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Deepwater Shallow Water Flow (SWF): Causes and Evasion

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Abstract

SWF represents a costly drilling challenge in deepwater. This study shows the impact of depth below the mud line (BML) vs. the subsea water depth (WD) on this phenomenon. It calculates the mud-up required to evade SWF occurrences at different WD / BML depths.

The backbone of this study is establishing the differential pressure between the sand vs. the shale beds. This is due to the fact that most of the SWF's take place while penetrating the shale – sand boundaries. Case histories from the Gulf of Mexico, where the upper Pleistocene depositional fan was and is still active, are utilized.

During compaction, sand's formation water rapidly influxes upward whereas shale's dewatering is very slow. The differential pressure (Δ P) value ranges from 630 psi (1.2 ppg) to 50 psi (0.2 ppg) at variable depths. All Δ P's show highest values between 1500 and 2500 ft BML which is where most of SWF take place. Moreover, Δ P noticeably increases near the ML at greater WD and can be the reason for the occasional conductor and well head sinking in the extra WD.

Choosing correct mud up values (Δ P) at depth is essential to combat SWF and avoid loss of circulation. The SAFE MW to combat SWF is calculated at different WD and depth BML. Algorithm and tabulations are systematically presented in this paper.

This pilot method can also be successfully applied in other young similar deepwater settings worldwide e.g. the Nile, Niger and Amazon Deltas, and as well as south Asian areas.

Introduction

The Bureau of Ocean Energy Management (BOEM), previously known as MMS, reported more than 160 cases of SWF in the Gulf of Mexico. Most of these cases occurred in the Mississippi and Green Canyons areas where the late Pleistocene depositional fan was and is still active. Occasionally, conductor and well heads sink and get lost in these areas as well.

The causes of SWF were discussed in several previous studies. Mud line topography, shallow structural features, mud flows, gas hydrate expulsion and over-geopressured sand are responsible for this phenomenon. Dutta et. al. (2010)[1] stated "Shallow water flow hazards can be characterized through deterministic indicators such as V_p / V_s ratios and density and also pore pressure that can be estimated quantitatively for the near sea floor sediments where conventional velocity analysis is not effective."

This paper introduces a new quantitative look at the shallow subsurface pressure profile zones that are related to the geologic deposition and compaction processes. The vertical generic pore pressure profile in the subsurface can be, in most cases, divided into four zones (Shaker, 2015a) [2] namely: free flow, hydrodynamic, transition and geopressured (A, B, C and D respectively). For the purpose of this article the upper two zones A and B will be discussed.

The free flow zone A is an extension of the hydrostatic gradient of the sea bed. Within zone B fluid starts escaping from deeper sediments to the shallower ones (hydrodynamic) and grain to grain contact increases. The gradual reduction of porosity due to compaction and dehydration (Burst 1969)[3] is usually represented by an exponential trend. It is usually referred to, in pore pressure practice, as the normal compaction trend (NCT). It is suggested here that it should be designated as the compaction trend (CT) instead of the normal compaction trend, since the normal hydrostatic pressure is only observed in the free flow zone A.

Establishing the extent of the hydrodynamic zone B from seismic velocity is crucial to the pressure prediction calculation (Shaker 2015b)[4]. The depth to the start and end depth of zone B is contingent on the lithofacies, overburden and any tectonic or structural stresses. The depth to the stress that can choke the low permeability sediment and prevent any further fluid expulsion is referred to as the top of geopressure (TOG).

Hydrogeology – Formation pressure

The Mississippi delta was very active during the Pleistocene time with high rate of sedimentation in the Mississippi and Green canyons areas. Thick clastic sediments; mostly shale, clay and sand, sometimes reaching 10,000 ft thick, were deposited in the last 1.7 million years (Figure 1). The compaction process of these deposits is still active and the continuing dewatering process is significant (Figure 2).

Zone A

In this zone, the depositional environment receives sediments as debris flow with above 50% water saturation. Rubey and Hubbert (1959)[5] stated that for depths of 1 to 2 km, pressure is a function of depth where fluid moves freely and exhibits a hydrostatic pressure gradient derived from the weight of the water column only. Zone A's pressure gradient in the Gulf of Mexico is 0.465 psi/ft (10.52 MPa/Km). Formation density gradually increases with depth and ranges from 1.2 g/cc at the mud-line to 1.8 g/cc (Figure 2) at the top of zone B (Schubert J., after Yong D. 2005)[6]. On the other hand, porosity decreases from 70% at the Mud line to 40% at the top of zone B (Dutta et.al 2009)[7] . This zone sometimes extends below the mud line to an average ±1,000 to 3,000 feet.

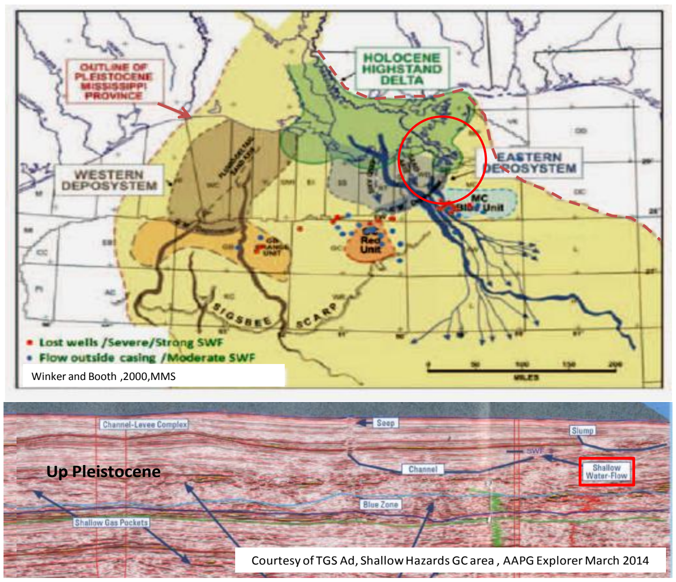

Figure 1: *On top, the large extend of the Mississippi delta during the Pleistocene – Holocene era (Dutta et.al., 2010). Red circle represents current delta. On bottom, a seismic display shows the chaotic events that indicates a mass transport system without well defined compartmentalization i.e. in communication.*

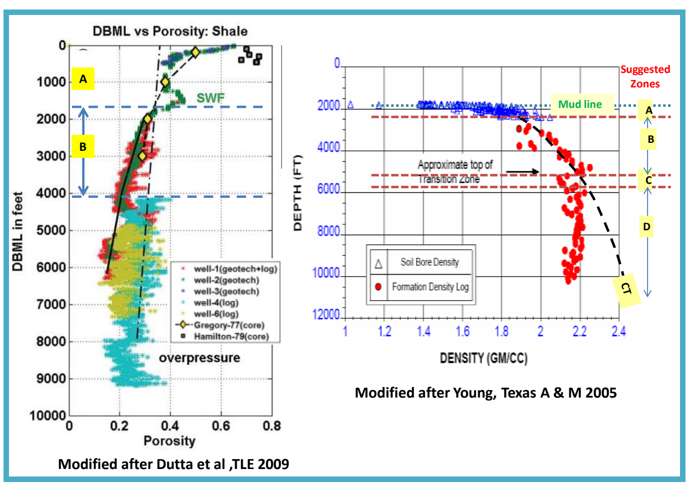

Figure 2: *On the left, a porosity profile vs. depth composite from several wells in Green Canyon area (Dutta et.al. 2009). Note the high porosity values at the SWF zone at ≈ 1,500 ft below the mud line. On the right is a density profile in shallow water (after Yong and Schubert.2005). Both plots are modified to show the proposed pore pressure zones.*

Zone B

This zone starts at a depth where the overburden's stress promotes the fine sediments to start the process of dewatering (Figures 2). The mathematical model of Smith (1970)[8] with negligible permeability at the base (i.e. a seal) shows a gradual reduction in the water flow rate and, conversely, an increase of pore-water pressure that coincides with the increasing of overburden and matrix frame pressure. This is consistent with the presence of hydrodynamic upward flow in zone B and the assumed minimal permeability in zone C. The upwards hydrodynamic gradient is usually greater than the normal hydrostatic gradient (Dahlberg, 1994[9]; and Shaker 2001[10]).

Shallow water flow occurs in wells drilled at subsea water depth ranging from 500 ft to 8,000 ft However, the overflow sand mostly takes place at an average depth range from several hundred ft to 3,000 ft below the mud line (Figure 3). Dutta et.al. (2010)[1] called for a method that can quantitatively estimate the pore pressure for the near sea floor sediments where conventional velocity analysis is not effective.

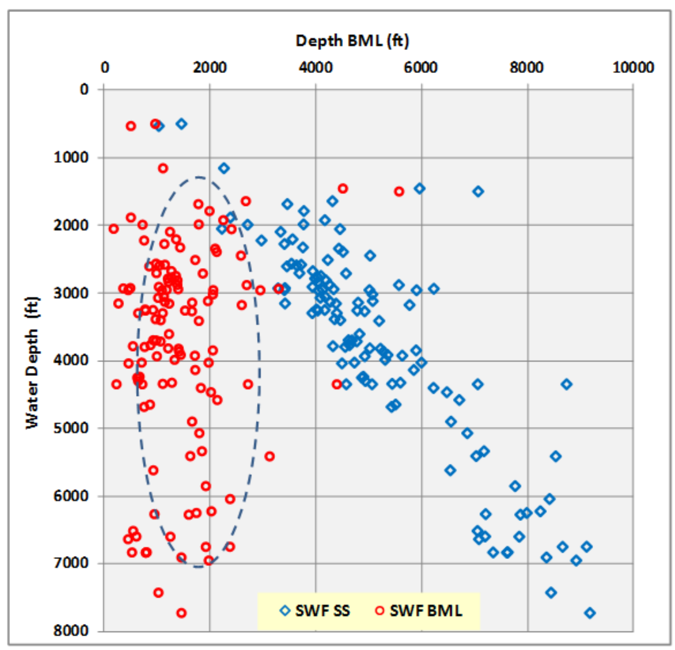

Figure 3: *A cross plot of the relation between the SWF subsea depth (blue) and the SWF below the mud line depth in red circles (data was mined from MMS records). Note most of the shallow water flow takes place between several hundred feet and ≈ 3,000 ft below the mud line (dashed oval shape). Moreover, water depth does not impact the depth of SWF below the mud line (BML). Therefore, age and rate of compaction can be the diagnostic cause for this phenomenon.*

Predictive modeling before drilling

Defining zones A and B from seismic before drilling:

Compressional seismic velocity (Vp) is the first petrophysical property that can be used to predict the depth to zone A and the extent of zone B. Normal moveout and RMS velocities can be used for a quick look and regional assessment. However, interval or Dix velocity (Vi) is the velocity recommended for 1D and 2D interpretations. Figure 4 shows velocity pairs from two depositional environments, deep water and flexure trend /outer shelf, and the estimated depth for these zones.

In zone A, the velocities average ≈ 5,000 ft/sec (≈ 200 µs/ft). In zone B the data values show a gradual exponential increasing trend and ranges between ≈ 6,000 ft/sec to ≈ 8,500 ft/sec. The pivot point where the velocity trend changes course from increasing to decreasing with depth is the proximate depth to the base of zone B.

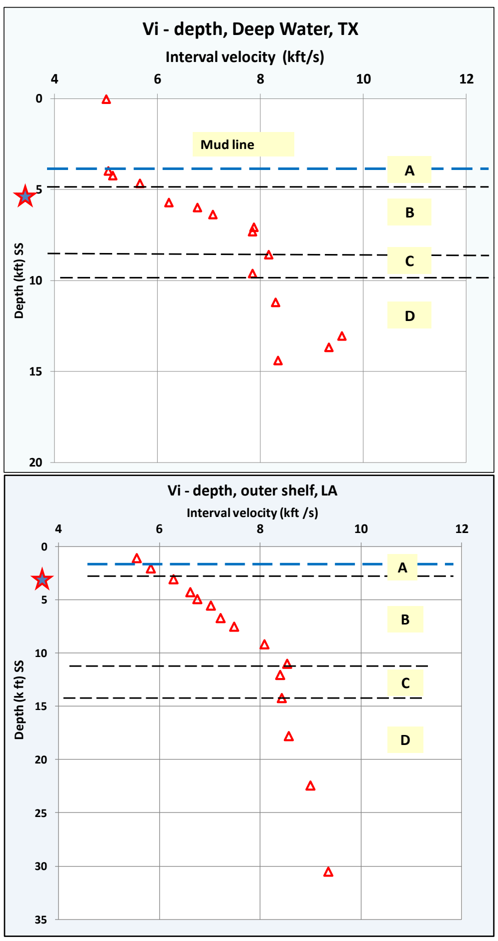

Figure 4: C*ross plots show the velocity change vs. depth due the presence of the four subsurface zones (A,B,C,and D) in two of geological settings: (upper) deep water (at 3,500 ft WD) and (lower) flexure trend / outer shelf (at 2,000 ft WD). Note the velocity exponential inclination as a result of compaction in zone B and also the reversal velocity trend at the base of zone B. Star indicates the possible depth of SWF.*

Calculating pressure and its implication in zones A and B:

Zone A

Pressure at depth (Pz_1) = (ρ g) * subsea depth = $\rho g z_1$

ρ= density of seawater g =gravity acceleration

z_1 = depth

Or $= Pz_1 = (\rho * 0.4335) * z_1$ (1)

where 0.4335 is the pressure gradient conversion factor from 1 g/cc to psi/ft . The hydrostatic pressure gradient of the Gulf of Mexico is usually 0.465 psi/ft where formation water density is 1.072 g/cc.

Jetting the 36 inch conductor into the sea bed is a common practice due the unconsolidated nature of zone A. Mackenzie et.al (2012)[11] concluded in their Jubilee Field's conductor jetting performance that "Geology was not considered to have been contributing factor, as the soil conditions at the slumped locations were similar to those elsewhere in the study area." Noort et.al (2009)[12] discussed the successful implication of hydraulic hammer for conductor installation to overcome the challenges as a result of the jetting process. Yong and Schubert, 2005[6] suggested establishing a relationship between the overburden and fracture gradients to define the conductor depth in Deepwater.

The conductor casing (e.g. 36") and well head sometimes sink and get lost in this fragile zone especially in deeper water e.g., Mississippi Canyon (block 711 well #2 and 755 well#1), Green Canyon block #854 well#1, and Atwater block 362 well #1.

Zone B

All the previous methods calculate the pressure in zone B as if a normal hydrostatic pressure exists. In this paper a new estimation method is introduced to calculate pressure in this hydrodynamic zone. The hydrodynamic pressure value at certain depth is a function of permeability and differential pressure between the bottom and top of each compartment in this zone. The pressure estimation in B zone follows Darcy's Law. However, Darcy's Law is probably more applicable in the laboratory than in a complex geologic setting. This is due to the presence of multiple litholgies with different permeability and the complexity of assigning the values of entry pressure in the system.

Mud weight increases from 9.5 ppg at the top of zone B to a value sometimes exceeding 11.5 ppg at the base to counter the hydrodynamic up flow. An intermediate (e.g. 9 5/8 inch) casing seat usually set in the shale section of the pressure ramp at the base of B zone (TOG).

Most of the SWF takes place during penetrating the shale – sand interface (Dutta 2009 [7] and 2010[1]; therefore the pressure differential relationship between the two rock-types needs to be established.

Pressure in sands:

Pore pressure is measured in sand and is predicted in shale. Occasionally, repeated formation tester (RFT) and modular formation dynamic tester (MDT) measurements were taken from this zone's sand beds in different deep water wells in the Gulf of Mexico. Measured data used in this study are collected from the Mississippi prodelta upper Pleistocene of four protraction areas in Mississippi Canyon (MC), Green Canyon (GC), Viosca Knoll (VK) and Atwater (AT) areas. Two piezoprobe insertions records from Atlantis and Mad Dog prospects (Orange D., 2003)[13] are added to this data base.

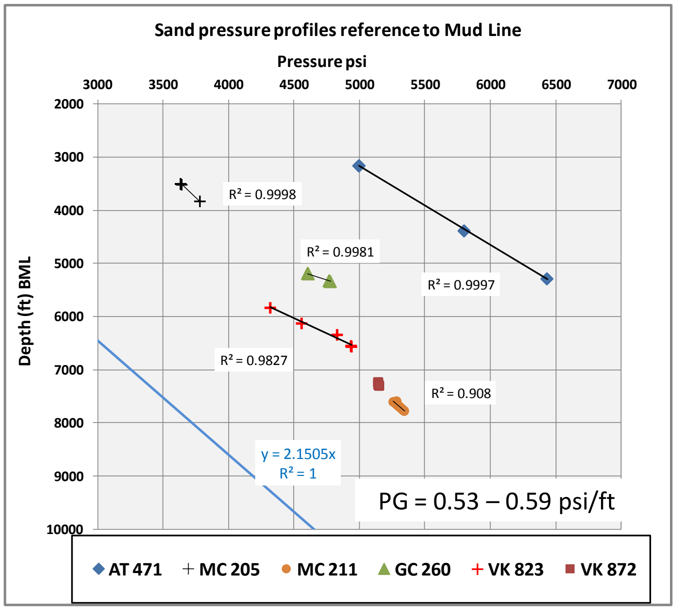

Figure 5*: Exhibits zone B measured sand pressure (psi) vs. BML depth plot of several wells. The pressure gradients (trend slope) range from 0.53 to 0.59 psi/ft. They show a higher gradient than the GOM hydrostatic gradient (blue trend on the left). They are in non-alliance positions due to the drastic changes of the sea floor topography.*

None of these wells experienced SWF, as it is not practical to run pressure measurements from over flowing sand zone while drilling. The pressure gradients in all of these wells, where mud pressure caps formation pressure, show a clear upward hydrodynamic flow (Figures 5 and 6) with higher gradient than the GOM hydrostatic (0.465 psi/ft). Below the mud-line pressure-depth plots of individual wells (Figure 5) exhibit pressure gradients range from 0.53 psi/ft (10.2 ppg mwe) to 0.59 psi/ft (11.4 ppg mwe) with different hydraulic head (Figure 5). On the other hand, the pressure trend in reference to the sea level of all the measured pressure values shows a concurrence average gradient of 0.54 psi/ft. (Figure 6). This is due to the fact that the Upper Pleistocene sediment is mostly represented by mass transport lobes which are in hydraulic communication (Figure 1).The least squares fit for all the sand data measurement are linear with R^2 values of 0.96 (Figures 6). The overall extrapolated average data values have a hydraulic head of 220 ft if sand flows freely to the sea floor (mud pressure absent). Therefore, freely flowing formation water can reach 220 ft below the sea level (i.e. above the mud line).

Predicting the sand's pressure in this zone is important to avoid any unexpected water overflow during drilling. Solution for equations on Figure 6 gives:

Average Upper Pleistocene sand pressure (psi) at any depth (z_2) within the B zone can be calculated as:

Sand pressure Pz_2 at any point in zone B

$$= (0.54 * z_2) - 120 \quad (2)$$

Mud pressure gradually increases to compensate for the pressure difference between the high flow sand and the low permeability negligible flowing shale. Usually, mud weight is raised at the shale-sand interface where drilling events require mudding up.

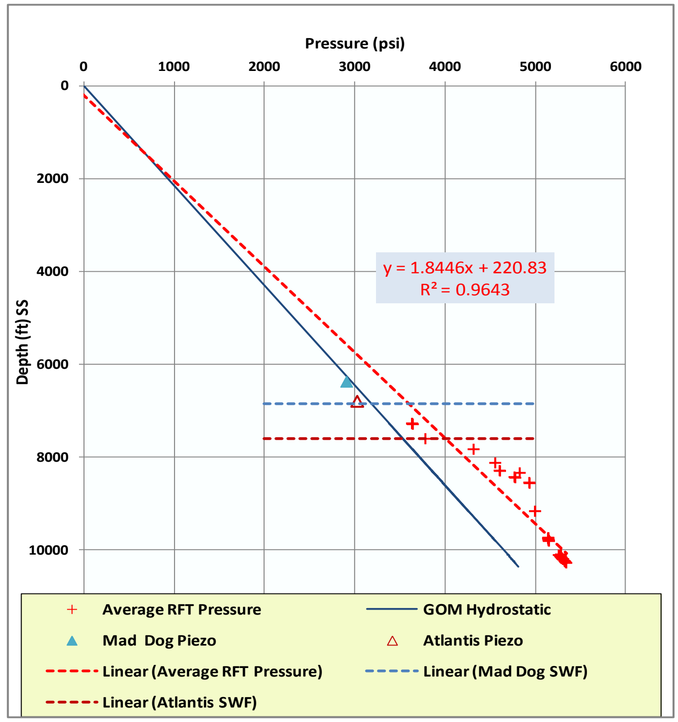

Figure 6: *Show the same measured pressure data (RFT-MDT) on figure 5 to be plotted in reference to the sea level (SS). Piezoprobe data from Atlantis and Mad Dog are added. An average linear trend (R^2 =0.96) with a pressure gradient of 0.54 psi/ft. Moreover, the resulting hydraulic head (intercept at 0 pressures) is about 220 ft below the sea level. Therefore, water in sand can flow above the mud line for great heights contingent on the water depth.*

Pressure in shale:

Calculating the average formation pressure of shale (feasible formation pressure) in this zone is estimated from the MW data sets. The mud pressure (ppg) at any depth (z_2) within zone B, is calculated from the average populated mud weight values of Mississippi Canyon (MC), Green Canyon (GC) , and Garden Banks (GB) areas (Figure 7). The depth value data (y axis) are in reference to the mud line due to the wide range of subsea depth to mud line. Average mud pressure required for keeping the borehole stable and avoiding any formation water flow is on the equation of Figure 7.

It follows an exponential trend. The least squares best fit for mud weight data ranges from 9.15 ppg to 11.7 ppg, can be calculated as:

Mud pressure (ppg) at any point within B zone (BML)
$= 1.88 \ln (z_2 - \text{MLdepth}) - \alpha$ (3)

The constant α for this data set is 5.18 ($R^2 = 0.71$).

Equation 3 was calibrated and validated with known mud weight from numerous offset wells.

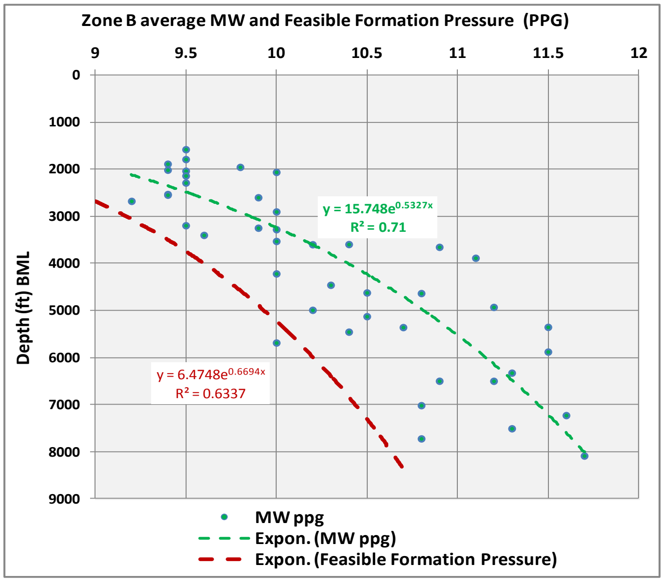

Figure 7: *Recorded data of mud weight (MW) used to drill several wells in zone B of the GOM deep water. They are from Mississippi Canyon, Green Canyon, and Garden Banks areas respectively. Note the MW increases with depth to combat the increase of the hydrodynamic pressure gradient. The average MW and feasible formation pressure (FFP) calculations of the entire collected data set in ppg below the mud line.*

The estimated average feasible formation pressure (FFP) was gauged by mud weight pressure from wells drilled with balanced mud and where SWF were not reported. It is also based on the drilling practices and safety regulations that are constrained by formation and fracture pressures. Mud weight is usually 0.5 ppg greater than the before drilling predicted pore pressure to the surface casing string (20"). It is 0.75-1.0 ppg greater than predicted pressure at intermediate casing strings (16" – 13 3/8"). The average FFP (ppg mwe) therefore follows similar exponential trend (Figure 7) and can be calculated at any depth below the mud line (z_2- depth BML) in zone B as follows:

Feasible formation pressure in ppg
$= 1.49 \ln (z_2 - \text{MLdepth})] - \alpha$ (4)

Constant α is 2.79 ($R^2 = 0.63$).

Constants and exponents are subject to modifications in different deepwater basins and the availability of additional new data.

Prevention of Shallow Water Flow

The objective is to calculate the pressure difference (psi) between the regional sand flow (Equation 2) and the average FFP (Equations 1 & 4) to avoid any unexpected SWF (Figure 8). Calculating the pressure difference (ppg mwe) between the linear sand over flow and FFP at the sand-shale interface foresees the required MW increase to combat the SWF without loss of circulation and avoid the flow-kill-breakdown (FKB) cycles (Figure 9). A predicted safe MW is calculated based on adding the pressure difference (ΔP) to the average mud pressure used to drill wells without SWF (Figure 10).

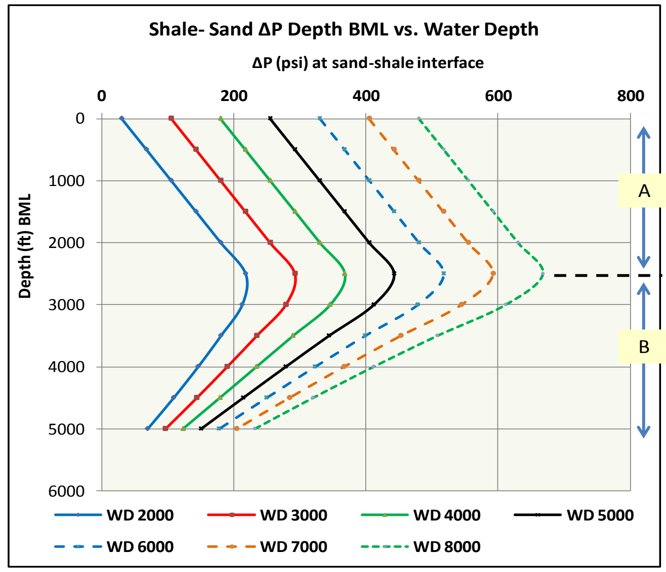

Figure 8: *Plot exhibits the sand-shale differential pressure (psi) vs. depth below the mud line for several water depth setting ranges from 2,000 ft to 8,000 ft (SS). The possible depth of zones A - B contact ranges from 2,000 ft to 3,000ft.*

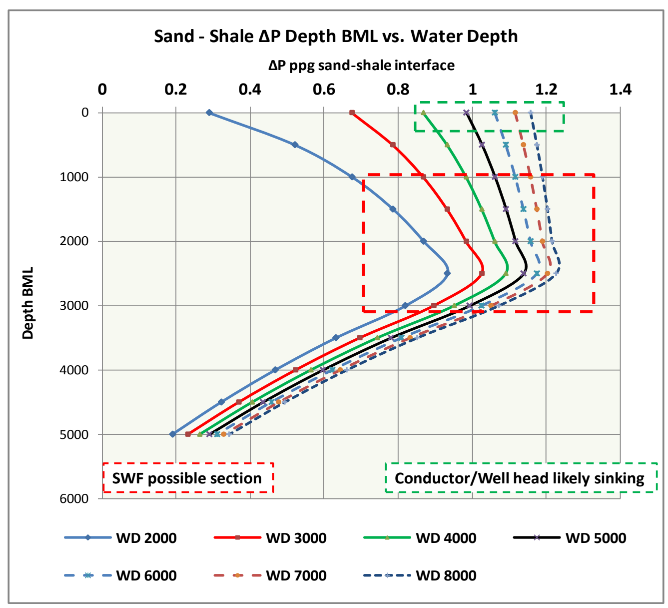

Figure 9: *Shows the same data on figure 8 converted to ppg mwe. An overbalance MW of 0.8 to 1.2 ppg is required to drill in water depth exceeds 4,000 ft. Moreover, the +/- 300 ft top soil section displays large ΔP in water deeper than 5,000 ft (where conductor subject to sink).*

Figures 8 and 9 show the ΔP change with depth below the mud line. It peaks between 2000 ft to 3000 ft BML that is where most of the SWF takes place if the programmed mud pressure (MW) does not balance the differential pressure between the sand and shale. Additional mud up may be required in case of high connection gas associated with penetrating the sand-shale interface (contingent on the estimated shallower fracture gradient).

WD ft	TD SS ft	TD BML	Sand PP psi	Sand PP ppg	FFP ppg	Δ P ppg	Δ P psi	Average MW	Min Safe Mud	PP Zones
5000	5300	300	2742	9.99	8.97	1.01	277.50	9.50	10.51	A
5000	5500	500	2850	10.00	8.97	1.03	292.50	9.50	10.53	A
5000	6000	1000	3120	10.04	8.97	1.06	330.00	9.50	10.56	A
5000	6500	1500	3390	10.07	8.97	1.09	367.50	9.50	10.59	A
5000	7000	2000	3660	10.09	8.97	1.12	405.00	9.50	10.62	A
5000	7500	2500	3930	10.11	8.97	1.14	442.50	9.53	10.67	A
5000	8000	3000	4200	10.13	9.14	0.99	411.61	9.87	10.86	B
5000	8500	3500	4470	10.15	9.37	0.78	343.68	10.16	10.94	B
5000	9000	4000	4740	10.16	9.57	0.60	278.18	10.41	11.01	B
5000	9500	4500	5010	10.18	9.74	0.43	213.91	10.63	11.07	B
5000	10000	5000	5280	10.19	9.90	0.29	150.15	10.83	11.12	B

Table 1: *Shows an example of sand pressure vs. FFP calculations at different depth ranges from conductor bottom (300 ft) to 5,000 ft BML. Calculation is based on water depth of 5000 ft subsea (SS). Notice the highest pressure difference (ΔP) are at depth ranges between ,1500 and 3,500 ft BML. This is where most of the SWF takes place (Figure 3).*

The calculation of pressure difference (ΔP) between the sand and shale (FFP) at different BML's depths and in a specific water depth, e.g.5,000 ft, shows the critical importance of this relationship (Table 1). This table shows ΔP at its peak at a depth of 2,000 – 3,000 ft BML and also exhibits a considerable decrease at depth greater than 3,000 ft BML. Moreover, the ΔP near the mud line (zone A) increases with water depth and that is where the well heads get lost due to top soil instability (Figure 9). Figure 10 exhibits the safe recommended mud weight to use when drilling from the base of the conductor to the surface casing shoe where most of the severe SWF takes place and disrupt operation.

Case Histories:

Applying the conventional shallow water shelf's mud weight program to the early deepwater drilling in the 80's resulted in unpredicted SWFs (e.g. GC 31 wells #1 – 2 and GC 32 #1). Figure 11 exhibits several wells from MC and GC where SWF took place due to drilling the shallow section between the conductor and the surface casing shoe with low mud weight (8.5 to 9.5 ppg).

Starting in the 90s, some of the safe new practices to avoid SWF were to drill this section with heavier mud weight (10 to 12 ppg). Some of these wells are in MC (348 #1, 686 #A-1, 739#1) and GC (60 #1, 142 #1 and 854#2). MW is usually reduced to drill deeper than the surface casing section (Figure 12). This is in agreement with the conclusions of this study to avert the SWF (Figures 9 and 10).

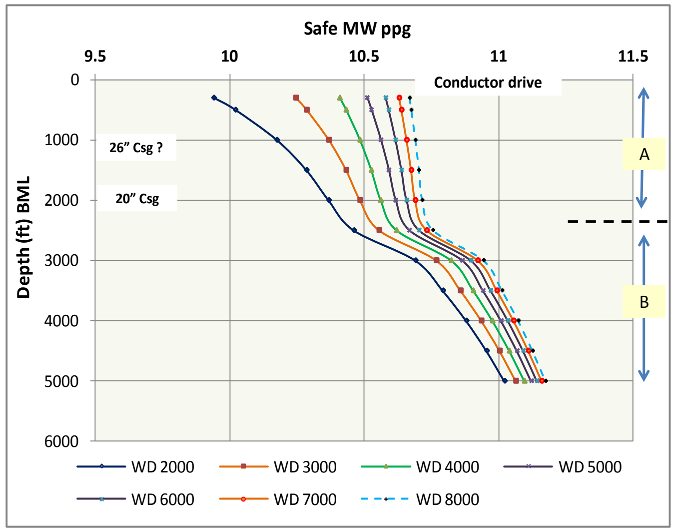

Figure 10: *A plot represents the safe mud weight required to drill the section between the base of the conductor to the surface casing and beyond in different water depth. Safe MW is reference to depth BML and WD.*

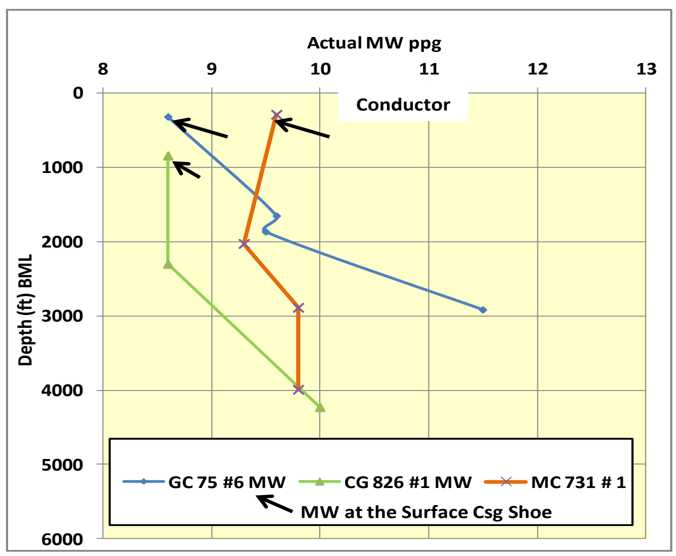

Figure 11: *Exhibits some of the early deepwater wells (with SWF) that had used the shelf light mud programs (8.5 to 9.5 ppg) to drill to the surface casing shoe. SWFs were costly to overcome.*

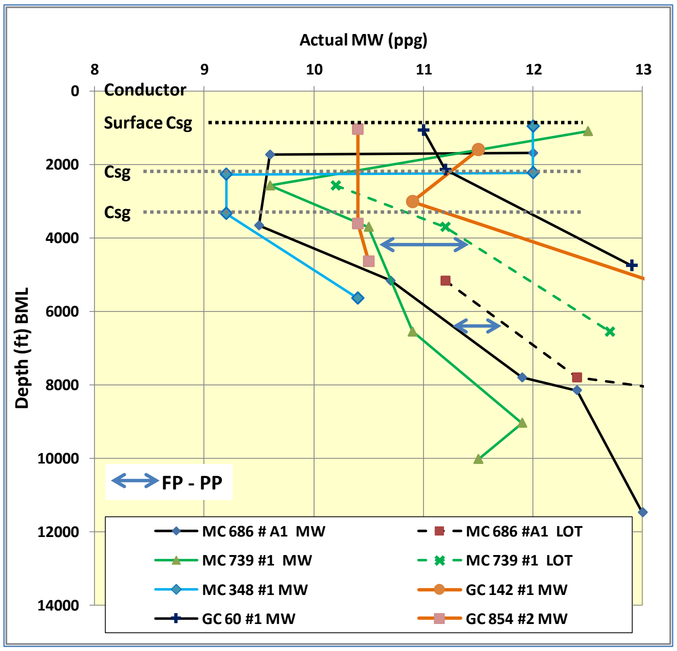

Figure 12: *Some of several wells were drilled using heavier mud (10.5 – 12 ppg) to drill from conductor to the surface casing shoe. Drilling was optimum and without SWF. These successful drilling cases are in concord with the results of this study. Notice the fracture pressure (LOT's) is ½ to 1 ppg higher than the used MW (e.g. MC 686 and 739). This is an evidence that fracture pressure is likely not responsible for SWF phenomenon. The reduction of MW between the second and third casing shoes is due to LOT's measurements.*

Summary and Recommendations

The newly introduced SWF potential prediction and prevention method before drilling is valid and applicable in the Pleistocene section of the Gulf of Mexico. It can also be successfully applied in other deepwater settings worldwide where relatively young sediments were fed into basins through major deltaic systems, such as the Nile and Niger Deltas, and also south Asian areas.

Application for pore pressure prediction:

1. Delineating zones A and B using seismic velocity is a keystone for any pre-drilling shallow hazard prediction.
2. The likely main possible cause of SWF is the pressure difference between the high linear sand overflow and the very slow shale exponential flow due to the compaction and dewatering process in zone B.
3. Empirical depth - pressure relationship should be established to predict pressure in the hydrodynamic zone B, instead of considering it as a hydrostatically pressured zone or applying one of the effective stress methods. Applying the effective stress methods, to predict pore pressure, is valid only in zones C and D (Shaker 2015a) [2].

Application for drilling practice:

1. Estimating the depth to zones A and B from seismic velocity can be done in conjunction with sequence stratigraphy and high resolution seismic in the Pleistocene section to pin point the shale– sand interfaces (potential hazard).
2. Shallow geological features (e.g. shallow faults, hydrocarbon seepage, mud-line gouges and slope failure) can also exacerbate this phenomenon. The surface location should avoid all these features.
3. Investigating the possible use of hydraulic hammering of the conductor (36 inches) instead of jetting it. This is to reduce the instability in this fragile zone (A). Moreover, exploring the depth increase of conductor insertion closer to zone B.
4. Estimating the mud up value at the shale / sand interface is essential to prevent SWF and avoiding the FKB cycle especially in the shallow sequence of the Pleistocene in MC and GC areas.
5. Safe MW to drill from the conductor base to the surface casing shoe can be calculated by using the algorithm in this paper. The specific equations and exponents in this study are applicable in the Mississippi pro-delta area. However, the same predictive methods can be used in different deepwater areas worldwide.

Finally, this is a new perspective tool that can be added to a list of a wide range of SWF predictive methods which includes Vp/Vs, 3D inversion modeling, and multi-component technique.

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Nomenclature

SWF	= *Shallow Water Flow*
Vp	= *Primary (compressional) velocity*
Vs	= *Shear velocity*
Vi	= *Interval velocity*
NCT	= *Normal Compaction Trend*
CT	= *Compaction Trend*
TOG	= *Top of Geopressure*
Δ P	= *Sand-Shale pressure differential*
ppg	= *pound per gallon*
ppg mwe	= *pound per gallon mud weight equivalent*
FKB	= *Flow-Kill-Breakdown cycle*
BML	= *below the mud line (sea floor)*
FFP	= *feasible formation pressure*

MW	*= mud weight*
RFT	*= repeated formation tester*
MDT	*= modular formation dynamic tester*
PP	*= pore pressure*
FP	*= fracture pressure*
LOT	*= leak off test*
H	*= hydrostatic gradient*
Csg	*= Casing*
g/cc	*= gram per cubic centimeter*
ft/sec	*= feet per second*
μs/ft	*= microsecond per foot*
WD	*= water depth*
Zone A	*= free flow zone*
Zone B	*= hydrodynamic zone*
Zone C	*= Transition*
Zone D	*= geopressured (over-pressured)*
MMS	*= mineral management services (now is BOEM)*

References

1. Dutta, N.C., Utech, R.W. and Shelander, D., 2010, Role of 3D seismic for quantitative shallow hazard assessment in deepwater sediments: THE LEADING EDGE, **29**,930-942.
2. Shaker, S.S. 2015 a, A new approach to Pore Pressure Predictions: generation, expulsion and retention trio, case histories from Gulf of Mexico, GCAGS Transaction, v.65, p.323-337.
3. Burst,J.F., 1969, Diagenesis of Gulf Coast clayey sediments and possible relations petroleum migrations, AAPG Bulletin, v.53, no 1, p.73-93.
4. Shaker, S.S., 2015 b, Velocity for pore pressure prediction modeling, SEG New Orleans annual meeting, extended abstract, P-1797-1801.
5. Rubey, W.W. and Hubbert, M.K.,1959, Role of fluid pressure in mechanics of overthrust faulting: AAPG Bulletin.,.**70**,no.2 , pp 167-184.
6. Yong, B. T, and Schubert, J., 2005, Risk assessment and evaluation of the conductor setting depth in shallow water, Gulf of Mexico, Master of Science Thesis submitted to the Texas A & M, MMS project no.495, pp 72.
7. Dutta,T., Mavko, G.;Mukerji, T and Lane T., 2009, Compaction trends for shale and clean sandstone in shallow sediments, Gulf of Mexico, THE LEADING EDGE, **28,** 590-596.
8. Smith J.E. 1970, The dynamics of shale compaction and evolution of pore-fluid pressures: Mathematical Geology, V.**3**, no. 3, p.239-263.
9. Dahlberg, E.C., 1994, Applied hydrodynamics in petroleum exploration: Springer-Verlag, New York,Berlin, London, Paris , 294 p
10. Shaker, S.S. 2001, Geopressure compartmentalization in Keathley Canyon Deepwater, Gulf of Mexico, GCAGS Transaction, vol. LI, p.293-304
11. Mackenzie, B., Frances, M., Garrett, I and Teggart, B. 2012, Conductor jetting experiences in deepwater offshore Ghana, Society of Underwater Technology, 7th international conference. London.
12. Noort R., Murrary R., Wise J., Williamson M., Wilde B., and Riggs J.,2009, Conductor pre-installation, Deepwater Brazil , OTC ,Houston, Texas.
13. Orange D., Saffer D. , Jeanjean P., Kafaji Z., Murphy G., Riley G., 2003, Measurements and modeling of shallow pore pressure regime at the Sigsbee Escarpment: successful prediction of overpressure and ground truthing with bore hole measurements..THE LEADING EDGE, **22,** 906-913.