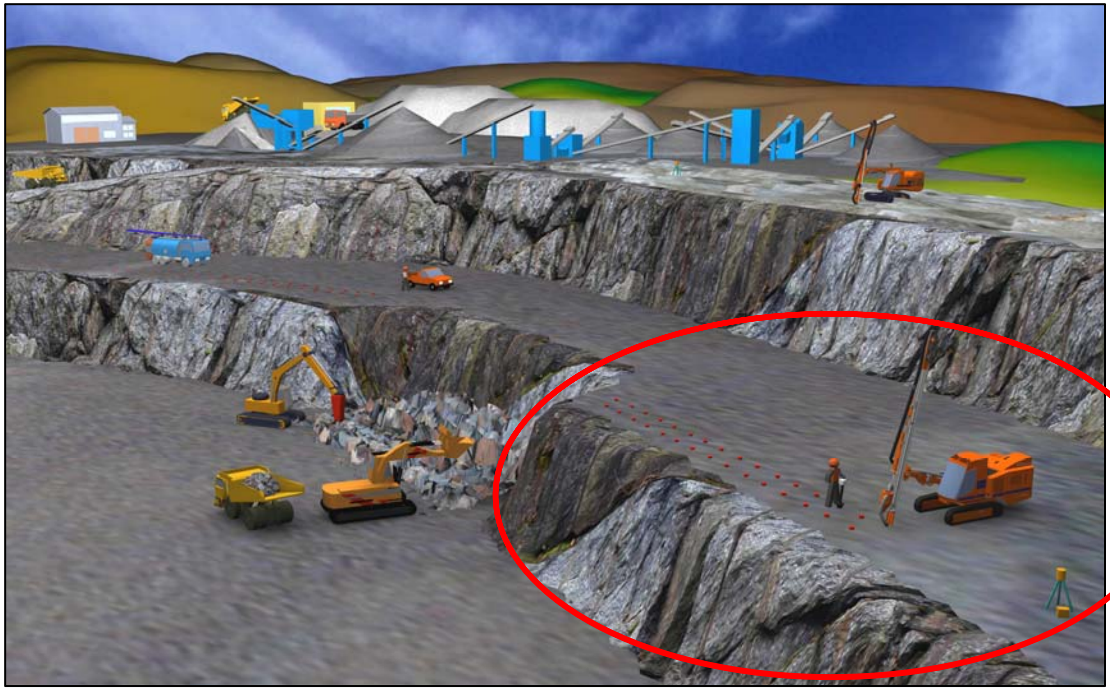
# Drilling

Arne Lislerud

QUARRY ACADEMY

# Agenda for drilling operations

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



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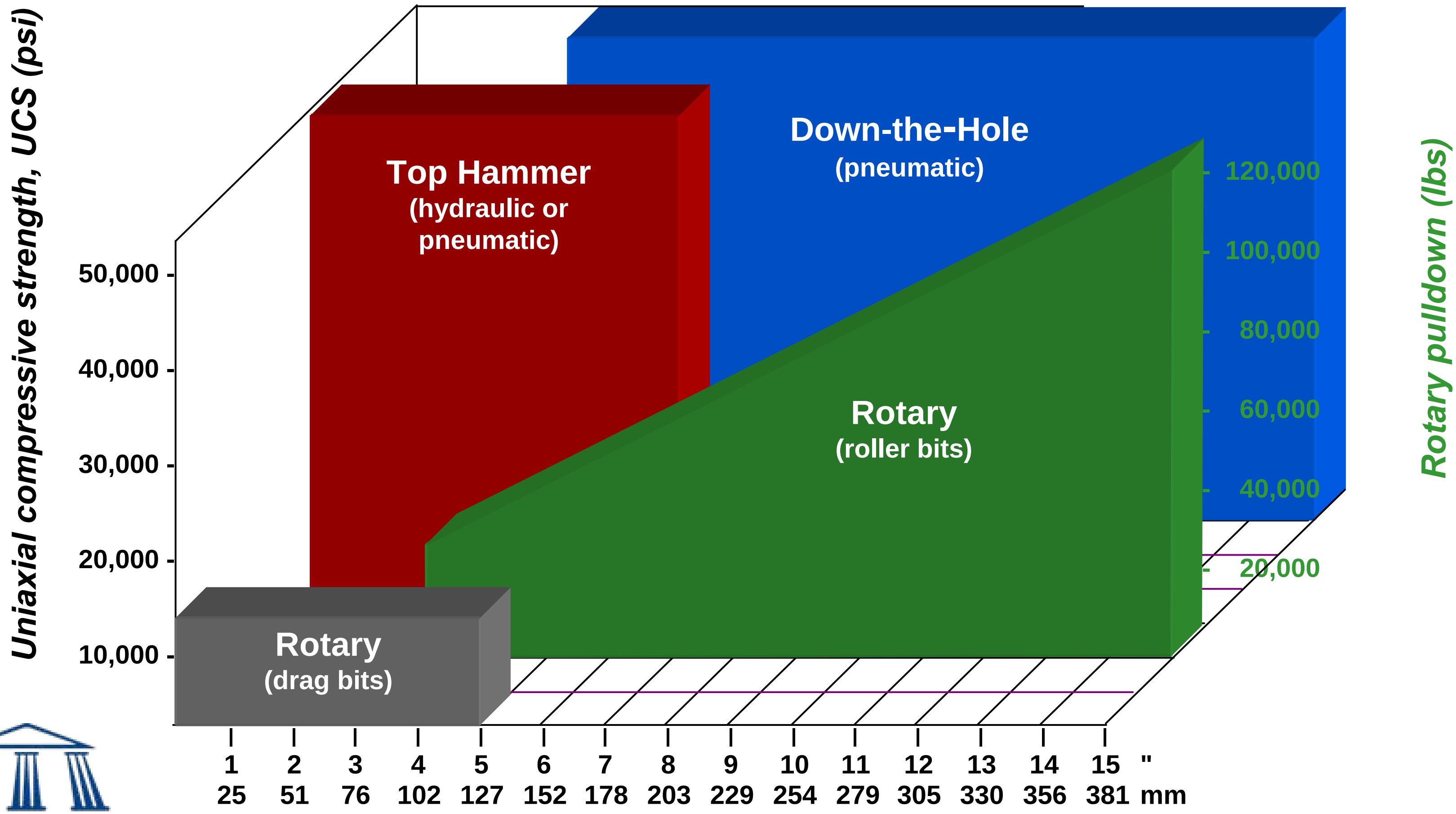
# The most common drilling methods in use

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# Drilling consists of a working system of:

- *bit*
- *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)*

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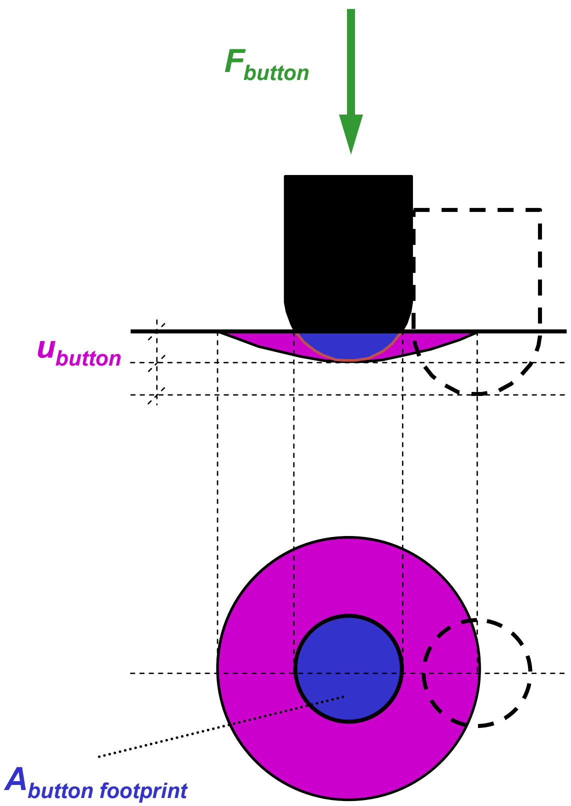
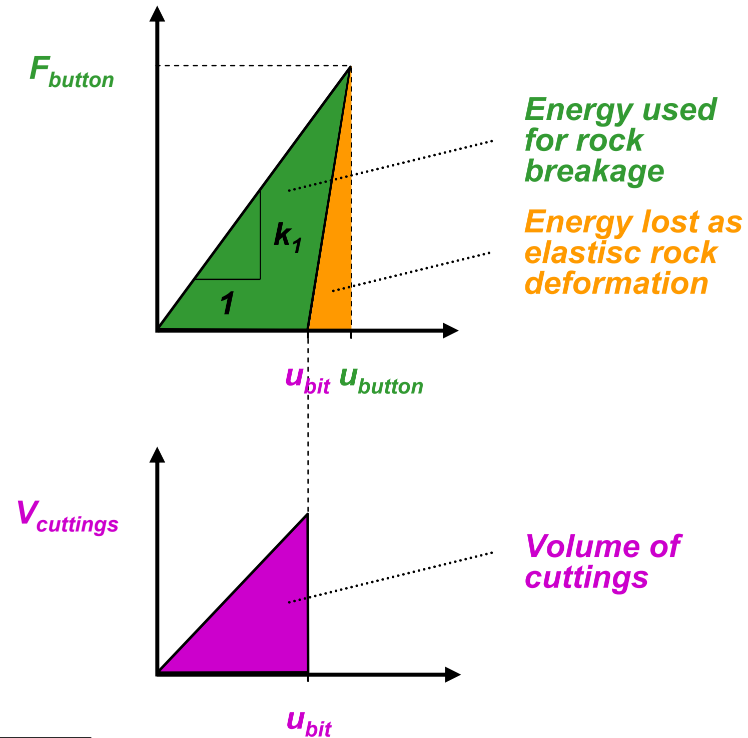
# How rock breaks by indentation

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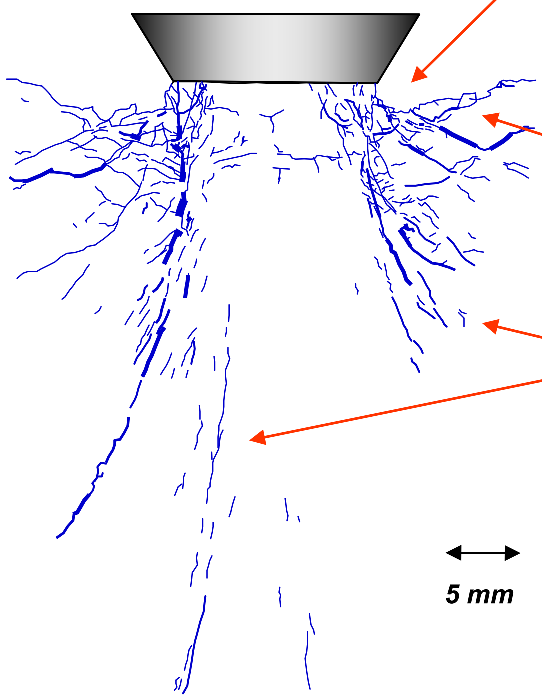
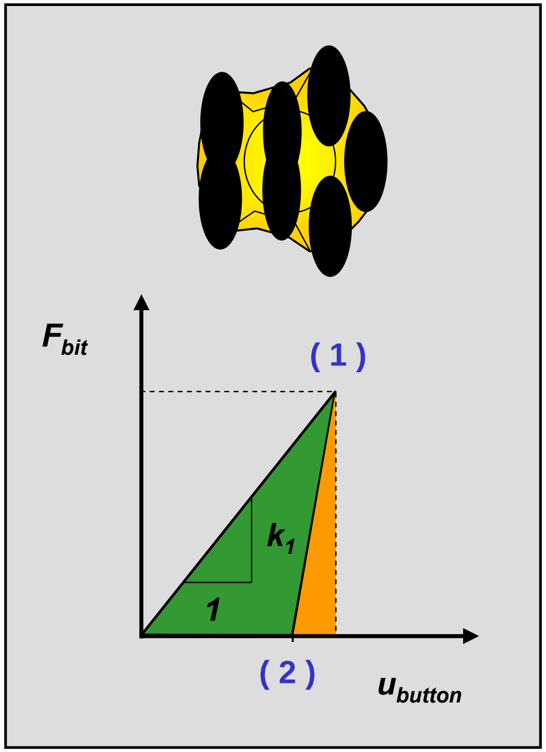
# Chipping – as the button is off-loaded



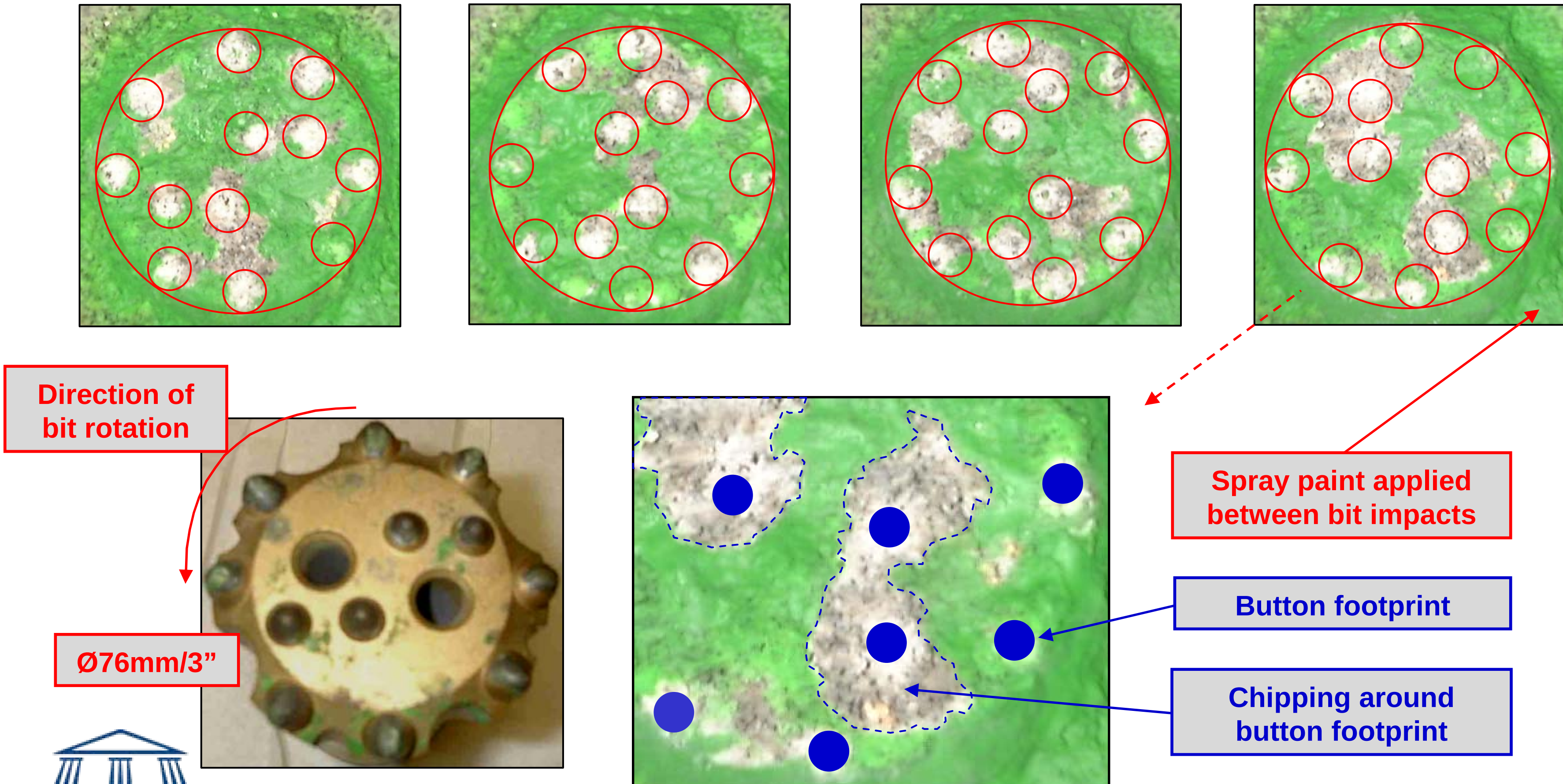

Chipping around the button footprint area

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

On-loading fractures created at ( 1 )



# Chip formation by bit indentation and button indexing

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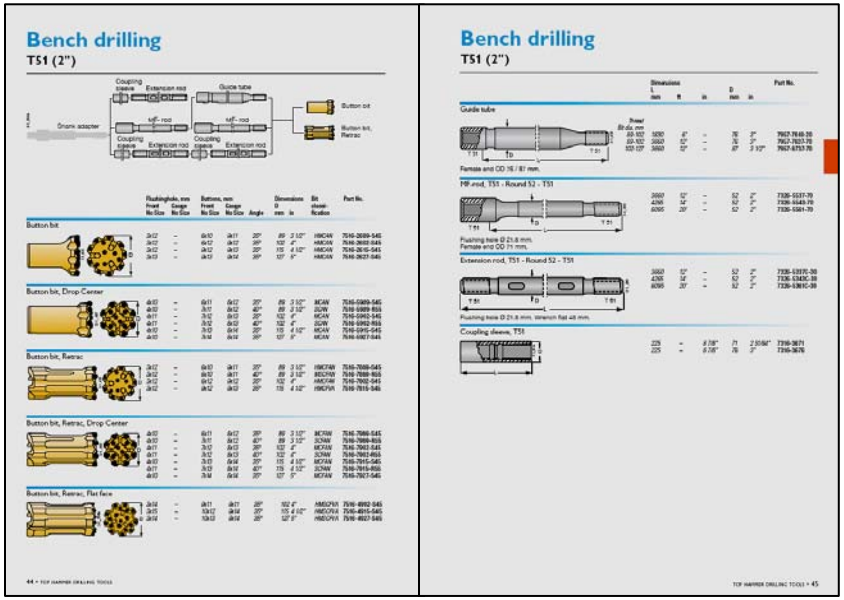
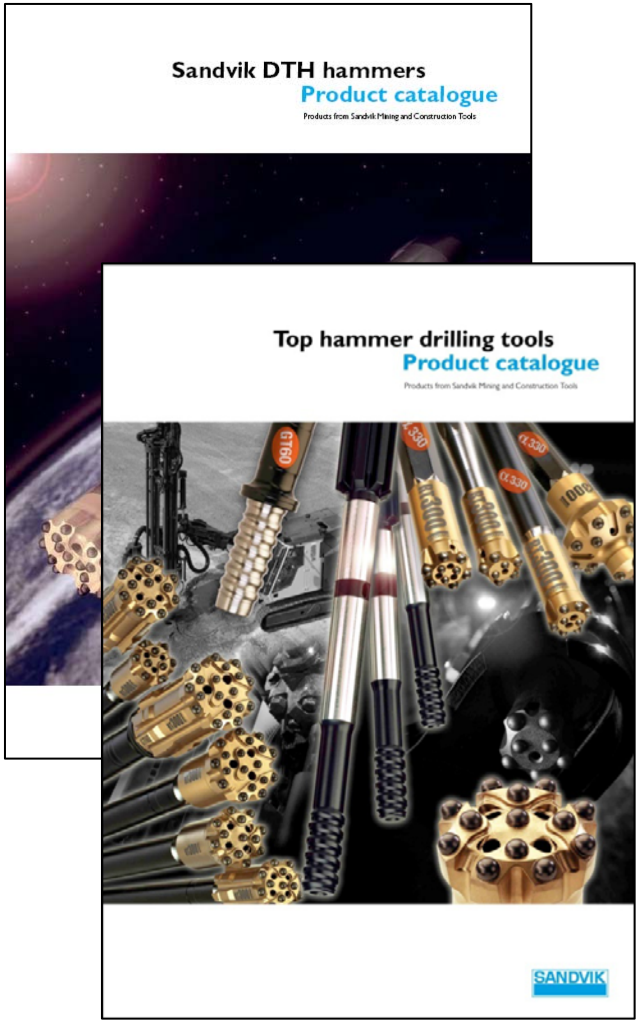
# Selecting drilling tools

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

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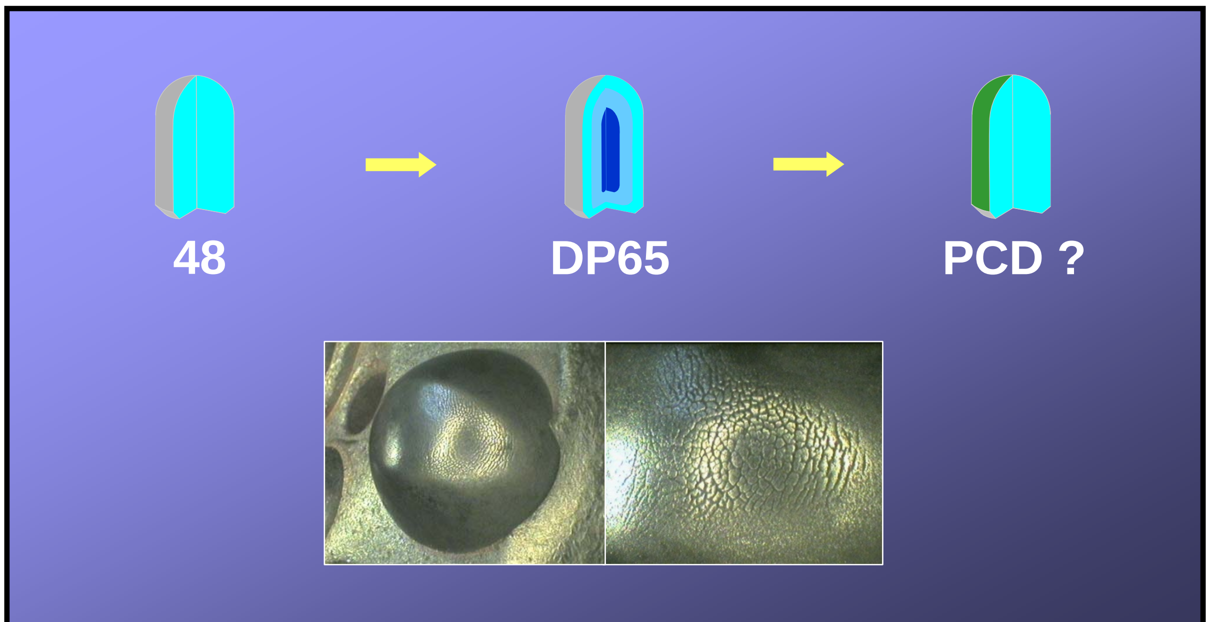
# Guidelines for selecting cemented carbide grades

- ***avoid excessive button wear (rapid wearflat development)***
  - ***=> select a more wear resistant carbide grade or drop 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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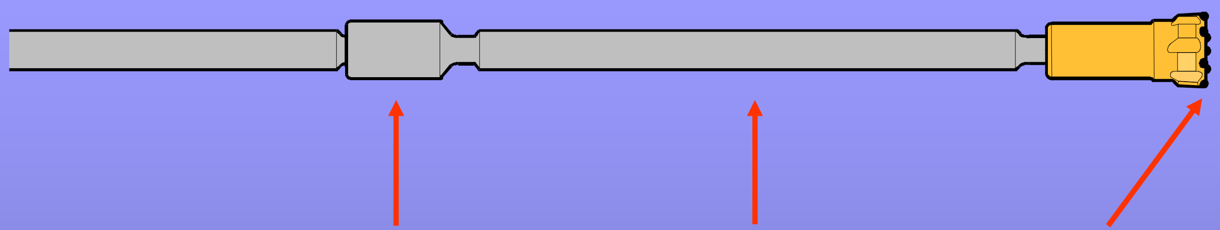
# Optimum bit / rod diameter relationship for TH



| Thread | Diameter coupling | Diameter | Optimum bit size |
|---|---|---|---|
| R32 | ∅44mm | ∅32mm | ∅51-2” |
| T35 | ∅48 | ∅39 | ∅57-2¼” |
| T38 | ∅55 | ∅39 | ∅64-2½” |
| T45 | ∅63 | ∅46 | ∅76-3” |
| T51 | ∅71 | ∅52 | ∅89-3½” |
| GT60 | ∅82 | ∅60 | ∅92-3.62” |
| GT60 | ∅85 | ∅60/64 | ∅102-4” |

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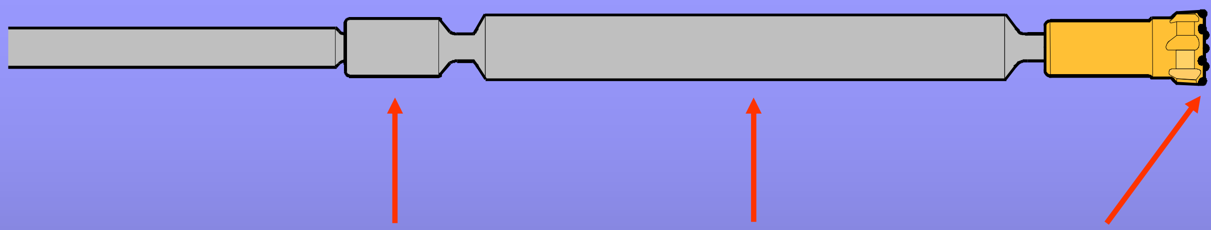
# Optimum bit / guide or pilot (lead) tube relationship for TH



| Thread | Diameter coupling | Diameter | Optimum bit size |
|---|---|---|---|
| T38 | ∅55mm | ∅56mm | ∅64-2½” |
| T45 | ∅63 | ∅65 | ∅76-3” |
| T51 | ∅71 | ∅76 | ∅89-3½” |
| GT60 | ∅85 | ∅87 | ∅102-4” |
| GT60 | ∅85 | ∅102 | ∅115-4½” |

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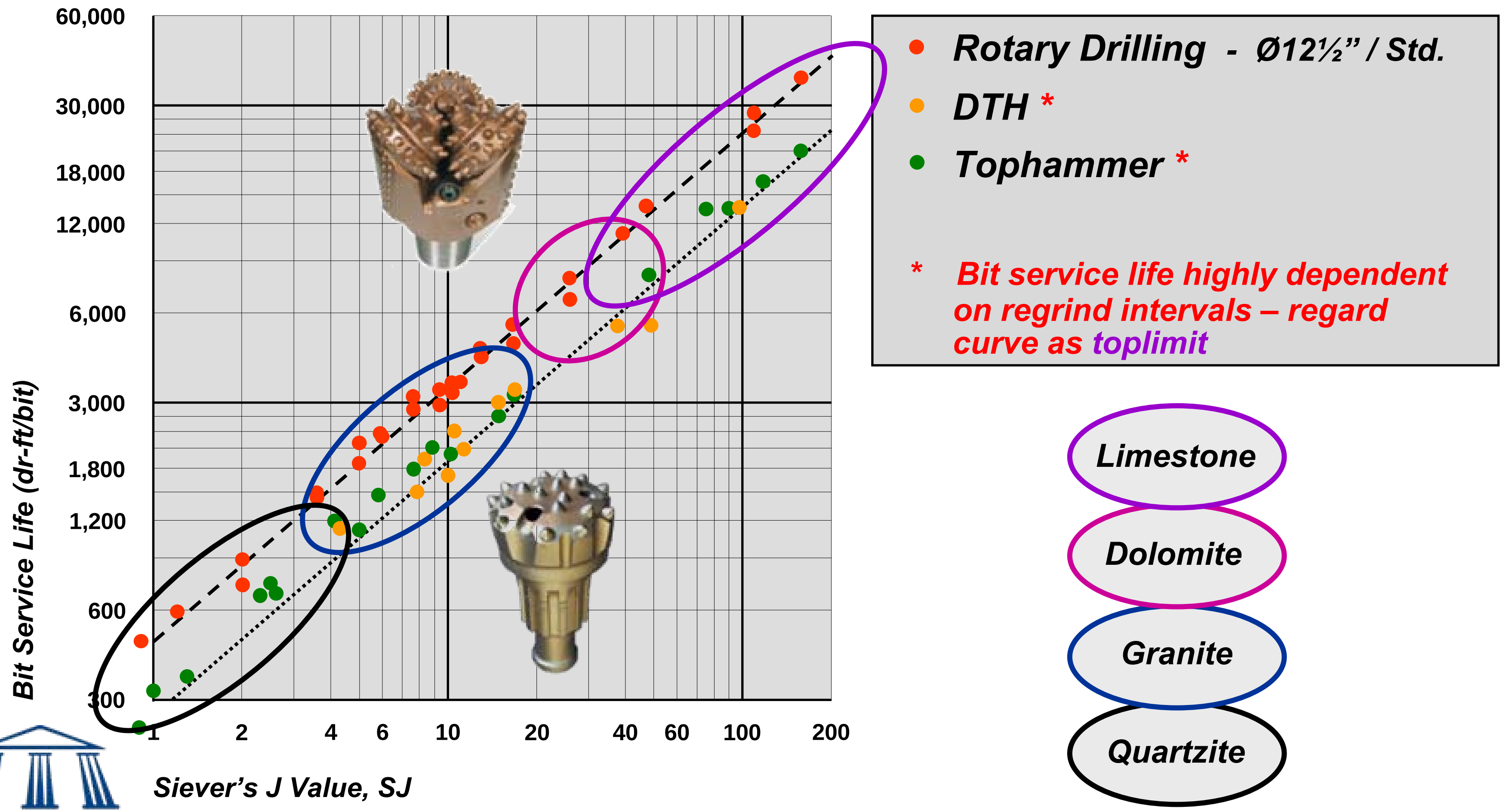
# Trendlines for bit service life

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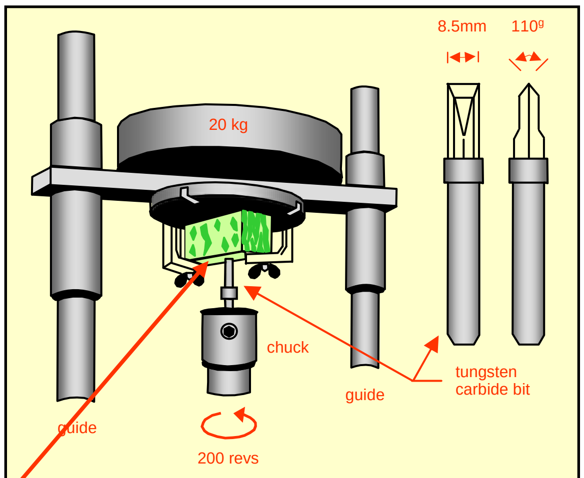
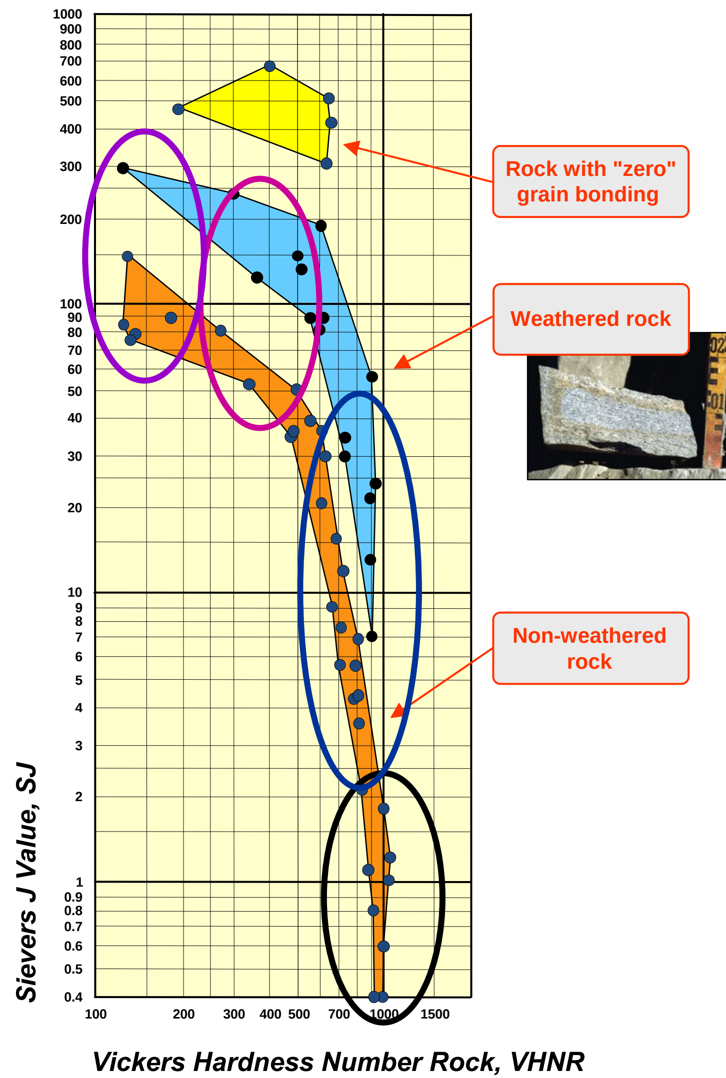
# Relationship between SJ and VHNR

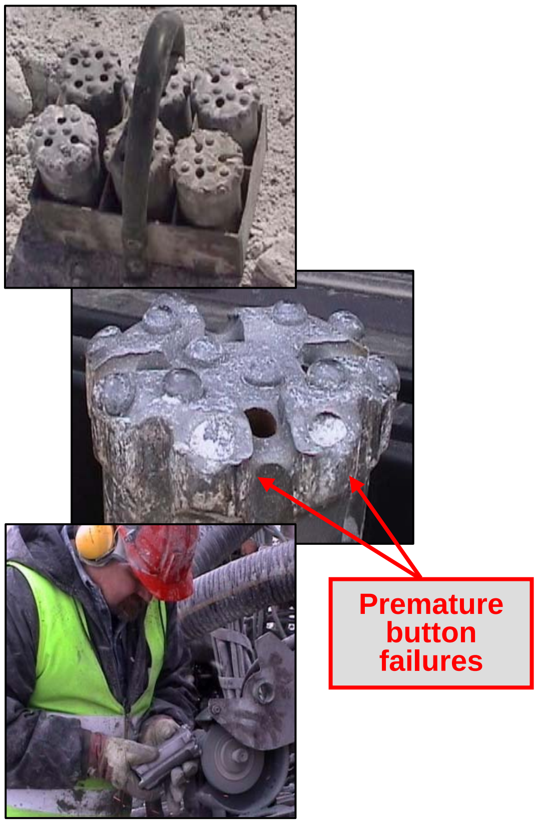
- ***rock surface hardness, VHNR***
- ***rock surface hardness, SJ***

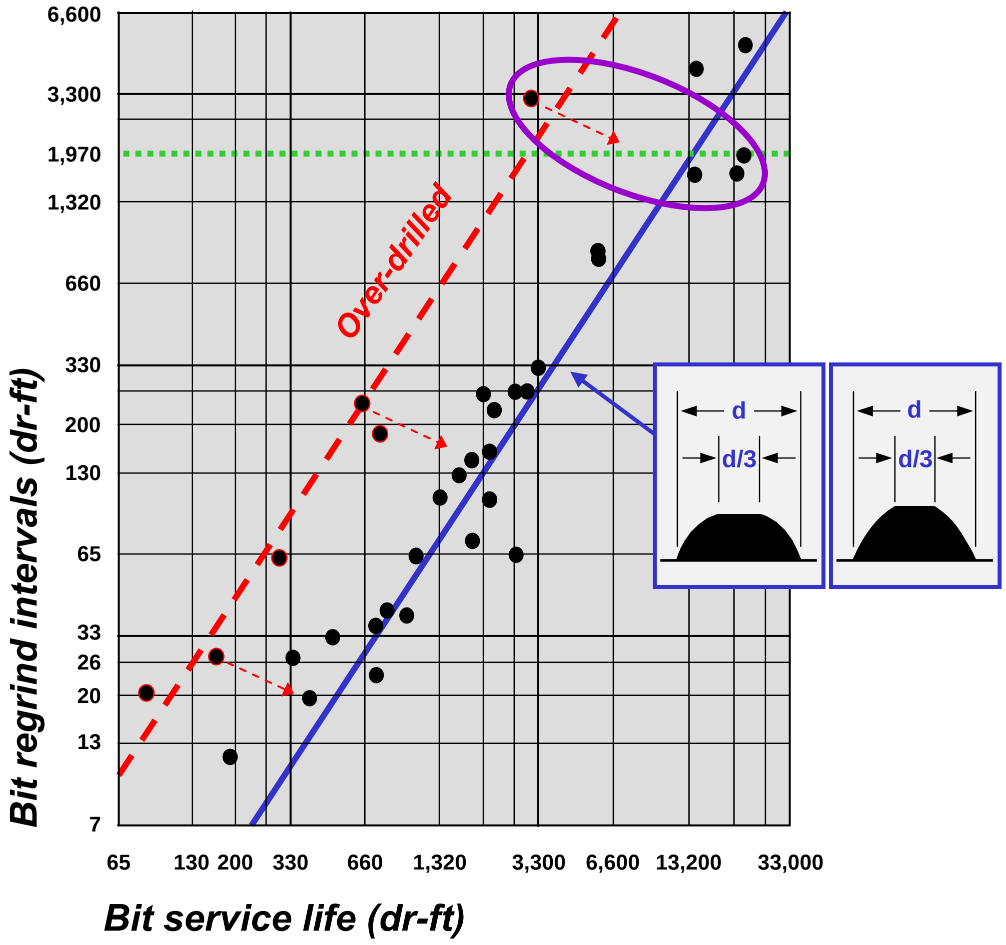






# Bit regind intervals, bit service life and over-drilling

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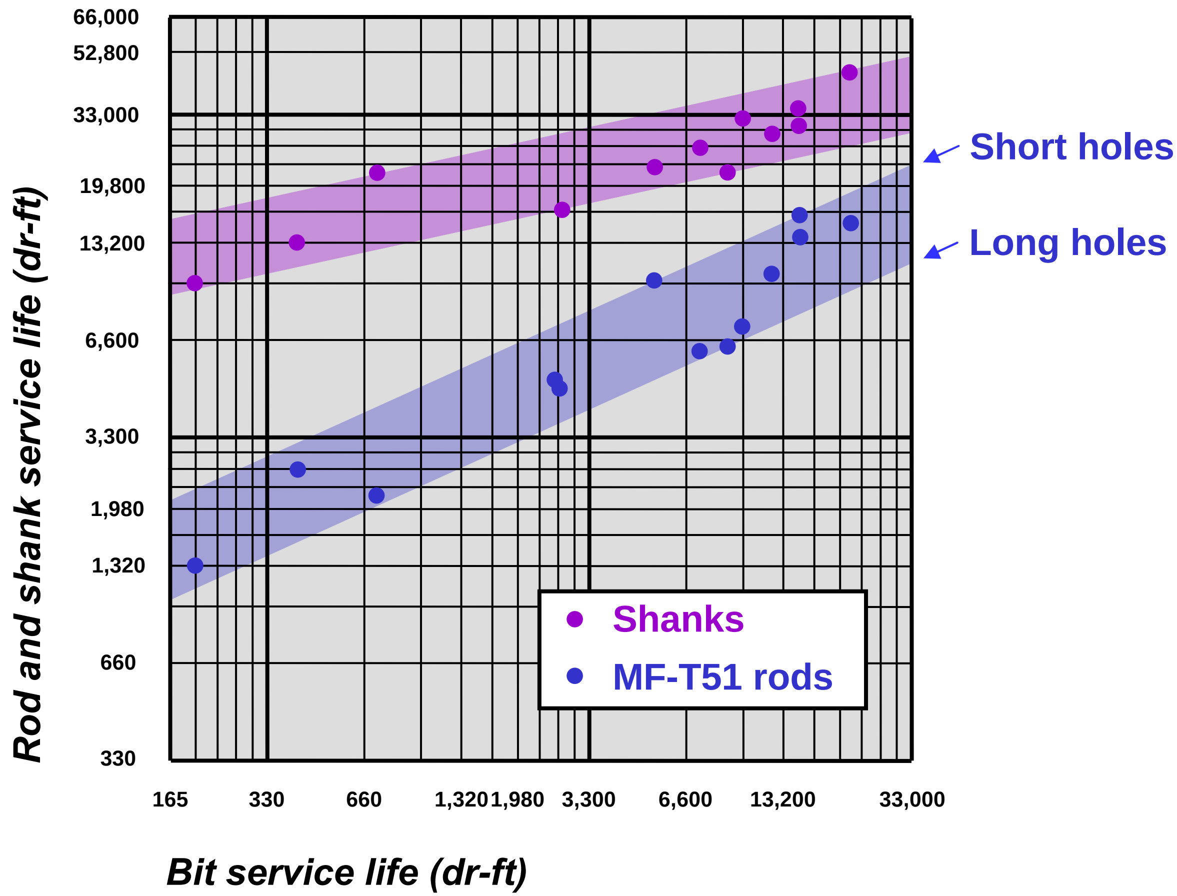
# Example of drill steel followup for MF-T51

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# KPI's for drill steel followup work

- ***drilling capacity drm/ph***
- ***drill-hole straightness***
- ***avg. percussion pressure***
- ***geological conditions***

- ***drill steel component life***
- ***bit regrind intervals***
- ***bit replacement diameter***
- ***component discard analysis***
- ***cost € per drm or m$^3$***

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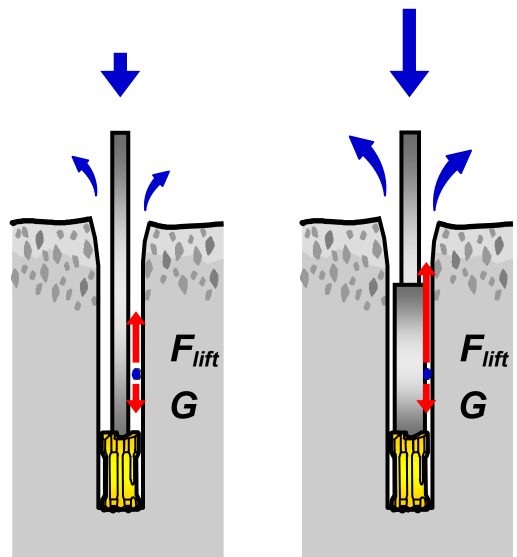
# Flushing of drill-cuttings

## *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 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 density air)*
- *large chips*

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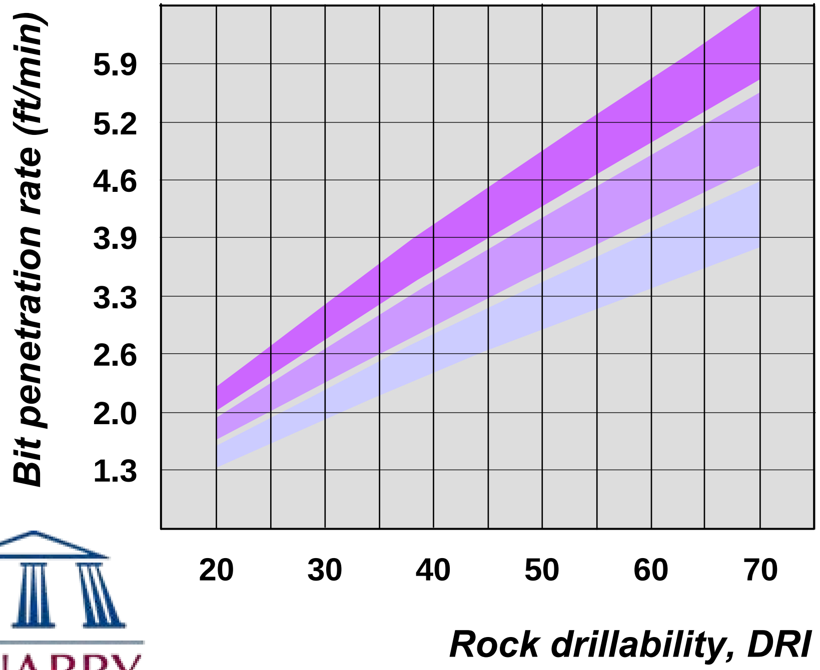
# Predicting bit penetration rates - TH

- ***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” |
| HL600 | 89 mm | 3.5” |
| HL710/800T | 102 mm | 4” |
| HL1000 | 115 mm | 4.5” |
| HL1500/1560T | 127 mm | 5” |

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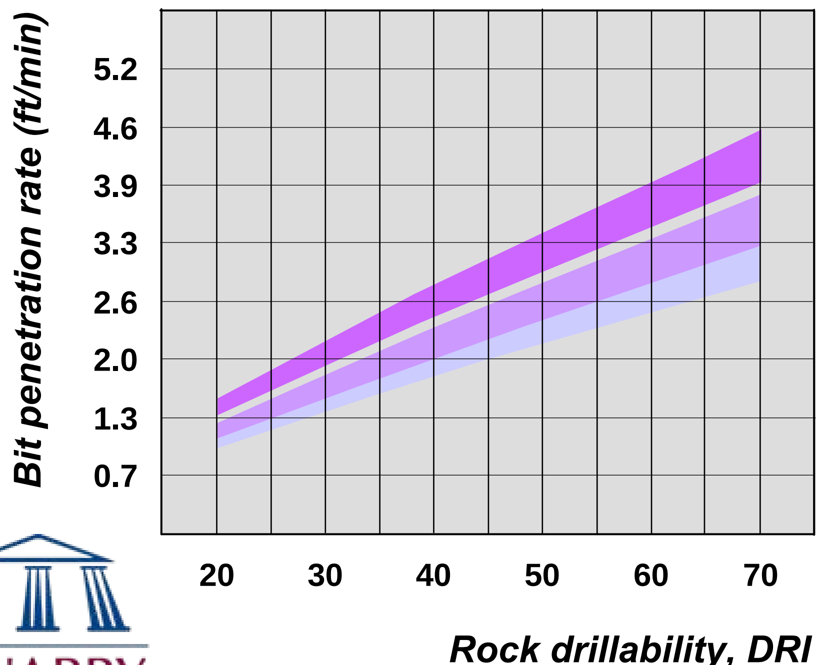
# Predicting bit penetration rates - DTH

- ***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” |

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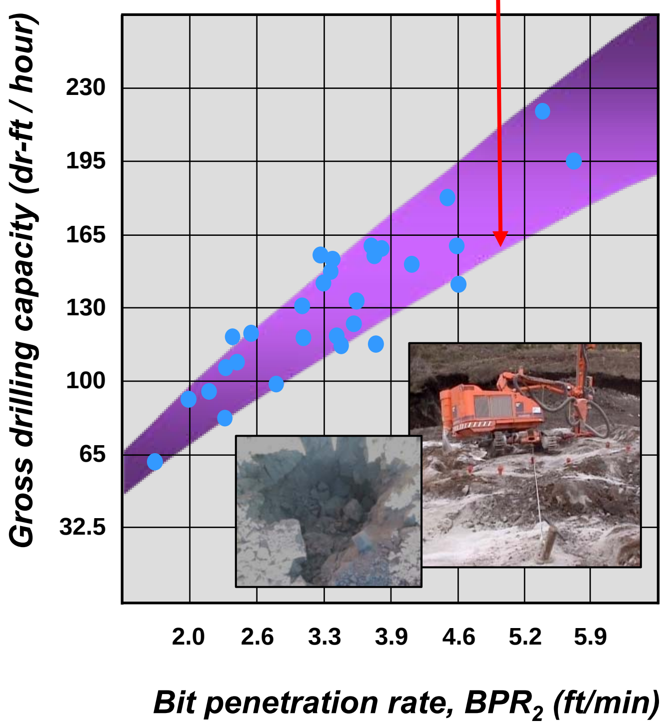
# Gross drilling capacities (dr-ft/h)

- *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

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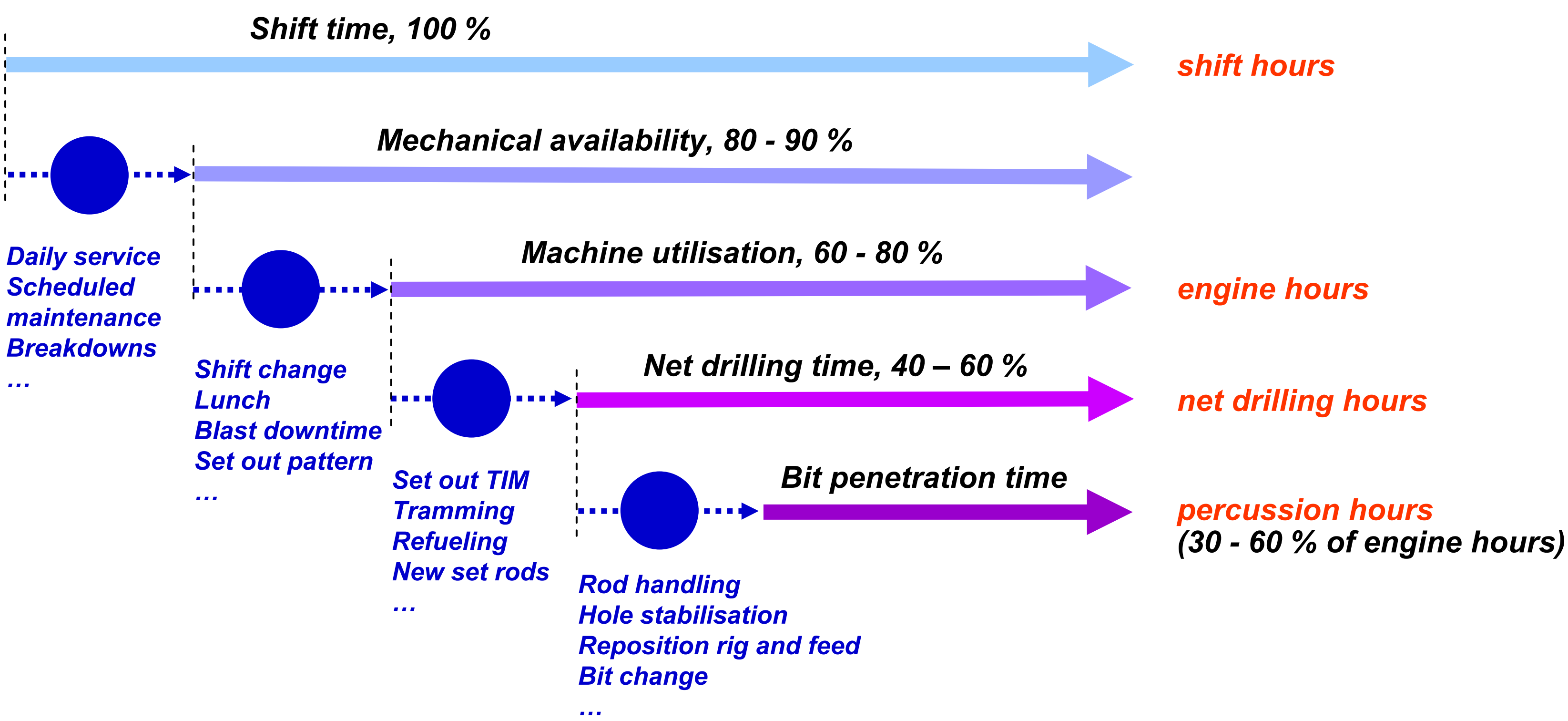
# Typical breakdown of longterm rig usage and capacities

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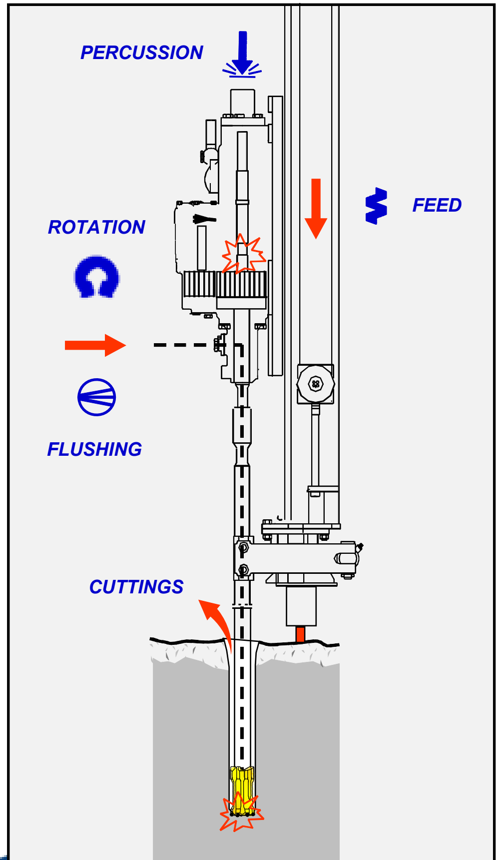
# Mechanics of percussive drilling




## 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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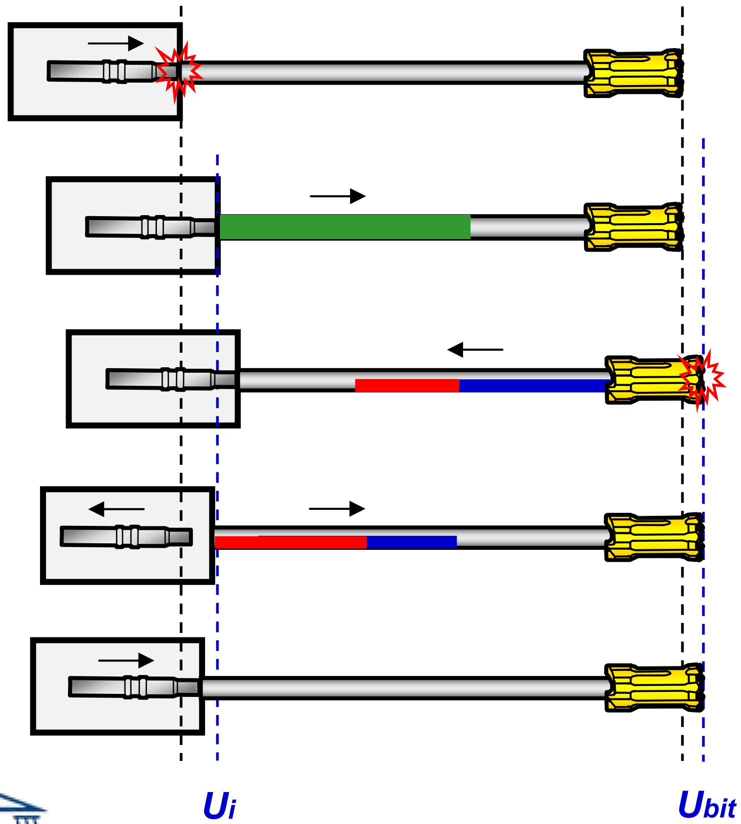
# Percussive impact cycle in TH drilling




***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***

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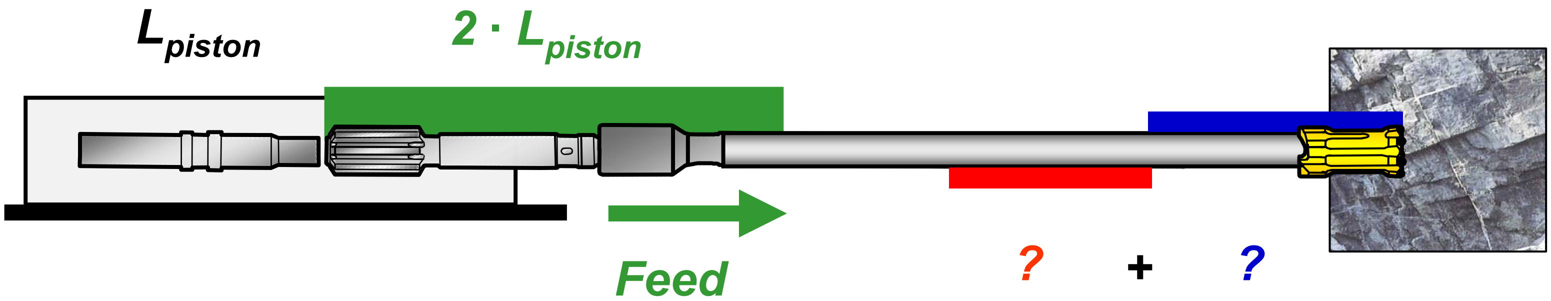
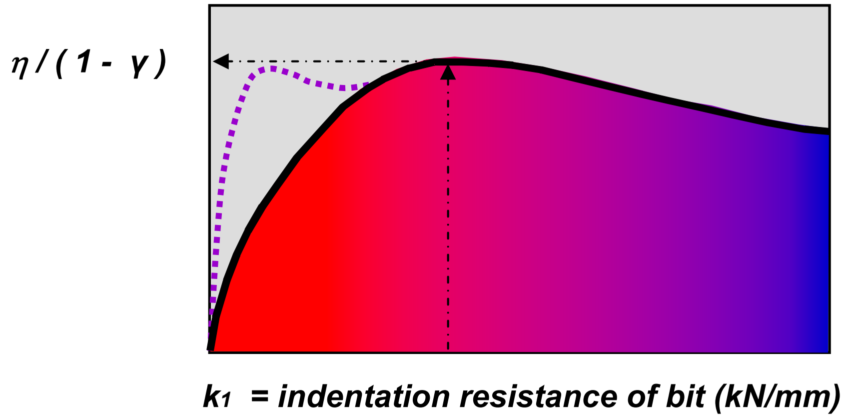
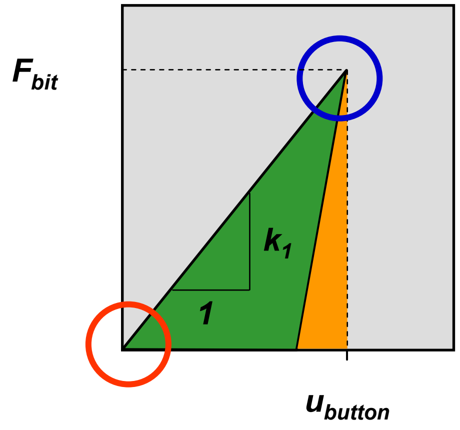
# Energy transfer efficiency in TH drilling

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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. buttons with too low protrusion***

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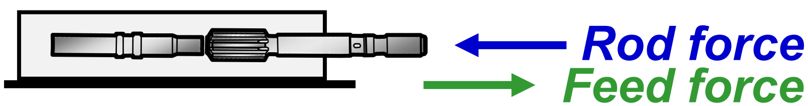
# Feed force requirements

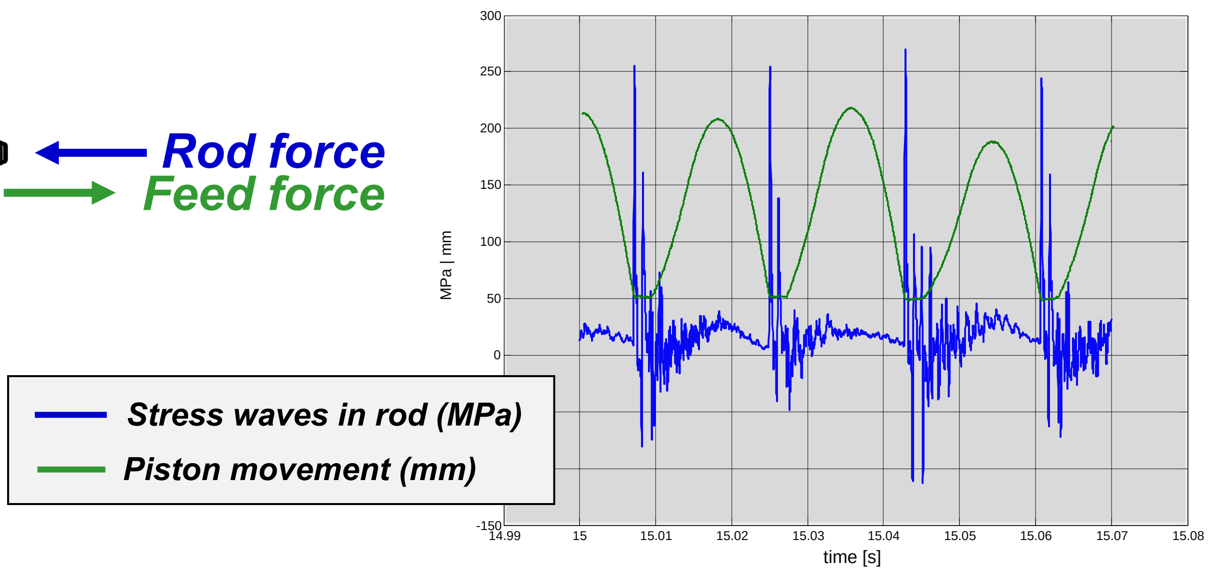
***From a drilling point of view***

- ***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***

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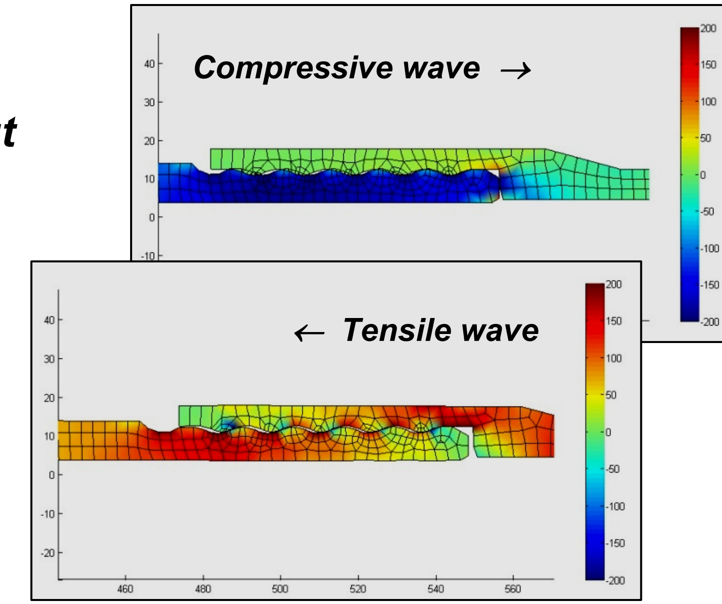
# Energy transmission efficiencies are divided into:

- ***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.***

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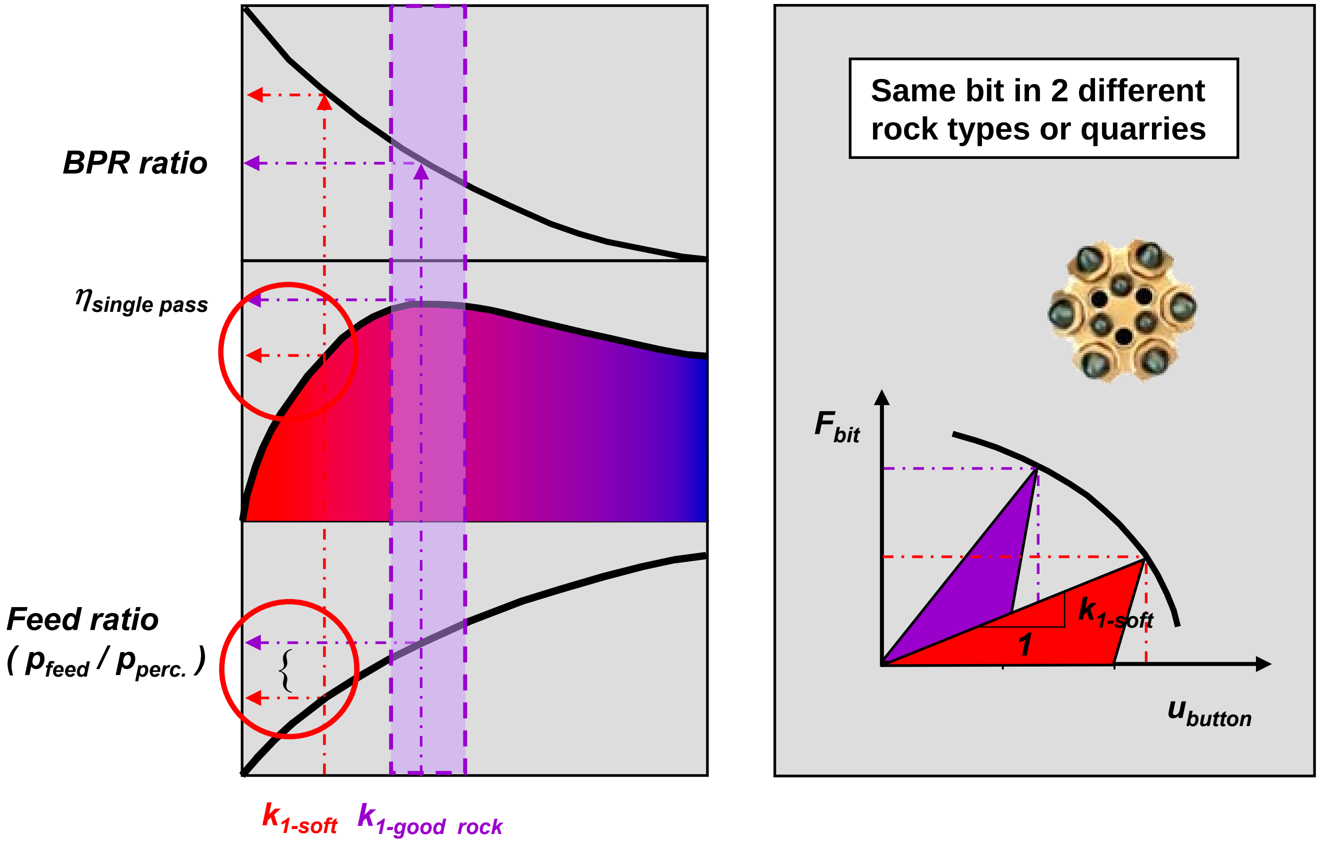
# Matching drill settings to site conditions

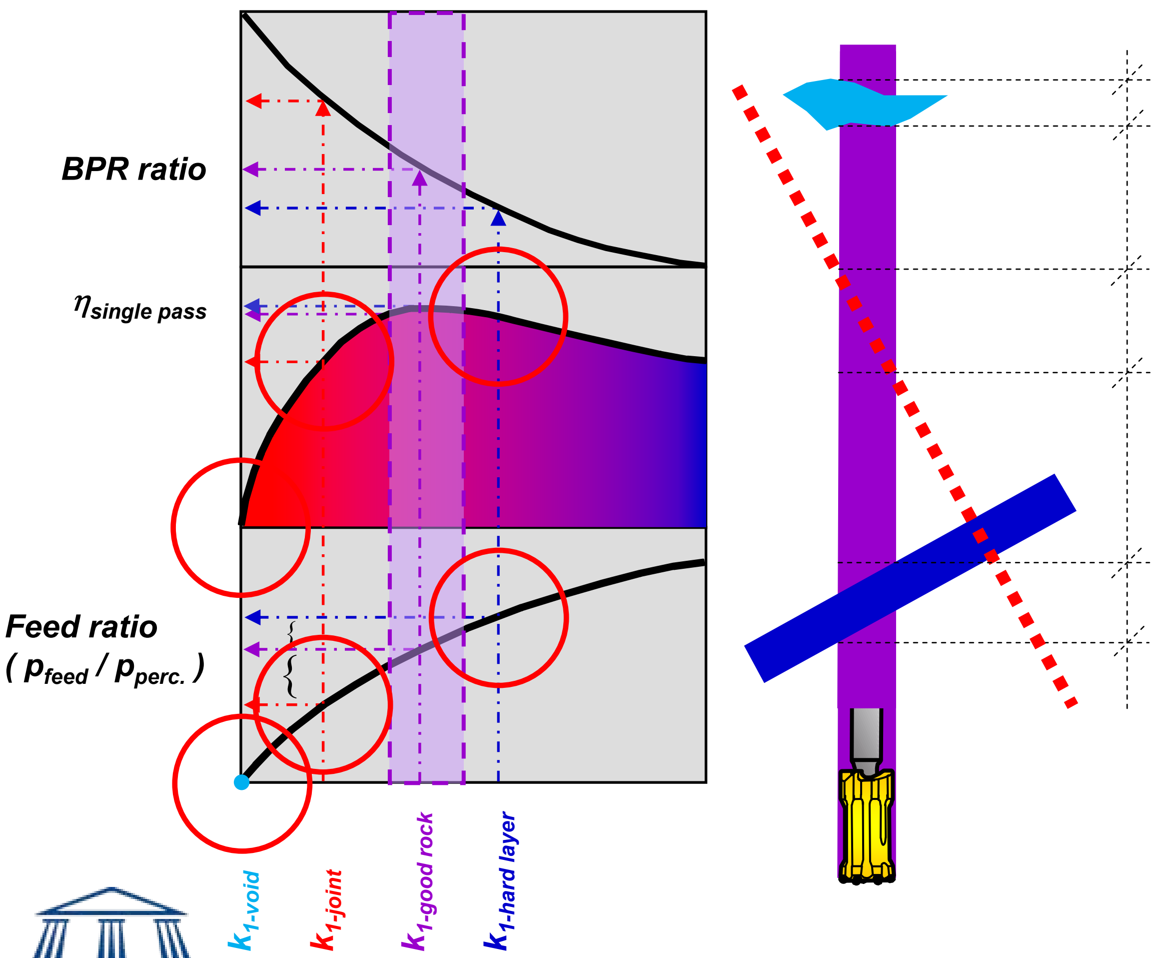



*Rock hardness* → ← *Chipping during bit indentation*

*Button count and size* →

*( and bit size )*

# 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 (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 |

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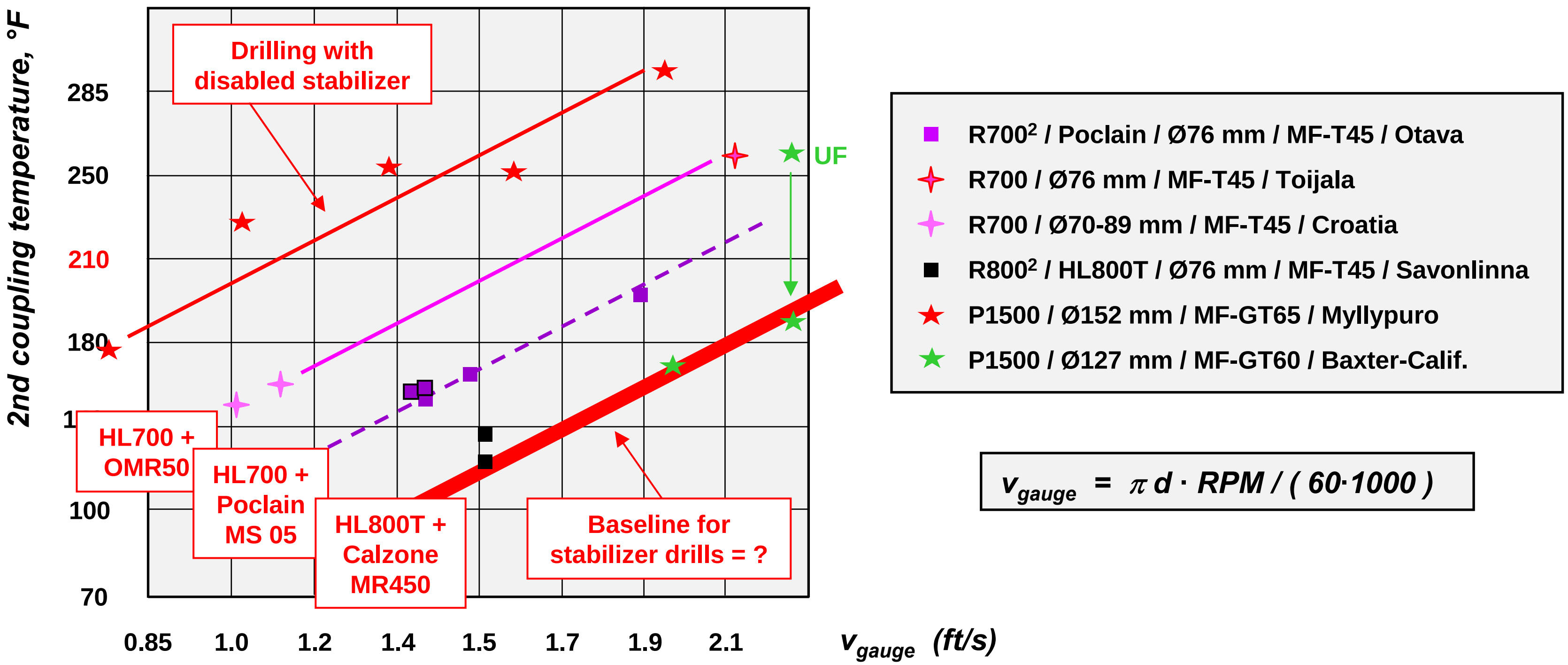
# Ranger DX700 and 800 / Pantera DP1500




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 66 | 79 | 92 | 105 | 118 | 132 | 145 | 158 | *RPM for Ø76mm – 3"* |
| 56 | 67 | 79 | 90 | 101 | 112 | 125 | 135 | *RPM for Ø89mm – 3½"* |
| 49 | 59 | 69 | 78 | 88 | 98 | 108 | 118 | *RPM for Ø102mm – 4"* |
| 39 | 47 | 55 | 63 | 71 | 79 | 87 | 95 | *RPM for Ø127mm – 5"* |
| 33 | 39 | 46 | 53 | 59 | 66 | 72 | 79 | *RPM for Ø152mm – 6"* |

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# Summary of drill settings - TH

- ***higher percussion pressure*** ***=> penetration rates increase proportionally with percussion power***
  ***=> more drill steel breakage if …***
  ***=> deviation increases with percussion energy***
- ***feed ratio ( Pfeed / Ppercussion )***
  ***=> ratio controls average feed levels***
  ***=> UF reduces drill steel life (heats up threads)***
  ***=> OF increases deviation (especially bending)***
- ***higher rotation pressure*** ***=> tightens threads (open threads reduce drill steel life)***
  ***=> increases with OF***
  ***=> increases with drill string bending***
- ***higher bit RPM*** ***=> increases gauge button wear (especially in abrasive rocks)***
  ***=> increases indexing of button footprints on drill hole bottom***
  ***=> straighter holes***
  ***=> higher thread temperatures***
- ***bits*** ***=> select bits with regard to penetration rates, hole straightness, stabile drilling (percussion dynamics), price, …***
  ***=> bit condition / regrind intervals / damage to rock drill***

# 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!***

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# Can we drill straight holes?

***Ventilation Shaft, Olkiluoto Nuclear Power Plant***

| | |
|---|---|
| ***Shaft diameter, Section I*** | ***Ø21.3'*** |
| ***Shaft length*** | ***49.2'*** |
| ***Rock type*** | ***Quartz Diorite*** |
| ***Contour hole size*** | ***Ø60mm – 2.36"*** |
| ***Contour hole charging*** | ***80 g/m cord*** |
| ***Contour hole spacing*** | ***1.3'*** |
| ***Contour row burden*** | ***2.3'*** |

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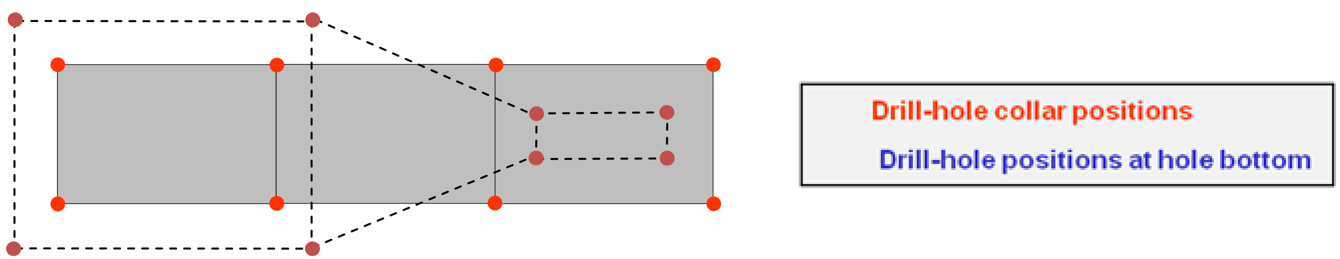
# What happens when we shoot holes that look like spaghetti?

- *floor humps* => *poor loading conditions, uneven floors*
- *poor walls* => *unstabile walls*<br>=> *difficult 1st row drilling*
- *flyrock* => *safety*
- *blowout of stemming* => *safety, dust, toes, …*
- *blast direction* => *quality of floors and walls*
- *shothole deflagration / misfires* => *safety*<br>=> *locally choked muckpiles (poor diggability)*
- *good practice* => *max. drill-hole deviation up to 2 – 3% for production drilling*

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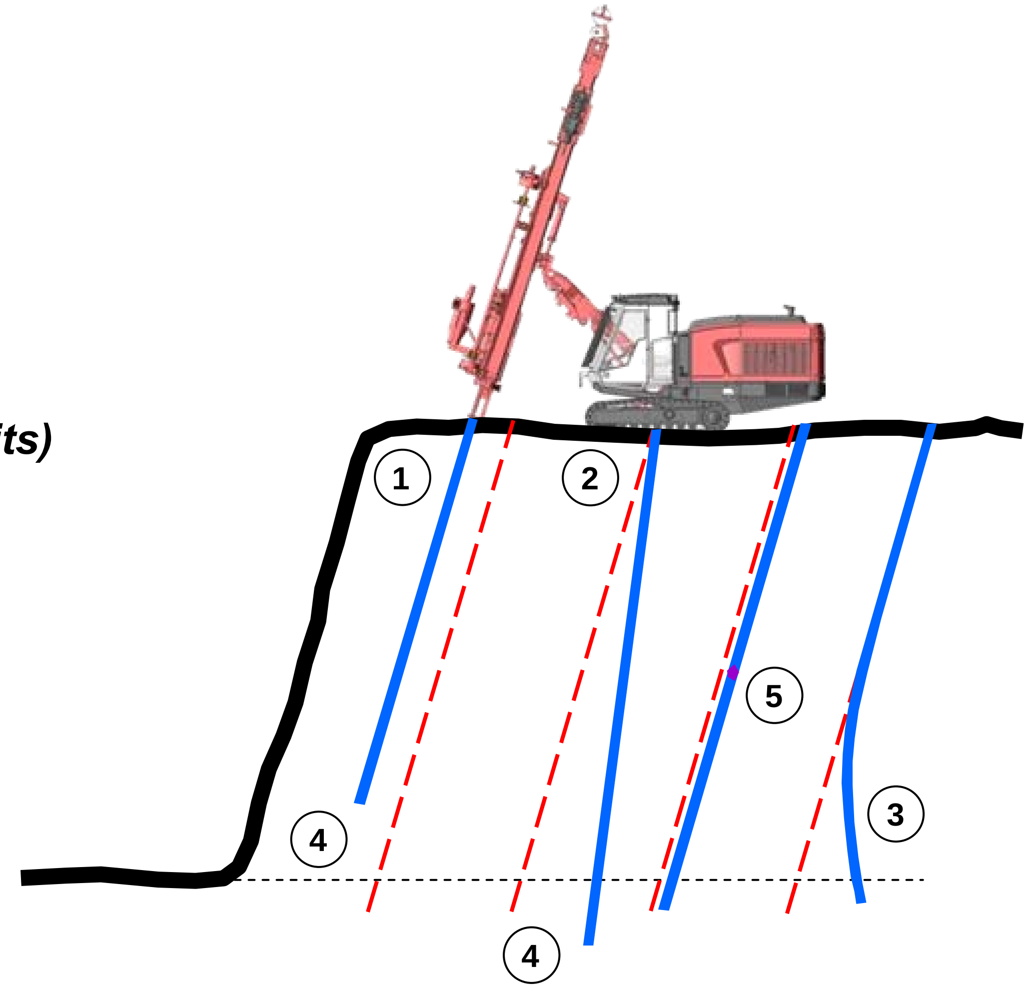
# Accurate drilling gives effective blasting

***Sources of drilling error***

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

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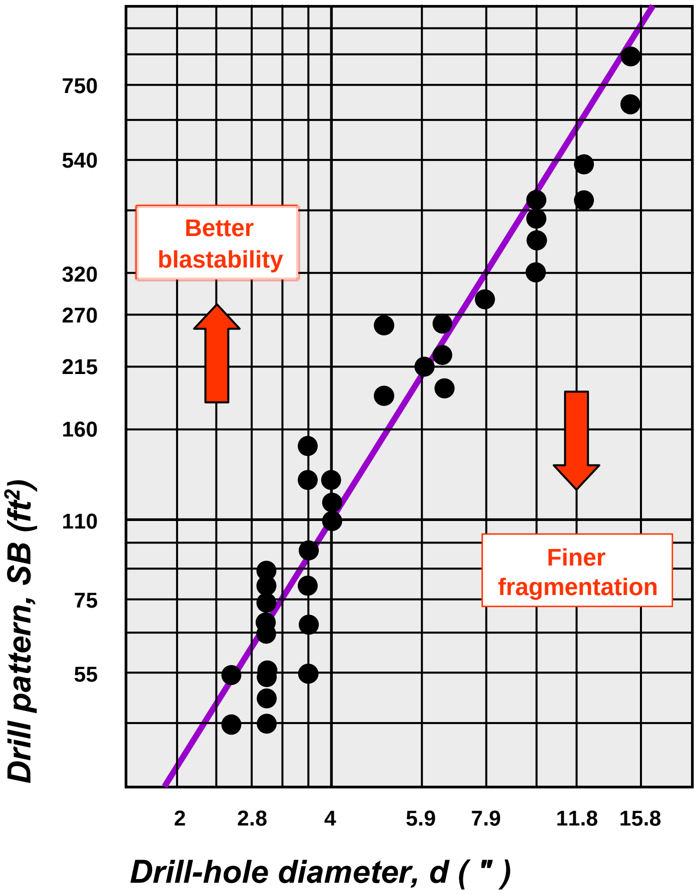
# Shothole diameter error control

- ***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 – 4"* |
| | *Diameter worn out* | *Ø89mm – 3½"* |
| | *Diameter loss* | *( 4 – 3½ ) / 4 = 12.8%* |
| => | *Drill pattern too big* | *( 4 / 3½ )$^{1.6}$ = 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

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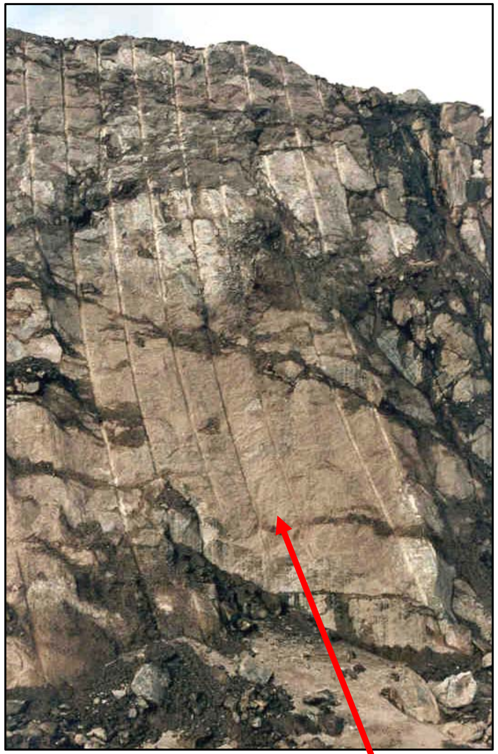
# Examples of drill-hole deviation

Directional error for Ø3½" retrac bit / T45 in granite



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

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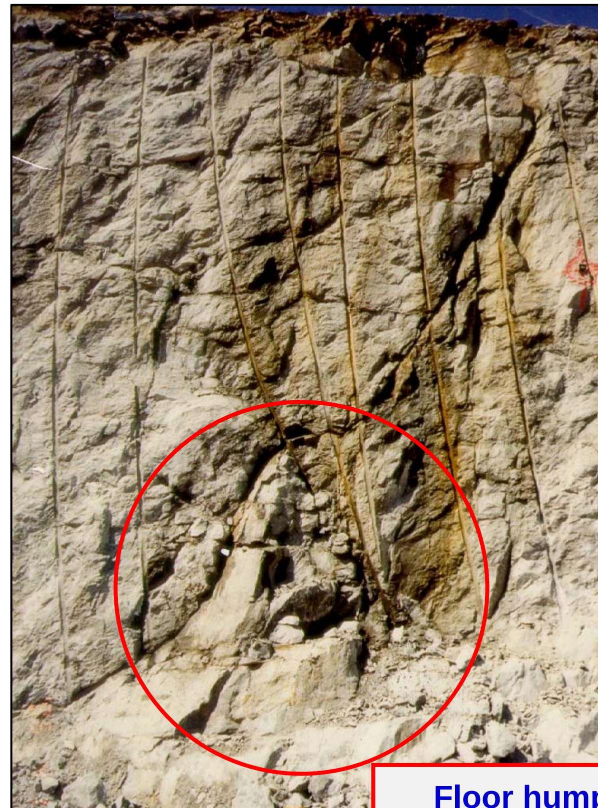
# Examples of drill-hole deviation

**Deflection with and without pilot tube for Ø3½" DC retrac bit / T51 in mica schist**



**Floor hump due to explosives malfunction – caused by drill string deflection**

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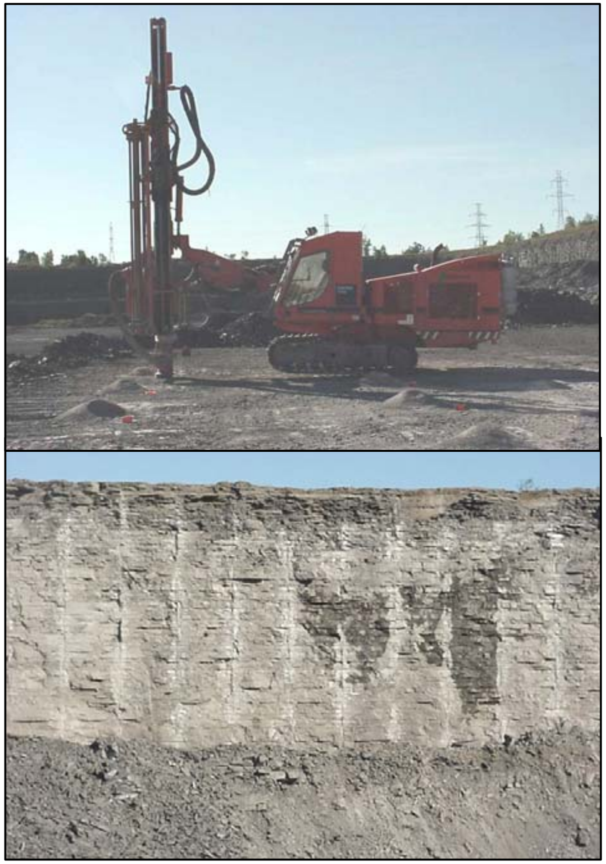
# Lafarge Bath Operations, Ontario

***Annual production*** ***1.6 mill. tons***
***Rock type*** ***Limestone***

| | |
|---|---|
| *Bench height* | *105'* |
| *Bit* | *Ø115mm - 4½" guide XDC* |
| *Drill steel* | *Sandvik 60 + pilot tube* |
| *Hole-bottom deflection* | *< 1.5 %* |
| *Gross drilling capacity* | *220 dr-ft/h* |
| *Drill pattern* | *14¾' x 15¾' (staggered)* |
| *Sub-drill* | *0' (blast to fault line)* |
| *Stemming* | *9¼'* |
| *No. of decks* | *3* |
| *Stem between decks* | *5.9'* |
| *Deck delays* | *25 milliseconds* |
| *Charge per shothole* | *520 lbs* |
| *Explosives* | *ANFO (0.95 & 0.85 g/cm$^3$)* |
| *Powder factor* | *0.34 kg/bm$^3$* |



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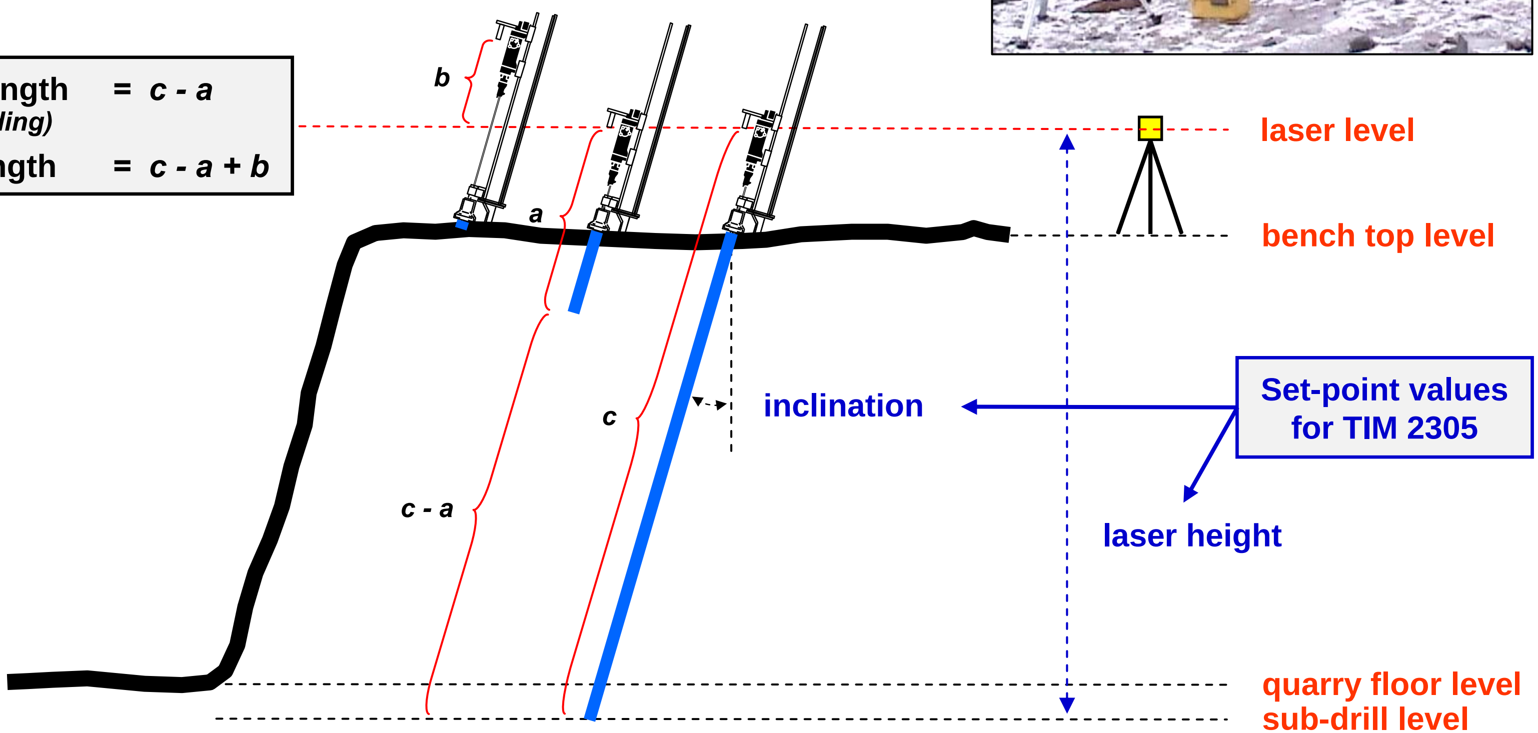
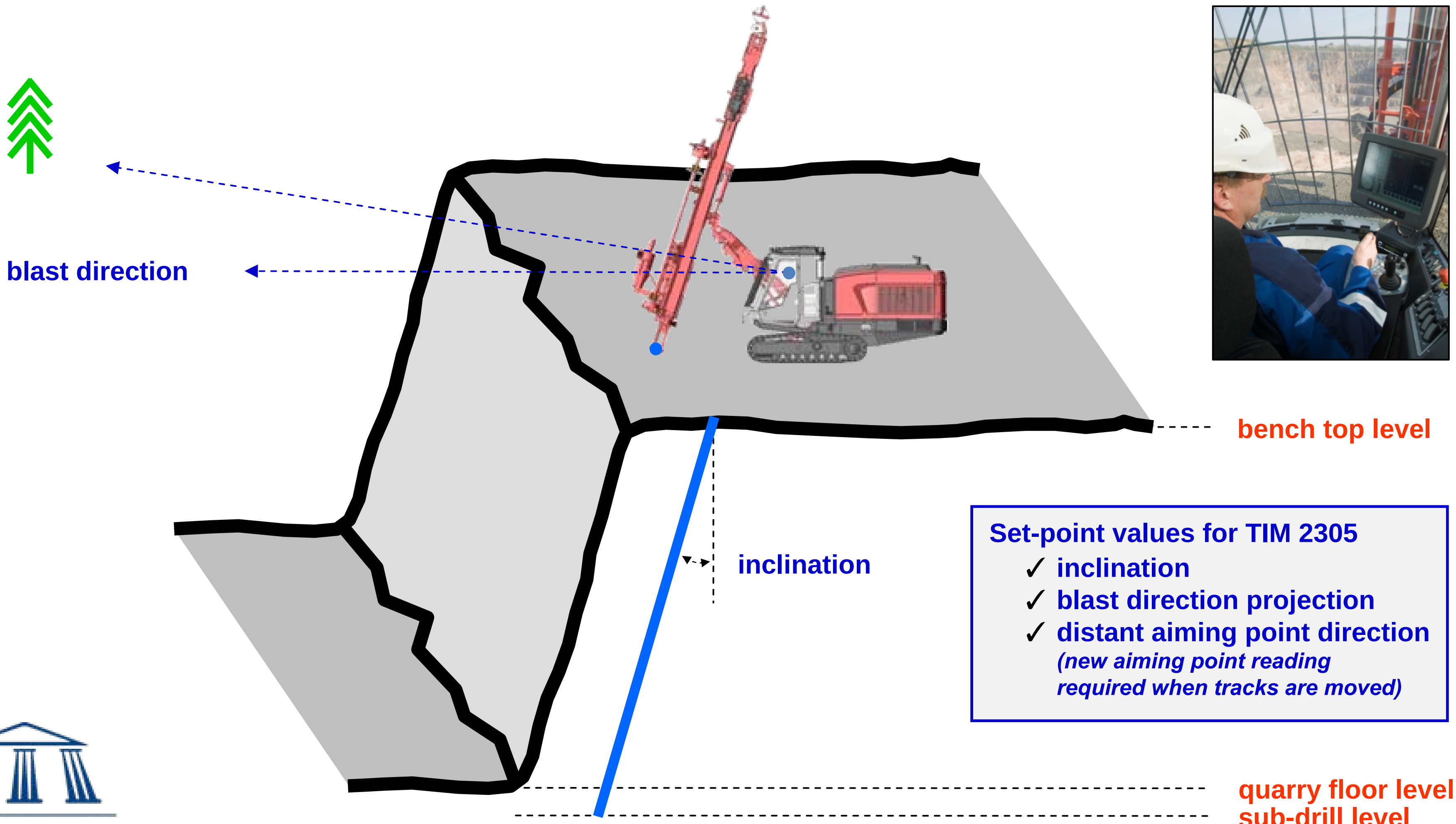
# Hole depth error control

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

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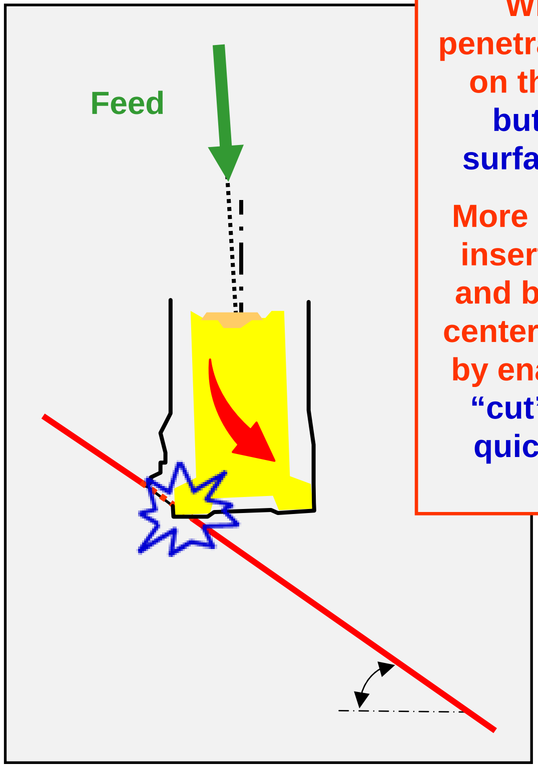
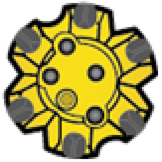
# How bit face designs enhance drill-hole straightness




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 the joint surface quickly - thus resulting in less overall bit deflection.



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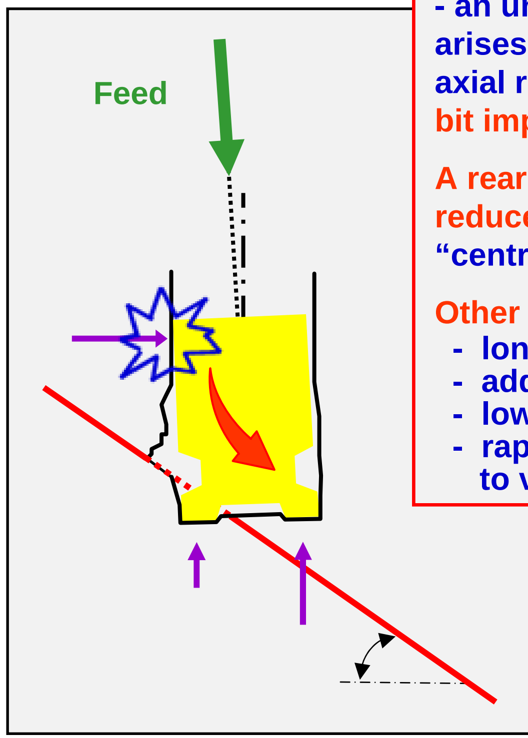
# How bit skirt designs enhance drill-hole straightness

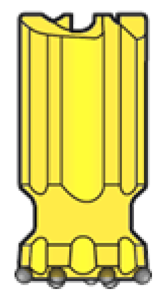



As the bit cuts through the joint surface - an uneven bit face loading condition arises; resulting in bit and drill string axial rotation - which is proportional to bit impact force imbalance.

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



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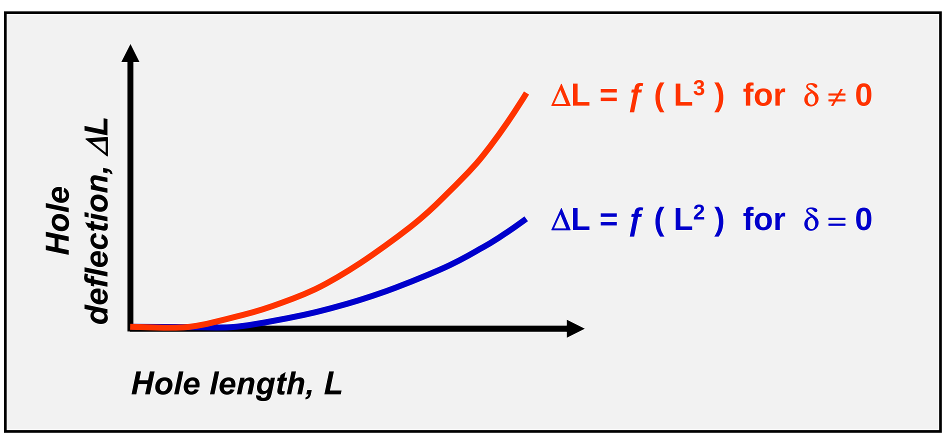
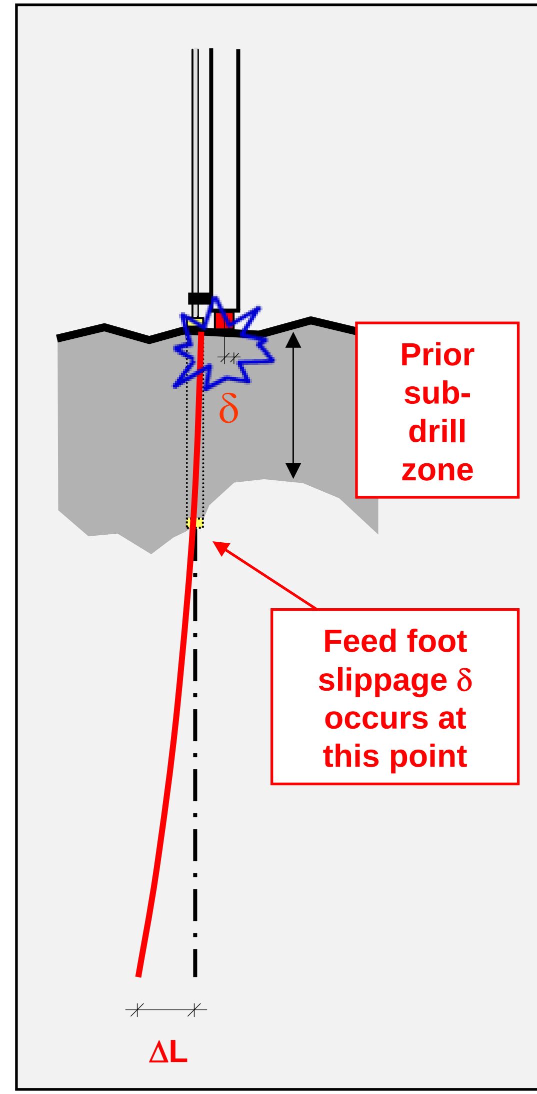
# Drill-hole deflection error control

- *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*
- *avoid **gravitational** effects which lead to **drill string sagging** when drilling inclined shot-holes ( > 15° )*
- *avoid inpit operations with **excessive bench heights***

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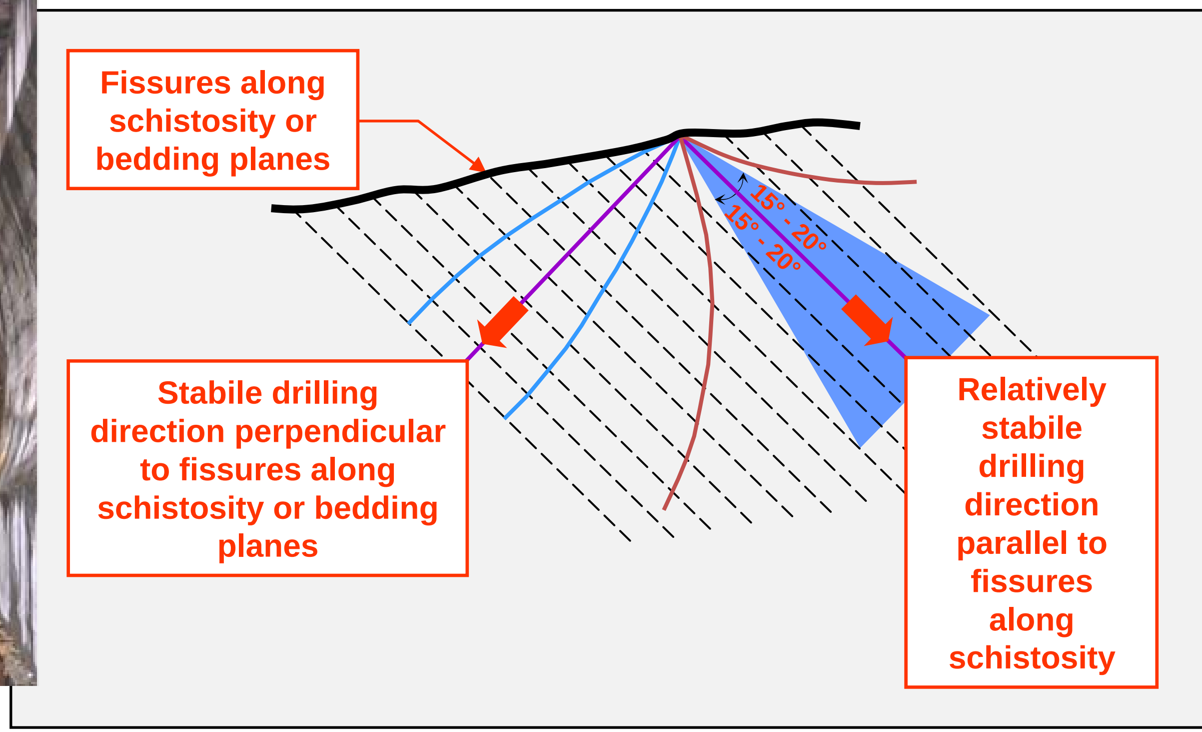
# Drill-hole deflection trendlines in schistose rock

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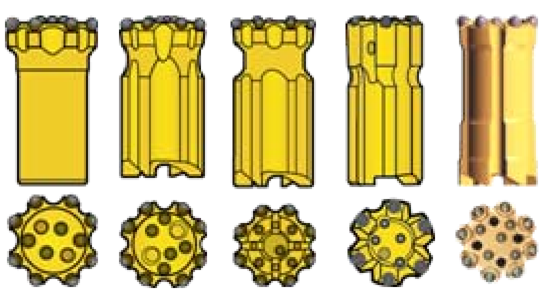
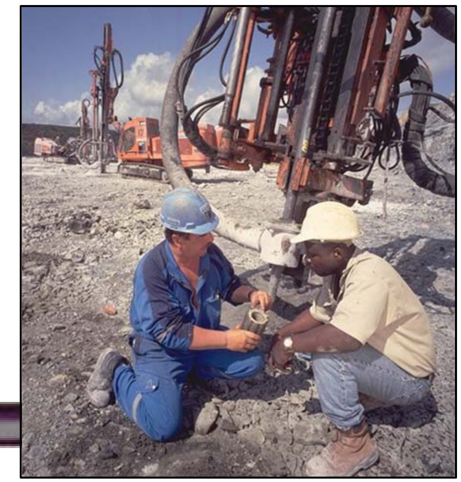
# Selecting straight-hole drilling tools - TH

- ***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***





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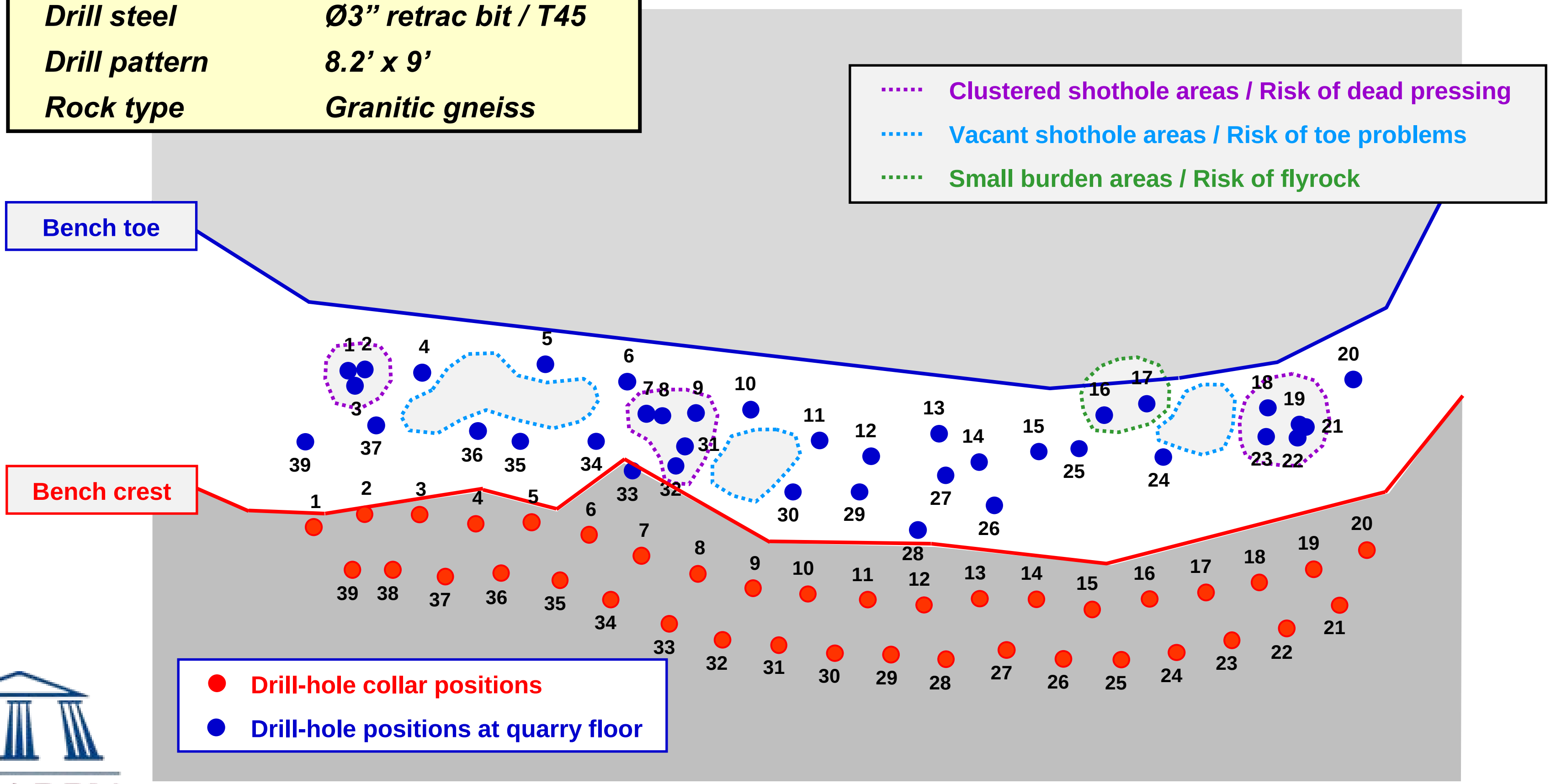
# Drill pattern at quarry floor

| | |
|---|---|
| ***Bench height*** | ***108 ft*** |
| ***Hole inclination*** | ***14°*** |
| ***Drill steel*** | ***Ø3" retrac bit / T45*** |
| ***Drill pattern*** | ***8.2' x 9'*** |
| ***Rock type*** | ***Granitic gneiss*** |

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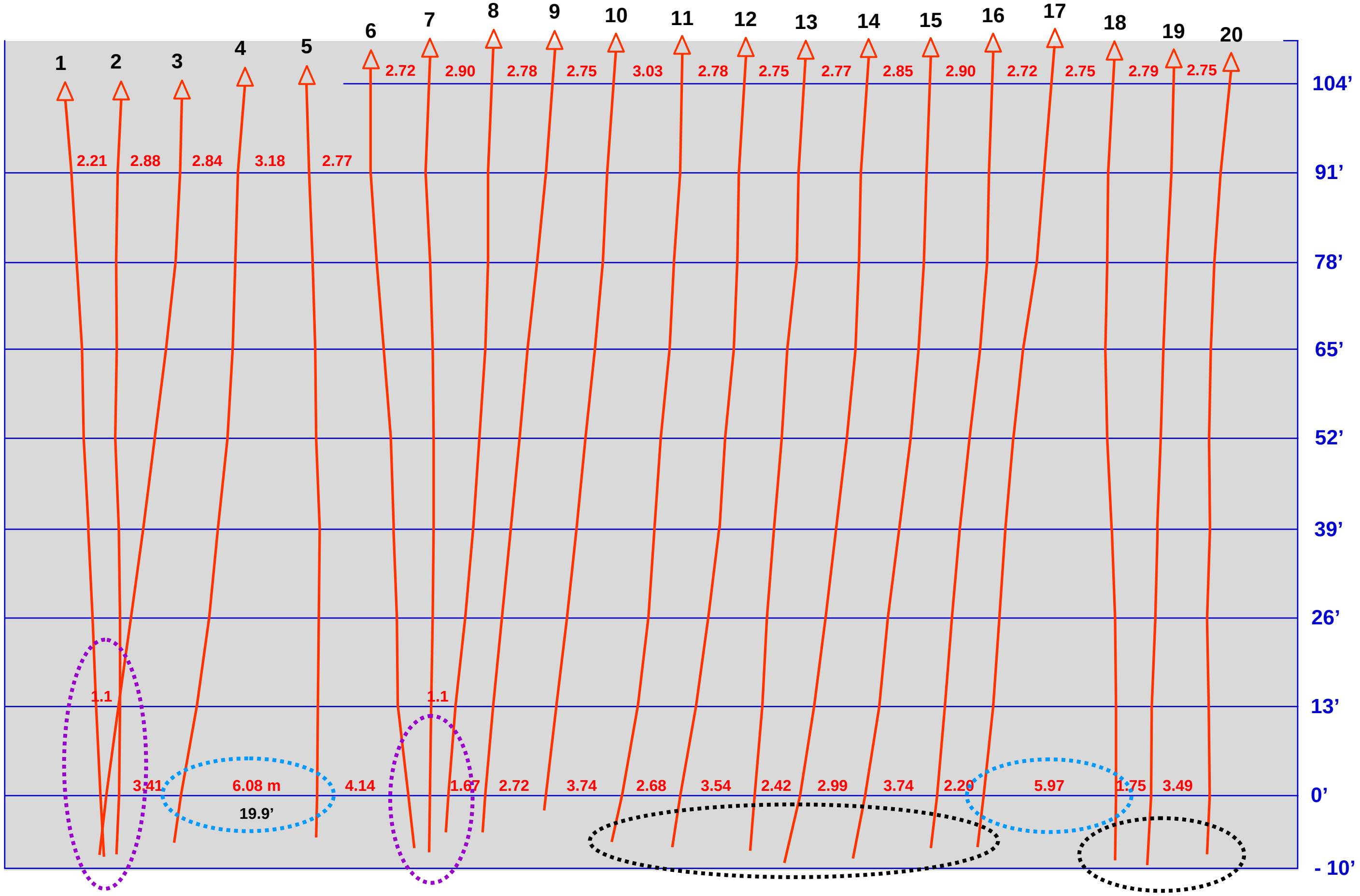
# Vertical projection of Row #1

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# 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 $\Delta L_{I+D}$ (mm) | Drill-hole Deflection $\Delta L_{def}$ (mm) | Drill-hole Deviation $\Delta L_{total}$ (mm) | Drill-hole Deviation $\Delta L_{total}$ / 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 |

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# 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!***

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# Mina Alumbrera - Double bench presplitting

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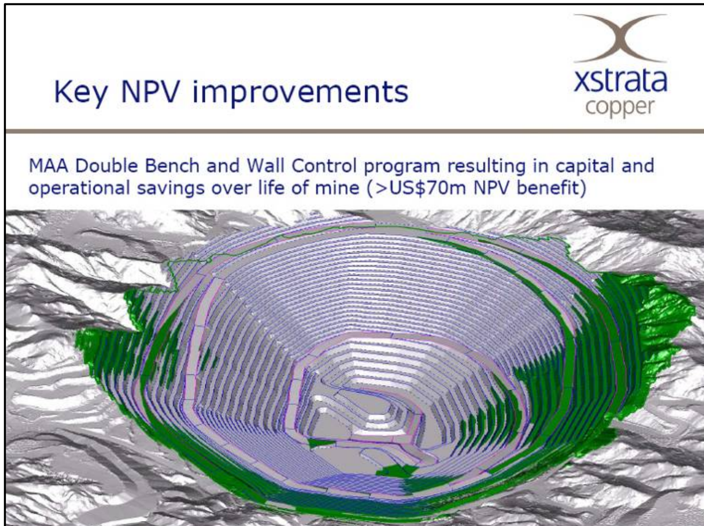
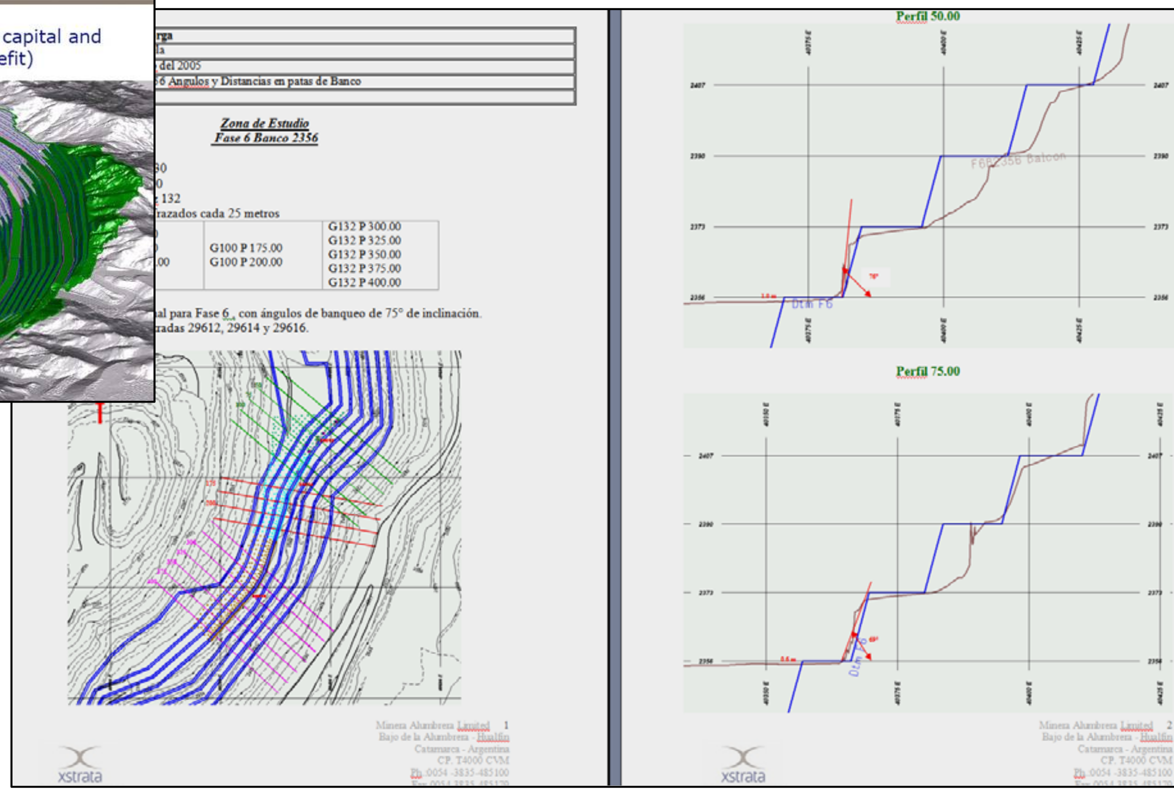
# Mina Alumbrera - Pitwall scanlines

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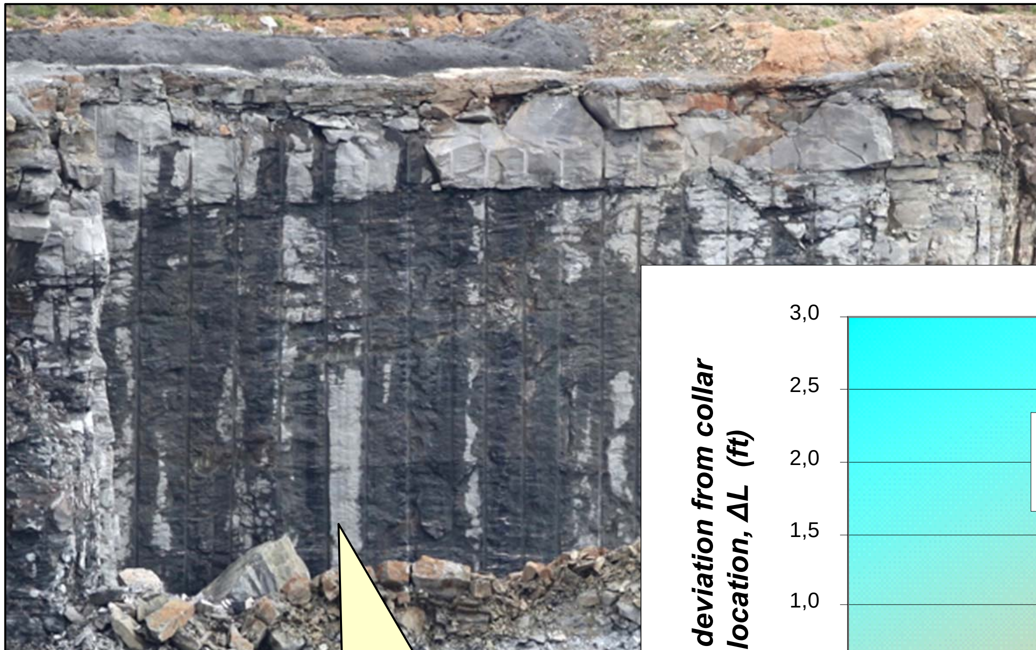
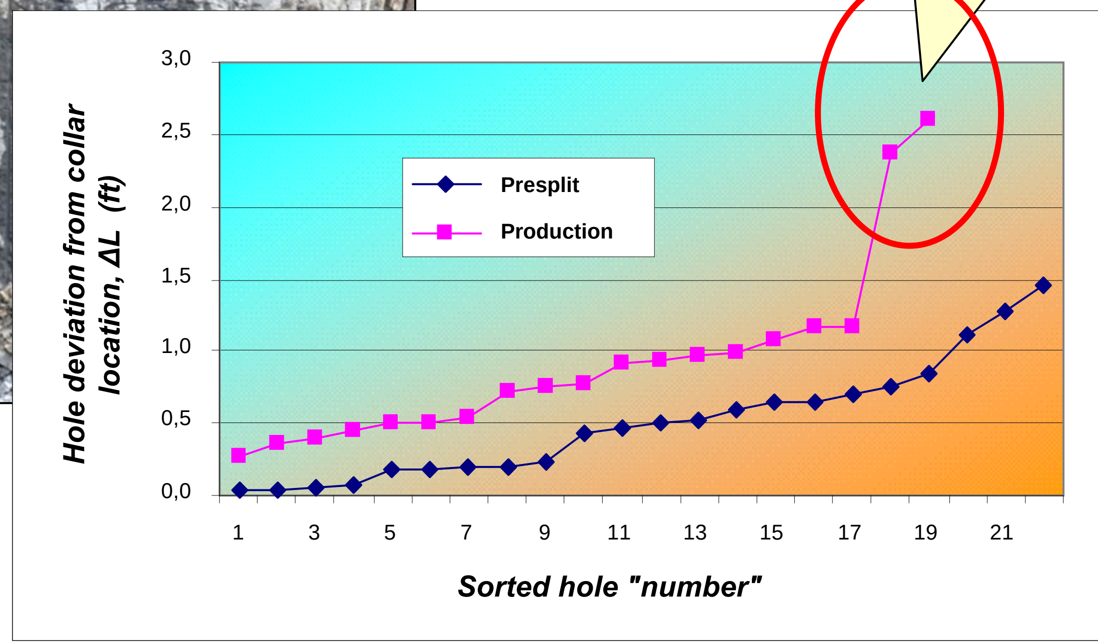
# Wall control drilling - Macon Quarry, GA



**DP1500 - Ø87/3½" Tubes - 80' Bench - Ø140/5½" Presplit**




**Excessive deviation due to feed foot slippage**

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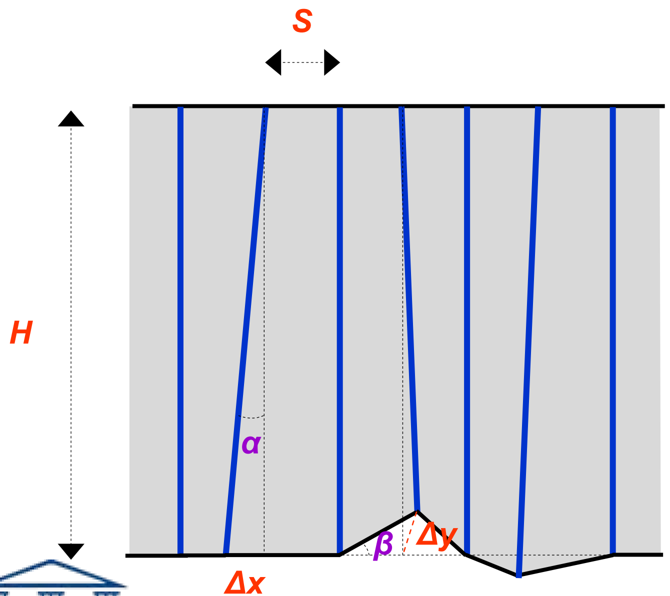
# Wall control drilling - Macon Quarry, GA

| | ΔL | % | Δx = Δy | α | β |
|---|---|---|---|---|---|
| *Max error* | 1.48 ft | 1.8 | 1.05 ft ( ≈ 2d ) | 0.75° | 12.0° |
| *Median error* | 0.49 ft | 0.6 | 0.36 ft ( ≈ d ) | 0.25° | 4.2° |




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

$\Delta y$ = *error perpendicular to wall is of greater importance to extent of blast damage in backwalls*

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

$\Delta x$ = *error parallel to wall - lesser importance*

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

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***Thank You***

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***Workshop ?***

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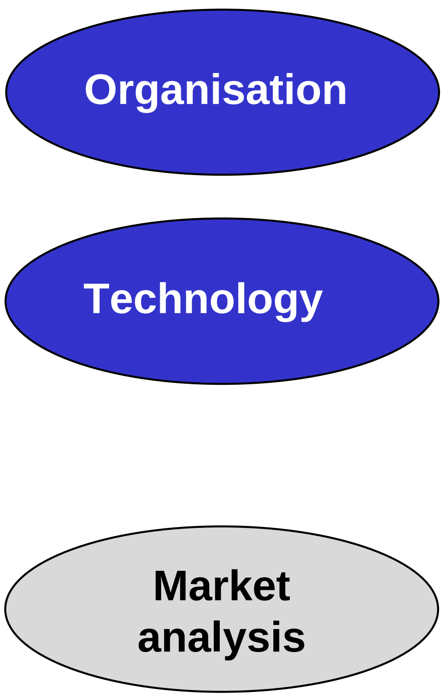
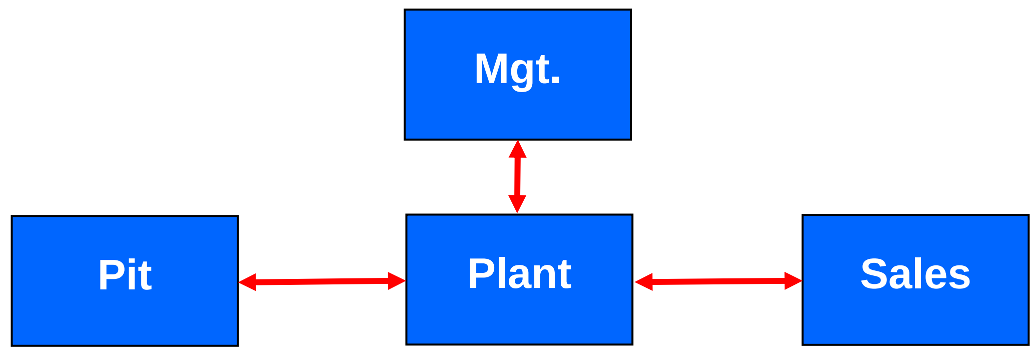
# Optimisation of quarrying => overview of operations, technology and markets



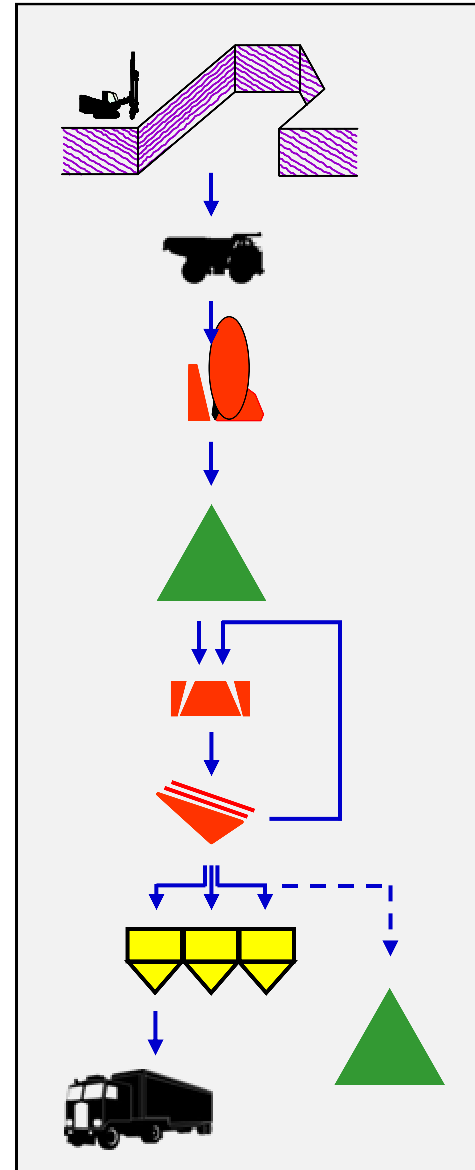




- ***end-product volumes***
- ***costs***
- ***prices***
- ***stockpiling***

***=> right mix of parameters?***

# Key Performance Indicators, KPI's

- ***key financial performance in period***
  - ü *overall quarry profitability*
  - ü *capital employed*
    *(especially unscheduled stockpiling)*
- ***key production performance in period***
  - ü *end-product tonnages, costs and margins*
  - ü *productivity and cost per machine*
  - ü *safety in operations*
  - ü *public relations*

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# Occupational health and safety

- ***work related accidents for:***
  - ***mobile equipment***
  - ***hazardeous work areas***
- ***emissions control***
- ***noise control***
- ***dust control***
- ***fly rock / charging / straight-hole drilling***
- ***falling rocks / wall control***

⇒ ***safety is linked as much to equipment as it is to attitudes***

⇒ ***health, safety and environmental issues are everyone's concern***

⇒ ***the ultimate safety target is zero harm – not just a mimimum occurrence of accidents***

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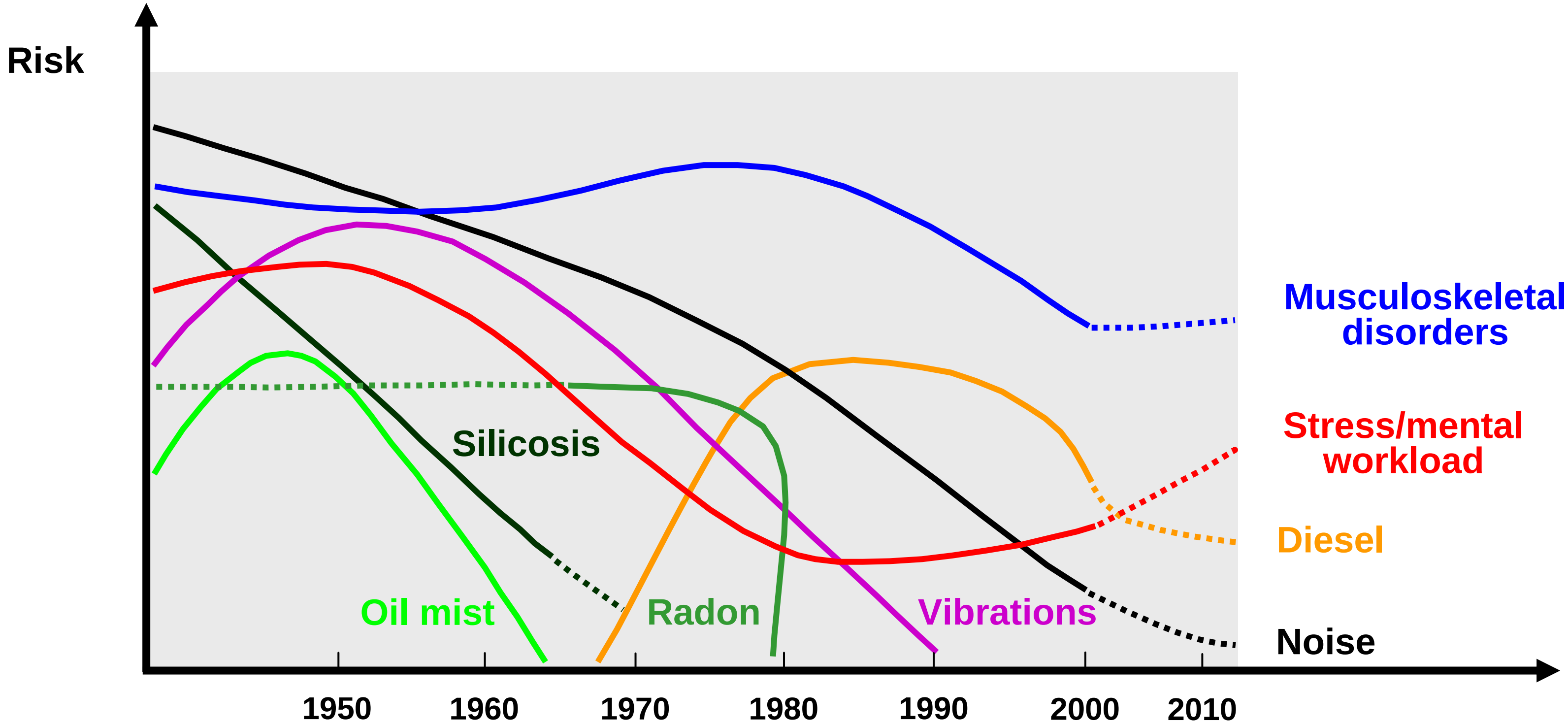
# Assessment of some work related health risks

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# Safety of inpit operations

- ***unwanted incidences do not just happen – they have root causes***
- ***actions can be taken so as to reduce frequency and consequences of unwanted occurrences***
- ***the relationship between complexity and knowledgein the workforce is often unbalanced - e.g. operator hazard training is a must!***

**Premature ignition of electric detonators and blast due to lightning**

**Pit wall failure burying 3 drill rigs in rubble**

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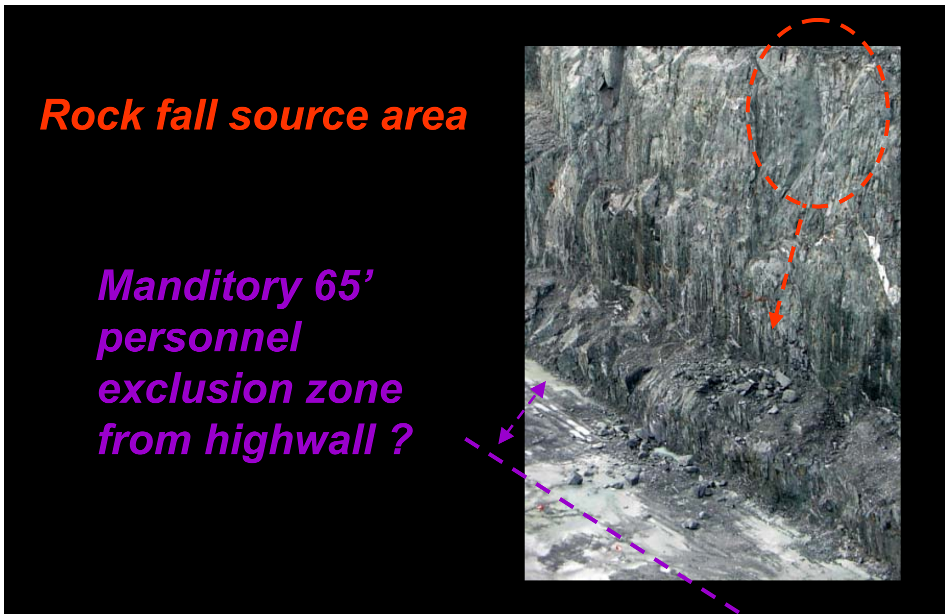
# Safety of inpit operations

- ***new equipment requirements for the future?***





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# 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 microfractures*
- *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*

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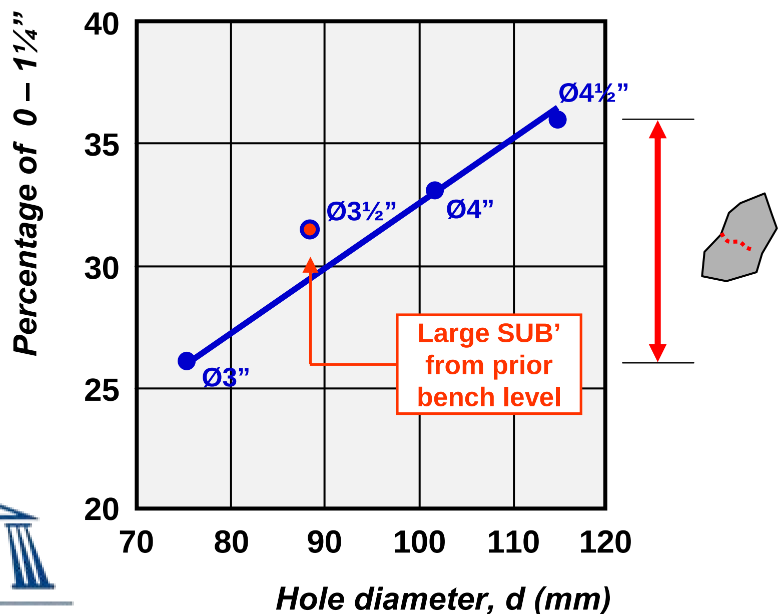
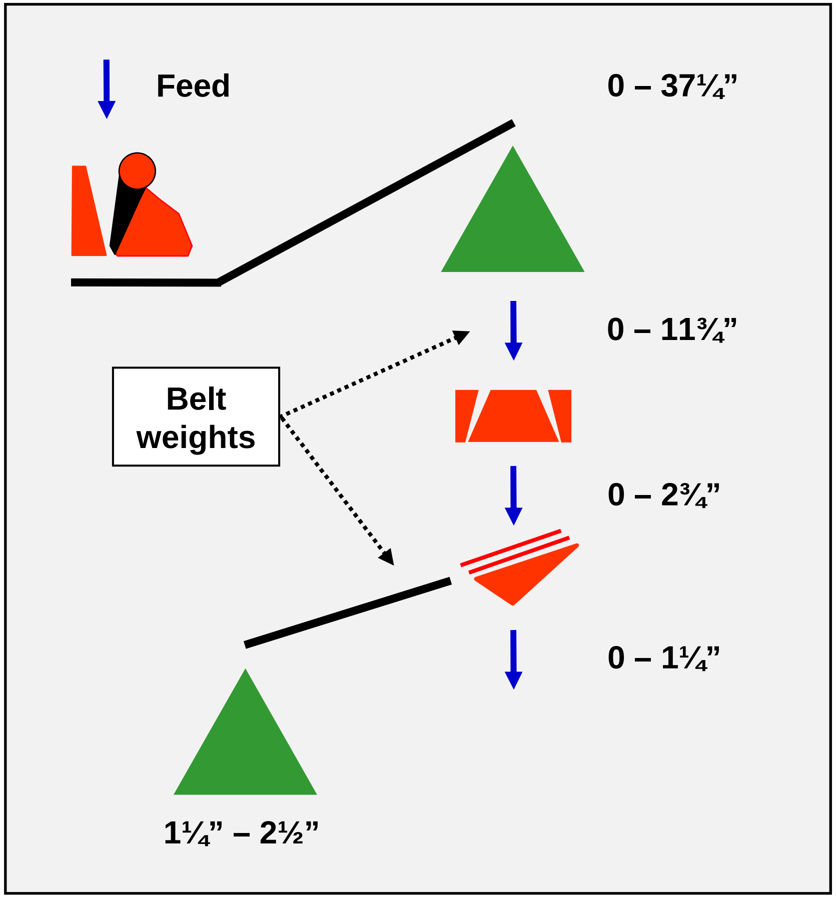
# Quality feed – handling boulders

- ***boulder count dependent on primary crusher opening (and to a lesser extent primary crusher capacity)***
- ***sort boulders from muck pile***
- ***down-size boulders before entering primary crusher***
- ***minimize boulder count using reduced uncharged height and/or tighter drill patterns***

# Quality feed – effect of micro-fracturing

| | |
|---|---|
| ***Rock type*** | ***Anorthosite*** |
| ***Explosive*** | ***Slurrit 50-10*** |
| ***Test blasts*** | ***4 x 50,000 tons*** |
| ***Bench height*** | ***36'*** |

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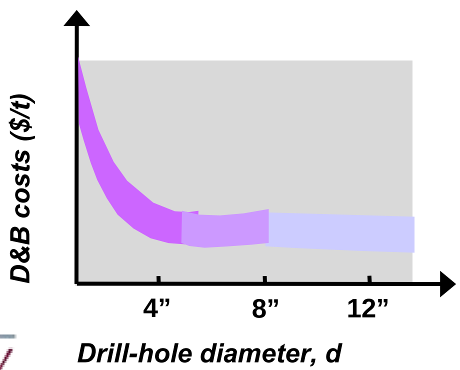
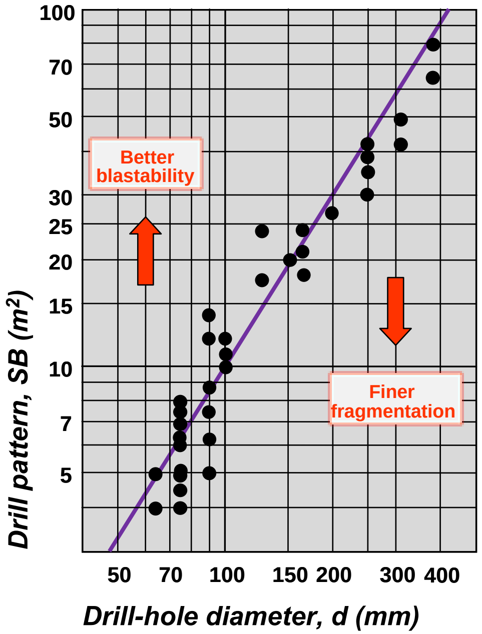
# Criteria for selecting drills

- *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 t*
- *level of automation*
- *operator training and support*
- *operator comfort and safety*
- *ease of transport between pits*

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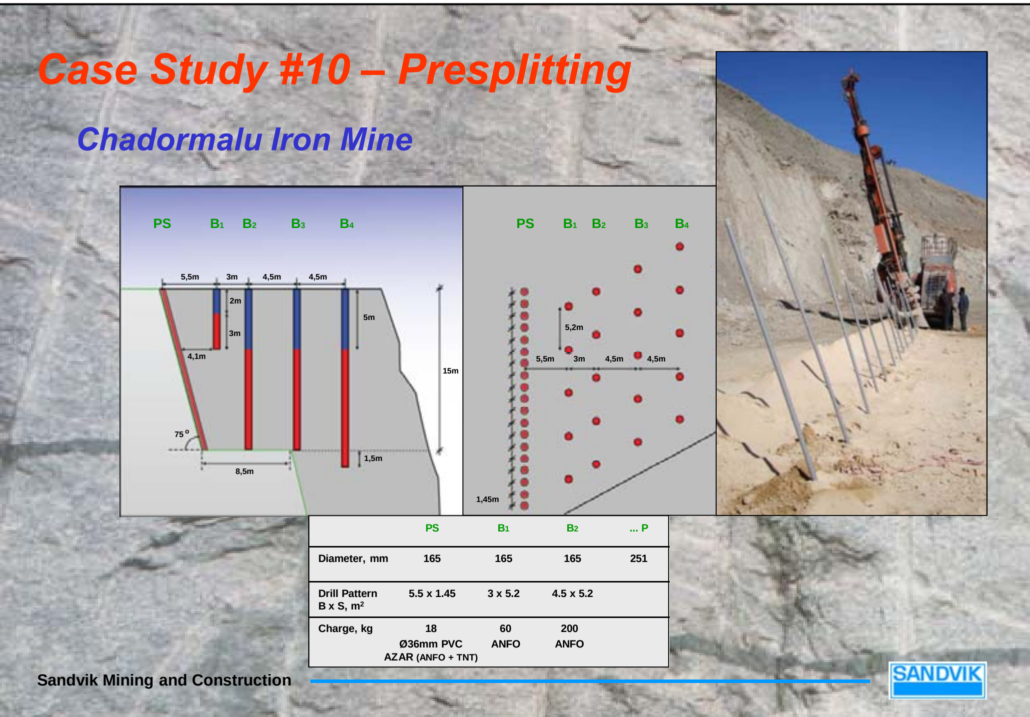
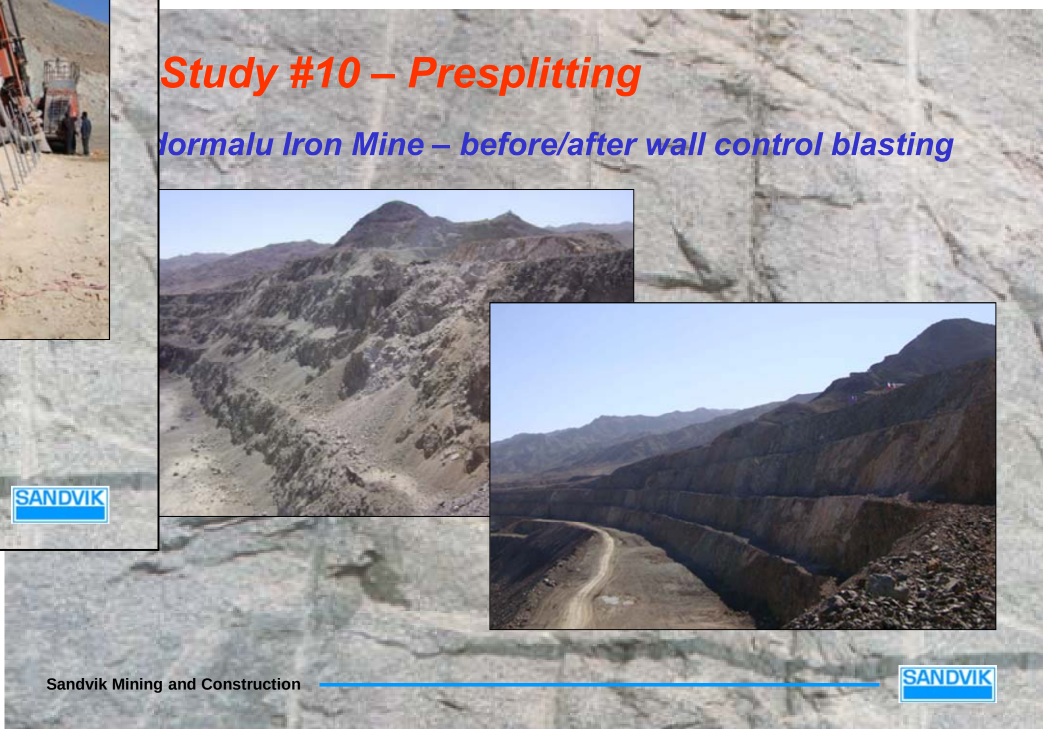
# Wall control D&B – Chadormalu Iron Mine

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LIGHTEN UP!