TANTALLON M-41 WELL

The Shell-PCI Tantallon M-41 (1986) was the last (and thus most recent) well drilled in the eastern Scotian Basin region. It was the first to be drilled in deep water and tested a large, gravity-driven low relief rollover anticline where it failed to encounter significant hydrocarbons and sand developments. It remains the only well drilled in the Call region, though the 12 previously noted wells were drilled in shallow water outside of and paralleling its northern boundary.

BACKGROUND & OBJECTIVES

Shell's Tantallon M-41 well is located south of the Banquereau Bank outboard of several shelf wells on the east side of the Late Jurassic to Late Cretaceous Sable delta complex. The structural anomaly is a large, low-relief rollover anticline on the downside of a down-to-basin listric fault based on 2D seismic from the early- to mid-1980's (Shell, 1986). The structure was presumed to be well defined though lacking the degree of fault offset observed at the Evangeline H-98 well located on the west-central part of the Scotian Slope. The target objectives were outer deltaic/shallow marine sandstones, and equivalent slope turbidite sands of the Early Cretaceous upper Missisauga and lower Logan Canyon formations (Cree Member) (Figures 1 and 2). It was spudded in 1540m of water on February 15, 1986 by the Sedco 709 semi-submersible rig and drilled to a TD of 5602 m with approximately 4038 m of Tertiary and Cretaceous sediments penetrated (RT=24.3 m). The rig was released on April 18th, 1986. It

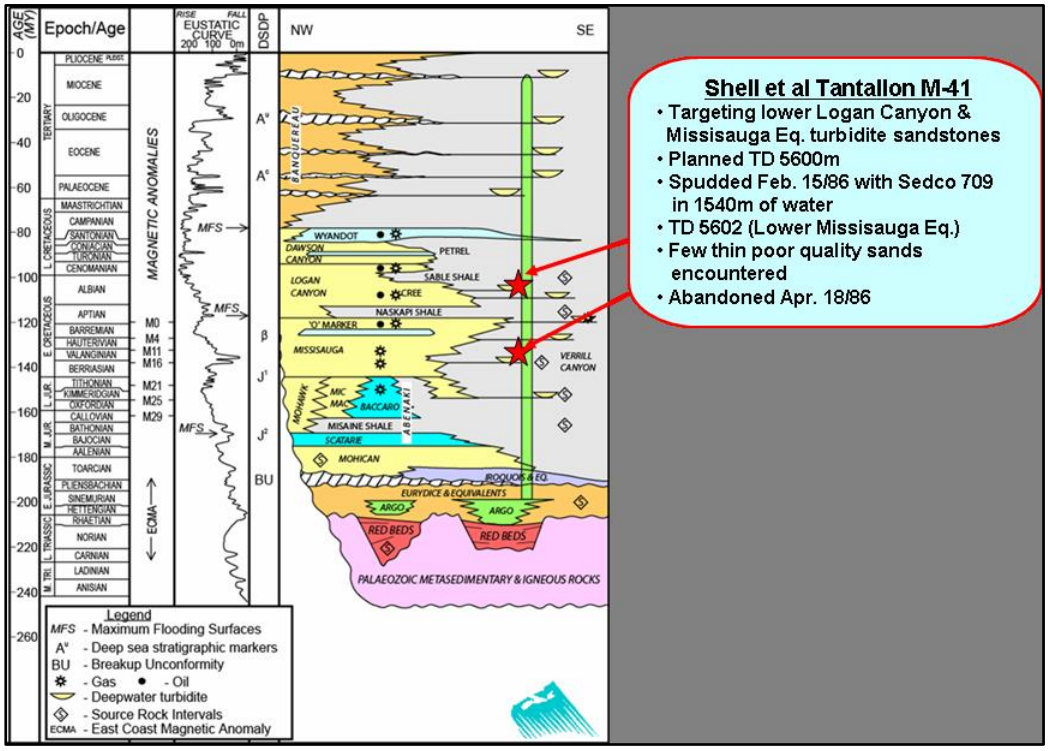

Figure 1. *Regional stratigraphic chart showing target intervals for Shell et al. Tantallon M-41.*

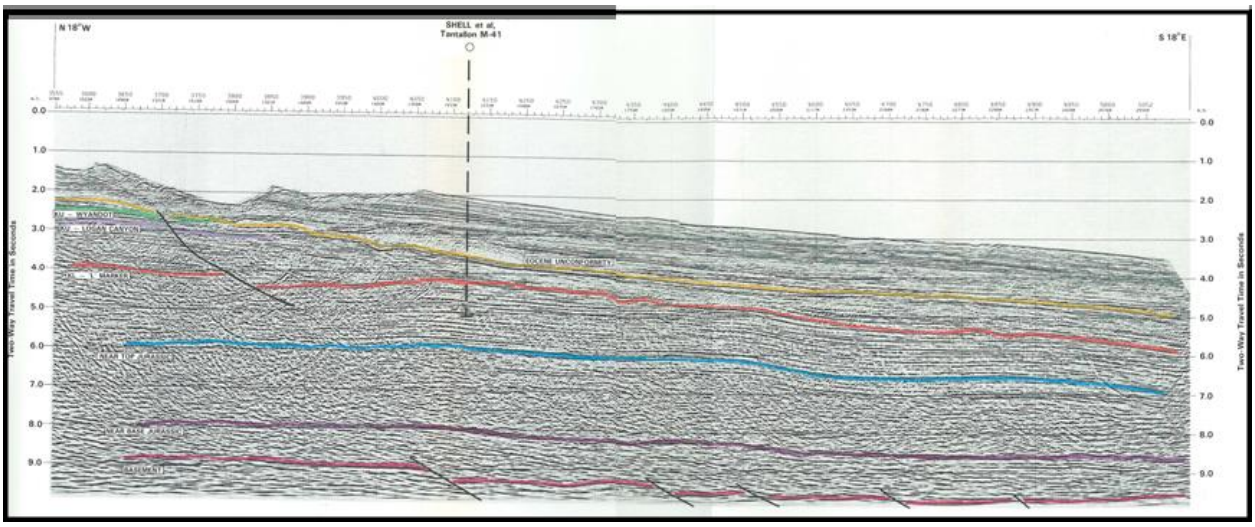

***Figure 2**. Pre-drill 2D seismic dip profile used to define the Tantallon M-41 structure and target interval defined by the Cretaceous L-Marker (red horizon) (Shell, 1986).*

DRILLING RESULTS

Tantallon M-41 was drilled vertically to a TD of 5602 m (5600 m planned TD) in the lower Missisauga formation distal equivalent section (late Valanginian). The lower Logan Canyon and Missisauga target intervals consisted primarily of shale with a few generally thin, poor quality sandstones and siltstones. No gas kicks or abnormal pressures were encountered in the well. The few zones of interest are described below in descending order (Figure 3).

Two Miocene age sands were encountered in the well. The upper sand at 2416 m is approximately 10 m thick and is poorly consolidated fine to coarse grained with sub-angular, moderately sorted sand grains (Figure 4). Since it is poorly consolidated, it washed out during drilling causing porosity readings across the zone to be unreliable. Although this data is questionable, sand resistivity is very low (0.7 ohms) and no mud-gas shows were detected during drilling indicating the zone is likely wet. The other Miocene sand was penetrated at 2484 m and is about 12m thick. It is described as a poorly consolidated fine to medium grained, subangular, moderately sorted sandstone. This zone is also washed out affecting the porosity logs; however the low resistivity readings suggest that this sand too is porous and wet.

At 5207 m, a 14m thick very fine to fine grained, sub-angular, well sorted sandstone with a fining-upward gamma ray profile was encountered in the Late Hauterivian (upper Missisauga Formation equivalent). With the exception of two thin (0.5 m) intervals with 11% porosity, (i.e., a total of 1m with porosity >10%) the remaining sand was tight with porosity <10% (Figure 5). With calculated water saturations (Sw) of approximately 60%, it is possible that the sand has some gas charge. However, the low porosities on the sand (majority <10%) makes the Sw calculation more interpretive.

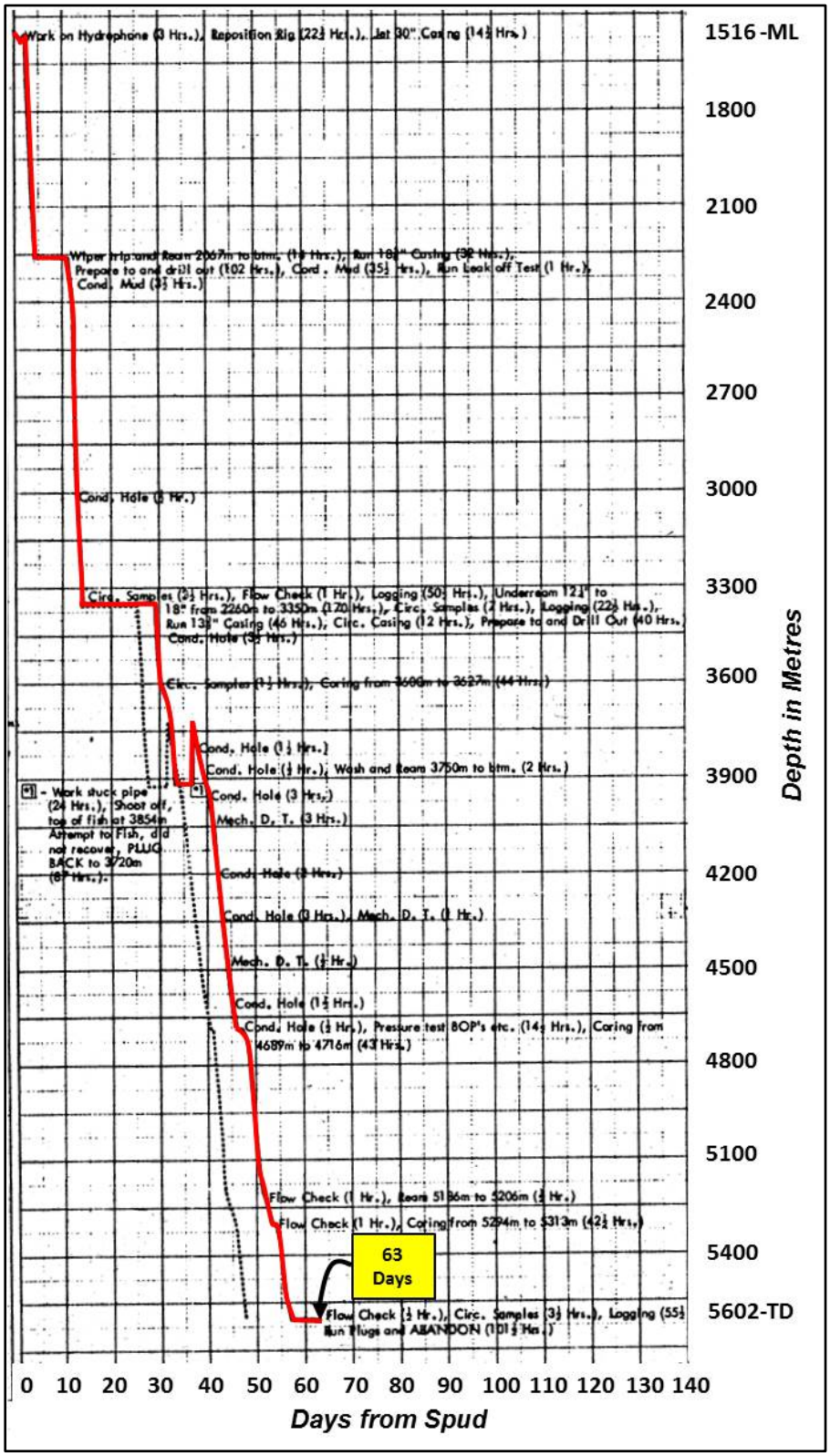

Figure 3. *Tantallon M-41 drilling curve (modified after Shell, 1986).*

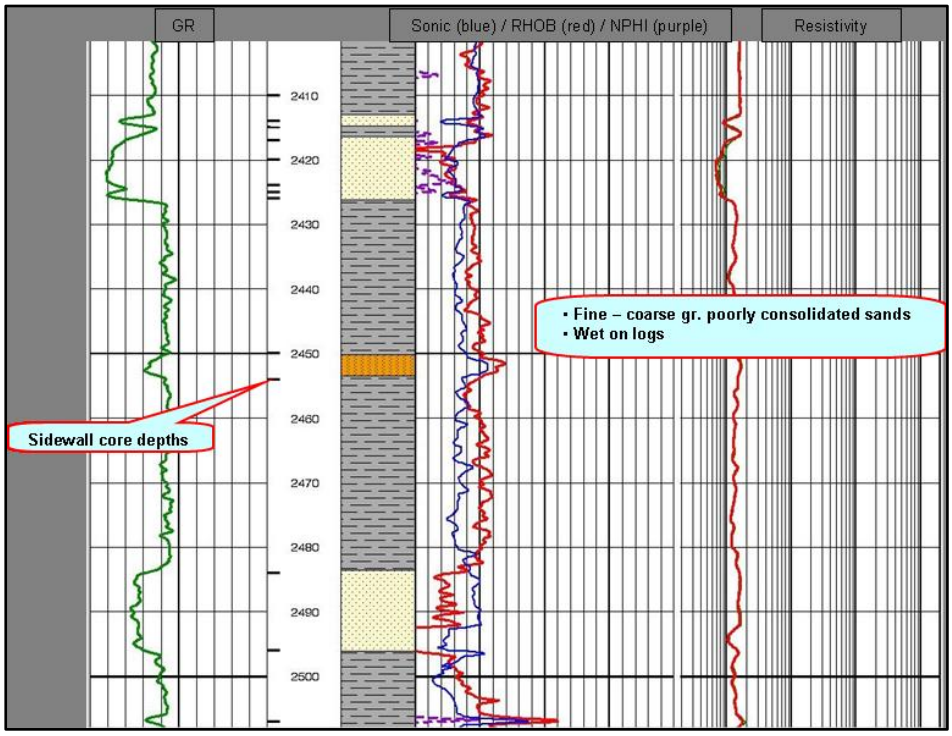

Figure 4. *Tantallon M-41: Well logs from the Miocene Sand interval.*

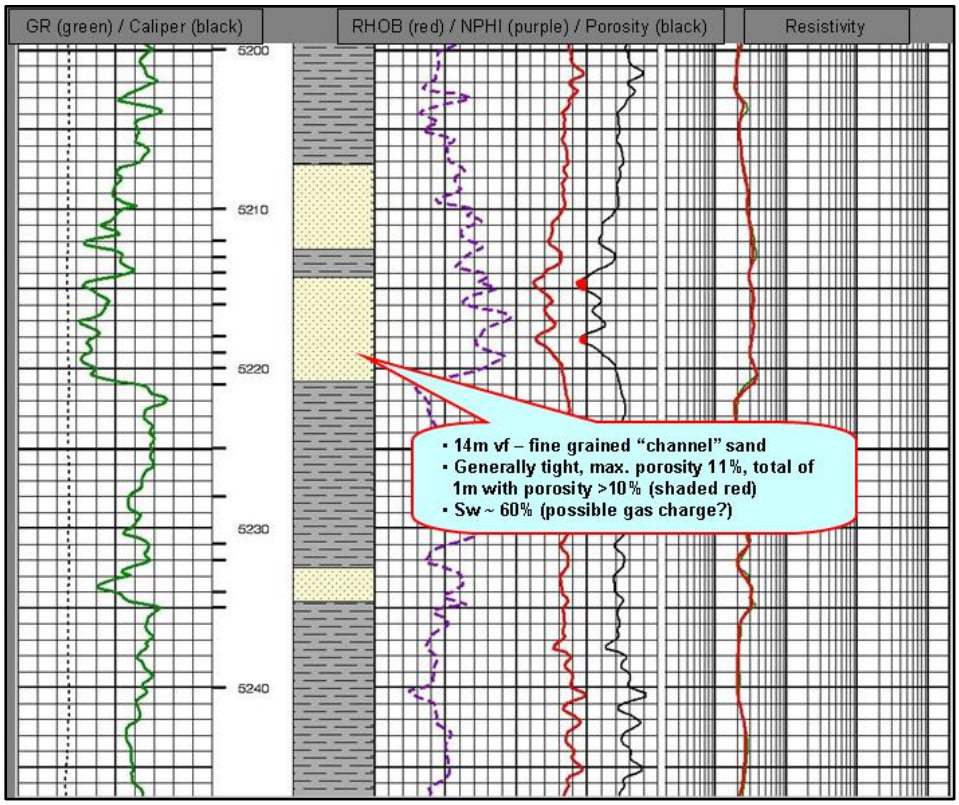

Figure 5. *Tantallon M-41: Well logs from Late Hauterivian sands (Missisauga Fm. equivalent).*

CONVENTIONAL CORES

Over 300 percussion sidewall cores, and three conventional cores, were cut in the well with the latter recovered from shale-dominated intervals containing only thin minor sandstones.

Core #1: 3600.0 – 3627.0 m, Rec. 23.5 m

This core was cut in Albian age sediments and consists primarily of grey calcareous partially bioturbated shale (Figure 6). Thin stringers of calcareous silt and very fine-grained sandstone lamina are occasionally present. Paleowater depths from biostratigraphic analysis indicate the water depths ranged from 100–1000 m which suggests the sediments may be prodelta shales or upper slope deposits (Robertson Research, 2000a).

Figure 6. *Tantallon M-41: Representative section of Core #1 (3619.3 – 3622.0 m).*

Core #2: 4689.0 – 4717.0 m, Rec. 28.0 m

Core #2 was cut in Early Aptian sediments and consists primarily of dark grey calcareous shale with minor siltstone. A portion of the core is shown in Figure 7; note the 0.5 m interval of siltstone with shale laminae present on the far right of the photograph. Biostratigraphic analysis suggests these sediments were deposited in 100–200 m of water in an outer shelf setting (prodelta shales and siltstones?) (Robertson Research, 2000a).

Figure 7. *Tantallon M-41: Representative section of Core #2 (4689.0 – 4691.5 m).*

Core #3: 5294.0 – 5313.0 m, Rec. 16.3 m

Core #3 was cut in Hauterivian age dark grey calcareous shale with thin calcareous siltstone and very fine-grained sandstone laminae. A portion of the core is shown in Figure 8. Biostratigraphic analysis interprets these sediments as being deposited in an outer shelf setting in a water depth range of 100–200 m (Robertson Research, 2000a). The “thickest” sandstone units, recovered in all three Tantallon cores, are shown in Figure 9 which is a close-up of a portion of this core (~5300m). At the bottom are two very fine-grained sandstones with that on the lower right are approximately 3cm thick.

Figure 8. *Tantallon M-41: Representative section of Core #3 (5303.1 – 5307.0 m).*

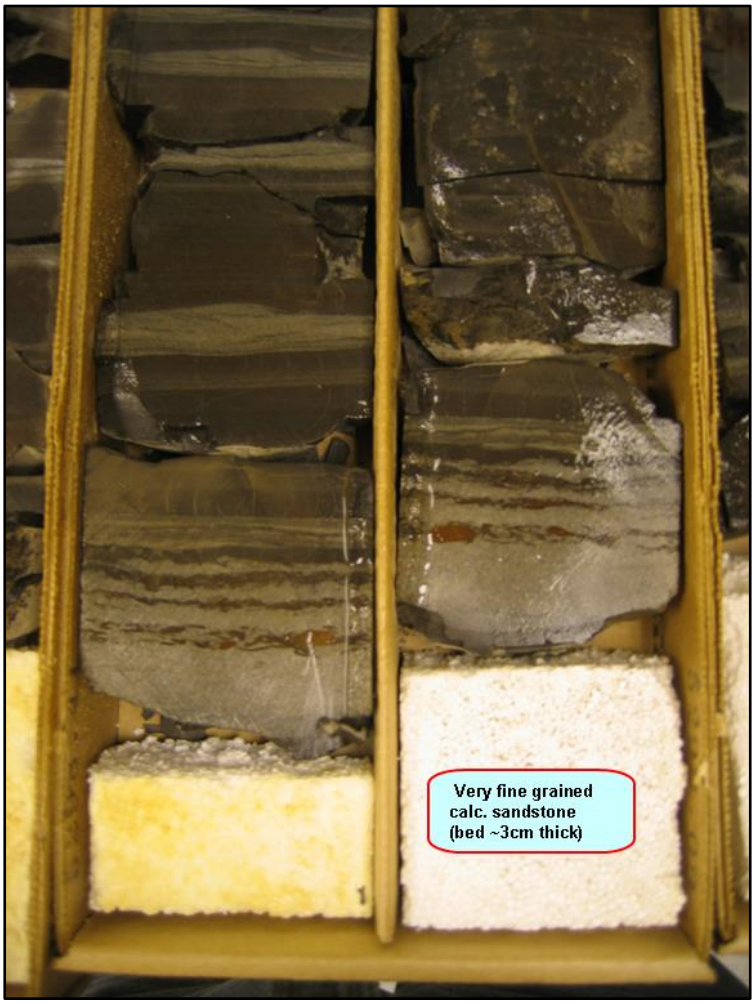

Figure 9. *Tantallon M-41: Enlarged view of sandy intervals in Core #3 at ~5300 m.*

Recent work by Piper *et al.* (2010) re-assessed the Tantallon well cores and their interpreted sedimentology. The Early to Late Cretaceous (Berriasian-Valanginian to Aptian-Albian) setting for the Tantallon area is interpreted as a subsiding outer shelf platform later overlain with shelf margin delta complexes. These deltas, some with clinoforms up to 300 metres high, prograded tens of kilometers across a wide, deep outer shelf platform that was subsiding and increasingly unstable due to the presence of deep underlying salt. A revised interpretation is provided in the "Eastern Scotian Slope Regional Interpretation" part of this Call package and detailed within.

Cores #1 (Logan Canyon Fm.) and #2 (Upper Missisauga Fm.) are interpreted to represent pro-delta deposition at the toe of delta complex clinoforms. They contain debris flow deposits with allochthonous clasts and sediments from shallow water deltaic facies. Core #3 (Middle Missisauga Fm.) sampled thin-bedded sandstone turbidites interpreted as overbank deposits adjacent to deep, wide channels. The M-41 well is shown to have been located on a paleo-high bounded by erosional channel-like features. This supports the interpretation that coarse grain sediments by-passed this part of the slope and were delivered into deeper water.

STRUCTURAL INTERPRETATION

The Tantallon structure was originally defined by an approximate Middle Cretaceous horizon (Shell's L-Marker) as observed in the time map (Figure 10) and cross section (Figure 11). Approximately 300 m of closure is calculated for this and underlying strata, though none is present in the overlying Santonian-Maastrichtian Wyandot formation.

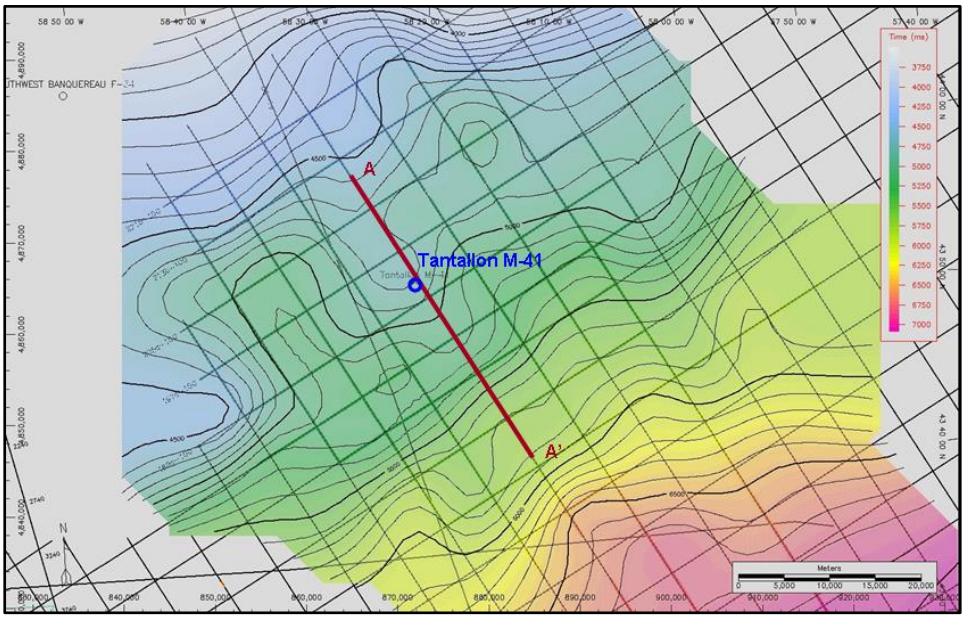

Figure 10. *Time structure map defining the Tantallon structure based on regional 2D seismic data, with profile A-A' shown in Fig. 4-11 (Kidston et al. 2007).*

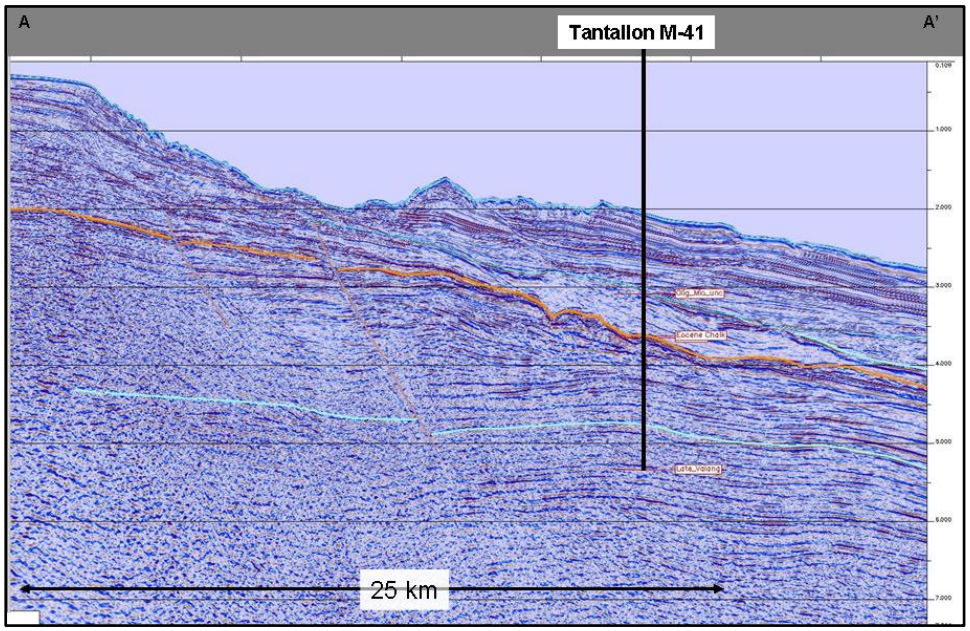

Figure 11. *2D seismic dip line through Tantallon M-41 (Kidston et al. 2007).*

Recent regional mapping of the K130 seismic marker (Figure 12, OERA, 2011, Plate 5-3-8b) does not display the deep closure but reveals it as a low saddle between two highs. Tellingly, this saddle area corresponds with a positive relief bathymetric nose, and negative relief embayments for the bounding highs. It therefore appears probable the earlier closure is an artefact of seismic processing.

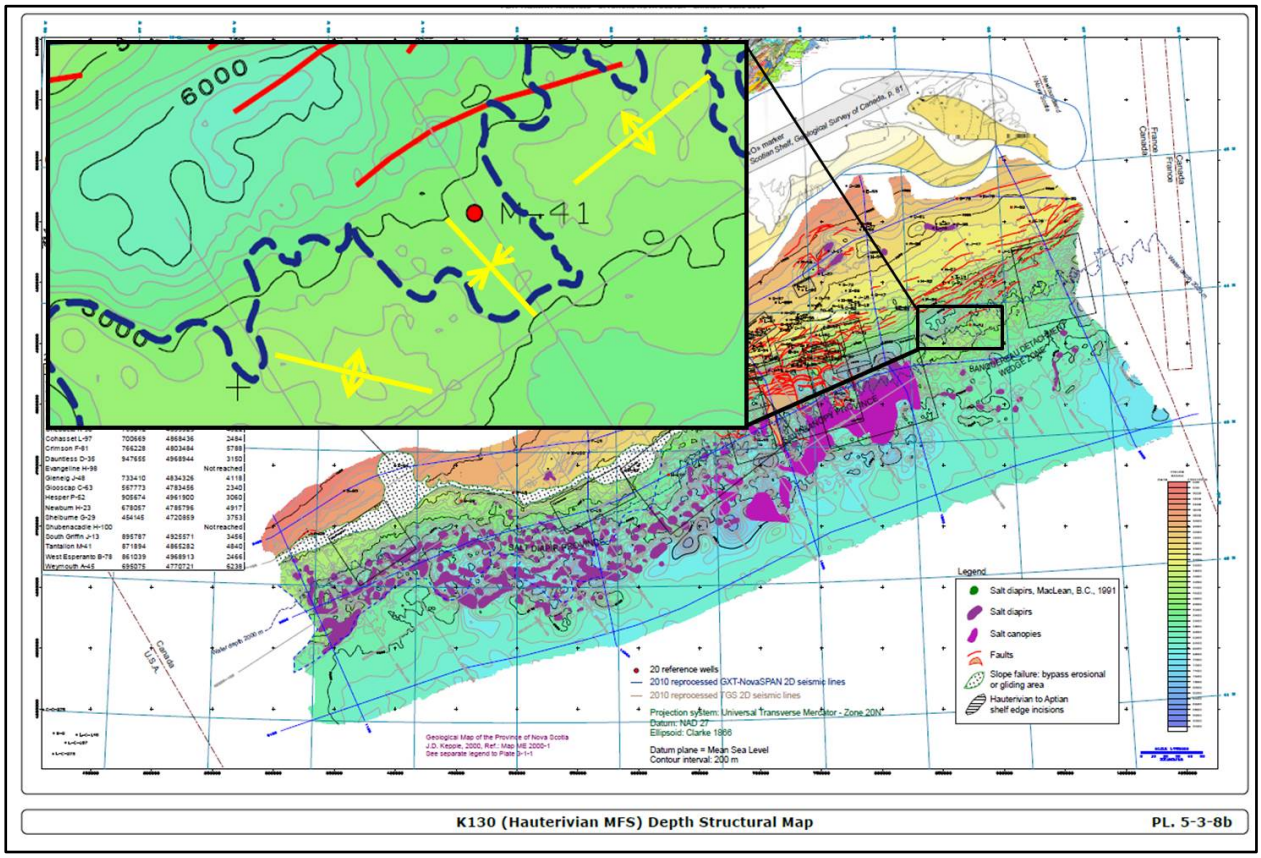

Figure 12. *K130 Hauterivian MFS regional depth structure map. The inset's (50x30 km) 2000 m bathymetric contour (blue dashed line) shows positive bottom relief over the approximate L-Marker low at Tantallon, and negative over the bounding highs (OERA 2011; Plate 5-3-8b).*

BIOSTRATIGRAPHY

The Tantallon M-41 well is the easternmost deep water test in the Sable Basin and to the east of the Sable delta system. For the Robertson Research biostratigraphic study (2000a, 2004), well sampling was initiated within shales and minor siltstones and sandstones in the top Banquereau formation (Pliocene to Late Miocene). This section rests on the ubiquitous Mid Miocene uncomformity that eroded older Miocene to Late Oligocene (Chattian) sediments. The Early Eocene unconformity is also observed representing a time gap of about 5 my. Thick chalks and marls (Wyandot) dominate the top Late Cretaceous interval and rest unconformably on shales and silts of the upper Logan Canyon formation. This Late Campanian to Early Turonian event removed the entire Dawson Canyon equivalent with a resulting 22 My time gap. The Logan Canyon sequence was deposited as an uninterrupted succession of shales (not

calcareous) with minor siltstones. The basal part of the Naskapi member (Logan Canyon) and top-most Missisauga formation are absent in the well (Mid-Late Barremian). The remaining 600m of upper to lower Missisauga shales and minor silts and sands were deposited without any internal erosional events, with the oldest sediments dated as Late Valanginian (Weston et al., 2012).

GEOCHEMISTRY

Information on source rock analysis and maturation / expulsion modelling for this and other wells related to this Call for Bids package can be found in the Call package "Source Rocks & Maturation" section.

PALEOENVIRONMENTS

Paleoenvironmental interpretation for the Tantallon well was made by the Geological Survey of Canada (Thomas, 1991; and Williams, 1992) and later Robertson Research (2000). Only the Tertiary and top Cretaceous section was studied by the GSC. Thomas (1991) based his interpretation on microfossils. Pliocene and Late Miocene sediments (above the Mid Miocene unconformity) were considered to have been deposited in an outer shelf to upper slope setting, with the underlying early Oligocene strata probably laid down on the upper slope. The remaining Eocene to Maastrichtian interval was interpreted as being deposited in outer shelf to upper slope conditions. Williams (1992), based on palynomorphs, concluded that the entire Tertiary succession was deposited mostly in outer shelf to upper slope environments.

A later synthesis by Wade *et al.* (1995) re-evaluated the M-41 well and considered all the Tertiary strata to have been deposited in the outer shelf to upper slope. Study of the well by Robertson Research (2000a) focused only on the Cretaceous section. Cenomanian (Logan Canyon) to latest Aptian were mostly deposited on the outer shelf to upper slope with the Late Aptian (Cree member) restricted to the upper slope. The remaining Early Aptian to Valanginian (Missisauga formation) occupied an outer shelf location with microfossils dominated by allochthonous remains.

Recently, Piper *et al.* (2010) supported this interpretation though cautioned that in this depositional setting careful study of the sediments is required to properly identify the allochthonous nature of shallow water sediments encountered there. A revised interpretation is provided in the "Eastern Scotian Slope Regional Interpretation" part of this Call package and detailed within.

EXPLORATION IMPLICATIONS

Review of the well results indicates that the Missisauga Formation reservoir zone was a subsiding deep water outer shelf platform that was channelized and directing coarse grain sediments further basinward. The well was located on a perceived interchannel high and intersected only thin, overbank turbidite deposits with reservoir sands by-passing this area. Legacy 2D seismic revealed that the Tantallon structure exhibited no growth interval within the target zone. However, new mapping with new regional 2D data reveals that the originally

interpreted positive structural relief was an artefact of the seismic processing. Furthermore, the well's upper slope position is now known to be in a sediment by-pass belt with potential sands existing in deeper water down slope (Deptuck et al., 2014; part of this Call for Bids package).

A technical paper by Goodway et al. (2008) describes an Amplitude Variation with Offset (AVO) and Lambda-Mu-Rho (LMR) analysis conducted over the Stonehouse exploration license held by Encana (EL 2414; January 1, 2002 to December 31, 2007). AVO analysis can be used to detect anomalies due to highly porous hydrocarbon-filled reservoirs, while LMR inversion can provide information about the rock properties of potential reservoirs. Modelled data based on the Annapolis G-24 and Tantallon M-41 wells predicts that high porosity gas sands thicker than 10 m will produce bright AVO class 3 or 4 responses that are clearly distinguishable from high porosity wet sands or low porosity wet or gas sands. The study also points to a significant number of positive Upper Missisauga AVO anomalies within the northern portion of Parcel 2.

REFERENCES

Avery, M.P., 1991
Vitrinite reflectance (Ro) of dispersed organics from Shell Tantallon M-41.
Geological Survey of Canada Atlantic, Open File Report 2381, 15p., Canada-Nova Scotia Offshore Petroleum Board File SR 1991-3.

CNSOPB, 2013
Geological context and parcel prospectivity for Call for Bids NS13-1: Seismic interpretation, source rocks and maturation, exploration history and potential play types of the central and eastern Scotian Shelf.
Canada-Nova Scotia Offshore Petroleum Board Call for Bids NS13-1, 66p.
http://www.callforbids.ca/sites/default/files/inline-pdf/cfb_ns13_summary-final_for_web_2.pdf

Goodway, B., Szelewski, C., Overell, S., Corbett, N., and Skrypnek, T, 2008.
Calibrated AVO and LMR analysis using a new DHI flat-spot AVO class 6 fluid contact to mitigate reservoir risk at Stonehouse, offshore Nova Scotia.
Canadian Society of Exploration Geophysicists Recorder, vol.22, no.8 (October, 2008), p.23-32.

Offshore Energy Technical Research Association (OETR Association), 2011.
Play Fairway Analysis Atlas - Offshore Nova Scotia.
Nova Scotia Department of Energy Report, NSDOE Records Storage File No. 88-11-0004-01, 347p. http://www.novascotiaoffshore.com/analysis

Piper, D.J.W., Noftal, R. and Pe-Piper, G., 2010
Allochthonous prodeltaic sediment facies in the Lower Cretaceous Tantallon M-41 well: Implications for the deep-water Scotian Basin.
American Association of Petroleum Geologists Bulletin, vol.94, no.1, p.87-105.

Robertson Research, 2000
Frontier Reservoirs of the North Atlantic, Report No.EM127.
Canada-Nova Scotia Offshore Petroleum Board File SR 1999-7, report plus enclosures.

Robertson Research, 2000a
Frontier Reservoirs of the North Atlantic, Volume 1, Appendix 1 & Enclosures: Tantallon M-41 - Report No.EM127.
Canada-Nova Scotia Offshore Petroleum Board File SR 1999-7.

Robertson Research, 2004
Nova Scotia Shelf: Biostratigraphic and Sequence Stratigraphic Correlation of the Early Cretaceous Strata in Seven Wells - Report No.6620/lb.
Canada-Nova Scotia Offshore Petroleum Board File SR(E) 2004-1.

Shell Canada Limited, 1986
Well History Report - Shell et al. Tantallon M-41.
Canada-Nova Scotia Offshore Petroleum Board File No. D.293, Report and Appendices plus Enclosures.

Smith, B.M., Makrides, K., Altheim, B. and Kendell, K., 2014
Resource Assessment of Undeveloped Significant Discoveries on the Scotian Shelf.
Canada-Nova Scotia Offshore Petroleum Board, 186p.

Thomas, F.C., 1991
Report on the Cenozoic biostratigraphy (Foraminifera) and depositional environments of the Shell et al. Tantallon M-41 well, Scotian Shelf, from 2265 to 3115 m (top of Cretaceous).
Geological Survey of Canada Atlantic Report No. BAS-PAL.4-91FCT, 6p.

Williams, G.L., 1992
Palynological analysis of the interval 2265-3235 m in Shell Tantallon M-41, Scotian Shelf.
Geological Survey of Canada Atlantic Report No. BAS-PAL.1-92GLW, 6p.