Pore Pressure prediction using seismic velocities

João Narciso

Supervisors:
Profº Drº Amílcar Soares
Profª Drª Maria Matilde Costa e Silva
Introduction and motivation

- The knowledge of the stress state, geological conditions and the formation pore pressure is essential to check the stability of wells and to optimize drilling processes.

- Abnormal Pore Pressure are encountered worldwide, often resulting in drilling problems such as borehole instability, stuck pipe, lost circulation, kicks and even blow-outs.

- To optimize drilling decisions and well planning in overpressured areas, it is essential to carry out pore pressure predictions before drilling.

- A predrill estimate of pore pressure can be obtained from seismic interval velocities calibrated with laboratory measurements.
Main Goals

• The main goal is to build a three-dimensional cube of pore pressure to analyse how the 3D geological and geomechanic modelling can contribute to the prediction of pore pressure.

• Obtain a compaction trend with depth from the relationship between the porosity, the vertical effective stress and the seismic velocities, developing laboratory measurements such as uniaxial and triaxial compression tests.

• Using this relation and seismic interval velocities, build up a 3D pore pressure model performing stochastic simulation.

• The pore pressure cube aims to support a better visualization of the mechanisms of overpressure generation and to help in a safer and economic drilling of wells.
Pore Pressure

- Pore pressure is defined as a scalar hydraulic potential acting within an interconnected pore space at depth.

- Formation pore pressure is divided into the three categories normal, abnormal and subnormal formation pressure.
Pore Pressure

- The term normal formation pressure describes the situation where formation pressure is approximately equal to the theoretical hydrostatic pressure of a given vertical depth. Abnormal and subnormal formation pressures represent pressures of respectively higher or lower values than this normal situation.
Abnormal formation pressures are found in many sedimentary basins in the world, and can have different origins. Common to all mechanisms providing overpressure is the requirement of a seal to contain the higher pressure values. The main mechanisms of overpressure can be listed as the following:

- **Rapid loading and undercompaction**, where a seal prohibits the dissipation of pore fluids as the sediments are buried and compacted.
- **Tectonic compression** may create overpressures in originally normal pressured zones.
- **Hydrocarbon column heights** can result in overpressure at the top of reservoir.
- **Aquathermal pressurization**
- **Centroid effects**
- **Hydrocarbon generation**
Seismic Pore Pressure Prediction

- Methods of evaluating abnormal pore pressures are divided into two categories: prediction methods and detection methods. The prediction methods are based on data obtained from seismic surveys, offset well logs and well history. Detection methods traditionally use drilling parameters and well log information obtained during the actual drilling of a well.

- Elastic wave velocities in rocks increase during loading due to reduction of porosity and increased contact at grain boundaries. Since any increase in pore pressure above the normal hydrostatic gradient reduces the amount of compaction that occurs, elastic wave velocities may be used for pore pressure prediction.
Seismic Pore Pressure Prediction

• It is assumed that the variation of elastic wave velocity with pore pressure and stress follows the effective stress principle, first formulated by Terzaghi (1943).

  – So if $\sigma_v = S_v - p$

  – $S_v$ is given by the combined weight of the rock matrix and the fluids in the pore space overlying the interval of interest.

  \[ S_v(z) = g \int_0^z \rho(z) \, dz \]

Eaton’s method estimates the vertical component of the effective stress from the seismic velocity $v$:

$$\sigma = \sigma_{\text{Normal}} \left( \frac{v}{v_{\text{Normal}}} \right)^n$$

$\sigma_{\text{normal}}$ and $v_{\text{normal}}$ are the vertical effective stress and seismic velocity expected if the sediment is normally pressured, and $n$ is an exponent that describes the sensitivity of velocity to effective stress.

The pore pressure is then given by

$$p = Sv - (Sv - p_{\text{Normal}}) \left( \frac{v}{v_{\text{Normal}}} \right)^n$$

To use Eaton’s method, the deviation of the measured velocity from that of normally pressured sediments ($v_{\text{normal}}$) with depth is given by

$$v_{\text{Normal}}(z) = v_0 + kz$$
To determine pore pressure from seismic velocities, the velocity to pore pressure transform must be calibrated using available pressure measurements, and lab measurements to determine the variation in vertical stress versus depth.

In order to address the calibration, I did some uniaxial compression tests in a limestone with porosity of 12%, measuring the P-waves velocities and shear-waves velocities during the tests.
Vertical effective stress vs. seismic velocities – Lab Measurements

Uniaxial Compression Test

\[ \sigma_v (\text{MPa}) \]
\[ V_p (\text{m/s}) \]

- Pedrogao 1
- Pedrogao 2
- A4
- A5
- A4 (Rep)
- A5 (Rep)

P-wave transducer
The Triaxial Compression Test was used to assess the mechanical properties of the rock, providing a measure of the confined compressive strength as well as the stress-strain characteristics of rock specimen.

Manual hydraulic pump to apply the confining pressure

Confining pressures used: 0.5 and 1 MPa.

Simultaneous were measured the P-waves and the shear-waves velocities.

Triaxial cell with P-wave and S-wave transducers
Vertical effective stress vs. seismic velocities – Lab Measurements

**Triaxial compression test, P-waves**

**Triaxial compression test, S-waves**
3D Pore Pressure model

- After developing the relationship between the vertical effective stress and the velocity of seismic waves, obtained the compaction trend of the geological formation based on laboratory measurements, and using the 3D estimates of velocity and vertical stress ($S_V$), plus their associated uncertainties, the distribution of pore pressure is going to be determined via stochastic simulation of both Eaton’s and Bowers relations.
References


http://www.glossary.oilfield.slb.com
http://www.cgg.com/

Thank you for the attention!