Fault/Fracture Permeability Estimated from Response of a Natural Marine Methane Seep to Underlying Hydrocarbon Production*

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Abstract

Natural methane seeps overly hydrocarbon reservoirs in the Santa Barbara channel of southern California. At one locality near Platform Holly, where seepage is monitored from two steel tents on the seabed, seepage rate can be related to wells producing 1 km beneath the tents. The seepage emanates from a fault and fractures in the underlying siliceous shales of the Monterey Formation. There has been an overall drop in production rate of gas from the platform by a factor of two over the past 20 years, whereas the seep tent has correspondingly dropped seepage rates by a factor of eight. The tent seepage follows the platform production drop by about a year. We have used changes in seep rate to quantify the permeability of the flow path from the reservoir to the 1860 m^2 tent area on the seabed.

A recently completed well, perforated at 914 m (3000 ft) beneath the collection tents, directly affects the seepage into the tents. When the well is shut down, seepage production rates increase at a constant rate of 45.3 m^3 day/day (1.6 MCF/day/day) to 31.2 m^3 day/day (1.1 MCF/day/day) over shutdown periods ranging from 21 days in 2003 to 45 days in 2005, respectively. Using these changes in flow rate, the known pressure differences between the seep tent and the perforation intervals in the well, we have calculated the permeability with respect to gas for the 914 m (3000 ft) fracture/fault flow path with an average cross section of 1860 m^2 from the Darcy equation. We compare this estimate to our earlier estimate of 19 md permeability with respect to water along on a bounding fault to the reservoir (Boles and Horner, 2003).

Reference

Boles, James R., and Steve Horner, 2003, Natural oil seepage at Coal Oil Point, Santa Barbara, California: Science, v. 170, p. 974–977.

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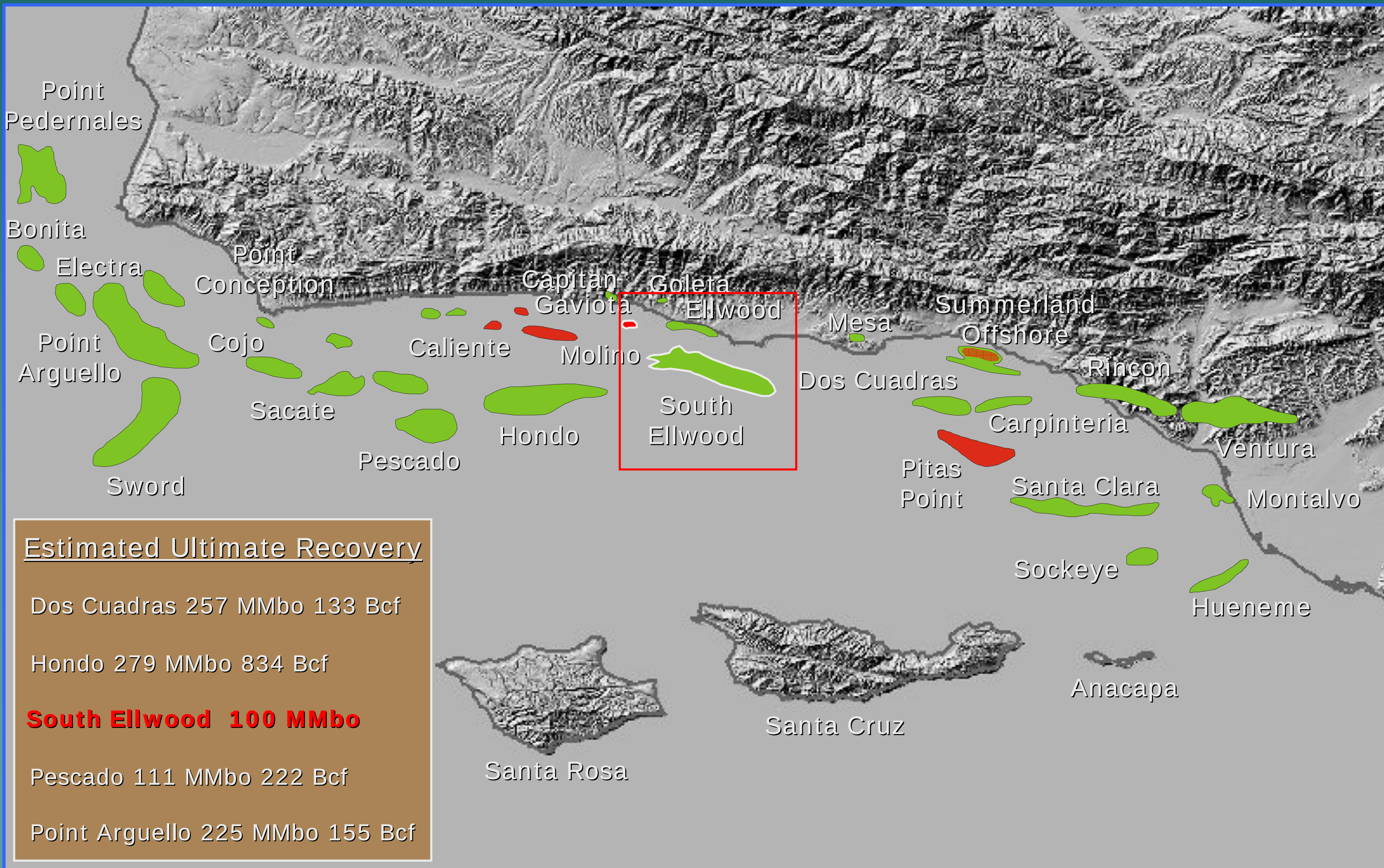
Major Oil and Gas Fields Of The Santa Barbara Channel



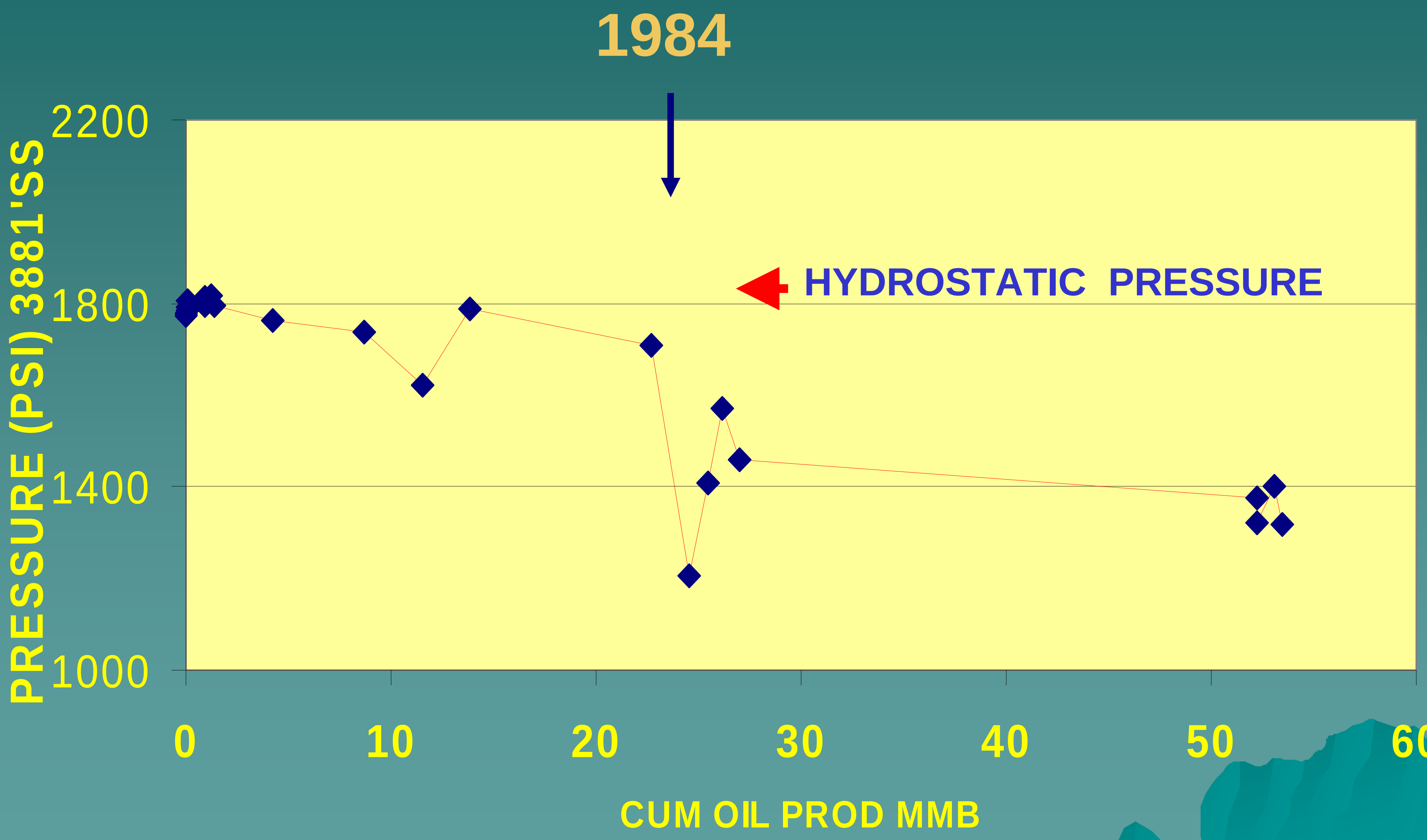
PLATFORM HOLLY
at South Ellwood Field

PLATFORM HOLLY FACTS

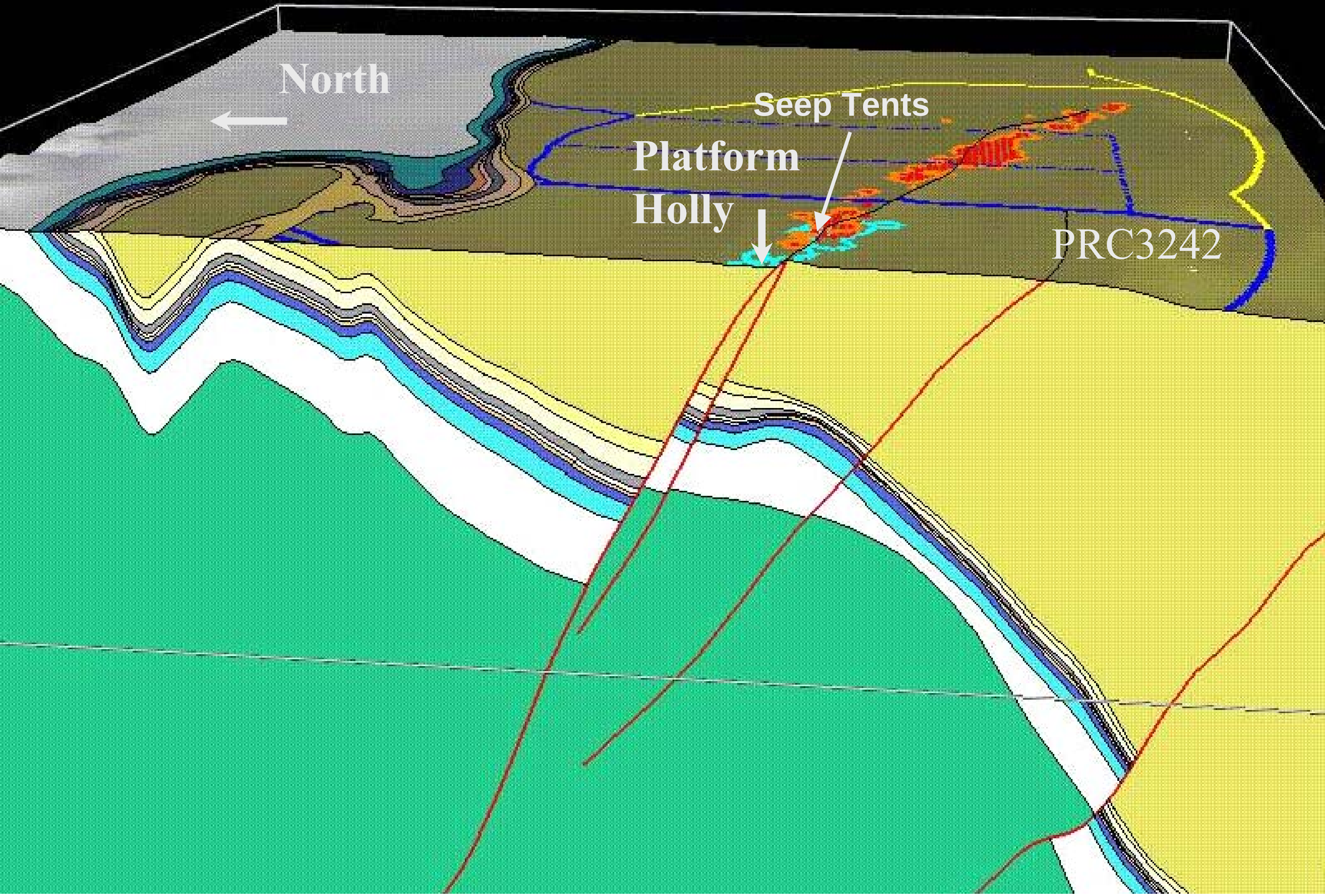
- PRODUCTION DEPTH 3600' SS
- FRACTURED MONTEREY FM (siliceous shale and carbonate)
- IN SITU PERMEABILITY 10mD
- PRODUCTION (1969-2008)

  OIL 60MMB GAS 52BCF

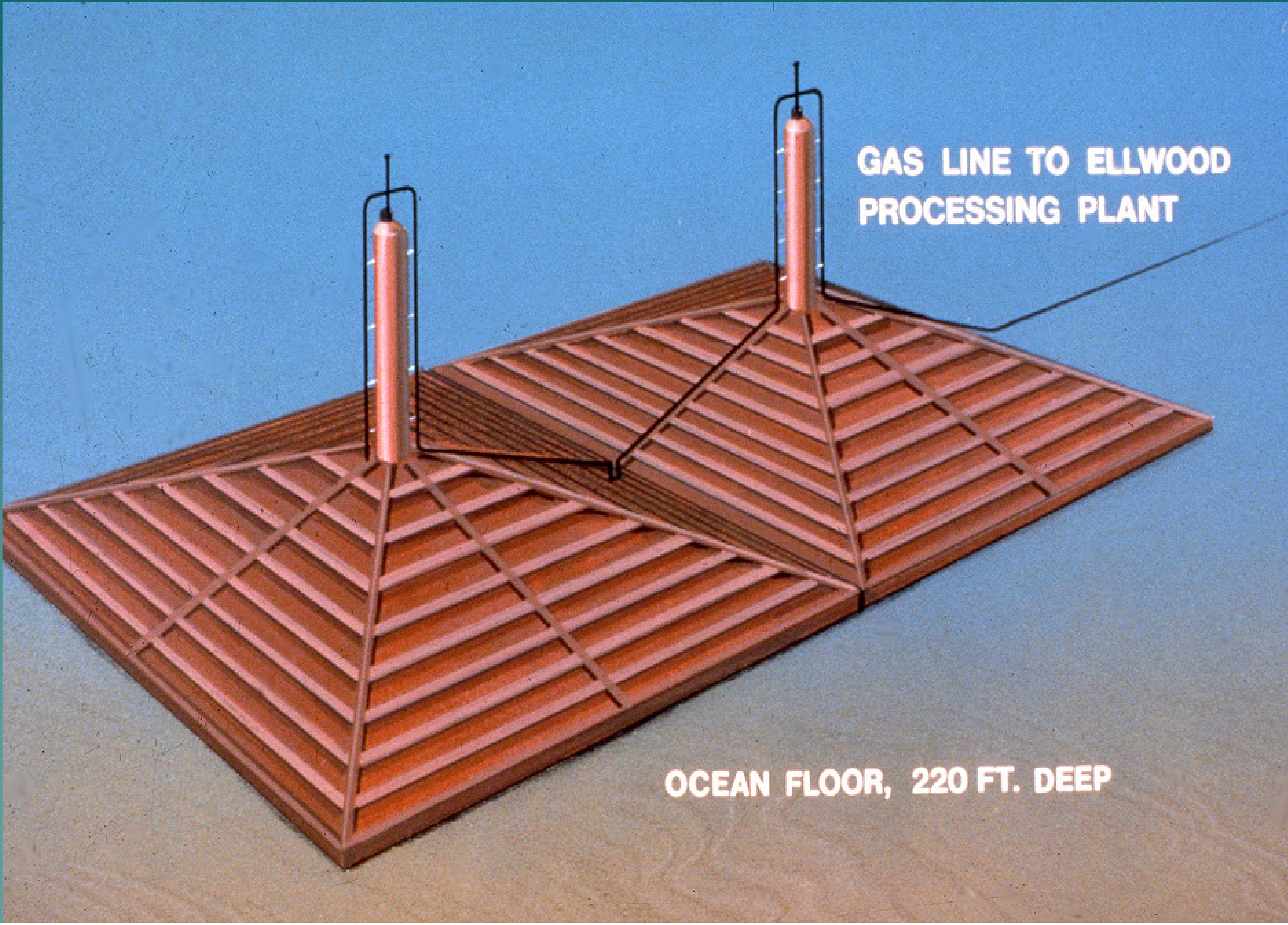
Monterey Reservoir Pressure is sub-hydrostatic



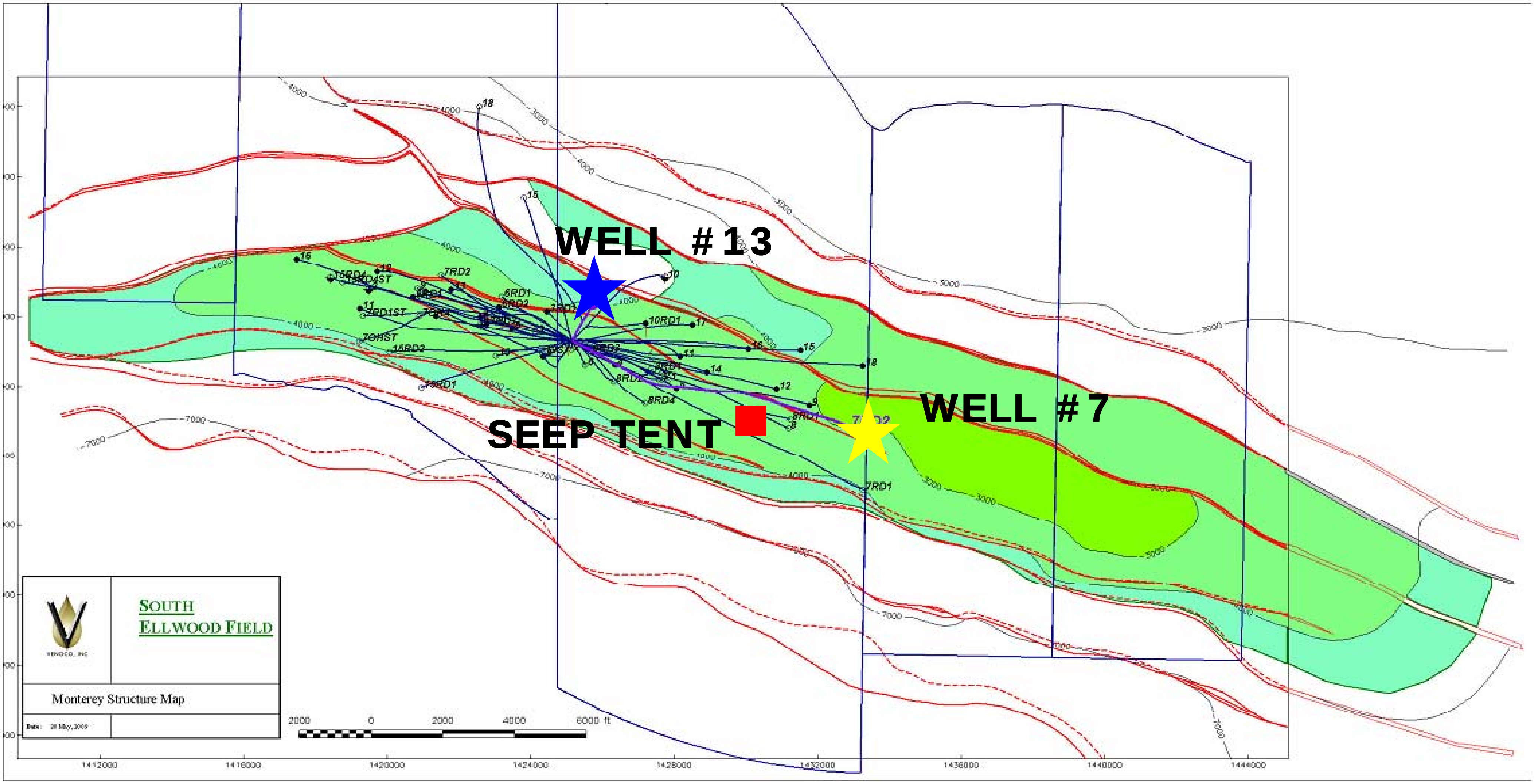
METHANE SEEPS FROM THE FAULT



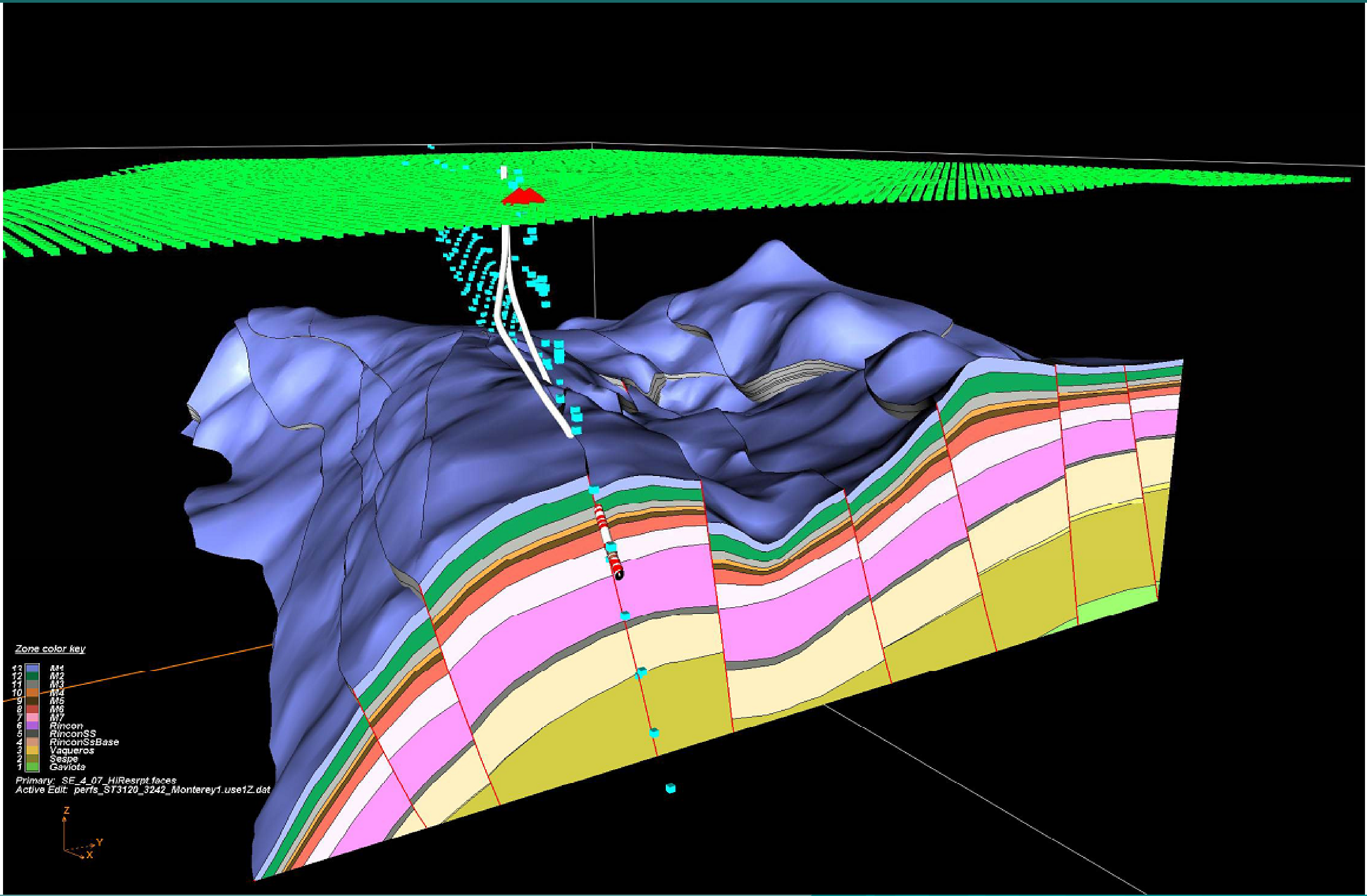
ARCO SEEP TENTS-1982

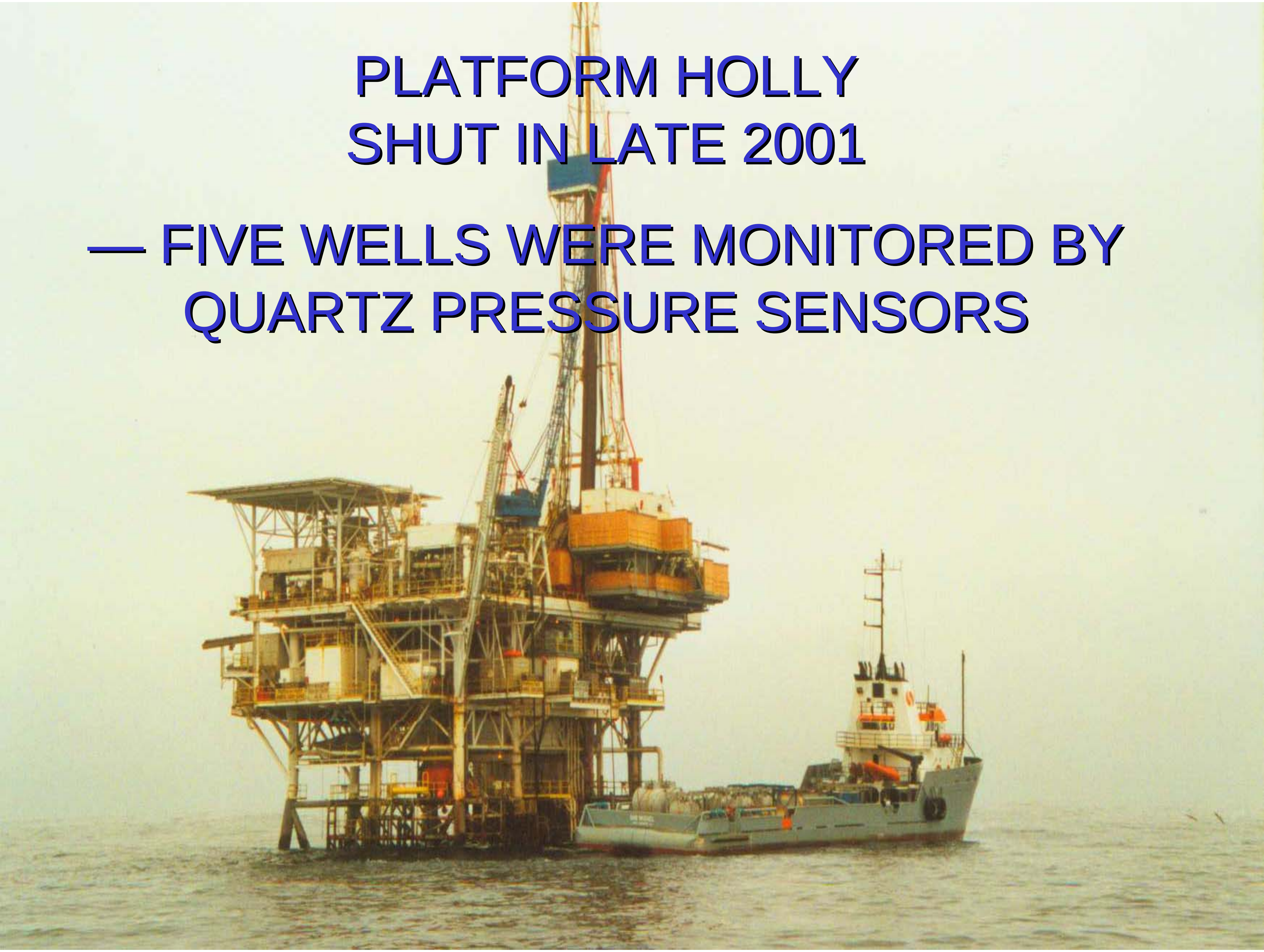


South Ellwood Field

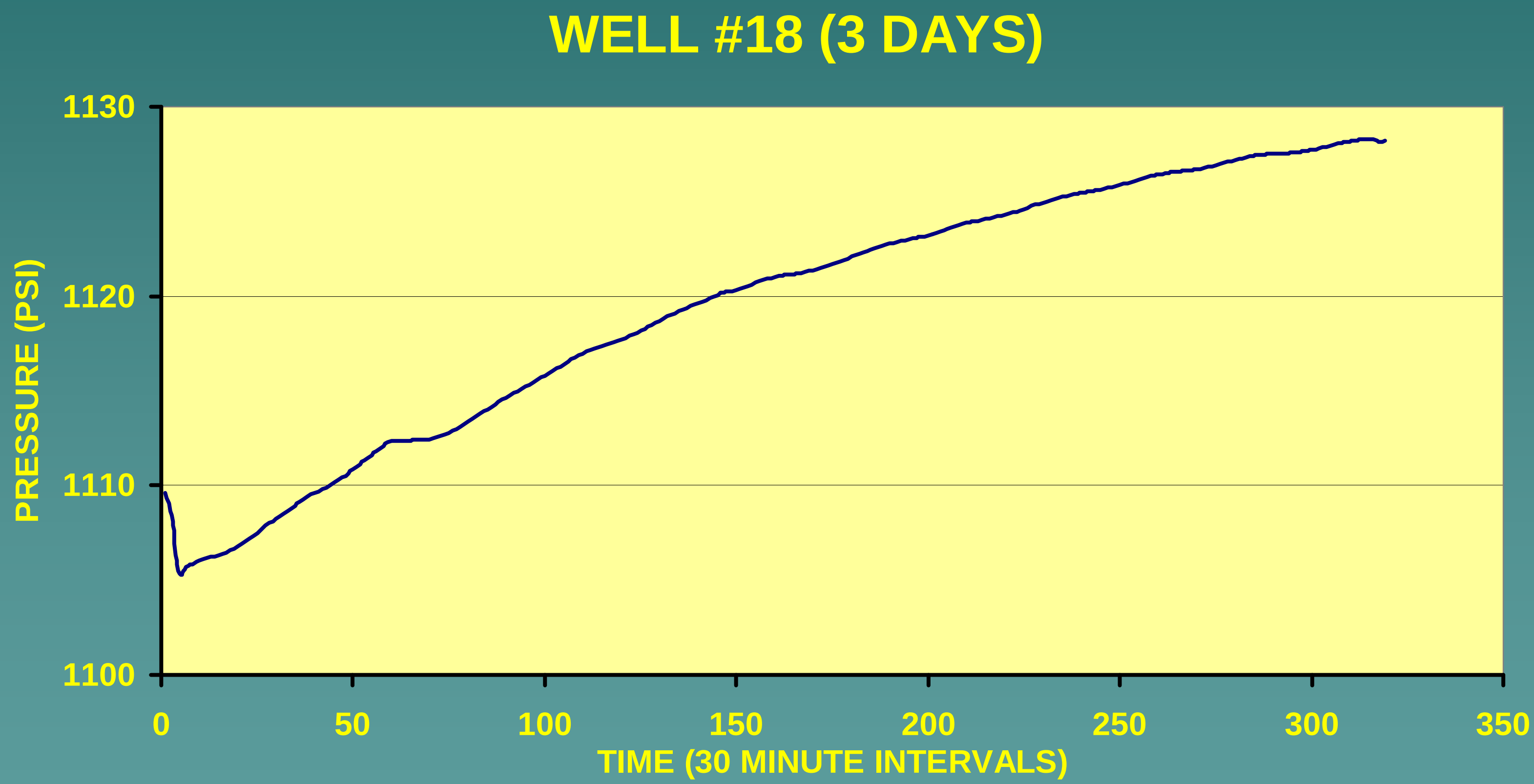


Location of Well #13 and #7

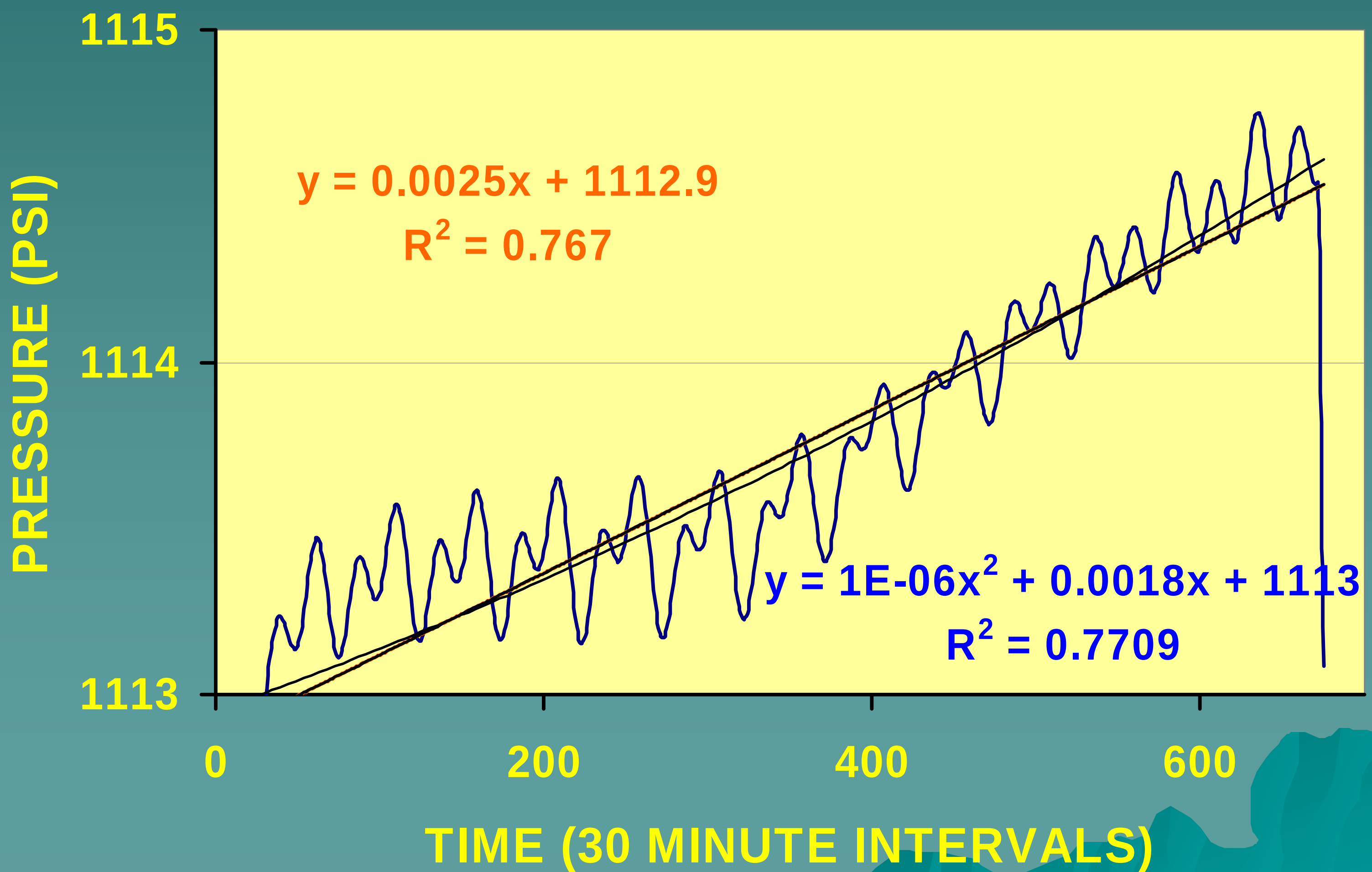



PLATFORM HOLLY
SHUT IN LATE 2001
— FIVE WELLS WERE MONITORED BY QUARTZ PRESSURE SENSORS

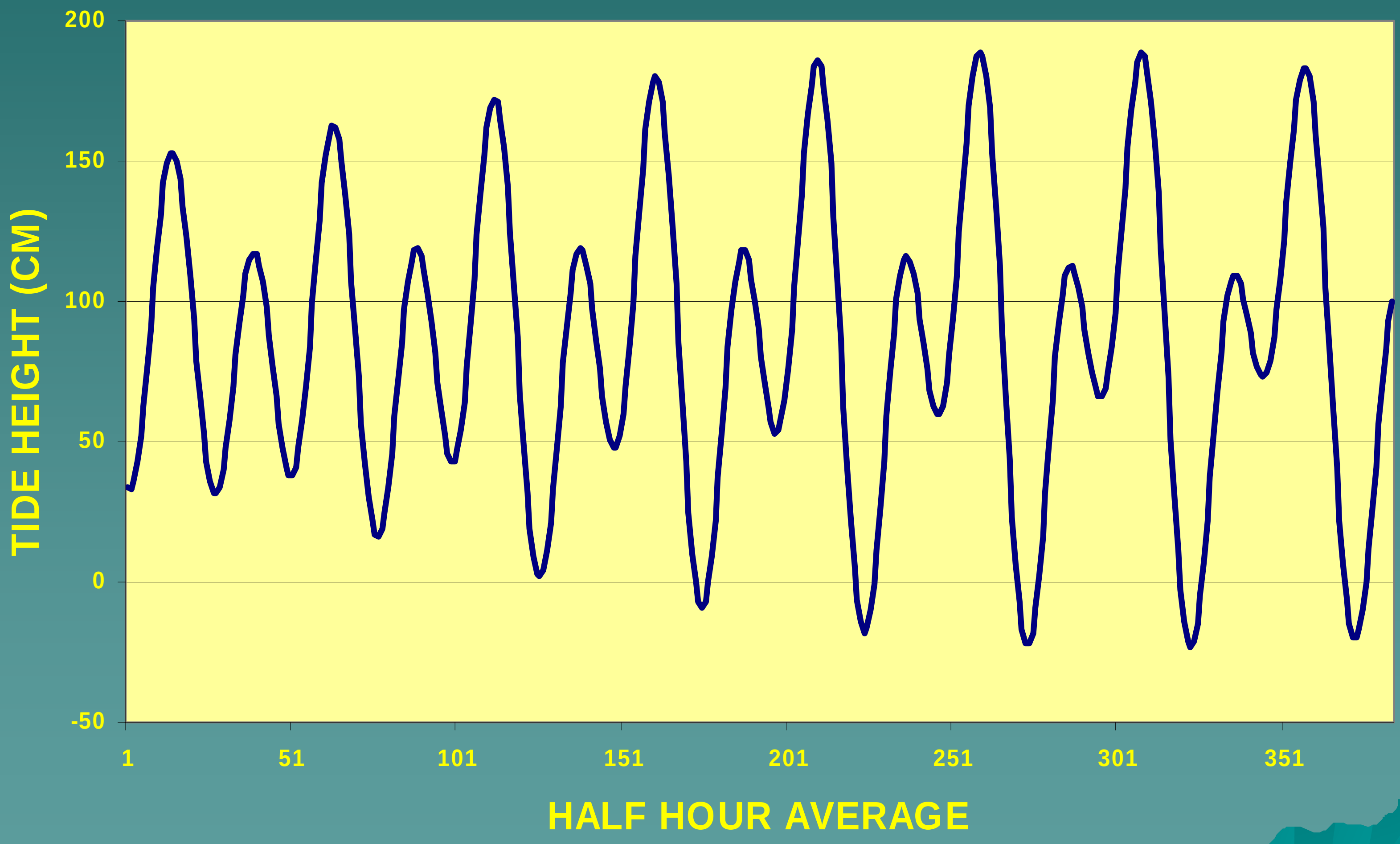
PRESSURE-TIME DATA FOR TYPICAL PRODUCING WELL (SHUT-IN) AT DISTANCE FROM FAULT



13 DAY SHUT-IN RECORD FOR WELL #13 (1 KM DEPTH)
-not produced for 10 years-



OCEAN TIDE @ HOLLY Nov 26, 2001 – Dec 3, 2001

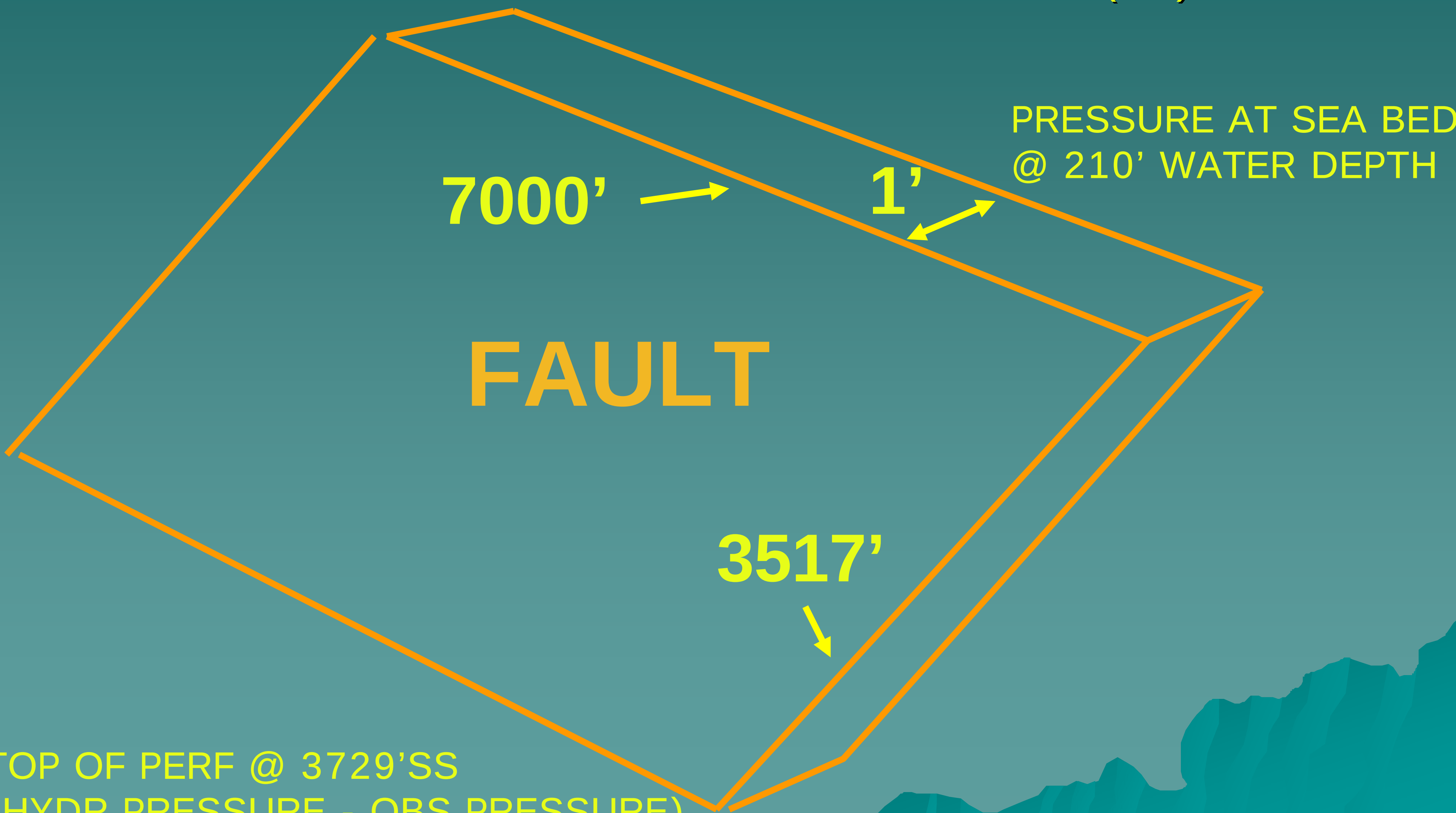


PERMEABILITY CALCULATION

- ESTIMATE VOLUME OF FLOW PATH (FAULT)
- CALCULATE RATE OF SEA WATER INFLUX INTO RESERVOIR FROM OBSERVED PRESSURE INCREASE

PERMEABILITY CALCULATION

PRESSURE POTENTIAL GRADIENT (ΔP)



TOP OF PERF @ 3729'SS
(HYDR PRESSURE - OBS PRESSURE)

PERMEABILITY CALCULATION

- FROM RESERVOIR COMPESSIBILITY
  DATA AND OBSERVED
  PRESSURE INCREASE OF
  .16 PSI/DAY (WELL #13)
- INFLUX OF
  26.5 cu ft WPD INTO RESERVOIR

◆ CALCULATE PERMEABILITY OF FAULT FROM DARCY'S EQUATION

$$Q = -K_W \gamma \text{ц}^{-1} A \, \Delta P L^{-1}$$

Where:

- Q = flow (bbl water/day)
- K_W = water permeability (darcy)
- γ = specific weight of fluid
- ц = fluid viscosity (cp)
- A = cross-sectional area of fault (ft^2)
- ΔP = pressure potential (psi)
- L = flow path length on fault (ft)

PERMEABILITY ESTIMATE FROM WELL #13 (WATER)

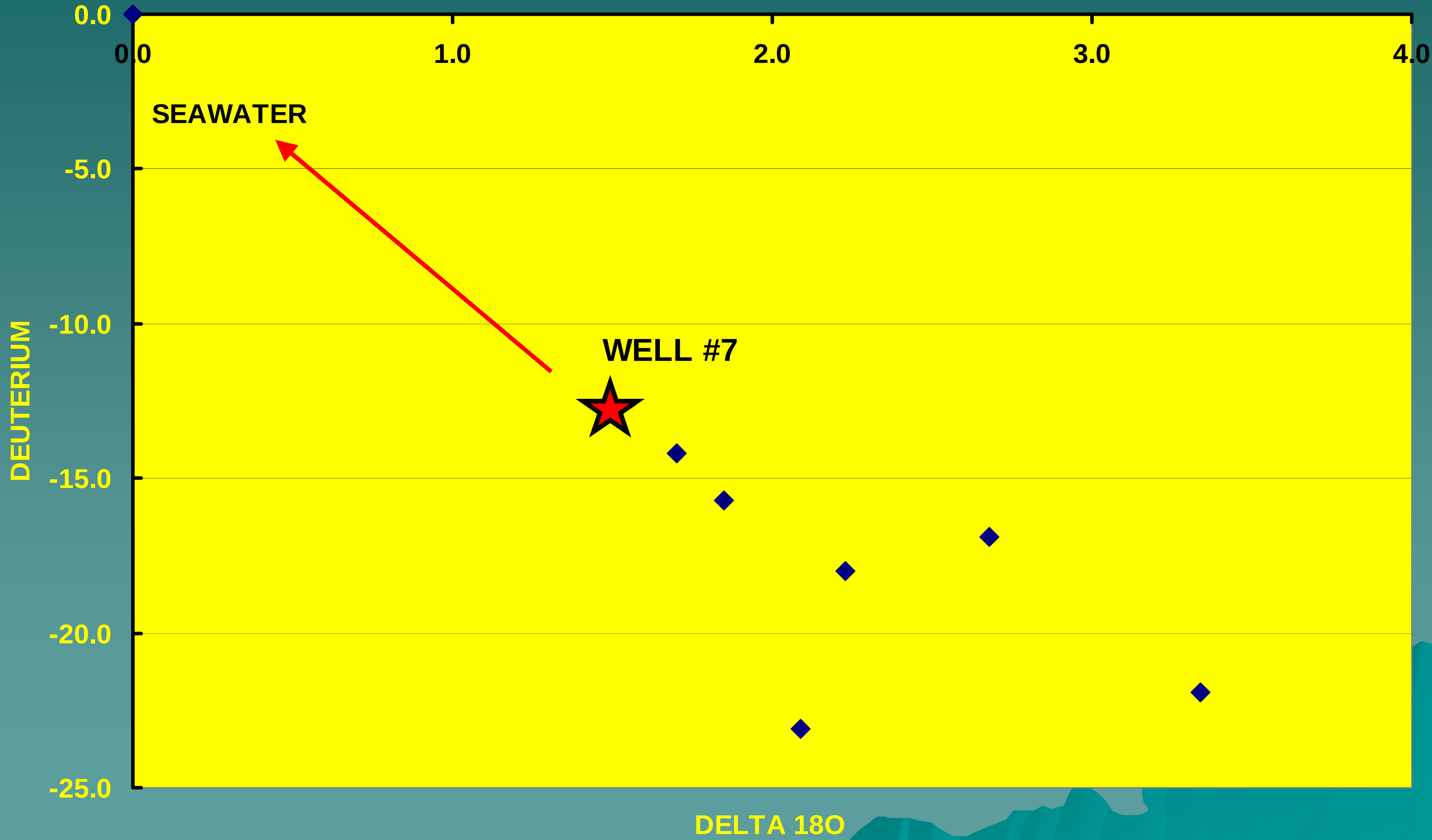
k= 19 mD

- Unable to sample Well #13 to verify seawater entry into the reservoir.
- New well (#7) drilled in 2002 showed a fault connection to seep tent.

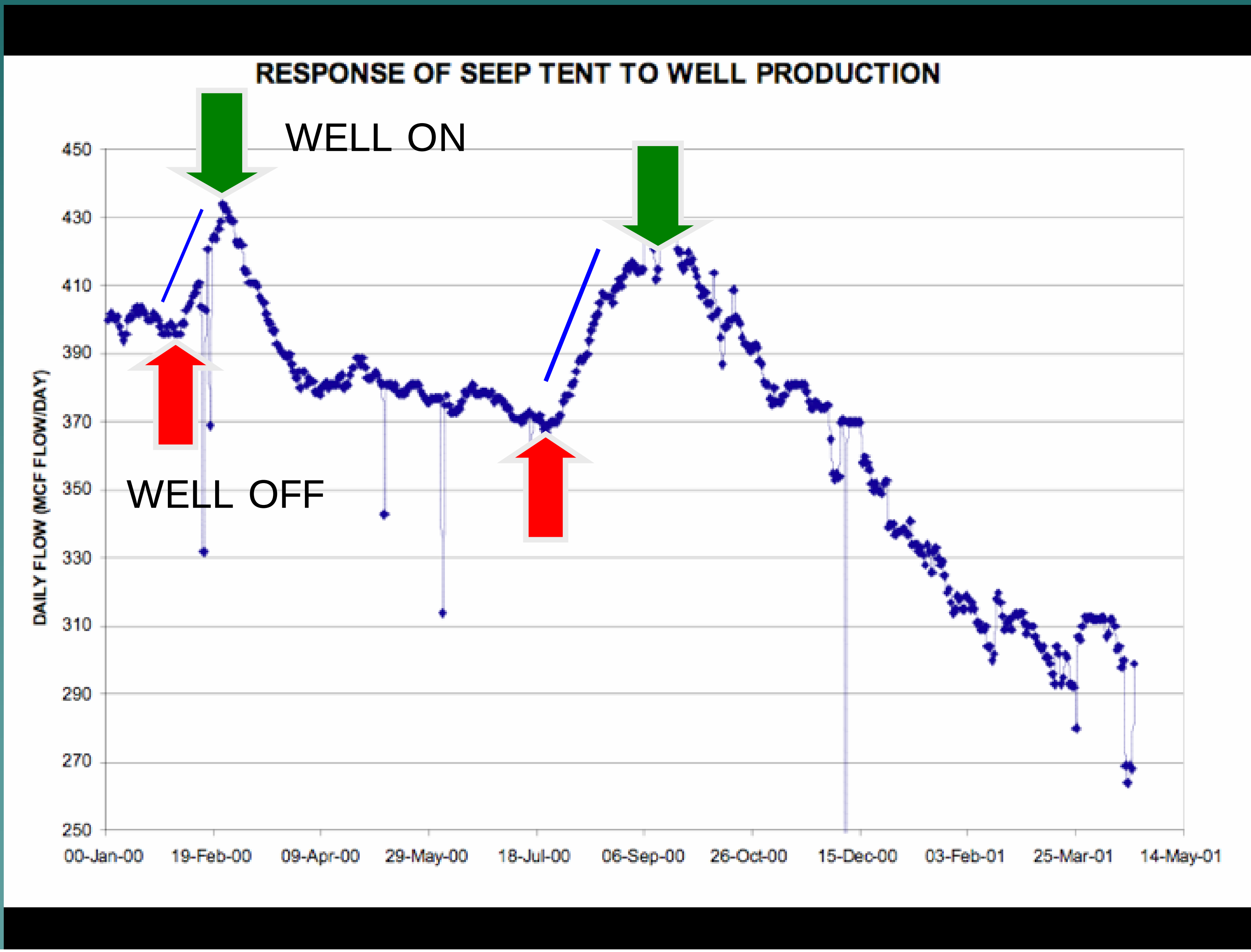
Formation water composition indicates sea water intrusion

Analyses (mg/l)	Ca	Mg	S04	Cl
Average Holly well (5)	57	29	102	15580
Well #7	120	72	120	18000
Seawater	412	1029	2712	19354

δ^{18} Oxygen vs Deuterium of formation water



Seep tent response to Well #7



Permeability calculation for Well #7

$$k = \frac{\mu(q_2 - q_1)}{\left\{\dfrac{P_2^{\,2} - P_1^{\,2}}{2P_m L}\right\}}$$

The physical parameters for South Ellwood are listed below:

ρ_0= 5.6 kg/m^3
ρ_1= 46.3 kg/m^3
ρ_2= 80.0 kg/m^3
μ= 9.73E-06 Pa-s~1.0E-05 Pa-s
g = 9.8 m/s^2
A=1860 m^2 (seepage tank area)
L=1000 m (depth of reservoir or length of flow domain)

Q_1= 370 MCF/day=10,477 m^3/day=0.1212616 m^3/s
Q_2= 430 MCF/day=12,176 m^3/day=0.1409259 m^3/s
$\therefore$ q_1= 6.519E-05 m/s
$\therefore$ q_2= 7.577E-05 m/s

P_o= 90 psi =0.6205 MPa
P_1= 800 psi =5.5158 MPa
P_2=1300 psi =8.9632 MPa
P_m=(P_1+P_2)/2

PERMEABILITY ESTIMATE FROM WELL #7 (GAS)

k= 30 mD

Sources of error for K estimates

- Opposing mass transfer
- Mass transfer restricted to fault zone
- Dimensions of fault zone

- Fault permeability estimates from two wells, using different methods, are similar -- ~ 20-30 mD, for water and gas.
- Estimates are TWO to THREE times higher than reservoir fracture permeability (est 10 mD).

CONCLUSION

- FAULTS CAN SIMULTANEOUSLY ACT AS PATHWAYS FOR OPPOSING MASS TRANSFER IN CERTAIN CASES

  - GAS ASCENDING BY BOUYANT FORCE

  - SEA WATER DESCENDING BY GRAVITATIONAL FORCE TO A SUB-HYDROSTATIC RESERVOIR

CONCLUSIONS

- Fault damage zone can have relatively high permeability (10's of mD) and communicate on the kilometer scale with shallower levels.

QUESTIONS?