Introduction

The Labrador Shelf extends from the Davis Strait in the north through the Saglek Basin and down to the Hopedale Basin in the south, along the NE margin of East Canada. The majority of wells have been drilled in the Hopedale Basin. The water depths of wells drilled to-date are typically 100-200m, with only rare wells such as Hopedale E-33 and South Labrador N-79 drilled in water depths > 500m. Mud-weights used in many of the Labrador wells are low; however, there are occurrences in wells such as Pothurst P-19 of very high kicks taken, implying under-balanced drilling and highly pressured shales at depth. These highly overpressured shales (and associated reservoirs) are likely a feature of the deep-water where they will present a drilling hazard, as in similar deep-water settings worldwide.

To-date, all drilling has been therefore on the Shelf, whereas recent shooting of seismic in offshore Labrador has suggested new interest in the deep-water. Following the announcement on September 13, 2011 to shoot large-scale multi-client 2D seismic survey of offshore Newfoundland and Labrador into the deep water, understanding the shelf-to-deep water transition becomes even more crucial. In the absence of well penetrations in the deep-water, the use of analogues becomes vital.

Therefore, this paper will summarise the experiences for pressure on the Shelf to-date and use worldwide analogues from Flemish Pass, West Greenland, Scotian Shelf and Mid-Norway to understand the likely pressure regimes in this exciting, new deep-water play.

Analogue Review: Mid-Norway

The Halten Terrace shelf area has over 150 wells that have been drilled approximately. The targets here are predominantly the Jurassic reservoirs that form the Kristin and Smorbukk accumulations for instance. These reservoirs are often heavily fault compartmentalized and as such, although stratigraphy older, are similar to the Lower to Mid-Cretaceous faulted syn-rift sediments of the Bjarni Formation in Labrador. In Mid-Norway these faults define a series of structurally-bound pressure cells. These reservoirs are overlain in Mid-Norway by the argillaceous Lange Formation, an equivalent of the Markland Formation (Figure 1). These shales are typically > 100°C in Mid-Norway and as such have been affected by chemical compaction, influencing the pressure regime.

![Figure 1 Stratigraphic column of the Labrador Shelf highlighting the dominant lithofacies and major unconformities.](image-url)
More recently, the deep-water Mid-Norway Voring Basin has seen exploration focus, with water depths of up to 1.5km (Figure 2). Here, the sediments are typically Cretaceous and Tertiary in age and include formations such as the Nise and Egga Sandstone Formation sands and the Brygge and Kai shales. Although some rifting is present in the Upper Cretaceous, these sediments are largely un-faulted and correspond to the post-rift Mokami Formation shales and Cartwright sands of the Labrador region. The Nise Formation consists of deep-sea fan deposits; these fans are locally amalgamated such that the overpressures in the aquifer are the same or similar, and are considered to form part of a hydrodynamic system, where pressures are escaping laterally, despite the deep burial depth. In more stratigraphically isolated parts of the fans, overpressures can be similar to the encasing shale pressures. These differential pressures enhanced seal capacity and establish the opportunity for hydrodynamic trapping; similar deep-water fan complexes are observed in the recently shot seismic in the Labrador area. The Base Tertiary Ormen Lange Field reservoir is hydrodynamic, with a tilted contact, affecting estimates of reserves and development of the field.

Also recognized from the recent seismic is a variation in the depth of Base Tertiary; this will impact on the degree of loading produced by the recent burial and influence pressures at depth. Simple relationships based on rates of sedimentation (Swarbrick et al., 2002) have been used successfully in Basins in the Tertiary North Sea and Jeanne d’Arc to predict theoretical shale pressures that match Kicks taken in wells. This approach can be potentially used in the Labrador Basins to similar give an indication of shale pressures, based on picking the seismic Base Tertiary reflector.

![Figure 2 Schematic based on a 2D seismic line showing main stratigraphic and structural relationships West/East from Voring Basin (deep-water) to Nordland Ridge, Halten Terrace, Shelf](image)

**Analogue Review: West Greenland**

The West Greenland area is not data-rich as less than 10 wells have been drilled, however the range in water depths may make this study very useful as an analogue with the Labrador Shelf in terms of drawing comparisons between the shelf and deep-water. For instance wells such as Kangamuit-1, Ikermuit-1 and Hellefisk-1 are shallow water and have very different pressures – based on the presence of thick shale packages and thick depositional units. Quelleq-1 which is a deep-water well has deep reservoirs that are normally pressured. If seismically resolvable, similar units in Labrador may help identify the likely pressure regime. Some wells have > 1.0 km of water and are laterally...
drained at depth – implying that the reservoirs in the deep water can communicate to the shore/seabed. The Greenland province is heavily influence by volcanics, both intrusive and extrusive so a parallel would need to be drawn with the Labrador shelf as to our knowledge, few volcanics are present – the volcanic influence sealing capacity, although often they are fractured allowing pressure communication, as well as affecting overburden weight. The G-37 well was featured in both the Greenland and this study so may make a useful well-tie between the areas. Seismic velocity data was used to generate pressure profiles for prospects – as in many of the recent seismic projects in East Canada, the seismic gave variable results – this was due to a combination of issues regarding the data itself i.e. acquisition, sampling, processing as well as “geological” issues such as non-shale lithologies, cemented rocks, lack of a porosity/effective stress relationship. Generally, the seismic data was useful in the Tertiary in all areas. The seismic results were constrained by use of an independent geological model based on rates of sedimentation (Swarbrick et al, 2002).

Analogue Review: Scotian Shelf

The Scotian Basin is a passive margin and has proven petroleum systems with past production from the Cohasset-Panuke oil fields, ongoing gas production from the Sable Project and the undeveloped Deep Panuke gas field, all on the shallow Scotian Shelf. However, exploration success has been variable, for instance, between 1970 and 2002, of the 21 exploration wells drilled on the Jurassic Abenaki carbonate platform offshore Nova Scotia, there has been only one significant discovery and the others, dry. Some of these wells such as Abenaki J-56 were drilled on the flanks of salt diapirs, demonstrating the complex range of tectonic styles and lithologies in the Basin.

Recently, exploration focus shifted to the deep-water Scotian Slope because of the impressive hydrocarbon discoveries and high success rates in deepwater of other circum-Atlantic basins such as the Gulf of Mexico, offshore Brazil and West Africa, and recently Northwest Africa (Mauritania). Between 2002 and 2004 industry drilled seven deep-water wells on the Scotian Slope with one gas discovery (Annapolis), one gas show (Newburn) and four dry wells (Balvenie, Crimson, Weymouth and Torbrook). The seventh well, Annapolis B-24, was a precursor to the discovery well that was abandoned due to a shallow gas kick (Figure 2). Four previous wells were drilled between 1982-1986 that were dry and abandoned e.g. Shubenacadie, Shelburne, Evangeline and Tantallon.

The Scotian Slope is 850km long and has an area of 80,000 km2 containing only ten wells in the deep-water. The reservoir targets are deep-water submarine fan sands that are transported from the shelf and deposited on the slope coeval with major changes in relative sea level (low-stands). This process has created erosional submarine canyons which act as conduits for the transport of vast quantities of sediments. Discovered gas in the Annapolis and Newburn wells confirms an active slope petroleum system. Annapolis found a cumulative 27m of generally thin gas-bearing sands, and Newburn encountered several thin (2-3m) gas-bearing sands. Furthermore, many of the gas-bearing sands were encountered unexpectedly below 5000m with average porosities from 14-19% which expands the zone of prospectivity.

The cost of recent deep-water drilling off Nova Scotia has been exacerbated by equipment difficulties and incorrect prediction of the geopressure regime. Figure 2 displays a correlation of four deep-water Scotian Slope wells. These wells penetrate dominantly shale-rich interval, with thin reservoirs. The sonic data (blue trace) in wells like Annapolis G-24 show significant straightening, approaching a constant value of Interval Travel Time, and suggestive of high overpressures.
Figure 2 Correlation of 4 deep-water Scotian Slope wells. Log traces are green (GR) and blue sonic, slow to the left). Note shale-dominated lithology and thick salt in Weymouth A-45.

Conclusions

The deep-water setting in Labrador is an exciting frontier area. The well control to-date exists only on the Shelf where kick data indicate the potential for high pore pressure. In the deep-water where new seismic has been shot, this overpressure is likely also a phenomena. Studies of analogue regions such as Mid-Norway are therefore vital in terms of reducing risk in drilling future wildcat wells in this new play. The pressure regime can also control the distribution of hydrocarbons via migration and presence of seals therefore integrating an understanding from other basins will identify and high grade acreage in Labrador.