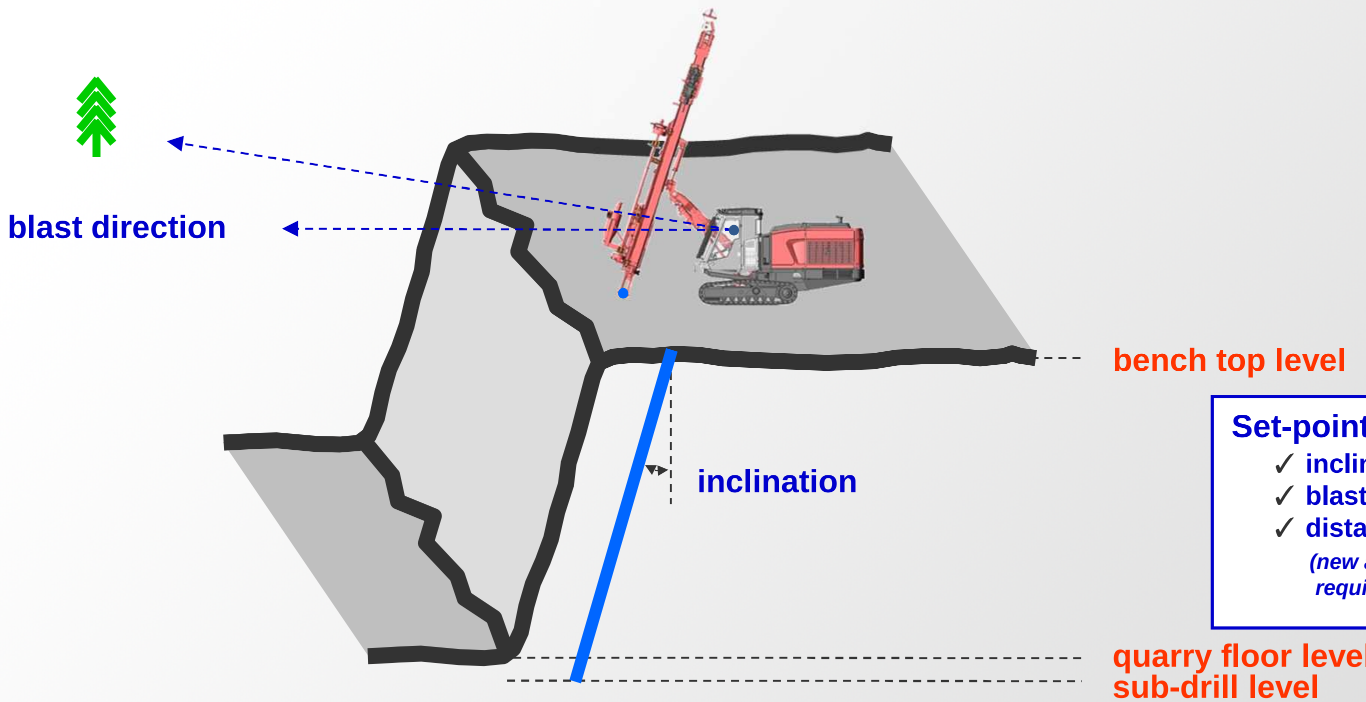
QUARRY ACADEMY

Hole depth error control

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



Inclination and directional error control

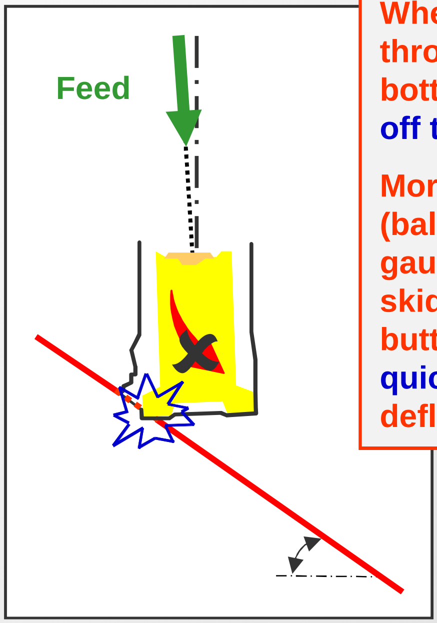


Set-point values for TIM 2305

- ✓ inclination
- ✓ blast direction projection
- ✓ distant aiming point direction

  (new aiming point reading required when tracks are moved)

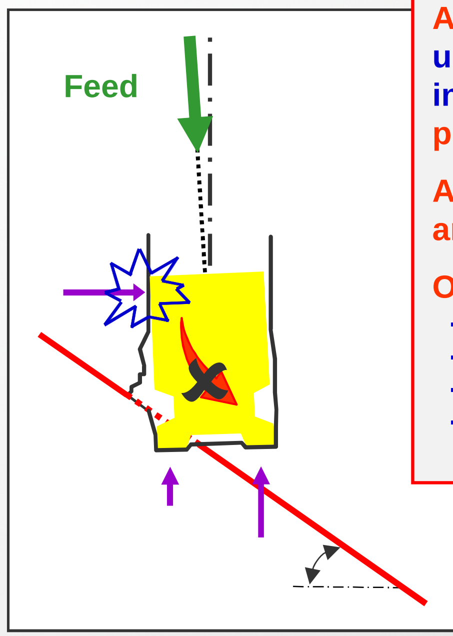
How bit face designs enhance drill-hole straightness



When the bit first starts to penetrate through the joint 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 gauge profiles (drop center) reduce this skidding effect by enabling the gauge buttons to "cut" through joint surfaces quickly - thus resulting in less overall bit deflection.

How bit skirt designs enhance drill-hole straightness

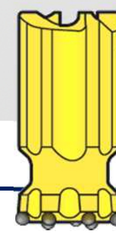


As the bit cuts through the joint surface - an uneven bit face loading condition arises; resulting in bit and drill string axial rotation - which is proportional to bit impact force imbalance.

A rear bit skirt support (retrac type bits) reduces bit and string axial rotation by “centralizing” the bit.

Other counter measures:

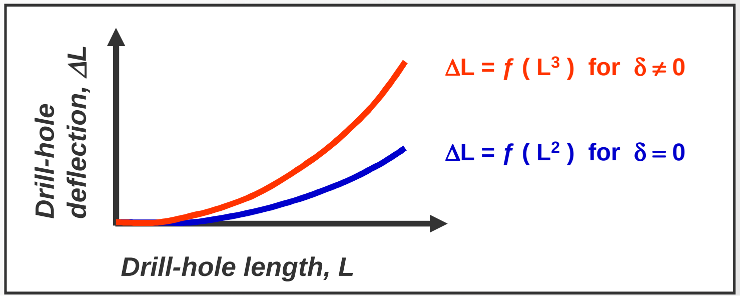
- longer bit body
- add pilot tube behind bit
- lower impact energy
- rapid drilling control system reacting to varying torque and feed conditions

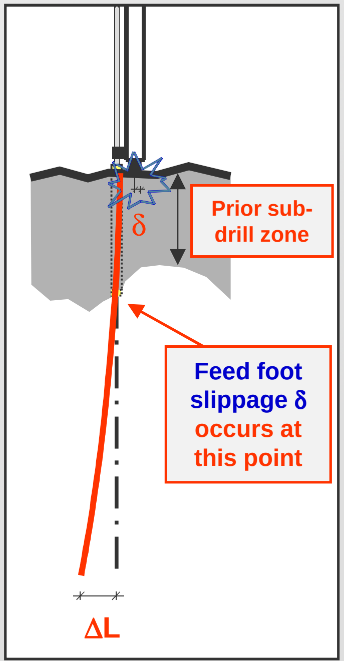


QUARRY ACADEMY

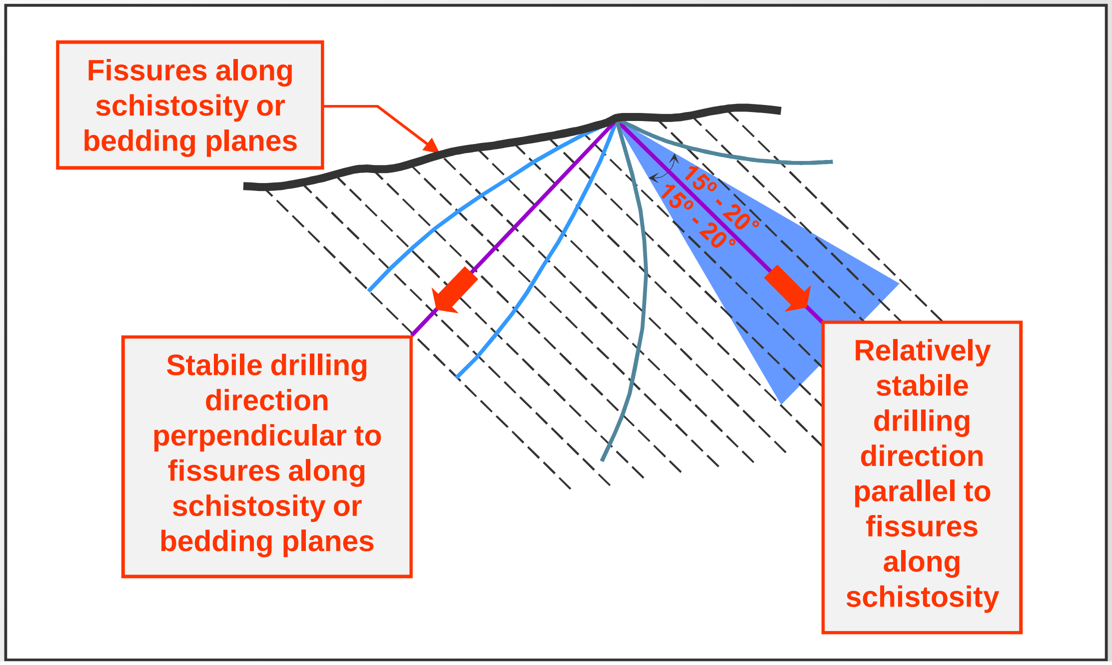
Drill-hole deflection error control

- 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 causes a misalignment of the feed leading to excessive drill string bending
- avoid **gravitational** effects which lead to **drill string sagging** when drilling inclined shot-holes (> 15º)
- avoid inpit operations with **excessive bench heights**





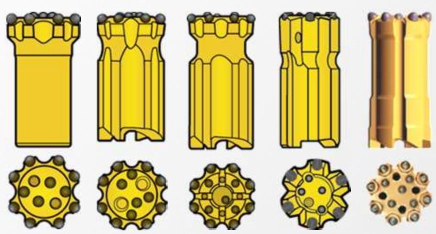
Drill-hole deflection trendlines in schistose rock

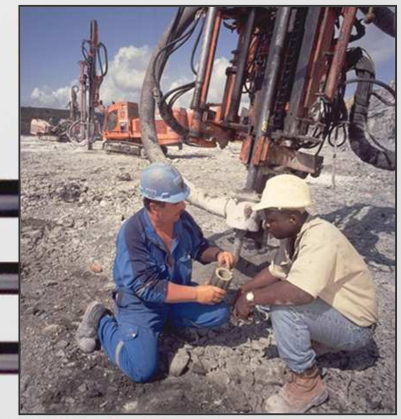


QUARRY ACADEMY

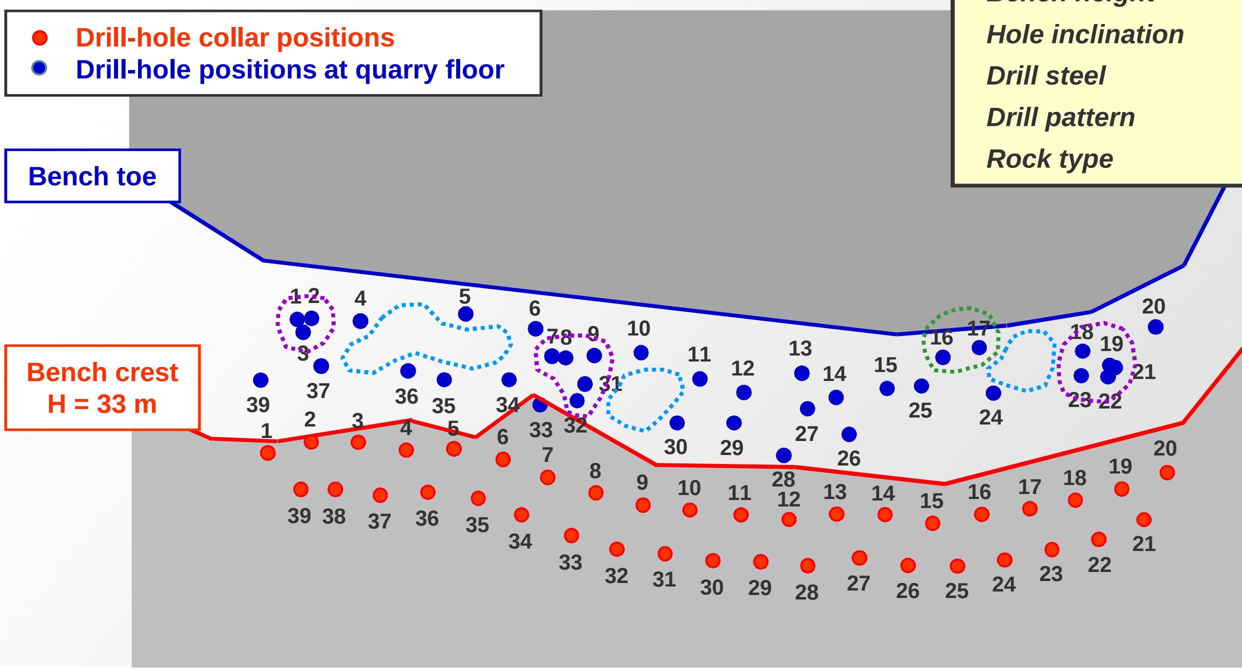
Selecting straight-hole drilling tools - TH

- 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



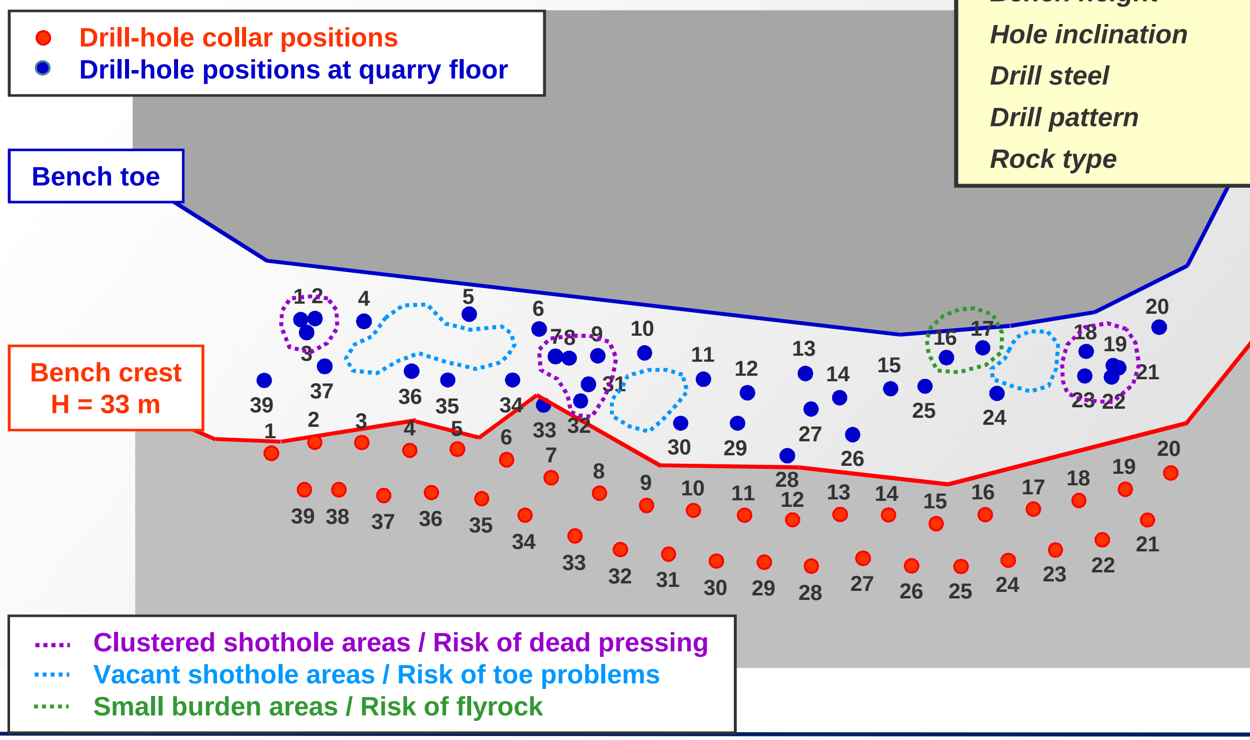


Drill pattern at quarry floor



Bench height	*33 m*
Hole inclination	*14°*
Drill steel	*Ø76 mm retrac / T45*
Drill pattern	*2.5 x 2.75 m²*
Rock type	*Granitic gneiss*

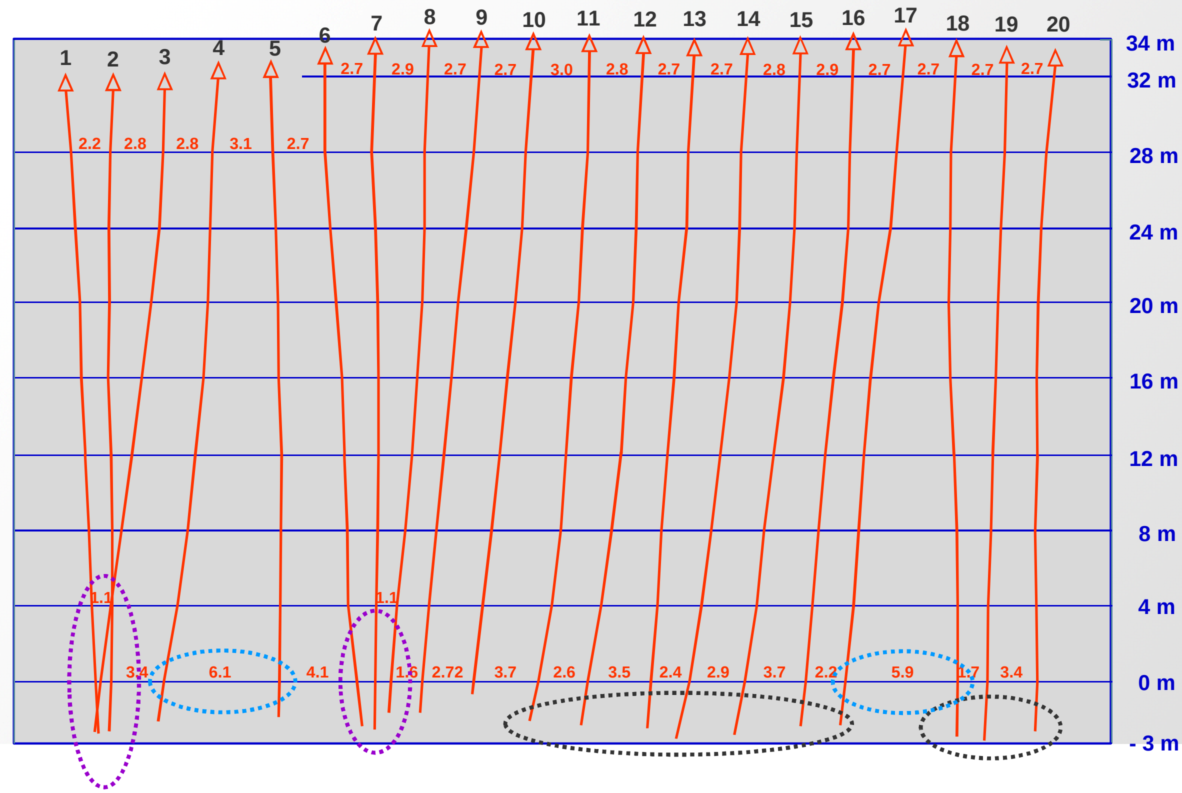
Drill pattern at quarry floor



Bench height	*33 m*
Hole inclination	*14°*
Drill steel	*Ø76 mm retrac / T45*
Drill pattern	*2.5 x 2.75 m^2*
Rock type	*Granitic gneiss*

QUARRY ACADEMY

Vertical projection of Row 1



QUARRY ACADEMY

Prediction of drill-hole 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. button	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

Factors affecting drill-hole deviation

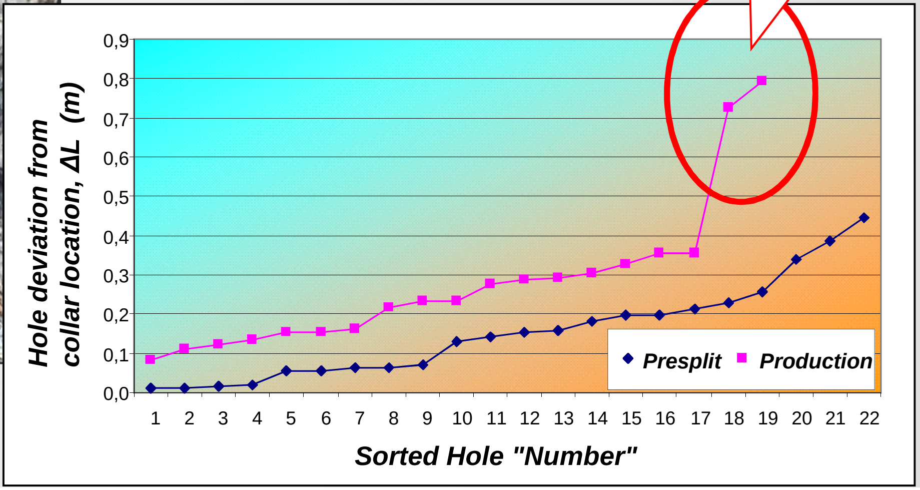
- drill string startup alignment
- bit will follow a joint if at sharp angle to bit path
- drill string stiffness and “tube” steering behind bit
- deviation increases with impact energy
- button shape, bit face and bit body design
- drilling with dull buttons (worn bits)
- bit diameter checks when regrinding
- feed foot slippage while drilling
- removal or controlled drilling through prior sub-drill zone
- drilling control systems, i.e.
  - applied feed, torque and percussion dynamics
- operator motivation!

QUARRY ACADEMY

Wall control drilling
Macon Quarry, GA

DP1500 - Ø87mm Tubes - 24.5m
Bench - Ø140mm Presplit

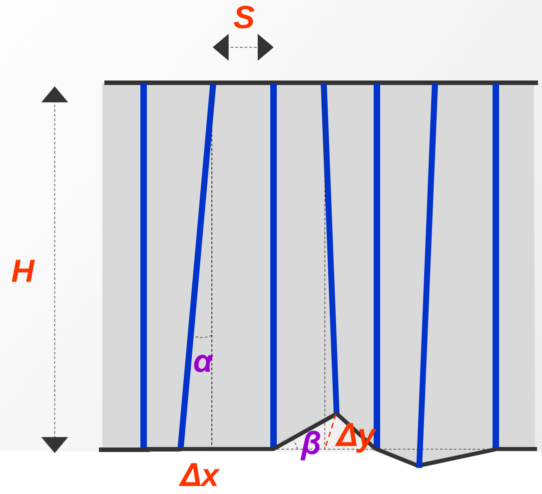
Excessive deviation due to feed foot slippage



QUARRY ACADEMY

Wall control drilling
Macon Quarry, GA

	ΔL	%	Δx = Δy	α	β
Max error	*0.45 m*	*1.8*	*0.32 m (≈ 2d)*	*0.75°*	*12.0°*
Median error	*0.15 m*	*0.6*	*0.11 m (≈ d)*	*0.25°*	*4.2°*



$\Delta L = (\Delta x^2 + \Delta y^2)^{1/2}$

Δy = error perpendicular to wall is of greater importance to extent of blast damage in backwalls

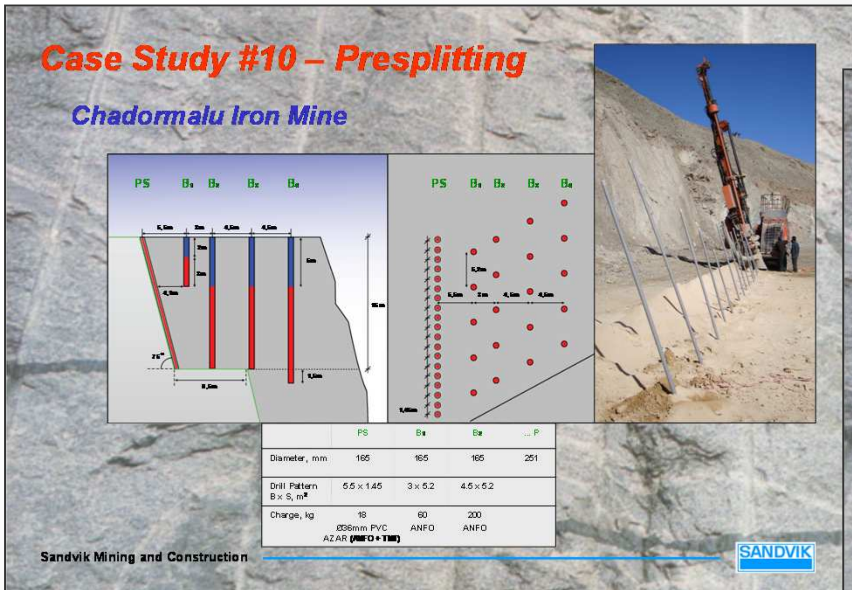
$\beta = \operatorname{atan} \Delta y / S$

Δx = error parallel to wall - lesser importance

$\alpha = \operatorname{atan} \Delta x / H$

QUARRY ACADEMY

Wall control D&B
Chadormalu Iron Mine



	PS	B_1	B_2	... P
Diameter, mm	165	165	165	251
Drill Pattern B × S, m^2	5.5 × 1.45	3 × 5.2	4.5 × 5.2	
Charge, kg	18 Ø36mm PVC AZAR (ANFO + TNT)	60 ANFO	200 ANFO	

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