SAND2008-2317P

Geothermal Research

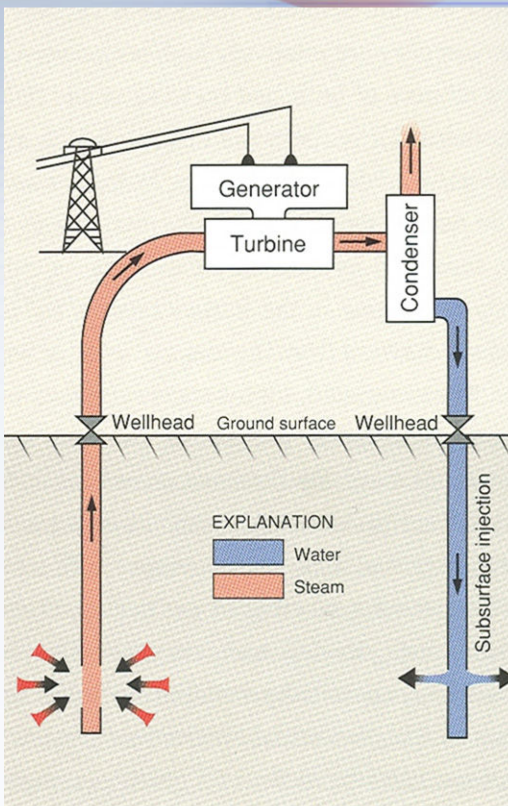
Geothermal Research Department
Sandia National Laboratories

April 8, 2008

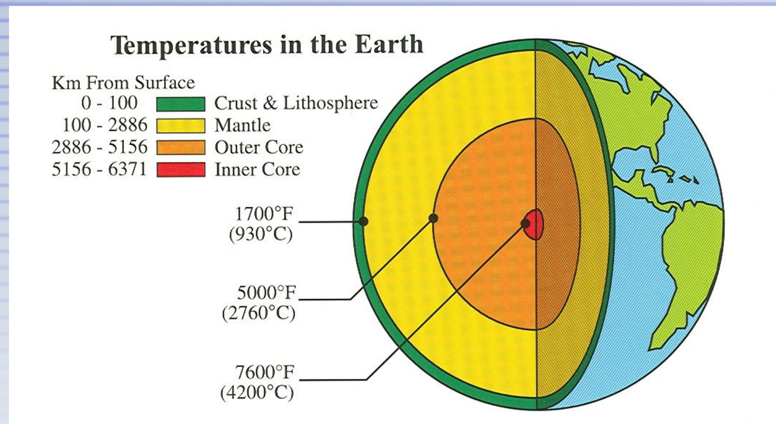
Sandia National Laboratories

Geothermal Energy Overview

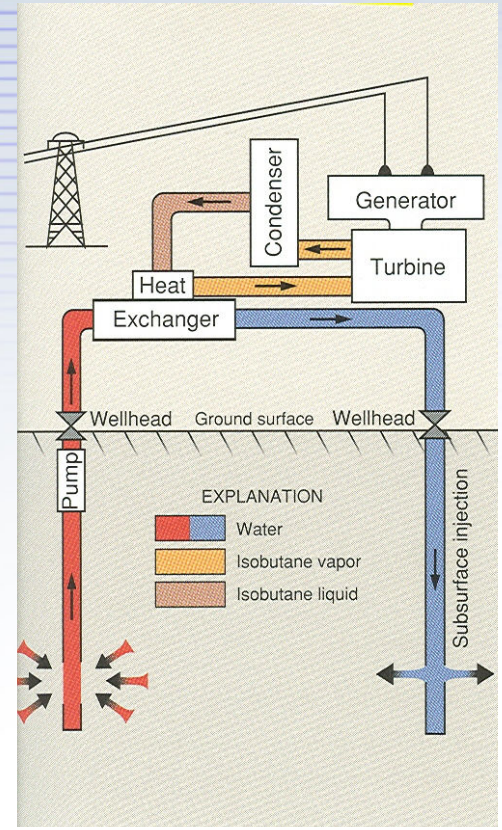
Ref: Tapping the Earth's Natural Heat, USGS Circular 1125, 1997.



Vapor-dominated hydrothermal system



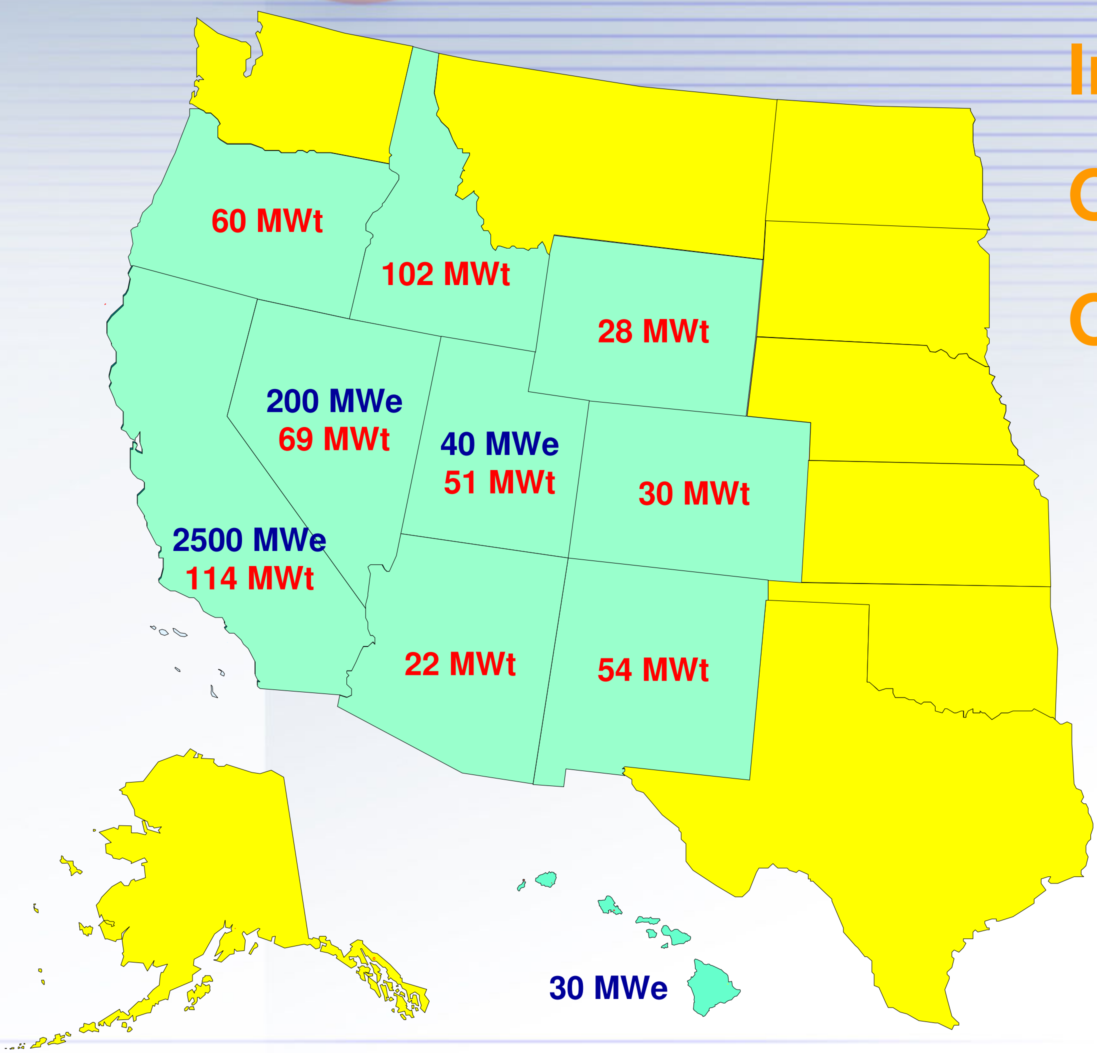
Geysers, Santa Rosa, CA



Moderate temperature binary system

Sandia National Laboratories

Geothermal Energy Installed Capacity



Installed:

Over 2800 MW (electric)

Over 500 MW (heat)

Greater Than 20 MW

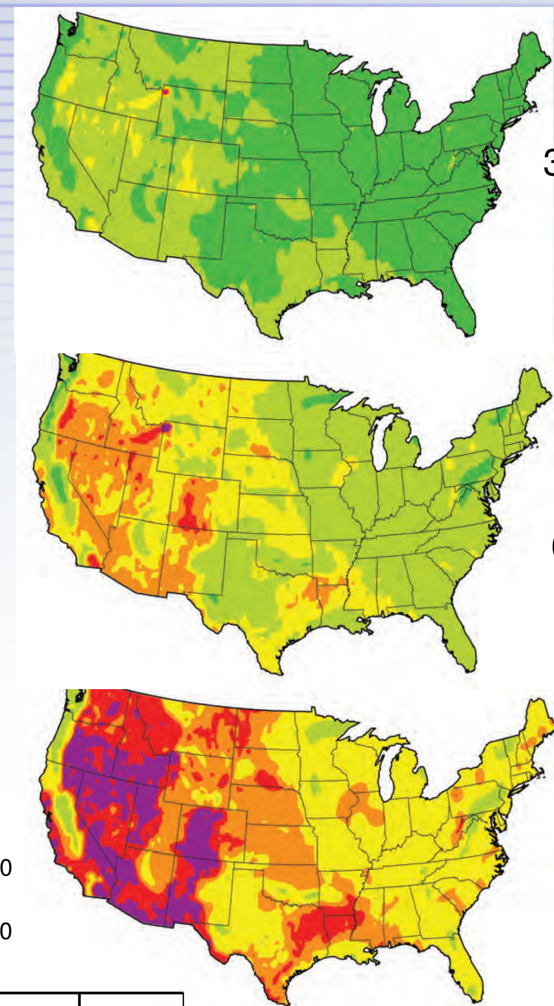
Less than 20 MW

Sandia National Laboratories

Enhanced Geothermal Systems

- DOE restructuring geothermal program
- Target entire US market
- Challenges
  - Drilling
  - Reservoir Creation
  - Reservoir Management
- Resource potential is large

Temperatures at depth



3.5 km

6.5 km

10 km

Estimated U.S. geothermal resource base to 10 km depth by category. (Reference "The Future of Geothermal Energy", Table 1.1, MIT, 2007)

Category of Resource		Thermal Energy, in Exajoules (1EJ = 10^{18} J)	Reference
Conduction-dominated EGS	Sedimentary rock formations	100,000	MIT Report
	Crystalline basement rock formations	13,300,000	MIT Report
	Supercritical Volcanic EGS*	74,100	USGS Circular 790
Hydrothermal		2,400 – 9,600	USGS Circulars 726 and 790
Coproduced fluids		0.0944 – 0.4510	McKenna, et al. (2005)
Geopressured systems		71,000 – 170,000**	USGS Circulars 726 and 790

50	100	150	200	250	300

Degrees C

Sandia National Laboratories

Drilling in Extreme Environments

- Drilling Challenges
  - Hard Rock
    - High compressive strengths
    - Abrasive
    - Low ROP & Bit Life
  - Wellbore Integrity
    - Large cracks
  - High Temperatures
    - Exceeding 600 °F (300C)

- Sandia's Approach
  - Increase drilling ROP
  - Detect problems early
  - Avoid problems whenever possible
  - Develop better solutions to problems if and when unavoidable
  - Make new technology as transparent as possible
  - Involve industry early
  - Reduce new technology to "standard" practice

Bottom Line

- ***Reduce the cost of drilling***
- ***Reduce drilling cost uncertainty and/or variability***

Geothermal Research
Drilling, Monitoring, and Analysis

- Geothermal well construction
  - "Most" difficult on a per-foot basis
  - Broad technology areas
    - High-temperature electronics
    - Diagnostics
    - Rock reduction technologies
    - Wellbore integrity and lost circulation
    - Drilling dynamics mod/sim
    - Vibration mitigation
    - Downhole telemetry
  - Key to future EGS
- Applying capability and technology to other industries and agencies
  - Frontier O&G, unconventionals, environmental, DOD, others

Significant Geothermal Accomplishments – Technology and Products to Industry

- Polycrystalline diamond compact (PDC) bits
- High-temperature electronics
- Diagnostics-while-drilling
- LEAMS
- Active vibration control
- Slimhole drilling
- Acoustic telemetry
- Rolling float meters
- Insulated drill pipe
- Cavitating mud jets
- Drilling dynamics simulator
- Well cost models
- …

Sandia National Laboratories

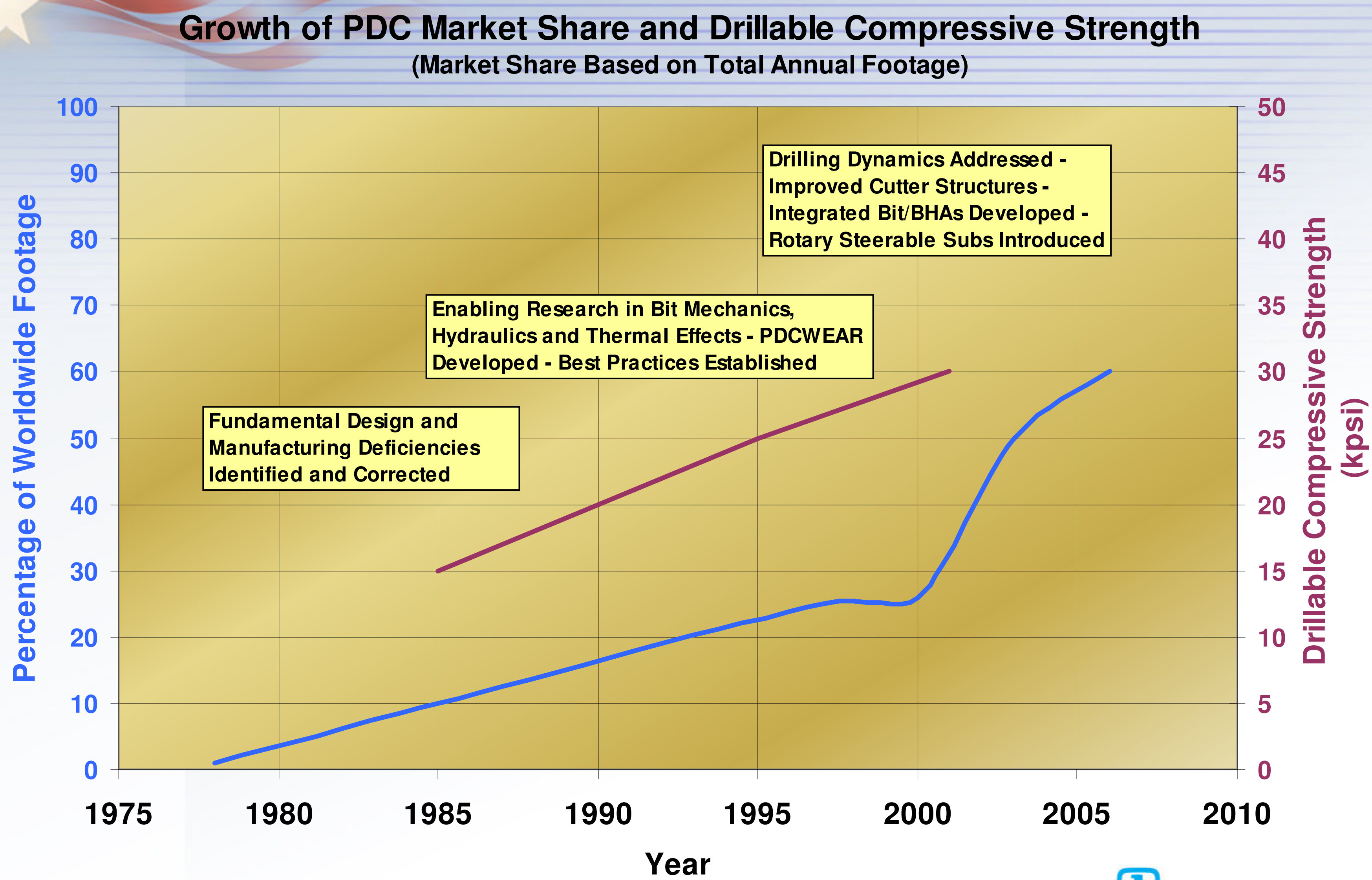
Polycrystalline Diamond Compact (PDC) Bits

- **Fundamental work**
  - **FEM analyses**
  - **Bonding**
  - **Cutter tests**
  - **Bit design / analysis**
  - **Lab / field testing**
  - **CRADAs**
- **Catalyzed a major industry**
- **PDC bits now a ~ $1.5 billion industry**
- **PDC bits save industry $ billions annually**
- **~ 60% of world footage in 2006**

DOE Energy 100 Award for *Synthetic Diamond Drill Bits*

Sandia National Laboratories

Growth of PDC Market Share



Sandia National Laboratories

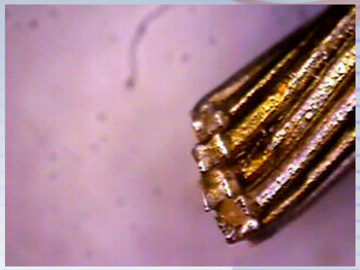
Acoustic Telemetry

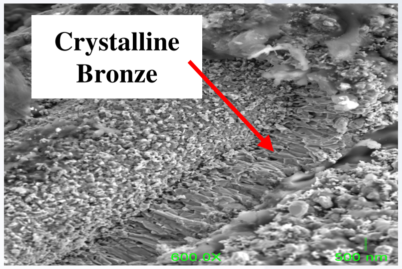
- **Communication between the bit and the surface via pressure waves in the drill pipe**
  - **Downhole telemetry a big need with today's tools**
  - **Mud pulse the standard (2 – 5 bits/sec)**
  - **Acoustic telemetry ~ 10x mud pulse**
- **Enabled by Sandia's theoretical, manufacturing and testing capabilities**
  - **Physics issues – propagating waves through drill pipe**
  - **Engineering and Applications Codes**
  - **Design and manufacturing of prototypes**
  - **Field testing**
- **Product licensed to several entities**
  - **Commercially available through Xact (STV and Extreme Eng JV)**

R&D 100 Award for *Acoustic Telemetry*

Sandia National Laboratories

High-Temperature Electronics





- Includes components, tools, seals, batteries, fiber, …
- The enabling technology
  - High Temperature = High Reliability
- De facto "UL Labs" for high-temperature components
  - Work with almost all manufacturers
- Analyze failure and provide solutions
  - Exploit capabilities from weapons programs
- Develop tools and fabrication methods
  - Prototypes supplied to industry
- Broad application
  - Geothermal, aerospace, auto, O&G, PV, …
- Long-term testing
- Extensive interactions w/ industry motivate work activities

R&D 100 Award for *Solid State High-Temperature Batteries*

Sandia National Laboratories

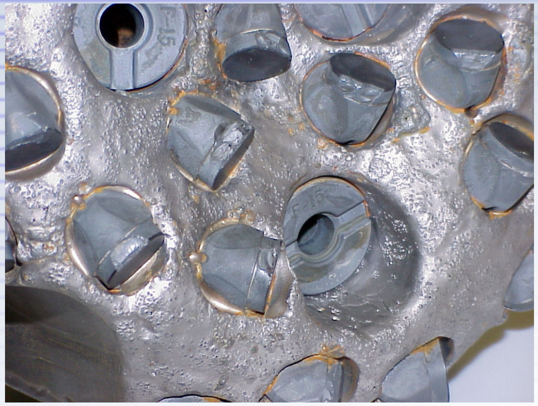
Working with the High Temperature Industry

- Some of the companies we work with

Quartzdyne, UT
MRA Labs, MA
Presidio Components, AZ
Welaco, CA
Paine Electronics, TX
Multilayer Prototypes, CA
Halliburton, TX
Mitco, CA
Honeywell SSCS, MN
Kulite Semiconductor Products, MA
BP, TX
Cissoid, Belgium
Weed Instrument Company, TX
JH Capacitors, NV
Pacific Processes, CA
RdF Corp, NH
Kemlon Products, TX
Semisouth Laboratories, MS
Custom Electronics, MA
Baker Inteq, TX
Rockwell Scientific/ GTI, CA
Endevco Corp., CA
Biotronics
Schlumberger, TX
Regal Plastic Supply Co.
Solid State Devices, CA
Honeywell Richmond, WA
General Atomics, CA
Diamond Research, TX
Advanced Products, CO
Electrochemical Systems, TN

Sandia National Laboratories

Drilling Dynamics Increase Drilling Costs



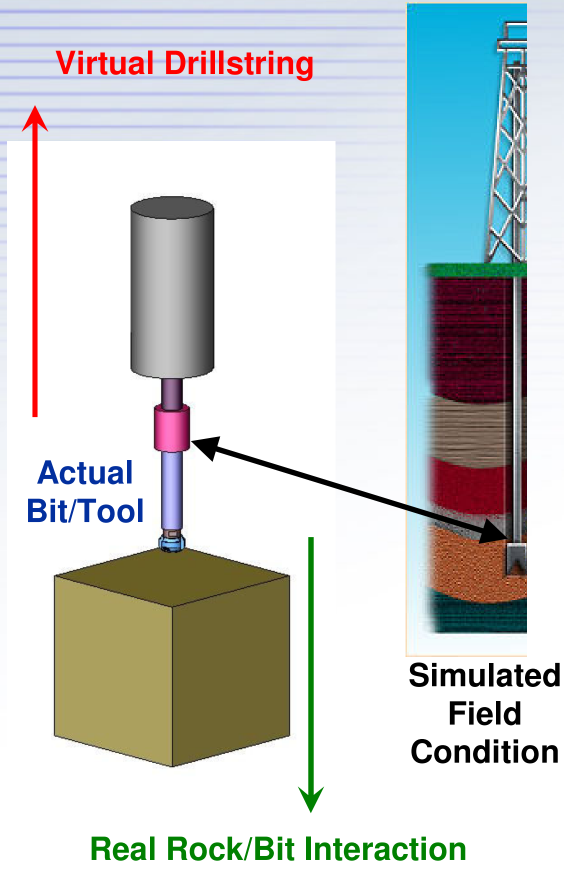
- Drilling dynamic dysfunctions are one of the leading causes of Non-Productive Time

- The bit, BHA / drillstring and formation interact in a complex way resulting in a variety of vibration related problems
  - Low Rate of Penetration -- Inefficient Drilling
  - Bit & Tool Failure -- Excessive Tripping

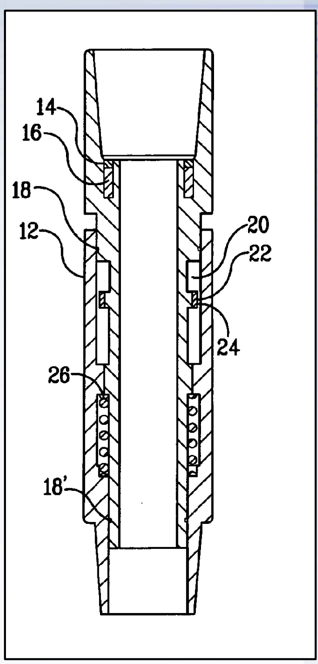
- Vibrations cause significant economic losses
  - For example: Tripping the drillstring to replace the bit on an off-shore rig can exceed 1 million dollars

Simulation of Drilling Dynamics

- Existing drilling research laboratories
  - Unrealistically rigid drill stems
  - Effective for evaluation of cutting structures, hydraulics, etc.
  - Don't address vibration
- Sandia is pursuing an innovative capability
  - Laboratory simulation of field conditions
  - Will improve bit and tool performance before committing to expensive field drilling
- Benefits
  - Improved capability for predicting bit vibration
  - Identify deficiencies in drill bit material properties and designs
  - Validate development of hardware and software for downhole tools that reduce vibration
  - Develop *Best Practices* for handling vibration



Active Vibration Control



- Drill bits are susceptible to failure under shock & vibration
  - Dampers installed in down-hole tools can help
  - Optimal damper for each drilling condition

- Active vibration control tool developed using controllable fluids
  - Based on Magneto-Rheological (MR) Fluids
    - Carrier fluid with iron particle suspensions
    - Controllable damping force
    - Fast response (~ milliseconds) and low power (~ Watts)
    - Remotely powered and controlled
  - Controllability ensures applicability to broad range of drilling conditions
    - Drillstring changes with depth
    - Variable rock lithologies
    - Sidewall friction, etc.

- Intellectual property licensed to industry

Sandia National Laboratories

Diagnostics-While Drilling (DWD)

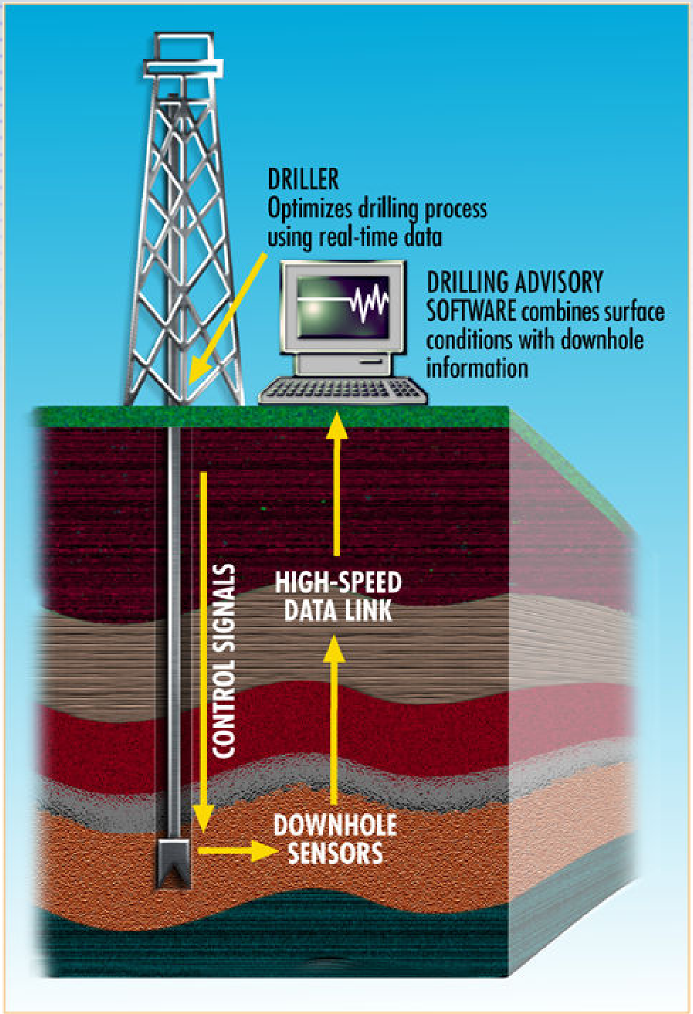
Measurement sub – **acquires, conditions, and transmits downhole sensor data**

Data Link - **carries information and control signals between surface and downhole**

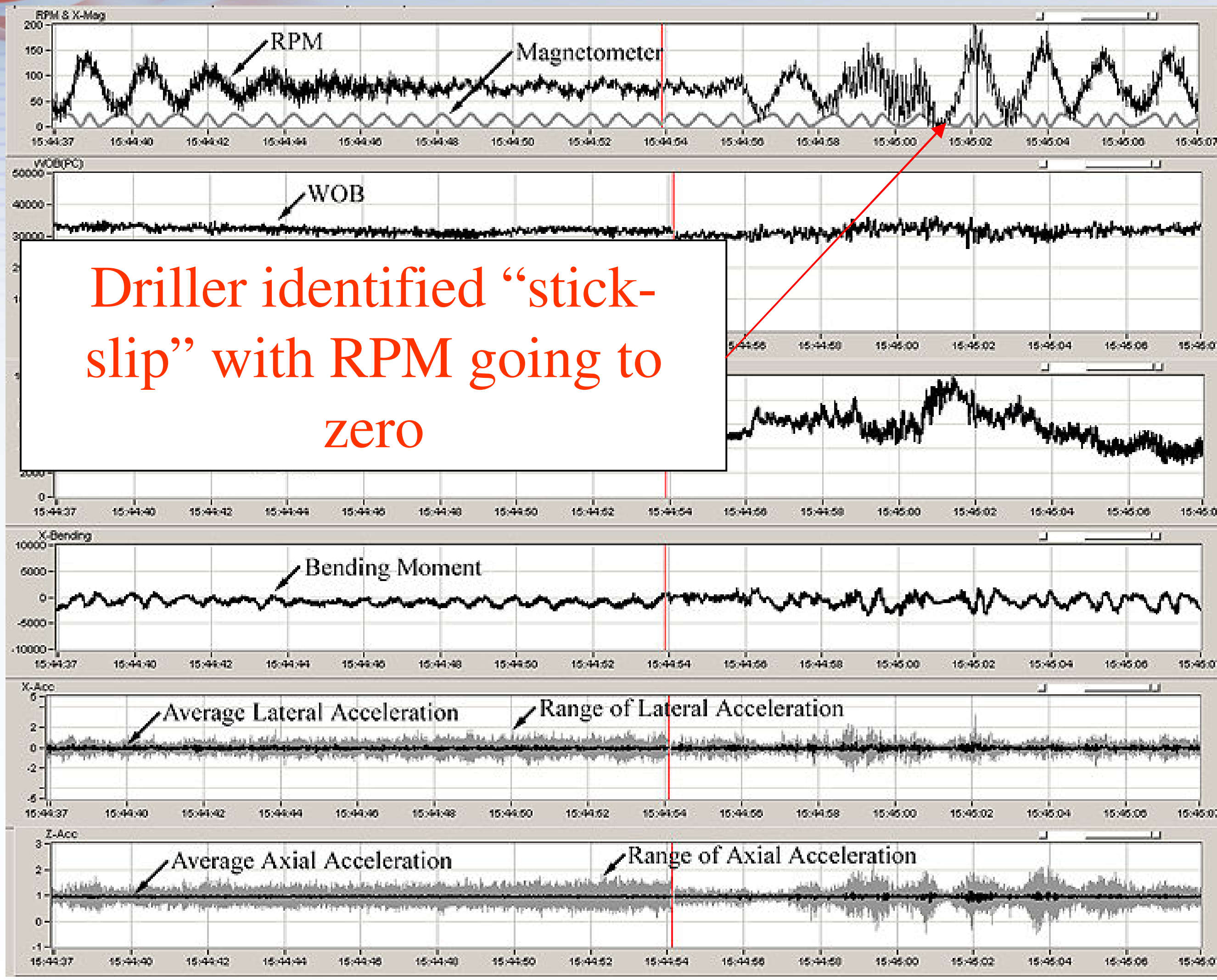
Instrumented Drill Rig – **provides for display and archive of surface drilling data**

Driller's Display - **displays selected set of real-time, high-resolution data from both downhole and surface. Display can be either raw or processed (FFTs, etc.) data.**

Driller – **experienced and willing driller can use more sophisticated display than traditional console.**



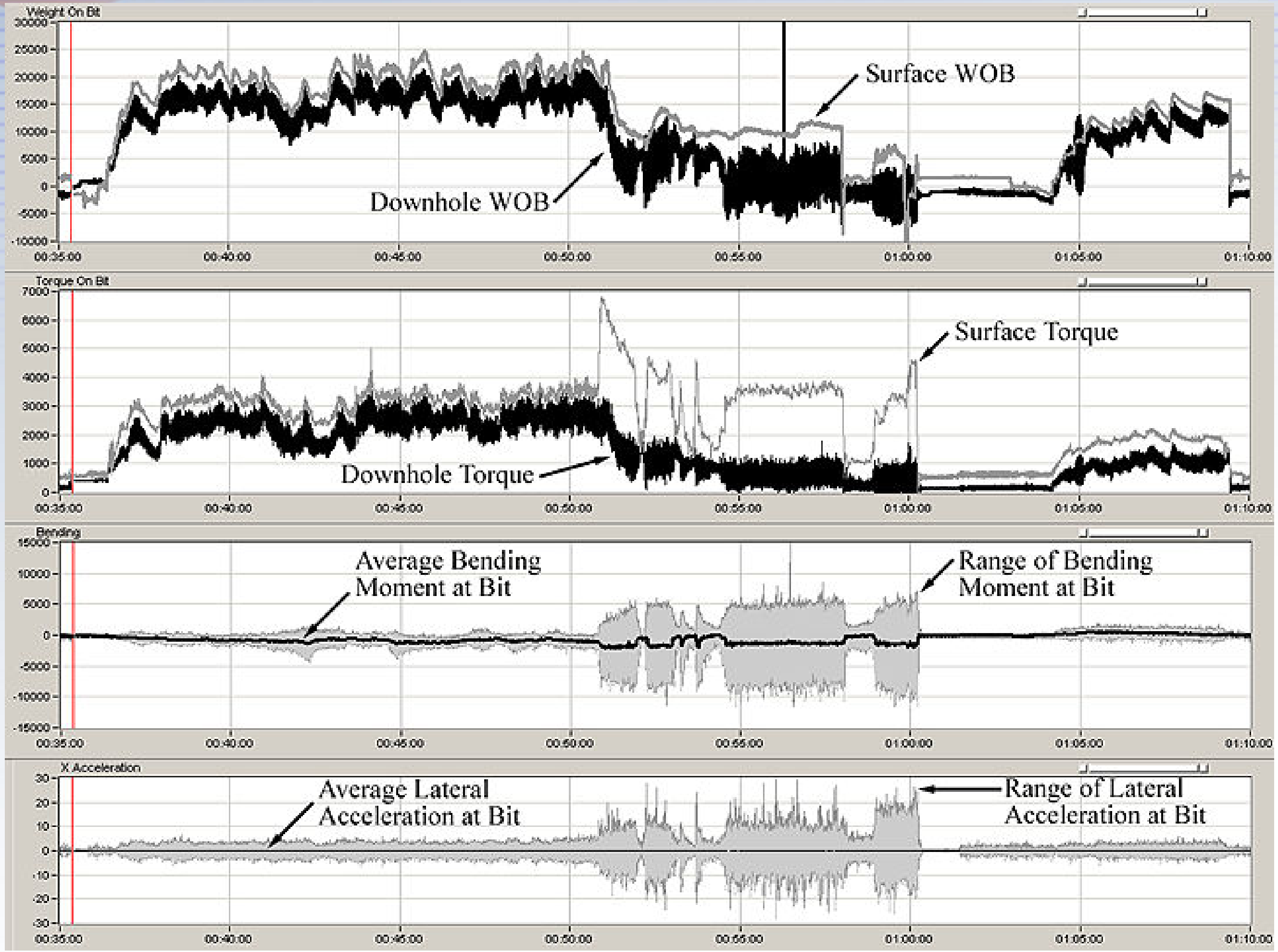
Drillers Can Use DWD



Driller identified “stick-slip” with RPM going to zero

Sandia National Laboratories

DWD Systems Can Help the Driller



Sandia National Laboratories