

A Novel Fit-for-Purpose Methodology for Predicting Pore Pressure Associated with Gas Hydrates in the Deep-Water Rakhine Basin, Bay of Bengal

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Abstract: Gas hydrates, solid crystalline substances composed of water and gas molecules with methane as the predominant component, are increasingly recognised as a significant industrial geohazard in oil and gas operations. Drilling deepwater targets is costly and risky, making reliable geohazard prediction and accurate well planning imperative. Understanding pore pressure is essential to avoid shallow hazards, as the riserless section is susceptible to fracturing given the narrow drilling margin and could even result in well loss. In the deep waters of the Rakhine Basin in the Bay of Bengal, the challenge was to distinguish the effects of cemented hydrates from overpressure, as they are acoustically fast and, at the base, create a velocity inversion. Velocity-based pore-pressure prediction requires a slowdown in interval velocity where overpressure occurs. It will not discriminate between normal and overpressure in faster gas hydrate-related sediments. In this context, an innovative approach was adopted. After interpreting the base of the gas hydrate stability zone (GHSZ) from seismic data, pore pressure was predicted by inverting Miles's pressure-temperature equations. Gas hydrates are thermodynamically stable in the low-temperature, high-pressure regimes of deep oceans. The inverse model-based pore pressure prediction was validated in the test well. It predicted more accurately than the velocity-based prediction, prompting its application in other wells. The technique works well in the gas hydrate-related shallow stratigraphy of deepwater wells in the Rakhine Basin in the Bay of Bengal (BOB). The inverse modelling technique, based on gas hydrate thermodynamics and the depth of the GHSZ base, is therefore a reliable tool for predicting gas hydrate pore pressure in the Bay of Bengal, which is surrounded by a host of sedimentary basins on both the eastern and western flanks, which become candidates for application of the methodology.

Keywords: Gas Hydrate Stability zone, Phase diagram, Latitude, Rakhine, Pore pressure prediction, Miles, Bay of Bengal

1. Introduction

Geohazards associated with natural gas hydrate deposits are generally classified as either "naturally occurring", resulting exclusively from geological processes, or "operational", potentially triggered by human activity¹. As a natural geohazard, gas hydrates increase the mechanical strength of the surrounding sediment. However, when they decompose, they release free gas and excess pore water, which can significantly reduce the geomechanical stability of the affected sediment. Because gas hydrates occur at shallower depths than conventional hydrocarbon reserves, they can pose risks during shallow drilling and well completion. Deepwater drilling is costly and risky, so accurate well planning and reliable geohazard prediction are essential for controlling costs, assessing risks, and implementing mitigation measures.

Industry practice commonly uses geologically conditioned seismic interval velocities to predict pore pressure, based on the principle that velocities below the normal trend indicate overpressure. Gas hydrates complicate this velocity-based approach because they produce much higher seismic velocities than hydrate-free deep-water sediments. Pure gas hydrate has a P-wave velocity of 3.65-3.75 km/s, far above the background velocity of 1.5-1.7 km/s in shallow deep-water sediments².

1.1 The Pore Pressure Prediction Challenge

The challenge was to distinguish the effects of cemented hydrates from overpressure: both are acoustically fast and create a velocity inversion at the base of the gas hydrate stability zone. Neither the gas hydrate-induced cementation above the bottom simulating reflector (BSR) nor the free gas below it reflects the effective-stress conditions assumed by the Eaton³ (1975) and Bowers⁴ (1995) transforms for pore-pressure prediction. Because the deepwater setting near the mudline narrows the drilling margin, pore pressure must be constrained precisely to avoid problems that could, in the worst case, result in the loss of the well.

2. Innovative Approach

Although the Miles⁵ temperature-latitude-phase-boundary framework has been used to compute gas hydrate stability-zone thickness and BSR depth in the Indian Basins of the Bay of Bengal, no published study has used gas hydrate stability conditions to predict pore pressure within gas hydrates.

In addition to the velocity-based approach, an innovative methodology has been adopted to predict gas-hydrate pore pressure. P.R. Miles⁵ in 1995 defined the potential base of the gas hydrate stability zone (GHSZ) based on the pressure-temperature phase boundary and calculated hydrate thickness. Once the stability zone is interpreted on seismic data, inverse modelling can predict pore pressure.

It uses hydrate thickness, temperature, and geothermal gradients to back-calculate pore pressure in the gas hydrate stability zone. This technique is applied to wells in the Rakhine offshore deepwater of the Bay of Bengal to ensure robust pore pressure prediction (Figure-1).

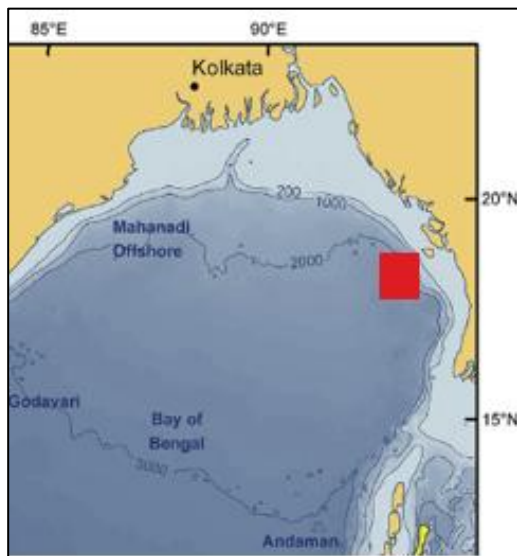


Figure 1: Rakhine Offshore, Bay of Bengal with the area of study (modified from Chandra et al., 1998⁶)

3. Global Gas Hydrate Occurrences

Global distribution of documented and extrapolated gas hydrates across marine environments and permafrost-related contexts, examined through systematic drilling initiatives. The colour scheme represents the predominant sediment composition at each site and indicates the probable classification of gas hydrate accumulation (Figure 2). This study focuses on the Rakhine Basin of the Bay of Bengal.

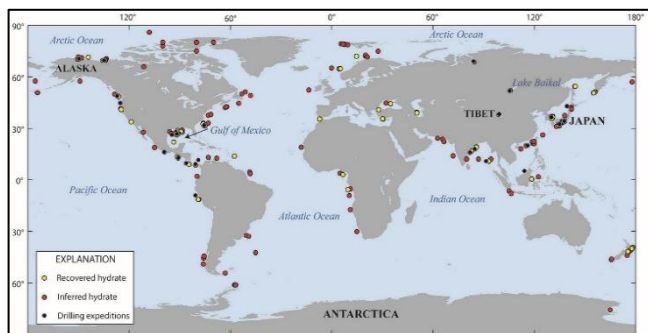


Figure 2: Map showing locations where gas hydrate has been recovered, where its presence is inferred from seismic data, and where drilling expeditions in permafrost or deep marine environments have recovered gas hydrate⁷

4. Geology of Rakhine Offshore Basin

The Rakhine- Andaman-Nicobar forearc system forms part of the dynamic Sunda-Andaman subduction complex, in which the Indian Plate is subducted beneath the Burma microplate⁸. This convergent margin is characterised by antiformal stacking associated with the accretionary prism, slope basins, and an inner volcanic arc chain, with the back-arc basin marking its eastern boundary⁹. Voluminous sediment sequences sourced from the Bengal Fan and

Irrawaddy River systems have been incorporated and extensively deformed by imbricate thrusting, duplexing, and antiformal stacking^{10,11} (Figure 3). These tectono-sedimentary characteristics, together with rapid sedimentation rates and substantial organic matter input, have created optimal conditions for gas hydrate development and hydrocarbon accumulation within the Bay of Bengal's slope and forearc basins¹². Figure 4 illustrates the possible offshore play types in the Rakhine Basin, based on a regional evaluation of geoscience data.

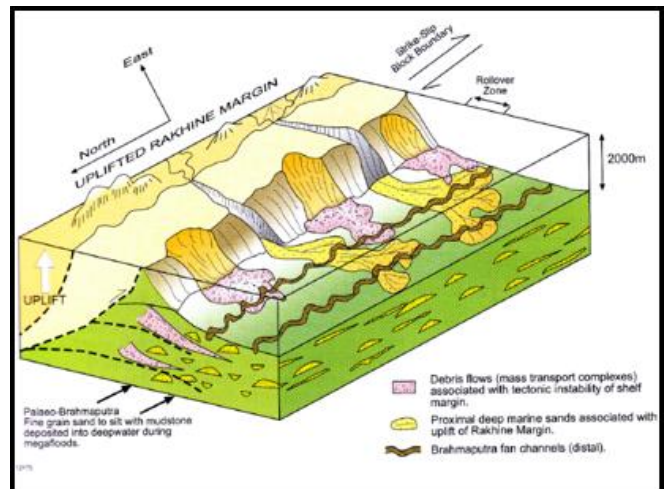


Figure 3: The deep-water portion of the Rakhine Basin beyond the shelf/slope break has two interacting depositional systems: the Brahmaputra Fan, part of the Bengal Fan, inputting sediment from the northern Indian subcontinent, especially during the Miocene period and the uplifted Rakhine margin, inputting sediment from the east during the Upper Pliocene-Pleistocene times¹⁰.

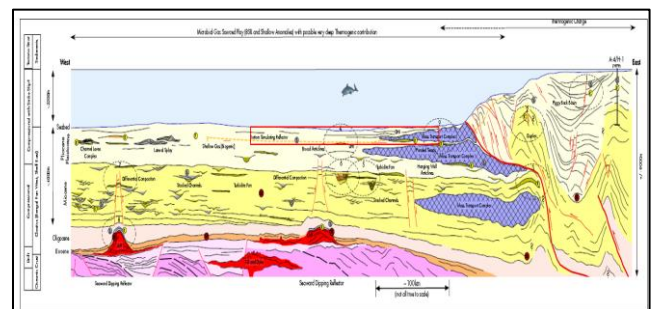


Figure 4: Cartoon illustrating the type of geological features(plays) along the Rakhine Basin

5. Mechanism of Overpressure Formation in Gas Hydrates

Overpressure in marine gas hydrate systems is fundamentally linked to permeability degradation caused by hydrate formation and the accumulation of free gas beneath bottom-simulating reflectors (BSRs). BSRs are key geophysical indicators marking the boundary between gas hydrate-bearing sediments and the free gas beneath. In marine sedimentary environments, overpressure typically develops within a low-permeability sediment layer above a natural gas accumulation, forming predominantly beneath a sulphate-methane interface (SMI) as anaerobic oxidation consumes methane above the SMI.

Methane hydrate deposits are typically found in sedimentary formations that occur within specific temperature and pressure ranges. If temperature or pressure exceeds the hydrate's stability threshold, the hydrate decomposes, releasing gaseous and aqueous phases. Because the overlying hydrate-saturated sediment layer has limited permeability, the confined release of gas and water from this decomposition generates elevated pore pressure¹³.

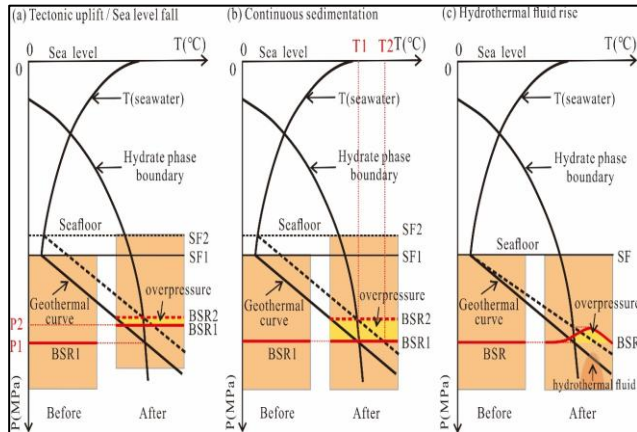


Figure 5: Overpressure generation resulting from gas hydrate dissociation triggered by tectonic uplift and/or eustatic sea level fall, coupled with ongoing sediment accumulation and ascending hydrothermal fluids (adapted from Foucher et al.¹⁴). T, temperature; P, pressure; SF, seabed; BSR, bottom-simulating reflector.

5.1 Three mechanisms for OP development in gas hydrates

When tectonic uplift or sea-level decline occurs, pressure within the gas hydrate stability zone decreases. Consequently, gas hydrate deposits near the BSR move outside their stable thermodynamic conditions and begin to decompose, releasing free gas into the sediment pore spaces. Because the overlying stratum remains within the gas hydrate stability regime, the liberated free gas becomes confined, leading to overpressure development (Figure 5a).

Ongoing sedimentation progressively thickens the sediment column and raises temperatures within the hydrate stability zone. As the sedimentary layer accumulates, gas hydrate deposits near the BSR move downward relative to the seabed. When the phase-equilibrium threshold is reached, gas hydrate begins to decompose (Figure 5b); consequently, persistent sedimentation displaces the hydrate zone's lower boundary upwards. The magnitude of the resulting overpressure depends on the sedimentation rate¹⁵.

Conversely, if the sedimentation rate is sufficiently rapid that gas liberated from hydrate decomposition lacks adequate time for migration, a new BSR will not develop, and the preexisting BSR may become attenuated or even vanish¹⁶. Hydrothermal fluid, which migrates from deeper basin regions via faults, mud diapirs, and mud volcanoes, among other pathways, may similarly induce hydrate decomposition (Figure 5c).

6. Gas Hydrate Stability Zone

No established methodology removes the effects of gas hydrates from pore-pressure predictions; natural features within the hydrate stability zone, such as an inversion beneath them, may reflect the free-gas zone. A closer examination of the area's sediment morphology could help assess the likelihood of increased pore pressure. Bottom-water temperatures may vary over time, causing hydrates beneath the seabed to warm and cool cyclically. During warming, pore-volume expansion could create cracks, while contraction could close them¹⁷. This process may resemble wellbore ballooning, but on a longer timescale. If pore pressures exceed the overburden, fracturing effects may be visible on the seabed. Hydrate formation reduces permeability, and repeated warming and cooling may weaken the seabed through overpressure at the base of the gas hydrates. Gas buoyancy could also contribute to fluid-flow-generated overpressure, fracturing the sediments. If such evidence is present, the elevated pore pressure would dissipate.

6.1 Base of Gas Hydrates:

The seabed temperature is about 4°C, and temperature increases with depth according to the geothermal gradient. In open-ocean conditions, the HSZ extends downward from the seabed at a water depth of about 450 m, reaching sub-seabed depths determined by the increasing sediment temperature, or geothermal gradient. Pressure also increases with depth, from hydrostatic to close to lithostatic at times. Increasing pressure stabilises gas hydrates, whereas increasing temperature eventually becomes too high for them to exist¹⁸. This defines the base of the gas hydrate stability zone (Figure 6)¹⁹. This is a classic seismic section from Uruguay that shows a hydrate indicator known as the Bottom Simulating Reflector (BSR).

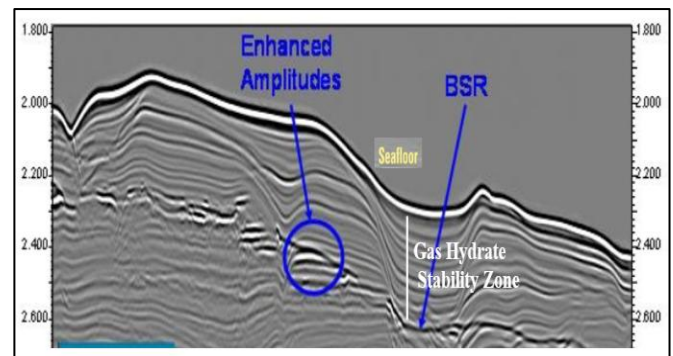


Figure 6: Seismic section acquired offshore Uruguay in 2008 showing BSR and enhanced amplitudes below the base of the gas hydrate stability zone, suggesting the presence of free gas¹⁹.

6.2 Gas Hydrate Stability Zone:

At a constant geothermal gradient, the GHSZ occurs at a consistent depth below the seabed, varying with water depth and forming the bottom-simulating reflector where present (Figure 7). Phase stability analysis confirms that current bottom-water pressure and temperature conditions support hydrate stability at or near the seabed in the Krishna Godavari Basin²⁰.

Active and passive continental margins constitute approximately one-third of the world's ocean floor. Subsurface conditions in these regions, characterised by sufficiently low temperatures and sufficiently high pore pressures, promote gas hydrate formation.

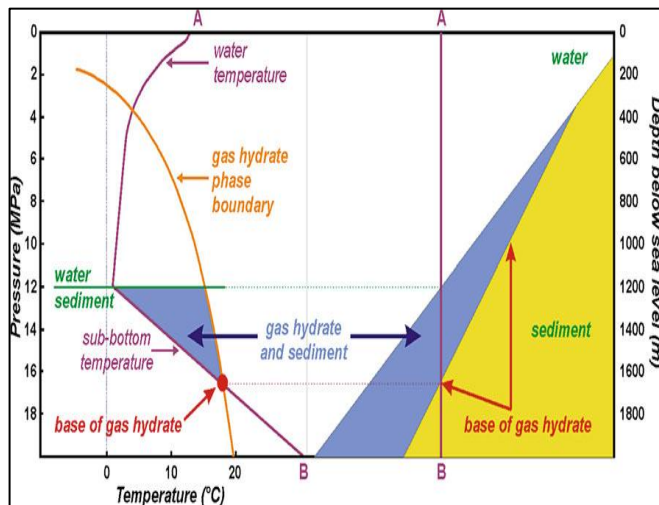


Figure 7: An example of gas hydrate stability in a continental margin setting²¹ (after Kayen and Lee 1991).

Left: methane hydrate stability curve (orange) and temperature-depth profile (purple). Blue regions show the GHSZ below the seabed. Hydrates are also stable in parts of the water column, but as they are lighter than water, they will float up and dissociate. Right: schematic diagram of a continental margin with the location of the phase diagram indicated by the vertical line A–B. GHSZ thickness increases with water depth, and hydrates are unstable in shallow waters.

The gas hydrate stability depth extends from the sediment-water interface to the sub-bottom depth at which the geothermal gradient intersects the methane hydrate-water equilibrium curve²². The gas hydrate phase diagram illustrates the thermodynamic conditions that govern gas hydrate stability. Bathymetry, ocean-bottom temperature, the geothermal gradient within the sediments, and latitude all significantly affect the thickness of the gas hydrate stability zone.

7. Potential shallow hazards

Gas hydrates pose drilling complications comparable to those encountered in free-gas and overpressured, sand-rich sedimentary formations. If pore pressures are not precisely measured, understood, and controlled, shallow strata may become unstable, leading to multiple geohazards primarily driven by geomechanical factors. Drilling in gas hydrate environments requires careful management of wellbore stability to prevent stress-related mechanical deterioration, borehole erosion, and fluid intrusion from gas hydrate decomposition. Hydrate-bearing sediments may destabilise spontaneously through natural geological mechanisms or during drilling. The P-T regime that controls the position of the gas hydrate phase can change, causing dissociation. Regardless of the cause, hydrate dissociation is expected to increase pore-fluid pressure. These considerations highlight the fragility of hydrates and their potentially serious implications for well siting, drilling, and casing programmes.

When drilling through hydrate zones, drilling companies have encountered;

- Problem of well control due to severe mud gasification
- Intensive cavity formation, rock collapse, tool sticking. Violent degassing, etc.
- Direct and reverse phase transition of water in rocks
- Freezing of water-based mud in the BOP, making it inoperative
- Gas release scenario: over-pressured free gas is encountered unexpectedly beneath a gas hydrate layer (Figure 8).

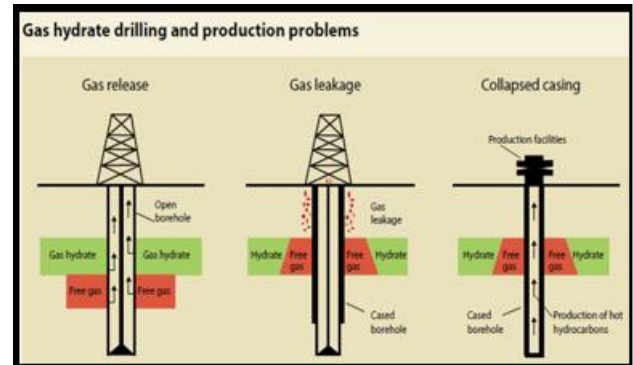


Figure 8: Potential geohazard in the shallow riserless section of deep water²³

7.1 Potential Drilling and Production Complications:

Figure 8 illustrates characteristic gas-hydrate-related drilling and production complications encountered during drilling operations in Arctic regions²³. Gas Release Scenario (left): unexpectedly encountered over-pressured free gas beneath a gas hydrate stratum. Gas Migration Scenario (centre): potential disruption of gas hydrate by drilling activities, leading to dissociation and subsequent free gas migration beyond the drill casing. Casing Failure Scenario (right): potential disruption of gas hydrate resulting from conventional production operations involving warm hydrocarbon extraction at depth.

7.2 Robust well planning:

Careful management of drill-mud weight can mitigate drilling hazards. The mud must provide sufficient downhole pressure to stabilise in situ gas hydrates without exceeding the pressure that could fracture downhole formations. Chemical additives can also help maintain gas hydrate stability in the formation and prevent dissociation in drill cuttings; avoid inhibitors that induce dissociation, such as salts and alcohols. Drilling through hydrates is currently viewed as a relatively short-duration hazard that can be readily managed in hydrate-prone regions through the proper application of standard industry drilling protocols focused on maintaining appropriate drill fluid temperatures.

8. Methodology for Predicting Gas Hydrate-Related Pore Pressure

8.1 Factors constraining the Temperature-Depth of Gas Hydrates. Bathymetry, seabed temperature, geothermal gradient, and latitude are among the most important parameters controlling the thickness of the gas hydrate

stability zone²⁴. This thickness is the vertical distance through the sediment cover from the seabed to the point where the phase-boundary curve intersects the geothermal-gradient curve. The HSZ is fairly uniform in thickness, typically hundreds of metres at a given seabed depth, and becomes thicker under higher pressure²⁵.

In addition to the requirements for low temperature and high pressure, the stability of gas hydrates also depends on the gas and pore-water composition, grain size, and available pore space. Together, these conditions control the thickness of the gas hydrate stability zone (GHSZ).

8.2 Gas Hydrate pressure- temperature phase diagram to determine the depth of HSZ:

The gas hydrate zone base can be determined from the phase equilibrium equation. The gas hydrate P–T phase diagram is valid between 0°C and 30°C and at a salinity of 33.5%, so hydrate formation is possible only under these conditions. The gas hydrate phase diagram and P–T equations of Miles are used to calculate the thickness of the gas hydrate stability zone in the marine environment. The depth to the base of the stability zone can be obtained from the equations below, as described by Miles⁵.

$$P = 2.8074023 + aT + bT^2 + cT^3 + dT^4 \quad (\text{equation 1})$$

where $a = 1.559474 \times 10^{-1}$, $b = 4.8275 \times 10^{-2}$, $c = -2.78083 \times 10^{-3}$ and $d = 1.5922 \times 10^{-4}$

The temperature-depth function from seabed temperature (T_0) and the geothermal gradient is

$$T_z = T_0 + (\Delta T / \Delta Z) Z \quad (\text{equation 2})$$

where T_z (°C) is the temperature at depth D in the sediment. $D = Z_0 + Z$ (bml), where Z is the water depth (m).

The pressure in MPa to depth (D) conversion gives

$$P = [(1 + C1) D + C2 D^2] \times 10^{-2} \quad (\text{equation 3})$$

where $C1 = (5.92 + 5.25 \sin^2(\text{lat})) \times 10^{-3}$ lat in degrees and $C2 = 2.21 \times 10^{-6}$

Transforming equation 2 into a function for Z and substituting into equation 3 gives

$$P = [(1 + C1)(Z_0 + (T_z - T_0)\Delta Z / \Delta T) + C2(Z_0 + (T_z - T_0)\Delta Z / \Delta T)^2] \times 10^{-2} \quad (\text{equation 4})$$

which is the pressure-temperature relationship within the sediments in the same units as equation 1. The simultaneous solution for equations 1 and 4 can be found analytically by an algorithm.

8.3 Predictive Edge over seismic velocity-based method

Because hydrate cementation alters seismic velocity independently of effective stress, the vertical effective stress (VES) calculated from velocity measurements underestimates the true VES, producing systematically elevated pore-pressure predictions. The Miles (1995) inverse temperature–pressure framework, as outlined in Equations 1–4 above,

directly addresses this specific limitation. The thermodynamic conditions governing gas hydrate formation in deep-water sediments can therefore serve as a predictive tool for determining pressure conditions within gas hydrate systems. The method is called Mile's GHSZ-derived pore pressure prediction for gas hydrates in this paper.

9. Application in Offshore Rakhine Basin

Typically, the area lacked shallow geohazard features. Pore pressure was inversely modelled using Equations 1–4, accounting for temperature uncertainties and the study area's latitude. The analysis was limited to the 0°C–30°C temperature range, where the method is valid. Within the gas hydrate stability zone, Helgerud et al. (1999)² documented the rock-physics decoupling between velocity and effective stress. Hydrates modify rock-fabric elasticity and pore-fluid elasticity. Hence, conventional velocity-based pore prediction is not appropriate.

Seismic interpretation determines the stability zone depth. Using Equations 1 and 3, along with temperature uncertainties and the location's latitude, the inverse modelling was performed to estimate pore pressure within the valid 0°C to 30°C temperature range. Figures 9 and 10 show the GHSZ model's predicted pore-pressure estimates, considering the GHSZ base, temperature, and location latitude independently. The estimates vary negligibly, by only about 80 psi. This inverse-modelling technique, based on the depth of the GHSZ base, reliably predicts pore pressures in gas hydrates in the deep-water Rakhine Basin, Bay of Bengal.

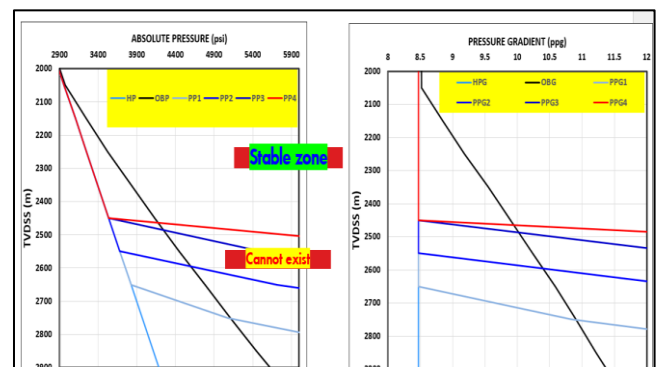


Figure 9: Pore pressure estimates with Mile's temperature model

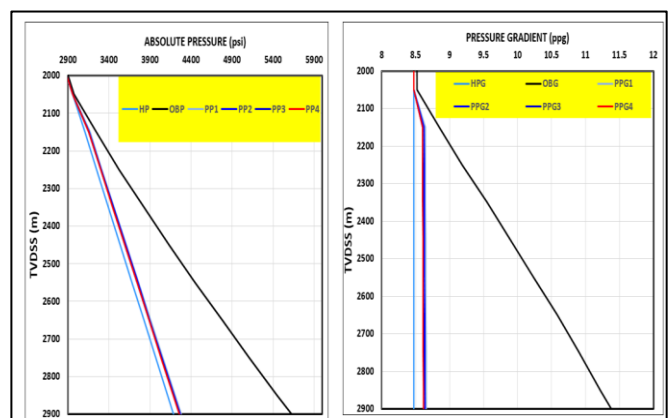


Figure 10: Pore pressure estimates with Mile's latitude model

10. Seismic Velocity-based pore pressure prediction

Figures 11a and 11b show pore pressure estimates with the uncertainty envelope on the left and the mid-case on the right, obtained by conventional velocity inversion to vertical effective stress and backing it out from the overburden. The predicted overpressure in the gas hydrate section is of the order of 200-400 psi.

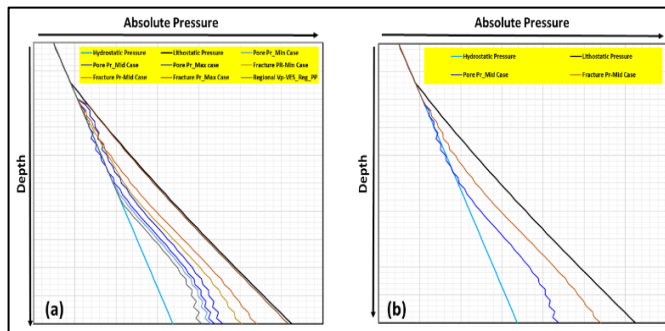


Figure 11: (a) Pore pressure and fracture gradient estimates with seismic interval velocities for all the uncertainty scenarios. (b) Pore pressure and fracture gradient estimates only for the mid-case scenarios

11. Comparison of the GHSZ-derived pore pressure with Seismic Velocity-based prediction

A composite pore-pressure plot highlights the differences between the two methodologies used to estimate pore pressure in the gas hydrate stability zone. The velocity-based PPP for the prospect with gas hydrate shows a decrease in velocity, but OP is 200-400 psi. The predictions differ markedly from Miles's GHSZ-derived pore pressure method, which predicts pressures close to hydrostatic, while the conventional velocity-based method predicts 200-400 psi of overpressure (Figure 12).

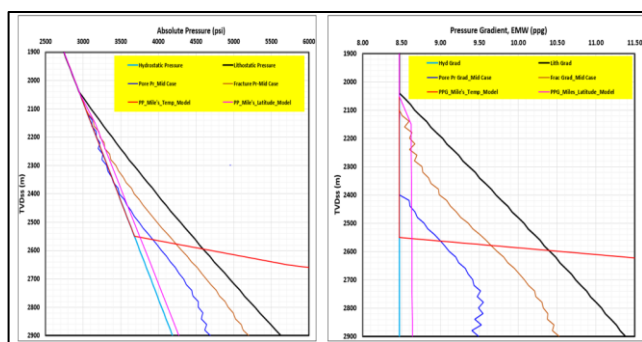


Figure 12: Integrated pore pressure prediction

The Miles method, using P-T phase diagram calculations to back out pore pressure through GHSZ thickness and BOB-specific latitude, indicates hydrostatic to only mildly overpressured conditions. Given the near consanguinity between the methods, pore pressure in gas hydrates and just below could be hydrostatic and, if overpressured at all, 200-400 psi higher. The free gas causing velocity reversal below the base of the gas hydrate zone could be in a dipping formation, where gas-inflationary pressure could act. The

shallow velocity slowdown 200-300 m below the seabed could also be a gas-hydrate signature in contiguous BOB basins. Seismic interpretation indicates no dipping formations in the area, and inflation due to lateral plumbing is unlikely (Figure 13).

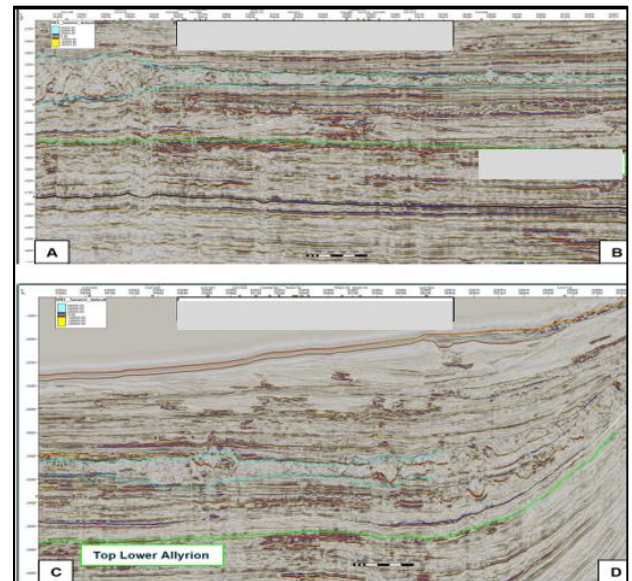


Figure 13: Horizontal reflections enabling ruling out of lateral fluid transfer

12. Why does a 200-400 psi variation in pore pressure matter?

For instance, deepwater pore-pressure regimes are likely to be overburden-parallel (Figure 3). These basic rules, derived from deepwater geology, enable more accurate well planning and constrain pressure interpretations derived from seismic velocity data. SWF poses a serious shallow hazard because overpressure and low formation fracture strength create a narrow drilling margin (NMD)²⁶. Excessive ECD could induce fractures in the formation, allowing overpressures to transmit to the seabed through the resulting fracture pathways and, in a worst-case scenario, may even result in catastrophic events like losing the hole in the riserless section requiring a resump (Figure 14).

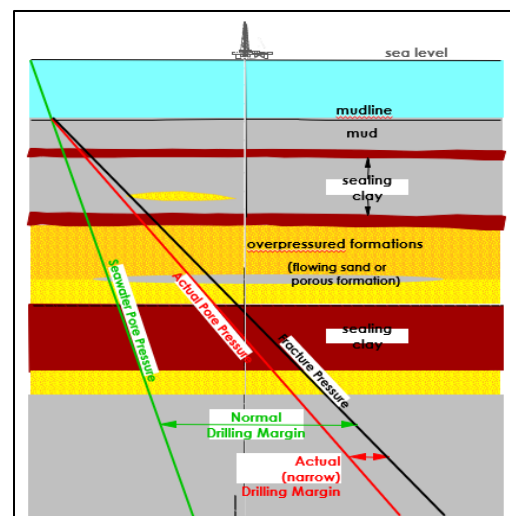


Figure 14: Typical Deepwater Pressure Profile²⁷

13. Drilling Results

The test well, where the innovative pore-pressure prediction was attempted, encountered gas hydrates in the riserless section, as expected. Pump-and-dump mud with a density of 1.12 SG had to be used reactively to control the mild flow associated with the gas hydrates (Figure 15). Based on the weak well activity, pore pressure was estimated to be 20-30 psi above hydrostatic. These results validated Miles's GHSZ-based pore-pressure prediction. The velocity-based prediction estimated an overpressure of 200-400 psi, which was too high; using it to design the mud could have fractured the shallow formations and jeopardised the well. The resulting overbalance would have been even higher, further challenging the narrow drilling margin in shallow deepwater sections. The explicit comparison and statistical validation against the conventional Eaton³ and Bowers⁴ velocity-based predictions demonstrate the value of this innovative approach.

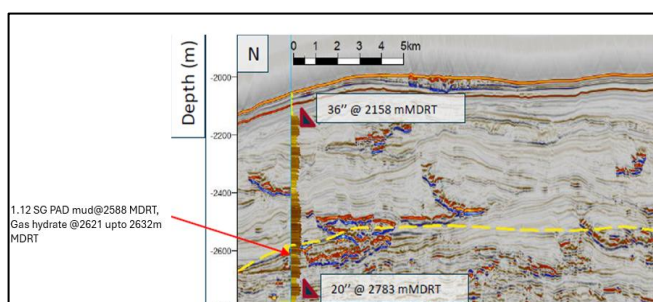


Figure 15: Gas hydrate occurrence in deepwater Rakhine, test well

12.1 Testing the repeatability of the methodology:

This methodology was applied in subsequent wells, using an integrated PPFG estimation to assess repeatability. The later wells could be drilled safely using seawater, as shown in a similar scenario in Figure 16. In these wells, too, the velocity-based prediction overestimated the overpressure by 300 psi relative to the hydrostatic pressure derived from Miles's GHSZ inversion, and the methodology proved successful.

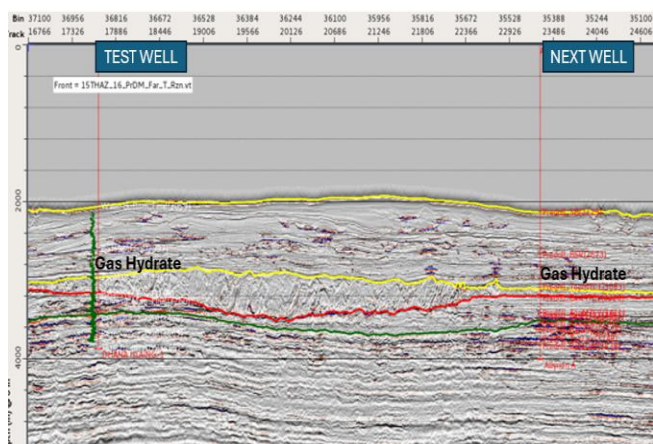


Figure 16: Gas hydrate occurrence in deepwater Rakhine, later well

14. Uniqueness of Applicability

This inverse pressure-temperature modelling approach estimates pore pressure independently of seismic velocity and constrains it directly using the thermodynamic conditions that define hydrate stability, but the gas hydrate stability zone definition comes from seismic analysis.

The proposed approach to pore-pressure prediction in gas hydrates is based on case-based reasoning from similar situations elsewhere. Case-based reasoning (CBR) is the process of solving new problems by drawing on the solutions to similar past problems (Figure 17). Data from riserless wells must be revisited, and observations calibrated to establish surrogates or proxies for pre-drill prediction and monitoring of future wells. Surrogates are substitutes or proxies for fracture observations²⁸. This analogy is extended to gas hydrate pore-pressure prediction.

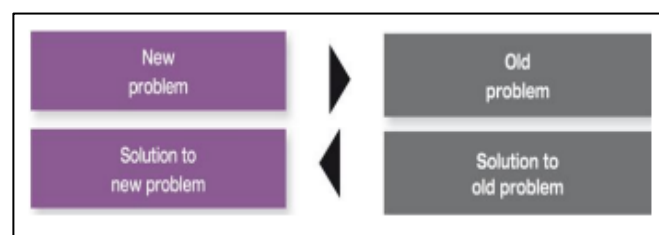


Figure 17: Case-Based Reasoning Model²⁹

The proposed surrogates, or proxies, include drilling parameters (ECD/ESD/flow) and mud-log observations, which help identify overpressured zones. Analysing this data facilitates safe drilling through gas hydrate-bearing formations. We recommend collecting and utilising this data in upcoming wells, alongside offset well data and existing research, to interpret gas hydrate pore pressures in any deepwater environment where gas hydrates are expected.

15. Conclusions

No established method exists to remove the cementation effects of gas hydrates, which occur naturally within the hydrate stability zone, when constraining pore pressure using conventional seismic interval velocity. In the deepwater Rakhine Basin, Bay of Bengal, the challenge was to distinguish the effects of cemented hydrates on seismic interval-velocity-based pore-pressure estimates from actual fluid pressure. Gas hydrates are acoustically fast and create a velocity inversion at the base of the zone, making velocity-based predictions unreliable. After interpreting the GHSZ base from seismic data, pore pressure was predicted using inverse modelling with Miles's pressure-temperature equations, which define the thermodynamic conditions for gas hydrates. Seabed pressure-temperature conditions and heat flow are the main factors controlling GHSZ thickness.

Accurate pore-pressure prediction is essential because the shallow, riserless section is susceptible to fracturing due to the narrow drilling margin, which could even result in losing the well. The inverse-modelling-based pore-pressure estimate (Mile's GHSZ-derived pore-pressure prediction) was validated in the test well. It proved more accurate than the velocity-based prediction, prompting its application in other

wells. The method performed accurately in gas-hydrate-related stratigraphic sections of deepwater wells in Rakhine. This inverse-modelling technique, based on GHSZ base-depth conditions, successfully and reliably predicts pore pressures in gas-hydrate-prone sections of deepwater wells in the Bay of Bengal.

Results from the Rakhine offshore wells confirm that this novel technique predicts gas hydrate pressures more reliably than conventional velocity-based methods, establishing a new link between hydrate phase equilibrium and pore-pressure prediction, particularly when hydrates are cemented. This method applies only to the geologic section between the seabed and the base of the gas hydrate zone. It may need refinement in areas of rapid sedimentation or transient heat flow, which can affect estimates of gas hydrate stability-zone thickness. It performs best in sediments with high hydrate saturation and well-constrained thermal gradients, as observed in the deepwater Rakhine Basin wells. Further studies should extend the gas hydrate P-T phase diagrams across the entire BOB sedimentary basin. More importantly, it could improve geohazard assessment and riskless economic well design across gas hydrate-prone offshore provinces in the Bay of Bengal and other convergent-margin settings. This study also offers valuable analogue insights for India's offshore and frontier-basin exploration, particularly in the Andaman-Nicobar region and adjacent areas of Myanmar.

Nomenclature

HSZ = hydrate stability zone

GHSZ = gas hydrate stability zone

BOB = Bay of Bengal

BSR = bottom simulating reflector

SWF = shallow water flows

SMI = sulphate-methane interface

OP = overpressure

NMD = narrow margin drilling

ECD = equivalent circulating density

P-T = pressure-temperature

VES = vertical effective stress

BOP = blowout preventer

MDRT = measured depth rotary table

PPFG = pore pressure gradient, fracture gradient

ESD = equivalent static density

PPP = pore pressure prediction

CBR = case-based reasoning

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