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Pore Pressure Detection:
Moving from an art to a science

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Contents

• Ground Truth
  – A Solution to the super charging issue
  – Relationship between sand and shale pressure

• Compaction Trends
  – The Art
  – The Science
Ground Truth

- Absolute Reference is a direct measurement of the pore pressure
  - Only in permeable formations
    - DST
    - MDT/RCI/RDT measurements:
      - Moderate to high permeability – reliable measurement of truth
      - Low permeability (>1 mD) – An art to interpret
        - Tool modifications now allow us to take measurements that are definitive at low permeabilities
Supercharging

Definition: Pressure above the \textit{in situ} pressure in a formation due to the presence of the borehole.

Can be caused by very low permeability and mud filtrate.

Or

By limited sand volume and mud filtrate.
MDT Example

Mobility indicates less than 0.2 md

First drawdown of 1.9cc, shut-in at 5564 psi

Second drawdown of 0.4cc, shut-in at 5313 psi

Second shut-in is lower than first, therefore this is supercharged.
MDT Example

First drawdown of 6.4cc, shut-in at psi 11827

Second drawdown of 1.0cc, shut-in at 11826 psi

Third drawdown of 1.1cc, shut-in at 11826 psi

All three shut-ins are the same, therefore this is NOT supercharged.
Supercharging Detection Principle

• If different volumes are removed from a formation and the resulting measured shut-in pressure does not change, then the measured pressure cannot be the result of formation supercharging.
Relationship of Ground Truth to Log Measurements

- Direct measurement of formation pressure (“ground truth”) is *ALWAYS* in permeable formations.
- Inference of pressure from log/drilling measurements (Dt, Rhob, Dxc, Rt) is usually in shale.
- How do sand and shale pressure relate?
Overpressure Trends
Shah Deniz Example (Sabunchi)

- **Sand Trend derived from MDT data**
- **Shale Trend derived from log data**

**TVDSS (m)**
- SDX-1
- SDX-2
- SDX-3

**Pore Pressure (psi)**
- 0 5000 10000 15000 20000 25000

**Sabunchi Mid-Point Depths**
- 2000
- 3000
- 4000
- 5000
- 6000
- 7000
- 8000
- 9000

**Legend**
- Shale Pore Pressure
- Sand Pore Pressure
Sand /Shale Pressure Relationship

• Sands are high permeability relative to shale
  – Pressure is transferred rapidly relative to shale
  – Darcy Vs. Nano-Darcy (nine orders of magnitude)
  – A pressure pulse that take three days to move across a 1 D sand takes 8 million years to move across an equivalent sized 1 nD shale.
Sand /Shale Pressure Relationship

• The rotation of sand and associated transfer of pressure is normally coincident with the deposition – Hence there is normally much time for the sand and shale to equilibrate.

• However, when events occur to allow pressure to bleed laterally out of a sand it can take millions of years for the adjacent shale to equilibrate.
Sand Pressure = Shale Pressure?

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**Diagram:**
- **meters:**
  - Water Bottom (529)
  - Pliocene (1493)
- **Equivalent Mud Weight, lbs/gal:**
  - Miocene - Messinian (2747)
  - Miocene - Tortonian (2900)
  - Miocene - Serravalian (3239)
  - TD (3377)
- **GR Acoustic**
  - Resistivity
  - Caliper
  - Resistivity

**Data Points:***
- Hj-1x
- Mdt
- Rft
- D46
- D16
- Mud
- Leakoff

**Presgraf/Alberty wd=529,ag=26,bht=hj-1x,cec=1.7,vcl=0.45,c=27500,p0=0.40,10k=0.83/185,hj-1x.rho,o1p6(3.)t1f9 i=.04 ,lum**
Compaction Trends

- Conventional Art
- Scientific Approach
  - Defined Trends
  - Mean stress versus vertical stress
  - Role of LOT
  - Unloading/Uplift
The Relationship Between Porosity and Pressure

As load is applied to a rock, the load is initially borne primarily by the pore fluid resulting in raised pore pressure.

As excess pore pressure bleeds off through natural permeability paths in the formation, the load is transferred to the rock frame resulting in pore volume compaction.

It is this physical relationship between excess pore pressure and porosity that allow us to infer pressure from porosity logs.
Compaction Trends – The Art

- Measurements of porosity are converted to pressure through compaction trends.
- Compaction trends relate the “porosity” measurement (Dt, Rhob, Dxc, Rt) to normal pressure.
- A velocity (or other porosity related measurement) is assigned to the normal pressure associated with each depth.
- The positioning of this trend is critical to the results.
- The relationship of the actual measurement to the normally pressured response is used to determine the pressure.
Normalization

Shale Travel-Time, µs/ft

Equivalent Mud Weight, g/cc
Normalization Assumptions

- Shallow sediments are normally pressured
- Lithology through the well is constant
- Sediments are at historical maximum effective stress (no unloading)
- “Straight line” compaction relationship
- Some cases: known pressure (kicks, FTs…)
- Sand pressure = shale pressure
Pitfalls of Normalization

- Absence of shallow normally pressure sediments
  - Shallow geopressure (SWF)
  - Uplift and erosion
  - High deposition rates
- Conversion of smectite to illite (diagenesis)
  - Typically begins at 71° C or 160° F
- Linearity of the response
Compaction Trends – The Science

• Each lithology has a unique porosity-effective stress response
• Effective stress is the difference between total stress and pore pressure
• Total stress is the mean stress and overburden can be used as a proxy in relaxed basins where sediments are at there maximum historical effective stress
Dutta/Wendt model removed for confidentiality reasons.
Lithology Compaction Trends

Effective Stress vs Velocity

Effective Stress (psi)

Velocity (ft/sec)

Smectite

Illite
• Trends established over decades
• Can be used to determine clay type
• Temperature are guidelines, may vary in different parts of the world
Generalised Vs Lithological Trends
Potential Pitfalls

- Using overburden as a proxy for mean stress
- Uplift/unloading
- Illitization – potassium starvation
- Poor quality porosity measurements
Conclusions

• Advances in formation tester measurements allow reliable pressure measurements in very low permeability formations.
• Do not assume sand pressures equal shale pressures, especially in areas where pressure bleeds off laterally.
• Normalization of compaction trends should be avoided – the results are unreliable in a safety critical area.
• Compaction trends are predictable and lead to more reliable estimates of shale pore pressure.
• Compaction trends must account for lateral stresses in tectonically active or unloaded basins.