Producing pore pressure profiles based on theoretical models in un-drilled deep-water frontier basins e.g. Labrador

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Introduction

World-wide, prospectivity has been proven in deep-water and discoveries made. Examples include Gulf of Mexico and West Africa. A frequent problem remains however, that is, these new plays have little if any well calibration therefore making assessment of risk on all levels, problematic.

A classic example is offshore Labrador where there are a number of wells drilled to-date on the shelf, in a series of basins such as Saglek and Hopedale, and a proven hydrocarbon system is present, however, there is no well penetration in deep-water. Recent seismic data has highlighted the presence of deep-sea fan complexes in this deep-water that by analogue with similar features in other basins (Lower Tertiary, Wilcox in the Gulf of Mexico, the Nise Formation in the Vøring Basin) are petroliferous so reservoirs are likely present. Also by analogue, deep-water environments are shale-prone (Figure 1) lithologies and therefore stratigraphic traps can be expected i.e. reservoirs encased in thick shales. The use of analogues for Labrador was highlighted in a recent conference paper by Green et al. (2013).

Once a prospect has been identified in the deep-water, the next stage is to de-risk this. One of the key components of this process is to use knowledge of the pressure regime to ascertain (a) the risk of top seal integrity from mechanical seal risking and (b) the drilling window(the fracture pressure minus the pore pressure), if this is too narrow then potentially a prospect is too risky/expensive to drill. Without any well calibration to estimate the likely pressure regime, (a) and (b) become very difficult and/or inaccurate.

To help reduce the risk in these unexplored environments we present in this paper several approaches that can be adopted to model pore pressure in deep-water settings, not just in Labrador, but globally. This theoretical or "geological modelling" approach can then be used to sense-check the pore pressure interpretation from seismic velocity.

Approach

There are two principle data types available for predicting the magnitude of shale pore pressure in frontier areas; seismic interval velocities and geological modelling. Seismic data allow for the quantification of the interval velocities but still require a normal compaction trend (or "NCT") from which pore pressure magnitudes can be generated. Geological modelling links the expected facies, i.e. marine shales or basin-floor sands, and structure, based on seismic reflection interpretation, to the expected behaviour of pore pressure within each package.

For shales, the technique highlighted here is termed the Swarbrick or Fluid Retention Depth (or "FRD") model. This based is based on several papers originally proposed by Swarbrick et al. (2002) and more recently Swarbrick (2012) which refined the approach with a larger dataset. All data are of Tertiary age thus the technique is only suggested to be applicable to Base Tertiary. The technique is based on using the rate of sedimentation (from seismic markers) and the shale-type i.e. clay or silt rich (from the facies model), linked together via an empirical dataset to estimate the depth below sea-floor at which overpressure begin to build parallel to the overburden; this is termed the FRD.

In new areas if a key marker, i.e. Base Tertiary (Top Markland in Labrador), can be identified from seismic at a new deep-water prospect location such as the one shown in Figure 1 ("Type Pressure Profile 2" or "TPP 2") then the sedimentation rate for that prospect can be estimated. Note that the sedimentation rate is calculated on the compacted thickness following the work by Swarbrick et al. (2002). Once the sedimentation rate is known, the dataset from Swarbrick (2012) can be used to estimate the FRD simply by reading off value(s) from the key chart.

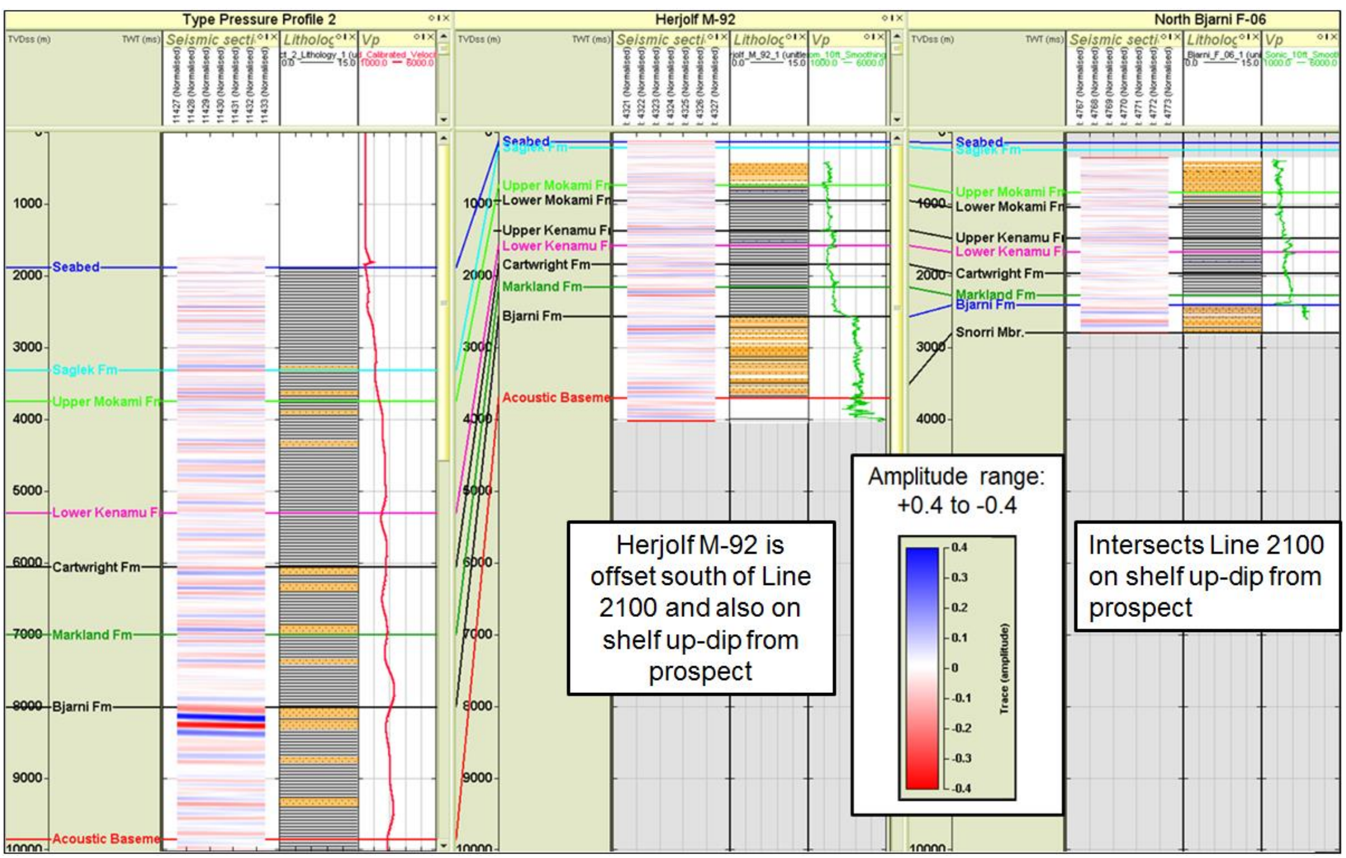

Figure 1 Reflectivity with interpreted lithology and extracted velocity for the shale-rich, deep-water TPP 2 and shallow water sand-prone offset wells North Bjami F06 and Herjolf M-92.

To predict the likely pressure regimes in any deep-water reservoirs, the approach is to use analogues from global datasets. In summary, where the net to gross is low as in the case of mud-rich fans, thin isolated reservoirs are developed. As these are low volume, their pressures are influenced by the encasing shale lithology, leading to high pore pressures (e.g. Lange Formation, Mid-Norway; Akata Formation Niger Delta). By way of contrast, where net to gross is high as in the case of sand-rich or amalgamated fans, single thick sand reservoirs are present (e.g. Nise Formation, Mid-Norway; Agbada Formation, Niger Delta; Wilcox Formation, Gulf of Mexico). These sands can drain pressure towards the onshore via feeder channels. In this case, the shales encasing the sands are more highly overpressured and the sands become pressure sinks. The mixed-sand-mud case leads to thick sands that have the ability to be variably drained, i.e. certain portions of the fan can be normally pressured whereas others are at shale pressure.

	Environment	**Deep-Water**	
	Case	**Lower**	**Upper**
Formation	Saglek	Connected	Connected
	Upper Mokami	Connected	Isolated
	Lower Mokami	Isolated	Isolated
	Upper Kenamu	Isolated	Isolated
	Lower Kenamu	Isolated	Isolated
	Cartwright	Connected	Isolated
	Markland (Freydis Mbr)	Isolated	Isolated
	Bjarni	Connected	Connected

Figure 2 Estimated connectivity for deep-water sands of various stratigraphic ages in the Labrador region based on global analogue. *Connected = sand drained. *Isolated = sand in equilibrium with shale. Lower and upper refer to uncertainty

Evidence from current well penetrations, Labrador

The only truely deep-water wells in Labrador are located in the Orphan Basin. In other basins such as Saglek and Hopedale water depths are shallow. There is little direct evidence for high pore pressure at depth in any of these wells at current drilling depths (often as the sand content is high), however, in Blue H-28 (Orphan Basin) and Pothurst P-19 (shallow water; Saglek Basin) kicks at depth suggest overpressures of 26850 kPa and 34250 kPa respectively. These kicks are associated with permeable units in thick shale packages. These are the type of packages observed in the deep-water from seismic data.

Using the age of the kick in the Pothurst P-19 well (Lower Tertiary), its depth and the Swarbrick (FRD) approach provides a consistent match. The kick in Blue H-28 is Middle-Cretaceous but was taken close to the Base Tertiary unconformity hence has also been tested using this approach with success.

This evidence suggests that the geological modelling approach has validity in the deep-water regions of Labrador to model shale pressure, at least to Top Markland Formation. Of note is that the geological modelling gives a theoretical, maximum shale pressure assuming minimal pressure dissipation. Any unconformities for instance will reduce shale pressure, however, deep-water environments tend to be less affected by uplift etc.

Conclusions

Deep-water settings generally have a series of common features. These features include being shale-prone, having less faulting and less uplift. Evidence for additional mechanisms of overpressure generation rather than disequilibrium compaction is less. All these features all impact the pressure regime, for instance, likely pore pressure regimes in the deep-water are overburden-parallel.

Seismic data from Nalcor Energy has resulted in the identification of new, potentially oil bearing, basins in the deep-water Labrador region. This seismic data has also revealed the similarity between Labrador and basins such as the Vøring Basin in Mid-Norway. In this basin, shale lithology dominate and many reservoirs form stratigraphic traps, where the sands have the same pressure as the shales. Regional pressure trends can be defined. Deep-sea fans are also visible on the seismic. In the case of the latter, the feeder channel acts as a pressure release value allowing the sands to de-pressurize, creating a mobile aquifer. Similar deep-water hydrodynamic fan systems are reported in the Tertiary of the Central North Sea (Dennis et al, 2005), although current water depths are shallow. Here, hydrodynamic trapping, results in tilted fluid contacts. Enhanced seal capacity is also a feature as is primary migration out of source rocks.

The Swarbrick or “FRD” technique is a simple yet powerful method to estimate the likely magnitude of pore pressure in shales within deep-water frontier basins. The distribution of these shales and their associated reservoirs can be derived from use of seismic reflectivity data. The method can allow for operators to recognize high overpressure early in the planning cycle to drill a new well guiding both operations and engineering decisions. If seismic velocities are present then the geologically modelling of discussed in this paper can be used to sense-check a pore pressure estimate from seismic

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