Origin of Overpressure and Pore Pressure Prediction in the Baram Delta Province, Brunei*

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Conclusions

- Distinguish between disequilibrium compaction and fluid expansion overpressures.
- Disequilibrium compaction and fluid expansion overpressures occur in geographically and geologically distinct areas.
- Sonic log data successfully predicts pore pressure in disequilibrium overpressures using an Eaton exponent of 3.0.
- Sonic log data responds to inflationary overpressures, and we can reasonably predict pore pressure using an Eaton exponent of 6.5.
- Foundations for PPP from seismic velocities and LWD.

References

Bowers, G.L., 1994, Pore pressure estimation from velocity data: accounting for overpressure mechanisms besides undercompaction: International Association of Drilling Contractors/SPE Drilling Conferences, SPE Paper 27488, p. 515-530, Web accessed 4 March 2011, http://www.onepetro.org/mslib/servlet/onepetropreview?id=00027488&soc=SPE

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Hermanrud, C., L. Wensaas, G.M.G. Teige, H.M. Nordgard Bolas, S. Hansen, and E. Vik, 1998, Shale porosities from well logs on Haltenbanken (Offshore Mid-Norway) show no influence of overpressuring, *in* B.E. Law, G.F. Ulmishek, and V.I. Slavin (eds.) Abnormal Pressures in Hydrocarbon environments: AAPG Memoir 70, p. 65-85.

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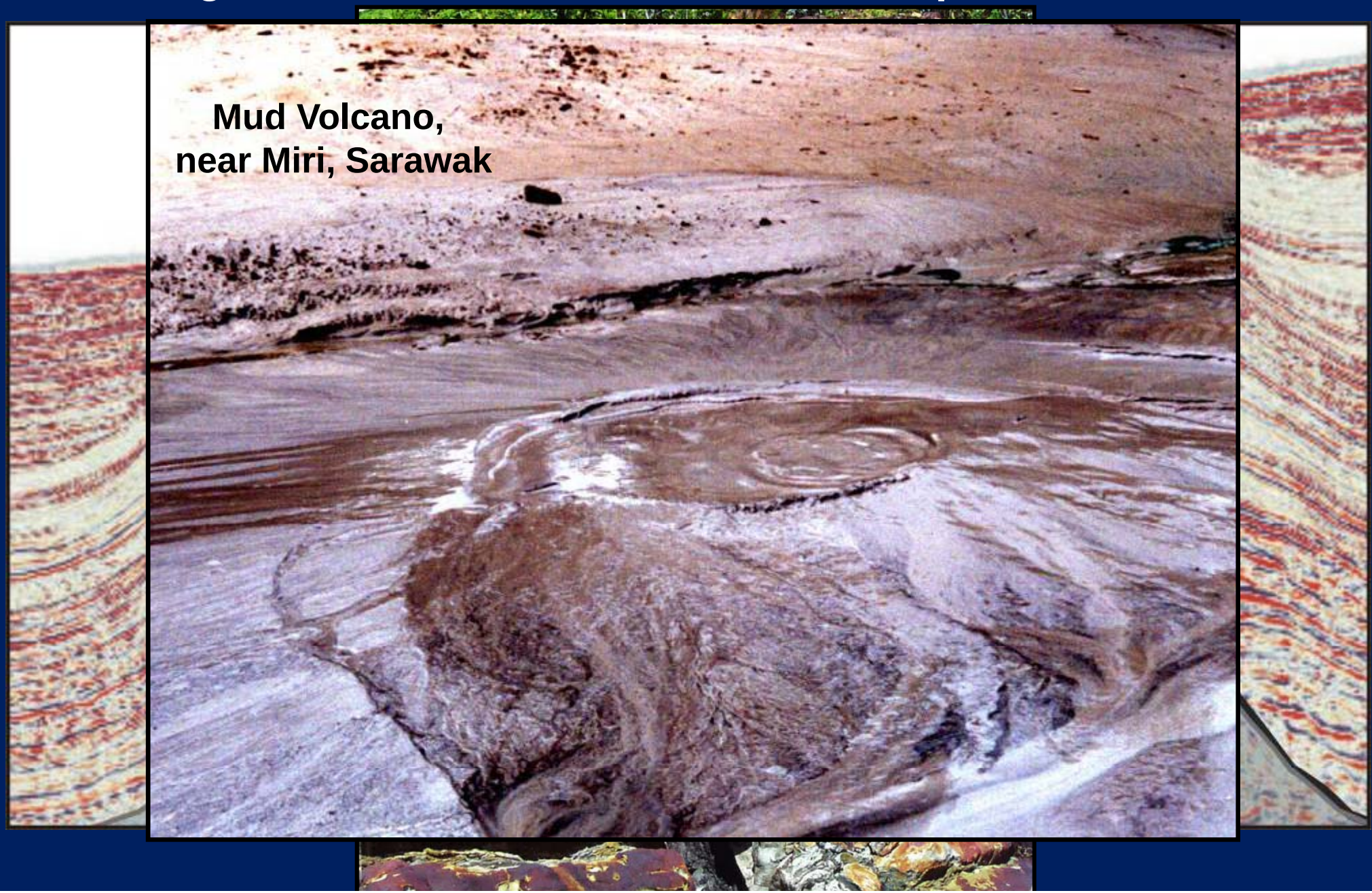
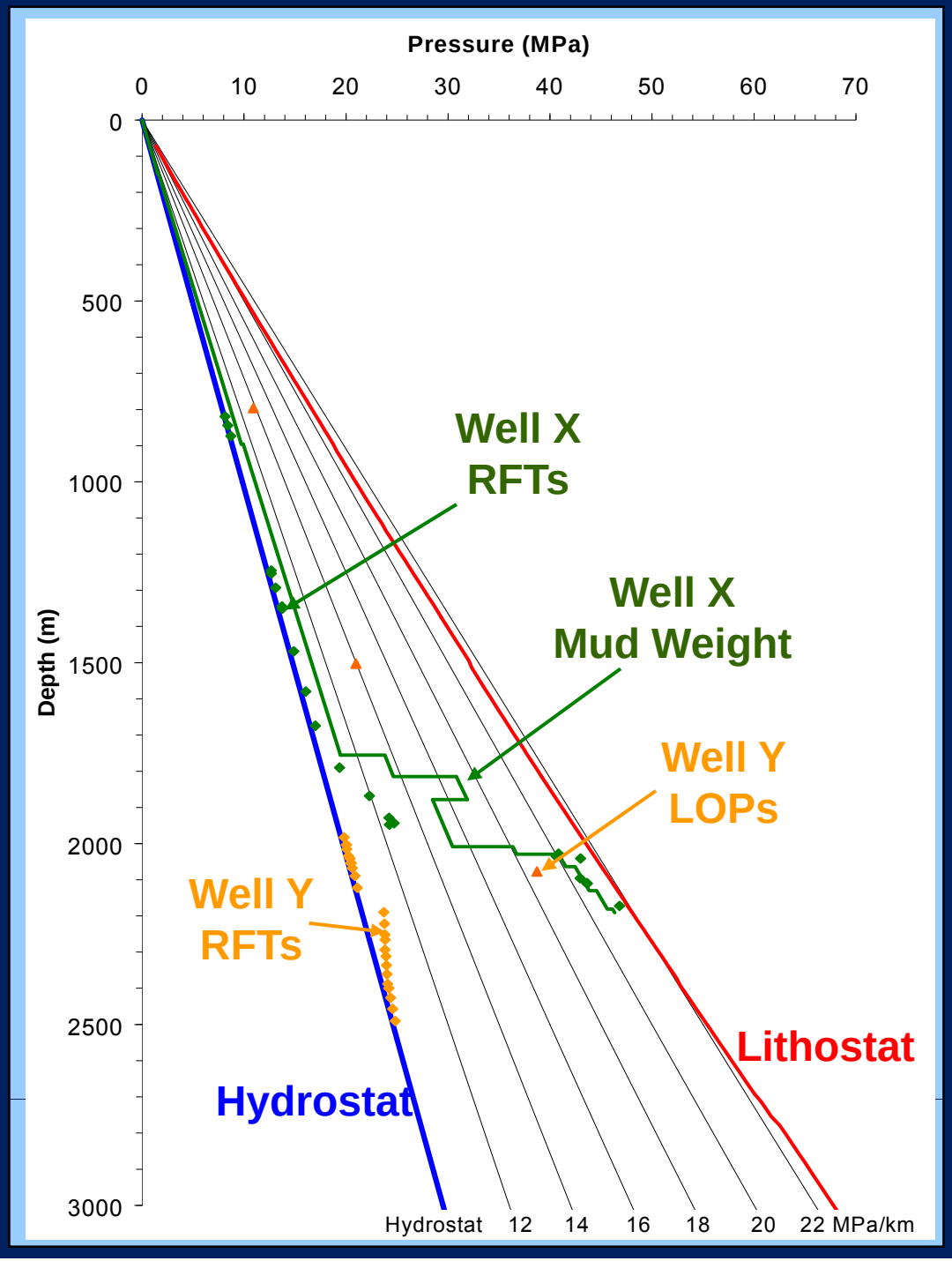
Geological Features associated with Overpressure in Brunei





Well X

- Pore pressure rises over 20 MPa in 100 m (from 12.5 to 21.5 MPa/km)
- Pore pressures are at approximately lithostatic gradients at 2000 m depth

Well Y

- Located 800m from Well X and separated by single resolvable fault of 60m throw.

Highly compartmentalized pore pressures and horizontal stresses

1979 Blowout, Offshore Brunei

Goal: accurate PPP from seismic & LWD data.

But what do we need to know first?

- What are the overpressure generation mechanisms?
- Where do different types of overpressure occur?
- How do different types of overpressure affect rock properties – can we detect overpressure from log data?
- Can we predict pore pressure from log data?
- Can we detect overpressure and predict pore pressure from seismic velocities and ‘Logging While Drilling’ data?

Overpressure Origin and PPP in Brunei

- INTRODUCTION
- DISTRIBUTION OF OVERPRESSURE
- OVERPRESSURE ORIGIN
- PETROPHYSICAL RESPONSE TO OVERPRESSURE
- IMPLICATIONS FOR PORE PRESSURE PREDICTION
- SUMMARY

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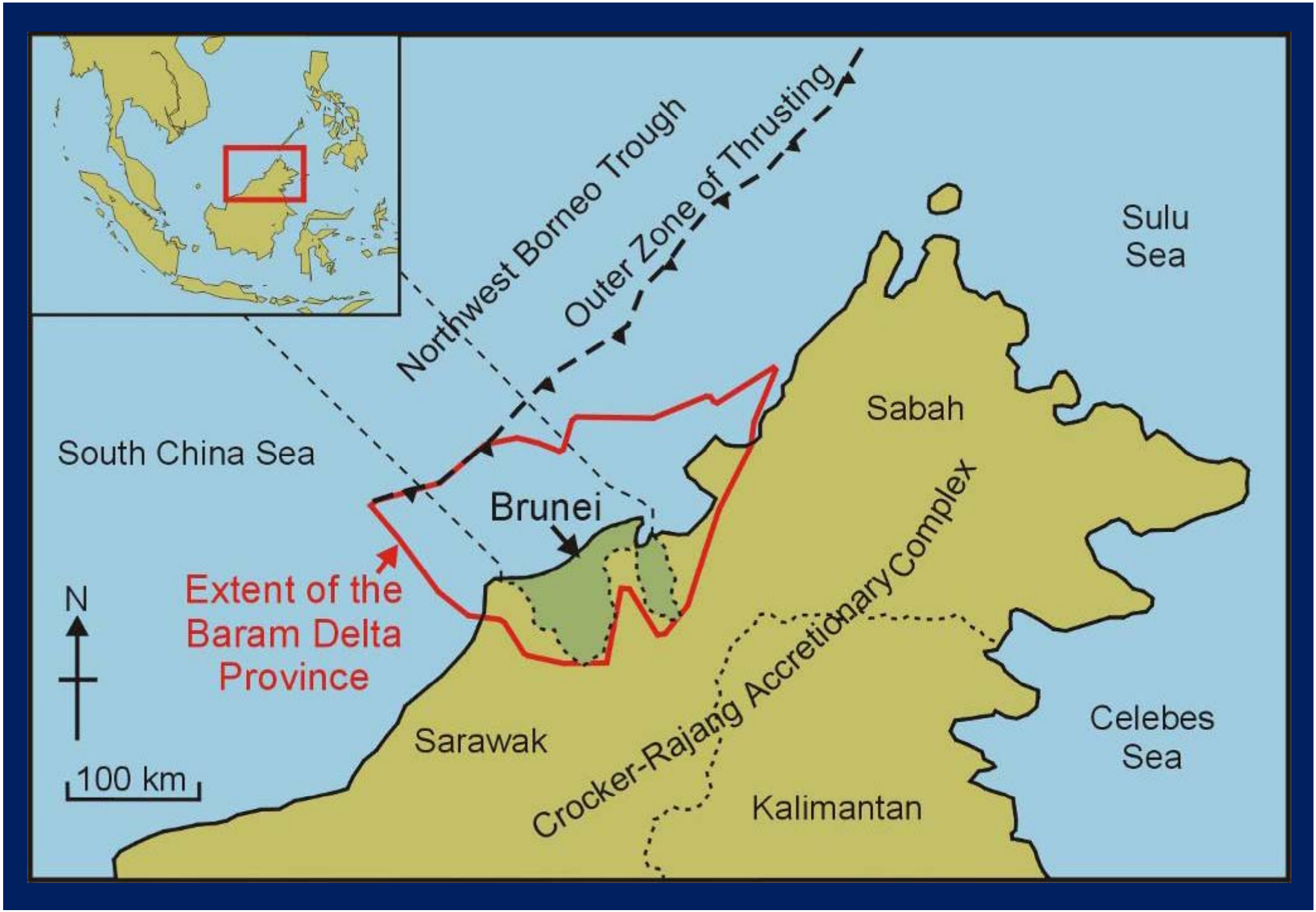
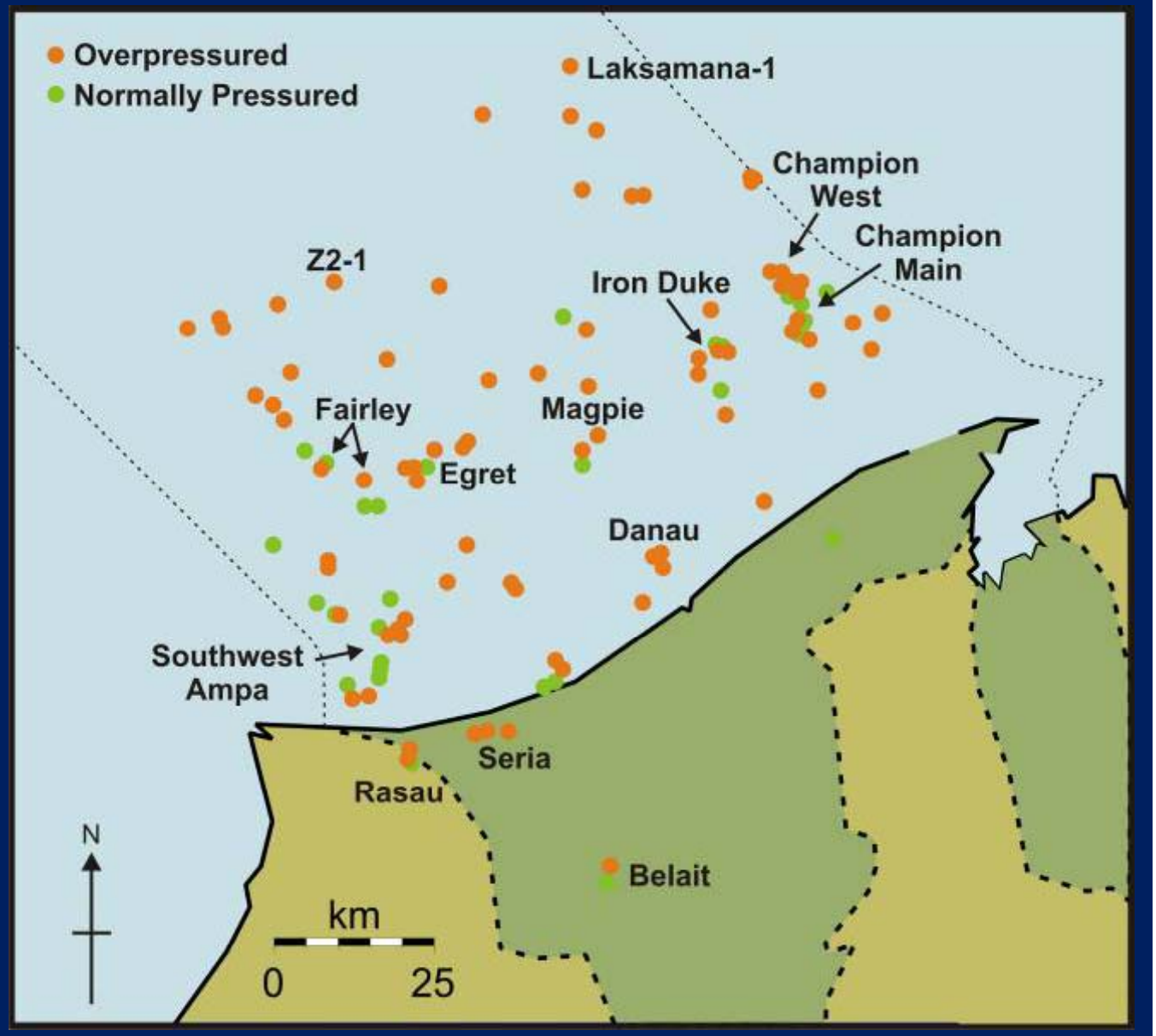

Northwest Borneo Trough
Outer Zone of Thrusting
Sulu Sea
Sabah
South China Sea
Brunei
Extent of the Baram Delta Province
N
100 km
Crocker-Rajang Accretionary Complex
Sarawak
Celebes Sea
Kalimantan

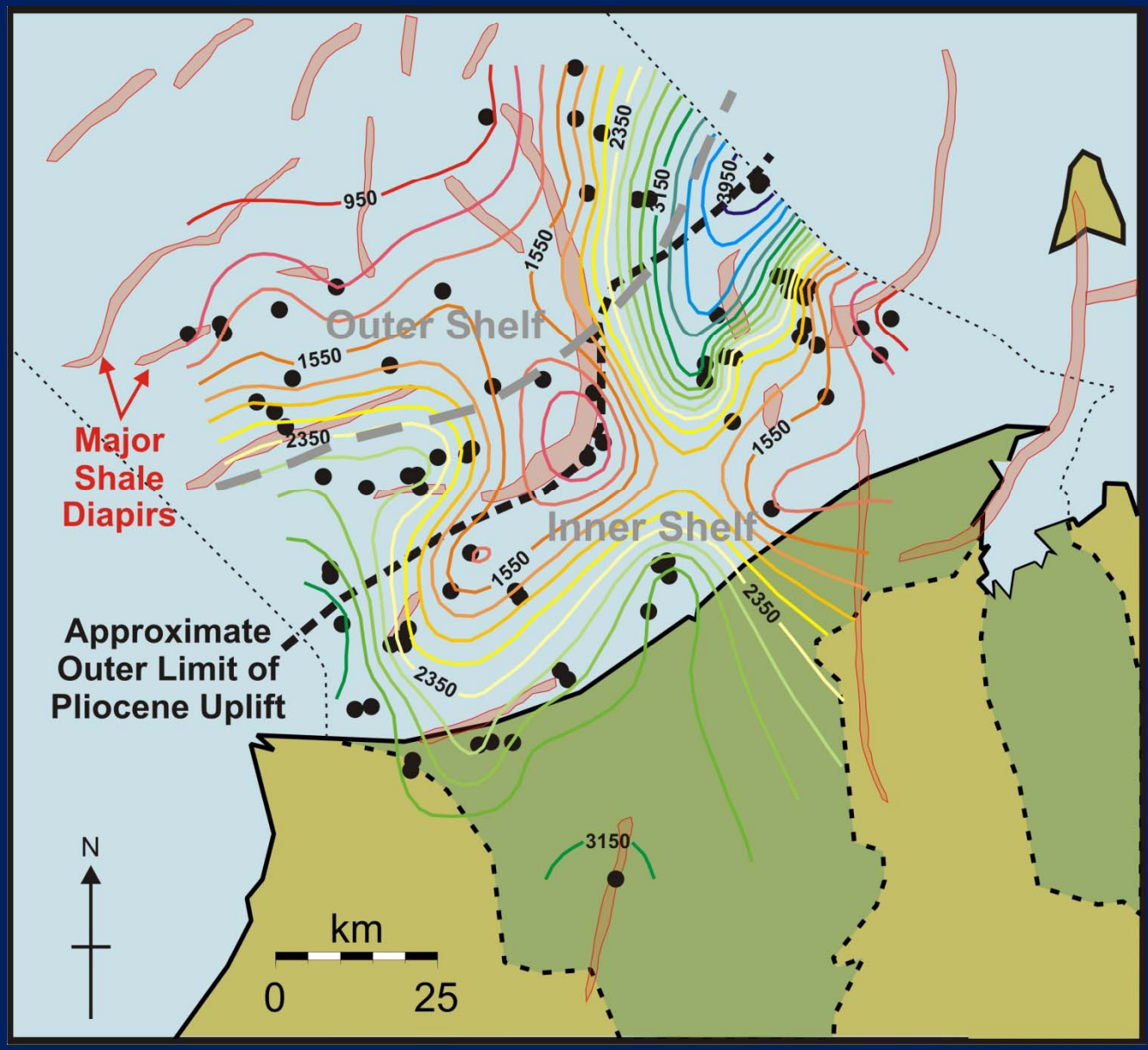
Distribution of Overpressure in Brunei

- RFTs, mud weights, LOTs, DSTs, kicks and losses collected for 157 wells in 61 fields.
- Overpressures observed in 101 wells in 54 fields (P_p >11.5 MPa/km).
- Sub-lithostatic pore pressure magnitudes observed in 42 fields.

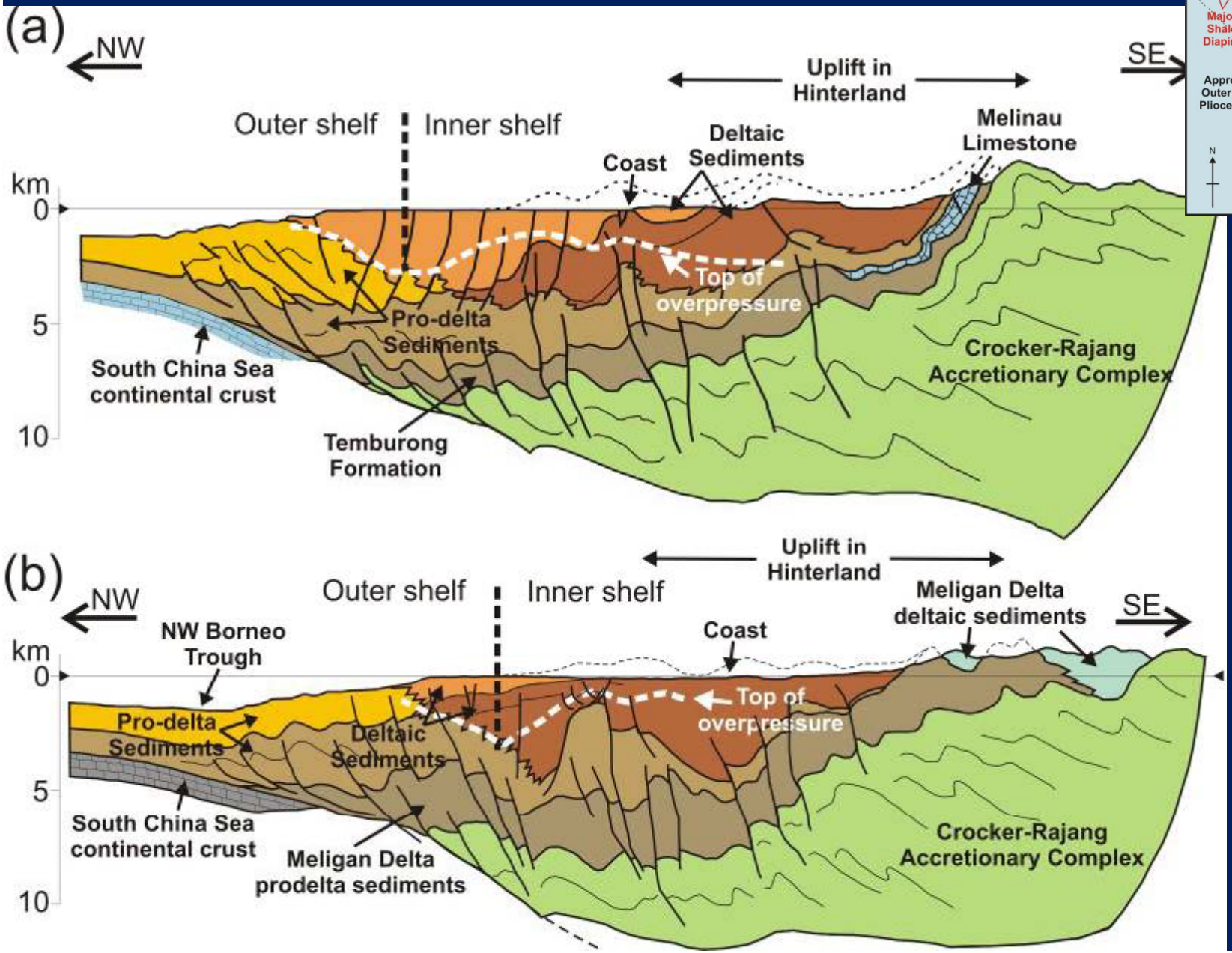


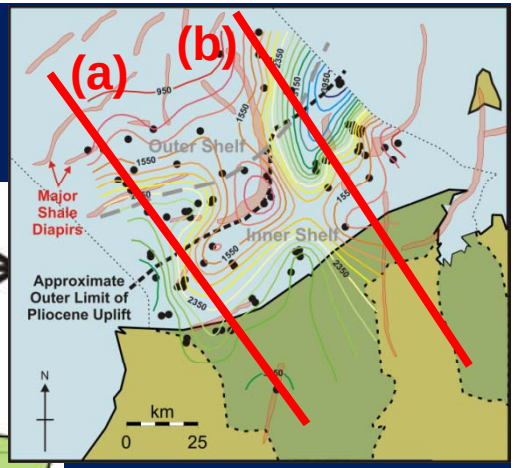
Depth to Top of Overpressure in Brunei

- Overpressures can be split into Outer and Inner Shelf Domains
- Inner shelf overpressures have sharply varying depth to onset and are highly compartmentalized.
- Outer shelf overpressures gradually shallow towards NW, onset at top of pro-delta shales.



Depth to Top of Overpressure in Brunei





Inner and outer shelf have different petroleum play types and sample different stratigraphic units:

Inner: Deltaics

Outer: Pro-delta shales

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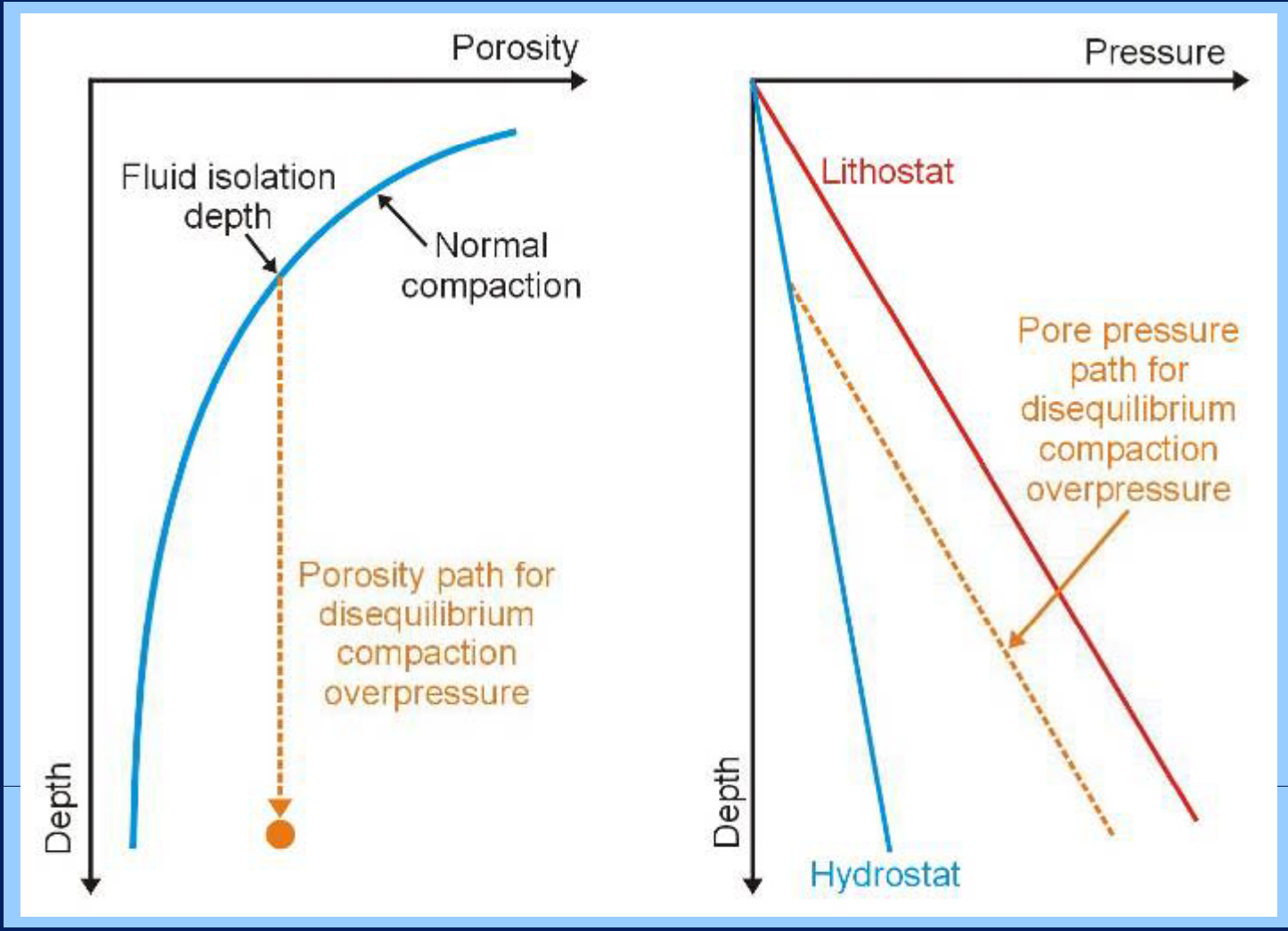
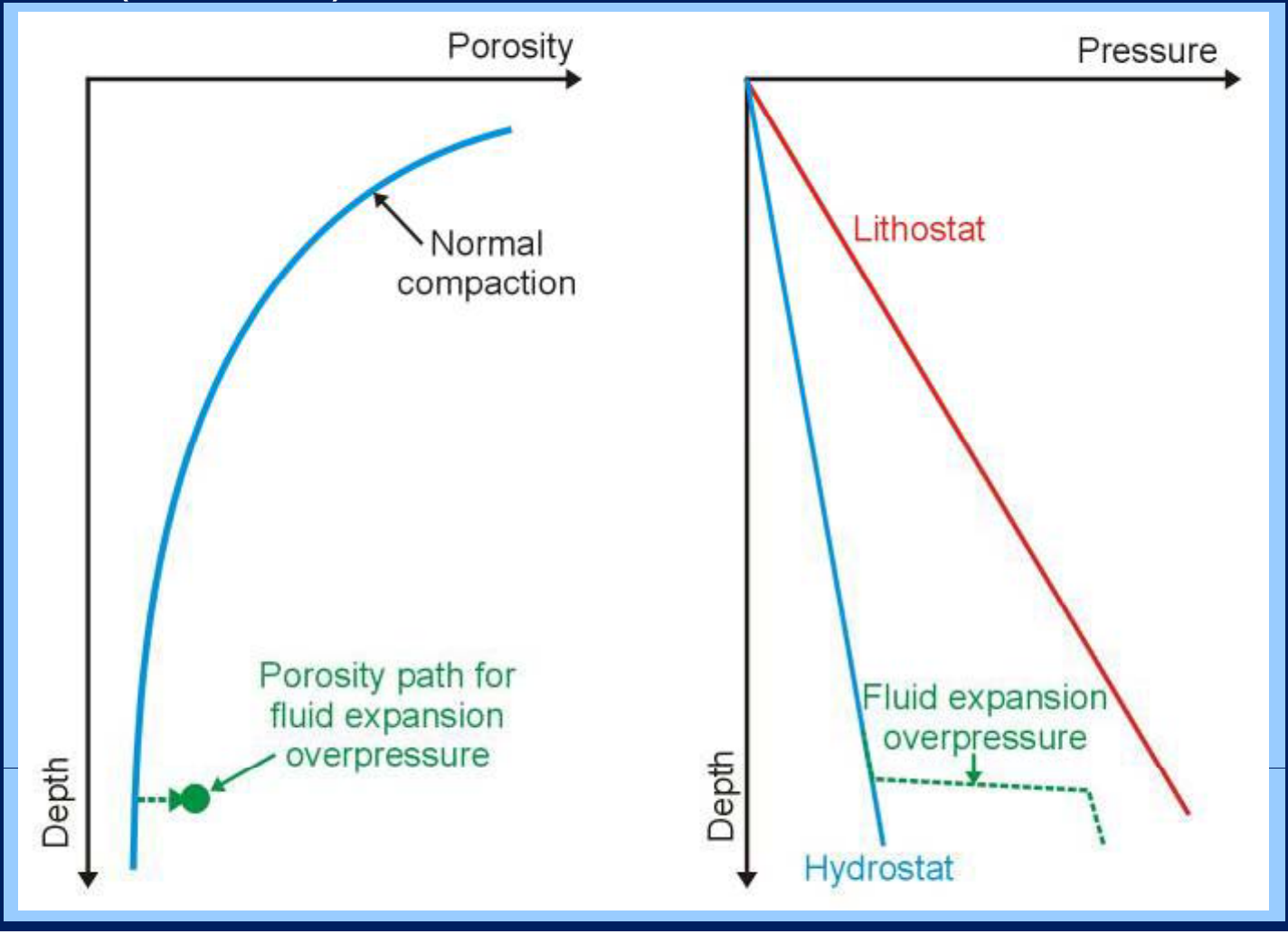
Disequilibrium Compaction Overpressure

- Occurs when fluid expulsion is impeded during compaction
- Pore fluids support some of the overburden and become OP'd

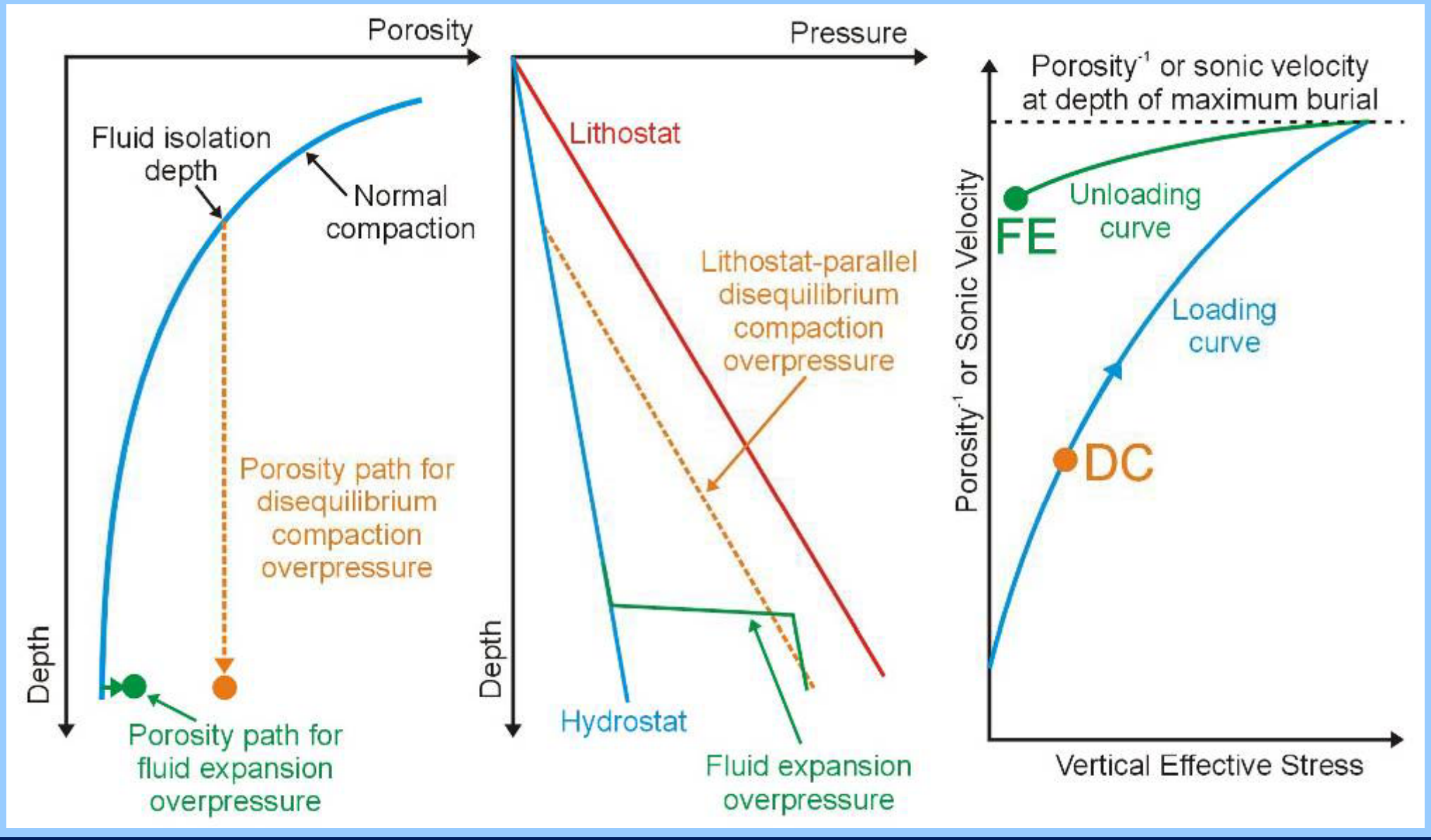


Fluid Expansion/Inflation Overpressure

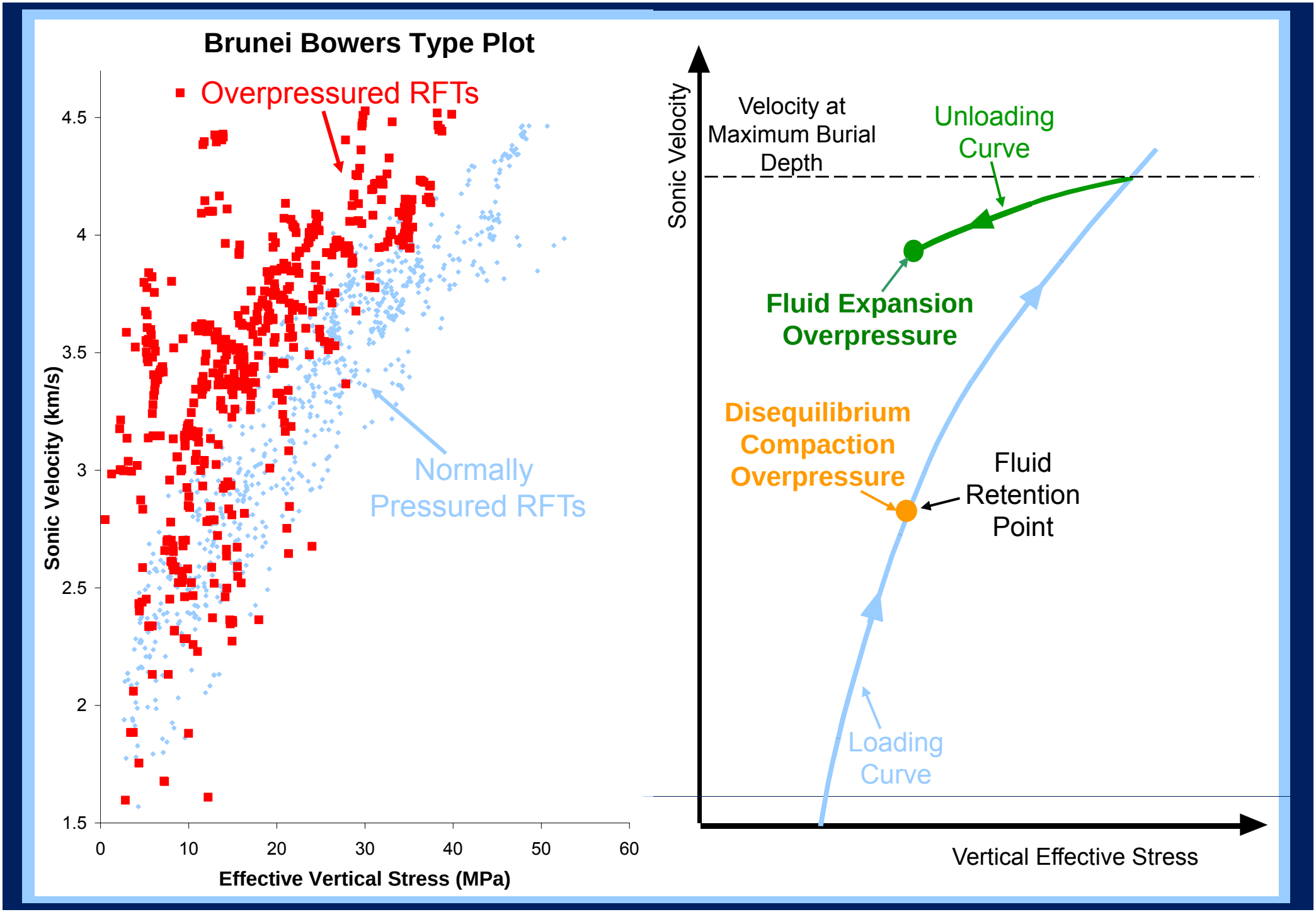
- Increase in fluid volume within a confined pore space.
- Kerogen-to-gas maturation, clay diagenesis, aquathermal expansion, vertical transfer along faults and fractures into shallower reservoirs (inflation).



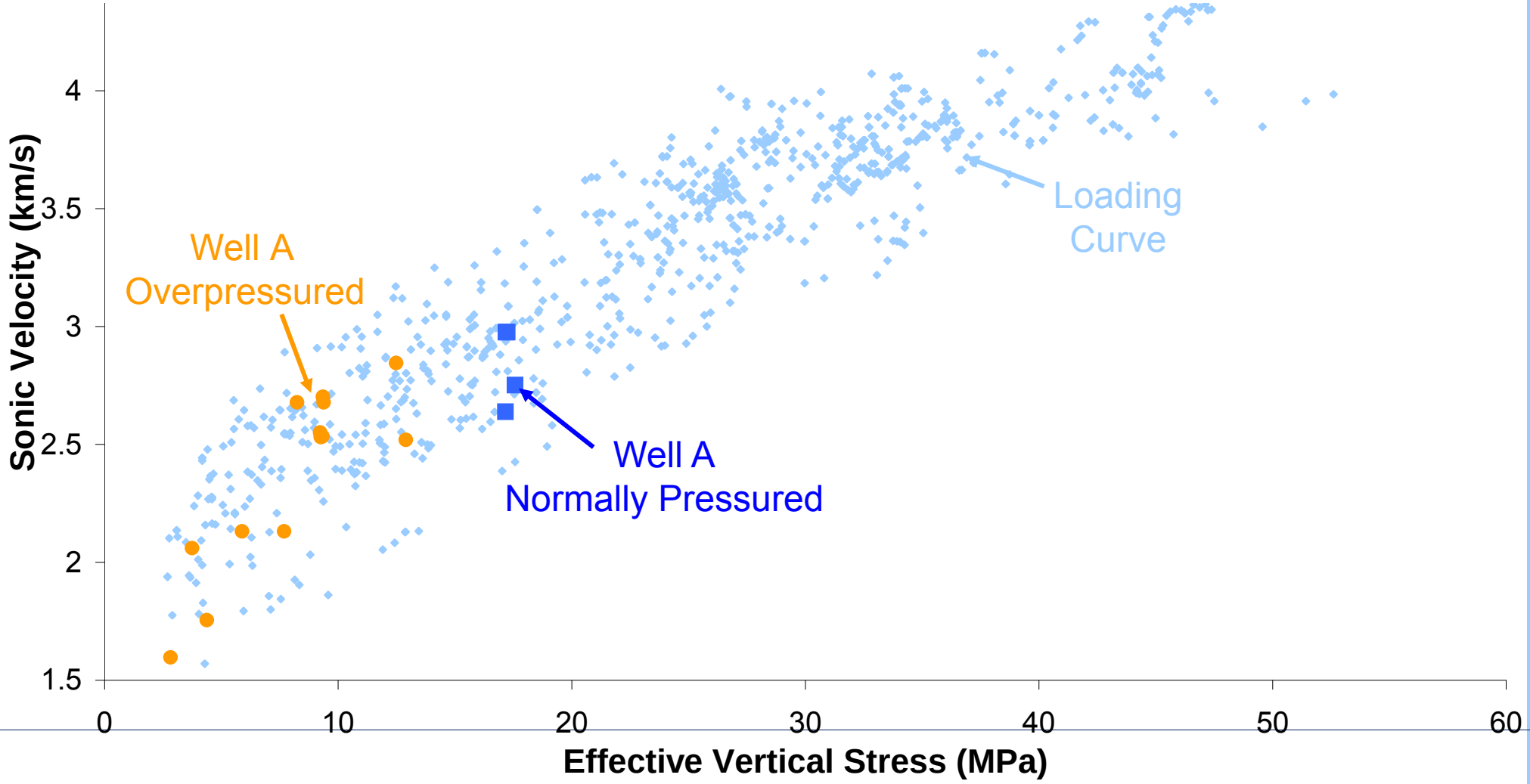
Determining Overpressure Origin: Porosity-Effective Stress Plots



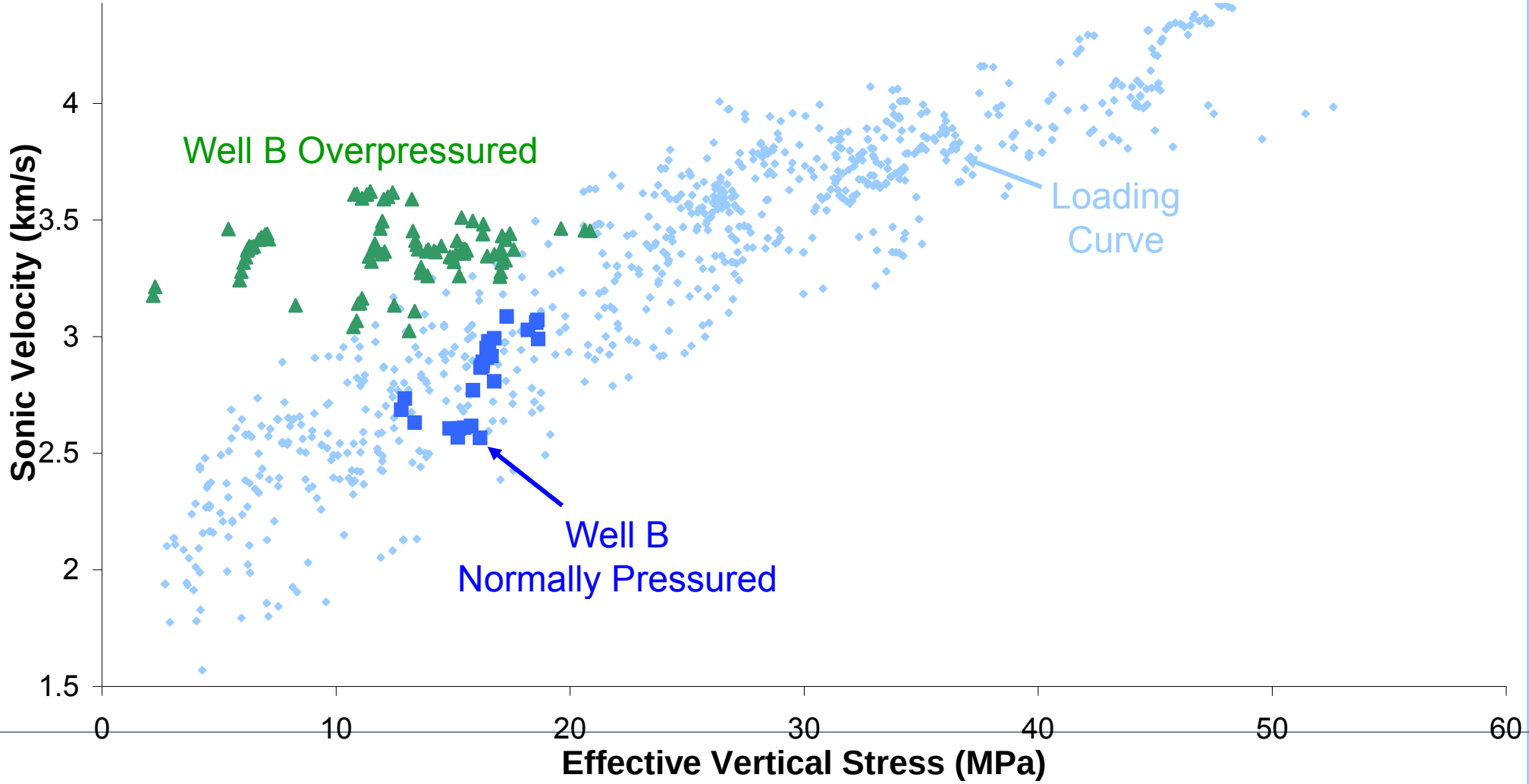
Modified after Bowers (1994)


Brunei Bowers Type Plot
Overpressured RFTs
Normally Pressured RFTs
Sonic Velocity (km/s)
4.5
4
3.5
3
2.5
2
1.5
0
10
20
30
40
50
60
Effective Vertical Stress (MPa)
Sonic Velocity
Velocity at Maximum Burial Depth
Unloading Curve
Fluid Expansion Overpressure
Disequilibrium Compaction Overpressure
Fluid Retention Point
Loading Curve
Vertical Effective Stress

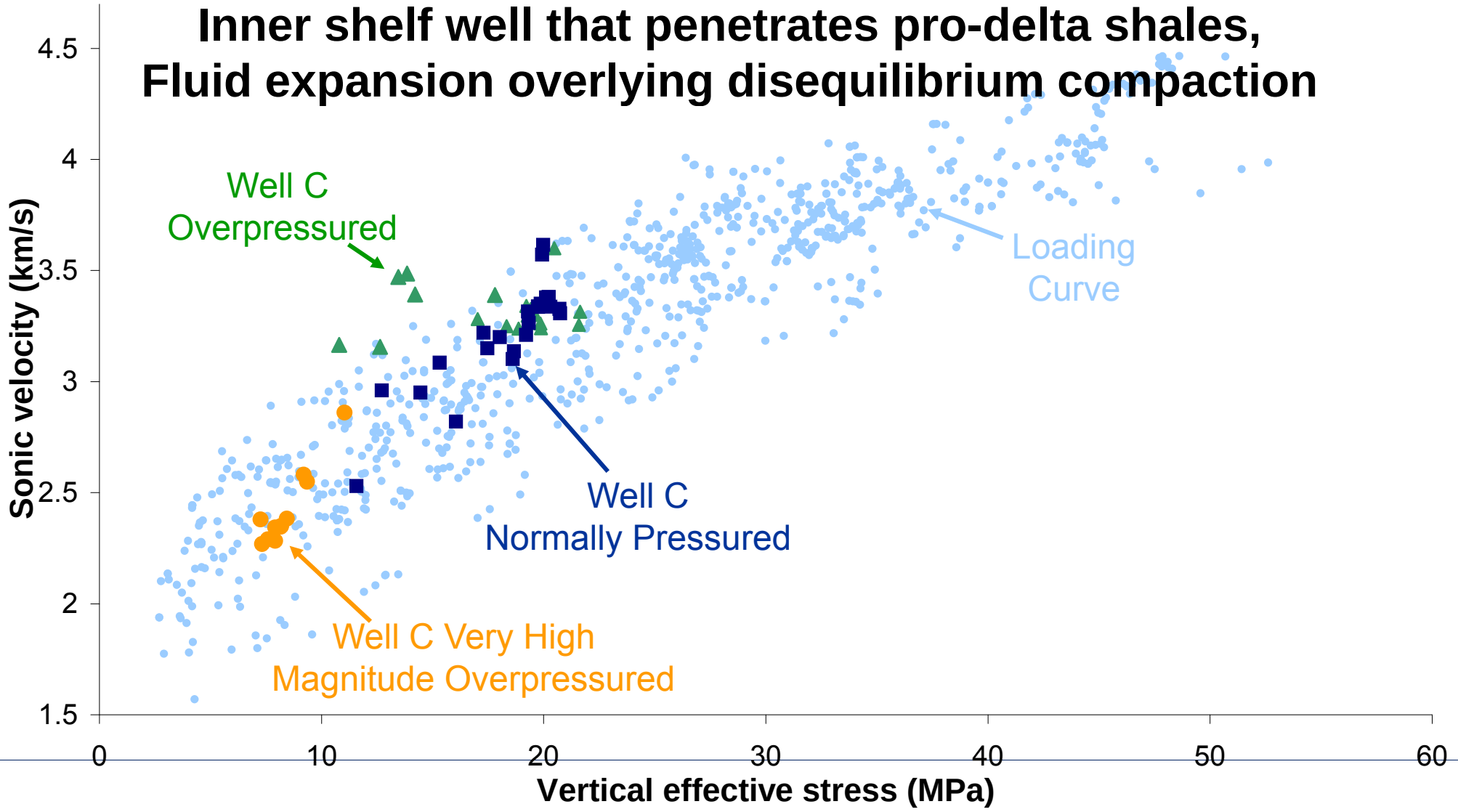
Well A Sonic Velocity-Effective Stress Plot
Outer shelf well – Disequilibrium Compaction

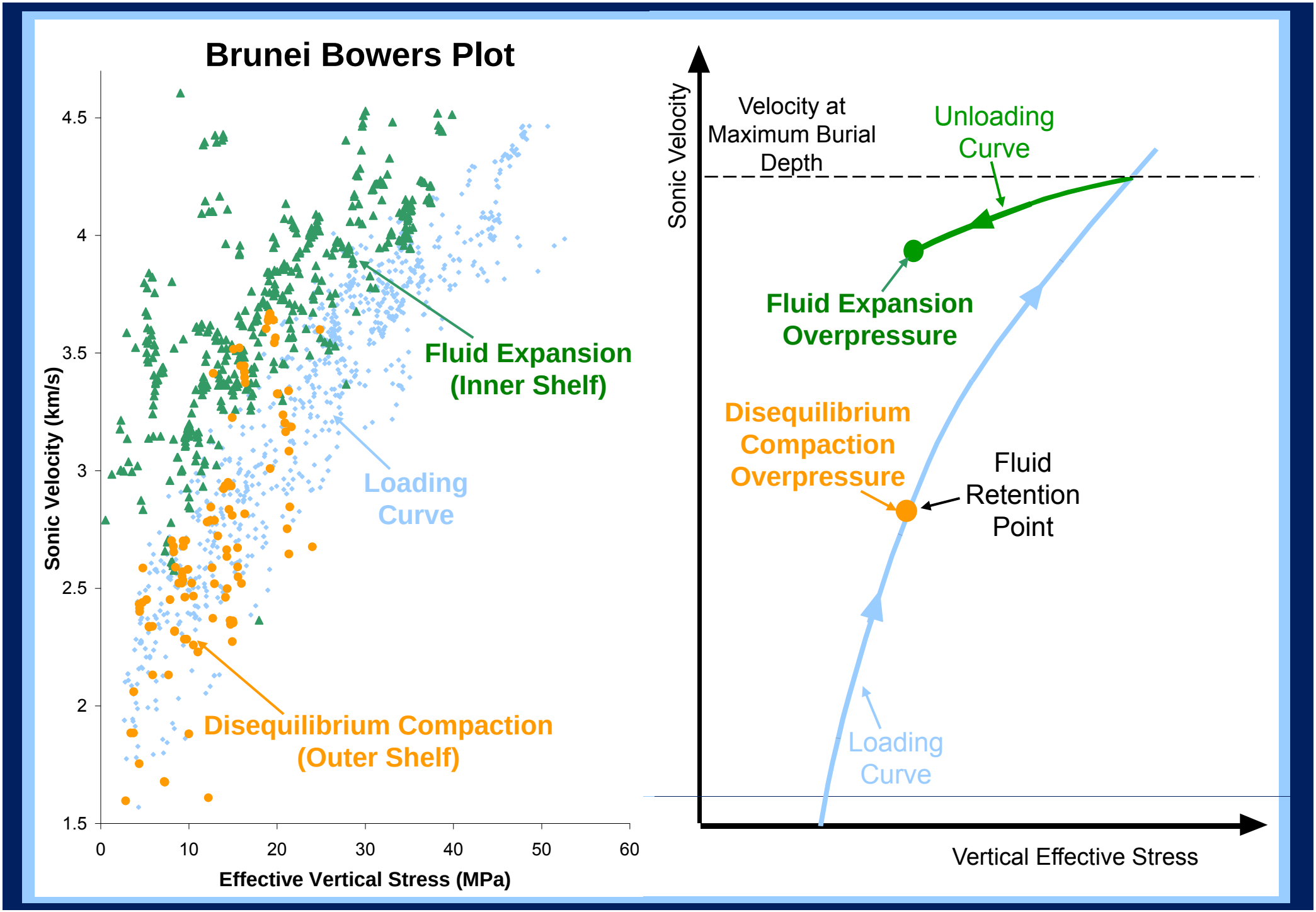


Well B Sonic Velocity-Effective Stress Plot
Inner shelf well - Fluid Expansion / Inflation

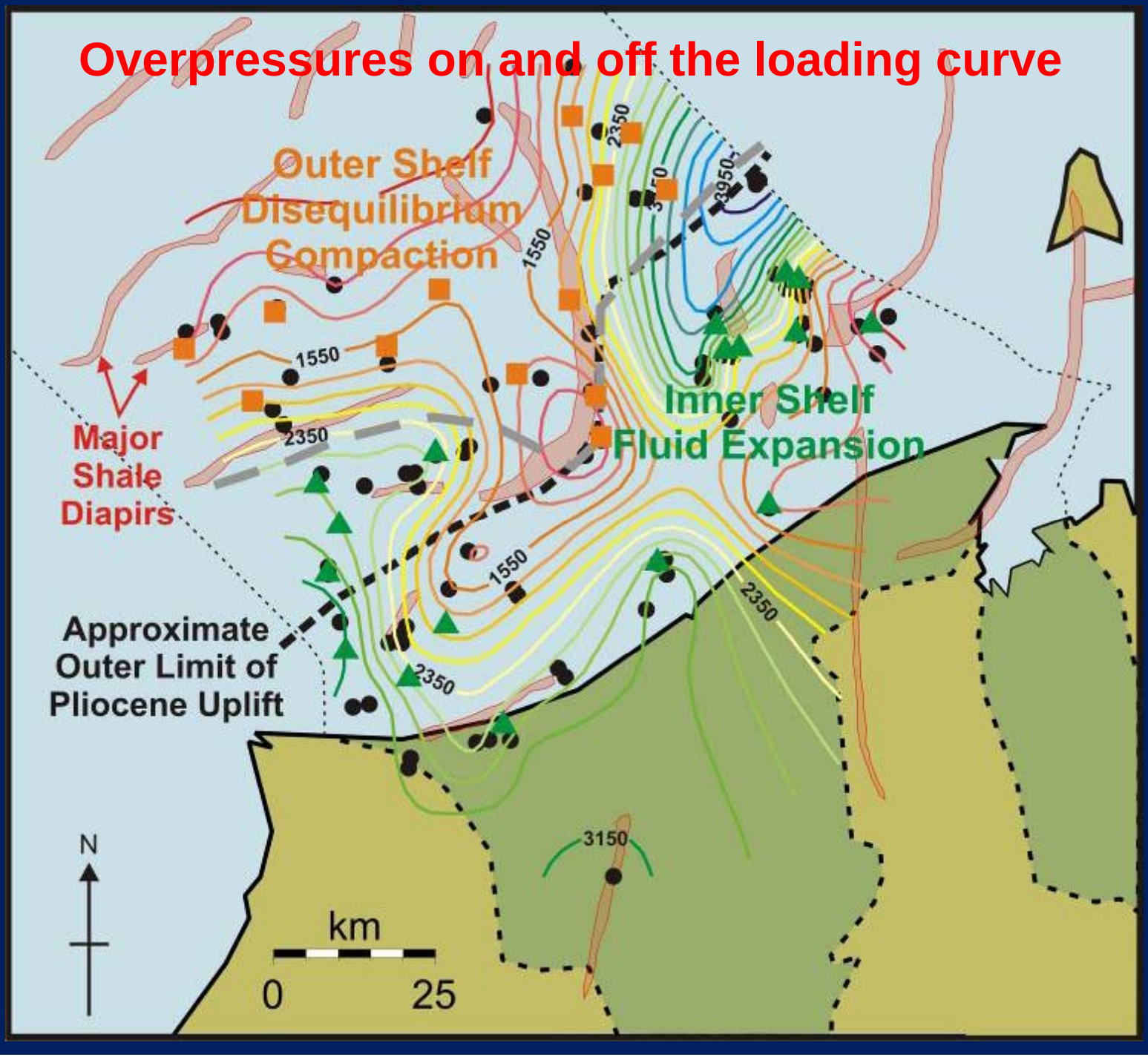


Well C Sonic Velocity-Effective Stress Plot
Inner shelf well that penetrates pro-delta shales, Fluid expansion overlying disequilibrium compaction

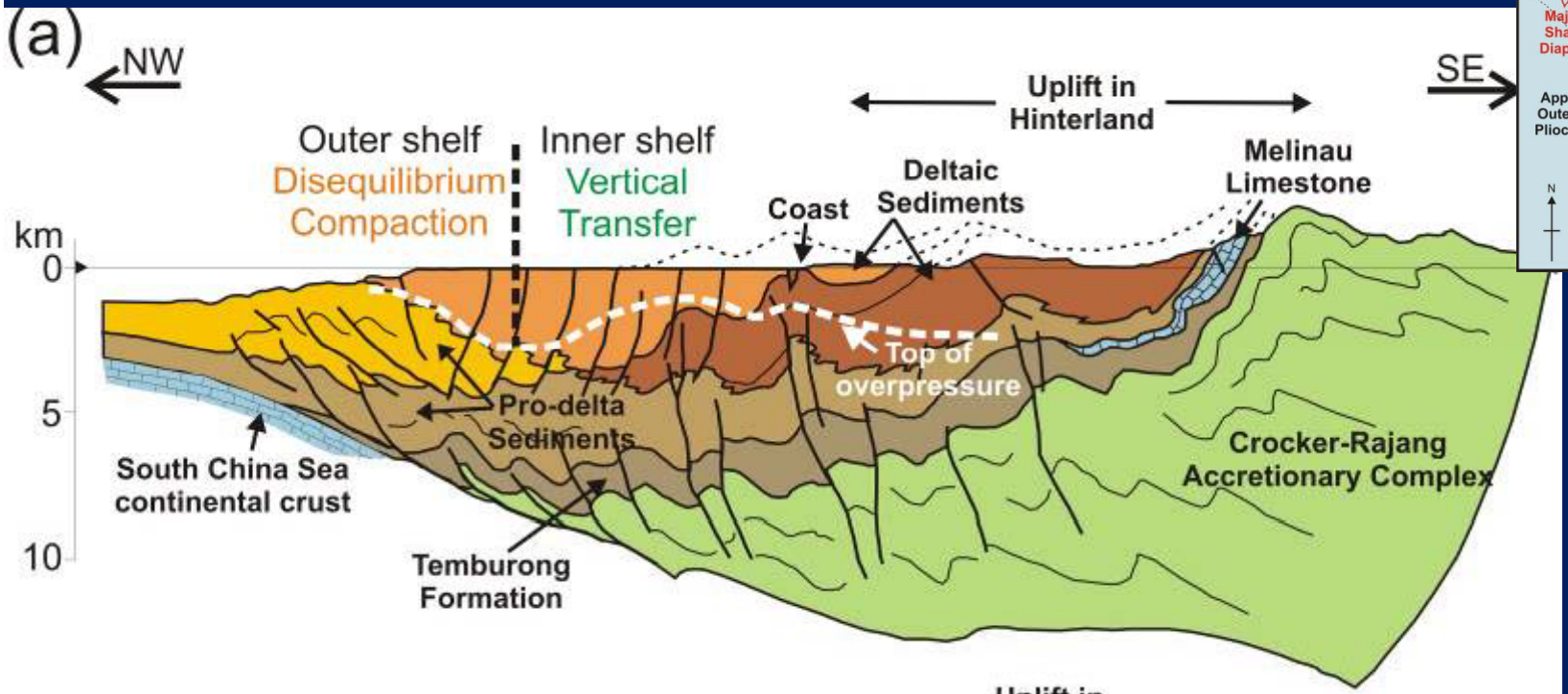


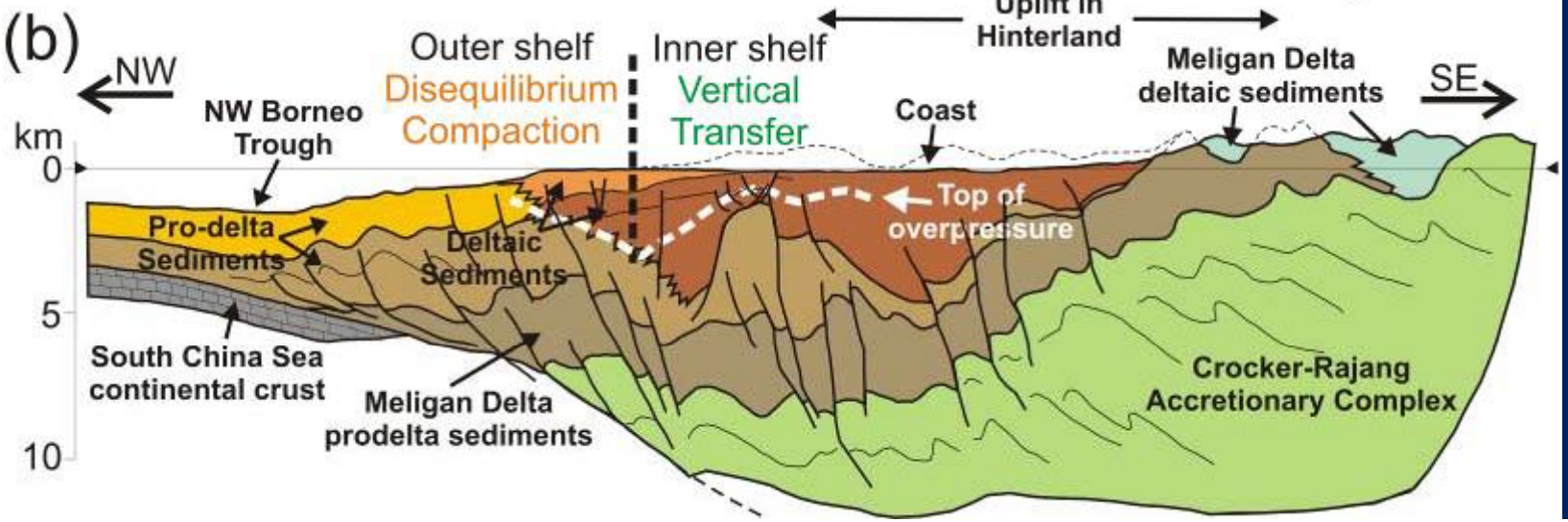

Brunei Bowers Plot
Sonic Velocity (km/s)
4.5
4
3.5
3
2.5
2
1.5
0
10
20
30
40
50
60
Effective Vertical Stress (MPa)
Fluid Expansion
(Inner Shelf)
Loading
Curve
Disequilibrium Compaction
(Outer Shelf)
Sonic Velocity
Velocity at
Maximum Burial
Depth
Unloading
Curve
Fluid Expansion
Overpressure
Disequilibrium
Compaction
Overpressure
Fluid
Retention
Point
Loading
Curve
Vertical Effective Stress

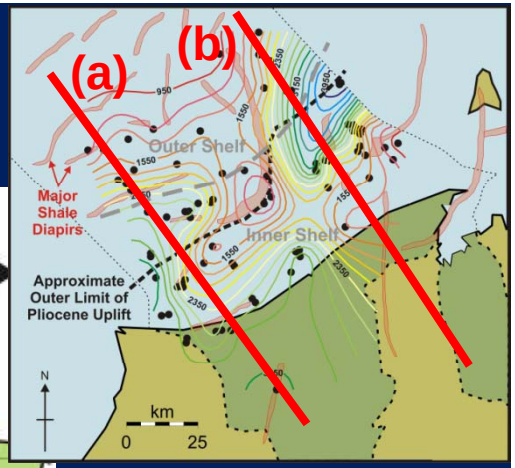
Overpressures on and off the loading curve



Which Fluid Expansion Mechanism?







No conventional fluid expansion mechanism exists for overpressures in the inner shelf deltaics.

Inner shelf region has undergone extensive inversion resulting in migration of huge volumes of fluid out of pro-delta shales (including oil & gas)

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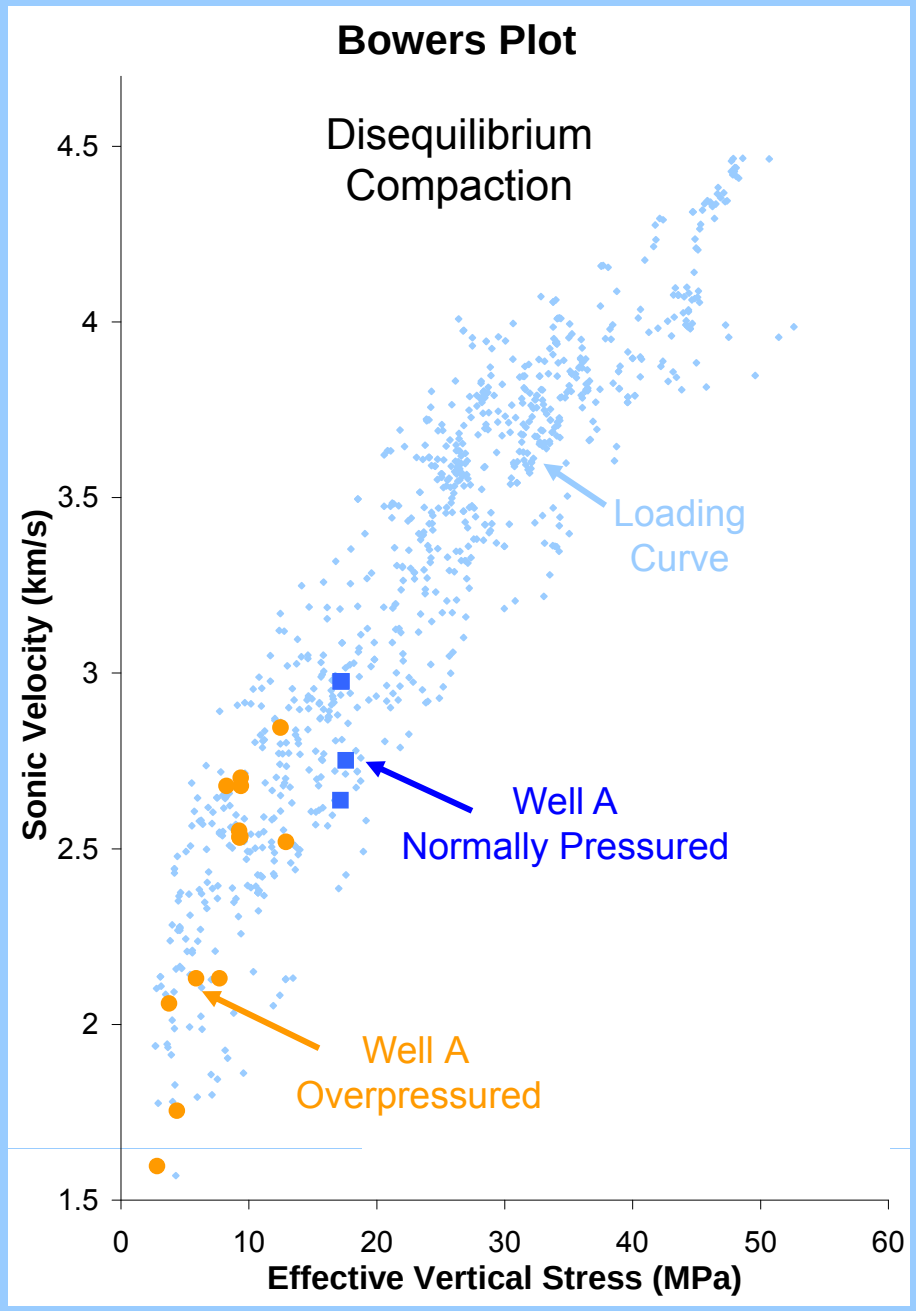
Petrophysical Response of Overpressure

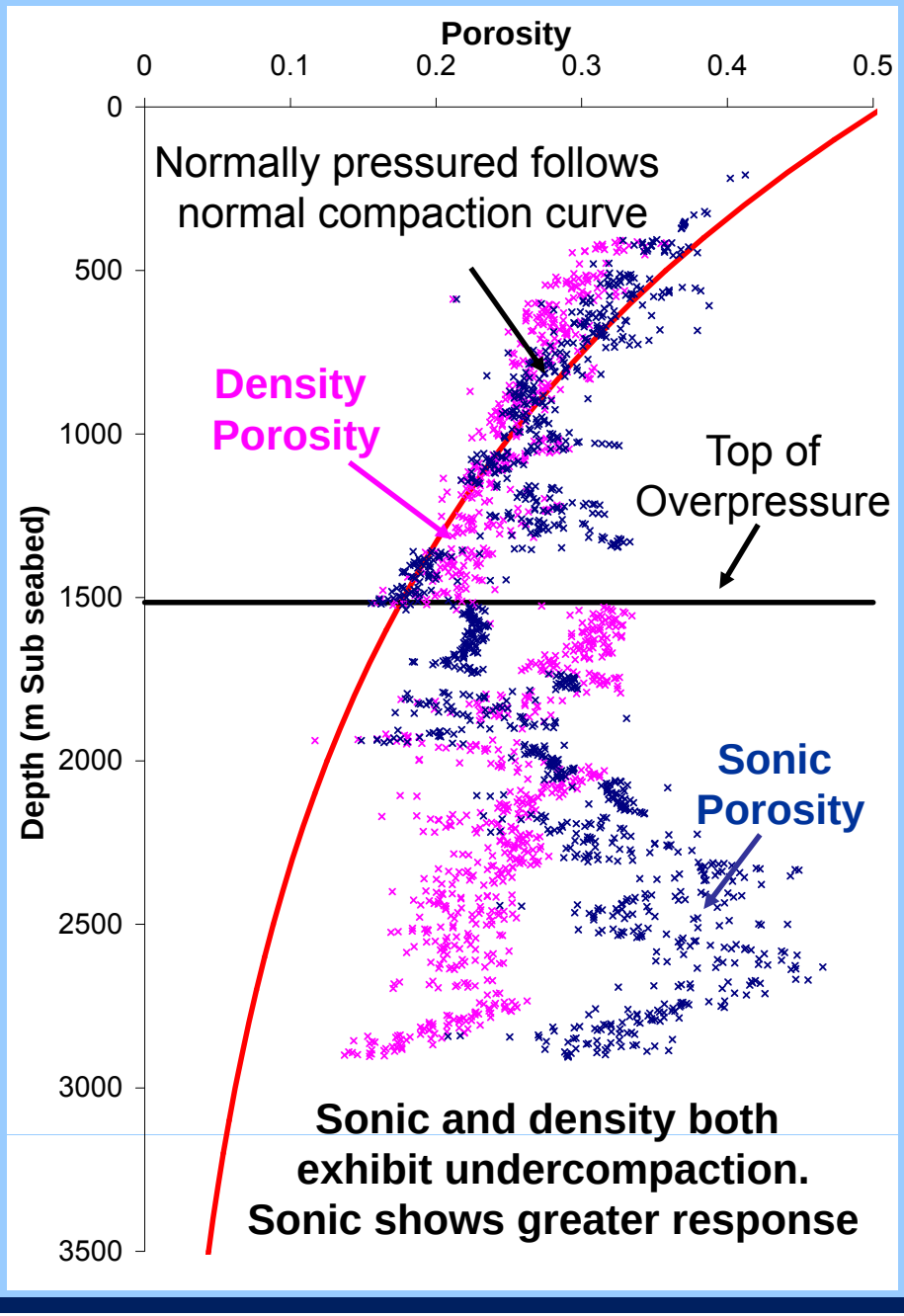
Can we detect vertically transferred overpressures?

- Calibrate sonic- and density-derived porosities in normally compacted, normally pressured shales

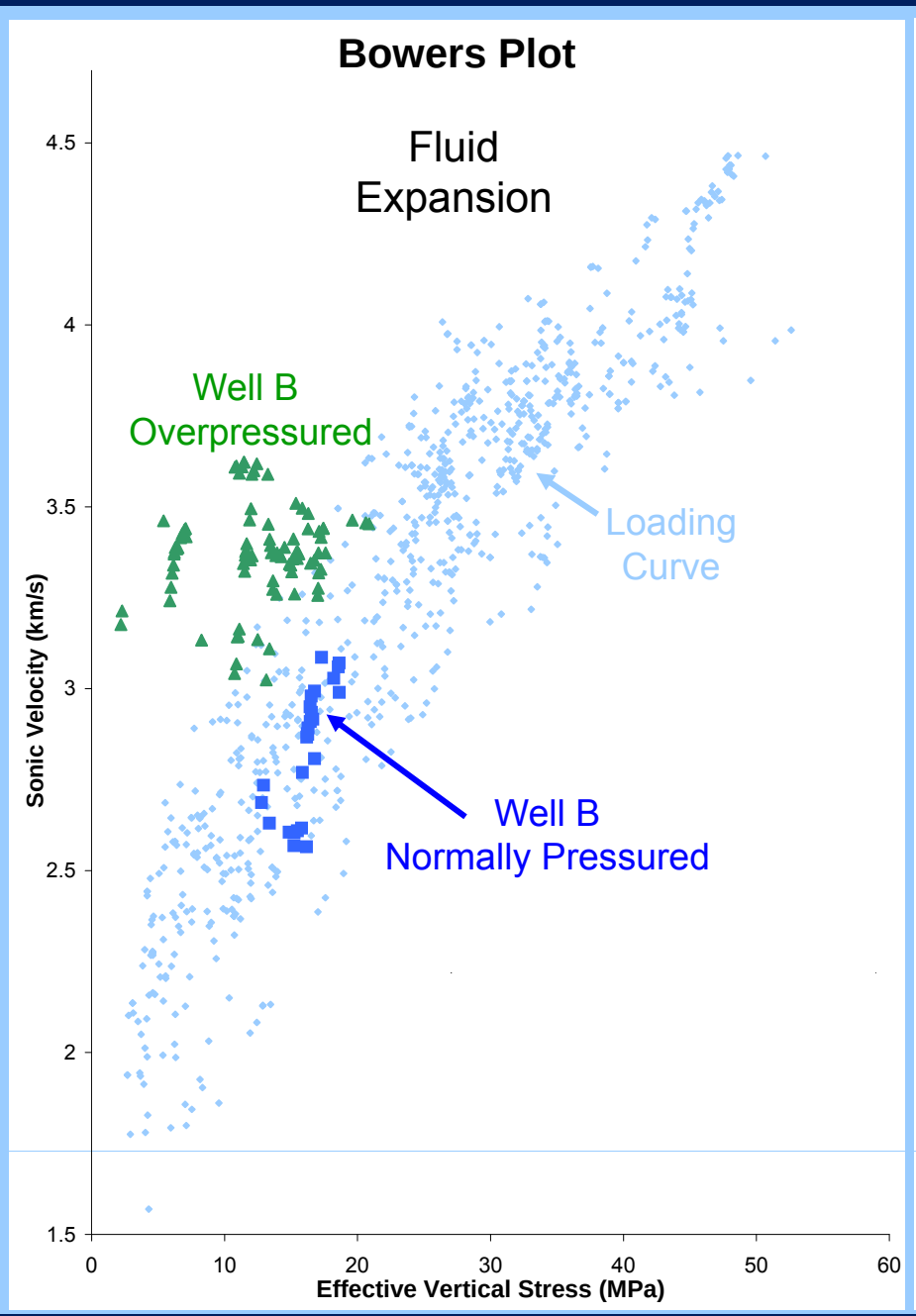
- Compare porosity estimated from density and sonic logs in different overpressure mechanisms

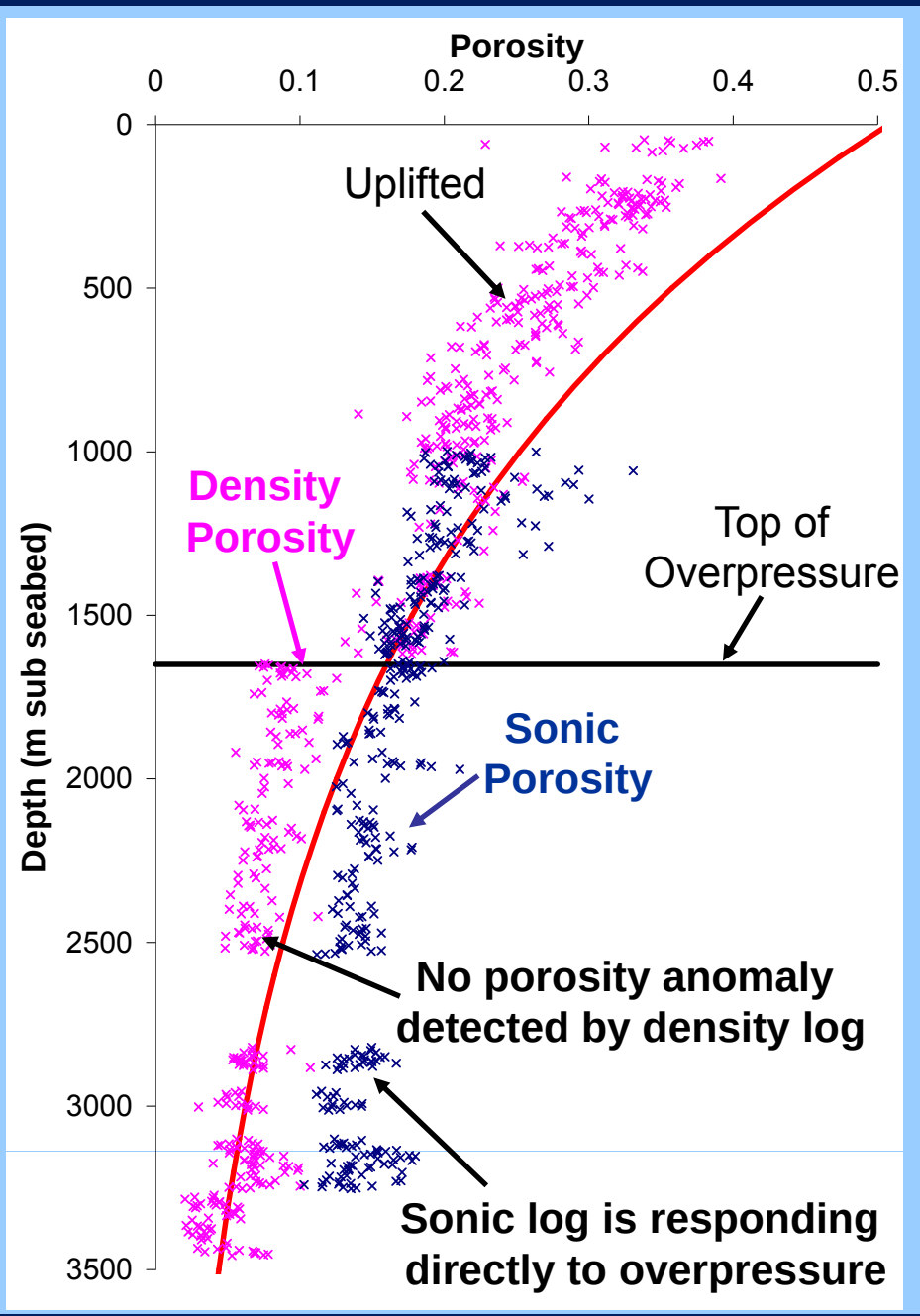
Well A: Disequilibrium Compaction



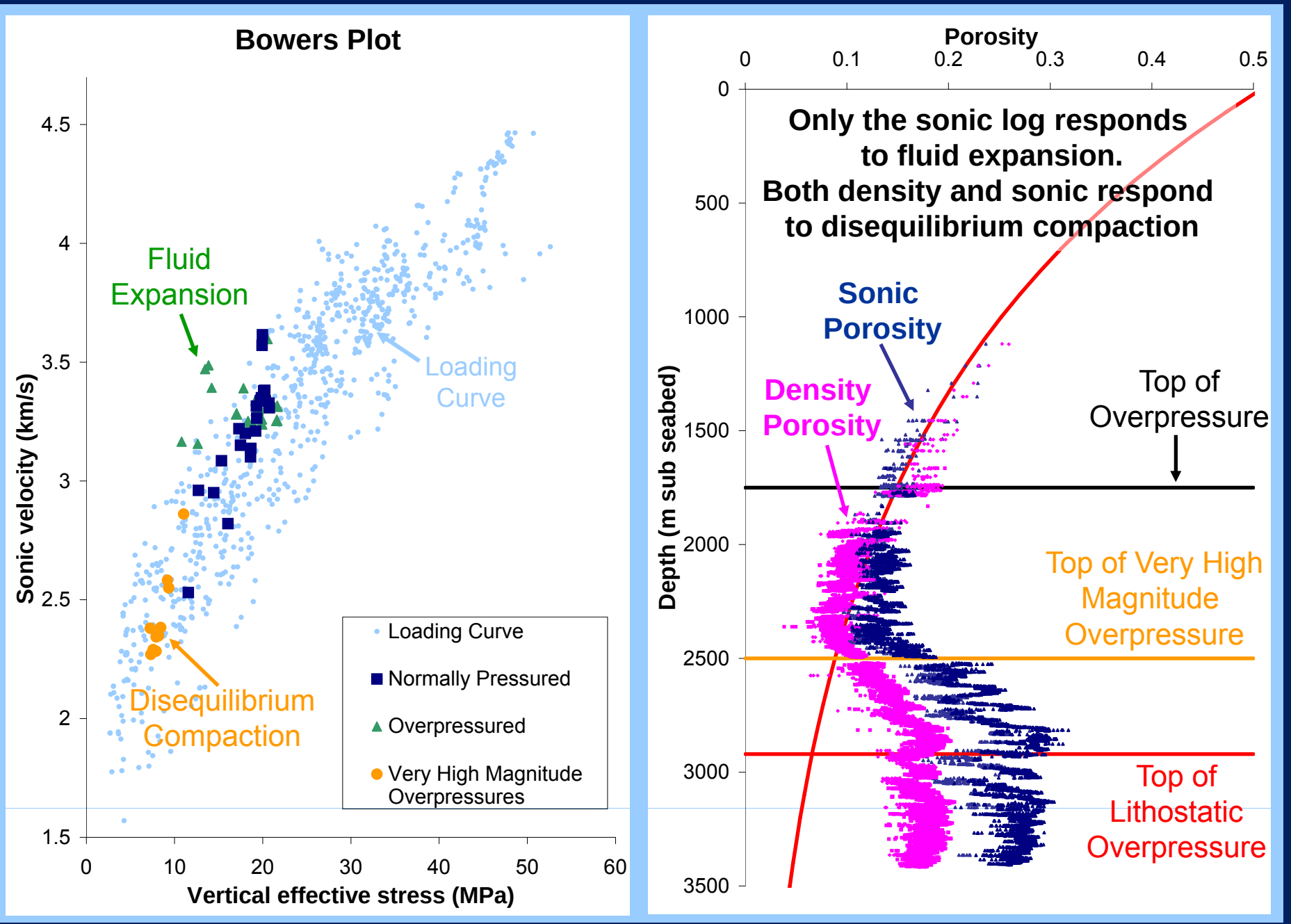


Well B: Fluid Expansion





Well C: Fluid Expansion & Disequilibrium Compaction



Petrophysical Response of Overpressure

- Sonic log shows response in vertically transferred overpressures – even though there is no porosity change.

- Hermanrud et al. (1998) suggest the sonic log is slower in fluid expansion overpressures due textural changes in the rock.

- ***There is hope for reliable pore pressure prediction in fluid expansion overpressures!***

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Pore Pressure Prediction

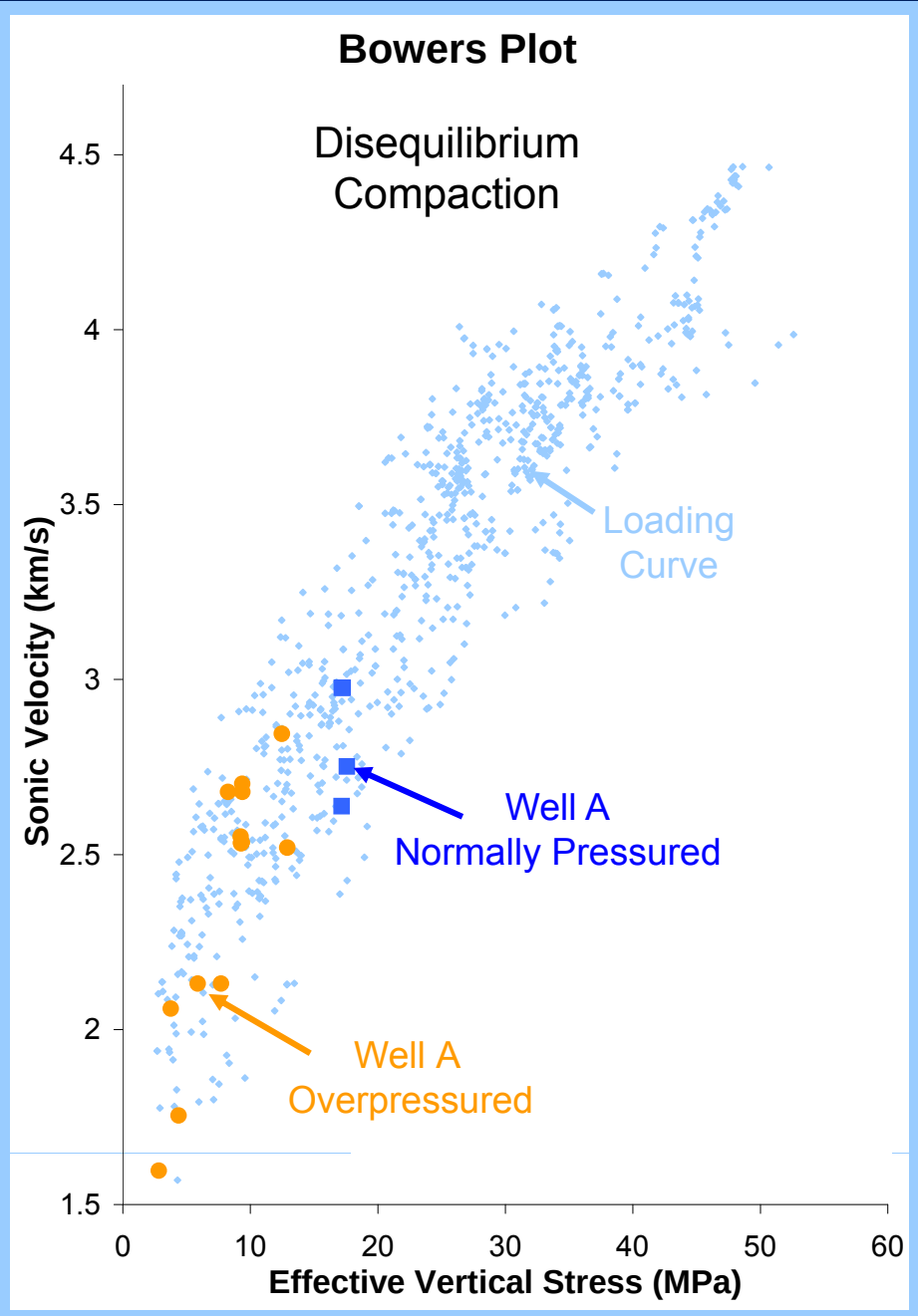
- Eaton method (1972):

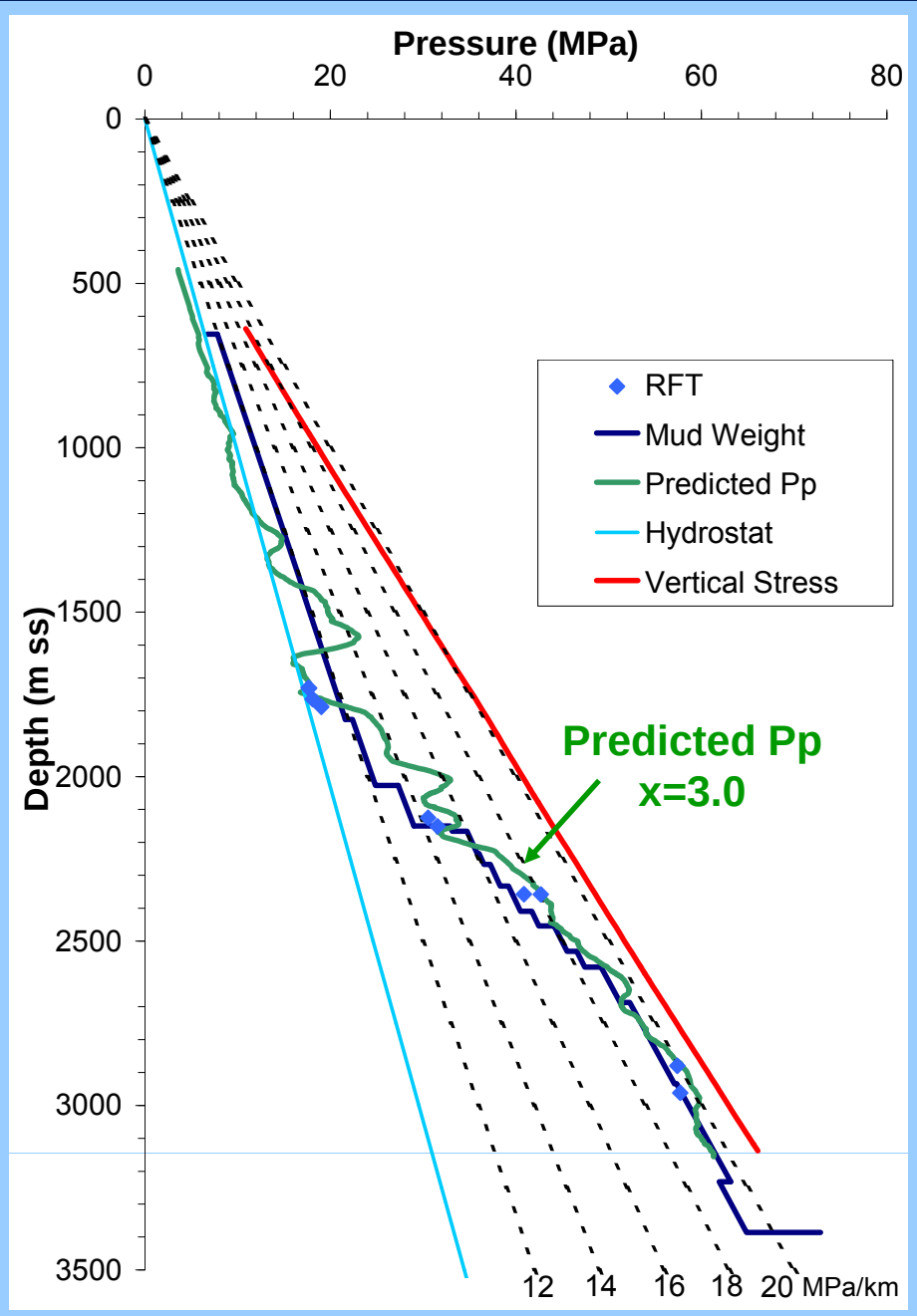
$$P_p = \sigma_v - (\sigma_v - P_{norm}) \times (\Delta t_{norm} / \Delta t_{obs})^x$$

- Disequilibrium compaction (outer shelf): x=3.0

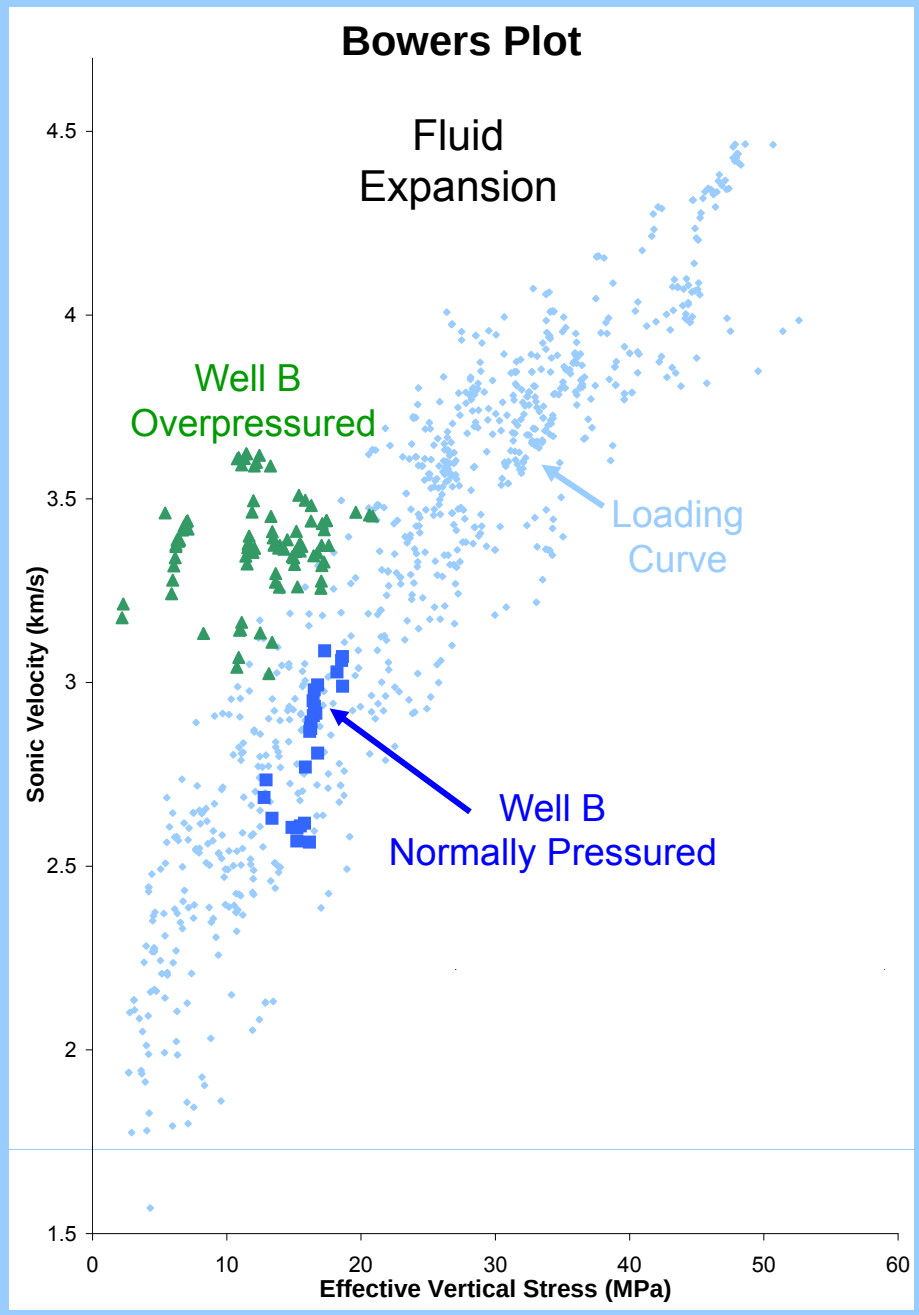
- Fluid expansion (inner shelf): x=6.5

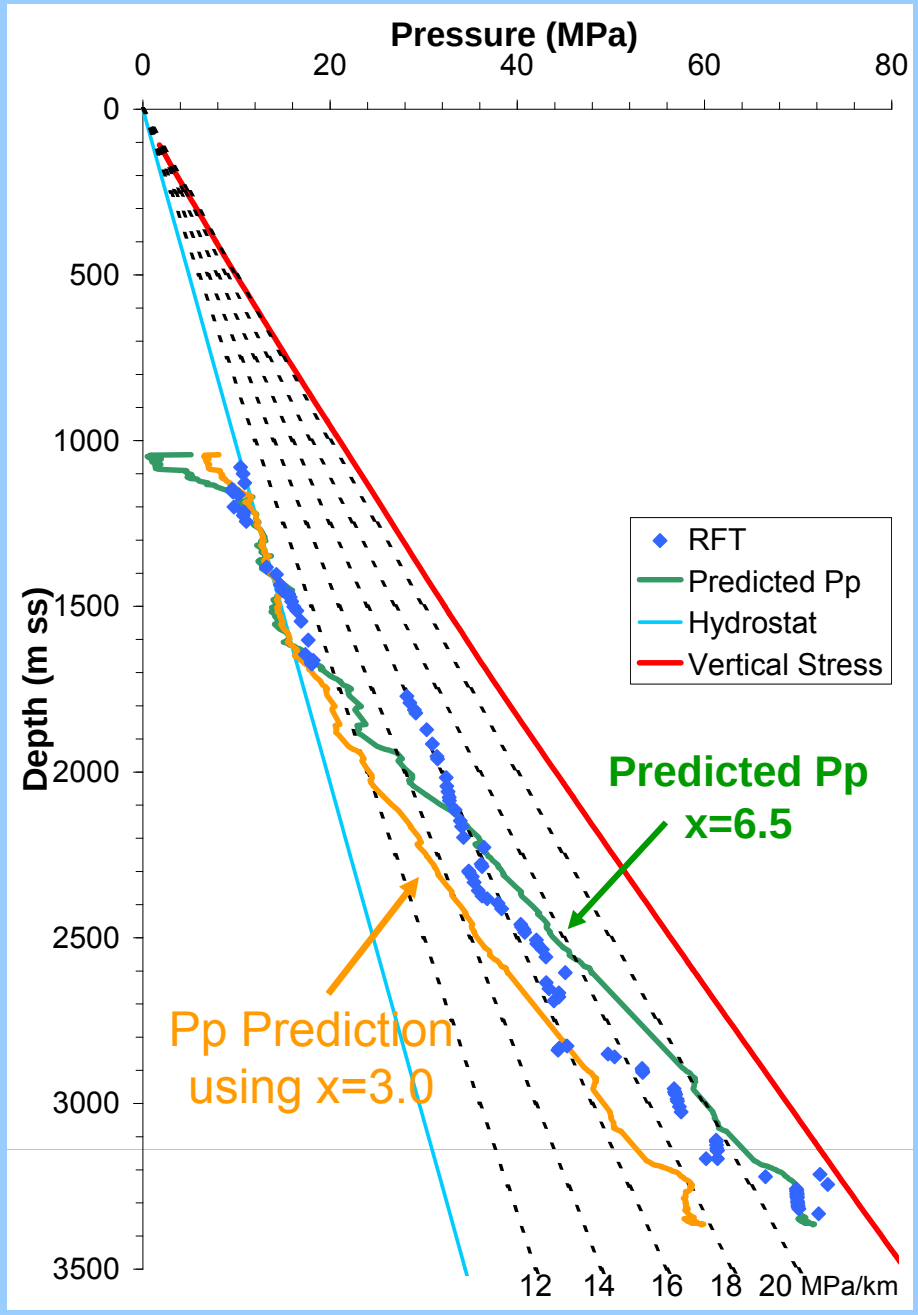
Well A: Disequilibrium Compaction



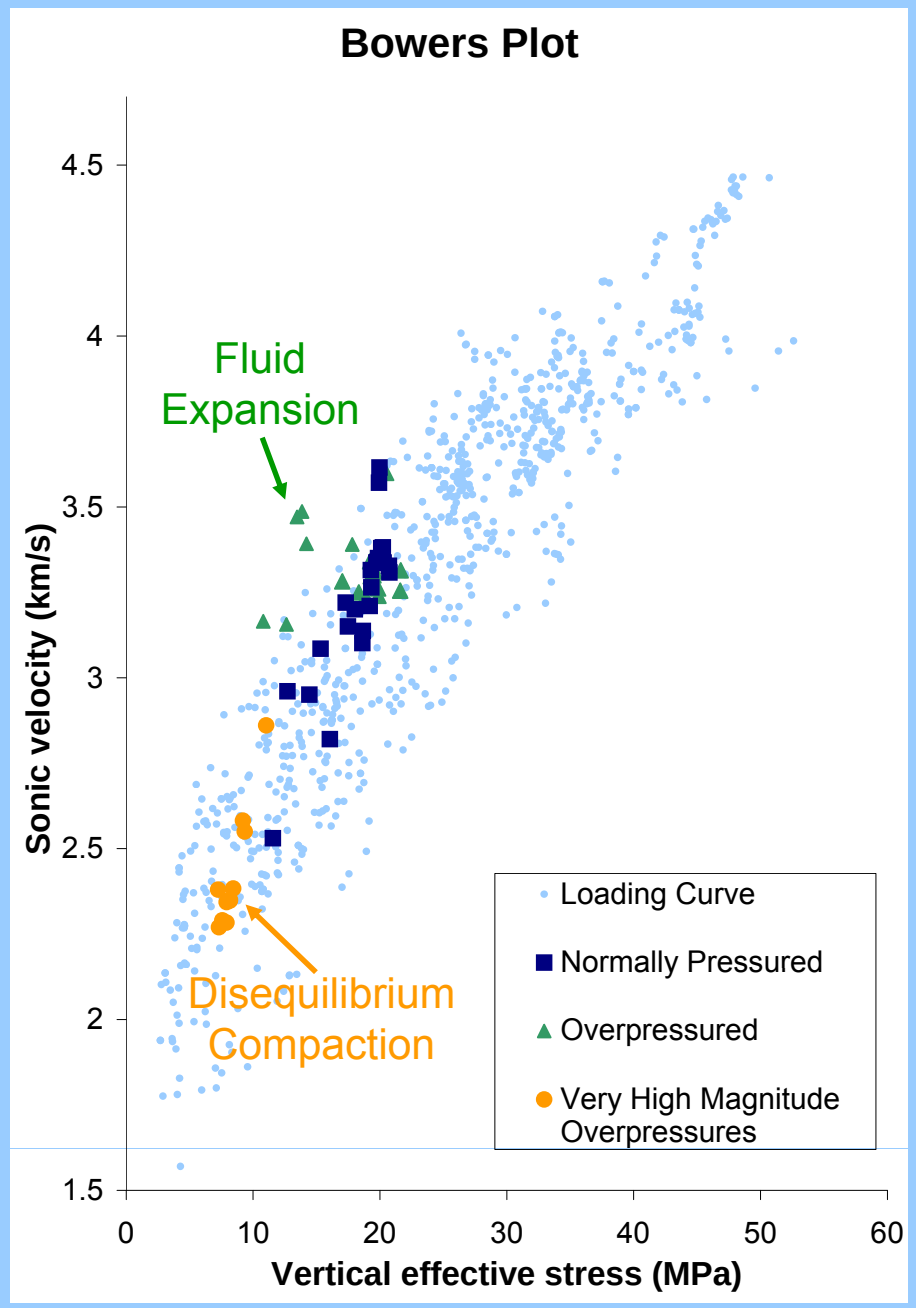


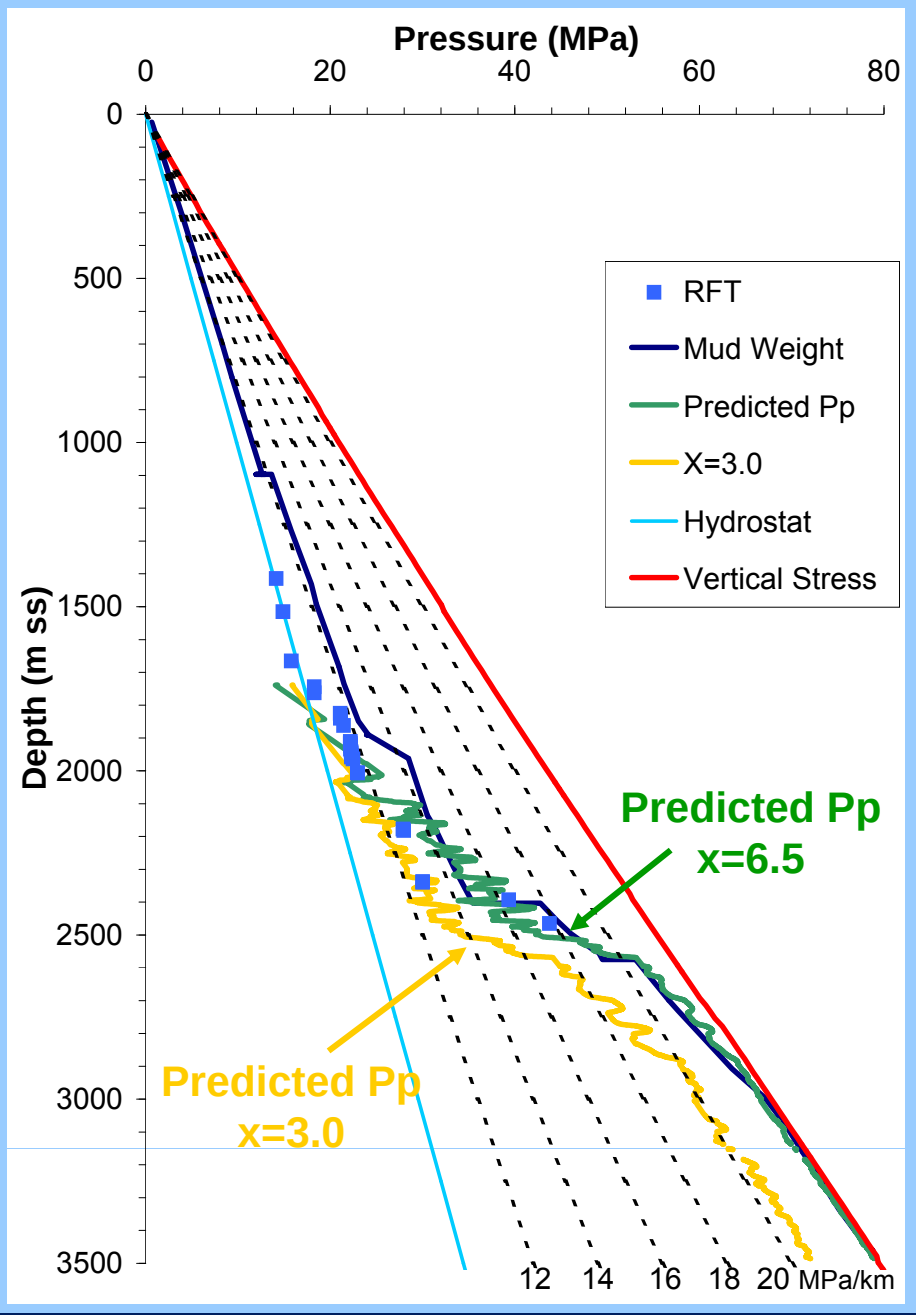
Well B: Vertical Transfer





Well C: Vertical Transfer & Disequilibrium Compaction





Pore Pressure Prediction

Issues with pore pressure prediction:

- sharp Pp increases are underestimated
- effect of uplift
- x=6.5 results in ‘noisy’ prediction in normal pressures

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Acknowledgements

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TOTAL FINA ELF