Permian Basin Seismicity: Looking Backwards, Moving Forwards*

Diane Doser[1] and Mark Baker[2]

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[1]Department of Geological Sciences, University of Texas at El Paso, El Paso, Texas (doser@utep.edu)
[2]Geomedia Research and Development, El Paso, Texas

Abstract

Seismicity in the Permian Basin represents a complex interplay between interaction of the Rio Grande rift with the Great Plains, fluid overpressuring, petroleum production, and enhanced recovery operations. The largest historic earthquake in Texas (magnitude~6.4) occurred < 50 km west of the edge of the Permian Basin and several faults < 50 km west of the Permian Basin have generated magnitude 7+ earthquakes in the Late Quaternary. Earthquake swarm sequences are also common throughout the region and their mechanism is poorly understood. Studies of Permian Basin seismicity conducted ~30 years ago highlight the need for a holistic approach to understanding the region's complex seismicity that integrates seismic reflection, potential fields, structure, stratigraphy, petrophysics, and geologic constraints. Important observations from this early work that need to be considered as we move forward include: 1) Velocity models for the location of earthquakes should a) account for anisotropy from macroscopic sedimentary layering of up to 20%, b) vary with stratigraphy/structure, and c) vary with amount of abnormal fluid pressuring. Improvements in the ability to correlate seismicity and rupture characteristics with known geology occur when velocity models used for event location are averaged to the wavelengths of the seismic recordings. 2) The geologic asymmetry of fault zones does not only control oil migration and traps. Permeability, velocity, mechanical stiffness, and porosity vary rapidly in fault zones with their possible controls on fluid pressures being greater than those due to stratigraphic layering. 3) In one fortuitous example with well-located earthquakes in the War-Wink Field, earthquakes ended with production-induced pressure drops. Reservoir pressure, constrained laterally by faulting and core analysis, showed late carbonate diagenetic sealing with vertical fractures consistent with the observed self-fracture pressure gradient.

Permian Basin Seismicity: Looking Backwards, Moving Forwards

Diane Doser, University of Texas at El Paso, Mark Baker, Geomedia R&D

Permian Basin Seismicity represents a complex interplay between:

- Tectonics (Rio Grande Rift-Great Plains boundary)
- Overpressuring
- Petroleum extraction
- Enhanced recovery

Earthquakes mislocated unless velocity models account for:

- Velocity anisotropy of up to 20% due to macroscopic sedimentary layering
- 3-D structure and stratigraphy
- Abnormal fluid pressuring
- Velocity model at scale of earthquake wavelengths

This does not look like a planar symmetric fault in a uniform stress state

Influence of Fault Zones:

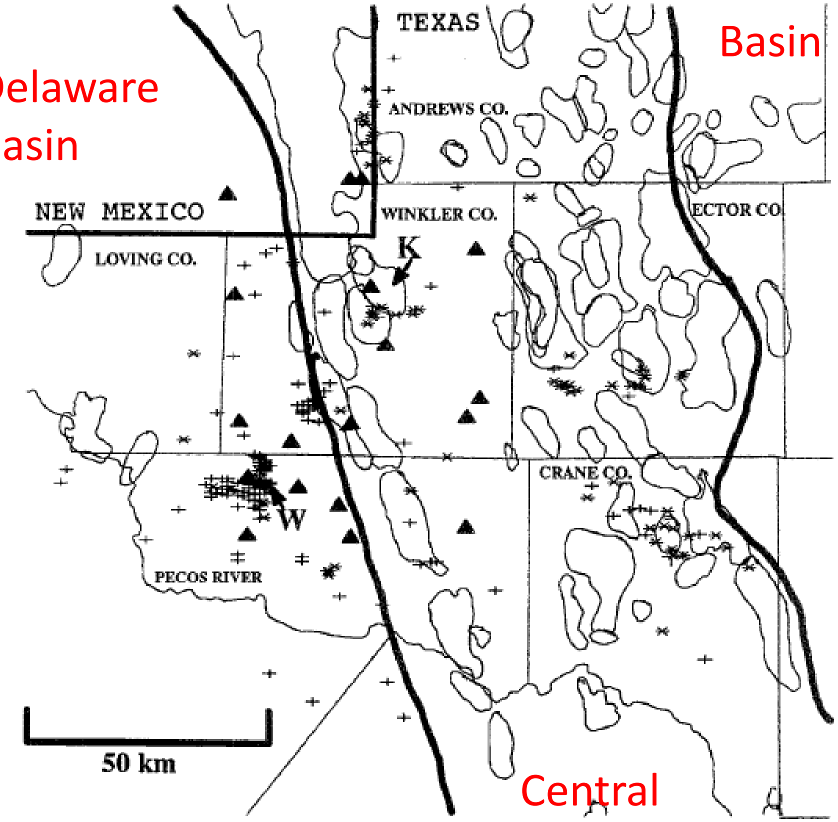
- Control oil migration and traps
- Permeability, velocity, mechanical stiffness, and porosity vary rapidly in fault zones and their possible controls on fluid pressures may be greater than those due to stratigraphic layering
- Simple-uniform models (permeability and geometry) are far from realistic

Permian Basin Seismicity

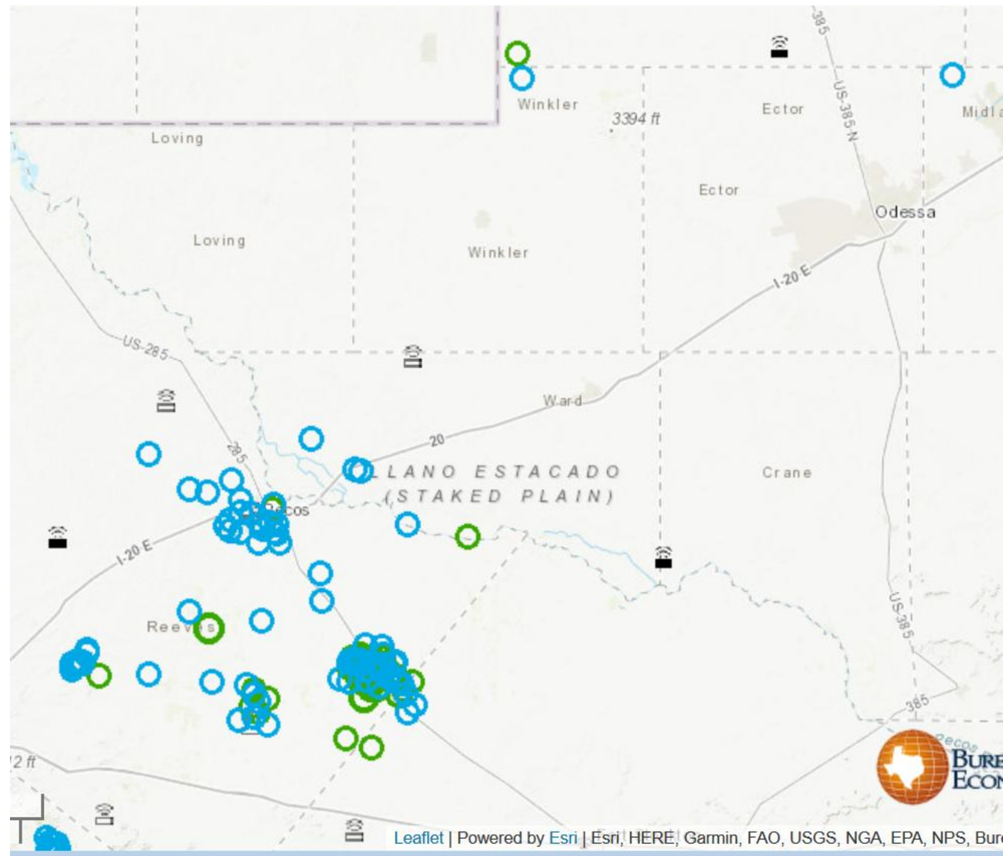
THEN (1976-1979) **NOW (1/2017-3/2018)**

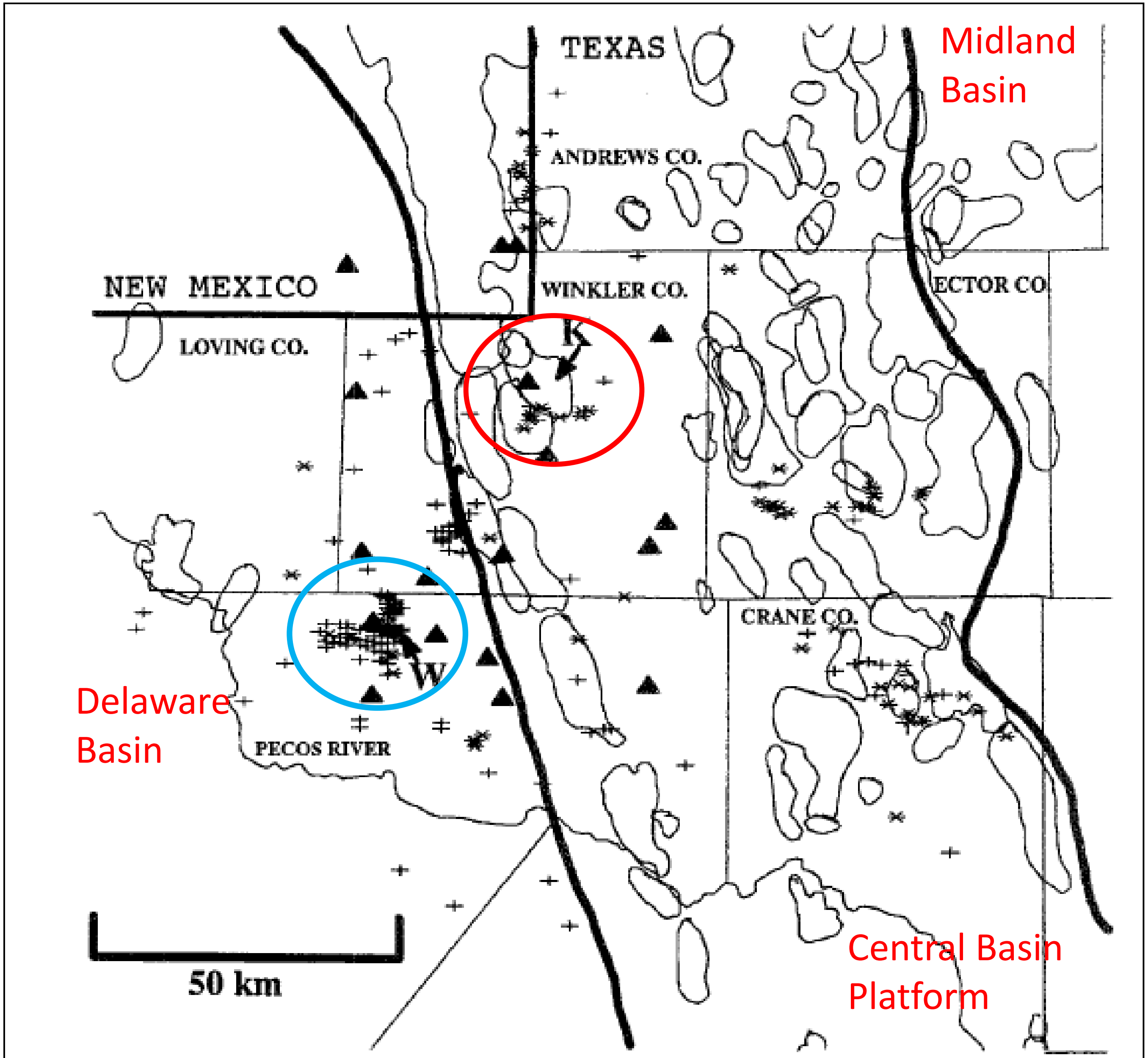
Midland Basin

Delaware Basin



Central Basin Platform

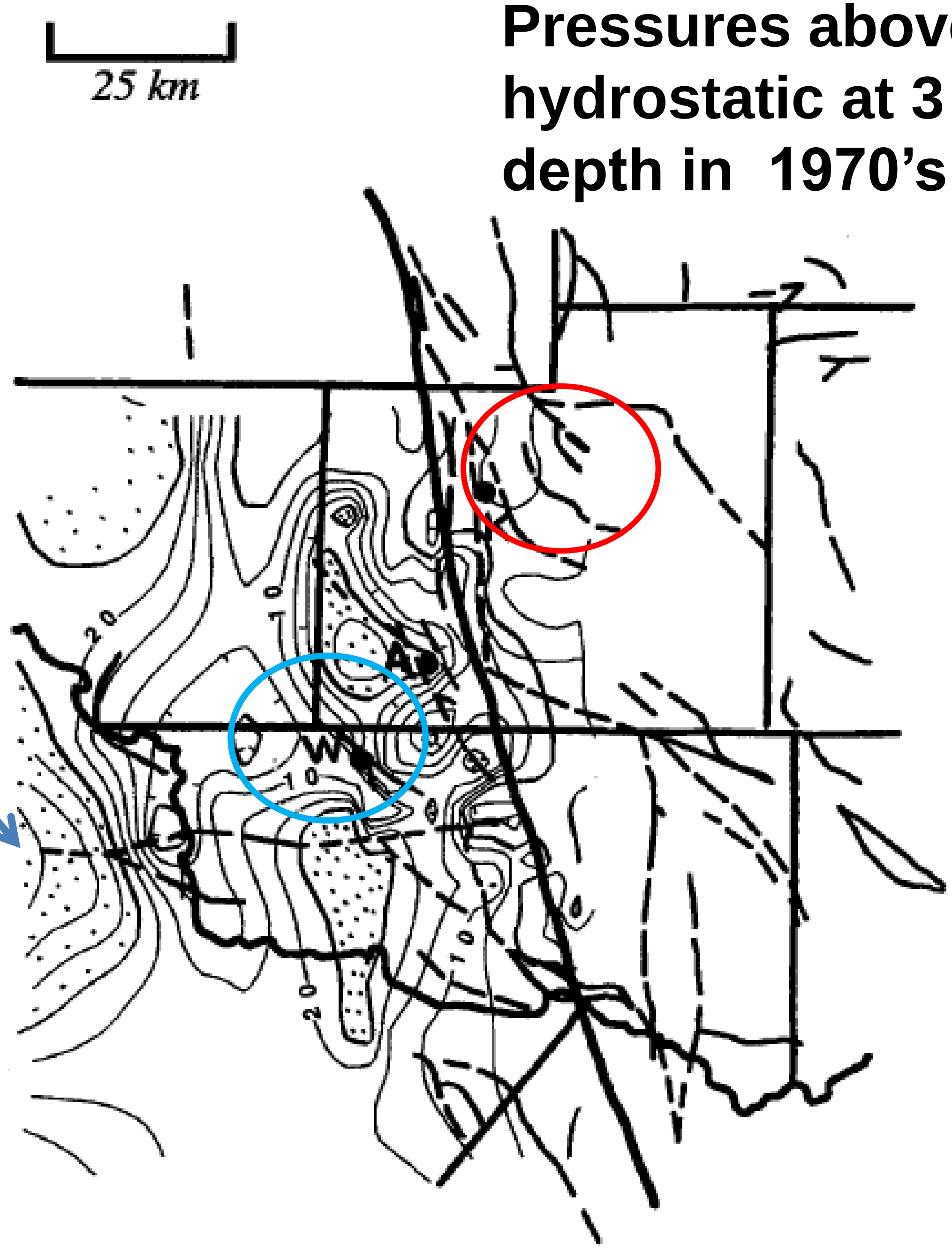




TEXAS
Midland
Basin
ANDREWS CO.
NEW MEXICO
WINKLER CO.
ECTOR CO
LOVING CO.
K
CRANE CO.
W
Delaware
Basin
PECOS RIVER
50 km
Central Basin
Platform

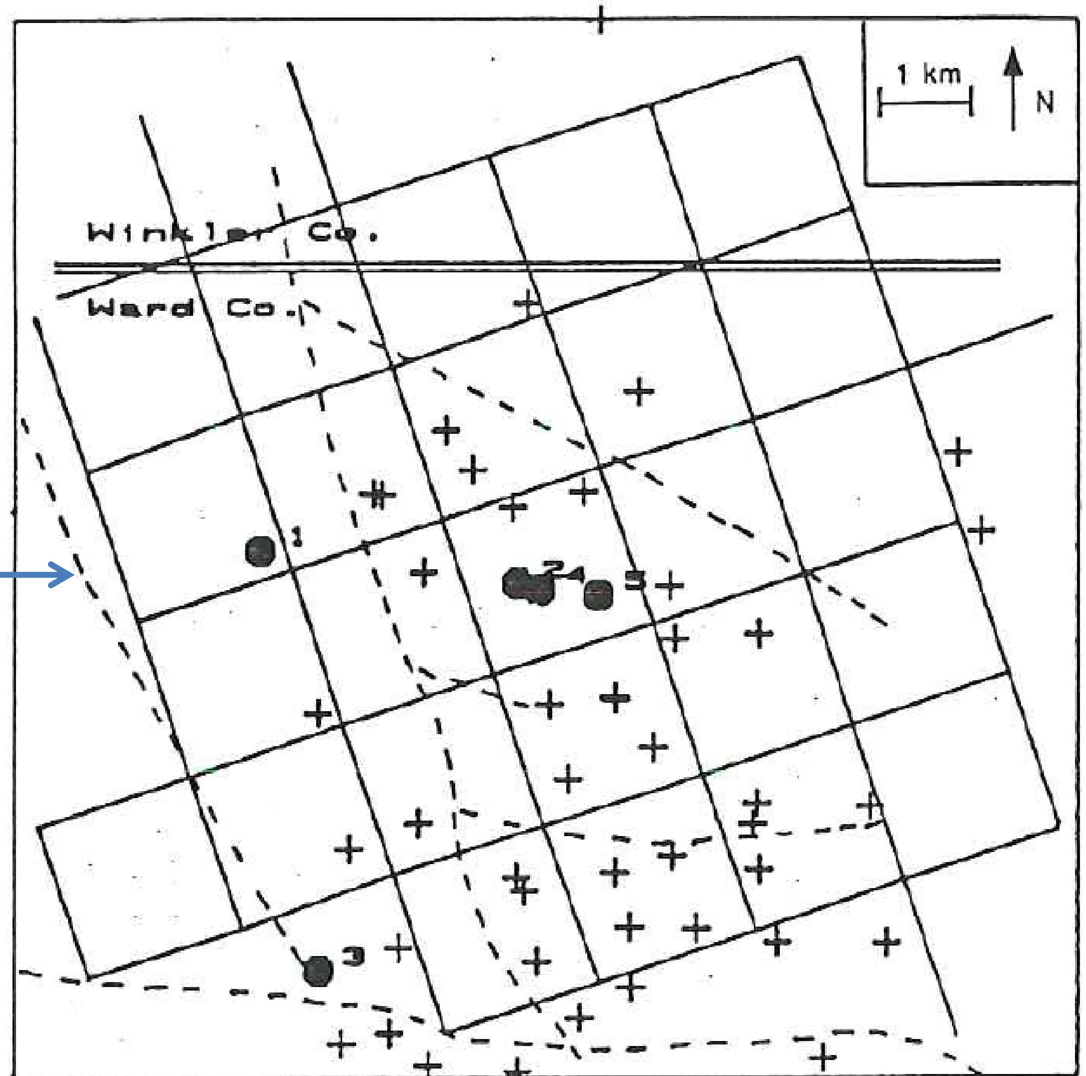
Pressures above hydrostatic at 3 - 4.3 km depth in 1970's

Highs > 25 MPa



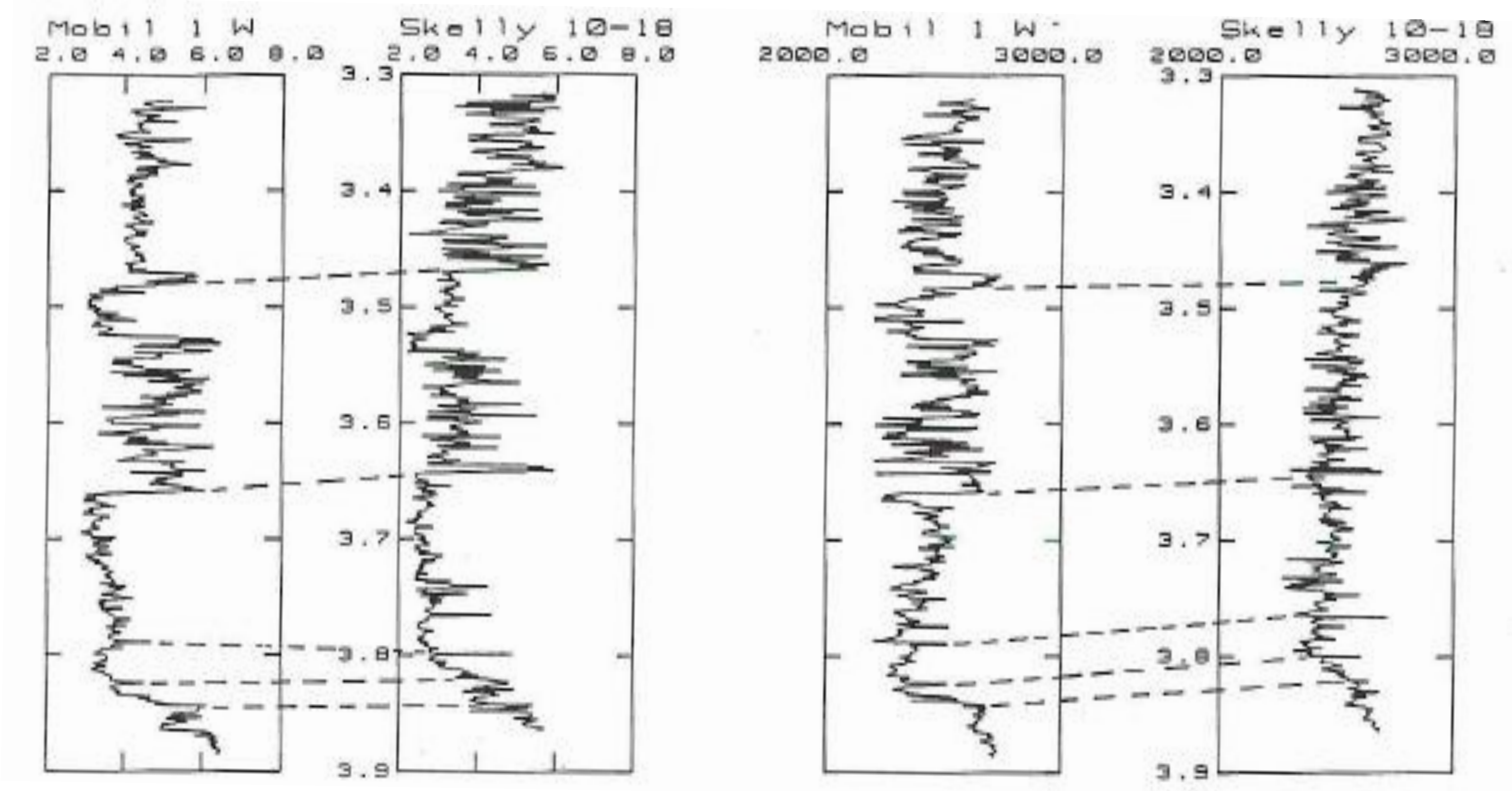
Well log control

Faults in Ellenburger



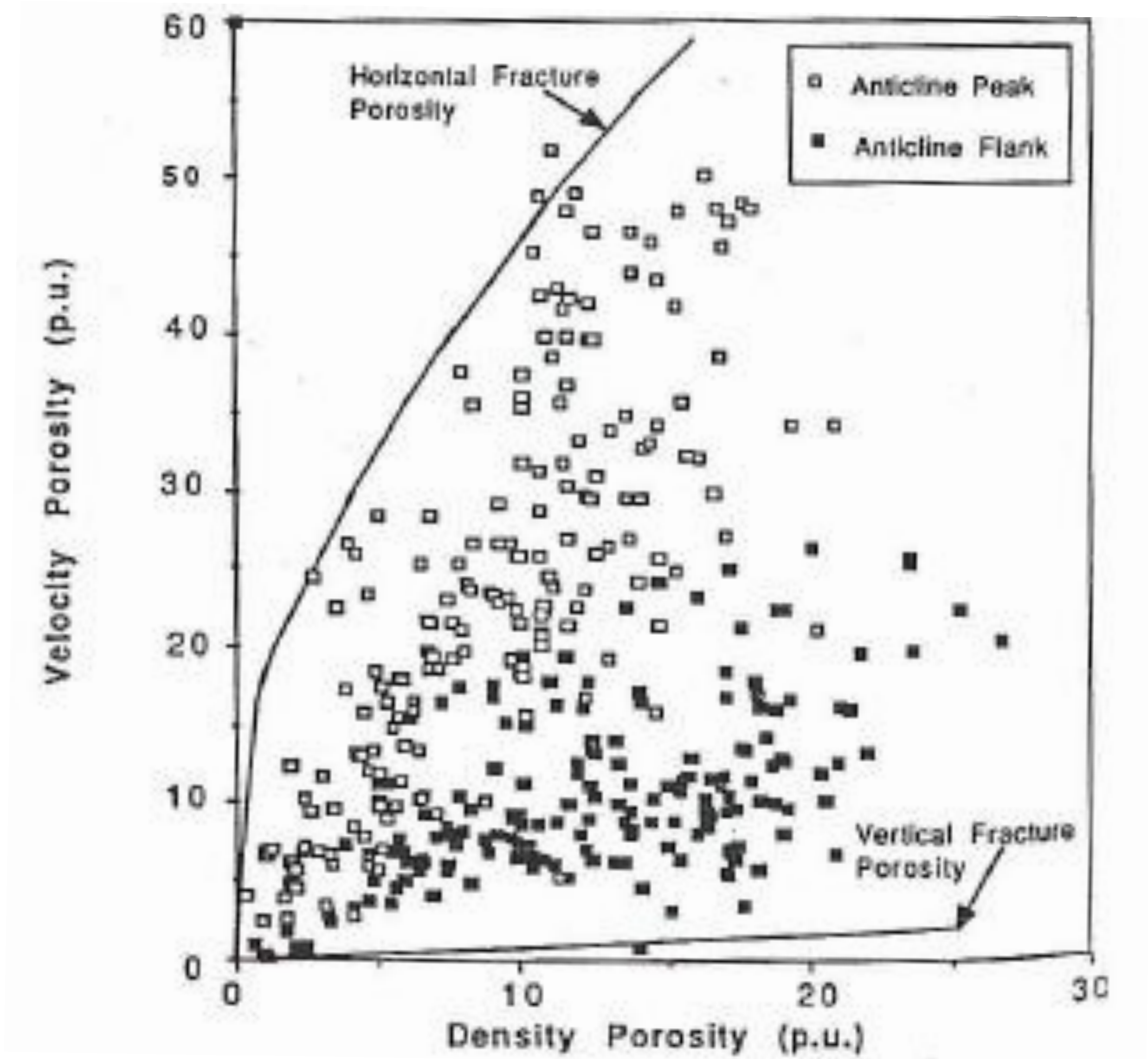
Velocity from Transit Time | **Density**

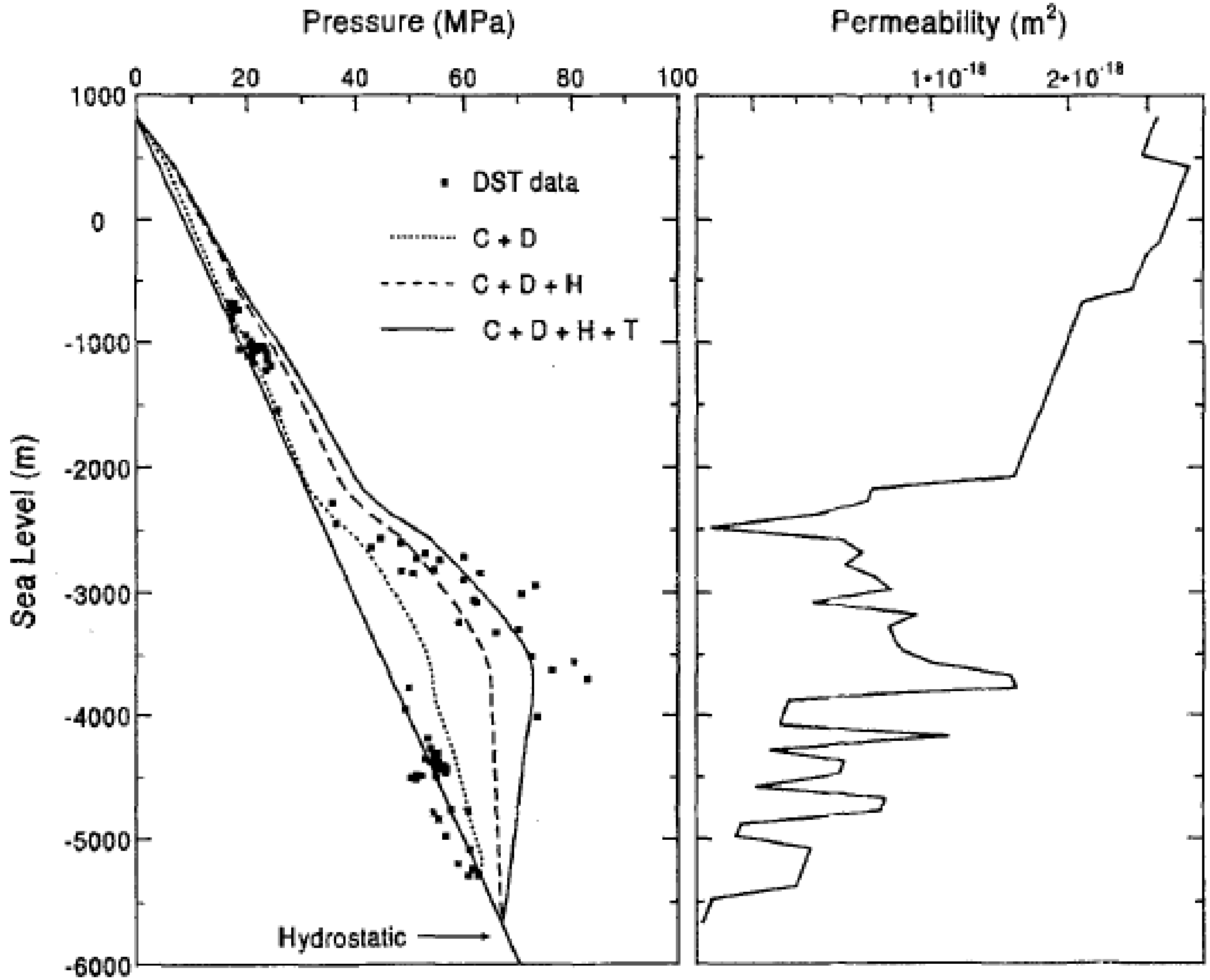
Anticline flank | Anticline crest | Anticline flank | Anticline crest



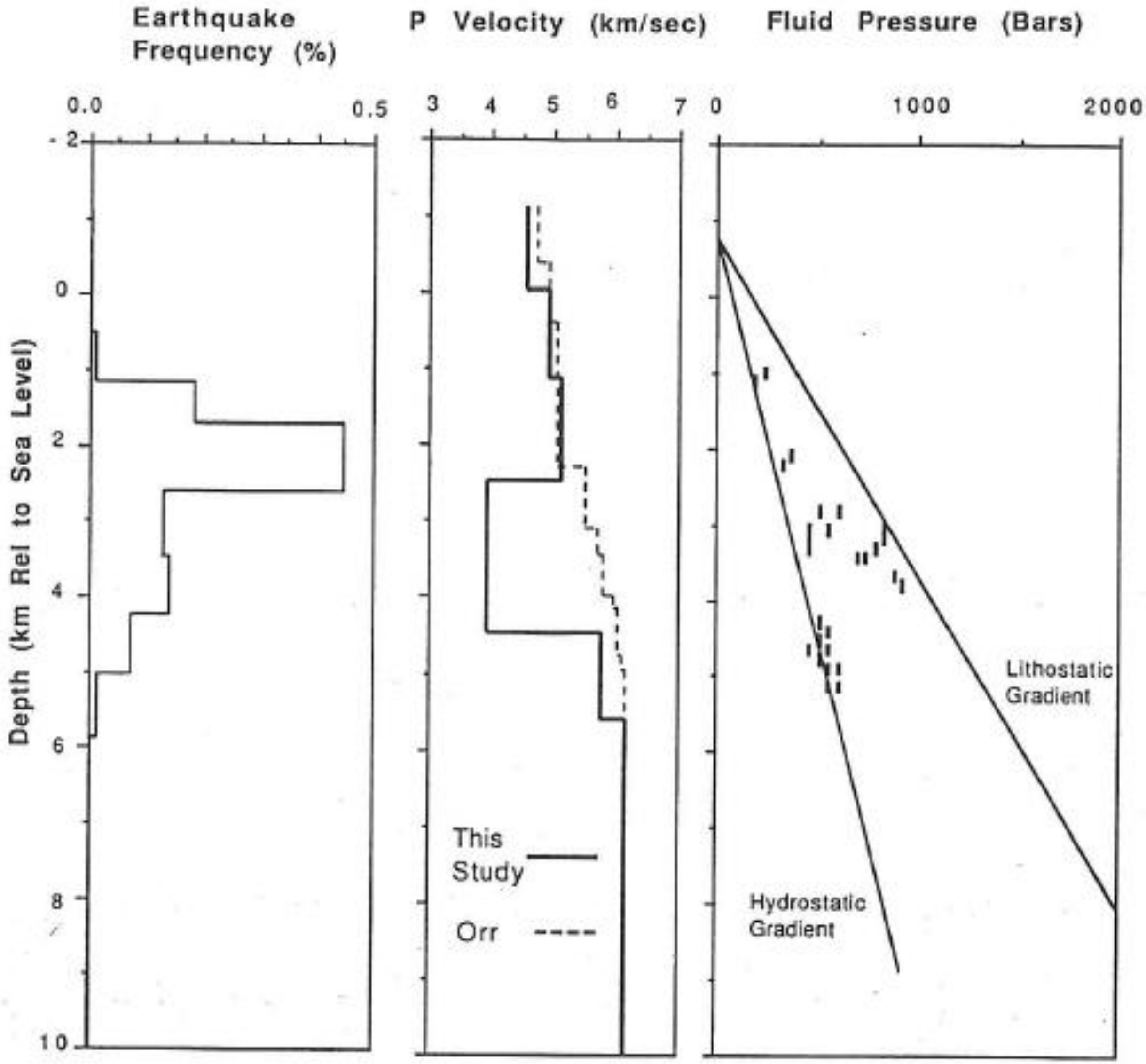
Lithology thins over anticline, the increase in density and decrease in velocity indicate compaction followed by overpressuring.

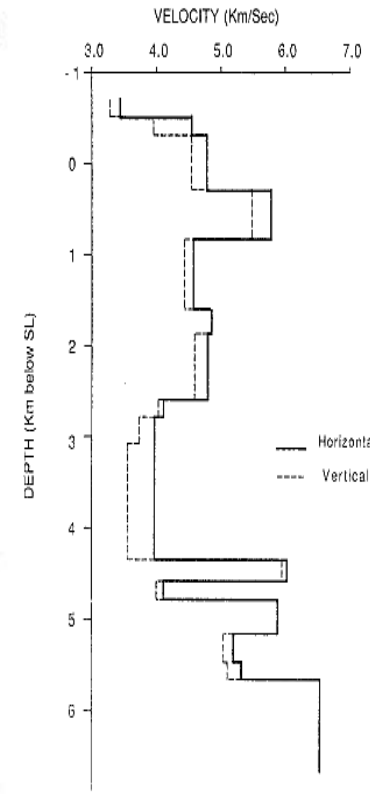
Sonic-density cross plot. Open squares at anticline peak fall near theoretical bound for full fluid support in horizontal fractures





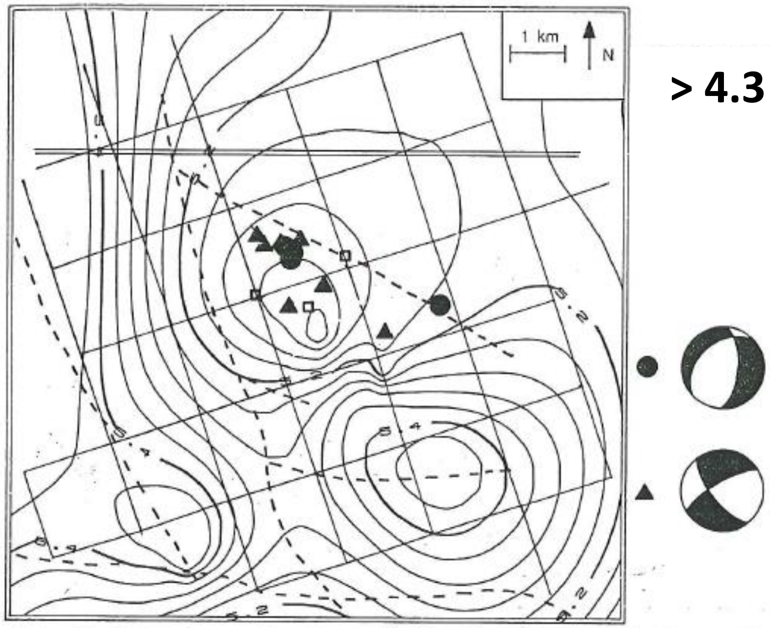
Overpressuring is a combination of compaction, clay dewatering, hydrocarbon generation and aquathermal effects.



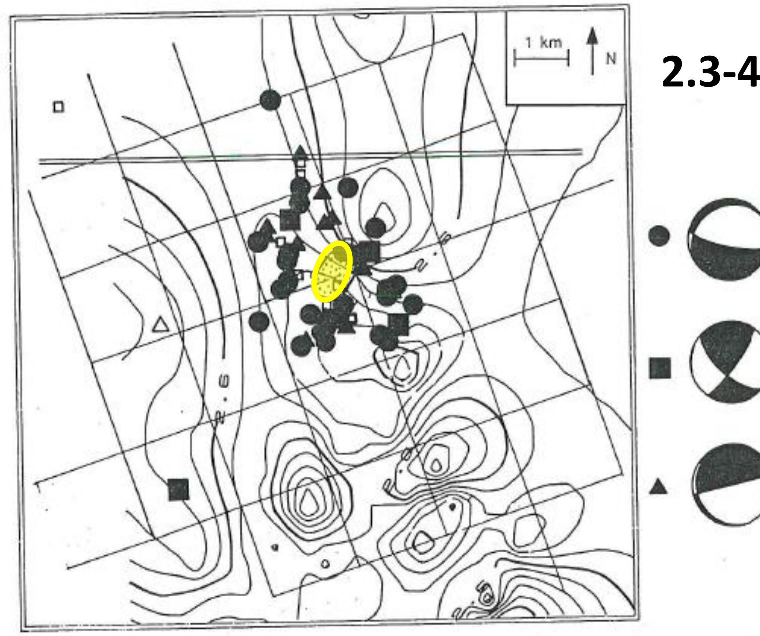


Sedimentary layering effects on velocity

Overpressuring and velocity

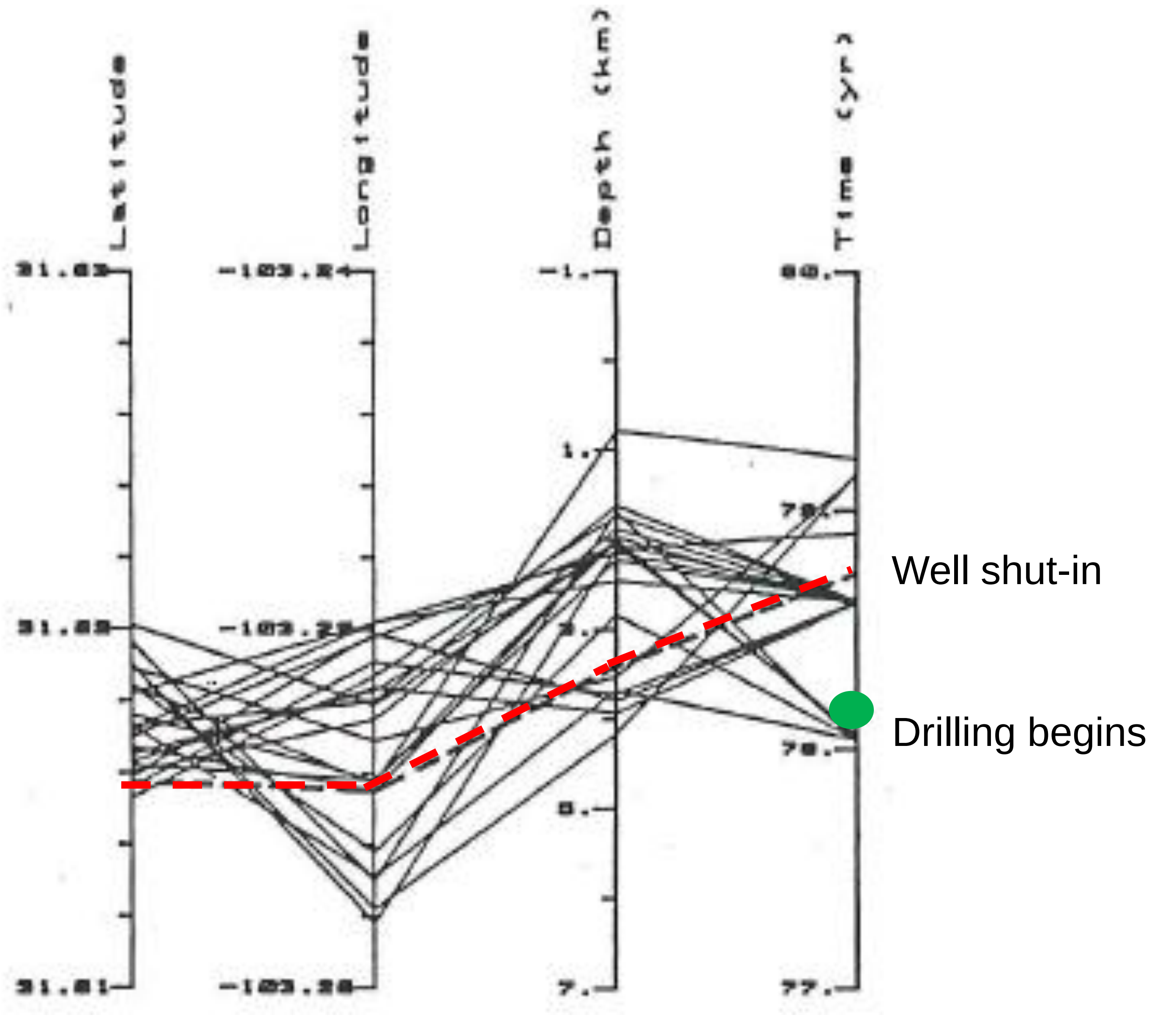


> 4.3 km

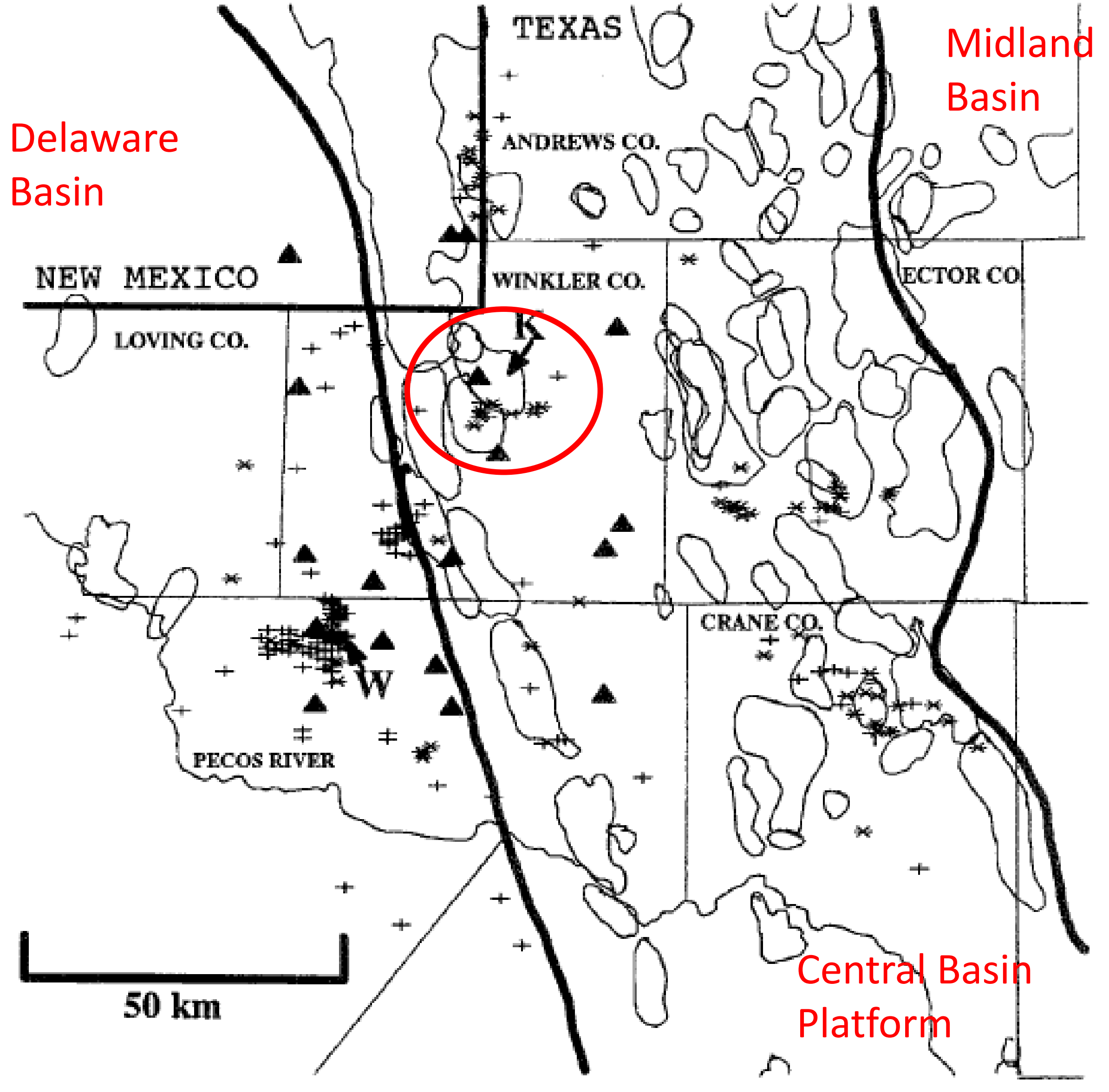


2.3-4.3 km

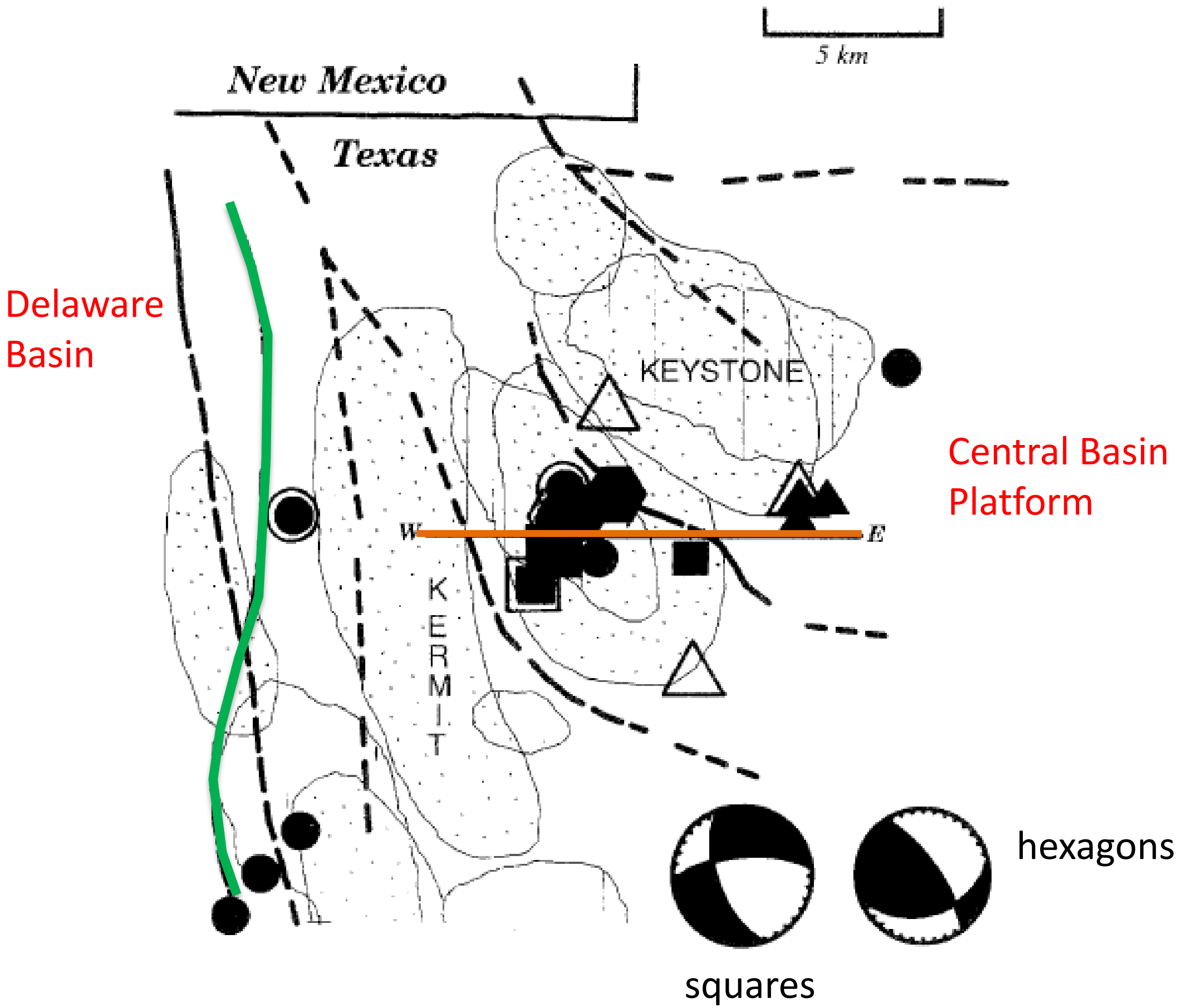
<2.3 km


Latitude
Longitude
Depth (km)
Time (yr)
Well shut-in
Drilling begins
-1.
1.
7.
77.

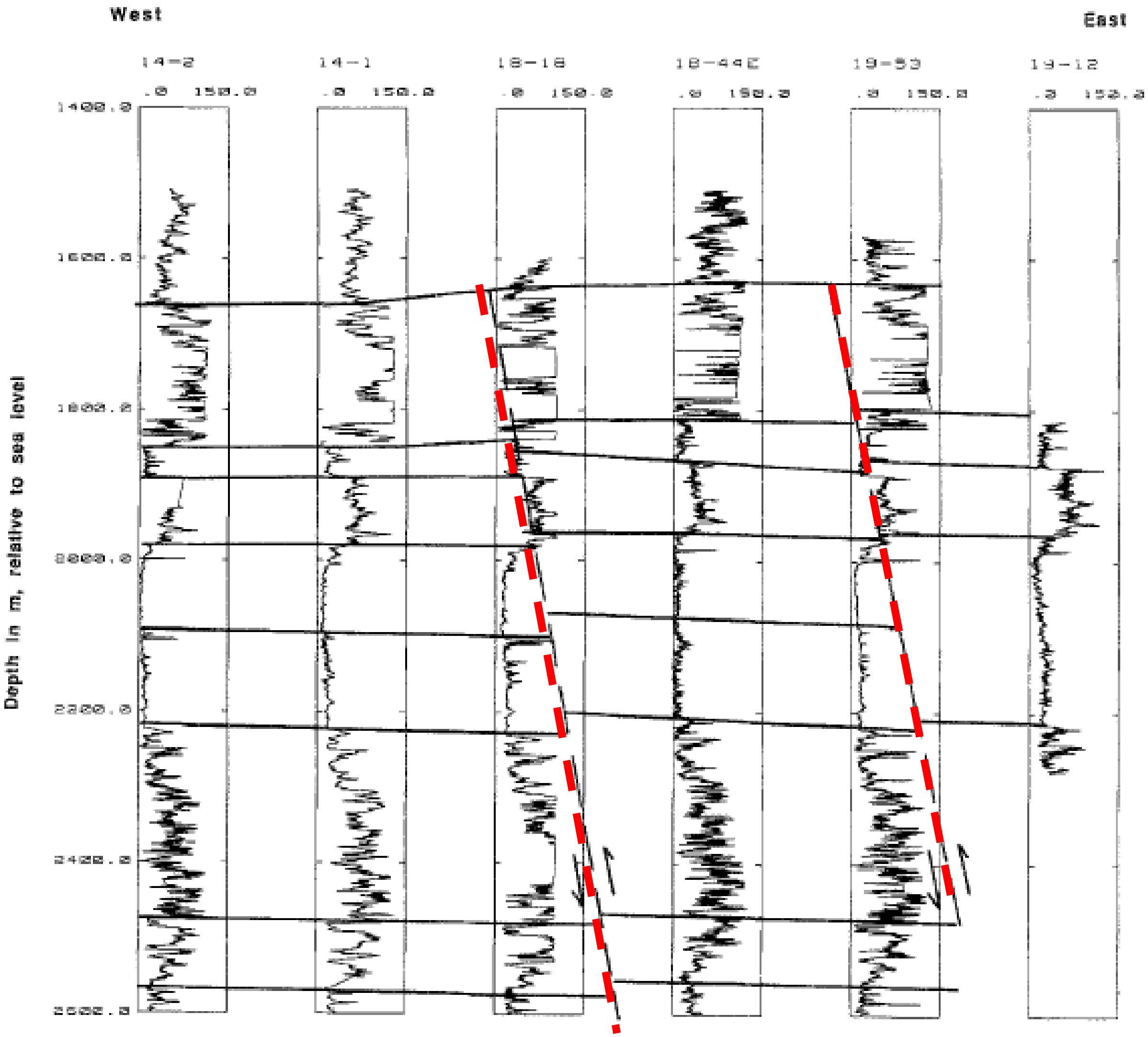
Keystone Field



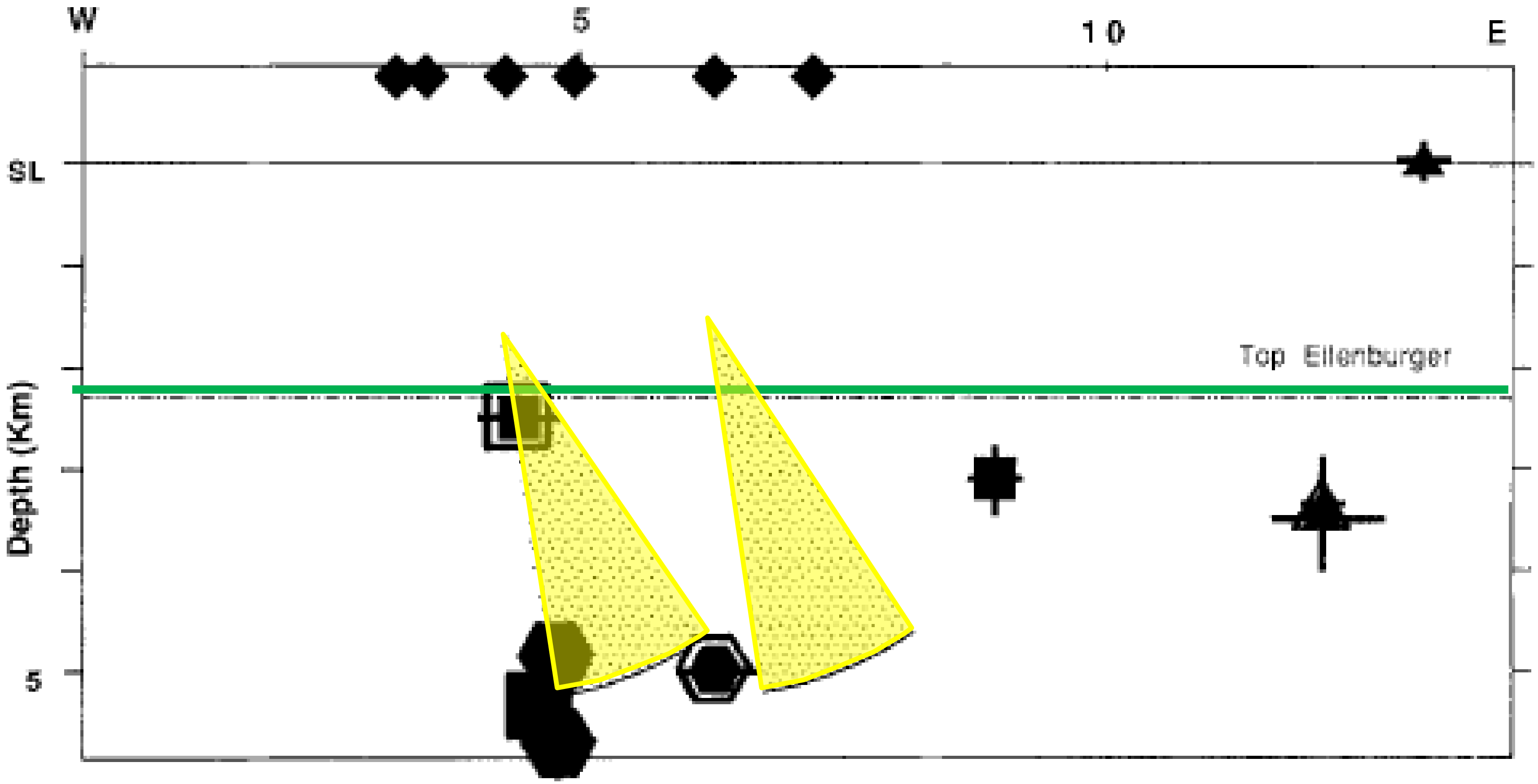
Keystone Field



Keystone Field Well Logs



Keystone Field



Conclusions

Velocity models:

-**Build 3D structure with anisotropy averaged at seismic wavelengths from well log data**

-Velocity inversions from surface data face problems since only estimating horizontal velocities, not vertical ones

-Velocity anisotropy varies laterally – both slow and fast velocities (i.e. Gröningen study has velocity problems with thin/fast evaporites that our locations handled at seismic wavelengths)

-Once the earthquake has occurred, the velocity model has changed

Conclusions (continued)

Fault models:

-Hanging wall usually fractured/permeable/low velocity

-Footwall gouge and cataclastic metamorphism lead to impermeability

- Pressure differences of 2000 psi in DSTs observed at same elevation across one fault in wells <500 m apart

Conclusions (continued)

Geologic Integration:

-**Warwink Field seismicity only made sense after Chevron gave us access to core**

- Conclusions without petrophysics and diagenetic input are suspect