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Pore-Pressure Prediction from Corrected D-Exponent Analysis: A Case Study of Hamra East-8, Muglad Basin

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Abstract

Accurate pore-pressure prediction is essential for safe mud-weight selection, casing-seat planning, and avoidance of kicks, losses, stuck pipe, and non-productive time. This paper presents a reproducible corrected D-exponent and Eaton-method workflow for Hamra East-8, Hamra oil field, Block 2A, Heglig area, Muglad Basin. The paper responds to reproducibility requirements by specifying the shale-screening rule, corrected D-exponent equation, reference mud weight, drilling-report averaging interval, overburden-density source, normal compaction trend fitting approach, Eaton exponent, depth reference, and a manual verification point inside the 1600 - 1700 mKB watch zone. Shale screening used a gamma-ray-derived shale volume criterion of $V_{sh} \geq 0.35$, with shale-prone intervals checked against lithological descriptions. Corrected D-exponent values were computed from 10 m mKB drilling-parameter averages and corrected with a 9.2 ppg reference mud weight. Overburden was calculated from a sonic-derived density curve using a Gardner-type velocity-density transform when measured density was unavailable. Eaton calculations used an exponent of 1.2, adopted from drilling-engineering practice and checked locally by manual verification. Five verification depths, including 1650 mKB in the watch interval, show close agreement between software and manual calculations, with an average absolute difference 26.8 psi and RMSE 32.8 psi. The 1600 - 1700 mKB interval shows only a slight pressure increase and remains close to normal hydrostatic conditions.

Keywords

Pore Pressure, Corrected D-Exponent, Eaton Method, Shale Screening, Normal Compaction Trend

1. Introduction

Reliable pore-pressure prediction is a fundamental requirement for safe and economic well construction. Underestimated pore pressure can cause kicks, influx, borehole instability, stuck pipe, and blowout risk. Overestimated pore pressure can lead to excessive mud weight, lost circulation, formation damage, and unnecessary drilling costs. The Hamra East-8 development well provides a useful case for evaluating a low-cost workflow based on drilling-response data and available logs. Standard drilling-engineering texts describe the operational consequences of pressure uncertainty and the role of pore-pressure surveillance in mud-weight and casing design [1]-[3].

Corrected D-exponent analysis is attractive where direct formation-pressure measurements, logging-while-drilling pressure data, or real-time pore-pressure services are not available. The method uses drilling parameters that are routinely recorded in daily drilling reports and converts departures from normal shale compaction behavior into pore-pressure estimates. However, the method is sensitive to lithology, bit performance, hydraulic conditions, mud-weight changes, and normal compaction trend selection. For this reason, reproducibility requires explicit documentation of shale screening, equations, reference mud weight, depth reference, trend fitting, and manual verification. The drilling-performance basis, mud-weight correction, and practical limitations of D-exponent pressure detection are described in the foundational and subsequent literature [4]-[7].

2. Geologic and Well Context

Hamra East-8 is a development well in the Hamra oil field, Block 2A, Heglig area, Muglad Basin. The well was drilled to evaluate Aradeiba and Bentiu objectives and reached approximately 1900 m total depth. The stratigraphic section includes alternating sandstone, shale, and claystone units. This mixed lithology is important because corrected D-exponent interpretation is most reliable in shale or argillaceous intervals and can be misleading in clean sandstones. The regional petroleum-geology context of the Sudan and Muglad Basin is described by Zayed [8].

Formation tops from the electric-log interpretation are summarized in **Table 1**. The main shale-prone intervals used for screening include Baraka Shale, Ghazal Shale, Aradeiba Upper Shale, and Aradeiba Lower Shale. The 1600 - 1700 mKB interval overlaps the lower Aradeiba section and is treated as the principal watch zone because the pressure curves show a slight increase relative to the hydrostatic reference.

Table 1. Formation tops are used as lithological control for pressure interpretation.

Formation/member	E-log top (mKB)	Thickness (m)
Nayil	436	174
Amal	610	298
Baraka Shale	908	245

Continued

Ghazal Shale	1153	58
Zarqa	1211	170
Aradeiba Upper Shale	1381	166
Aradeiba Main Sand	1547	76
Aradeiba Lower Shale	1623	42
Aradeiba E	1665	45
Aradeiba F	1710	23
Bentiu 1	1733	39
Bentiu 2	1772	129

3. Methodology

The complete analysis sequence, from drilling-data quality control and shale screening through Eaton conversion and verification, is summarized in **Figure 1**.

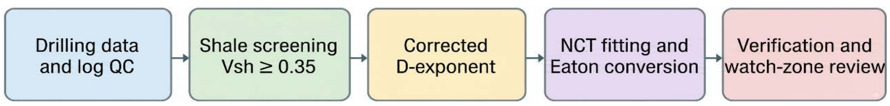

Figure 1. Pore-pressure workflow showing shale screening, corrected D-exponent calculation, normal compaction trend fitting, Eaton conversion, and watch-zone verification.

3.1. Depth Reference and Sampling Interval

All calculations in this workflow use measured depth referenced to the Kelly bushing, reported as mKB. The well is treated as near vertical for the purpose of pore-pressure gradient calculation; therefore, mKB is used consistently as the working depth reference and converted to feet using 1 m = 3.28084 ft. Pore pressure, overburden pressure, hydrostatic pressure, and pressure gradients are therefore reported against the same mKB depth scale. This convention removes ambiguity caused by mixing measured depth, true vertical depth, and mKB descriptors.

Drilling-report inputs were averaged over 10 m mKB depth bins before D-exponent calculation. For each bin, rate of penetration, rotary speed, weight on bit, mud weight, and bit diameter were represented by the median of valid drilling records. Median averaging was selected to reduce the influence of short operational disturbances, connection effects, and isolated drilling dysfunction. Intervals affected by bit trips, major bit-size changes, motor runs, severe vibration, or obvious lithological discontinuity were not used for fitting the normal compaction trend.

3.2. Shale Screening Rule

The shale-screening rule used for corrected D-exponent interpretation was based on the gamma-ray-derived shale volume. The gamma-ray index was computed as IGR = (GR − GRclean)/(GRshale − GRclean), where GRclean and GRshale are the local clean-sand and shale endpoints selected in Interactive Petrophysics from the Hamra East-8 log response. Shale volume was then defined as Vsh = max (0, min

(1, IGR)). Intervals with Vsh ≥ 0.35 were treated as shale-prone and eligible for corrected D-exponent trend interpretation. As a practical cross-check, intervals with gamma ray approximately ≥ 75 API were also considered shale-prone where local endpoint uncertainty existed. Clean sandstone intervals and mixed intervals with Vsh < 0.35 were excluded from normal compaction trend fitting and from pressure interpretation unless supported by lithological descriptions.

This screening was necessary because clean sandstone can drill faster than shale and may produce anomalously low D-exponent values unrelated to abnormal pore pressure. The screening criterion therefore restricts the pressure workflow to shale-dominated or argillaceous intervals where compaction-based pressure methods are more physically meaningful.

3.3. Corrected D-Exponent Equation and Mud-Weight Correction

The drilling D-exponent was calculated from drilling parameters using Equation (1):

$$D = \log 10\left[\mathrm{ROP}/(60\mathrm{N})\right]/\log 10\left[12\mathrm{WOB}/(1000\mathrm{B})\right] \tag{1}$$

where D is drilling D-exponent, ROP is the rate of penetration in ft/h, N is the rotary speed in rev/min, WOB is the weight on bit in lb, and B is the bit diameter in in. The corrected D-exponent was then calculated using Equation (2):

$$Dc = D \times (\mathrm{MWref}/\mathrm{MWa}) \tag{2}$$

where Dc is the corrected D-exponent, MWref is the reference normal mud weight, and MWa is the actual mud weight used in the drilled interval. The reference mud weight used in this workflow was 9.2 ppg, corresponding to the lowest initial mud-weight stage in the reported Hamra East-8 mud program. The actual mud weight varied from 9.2 to 10.8 ppg, as shown in Figure 2. Using a fixed 9.2 ppg reference made D-exponent values comparable across intervals drilled with different mud densities.

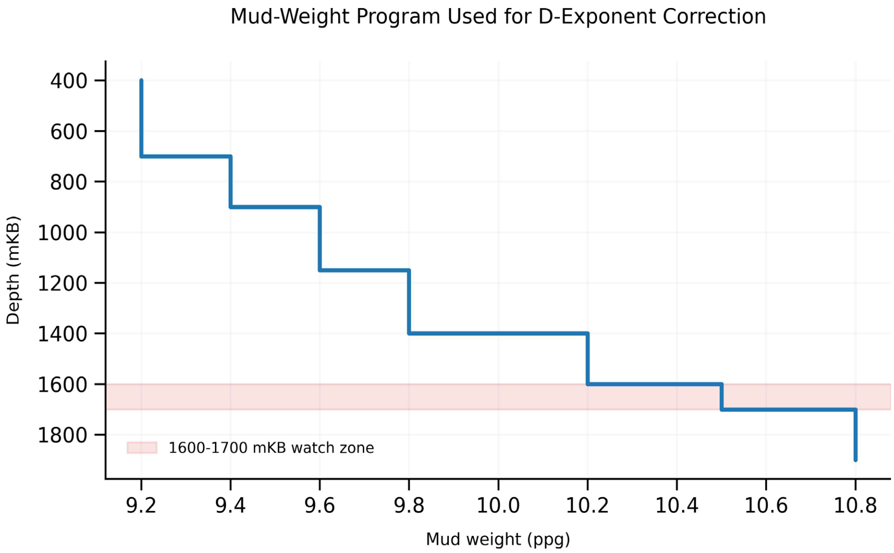

Figure 2. Reported mud-weight program used in the corrected D-exponent mud-weight correction. The shaded interval marks the 1600 - 1700 mKB watch zone.

3.4. Overburden Derivation and Density Source

Overburden pressure was derived from the bulk-density curve used in Interactive Petrophysics. The supplied workflow indicates that density was estimated from sonic input rather than taken entirely from a measured density log. Where measured density was unavailable or incomplete, the density curve was reconstructed from sonic velocity using a Gardner-type velocity-density transform:

$$\rho b = 0.23Vp^{0.25} \tag{3}$$

where ρb is bulk density in g/cm³ and Vp is compressional velocity in ft/s. Sonic slowness was converted to velocity using Vp = 10^6/Δt, where Δt is sonic slowness in μs/ft. Gardner-type density-velocity transforms are commonly used when density logs are missing or incomplete; the standard coefficients 0.23 and 0.25 are widely reported for sedimentary rocks [9]. Because sonic-derived density is empirical, the resulting over-burden curve should be considered a screening-level estimate and should be recalibrated if measured densitylog or core-density data become available.

Overburden pressure was calculated by integrating density with depth. For discrete depth samples, the working expression was Equation (4):

$$\sigma ov(z) = 0.433 \times \Sigma[\rho b, i \times \Delta zi] \tag{4}$$

where σov is overburden pressure in psi, $\rho b,i$ is interval bulk density in g/cm³, and Δzi is depth increment in ft. For manual single-point checking, the same relationship was applied using the cumulative density-derived overburden at the selected depth.

3.5. Normal Compaction Trend and Eaton Conversion

The normal compaction trend was fitted only through shale-screened intervals satisfying Vsh ≥ 0.35 and showing no obvious drilling dysfunction or sharp lithological break. The trend was constructed as a least-squares linear fit of corrected D-exponent against mKB depth through normally pressured shale-prone intervals above the interpreted watch zone. The Aradeiba Main Sand and other clean-sand intervals were excluded. The 1600 - 1700 mKB interval was not used to define the trend; it was retained as an independent interval for evaluation and verification.

Pore pressure was calculated with Eaton's D-exponent form, Equation (5) [10]:

$$PP = \sigma ov - (\sigma ov - Pn) \times (Dco/Dcn)^{1.2} \tag{5}$$

where PP is pore pressure in psi, σov is overburden pressure in psi, Pn is normal hydrostatic pore pressure in psi, Dco is observed corrected D-exponent at the depth of interest, and Dcn is the normal-trend corrected D-exponent at the same depth. Eaton exponent 1.2 was used. The exponent was adopted from the drilling-engineering practice documented in the original Hamra East-8 workflow and was locally checked through manual verification rather than recalibrated by direct formation-pressure measurements. Normal pressure was compared against freshwater and saline hydrostatic gradients of approximately 0.433 and 0.465 psi/ft, respectively. The principal parameter choices and screening rules are consolidated in **Table 2**.

Table 2. Reproducibility parameters.

Workflow item	Specified value or rule	Purpose
Shale-screening rule	Vsh ≥ 0.35 from GR index; practical GR cross-check ≥75 API	Restrict D-exponent interpretation to shale-prone intervals
Depth reference	mKB used consistently; m converted to ft using 3.28084	Avoid MD/TVD/mKB ambiguity
Drilling-data averaging	10 m mKB median bins from DDR/FWR drilling records	Reduce connection and drilling-noise effects
Reference mud weight	MWref = 9.2 ppg	Normalize D-exponent for mud-weight changes
Density source	Sonic-derived density where measured density unavailable	Support overburden calculation
Density transform	$\rho b = 0.23Vp^{0.25}$, Vp in ft/s	Reconstruct bulk density from sonic
NCT fitting	Least-squares trend through shale-screened normal intervals, excluding sands and 1600 - 1700 mKB watch zone	Improve trend reproducibility
Eaton exponent	n = 1.2	Convert D-exponent departure to pore pressure

4. Results

4.1. Verification of Software and Manual Eaton Calculations

The original four verification points at 900, 1000, 1200, and 1400 mKB showed an average absolute difference of 30.5 psi, RMSE of 36.2 psi, and mean absolute percentage difference of 2.0% an additional verification point was added at 1650 mKB within the 1600 - 1700 mKB watch zone. This point lies in the Aradeiba lower interval and directly checks the main interval where the pore-pressure curve showed a slight increase. The five verification calculations are reported in Table 3.

With the added 1650 mKB check, the five-point average absolute difference is 26.8 psi, RMSE is 32.8 psi, and mean absolute percentage difference is 1.7%. The 1650 mKB manual Eaton result is 2556 psi compared with an IP-read value of 2568 psi, giving an absolute difference of 12 psi and a pressure-gradient comparison. The software and manual pressure profiles are compared in Figure 3.

0.472 versus 0.474 psi/ft. This direct watch-zone check supports the interpretation that pressure is slightly above the saline hydrostatic reference but does not represent a strong abnormal-pressure condition.

Table 3. Manual verification of pore-pressure calculation, including added 1650 mKB watch-zone point.

Depth (mKB)	Depth (ft)	IP PP (psi)	Manual PP (psi)	Abs. diff. (psi)	Diff. (%)	IP gradient (psi/ft)	Manual gradient (psi/ft)
900	2952	1329	1304	25	1.88	0.450	0.442
1000	3280	1446	1504	58	4.01	0.441	0.459
1200	3936	1764	1729	35	1.98	0.448	0.439
1400	4592	2032	2028	4	0.20	0.443	0.442
1650	5413	2568	2556	12	0.47	0.474	0.472

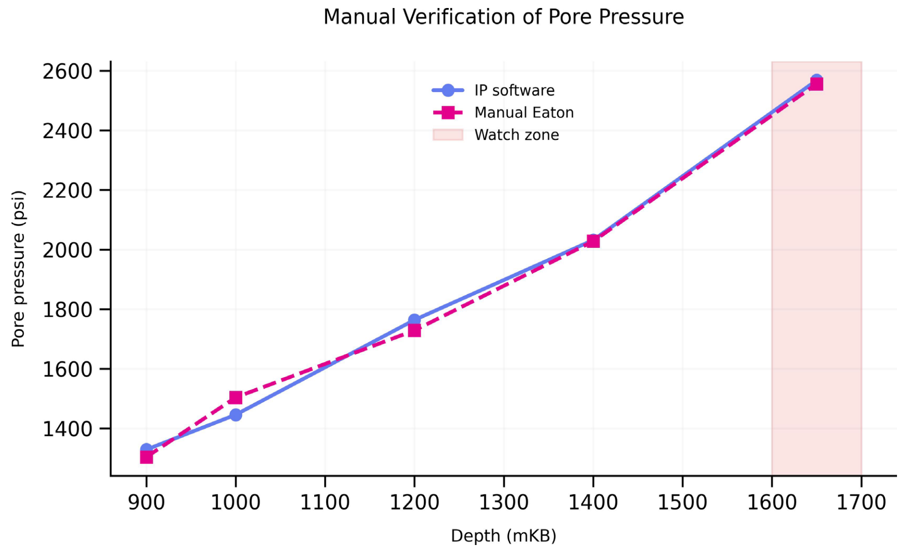

Figure 3. Comparison between IP-derived pore pressure and manual Eaton-equation checks, including the 1650 mKB watch-zone verification point.

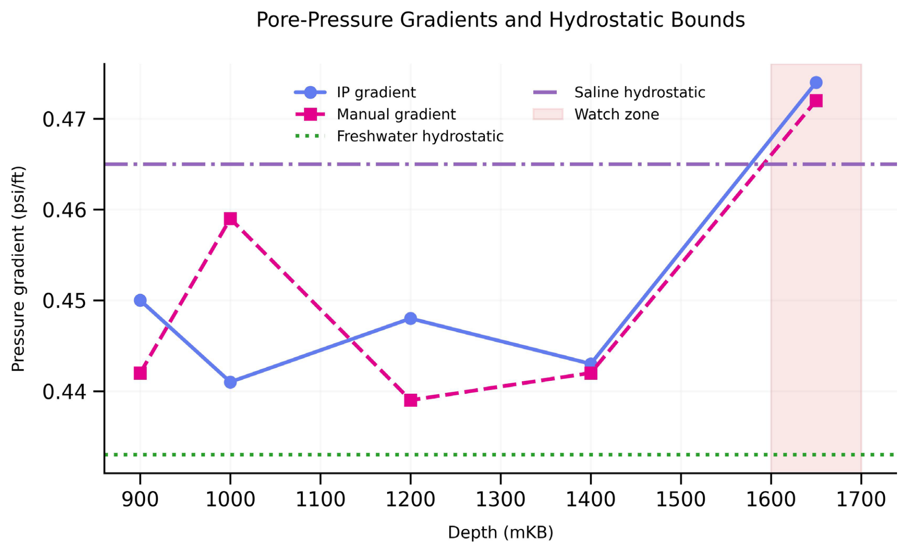

Figure 4. Pore-pressure gradients compared with freshwater and saline hydrostatic bounds. The added 1650 mKB point confirms only a modest watch-zone increase.

4.2. Pressure Regime Interpretation

The calculated gradients at 900, 1000, 1200, and 1400 mKB remain between approximately 0.439 and 0.459 psi/ft for the manual calculations, which lie within or close to the normal freshwater-to-saline hydrostatic range. The added 1650 mKB point has a manual gradient of approximately 0.472 psi/ft and an IP gradient of approximately 0.474 psi/ft. This value is slightly above the 0.465 psi/ft saline hydrostatic reference, supporting the interpretation of a modest pressure increase in the 1600 - 1700 mKB interval. Figure 4 compares these results with the freshwater and saline hydrostatic reference gradients.

The result does not indicate a major abnormal-pressure zone because the gradient increase is small and the mud-weight program remains above the interpreted pore-pressure requirement. The interval should nevertheless be treated as an operational watch zone because it coincides with the deeper Aradeiba interval and precedes the Bentiu target section. Small pressure increases in this zone can reduce mud-weight safety margin and should be monitored with drilling parameters, gas readings, cuttings behavior, and any available pressure-while-drilling or formation-test data in future wells.

5. Discussion

The workflow improves reproducibility by explicitly defining each step that controls the corrected D-exponent and Eaton pressure estimate. The shale-screening rule limits the analysis to intervals where compaction behavior is expected to be meaningful. The 10 m median averaging interval reduces short-term operational noise while preserving depth resolution adequate for field-scale pressure surveillance. The use of mKB as the single depth reference prevents errors caused by mixing measured depth, true vertical depth, and rig datum references.

The overburden calculation remains one of the main uncertainty sources. The available workflow indicates that density was estimated from sonic input, not solely from a measured density log. Gardner-type transforms provide a practical solution when density data are missing, but they are empirical and may not fully capture local lithology, compaction, fluid, and calibration effects. Therefore, overburden and Eaton pore-pressure values should be updated if a measured density log, check-shot velocity calibration, or core-density measurements become available.

The Eaton exponent of 1.2 was adopted from established D-exponent practice rather than calibrated from direct formation-pressure measurements in Hamra East-8. The manual checks show internal consistency between software and hand calculations, but they do not independently prove the true formation pressure. Direct pressure measurements such as repeat formation tester data, drill-stem tests, pressure-while-drilling data, or calibrated offset-well pressure points would be required for full calibration. Until such data are available, the corrected D-exponent result should be used as a surveillance indicator and not as the only basis for final mud-weight or casing decisions. Log-derived pressure indicators and seismic predrill prediction provide complementary constraints when direct pressure data are limited [11]-[13].

6. Conclusions

1. The Hamra East-8 workflow specifies a reproducible shale-screening rule: corrected D-exponent interpretation is restricted to shale-prone intervals with Vsh ≥ 0.35, supported by gamma-ray and lithological checks.
2. The corrected D-exponent equation, mud-weight correction, 9.2 ppg reference mud weight, and 10 m mKB drilling-parameter averaging interval are now explicitly documented.
3. Overburden pressure was derived from a sonic-based density estimate where

measured density was unavailable, using a Gardner-type velocity-density transform. This should be recalibrated if measured density or core data become available.

4. The normal compaction trend was fitted by least-squares through shale-screened normally pressured intervals and excluded clean sands and the 1600 - 1700 mKB watch zone. Eaton's exponent was set to 1.2 and was adopted from drilling-engineering practice rather than locally calibrated with direct pressure measurements.
5. All pressure calculations use mKB as the consistent depth reference. The well was treated as near vertical, and depths were converted to feet for pressure-gradient calculation.
6. An added verification point at 1650 mKB directly checks the main watch zone. The IP and manual Eaton pressures are 2568 and 2556 psi, respectively, giving a 12 psi difference and confirming only a modest pressure increase close to normal hydrostatic conditions.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Adams, N. (1985) Drilling Engineering. PennWell Publishing Company.

[2] Bourgoyne, A.T., Millheim, K.K., Chenevert, M.E. and Young Jr., F.S. (1991) Applied Drilling Engineering. Society of Petroleum Engineers.

[3] Rabia, H. (2002) Well Engineering and Construction. Entrac Consulting.

[4] Jorden, J.R. and Shirley, O.J. (1966) Application of Drilling Performance Data to Overpressure Detection. *Journal of Petroleum Technology*, **18**, 1387-1394. https://doi.org/10.2118/1407-pa

[5] Rehm, B. and McClendon, R. (1971) Measurement of Formation Pressure from Drilling Data. *Fall Meeting of the Society of Petroleum Engineers of AIME*, New Orleans, 3-6 October 1971, SPE-3601-MS. https://doi.org/10.2118/3601-ms

[6] Salano, P. (2006) A Modified Approach to Predict Pore Pressure Using the D-Exponent Method: An Example from the Carbonera Formation, Colombia. *CT&F—Ciencia Tecnología y Futuro*, **3**, 103-111.

[7] Zhang, J. (2011) Pore Pressure Prediction from Well Logs: Methods, Modifications, and New Approaches. *Earth-Science Reviews*, **108**, 50-63. https://doi.org/10.1016/j.earscirev.2011.06.001

[8] Zayed, K.A. (2015) Petroleum Geology and Resources of the Sudan. Geozon Science Media.

[9] Gardner, G.H.F., Gardner, L.W. and Gregory, A.R. (1974) Formation Velocity and

Density; the Diagnostic Basics for Stratigraphic Traps. *Geophysics*, **39**, 770-780. https://doi.org/10.1190/1.1440465

[10] Eaton, B.A. (1975) The Equation for Geopressure Prediction from Well Logs. *Fall Meeting of the Society of Petroleum Engineers of AIME*, Dallas, 28-September-1 October 1975, SPE-5544-MS. https://doi.org/10.2118/5544-ms

[11] Hottmann, C.E. and Johnson, R.K. (1965) Estimation of Formation Pressures from Log-Derived Shale Properties. *Journal of Petroleum Technology*, **17**, 717-722. https://doi.org/10.2118/1110-pa

[12] Pennebaker, E.S. (1968) Detection of Abnormal-Pressure Formation from Seismic Field Data. *World Oil*, **166**, 73-82.

[13] Sayers, C.M., Johnson, G.M. and Denyer, G. (2002) Predrill Pore-Pressure Prediction Using Seismic Data. *Geophysics*, **67**, 1286-1292. https://doi.org/10.1190/1.1500391