PS A New Perspective on Shallow Water Flow (SWF) Prediction and the Prevention of Sinking Well-Heads in Deepwater*

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Abstract

A new study integrating the seismic velocity profile with a proposed subsurface geopressure partition sheds light on one of the possible main causes of shallow water flow (SWF) and sinking well head in deep water. The Bureau of Ocean Energy Management (BOEM), previously known as MMS, reported 157 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 active. Occasionally, surface casings and well heads sink and get lost in these areas as well.

Study the pressure gradients of sand vs. shale in the proposed subsurface zones (A, B, C, and D) points to a possible source of these two events. The fragile nature of the unconsolidated shallow hydrostatic zone A is mostly responsible for the loss of well head. This shallow zone gradually transforms to a compacted hydrodynamic system (zone B), associated with dewatering process that can lead to SWF.

Calculating the linear pressure gradient in the sand beds vs. the feasible formation pressure in the shale layers in zone B is the backbone of this study. The sand rapidly flows upward at a linear gradient (0.536 x z – 123) ranging from 0.53 to .59 psi/ft. On the other hand, slow compaction of shale and dewatering process follow an exponential pressure gradient rate of 1.49·Ln (z-MLdepth) - α. During drilling, penetrating the interface between the shale and the underlying sand causes water flow that overcomes the mud pressure and SWF takes place.

Mitigating these events should be assigned before drilling any well in the deep water. Seismic velocity, sequence stratigraphy and geopressure modeling can identify these zones so that precautions can be taken to combat and avoid these challenges during operation. Choosing the right depth for surface casing and adjusting the value of the mud up during drilling to avoid SWF are suggested in this paper.

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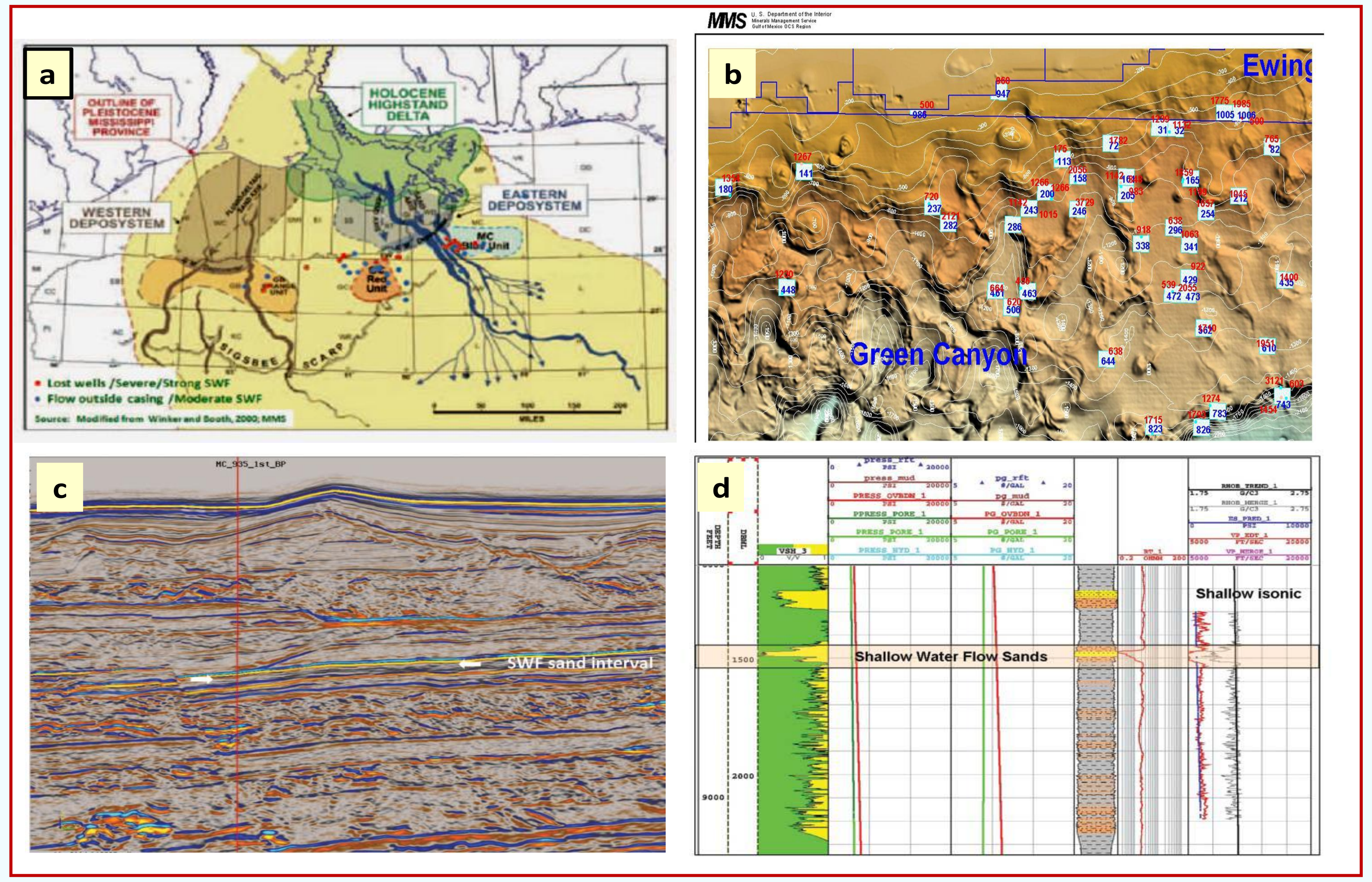
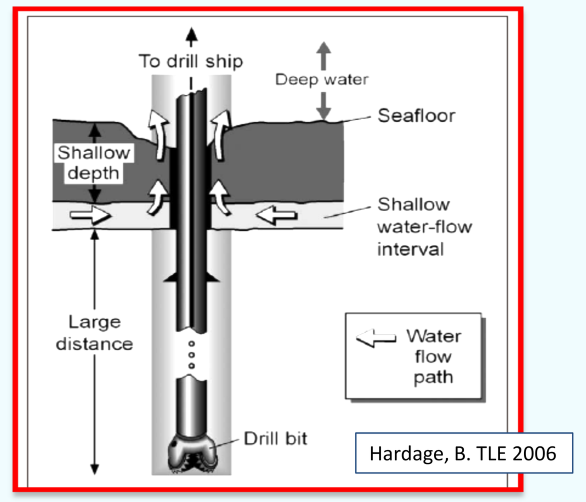
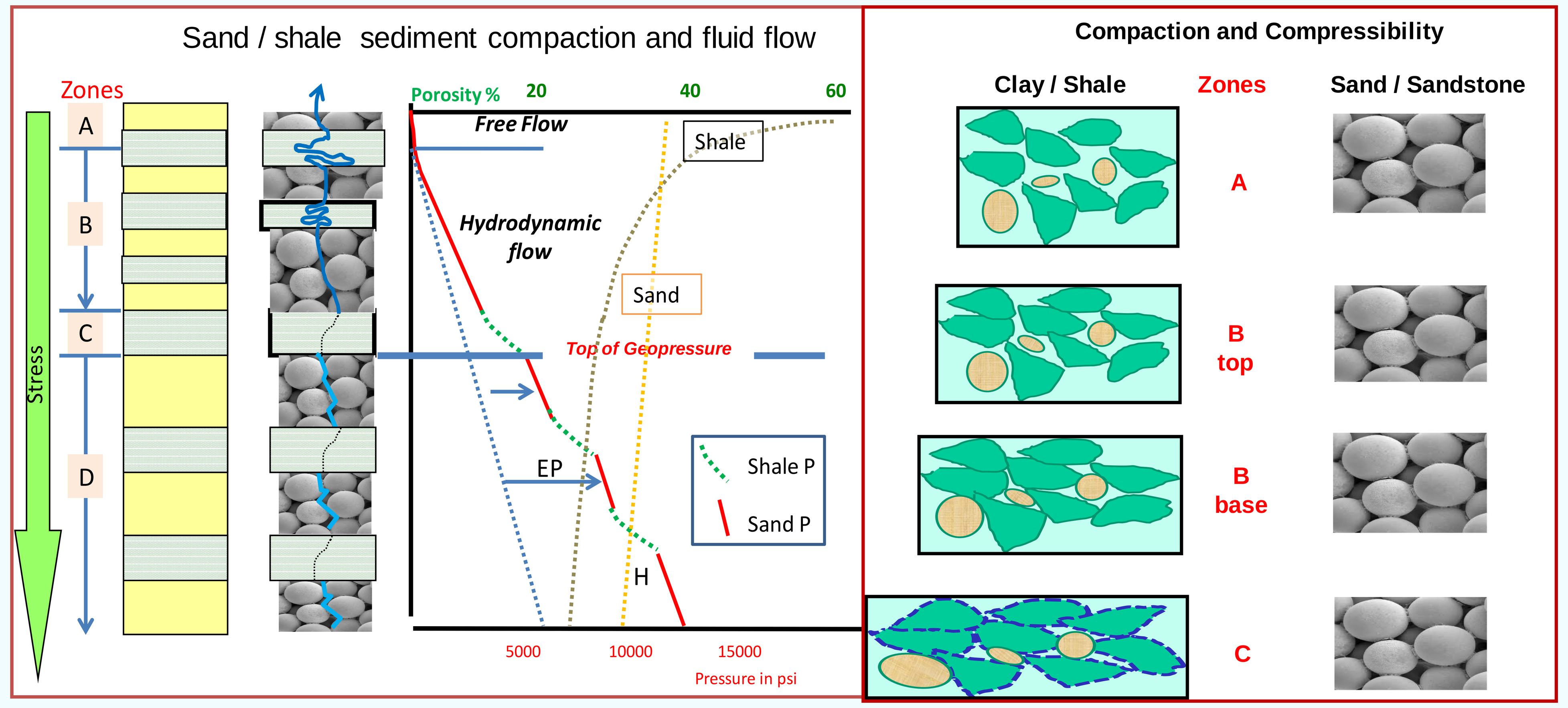
GEOLOGICAL SETTING



(a) The extent of the Mississippi delta during the Pleistocene – Holocene era (Dutta et.al., 2010). (b) The sea floor topography in Green Canyon area. Note the deep gouges due to the active feeder system. Blue numbers are block numbers whereas red ones are the depth to the SWF (after MMS). (c) A seismic line goes across British Petroleum – MC 905 #1 that shows the SWF sand reflector extent (Dutta et.al., 2010). (d) A subsurface log composite from Green Canyon area exhibits the SWF's sand encased in a thick shale section (Dutta et.al.2009).

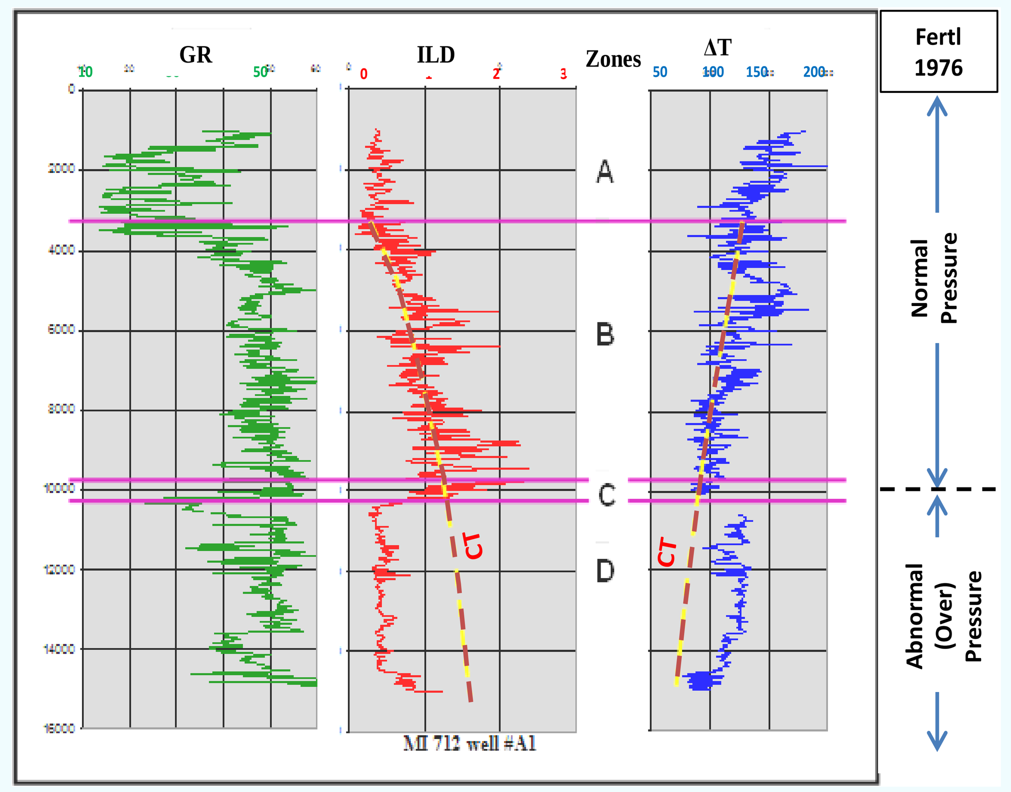


SEDIMENTATION - COMPACTION - DEWATERING :



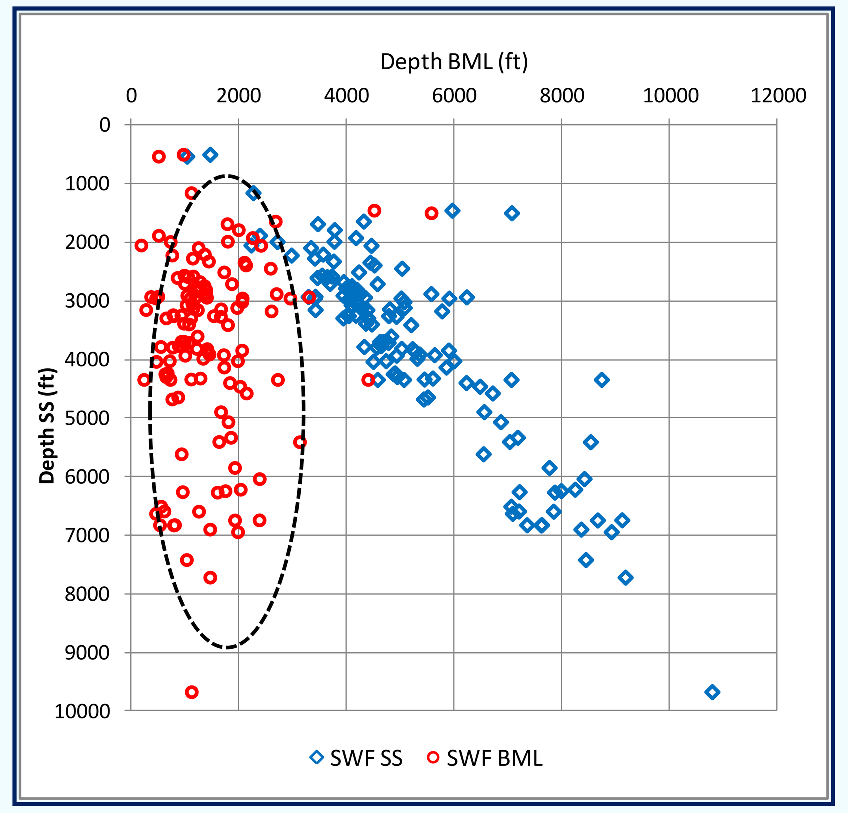
The impact of clastic sedimentation load (stress) and basin subsidence on the compaction and compression processes of the matrix and fluid. Note the exponential porosity trend in shale vs. the linear trend in sand in all the four zones A,B,C and D. Fluid in zone A is hydrostatic and is in communication with sea floor. On the other hand, water flow in zone B is hydrodynamic due to compaction and dewatering process. The shale platelets under compression form a seal at zone C and cease the fluid flow. Shale is susceptible to compaction and compression, whereas sand grains are rigid.

PETROPHYSICS IN THE FOUR ZONESAS RESPONSE TO POROSITY AND PRESSURE

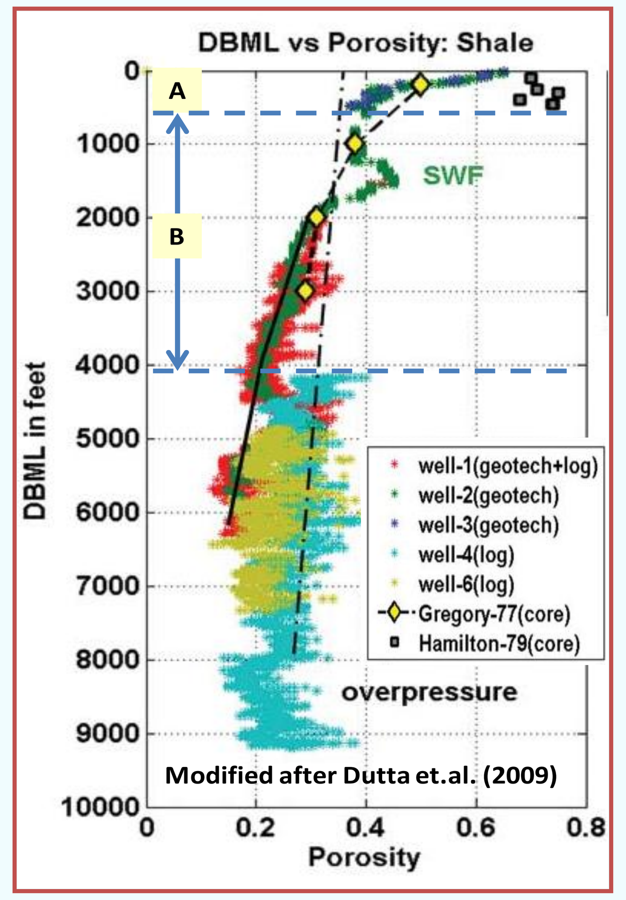


Exhibits the impact of the subsurface four zones (A, B, C and D) on the resistivity and sonic . The dashed yellow line represents the compaction trend in zone B and its extrapolated values in deeper zones (C and D). Note the exponential trend of the resistivity and ΔT (velocity reciprocal) which represent the compaction trend (CT) in Pore Pressure Prediction practices. Notice the difference between the conventional pore pressure partition (Fertl 1976) and the newly proposed subsurface pressure four zones (Shaker, 2012).

SWF RELATVE TO MUD-LINE DEPTH

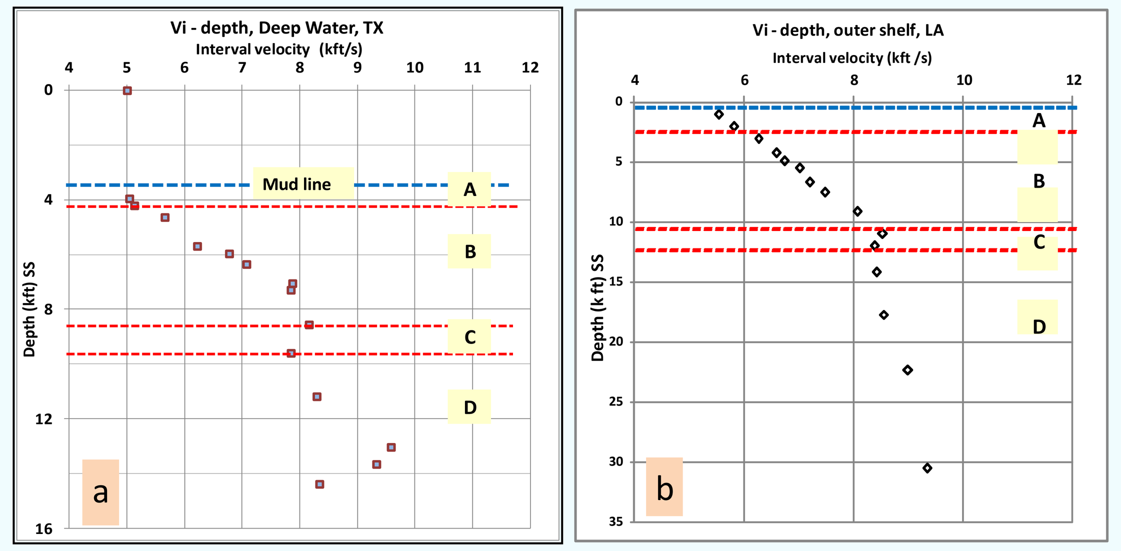


A cross plot of the relation between the SWF subsea depth (blue) and the SWF below the mud line depth (data was mined from MMS records). Note most of the shallow water flow takes place between several hundred feet and ≈ 3500 ft below the mud line (dashed oval shape). Moreover, water depth does not impact the depth of SWF BML. Therefore, age and rate of compaction can be the diagnostic cause for this phenomenon.

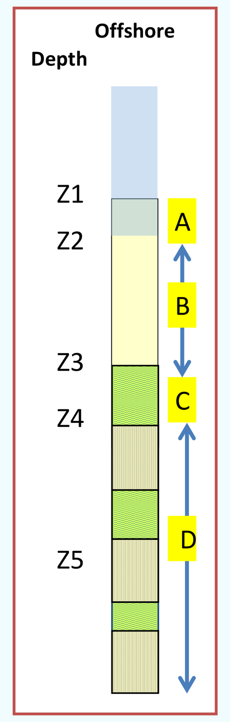


A porosity profile vs. depth composite from several wells in Green Canyon area (Dutta et.al. 2009). Note the sand high porosity values at the SWF zone at ≈ 1500 ft below the mud line. This figure is modified to show the hydrostatic free flow zone A and the hydrodynamic zone B, where SWF was recorded.

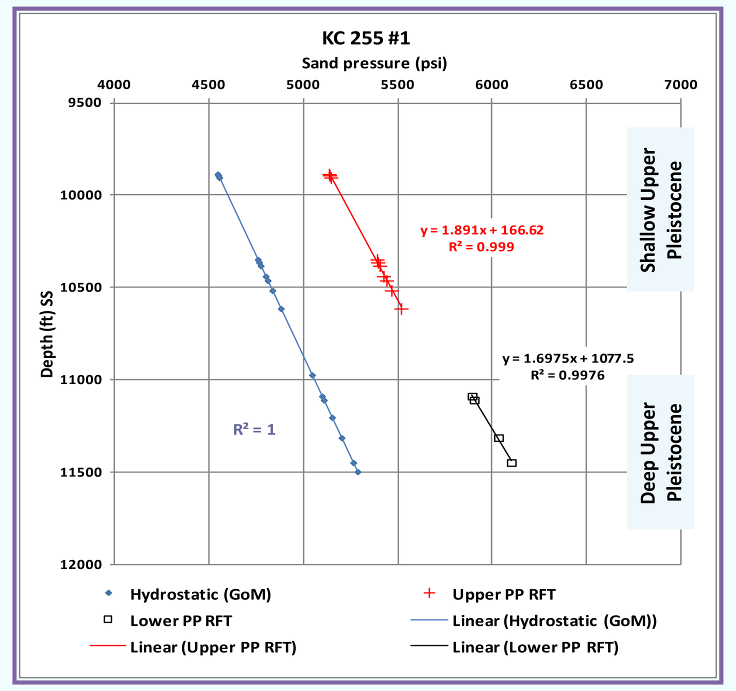
ESTABLISH DEPTH TO ZONES A,B & C FROM SEISMIC VELOCITY



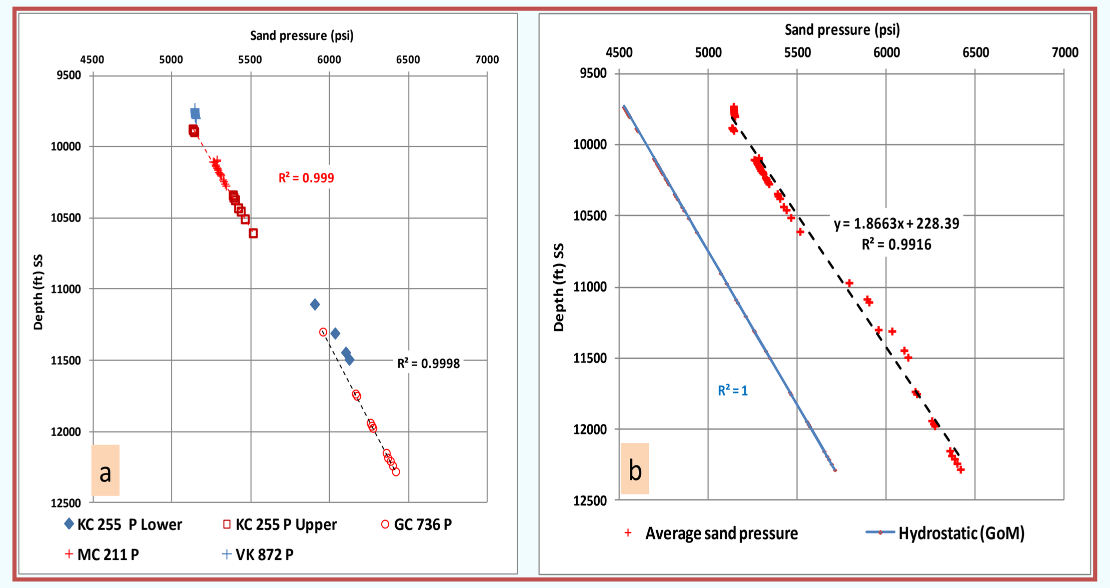
Cross plots show the velocity change vs. depth due the presence of the four subsurface zones (A,B,C,and D) in two of geological settings: (a) deepwater (at 3500 ft WD) and (b) flexure trend / outer shelf (at 2500 ft WD). Note the velocity exponential inclination as a result of the dewatering process due to compaction in zone B and also the reversal velocity trend at the base of zone B.



SAND PRESSURE CALCULATIONS



A plot displaying zone B Upper Pleistocene sands pressure – depth relationship in deepwater well (Keathley Canyon 255#1). The measured pressure data (RFT-MDT) shows shift in pressure gradient (trend slope) from 0.59 to 0.53 psi/ft between the deep and the shallow section respectively.



Several wells with measured pressure data in the lower and upper sections of the Upper Pleistocene. (a)Note the change in pressure gradient between the sand beds of the two sections. (b) Exhibits the average linear trend of all the sand pressure data collected from zone B (red dataset).

THE ALGORITHMS

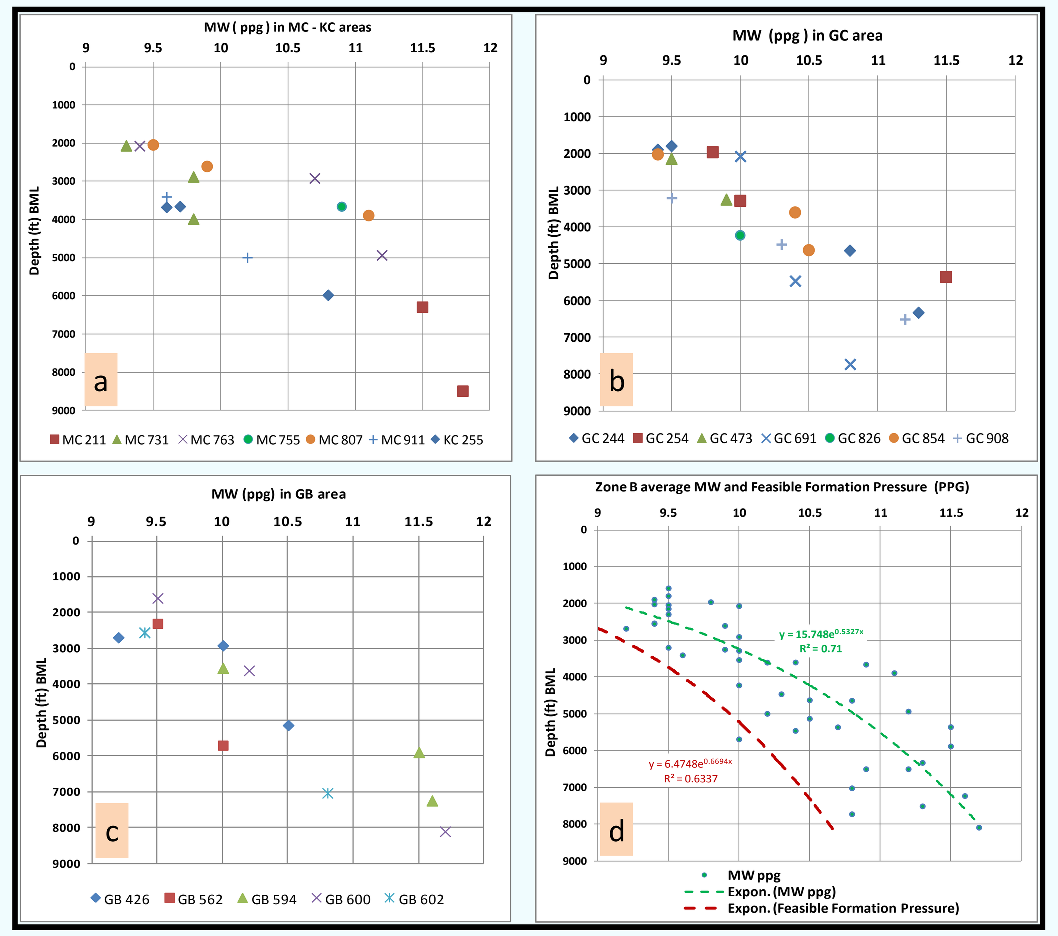
Sand pressure in the shallow Upper Pleistocene at depth z3 can be calculated as:
Pressure (psi) = (0.529 * z3) – 88
Sand pressure in the deep Upper Pleistocene at depth z3 can be calculated as:
Pressure (psi) = (0.589 * z3) – 635
Average Upper Pleistocene (psi) at any depth (z3) within the B zone can be calculated as: = (0.536 * z3) – 228
Pz_3 mud pressure (ppg) at any point within B zone (BML)
= [1.88 * (*Ln* z_3-MLdepth)] – α
Feasible formation pressure in ppg = [1.49 * (*Ln z3*-MLdepth)] – *α*

SAND - SHALE PRESSURE DIFFERENCE – MUD UP ADJUSTMENT

Water Depth ft.	TD SS ft.	TD BML ft.	Sand PP psi	Sand Pg ppg	FFP ppg	Δ P ppg	Δ P psi	Pressure zone
5000	At ML	0	2452	9.46	8.97	0.49	127	A
5000	5500	500	2720	9.54	8.97	0.57	163	A
5000	6000	1000	2988	9.60	8.97	0.63	198	A
5000	6500	1500	3256	9.67	8.97	0.70	233	A
5000	7000	2000	3524	9.71	8.53	1.18	420	B
5000	7500	2500	3792	9.76	8.86	0.90	350	B
5000	8000	3000	4060	9.78	9.14	0.64	265	B
5000	8500	3500	4328	9.82	9.37	0.45	199	B
5000	9000	4000	4596	9.85	9.57	0.28	130	B
5000	9500	4500	4864	9.88	9.73	0.15	74	B
5000	10000	5000	5132	9.91	9.9	0.01	5	B

Table 1. Calculations of sand pressure vs. FFP at different depth ranges from 1000 ft to 5000 ft below mud-line (BML). Calculation is based on water depth of 5000 ft subsea. Notice the highest pressures difference (Δ P) are at depth ranges between 1000 ft and 3500 ft below the mud line. This is where most of the SWF takes place. Mud up values are Δ P ppg to avoid SWF and Flow-Kill-Breakdown cycle.

FEASIBLE FORMATION PRESSURE CALCULATION



Recorded data of mud weight (MW) used to drill several wells in zone B of the GOM deepwater. Plots (a), (b) and (c) are the MW from Mississippi Canyon, Green Canyon, and Garden Banks respectively. Note the MW increases with depth to combat the increase of the hydrodynamic pressure gradient. A subtle difference can be noticed on the MW- depth distribution charts among the different areas. Plot (d) is the average MW and feasible formation pressure (FFP) calculations of the entire collected datasets in ppg.

SUMMARY AND RECOMMENDATIONS TO AVERT SWF & SINKING WELL-HEAD

Application for pore pressure prediction:

1. Delineating A and B zones using seismic velocity semblance
2. Shallow water flow is independent from mudline's water depth
3. One of the main possible causes of SWF is the pressure difference between the sand linear high flow and the exponential shale very slow flow due dewatering process in zone B.
4. Assuming the sedimentary section above the top of geopressure (i.e. zones A and B) as hydrostatically (normally) pressured can lead to unexpected SWF.
5. Empirical depth-pressure relationship should be established in this hydrodynamic zone B instead of considering it as a hydrostatically pressured zone or applying one of the effective stress methods.
6. The exponential trend line that connects the data points, in zone B, is called the compaction trend (CT) instead of normal compaction trend (NCT).

Application for drilling practice:

7. Possible deeper extension of the surface casing (36 inches) to zone B to avoid well head sinking.
8. Estimating the mud-up value at the shale / sand interface is essential to prevent SWF
9. Estimating the depth to zones A and B, from seismic velocity
10. Finally, this is a new tool can be added to a list of wide range of SWF predictive methods

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