Limitations of seismic pore pressure prediction - what is the alternative?

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Pore pressure prediction is becoming even more critical to successful drilling as conditions for exploration and exploitation of oil and gas reserves move into more hostile environments. Rock property relationships (including seismic interval velocity) tend to under-predict pore pressures when temperatures exceed about 120^{o}C. Understanding of the geological setting (tectonic stress history) and lithology control on pressure mechanisms provides the basis for a geology-model based approach, which can yield more realistic predictions in these high-temperature settings.

Introduction

Most pressure prediction algorithms were developed in the Gulf of Mexico shelf setting in the 1960s and 1970s - young, clastic sequences with shales rich in smectite. Such relationships work in other low-temperature, clastic-dominated settings, sometimes with modification for low-smectite rocks. Wells provide calibration for seismic volumes to prediction pore pressures at new well locations. Seismic-based prediction depends on good data, reliable processing velocities generally picked for the purpose of pressure prediction, and many assumptions about lithology and compaction behaviour of shales. This paper explores these assumptions, the relation between shales and their associated reservoirs, and examines where and why seismic-based prediction is limited, especially at depth.

Traditional approach based on compaction and effective stress

Compaction occurs when the stress exerted on a rock increases, and the response in a compressible rock is a reduction in porosity. This mechanical porosity reduction involves fluid expulsion from the pore system. Shales have a lot of porosity to lose and fluid to expel. If the fluid cannot escape to balance the stress a higher porosity is retained the rock is overpressured. Hence the use of seismic velocity for pore pressure prediction is focussed on an interpretation of velocity as a proxy for porosity, with comparison between the actual and expected interval velocity on the "normal compaction curve". Pressure in the shales can be quantified exploiting the relationship between total stress (normally vertical stress tied to the estimation of the overburden) and vertical effective stress based on the interval velocity (porosity) comparison. The broad assumptions in using seismic data for pore pressure prediction at an undrilled location are: (1) rock is dominated by shale; (2) porosity change has been governed by mechanical compaction only; (3) seismic velocities have been picked at sufficient density; (4) an appropriate normal compaction curve is available. Calibration of the results is best accomplished from nearby wells where there are direct reservoir pressures in relatively low volume, shale-encased reservoirs in approximate equilibrium with the shale's pressures. These conditions are classically met in Tertiary deltas such as the Nile, Niger and Mississippi.

Where does the seismic method have limitations and/or not work as a technique?

Non-clastic rocks, such as carbonates and evaporites, are not suitable candidates for pore pressure prediction as they do not exhibit recognisable relationships between stress and porosity. At elevated temperatures mineralogical change and other rock property modifications with potential to strengthen and/or weaken the shales as temperatures rise. At temperatures above about 100 to 120^{o}C (as a general guideline), corresponding to depths of approximately 2.5 to 4.0 km in most basins, shale rock properties become strongly influenced by diagenetic reactions in shales. Further at these elevated temperatures additional overpressure may be created by a variety of processes (e.g. oil to gas cracking, dehydration processes and framework collapse) taking the rock further from the original relationship between expected and actual porosity from which pressure is estimated/predicted.

What do we do when seismic does not offer a solution?

There are techniques such as the Bowers Unloading model to handle elastic response in shales during "unloading" (decreasing vertical effective stress) but rarely do we establish that there is pure unloading in areas of high pore pressure. Experience worldwide shows a tendency for increase in density associated with mineralogical or textural changes in the shales, and a velocity response which is poorly constrained in terms of vertical effective stress. Whilst it is normal to process the data for pore pressure prediction in the usual way Ikon GeoPressure has developed a geological-based method to estimate the magnitude of overpressure created during vertical loading. The method relies on a relationship between age, depth, vertical loading rate and vertical effective stress, and predicts the pressure profile for a continuous column of shales, deposited under constantly increasing load. As this method is independent of velocity, it is a suitable method at elevated temperatures (with some restrictions depending on geological history) to create a satisfactory pore pressure prediction.

Case Study

A well was targeted at Miocene shales and associated reservoirs with a normally pressured, sand-rich, delta-top sequence almost 4.0 km thick, and at temperatures approaching 140^{o}C. The pre-drill prediction was based on seismic velocity alone. The interval velocities in this deep section are in the region of 4200 m/sec, which when using classical rock properties and global shale normal compaction trends predicts up to 17.0 MPa overpressure when using realistic normal compaction curves for standard shales. The expected, pre-drill overpressure in this section was 17.0 MPa (Figure 1). When the well was drilled problems were encountered on account of severe under-prediction. Subsequent analysis of this well has revealed shales with densities in the region 2.6 to 2.65 g/cc, indicative of porosities on the order of 5.0%. Using the geological model applied to the well data (and seismic) gives an overpressure prediction on the order of 50.0 to 55.0 MPa. Subsequent deep drilling has since revealed a maximum overpressure of 51.5 MPa at the base of a sharp pressure transition zone. The measured overpressure falls within the prediction using a geological model. The ultra-high densities indicate very low porosity which is not consistent with such overpressure. Seismic velocities do not relate directly to vertical effective stress and the geological approach is a more useful prediction for well planning than the use of rock properties alone.

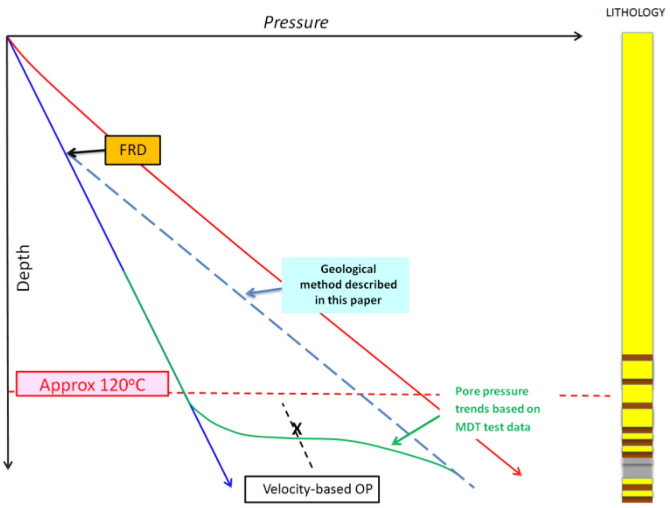

Figure 1 *Schematic pressure-depth plot for a well drilled in a deltaic environment with shallow, normal pressure sandstones and a sharp pressure transition zone. The standard prediction method based on velocities severely under-predicts the actual pressures (black dashed line), which are captured at these depths in shales by a geological model approach (blue dashed line).*

Conclusion

Seismic interval velocities and other rock properties cannot be used with traditional vertical effective stress relationships to predict pore pressure when temperatures exceed about 120^{o}C. An alternative geological-model approach can deliver more accurate predictions in many circumstances. In all cases understanding the geological setting and history is key to successful predictions, and provides solutions when disequilibrium compaction is not the only cause of overpressure.