# Horizontal Well Completions

- Objectives
  - To provide a clear, applications oriented view of horizontal well completions and workovers.
  - To enable the class participant to design an effective horizontal well completion.

    **What data to collect and why it is important**

    **How to select a candidate**

    **What computer models to use / Who can help**

    **What completion is probable, possible and practical**

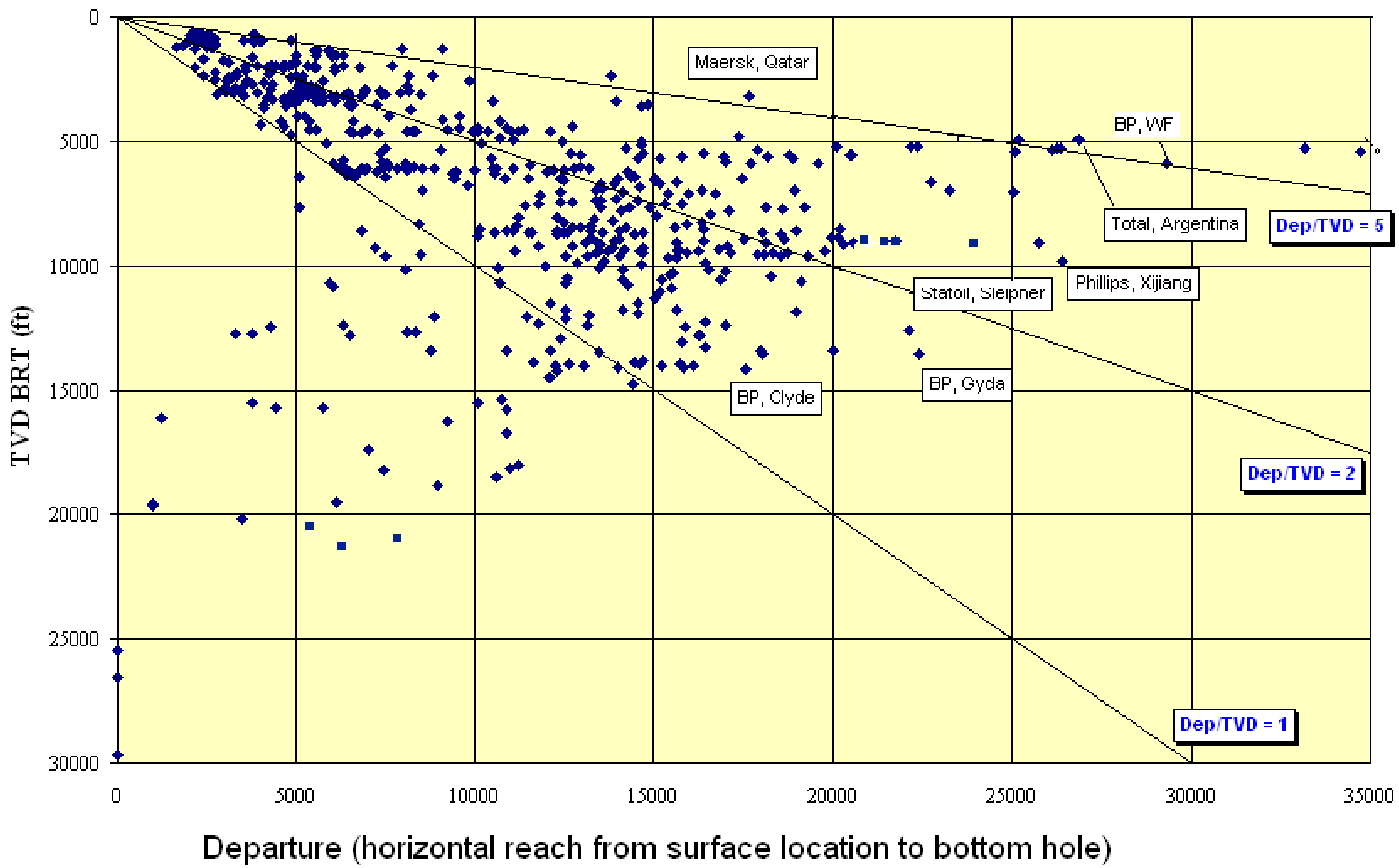
    **What to expect on production / How to operate it**

    **How to design it.**

# Horizontal Wells

- First conceived in US and USSR in 1930’s
- First serious attempts in 1950’s
- First successful completions in 1970’s
- Caught on world-wide in 1980’s
- Now a standard well configuration

# The start of the current era - extended reach well records at start of the year 2000




Slide modified from BP

# Uses of Horizontal Wells

- increasing reservoir contact
- water/gas coning control
- water/steam injection
- extended reach capability
- minimizing surface locations, slot saving
- improving wellbore location
- prospecting and gathering reservoir info.
- drain individual compartments

# Other Uses

- Prospecting - as a tool to prove up seismic in an area
- Accessing all parts of the field - flank wells a favorite in offshore reservoirs
- As a platform for fracturing
- As a “gathering system” - Amoco Canada’s “Big Kahuna”

# Favorite Targets

- Naturally fractured chalks and shales
- Water coning problem areas
- Field edges

# Best Candidates from a Reservoir Perspective

- 1. Must still have good volume of reserves, pressure and fluids of value.
- 2. Permeability values (horizontal and vertical) more a design consideration than a limit.
- 3. Oil was thought to be a better candidate than gas because of hydraulic fracturing, however, horizontal wells with multistage fracturing are a common completion for low permeability gas plays.

# Best - non stimulated candidates

- No vertical barriers and generally high permeability reservoirs.
- Kv/Kh > 0.1 to 0.5 (opinion) (consider frac if perm is too low)
- natural fractures often viewed as “good”, but watch effects on the drainage profile and also bottom water.

# Red Flags - for unstimulated horizontals

- Poor quality reservoirs - need something to start with.
- Very low Kv, vertical flow barriers
- Some extremely thick zones

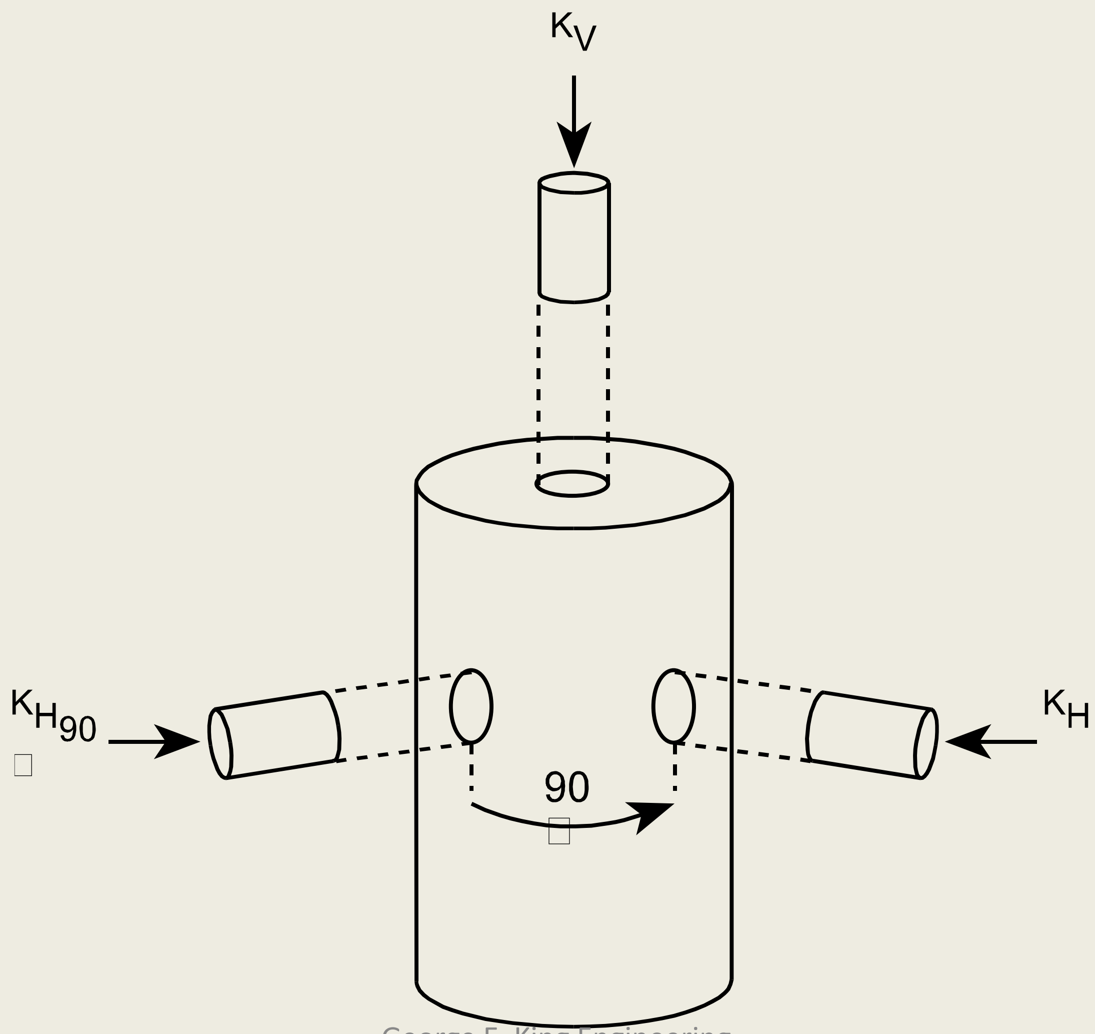
# Reservoir Considerations

- Will reduced footprint help? (offshore and high land cost or political areas)
- Will there be improvements in contact with <u>some</u> dipping beds.
- Pay configuration issues:
  - layers
  - boundries
  - anisotrophy

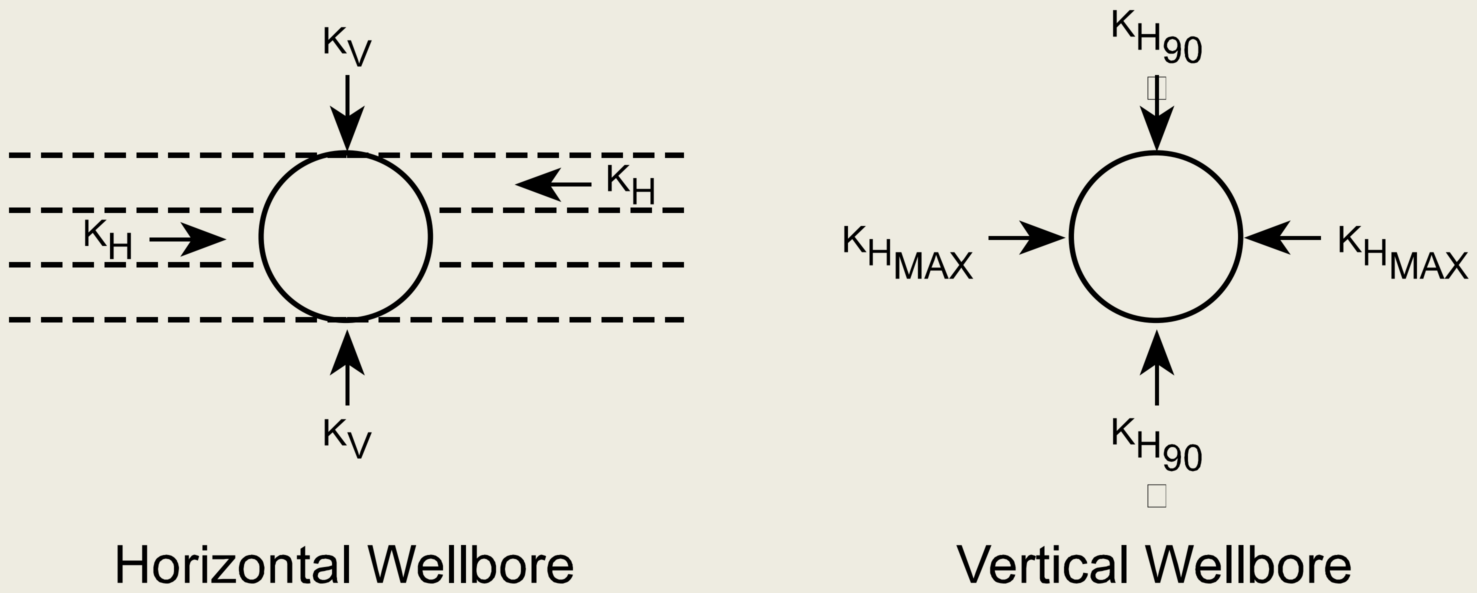
# Permeability Variance

- $K_h$, $K_H$, $K_v$
- Barriers
- Bed angle (a vertical well can be horizontal to the bedding plane in some instances

# Directional Permeability

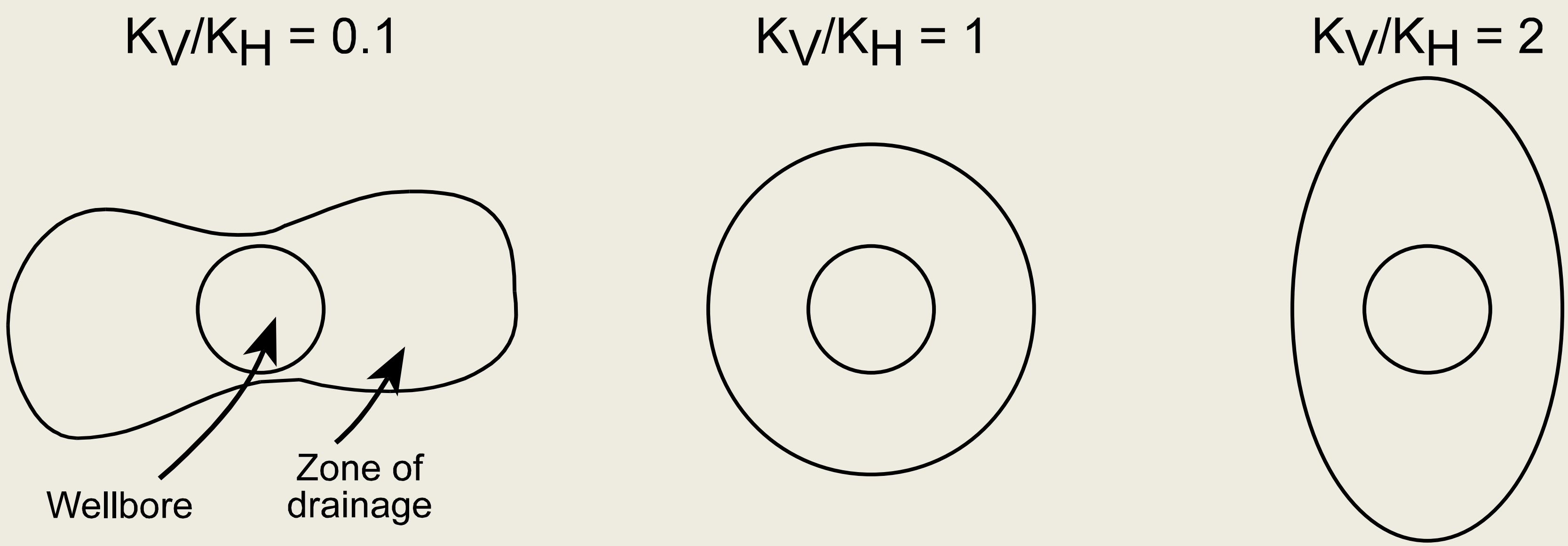


# Permeability Contribution from Vertical and Horizontal Permeability




50423004

# Drainage in a Horizontal Well for Cases of Permeability Anisotropy




50423005

# Placement of the Horizontal Above the O/W Contact

- Depends on:
  - vertical permeability
  - fluid viscosities
  - pay zone thickness
  - anomolies in the zone
  - depth (?) and formations above the pay zone

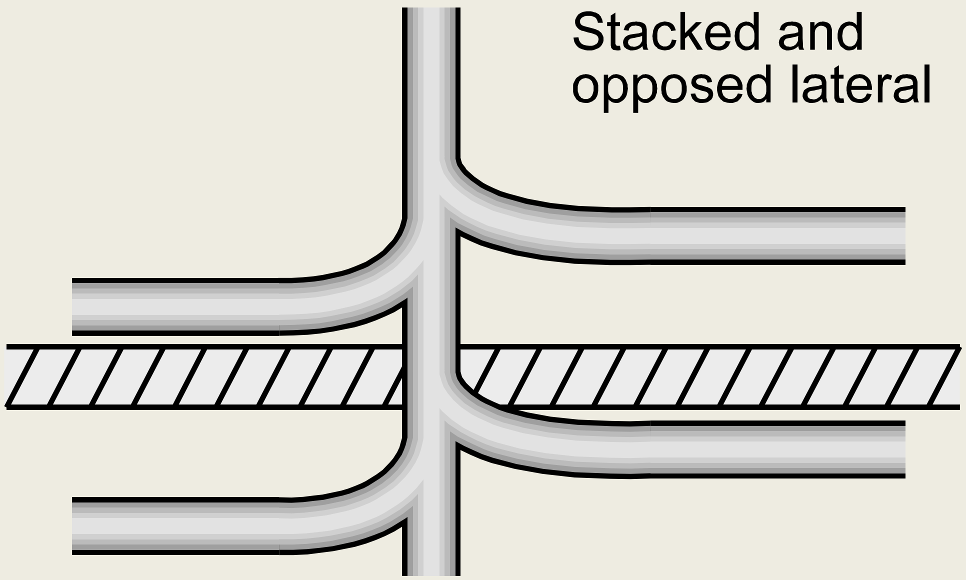
# Pay Zone Thickness

- no minimum or optimum
- vertical and horizontal permeability more critical
  - fractures
    - **incidence of fractures**
    - **location of fractures**
    - **permeability of fractures**
    - **good or bad? - water???**

# When is a Multi-lateral Required?

- Wherever compartmentalization reduces the ability of a single wellbore (stimulation?) to effectively and economically drain the reservoir.

# Stacked and Opposed

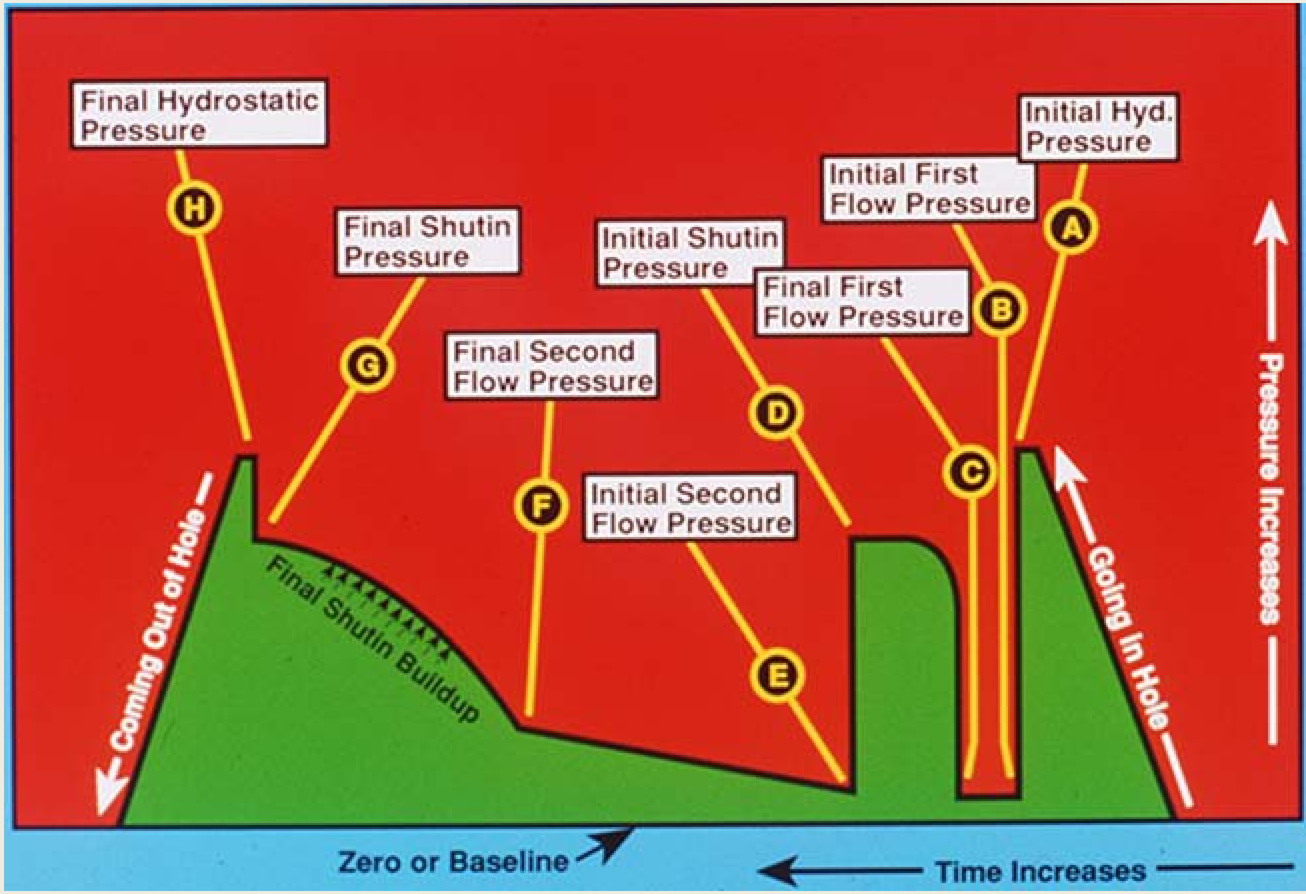


# Compartment Recognition

- Geological clues
- DST’s
- Production behavior
- Hydrocarbon source variances (oil fingerprinting)

- Early Recognition - addressed in design
- Later Recognition - requires a workover

# A two flow period test of reservoir potential – what does it tell?




Information available from downhole gauges and flow tests.

- Reservoir pressure
- Perm estimates
- Depletion
- Barriers
- Damage
- Compartmentalization

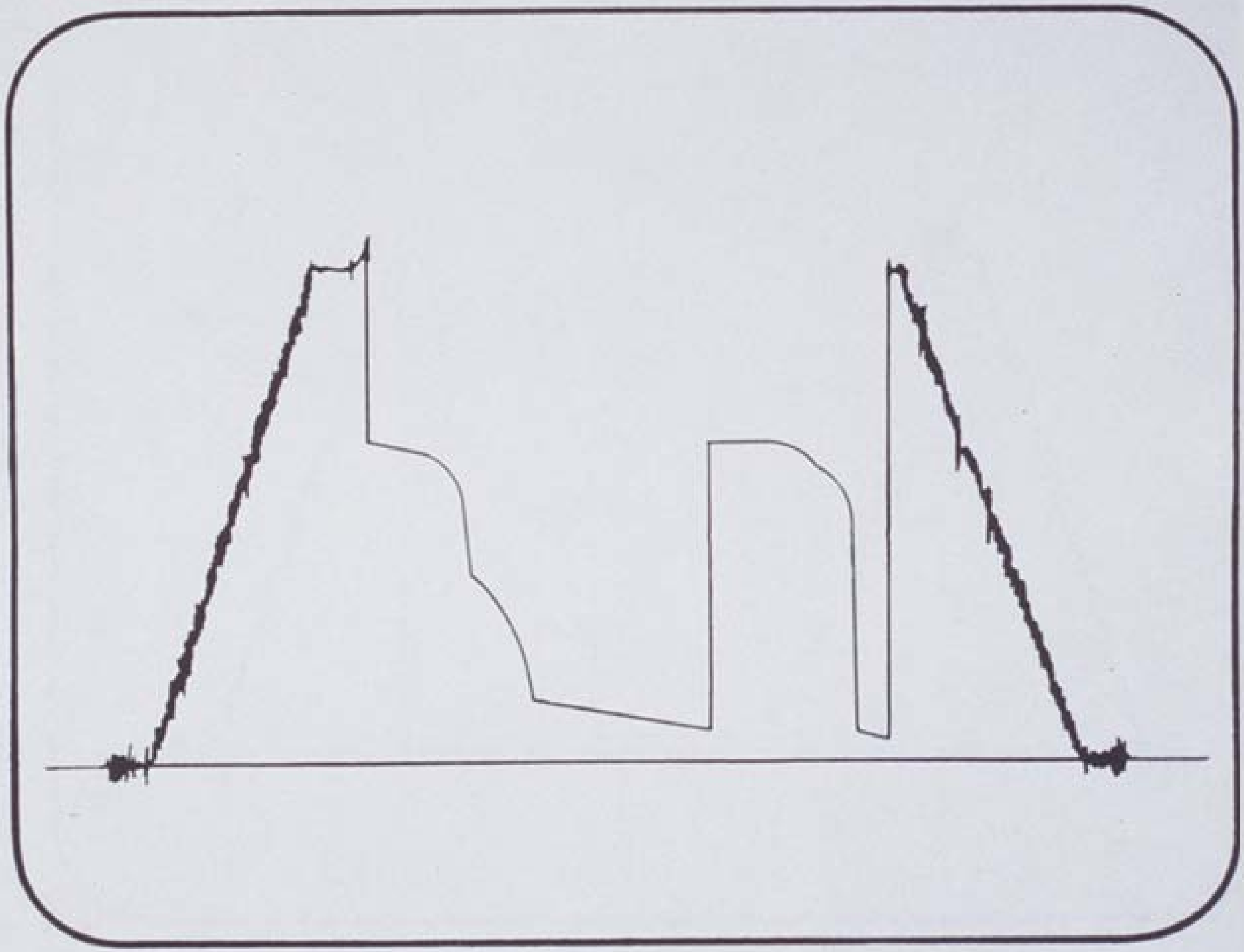
# Recognizing Compartmentalization

TWO ZONE EFFECT

Two entirely different producing zones exposed in a test interval

One zone has higher reservoir pressure or better permeability

Fair permeability



Slide from George Tews

# Horizontal Well Expectations

- Uncertainty???
  - can it be drilled?
  - can it be completed?
  - can it be operated/produced?
  - is it really a good candidate?
  - is fracturing needed?

# Horizontal  and Lateral Drilling

- An introduction to horizontal well drilling technology:
  - Goal is to make the engineer/foreman aware of some problems and solutions available in drilling operations that can have a major effect on completions and production.

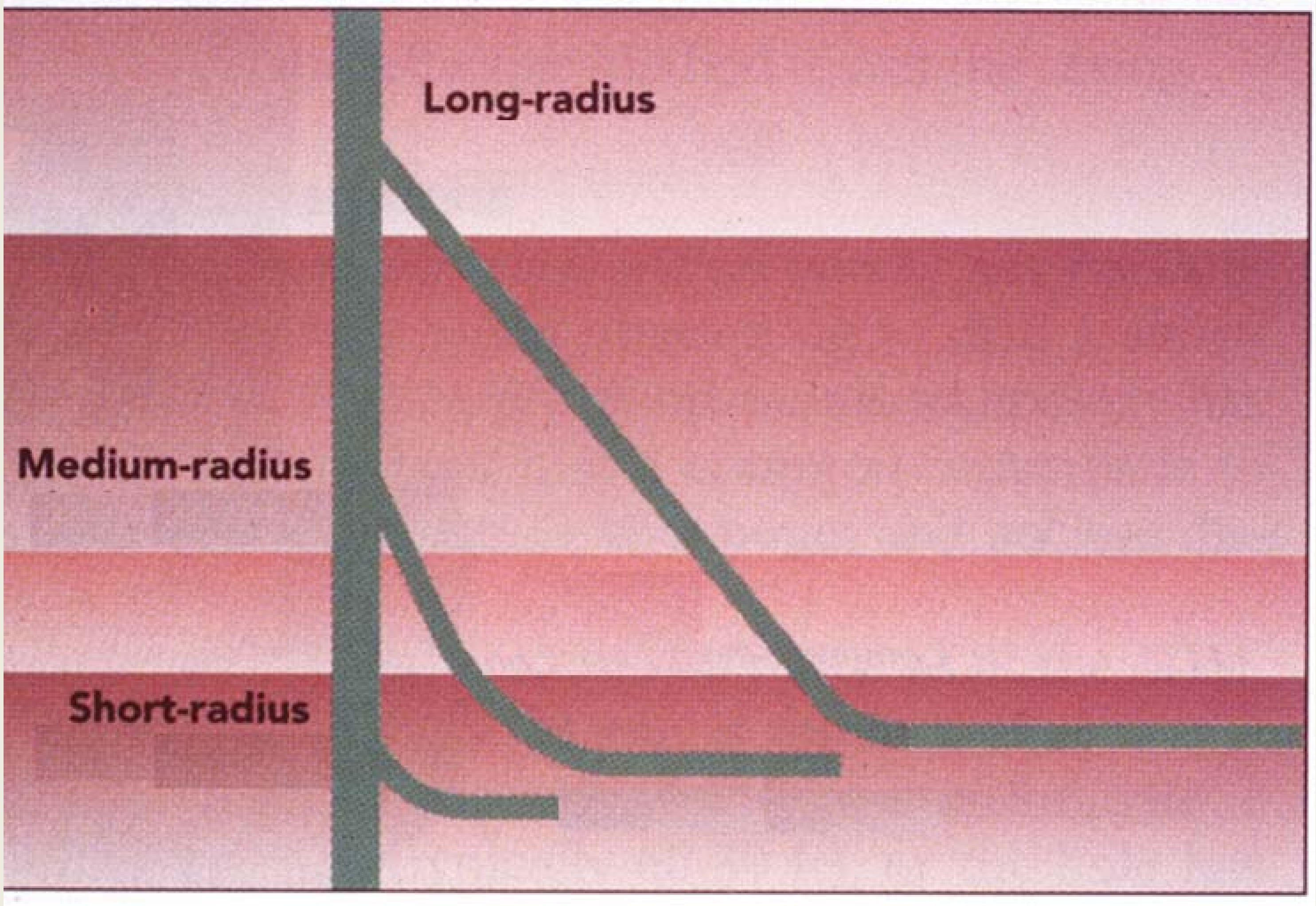
# Types of Horizontal Kick-Off designs.

## Increasing the angle limits weight transfer to the bit.

Long radius wells at 2 to 6$^o$ are used for extended reach.

Medium radius wells at 6 to 8$^o$ minimize drilling but lose some extension capacity.

Short radius wells over 8 to 10$^o$ can miss problem zones above the pay, but are short.



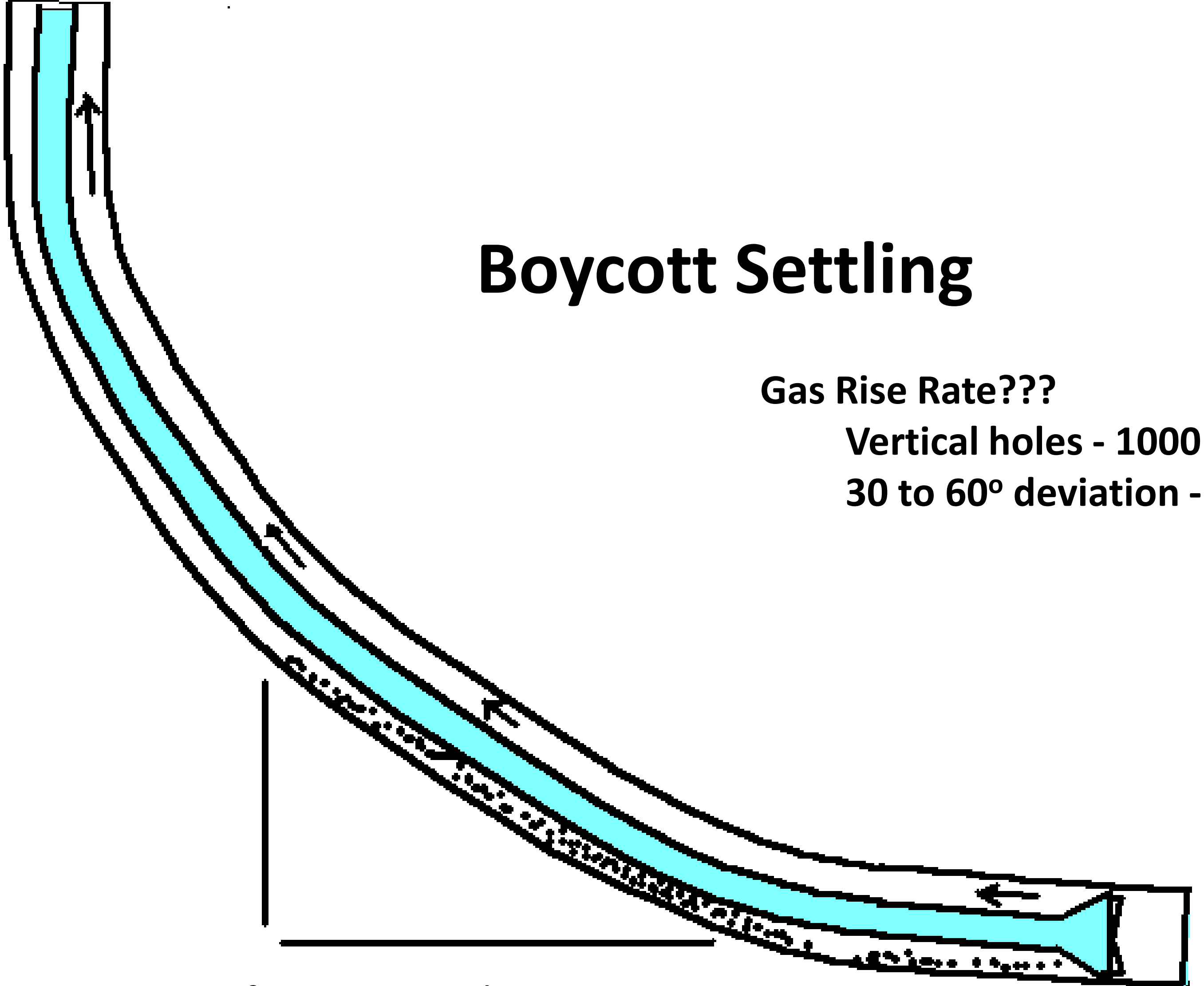
# Ability to Lift Cuttings

- Must reach high enough velocities to carry particles upward.
  - Problems in horizontals:
    - limited circulation rate
    - large annular areas = low flow velocity
    - striated flow regimes – especially at $30^o$ to $60^o$
    - difficult in all liquid systems (rate)
    - difficult in all gas systems (striation)

# Cuttings Beds

- Symmetric suspension - constant concentration in cross section
- Asymmetric suspension - all carried, but more at bottom
- Moving bed - like a dune
- Stationary bed - builds to height dictated by flow rate
- Boycott settling - explains severe solids drop out in the 30 to 60 degree range.

# Boycott Settling



**Gas Rise Rate???**

**Vertical holes - 1000 ft/hr**

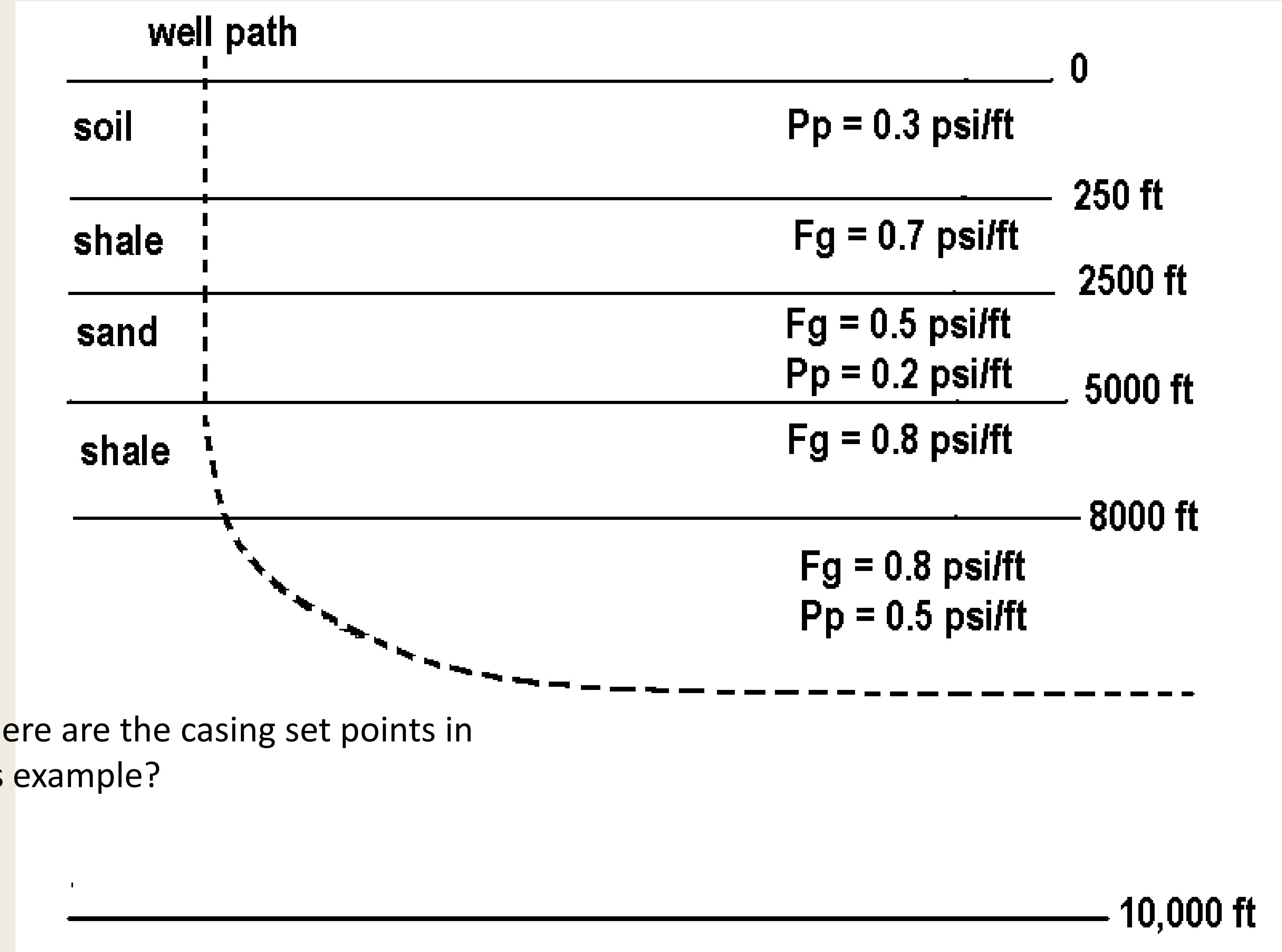
**30 to 60$^{o}$ deviation - 4000 to 7000 ft/hr**

Lighter fluids rise to the top side of the wellbore (striatation) and dense fluids and cuttings drop out to the bottom out of the fast moving upper fluids – result is poor hole cleaning and sticking of strings.

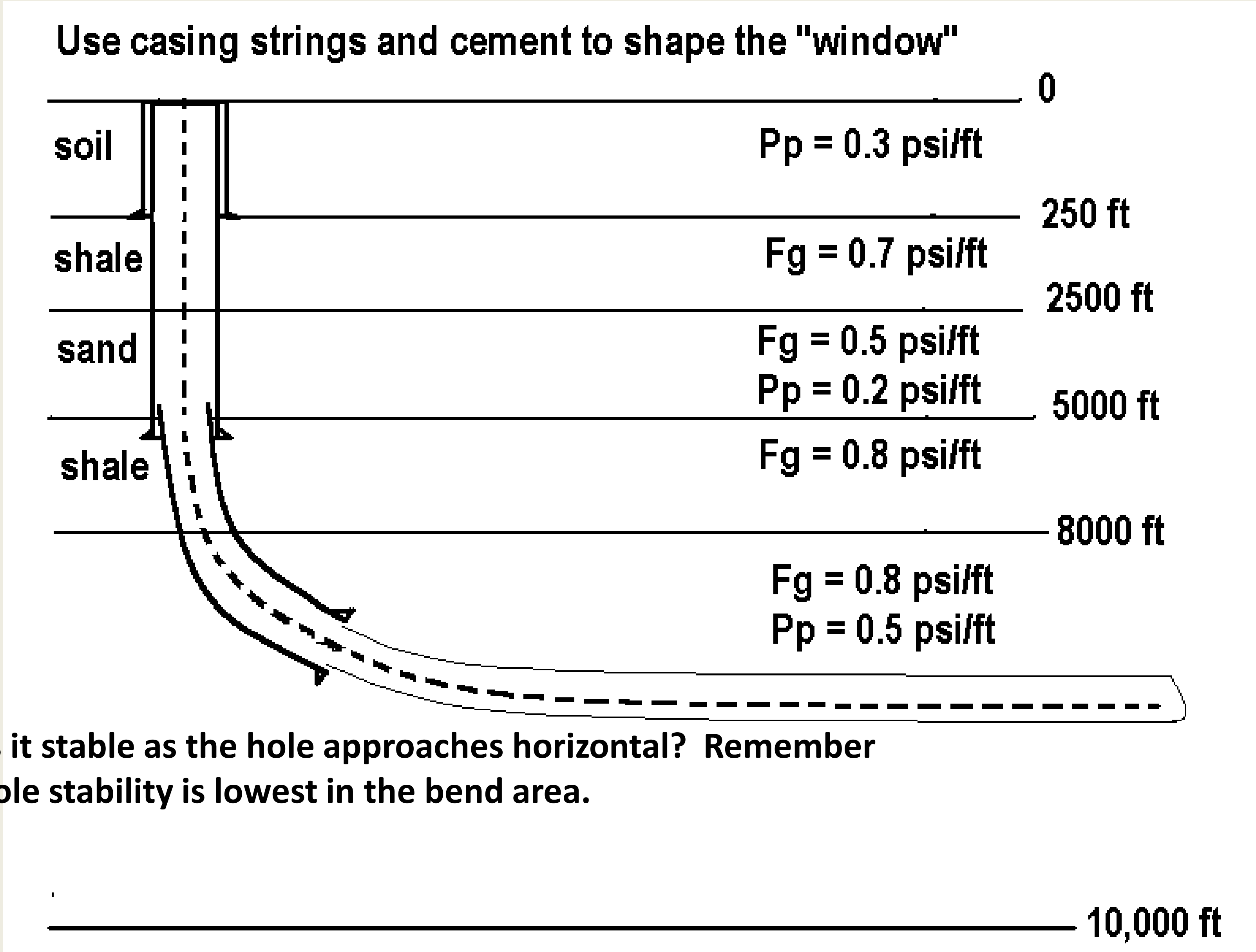
Region of greatest settling Problems, 30 to 60 degrees – the Boycott Region

# Consequences of Poor Hole Cleaning

- Bridging - sticking pipe
- Failure to run to bottom
- Debris in perfs
- Emulsions and scale “seeds” left in the well?
- Cave-ins? - probably not




Where are the casing set points in this example?



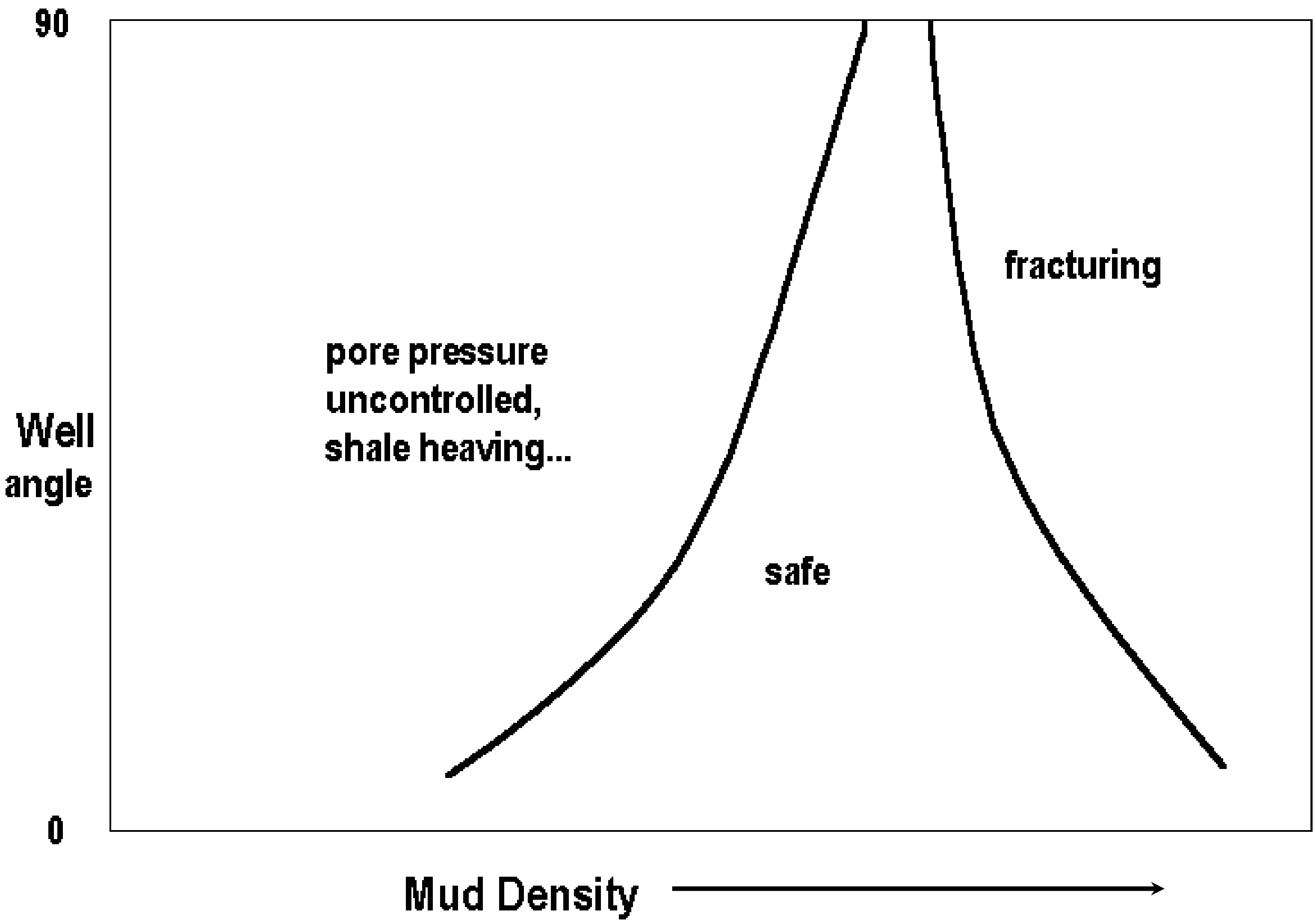

**BUT, is it stable as the hole approaches horizontal? Remember that hole stability is lowest in the bend area.**

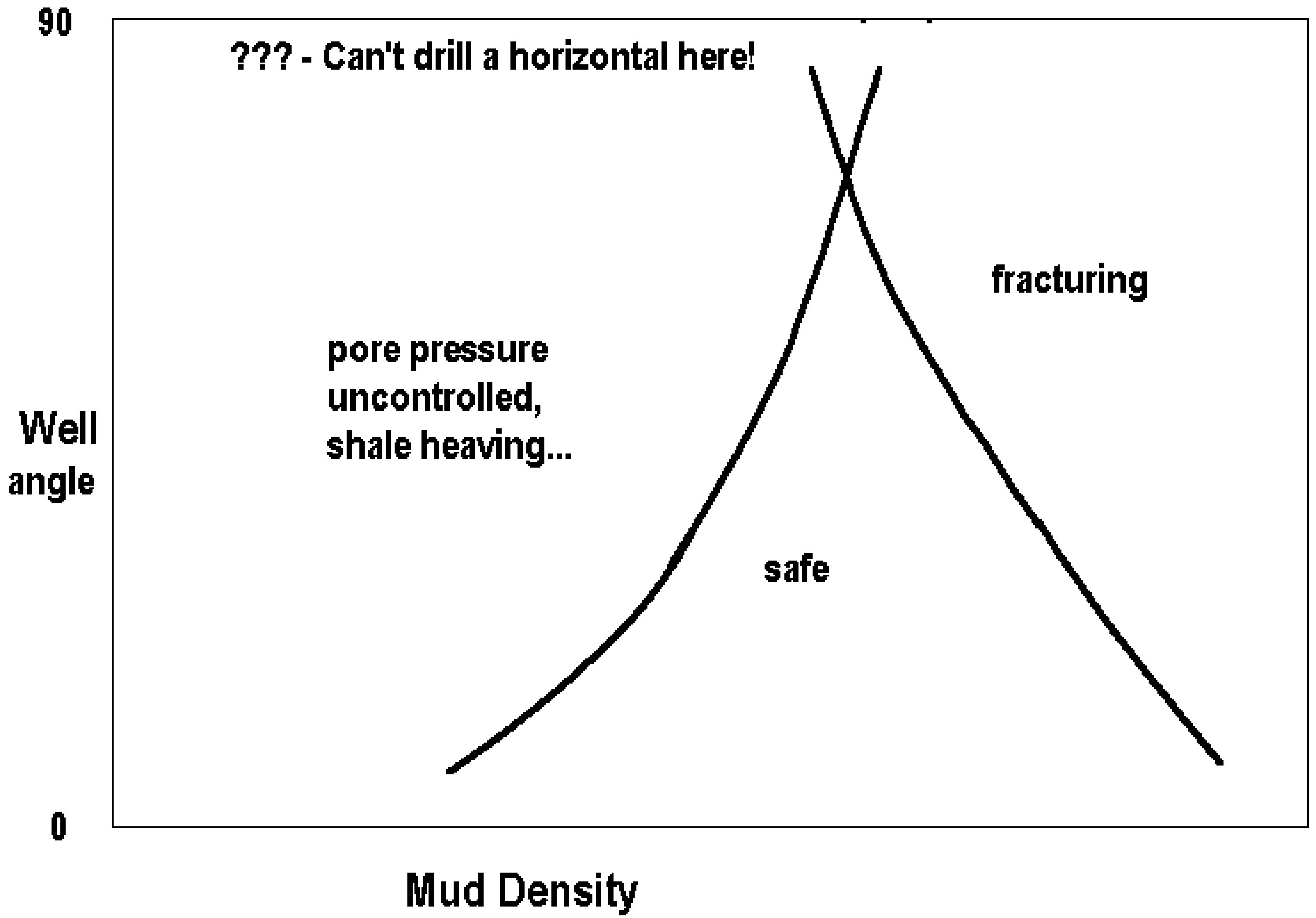
# Drilling Fluid Operating “Window”

- Mud density must be higher than the pore pressure to keep fluids from entering the well.
- Mud density must control tendency of shale to spall particles into wellbore
- Mud density must be less than the formation fracture (extension) gradient – corrected for friction pressures while circulating.  The pressure exerted by the fluid at any depth is a function of its density plus the friction pressure in the circulating path back to the surface.

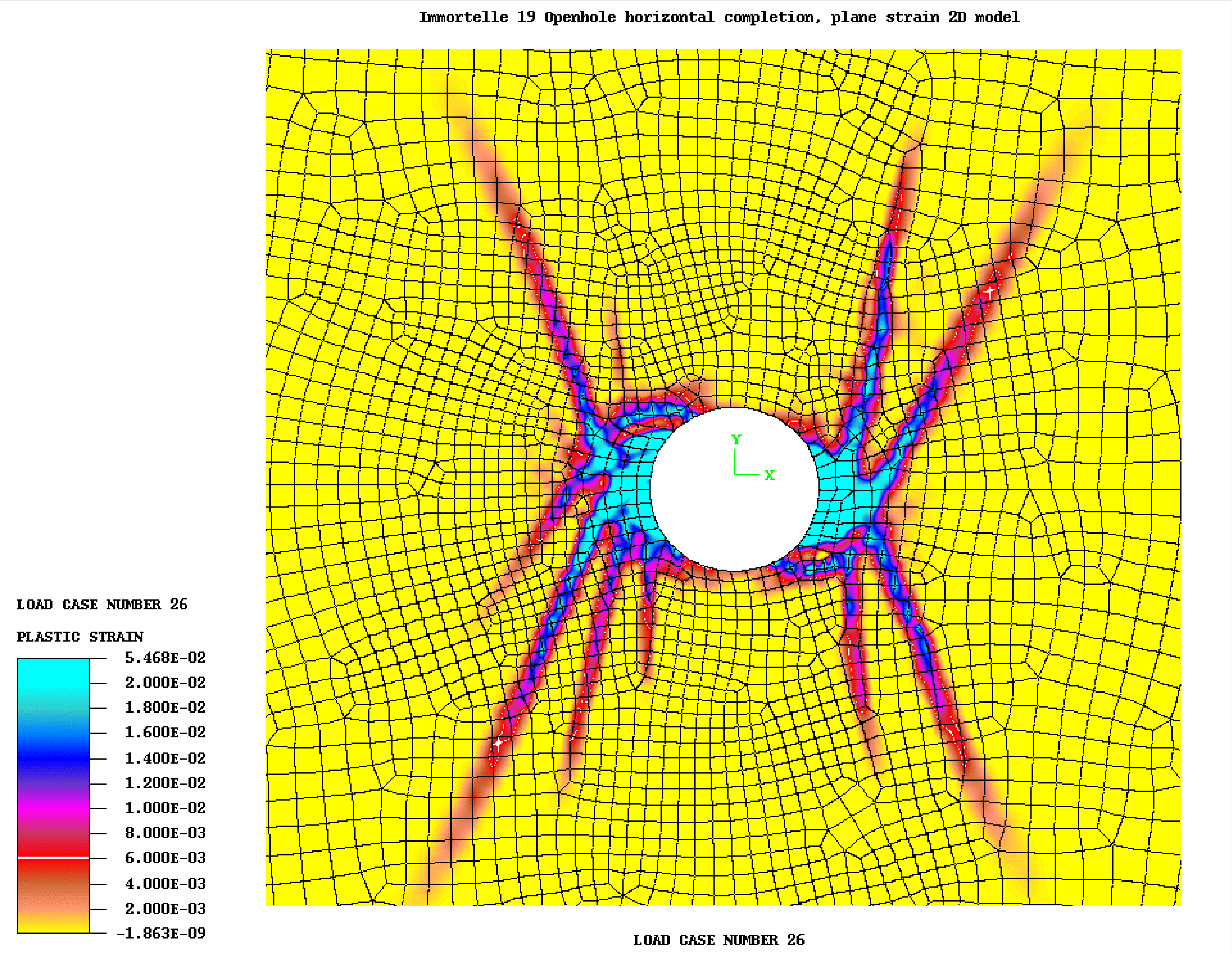
# Drilling Wellbore Stability

- Issues - during drilling, completion and production
- Destabilizing Mechanism
  - support pressure too low (spalling)
  - support pressure too high (fracturing)
  - Rx with drilling fluids (sloughing, swelling)
  - formation stress unloading


90
Well
angle
0
pore pressure
uncontrolled,
shale heaving...
safe
fracturing
Mud Density


90
??? - Can't drill a horizontal here!
fracturing
pore pressure
uncontrolled,
shale heaving...
Well
angle
safe
0
Mud Density

A model of wellbore stability (most stressed regions in blue) of a horizontal wellbore.



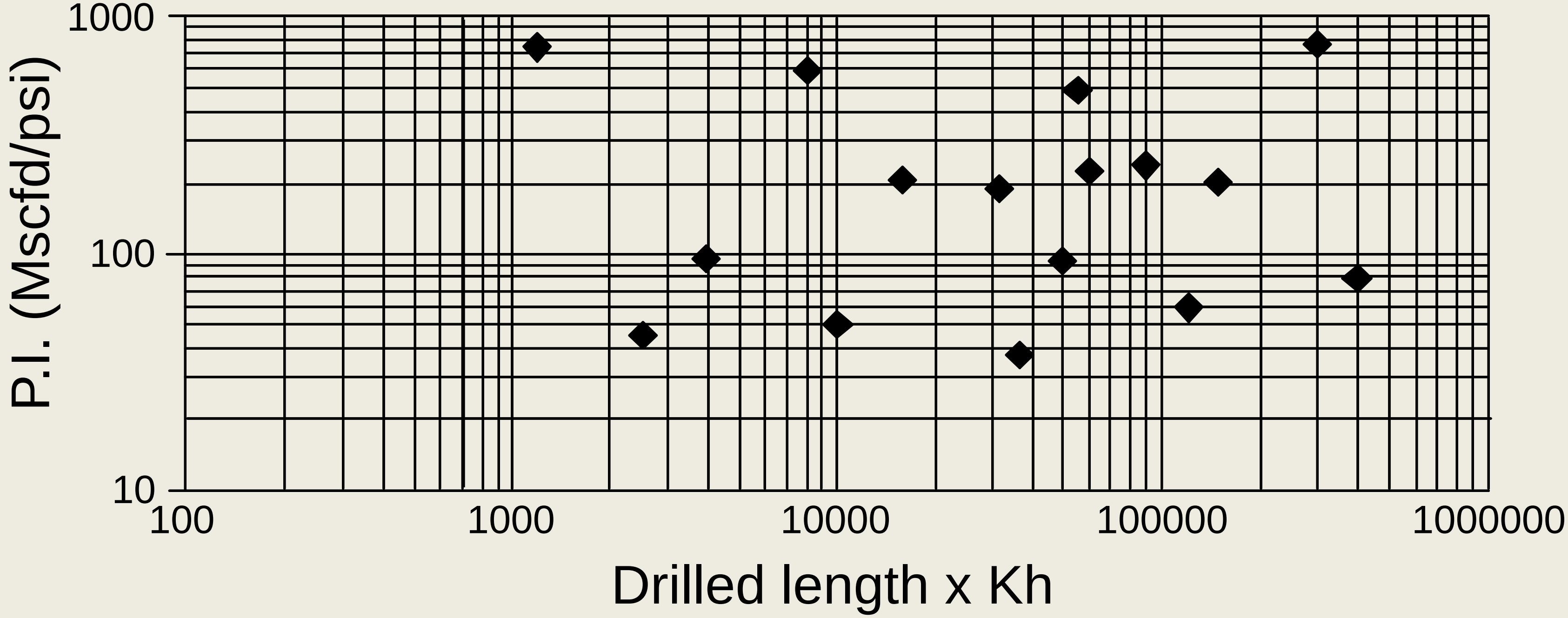
# Broad Based Conclusion

- Most Important Failure Factors
  - pore pressure prediction
  - weak, fissible beddling planes
  - low support pressures
  - time dependent loss of strength
- Open holes best in stable formations (carbonates, clastics)
- Most instability problems in the shales

# So, how far do you drill?

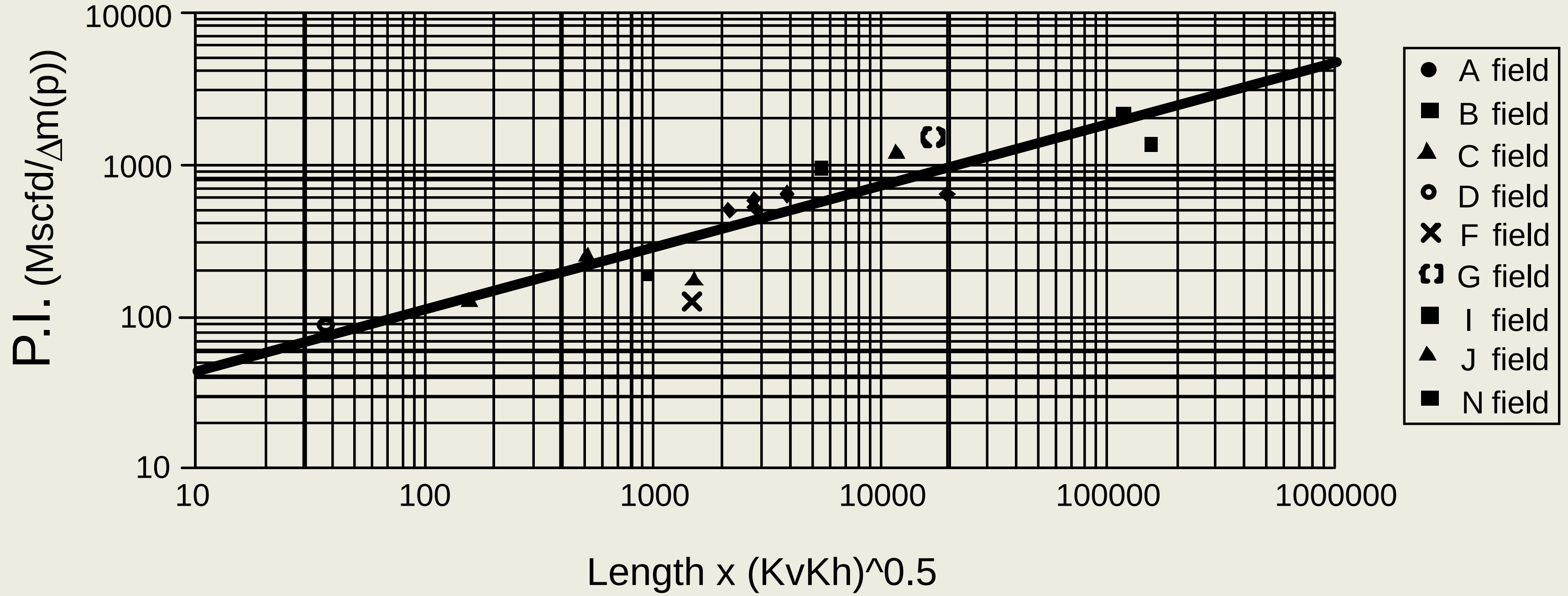
- Consider edge boundries
- Consider drilling costs (usually low in lateral)
- Consider vertical perm

# Effect of length and horizontal permeability on PI in horizontal wells



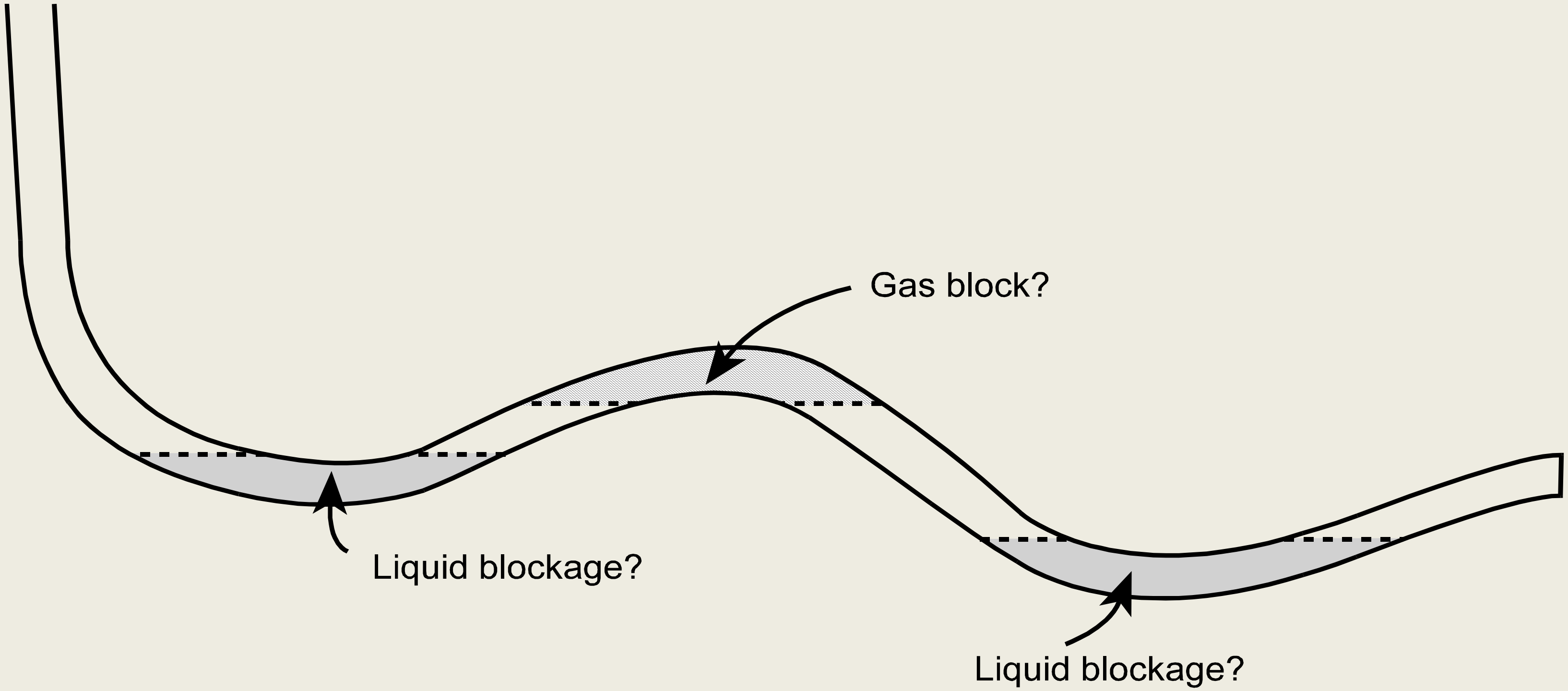

Hariot-Watt Horizontal Study

# Effect of horizontal well factors on PI



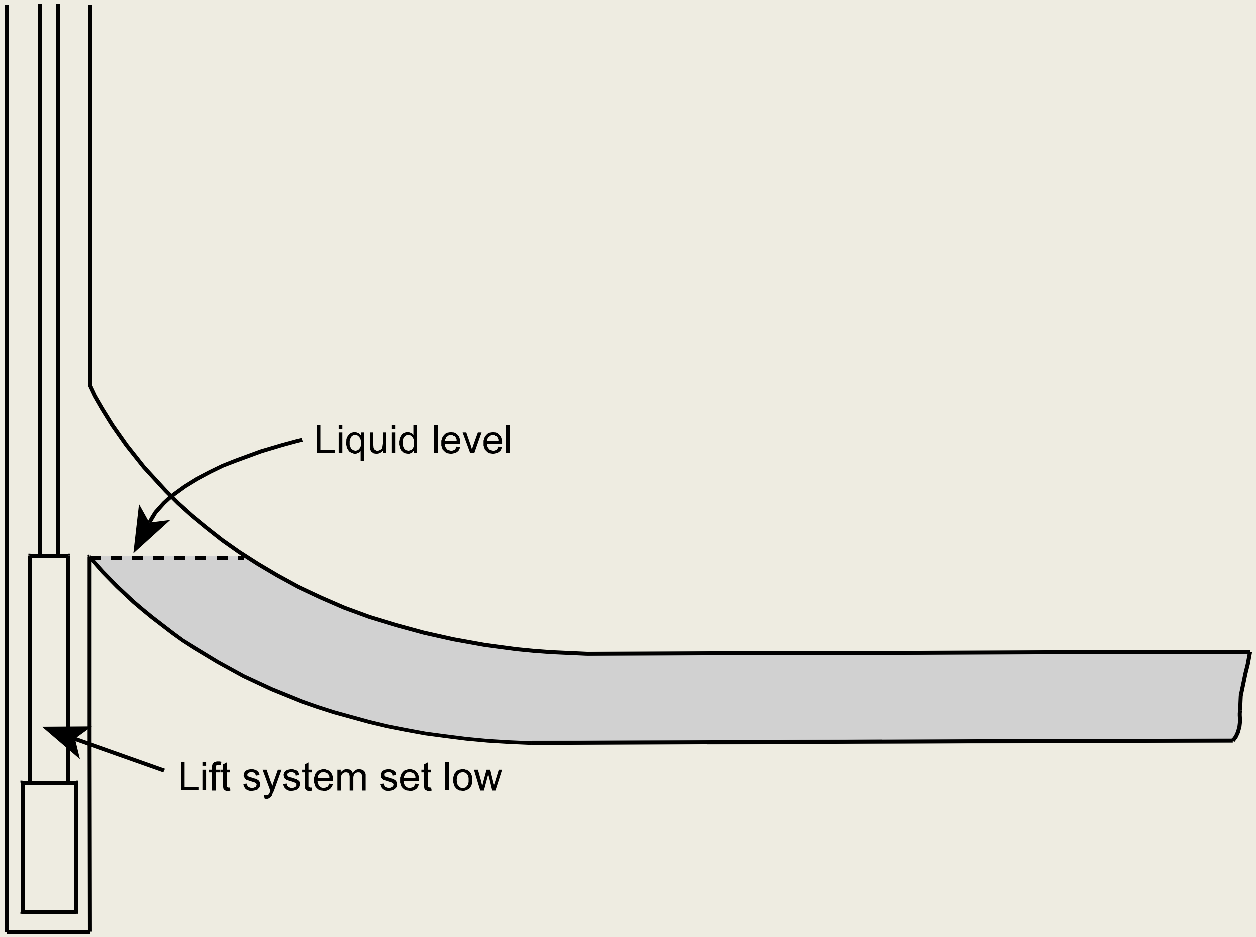

Hariot-Watt Horizontal Study

# Undulation Problems Within the Horizontal Well




**How long a well can you effectively complete and produce?**
**Depends on shape, angle, path and fluids.**

# Improving Artificial Lift for Horizontal Wells by Using Rat Hole on Short Radius




50423011

# Production Index Factors

(a comparison to horizontal well performance)

- Theoritical PIF's may range from 1 to 8.
- Actual PIF's range from 1 to about 4 or 5.
- Causes:
  - reservoir not homogeneous
  - reservoir "estimates" too generous
  - completion design was an after-thought

# Horizontal Well PIF's (1300 well study)

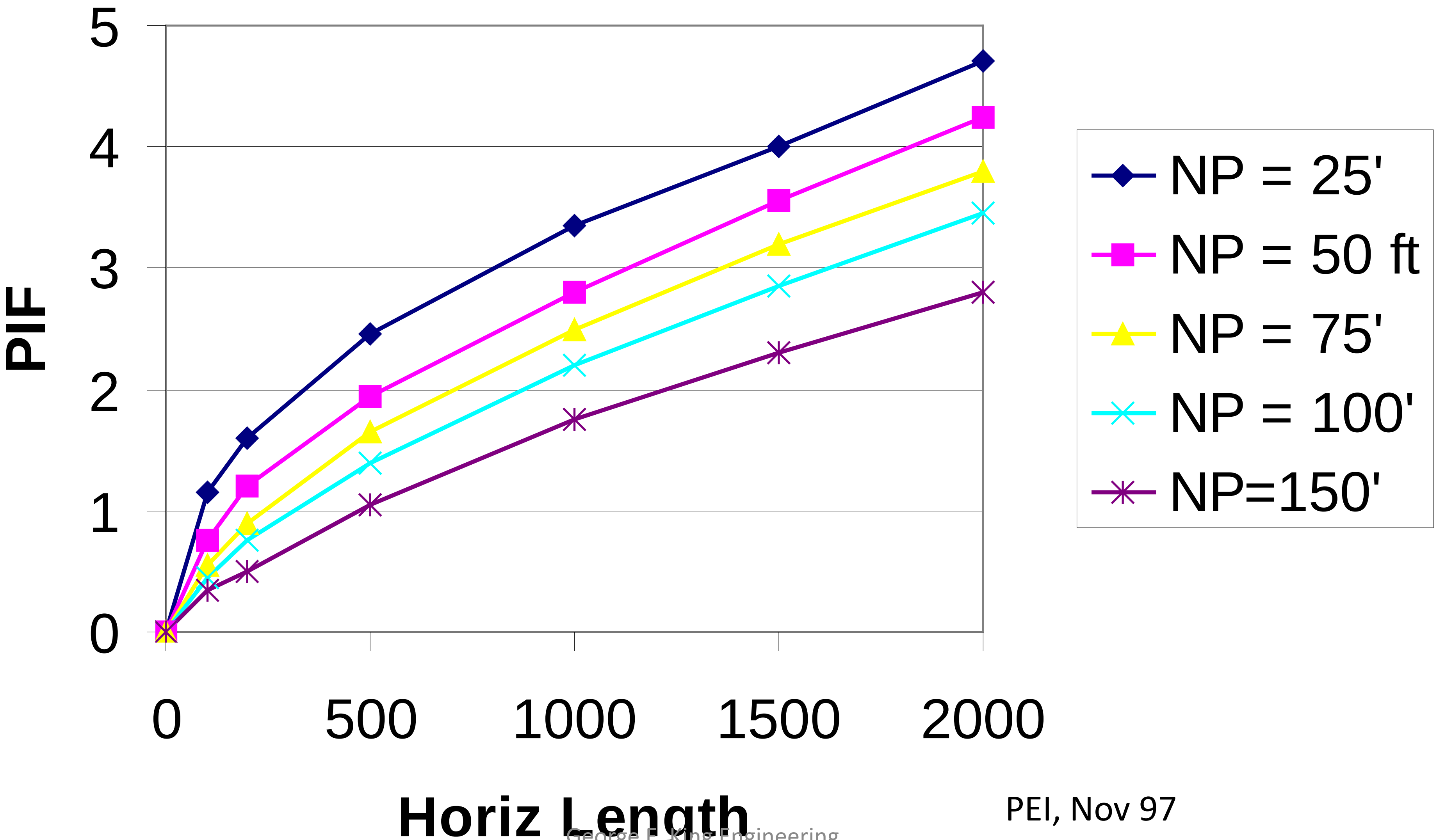
| Reservoir Type | PIF Average (Mean) |
| --- | --- |
| **Conventional Reservoirs** | 4 |
| **Heavy Oil Reservoirs** | 7 |
| **Fractured Reservoirs** | 12 |
| **All reservoirs comb.** | 5 |

**PIF = Prod. Improvement Factor: comparison of horizontal to vertical prod of wells at the same location.**

# Lower Than Expected Production?

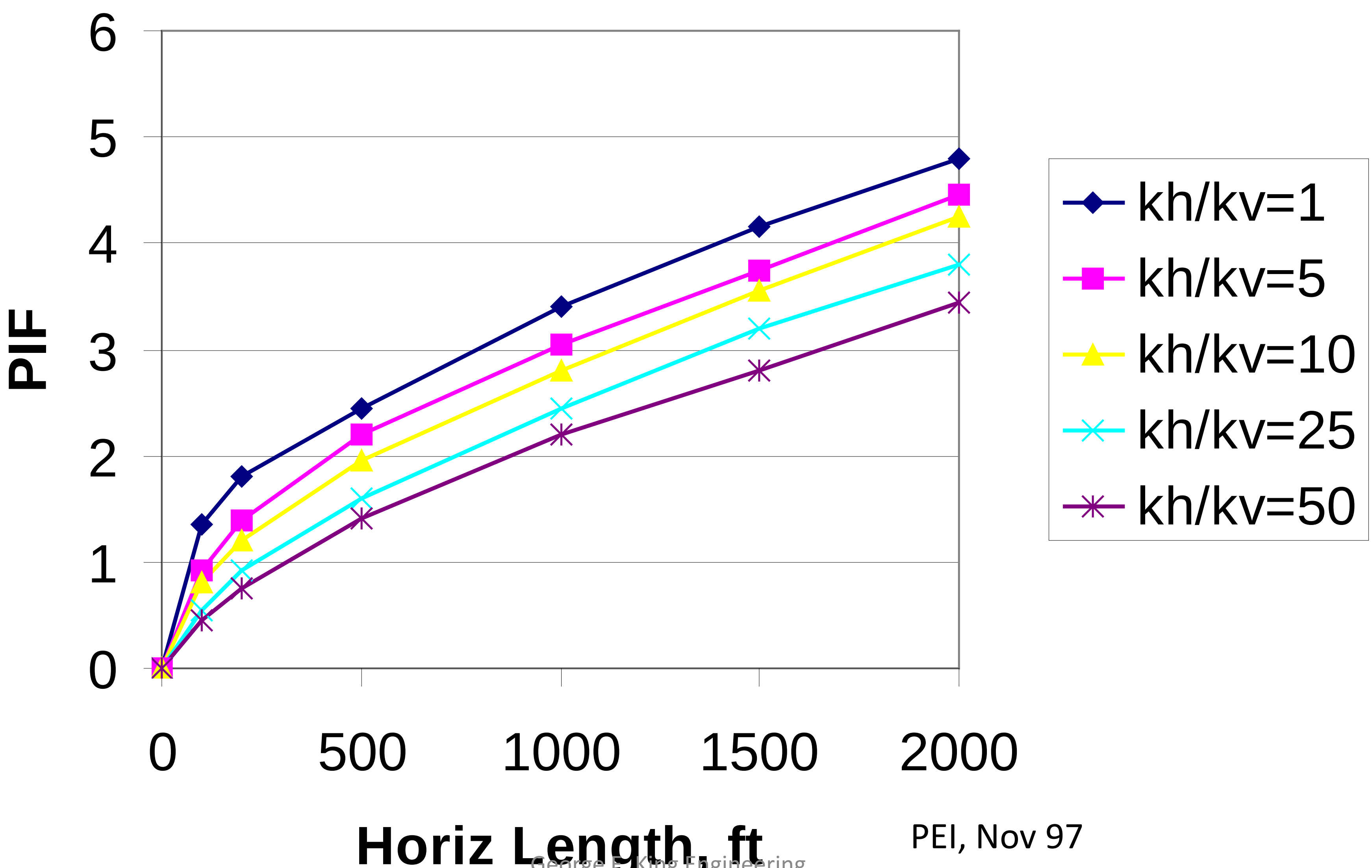
- 1. Low vertical perm.
- 2. Formation damage
- 3. Reservoir quality variance
- 4. Pressure drop along the lateral ?? - few psi at max, but can be important.
- 5. Poor initial knowledge and assumptions.

# Pay Thickness Effect



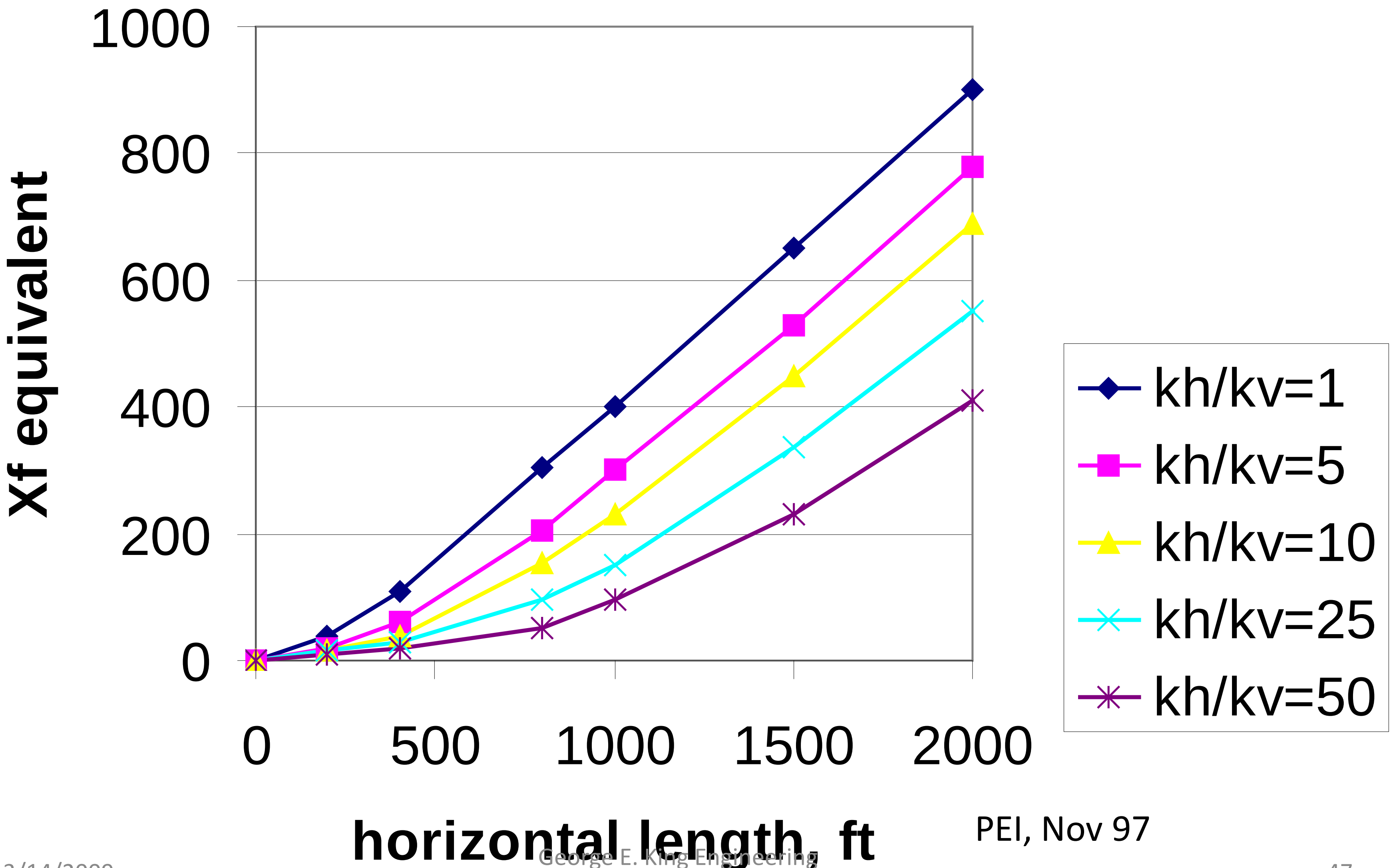

PEI, Nov 97

# Effect of Kh/Kv




PEI, Nov 97

# Horiz vs Frac




PEI, Nov 97

# Horizontal Uses?

- Consider them any time a well is designed.
- Particularly good for:
  - Coning control,
  - Extending reach,
  - Increasing reservoir contact,
  - Lowering drawdown per unit area,
  - As a platform for multiple fracture stimulation
  - In some water injector projects.