

Quiz#2
PETE4313
Spring 2017

Name: Quiz #2 Solution

One ft³ is equal to 7.48 gallons

1. (3) List three main components of the hoisting system.

- a. Drawworks
- b. Travelling block
- c. Crown block

} Did accept some other components!

2. You are drilling a vertical well at a depth of 12,000 ft. The pore pressure at this depth is equal to 0.65 psi/ft. If you are to drill the well with an overbalance of 400 psi at 12,000 ft.

a. (3) What mud weight will you have to use?

$$p_p = 0.65 \times 12,000 = 7800 \text{ psi}$$

$$p_m = 7800 + 400 = 8200 \text{ psi}$$

$$\rho_{\text{mud}} = \frac{8200}{0.052 \times 12,000} = 13.14 \text{ ppg}$$

3. A drill bit which costs \$20,000 drilled from 7,000 ft to 8,500 ft with an average rate of penetration (ROP) of 10 ft/hr. The connection time is 5 min per 30 ft connection, the tripping time is 1 hr/1000 ft and the rig rate is 80,000 \$/day.

a. (4) What is the \$/ft for this bit run?

$$t_{\text{con}} = (8,500 - 7,000) \text{ ft} \left(\frac{5 \text{ min}}{30 \text{ ft}} \right) = 250 \text{ min} = 4.17 \text{ hrs}$$

$$t_{\text{trip}} = (7,000 + 8,500) \text{ ft} \frac{1 \text{ hr}}{1000 \text{ ft}} = 15.5 \text{ hrs}$$

$$t_{\text{rot}} = \frac{(8,500 - 7,000) \text{ ft}}{10 \text{ ft/hr}} = 150 \text{ hrs}$$

$$C_{\text{rig}} = \frac{\$80,000}{24 \text{ hr}} = 3,333 \text{ $/hr}$$

$$C = \frac{(4.17 + 15.5 + 150)(3,333) + 20,000}{(8,500 - 7,000)} = 390.4 \text{ $/ft}$$

PETE 4313

Handout #4

Drilling Bits - Drag Bits

Quiz#3 – Thursday, February 16
(From Quiz#1 and #2 – similar - understand the concepts!)

Homework #4 - Due February 21
Problem #1.24, WOB problem at the end of this handout

Read: *ADE, Ch.5 (bits)*



Contents

- The Ideal Bit
- Drag Bits
 - Fishtail Type
 - Natural Diamond
 - Polycrystalline Diamond Compact (PDC)
- Relative Costs of Bits



Rotary Drill Bits

The purpose of Chapter 5 (ADE) is to introduce the student to the:

- **different** types of drill bits
- **selection** and
- **operation** of rotary drilling bits.

➤ ***Read: ADE, Ch.5 (bits)***



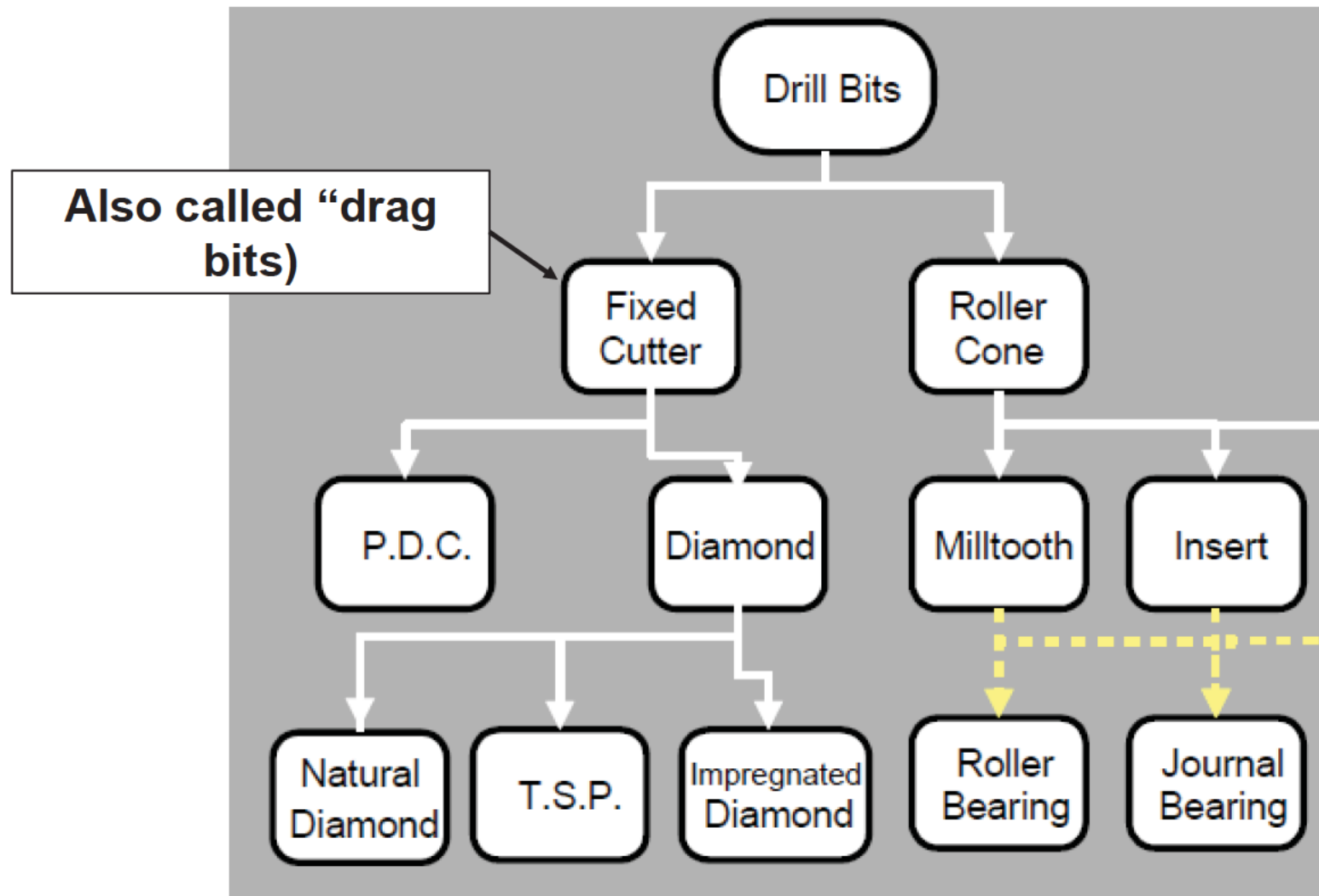
Bit Types Available

- **Drag bits** (fixed cutter blades)
 - Fishtail bit
 - Natural diamond bits
 - PDC Bits (Polycrystalline Diamond Compact)

- **Rolling cutter bits** (rock bits - with cones)
 - Mill tooth bits
 - Tungsten carbide bits



Drill Bit Classification



<https://www.youtube.com/watch?v=4gbI0wDUj0U> (3 Min)

General Tricone and PDC

Commonly Used Bit Sizes For Running Casing

Casing Size (OD in.)	Coupling Size (OD in.)	Common Bit Sizes Used (in.)
4 1/2	5.0	6, 6 1/8, 6 1/4
5	5.563	6 1/2, 6 3/4
5 1/2	6.050	7 7/8, 8 3/8
6	6.625	7 7/8, 8 3/8, 8 1/2
6 5/8	7.390	8 1/2, 8 5/8, 8 3/4
7	7.656	8 5/8, 8 3/4, 9 1/2
7 5/8	8.500	9 7/8, 10 5/8, 11
8 5/8	9.625	11, 12 1/4
9 5/8	10.625	12 1/4, 14 3/4
10 3/4	11.750	15
13 3/8	14.375	17 1/2
16	17	20
20	21	24, 26

The Ideal Bit *

1. High drilling rate
2. Long life
3. Drill full-gauge, straight hole
4. Moderate cost

*** (Low cost per ft drilled)**



The Ideal Bit

“The Ideal Bit” will depend on the type of formation to be drilled

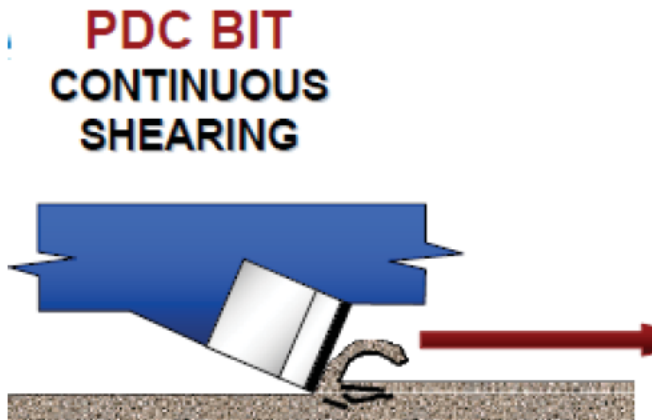
- Hardness (soft, medium, hard)
- Abrasiveness
- Cuttings stickiness (bit balling?)
- Other considerations ... e.g. cost



Bit Failure Mechanisms

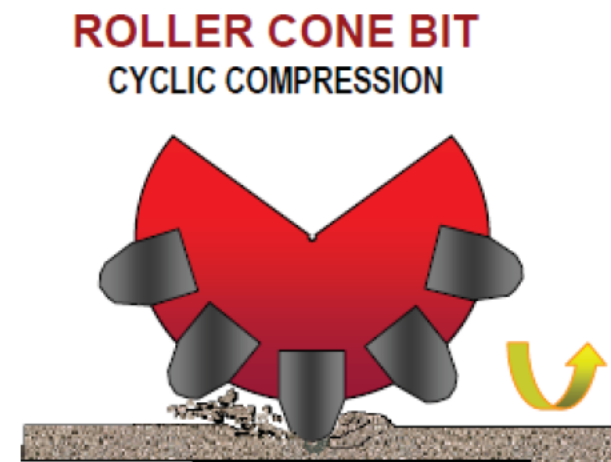
Shear Failure

- PDC cutters are used to shear the rock with continuous scraping motion
- Shear/gouging failure will also occur when using aggressive roller cone bits due to cone offsets



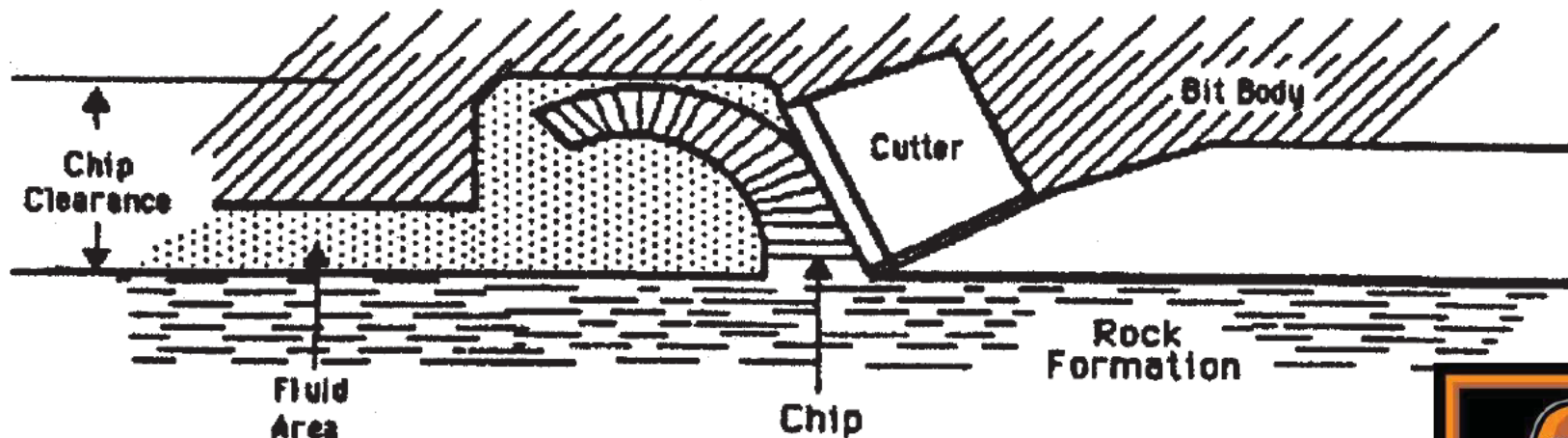
Compressive Failure

- Rollercones are mainly designed to crush the rock
- Compressive failure might occur when using a dull PDC



Drag Bits

Drag bits drill by physically “plowing” or “machining” cuttings from the bottom of the hole.



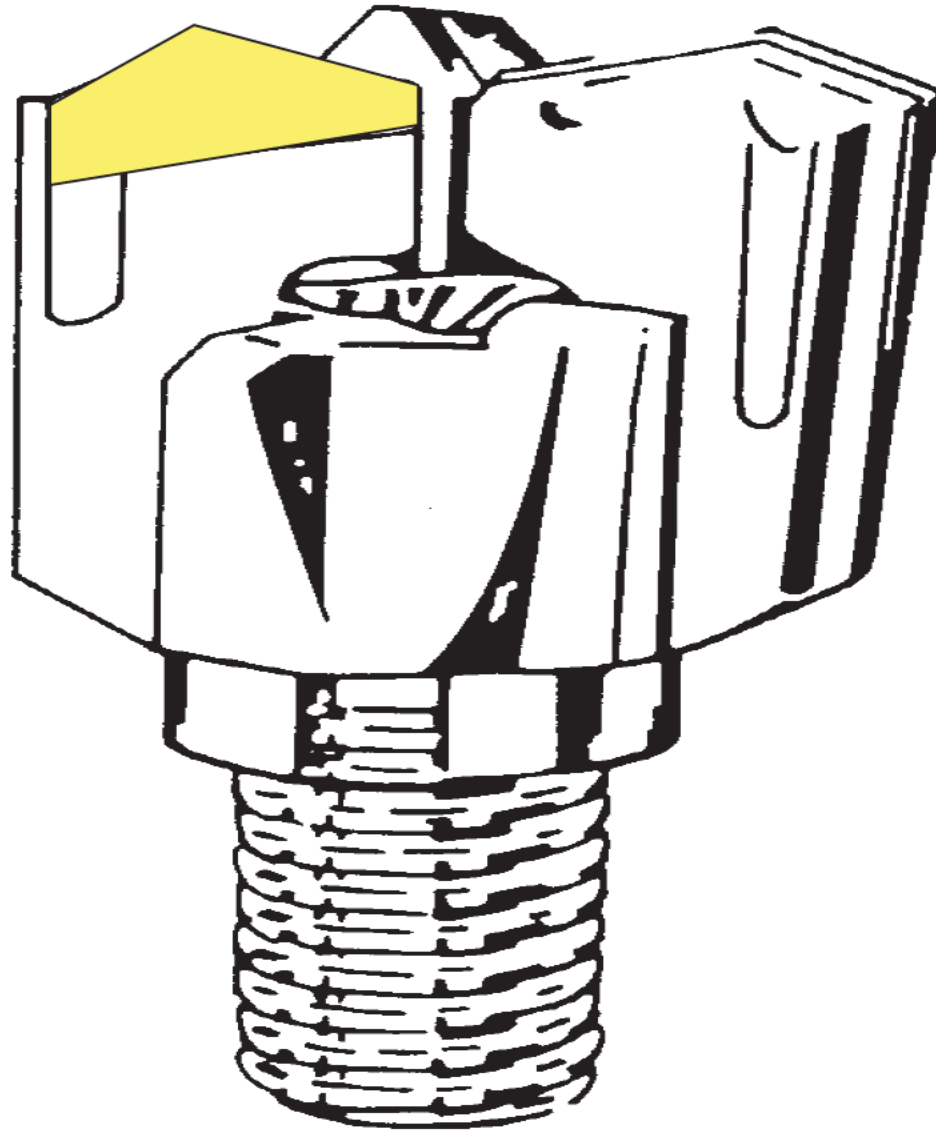
Drag Bits

Cutter may be made from:

- Steel
- Tungsten carbide
- Natural diamonds
- Polycrystalline diamonds (PDC)

Drag bits have no moving parts, so it is less likely
that junk will be left in the hole!





Fishtail type drag bit



Most Common Drag Bits



Natural Diamond Bits

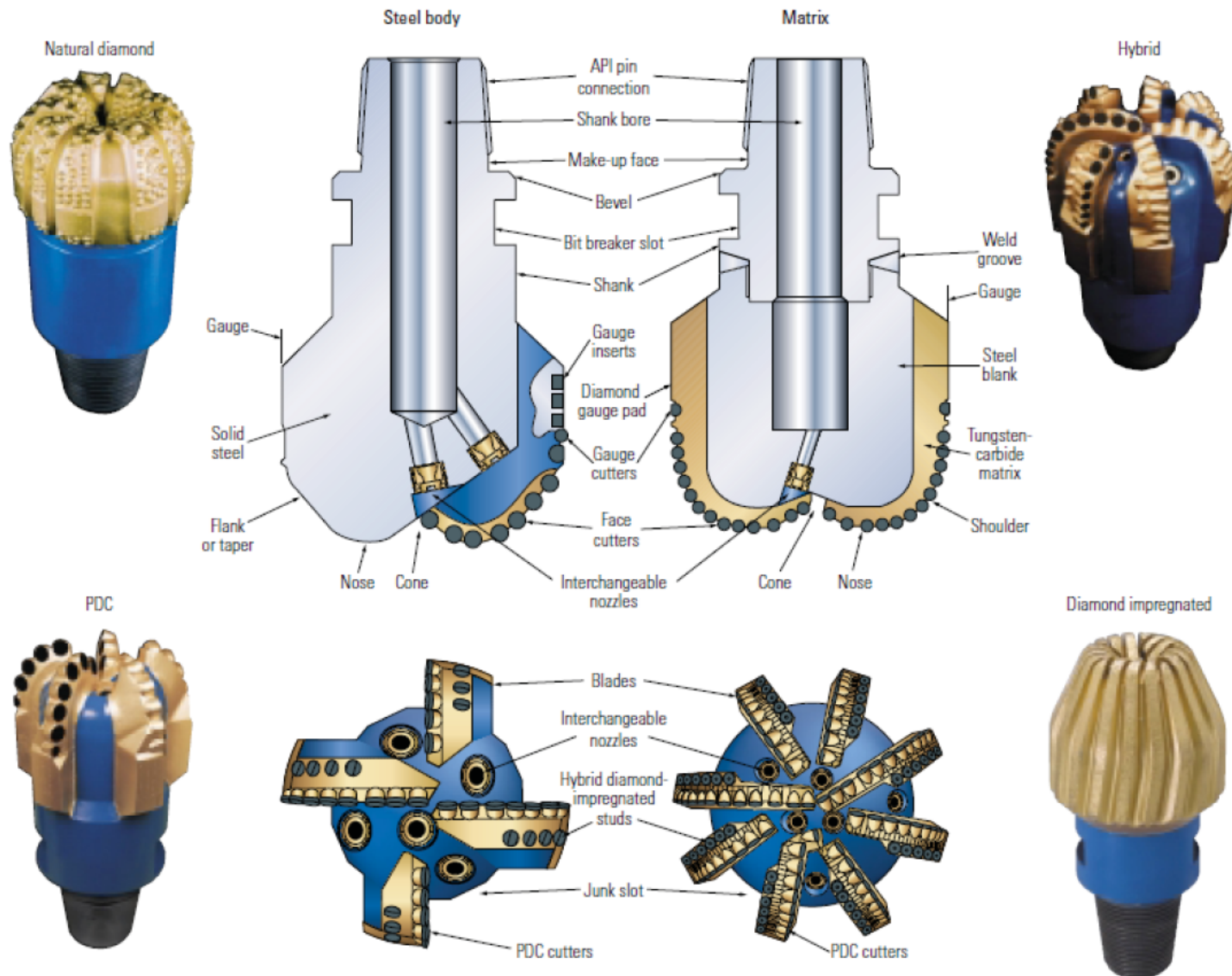


PDC Bits

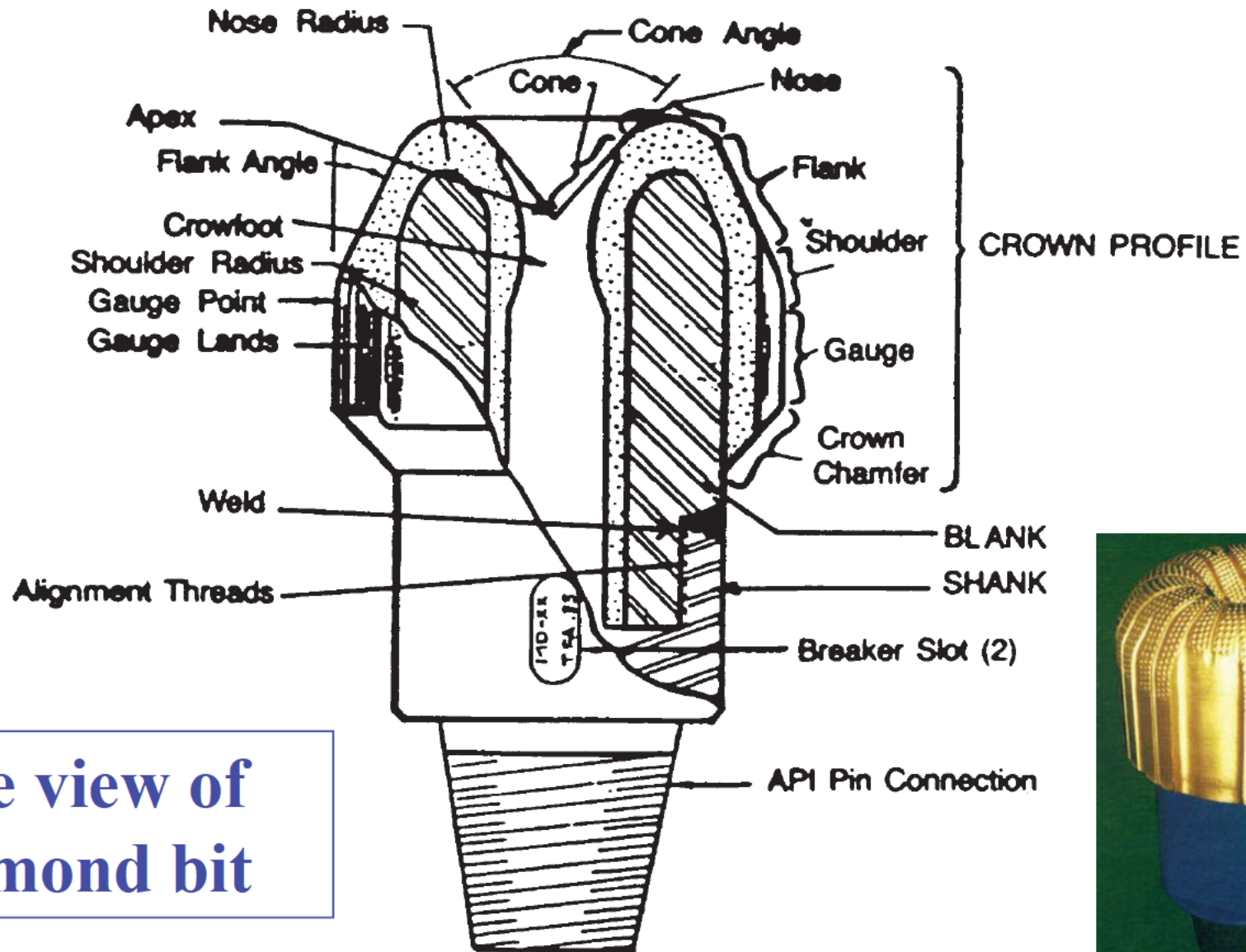


Drag Bits

Fixed-Cutter Bit Types



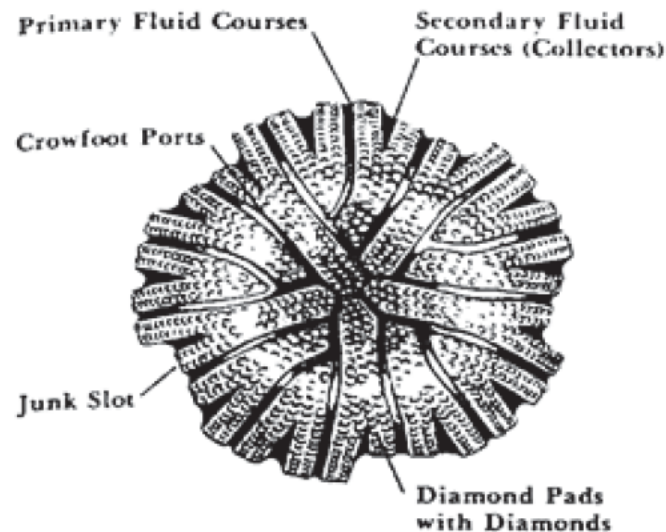
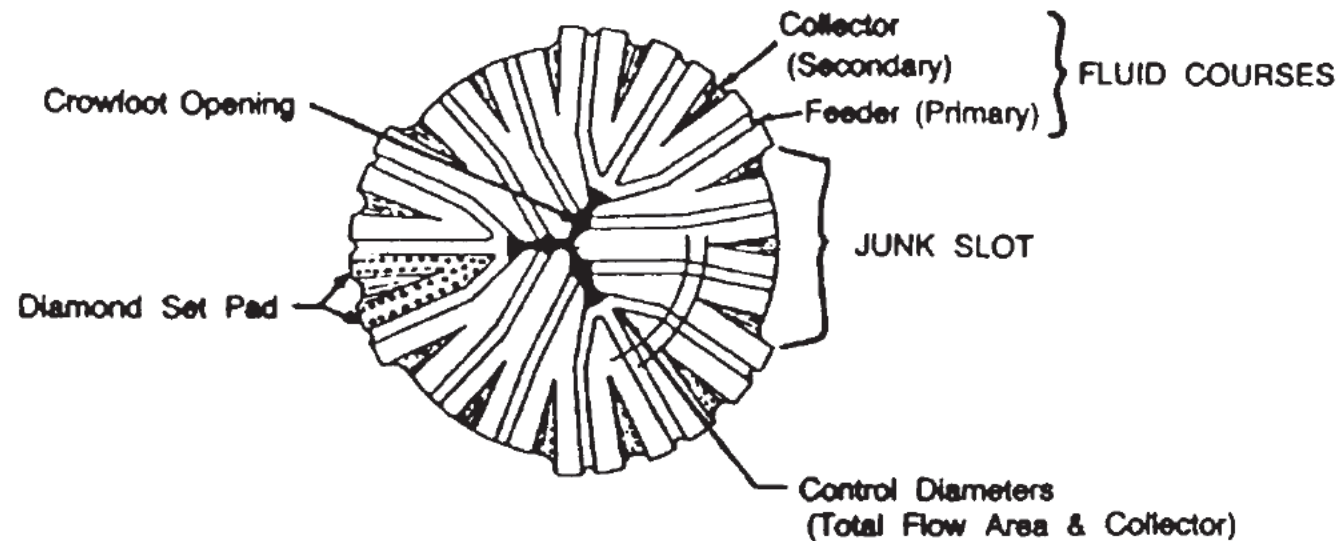
Natural Diamond Bits



Side view of
diamond bit

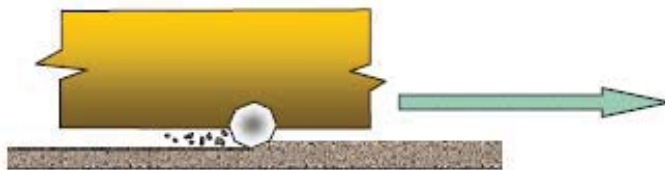


Top view of diamond bit



Diamond Bit - Compressive and Shear Cutting Mechanism

- Shear/Compressive Failure



Diamond Bit
CONTINUOUS
CRUSHING & ABRASION



Natural diamond

- Natural Diamonds
 - Size
 - Shape
 - Quality



Today we use most industrial “man made” diamonds

Natural Diamonds

The size and spacing of diamonds on a bit determine its use.

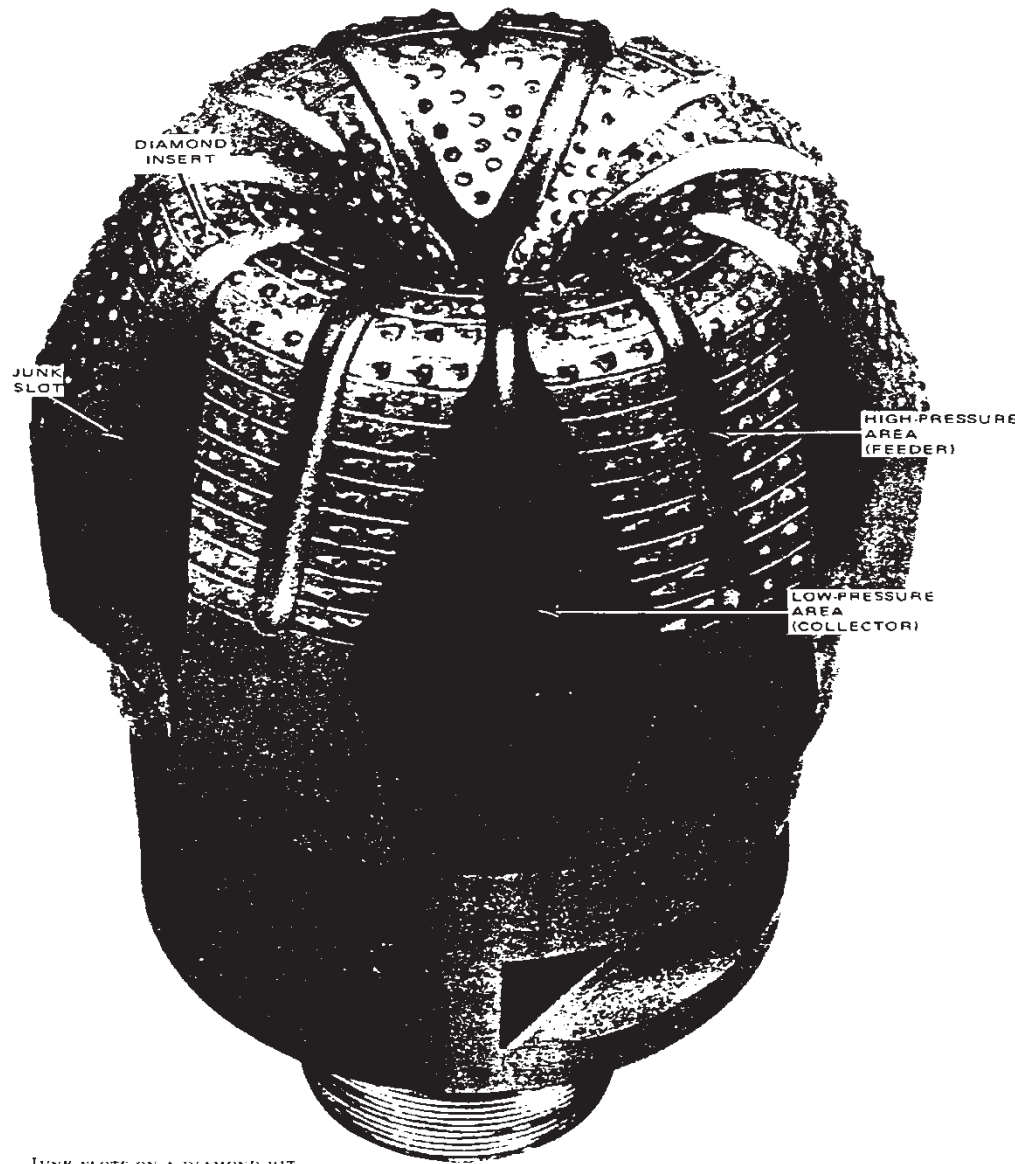
NOTE: One carat = 200 mg ← precious stones



Natural Diamonds

- **1-3 carats** - widely spaced diamonds are used for drilling **soft** formations such as soft sand and shale
- **1/4 - 1 carat** - diamonds are used for drilling sand, shale and limestone formations of varying (**intermediate**) hardness.
- **1/8 - 1/4 carat** - diamonds, closely spaced, are used in **hard and abrasive** formations.





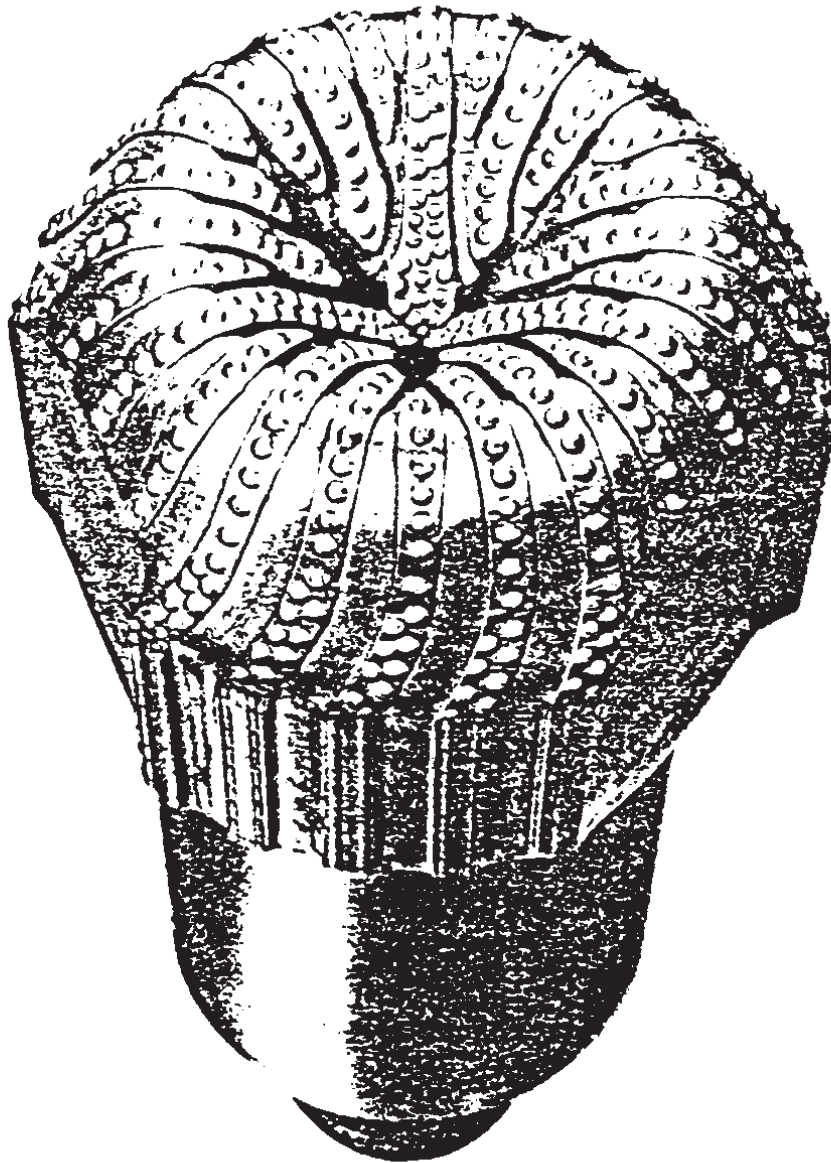
JUNK SLOTS ON A DIAMOND BIT

COURTESY OF AMERICAN COLIDSET CORPORATION

Natural Diamond bit

junk slot
cuttings
radial flow

high Δp
across face!!

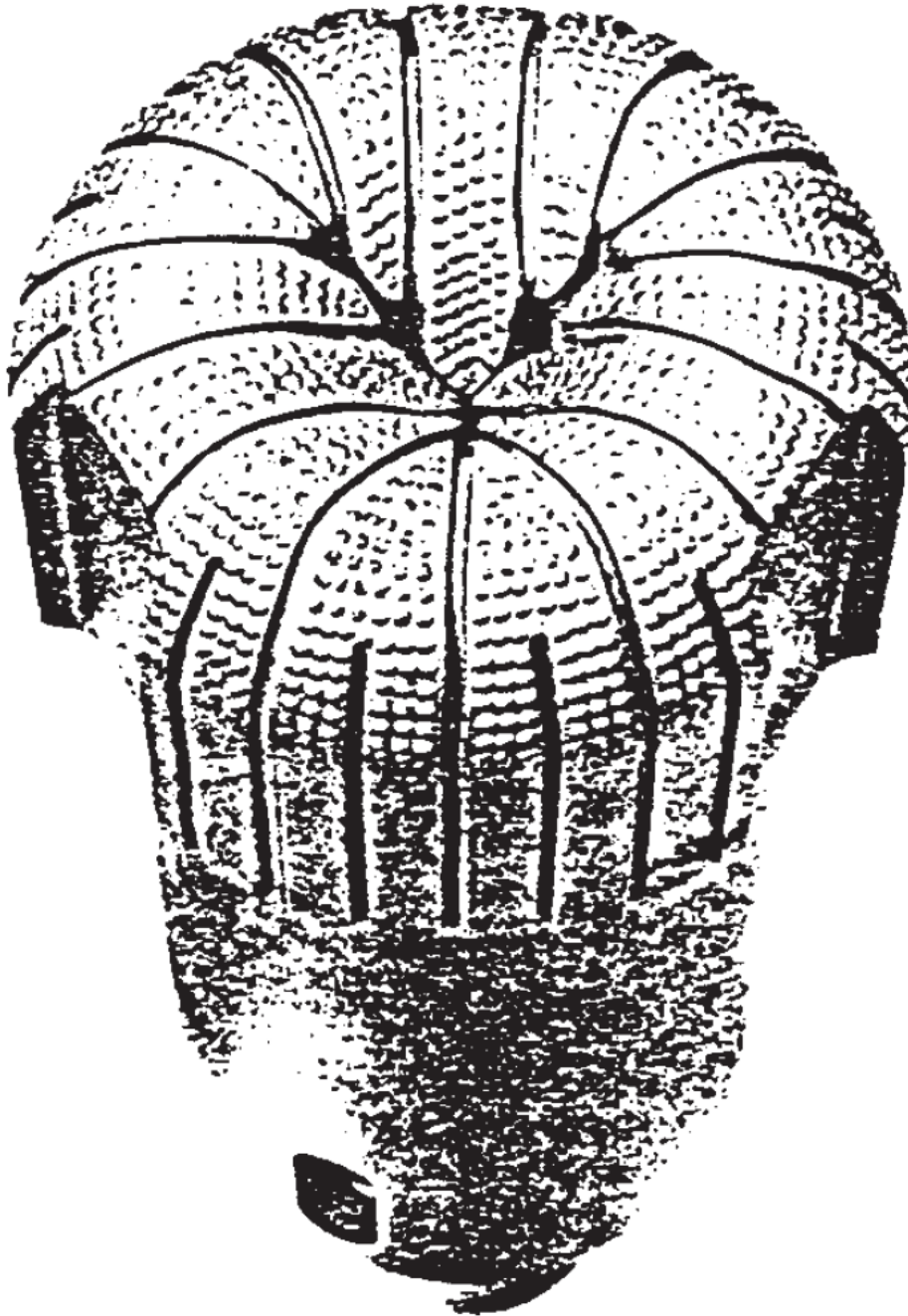


SOFT-FORMATION DIAMOND BIT

COURTESY OF NL HYCALOG

Soft Formation Diamond bit

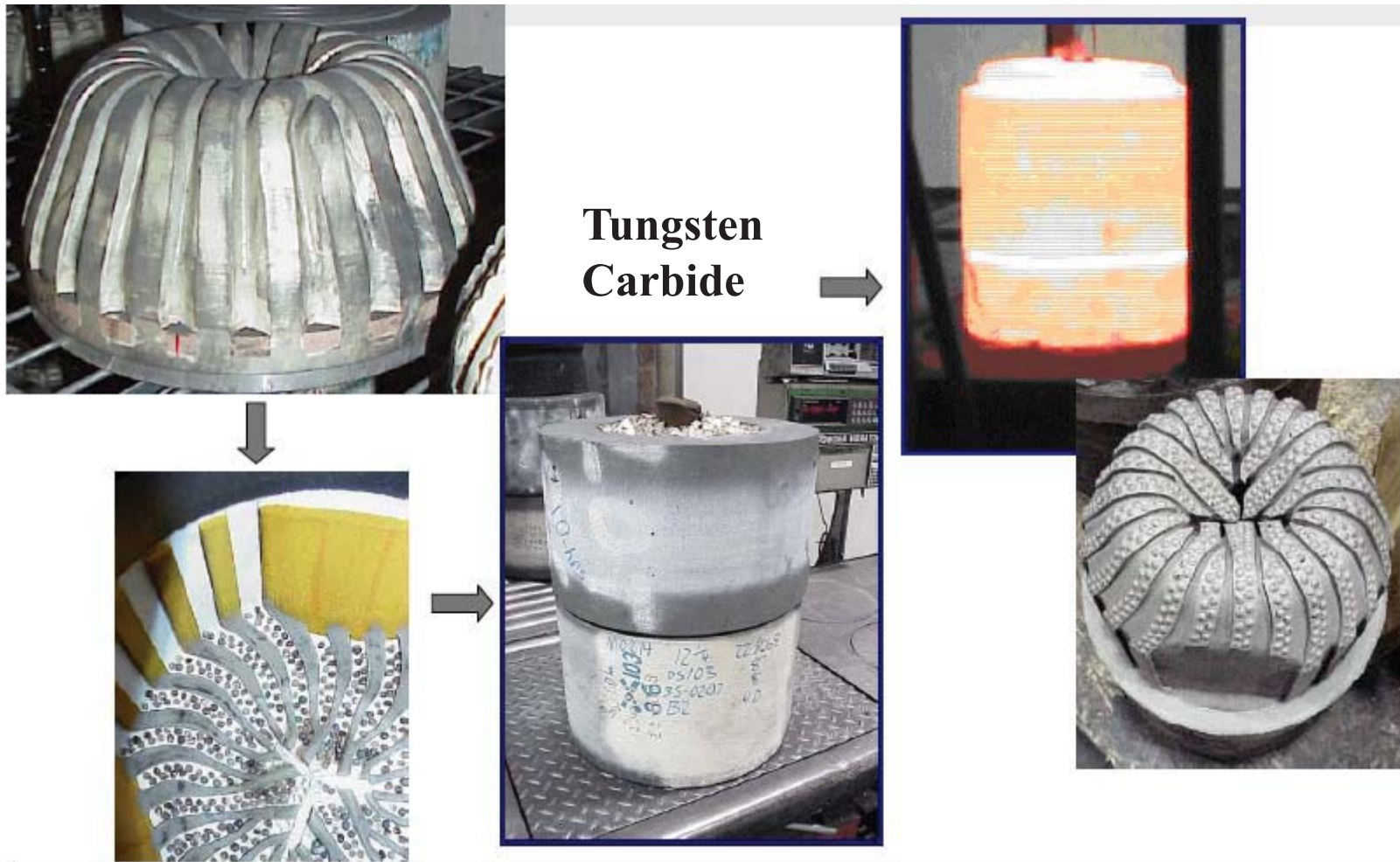
- Larger diamonds
- Fewer diamonds
- Pointed nose



Hard Formation Diamond bit

- **Smaller diamonds**
- **More diamonds**
- **Flatter nose**

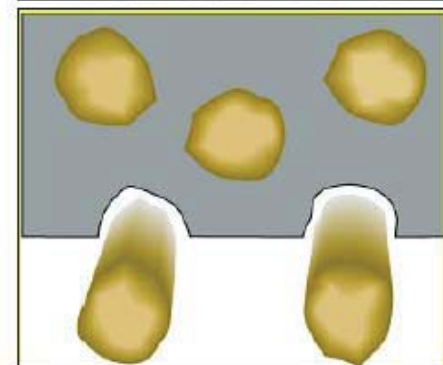
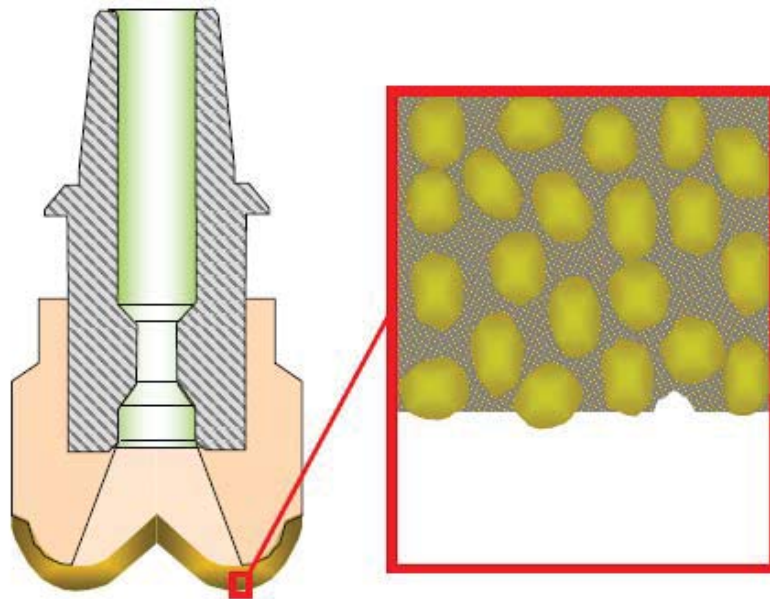
Diamond Bit Matrix Body



Impregnated Diamond Bits

Impregnated bits are a PDC bit type in which diamond cutting elements are fully imbedded within a PDC bit body matrix

- Impregnated Diamond Blades



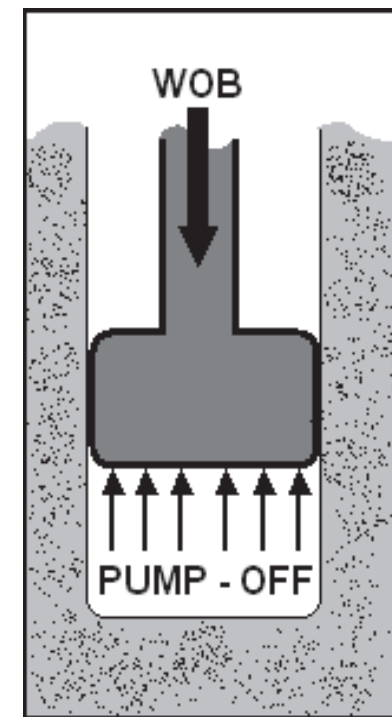
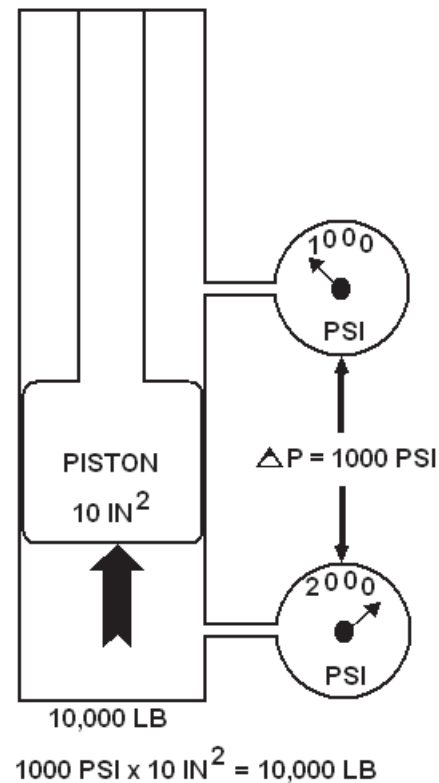
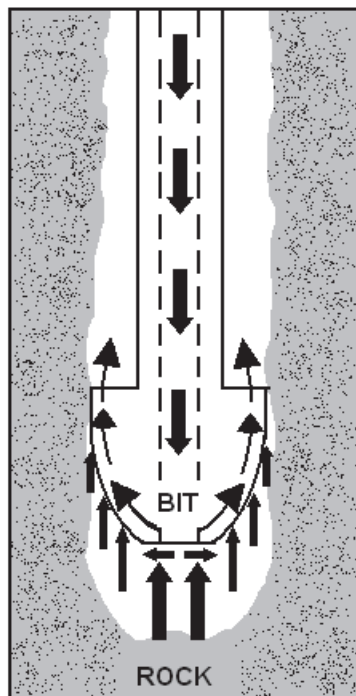
When to Consider Using a Natural Diamond Bit?

1. Penetration rate of rock bit < 10 ft/hr.
2. Hole diameter < 6 inches.
3. When it is important to keep the bit and pipe in the hole.
4. When bad weather precludes making trips.
5. When starting a side-tracked hole.
6. When coring.
- * 7. When a lower cost/ft would result



Natural Diamond Bits Have Pump-Off

- Natural Diamond bit have a large pressure drop under the bit.
- Fluid flows from the center “crowfoot” to the outside of the bit “gage”.
- Because Natural Diamond bits have a small gap between the rock and the bit body.
- Bit acts like a piston



Natural Diamond Bit Have Pump-Off

- The pressure drop under the bit generates a force opposite the WOB
- Actual WOB is equal to

$$WOB_{\text{actual}} = WOB_{\text{applied}} - F_{\text{pumpoff}} \text{ where,}$$

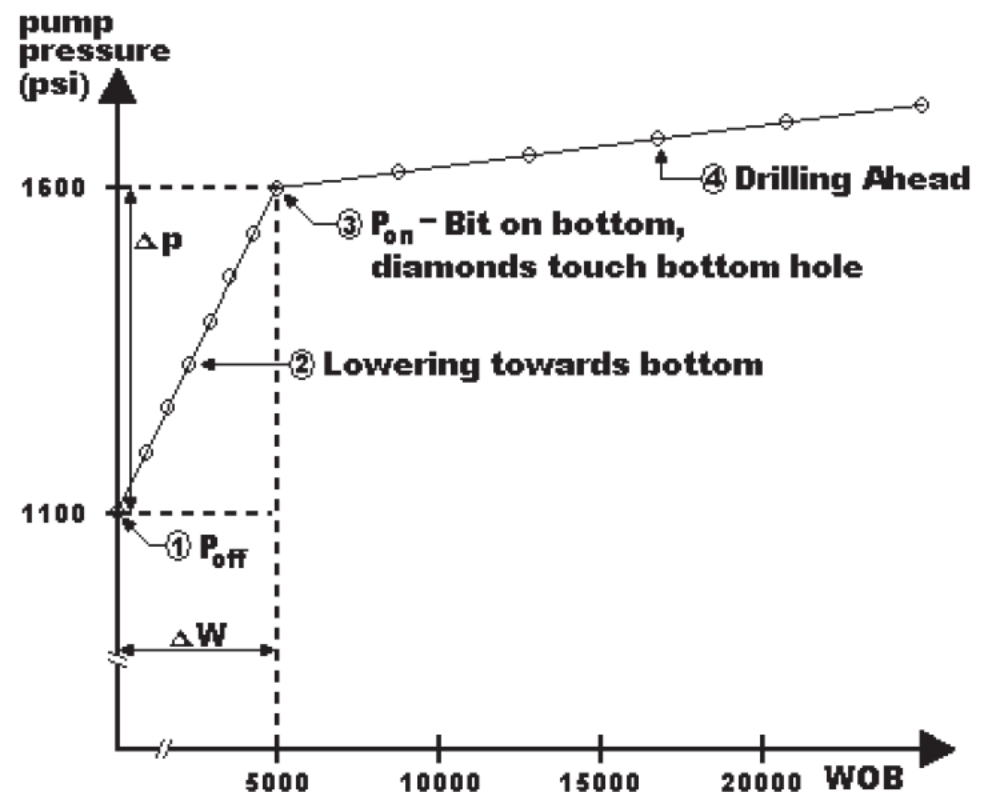
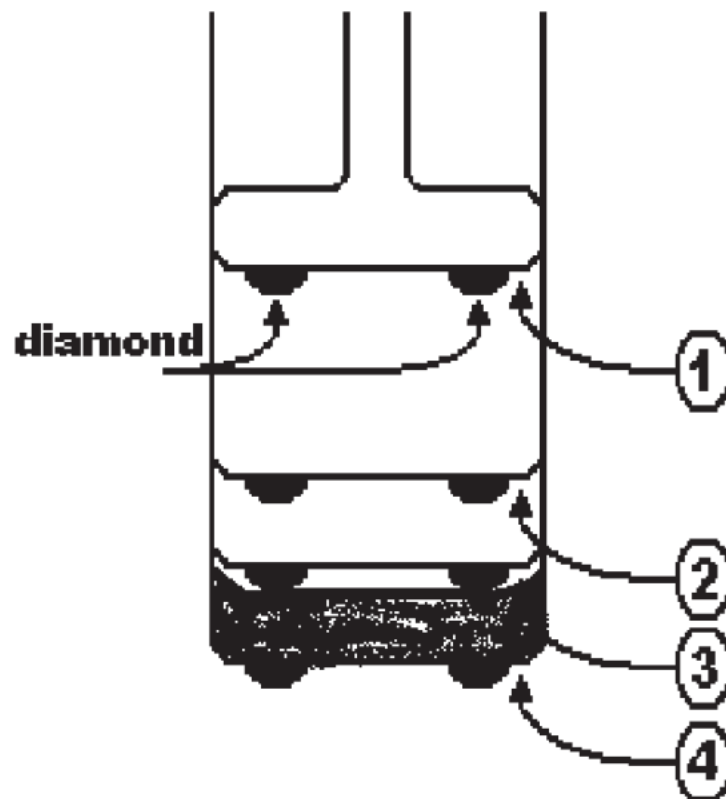
$$F_{\text{pumpoff}} = (P_{\text{on-bottom}} - P_{\text{off-bottom}}) * A_{\text{pump-off}}$$

- Therefore you need to know the pump off area of a bit
- Obtained from pump-off tests

Pump-Off Test Procedure

Slowly lower bit to bottom while rotating and circulating

$$A_{po} = dWOB / \Delta PP$$



$$WOB_{actual} = WOB_{applied} - A_{po} * \Delta PP$$



Pump-Off Modeling

(example Flowrate=869 gpm, Mud Weight = 16 ppg)

Pump - Off Area

$$A_{Po} = \frac{\text{deltaWOB}(lbs)}{\text{deltaPP}(psi)} \Rightarrow$$
$$A_{Po} = \frac{5000}{(1600 - 1100)} = 10 \text{ in}^2$$

$$\text{WOB}_{\text{actual}} = \text{WOB}_{\text{applied}} - A_{po} * \text{deltaPP}$$

If flowrate is to be changed you need to know apparent nozzle area

Apparent Nozzle Area (using the nozzle equation in field units)

$$A_{App} = \text{sqrt}\left(\frac{(\text{Flowrate}(GPM)) * (\text{Flowrate}(GPM)) * \text{Density}(ppg)}{12031 * \text{deltaPP}(psi)}\right)$$
$$A_{App} = \text{sqrt}\left(\frac{(869) * (869) * (16)}{(12031 * 500)}\right) = 2.0 \text{ in}^2$$

Now you can change the flowrate in the nozzle equation and calculate the new deltaPP without having to run another pump off test!

Pump-Off Modeling Usage

- If you are given the A_{app} and the A_{po} you can calculate the actual WOB if you know the mud weight and flowrate!
- First you calculate the deltaPP from the nozzle equation.
- Then you multiply with the deltaPP with the A_{po} .
- Then you subtract the pump off force from the $WOB_{applied}$.

$$WOB_{actual} = WOB_{applied} - A_{po} * \text{deltaPP}$$



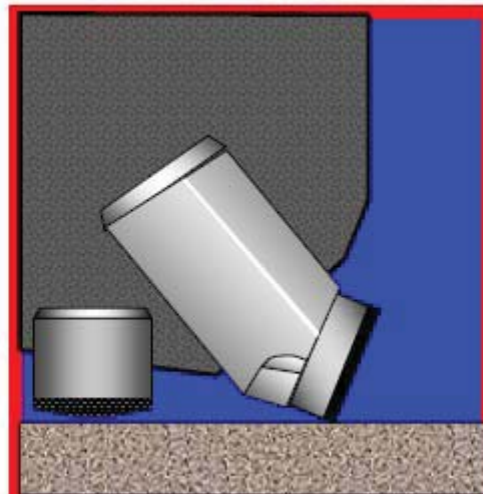
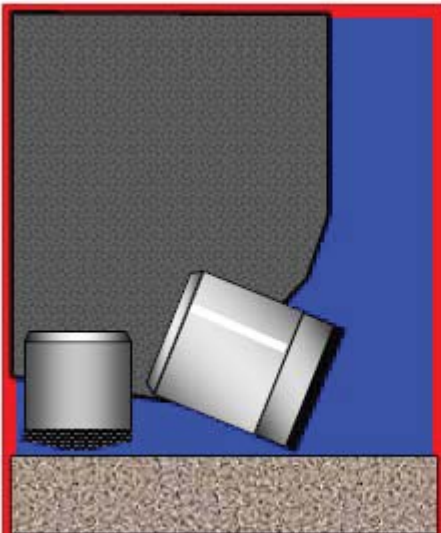
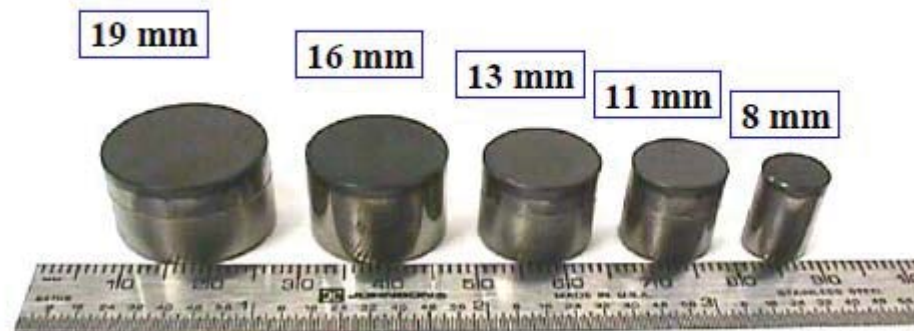
PDC bits

Courtesy
Smith Bits

PDC Bits Applications

- PDC bits are used primarily in deep and/or expensive wells
- Soft-medium hard formations
- Advances in metallurgy, hydraulics and cutter geometry
 - Have increased cost of individual bits
 - Have allowed PDC bits to drill longer and more effectively
 - Allowed bits to withstand harder formations
- PDC bits advantageous for high rotational speed drilling and in deviated hole section drillings
- Most effective: weak, brittle formations (sands, silty claystone, siliceous shales)
- Least effective: cemented abrasive sandstone, granites

PDC Cutters



<https://www.youtube.com/watch?v=pojak1sKF3s> (1 Min)

Polished Cutters - Staysharp

PDC IADC code

Bit Data	Body Material	Total PDC	Cutter Size	Profile Type
	Steel	108	19	Medium
IADC Code	S	4	2	3

Linked to Formation Hardness

PDC IADC code

<u>IADC classification : PDC bits</u>							
A		B		C		D	
Bit body		Formation type		Cutting structure		Bit profile.	
"M"	Matrix	1	Very soft	2	PDC, 19mm	1	Short fishtail
"S"	Steel			3	PDC, 13mm	2	Short profile
"D"	Diamond			4	PDC, 8mm	3	Medium profile
		2	Soft	2	PDC, 19mm	4	Long profile
				3	PDC, 13mm		
				4	PDC, 8mm		
		3	Soft to medium	2	PDC, 19mm		
				3	PDC, 13mm		
				4	PDC, 8mm		
		4	Medium	2	PDC, 19mm		
				3	PDC, 13mm		
				4	PDC, 8mm		
		5	no code				
		6	Medium hard	1	Natural diamond		
				2	TSP		
				3	Combination		
		7	Hard	1	Natural diamond		
				2	TSP		
				3	Combination		
		8	Extremely hard	1	Natural diamond		
				4	Impregnated diamond		

Example	
M	Matrix
4	Medium
3	PDC 13mm
4	Long profile

PDC IADC Code “Profile”

SHORT



MEDIUM



LONG



FISHTAIL



PDC Manufacturing

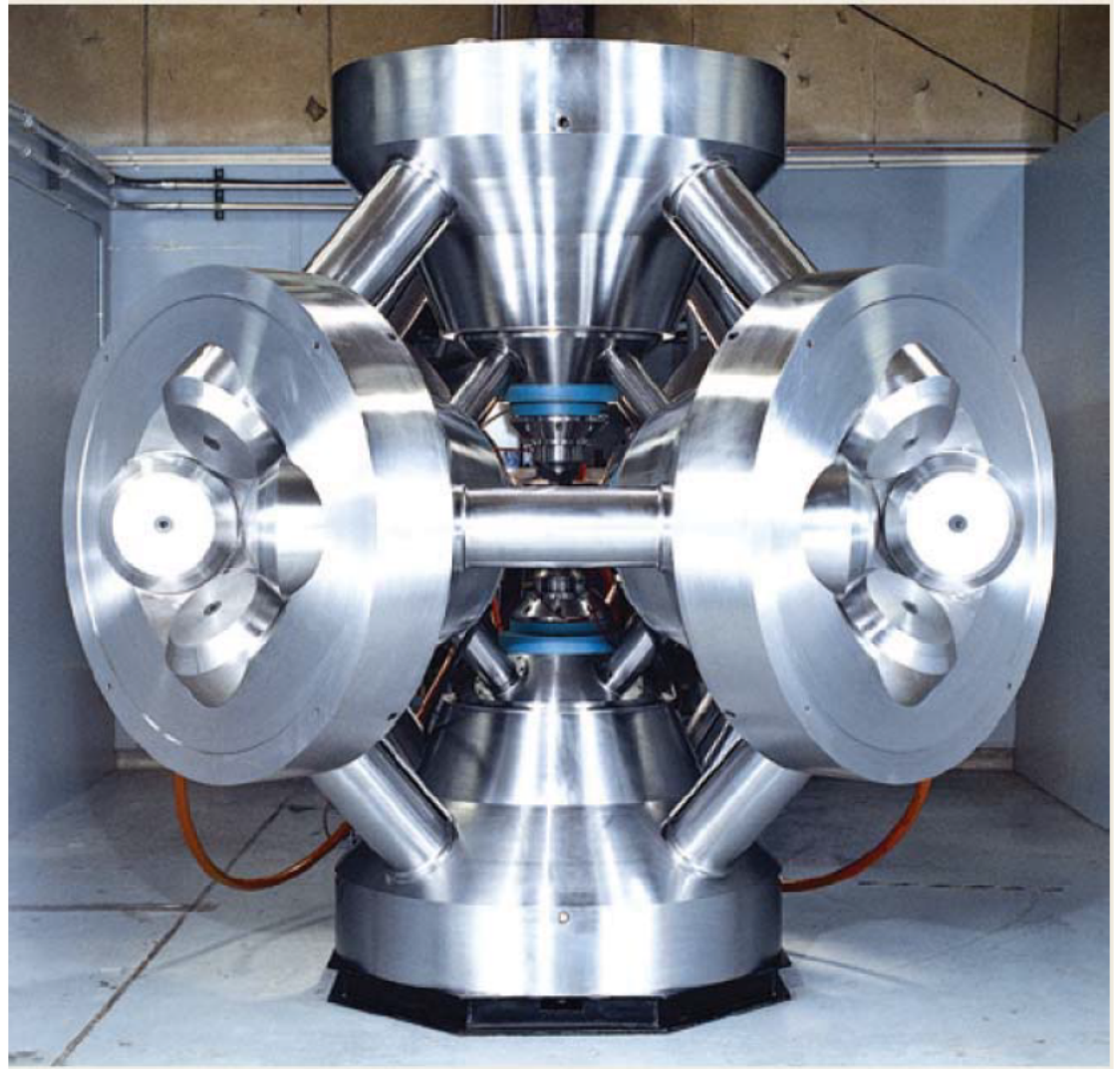
PDC pressure cell.

Carbon graphite and cobalt are stacked and pressed to 2 million psi and heated to 2700° F.



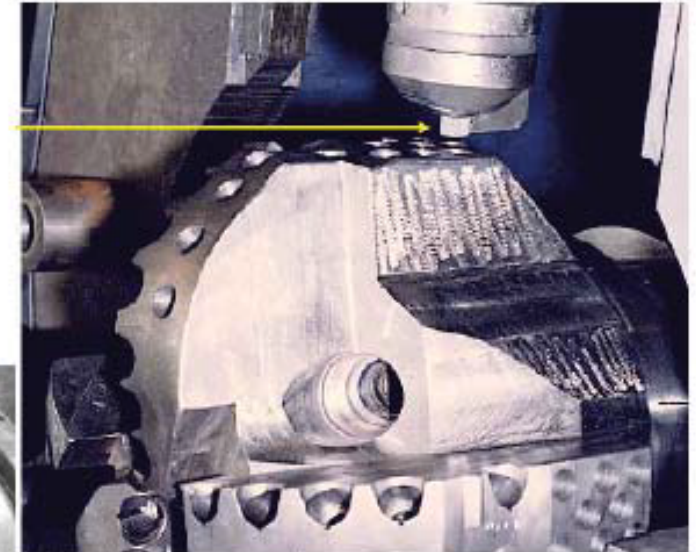
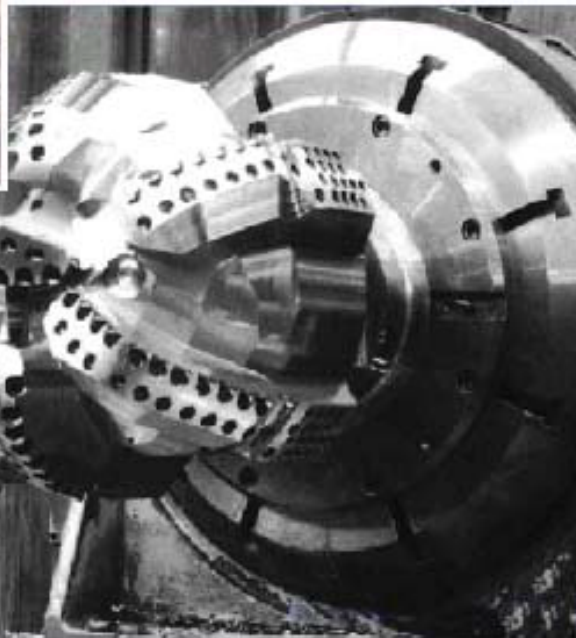
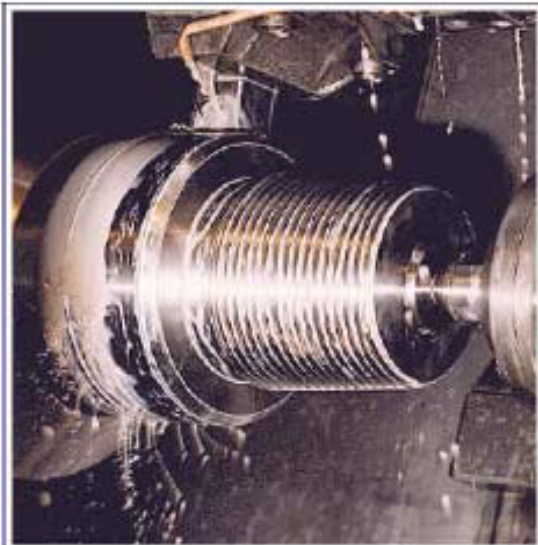
Niobium can

Diamond grit
Tungsten carbide substrate

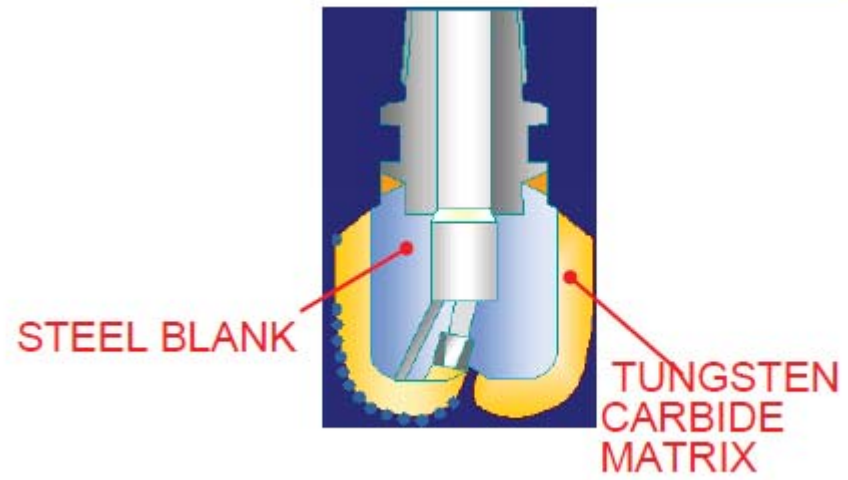
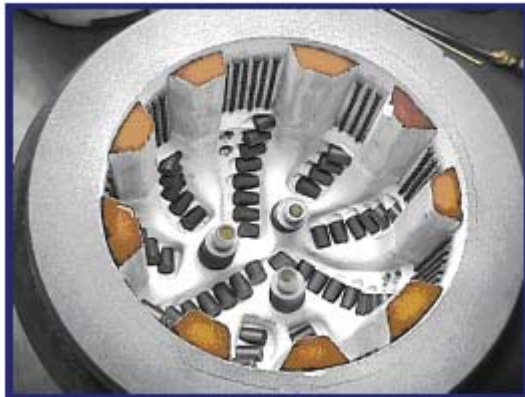


Source: Bellin et al., 2010 World oil , October 2010 issue

PDC Steel Body (Milled)



PDC Matrix Body

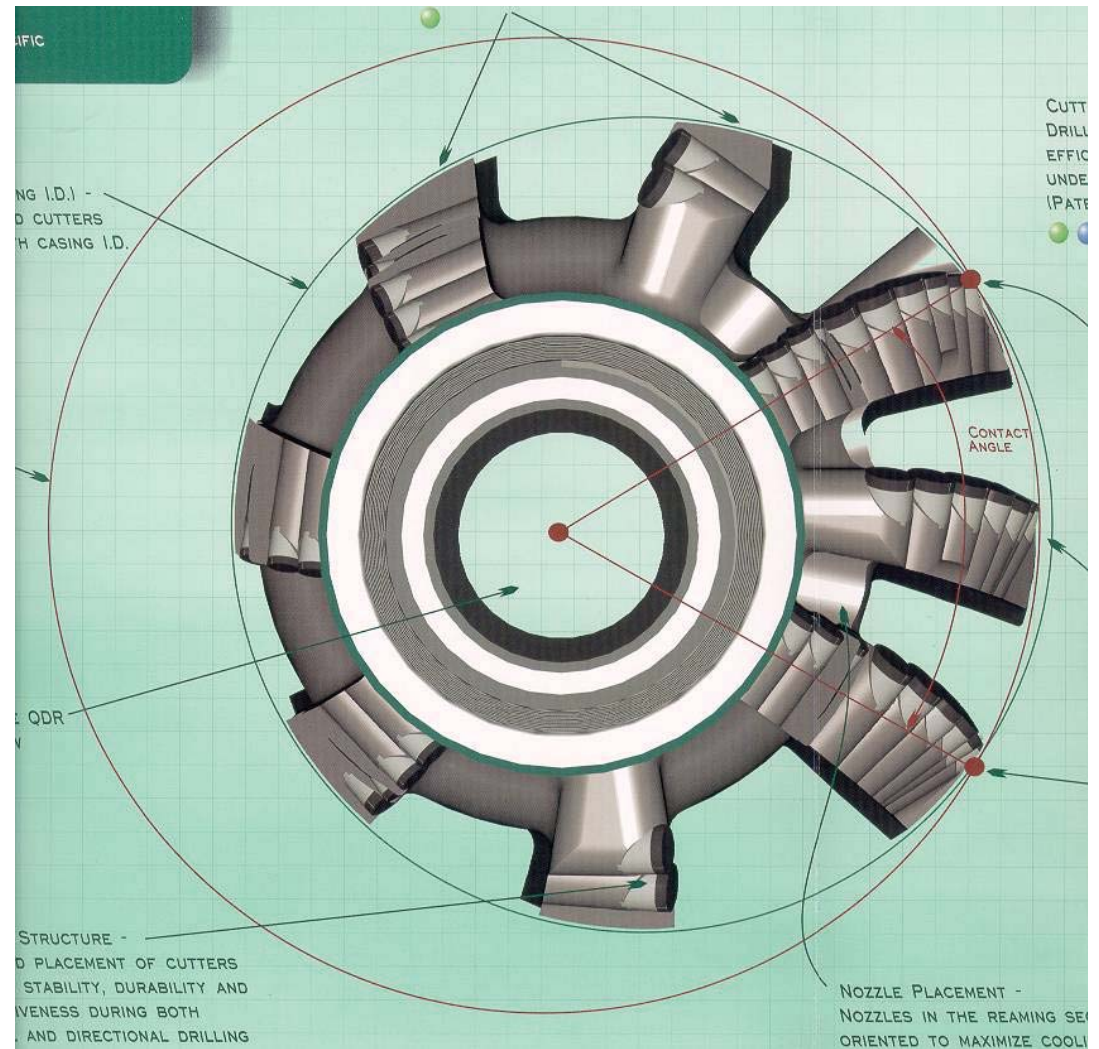




PDC
Matrix
Body

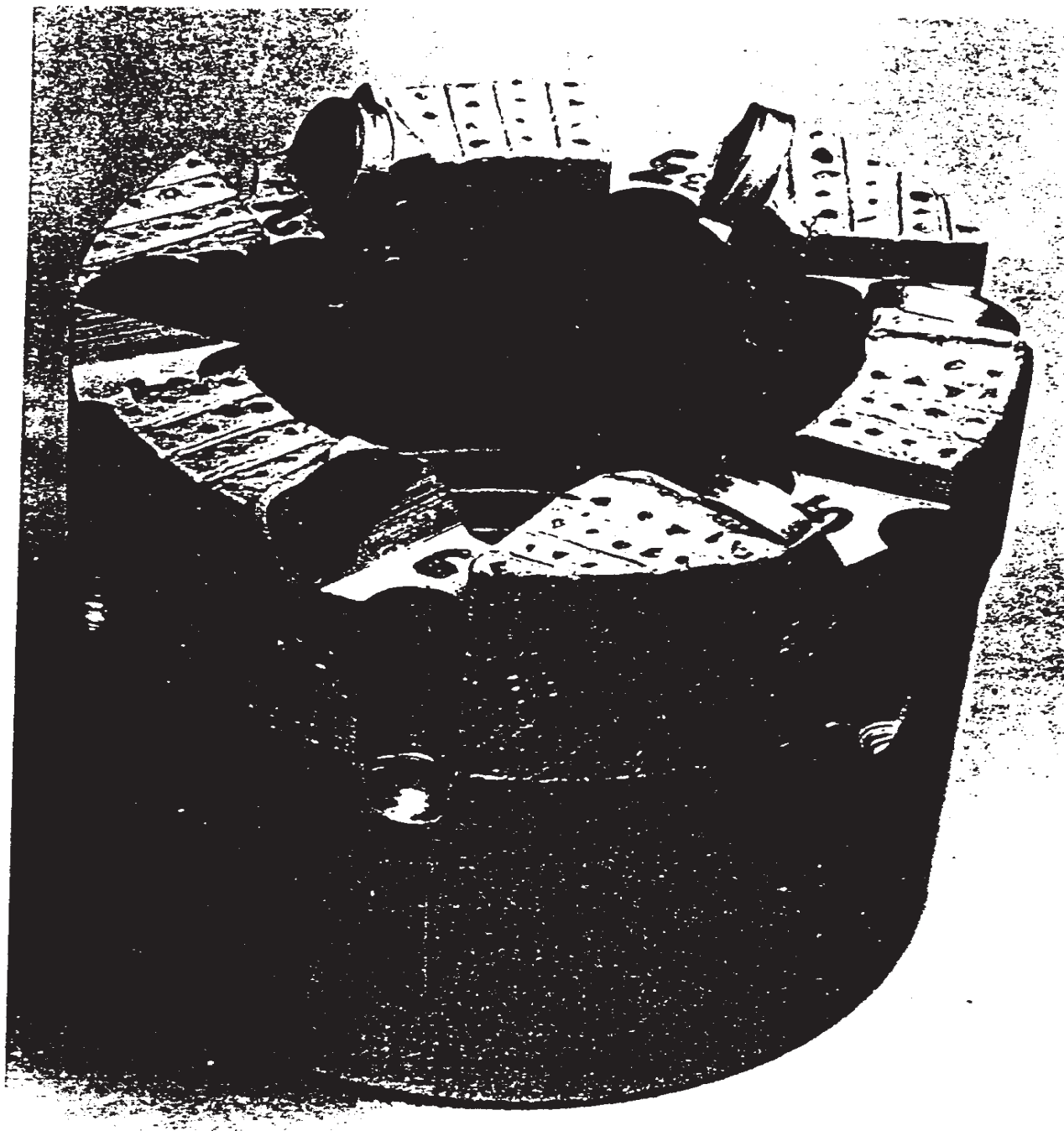


Bi-Center Bit



Courtesy Smith Bits

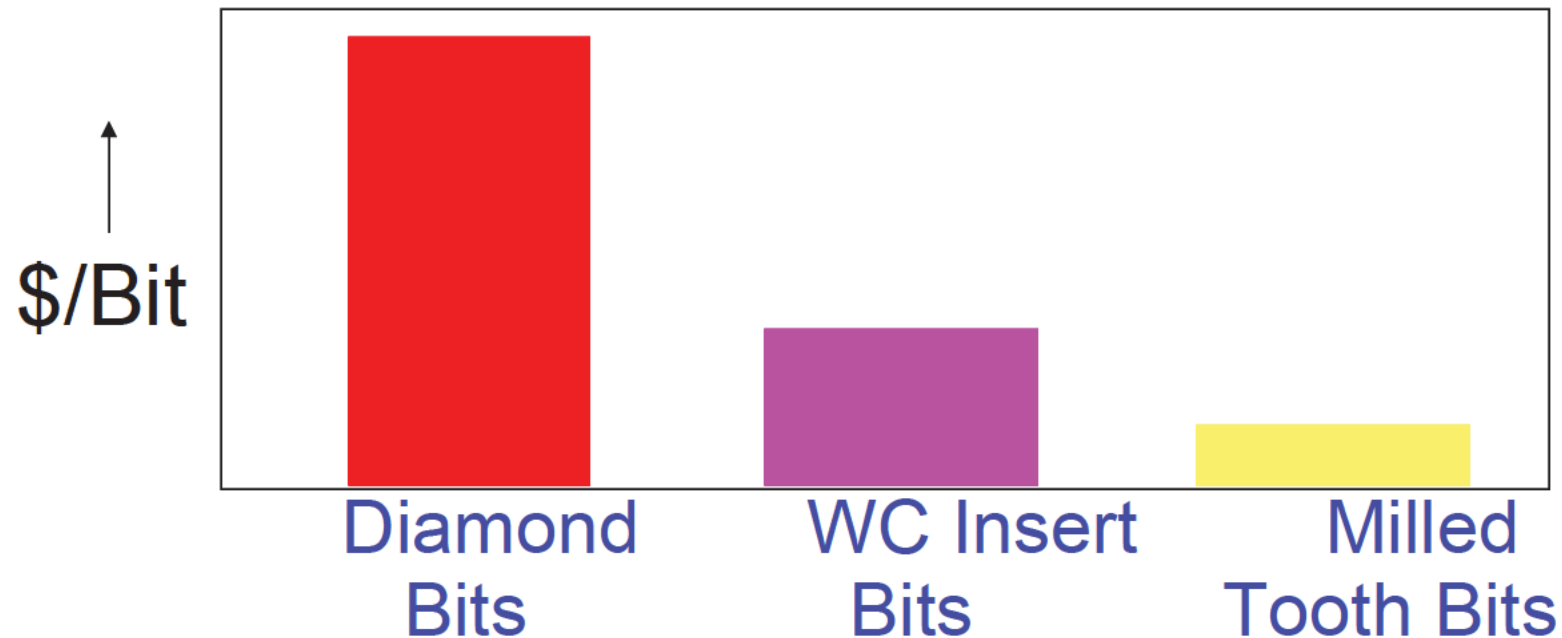
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Core Bit

PDC +
natural
diamond

Relative Costs of Bits



- Diamond bits typically cost **several times** as much as tri-cone bits with tungsten carbide inserts (same bit diam.)
- A TCI bit may cost **several times** as much as a milled tooth bit.



PDC Bits

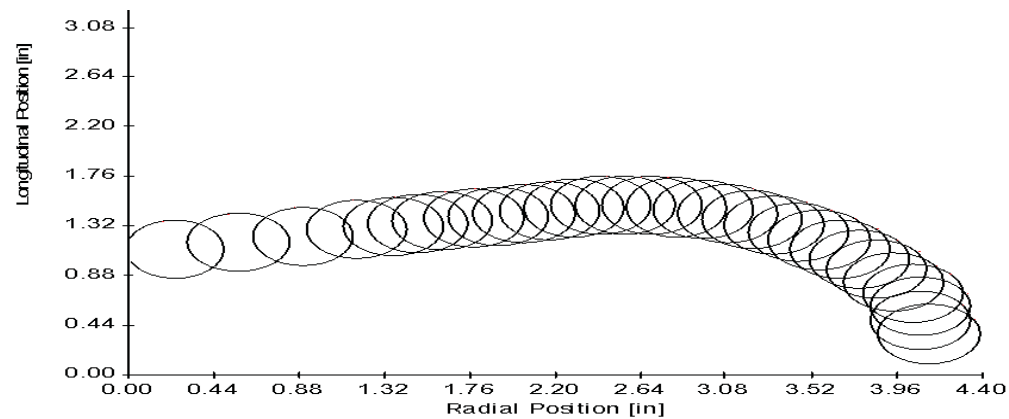
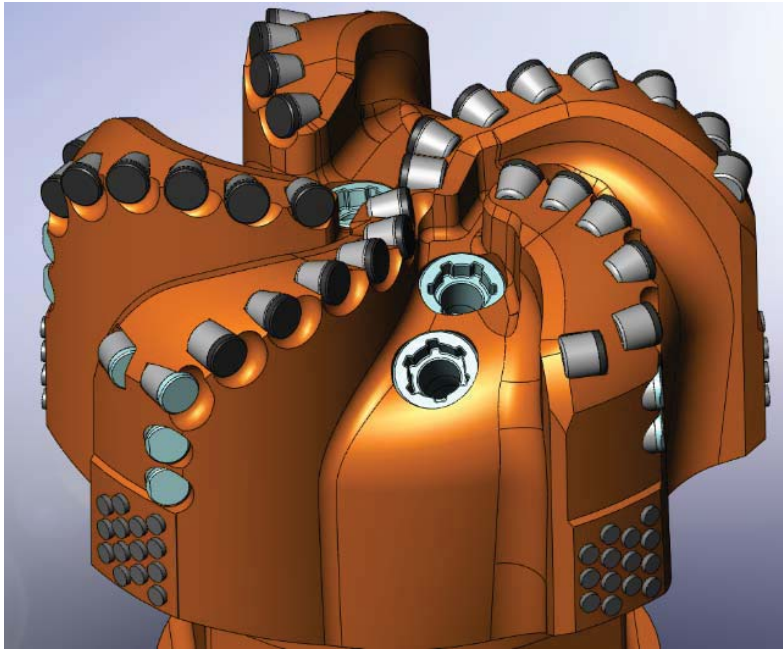
- Increase penetration rates in oil and gas wells
- Reduce drilling time and costs
- Cost **5-15** times more than roller cone bits
- **1.5** times faster than those **2 years** earlier
- Work better in oil based muds; however, some areas are regulated

PDC Bits

- Parameters for effective use include
 - weight on bit
 - mud properties
 - bit hydraulics
 - flow rate
 - rotational speed

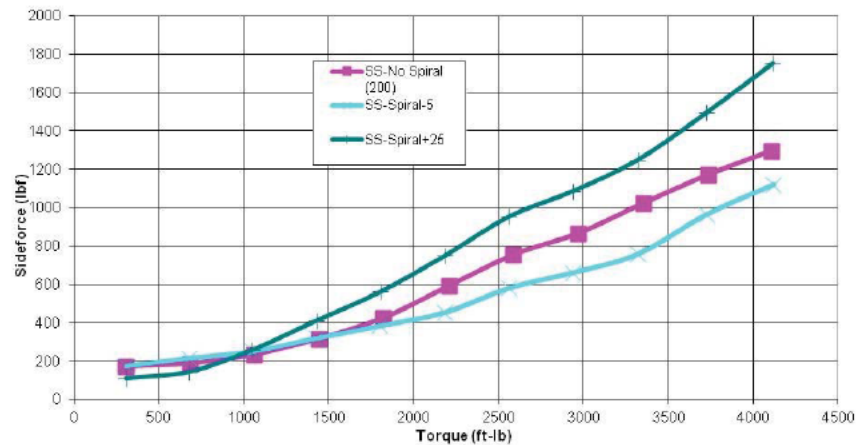


PDC Bit Design

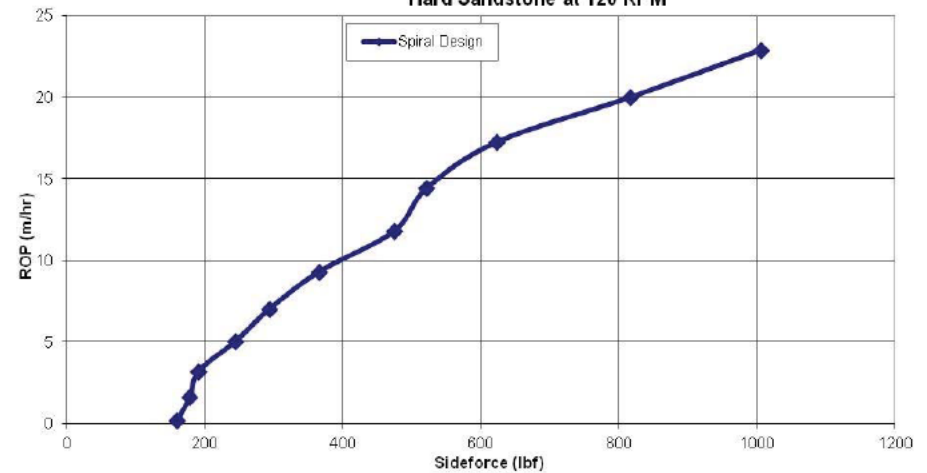


PDC Bits Design Evaluation (for illustration purposes)

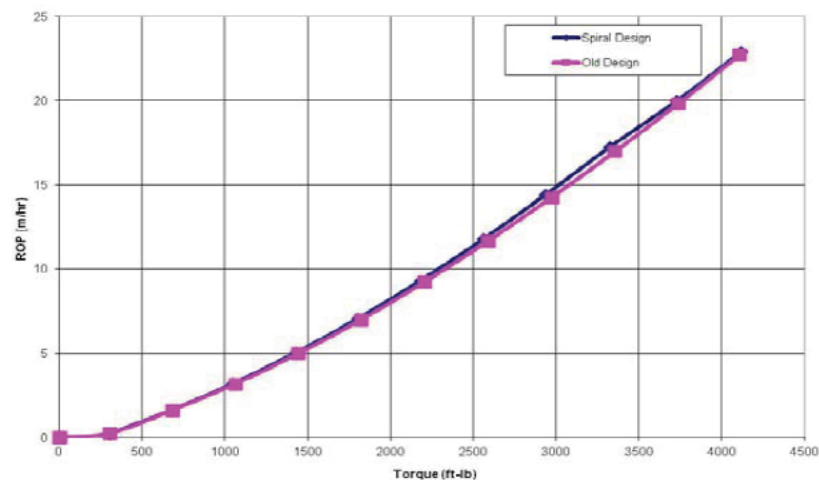
NB513-Spiral 222mm Performance in Hard Sandstone at 120 RPM



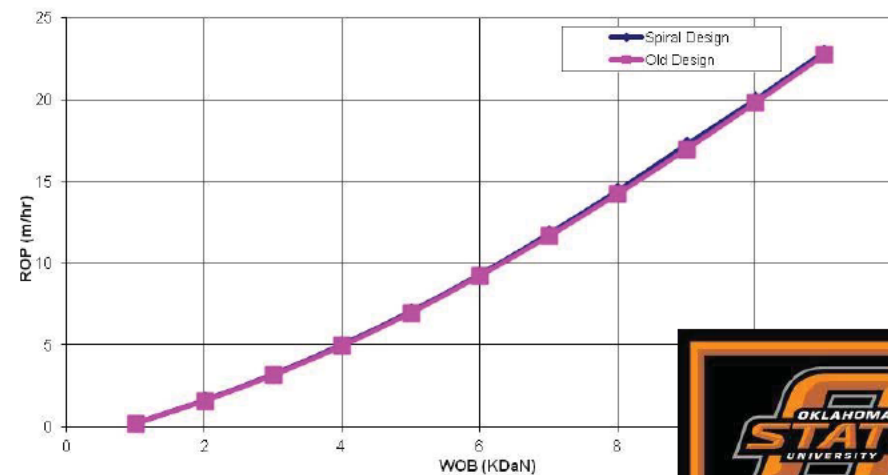
NB513 222mm Performance Comparison between Spiral and Non-Spiral Design in Hard Sandstone at 120 RPM



NB513 222mm Performance in Hard Sandstone at 120 RPM



NB513 222mm Performance in Medium Hard Shale and Hard Sandstone at 120 RPM



8.75” PDC Bit

features

Engineered from the ground up, Synergy Series PDC drill bits incorporate the latest advances in downhole physics, including:

Compact, single steel body

Engineered and manufactured via computerized design and CNC milling ensures precision and consistency

Physics-Balanced cutting model

Unique converging spiral design and non-symmetrical model provides maximum cut, steerability, and durability

Gauge control & backream support

Enhanced gauge protection with optional backream capability and protection



8.75” PDC Bit

features

Engineered from the ground up, drill bits incorporate the latest advances in downhole physics, including:

Surface-Velocity contoured profile

Velocity and directional control of fluid across flutes and cutters maximizes cooling and enhances cleaning

Torque normalization

Blade and cutter torque compensation characteristics
mitigate imbalanced loading and enhance stability

Integrated standard hex breaker

A tough, standard hex breaker incorporated directly into the shank allows convenient orientation



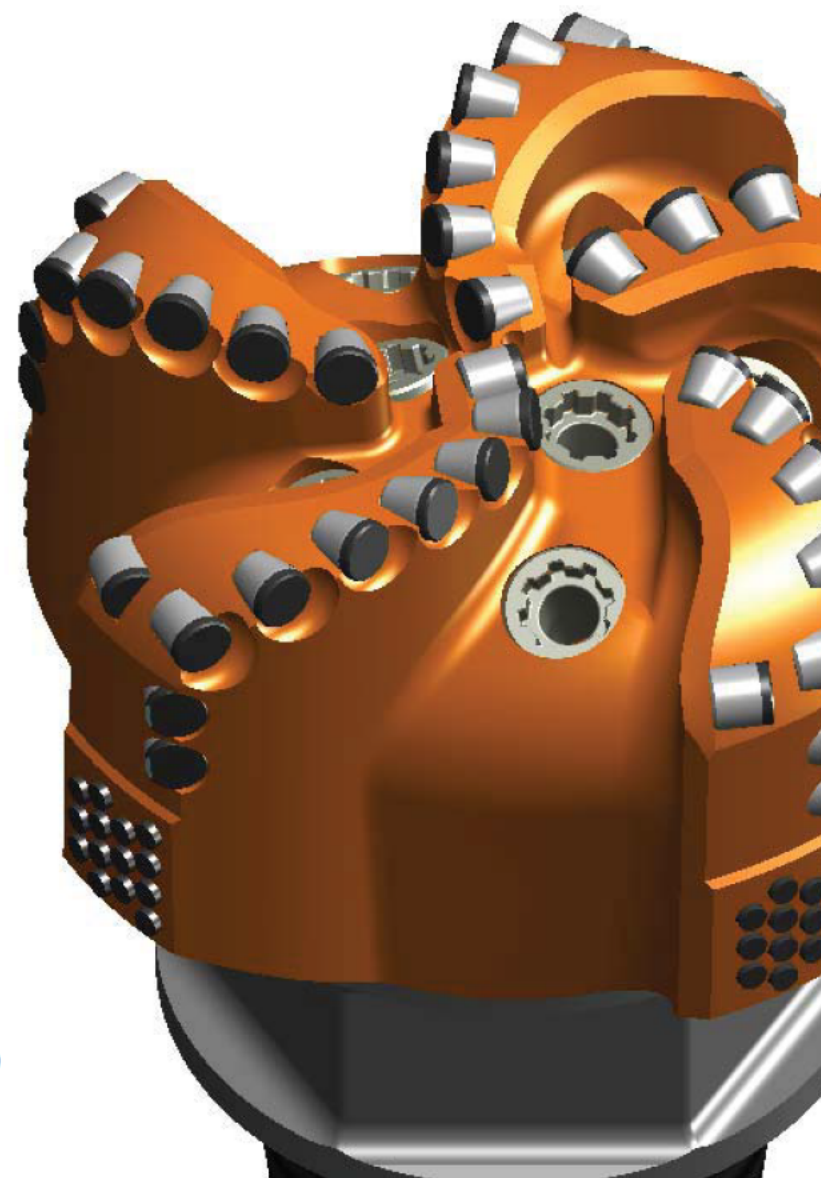
8.75” PDC Bit technical specifications.

cutting structure

gauge	222 mm (8.750 in)
blade count	5
total cutters	45
cutter size	13 mm
face cutters	30
gauge cutters	10
back-up cutters	5
backream cutters	optional

hydraulics

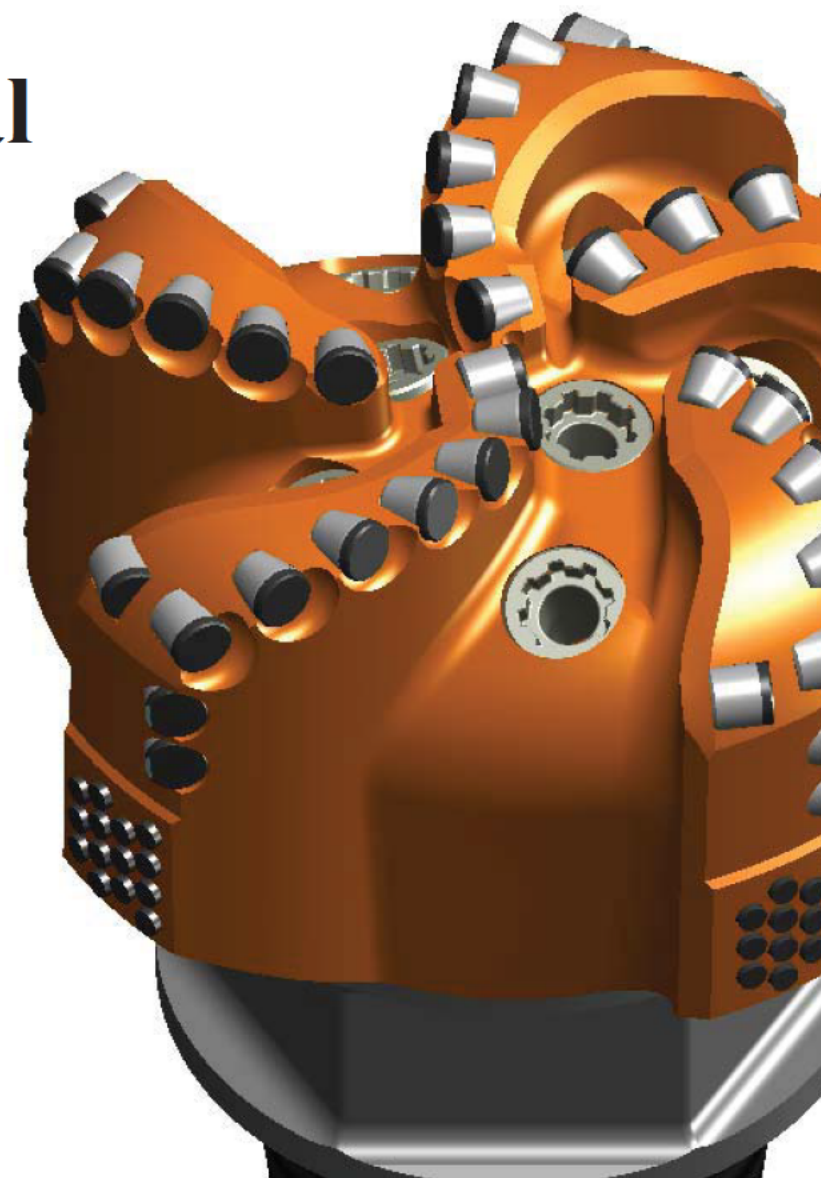
nozzles	7 x interchangeable
nozzle sizes	7 x NB0832 - 2032 (8/32" - 20/32")



8.75" PDC Bit technical specifications.

design profile

junk slot area	111 cm ² (17.25 in ²)
gauge length	78.7 mm (3.10 in)
gauge protection	Carbide & Diamond
make-up length	206.6 mm (8.14 in)
overall length	303.5 mm (11.95 in)
bit connection	4.500" API Regular
fishing neck	152.4 mm (6.000 in)



Courtesy of



NorthBasin
energy services inc.



PDC Bits –Typical Spec Sheet



222.25MM

M76

IADC M123

ER 20003

–Drilling Application–

The M76 is a matrix body bit designed with stability enhancing features. Applications ranging from soft to medium formations. Good for transitional and directional drilling.

–Design Specifications–

Total Cutters	32
Cutter Size	18mm (5/8")
Face Cutters	(27) 18mm
Gauge Cutters	(5) 18mm
Cone Cutters	
Nozzles	5 Standard Series 60N
Bit Connection	4-1/2" API Reg.
Junk Slot Area	20.5
Face Volume	81
Void Volume Ratio	75.8

Gauge

Length	50.8MM
Protection	Options Available

Make-Up

Length	10.28
Overall	14.47

Fishing Neck

Diameter	6
Length	4.32

–General Operating Parameters–

Flow Rate	325 to 800
Hydraulic Horsepower	1 to 6
Rotary Speed	Suitable for Rotary & PDM
Weight-on-Bit	4000 to 30000 (lbs) 1818 to 13635 (daN) 2 to 14 (Tonnes)

–Features–

- Incremental Back Rake
- Spiral Blades and Gage
- Unsymmetrical Blade Layout



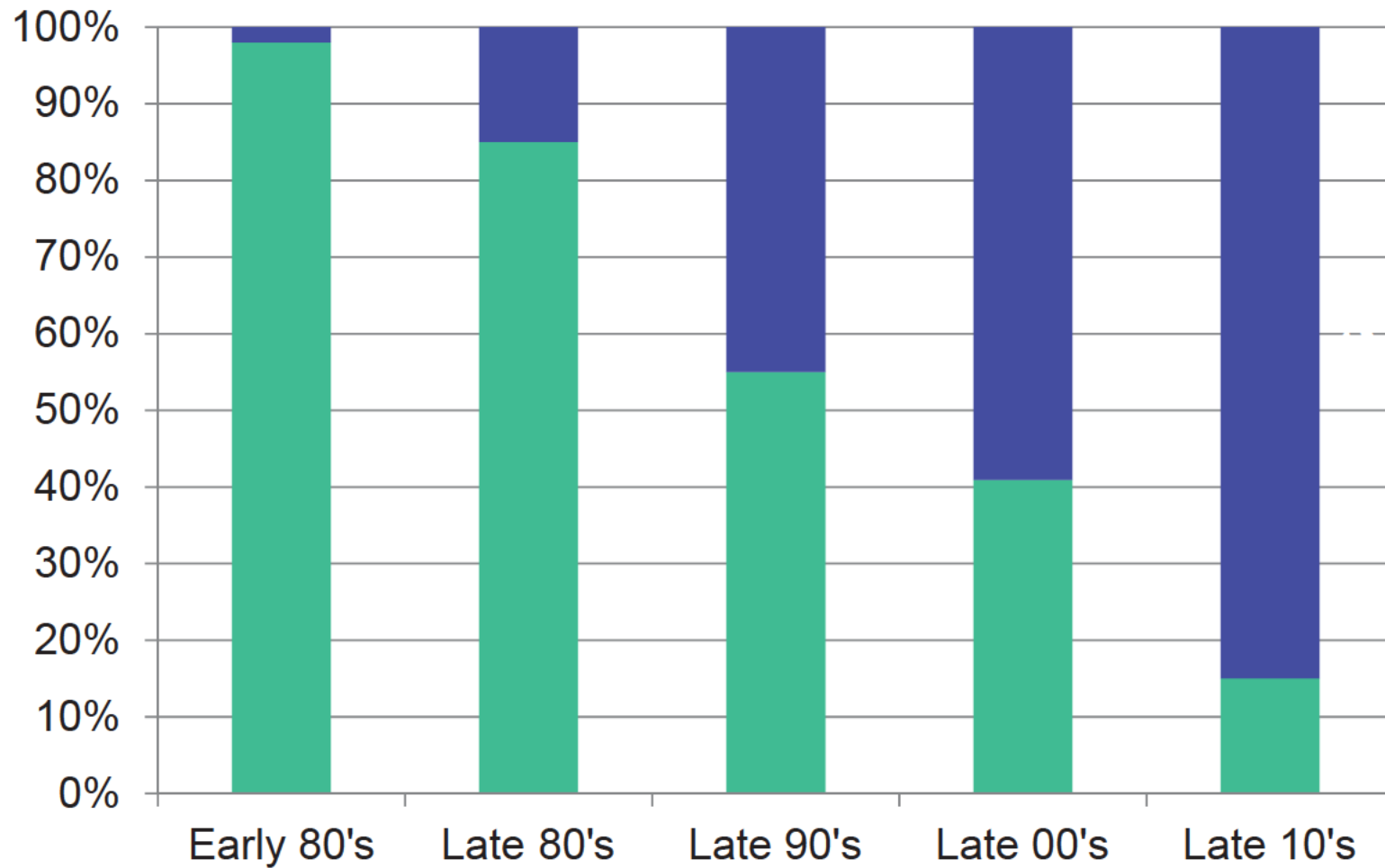
PDC Bits

➤ Economics

- Cost per foot drilled measures Bit performance economics
- Bit Cost varies from 2%-5% of total cost, but bit affects up to 60 % of total drilling cost
- Advantage comes when
 - the No. of trips is reduced, and when
 - the penetration rate increases



PDC Bit Market Share



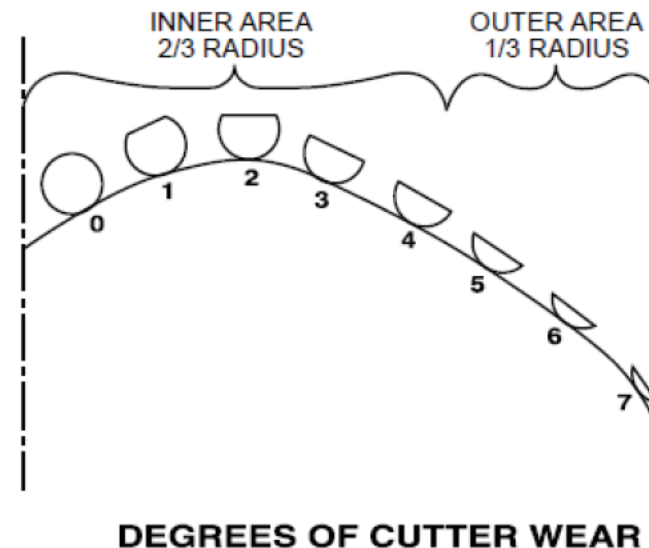
Grading of Worn PDC Bits

IADC DULL GRADING SYSTEM CHART							
Cutting Structure				B	G	Remarks	
Inner Rows	Outer Rows	Dull Characteristics	Location	Bearing Seals	Gauge 1/16"	Other Characteristics	Reason Pulled
2	6			X			

$$\frac{(4 + 3 + 2 + 1 + 0)}{5} = 2$$

$$\frac{(5 + 6 + 7)}{3} = 6$$

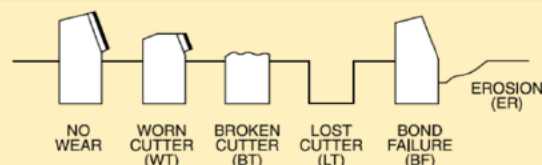
The cutting structure is graded from 0 to 8 depending on the proportion of cutting structure lost (0 = Intact, 8 = 100% worn).



Grading of Worn PDC Bits

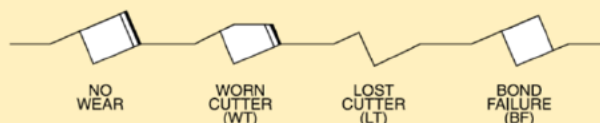
IADC DULL GRADING SYSTEM CHART							
Cutting Structure				B	G	Remarks	
Inner Rows	Outer Rows	Dull Characteristics	Location	Bearing Seals	Gauge 1/16"	Other Characteristics	Reason Pulled
		WT		X		RO	

FIGURE 2A. STUD CUTTERS



WEAR CHARACTERISTICS: POST OR STUD CUTTERS

FIGURE 2B. CYLINDER CUTTERS



WEAR CHARACTERISTICS: CYLINDER CUTTERS

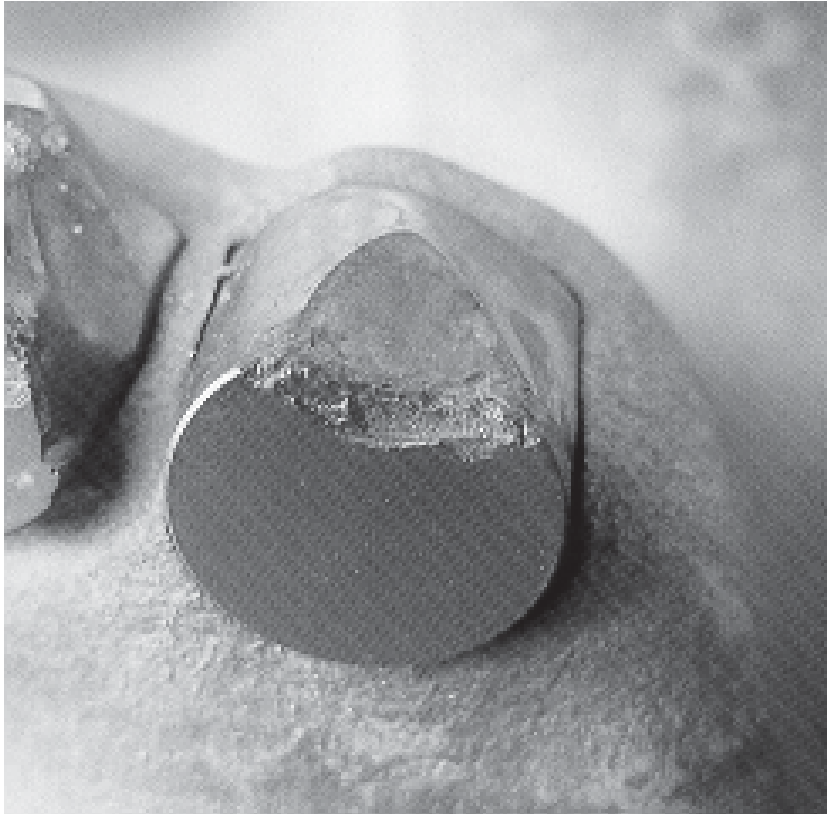
- *BC - Broken Cone
- BF - Bond Failure
- BT - Broken Teeth/Cutters
- BU - Balled Up
- *CC - Cracked Cone
- *CD - Cone Dragged
- CI - Cone Interference
- CR - Cored
- CT - Chipped Teeth/Cutters
- ER - Erosion
- FC - Flat Crested Wear
- HC - Heat Checking
- JD - Junk Damage
- *LC - Lost Cone
- LN - Lost Nozzle
- LT - Lost Teeth/Cutters
- NO - No Major/Other Dull Characteristics
- NR - Not Rerunnable
- OC - Off-Center Wear
- PB - Pinched Bit
- PN - Plugged Nozzle/Flow Passage
- RG - Rounded Gauge
- RO - Ring Out
- RR - Rerunnable
- SD - Shirttail Damage
- SS - Self Sharpening Wear
- TR - Tracking
- WO - Washed Out Bit
- WT - Worn Teeth/Cutters

*Show cone number(s) under "Location".

NOTE: If no "Dull Characteristic" is visible, mark this space "No". If no "Other Characteristic" is visible, mark this space "No".

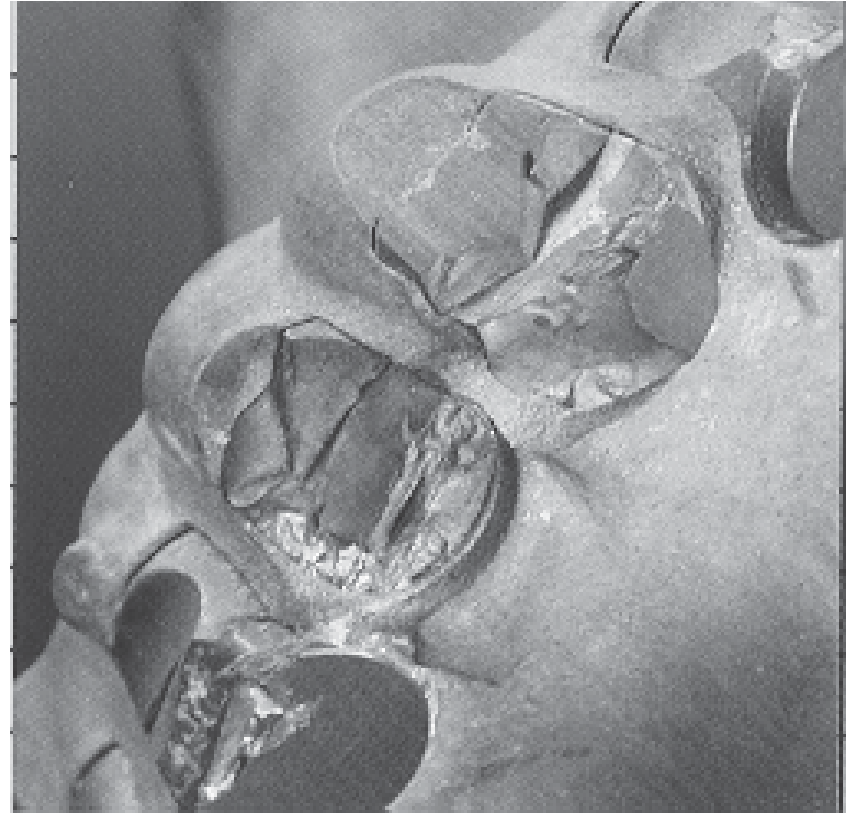
- BHA - Change Bottomhole Assembly
- DMF - Downhole Motor Failure
- DSF - Drillstring Failure
- DST - Drill Stem Test
- DTF - Downhole Tool Failure
- LOG - Run Logs
- RIG - Rig Repair
- CM - Condition Mud
- CP - Core Point
- DP - Drill Plug
- FM - Formation Change
- HP - Hole Problems
- HR - Hours
- PP - Pump Pressure
- PR - Penetration Rate
- TD - Total Depth/CSG Depth
- TQ - Torque
- TW - Twist Off
- WC - Weather Conditions
- WO - Washout Drillstring

Grading of Worn PDC Bits



CT - Chipped Cutter

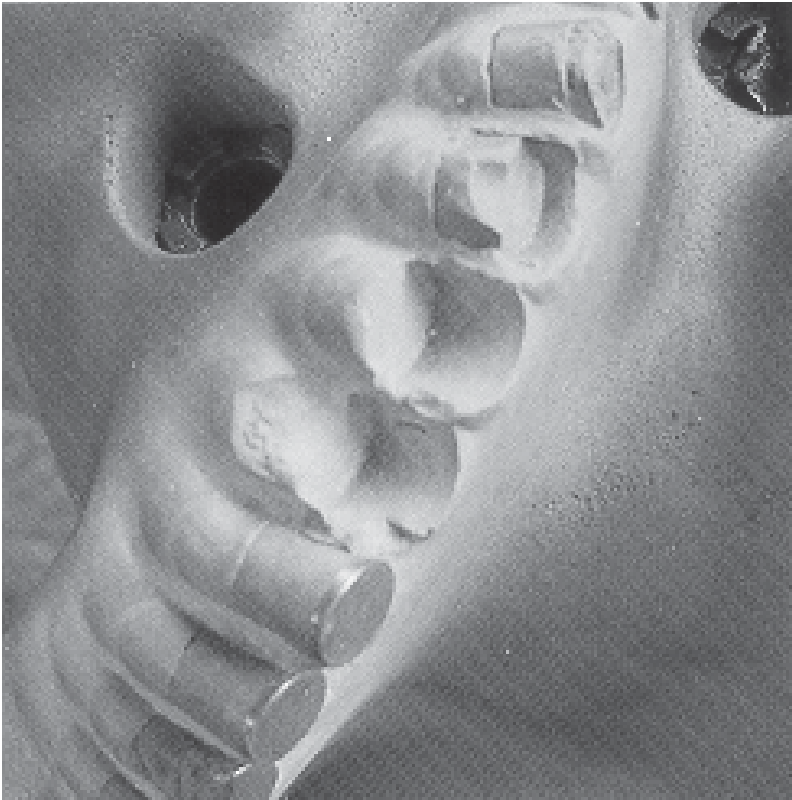
Less than 1/3 of cutting element is gone



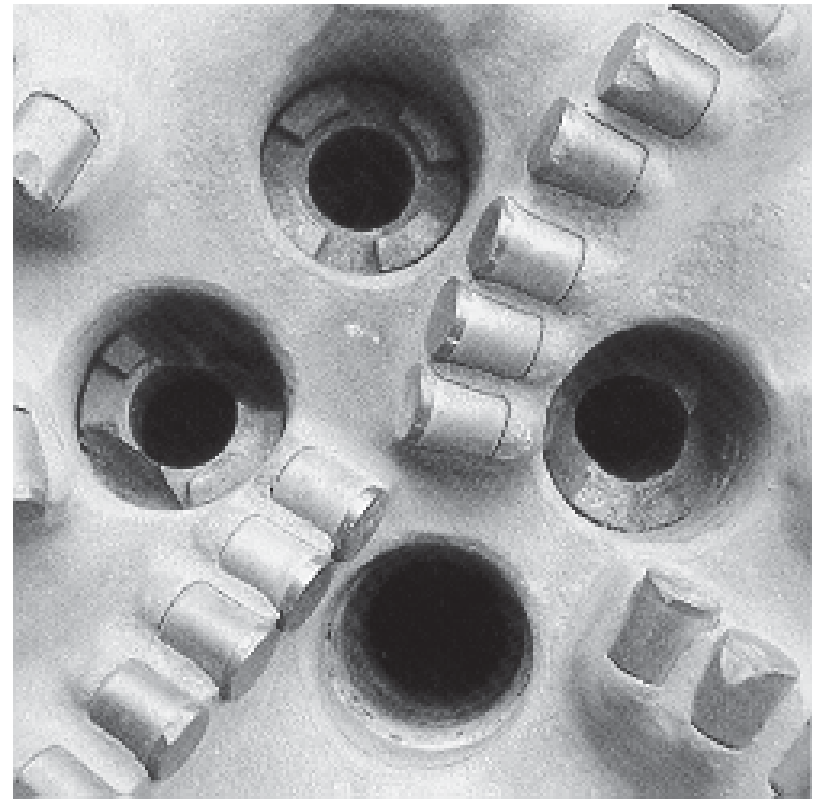
BT - Broken Cutter

More than 1/3 of cutting element is broken to the substrate

Grading of Worn PDC Bits – cont'd

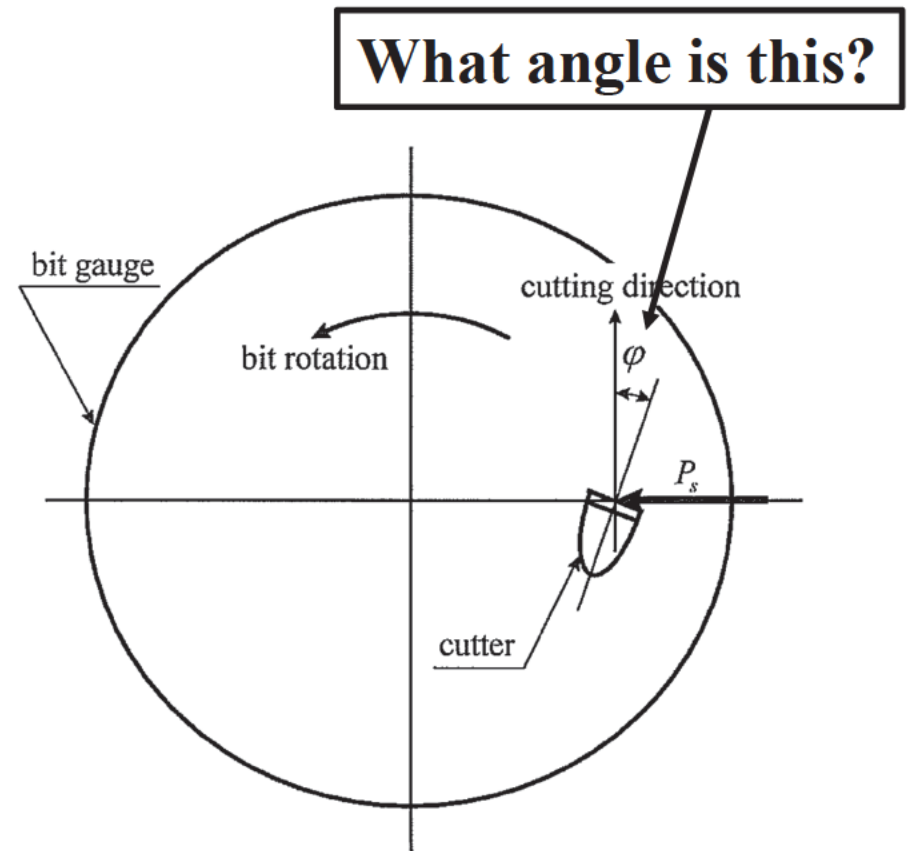


LT - Lost Cutter
Bit is missing one or more cutters



LN - Lost Nozzle
Bit is missing one or more nozzles

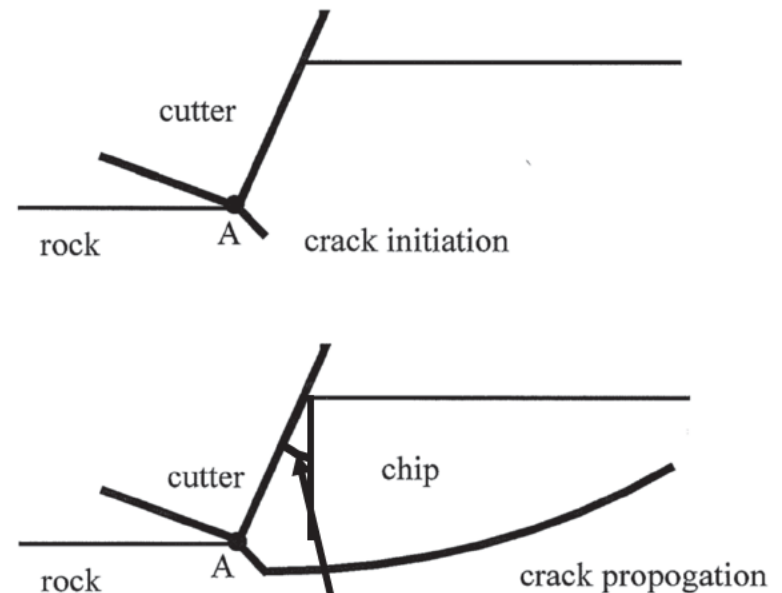
PDC Bit Cutting Action



PDC Cuttings Development



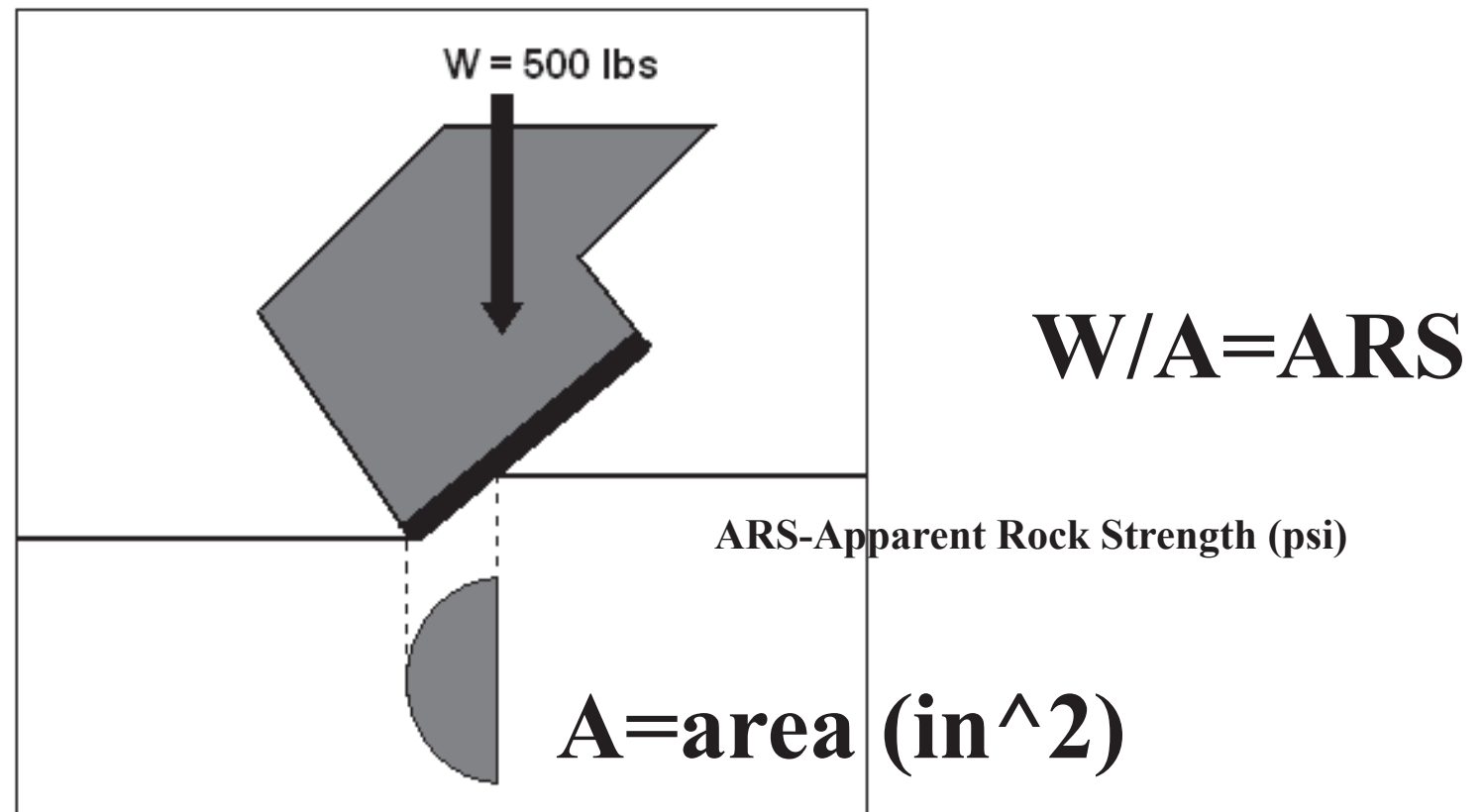
Chip development



What angle is this?

PDC Model

➤ Single cutter vertical force balance

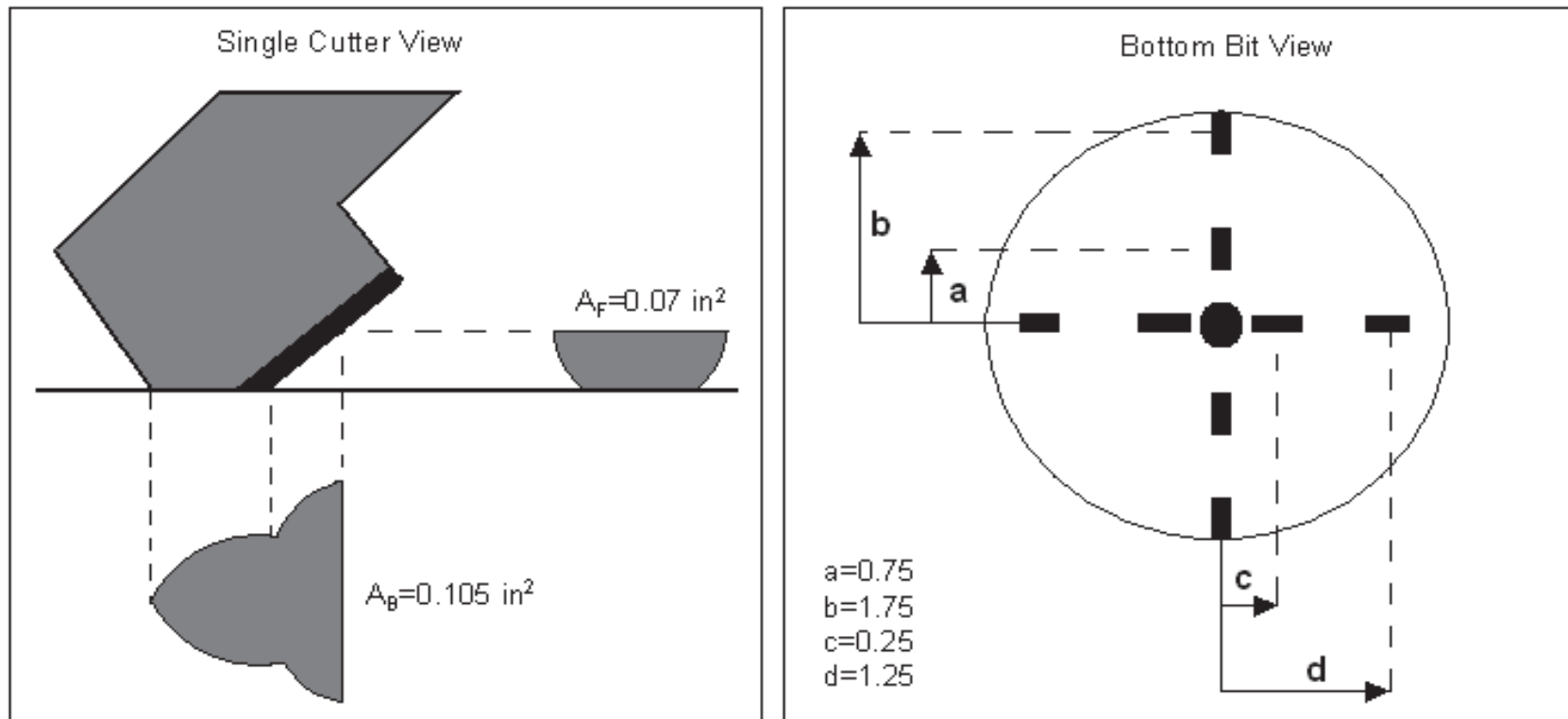


If rock is harder what and W is constant, what happens to area?
Depth of cut and ROP?

PDC Bit With 8 Cutters

Sample Calculations

ARS=Apparent Rock Strength = 10,000 psi



Back Rake? Side Rake?

PDC Model

Sample Calculation

ARS-Apparent Rock Strength

$$\sigma = \frac{W_B}{A_B \cdot (8)} \Rightarrow$$

WOB

$$W_B = A_B \cdot \sigma \cdot (8) = (0.105 \text{ in}^2) \cdot (10,000 \text{ psi}) \cdot 8 \\ = 1050 \text{ lbs} \cdot 8 = 8400 \text{ lbs}$$

Torque

$$T = W_F \cdot d \\ = W_F \cdot [(0.25" + 1.25") \cdot (2) + (0.75" + 1.75") \cdot (2)] \\ = A_F \cdot \sigma \cdot 8 \\ = (0.07) \cdot (10,000) \cdot (8) \\ = 5600 \text{ lbs} \cdot \text{in} = 465 \text{ lbs} \cdot \text{ft}$$

WOB Vertical Direction

ARS=Weight/Area

Weight=ARS*Area

Area downward projection

Torque –Later Direction

Wf is the force in front

d is the distance center to cutter

Area front projection

TSP Bit

- TSP (**T**hermally **S**table **P**DC)



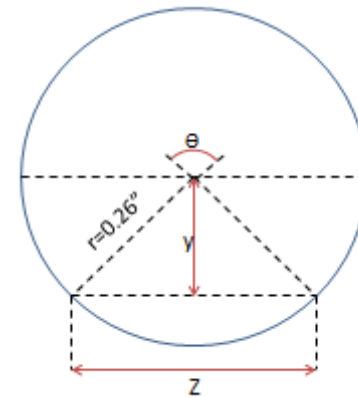
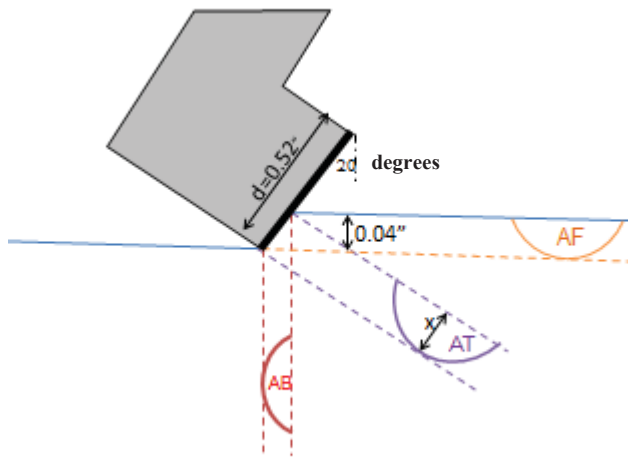
Homework #4 - Due February 21

Problem #1.24 and problem below

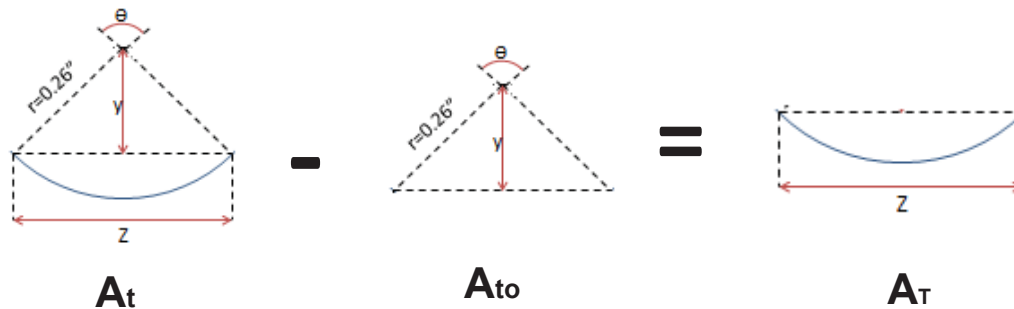
- Cutter size is 0.75"
- Depth of cut for all cutters is 0.08"
- Bit is "green" and has 5 blades with 32 cutters
- Cutter backrake is 20 degrees and siderake is 0 degrees
- The rock strength is 15,000 psi
- Assuming perfect cleaning, 100% contact area between cutters and rock
- Calculate the static WOB!

Homework: Problem#2

Cutter Diameter and Depth of Cut is Different



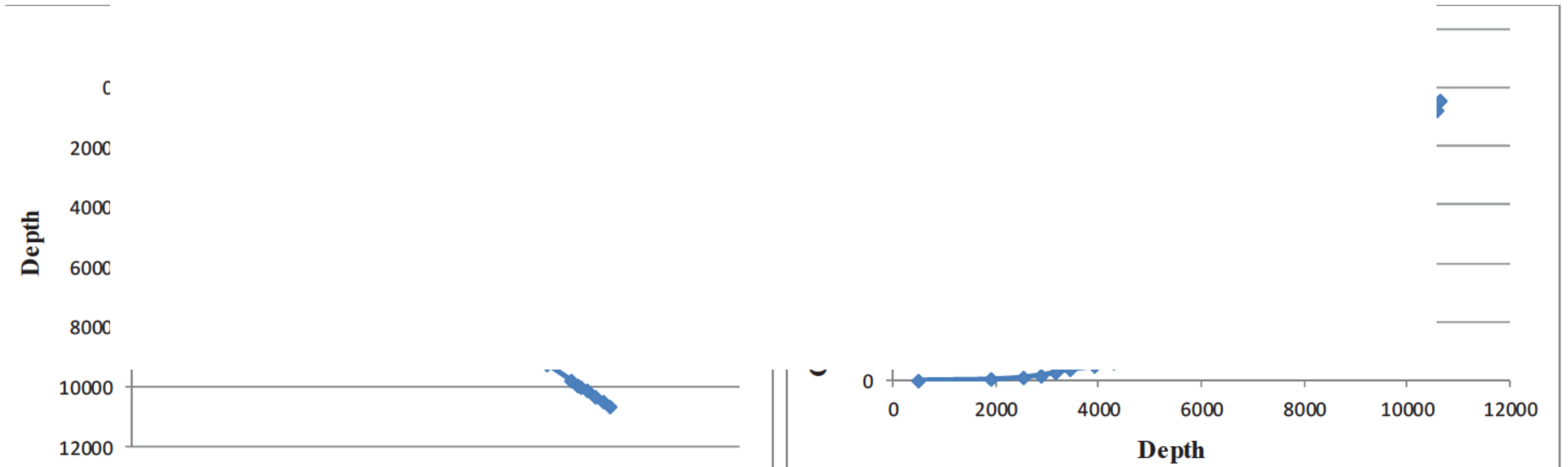
In your HW example the cutter diameter and depth of cut is different!



Homework #1.24 Solution



I will remove this in class!





<https://www.youtube.com/watch?v=4dqXHIO3A88> (2 Min)

Hybrid Bit

Typical Video on New Cutter Technology

http://www.youtube.com/watch?v=2iDtgRgVa_w (10 Min)

Sales SPE Baker – Staycool Cutters

**END
of
Handout #4
- Drag Bits –**