Origin and Distribution of Overpressure in the Northern Malay Basin*

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Abstract

Pore pressure data and sonic velocity-vertical effective stress plots from 31 wells reveal that overpressures in the northern Malay Basin are primarily generated by fluid expansion and located basin-wide within the 2A, 2B and 2C source rock formations. Overpressure magnitude increases towards the basin-centre, with maximum pore pressure gradients of >19.0 MPa/km observed in the southeast part of the study area. The overpressures are predominately associated with gas, with gas sampled in over 83% of overpressure measurements. The association of overpressures with gas, combined with a regional geology that largely precludes other fluid expansion overpressure mechanisms, provides the first convincing in-situ evidence for basin-wide gas generation overpressure.

Overpressure magnitude analysis indicates that gas generation accounts for approximately 46-67% of the measured excess pore pressure in the region, with the remaining 33-54% being generated by coincident disequilibrium compaction. Thus, the data herein suggests that gas generation, if acting in isolation, produces a maximum pressure gradient of 15.2 MPa/km (0.672 psi/ft), and not lithostatic magnitudes as is often hypothesized. The gas generation overpressures in this study are not associated with a significant porosity anomaly and thus represent a major drilling hazard, with traditional pore pressure prediction techniques underestimating pressure gradients by 2.3 ±1.5 MPa/km (0.102 ±0.066 psi/ft). However, pore pressure prediction is possible using a modified approach after careful smoothing and picking of velocity data.

References

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O'Connor, S.A., R.E. Swarbrick, J. Hoesni, and R.W. Lahann, 2011, Deep pore fluid pressure prediction in challenging areas, Malay Basin, S.E. Asia: Proceedings of 35th Indonesia Petroleum Association Conference, Jakarta, 15 p.

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Origin and Distribution of Overpressures in the Northern Malay Basin

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Paper in press – AAPG Bulletin

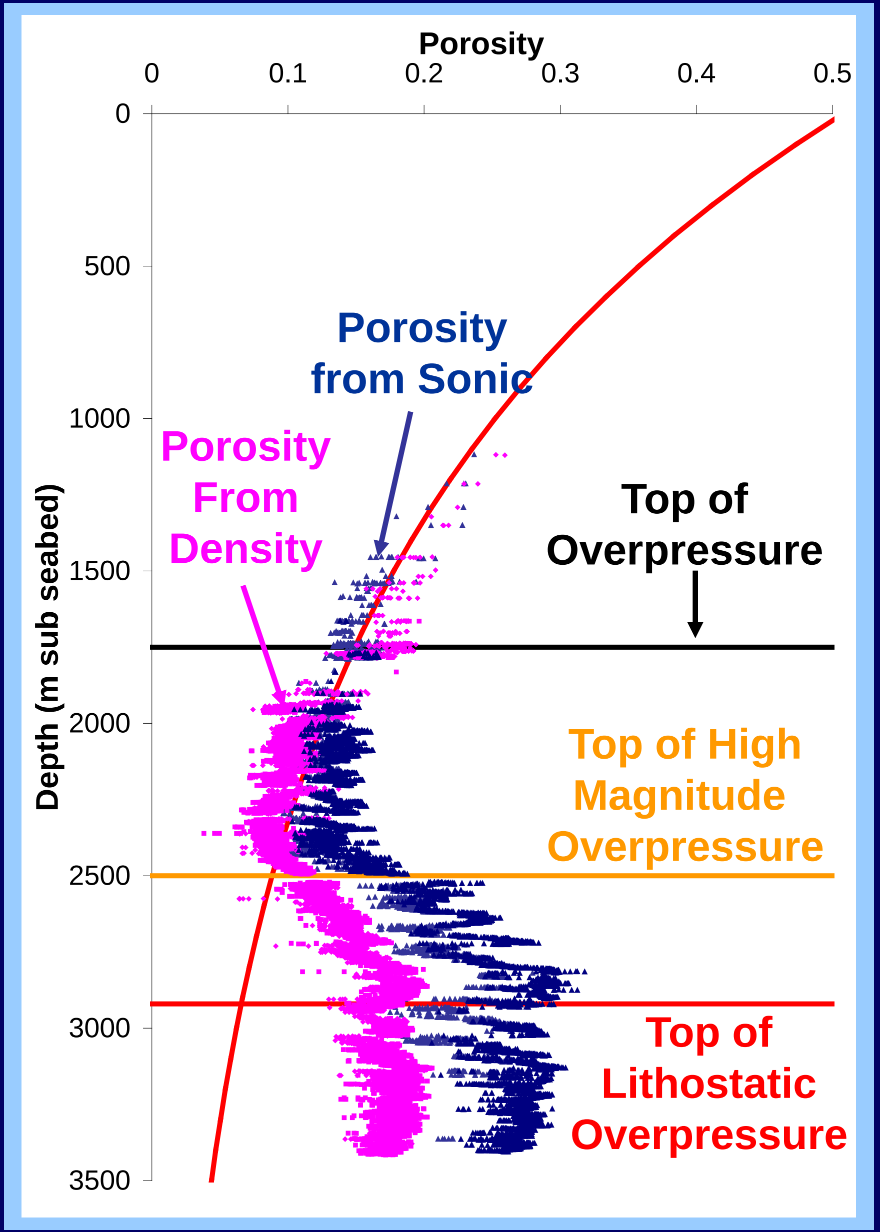
Importance of Overpressure Origin

- Pore pressure estimated from the ***porosity*** anomaly often associated with overpressure.

- ‘Undercompaction’ only associated with disequilibrium compaction.

- ***Other overpressure mechanisms have no/little porosity anomaly – pore pressure underestimated*.**

DIFFERENT OVERPRESSURE ORIGINS REQUIRE DIFFERENT PREDICTION STRATEGIES



Example of undercompaction associated with overpressures, offshore Brunei.

Overpressure Origins?

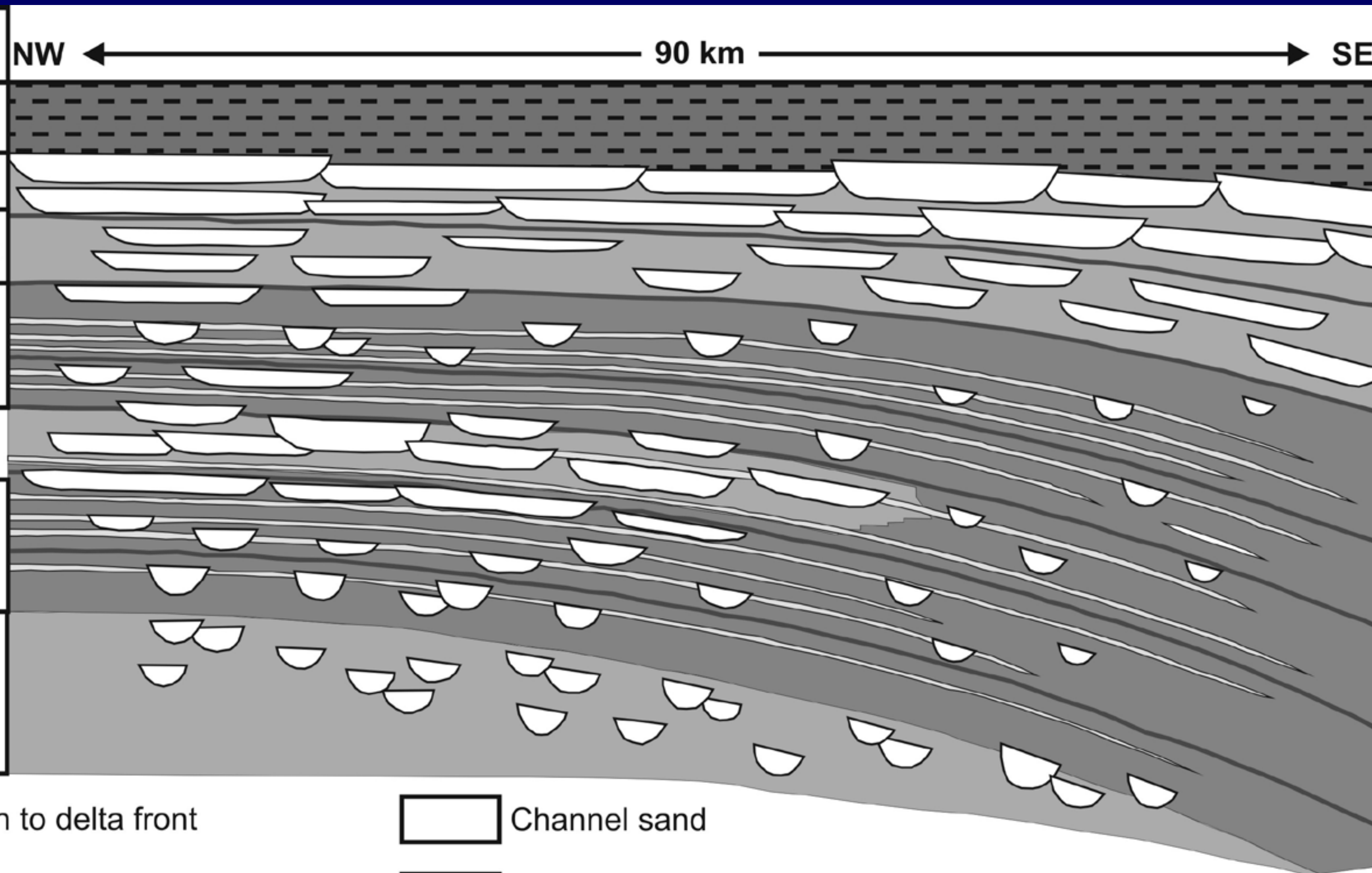
- Disequilibrium compaction (most common).
- Smectite-Illite (and other diagenetic processes), gas maturation, aquathermal expansion, lateral transfer, load transfer, vertical transfer.
- Gas maturation often hypothesized to generate high magnitude pressures – rarely shown in-situ or regionally.

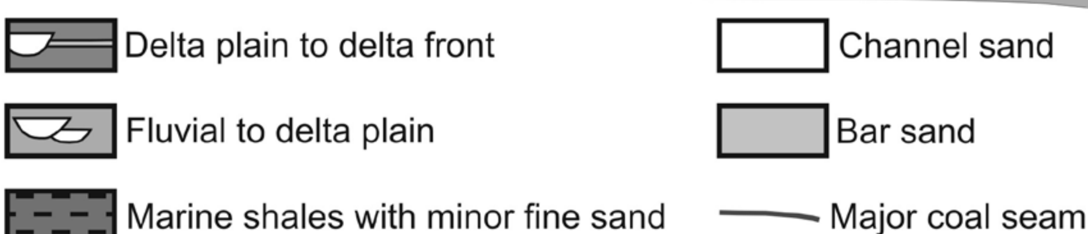
Overpressure mechanisms affect rocks in different ways – we need to first understand overpressure generation mechanism to reliably predict pore pressure (and avoid potential disastrous consequences).


Study Area
South China Sea
Philippine Sea plate
Birds Head
Molucca
Banda Sea
Indo-Australian plate

Geological Overview

Age	Depositional Environment	Unit	Net to Gross
Late Mio-Recent	Marine	Fm3	Low
Late Mio-Recent	Fluvio-Deltaic	2E	High
Late Mio-Recent	Upper to Lower Delta Plain	2D	Medium
Early-Middle Miocene	Offshore to Delta Front	2C	Low
Early-Middle Miocene	Upper Delta Plain	2B	Low to Medium
Early-Middle Miocene	Delta Plain to Delta Front	2A	Low
Early-Middle Miocene	Alluvial Plain	Fm1	Low to Medium





Origin and Distribution of Overpressure in the Northern Malay Basin

- INTRODUCTION AND AIMS
- OVERPRESSURE DISTRIBUTION
- OVERPRESSURE ORIGIN
- IMPLICATIONS & CONCLUSIONS

Data Summary

- 990 WFTs, 20 DSTs, mud weights, formations, petrophysical log and pore fluid data provided for 35 wells throughout Northern Malay Basin (Thailand section).

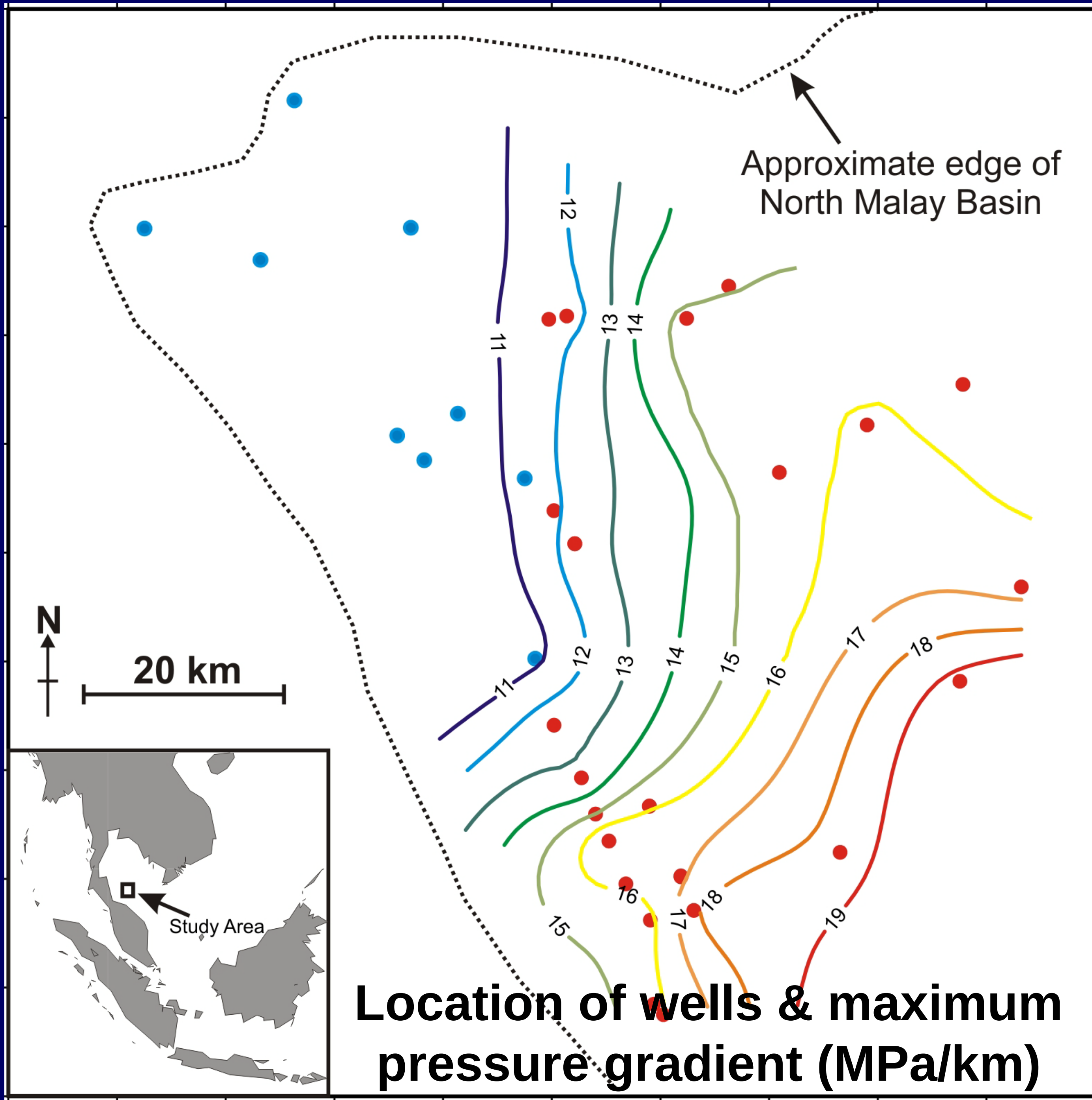
- Overpressures (WFT/DST >11.5 MPa/km or >0.51 psi/ft) in 27 wells (in southeast of study area).

- Moderate-high magnitude overpressures (>14.0 MPa/km or > 0.62 psi/ft) observed in 14 wells.

- Overpressures observed in formations 2C, 2B and 2A.

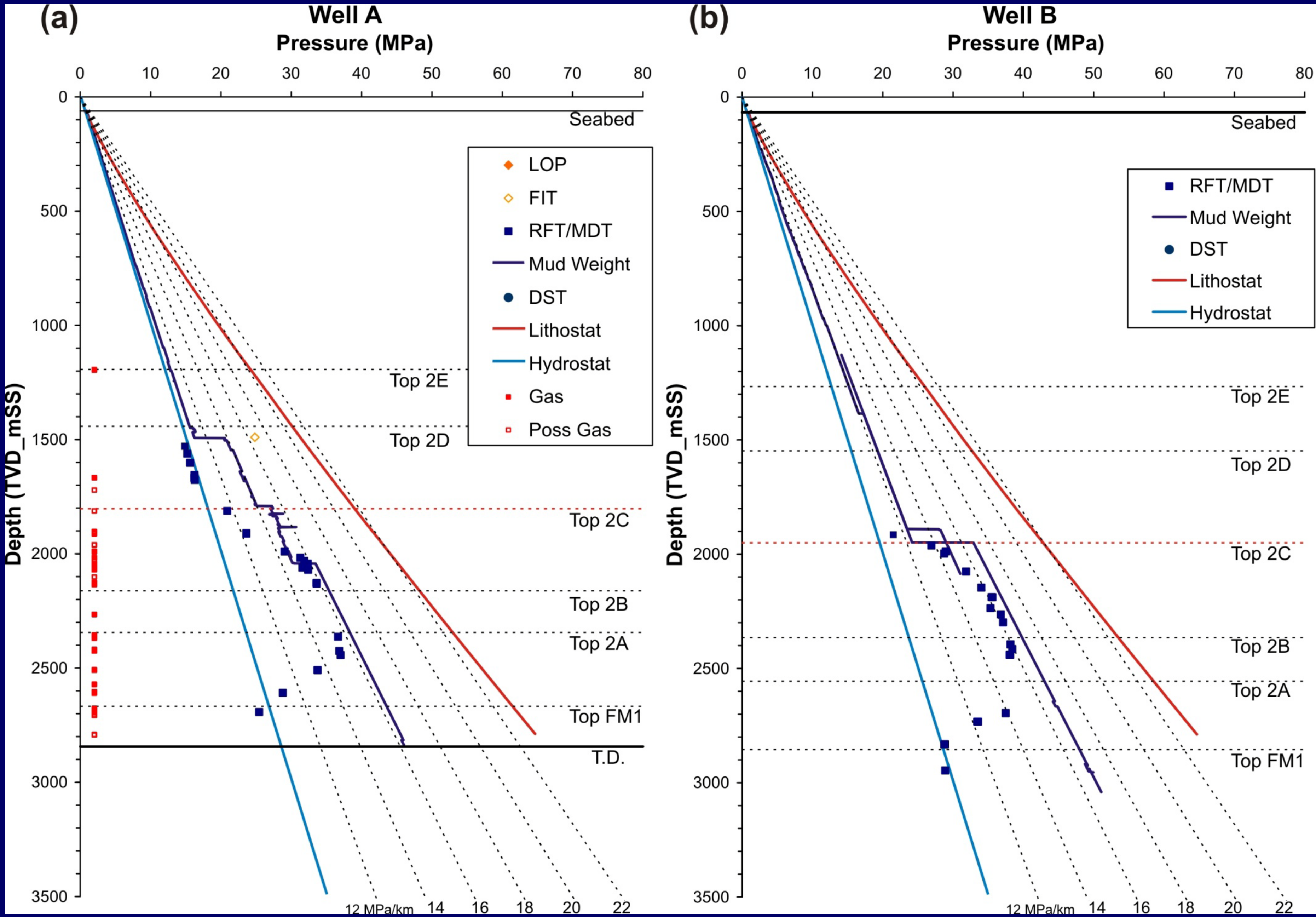
Overpressure Distribution and Magnitude

- Overpressures (red) in southeast of study area
- Overpressures not observed in northwest (blue)
- Pressures greater in magnitude towards southeast



Location of wells & maximum pressure gradient (MPa/km)

Typical Overpressured Well Profiles

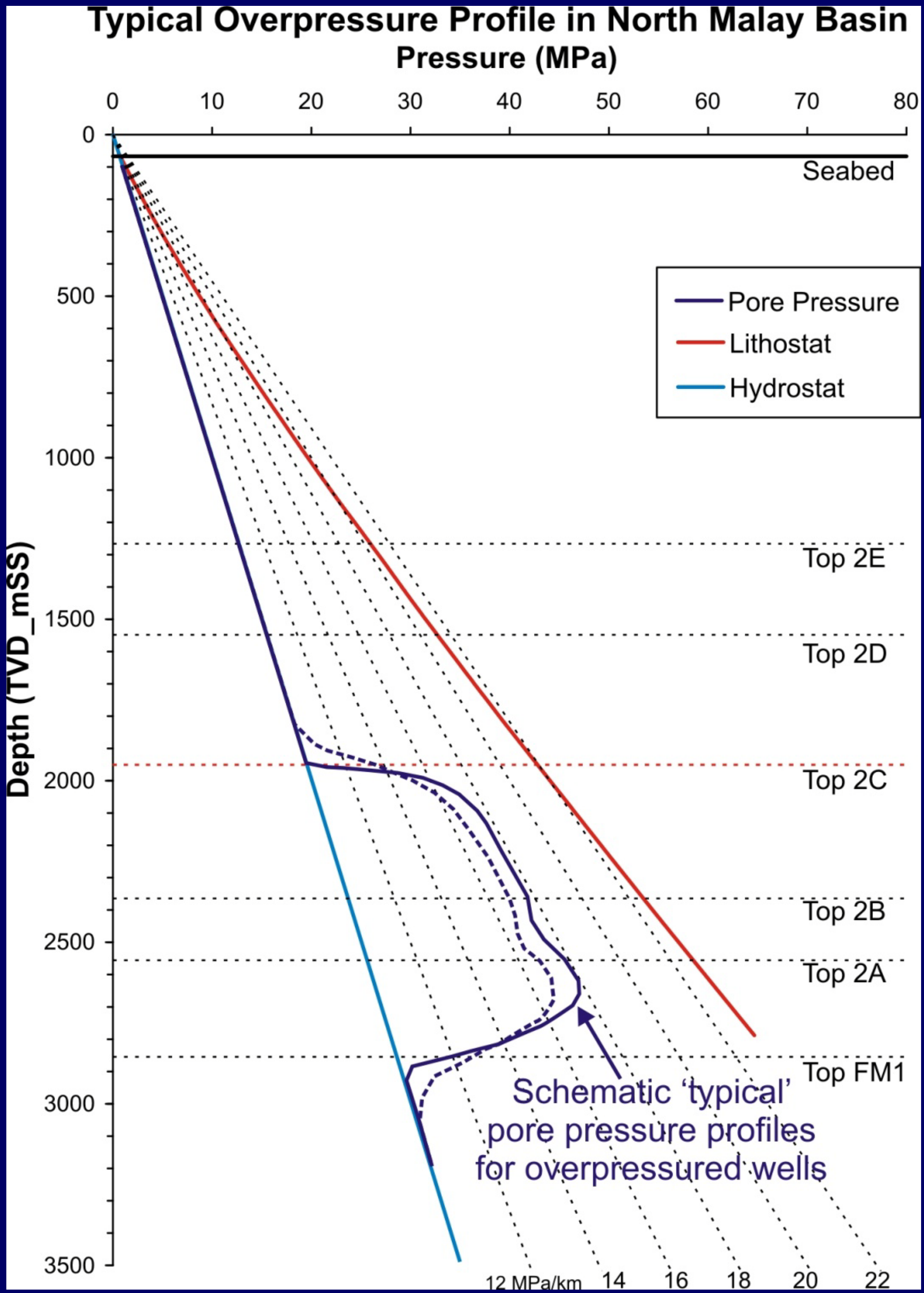


Typical Overpressure Profile

- Whilst magnitude varies, pressures tend to follow the same profile with depth:
  - ➢ top overpressure at/near top of 2C Fm;
  - ➢ approximately constant gradient through 2C, 2B, upper 2A formations;
  - ➢ return to hydrostatic near base 2A Fm.

- Some minor overpressures in base 2D and top fm 1 (vertical transfer?).

- Overpressure magnitude appears inversely proportional to net-to-gross.



Schematic of typical pore pressure trend with depth and formation.

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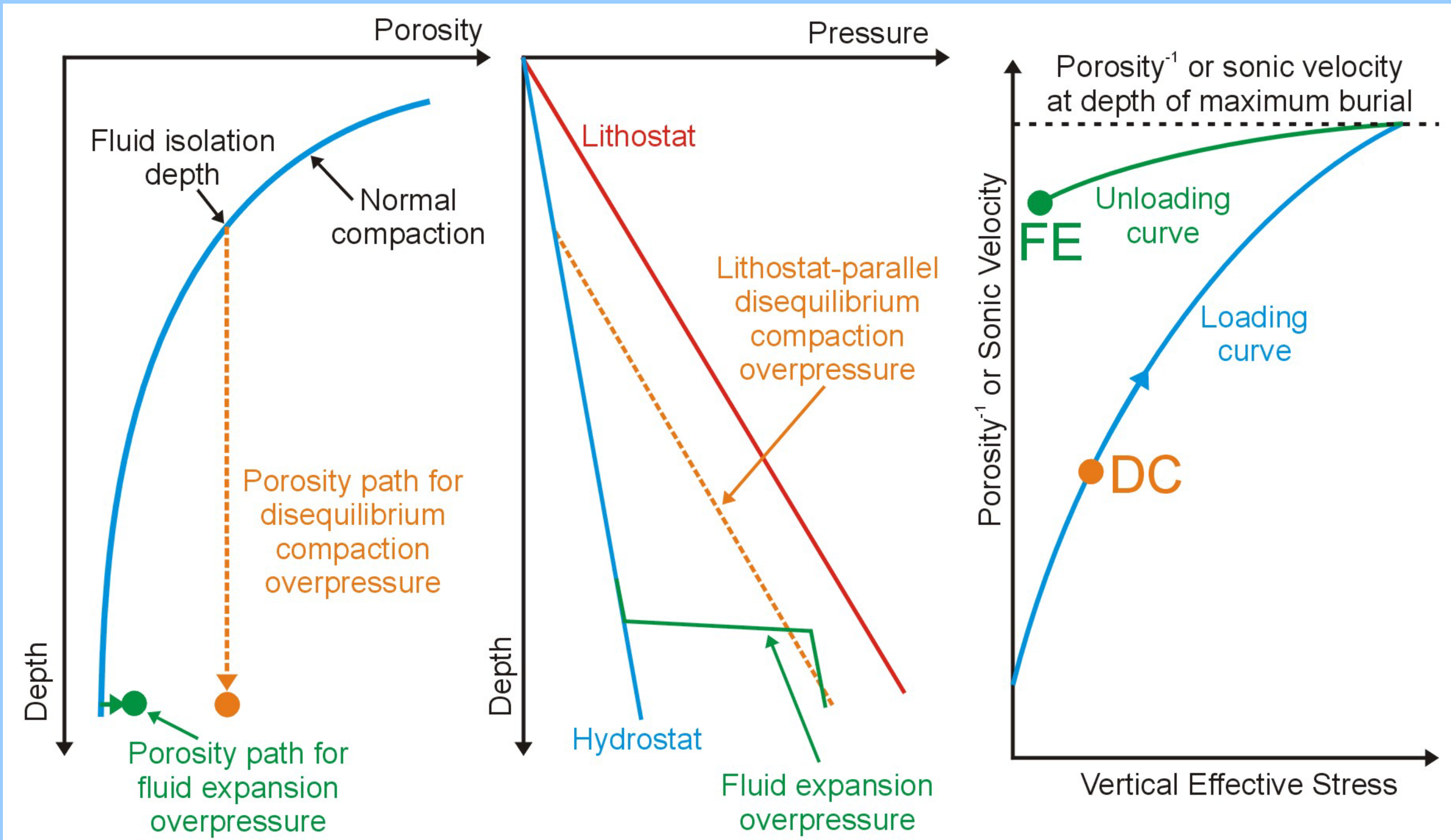
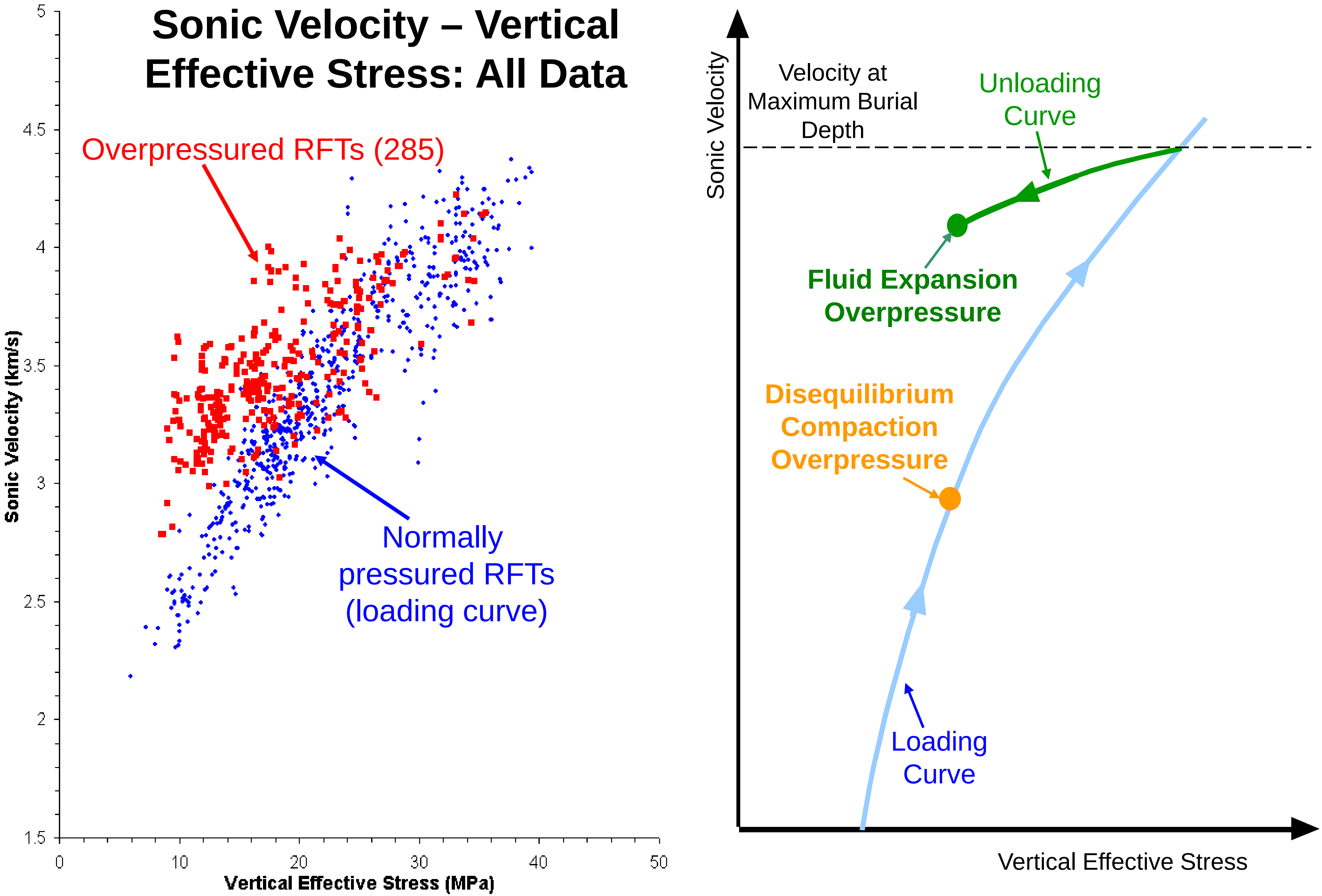
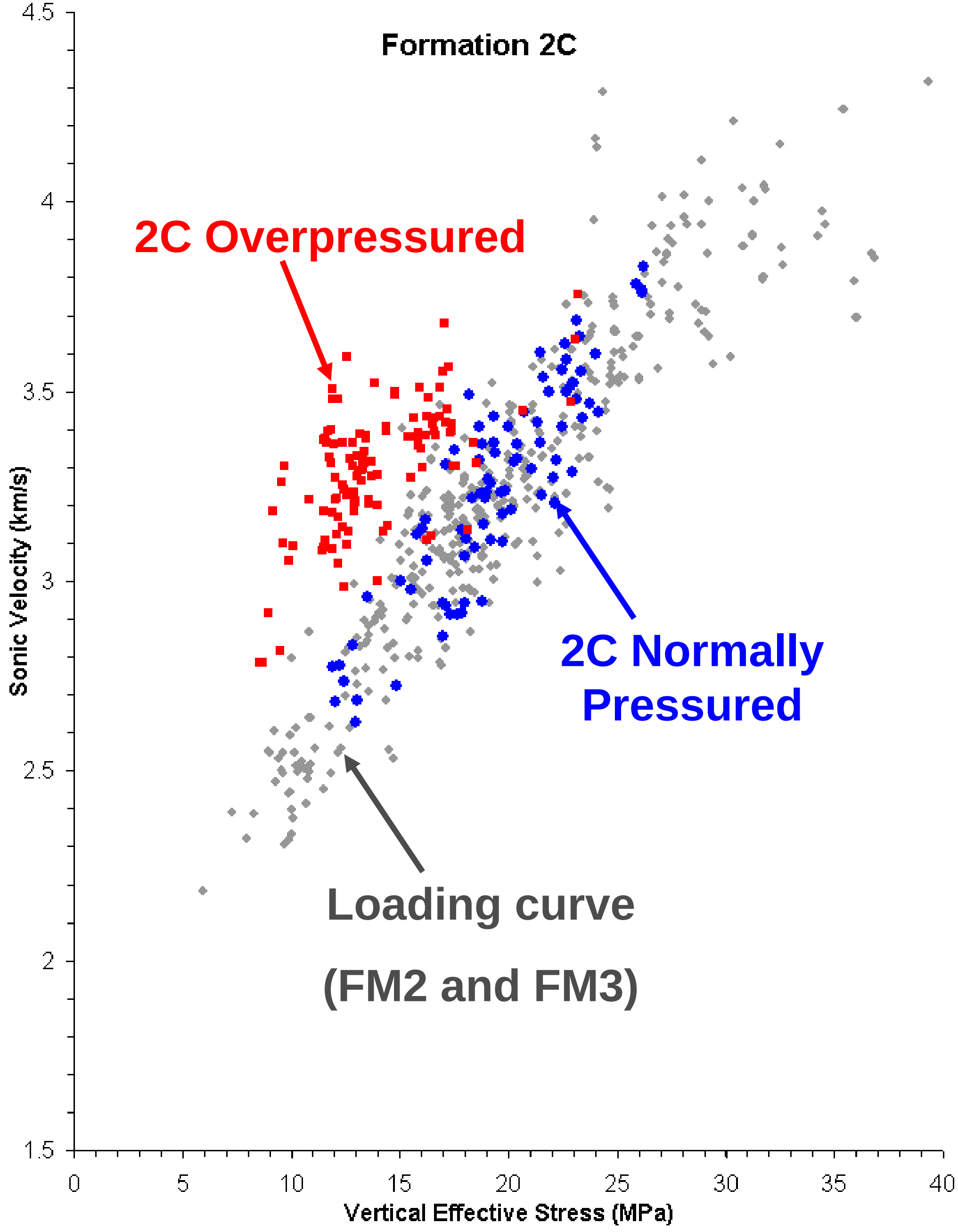
Determining Overpressure Origin: Porosity-Effective Stress Plots

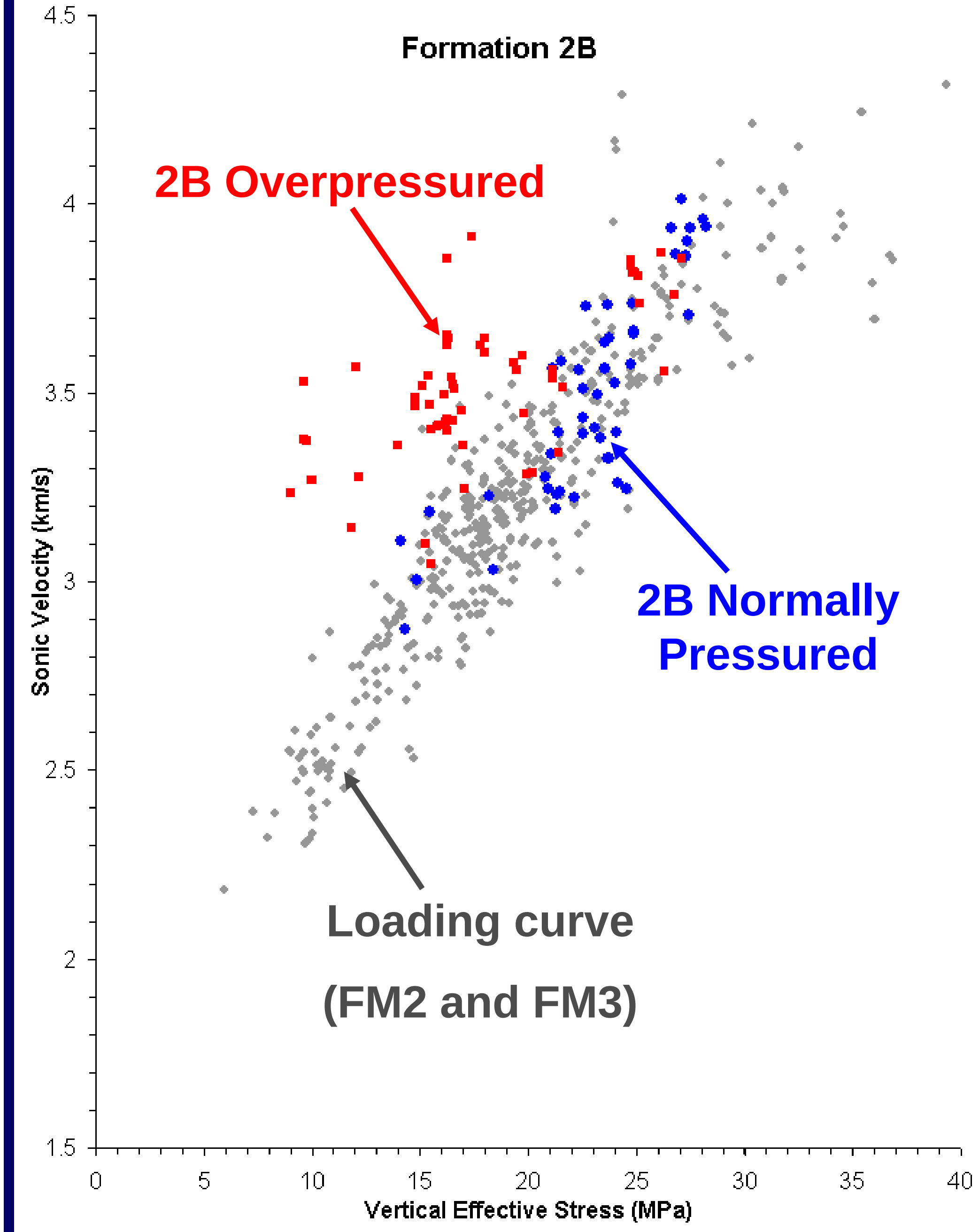




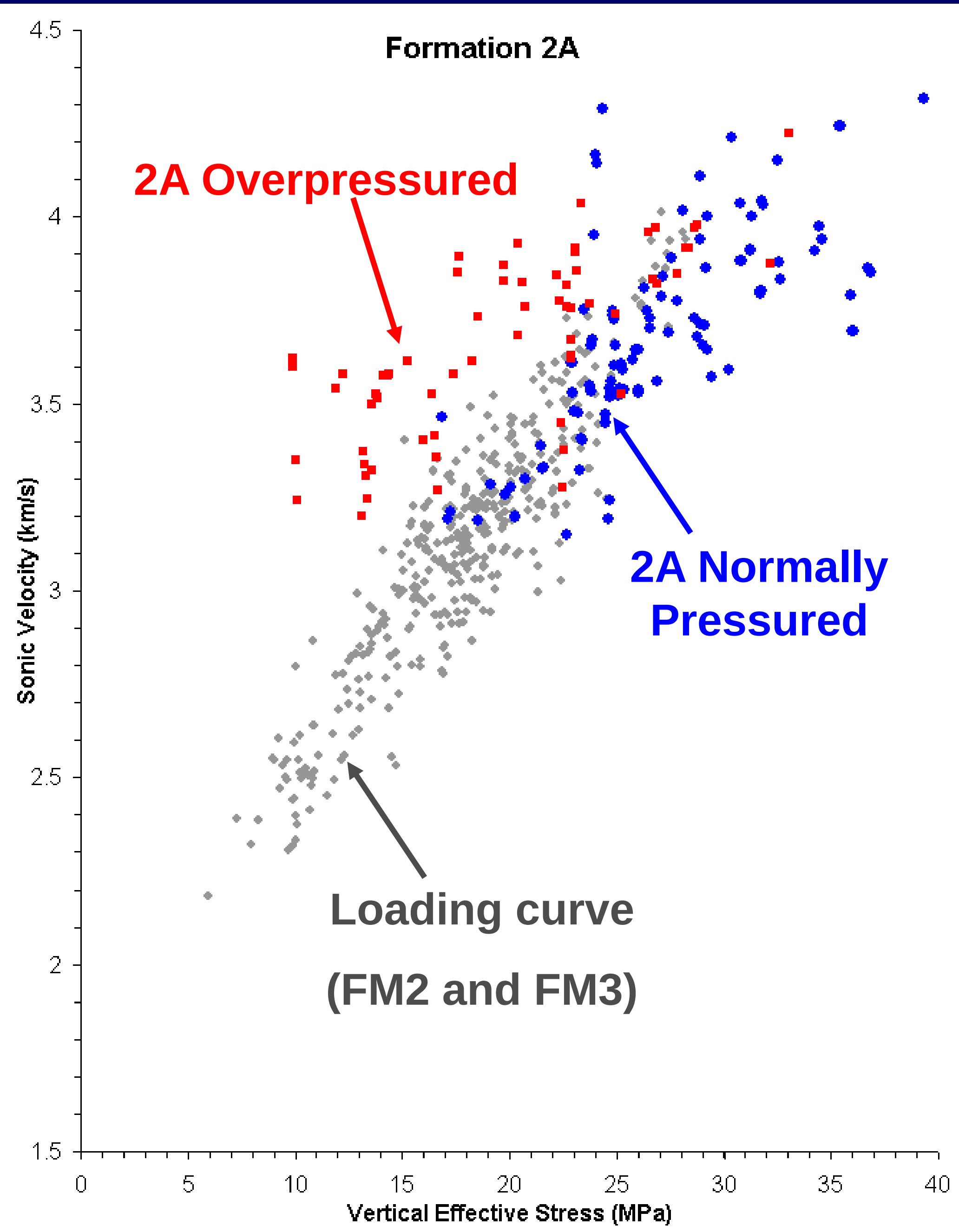
Sonic Velocity – Vertical Effective Stress: All Data
Overpressured RFTs (285)
Normally pressured RFTs (loading curve)
Sonic Velocity (km/s)
Vertical Effective Stress (MPa)
5
4.5
4
3.5
3
2.5
2
1.5
0
10
20
30
40
50
Sonic Velocity
Velocity at Maximum Burial Depth
Unloading Curve
Fluid Expansion Overpressure
Disequilibrium Compaction Overpressure
Loading Curve
Vertical Effective Stress

Sonic Velocity-Vertical Effective Stress: by Formation





Sonic Velocity-Vertical Effective Stress: by Formation

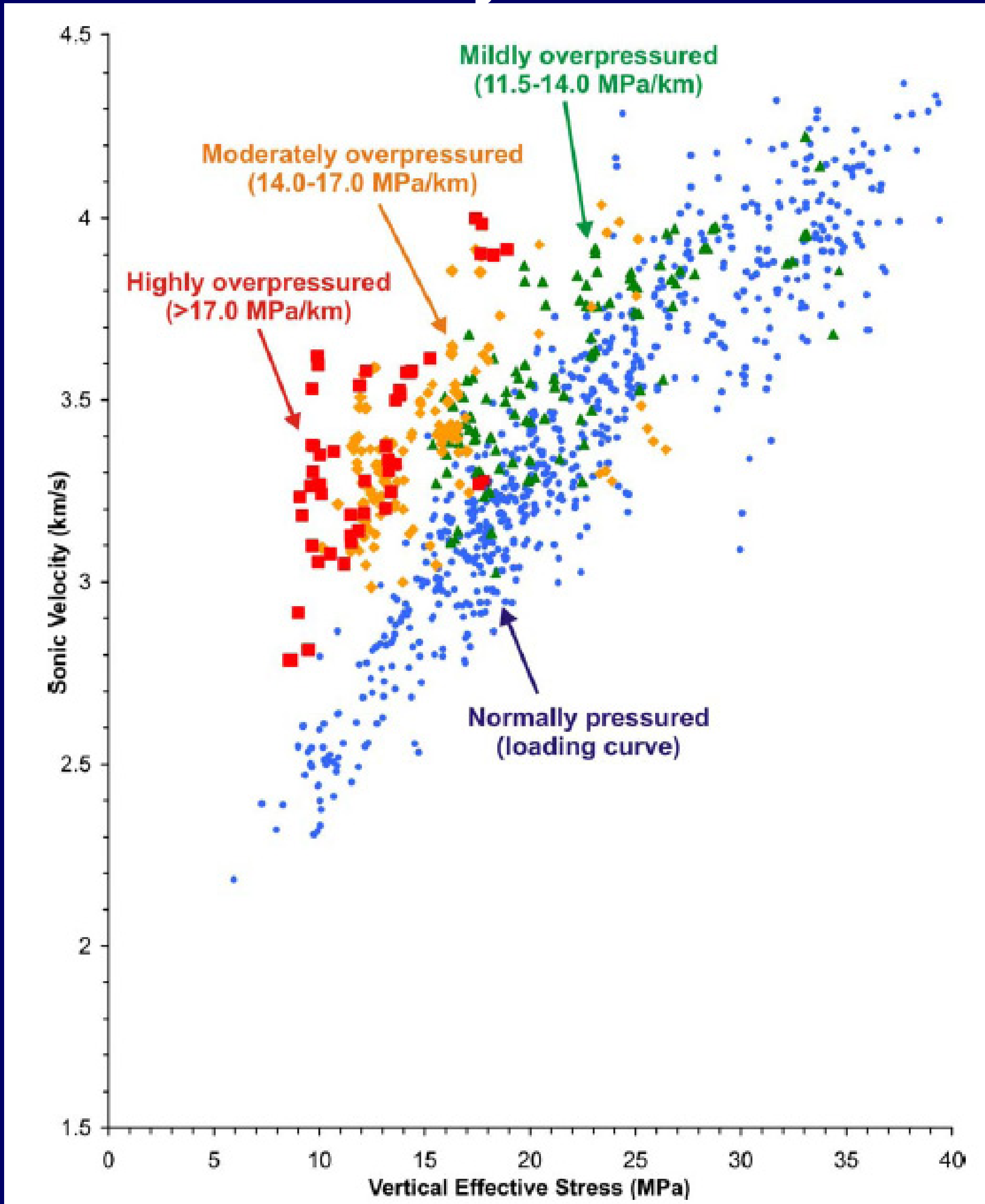


FM 2C, 2B, 2A Summary:

- Overpressures in 2C, 2B and 2A formations plot mostly ‘off’ of the loading curve.

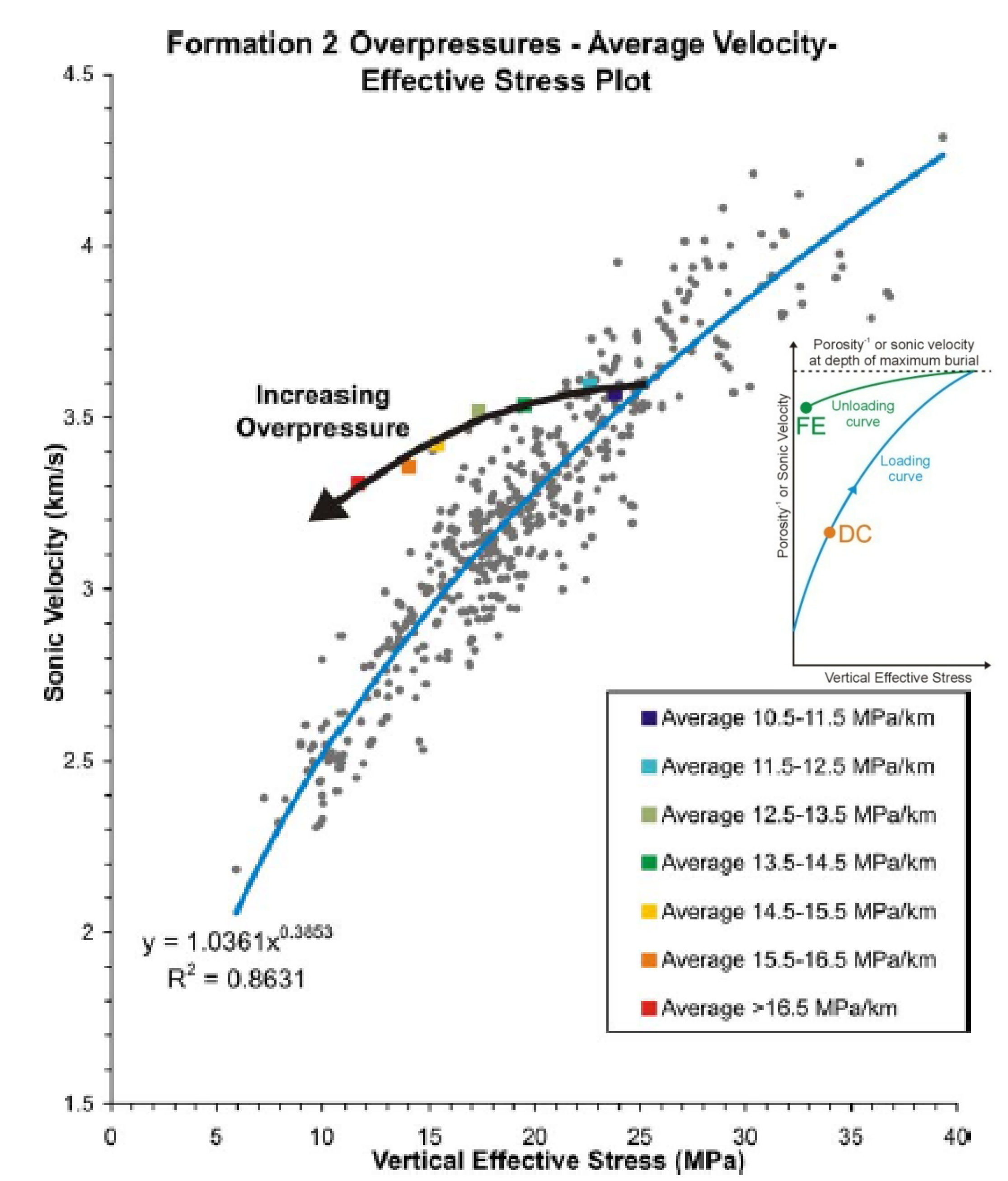
- Indicates that some of overpressure generated by a fluid expansion or transfer mechanism.

Sonic Velocity-Vertical Effective Stress: by Magnitude



- Higher magnitude overpressures lie further off of the loading curve.

- Further indication that significant component of overpressure is generated by a fluid expansion mechanism.

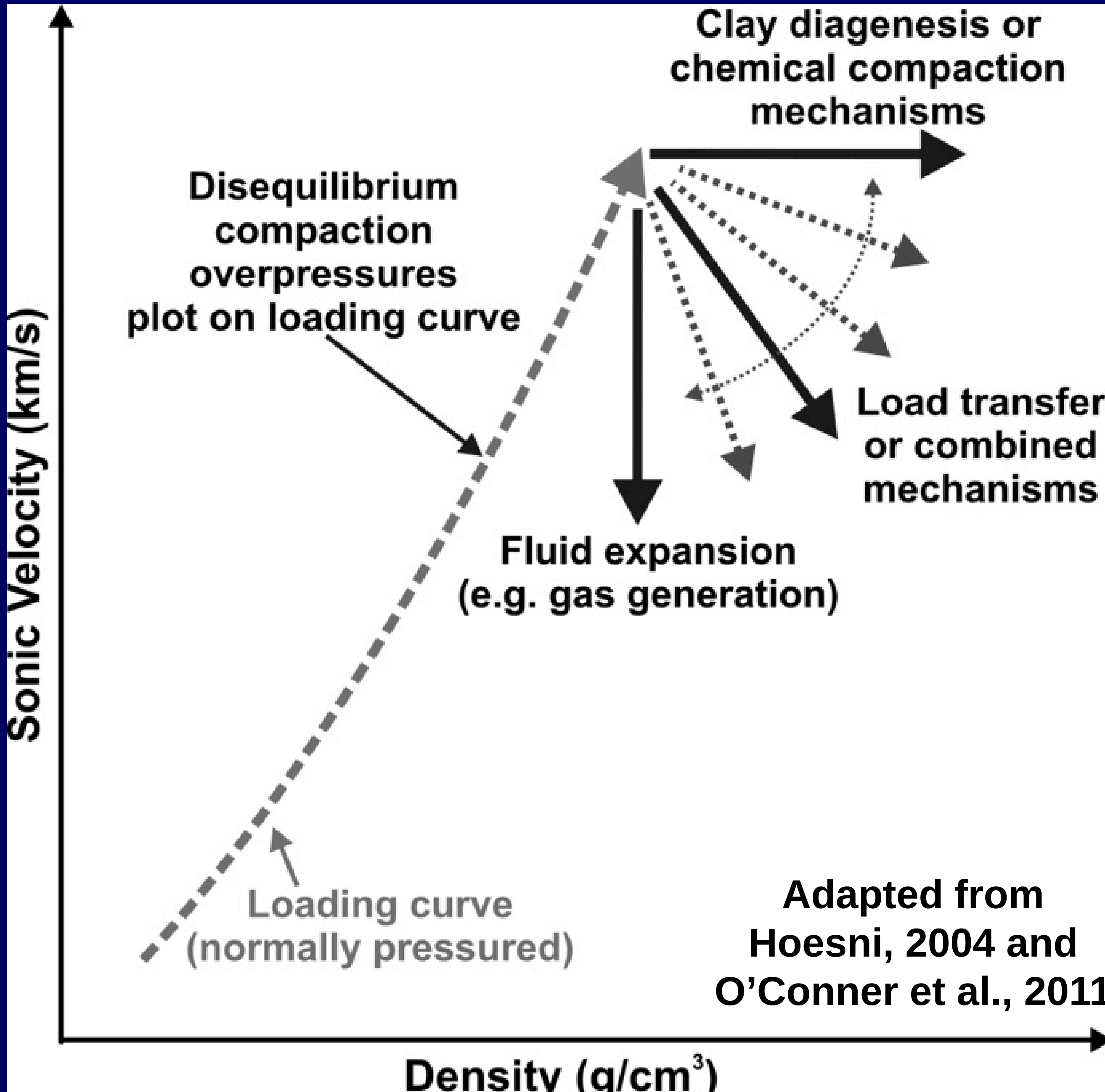


Overpressure Origin Summary:

- Significant component generated by fluid expansion – but which mechanism?

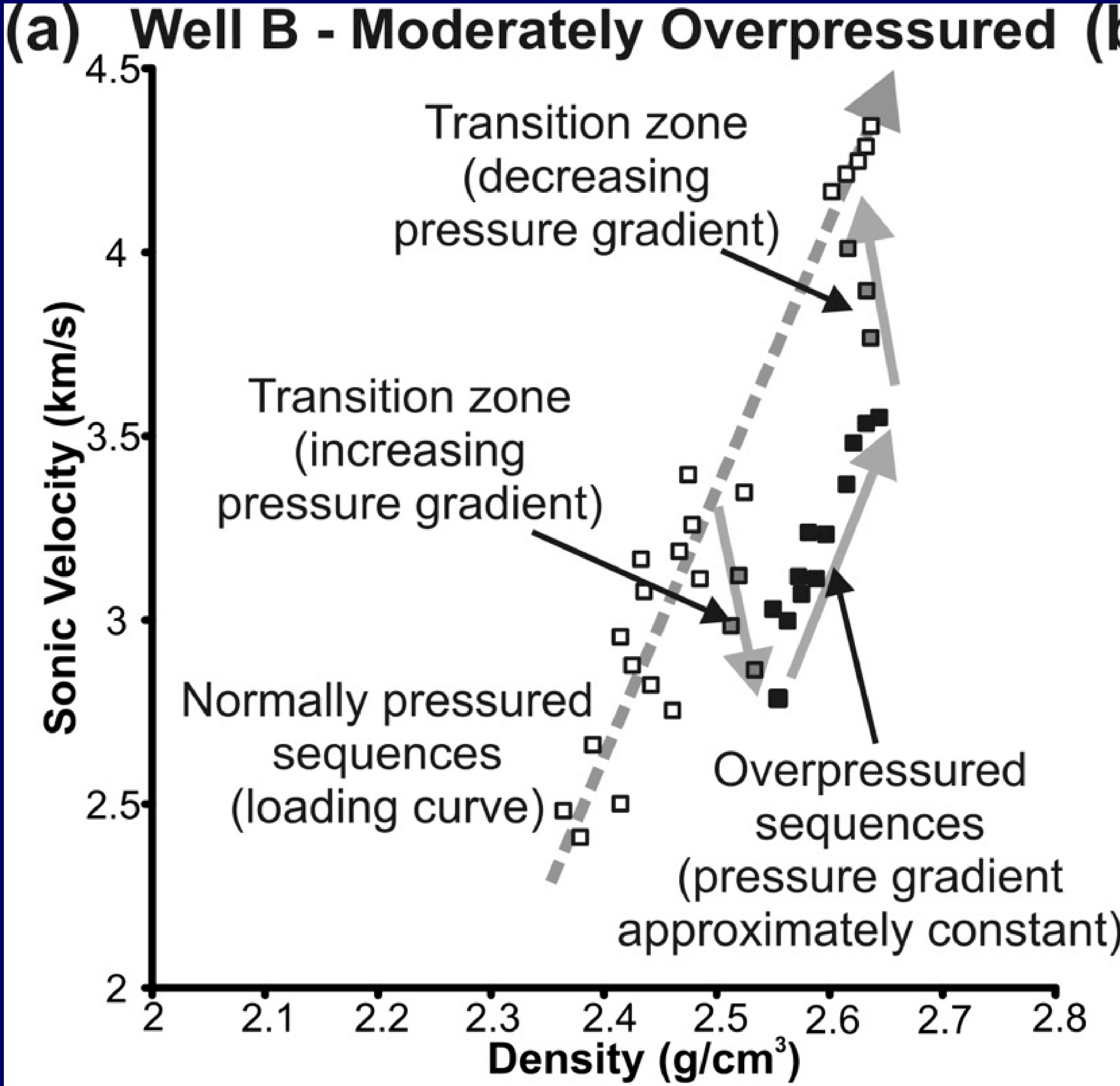
- Low smectite content, stratigraphically confined to low net-to-gross sequences: smectite-to-illite and load, vertical or lateral transfer unlikely.

Sonic Velocity-Density Cross Plots

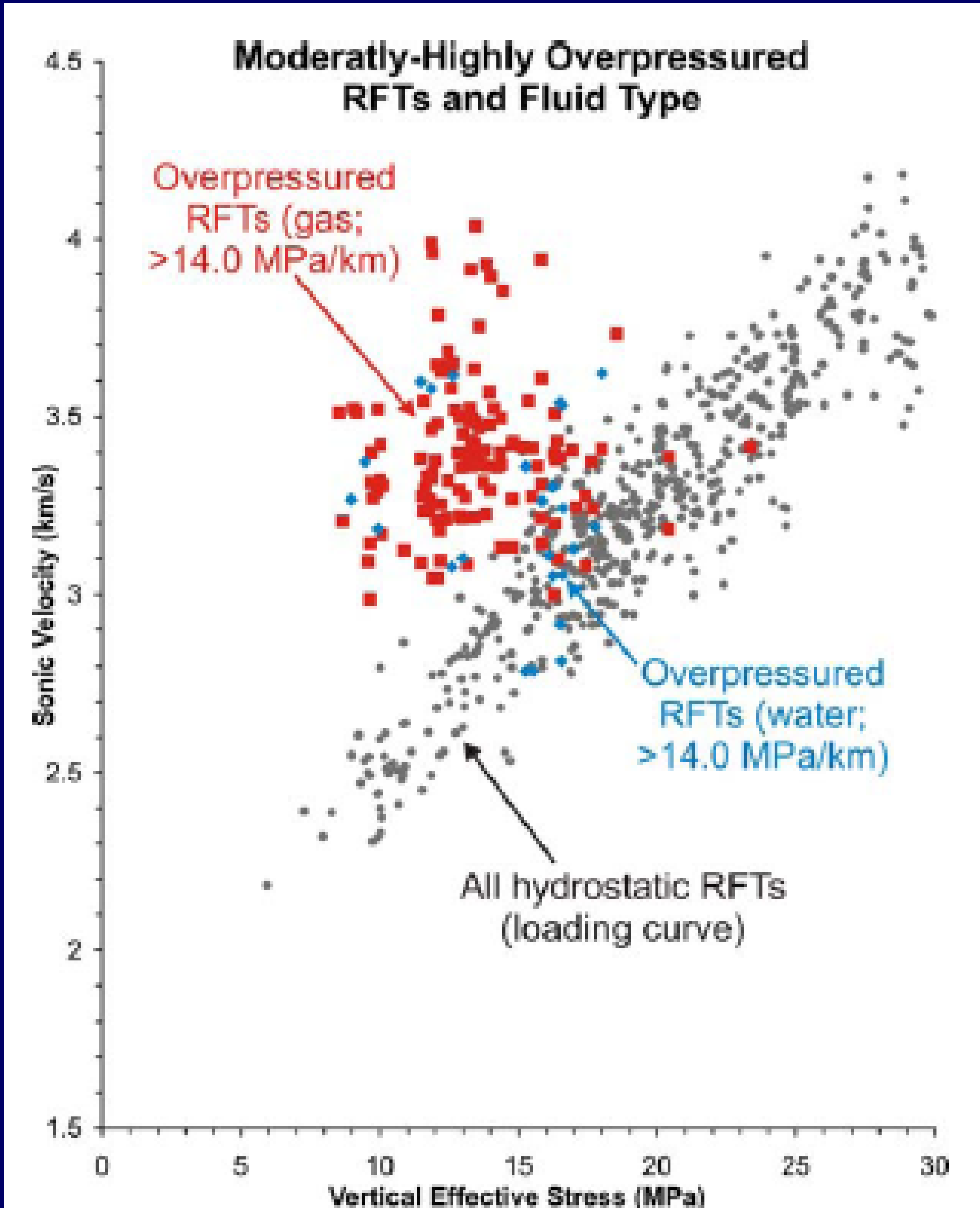


Adapted from Hoesni, 2004 and O'Conner et al., 2011

Sonic Velocity-Density Cross Plots



- Classic gas generation signature with increasing and decreasing pressure gradient
- Sediments still compacting with increasing depth

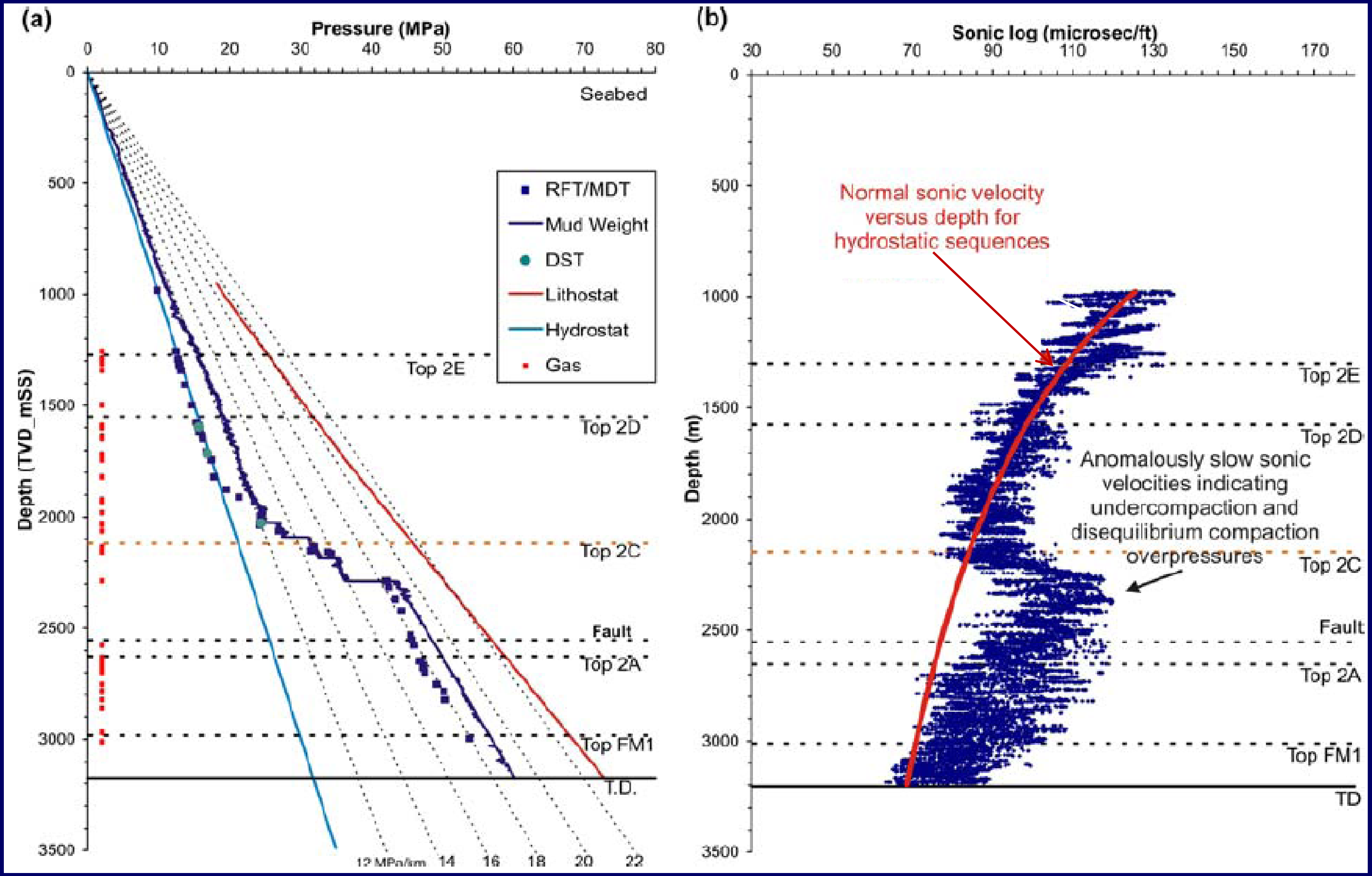


Sonic Velocity-Vertical Effective Stress – Fluid Type

- 84% of all overpressured RFT measurements sampled gas (c.f. 60% normally pressured).
- Fm 2 A-C is source rock for most produced hydrocarbons.
- Suggests kerogen-to-gas maturation as likely dominant overpressure cause in 2A-C.
- Some other overpressure, likely disequilibrium compaction (on loading curve).

Evidence for Disequilibrium Compaction?

• All overpressure requires a good seal – but if seal exists during burial or loading, disequilibrium compaction should also occur!



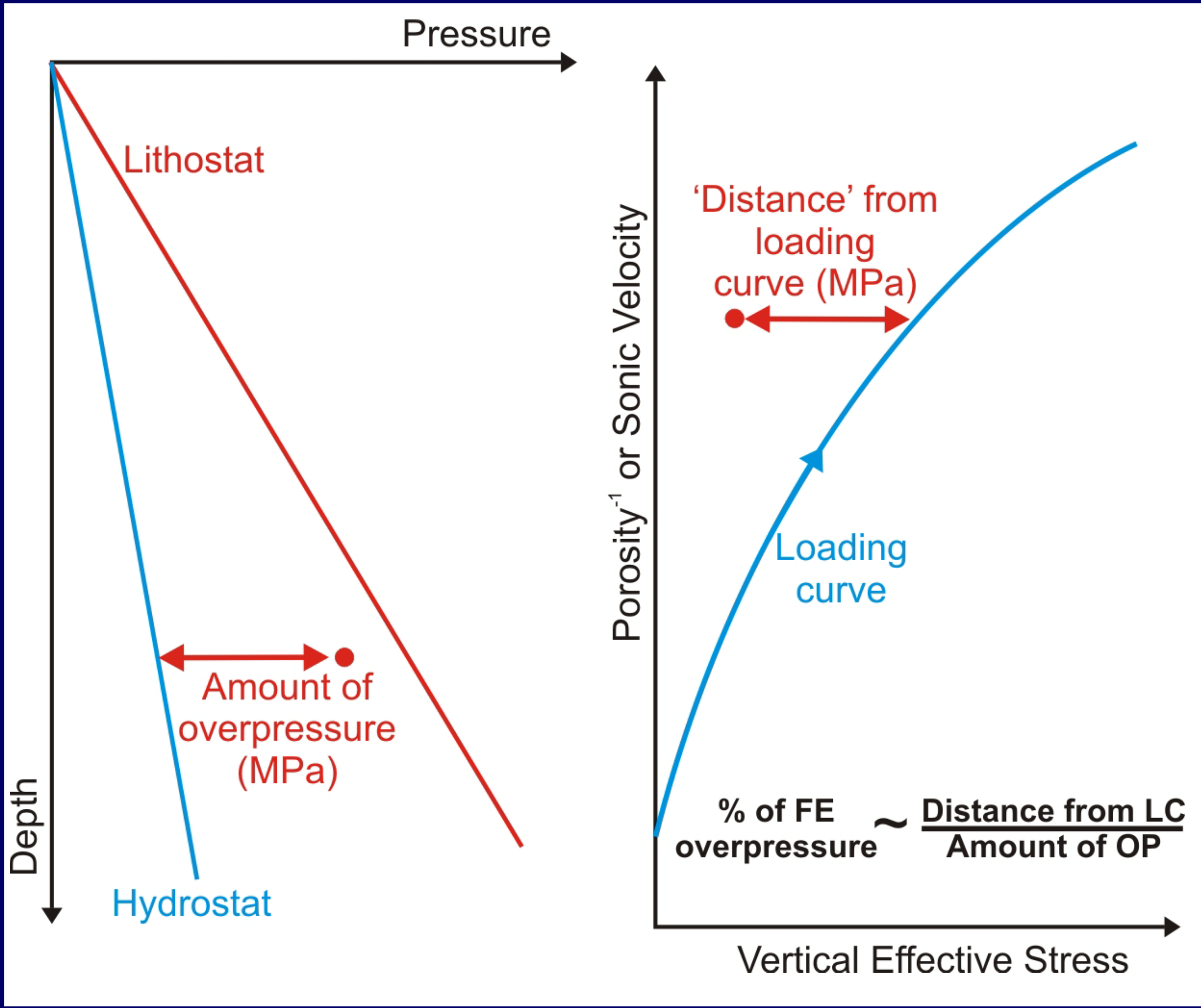
• Evidence of undercompaction, especially towards basin centre

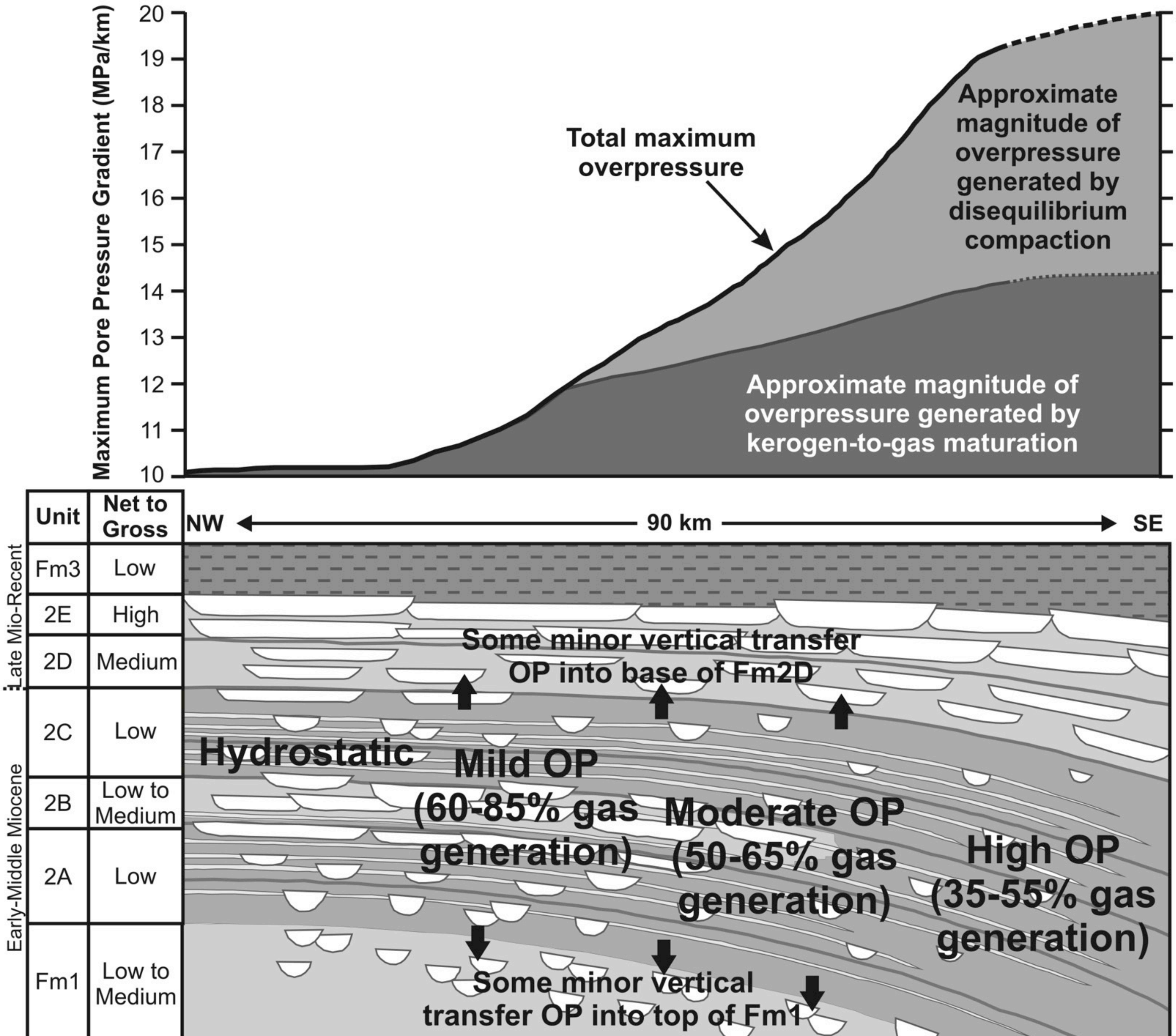
How Much Gas Generation Overpressure?

- **'Distance' from loading curve less than amount of overpressure**

- **Magnitude of gas overpressure *increases* towards basin centre.**

- **Proportion of gas overpressure *decreases* towards basin centre.**





Maximum Pore Pressure Gradient (MPa/km)
20
19
18
17
16
15
14
13
12
11
10
Total maximum overpressure
Approximate magnitude of overpressure generated by disequilibrium compaction
Approximate magnitude of overpressure generated by kerogen-to-gas maturation
Unit
Net to Gross
NW
90 km
SE
Late Mio-Recent
Early-Middle Miocene
Fm3
Low
2E
High
2D
Medium
2C
Low
2B
Low to Medium
2A
Low
Fm1
Low to Medium
Some minor vertical transfer OP into base of Fm2D
Hydrostatic
Mild OP (60-85% gas generation)
Moderate OP (50-65% gas generation)
High OP (35-55% gas generation)
Some minor vertical transfer OP into top of Fm1

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Implications for Pore Pressure Prediction

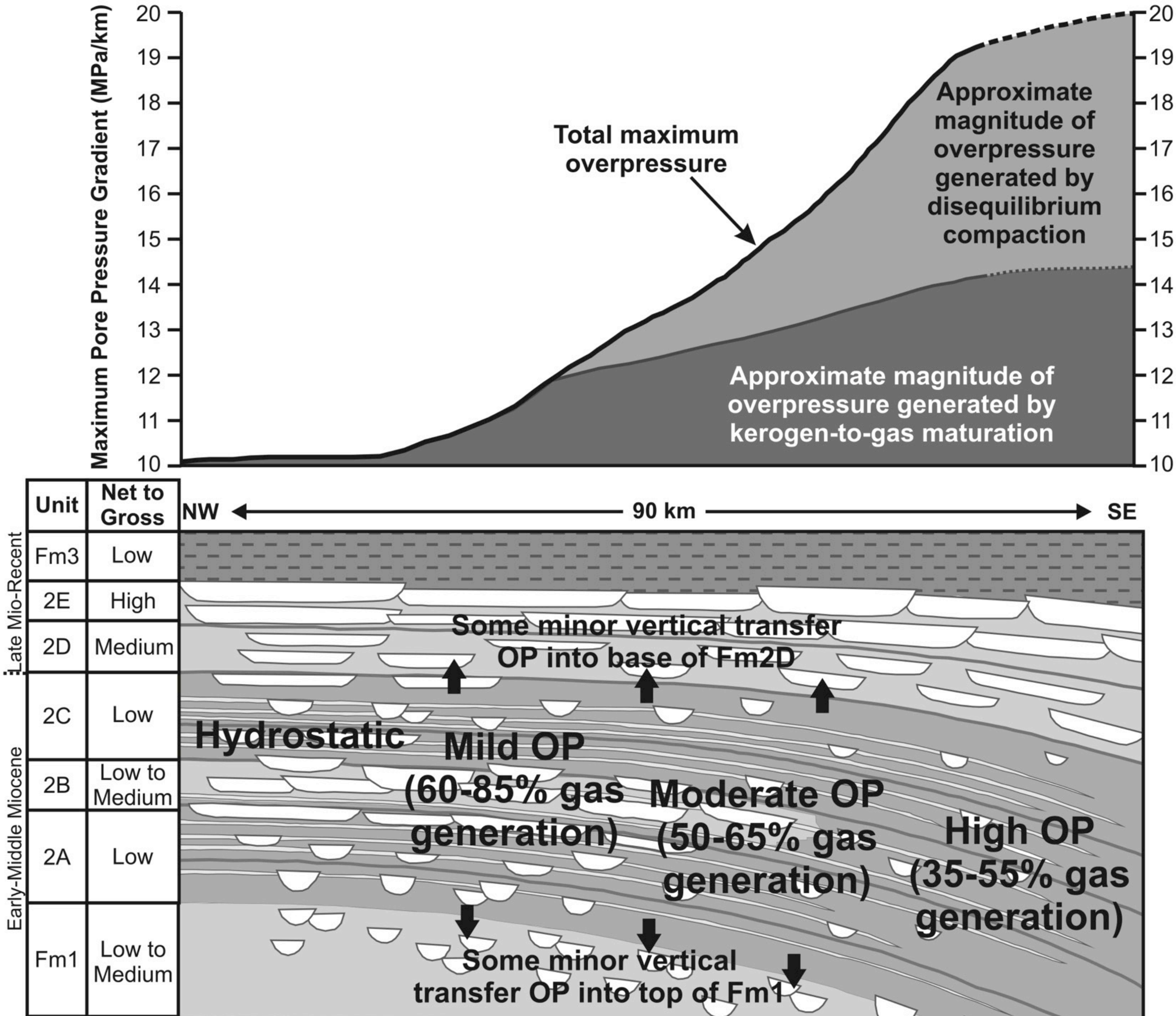
- Overpressures often do not have a significant porosity anomaly and difficult to predict!

- Typical pore pressure prediction methods all underestimate pore pressure gradient.

- Underestimation significant - generally by 1.0 to 4.0 MPa/km (0.04 to 0.17 psi/ft or 0.8 to 3.3 ppg).

- Worse in high pressure areas – numerous drilling problems observed.

New Play Type?



Summary

- Overpressures primarily occur in the 2C, 2B and 2A formations in the SE part of the North Malay Basin.
- Overpressures lie significantly off loading curve, suggesting component of overpressure generated by fluid expansion.
- Stratigraphic confinement to source rocks and association with gas suggests probable kerogen-to-gas maturation overpressure.
- Disequilibrium compaction also occurs, particularly in deeper, rapidly deposited regions towards basin centre (into Malaysia?).
- Overpressures in formations 2A-C are NOT associated with large porosity or sonic velocity anomaly – potential dangerous underprediction using usual methods!
- Potential for HP/HT stratigraphic gas plays towards basin centre.

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SUB CRUCE LUMEN

Australian Government

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