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Integrated Carbonate Reservoir Development and Management

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Temporal Dynamics and Modelling Challenges of a Highly Overpressure Gas Reservoir: A Case Study from Sarawak Offshore, Central Luconia Carbonate Province, Malaysia"

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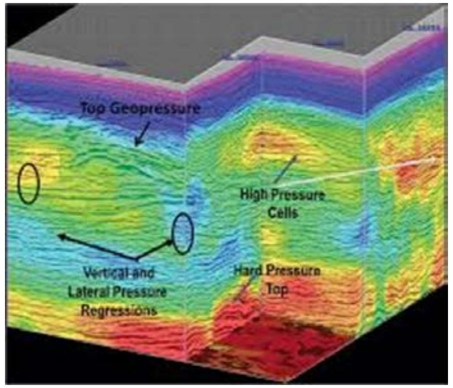
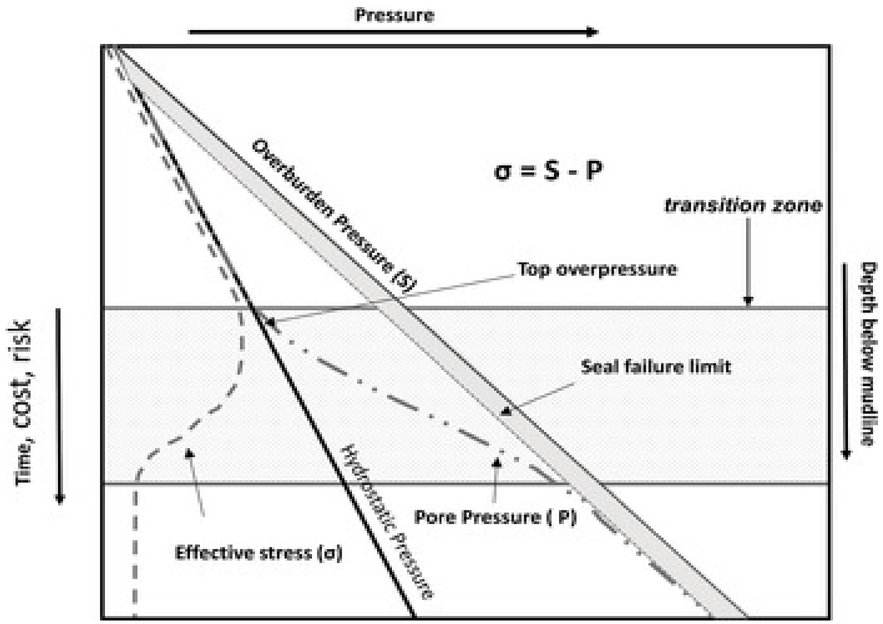
What is an 'Overpressure Reservoir'?



"OVERPRESSURE RESERVOIRS"

"Abnormally pressured oil & gas accumulations that typically occur in regions characterized by post depositional tectonic activity or rapidly deposited sedimentary basins"



- Effective stress or net overburden pressure exerted by the sediment's grains through grain-to-grain contact is minimum in overpressure regime, but
- The effective stress increase with pressure depletion in reservoir

Origin of Overpressures

(Areas of Compressional folding & Relatively young sediments)

1. Tectonic Stress	**2.Undrained compression**	3. Clay Transformation	4. Aquathermal Pressuring	5. Oil and Gas Generation	6. Osmotic Pressures
Regional compressive force resulted transfer of tectonic stress to the fluids (Hubbert & Rubey)	Over pressure as result of slow dewatering of sediments during rapid deposition and burial in basin containing younger sediments (Dickinson)	Increased temperature cause transformation of smectite illite mixed layer clays expel water in shale.	Pore water expands with increasing temperature. The volume increase of the water is much greater than expansion of clay minerals normally present in clays.	Conversion of solid organic matter or kerogen to liquid or gaseous petroleum result in volume increase.	Differences in water salinity know to occur, osmotic pressure may be generated by flow of ions from more saline to the less saline waters. (Jones)

Outline

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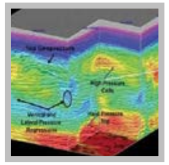

What is an Overpressure Reservoir

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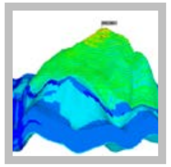

Field Overview and Modelling Challenges

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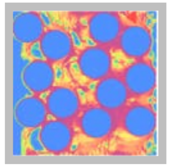

Rock Properties Dynamics

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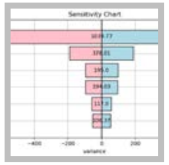

Classical understanding from MBE

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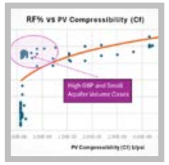

Recovery Sensitivities – Dynamic model

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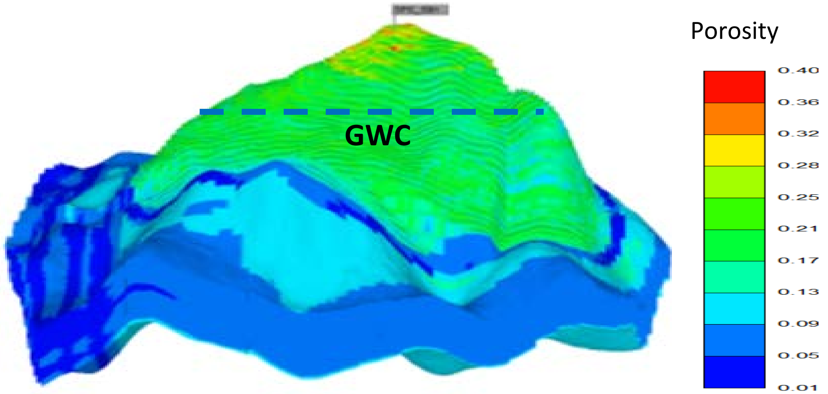
Summary and Conclusions

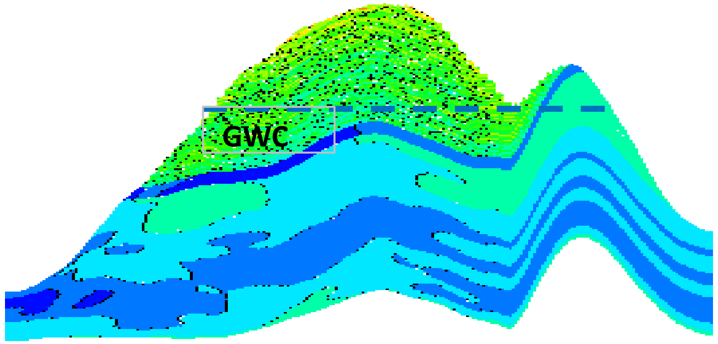
Field Overview: SK-B Field

- SK-B Field, a **highly over-pressured (~ 17 ppg of EMW),** underfilled gas reservoir discovered in 2010 in the Central Luconia carbonate province, SKO, Malaysia
- Circular pinnacle carbonate structure developed during Cycle V of late Miocene deposition.
- ~280m of gas column, Depth ~3000m, Average porosity ~22%, Permeability 200mD to 5 Darcy. Proven GWC penetrated by the exploration well.
- The reservoir underlaid by very thick water bearing zone, ~40X size of the reservoir.
- The upper pinnacle having higher porosity, separated by tighter facies layer.
- The post drilled GIIP estimated was 3X bscf with associated condensate.
- Single well development and put on production since 2017.
- **Conducted a series of static and dynamic modelling studies consecutively within 4 years to ascertain the time of Cease of Production (CoP).**
- **The successive studies indicated delayed in CoP, higher GIIP and RF .**

Structure: Pinnacle Carbonates

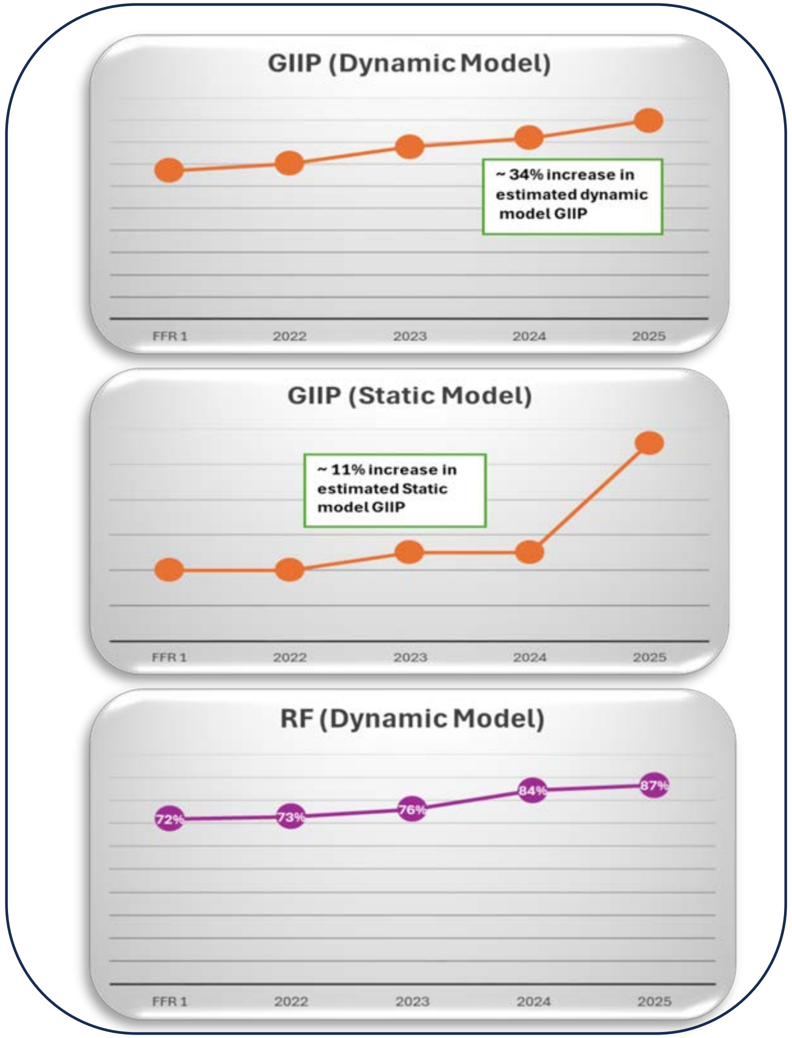


X-Section through the Crest of the structure



Volume Movement and CoP Prediction

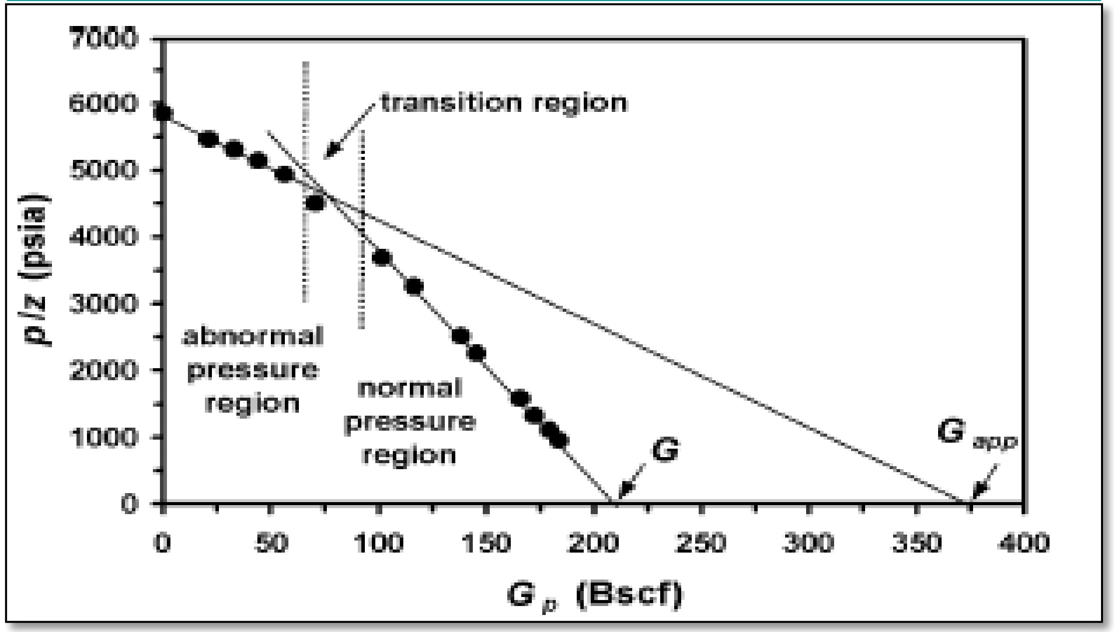
- Cease of Production (CoP) extended by one year at each successive 5 studies, even without change in ACQ.
- Estimated EUR increase by 61% from 1st Full Field Review (FFR) study.
- However, static model GIIP increased by 11% and history matched dynamic model GIIP improved by 34%
- RF improved from 72% to 87%.
- P/Z analysis suggested significantly higher GIIP.



P/Z Plot Characteristics

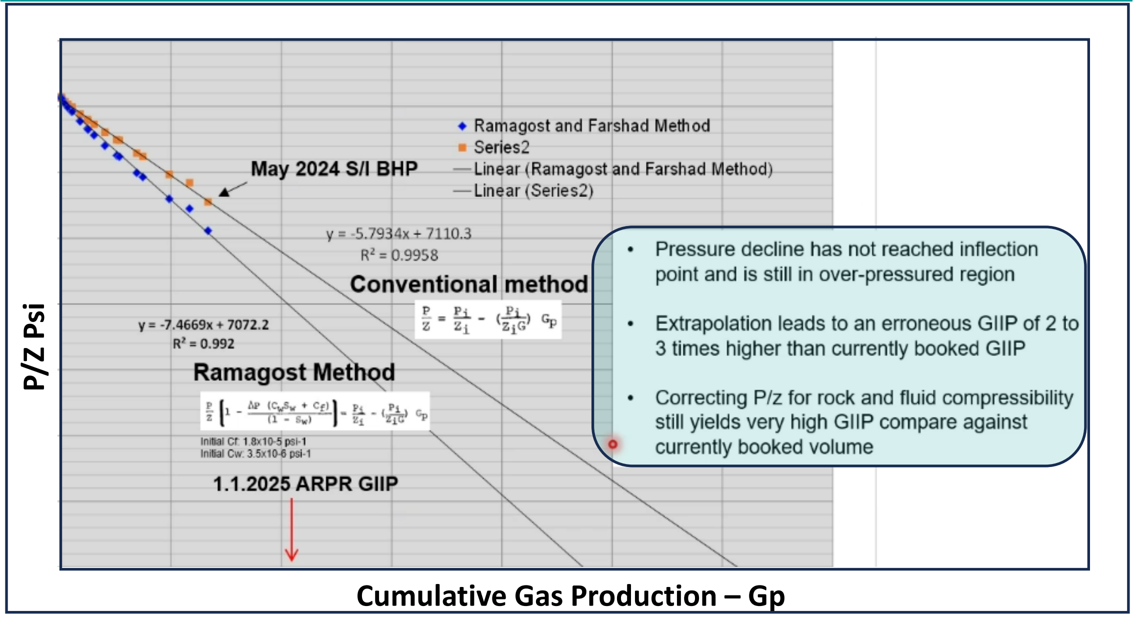
- The p/z plot versus cumulative gas production (Gp) is a acceptable method used to estimate original gas in-place (GIIP) in volumetric gas reservoirs.
- However, abnormally pressured reservoirs usually exhibits rock compaction and water expansion in addition to gas expansion,.
- As the total compressibility approaches gas compressibility, the p/z curve tends to bend downward, making "straight line extrapolation" questionable.
- The p/z curve of SK-B demonstrate that the curve not reached normal P region.
- GIIP estimated from the p/z straight line assumption is 2 -3 times of Booked Volume

Typical Behaviour of a Overpressure Gas Reservoir

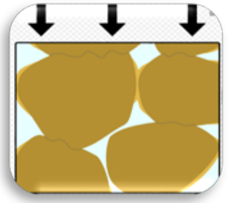


Source: SPE 71514

P/Z vs Gp - SK-B Reservoir

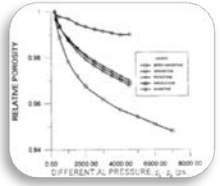


Modelling Challenges



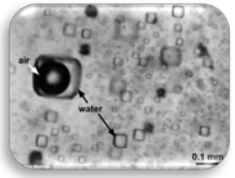
1. PV Compressibility (C_f)

Pore volume compressibility varies with effective stress at grain-to-grain contact
Significantly contribute to drive energy



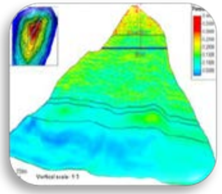
2. Porosity & Permeability Dynamics with Pressure

Pore collapse leads to porosity and permeability reduction; impacts aquifer influx and well PI..



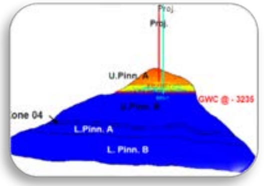
3. Trapped Gas Saturation

Gas becomes trapped in pore space due to water encroachment. No data available to calibrate the model.



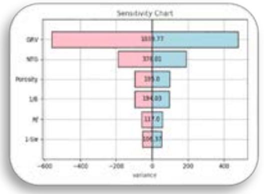
4. Baffles Transmissibility

Effect on connected aquifer volume, influx rate and drive energy



5. Aquifer Parameters Uncertainty

Underfilled reservoir with thick water column.



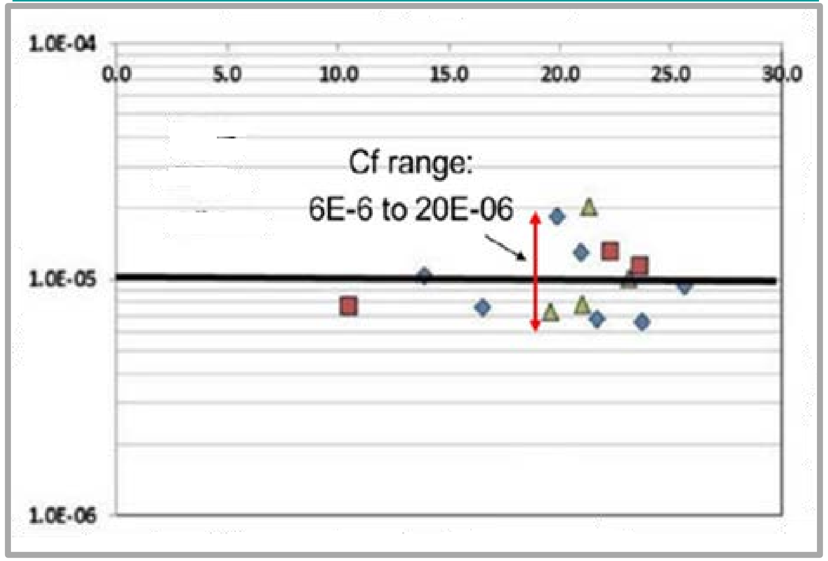
6. Volume Uncertainties

Single well data, correlation coefficient of porosity seismic AI is not good. TOC uncertainty.

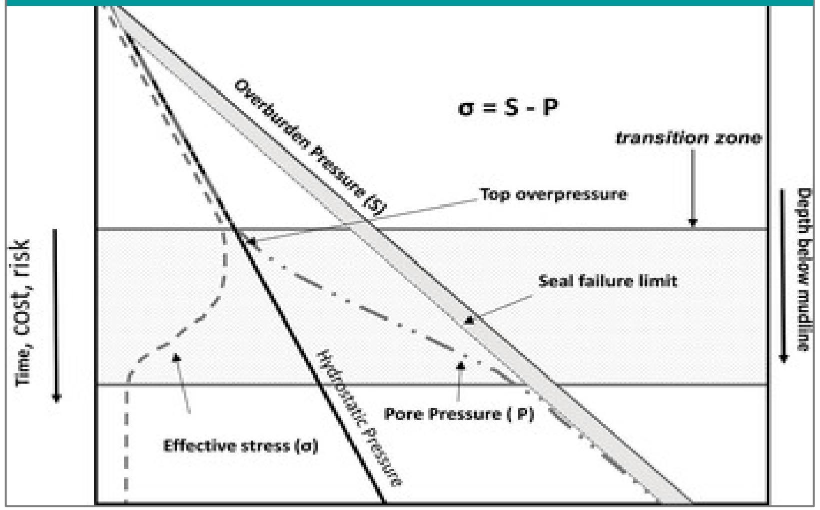
PV Compressibility

- PV Compressibility (Cf) describes the variation in pore volume with change in pore pressure at constant confining stress.
- Reliable compressibility values are essential for resource estimation, pressure maintenance, drive assessment subsidence evaluation.
- C_f measured in a few carbonate fields in Central Luconia cluster around $6E^{-6}$ to $20E^{-6}$ 1/psi.
- **Issues:**
  - Sigle point data for a particular porosity group. No data on pressure dependent pore compressibility.
  - Effective stress change due to production and causes volumetric changes in the pore space in a reservoir.

Cf –Analogue (?) the Fields in Central Luconia



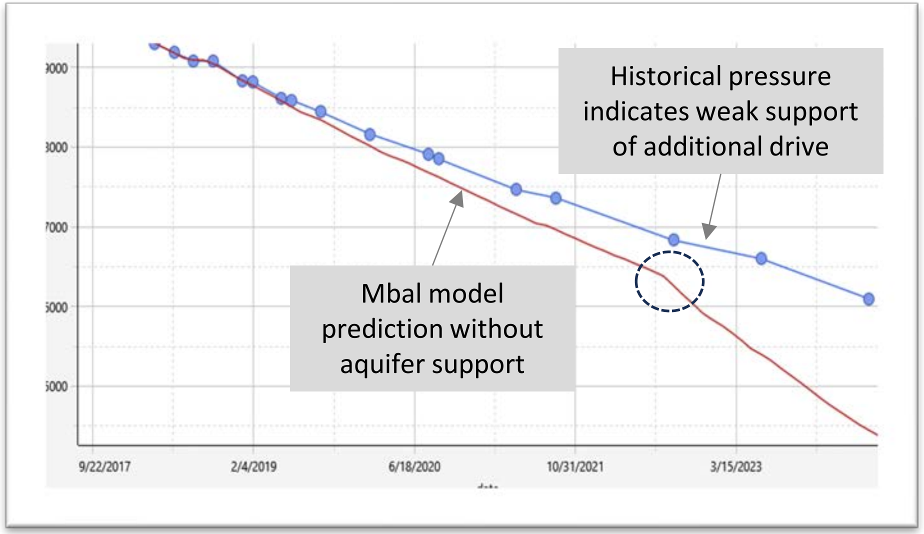
Effective Stress and Pore Pressure for a Typical Overpressure Reservoir

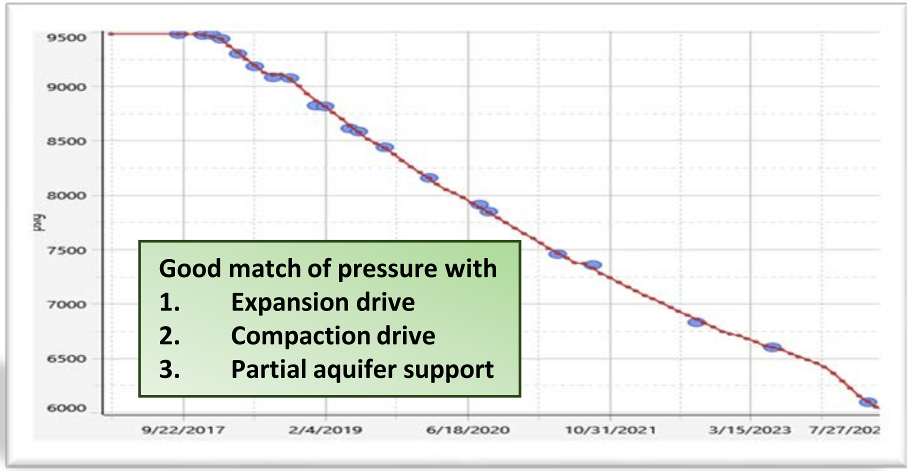


Material Balance Analysis

- A quick material balance model constructed based on the static model understanding with following assumptions.
  - Upper pinnacle mainly gas is separated by baffle
  - A large aquifer connected through baffle.
  - Pressure dependent Cf
  - Inflection point at ~5600 psia
- The prediction indicates water drive could have weak support in addition to expansion and compaction drives. The source could be
  - ➢ Bottom water
  - ➢ Shale water expulsion
- Pressure could be matched with high case GIIP and all 3 drives, i.e. compaction, fluid expansion and aquifer drives are active

Material Balance Model Prediction: SK-G

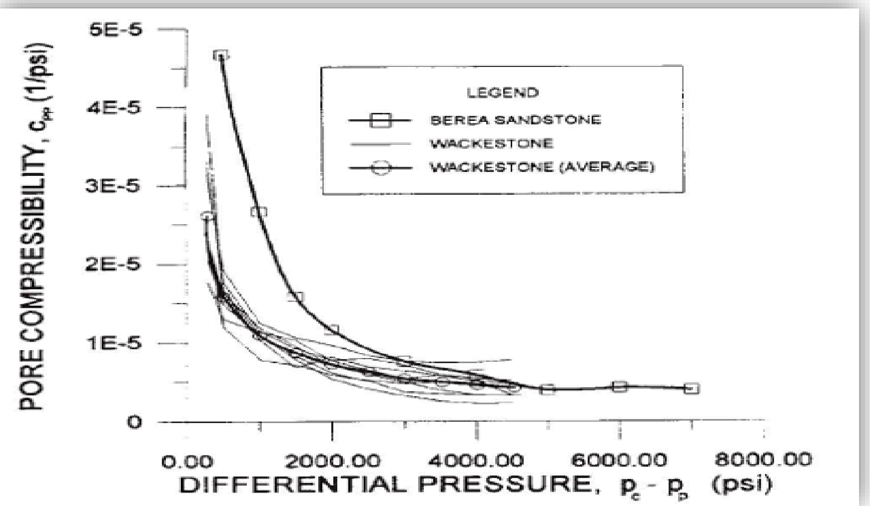


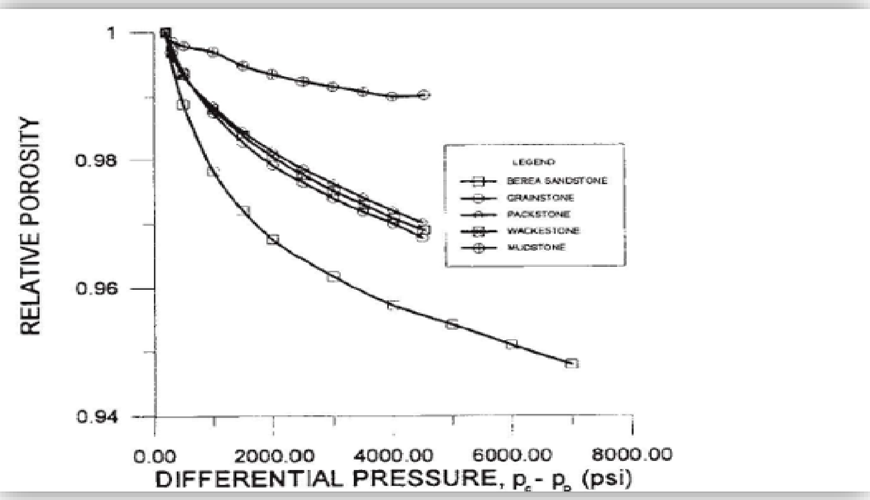


PV Compressibility of Arabian Carbonates

*Source: SPE 27625

- Four groups of limestone samples consisting of Grainstones, Packstones, Wackestones, and Mudstones were studied.
- The average pore compressibility found to be approximately 30 x 10^{-6} I/psi at differential pressure $(Pc - Pp)$ of 200 psi. However, their average compressibility dropped to 5 x 10^{-6} at differential pressure of of 4,500 psi.
- During a preliminary analysis of the compressibility data, it was observed that there was an almost linear relationship between pore compressibility and differential pressure on a log-log scale.
- Percentage reduction in porosity because of hydrostatic compression from 0 psi to 4,500 psi was
  - 3.20% for Grainstones,
  - 2.98% for Packstones,
  - 3.10% for Wackestones,
  - 0.98% for Mudstones, and
  - 4.43% for Berea sandstone



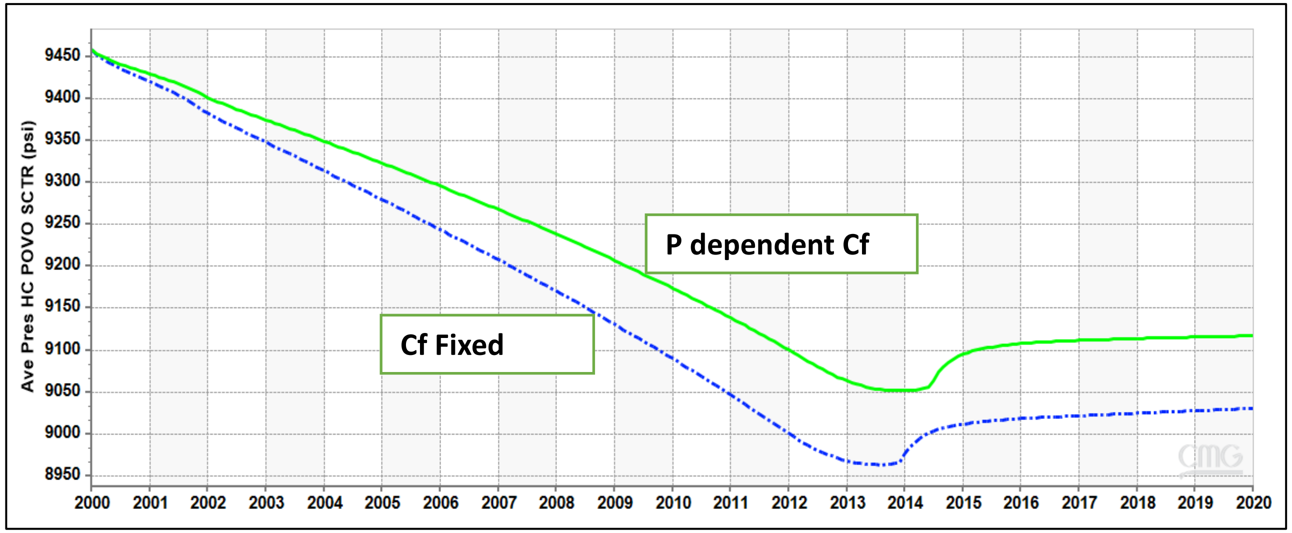


Pressure Dependent PV Compressibility (Cf) Impact

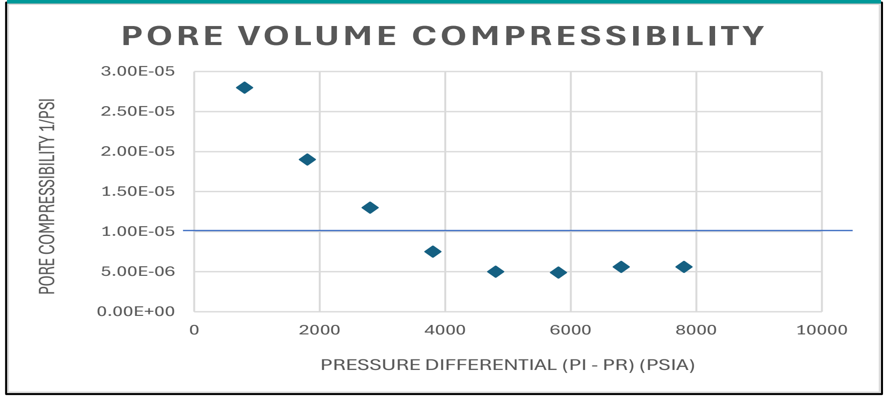
The dynamic model under same production constraints predicts pressure dependent Cf

- Delays the date of Cease of Production due to late water breakthrough.
- Relatively slower rate of pressure depletion

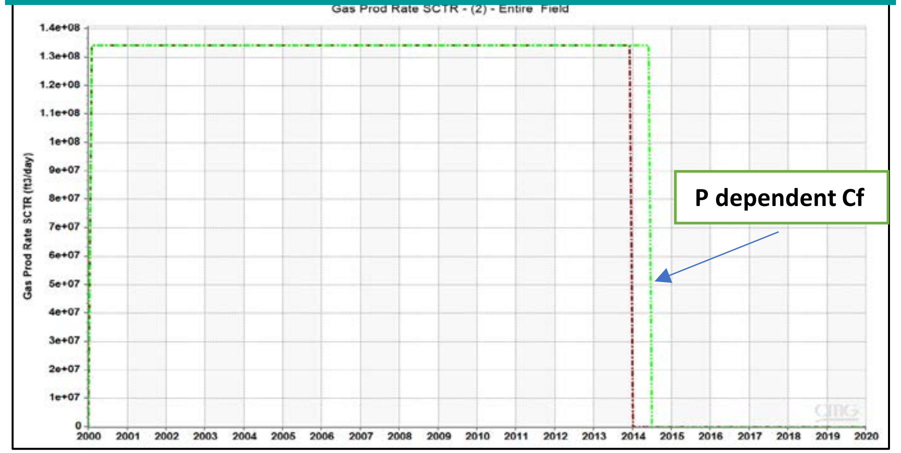
Response on Average Reservoir Pressure



Pressure dependent PV Compressibility



Pressure dependent Cf impact on COP



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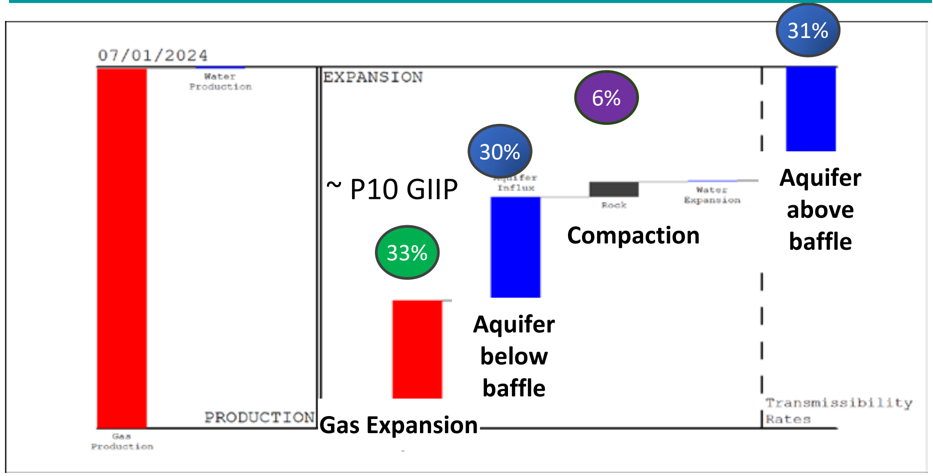
PV Compressibility Impacts on GIIP – MBAL

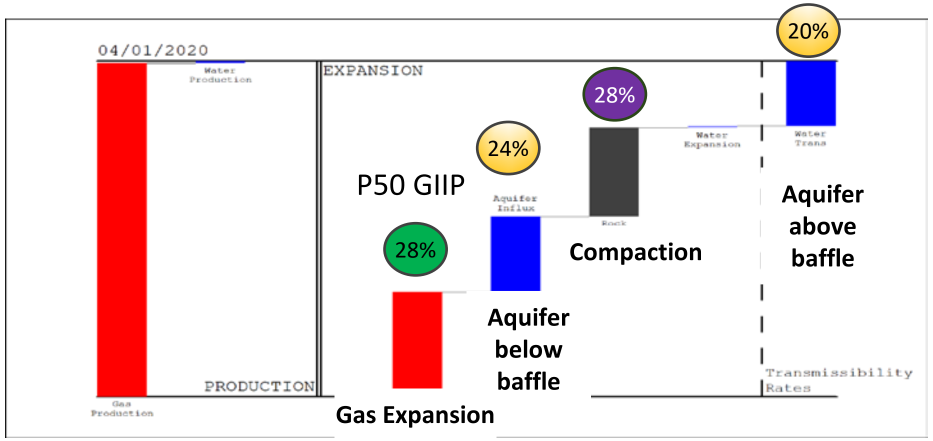
- Model Assumptions: 3 drives are active
  - a) Gas Expansion – function of GIIP
  - b) Rock Compressibility – Compaction Drive
  - c) Aquifer drive/Water influx – Water below and above the baffle

- Observations:
  - Accounting for higher compressibility would lead to lower GIIP, lower water influx and delayed CoP
  - P50-P10 range of static volume estimates could still be valid with higher rock compressibility.

Drive Contributions – Low PV compressibility (8 microsips) Case

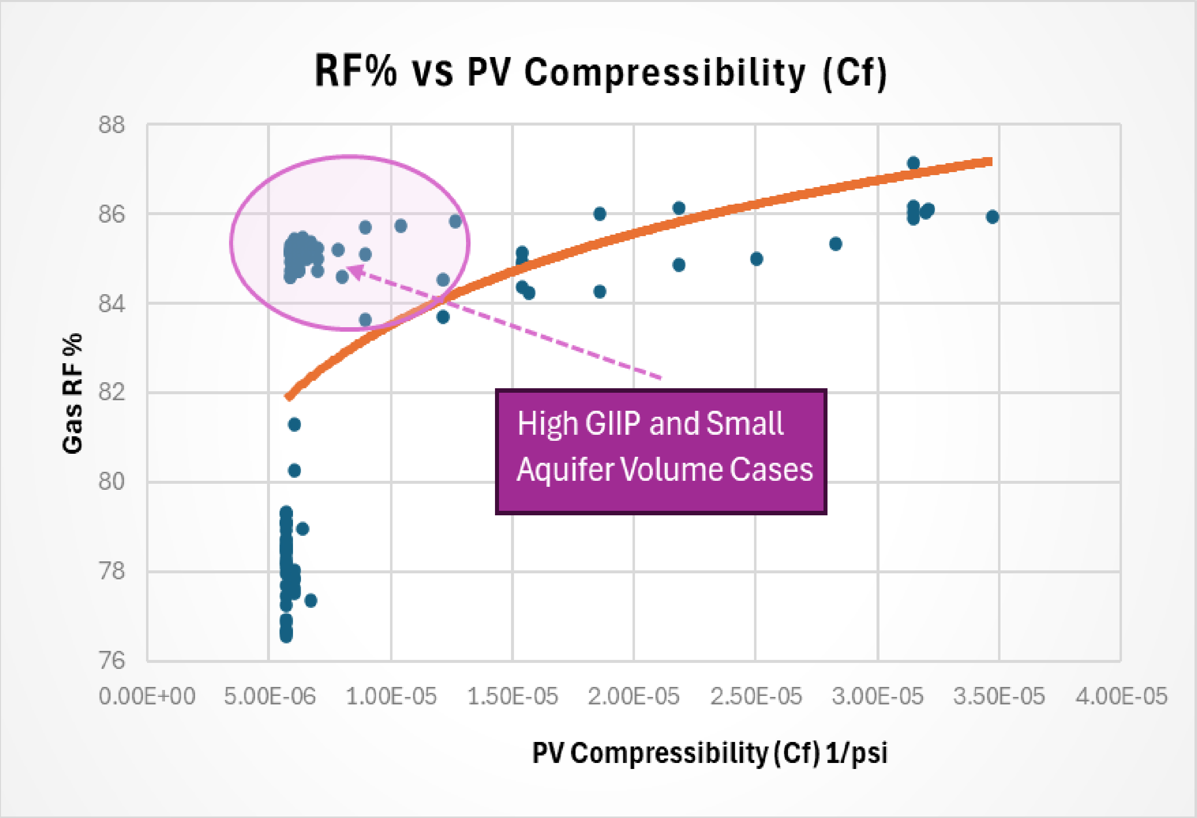


Drive Contributions – High PV compressibility (42 microsips) Case



PV Compaction Impact on RF%

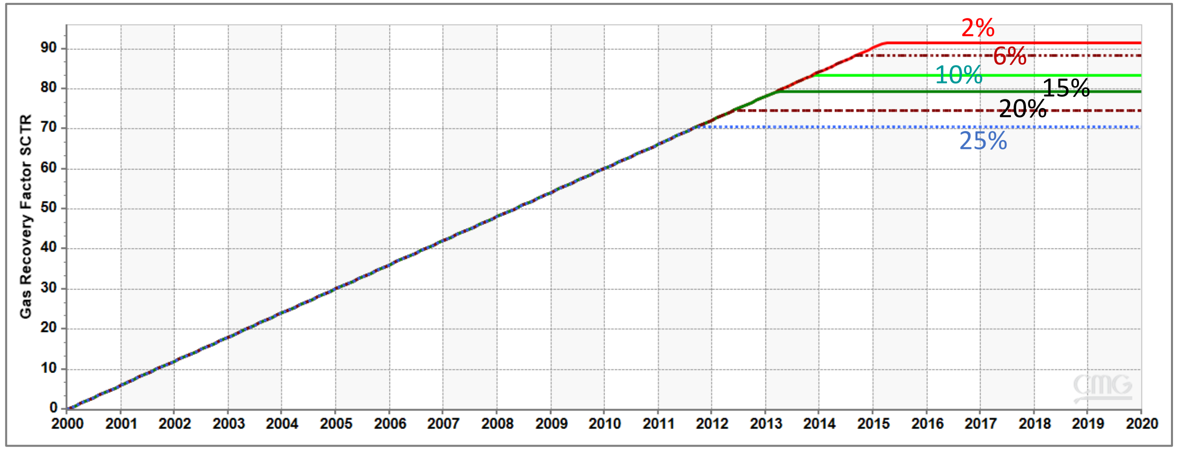
- A dynamic model with half a million grid cells was constructed to sensitise the Cf, aquifer volume, baffle transmissibility and porosity to understand the impact on recovery and Cease of Production (CoP) timing.
- The dynamic model is not exactly same as SK-B simulation model, but have similarity in reservoir structure, static properties and dynamic model prediction constraints.
- Selected the cases from about 200 realizations created by Latine Hypercube (LH) and Differential Evolution (DE) experimental design with similar pressure trend.
- The prediction indicated RF improvement with increased PV compressibility.
- The RF also improves if the aquifer influx is low.



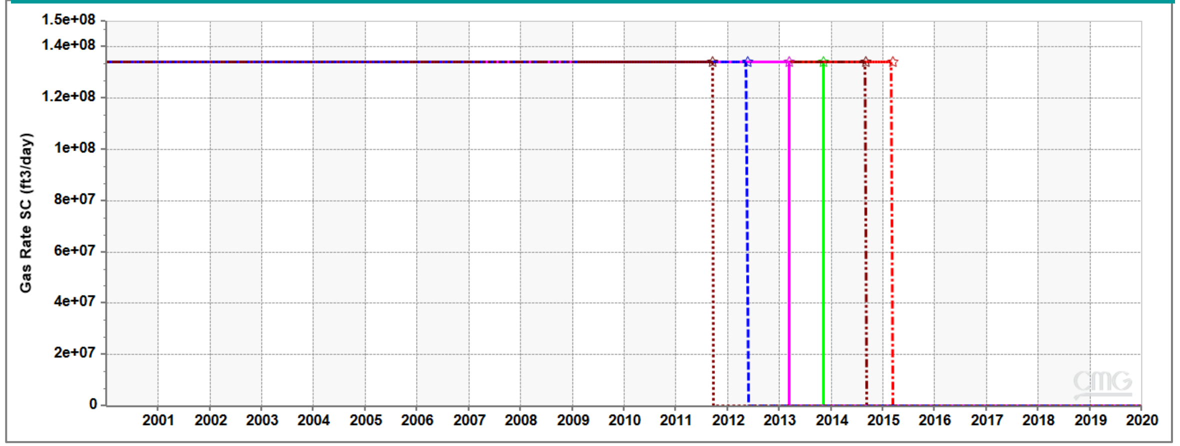
Gas Trapping –Sg Trap

- When a gas reservoir is under **water drive**, the encroaching aquifer pushes water into the reservoir as gas is produced. This process leads to **gas trapping.**
- **The volume of gas trapping depends on**
  - Reservoir heterogeneity – capillary trapping
  - Hysteresis in relative permeability in water wet reservoir
  - Aquifer strength and rate of influx
  - Production rate and reservoir pressure depletion
  - Well placement and development concept
- Gas trapping is modelled using "**Carlson Hysteresis"** and **Linear gas trapping (Sg Trap) model**.
- The model prediction demonstrates the gas trapping % has significant impact on RF and CoP time.

RF Improves with Low Volume of Gas Trap in Reservoir



Gas Trap Percentage Impact on CoP



Summary and Conclusions

- Pore volume compressibility is pressure dependent as net overburden stress on rock grain change with pore pressure depletion especially for a overpressure reservoir.
- Gas reservoirs are easy to manage, but highly challenging for modelling a overpressure reservoir due to:
  a. Compaction drive contribute significantly at early to mid production region.
  b. Due to lack of data, a modeller ignores the pressure dependent Cf.
  c. Permeability and porosity reduction with pressure is not factored in dynamic model.
  d. Shell water expulsion and its contribution to producing drive is poorly understood.
  e. Sg trap modelling and assumption
- Compaction drive has significant contribution to the reservoir energy, and can influence the history match GIIP, RF and timing of CoP.
- Cf data for full range of net overburden stress is desired during SCAL experiment.

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Q & A