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Overview of Rock Reduction Technology

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National Nuclear Security Administration

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Some Starting Points

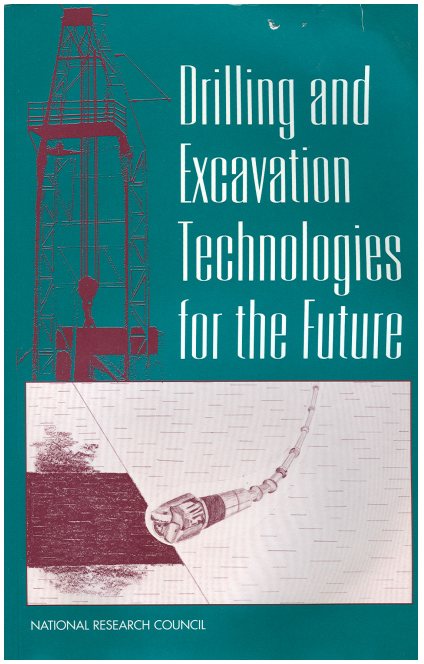
- **History**
  - PDCWEAR
  - Advanced Synthetic-Diamond Drill Bit Development Program
    - DOE's Oil & Gas Technology Partnership
    - DOE Office of Geothermal Technologies

- **Technology Status – A Decade Ago**
  - Roller Cone Bit technology mature - seal and bearing issues remain
  - Synthetic Diamond technology still young
    - Sandia's (Glowka,1987) cutter database available to the industry
    - PDCWEAR code available to industry
    - Limited bit product lines
    - Influence of cutter parameters not clearly understood
  - Drilling for easy targets
    - Oil & Gas: Medium-hard rock with hard-stringers
    - Geothermal: hydrothermal dominated resources
  - Drilling dynamics surfacing as a significant problem
    - Oil & Gas: not a show-stopper but heterogeneous formations introduce vibrations
    - Geothermal: Predominantly roller cones
  - Bottom hole telemetry via MWD alone
  - Limited active control technologies available downhole to modify conditions

Mechanical Drilling with Some Unconventional Methods

- **Drilling and Excavation Technologies for the Future, p54:**

  "A large number of unconventional methods of rock removal have been studied. When compared with mechanical drilling, these techniques have so far been found to be quite ineffective ...Nevertheless, the existing information on them should be reevaluated to reach firm quantitative conclusions concerning their potential, particularly for use in conjunction with mechanical drilling."



- **Direction from our DOE sponsorship:**
  - Address near-term improvements in-lieu of revolutionary approaches to rock reduction

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The challenges a decade ago
Ch. 5: Priorities for R&D - *Rock Excavation Tools*

1. **Physics of rock-tool interactions**

   "Research that focuses on the physics of rock removal processes is a prerequisite for designing improved drilling tools and should have a high priority for support."

2. **Improved cutter materials and bearings**

   "Additional R&D is needed on these wear-resistant cutter materials, and on these and other wear-resistant materials for high-speed bearings."

3. **Novel-hybrid drilling technologies**

   "The development of hybrid systems, in which novel drilling tools are used to lower the strength of the rock, and conventional mechanical drilling tools are used to break and remove it, are especially promising and should be pursued."

4. **Improved-mechanical drills**

   "Significant improvements in rock removal rates can also be obtained through evolutionary advances in conventional mechanical drilling tools. R&D efforts should focus on development of the following:

   - High-speed, high-power downhole motors
   - Guided percussion drills
   - Slim-hole drilling tools…

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Sandia's Role in Drilling Technology Advancements

- Sandia Research & Development program has closely paralleled the recommendations of the Committee on Advanced Drilling Technologies

- Sandia's Approach
  - Computational Modeling
  - Laboratory Testing
  - Field Trials
  - Partnerships
    - Industry (cost-sharing, CRADAs, etc)
    - University Collaborations
    - Industry Interaction

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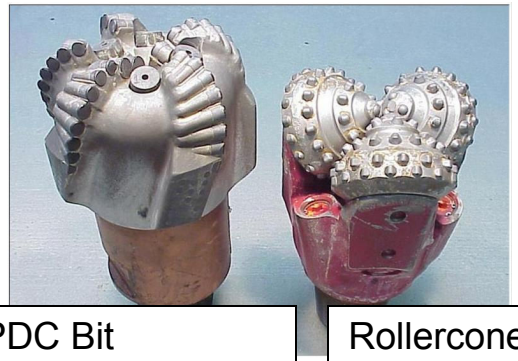
Why R&D on Drag Cutters for Drilling Hard-Rock ?

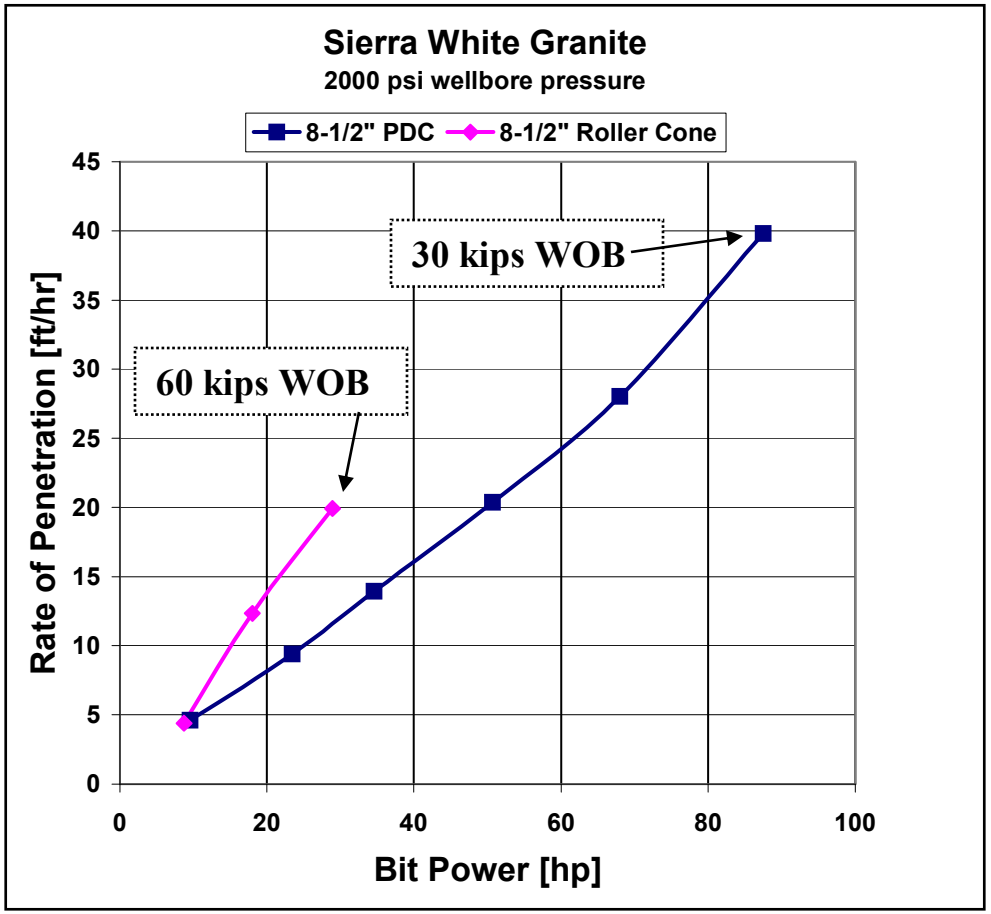
- **Sandia conducted testing at TerraTek that validates performance improvements available with drag cutters in Hard-Rock**

- **Roller Cones**
  - x Slow penetration rates
  - x Cone rotation required
  - x Moving parts subject to fail
  - x Bearing seals can fail at high temperatures
  - x Technology is mature, significant improvements unlikely
- **PDCs**
  - ✓ Aggressive cutting structure
  - ✓ No moving parts
  - ✓ High-temperature resistance



PDC Bit
(Matrix body, Medium-set)

Rollercone
(IADC 6-2-7)



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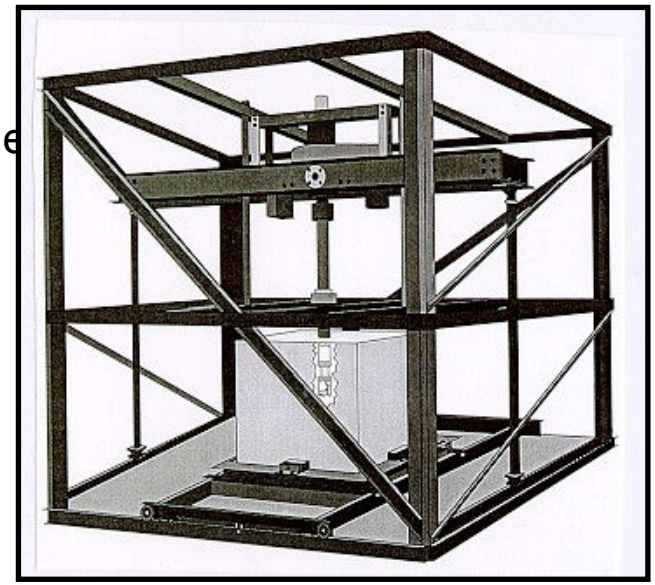
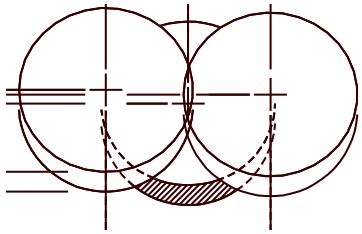
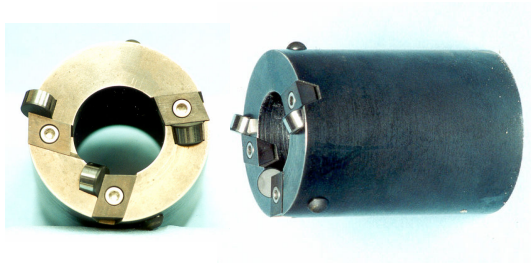
Facilities Developed to Support Research

- **Single Cutter Testing**
  - Linear Mill-Performance Testing
    - Cutter interaction testing (engagement tests, etc)
    - Industry support to evaluate track-set cutting structures
  - Vertical Turret Lathe-Abrasive Testing
    - Thermally accelerated wear experimentally observed

- **Hard-Rock Drilling Facility**
  - Allows cutter wear-testing
  - Emulates drilling configuration
  - Platform for evaluation of other candidate technologie
  - Testing has validated economic viability of PDCs in Hard-Rock







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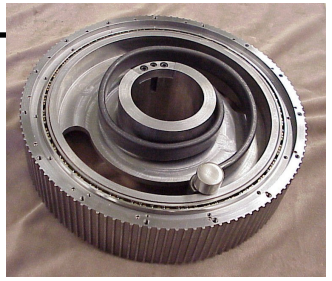
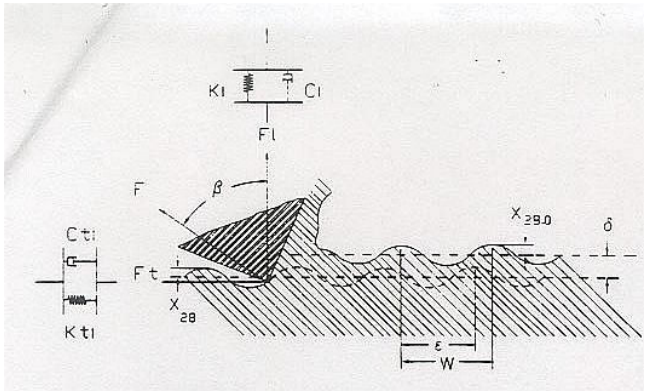
Laboratory simulation of drillstring compliance



- **Interaction between the rock, bit & drillstring**
  - Axial & Rotational compliance representative of a field drillstring
  - Fully instrumented
  - Drilling tests to determine influence of rock, bit design and drillstring properties
  - Demonstrated coupling between degrees of freedom
  - self-induced bit vibrations observed
  - Made comparisons to machine tool theory
  - Highlighted problem of drillstring vibrations
  - Demonstrated benefit of modification of drillstring compliance by testing various damper configurations



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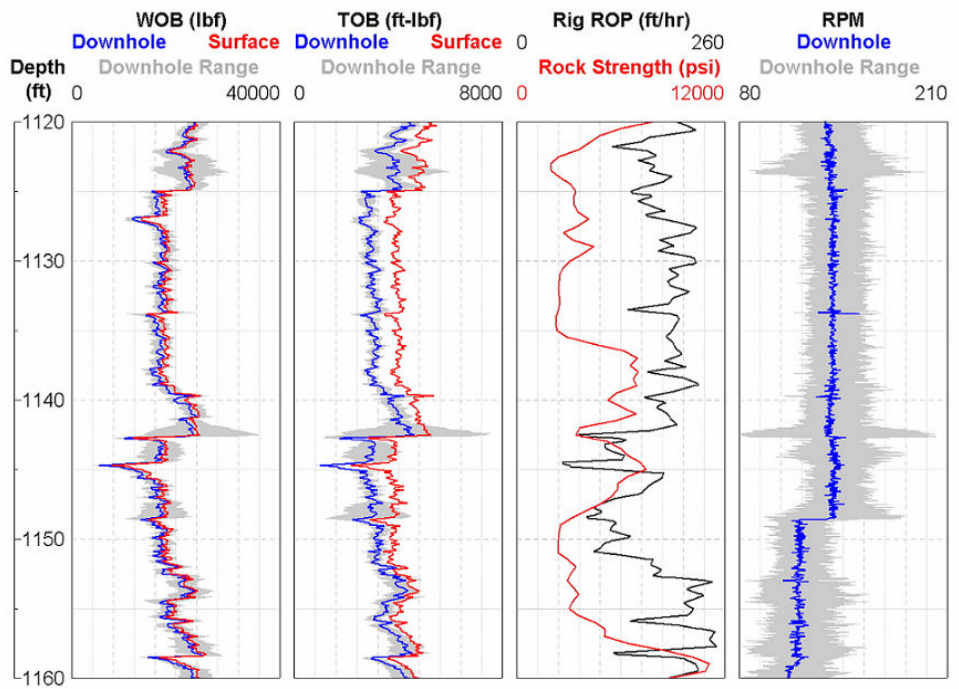
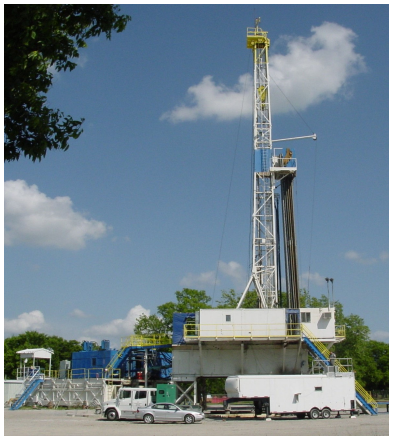
Addressing rock-tool-system interactions while drilling in the field

- Demonstrated a *viable DWD system* for acquiring, displaying, and applying real-time downhole data for:
  1) *active control* of the drilling process, and
  2) *post-test analyses* of bit designs and operational strategies

- DWD system allowed monitoring of rock-bit interaction in situ
  - Revealed dynamic nature of drilling process
  - Highlights performance of operating conditions for vibration mitigation
  - Demonstrates need for integrated bit/BHA & drillstring design





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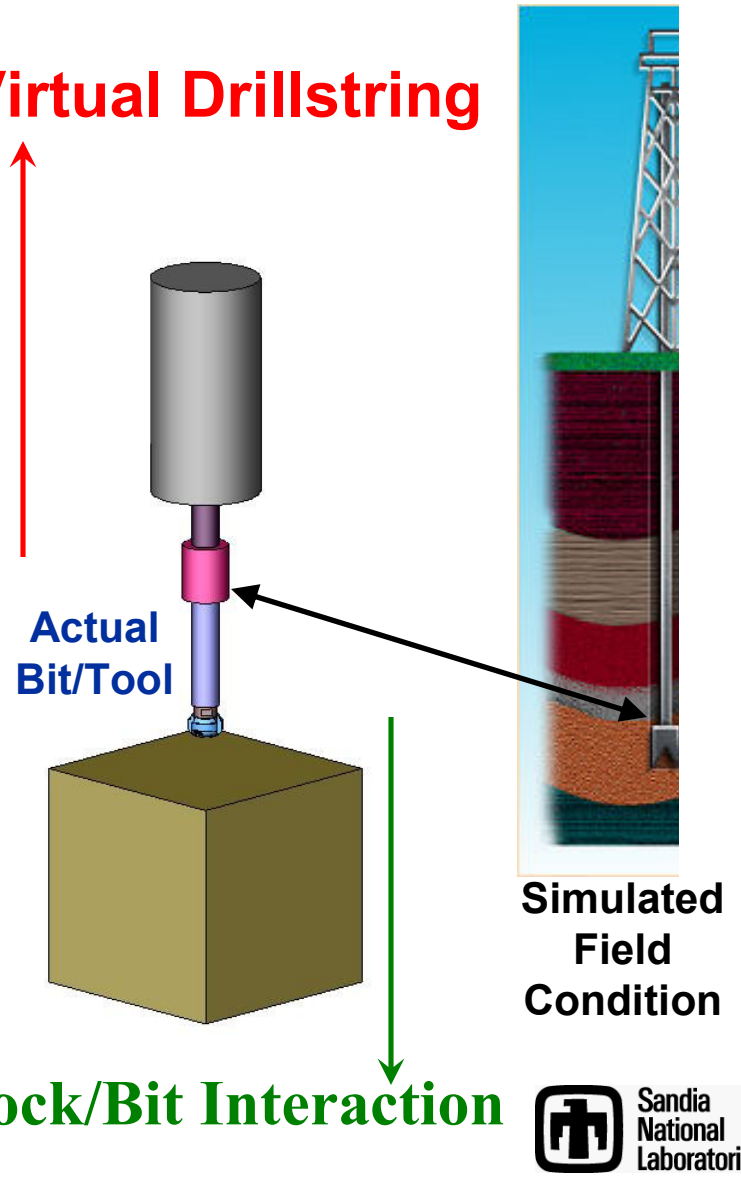
Advanced Drilling Dynamics Simulator

- A controlled laboratory setting for a drill bit that is representative of a simulated field drilling condition so that the bit response may be monitored and characterized before committing the bit and tools to expensive field drilling conditions
  - *Research causes of vibration*
  - *Identify deficiencies in drill bit material properties and designs*
  - *Validate hardware and software for downhole tools*
  - *Evaluate Best Practices*

➡ An enabling technology for developing advanced systems to penetrate hard rock



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Advanced Drilling Dynamics Simulator (cont.)

- Integrate advanced technology in servo-hydraulics, computational modeling and controls to represent the dynamic properties of virtually any drillstring in the lab

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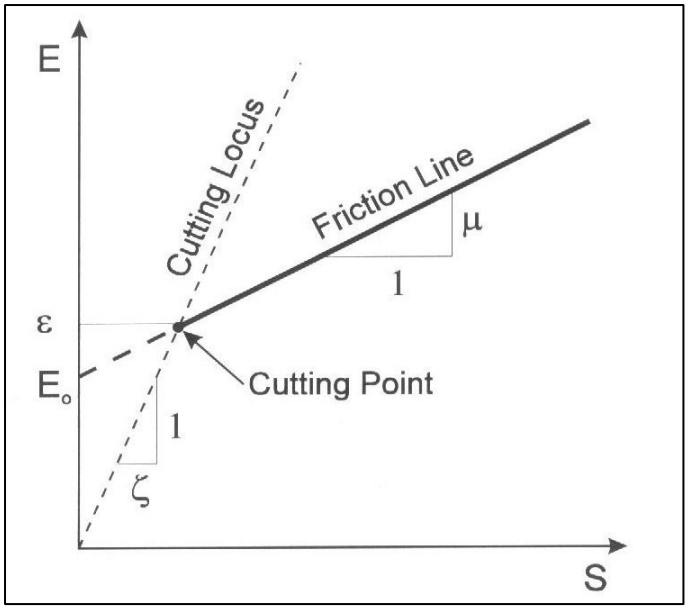
Physics of rock-tool interactions
Technology Status

- **Specific Energy Monitoring**
  - Glowka's single cutter data
  - Detournay model
  - Correlations between specific energy and compressive strength (Ref. Teale, 1964)
  - Mechanical Specific Energy monitoring by Industry (e.g., ExxonMobil's Fast Drill Process, others)



- **Relevant Industry Trends**
  - New emphasis on Integrated Bit/BHA Selection
  - Services emerging to predict dynamics that have a detrimental effect on directional control, tool reliability, drill string integrity, and drilling performance (e.g., Smith i-DRILL)

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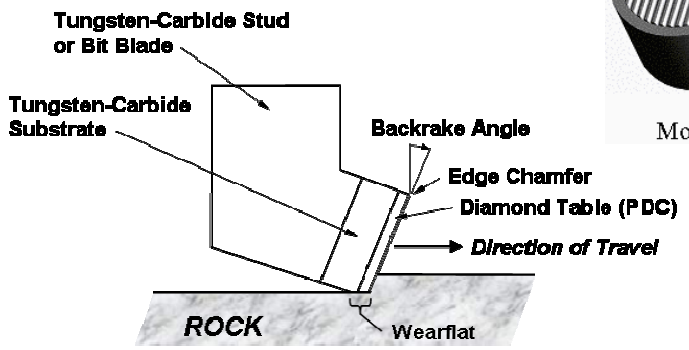
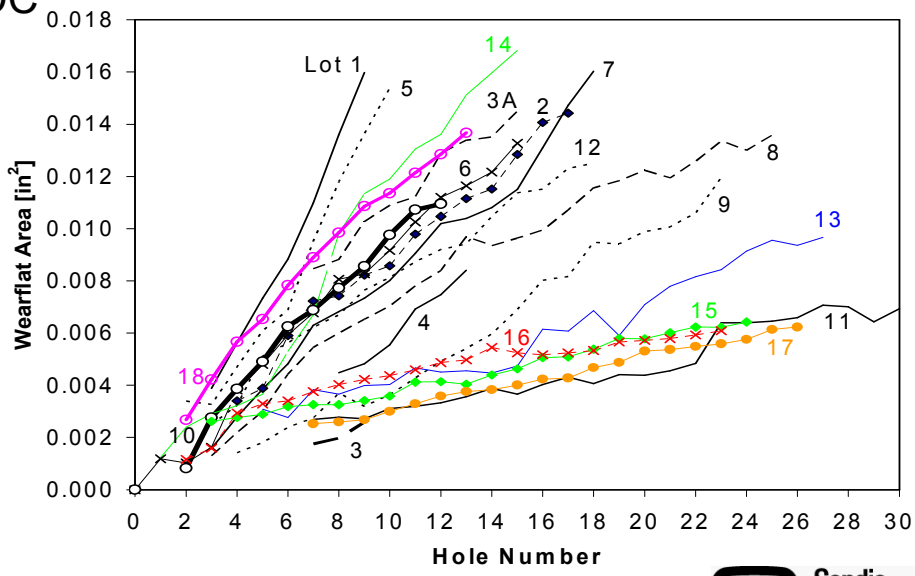
Advanced Cutter Development

- Fundamental Parameter Study with US Synthetic
  - Controlled study to examine influence of cutter parameters on drilling parameters and cutter integrity
  - Abrasion: Achieved factor-of-10 improvements in cutter life
  - Revealed combined impact and abrasion resistance for fine-grained cutters
  - Design and processing parameter variations strongly affect the drilling, abrasion, and impact performance of PDC cutters
- TSP Cutter Developments with Technology International
  - Microwave brazed attachment bonds
- Boron sub-oxide cutters (Explosively-Compacted) with NM Institute of Mining and Technology
- Claw Cutter evaluation with Dennis Tool Company





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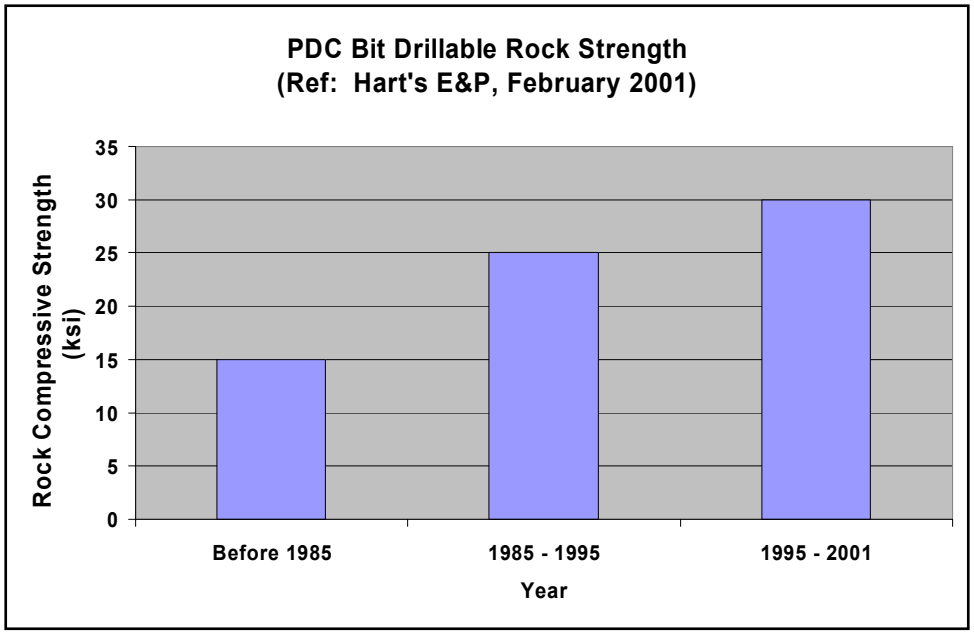
Improved cutter materials
Technology Status

- **PDC Evolution**
  - *Technology maturity*
  - *Thicker diamond tables*
  - *Non-planer diamond/carbide interface*
  - *Functionally-graded diamond*
  - *Processing conditions*
  - *Quality control*
  - *Inspection techniques*
  - *Laboratory testing*
- **Status of Abrasive Cutters**
- **Roller cone inserts**



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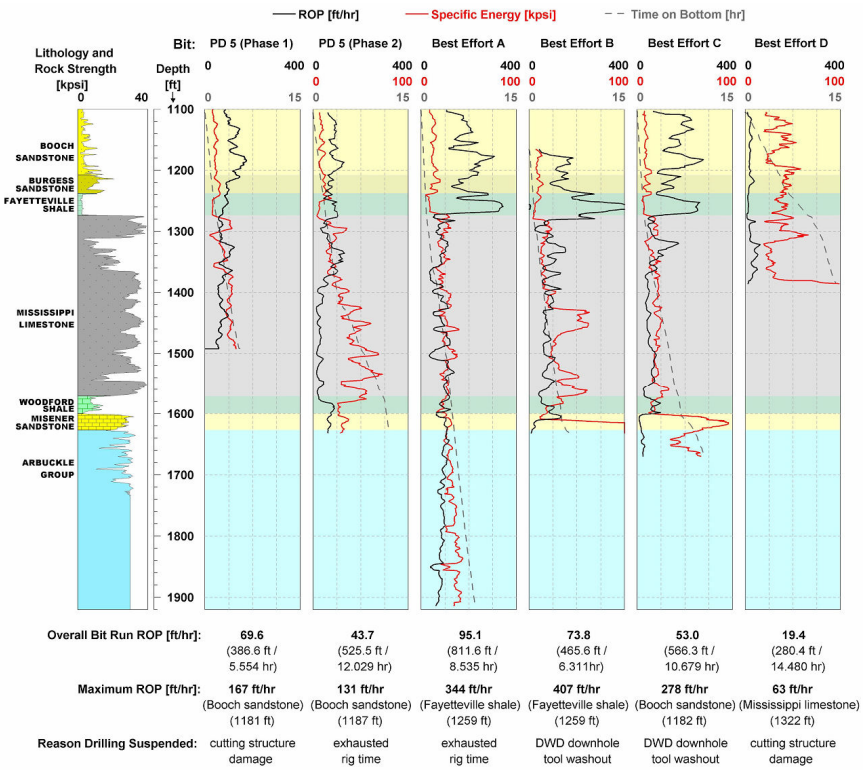
Improved Bits

- PDC Bit CRADA (Field demonstration)
  - Established *benchmark hard-rock drilling data* for conventional and “best effort” drag bits.
  - Achieved *improved drilling performance* through *joint deployment* of *advanced bit technology* and *DWD* capabilities.
  - *Exceeded baseline roller bit ROP* (20 ft/hr) *by a factor of 2.6 to 4.8*, surpassing the factor-of-two improvement objective.
- Evolutionary Improvements PDC Bit Designs
  - Anti-whirl (Track-set, Low-friction wear-pad, etc)
  - Impact arrestors
  - Bits Custom Designed for Application by ADEs world-wide



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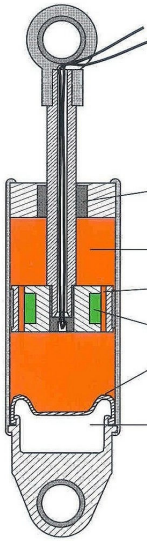
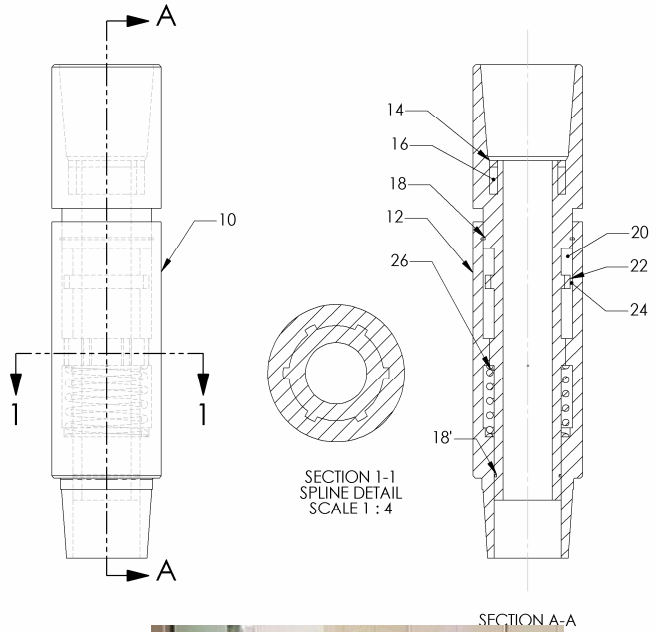
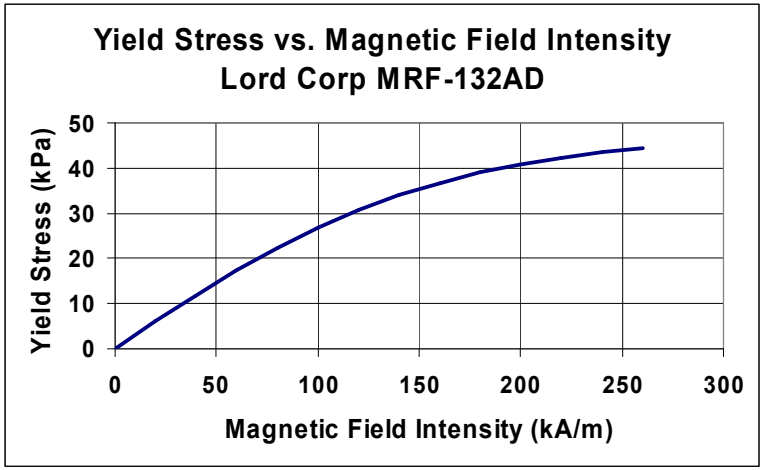
MR Fluid-Based Dampers for Drilling Heterogeneous Formations



- Bit vibration mitigation using Magnetorheological (MR) Fluids
  - Carrier fluid with iron particle suspensions
  - Yield stress varies with magnetic field intensity
  - Damping force controllable with coil current
  - Fast response (few ms) and low power (few Watt
  - Can be remotely powered and controlled
- Prototype testing completed
- Patent issued to Sandia Corporation
- Pursuing commercial partner/field trials

US Patent 7,036,612 B1





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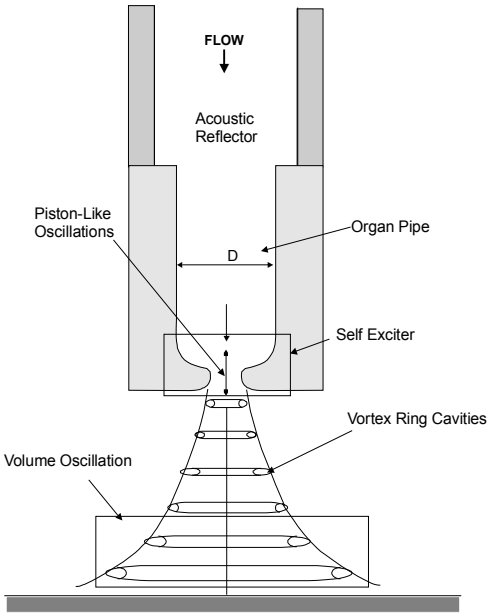
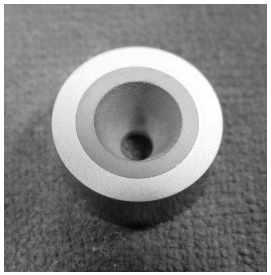
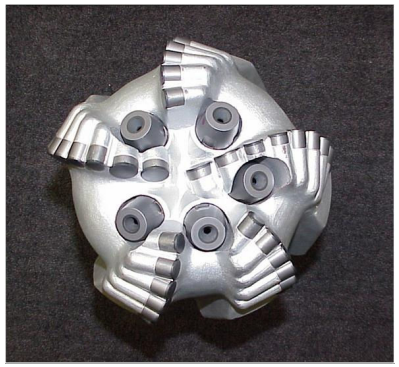
Passively-Pulsating, Cavitating Bit

- Cooperative project between Sandia, DynaFlow, Security DBS & TerraTek
- Use pulsating, cavitating jet technology (Resonance established in a tuned chamber upstream of the nozzle orifice);
- Collapsing cavities spawn microjets that produce very high impact pressures capable of breaking the rock
- Advantages
  - More erosive than conventional jets at a given pressure differential;
  - Create negative pressure distribution aiding bottom hole cleaning;
  - Cavitate at lower pressure differential at a given ambient pressure than conventional nozzles.
  - Demonstrated 20-40% improvements in ROP in confined drilling tests at TerraTek
  - Commercialization currently underway





Direct-Sintered PDC Orifice



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Progress in Rock Reduction towards a Smart Drilling System

- **Technology Status – Today**
  - Roller Cone technology is mature – few improvements likely
  - Synthetic diamond technology still maturing
  - Custom bit design – Many companies have integrated CAD/Cutting structure models
  - Oil & Gas & Geothermal have similar targets
    - Hot Formations
    - Hard Rock
    - Deep Reservoirs
  - Rotary Steerable Systems have made drilling for specific targets more versatile
  - Drilling dynamics continues to be a cause of Non-Productive Time in hard formations

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Progress in Rock Reduction towards a Smart Drilling System

- **Progress has been made towards a**

  SMART DRILLING SYSTEM, that is

  – equipped with hard cutter materials, and includes emerging technology for
  – compensating BHAs (controllable dampers) to reduce bit vibrations, and
  – high speed bi-directional telemetry to the surface, to
  – monitor the state of the drilling unit so we can
  – modify drilling inputs (i.e., specific energy matches inputs to measured resistance) to allow us to
  – control the spatial position of the bit (i.e., RSS), and
  – drill the range of heterogeneous formations that may be encountered.

- **Research & Development in advanced drilling technology has improved the drilling system resulting in:**
  – Higher ROPs & Longer Bit Life
  – Decreased cost per foot
  – Improved target access

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Recommendations

Priorities for Research

- Develop Advanced Drilling Dynamics Simulator to address:
  - Platform for researching bit vibrations
  - Support development of advanced drill bit designs & materials
  - Test & evaluation of downhole hardware
  - Evaluation of best practices, and
  - Foster development of Smart Drilling Systems
- Address Integrated Bit-BHA-DS selection
- Continue work aimed at the development and validation of a new class of ultra-hard drag cutters
- Field testing & commercialization of MR Fluid-Damper for BHA stabilization
- Continue development of unconventional methods of rock reduction

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