SAND2006-5692C

Development and Testing of a PDC Bit with Passively-Pulsating Cavitating Nozzles

Presented at the
Geothermal Resources Council Annual Meeting
September 12, 2006

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National Nuclear Security Administration

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under contract DE-AC04-94AL85000.

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Introduction

- Sandia/DOE Mission
  - Develop technology to reduce drilling costs and thereby foster exploration and development of geothermal resources
- Short-Term Approach
  - Improve the penetration rate and life of conventional drill bits used by the drilling industry for geothermal well-field construction
  - Notable among the conventional bits currently used by the drilling industry at large are Polycrystalline Diamond Compact (PDC) drill bits

Why R&D on PDC Bits for Geothermal Drilling?

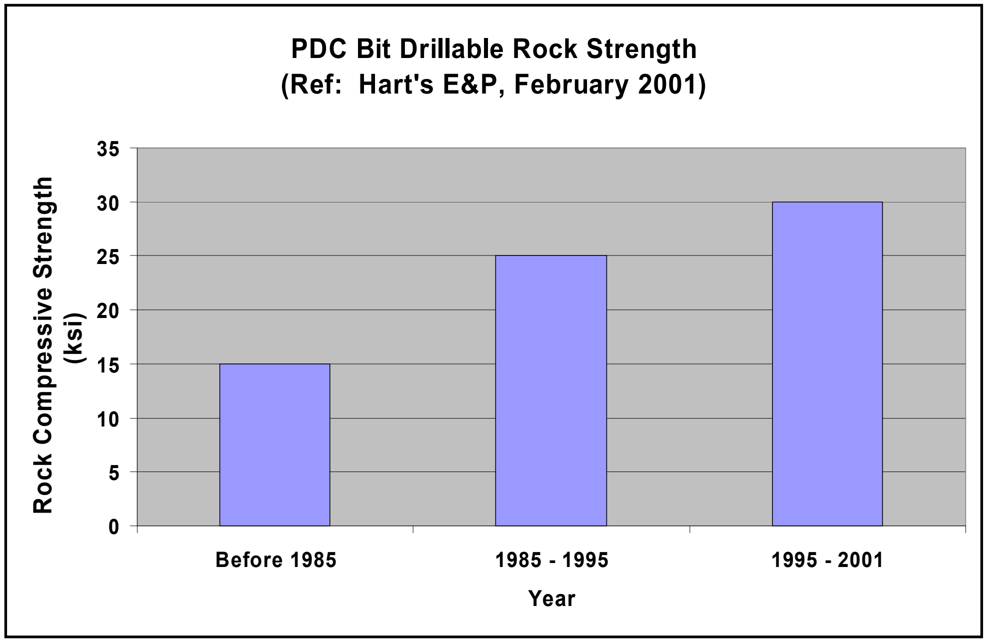
- PDC Bits have promise over existing bit technology

PDCs

✓ Aggressive cutting structure
✓ High ROP
✓ No moving parts
✓ High-temperature resistance

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*



- Drillable compressive strength is achieving geothermal-like formations

- **PDC Bits are challenged by Abrasion & Impact Damage**
- **Consider hydraulics for improvements**

Project Focus

- The hydraulic horsepower on a conventional drill rig is significantly greater (10x) than that delivered to the rock solely through bit rotation

- This project seeks to leverage this hydraulic resource to help extend PDC bits to geothermal drilling

Hydraulics Research by Others

- High Pressure (>10,000 psi)
  - Attempts have been made to commercialize
  - Invariably failed because of difficulties of using high pressures on a drill rig
  - Equipment maintenance is a costly nuisance

- Moderate Pressure (<10,000 psi)
  - Researchers have observed reduced rock cutting forces when a moderate-pressure water jet is directed at the rock surface ahead of a drag cutter
    - Hood found that a 7,000-psi waterjet reduced cutting forces on a tungsten carbide cutter in Norite (44,000-psi compressive strength) by about 50%
    - Dubugnon showed 10-20% reductions in drag cutter forces with nozzle pressures as low as 1,000 psi in Bohus Granite (29,000-psi compressive strength)

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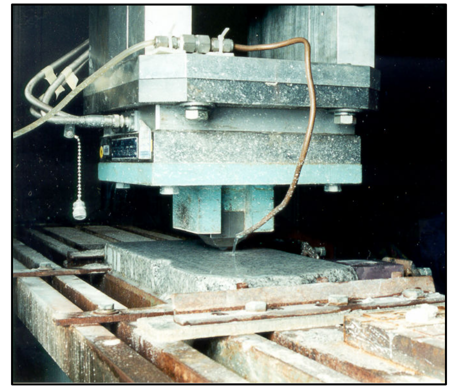
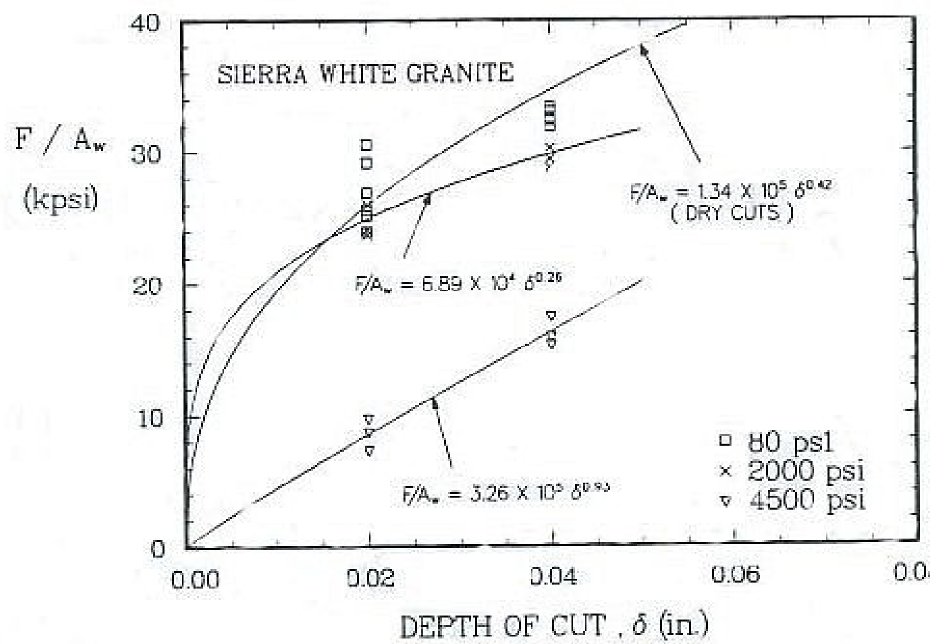
Hydraulics Research at Sandia

Mechanical Cutting with Jet Augmentation

- Linear PDC cutter scratch tests by Glowka
  - 4,500 psi water jet
  - 50-65% reduction in penetrating stress required to cut the rock



- High pressure jets are able to increase ROP in PDC bits by two mechanisms:
  - High pressure fluid enters the rock fractures created by the cutter, hydraulically extending the fractures and reducing the mechanical forces required to form a rock chip
  - Jets blast away very fine rock flour increasing the stress concentration in the rock and decreasing the forces required to cut the rock



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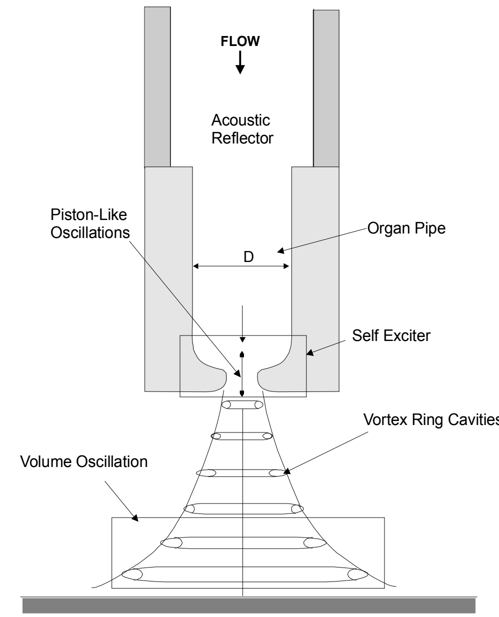
Cavitating Jet Technology

- Cavitation introduces pressure enhancements
- Moderate pressures can induce cavitation
- Concept used on this project:
  - Passively-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



StratoJet® Concept

- 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

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Technical Approach

- Form cooperative team
  - DynaFlow - *owner of the StratoJet® patents*
  - Security DBS - *a PDC bit manufacturer*
  - TerraTek - *a drilling laboratory*
  - Sandia National Laboratories - *overall project integrator*
- Work Scope
  - Develop Prototype Bit
    - Select Bit (cutting structure)
    - Specify Hydraulic Parameters
    - Specify Nozzle / Orifice Configuration
    - Develop Cavitation Resistant Orifices
    - Integrate Hydraulic Design
    - Fabricate Bit
  - Conduct laboratory-based drilling demonstration tests
    - Use realistic hydrostatic pressures
    - Obtain meaningful penetration-rate data
    - Evaluate cavitation suppression

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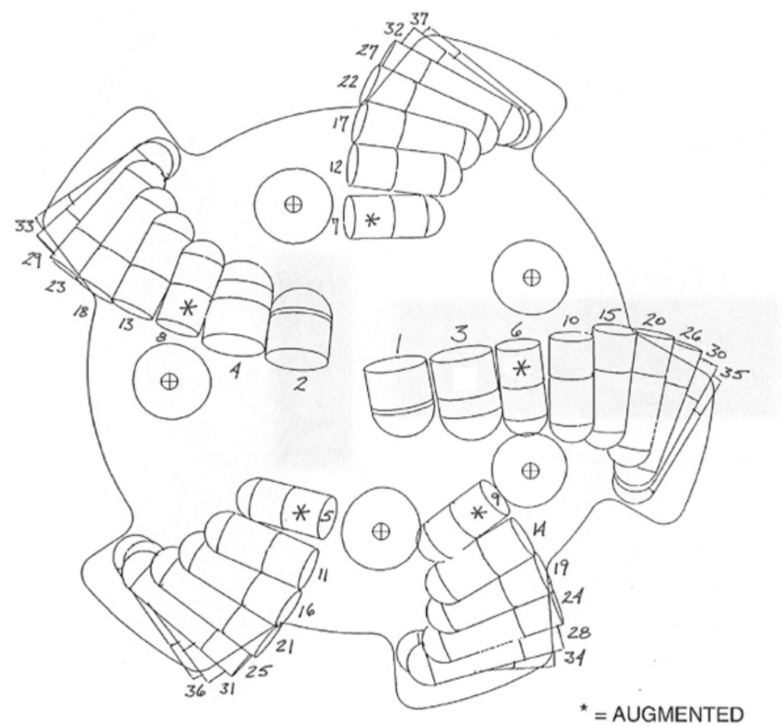
Bit Selection

- Bit Size
  - Diameter 8½ inches
  - Applicable to geothermal wellbore construction
  - A range is required - well diameters at TD often near 8½"
- Use bit from existing product line at Security DBS
  - Proven cutting structure
  - Modify to accommodate organ pipes/cavitating nozzles
- Matrix-body type bit
  - Cast tungsten-carbide material
  - Superior erosion resistance to that offered by steel-bodied bits
- Cutting Structure
  - Five-blade, medium-set, matrix body PDC bit
  - Track set bit
  - Conventional implementation incorporates one nozzle per blade

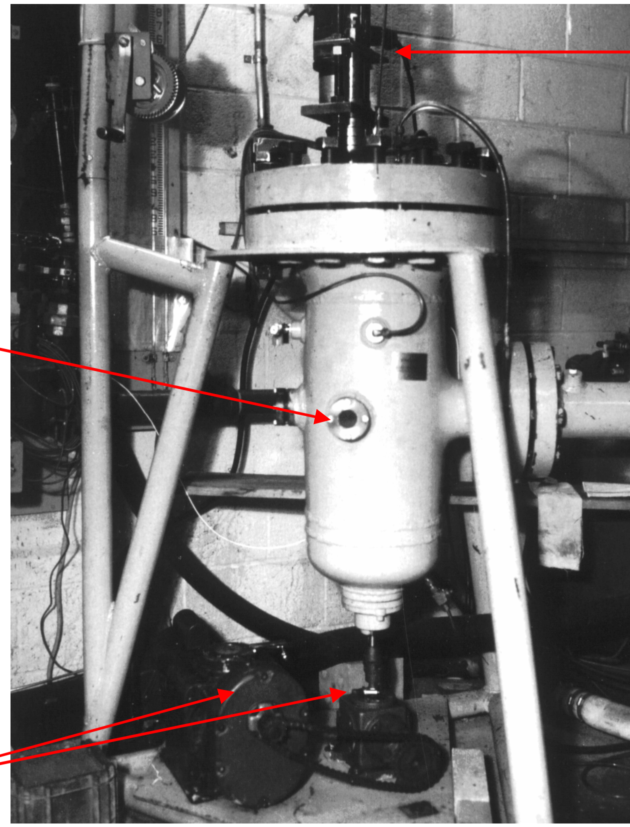


Bit Cutting Structure

Hydraulic Parameter Selection

- Differential pressure across the orifices
  - Large to ensure advantage apparent in bit performance
  - 5,000 psi
  - Compatible with cutter testing that showed significant cutter force reductions in Sierra White Granite when the pressure drop reaches 4,500 psi
- Flowrate
  - 300 gpm for an 8½ inch diameter bit
- Mud Properties
  - 10 lb/gal water-based drilling fluid
  - Commonly used in geothermal drilling

Testing Conducted at DynaFlow
Specification of Nozzle/Orifice Configurations



DYNAFLOW's
High Pressure Cell (HPC)
Ambient Pressures Up to 2800 psi

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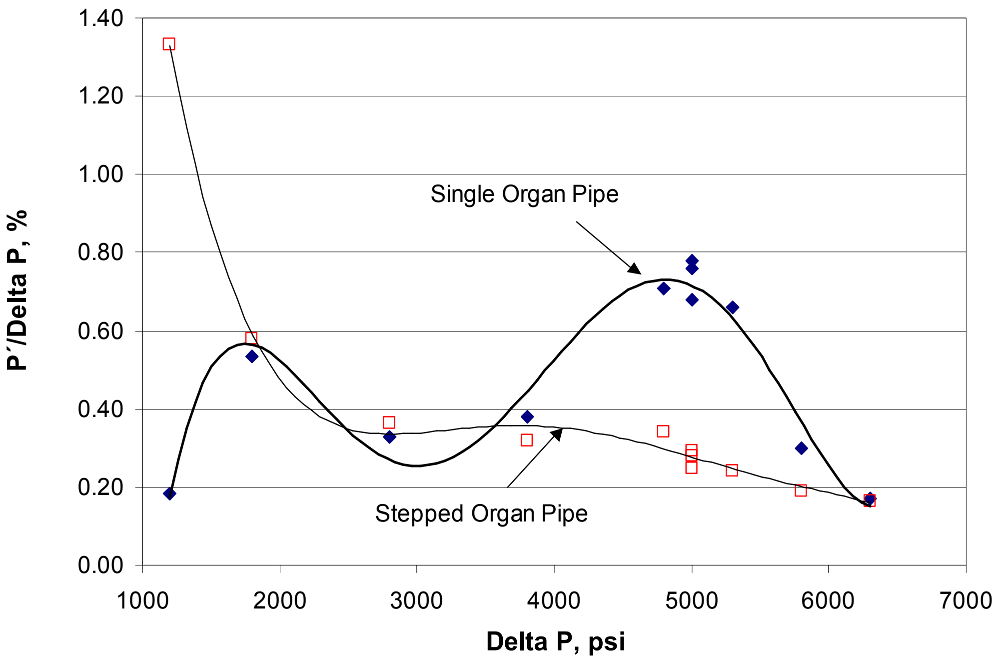
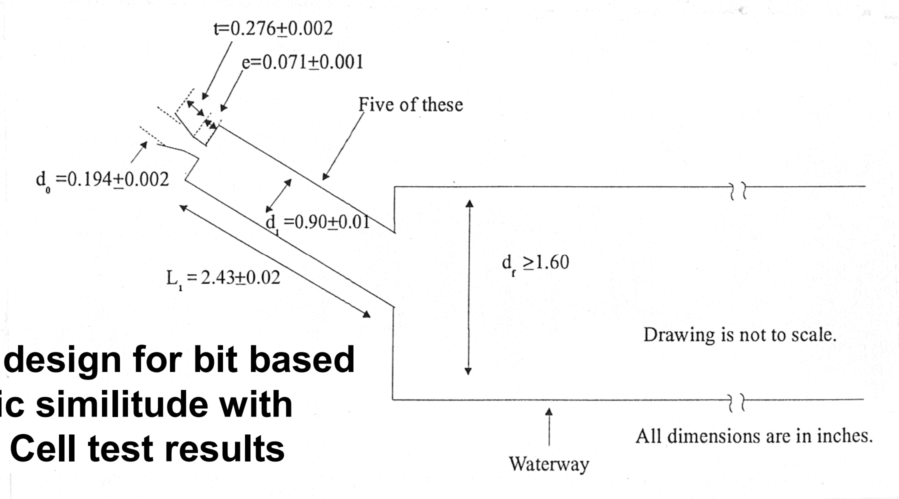
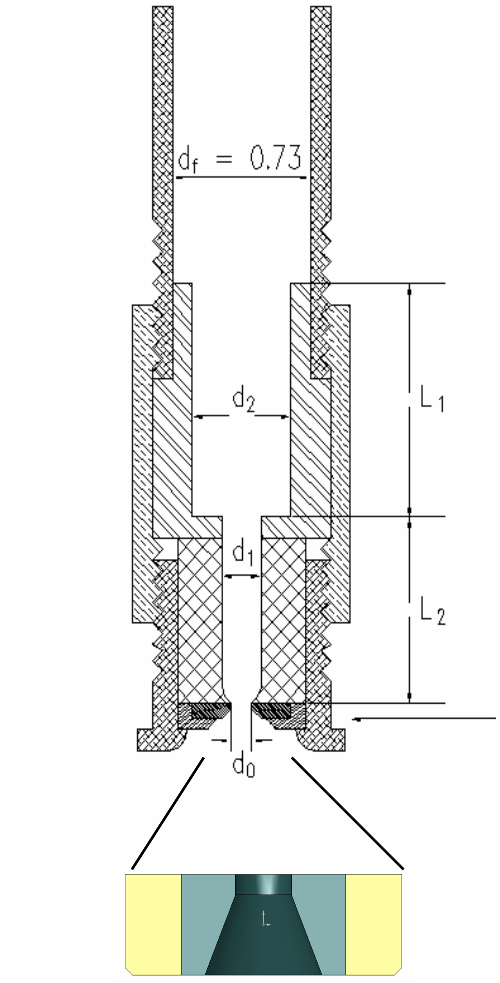
Specification of Nozzle/Orifice Configurations (cont.)

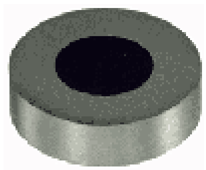




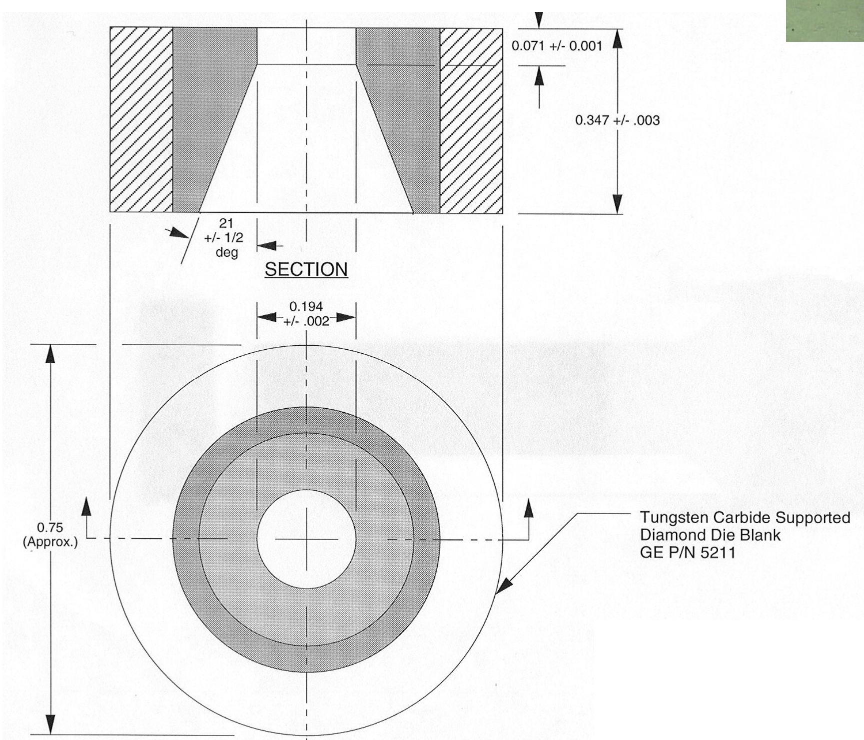


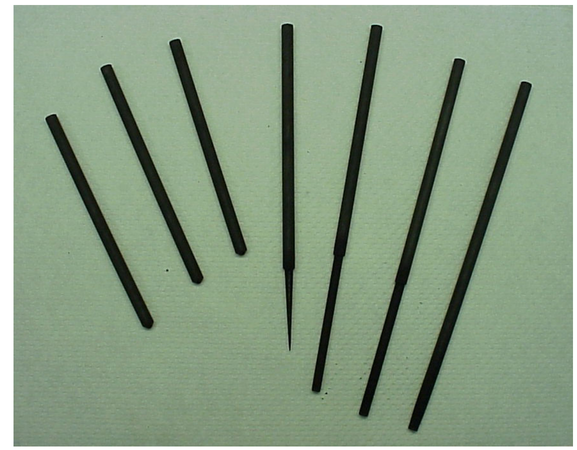
Nozzle/Orifice design for bit based upon geometric similitude with High Pressure Cell test results

Development of Cavitation-Resistant Orifices

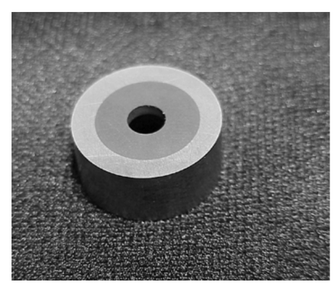


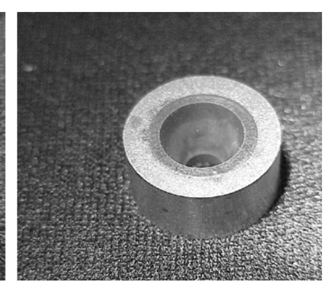
Orifice profile within the tungsten carbide supported polycrystalline diamond





Entrance (left) and exit views (right) of orifice produced from tungsten carbide supported polycrystalline diamond





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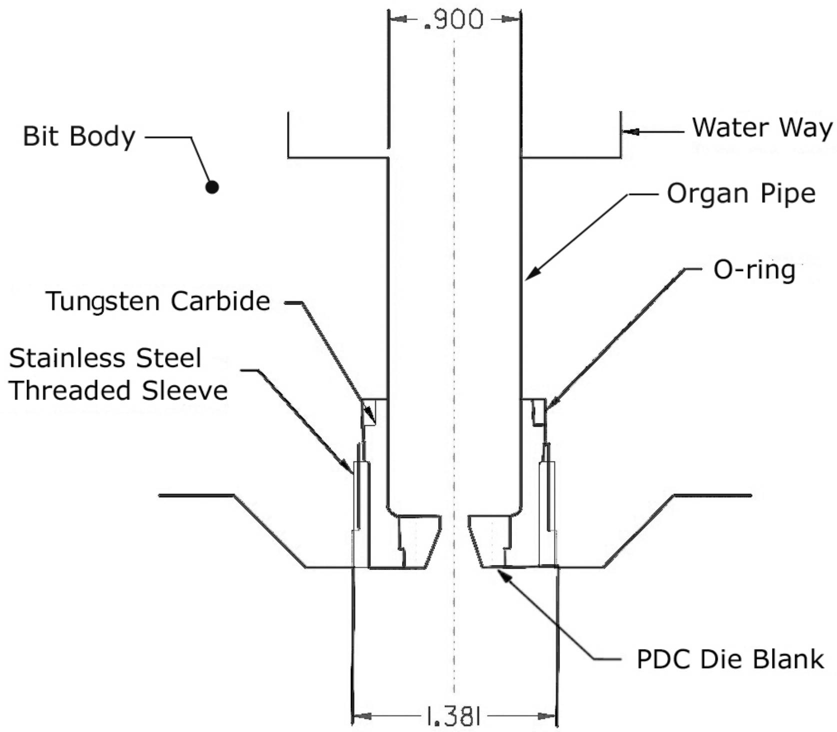
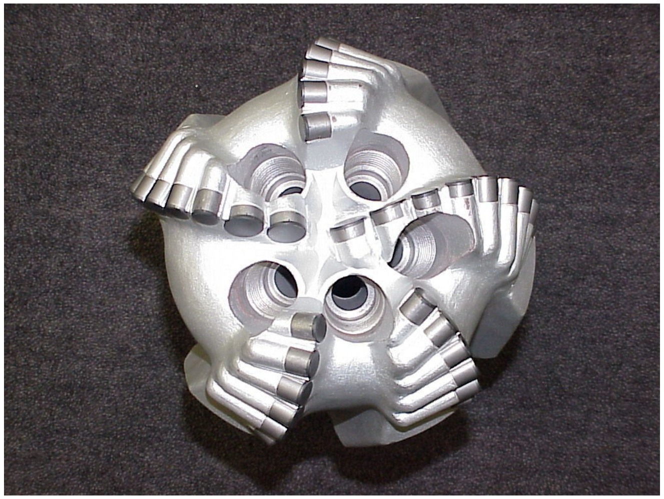
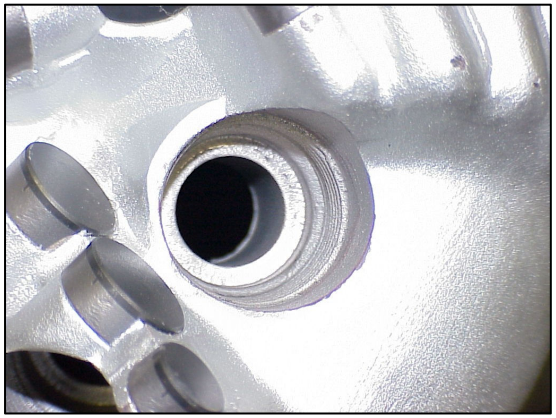
Prototype Bit Development

- Interchangeable nozzle design







Approach to integrate an interchangeable nozzle design with an organ pipe cast into the bit body

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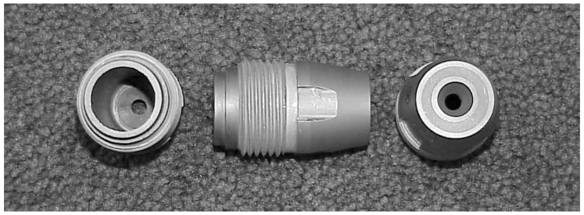
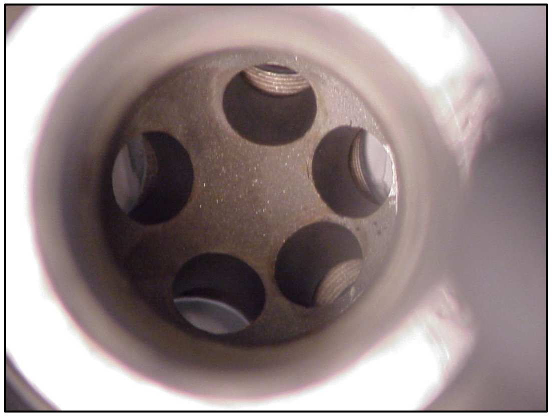
Prototype Bit Development (cont.)

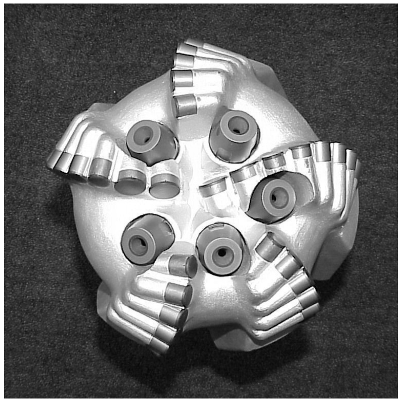
Isometric view of the nozzles,
organ pipes, and central waterway of the bit



Nozzle assemblies consisting of a tungsten carbide body with brazed-in PCD orifice



View down bit waterway



Bit with cavitating nozzles installed

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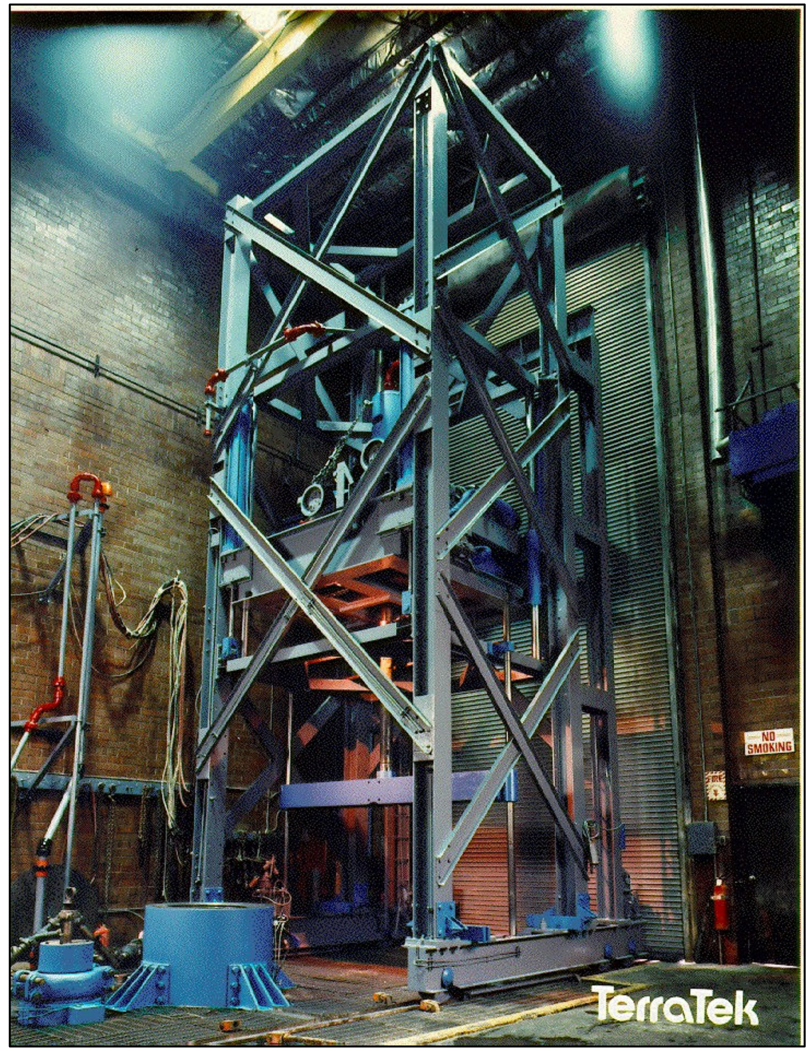
Full Scale Drilling Tests at TerraTek



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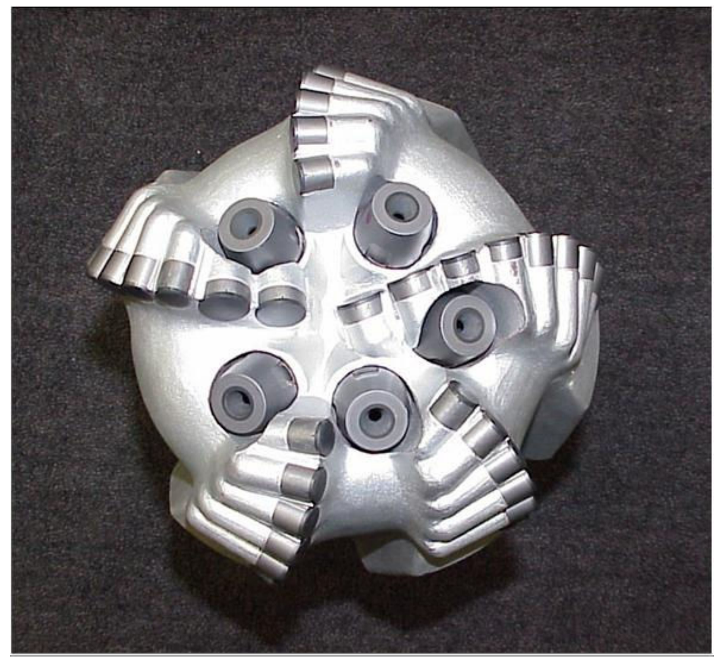
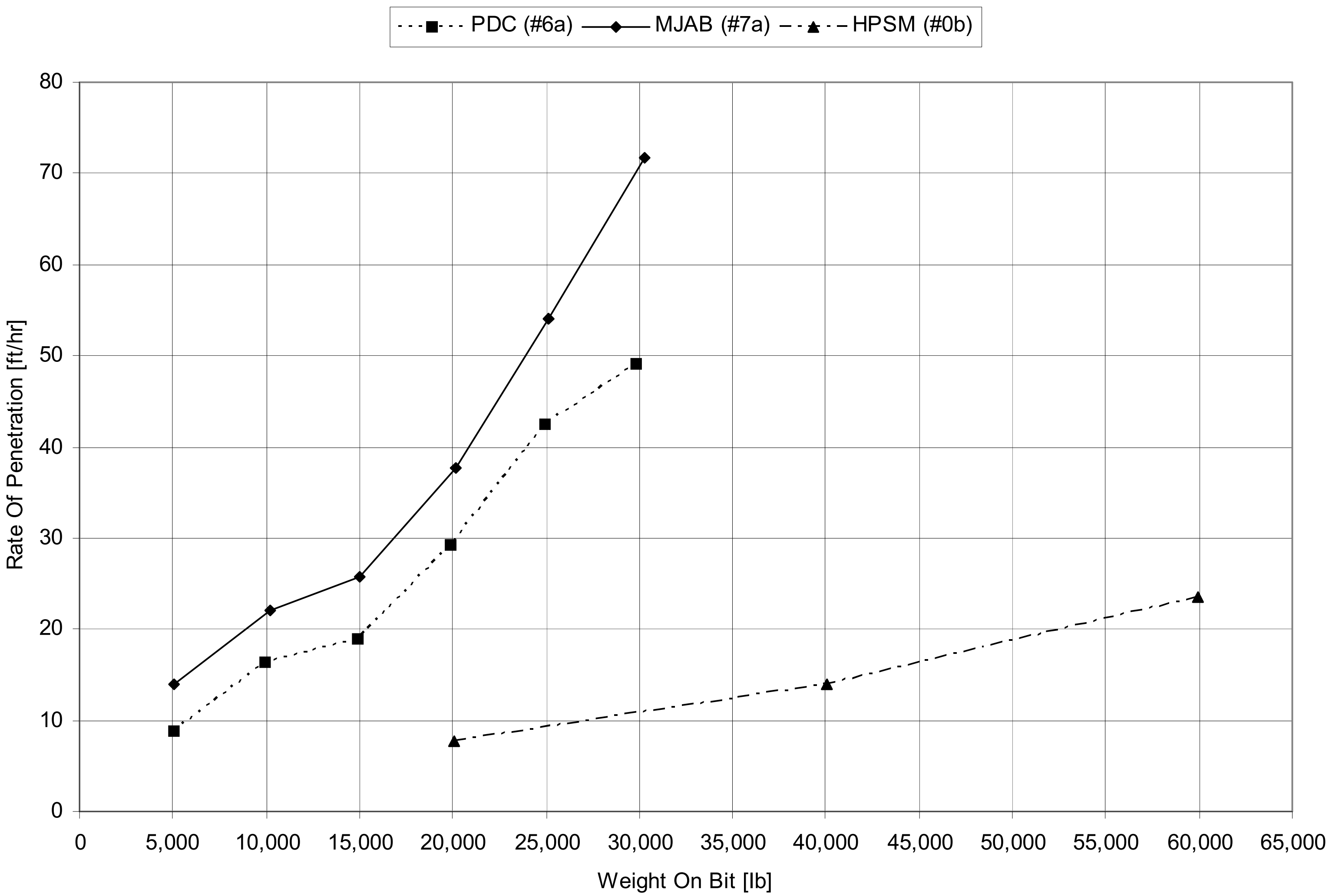
Flow Test Results

- Qualify bit for drilling tests
- Observe nozzle/orifice performance

Erosion pattern created in
Nugget Sandstone (18,000 psi UCS) during flow test



Laboratory Test Results



Rate of penetration versus weight on bit in Crab Orchard Sandstone at 2000 psi wellbore ambient pressure.

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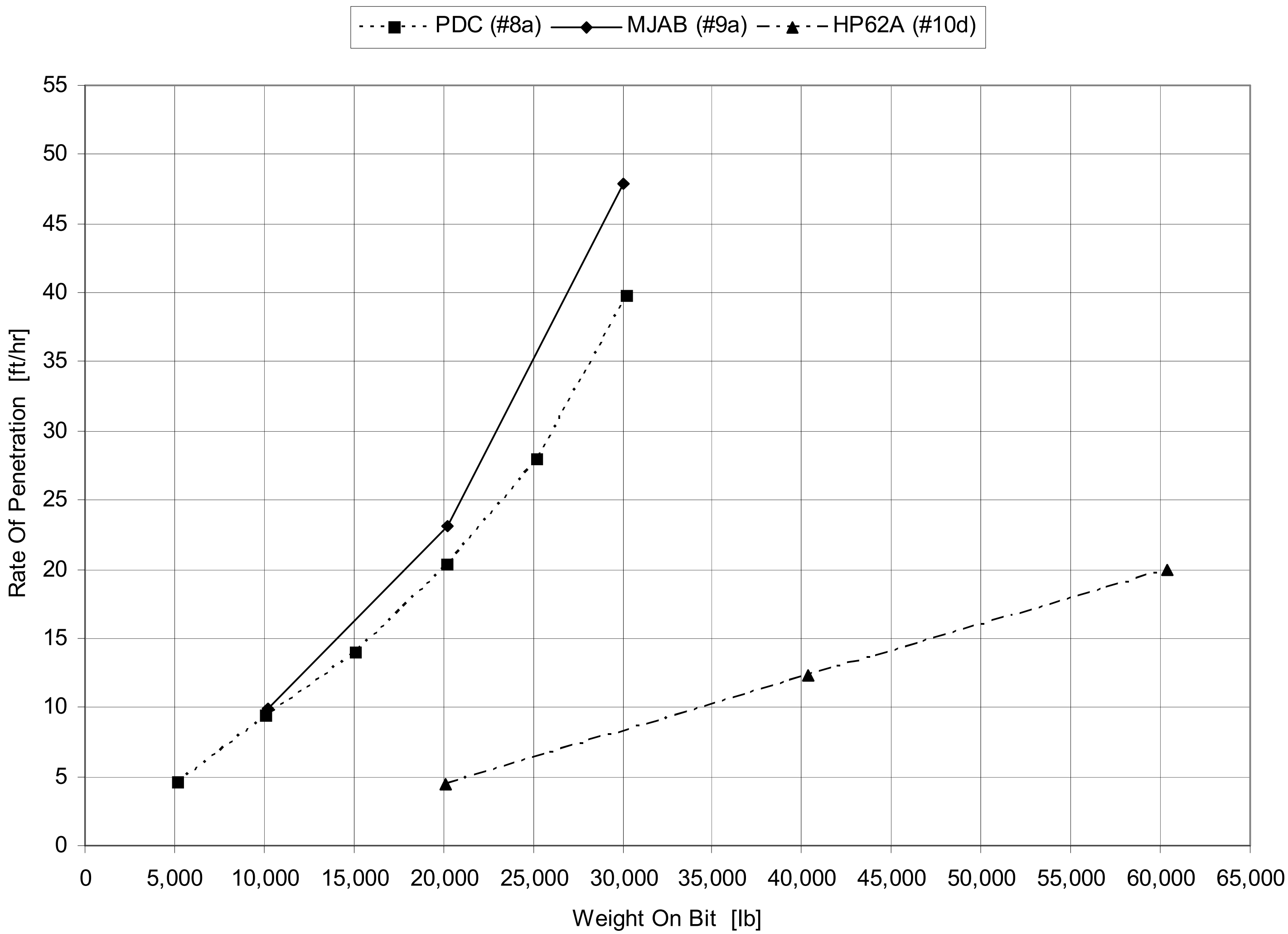
Laboratory Test Results



Rate of penetration versus weight on bit in Sierra White Granite at 2000 psi wellbore pressure.

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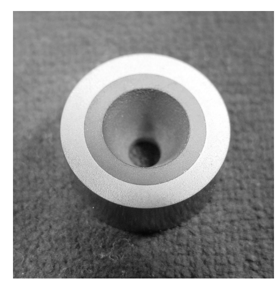
Results

- Demonstrated 20-40% improvements in ROP in confined drilling tests
- Reduced cutter forces
- No evidence of cavitation suppression in bit performance
- Some erosion apparent on bit face
- Further performance improvements are possible with an integrated approach to hydraulic/cutting structure design
- Development of cavitation-resistant orifices from tungsten carbide supported PDC is significant
- Direct-Sintered PDC orifices have since been developed by US Synthetic reducing orifice development costs

Bit near completion of testing indicating some erosion (Note installation of standard nozzles)



Direct Sintered Orifice

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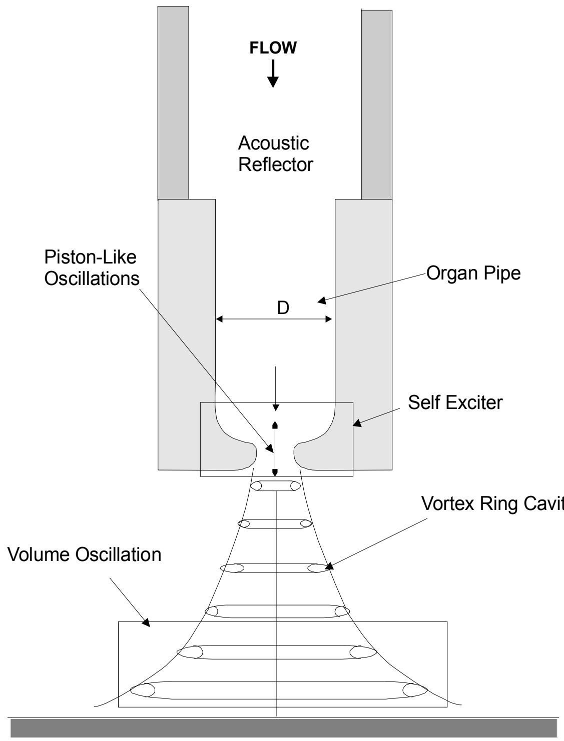
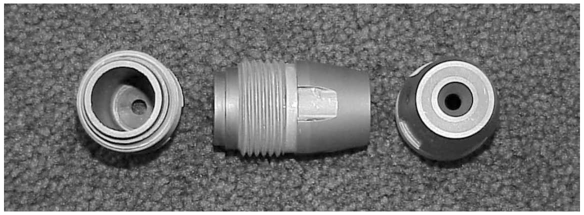
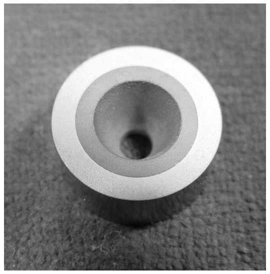
Summary and Conclusions

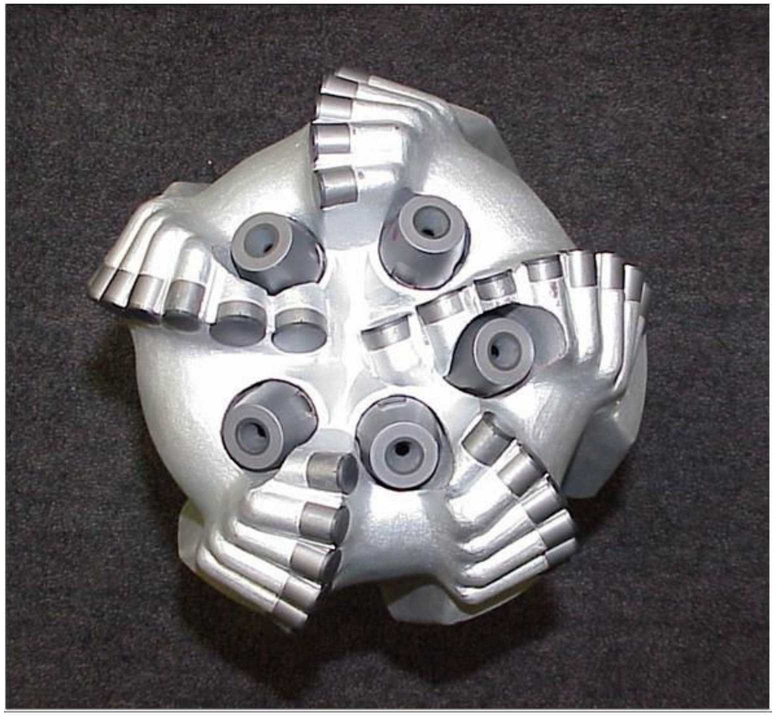
- Successfully demonstrated a Passively-Pulsating Cavitating Bit
- Enabling technology for PDCs in geothermal drilling
- Field testing is needed
- Commercialization currently underway
  - Low delta-p bit (1500-2000 psi) currently under consideration for development by a large operator

Questions?









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