# MWX - The Multiwell Experiment in the Piceance Basin, Colorado: Reprise from 30 Years Ago*

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## Abstract

A review of the tight-gas experiments from thirty years ago illustrates the effort required to arrive at today's understandings and successful technologies. In the late 1970's the US government decided that given the recent oil embargo, America might someday need the natural-gas resources of the low-permeability Rocky Mountain sandstone reservoirs. However, it was unclear why, even when stimulated with Massive Hydraulic Fractures and nuclear blasts, gas did not flow readily from these formations. After several failed engineering-only tests, the government decided on a radical approach: characterize and understand the reservoirs before applying technology. The Multiwell Experiment (MWX), funded by the US DOE, was an applied-research field test located in the Rulison field. At the time there were 12 wells in the field, with 640-acre spacing. Borehole-image logs did not exist, few cores were taken, and the available fracture-identification logs turned out to be remarkably unreliable. The reservoirs were not thought of as being fractured, and the few cored fractures were considered to be anomalies. One revelation of the MWX project, derived from characterization of 4500 ft of core from three vertical and a deviated well, was that fractures are pervasive, with average spacings of a few feet. Engineering tests could then document the previously unrecognized contribution of fractures in converting microdarcy-matrix rock into reservoir systems with highly anisotropic, millidarcy-scale permeabilities. Pre- and post-stimulation production tests showed that the standard completions of the day were actually damaging the fracture-permeability system, which was also stress-sensitive. MWX data showed that pore pressures and the in situ stresses had to be accommodated during drilling, completion, and production. $40 million were spent to reach these conclusions over a span of 10 years in this multidisciplinary, multi-organizational effort. Core from the MWX program is now stored in the USGS CRC in Denver, and much of the data set is accessible on the Internet.

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# MWX - The MultiWell Experiment in the Piceance Basin, Colorado: Reprise from 30 Years Ago

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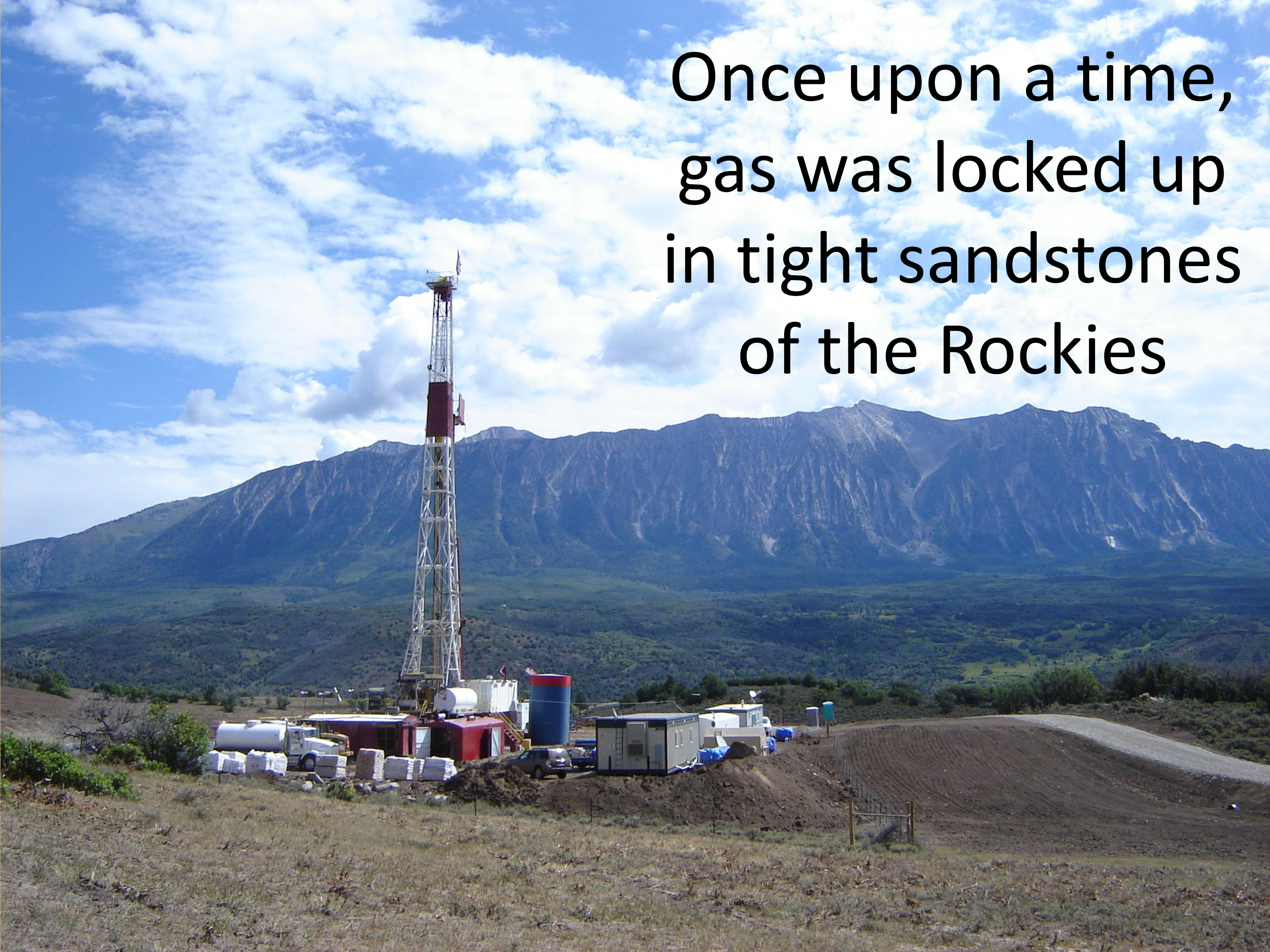

Once upon a time,
gas was locked up
in tight sandstones
of the Rockies

# Attempts to extract the gas: 1969 – the Rulison Nuclear "Shot"

- 40 kilotons, 4.9 seismic event, 8427 ft depth
- 200-400% production increase
- 11% water vapor, 26% $CO_2$


Lorenz, 2001

# Attempts to extract the gas: 1972 -- Massive Hydraulic Fracturing

- Large volumes of fluid and sand
- Pre-stimulation 40-60 MCF
- Post-stimulation 60-160 MCF

# New motivation to access the gas: The 1973-74 Oil Embargo

Rumors of tankers hovering off the east coast

You don’t like today’s expensive gas...?

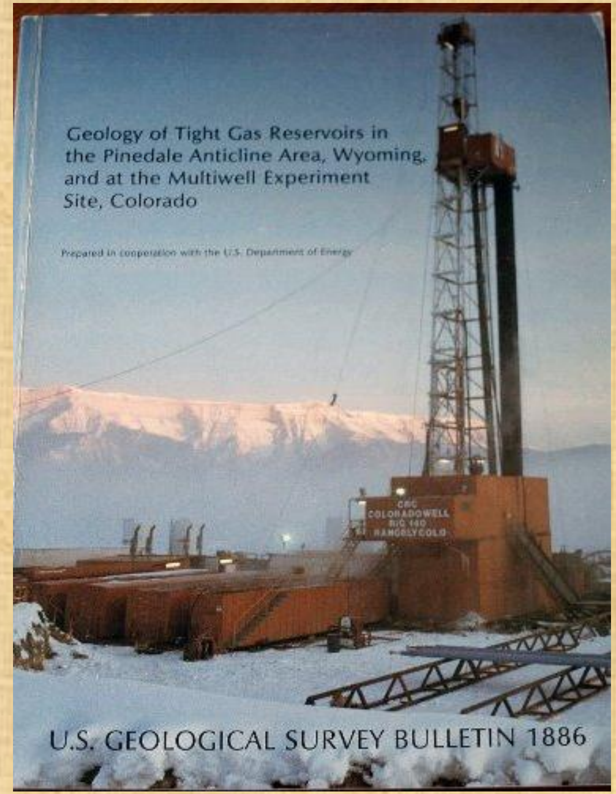
# ...try no gas at any price!


# Here's an idea: let's figure out what we're drilling into before applying the technology

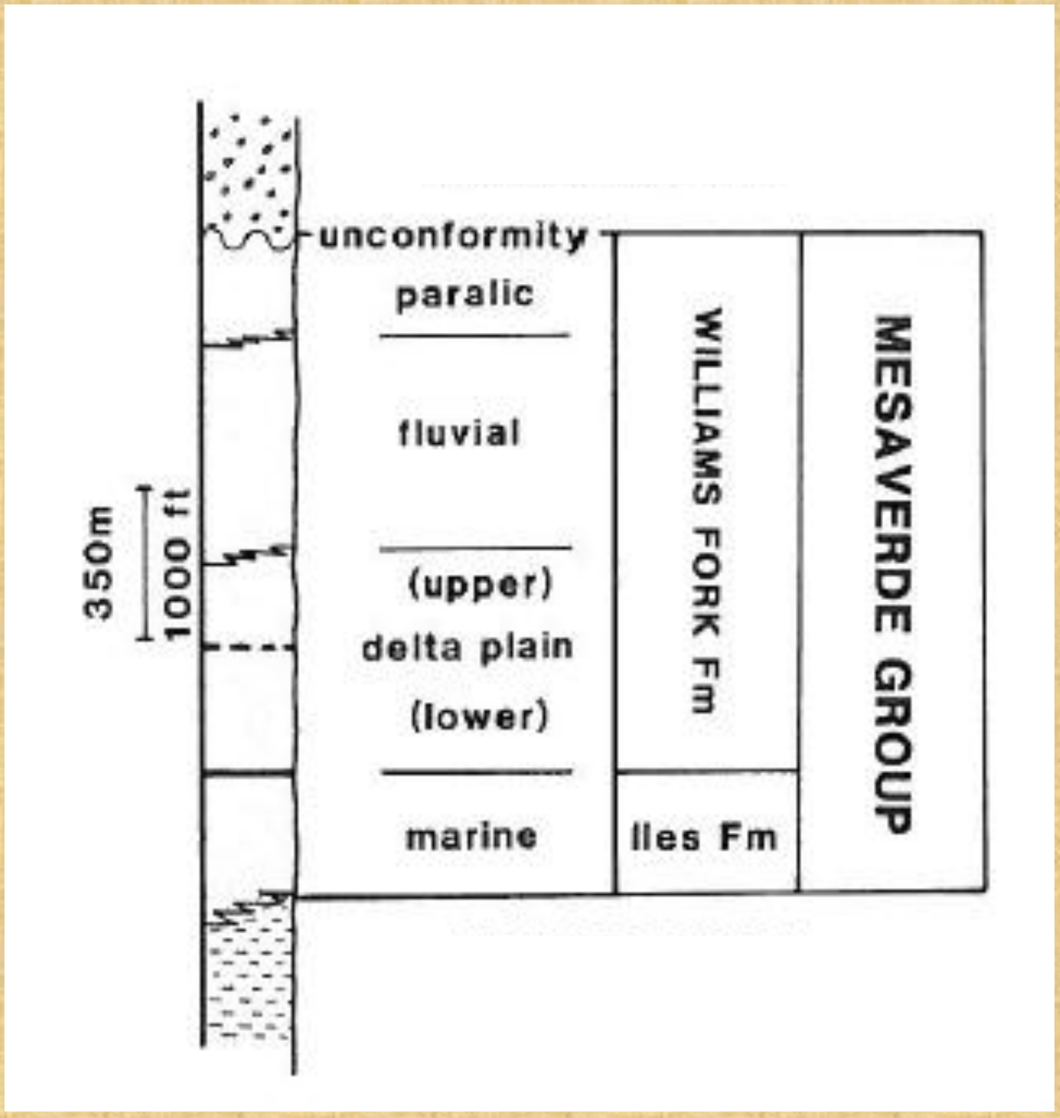
- Geological characterization before/while testing
- Thousands of feet of core
- Every wireline log known
  - (Pre-wellbore image log development)
- Various stimulation techniques
- Pre- and post-stimulation production tests
- Extensive well testing

MWX: 1979-1988

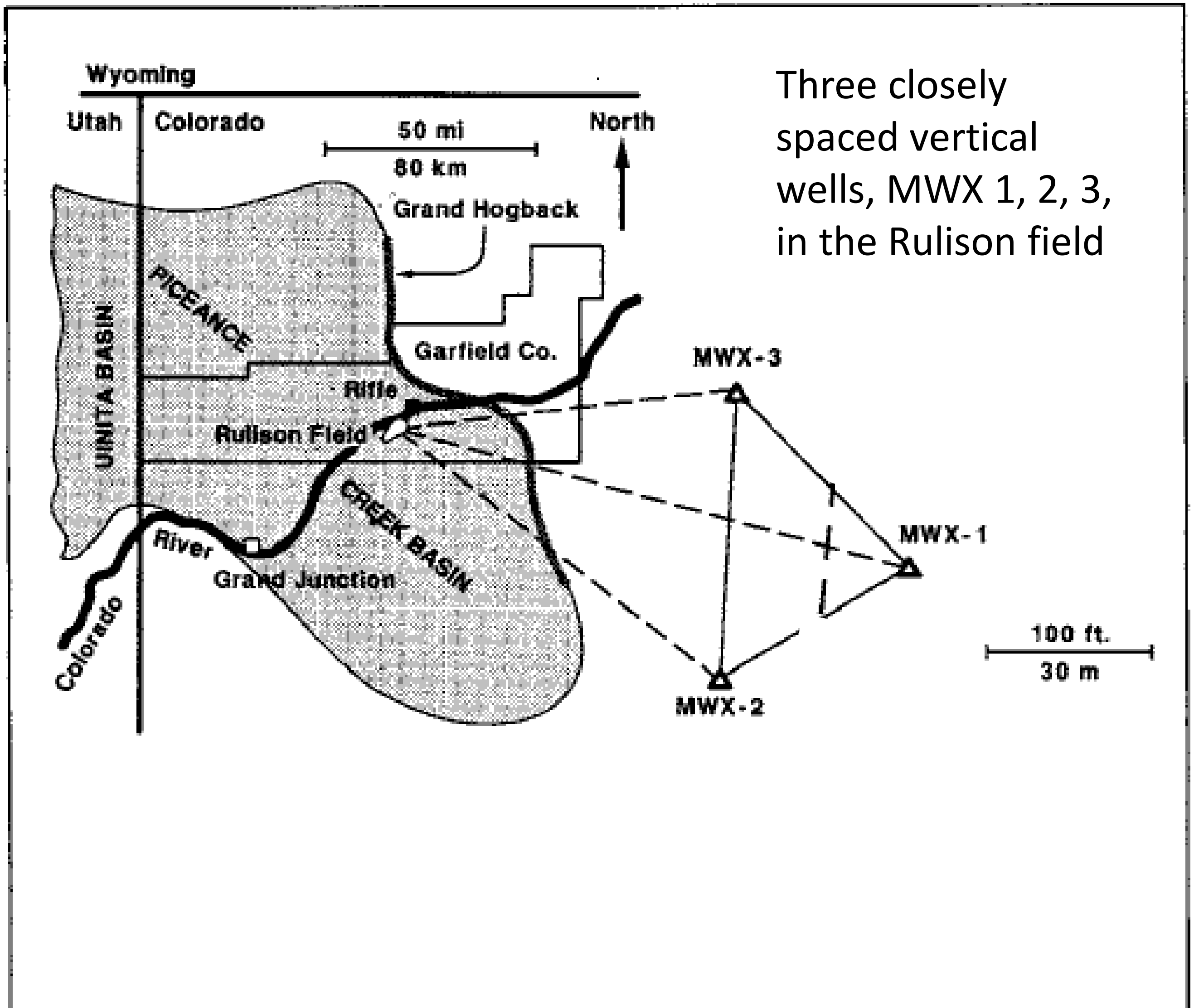
- US DOE: funding, overall direction
- CER Corp: logistics
- SNL: scientific direction
- Other contributors
  - USGS
  - GRI/GTI
  - Industry technical advisory group



# Target: Low-Permeability Mesaverde Sandstones

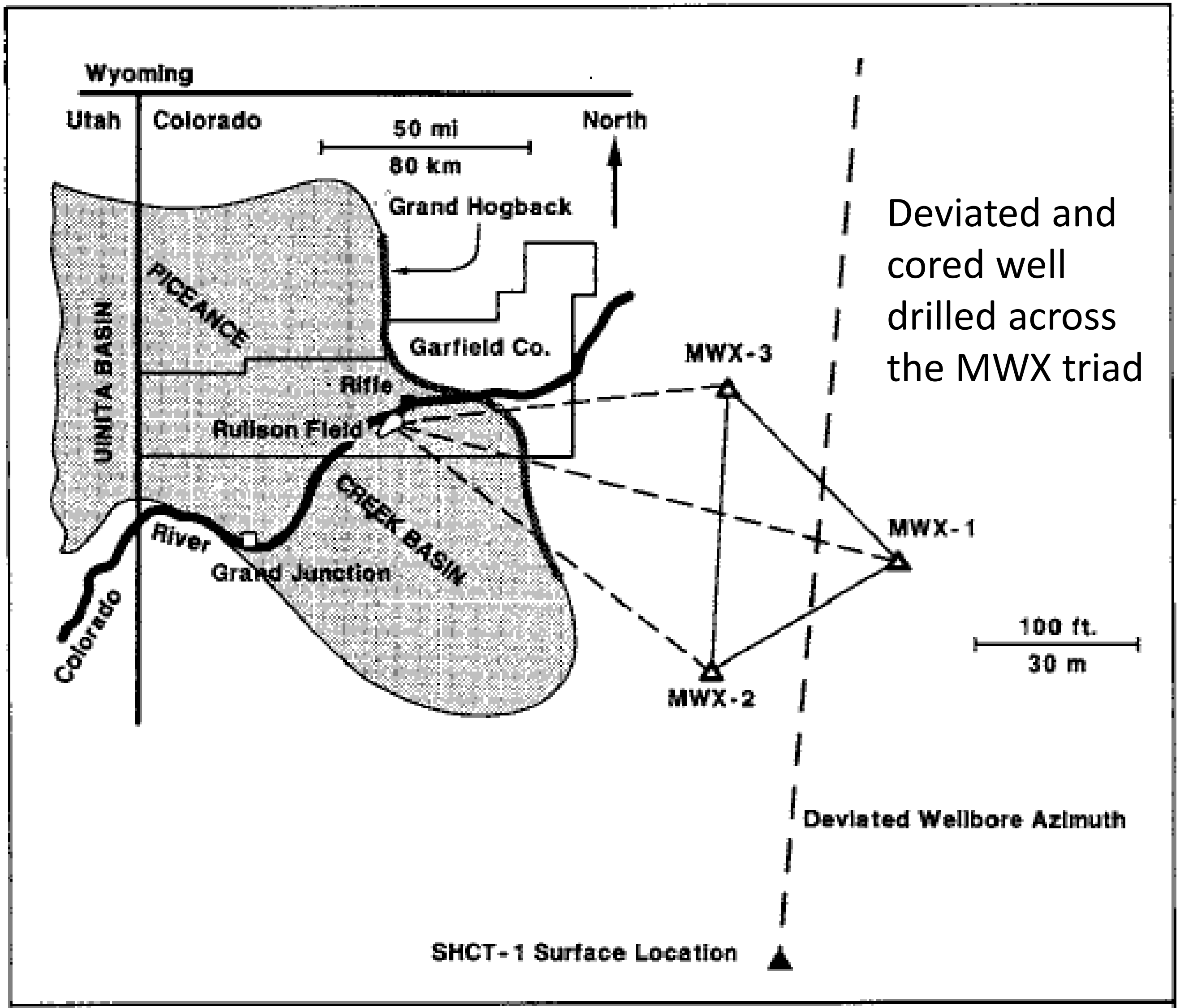


# The MultiWell Experiment (MWX)



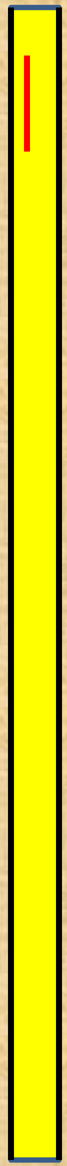

Three closely spaced vertical wells, MWX 1, 2, 3, in the Rulison field

# The Slant Hole Completion Test (SHCT)

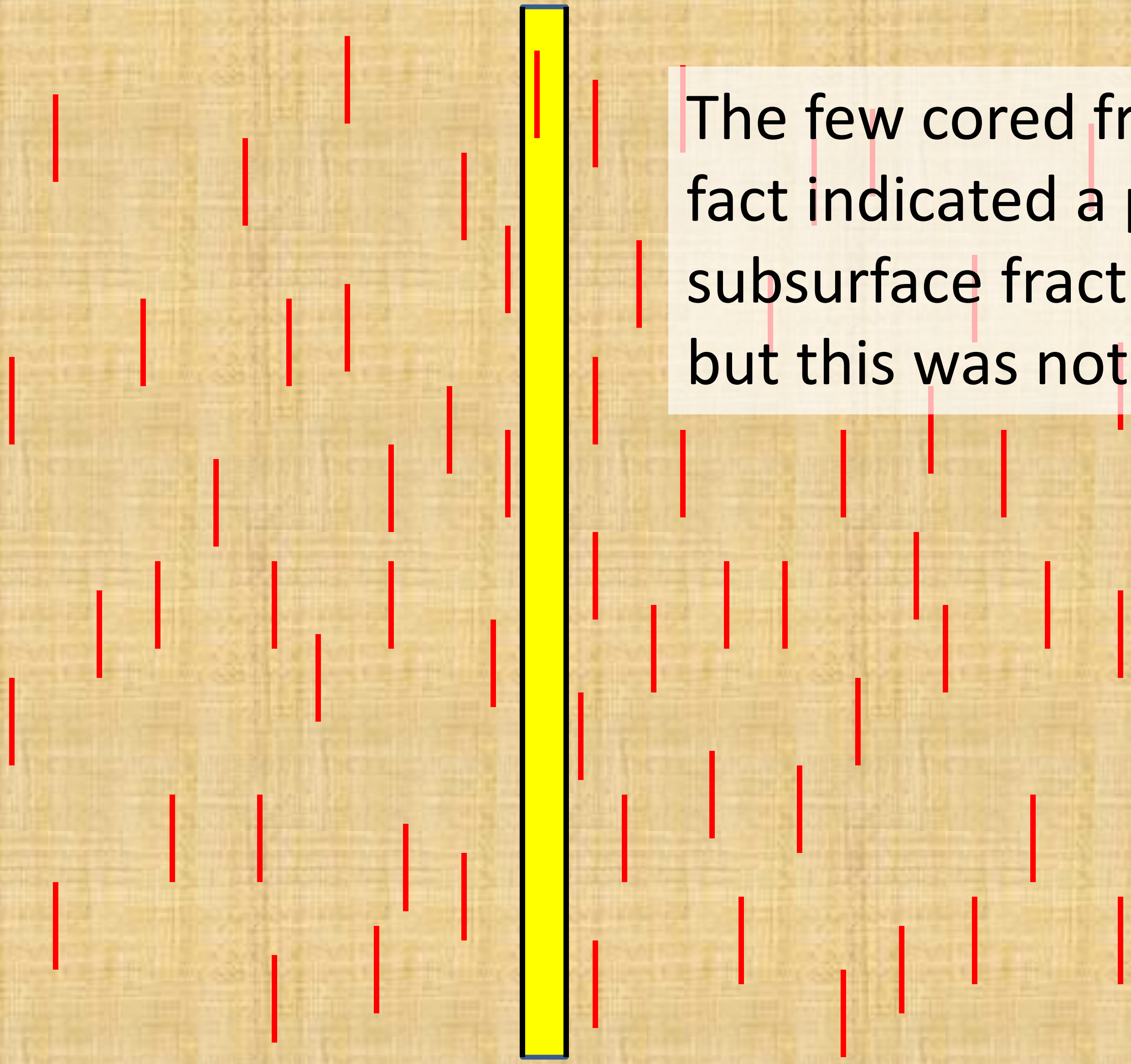



Deviated and cored well drilled across the MWX triad

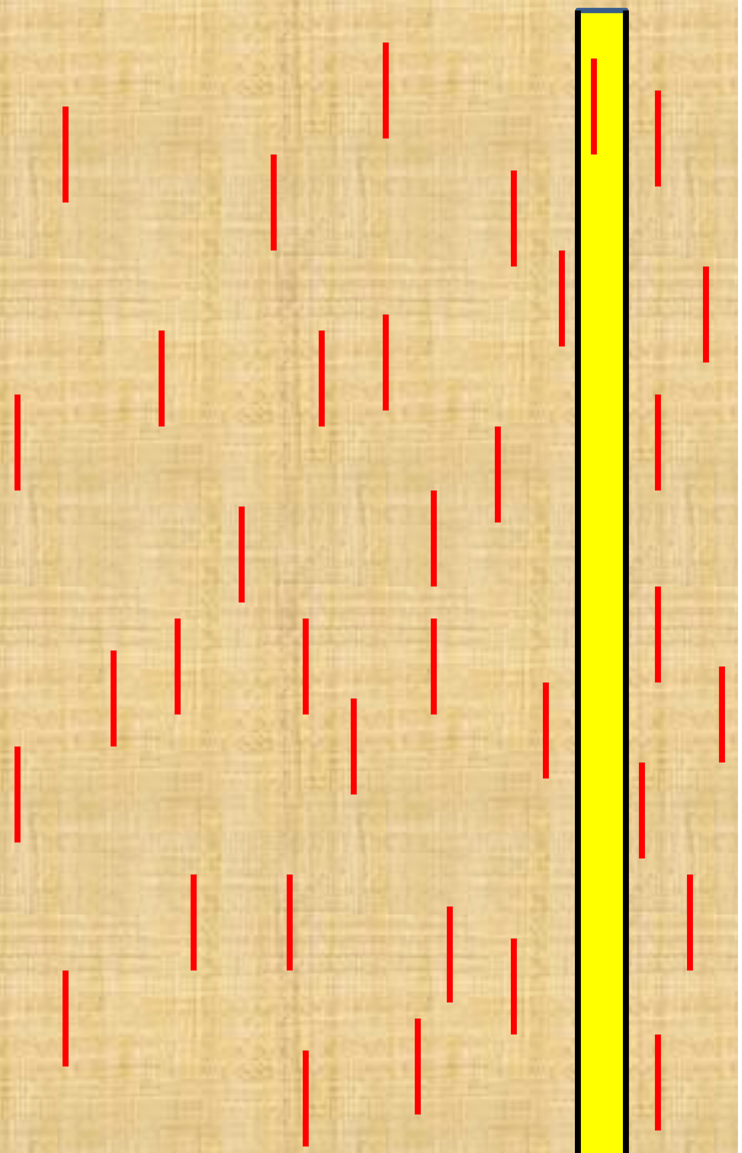
Pre- 1980: Natural fracture distributions and effects were not well understood



1. Few wells
2. Little core taken
3. Core taken only in thick ss (where spacing is generally wider)
4. The few cored fractures were considered to be anomalies



The few cored fractures in fact indicated a pervasive subsurface fracture system, but this was not recognized



MWX: 4200 ft of vertical plus 300 ft of deviated core; demonstrated that:

-1900 natural fractures

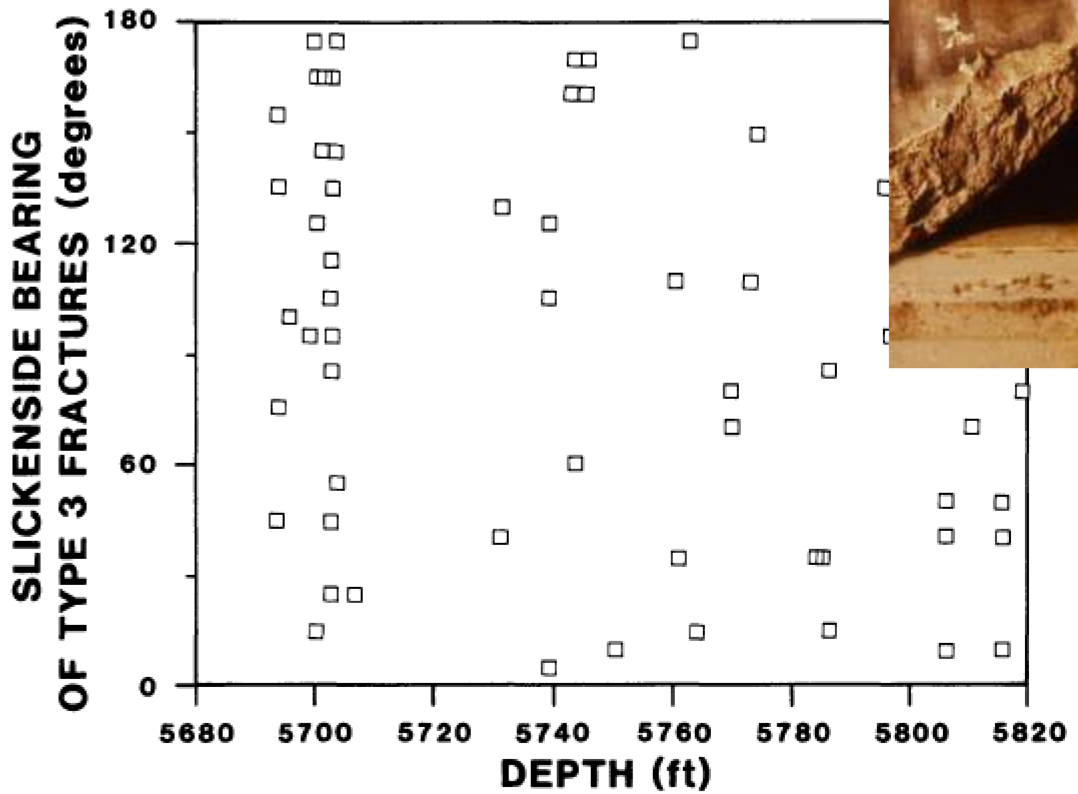
-7 fracture types

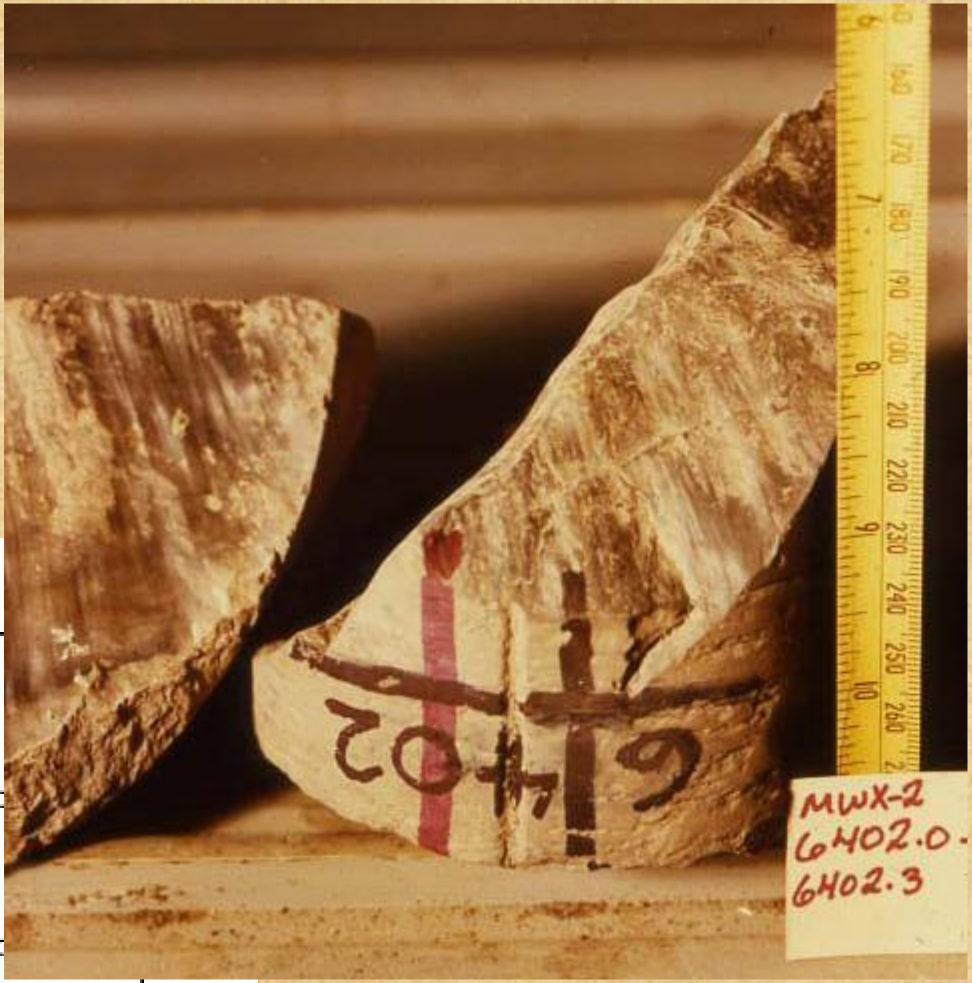
-1 fracture/0.45 ft core

-average spacing = 3 ft

-dominant strike WNW
(Finley and Lorenz, 1988; Lorenz and Finley, 1989; Lorenz, 2003)

# Some fractures are ineffective: compaction shears



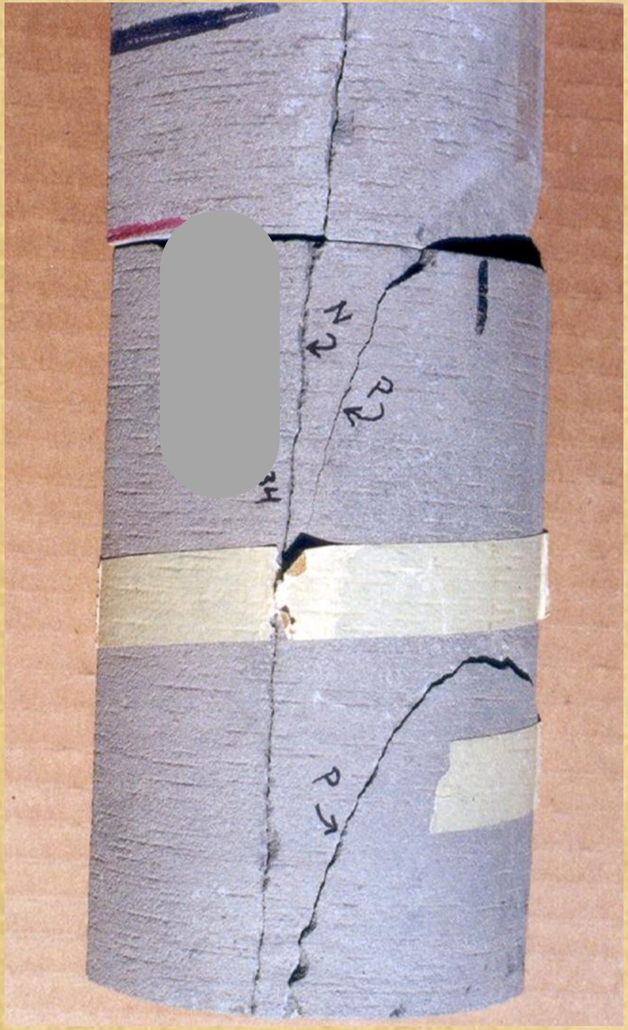




Finley and Lorenz, 1988

# Some fractures are induced: petal and centerline fractures

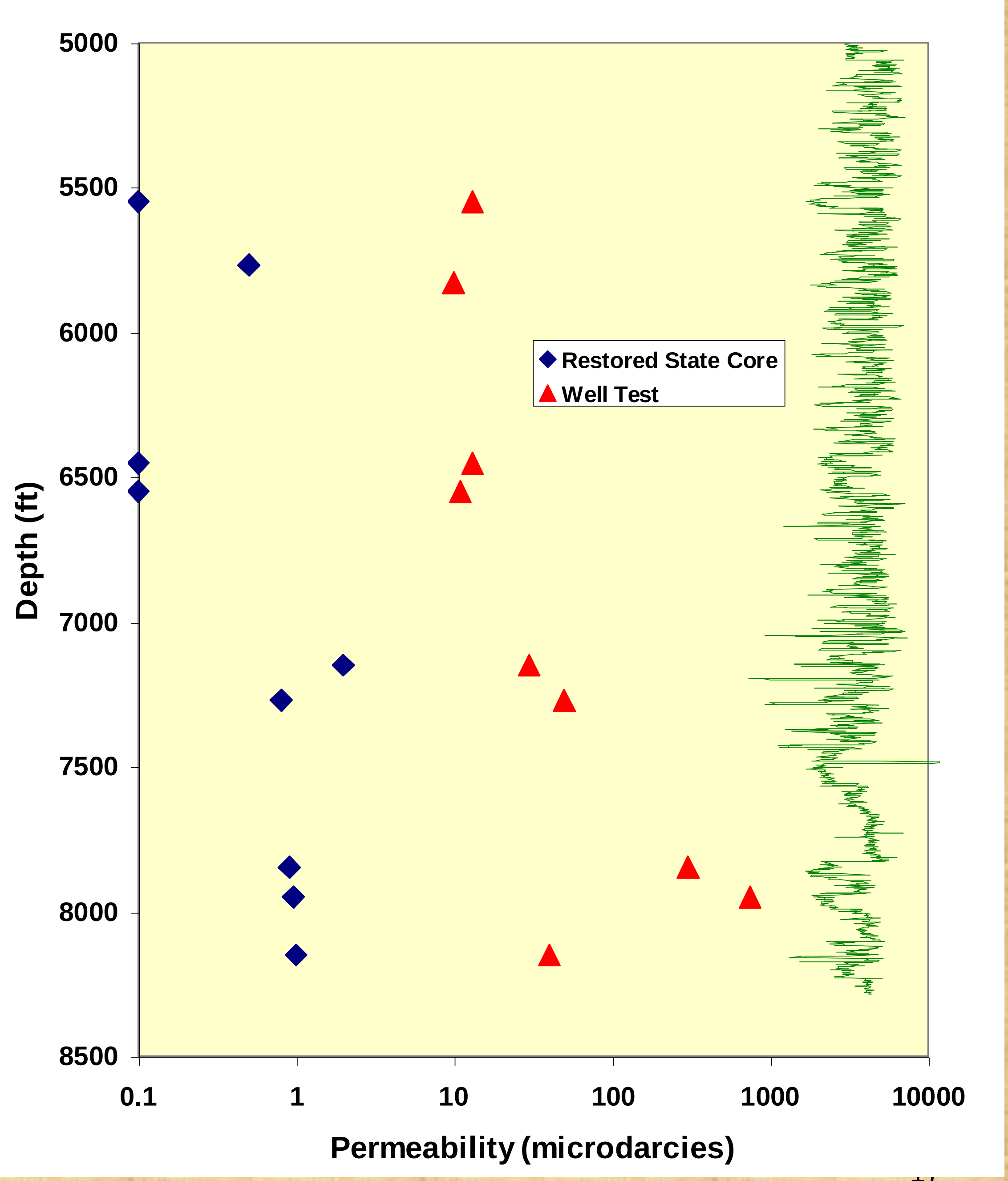
- Form during coring
- Parallel to $\sigma_H$
- Consistent strikes

Lorenz et al., 1990



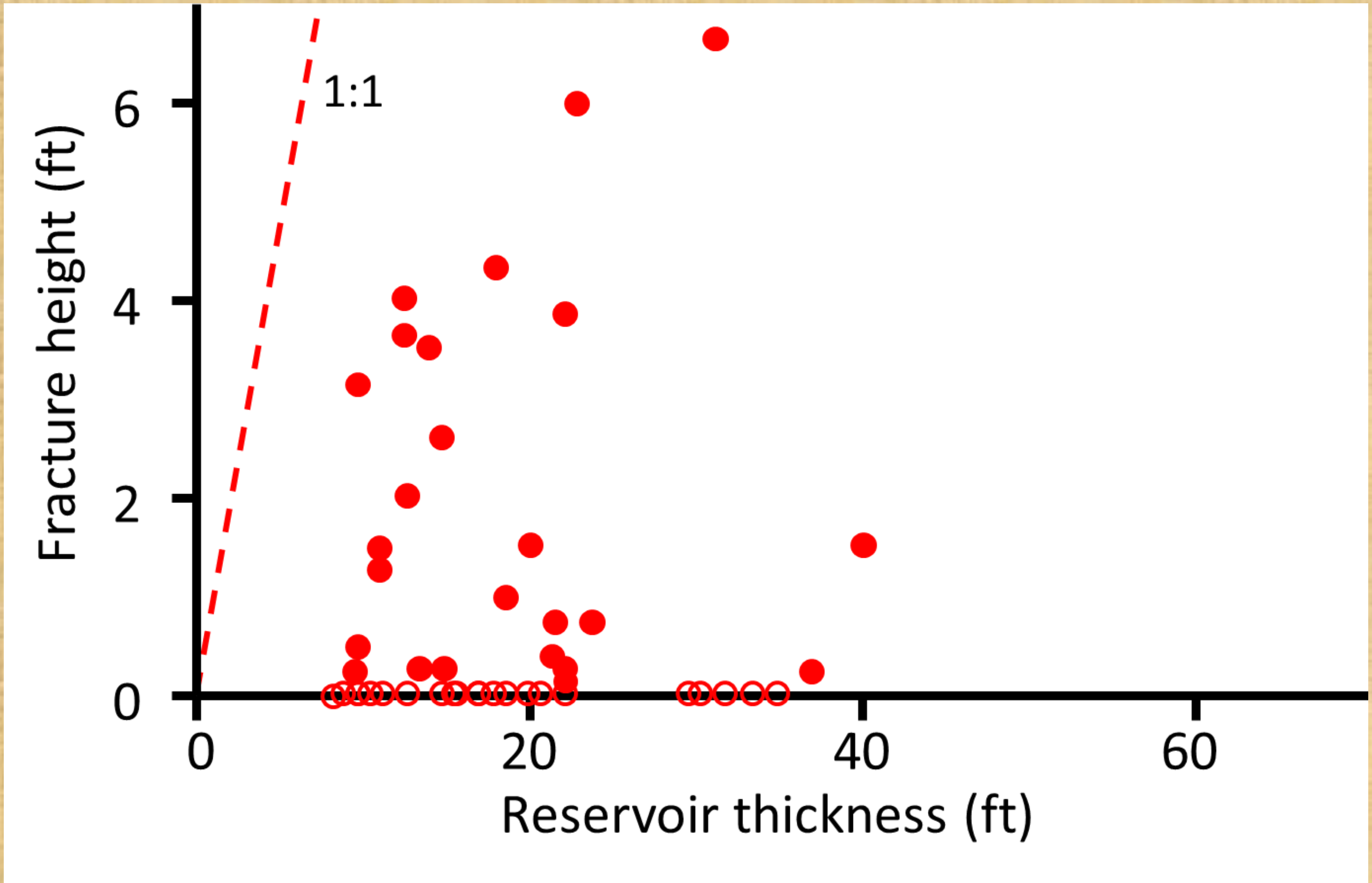
System perm >> matrix perm:

Fractures make the difference



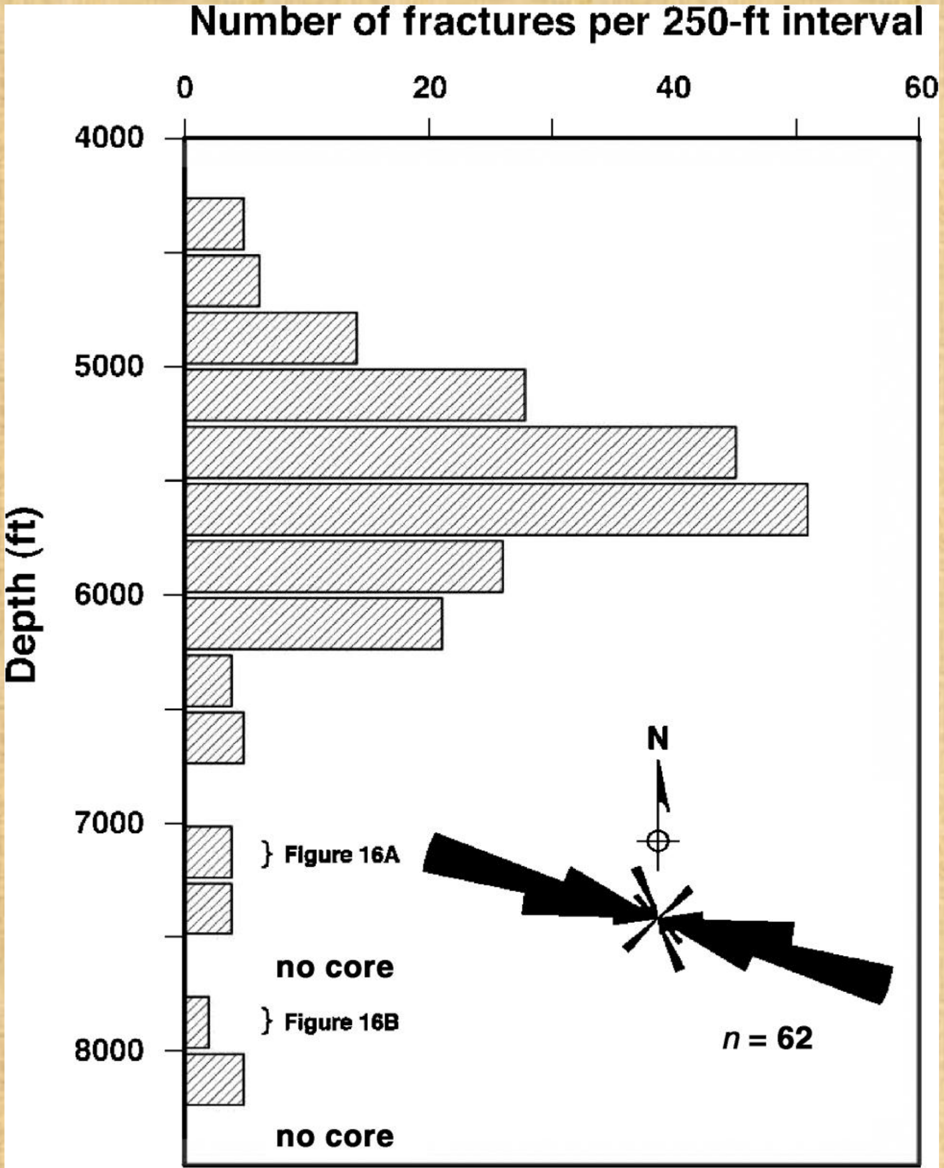

Warpinski and Lorenz, 2008

# Sedimentary heterogeneity = irregularity in fracture distribution




Finley and Lorenz, 1988;
MWX final reports

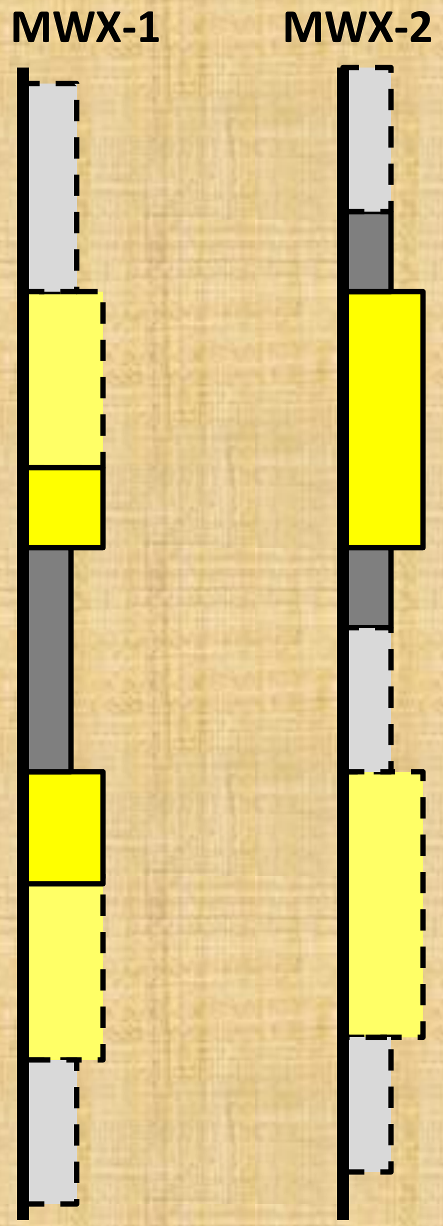
# Non-uniform vertical fracture distribution and mineralization



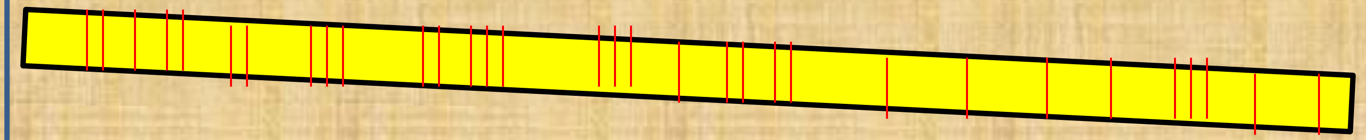

Finley and Lorenz, 1988; Lorenz and Finley, 1989

# Fracture spacing

Lorenz and Hill, 1992; 1994



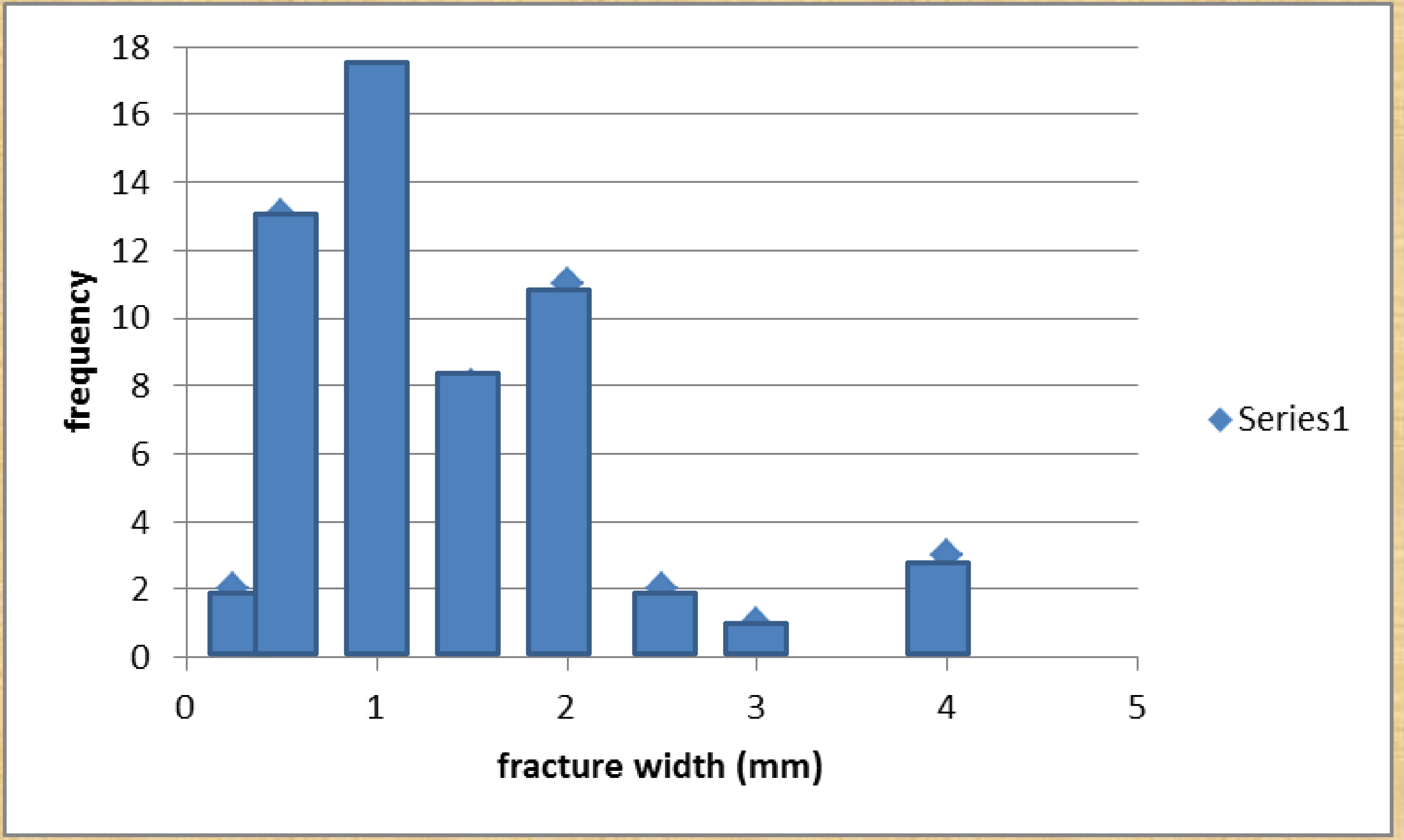

**vertical core, no fractures**




**horizontal core in same interval: average 3 ft**

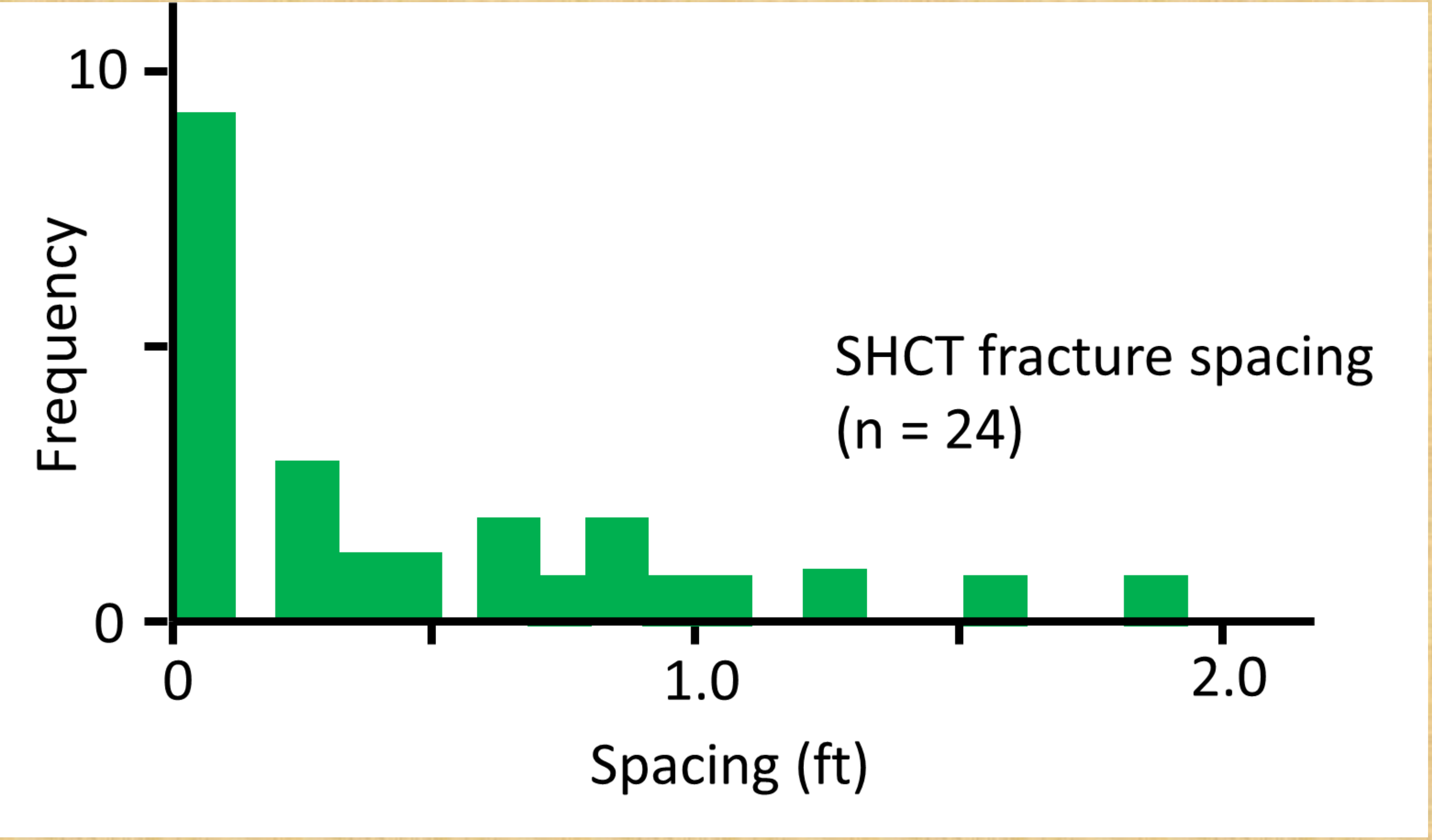
# Fracture widths: log-normal distribution

Lorenz and Hill, 1994



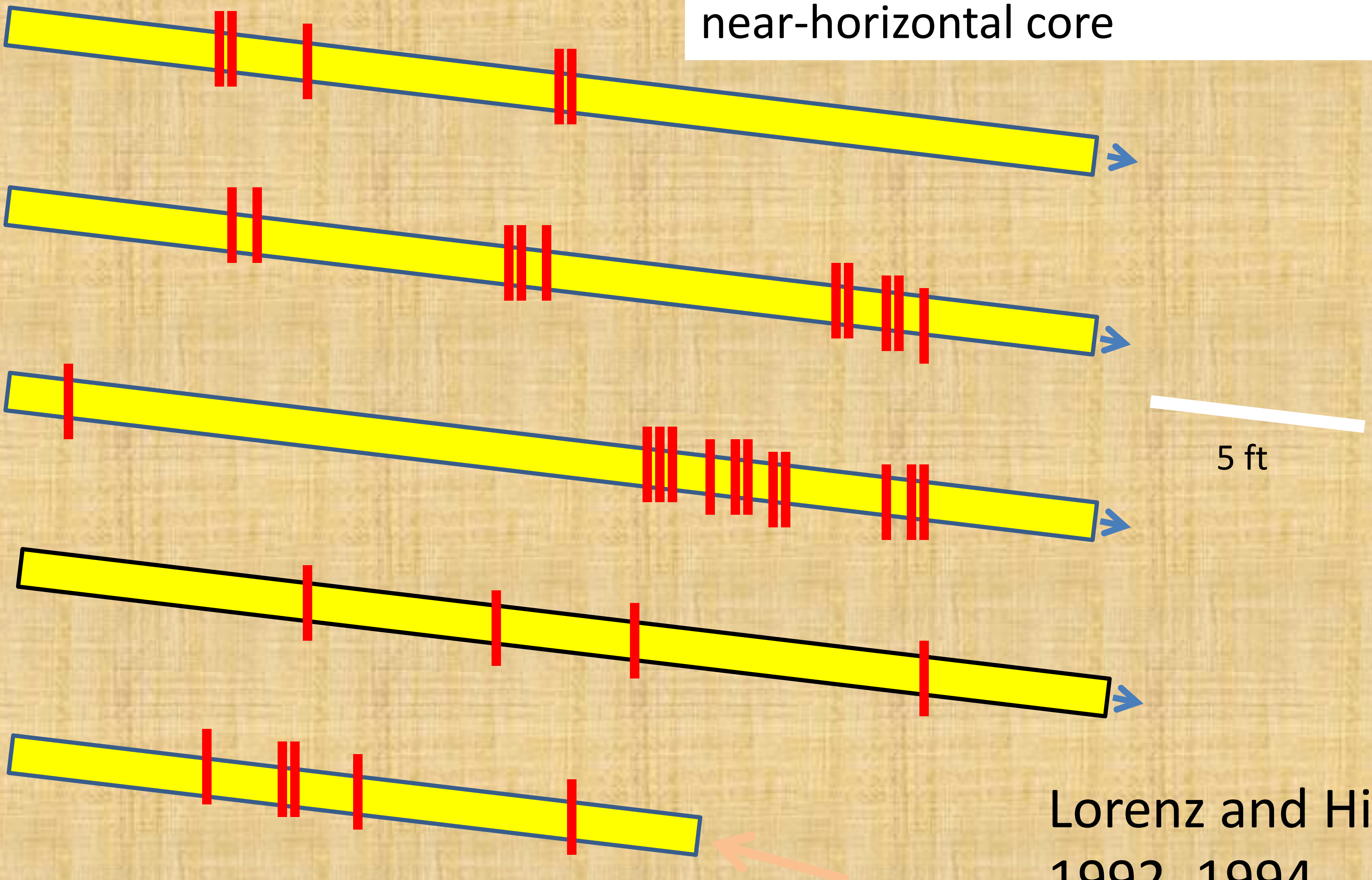

Aperture, Height, Length, Spacing

# Fracture spacings: log-normal distribution




Lorenz and Hill, 1994

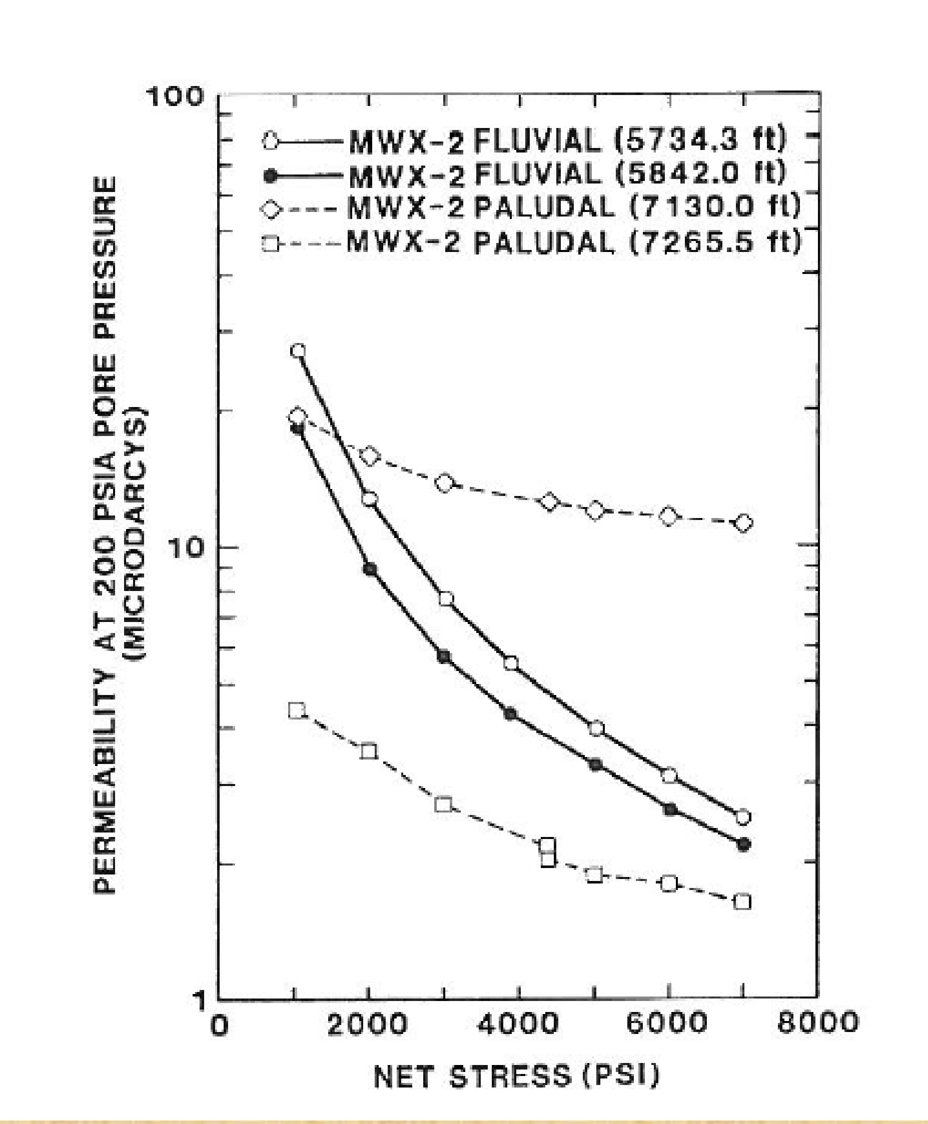
# Fracture locations in 117 ft of near-horizontal core




Lorenz and Hill, 1992, 1994

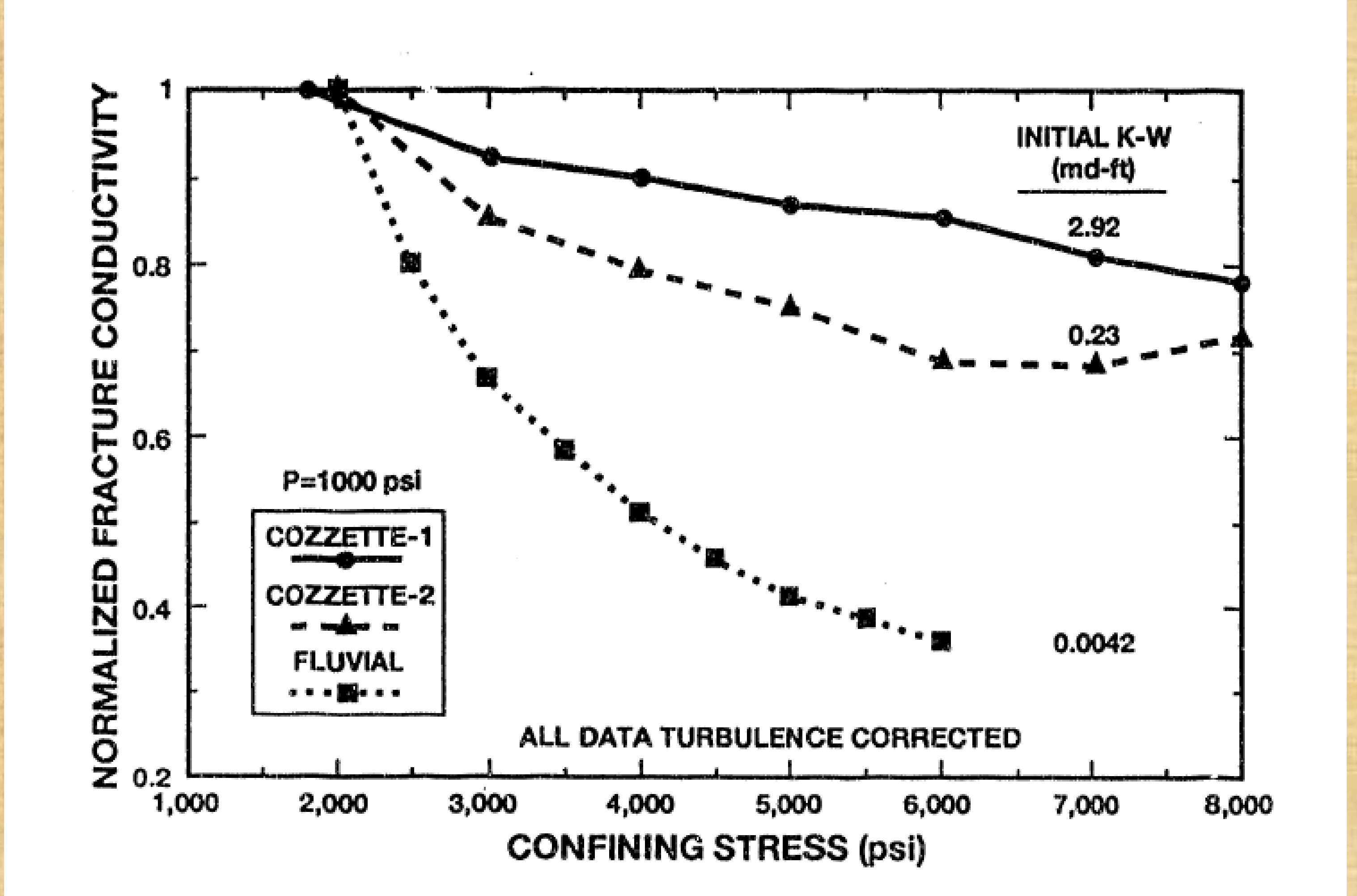
Use fracture swarms for system perm calculations, not the 3-ft average spacing

# Stress-sensitive matrix permeability



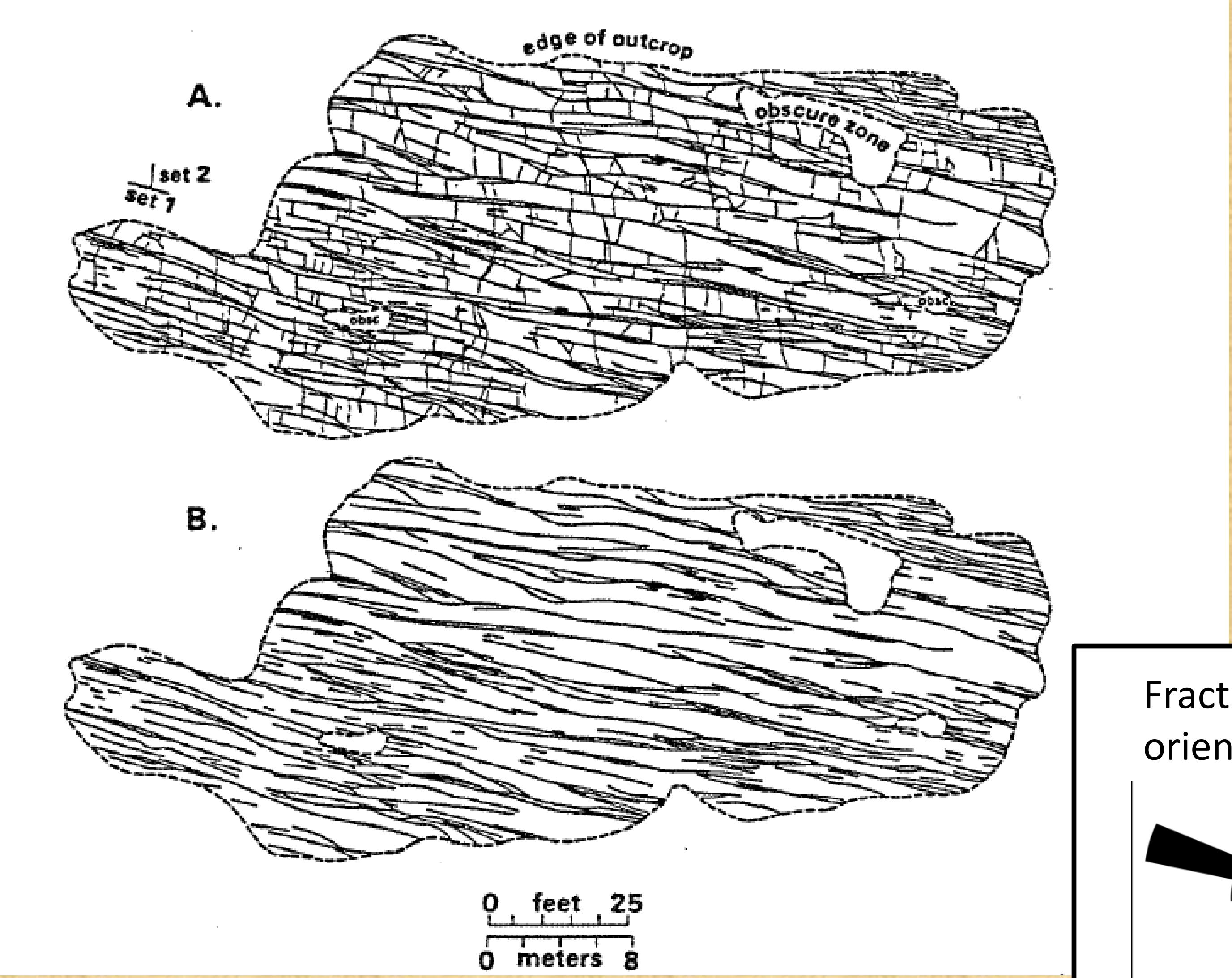

MWX final reports

# ***Fracture*** perm is also stress-sensitive



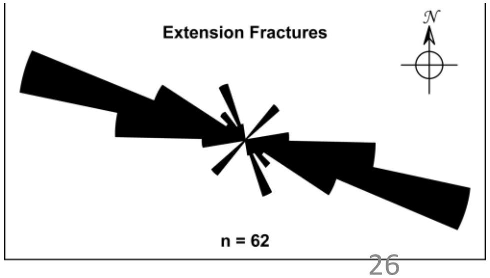

MWX final reports; Sattler et al., 1989

# Outcrop analog to subsurface fracture texture: plan view of fractures on a sandstone surface, Rifle Gap



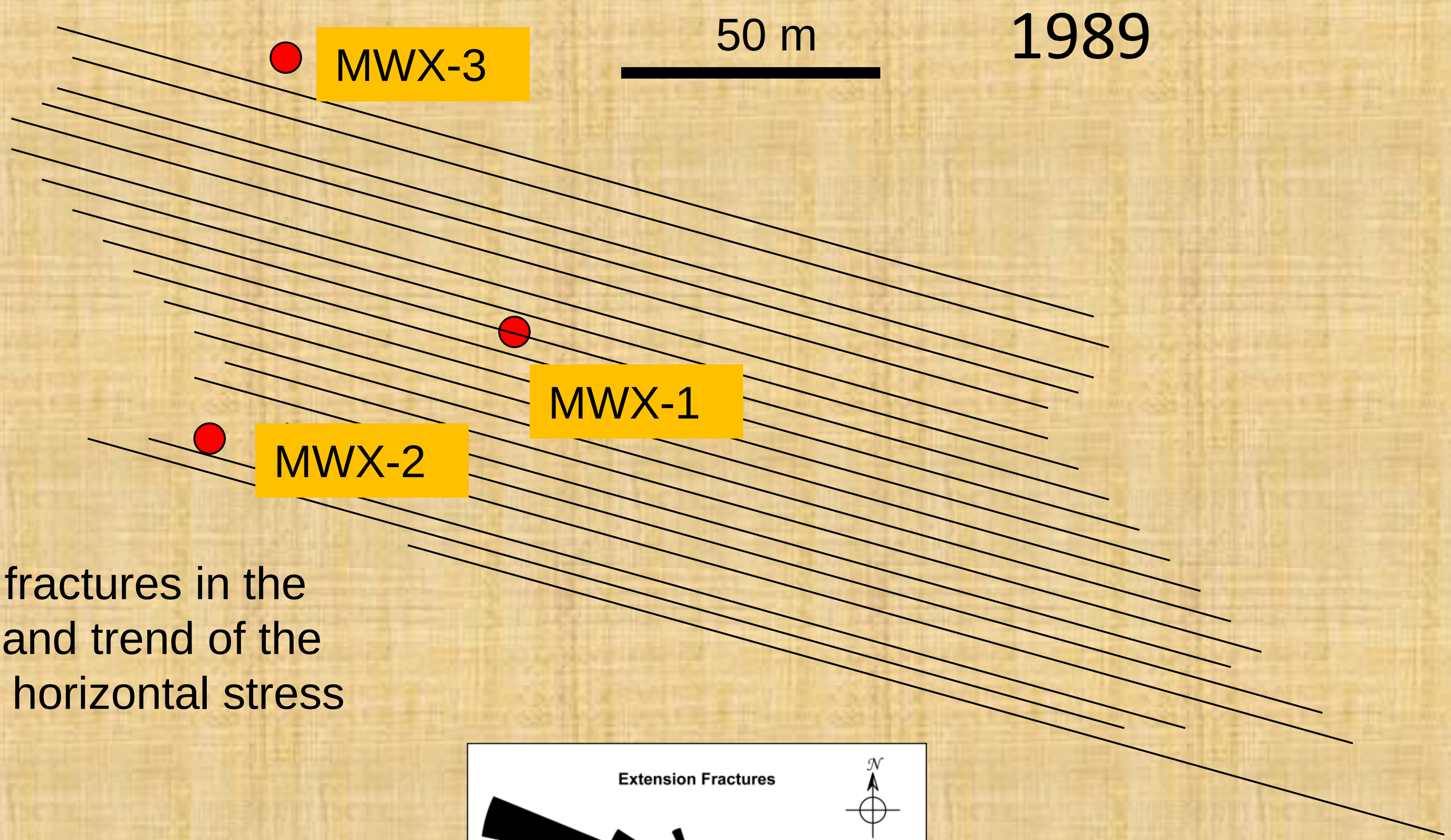

Lorenz et al., 1991a,b

Fracture strikes in oriented MWX core

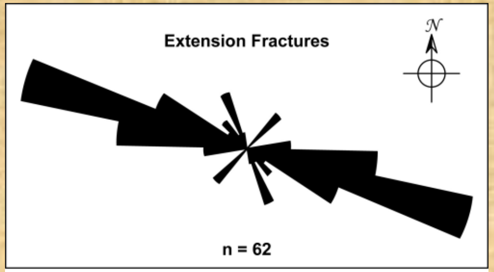


# Up to 100:1, $k_H$:$k_h$ shown by well tests

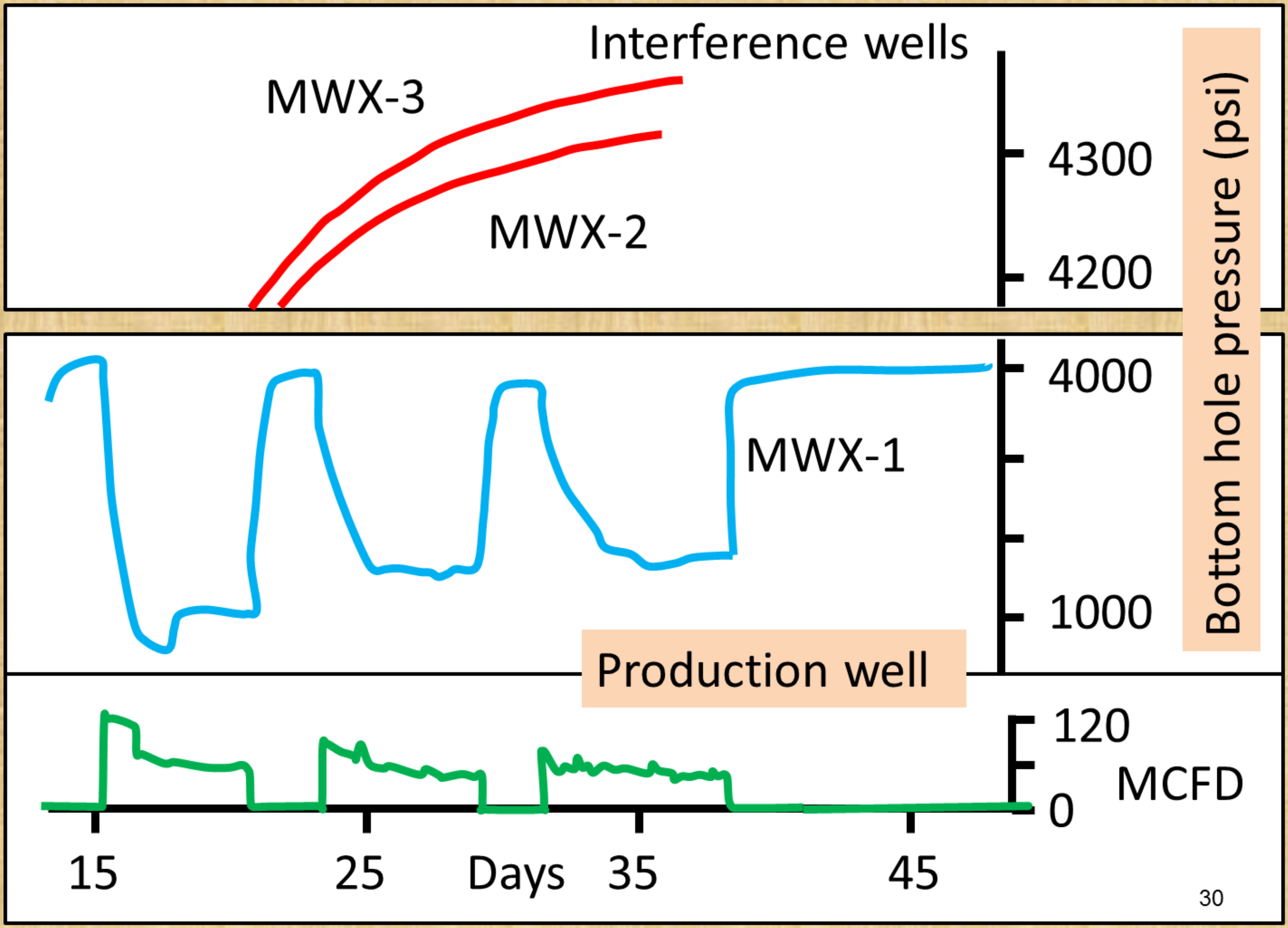
Lorenz et al., 1989




Strikes of fractures in the reservoir, and trend of the maximum horizontal stress



# No interference, due to anisotropy



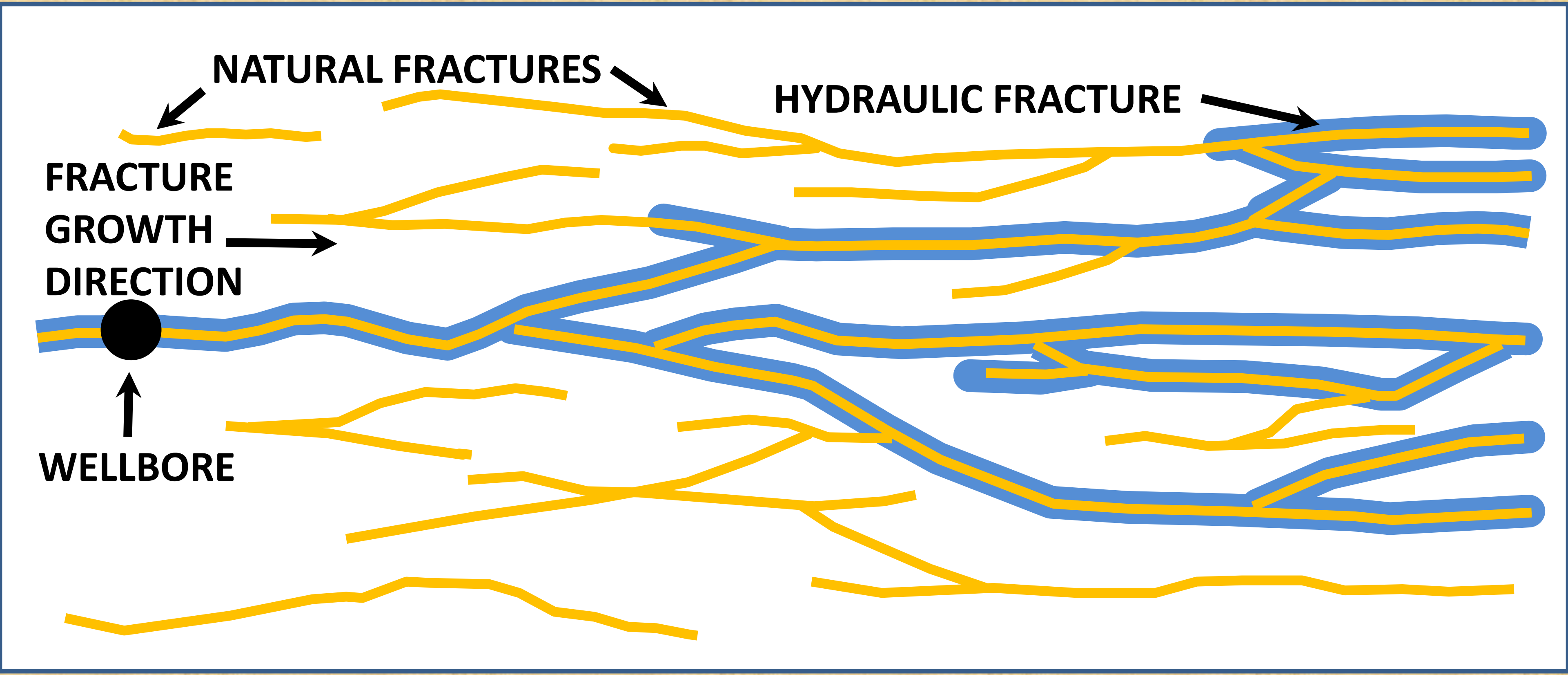

Lorenz et al., 1989

# MWX showed that the 1980s stimulation technology was ineffective

- 5 of 6  MWX stimulation tests ***cut*** production
  - Viscous gels plugged apertures
  - Proppant added stress
  - Reversible
- Go to $N_2$ foam fracs
- Successor is slickwater

MWX Final Reports

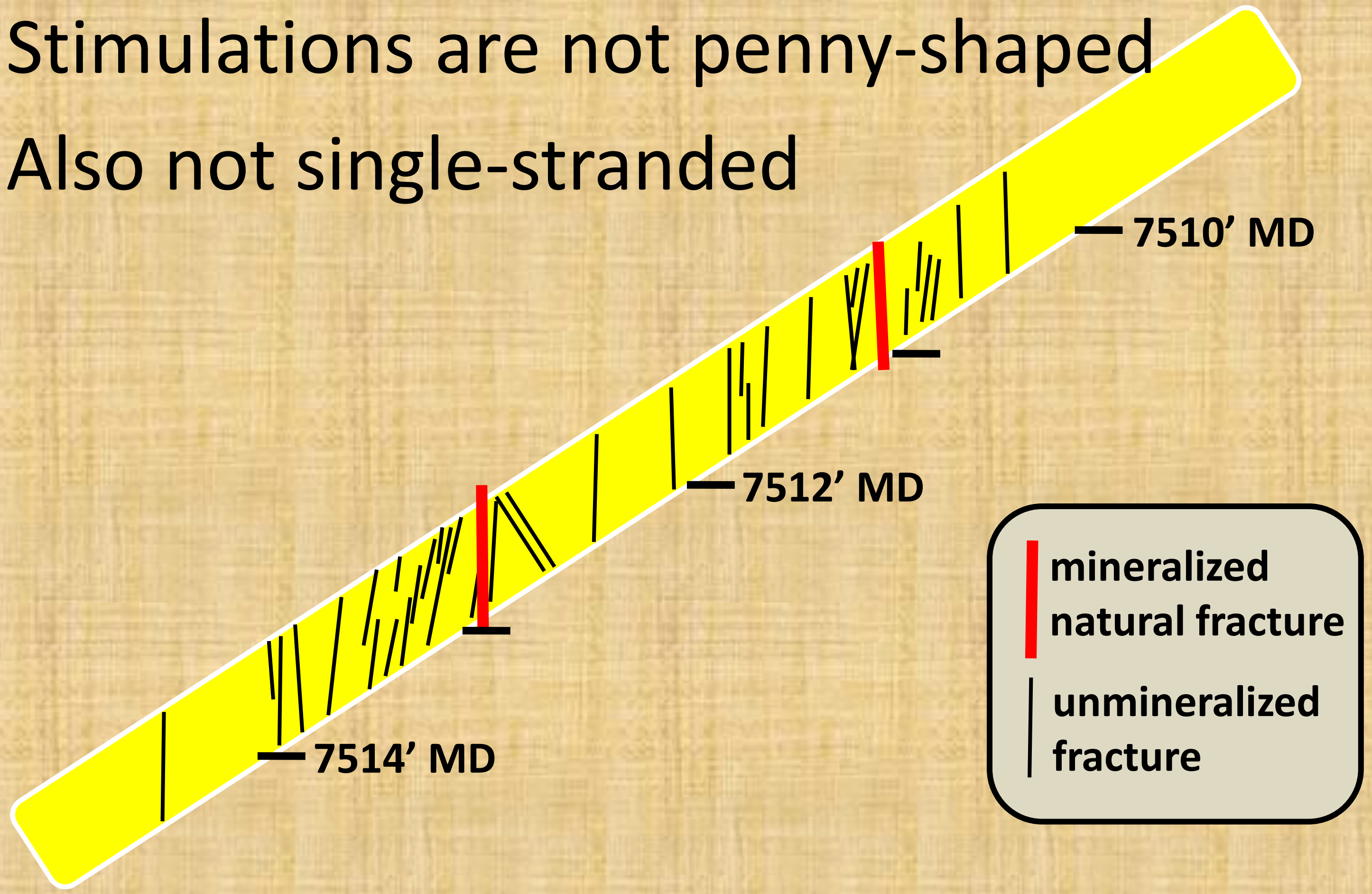
# Initial concept: complex fracturing due to natural fractures




MWX Final Reports

# Cored hydraulic fracture in SHCT-1 showed even more complexity

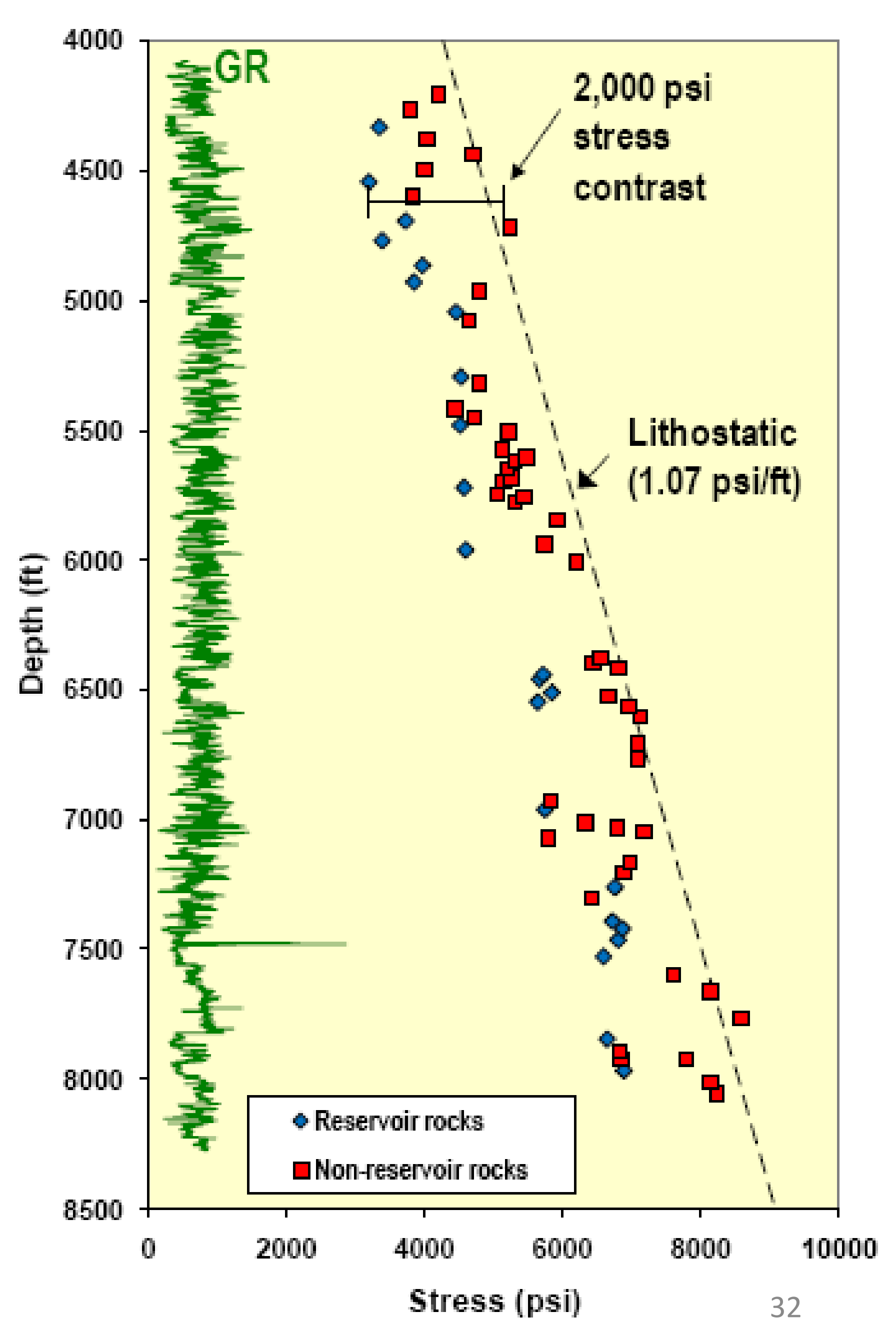
- Stimulations are not penny-shaped
- Also not single-stranded




Warpinski et al., 1993

MWX stress profile showed reasons for vertical stimulation fracture containment: High stresses in the mudstones, lower stresses in the interbedded sandstones

MWX Final Reports; Warpinski—see www.epa.gov/hfstudy/measurementandobservationsoffractureheightgrowth.pdf



# Early development of micro-seismic surveys

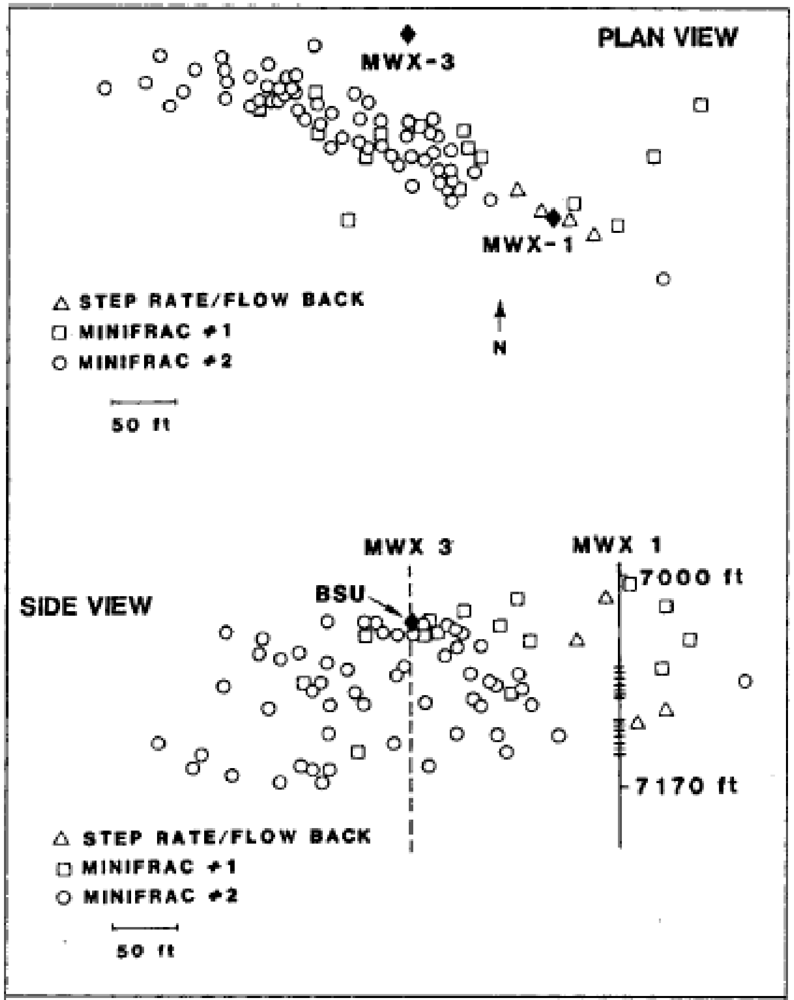
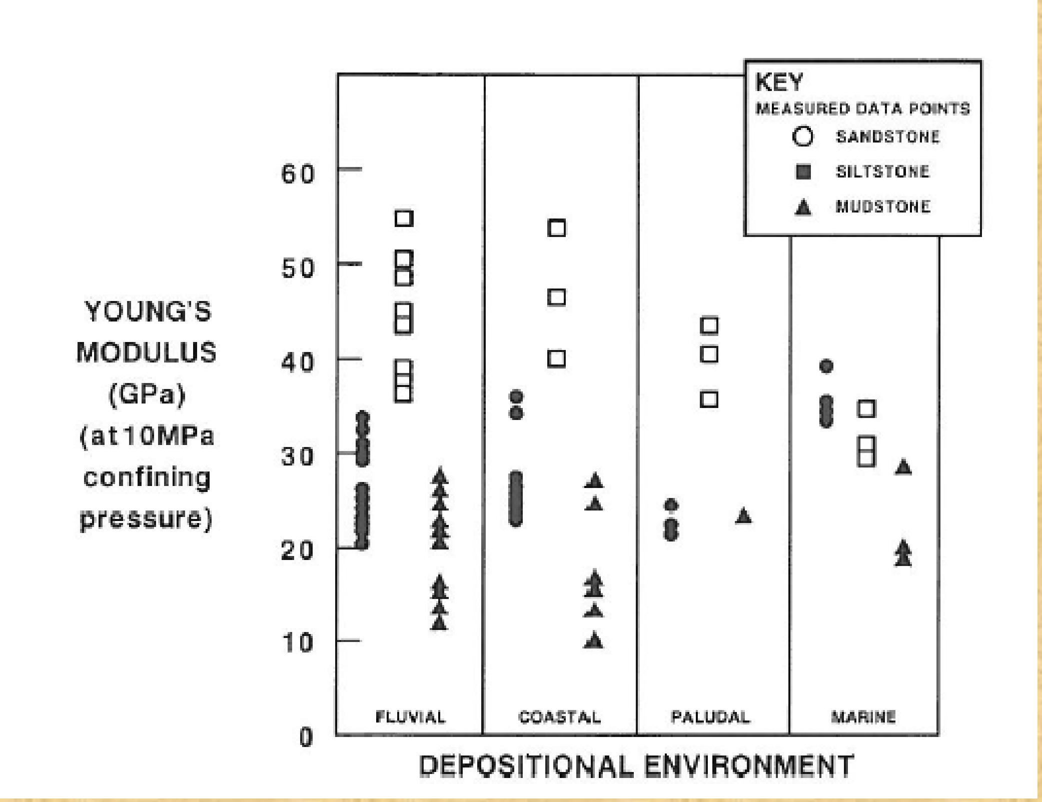



Fig. 2—Borehole geophone results.

Warpinski

# Data Base: Mechanical properties by lithology and by formation

- Poisson's ratio
- Strength
  - Compressive
  - Tensile
- Fracture toughness
- Cation exchange
- Petrology
- P&P




MWX final reports; Lorenz et al., 1989; Sattler et al., 1989

# Sedimentological studies of Mesaverde reservoir dimensions and trends

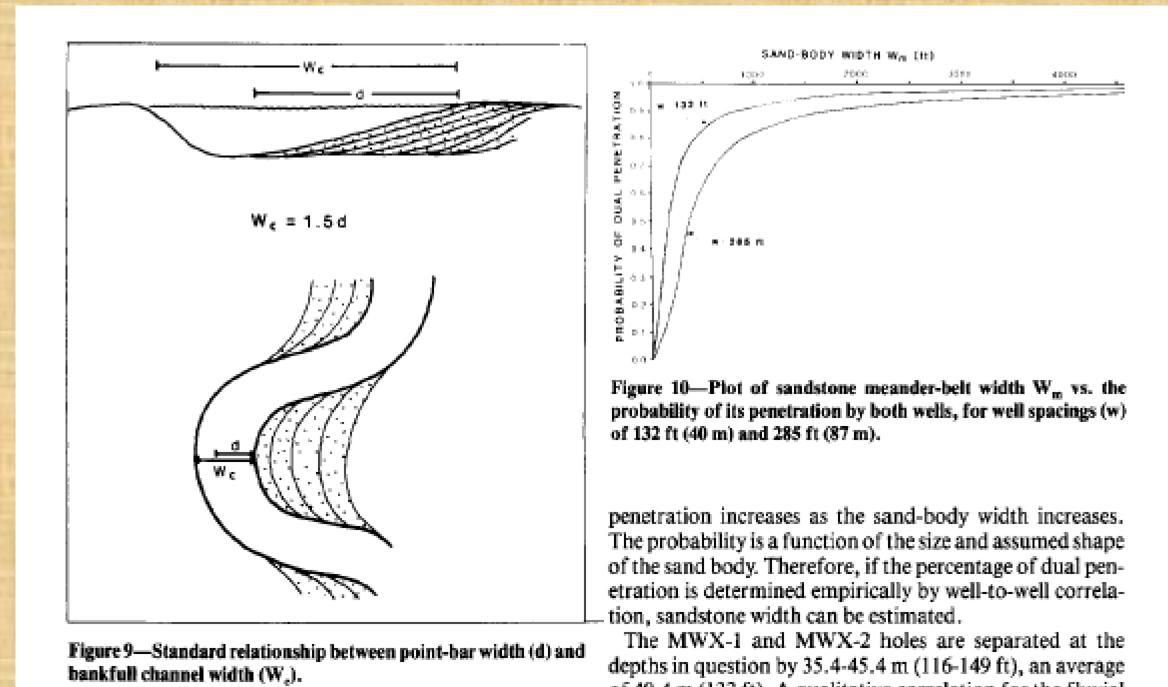



Figure 9—Standard relationship between point-bar width (d) and bankfull channel width ($W_c$).

Figure 10—Plot of sandstone meander-belt width $W_m$ vs. the probability of its penetration by both wells, for well spacings (w) of 132 ft (40 m) and 285 ft (87 m).

penetration increases as the sand-body width increases. The probability is a function of the size and assumed shape of the sand body. Therefore, if the percentage of dual penetration is determined empirically by well-to-well correlation, sandstone width can be estimated.

The MWX-1 and MWX-2 holes are separated at the depths in question by 35.4-45.4 m (116-149 ft), an average of 40.4 m (132 ft). A qualitative correlation for the fluvial

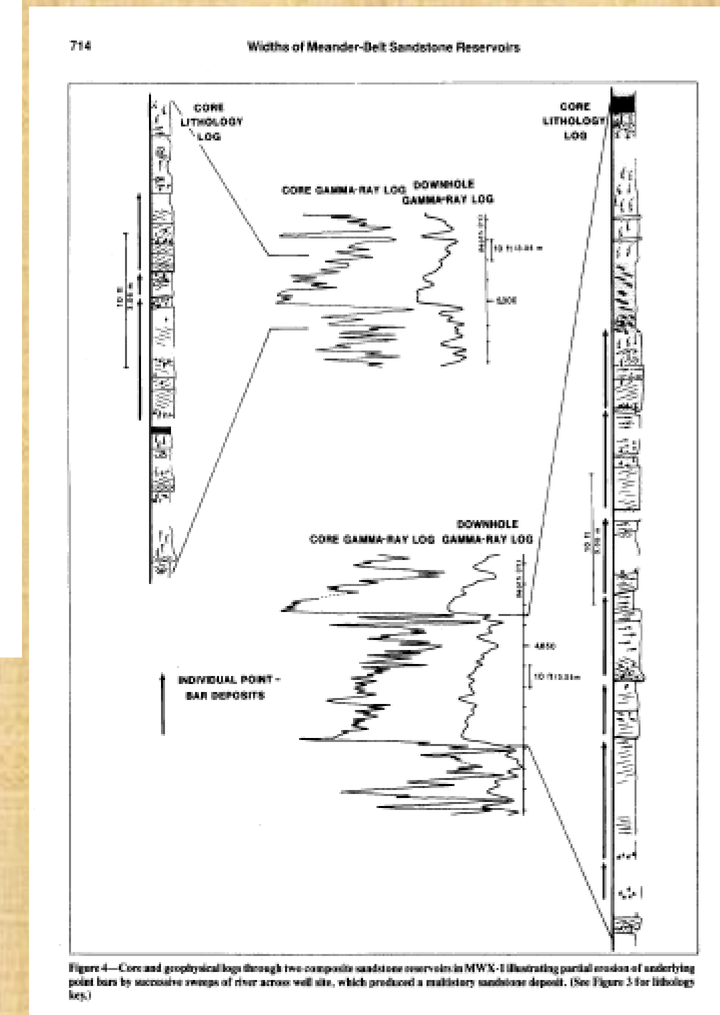



Figure 4—Core and geophysical logs through two composite sandstone reservoirs in MWX-1 illustrating partial erosion of underlying point bars by successive sweeps of river across well site, which produced a multistory sandstone deposit. (See Figure 3 for lithology key.)

Lorenz, 1983, 1989;Lorenz and Rutledge, 1987;

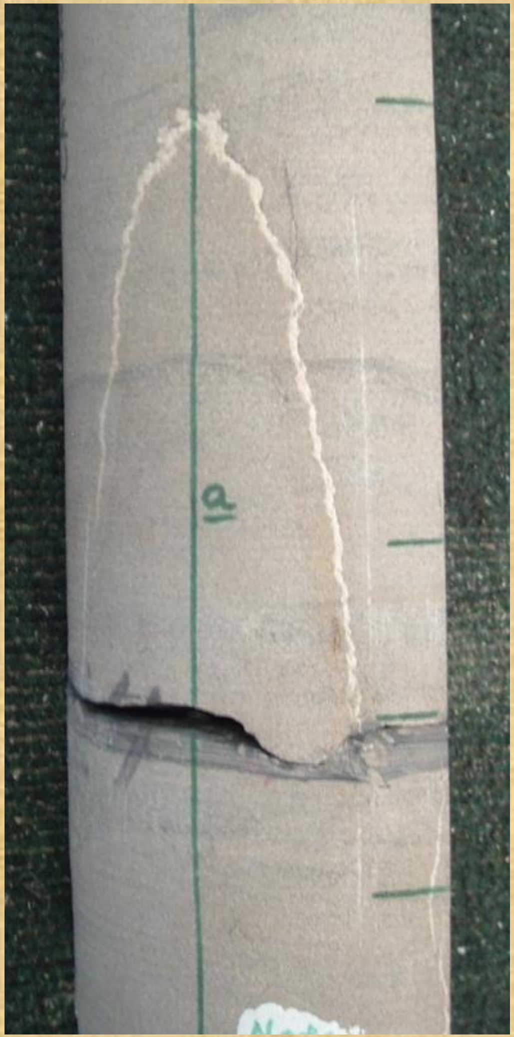
Lorenz et al., 1985, 1989, 1991c

# MWX contributions

- Geomechanical and petrographic data bases
- Stimulations
  - Multi-strand, strata-bound
  - Potentially damaging

# MWX contributions

- Natural fractures:
  - Abundant
  - ***The*** production mechanism
  - Susceptible to damage
  - Stress-sensitive
  - Distributions
    - Irregularly spaced
    - Log-normal populations



# MWX contributions

- Natural Fractures:
  - Not all equal
  - >10:1 drainage anisotropy
- Utility of induced fractures
- Origin of regional fractures
  - High pore pressure makes even shale brittle

# MWX contributions

- Investigators were encouraged to publish

- $40 million in taxpayer dollars

# References

pdf’s of many of these references, including the MWX final reports, are available at www.fracturestudies.com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