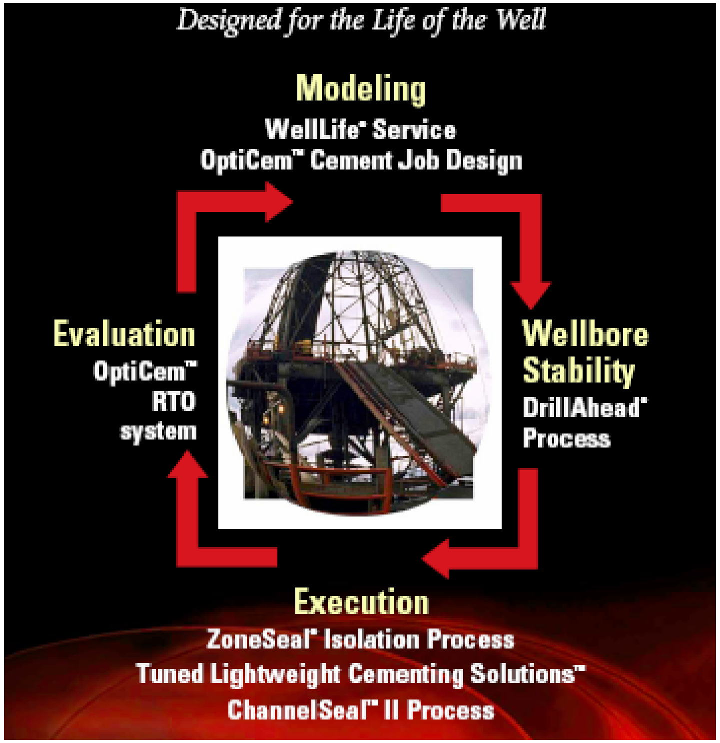
Geothermal Prospects
Well Integrity Considerations

Long Term Well Integrity



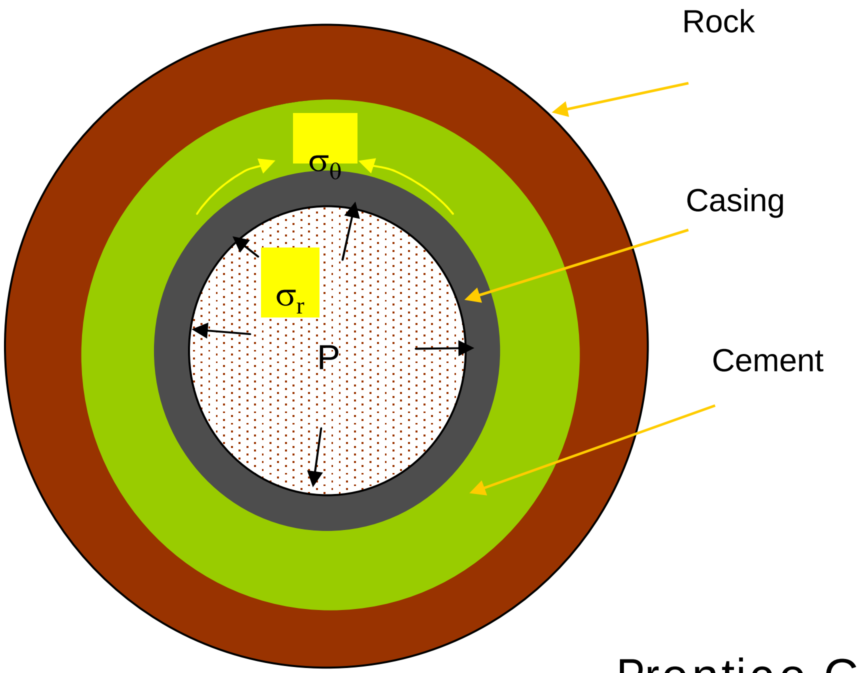
Designed for the Life of the Well

Modeling
WellLife® Service
OptiCem™ Cement Job Design

Wellbore Stability
DrillAhead® Process

Execution
ZoneSeal® Isolation Process
Tuned Lightweight Cementing Solutions™
ChannelSeal™ II Process

Evaluation
OptiCem™ RTO system



Prentice Creel, PE

Halliburton

Objectives on Well Integrity Management

•Create value by extending the economic life of the well and optimizing the hydrocarbon produced, through fit for purpose well construction and repair

-Engineer sealant properties for the wellbore, reservoir and loading conditions

-Design suitable sealant from services' portfolio

-Deliver the sealant – simulation analysis via Opticem®

-Monitor, Control and Document the well performance, in RealTime

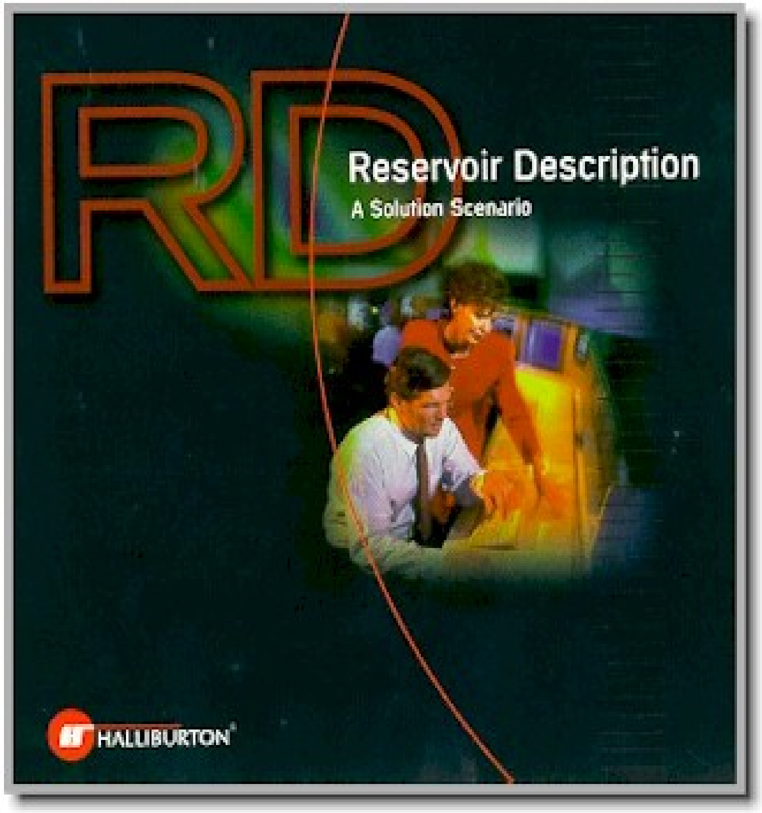
- Dual possibilities at end of normal well-life production
  - Geothermal resources
  - Heat exchange for lifting assist via electricity generation

Reservoir Description and Characterization

First understand the potential

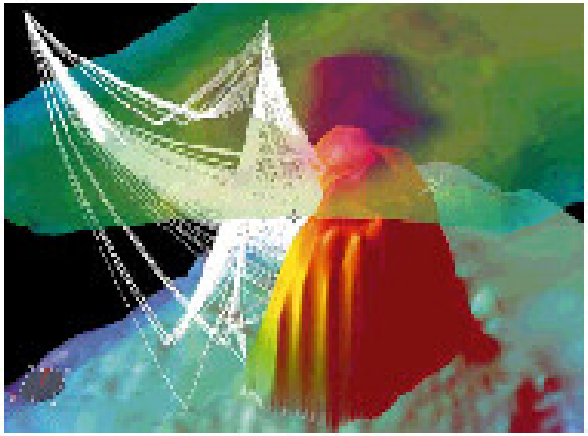
- Geological data
- Petrophysical data
- Well completion data
- Production/injection plans and past log data
- An open mind to new resources and technology

Reservoir Description



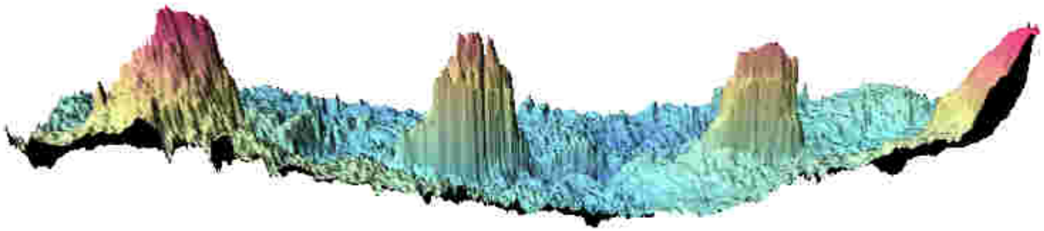
Data Collection

- Existing Data
  - Geological Description and Reservoir Understanding
  - Production and Injection History
  - Completion History and Well Construction
  - Production Equipment and Facilities
- Additional Data for Better Understanding
  - Production Tests
  - Tracers
  - Cased Hole Logging
  - Injection Analysis
  - Down Hole Video
  - Research and Developments

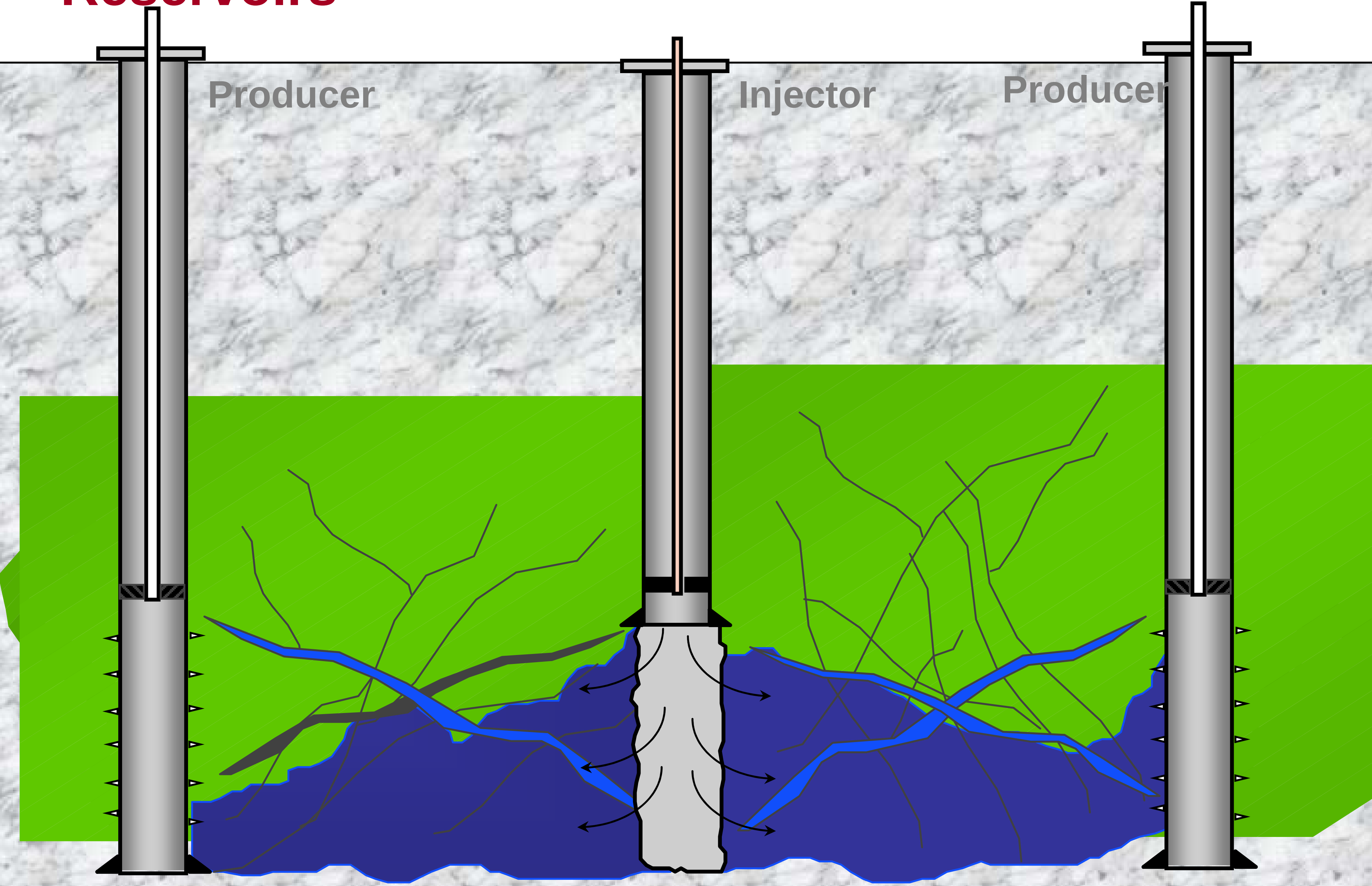


Data - Geological Description

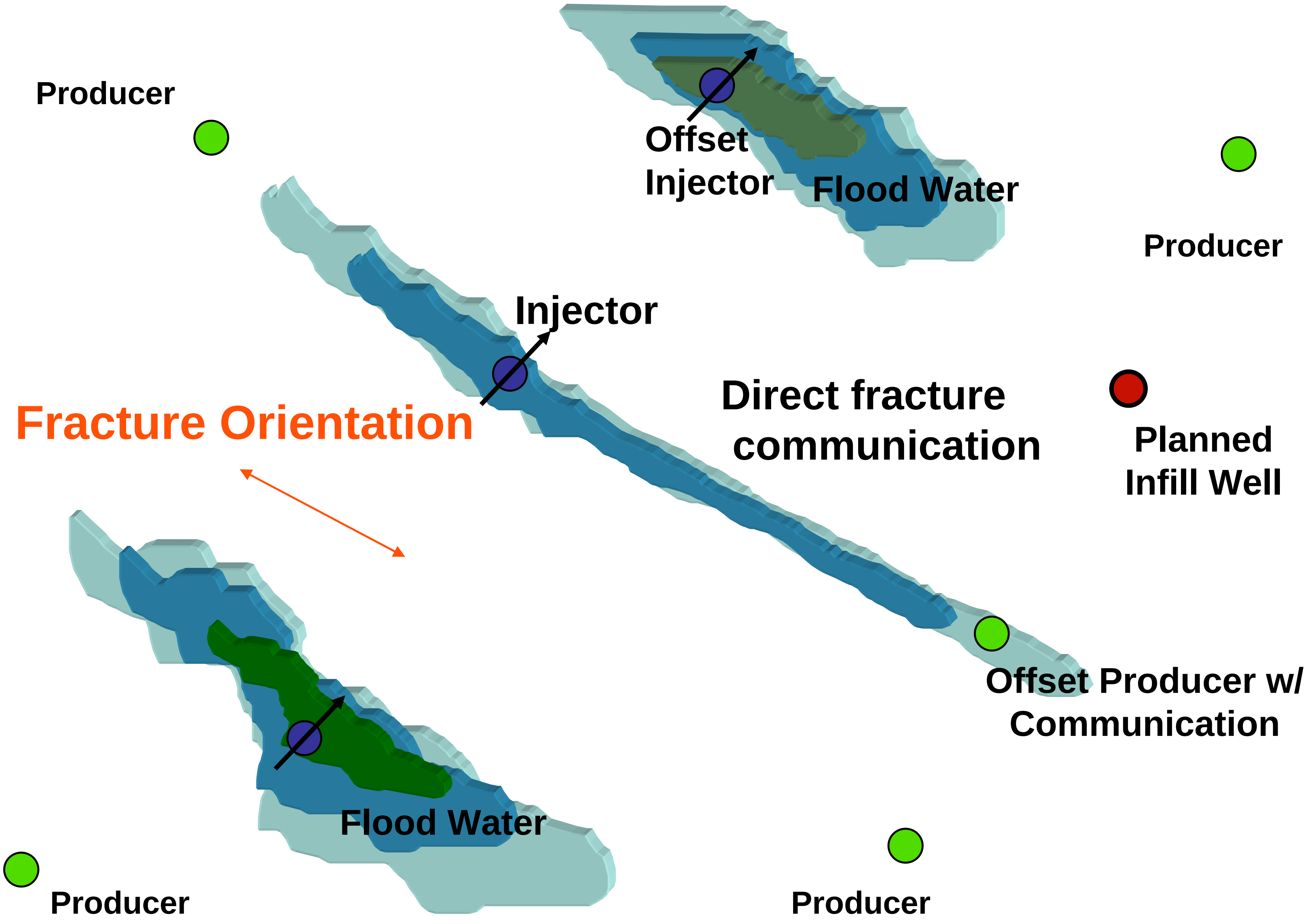
- Depositional Environment
- Reservoir Geometry
- Fluid Saturation Distributions & Contacts
- Faults and Barriers
- Stratigraphic Boundaries
- Sedimentary (Laminates, Cross Bedding)
- Microscopic (Clays, Texture, Pore Geometry)
- Temperature Resources - Data



Fractures/Fissures and Faults occurring in Reservoirs



Flooded Field with Fracture Communication



Abandonment Costs Equal Salvage Costs

- **Concept may no longer be true**
  - 20,000 ft well plugging cost $75,000 – $ 250,000 ???

Prepare now for Abandonment

- **Identify tasks required to meet regulatory and lease requirements.**
- **Conduct lease remediation and clean up activities as part of routine lease operations.**
- **Document your activities and lease conditions.**

Factors to Consider when Determining Abandonment Costs

- Regulatory Requirements
- Lease Requirements
- Operational History
- Surrounding Environment

Other Considerations

- Advancements in technology
- Scientific discoveries related to human health and the environment
- Changes in public opinion

Have good practices

- **Evaluate Abandonment Issues**
- **Incorporate remediation and cleanup activities into routine operations**
- **Minimize waste and impact on the area surrounding the field operations**
- **Document activities and field conditions**

How about selling to another Operator seeking usage of your wellbore

Remedial Technologies

Wellbore Integrity Solutions for extended Well-life

Current Casing Parameters

- Was the casing string cemented to surface ?
- Is there cement behind the casing ?
- Where are water influx intervals ?
- Where are fragile intervals with possible associated fractures ?
- What is the extent and length of casing with erosion, pitting, and leaks ?
- What is needed to give an extended well-life with production considerations or sources of new economic benefits

Considerations on Casing Repairs – Determine the Initial Construction

- Loss Circulation and Influxes
  - Focal Point Definitions
  - Diagnostics
  - Applicable technologies
- Deviations in Hole Placement
  - Horizontal
  - Multi-lateral
- Temperatures and Pressures
  - Accurate testing on slurries – API Specifications
- Fracturing and Communication
  - Natural and Induced – Hydrostatic Conditions
  - Cross-flows [water – gas] and Potentials of Deteriorative Affects
- Subsidence and Stability of Strata
  - Clay, Shale, Salt Sections, etc.
- Up-front involvement – Proactive in addressing conditions – WellLife

Addressing Completion Methods

Past & Present

- Cemented Casing with Perforated Intervals
- Open Hole Completions
- Gravel Pack Completions
- Slotted Liners
- Deviated & Horizontal Wells
  - Cased & Cemented
  - Slotted Liners
  - Open Hole Completions
  - Drilling Orientations
    - Lateral or Transverse

Repairing Wells for Long Term Zonal Isolation and Integrity

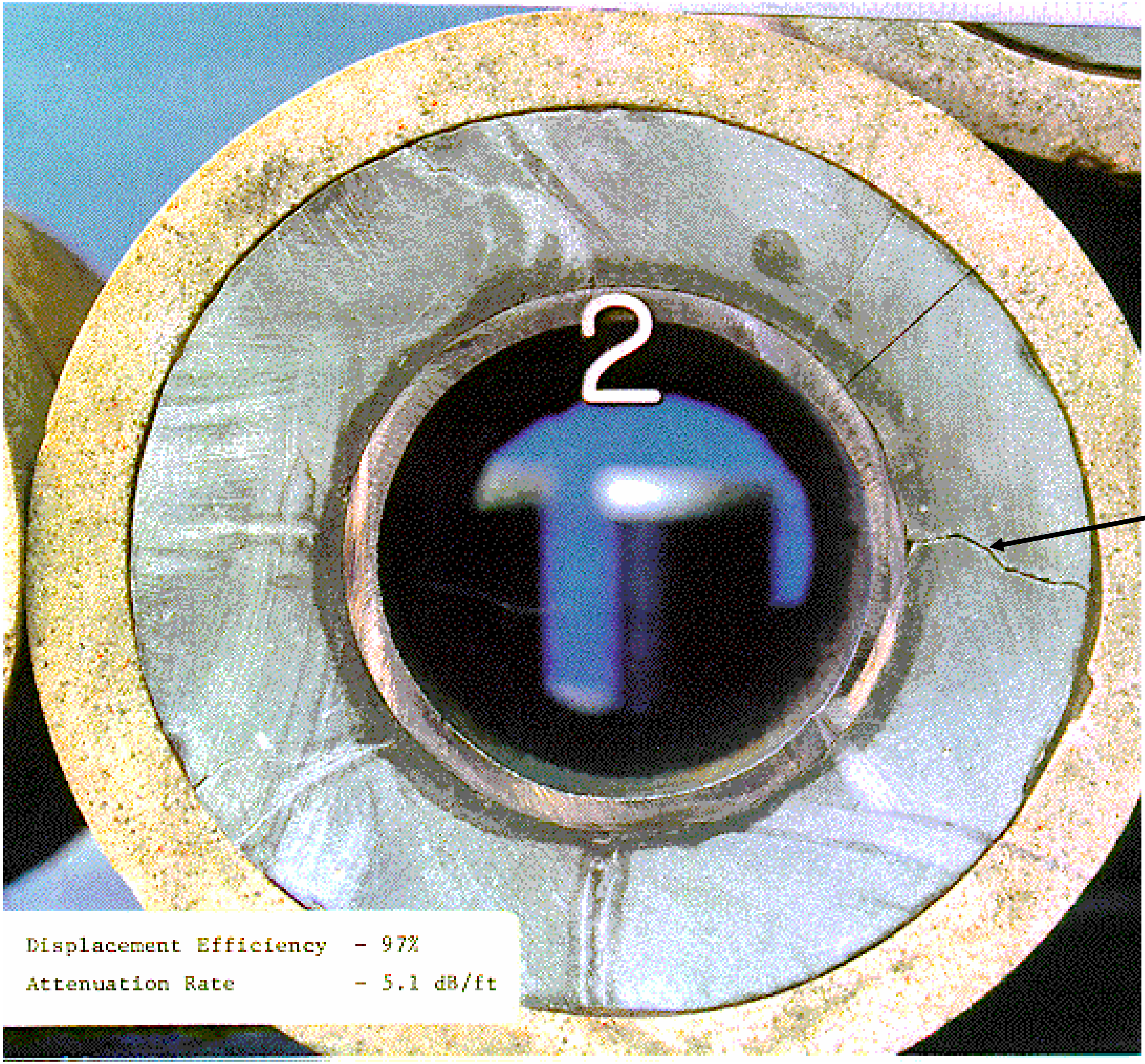
OBTAINING A GOOD ANNULAR SEAL

- Complete planning with the aid of accurate job models
- Proper well cleanout and drilling fluid preparation
- Proper centralization of the pipe
- Proper volumes and design of spacer
- Effectively designed slurries
- Pipe movement
- Continuous pumping
- Maximum flow rates
- Zero closed-in pressure during WOC time

Lack of Integrity and its Causes

Production Operations

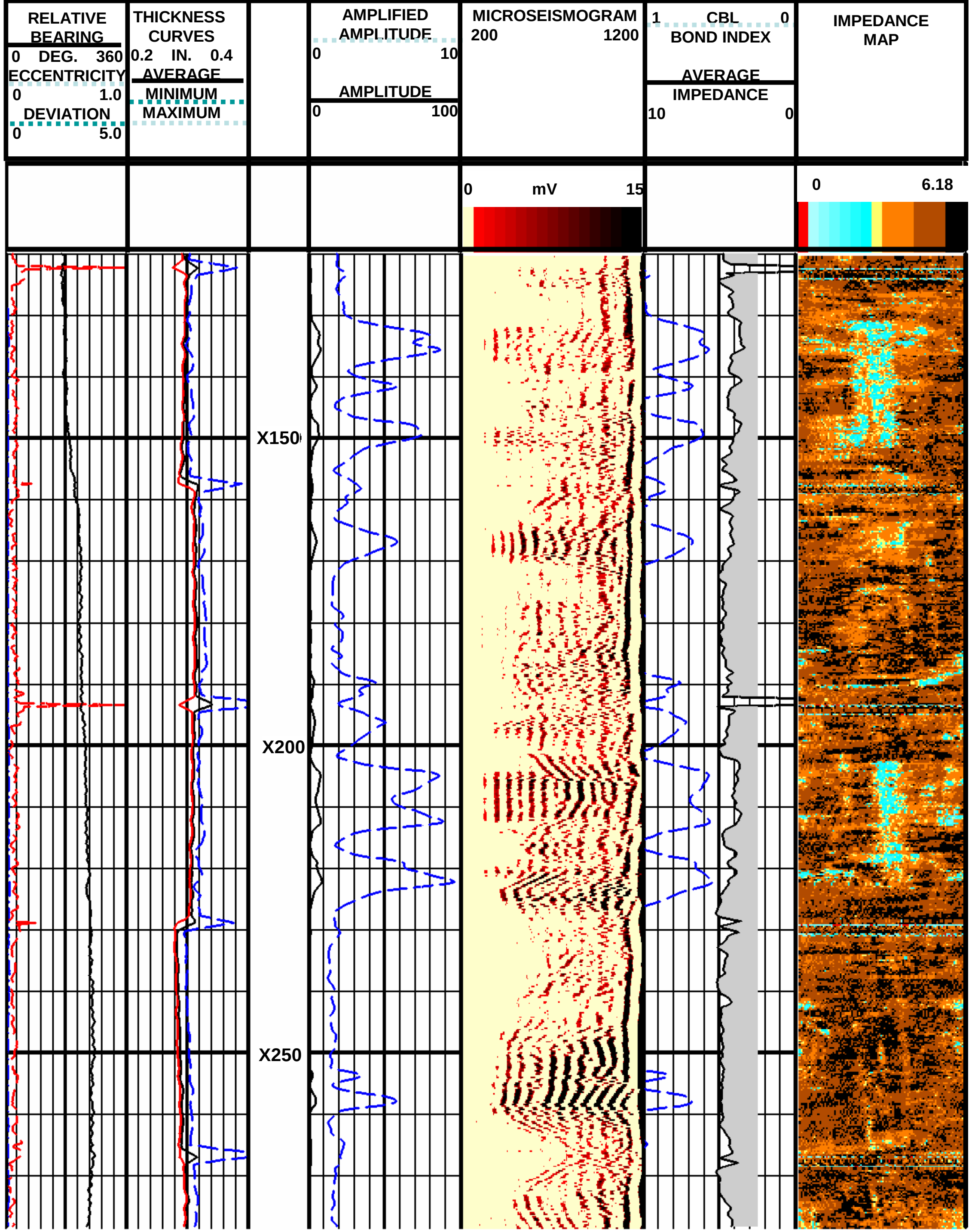
- Influxes continuing following primary cementing
- Annular pressure differences causing cross-flows
- Casing pressure cycling during the well's productive life
- Perforating and initial acid breakdowns
  - Cracking cement sheaths
  - Removal of formation barriers
- Stimulation treatments going out of zone
- Injectants dissolving and eroding rocks



Displacement Efficiency - 97%

Attenuation Rate - 5.1 dB/ft

Cracked Cement Sheath

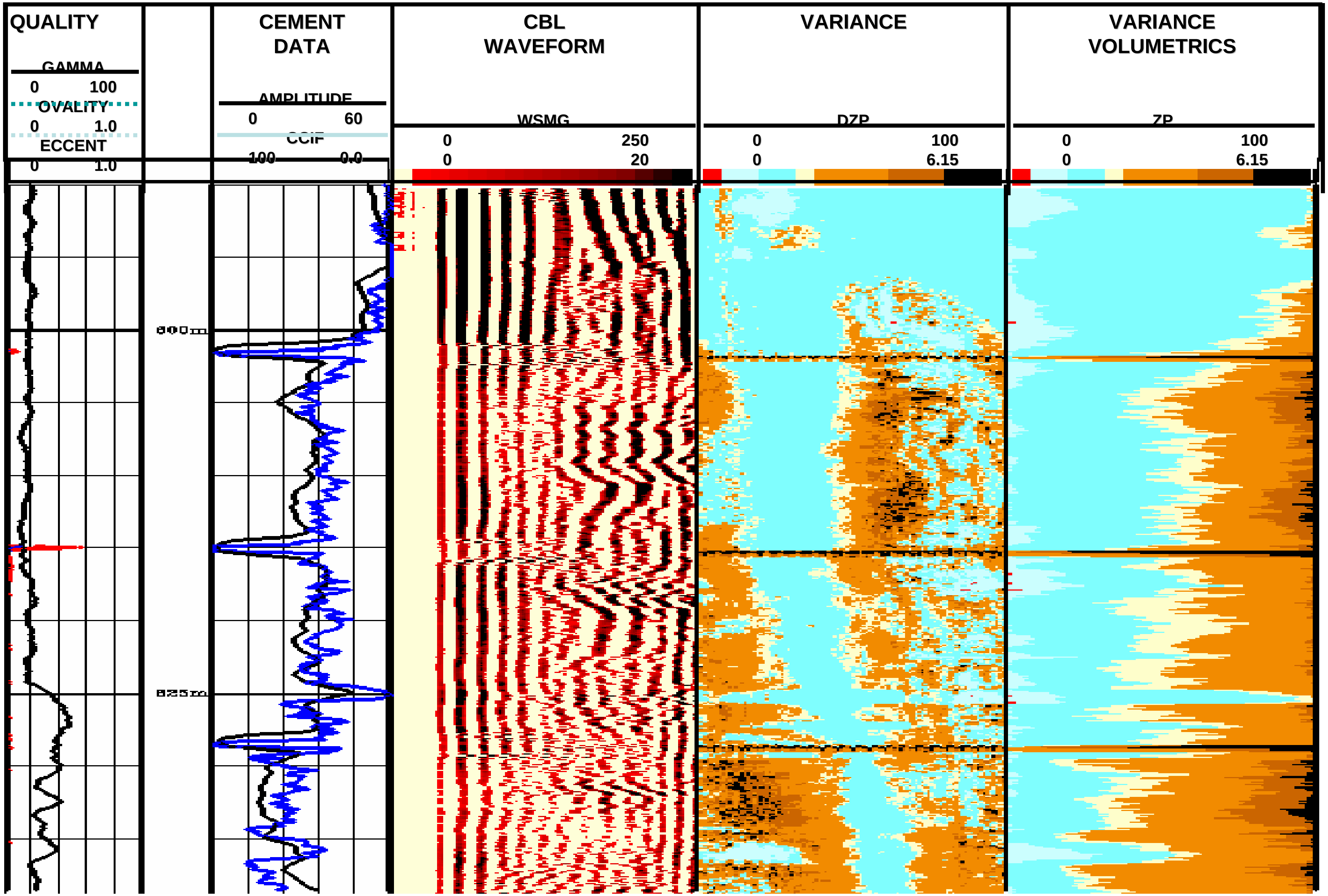


Ultra-Sonic Image Logs

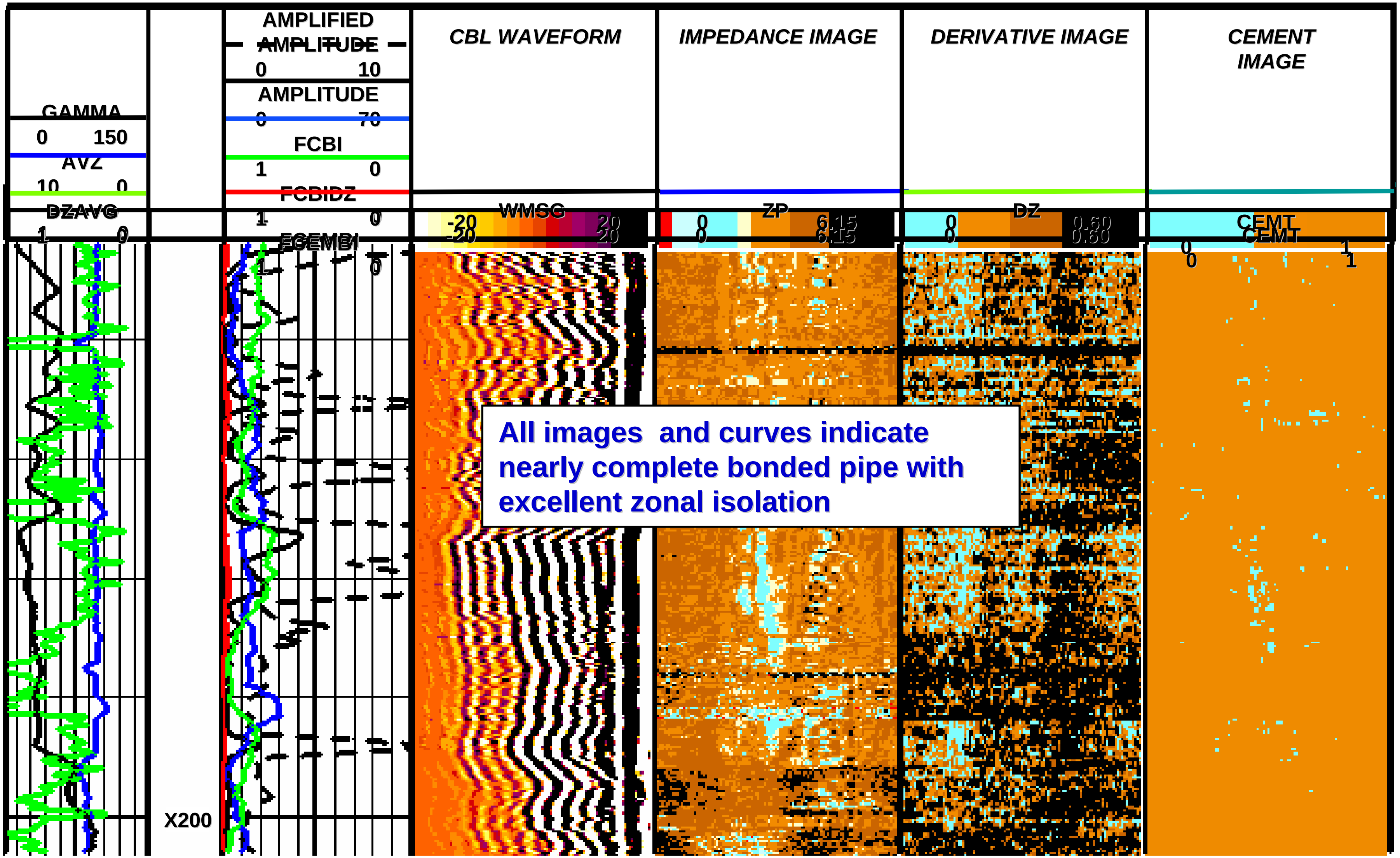
- Rotating Transducer for 360^0 Measurements Aid in Channel Identification
- Evaluate Pipe to Cement Bond
- Cement Image Display From Acoustic Impedance or Variance for Improved Interpretation

SPE # 55649

Example of Cement Evaluation Logs

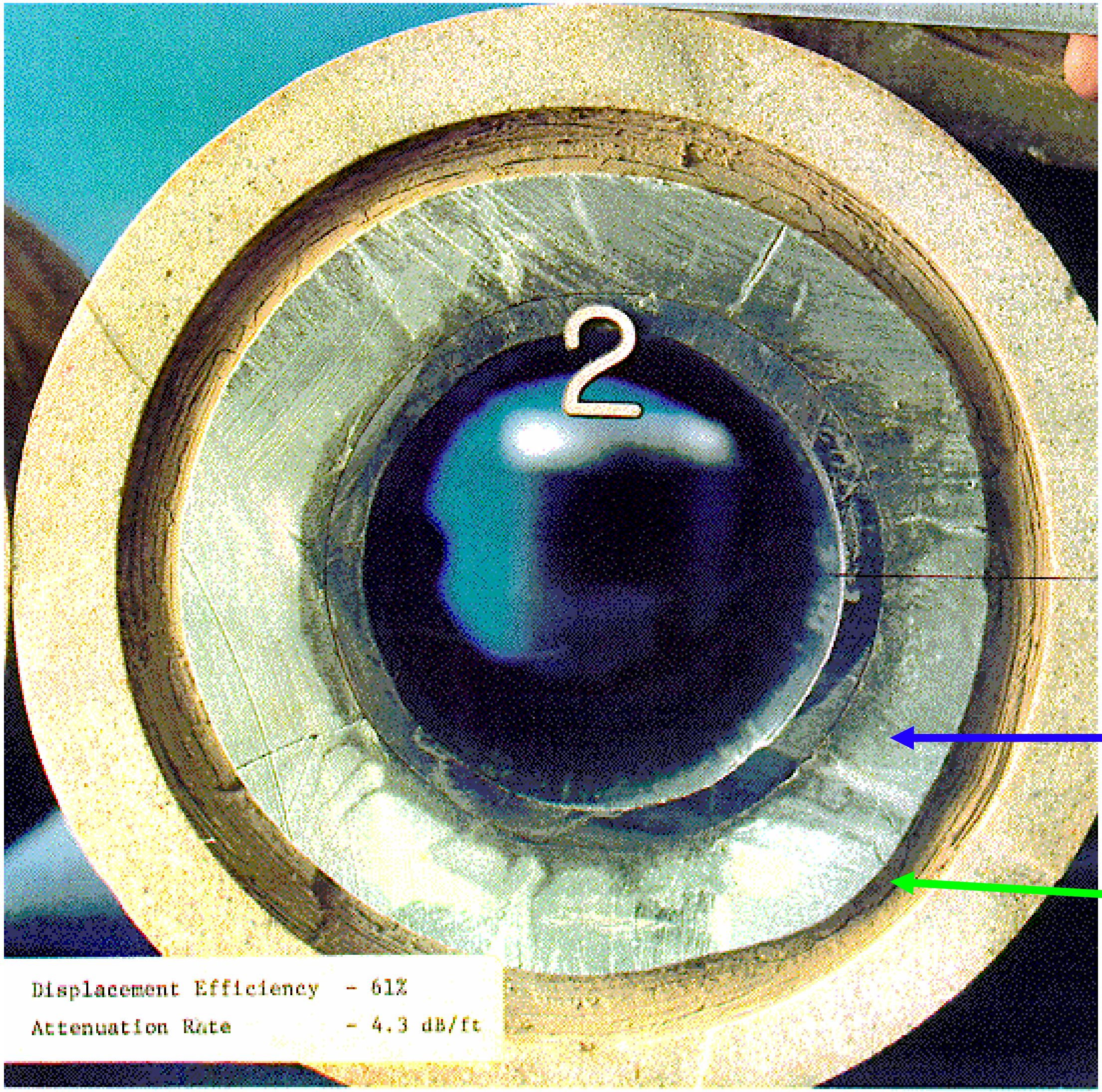


Foamed Cement Analysis in Bonded Pipe



All images and curves indicate nearly complete bonded pipe with excellent zonal isolation

Analysis of Results on Casing Integrity



Displacement Efficiency - 61%
Attenuation Rate - 4.3 dB/ft

Cement

Mud Filter Cake

- Bond Log
- Measure Displacement Efficiency

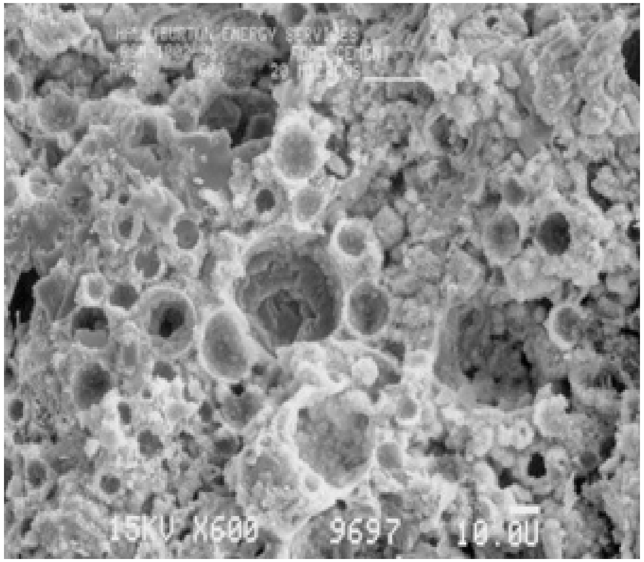
What is ZoneSeal Cement?

- A mixture of cement slurry, foaming agents, and gas (usually nitrogen)
- It visually resembles gray shaving cream
- It is a low-density cement matrix with low permeability and relatively high strength

Advantages of Foamed [Energized] Systems

In Set Cement

- Key to preventing annular pressure
- Compressible system with elastic properties
  - Bubbles allow crystalline bonds to flex without breaking
  - Greater resistance to stress cracking
  - Bond remains intact
  - Eliminates micro-annulus



Foamed Cement Attributes and Benefits

- Elastomeric Cement Systems
  - Improves Bond Characteristics
  - Resilient/Withstands Pressure Cycling
  - Helps Maintain Zonal Isolation
- Help Prevent Gas & Water Migration
  - Withstands influxes during transition state
  - Compressibility
    - Is compressible or expandable in nature
  - Energized and Stable
  - Uniform true solution (maintains system integrity)
- Improved Fluid Displacement
  - Primary and Remedial Cementing
  - Repair Casing and Providing Zonal Isolation
- Simplified Material System

Foamed Cement Characteristics and Properties

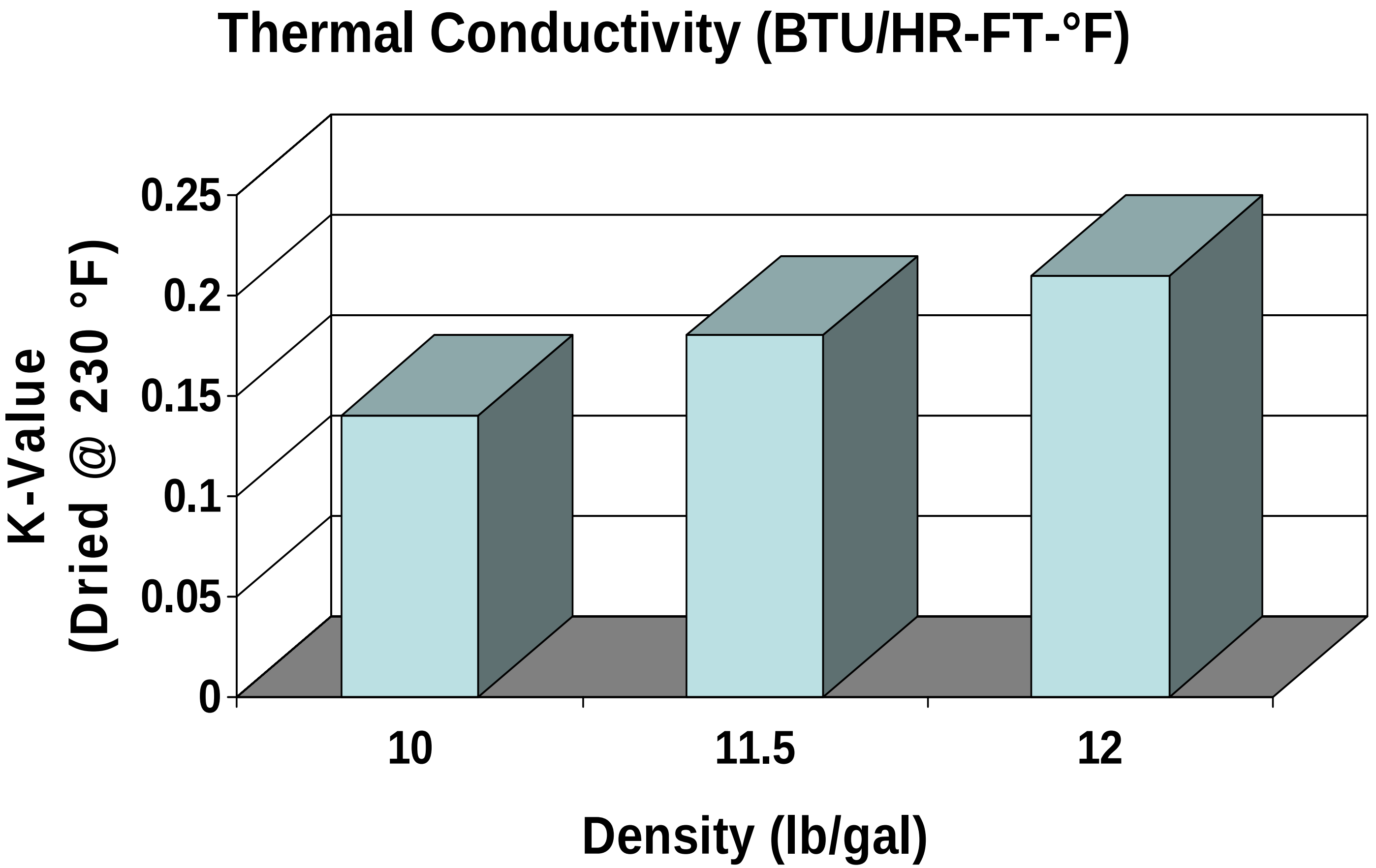
- High strength for low density material
- Virtually zero fluid loss & free water
- High viscosity
  - enabling thorough filling of channels, vugs, and voids
- Excellent displacement properties
- Properly produced foams are:
  - stable and have desired texture
- Greater resistance to stress cracking caused by cyclic activity
- May be developed to serve as an excellent production and perforating cement
- Foam matrix provides space for crystalline growth associated with temperature retrogression

Casing Cementing Parameters
“Making a Decision”

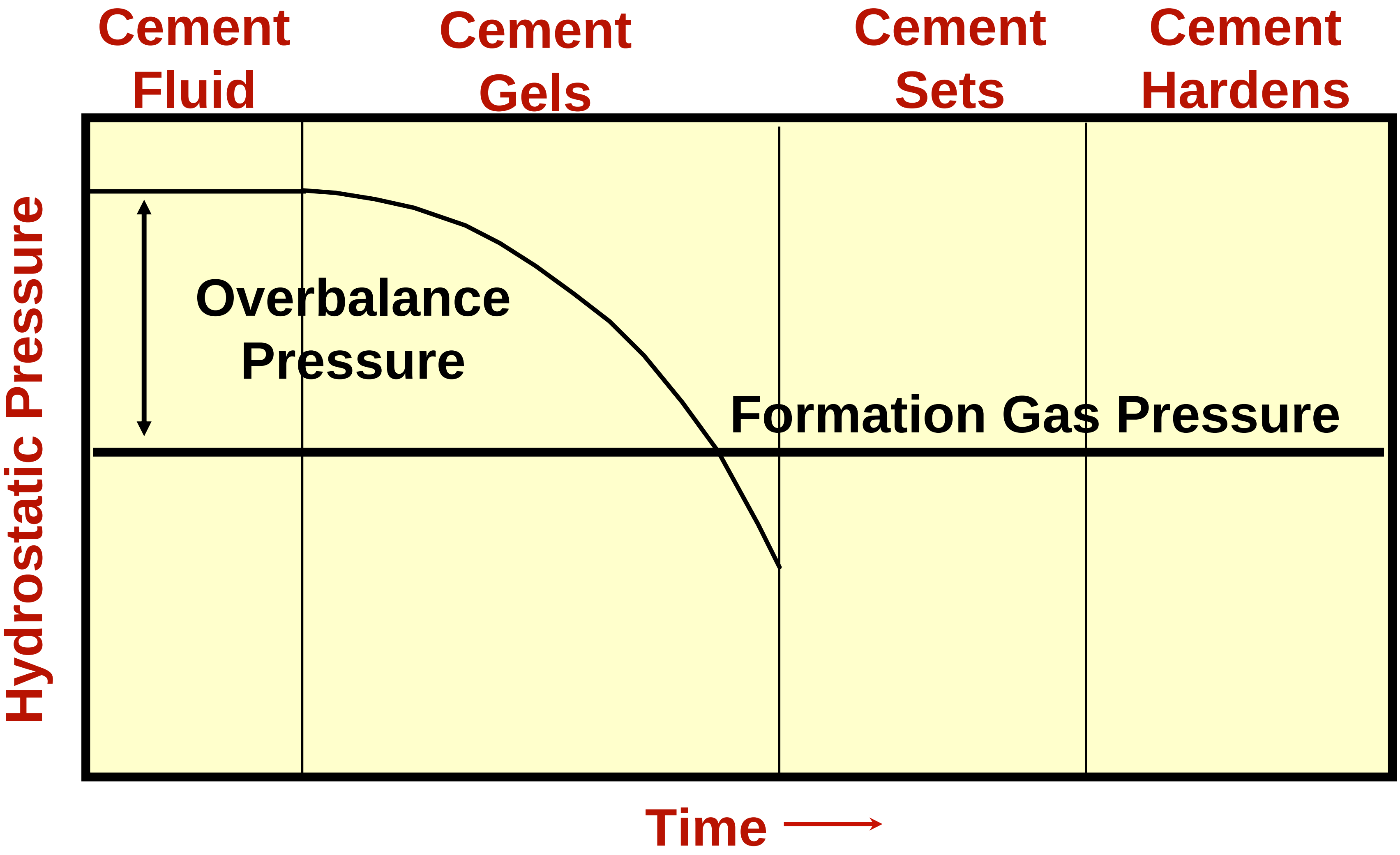
- Is it easier to fix an invasion or loss circulation problem by changing directions annular placement is conducted ?
  - Where are gas influx intervals ?
  - Where are water influx intervals ?
  - Where are fragile intervals with possible associated fractures ?
- What is the extent and length of problem zones ?
- What is the easiest way to achieve zonal isolation ?
- What attributes are needed to achieve a successful remedy ?

Best Practices: Find and utilize the focal points in applications and placement methods

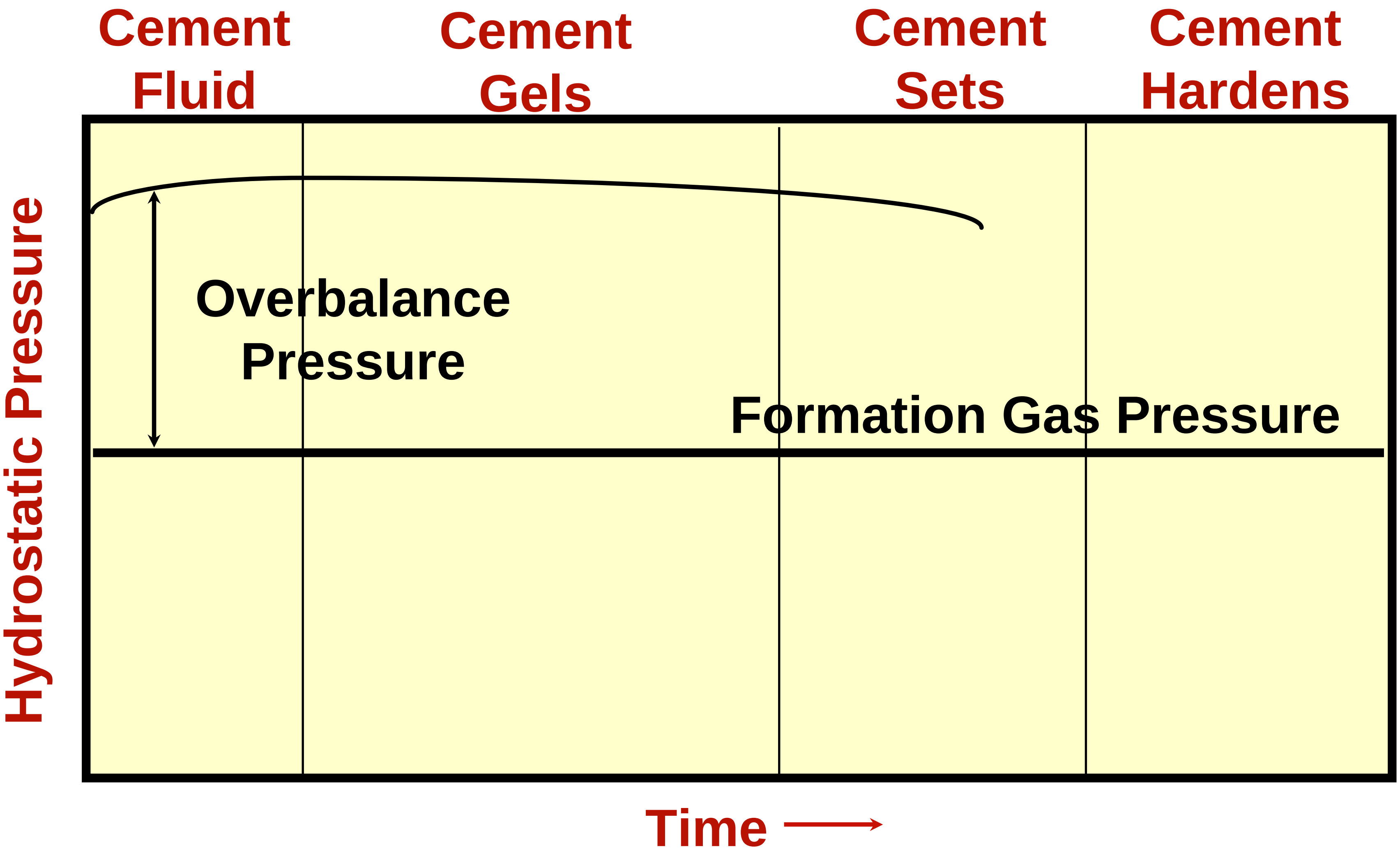
Thermal Conductivity of Foamed Cement



Hydrostatic Pressure Loss

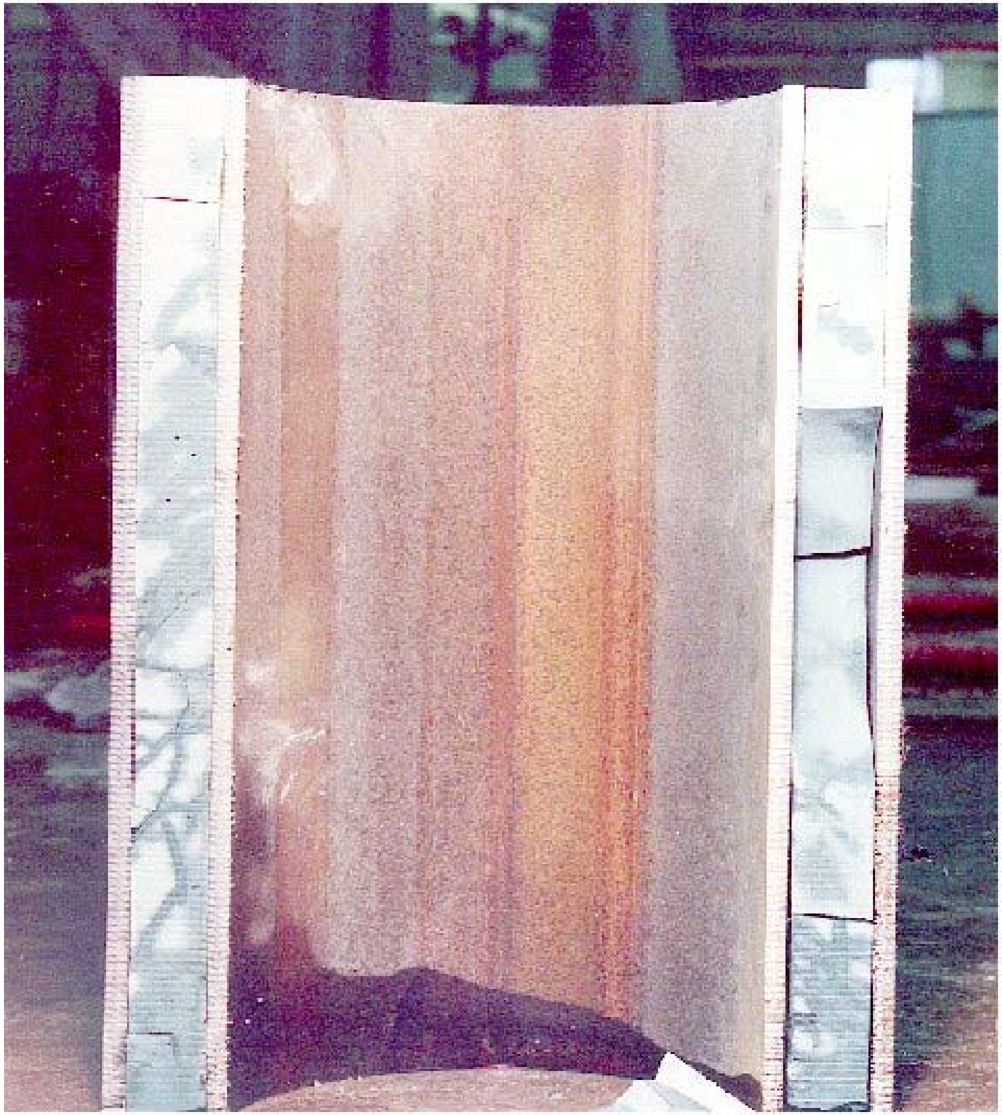


Energized Cement



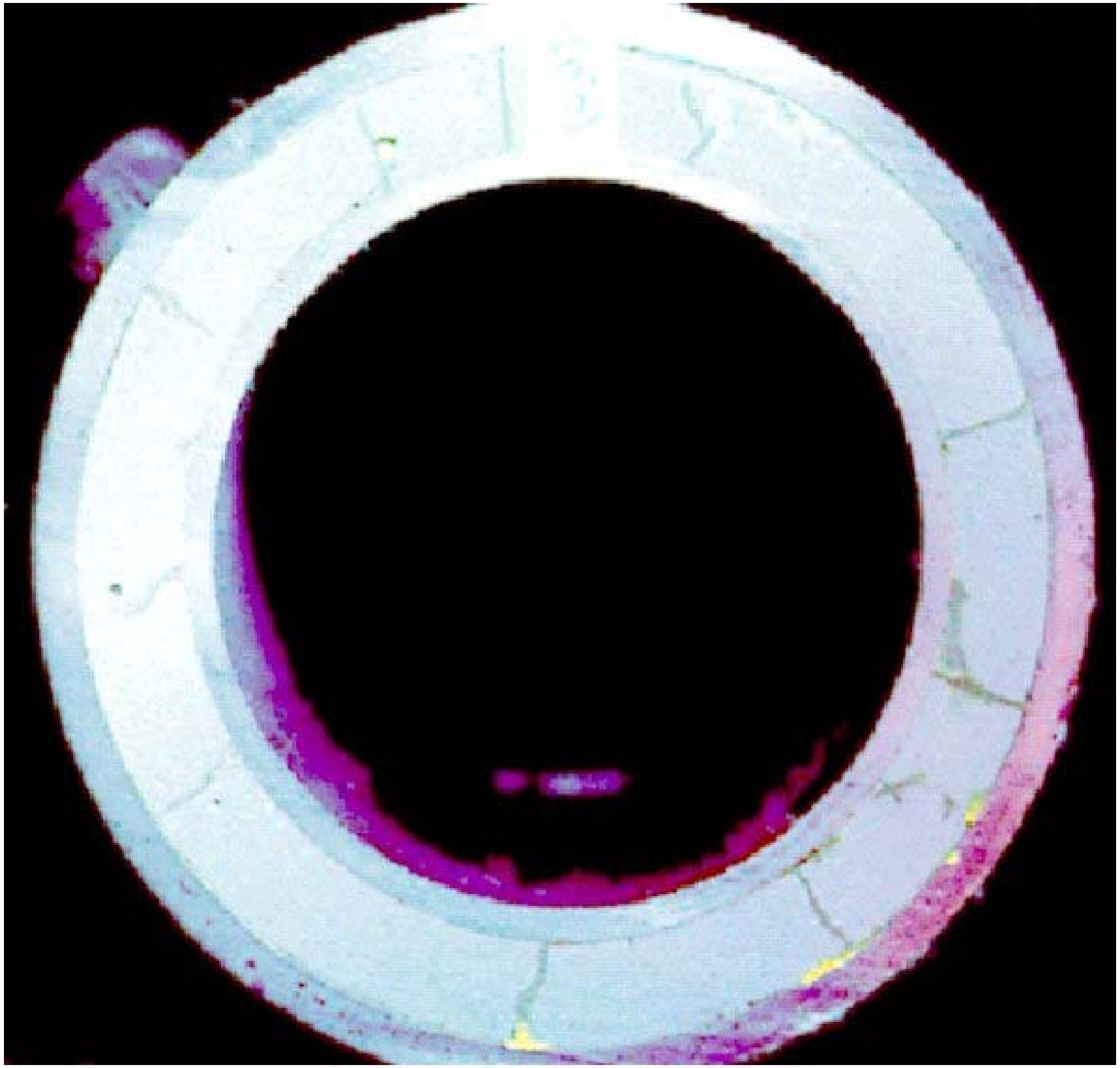
Large Scale Stress Testing

Conventional Cement



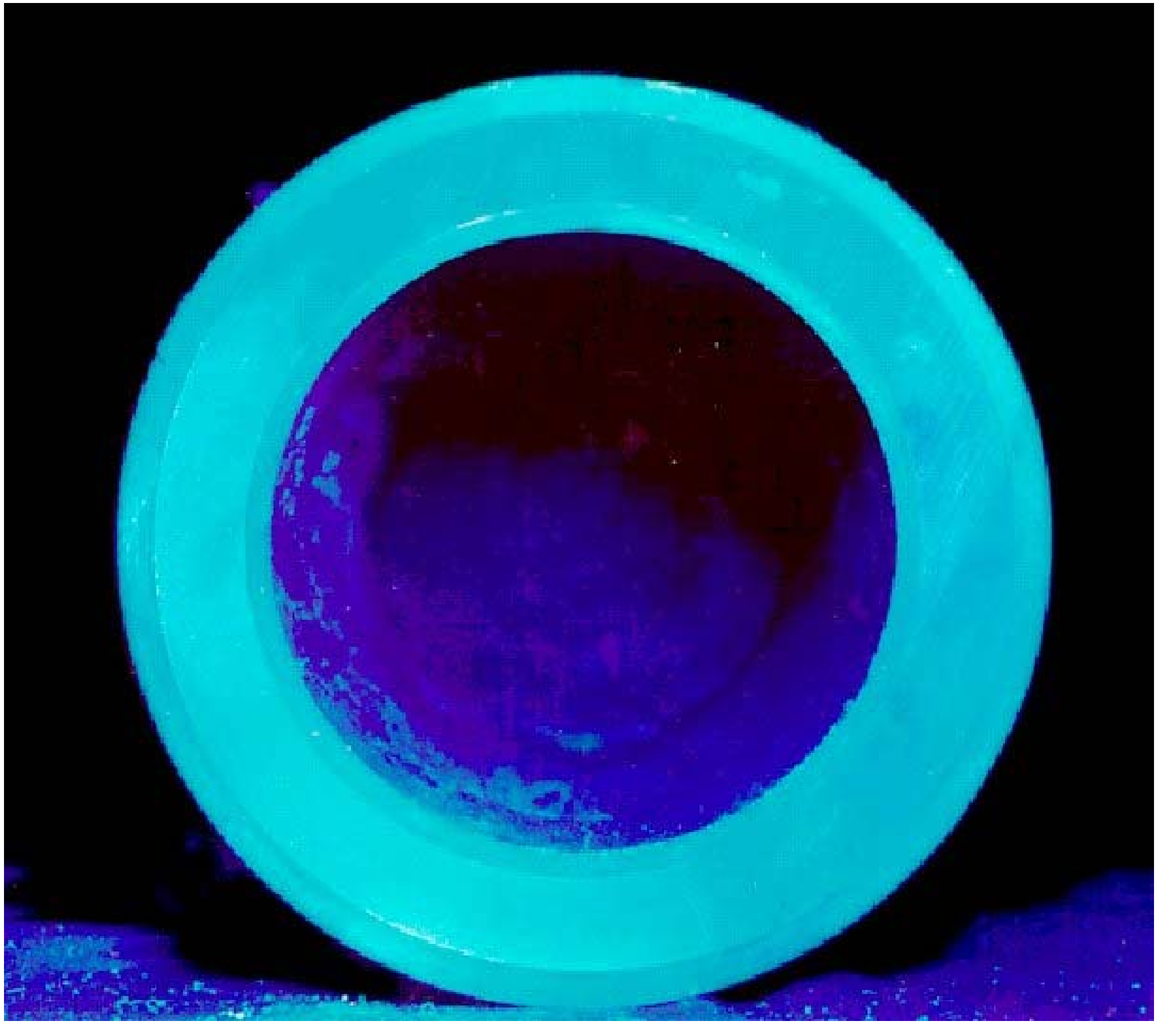
- 5 1/2” pipe cemented inside 7 5/8” casing
- Inner pipe pressured in stages until cement failure was indicated at 4500 psi.

Large Scale Stress Testing
Conventional Cement



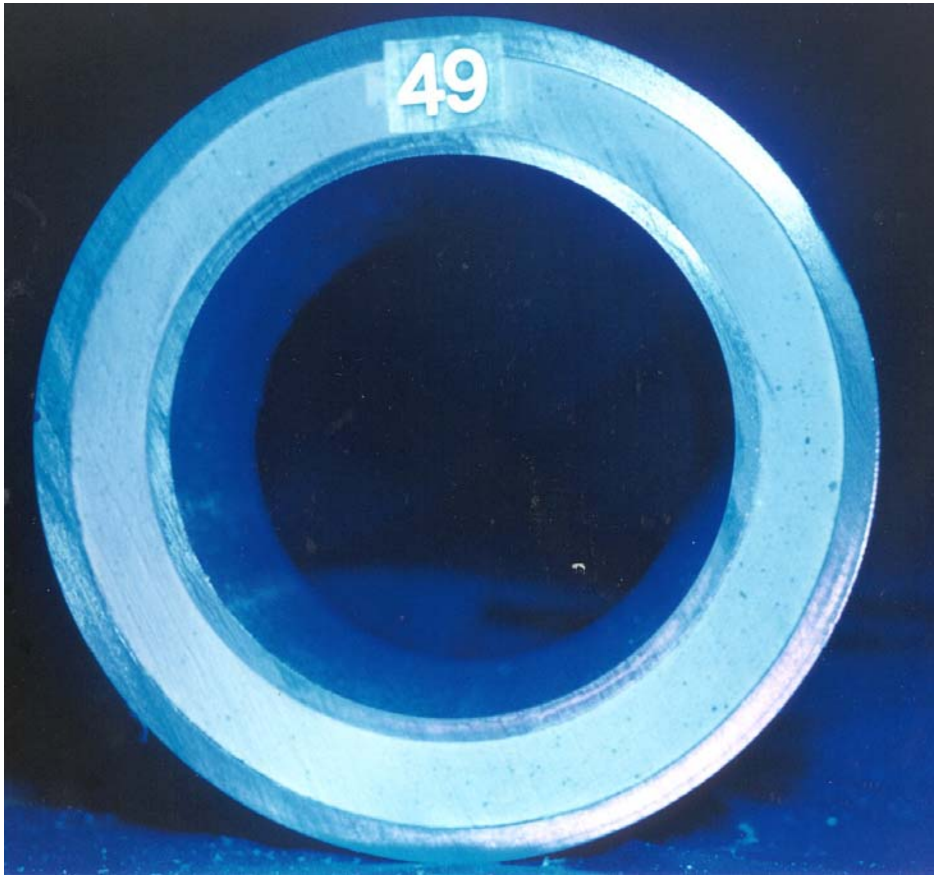
- Cement became brittle
- Radial cracks formed
- Longitudinal communication occurred
- Cement bond failed creating a microannulus

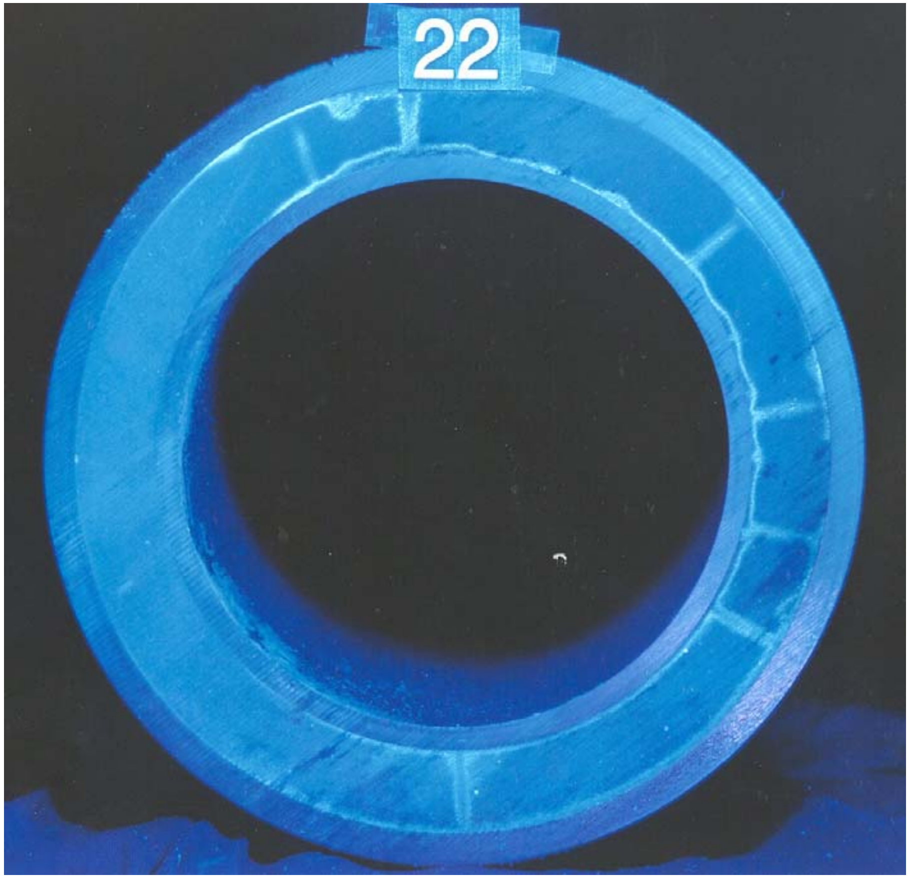
Large Scale Stress Testing
Foamed Cement



- No radial cracks
- Only slight debonding
- Foamed cement deformed and absorbed the expansive energy without failure due to its elastic nature

ZoneSeal vs Conventional Cement





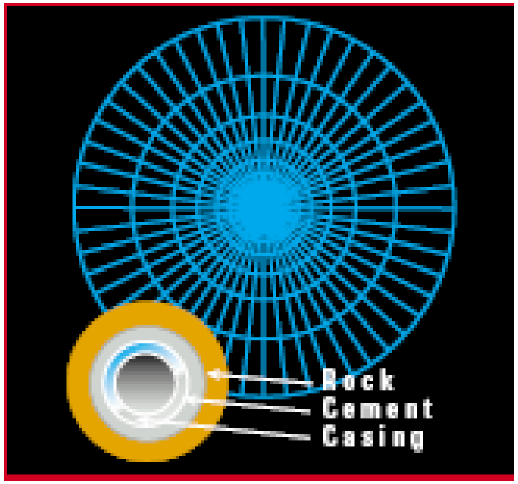
Cementing High Temperature and Pressure Wells

- General Issues
  - Zonal Isolation
  - Support Casing
  - Temperature Cycling
  - Low Fracture Gradient Formations
  - Exposure to Steam
  - Variable Hole Sizes
  - Long Well Life

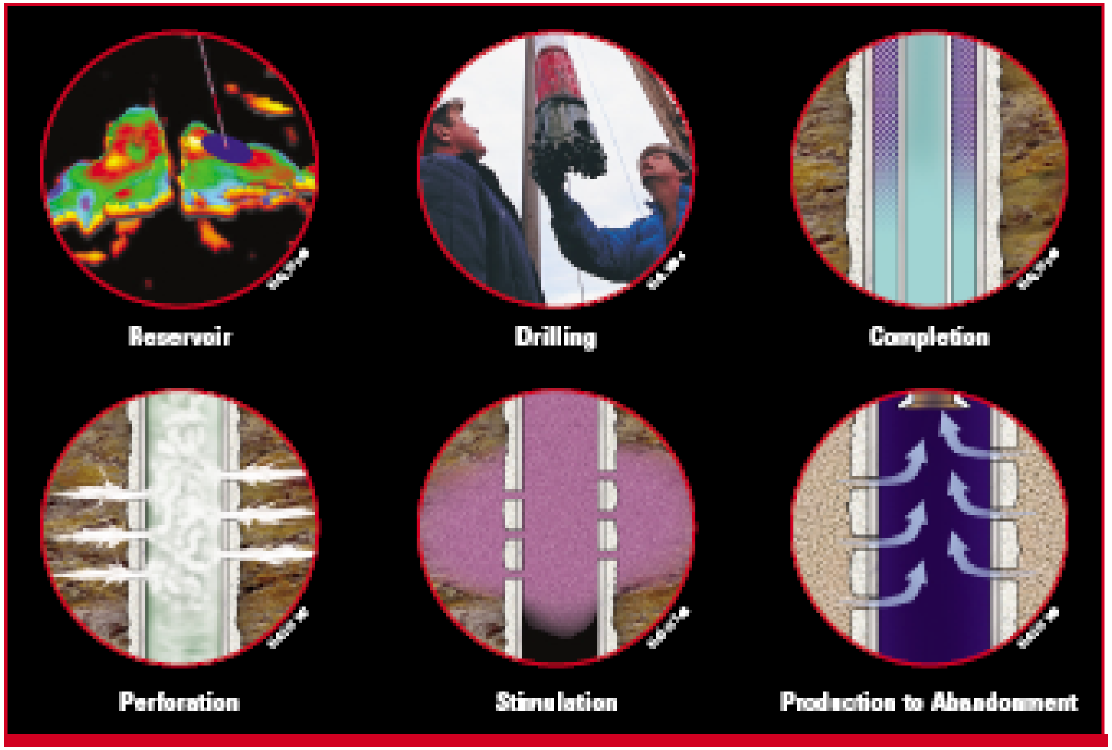
- Specific Issues
  - High Steam Pressure
    - > Fracture gradient
    - 550 to 600 deg. F.
  - Frequent Cycling
    - 10 to 15 cycles per year
  - Long Pay Interval
    - ~1/3 of total well depth
    - Maintain zonal isolation for 2 or 3 intervals
      - 5 to 10 years each

WellLife℠ Service

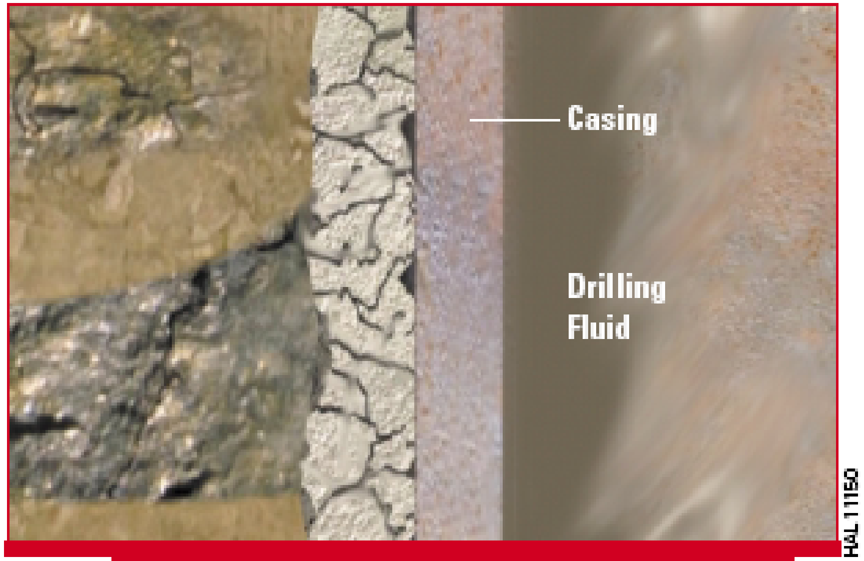
Advanced Technology for Long Term Zonal Isolation



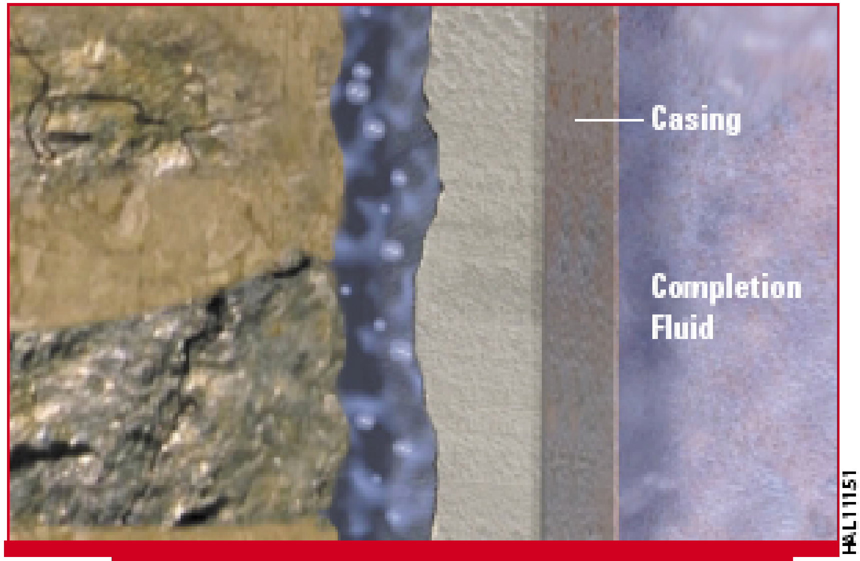
Life of the Well Events



Modes of Annular Sealant Failure



Above is a graphic depiction of a cement sheath that has shattered due to extreme pressure effects encountered during a fracturing operation. Depending on the length and location of the crush zone, interzonal communication could be a distinct possibility.

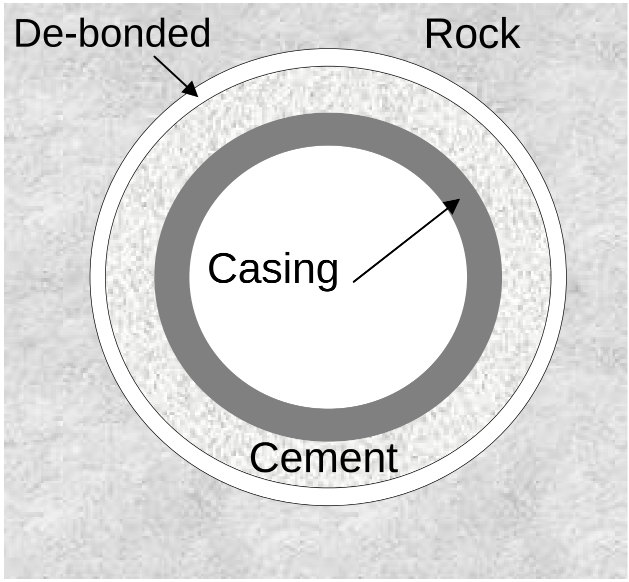


This scenario depicts debonding of the cement sheath due to casing contraction caused by replacing a heavy-weight drilling fluid with a light weight completion fluid.

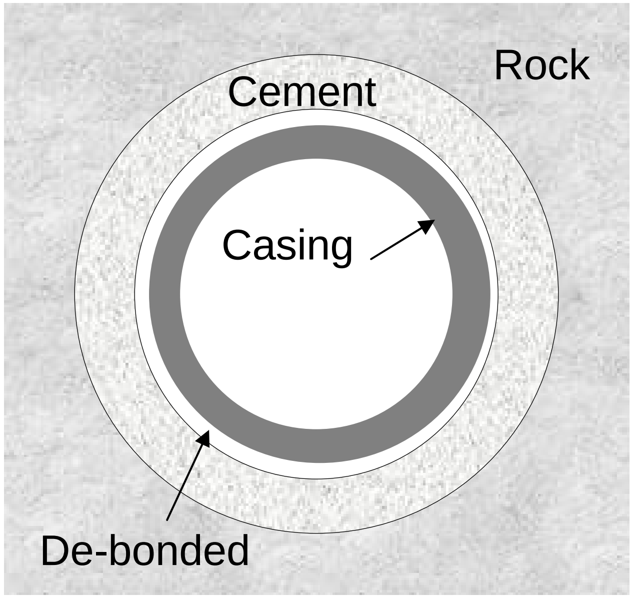
Modes of Cement Failure

- De-bonding

@ rock-cement interface

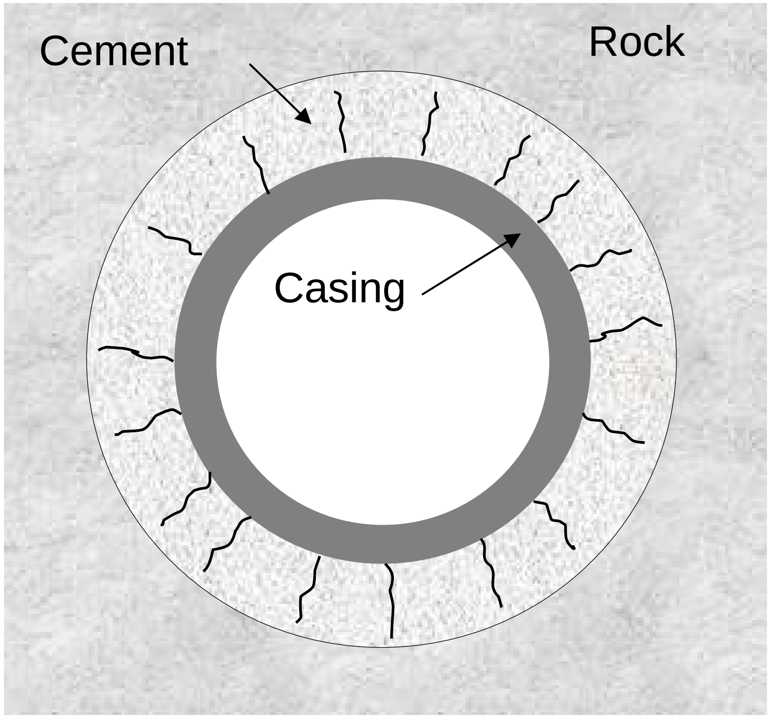


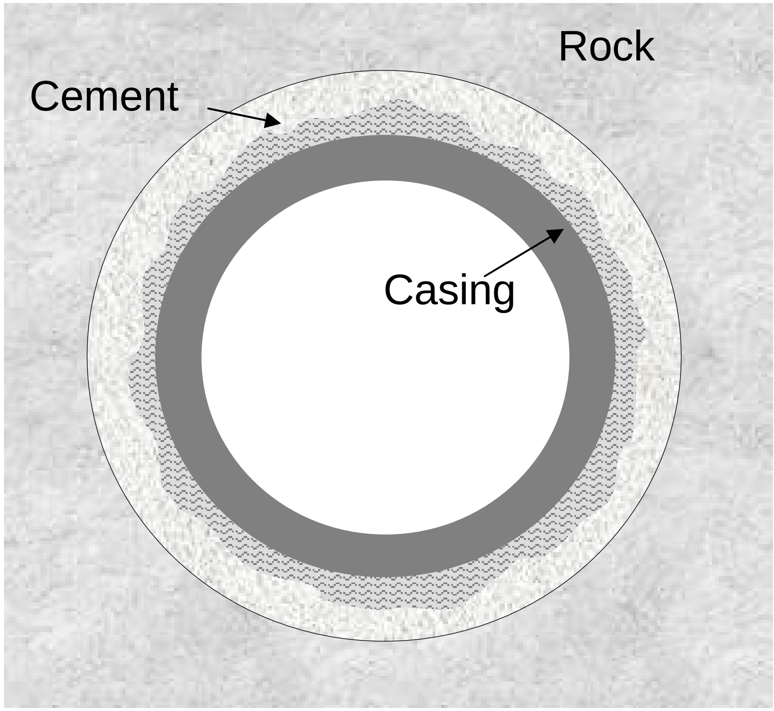
@ cement-casing interface



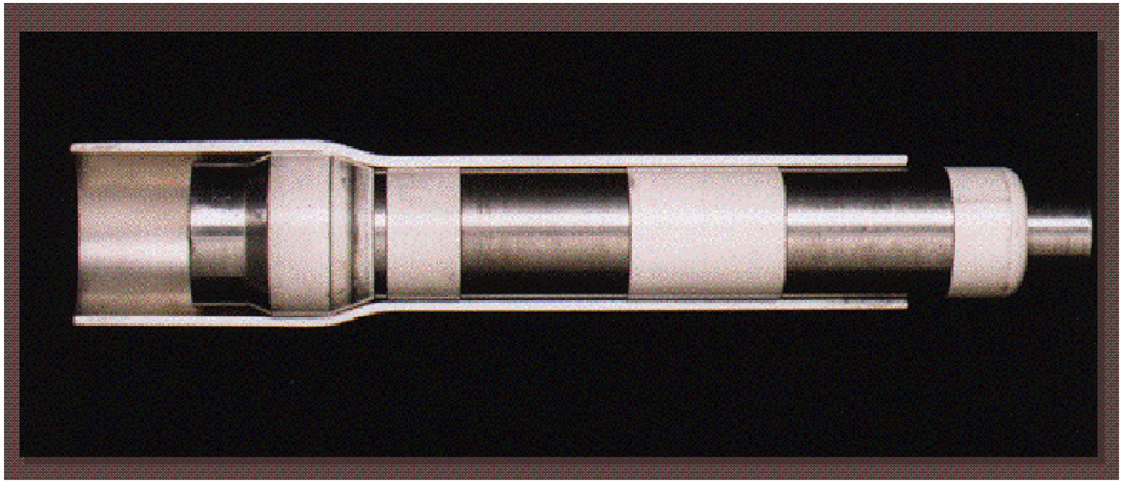
Modes of Cement Failure

- Cracks
- Deformation

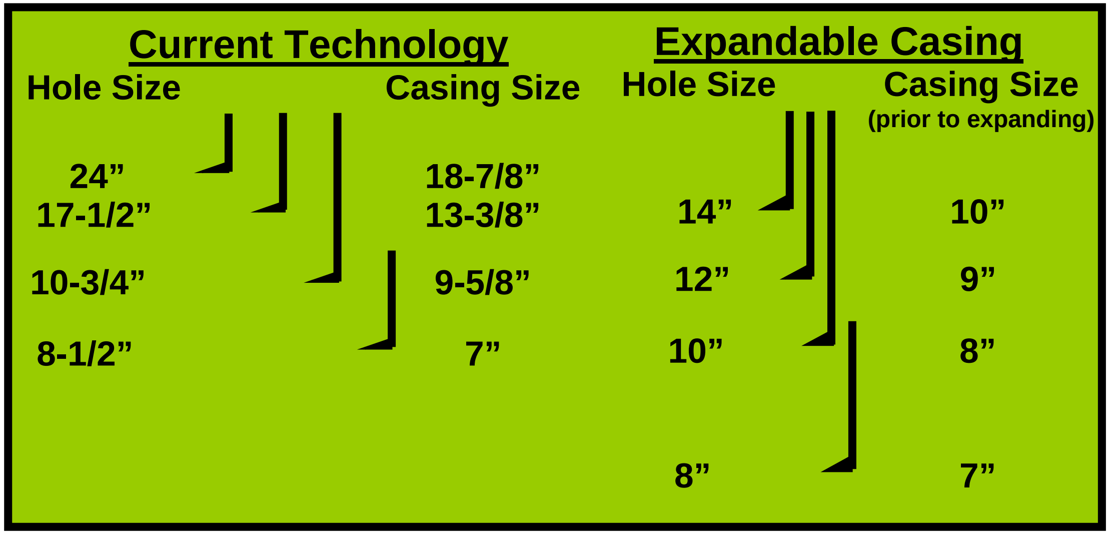




Expandable Casing - Products and Services



Cross section of expanded pipe and pig



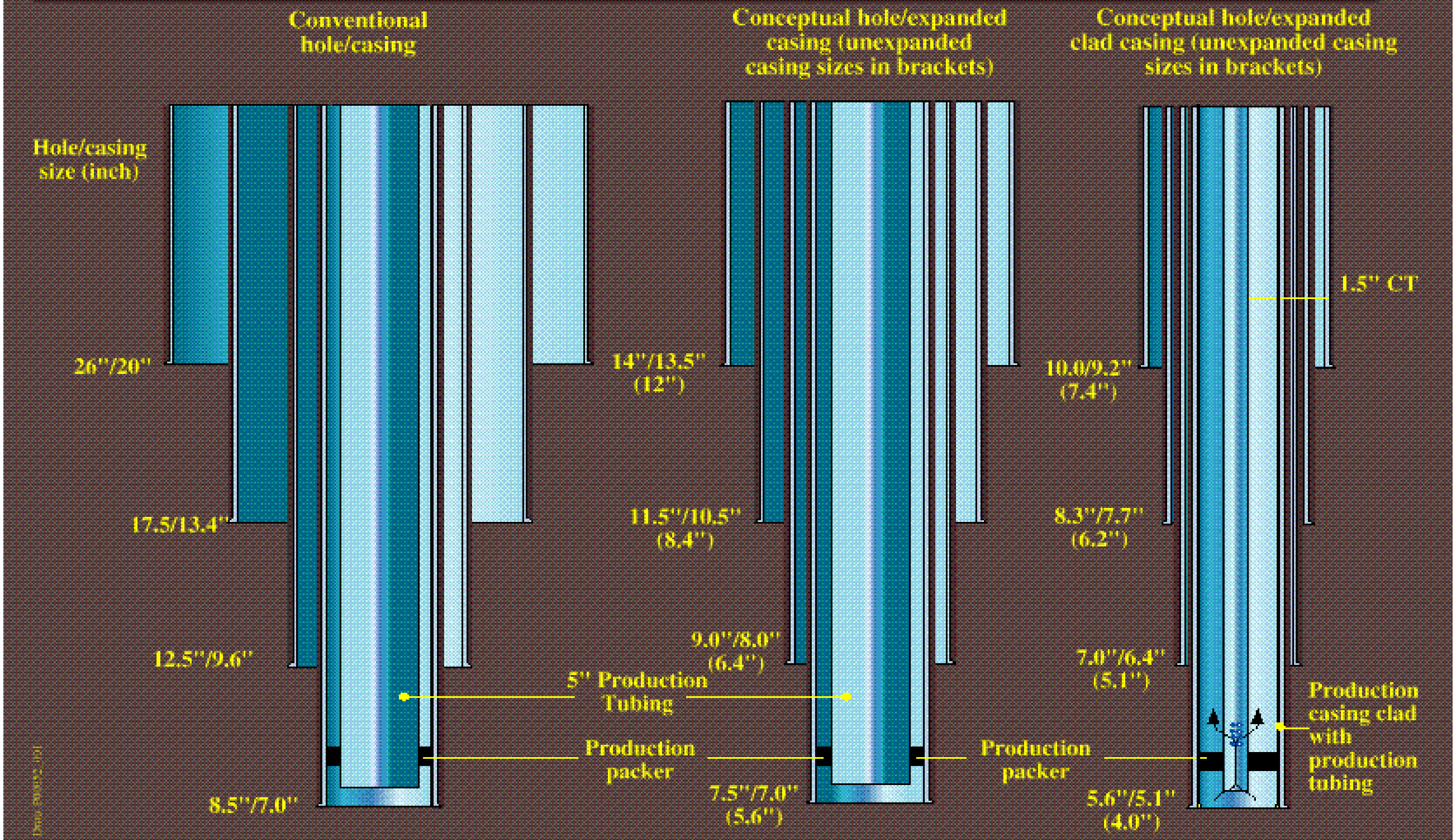
Current Technology

Hole Size	Casing Size
24”	18-7/8”
17-1/2”	13-3/8”
10-3/4”	9-5/8”
8-1/2”	7”

Expandable Casing

Hole Size	Casing Size (prior to expanding)
14”	10”
12”	9”
10”	8”
8”	7”

Comparative well designs using unexpanded and expand tubulars



Strategies for Reducing Oil Field Power Costs

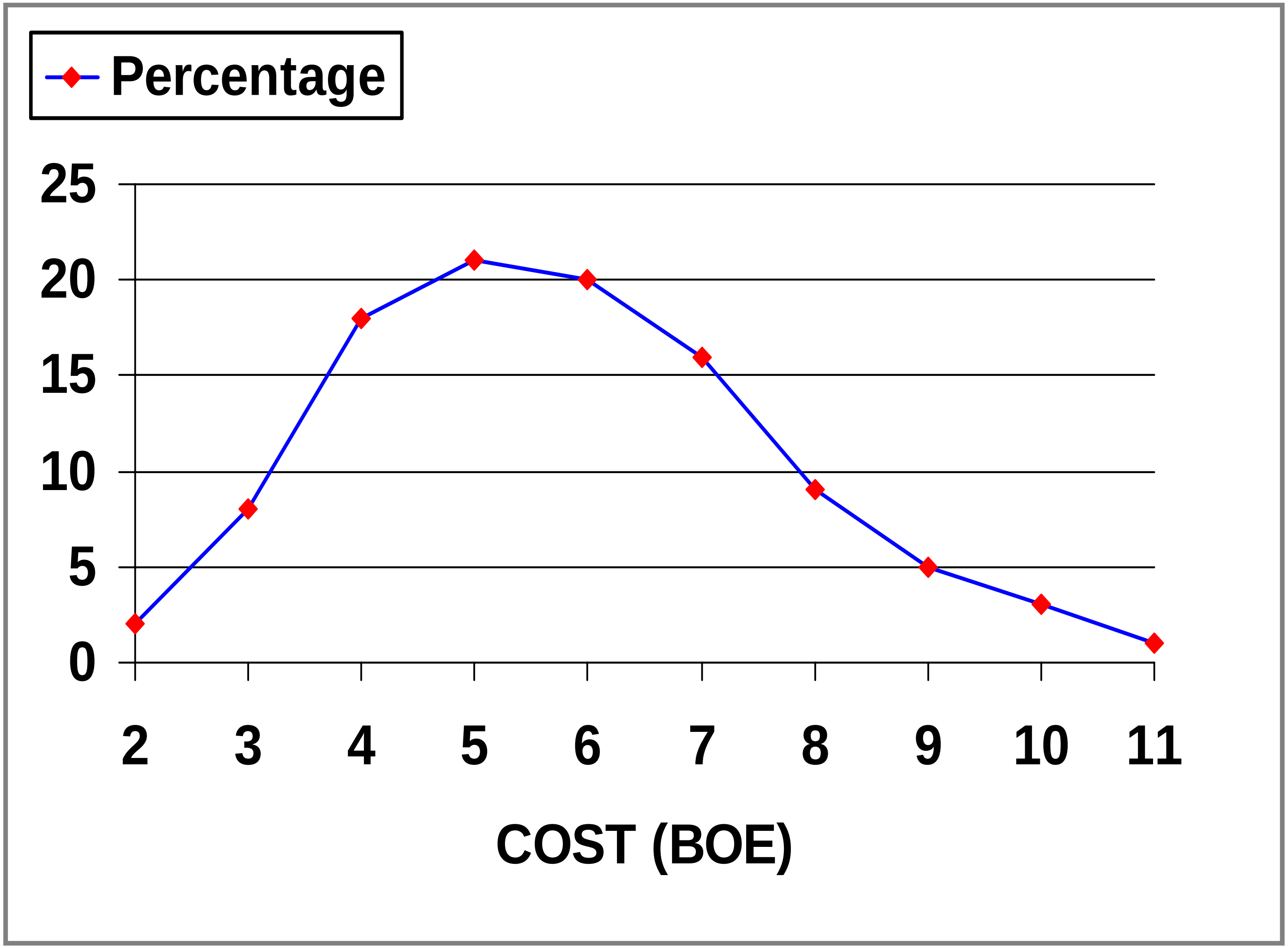
- Electricity is a large percentage of operating costs in the production of oil and gas **(up to 40-50% in 2000) (up to 55% in 2005??)**

- Historically power costs have received limited focus
  - Specialized, non-core technical skills
  - Conventional suppliers are regulated monopolies

- Several studies have recommended methods to reduce power costs
  - Optimize mechanical systems
  - Optimize electrical systems
  - Optimize usage against a regulated rate structure

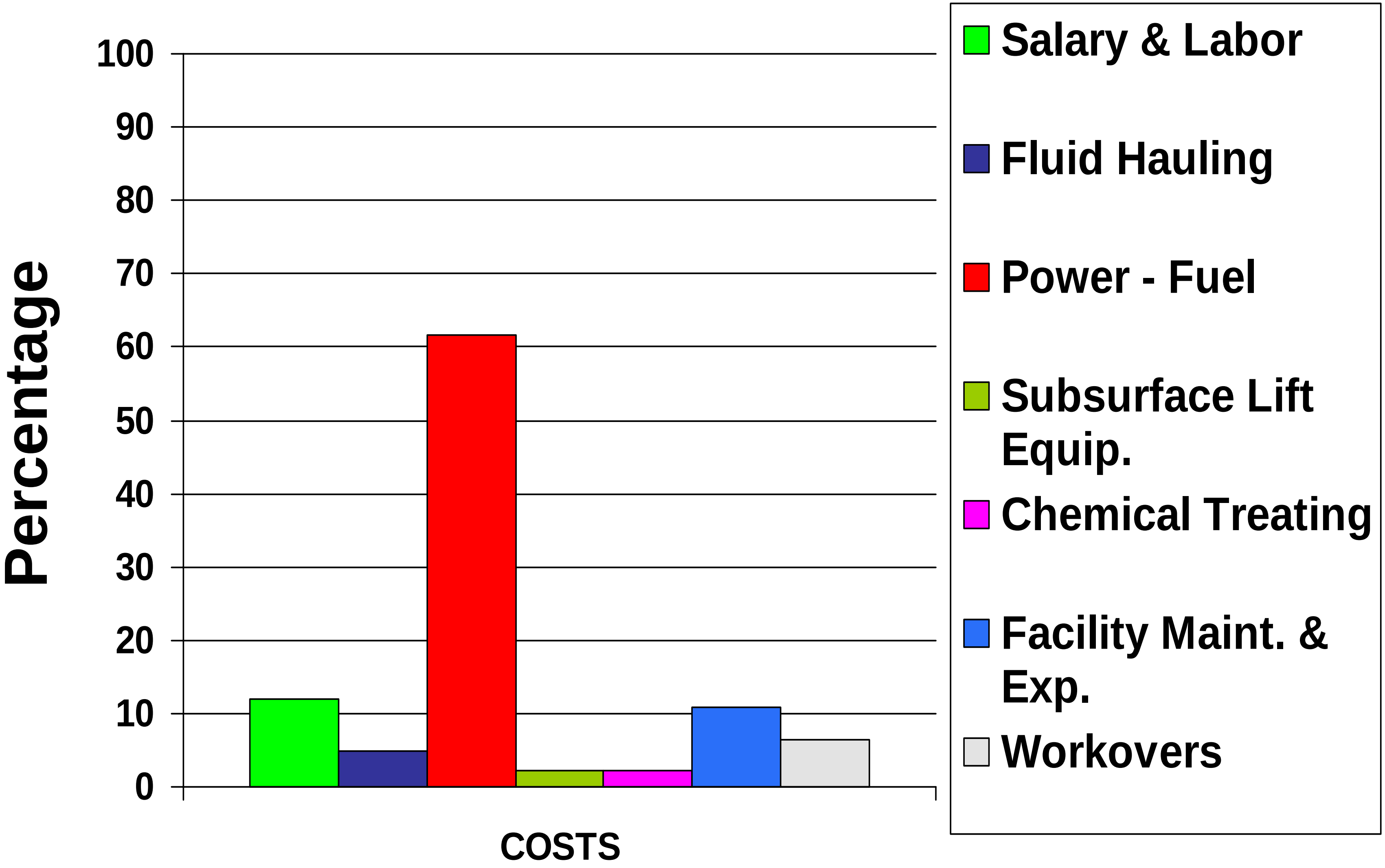
- What will happen in future developments ?

Average Lifting Costs in Permian Basin ($5-6/BOE)



Operational Expenses

Typical Permian Basin Operation w/ $4.35 BOE Lifting Cost



Largest Cost - Monitoring and Control

- The underlying cost of electricity is influenced by when it is consumed
- Loads with excessive peaks increase the cost of electricity
- Historically electricity has been priced independent of time
- With deregulation the end user will begin to see more of the underlying variation in the cost of electricity and either
  - Pay someone a premium to absorb this volatility
  - Manage volatility through load management

In-field Generation

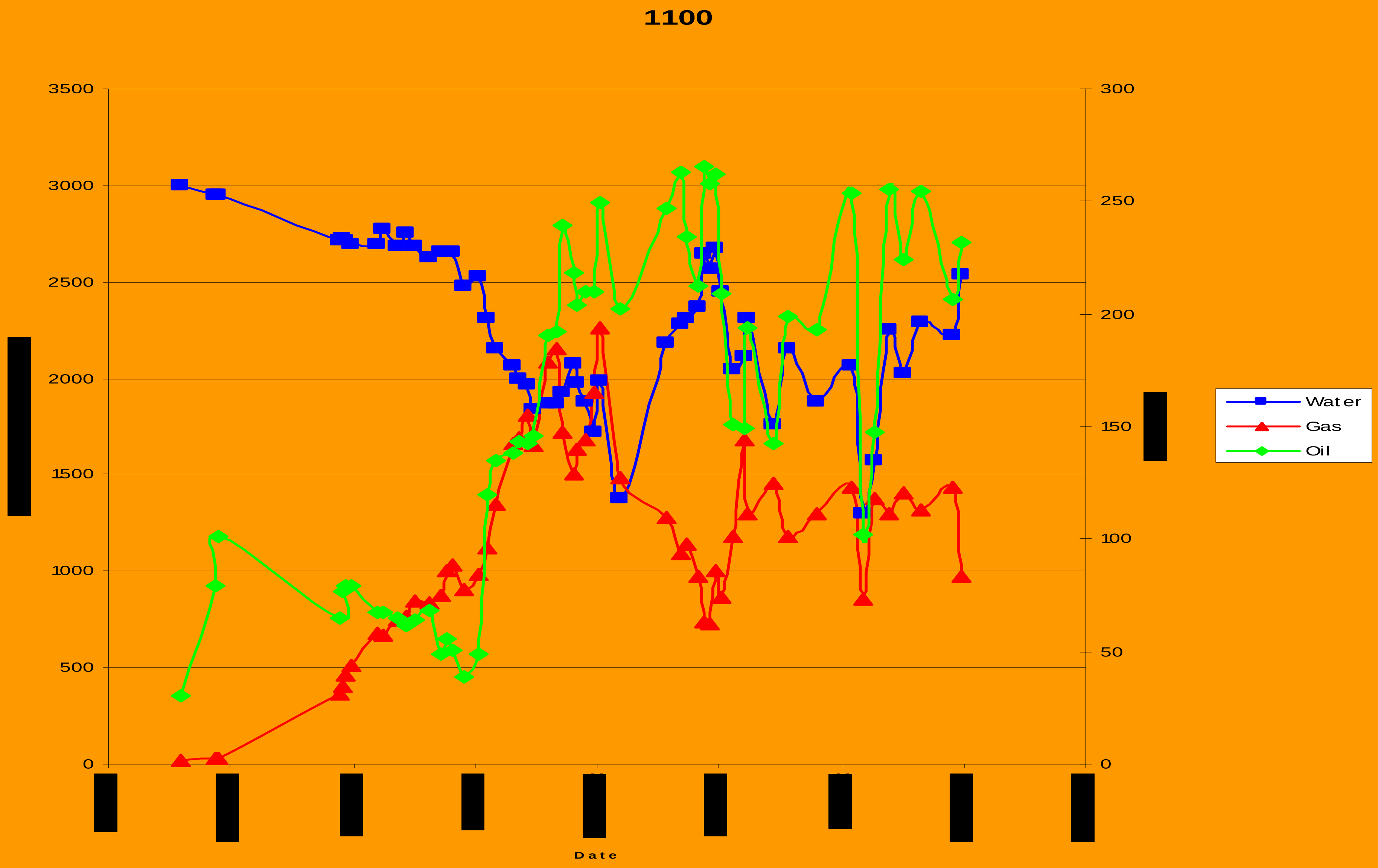
- Grew out of the Public Utility Regulatory Act of 1978 (PURPA)
  - **Required the utilities to purchase power generated by a “qualified” facility**
  - **Normally associated with co-generation or use of the exhaust heat at site**
  - **Purchase price of electricity in excess of load was most often not sufficient**
- Projects involve producing electricity with in-field generators
  - **Usually natural gas driven**
  - **Gas Engines or gas turbines**
  - **200 Kw to 10 Megawatt in size**
- Cost to generate is a function of gas price, capital cost and O&M

In cents/Kw-hr	**Cost of Conversion**	**Fuel Cost**	**Total Cost**
Flared Gas	2.5	0	2.5
$2.00/mmBtu	2.5	2.2	4.7
$4.00/mmBtu	2.5	4.4	6.9
$5.00/mmBtu	2.5	5.5	8.0

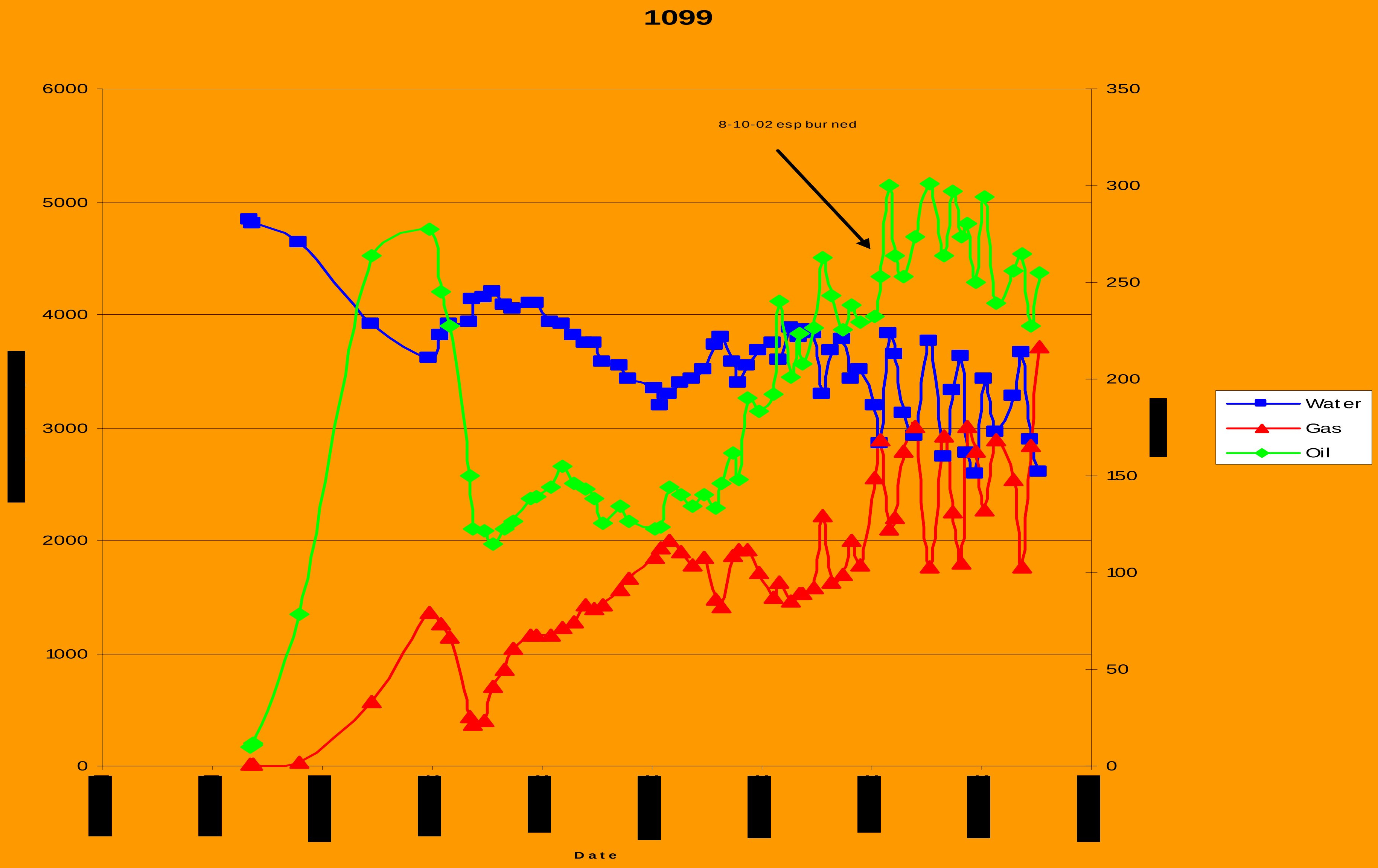
In-field Generation – Past Considerations

- If operator can generate power for less than purchasing from the grid then in-field generation can make sense
- With deregulation more options exist for selling power generated in excess of the load
- Monetizing stranded or distressed gas
  - Gas that has reduced value because of some kind of physical constraint that cannot be economically solved using conventional methods
    - **Too far away or expensive to hook up to a pipeline**
    - **Low volume or low deliverability wells**
    - **High impurities or low pressure**
  - A solution would be to burn the gas in a generator located at the source and consume or sell onto the grid
- In-field generation may make sense if the operator has low value gas, high field electricity rates, or thermal heat requirements

Water and Gas



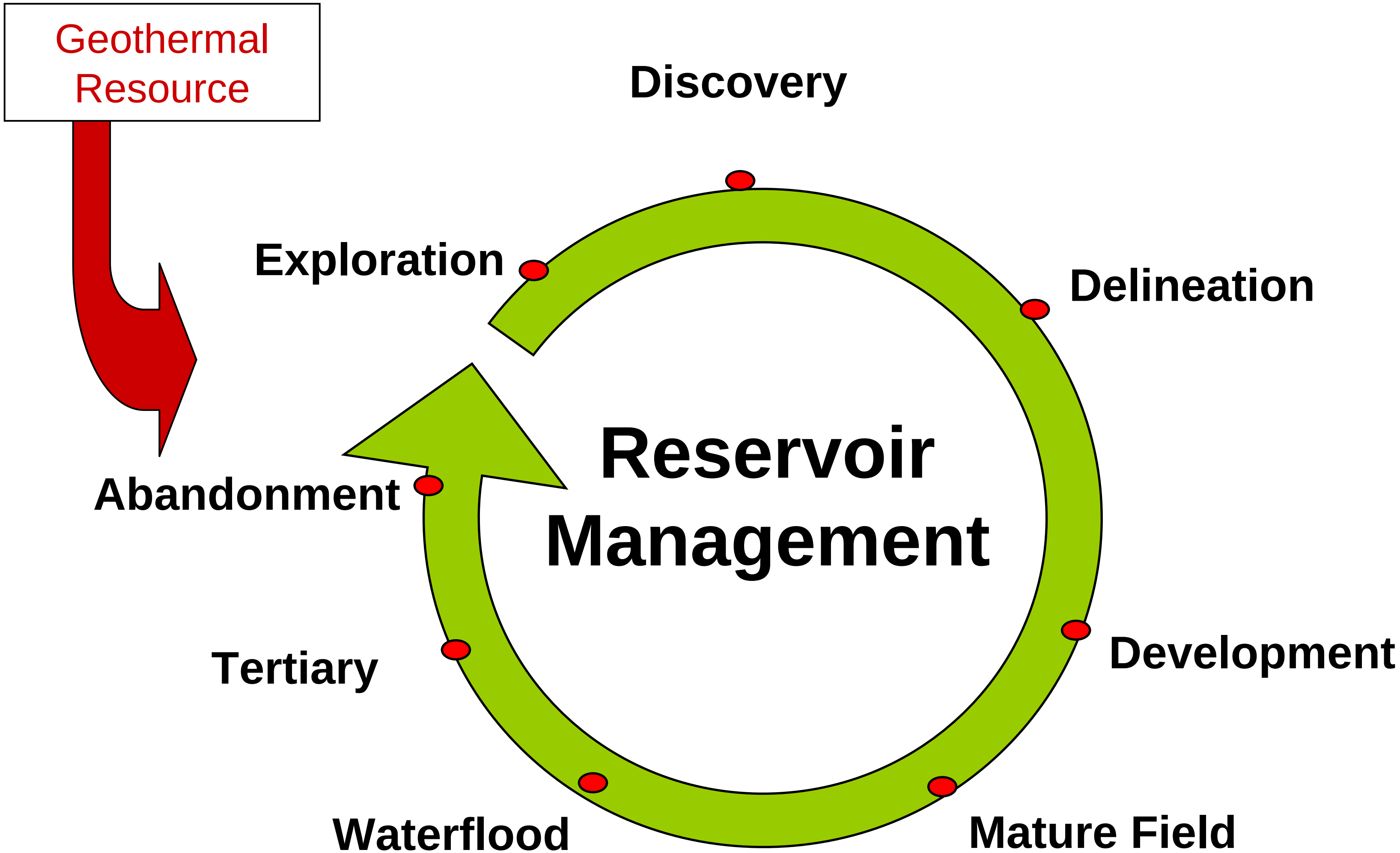
Water & Gas – Hydrostatic Head Relationship



Who is over the new developments – Invention or Status Quo

Technology Barriers

Reservoir Life Cycle



Geothermal Resource

Discovery

Exploration

Delineation

Reservoir Management

Abandonment

Development

Tertiary

Waterflood

Mature Field

PRODUCTION