Pressure Trends in Lower Viosca Knoll and Mississippi Canyon, Gulf of Mexico Deep Water: Implications for Seals, Column Heights and Hydrocarbon Migration

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Analysis of pressure data from forty-one deepwater wells in the northern Gulf of Mexico has revealed consistent patterns in the rates of increase of both pore pressure and fracture gradient with increasing depth. Several conclusions may be drawn from these patterns, including:

Pore pressure (PP) and fracture pressure (FP) trends are not parallel with increasing depth. PP and FP converge at the mudline. The small differences between pore pressure and fracture pressure in the shallow section of a well directly influence the openhole drilling distance allowable between casing sets. In addition, these close tolerances can exacerbate problems in controlling shallow water or gas flows that may be encountered.

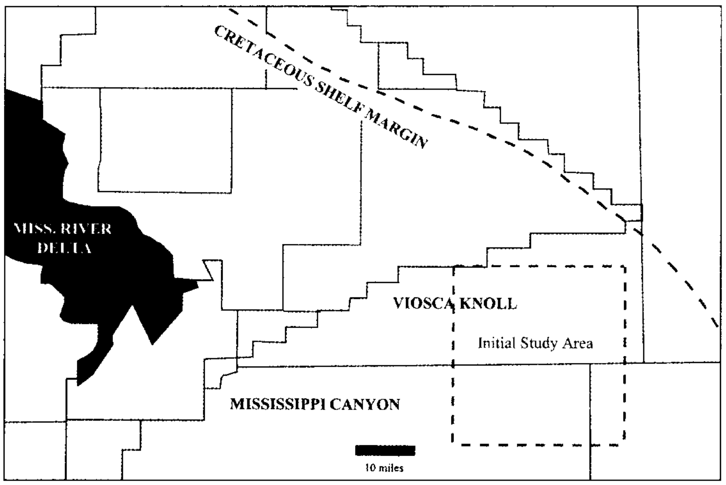

Figure 1: *Index map of study area.*

Pore pressure is elevated above a "normal" hydrostatic trend at shallow sediment burial depths. Indications are that top seals form with as little as 1500'–2000' of sediment burial. Such early seal formation is favorable to the formation of stratigraphic traps. It also sets a maximum depth for conventional riserless drilling.

Pore pressure and fracture pressure trends diverge with increasing depth in sedimentary sections with high sedimentation rates. This divergence, DPP < DFP, directly limits the column height. As the difference increases, the maximum column height possible also increases.

Conversely, pore pressure and fracture pressure converge, DPP > DFP, in deeper sections associated with lower sedimentation rates and unconformities. As a result, maximum possible column heights decrease in these intervals and may actually preclude sealing any significant volumes of hydrocarbons.

These trends of increasing/decreasing sealing capacity have application to models of generation, expulsion, primary and secondary migration and accumulation of hydrocarbons in this area. Areas of reduced sealing capacity in the deeper sedimentary section will "frac," allowing vertical migration of fluids to zones with higher sealing capacities.

Introduction

Pore pressure trends were analyzed in forty-one wells to support deepwater drilling activity, particularly in the Viosca Knoll and Mississippi Canyon protraction areas (Figure 1). The goal was to predict pressure cells as an aid to well design, prior to drilling, because of the high costs of deepwater operations. Pressure trends were analyzed to define regional patterns of pressure increase with depth. As this effort continues, a number of characteristic patterns in the relative rates of increases of pore pressure and fracture pressure were observed in all the wells analyzed. Implications drawn from these patterns extend beyond the original drilling-related focus of the project to include influence on column heights, sealing capacity and hydrocarbon migration issues.

Methods

Pressure data were compiled for the existing wells in the area prior to Amoco initiating its drilling program in 1992. As additional wells were drilled they were included in the database. The data collected included direct pressure measurements from drill stem test (DST) and repeat-formation (RFT) or modular-dynamic (MDT) testing tools with pressure equivalents from drilling mud weights and associated leak off tests (LOT). In addition, pressure estimates from empirical relations of travel time and resistivity were applied to acoustic and resistivity logs. The acoustic algorithm was also applied to seismically derived velocity profiles from migration before stack (MBS) data for pre-drill pressure prediction.

All the data were analyzed using PRESGRAF, a proprietary PC-based program that allows analysis and presentation of pressure data of various types and from multiple wells (Traugott, 1997). The methodology employed was first to create a calibrated pressure profile for known wells and then to extrapolate the profile to new drilling locations, usually using MBS seismic data. A plot from a typical well is presented in pressure (psi) vs. depth (Figure 2) and mud-weight vs. depth (Figure 3).

First an overburden trend (pressure vs. depth) was created for an existing well. There are two components to overburden in deepwater. First, the water column pressure (water depth x 0.455 psi/ft). The average lithostatic pressure component was established using the density log from the well. Total overburden at any depth below mudline is the sum of the water column and lithostatic overburden components. Estimates of the overburden trend can be compared to measured LOT data which imposes a boundary condition on the estimate.

Second, after establishing an overburden trend, measured pore pressure data from DST or the RFT/MDT log was input. Mud-weight and LOT data was also input at this time. These measured values set boundary conditions on subsequent estimates of pore pressure created from wireline log data.

Sonic log data were incorporated next and was processed iteratively with a pressure estimating algorithm within PRESGRAF. The general relation of the algorithm is: pore pressure (PP) is proportional to travel time (DT), porosity at the surface/mudline (P_O), volume clay (V_{cl}) and a compaction constant (C).

$$PP\ \mu\ DT \times P_O \times V_{cl} \times C$$

Some of these values may be estimated from log or geotechnical core data (Vcl, Po). The others are varied iteratively to produce a result that conforms to the pre-existing boundary conditions imposed by mud-weight and measured pressure data.

Finally, an independent estimate is made using the resistivity data. Though it uses a different algorithm than the sonic estimate, a number of variables are common to both; P_O, V_{cl} and C. The new variables in the resistivity estimate are resistivity (RT) and the cation-exchange-capacity (CEC). A temperature profile for the well is also necessary due to the variations in RT with temperature. The resistivity estimate is computed and compared to the sonic value. The two algorithms are solved iteratively until a close match is achieved using common values for P_O, V_{cl} and C.

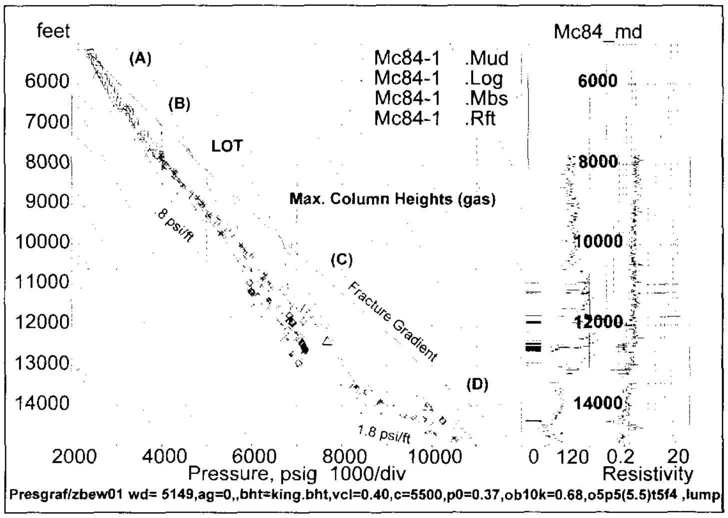

Figure 2:. *Pressure (psi) versus Depth (ft.) for a typical well, MC 84*

Once a calibrated model was created for a known well, that model (with adjustments for variations in water depth) was used for pre-drill estimates of pressure for new drilling locations. The sonic algorithm was especially useful for pre-well locations that had MBS seismic. A velocity profile extracted from the MBS velocity volume can be processed in a similar manner to the sonic log. This gives a direct pre-drill estimate of pressure at the well location. Seismic velocity uncertainty will propagate through the model as a resultant uncertainty in the absolute estimated pressure, however the rates of change in estimated pressure and any associated inflection points in the pressure profile, have significance in establishing depths to major pressure cell boundaries.

During drilling operations, the calibrated resistivity model values may be applied to measured-while-drilling (MWD) resistivities to evaluate pressure trends in the well in real time.

Conclusions

Several general conclusions can be drawn from the data. Most are easily extrapolated to other areas in the Gulf of Mexico offshore and to other clastic, passive margin basins. Others are currently specific to the geology of the local area, and cannot yet be extrapolated to other areas.

Fracture pressure and pore pressure trends converge near the mudline (point "A" in Figures 2 and 3). This convergence sets a physical limit on the amount of open-hole that can be maintained before setting additional casing strings becomes necessary. In this shallow section below the mudline, more time and expense are expended setting and cementing casing than in drilling.

These narrow tolerances, typically a few tenths of a pound-per-gallon (PPG) equivalent, between PP and FP can make control of shallow pressure flows difficult. While increasing mud weight to control flows a slight overbalance can break down formation causing loss of drilling fluid. After this loss, the flowing formation comes back into the well. This cycle of flow/ kill/breakdown/ flow can result in substantial well cost overruns.

Seals form earlier and at shallower depths below mudline in the deep water environment compared to shelf sediments (point "B" in Figures 2 and 3). Water column is a contributing factor, with the water column providing an overburden stress approximately equivalent to a column of rock half this thickness. The water column effect is most noticeable in water depths exceeding ~2000'. Pore pressures are elevated above hydrostatic pressure with as little as 1500'–2000' of sedimentary overburden deposited. This early top-seal formation sets up a favorable system to trap early migrating hydrocarbons. The study area has a relatively large number of fields/discoveries with significant stratigraphic components.

Pore pressure and fracture pressure increase at different rates with increasing burial depths. These differential rates of pressure increase result in variations of potential column heights with increasing depth. In the younger, expanded Miocene sections, characterized by high sedimentation rates, the rate of pore pressure increase is lower than the increase in fracture pressure (DPP< DFP). In the deeper, older section there are transitions into higher pressure cells where the rate of change in pore pressure is higher than the

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fracture trend gradient (DPP > DFP).

In the expanded Miocene section of the study area, pore pressure increases at ~0.8 psi/ft, whereas fracture pressures increase uniformly at ~1.0 psi/ft. (point "C" in Figures 2 and 3). This separation results in increased seal potential and therefore greater possible maximum column heights with increasing depth. Three fields in the area are filled to spill, having hydrocarbon columns of 2100' (Neptune), 1900' (Marlin) and 1400' (King). An additional benefit, this pressure gradient differential increases the depth interval that can be drilled after each succeeding casing point resulting in reduced total drilling time.

A few wells drill completely through the expanded Miocene to the Lower Tertiary and Upper Cretaceous sections. This older stratigraphic section has significantly lower rates of sedimentation, as well as significant unconformities, and is associated with a notable transition to higher pressures. The pore pressure gradient increases abruptly (1.8 psi/ft) in the transition zone (point "D" in Figures 2 and 3). The separation between pore pressure and fracture trends is substantially reduced, resulting in diminished seal capacity and an accompanying reduction in maximum possible column height. An additional drilling consideration is that the transition may be quite abrupt with pressure differentials of 2000–3000 psi occurring in as little as 120' of vertical section.

In this local area the succession from the mildly pressured Miocene reservoirs, with high seal capacity, to the lower Tertiary and Cretaceous source rocks, with significantly decreased sealing capacity, provides a probable mechanism for expulsion and vertical migration of hydrocarbons. On deep high relief structures in the deep source section, any significant accumulation of hydrocarbons will result in buoyancy pressures that exceed the fracture pressure sealing capacity. At that point, hydrocarbons can fracture the top seal and move vertically along salt/sediment interfaces or faults that extend up to the Miocene. Once above the pressure transition, hydrocarbons thencharge lower pressured sands that have higher sealing capacity.

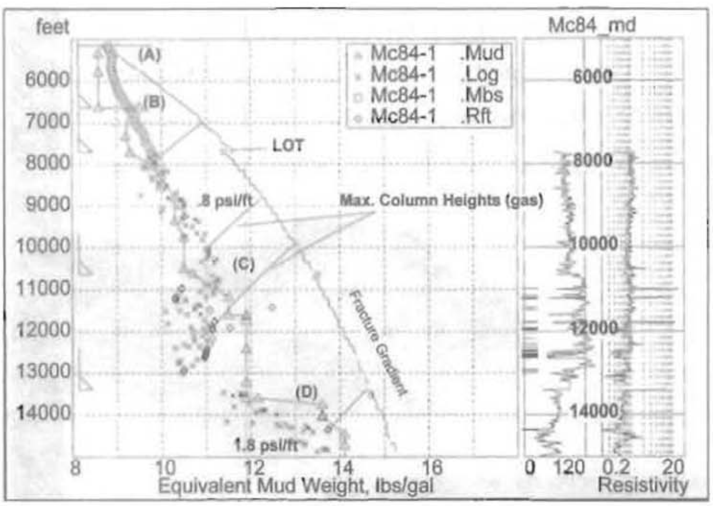

Figure 3: *Mud weight (ppg) versus depth (ft.) for a typical well, MC 84 #1. Pressure (psi) versus depth (ft.) for a typical well, MC 84*

Biographical Sketch

Bruce Wagner earned B.S. and M.S. degree in geology from Florida State University. He has worked at Amoco since 1982 in exploration and exploitation assignments on the shelf and in deep water. Since 1991 he has been engaged in exploration and drilling in the GOM deep water, primarily in Mississippi Canyon and Viosca Knoll. In addition to prospecting, Wagner's geoscience interests include petroleum systems, geochemistry and pressure issues.

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