Best Practices in Exploration: Drilling, Casing and Cementing

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December 6, 2011

Dr. Fleckenstein's Background

- Industry Experience
  - Roughneck on Drilling Rigs
  - Drilling/Completions/Workover Supervisor
  - Drilling/Completions/Workover Engineer
  - Area Engineer

- Academic
  - Doctorate from Colorado School of Mines
  - BP Adjunct Professor, specializing in unconventional reservoirs
  - PERFORM Research Director at Colorado School of Mines
  - Finite Element Modeling of Cased Wellbores
  - Stimulation Research

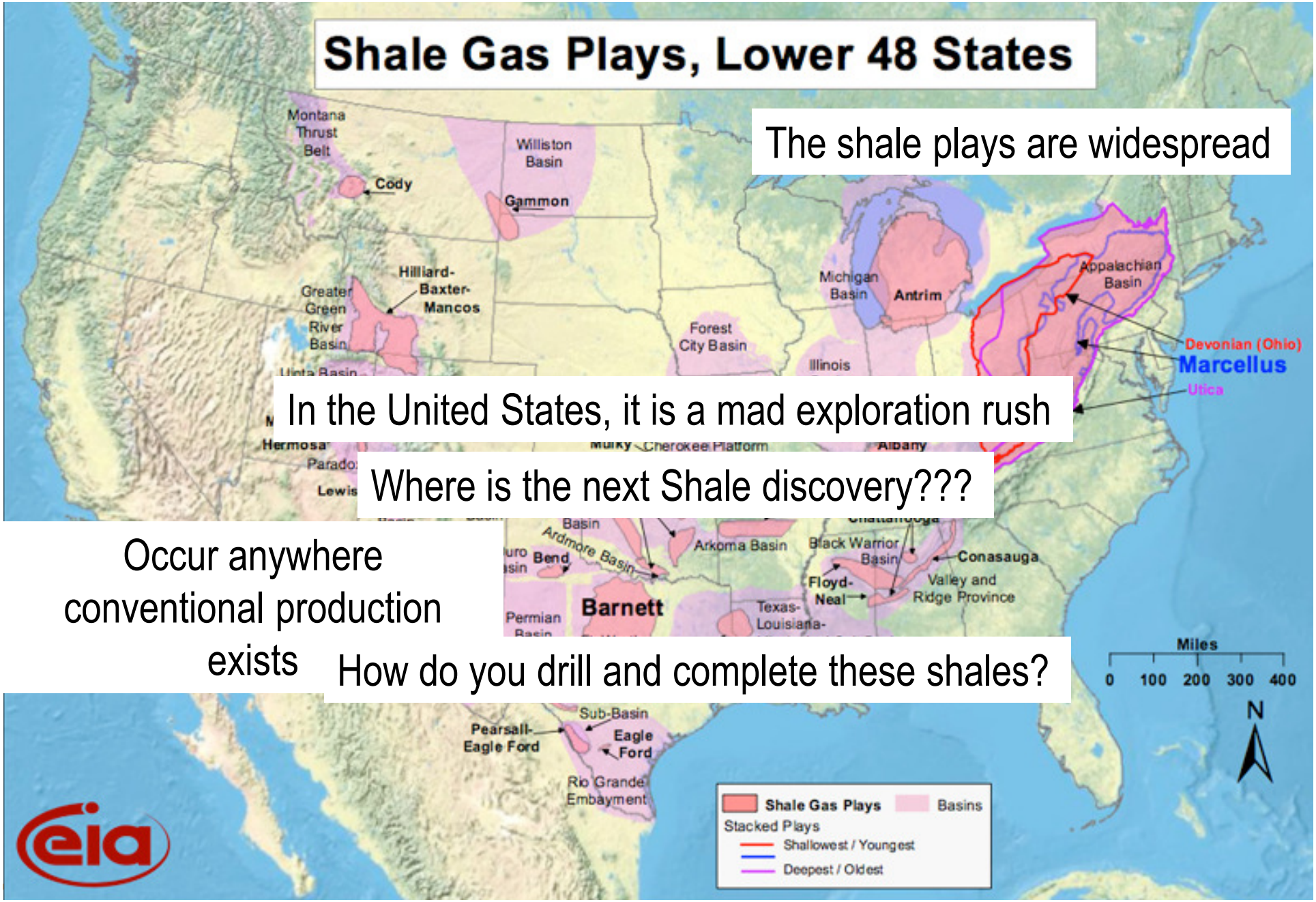
Important Shale Development Topics

1. Drilling
   - Modern horizontal drilling began in 1990, with the widespread acceptance of MWD (Measurement While Drilling) to steer the wellbore horizontally.
   - This allowed the experimentation in the Barnett Shale by George Mitchell, resulting in horizontal laterals, coupled with multi-stage fracturing, to develop shales

2. Casing
   - The curvature of wellbore meant that the casing had to curve also, resulting in connections designed to withstand the torque and drag of a horizontal well
   - The casing many times has to be rotated to bottom, driving the acceptance of top drives on rigs, and special tools to facilitate this rotation

3. Cementing and Isolation
   - Special tools and cements were developed to cement these wellbores, including expandable liner hangers and inflatable packers.
   - “Swellable” packers were developed to isolate fracturing treatments.

Shale Drilling


Shale Gas Plays, Lower 48 States
The shale plays are widespread
In the United States, it is a mad exploration rush
Where is the next Shale discovery???
Occur anywhere conventional production exists
How do you drill and complete these shales?
Montana Thrust Belt
Williston Basin
Cody
Gammon
Hilliard-Baxter-Mancos
Greater Green River Basin
Forest City Basin
Michigan Basin
Antrim
Appalachian Basin
Devonian (Ohio)
Marcellus
Utica
Illinois
Arkoma Basin
Ardmore Basin
Bend
Barnett
Permian
Black Warrior Basin
Conasauga
Floyd-Neal
Valley and Ridge Province
Texas-Louisiana-
Pearsall-Eagle Ford
Sub-Basin
Eagle Ford
Rio Grande Embayment
Miles
0 100 200 300 400
N
Shale Gas Plays
Basins
Stacked Plays
Shallowest / Youngest
Deepest / Oldest

Tremendous Amount of Experience Drilling and Completing Horizontal Wells in the United States

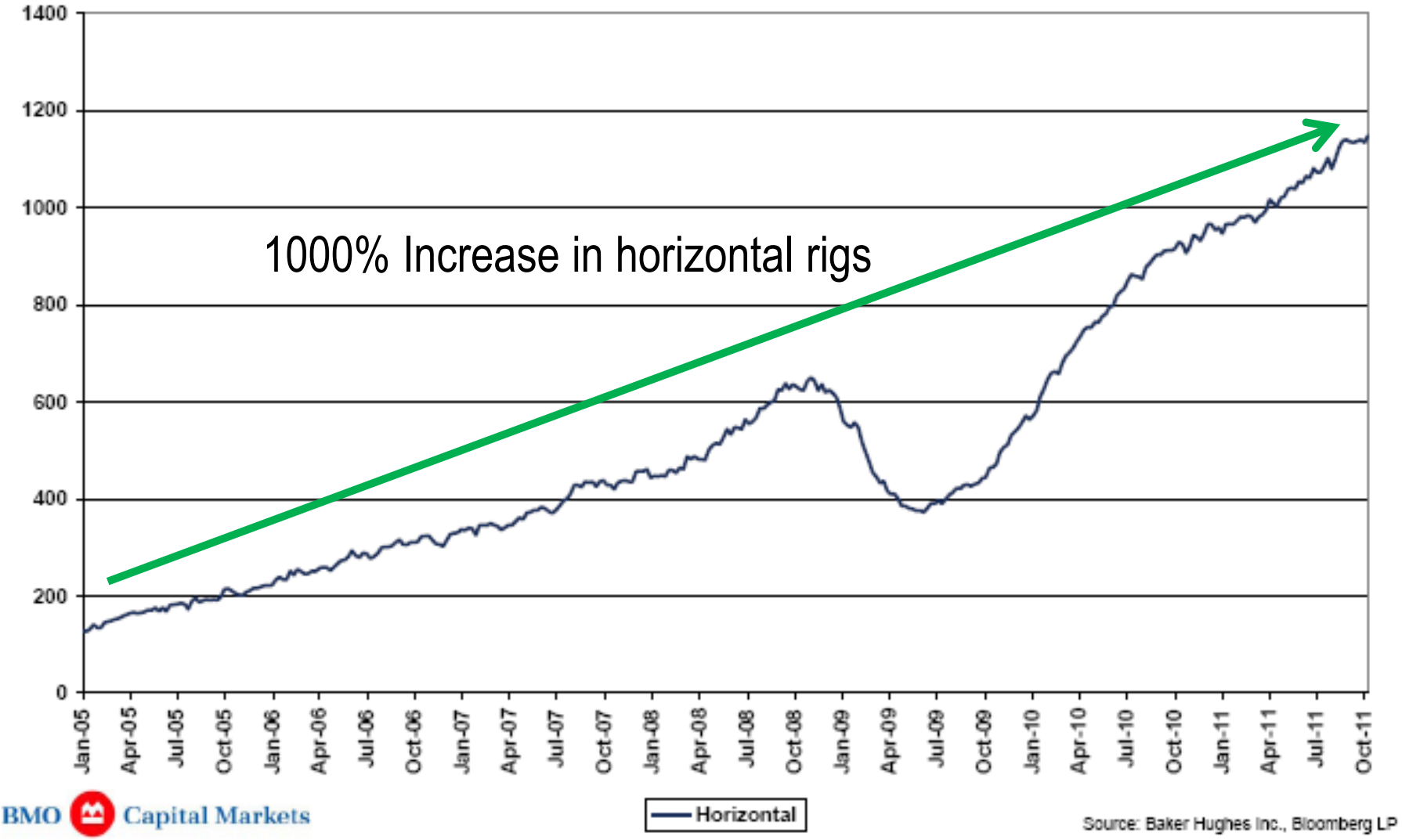
Currently ***1148 rigs*** are drilling horizontal wells in USA

Breakout Information	This Week	+/-	Last Week	+/-	Year Ago
Oil	1070	10	1060	380	690
Gas	935	12	923	-36	971
Miscellaneous	7	0	7	-3	10
Directional	246	8	238	33	213
Horizontal	1148	13	1135	219	929
Vertical	618	1	617	89	529

Nearly twice as many rigs drilling ***horizontally*** than ***vertically***

The experimentation on how to drill shale wells has been done in the US

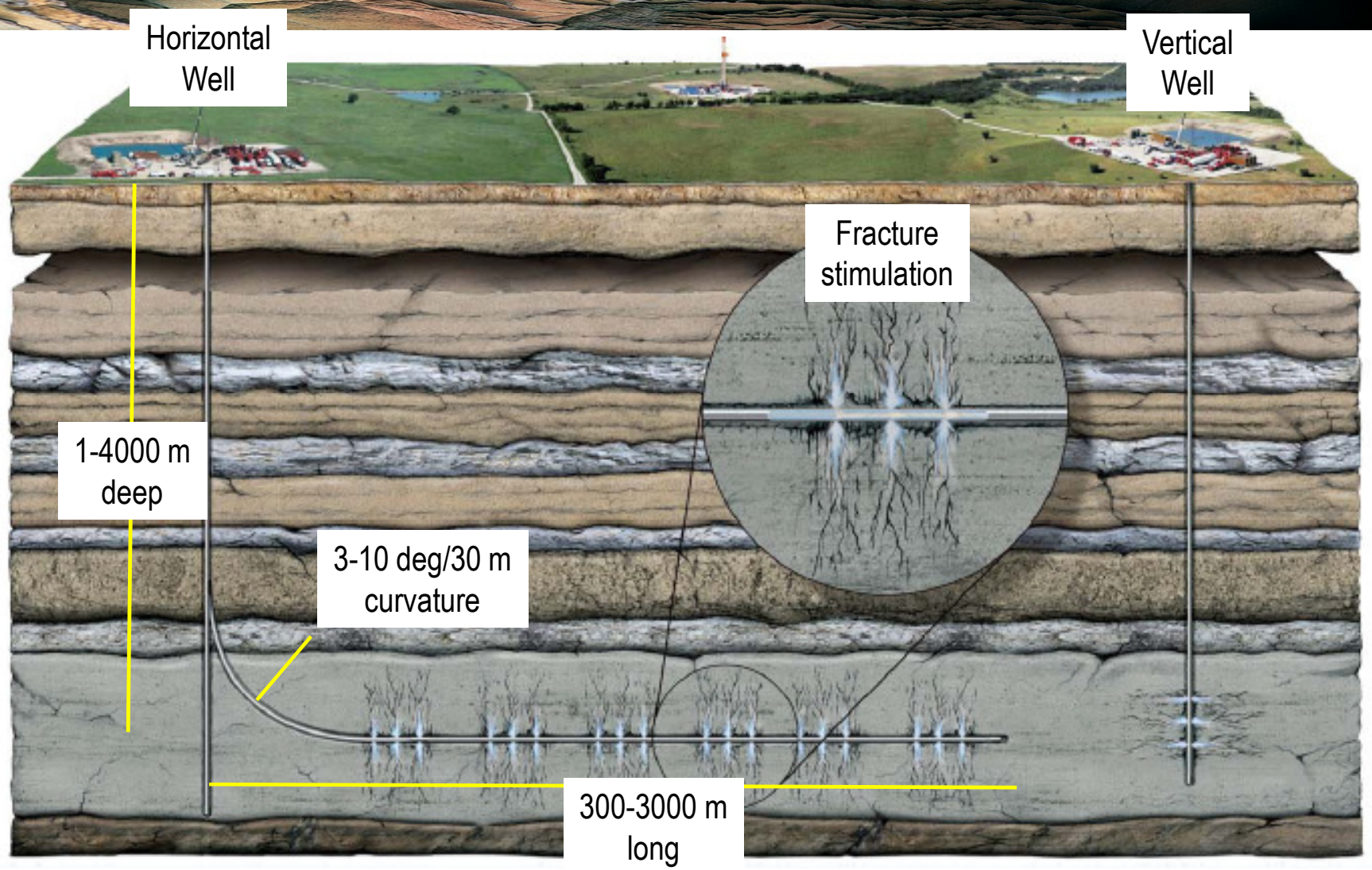
United States Horizontal Rotary Rig Count



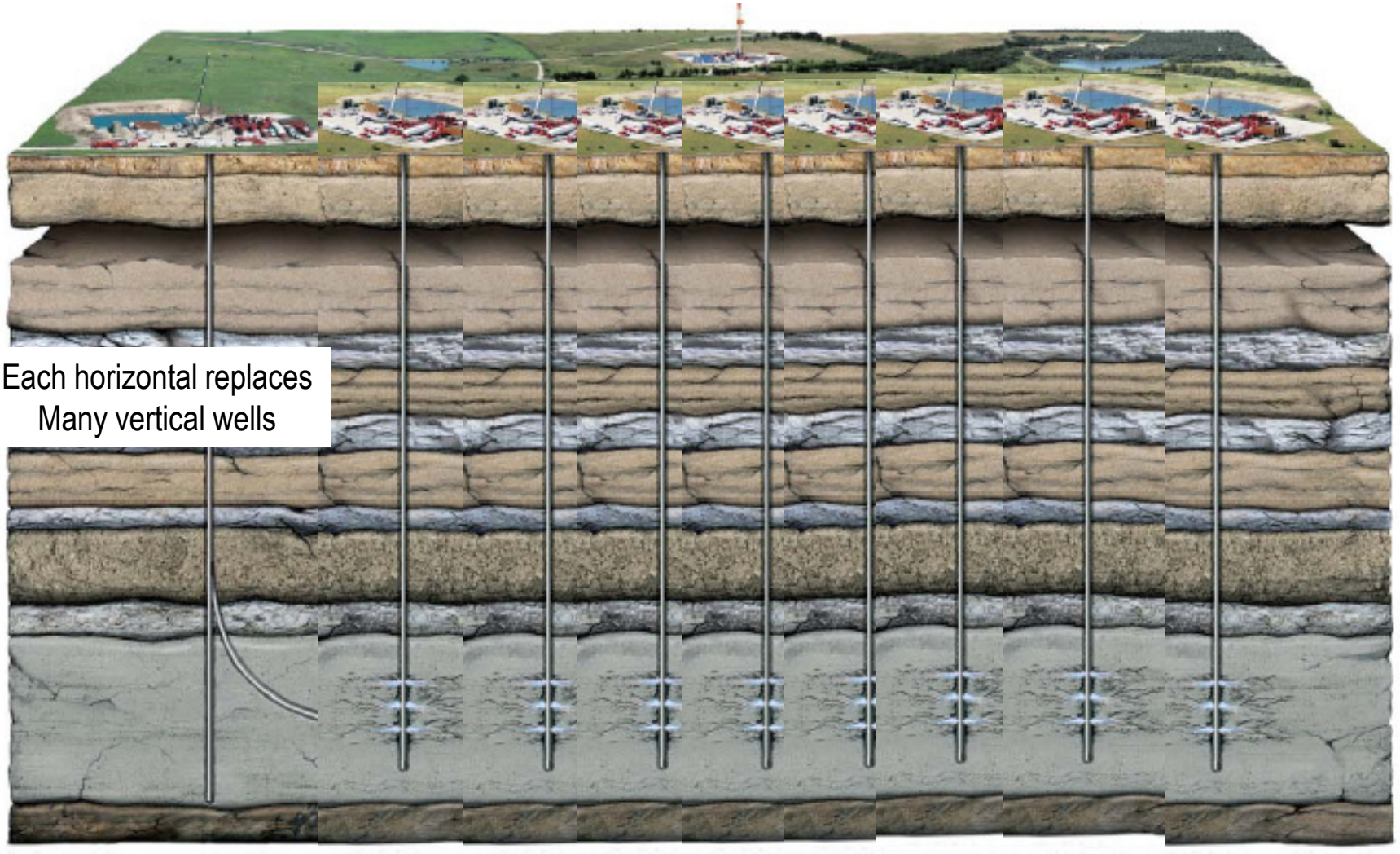
BMO Capital Markets

Source: Baker Hughes Inc., Bloomberg LP

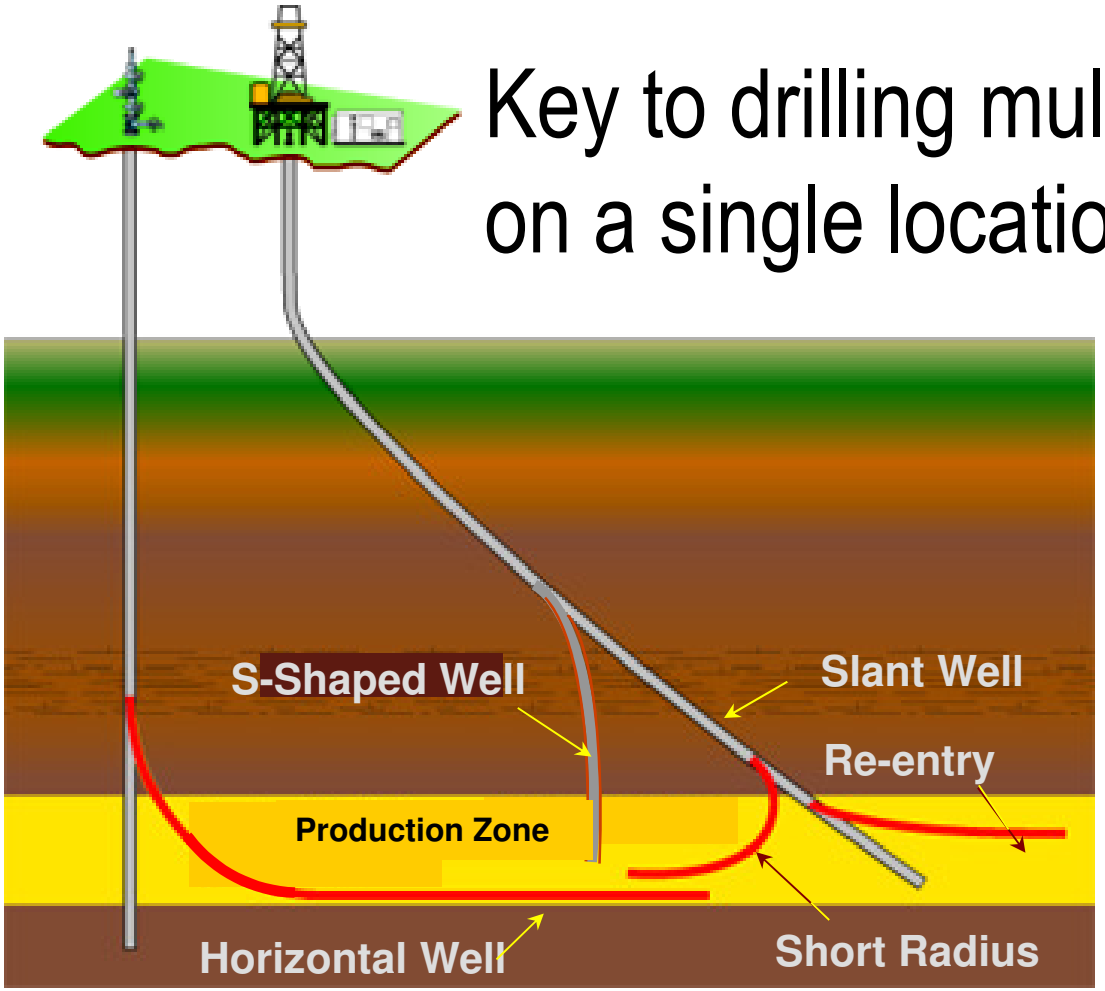
Vertical vs. Horizontal Drilling



Vertical vs. Horizontal Drilling

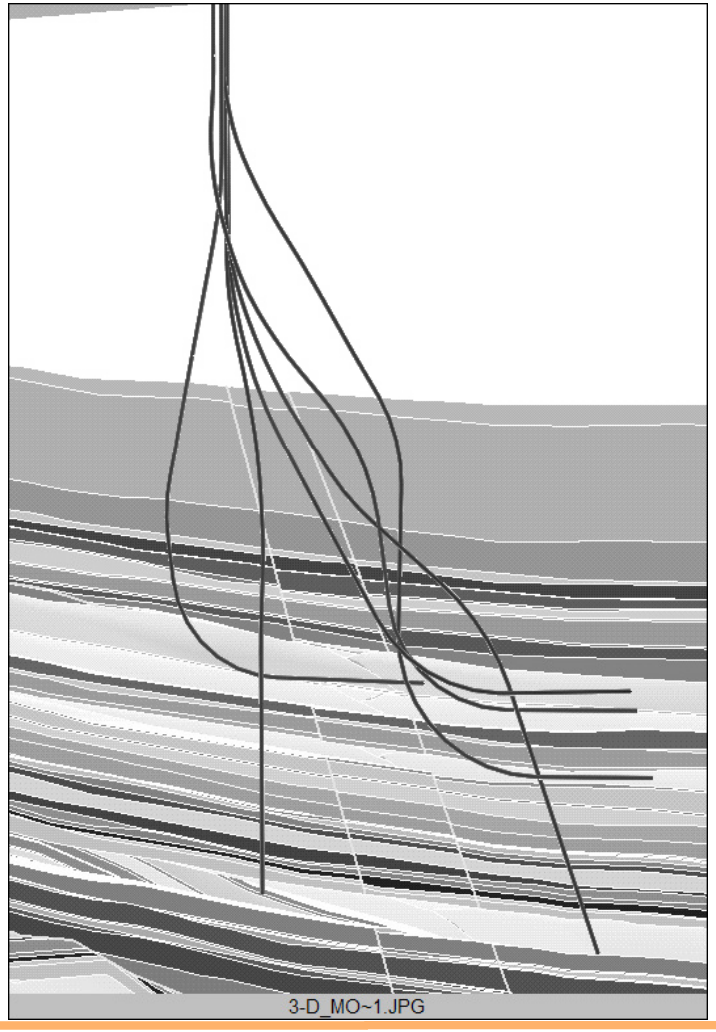


Directional well possibilities



Key to drilling multiple wells on a single location

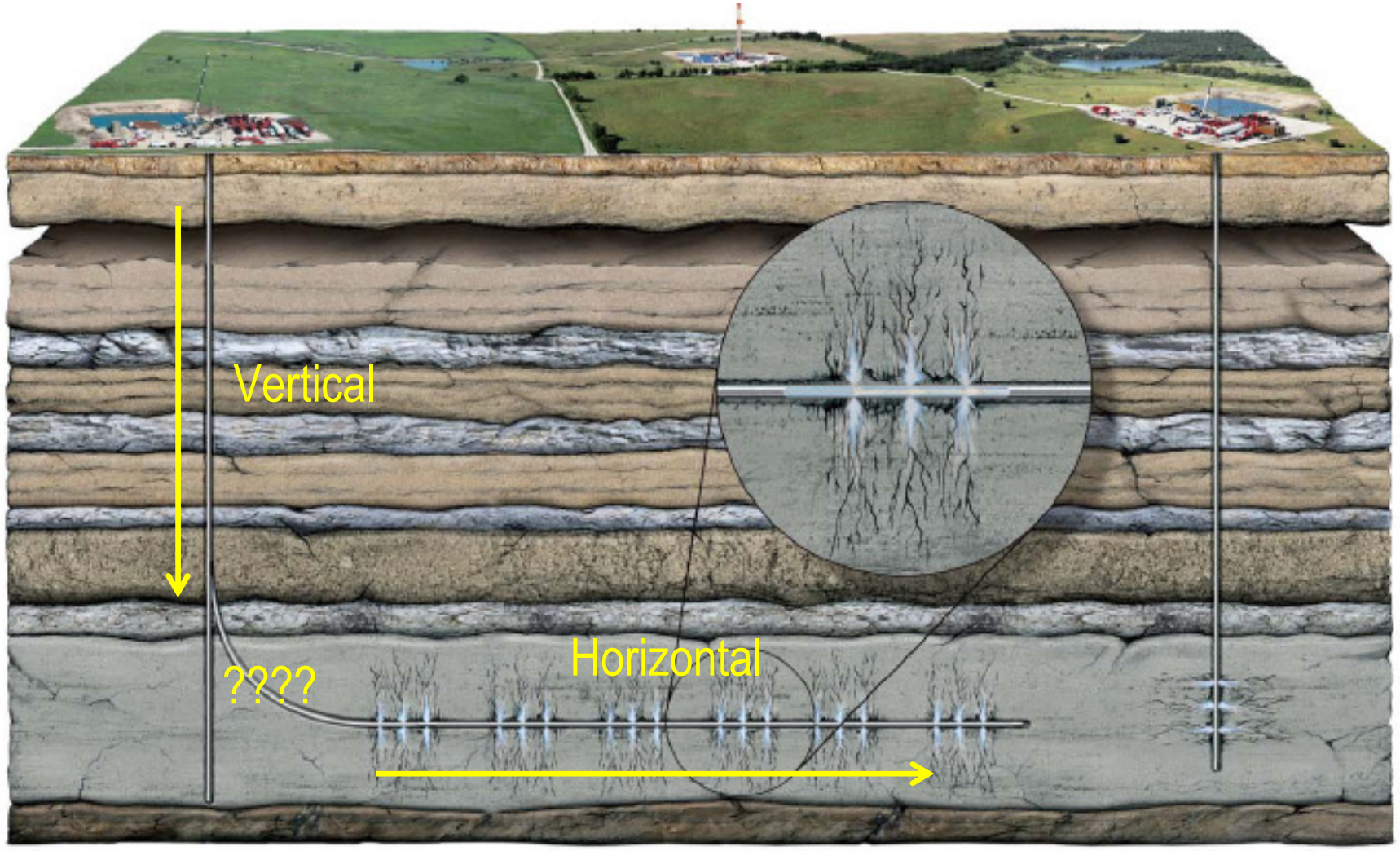
Horizontal Drilling Project by Dr. Fleckenstein



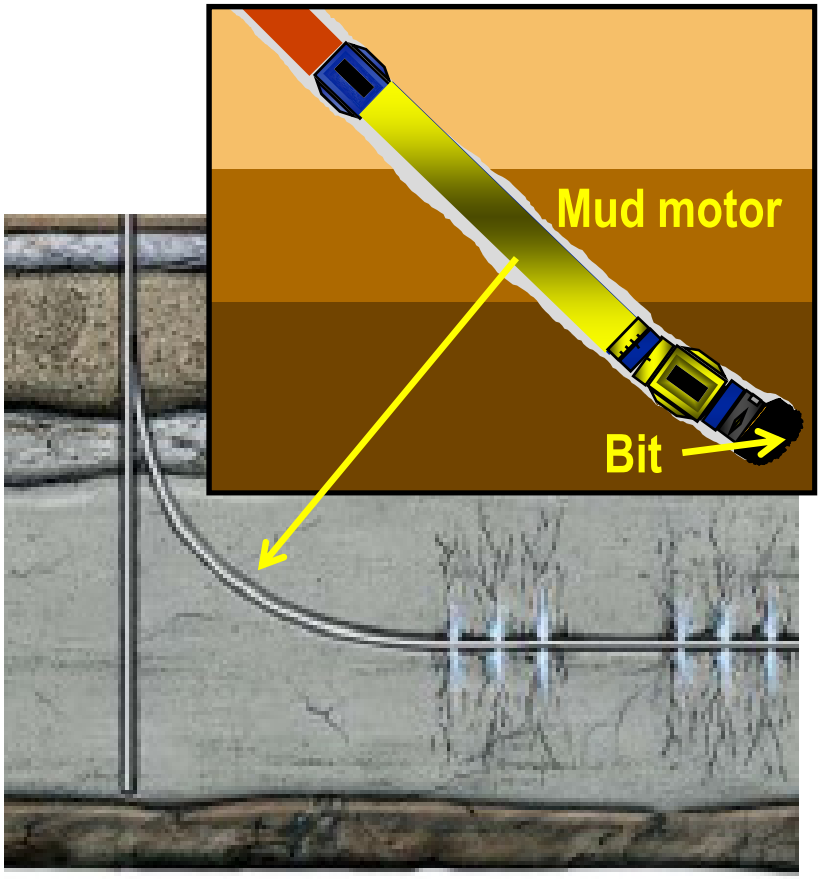
Six complicated wells drilled from a single surface location in California

How do we drill a horizontal well?

Horizontal Drilling with Fracking is *the* primary shale development tool



How do we drill a horizontal well?



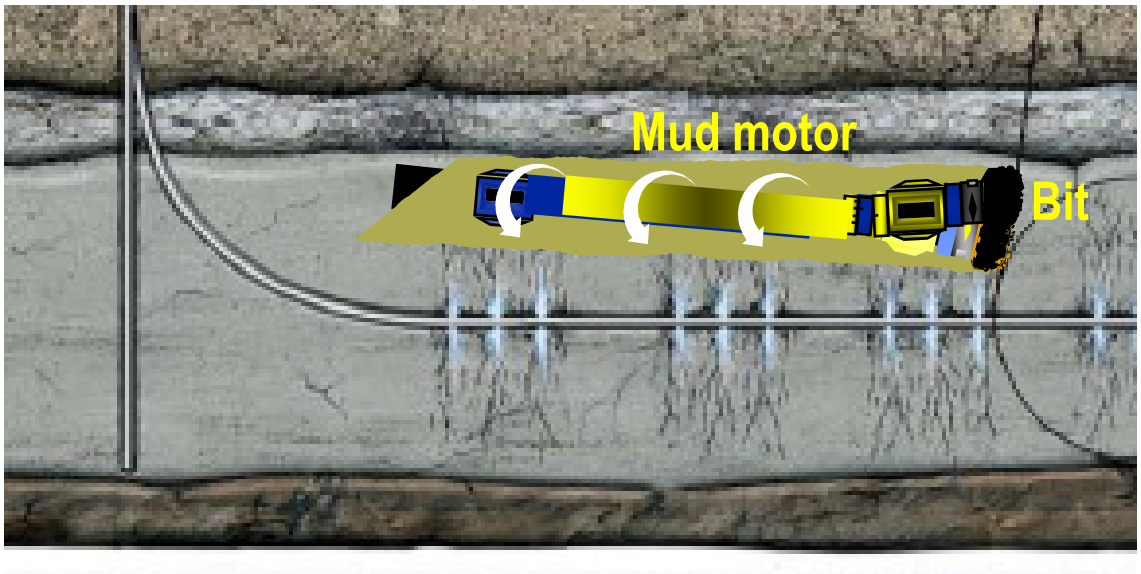
Change direction by rotating bit with a downhole motor, or a rotary steerable system – deflect the bit

Controlled curvature

Controlled direction

No drill string rotation

How do we drill a horizontal well?



- Drill straight by rotating the drill string, so that the bit is never pointed in a single direction
- Maintain direction of the bit
- Rotary steerable or mud motor system
- Drill string rotation may or may not be necessary

Traditional Drilling Rig

1. Drill Pipe
2. Rotary Table
3. BOP & Wellhead
4. Crown Block
5. Derrick
6. Traveling Block and Hook
7. Closing Unit
8. Choke Manifold

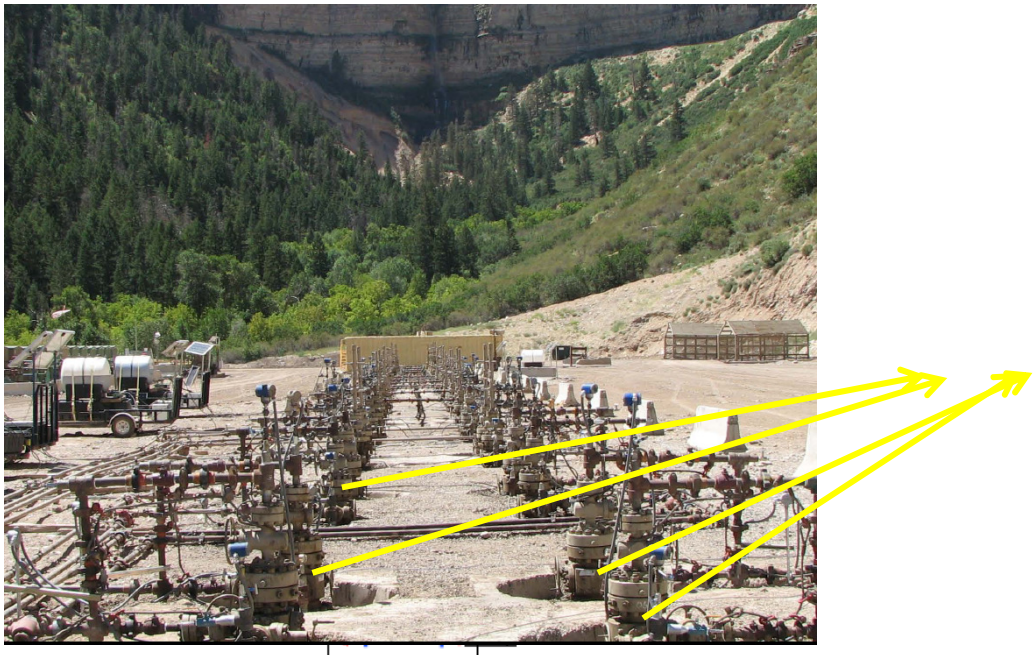
Drilling Rig Modified for Horizontal Wells

Bigger, more powerful pumps

Well Construction and Surface Disruption

Drilling rigs are very large and result in 150 direct and indirect jobs per rig.

The drilling rig needs good roads, bridges etc. to move. The best rig move is to not move very far, but to drill multiple wells from 1 location.



Colorado wellsite

Proper well siting allows multiple wells to be drilled from the same location.

The drilling rig “walks” from well to the next, minimizing time, costs and allowing the least surface disruption

Risk Management – Laws of Physics Still Apply

Experience helps eliminate mishaps!!!
Less rig moves equal less “problems”

Shale Casing Programs

What is a wellhead?

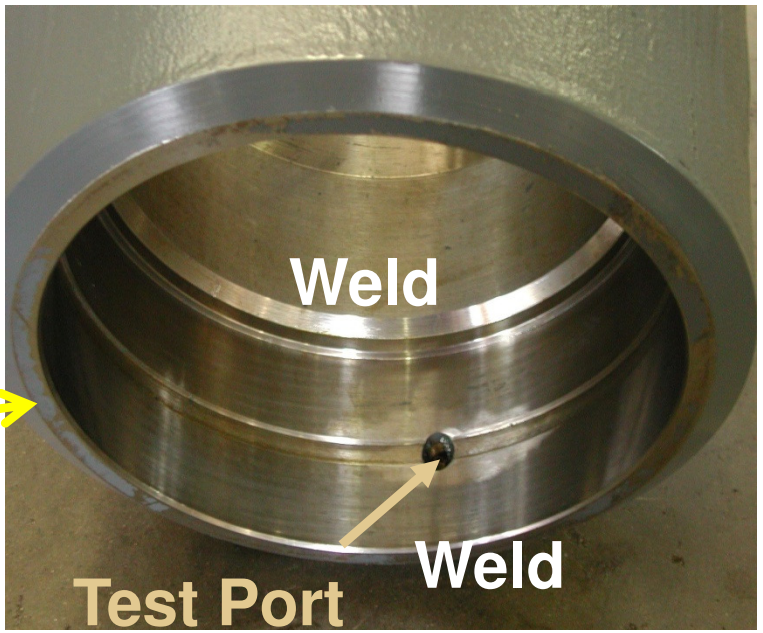
Conventional wellhead assemblies include:

- Casing head
- Casing hangers
- Spool sections
- Tubing heads
- Tubing hangers
- Valves and fittings (Christmas Trees)

What is a wellhead?

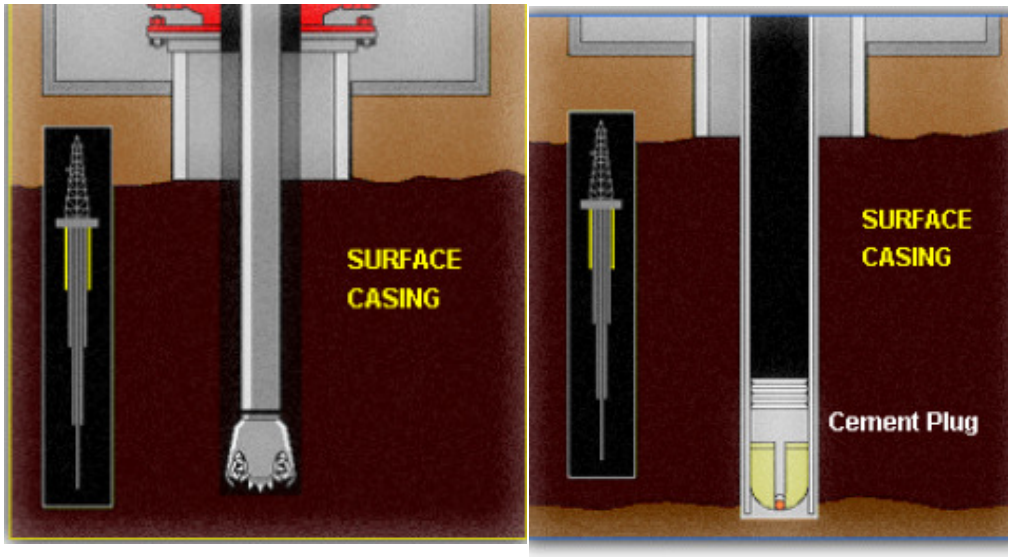
All welds and connections must be tested.

If not tested, how do you know???



Surface Casing

1. The hole is drilled for the first string of casing.
2. The casing is then cemented in the wellbore to the surface.



Surface Casing Purpose

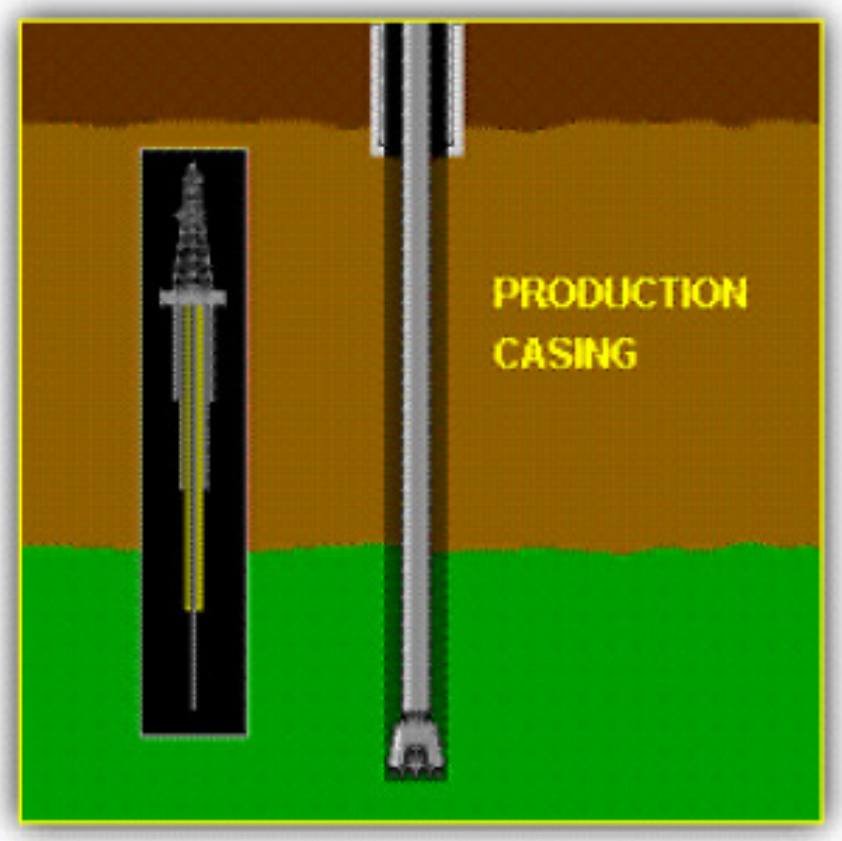
1. Protect Surface water
2. Anchor BOPE
3. Support casing strings
4. Well Control

Cementing Process

Intermediate Casing Casing

Run intermediate casing
- Protects hole
  - Sloughing
  - High pressure
  - Low pressure
  - Salt

Production Casing

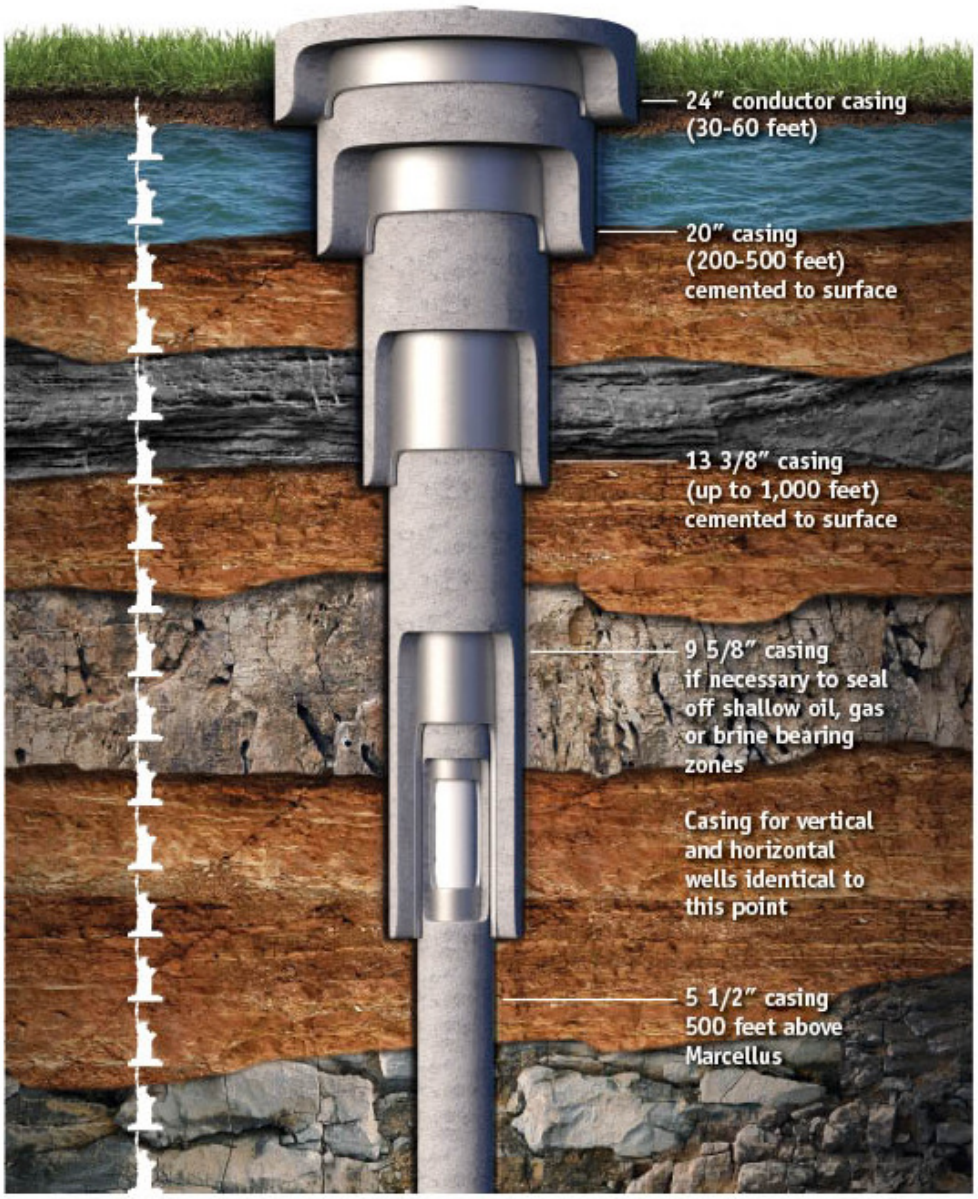


Production casing

- Usually run to total depth (TD) of well
- Normally cemented
- Isolates producing formation
- Fracturing fluid path

General Marcellus Well Casing Design

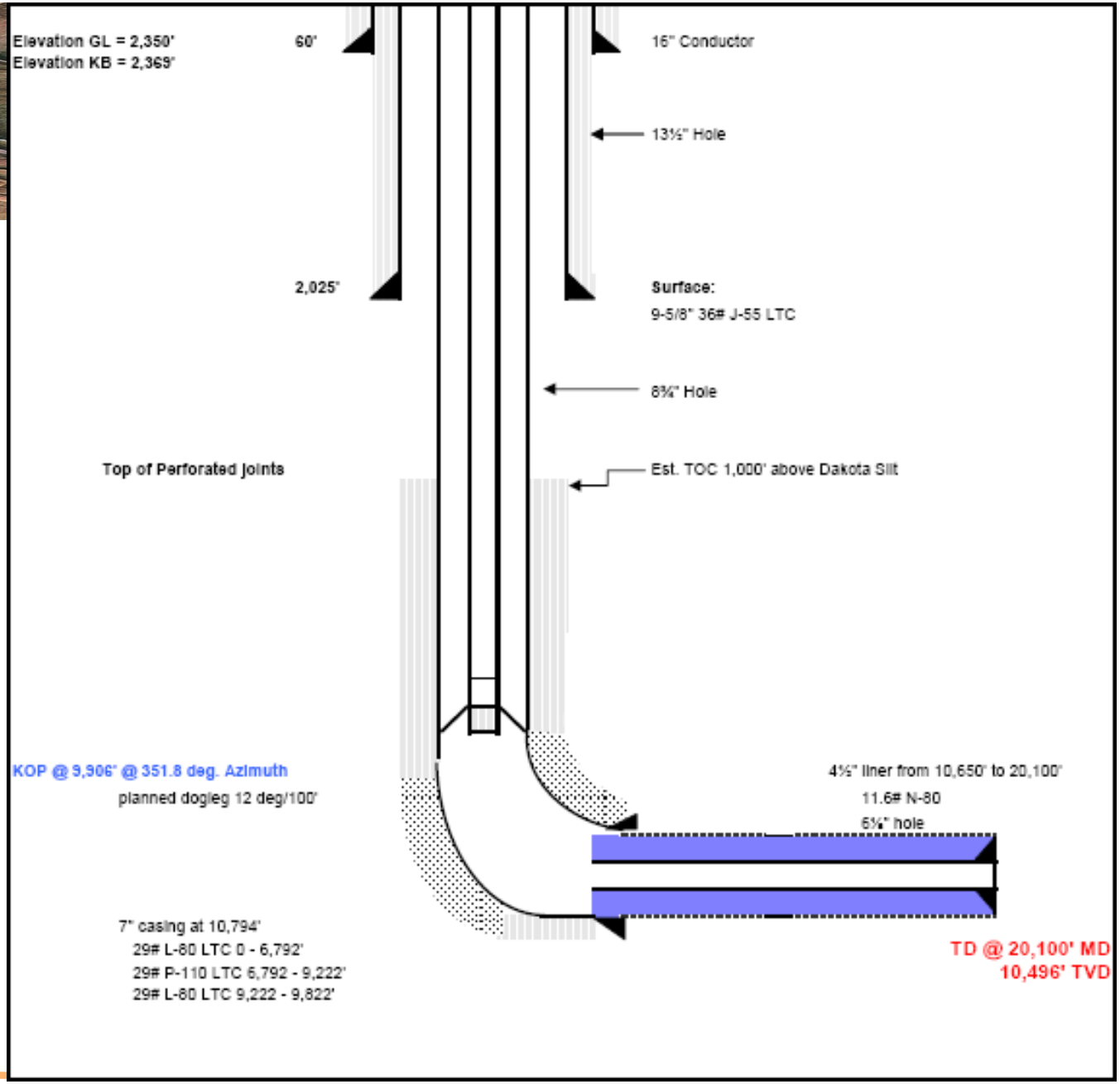
- 5 ½" casing is production casing, vertical and horizontal wells
- 5 ½" casing is fracture stimulated through
- Other casing strings protect surface water and protect against migration



Courtesy of Range Resources

Typical Bakken Well Casing

- 4 ½” production liner
- 4 ½” liner and 7” casing is fracture string
- Other casing strings protect surface water and protect against migration

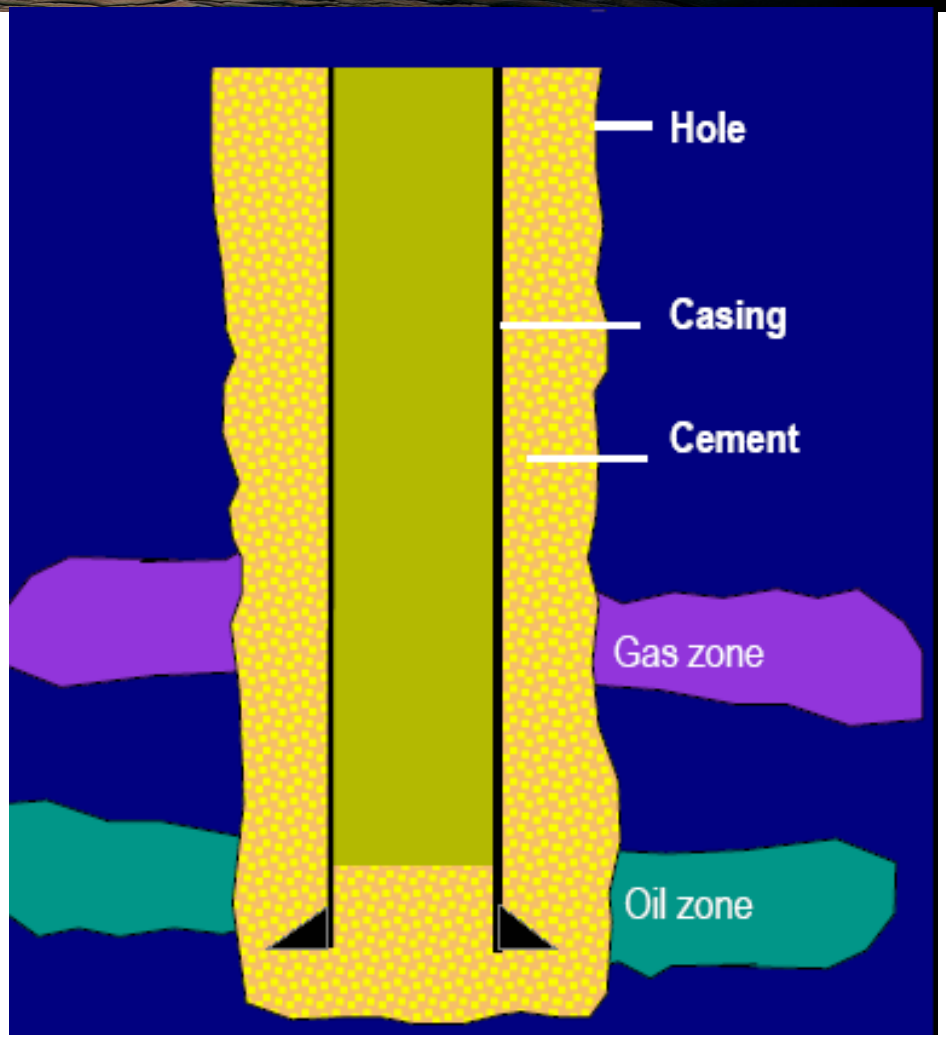


Shale Casing Cementing

Primary Cementing Objectives

- Anchor the casing
- Protection casing against corrosion and erosion
- Support borehole walls

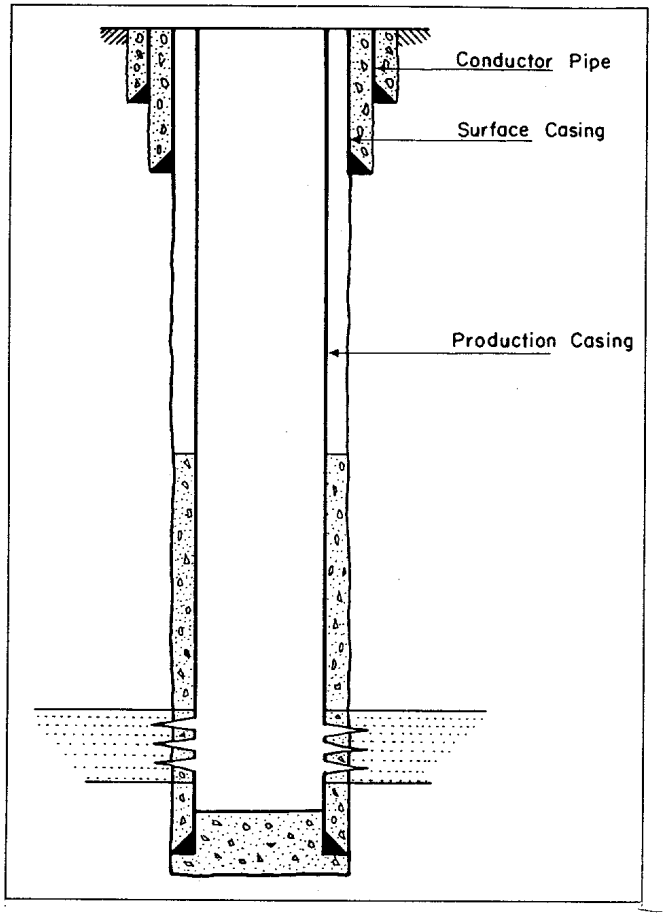
- **<u>Zonal Isolation</u>**



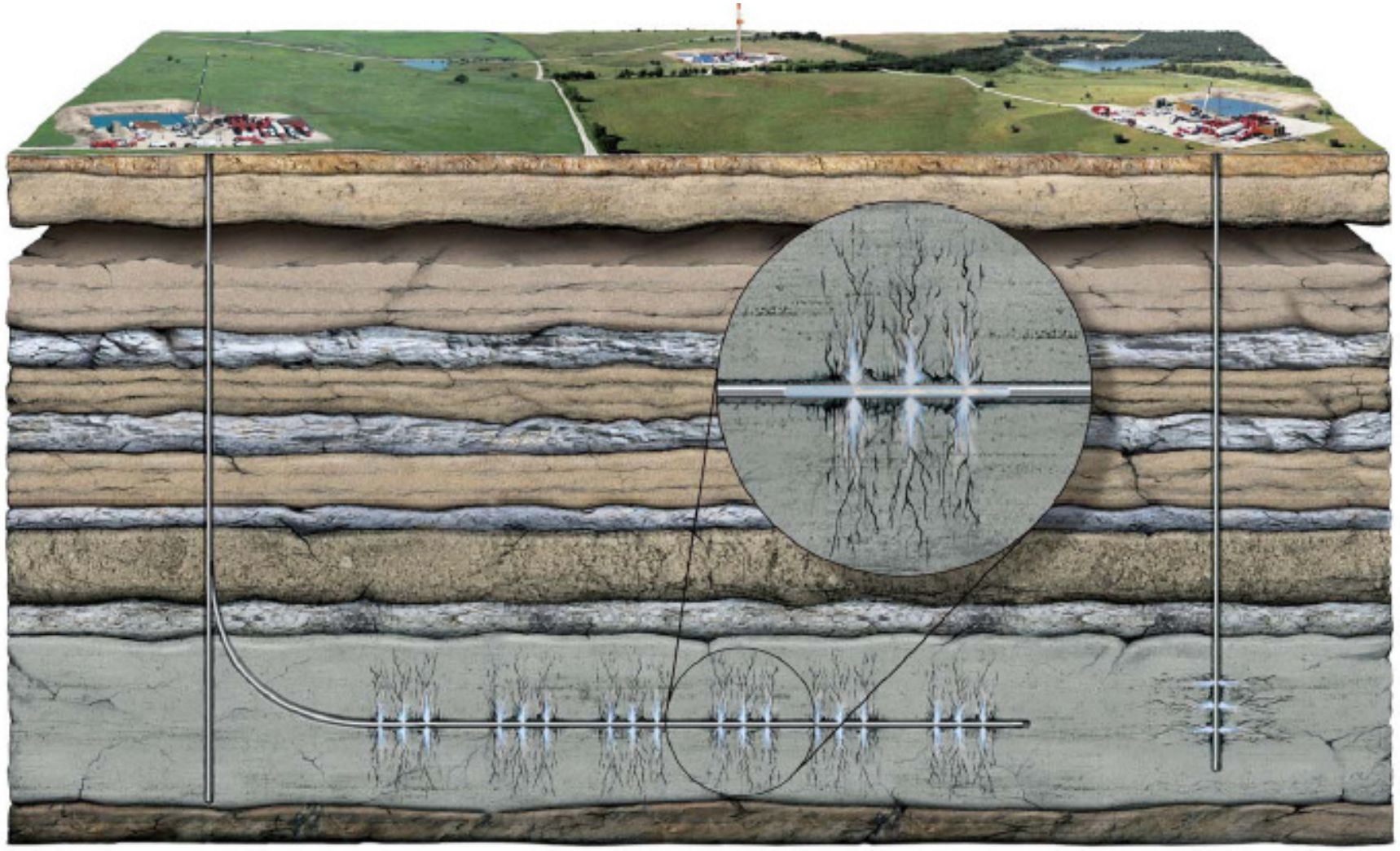
Couple of important points on cementing

Getting a good cement job means:

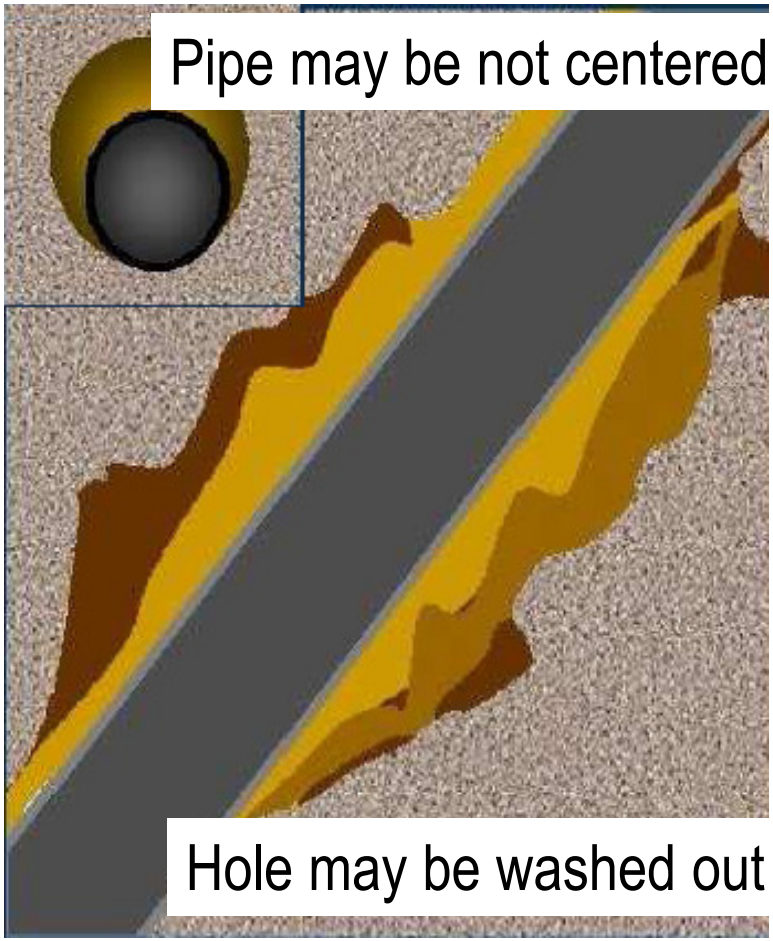
- Centralization
- Pipe movement and fluid velocity (looking for turbulence)
- Spacer design
- Rheology properties of mud
- Other specific issues to a cement job.



How do we cement a horizontal well?



Cementing Difficulties



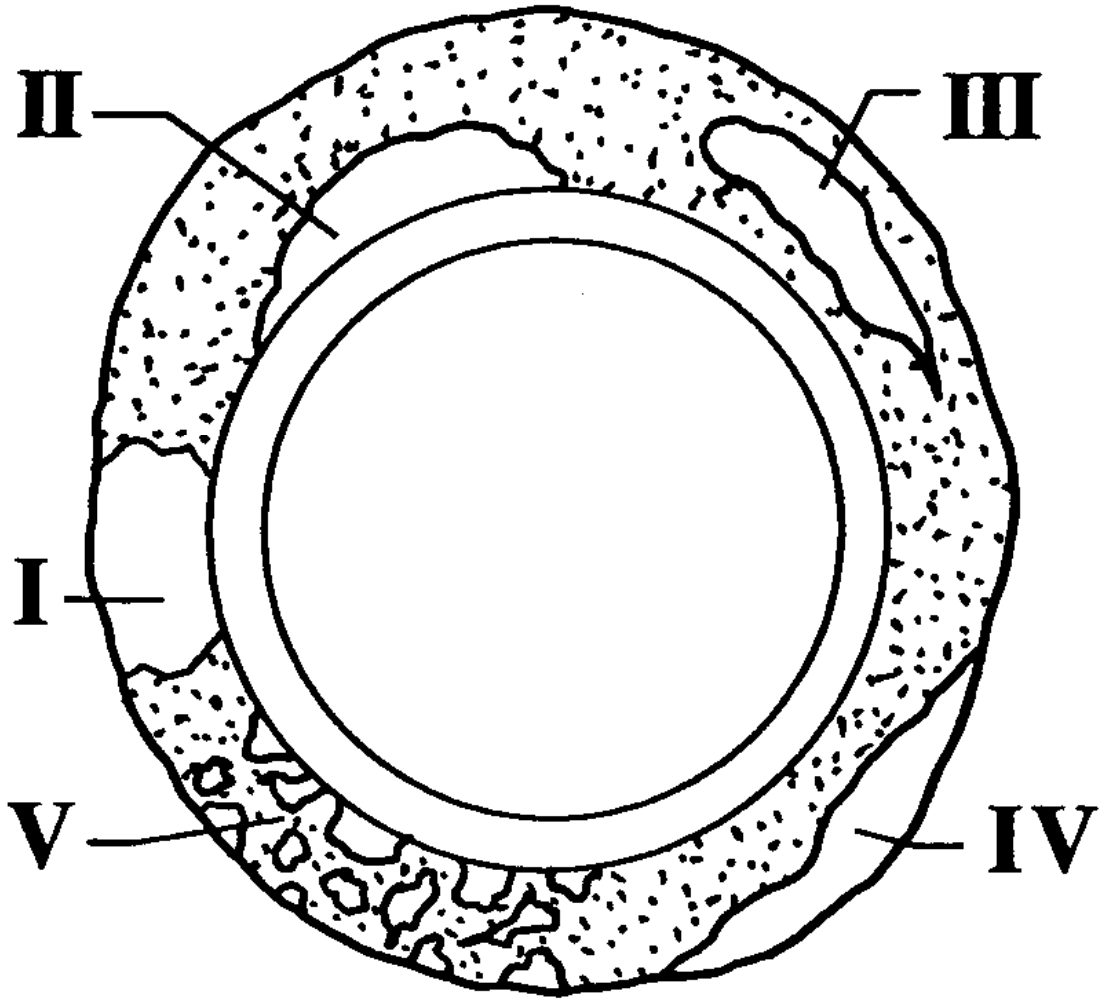
Question:

How do we know the Cement job is good?

Answer:

We take a picture of it!

Cement Evaluation - What are you trying to detect?



I - Full Channel

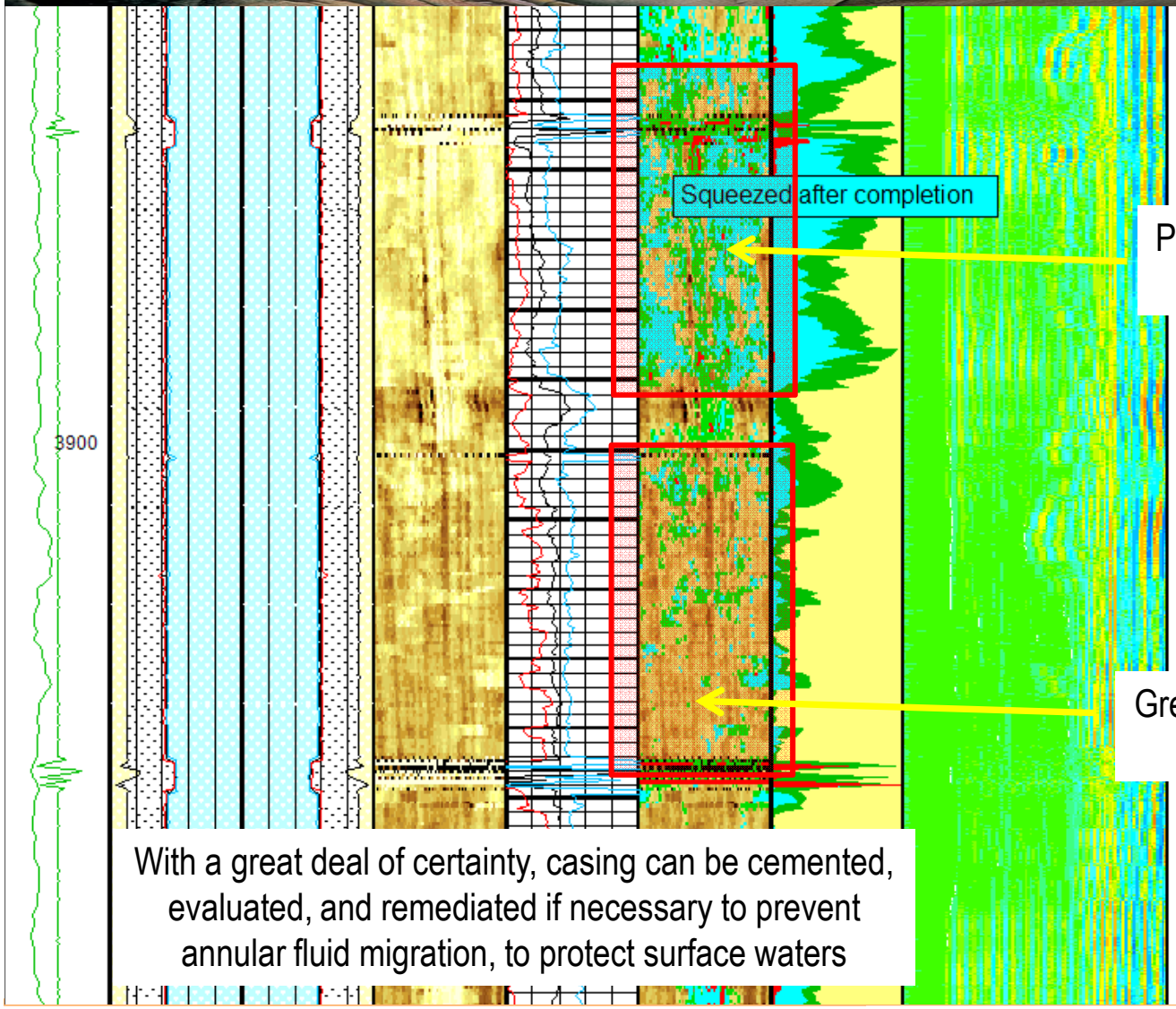
II - Void against Casing

III - Void in Cement Sheath

IV - Void against Formation

V - Gas Cut Cement

Ultrasonic Image of the Cement Sheath

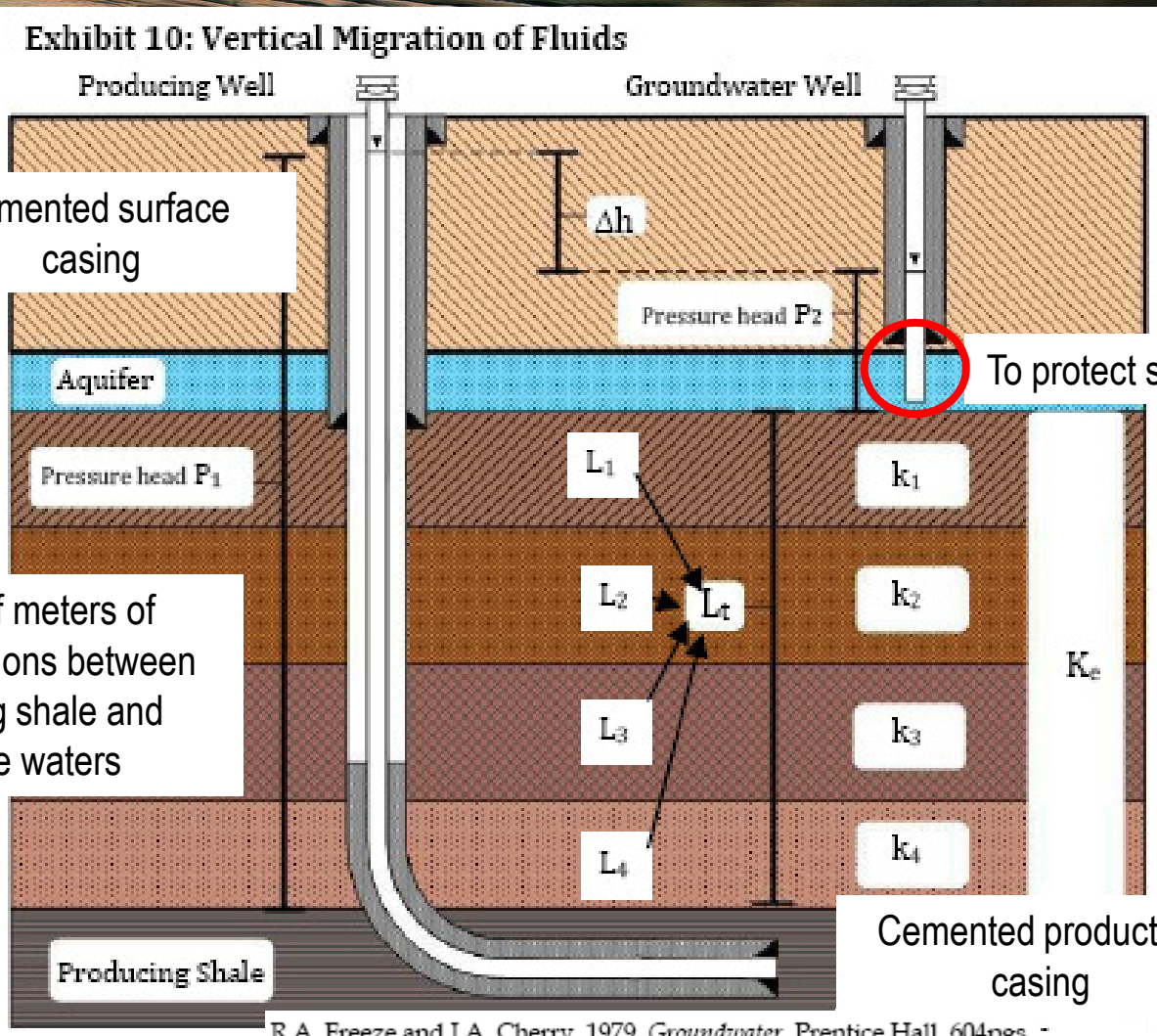


Poor cement isolation

Great cement isolation

With a great deal of certainty, casing can be cemented, evaluated, and remediated if necessary to prevent annular fluid migration, to protect surface waters

Shallow Aquifer Protection in General



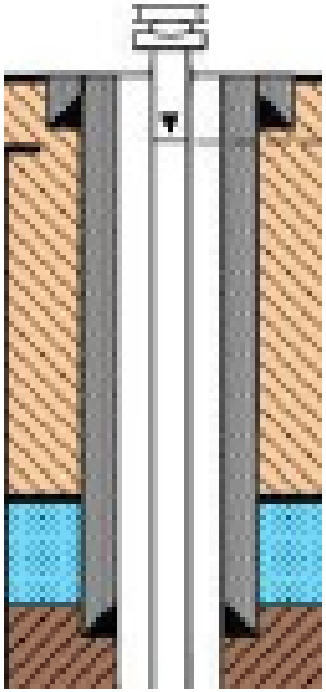
Cemented surface casing

To protect surface water

1000's of meters of rock formations between producing shale and surface waters

Cemented production casing

Colorado Example
Regulations Governing Surface Casing

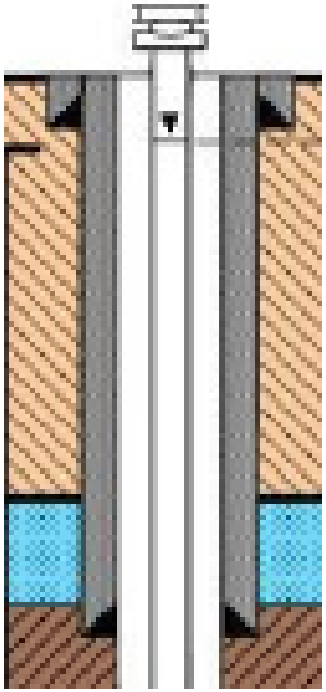


e. Surface casing where subsurface conditions are unknown. In areas where pressure and formations are unknown, ***sufficient surface casing shall be run to reach a depth below all known or reasonably estimated utilizable domestic fresh water levels*** and to prevent blowouts or uncontrolled flows and shall be of sufficient size to permit the use of an intermediate string or strings of casings**.**

Surface casing shall be set in or through an impervious formation and shall be cemented by pump and plug or displacement or other approved method with sufficient cement to fill the annulus to the top of the hole, all in accordance with reasonable requirements of the Director

R.A. Freeze and J.A. Cherry. 1979. *Groundwater*. Prentice Hall. 604pgs.

Regulations Governing Surface Casing



Alternate aquifer protection by ***stage cementing***. In areas where fresh water aquifers are of such depth as to make it impractical or uneconomical to set the full amount of surface casing necessary to comply fully with the requirement to cover or isolate all fresh water aquifers as required in subparagraph e. and f., the owner may, at its option, comply with this requirement by stage cementing the intermediate and/or production string so as to accomplish the required result.

What is Stage Cementing?

Stage cementing allows the upper portion of the casing to be cemented, separate from the lower portion. This allow cement to be placed across water aquifers in the upper portion of the casing, or above fractured formations, such as coals, that would not allow a proper cement job

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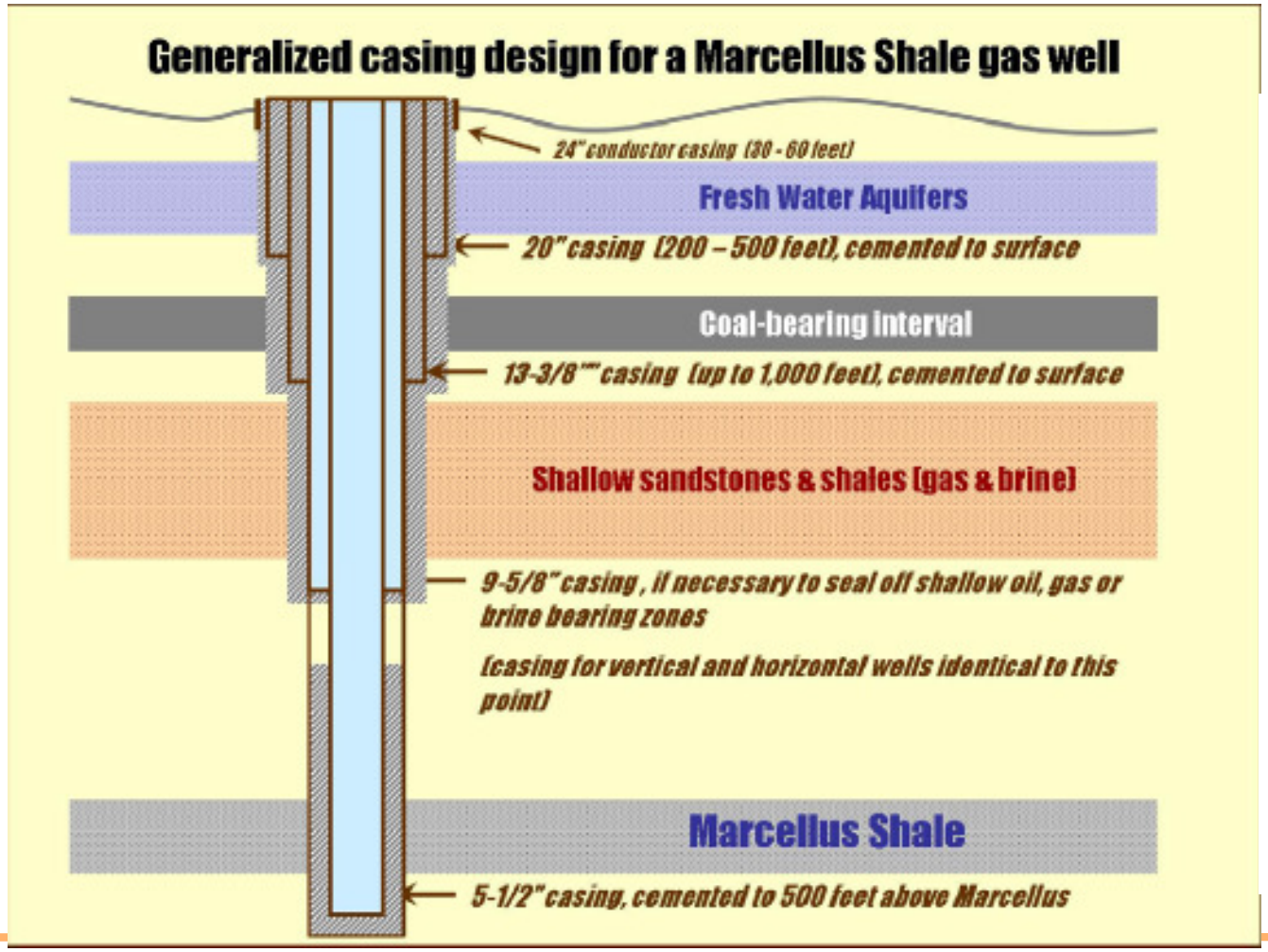
Aquifer Protection for a Marcellus Gas Well



Surface casing protection of aquifer is complicated by presence of near surface coals

These coals may cause lost circulation while cementing the surface casing, requiring extra care

It is important during the initial evaluation program to identify where the fresh water aquifers are, and any problems, such as coals, that may cause problems

Effectiveness of Groundwater Protection

Over the past 60 years, more than one million U.S. wells have been safely produced in the U.S. using hydraulic fracturing.

"After review of DEP's complaint database and interviews with regional staff that investigate groundwater contamination related to oil and gas activities, no groundwater pollution or disruption of underground sources of drinking water has been attributed to hydraulic fracturing of deep gas formations." -
Joseph J. Lee, Jr Pennsylvania Department of Environmental Protection, June 2009

"Though hydraulic fracturing has been used for over 50 years in Texas, our records do not indicate a single documented contamination case associated with hydraulic fracturing."
Victor G. Carrillo, Chairman Railroad Commission of Texas, May 2009

To the knowledge of the Colorado Oil and Gas Conservation Commission staff, there has been no verified instance of harm to groundwater caused by hydraulic fracturing in Colorado.
David Neslin, Director, Colorado Oil and Gas Conservation Commission, June 2009