Drilling – Understanding Fundamentals

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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 drill steel yields low cost drilling***
- ***straight hole drilling yields safe and low cost D&B operations***

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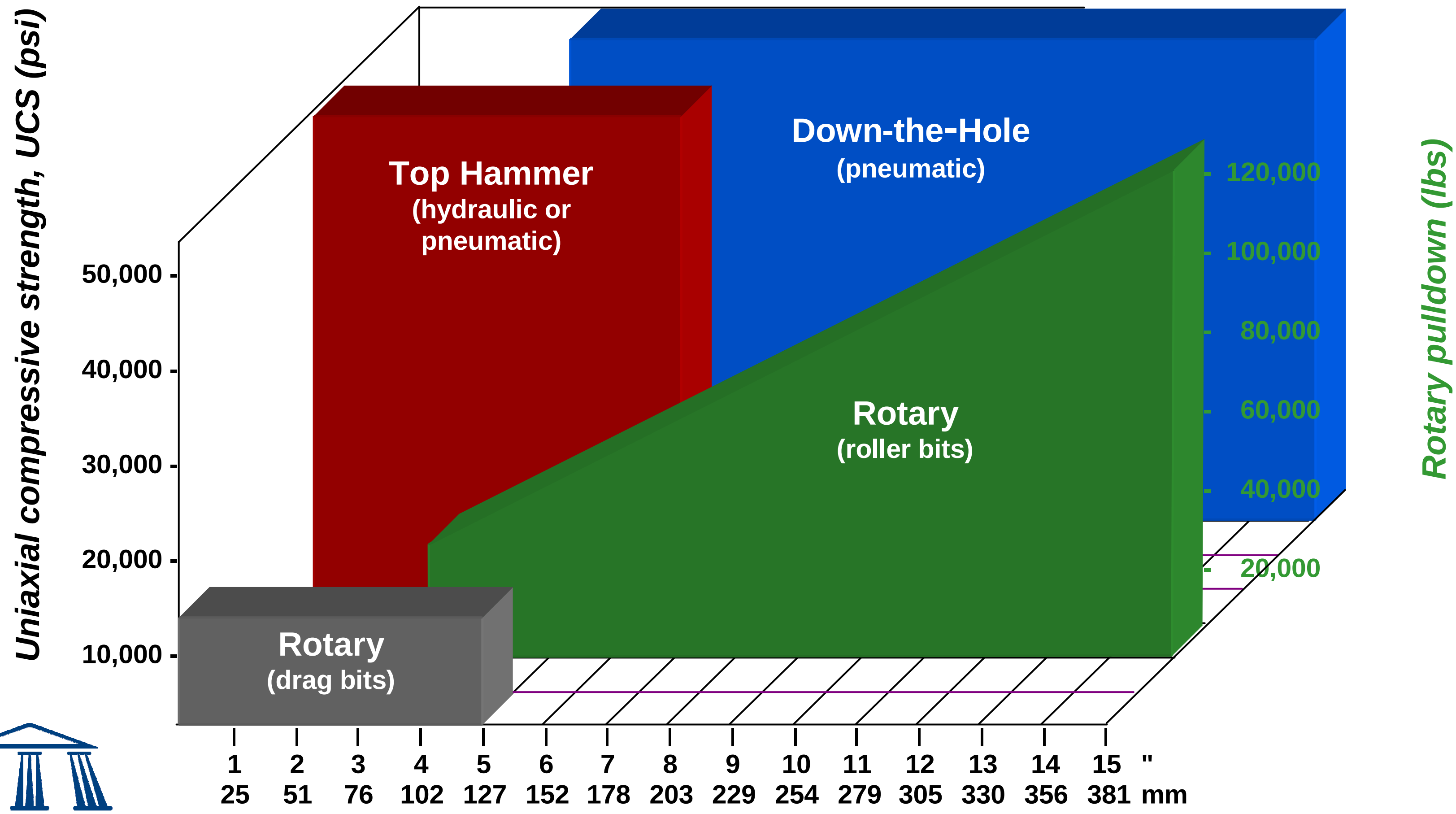
The most common drilling methods in use



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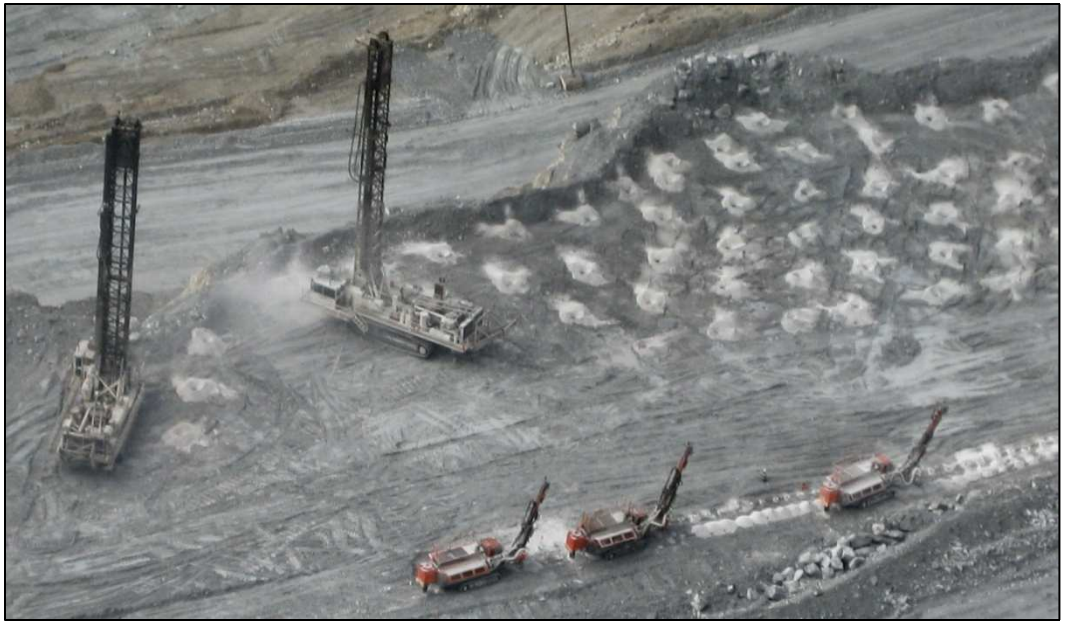
Drilling consists of a working system of:

- ***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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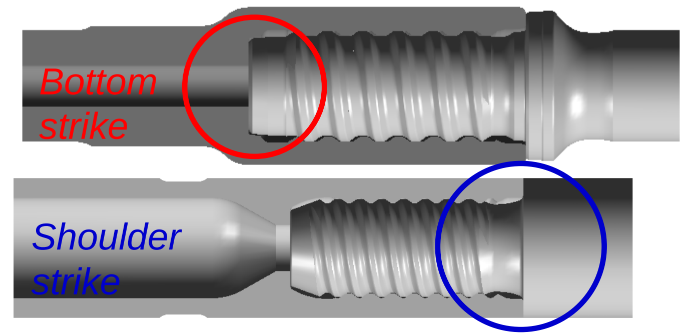
Case study – Singrauli Coal Mine, India

- **_Rock_** — **_Overburden sandstone_**
- **_Drill rig_** — **_P1524 / HL1560 / chain feed_**
- **_Tubes_** — **_ST68 threads / Ø96mm / 2 x 12' SP_**
- **_Bits_** — **_6" Retrac_**



- **_Bit penetration rate_** — **_367 ft/ph = 6.13 ft/min_**
- **_Feed ratio_** — **_90 bar / 150 bar = 0.60_**

- **_bit service life_** — **_18,620'_**
- **_shank service life_** — **_11,770' / 62,745' / 84,720'_**
- **_tube shank service life_** — **_4,465' / 16,585' / 36,680'_**

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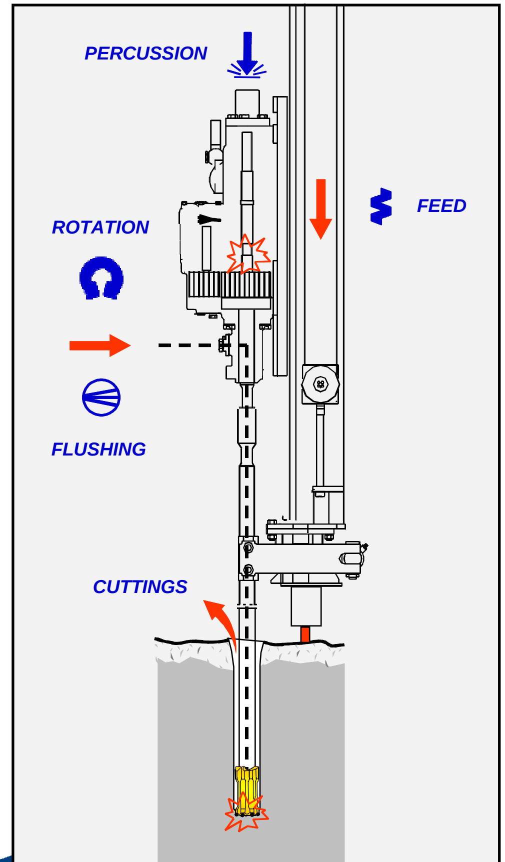
Mechanics of percussive drilling



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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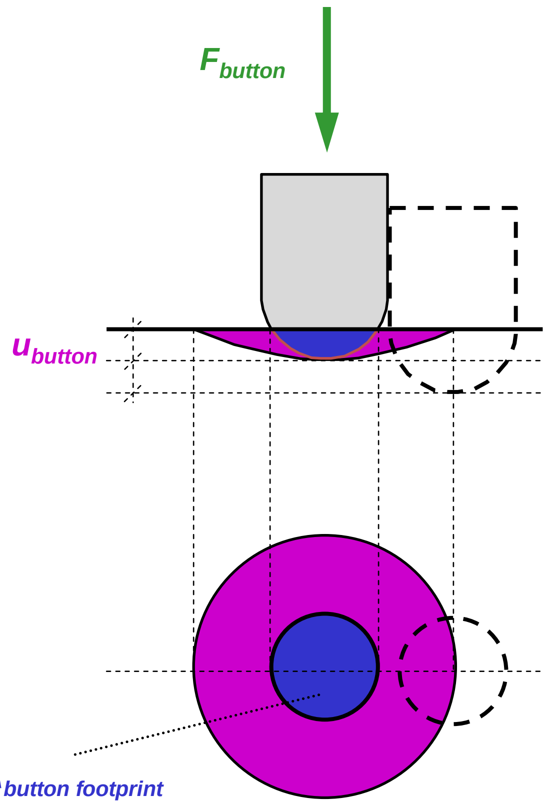
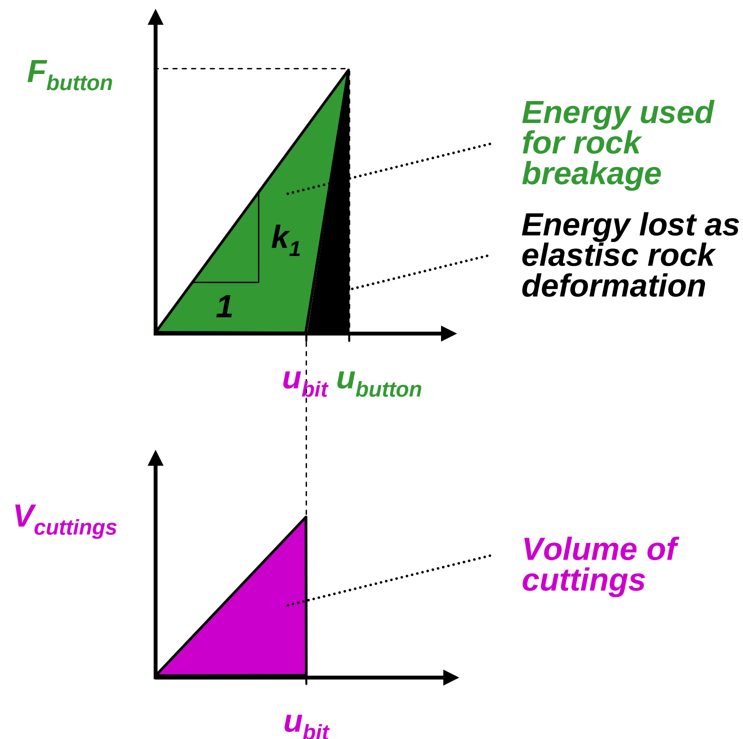
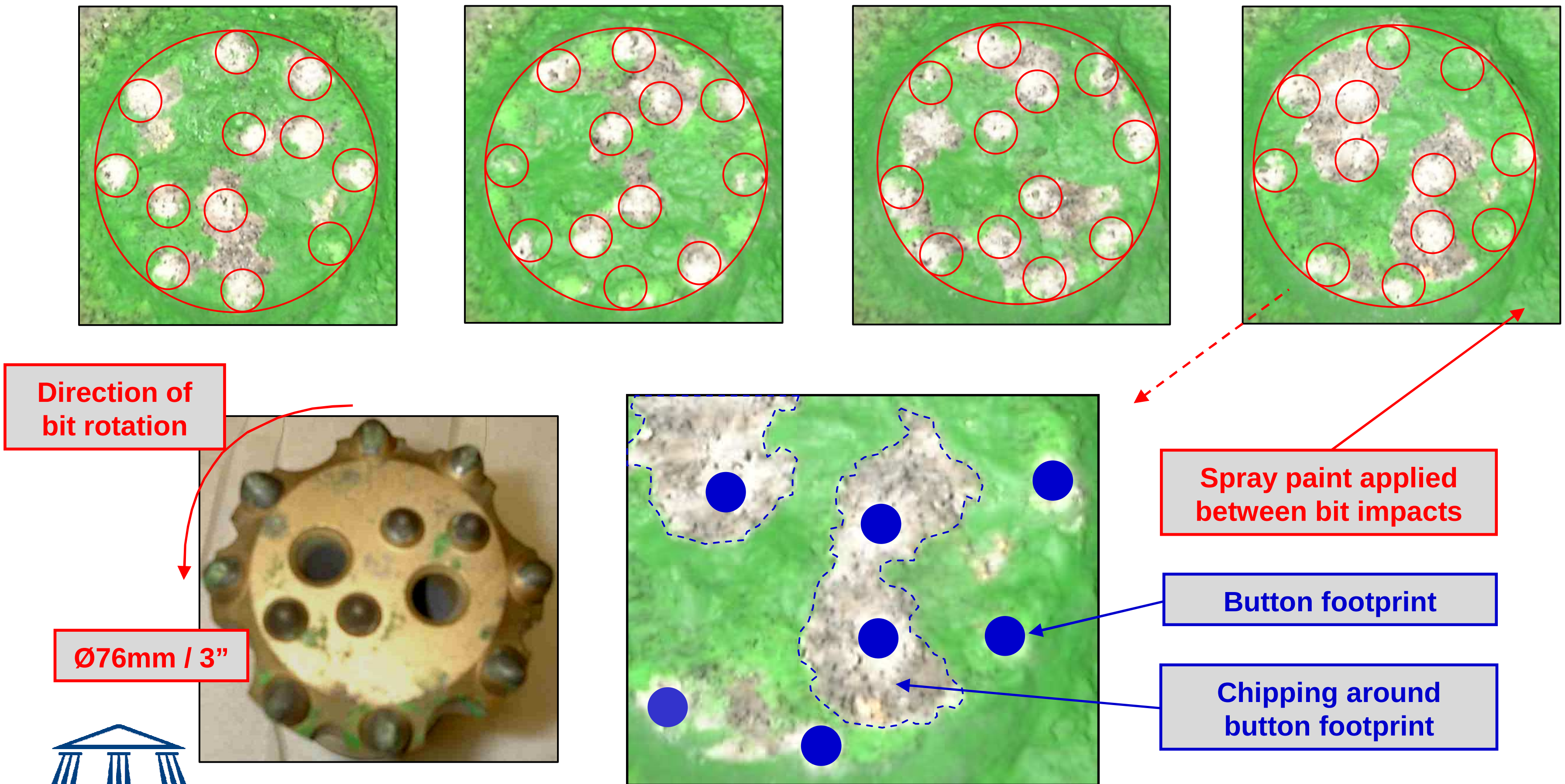
How rock breaks by indentation





Chip formation by bit indentation and button indexing



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How flushing works along the drill string

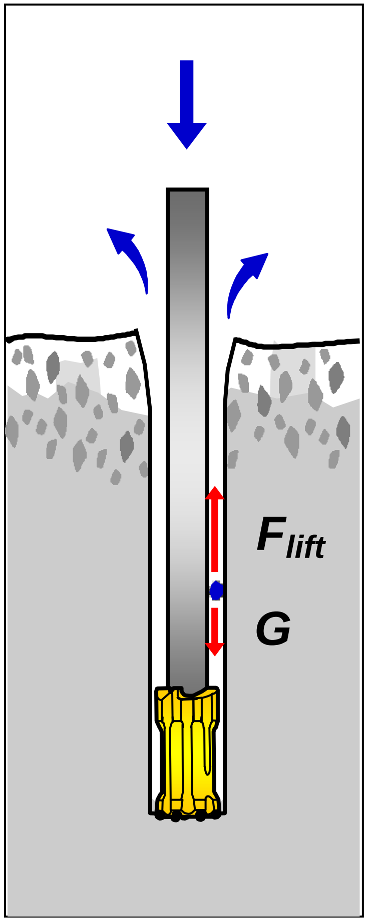
Lift force $F_{lift} = 1/2 \cdot \rho_{air} \cdot v_{air}^{2} \cdot A_{particle} \cdot c_v$

$v_{air} = Q / A$

$c_v = 0.3$ *for spheres*

Gravity $G = \rho_{particle} \cdot V_{particle} \cdot g$

Return air velocity profile:
- **highest along hole wall**
- **lowest along drill string**



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Flushing of drill-cuttings

Insufficient air < 50 ft/s

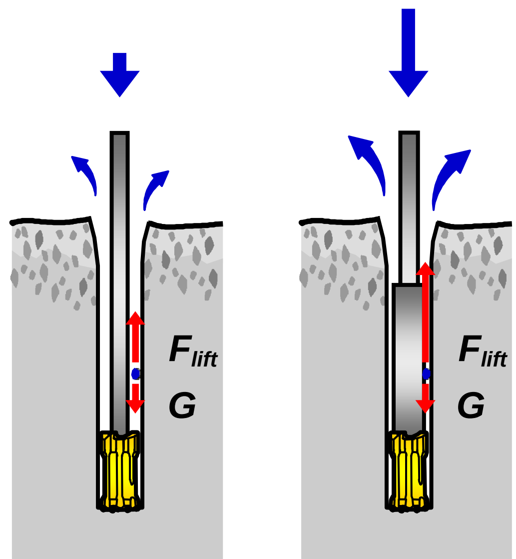
- ***low bit penetration rates***
- ***poor percussion dynamics***
- ***interupt drilling to clean holes***
- ***plugged bit flushing holes***
- ***stuck drill steel***
- ***"circulating" big chip wear***

Too much air > 100 ft/s

- ***excessive drill steel wear***
- ***erosion of hole collar***
- ***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***



Collar erosion – stabilisation

With water injection (or foam)

- ***cleaner collars***
- ***no loose stones***
- ***holes easy to charge***

No water injection

- ***loose stones can make holes "unchargeable" – requiring redrilling***
- ***problems increase with water saturation and thickness of prior sub-drill zone***
- ***drill-hole deviation starts with poor collaring***

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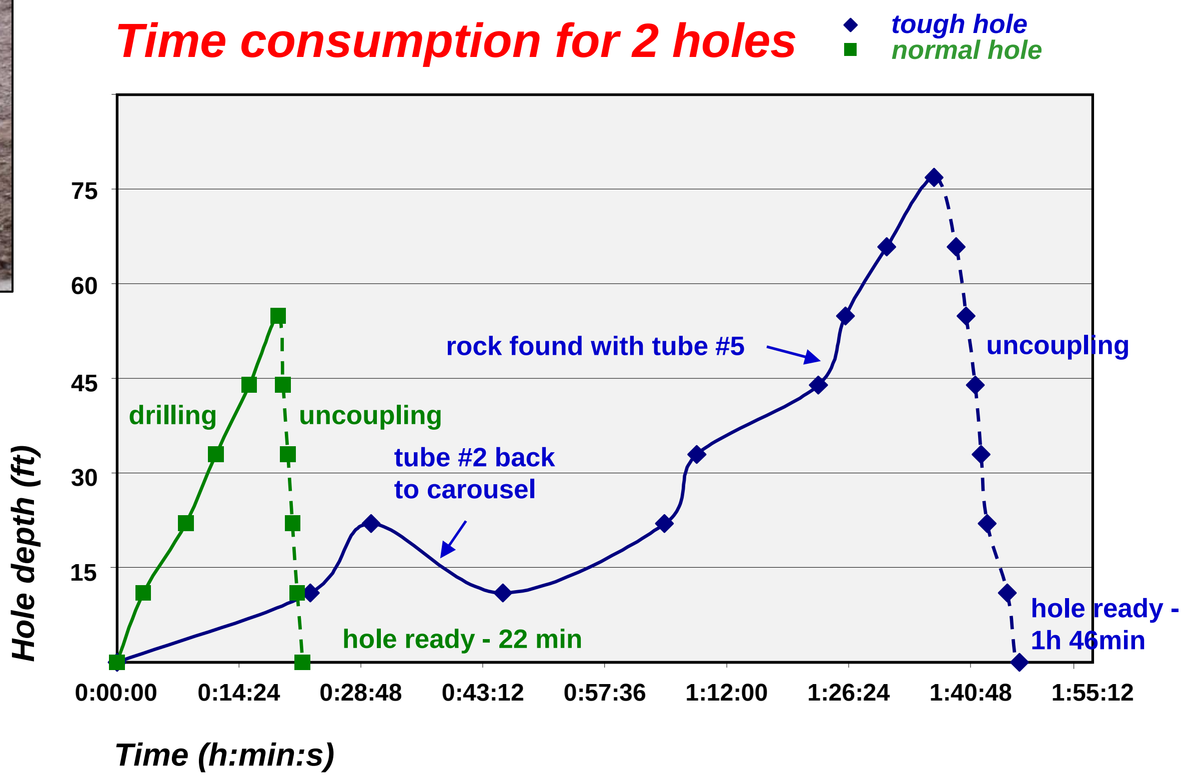
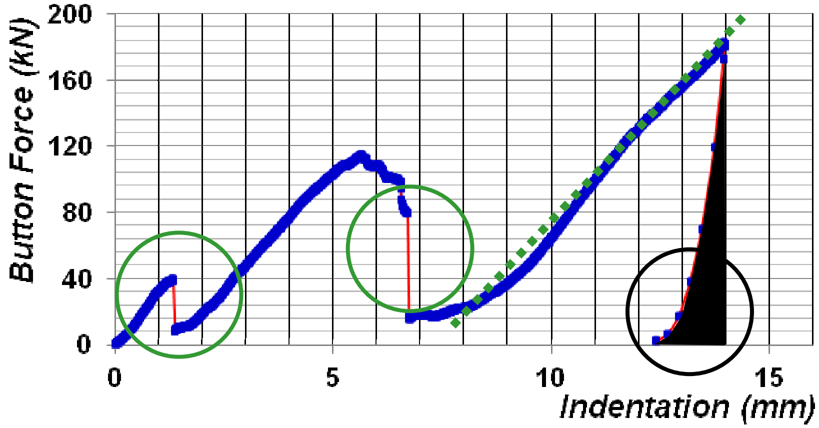
Foam flushing – an aid for drilling in caving material

Burst of inhole water



Indentation with multiple chipping



k_1 = 30 kN/mm for on-loading

k_2 = 112.5 kN/mm for off-loading

$\gamma = k_1 / k_2 = 0.27$

chipping while on-loading

chipping after off-loading

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

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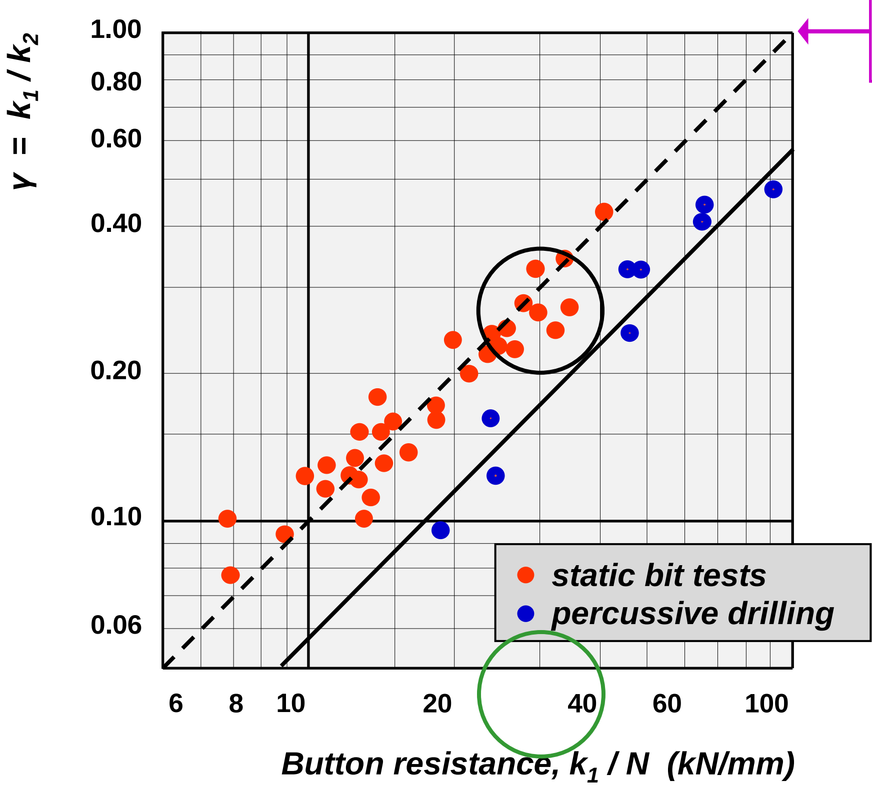
Energy transfer efficiency η related to rock chipping



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

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

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

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

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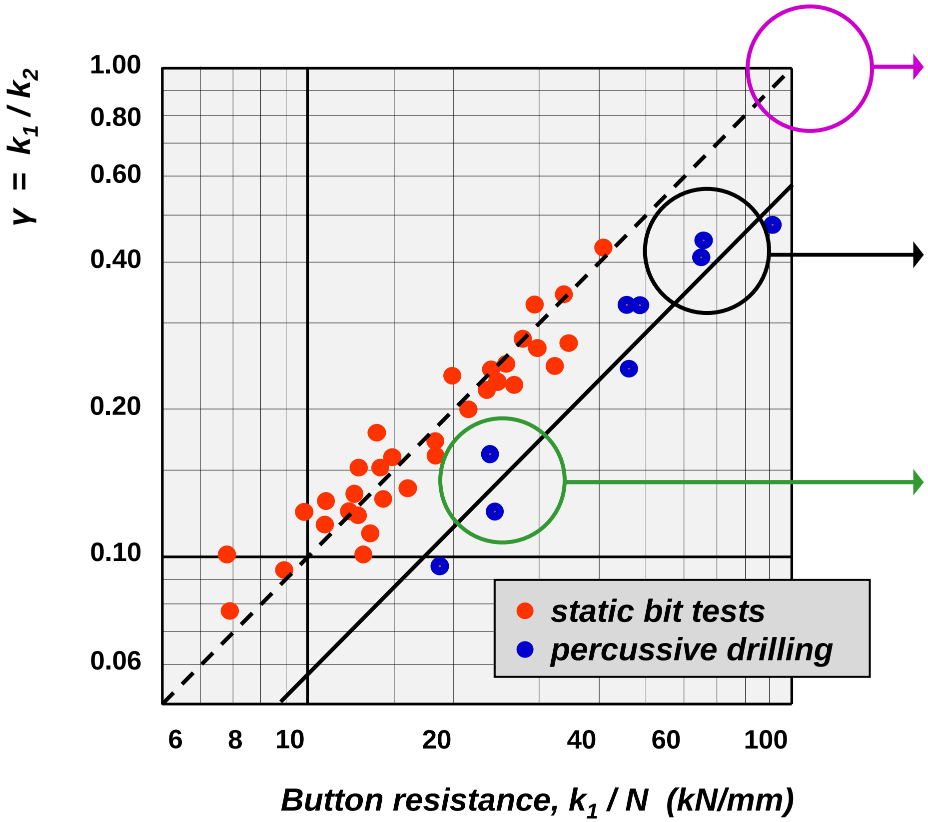
How does this apply to practical drilling?

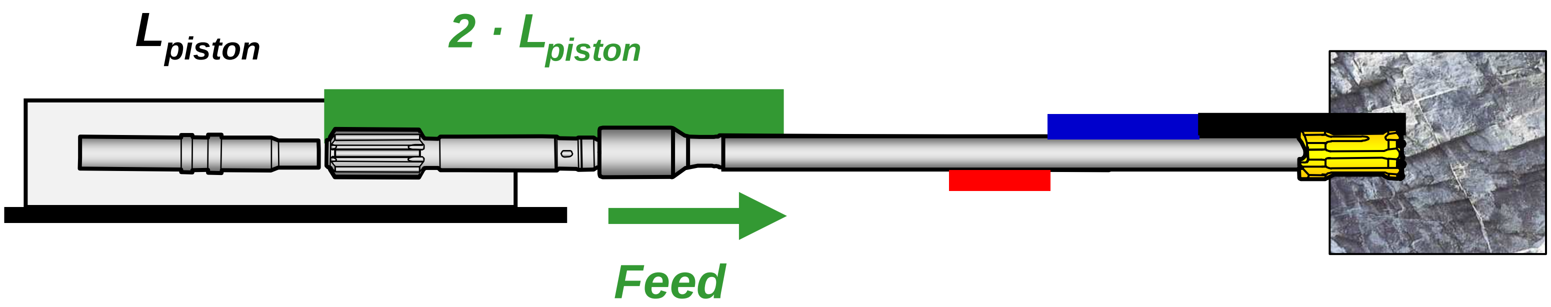


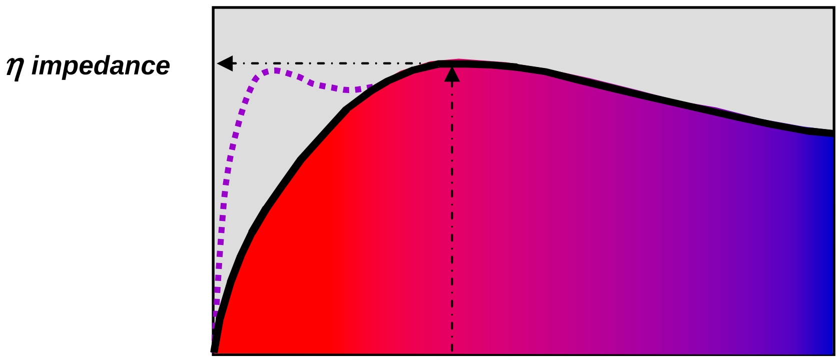
"Hopeless" drilling situation
- no bit advance rate for γ = 1.0

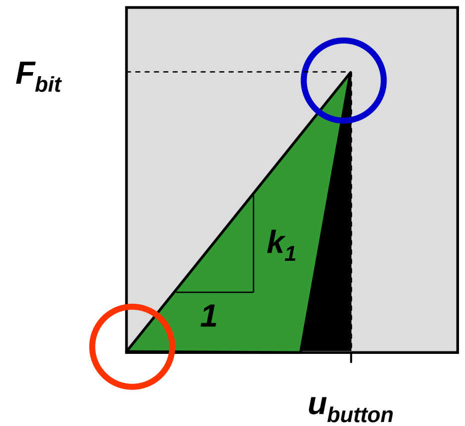
"Poor" drilling situation
- chipping after off-loading
- potential for severely reduced drill steel life
- correct choice of bit design and size?
- sufficient bit regrinding (resharpening)?

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

Energy transfer efficiency η related to impedance matching between bit and drill steel forces







k_1 = indentation resistance of bit (kN/mm)

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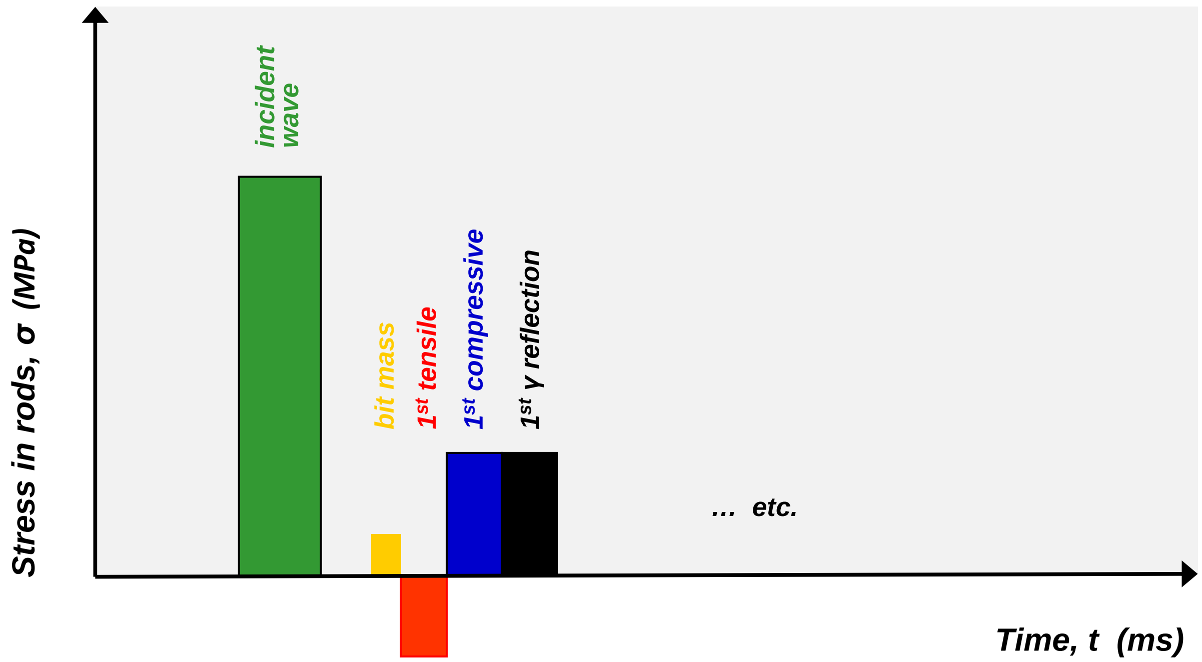
How do we study energy transfer issues?

- ***strain gauge measurements on rods/tubes while drilling***
- ***on-line stress waves measurements by lasers***
- ***numerical modelling***

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



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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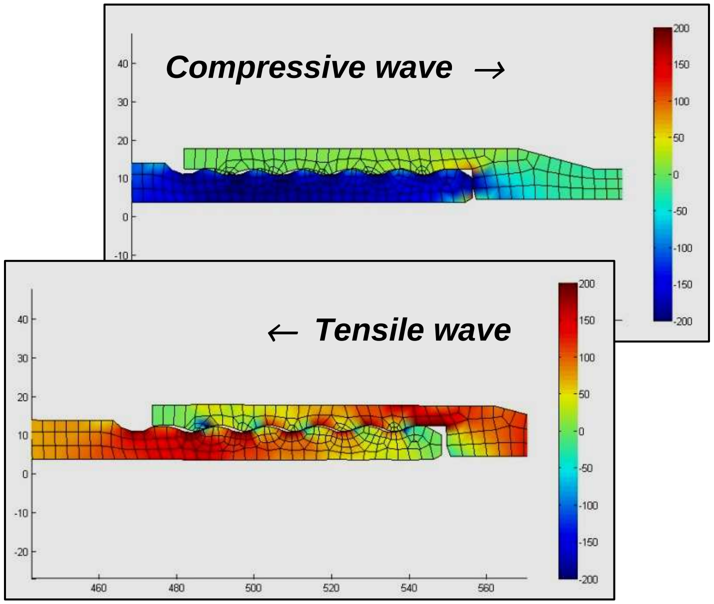
Energy transmission efficiencies are divided into:

- ***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.

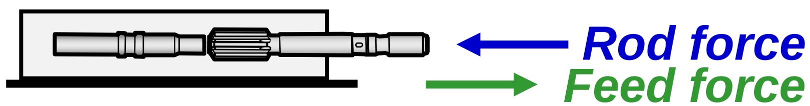
Feed force requirements

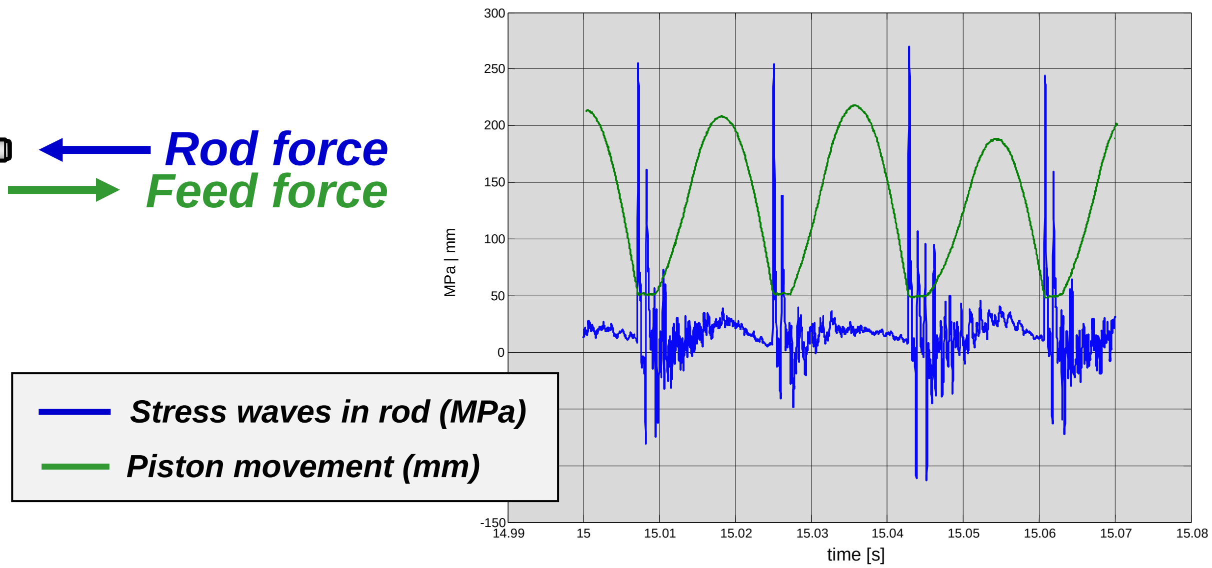
From a drilling point of view

- *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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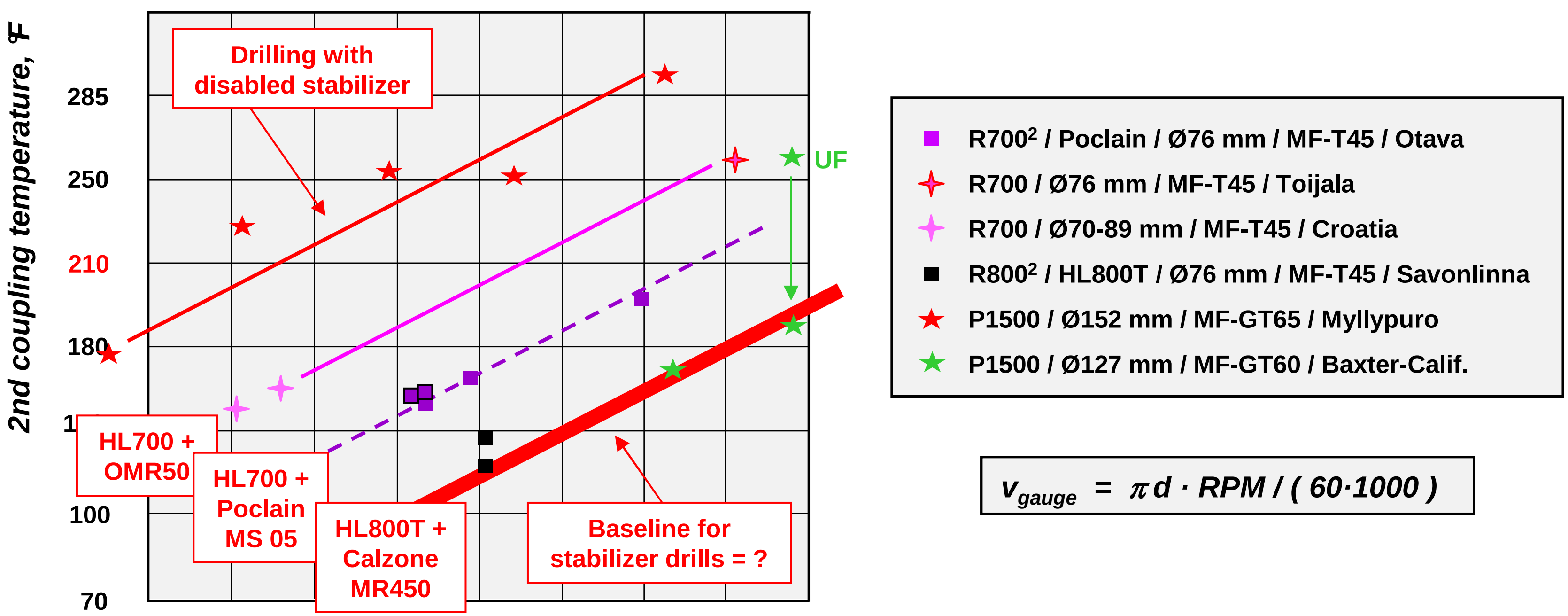
Ranger DX700 and 800 / Pantera DP1500



0.85	1.0	1.2	1.4	1.5	1.7	1.9	2.1	*v_{gauge} (ft/s)*
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 (P_{feed} / $P_{percussion}$)***
  => *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*

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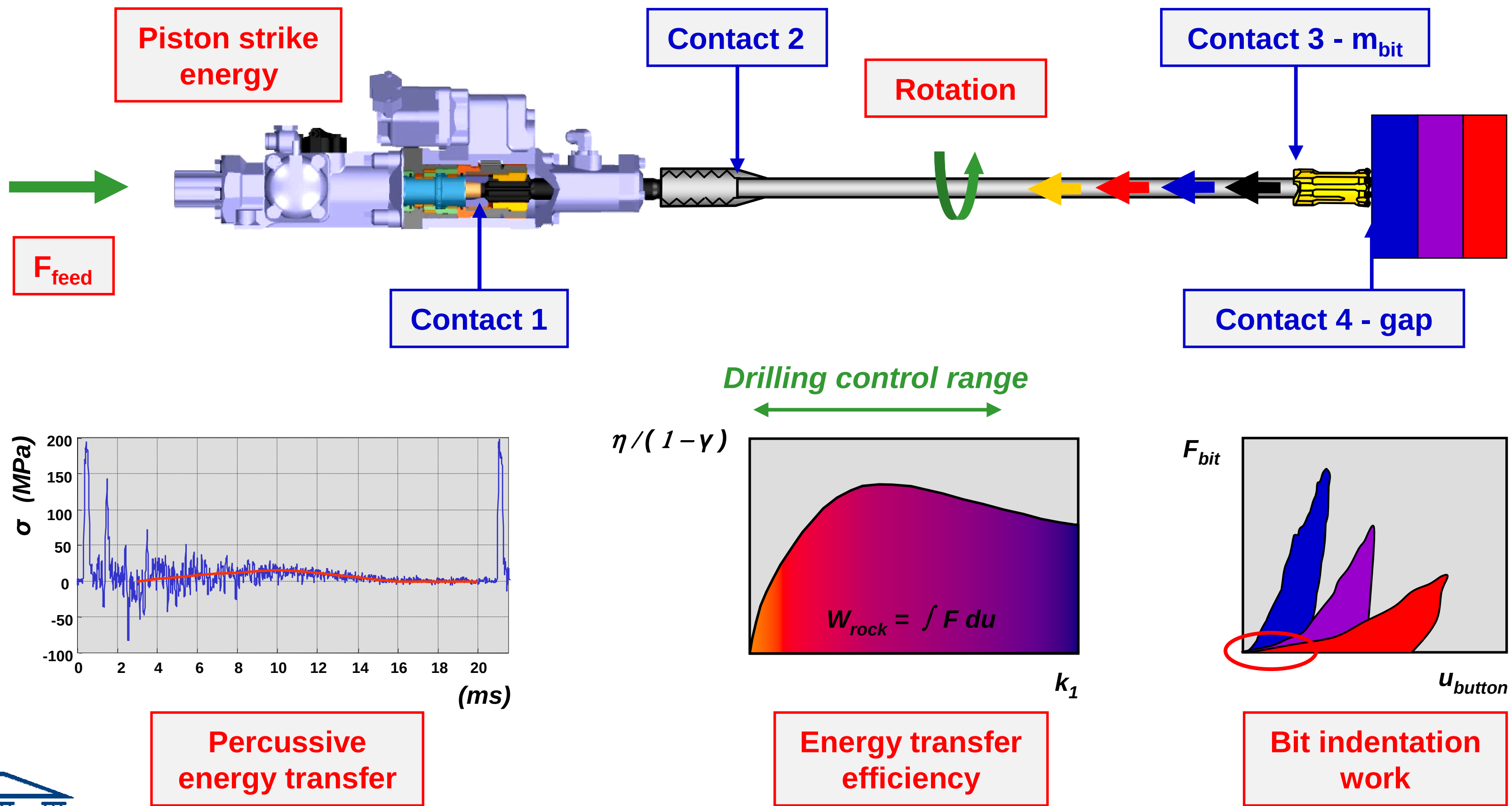
Summary of TH percussion dynamics



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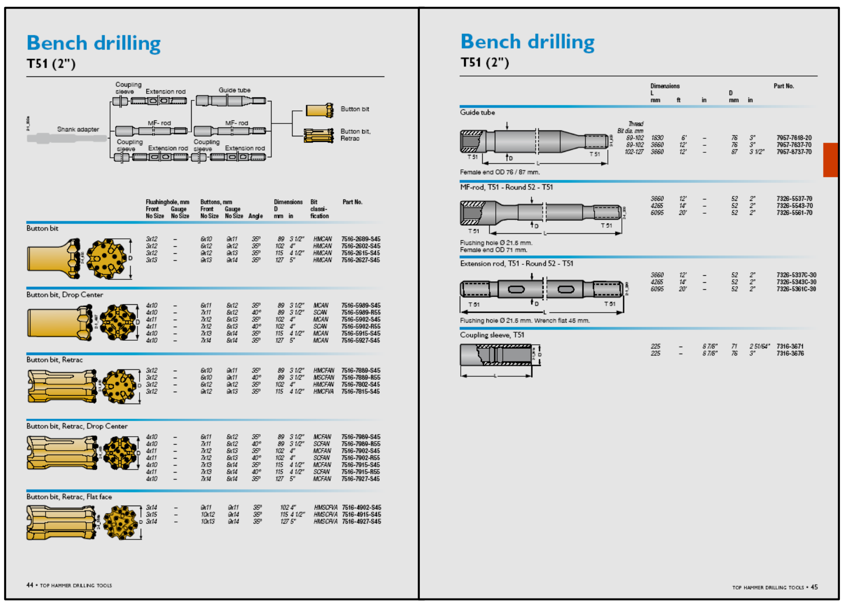
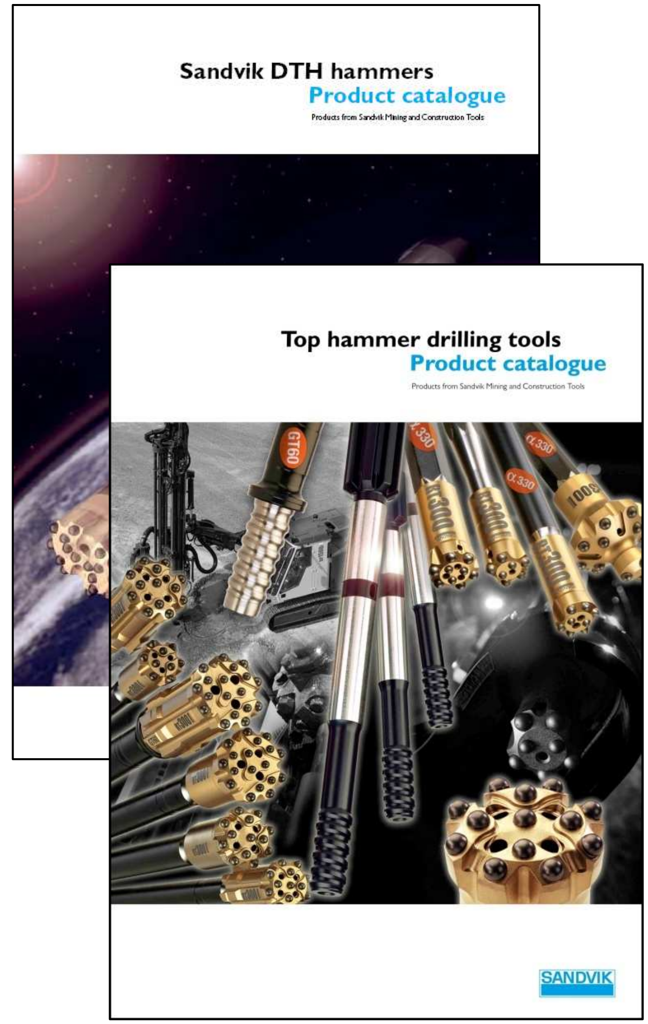
Selecting drilling tools

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





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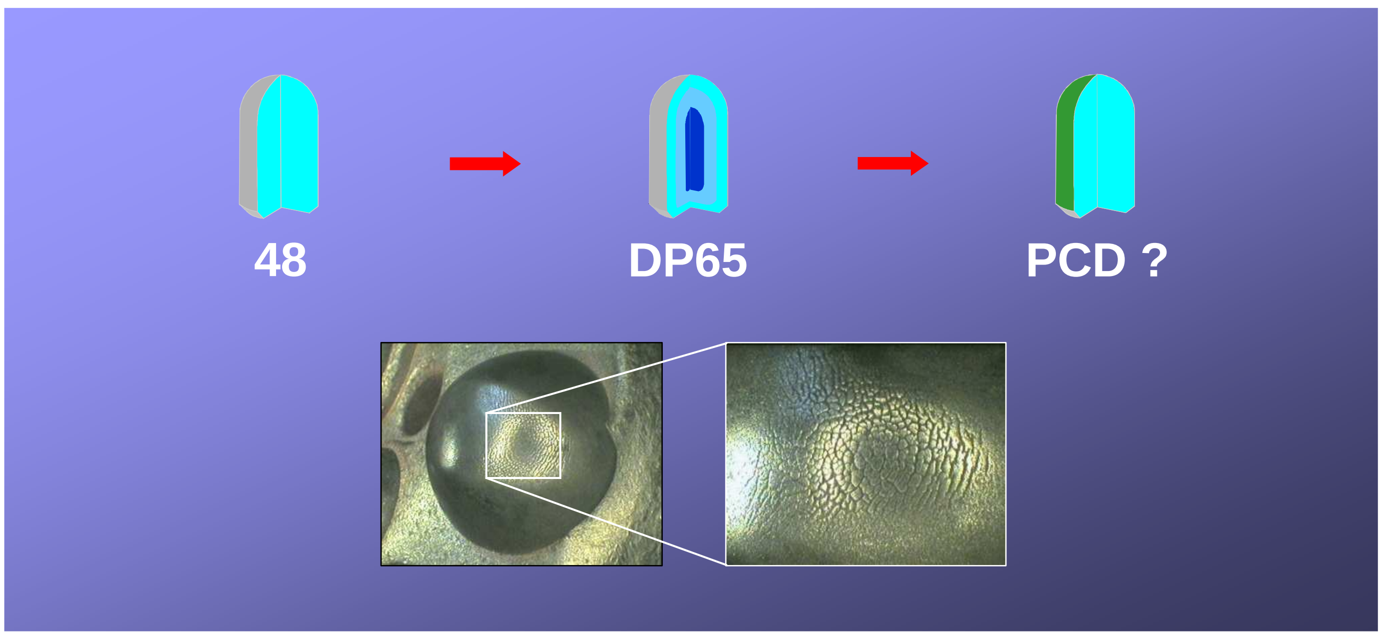
Guidelines for selecting cemented carbide grades

- ***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***



Selecting button shapes and cemented carbide grades

Spherical buttons
DP65

S65

Robust ballistic buttons
48

R48

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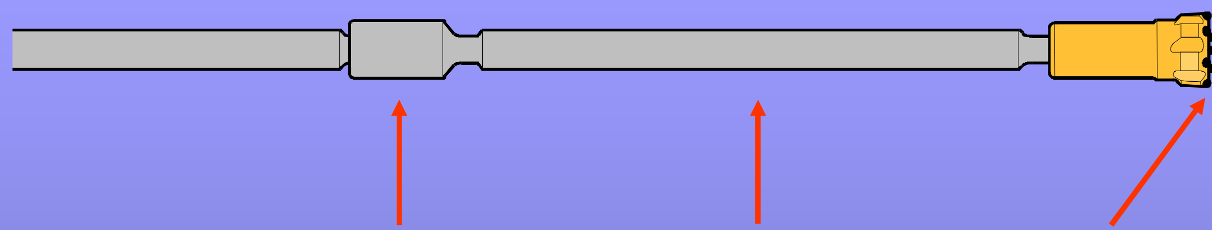
Optimum bit / rod diameter relationship for TH



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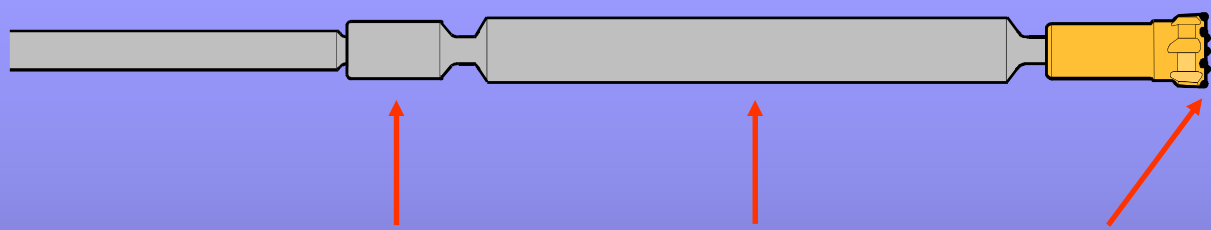
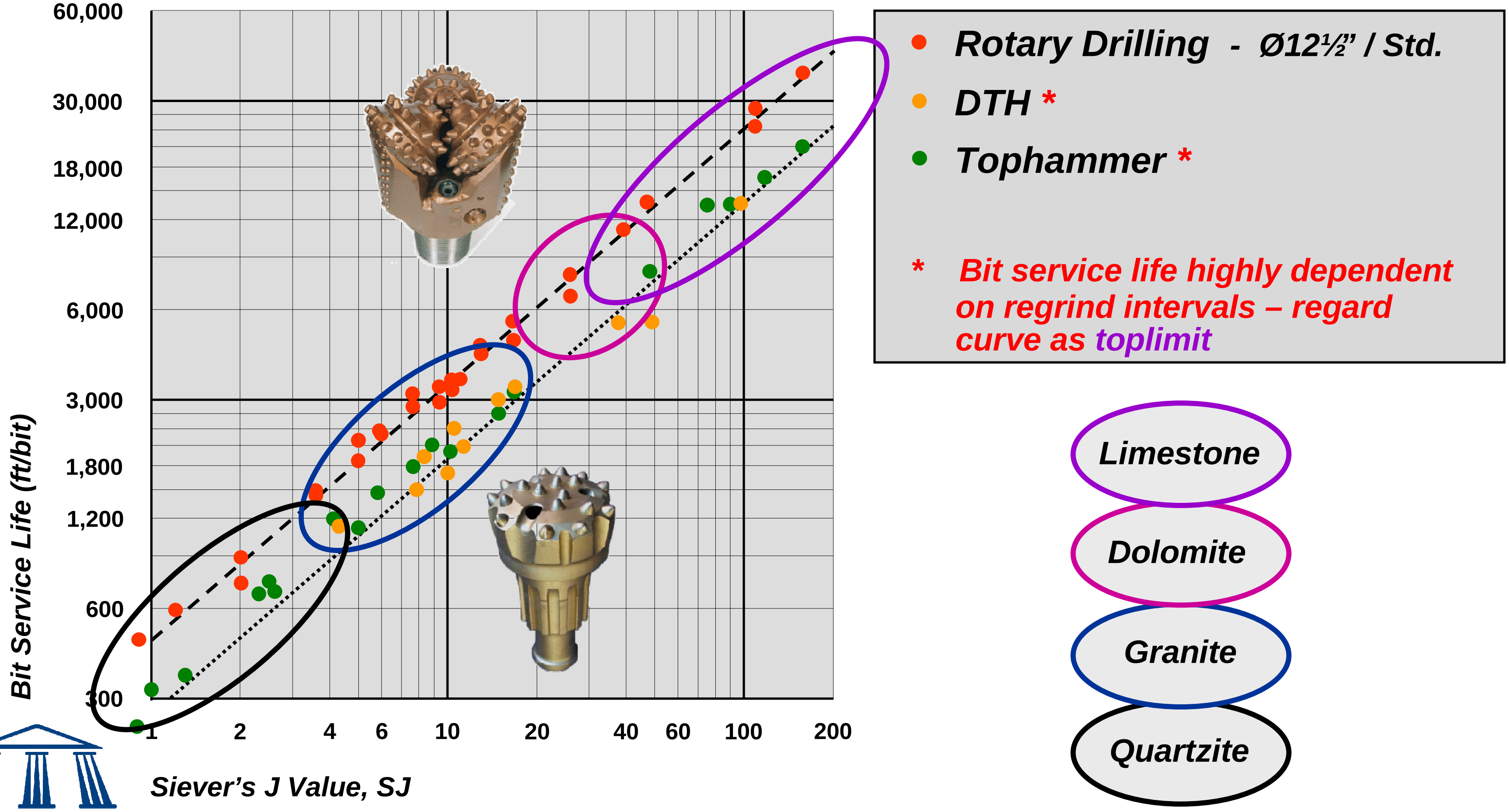
Optimum bit / guide or pilot (lead) tube relationship for TH



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"

Trendlines for bit service life



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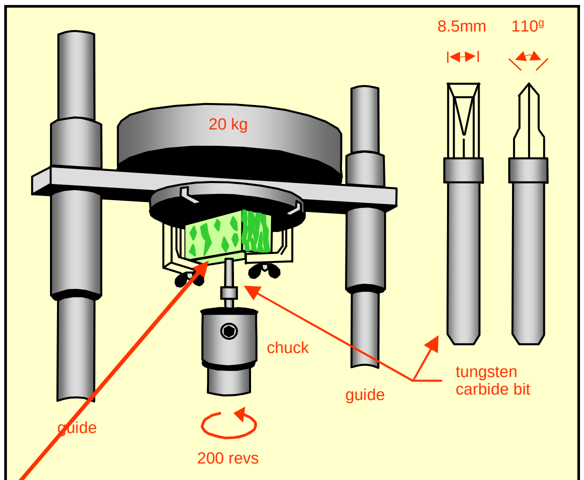
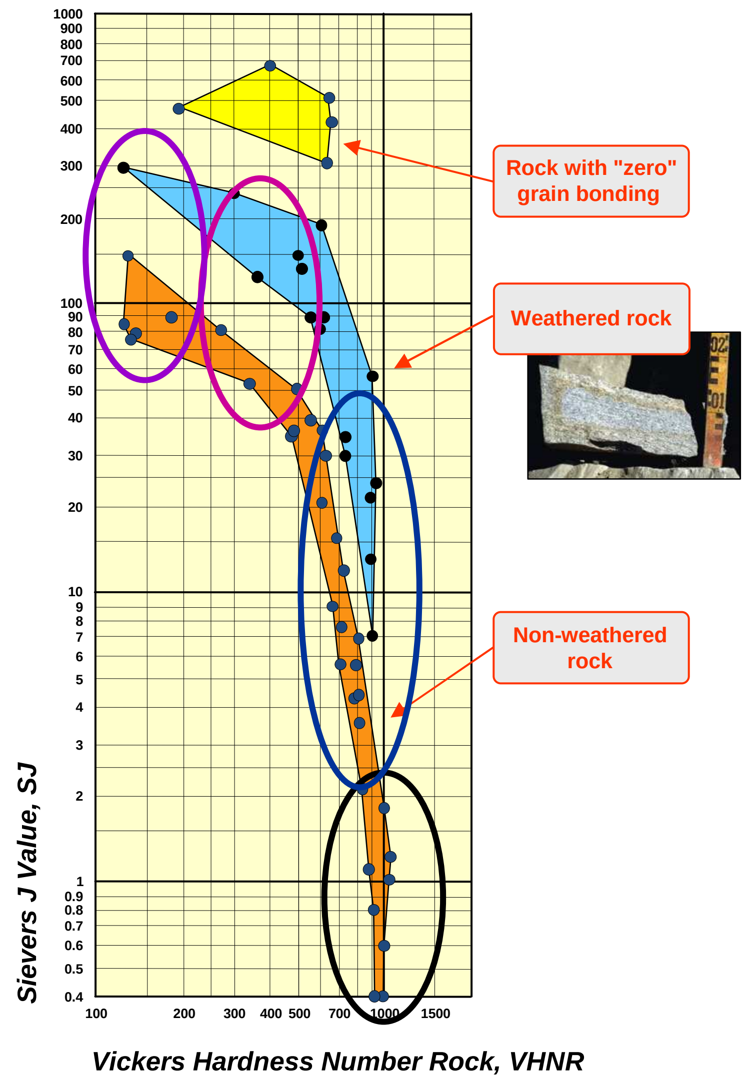
Relationship between SJ and VHNR

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





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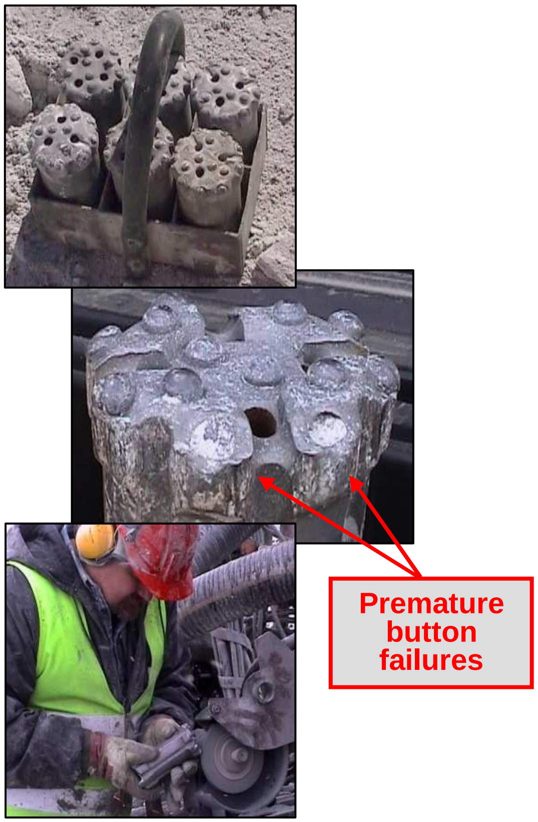
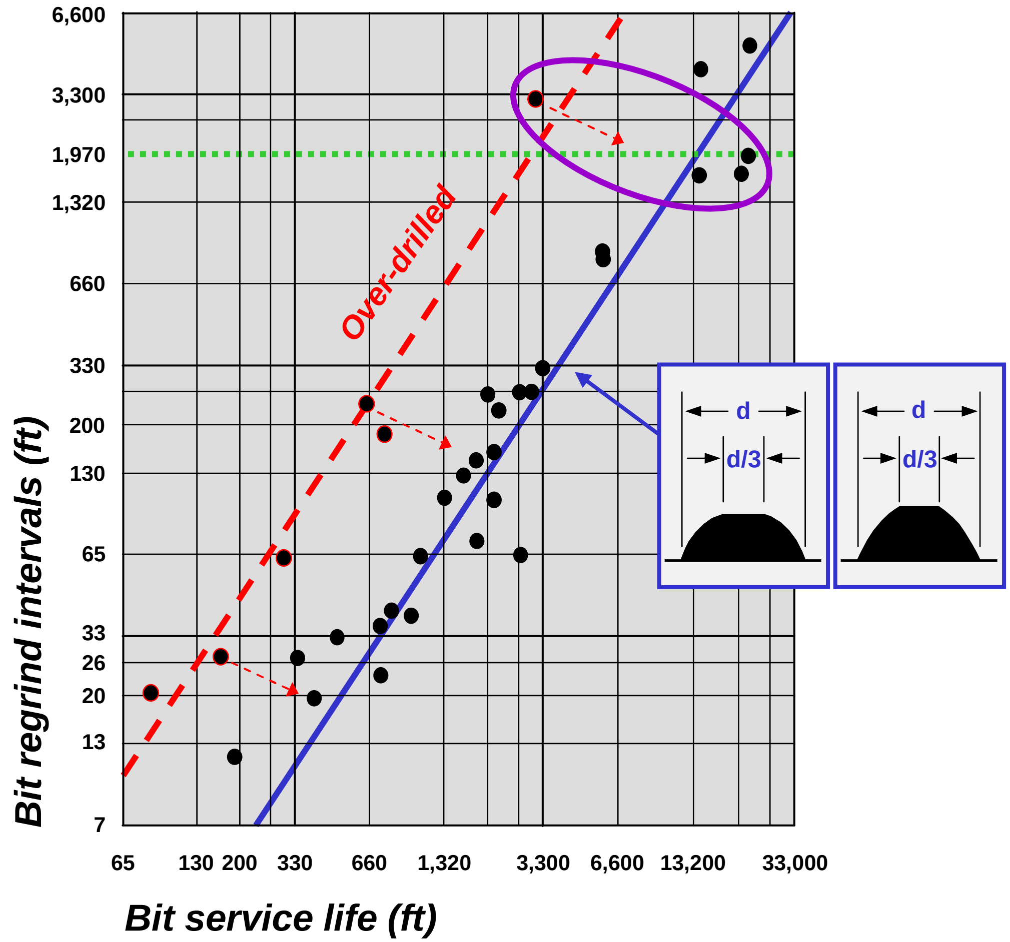
Bit regind intervals, bit service life and over-drilling





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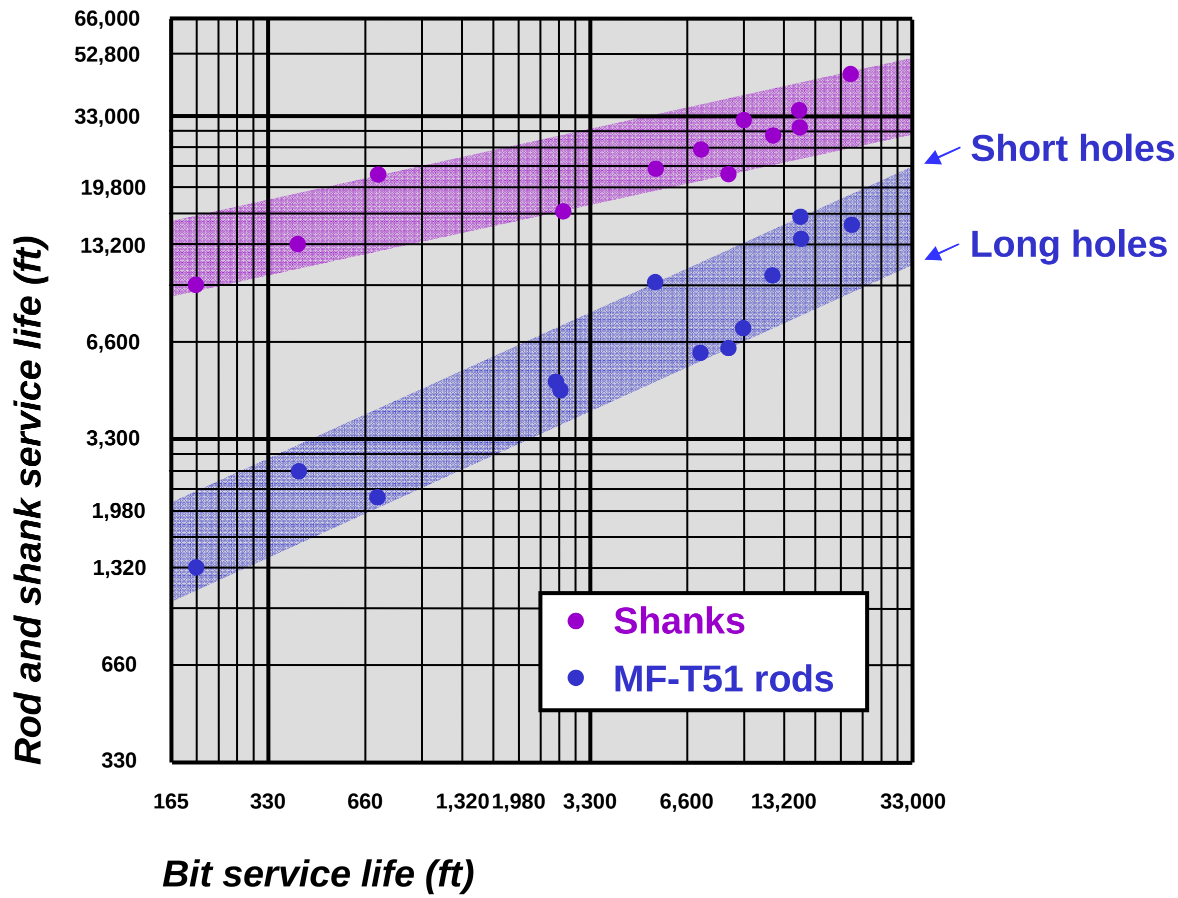
Example of drill steel followup for MF-T51



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Jobsite KPI's for drill steel

- ***drill steel component life***
- ***bit regrind intervals***
- ***bit replacement diameters***
- ***component discard analysis***
- ***cost in $ per dr-ft or yd*** ^{3}

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