High Fluid Pressures and High Fluid Flow Rates From a Zone of Natural Hydrofractures Associated with a Major Out-of-Sequence Thrust Zone, Convergent Margin, Southwest Japan*

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Abstract

The convergent margin of SW Japan is a fold and thrust belt characterized by active in-sequence and out-of-sequence thrusts. The margin is composed of deep water siliciclastic deposits. This margin has been transected by 11 drilling sites including 9 riserless and 2 riser sites during the IODP Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE). NanTroSEIZE is designed to analyze the complete architecture of a convergent margin while studying and instrumenting faults that produce the great earthquakes of this region. Because it strongly influences fault behavior, multiple efforts have been made to measure fluid pressure, including packer measurements, leakoff tests, long-term instrumentation, and measurements of annular pressure while drilling.

Annular pressure while-drilling data shows high fluid overpressures at Site C0001 in part of the out-of-sequence thrust zone. Mostly normal pressures occur at three other sites, including two penetrating major faults. The two holes at Site C0001 show a step-up to lithostatic fluid pressure at about 500 mbsf (meters below seafloor), following initial indicators of overpressure at about 375 mbsf. The fluid pressure remains high and increasing to total depth of 1000 mbsf. The pressure curves resemble those associated with shallow water-flow in the Gulf of Mexico. Seismic lines through the site show bright reflectors in the zone of initial fluid pressure increase. Borehole images, sonic velocities, and resistivity all suggest a zone of fractures in mudstones at around 500 mbsf and below. A hydraulic model of the fluid system explains the observed pressures by influx of formation fluid at about 500 mbsf. The combination of a natural influx of 3300 l/m plus 2200 l/m from the drilling system can explain the observed fluid pressures. The overpressured Site C0001 occurs in the probable shallow extension of the fault zone of the 1944 great earthquake and may represent a related but incompletely healed fracture system.

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Website

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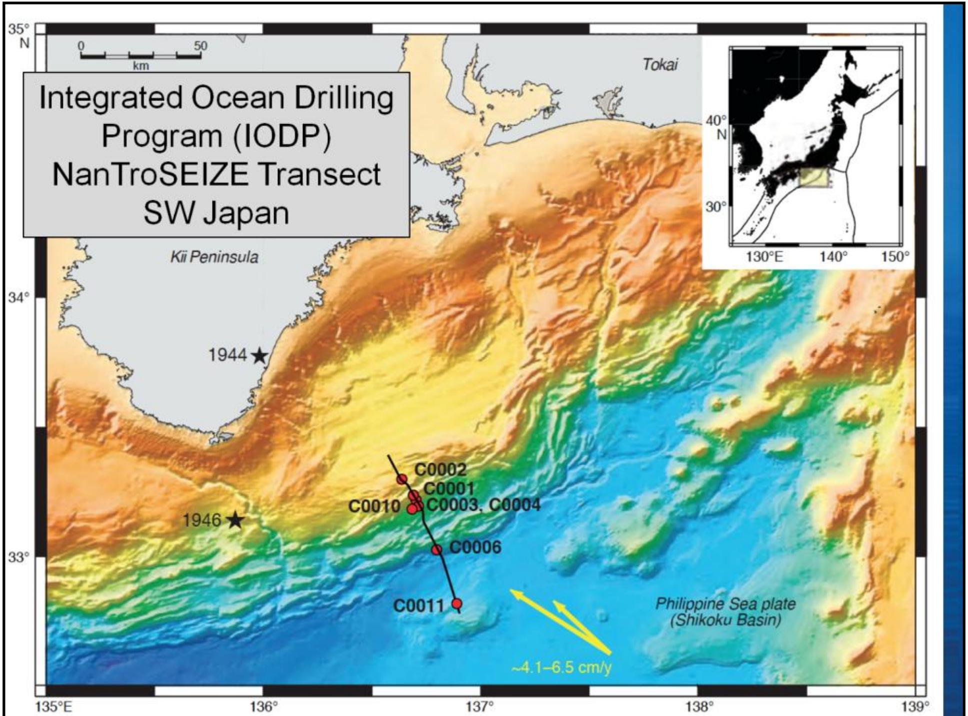
JAMSTEC
Japan Agency for Marine-Earth Science and Technology

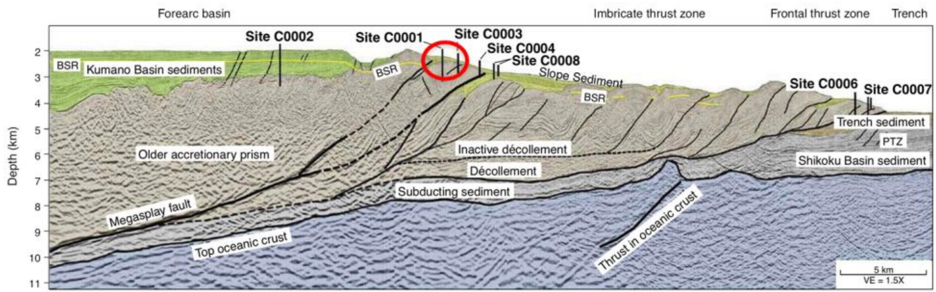
IODP
INTEGRATED OCEAN DRILLING PROGRAM

High Fluid Pressures and High Fluid Flow Rates From a Zone of Natural Hydrofractures

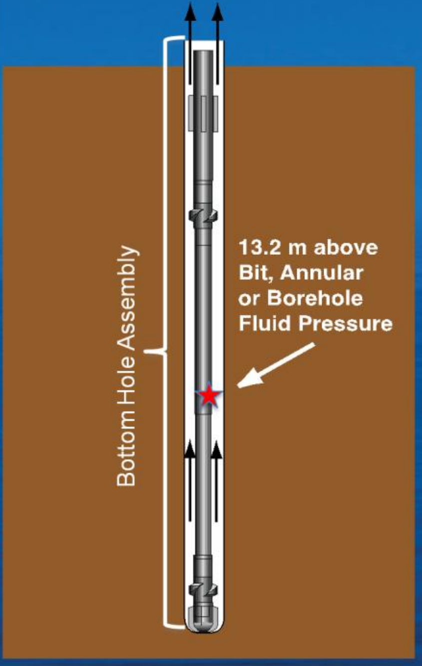
- Tectonic Setting
- Technology Applied
- General Pressure Regimes
- Pressure Anomalies
- Structural Context of High Pressures
- Modeling of High Flow Rates
- Potential Sealing Mechanisms
- Gulf of Mexico Analogues


Integrated Ocean Drilling Program (IODP) NanTroSEIZE Transect SW Japan
Tokai
Kii Peninsula
1944
1946
C0002
C0001
C0010
C0003, C0004
C0006
C0011
~4.1–6.5 cm/y
Philippine Sea plate (Shikoku Basin)
0
50
km
35° N
34°
33°
135°E
136°
137°
138°
139°
40° N
30°
130°E
140°
150°

Cross Section of Convergent Margin of SW Japan

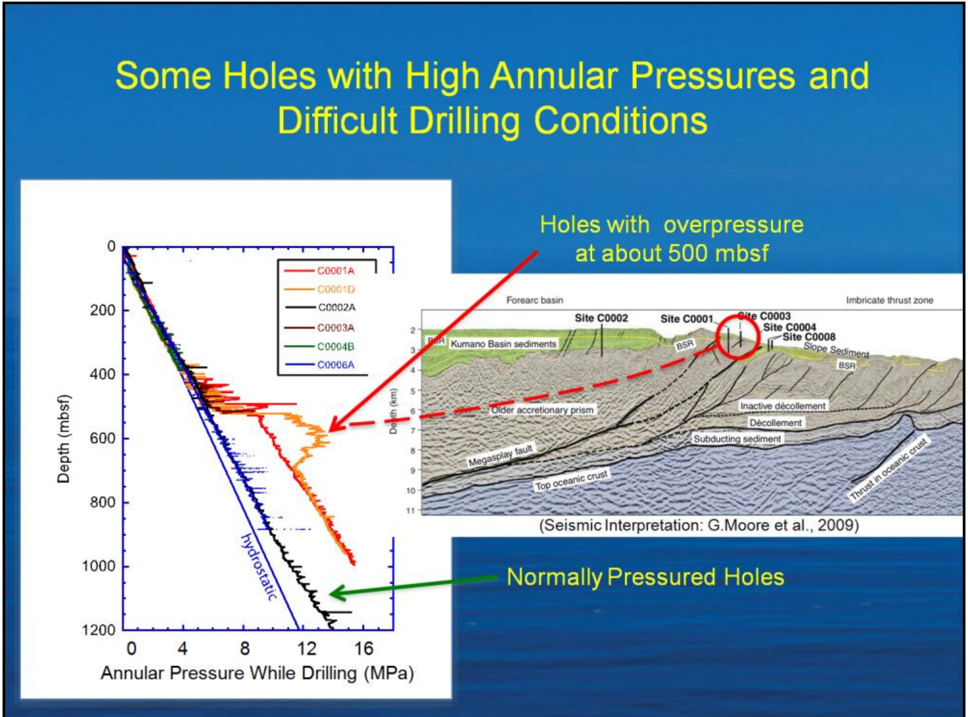


(Seismic Interpretation: G.Moore et al., 2009)

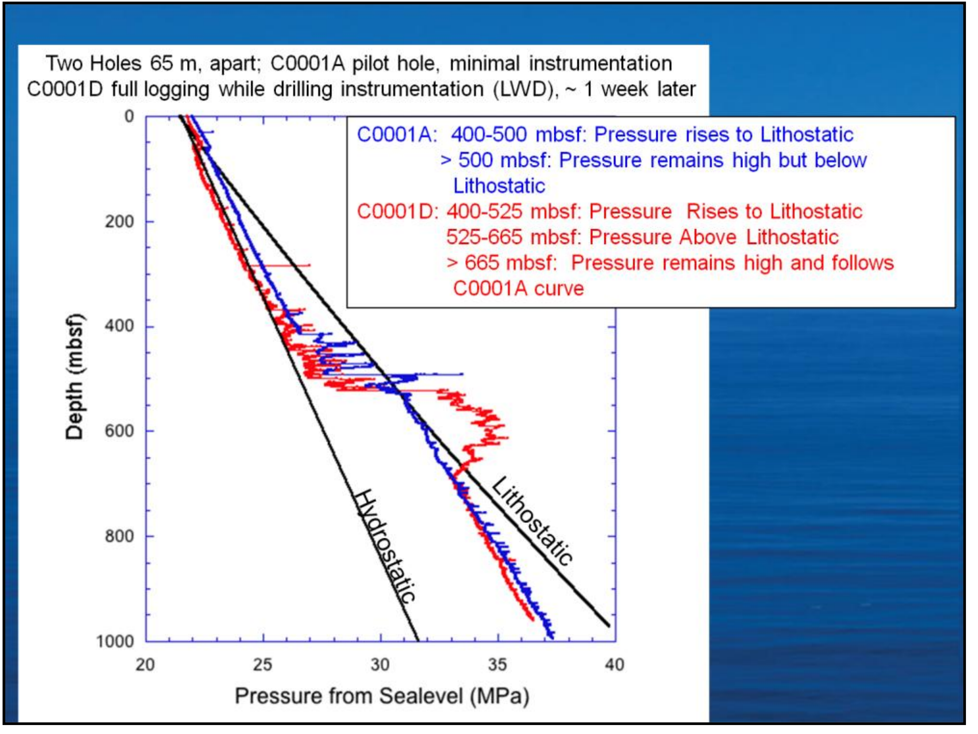


Annular Pressure While Drilling

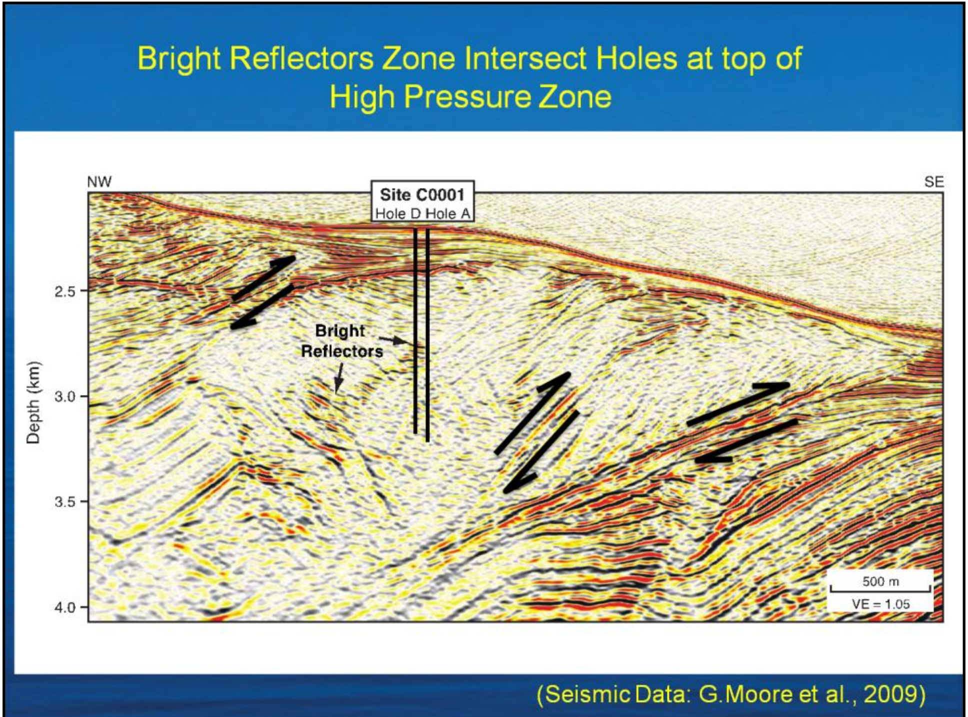
- Borehole Fluid Pressure measured in riserless open hole
- Records **Hydrostatic Column** above tool plus **Mud** and **Cuttings Load** plus **Viscous Resistance** to flow due to **Rig Floor Pumping** and **Flow From Formation**
- Typically Pressure is modestly above hydrostatic



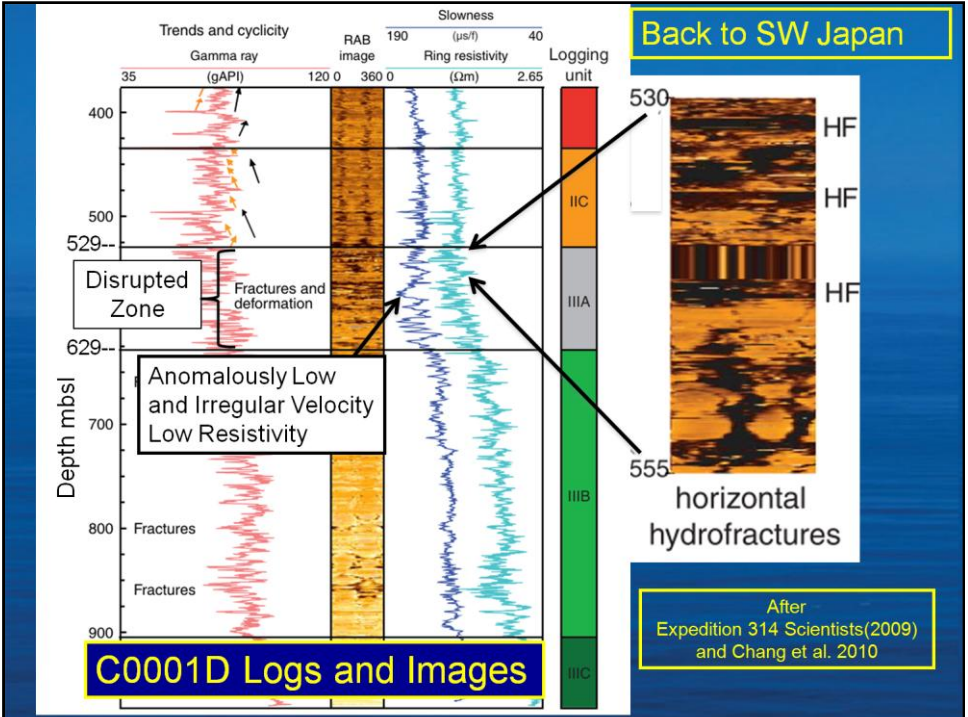
Presenter's notes: Just to be clear, we are dealing with the holes in the upper splay fault zone, where drilling was notably difficult.



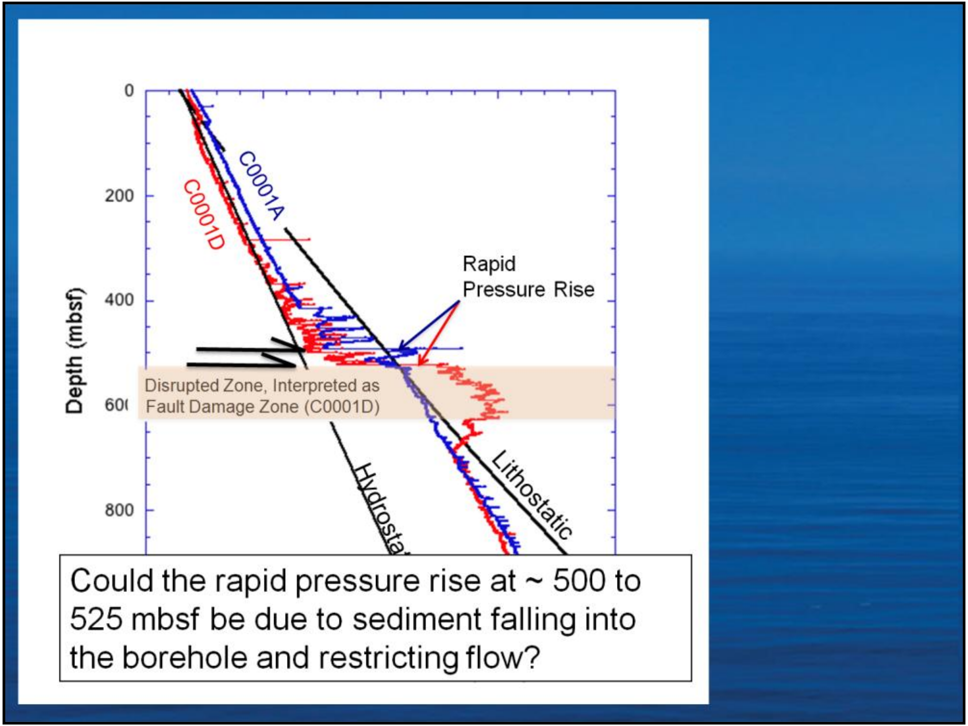
Presenter's notes: Focus is on C0001A and C0001D, two holes 65 m apart, drilled about 1 week apart. Both tend to follow hydrostatic gradient or slightly above; then pressures shoot-up to lithostatic values at about 500 mbsf. Note. Fluid pressure at C0001A rockets upward at less than 500 m, but they (drilling tools) became stuck at 508 m.



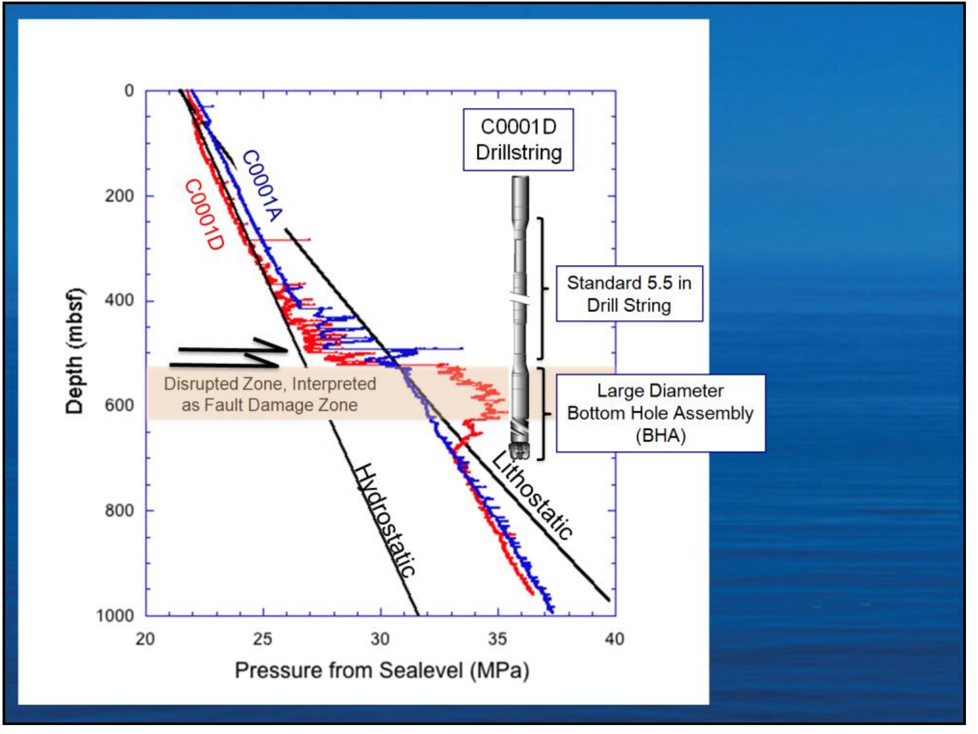
Presenter's notes: Bright reflectors intersect both boreholes at the depth of the anomalous pressure increase. If rapid pressure rise is from same structure in both holes, then fault would be dipping at about 21 degrees, given 25 m vertical separation and 65 m horizontal separation.



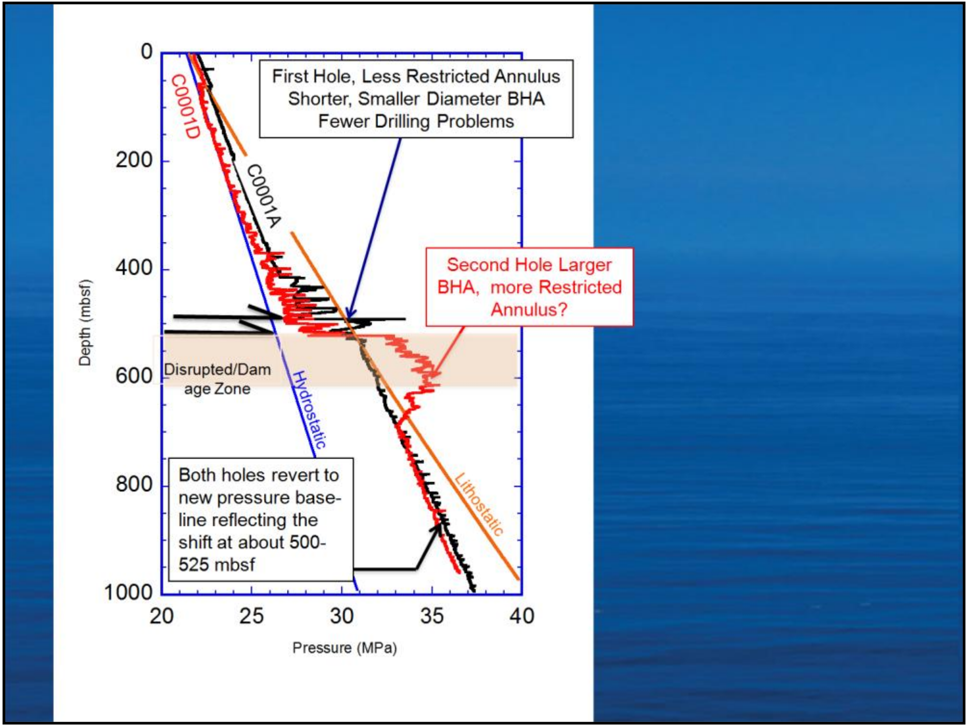
Presenter's notes: Hole C0001D shows a disrupted zone between 529 and 629 mbsf with anomalously low and irregular velocity. Images suggest large horizontal hydrofractures.



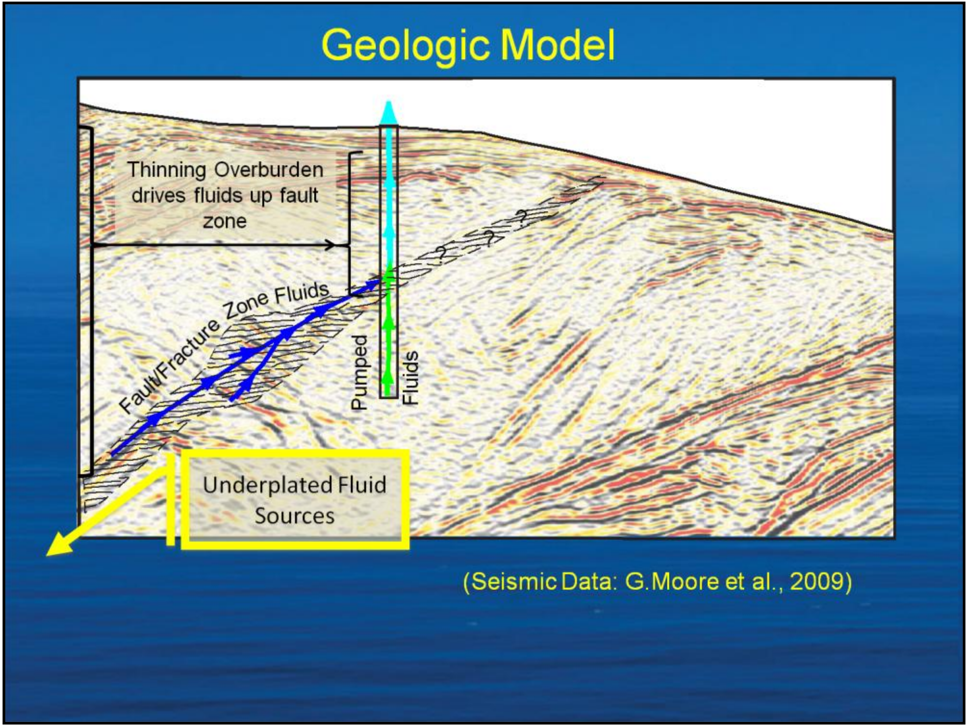
Presenter's notes: We think the zone of rapid pressure rise at about 525 m is due to a fault zone, with the disrupted zone representing a damage zone.



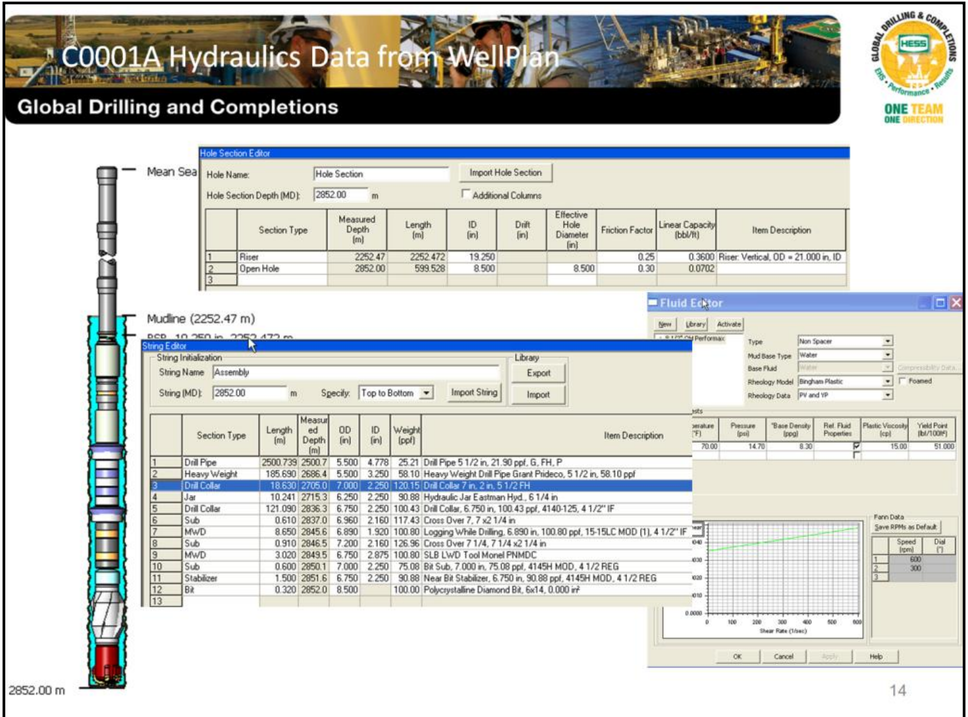
Presenter's notes: BHA is about 172 m in length.



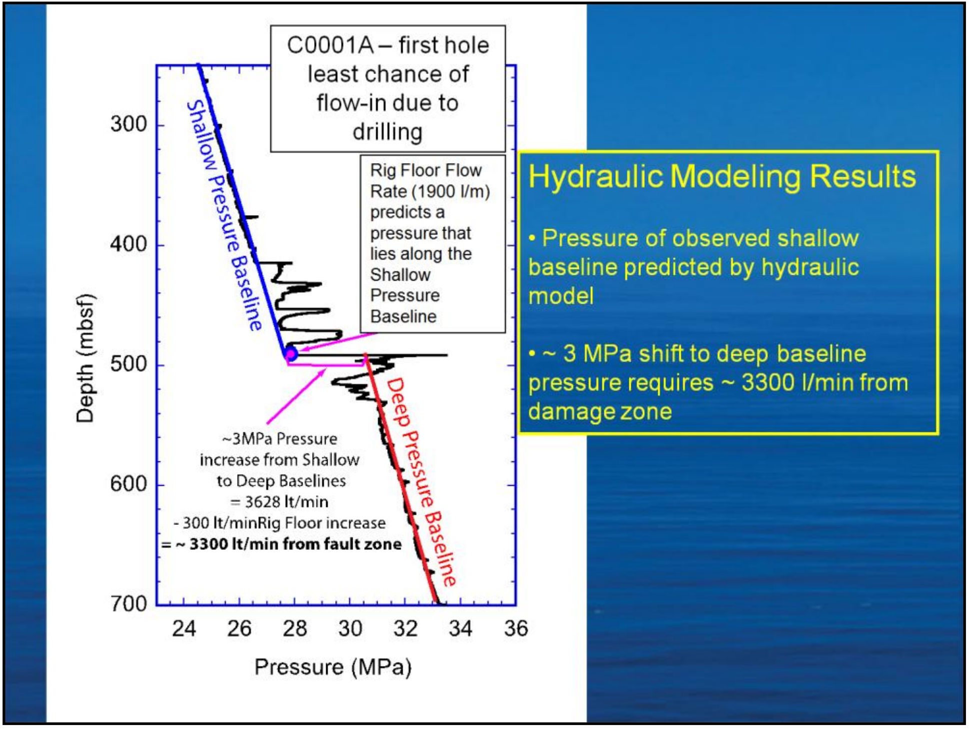
Presenter's notes: Reverting to similar gradients at depth and fidelity of time data over this and higher intervals strongly suggests that pressure signal is real.



Presenter's notes: The geologic model explaining the increase in fluid pressure at about 500 m is the addition of fluids from natural fractures encountered at about that depth. Apparently these fluids are migrating along some fracture zone, perhaps related to the series of documented thrust faults in this region.

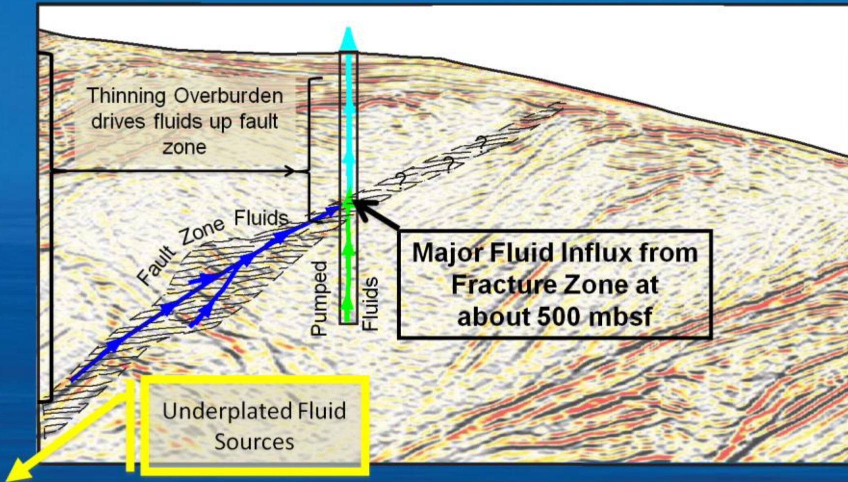


Presenter’s notes: The observed pressures can be tied to flow rates (by co-author Myles Barrett). The model uses the known geometry of the drill string, the borehole diameter, and known pumping rate and interprets the flow rate necessary to explain the observed pressures in this particular annulus geometry.

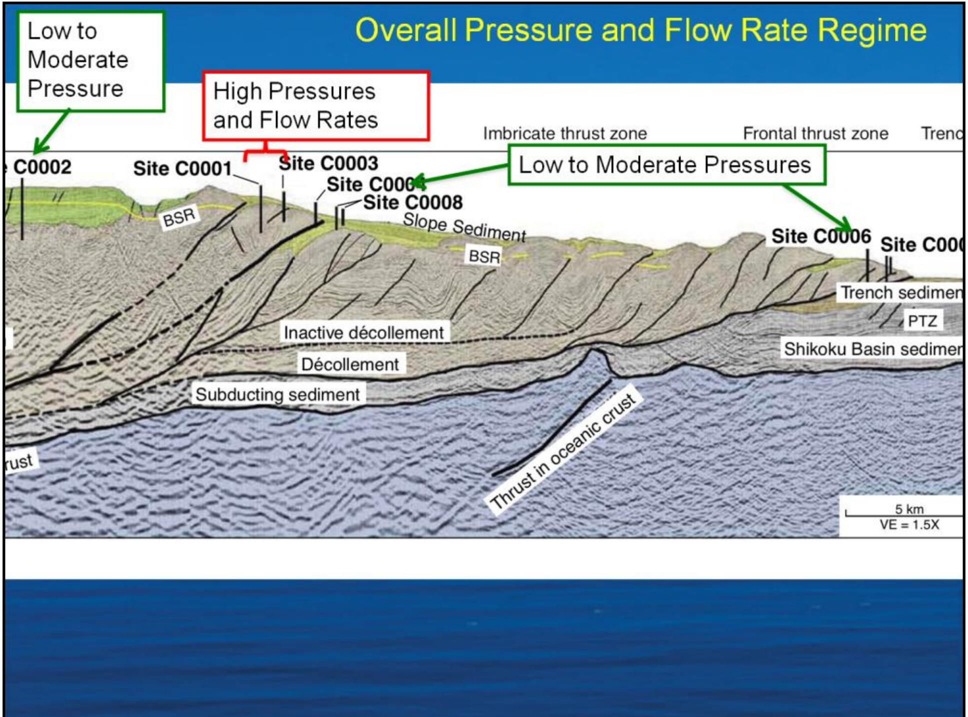


Presenter's notes: For example, the observed shallow baseline pressure predicts a flow rate of 1900 l/m. This pressure is about 27 MPa total, or about 5 MPa above sea-bottom pressure. The 3 MPa pressure increase to the deep baseline trend requires an additional pumping rate of ~ 3600 l/m, of which 300 was due to an increase of pumping rate on the rig floor. Thus the flow in/through the naturally fractured zone is about 3300 l/m.

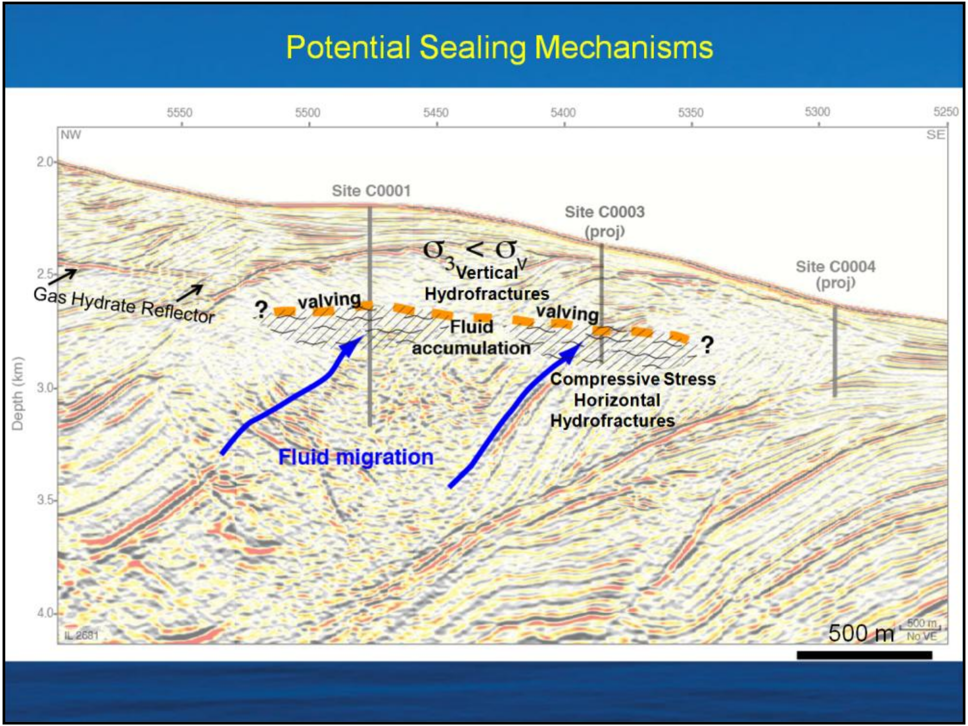
Geologic Model



(Seismic Data: G.Moore et al., 2009)

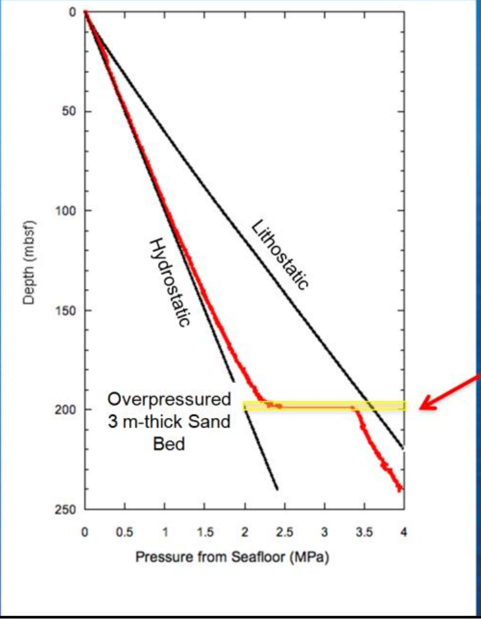


Presenter's notes: High pressures, unique to part of out-of-sequence thrust, are perhaps associated with 1944 M8 earthquake.

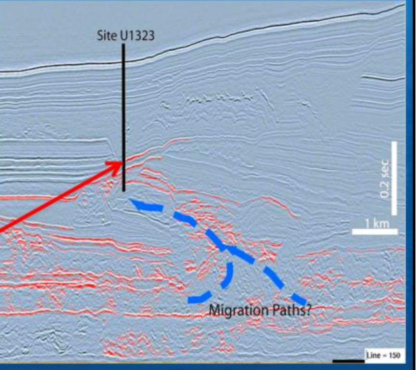


Presenter's notes: Some evidence exists for increase of lateral horizontal compressive stress with depth. Once the compressive stress is greater than the overburden and the latter is the minimum principal stress, horizontal hydrofractures are possible and could store fluid

Pressure Increase Similar to Shallow Water Sand in Ursa area, Gulf of Mexico,



Mississippi Fan Overpressured Sand Bed with Deeper Sources:



Modified from Flemings, P.B., Behrmann, J.H., John, C.M., and the Expedition 308 Scientists Proceedings of the Integrated Ocean Drilling Program, Volume 308, Site 1323

Conclusions

1) Annular Pressure While Drilling curves from NanTroSEIZE Holes C0001A and C0001D suggest high fluid pressure and high flow rates from fractures associated with out-of-sequence thrust system.

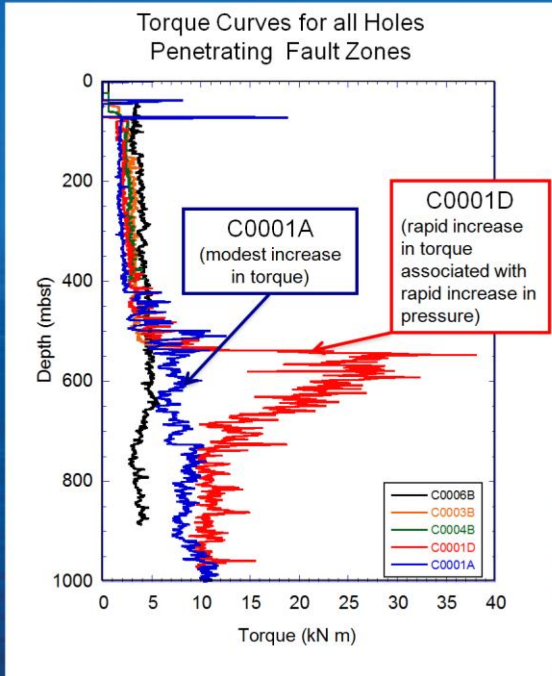
2) Natural fluid pressure in fracture zone estimated at about 3 Mpa above "normal" values at about 500 mbsf

3) Fracture flow rate estimated at about 3300 l/min assuming in-gauge borehole geometry

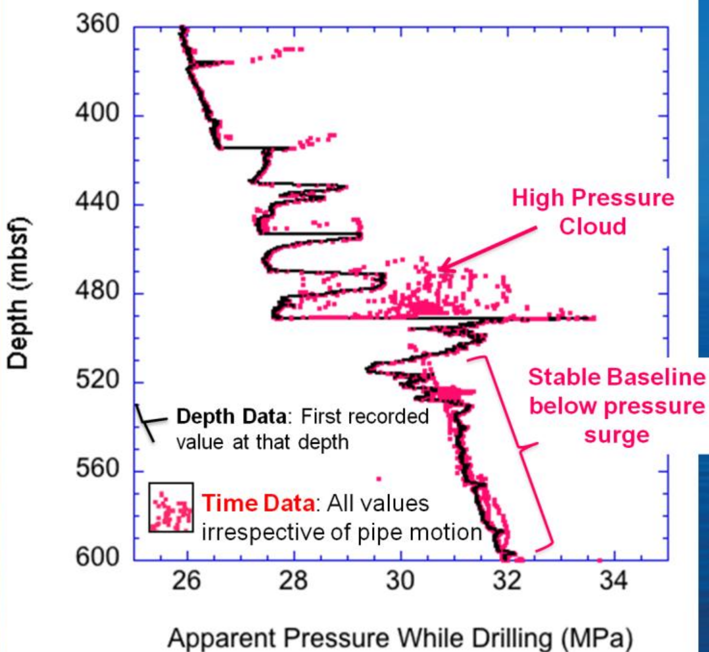
4) Fluid accumulations at about 500 mbsf may be due to compressional state of stress at that depth that allows development of shallowly dipping hydrofractures.

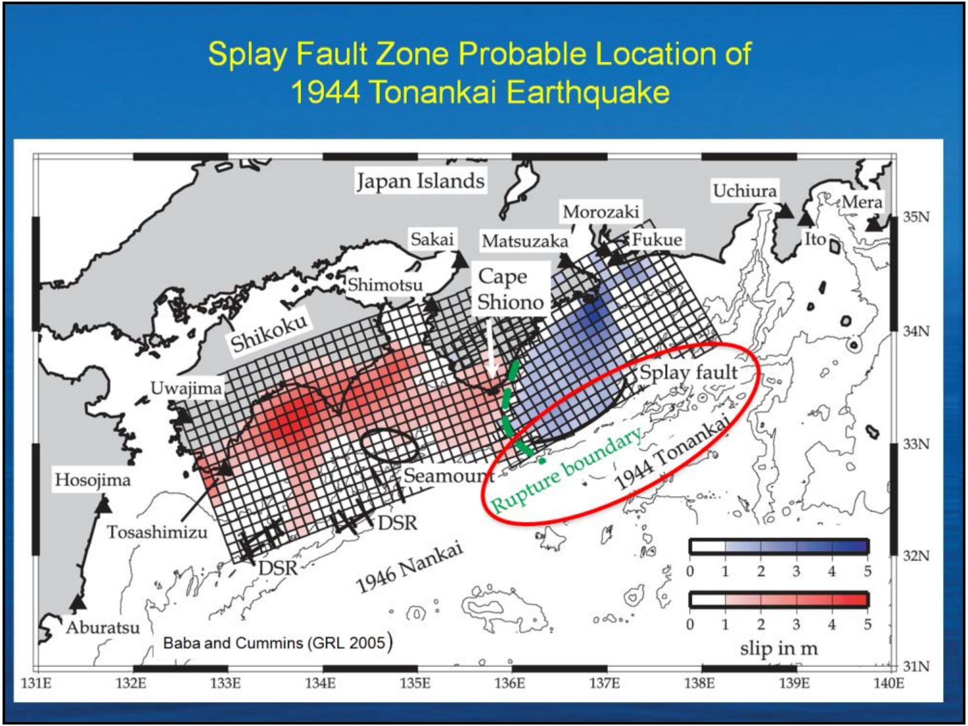
5) Alternatively, a possibility of a gas hydrate seal.

Addendum:


Torque Curves for all Holes
Penetrating Fault Zones
C0001A
(modest increase in torque)
C0001D
(rapid increase in torque associated with rapid increase in pressure)
Depth (mbsf)
0
200
400
600
800
1000
0
5
10
15
20
25
30
35
40
Torque (kN m)
C0006B
C0003B
C0004B
C0001D
C0001A

Time data reveals more complete picture of pressure log





Presenter's notes: Seismologists invert tidal gage records, using small subfaults--in agreement with previous larger scale inversions, but more detailed. Note activity of splay fault or large OST.

-photos by Andrew Tunks via Ric Sibson (see Tunks et al.2004: J. Struct. Geol. 26, 1257-1273)

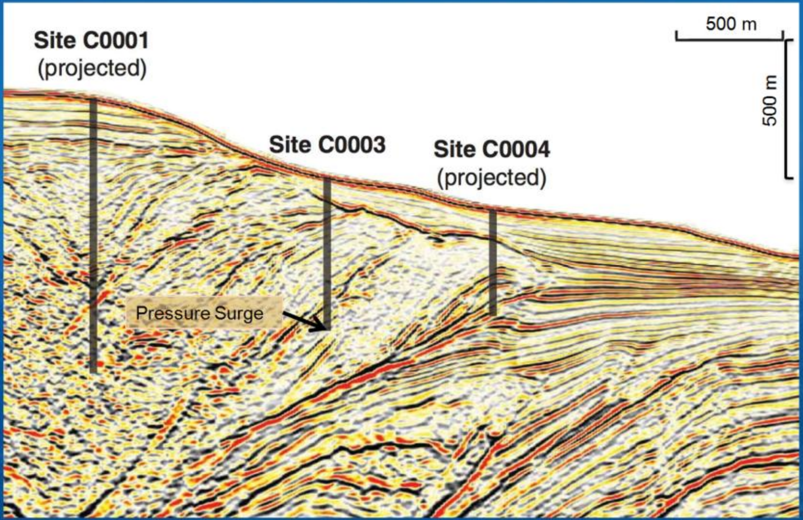
Fault Zones showing fractures as veins– perhaps similar to those providing large volumes of fluid in megasplay fault zone

Artesian Well in Oklahoma
3500 gallons/min.
~ 13,200 liters/min in 1922

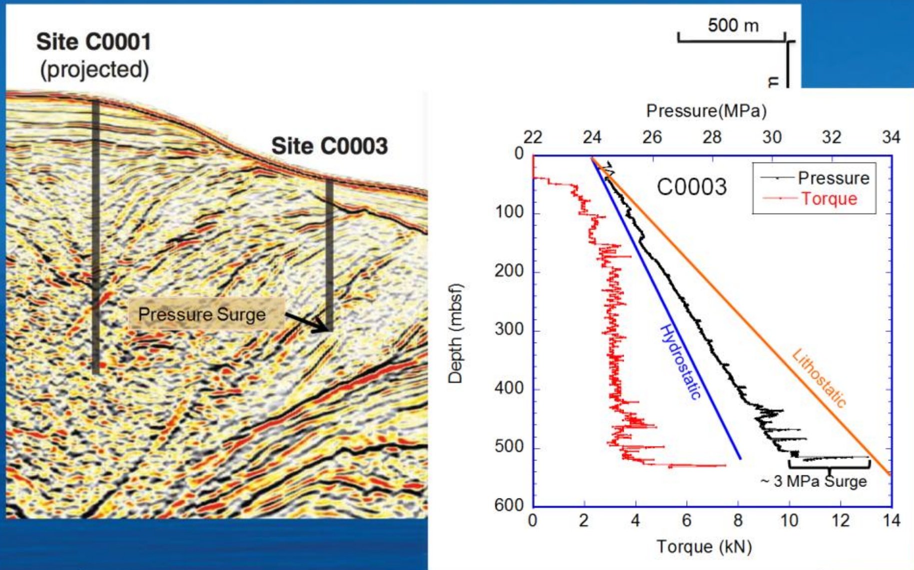
or 500 gal/min or 1900 l/min
~ 1900 liters/min. today

Estimated Fault Flow Rate for C0001A Hole is Reasonable.

http://www.okgenweb.org/~okmurray/Murray/images/vendome/vendome_artesian_well.htm

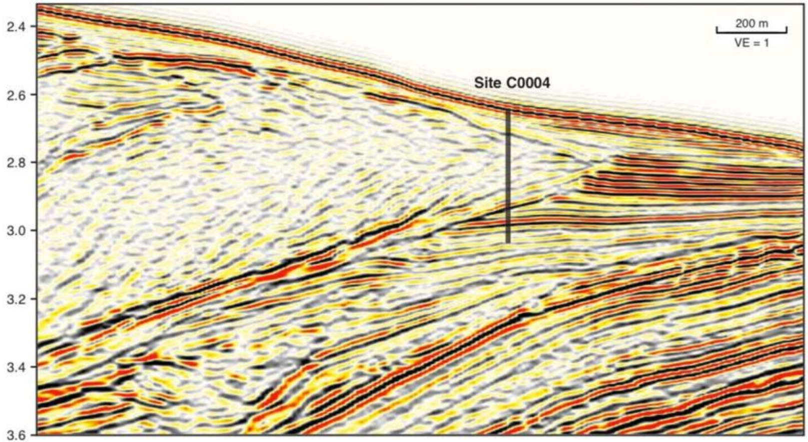


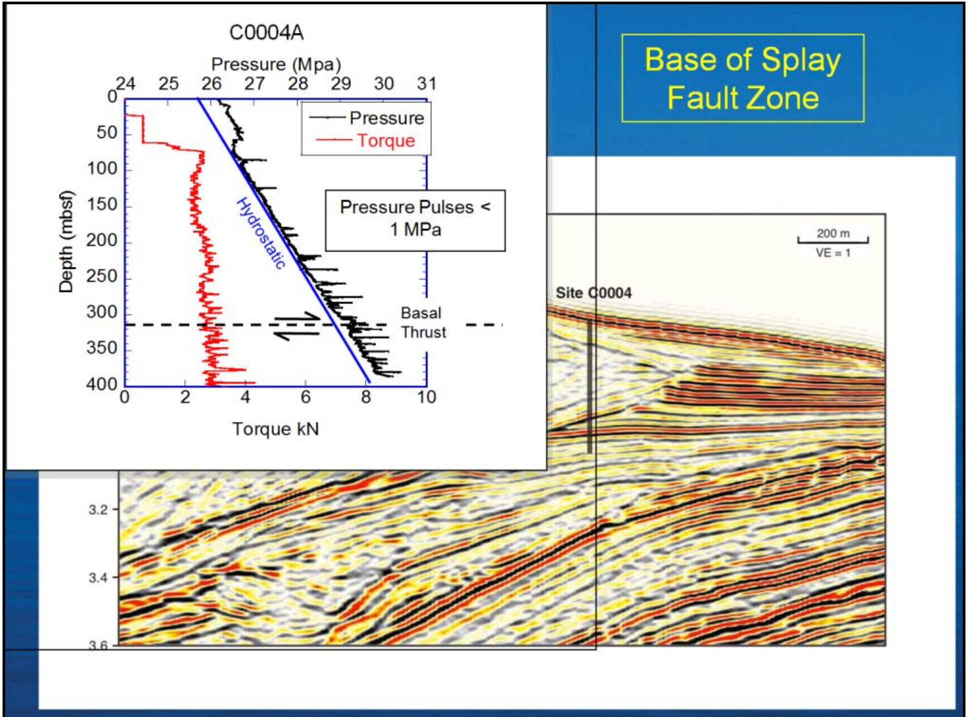
Pressure surge at C0003 to near lithostatic values similar to C0001



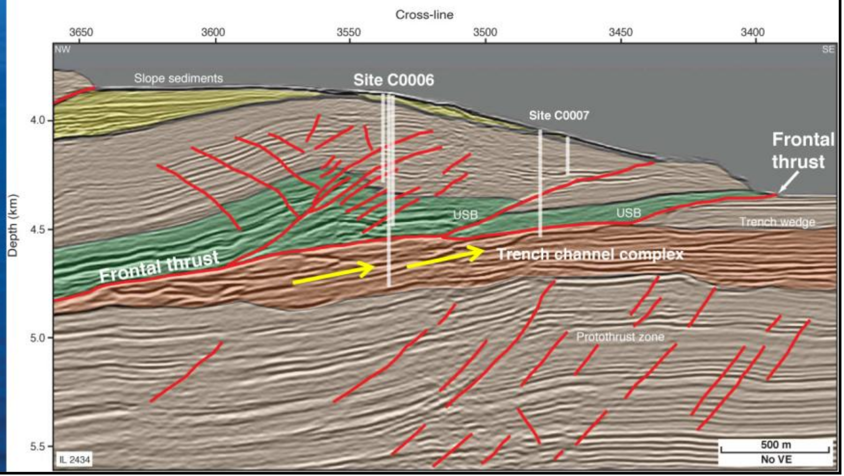
Pressure surge at C0003 to near lithostatic values similar to C0001

Base of Splay Fault Zone




C0004A
Pressure (Mpa)
24 25 26 27 28 29 30 31
Pressure
Torque
Depth (mbsf)
0 50 100 150 200 250 300 350 400
Hydrostatic
Pressure Pulses < 1 MPa
Basal Thrust
0 2 4 6 8 10
Torque kN
Base of Splay Fault Zone
200 m
VE = 1
Site C0004
3.2
3.4
3.6

Fluid Escape through Trench Channel Complex due to Loading by Accretionary Wedge



Fluid Escape through Trench Channel Complex due to Loading by Accretionary Wedge