CNSOPB Call for Bids NS21-1 - Southwestern Scotian Margin

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1. Overview

CNSOPB Call for Bids NS21-1 comprises two parcels located on the outer shelf and slope of the lightly explored southwestern Scotian margin. Both parcels are located east of the Georges Bank Prohibition Area and former exploratory permits (Figure 1). Parcel 1 - located north and east of Equinor's Exploration Licences (ELs) 2435 and 2436 - covers 4708 km^2 mainly on the upper continental slope in water depths generally shallower than 2500 m. The landward portion of Parcel 1 extends onto the outer continental shelf where water depths shallow to 125 m. Parcel 2 - located south and east of ELs 2435 and 2436 - covers 5128 km^2, mainly on the mid to lower continental slope in water depths generally ranging from 1700 to 3500 m.

This short report summarizes the geological setting and exploration potential of the two NS21-1 parcels. The reader is referred to Deptuck (2020) and citations therein for a more detailed description of the exploration history, geology and exploration potential in the NS21-1 region. Additional geological information can also be found in Wade and MacLean (1990), Deptuck (2011), Weston et al. (2012), Deptuck et al. (2015), OERA (2015), and Deptuck and Kendell (2017, 2020).

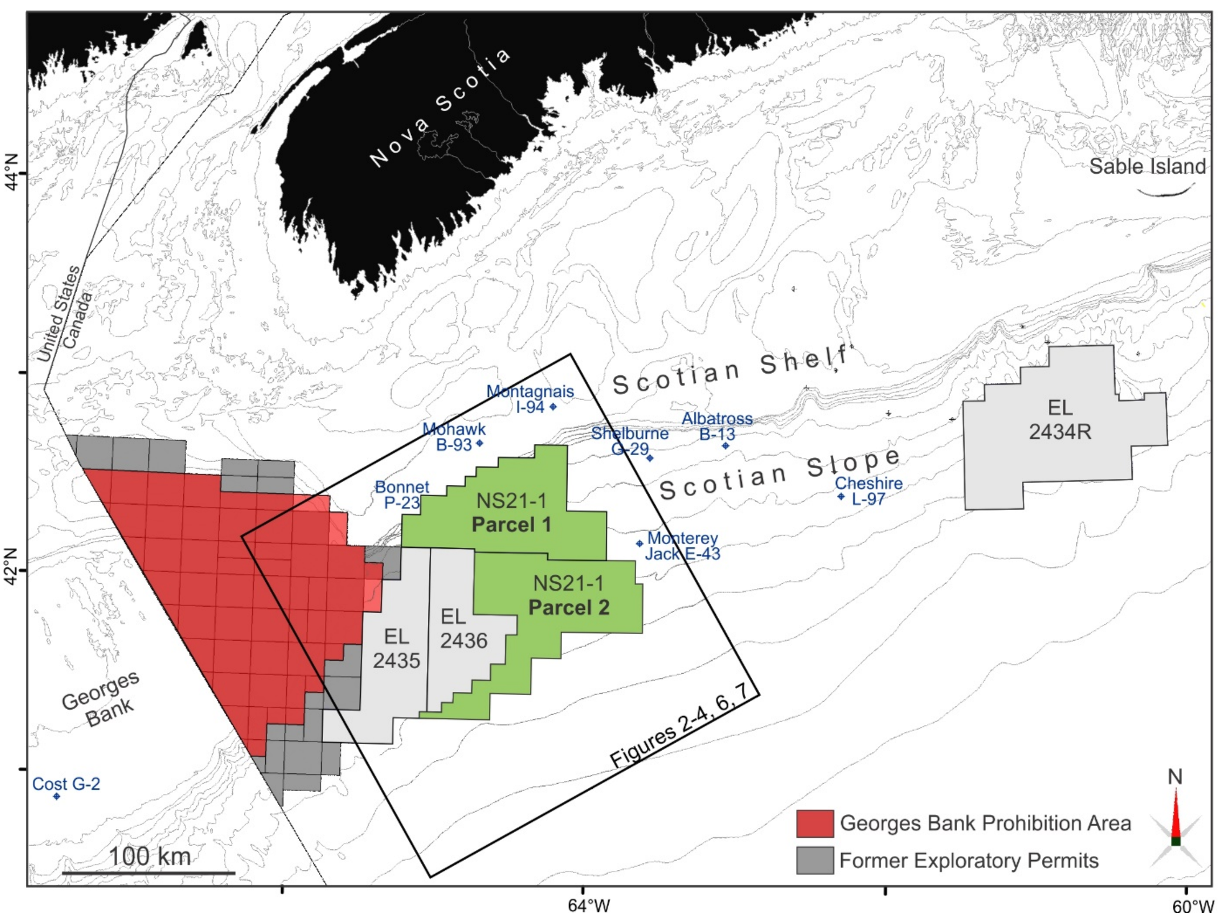

Figure 1. Map showing the location of exploration licences and key wells along the southwestern Scotian margin. Black box shows the location of Figures 2-4, 6, 7.

2. Data coverage

Five wells are located within a 75 km radius of the Call for Bids NS21-1 parcels, providing only limited stratigraphic calibration of the southwestern Scotian margin (Figure 1). Of these, three wells are located on the platform, but due to substantial missing section beneath a widespread early Eocene unconformity at Montagnais I-94 (which penetrated the central uplift of an Eocene impact crater on the shelf; see Jansa et al. 1989), only Mohawk B-93 (drilled in 1970) and Bonnet P-23 (drilled in 1984) calibrate Mesozoic seismic markers on the shelf.

Aside from minor gas shows in Montagnais I-94 and Bonnet P-23 (landward part of Parcel 1), there are no significant oil or gas discoveries in these wells. Shelburne G-29 (drilled in 1985) and Monterey Jack E-43/E-43A (drilled in 2016), located east of Parcels 1 and 2, provide the only calibration of slope strata near the study area (Figure 1). No hydrocarbons were encountered in either well, and both showed limited reservoir development.

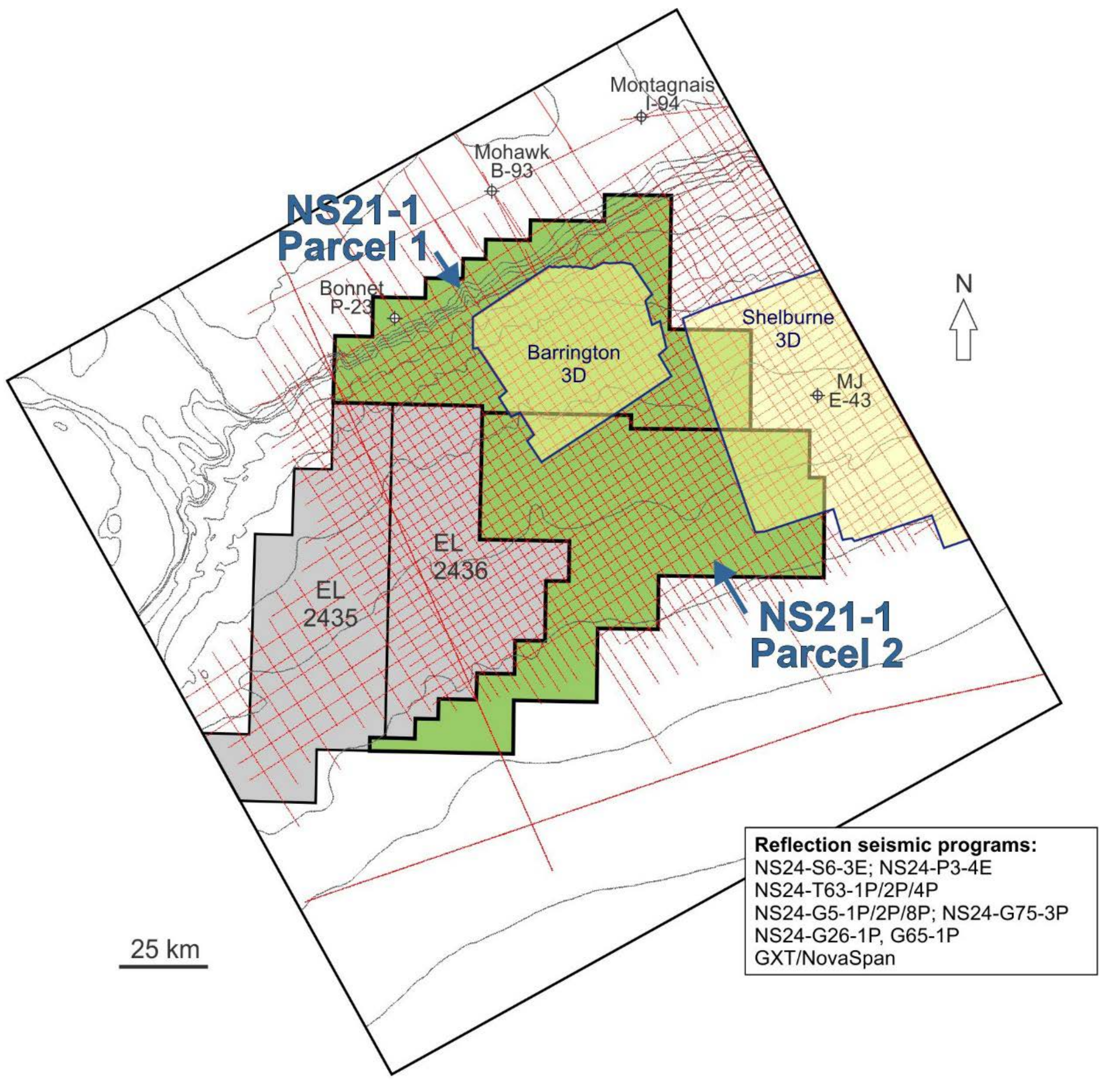

Figure 2. Map showing location of well data and available post 1990's seismic data in the Call for Bids NS21-1 area (2D seismic lines in red; 3D seismic volumes in yellow).

A number of multichannel reflection seismic programs cover Parcels 1 and 2, including two 3D seismic volumes (Figure 2). The Barrington 3D seismic volume (CNSOPB program number NS24-P3-4E), originally acquired by PanCanadian (now Ovintiv) in 2001, covers 1795 km^2 on the southwestern Scotian Slope in water depths ranging from 660 to 2200 m (Figure 2). The survey is mainly located in Parcel 1, covering approximately a third of its area. The southwestern corner of the survey extends into Parcel 2 (covering roughly 190 km^2). The Shelburne 3D seismic volume (CNSOPB program number NS24-S6-3E), acquired by Shell in 2013, is a large wide azimuth survey covering approximately 10 400 km^2 in water depths ranging from 1435 to 3460 m. The survey is located mainly above the Shelburne Subbasin, but covers the easternmost parts of parcels 1 and 2 (covering less than 10% of the total parcel area, or ~950 km^2) (Figure 2).

In 2015, Equinor acquired the only two active exploration parcels in the West Shelburne Subbasin (ELs 2435 and 2436; Figures 1, 3). No new drilling or reflection seismic acquisition has taken place yet over the Equinor acreage.

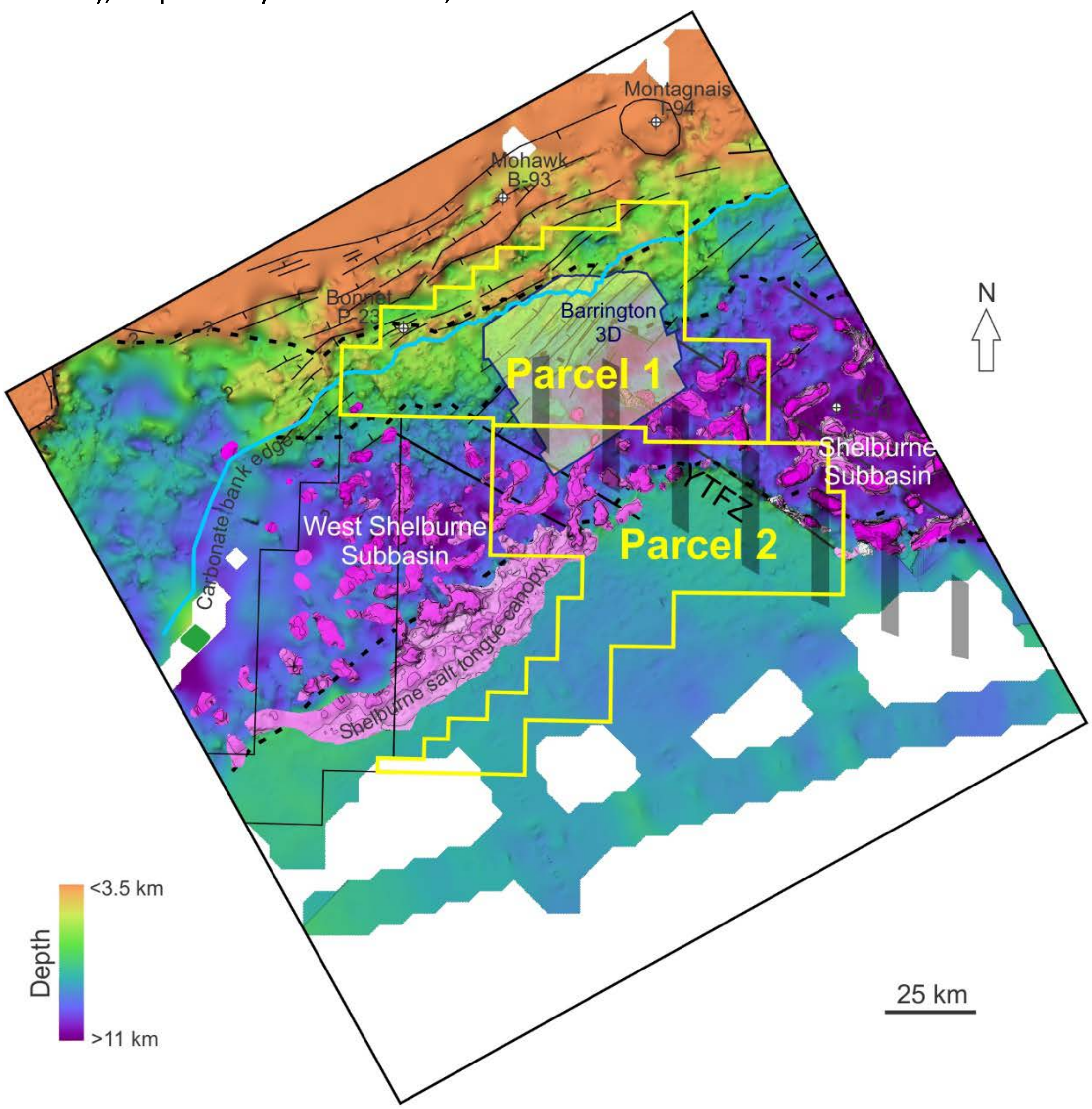

Figure 3. Top basement structure map, southwestern Scotian margin. Salt diapirs shown in pink. Boundaries between crustal domains shown in black dashed lines (see figure 4), and carbonate bank edge shown in blue. YTFZ = Yarmouth transform fault zone (hachered area).

3. Geologic setting and exploration potential

Figures 3 and 4 show the general geologic setting of Call for Bids NS21-1 Parcels 1 and 2. They straddle the boundary between the *West Shelburne* and *Shelburne Subbasins* – local depocenters separated by one or more northwest trending synrift transfer faults or accommodation zones (Yarmouth Transfer Fault Zone – YTFZ - described by Deptuck and Kendell 2017; Deptuck 2020). Parcel 1 is located mainly above crust of the necking to hyperextended domains; its landward part extends onto thicker crust of the proximal domain. Parcel 2 is located above hyperextended crust, extending seaward across igneous crust of the outer domain where the top basement surface shallows seaward of the primary salt basin (Figure 3, 4). The crust here is veneered by younger southeast advancing volcanic wedges associated with seaward dipping reflections (SDRs) on dip-oriented seismic profiles.

Focused accumulation of SDRs seaward of the West Shelburne Subbasin, the marked offset in salt basin position, and the change in salt tectonic style (see Deptuck and Kendell 2017), indicate the western

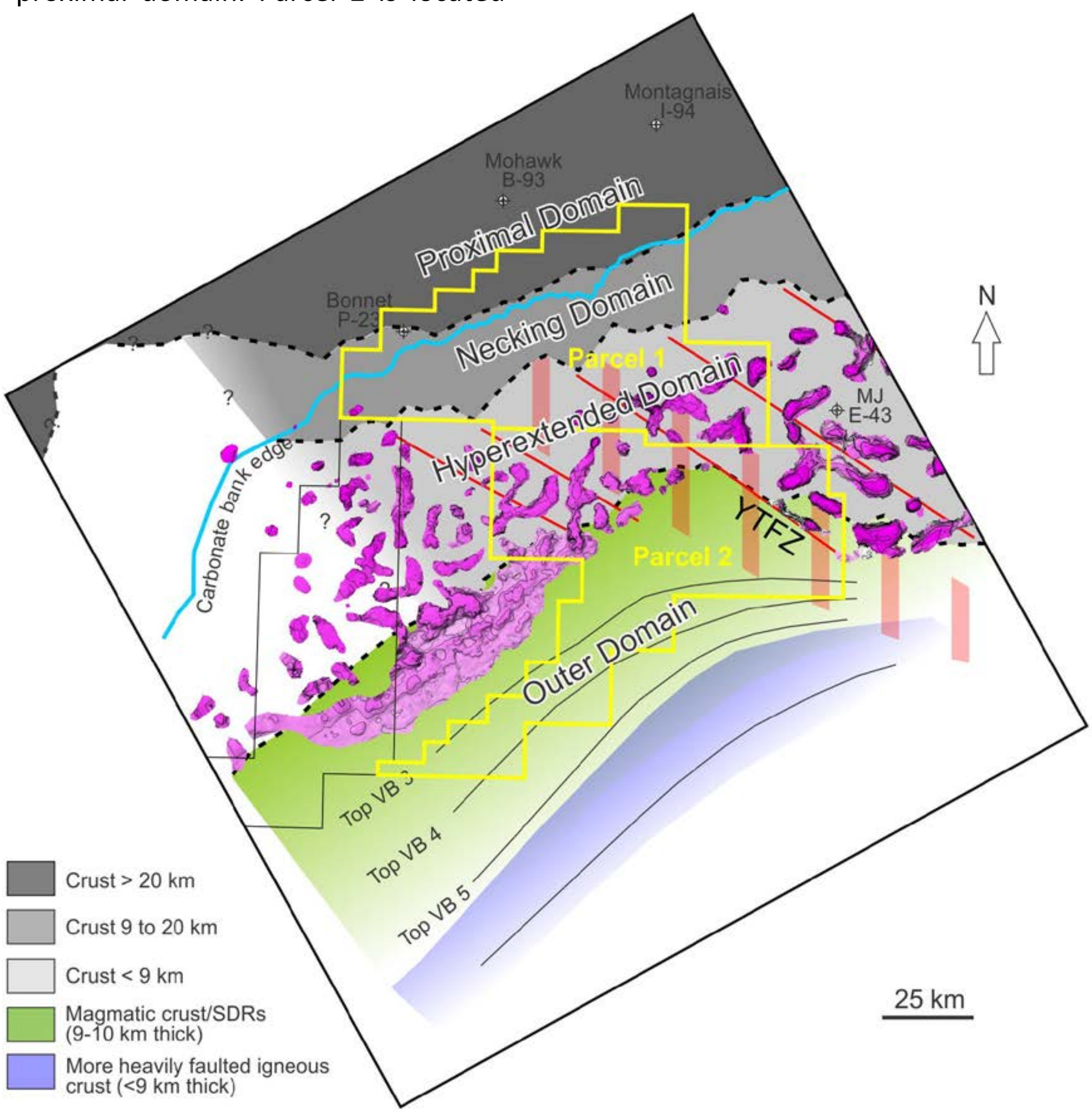

Figure 4. Crustal domains along the southwestern Scotian margin. Crustal thickness based on 6.5 km/s crustal velocity. Salt diapirs in pink. Transfer faults in red. YTFZ = Yarmouth transform fault zone (red hachured). Carbonate bank edge in blue. VB = volcanic belt. See Deptuck (2020) and Deptuck and Kendell (2020) for a more detailed description of the crustal domains.

Scotian margin was strongly segmented during early margin development, with important changes in crustal evolution taking place southwest versus northeast of the YTFZ.

Proximity to the Jurassic to mid-Cretaceous Shelburne Delta also differentiates the West Shelburne Subbasin from the Shelburne Subbasin immediately east, improving reservoir expectations in the former (OERA 2015). Likewise, geochemical analyses of source rocks and hydrocarbons from Moroccan wells (APT 2019) and seismic palinspastic reconstructions and petroleum systems modeling of the Nova Scotia-Morocco conjugate margin (OERA 2019), suggests there is strong potential for more favorable environments for the accumulation of Lower Jurassic source rocks west of the YTFZ. Particularly noteworthy are the oils in Upper to Middle Jurassic carbonate reservoirs in the Cap Juby area in the Tarfaya Basin, offshore Morocco (Figure 5). These oils were likely expelled from a marly Lower Jurassic restricted marine source rock (APT 2019), and plate reconstructions indicate that this area conjugates to the West Shelburne Subbasin along Nova Scotia's volcanic passive margin (Figure 5). Such source rocks could be associated with, or slightly post-date, the emplacement of SDRs, similar to SDR-related source rock depositional scenarios proposed for other frontier basins off Namibia and Argentina (e.g. Eastwell et al. 2018; see Deptuck 2020 for a more detailed discussion).

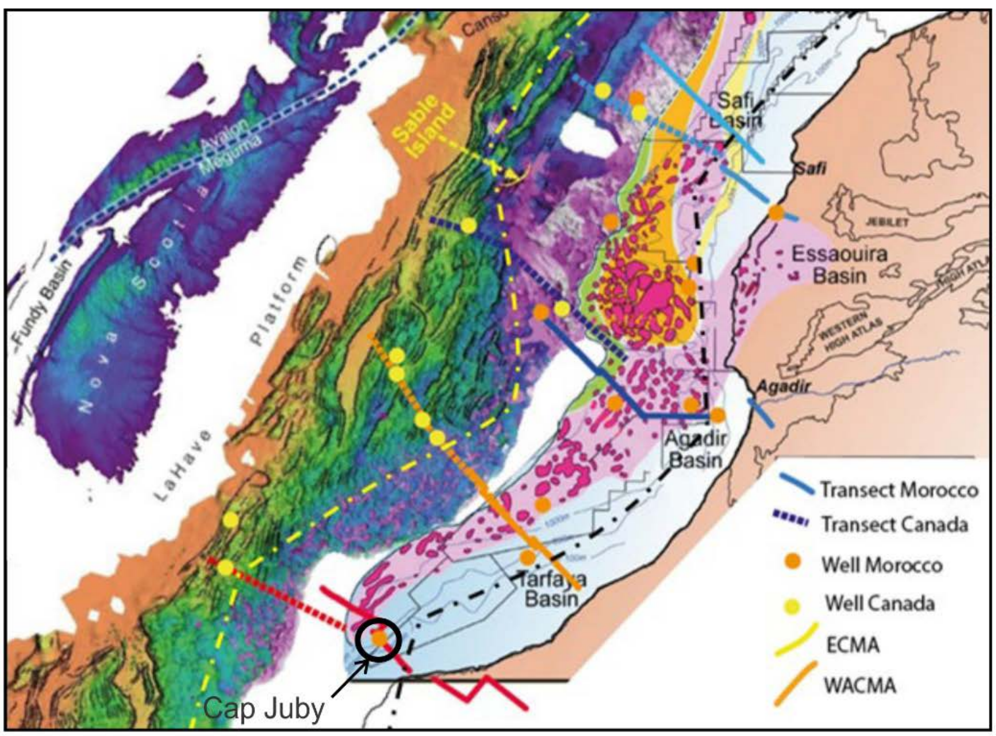

Figure 5. Plate reconstruction at 190 Ma (modified from OERA 2019). Basement map on Nova Scotia side is from Deptuck and Altheim (2018) and salt map on Moroccan side is from Tari et al. (2012). The southern part of the figure forms the matching margin pair to this study, implying this part of the Moroccan margin must also be volcanic (obscured by younger Canary Island volcanism?). The Cap Juby oil discovery in Middle to Upper Jurassic carbonates, was probably sourced from a rich Lower Jurassic marine source rock that may also exist on the southwestern Scotian margin. *Accessed in May 2020 from*: https://oera.ca/research/seismic-reconstruction-and-petroleum-systems-modeling-nova-scotia-morocco-conjugate-margin

A number of potential hydrocarbon trap configurations and reservoir modes are possible in the Call for Bids NS21-1 area. *Four* main play concept areas (I through IV) are shown in Figure 6 and described below. They mimic the distribution of crustal domains, changes in salt tectonic style, and water depth. The northern part of Parcel 1 covers ***play concept area I*** (PCA I), a narrow roughly 100 km reach of the Upper Jurassic carbonate bank edge with potential for porous reef margin reservoirs. Although water breakthrough made production of gas from similar carbonate reservoirs in the Deep Panuke field (Sable Subbasin) challenging, liquid hydrocarbons would pose fewer production issues from such reservoirs. Bonnet P-23 tested PCA I 36 years ago, but the well intentionally targeted porous Jurassic siliciclastic reservoirs that had been identified 14 years earlier still at Mohawk B-93. The well is located about 6 km inboard of the highly faulted bank edge, where no reef-related facies were encountered. Modern 3D seismic surveys are needed to identify leads associated with reef margin reservoirs, and to ensure a proper top seal is present; breaching of traps during Cretaceous to early Paleogene erosion is considered a significant risk in PCA I.

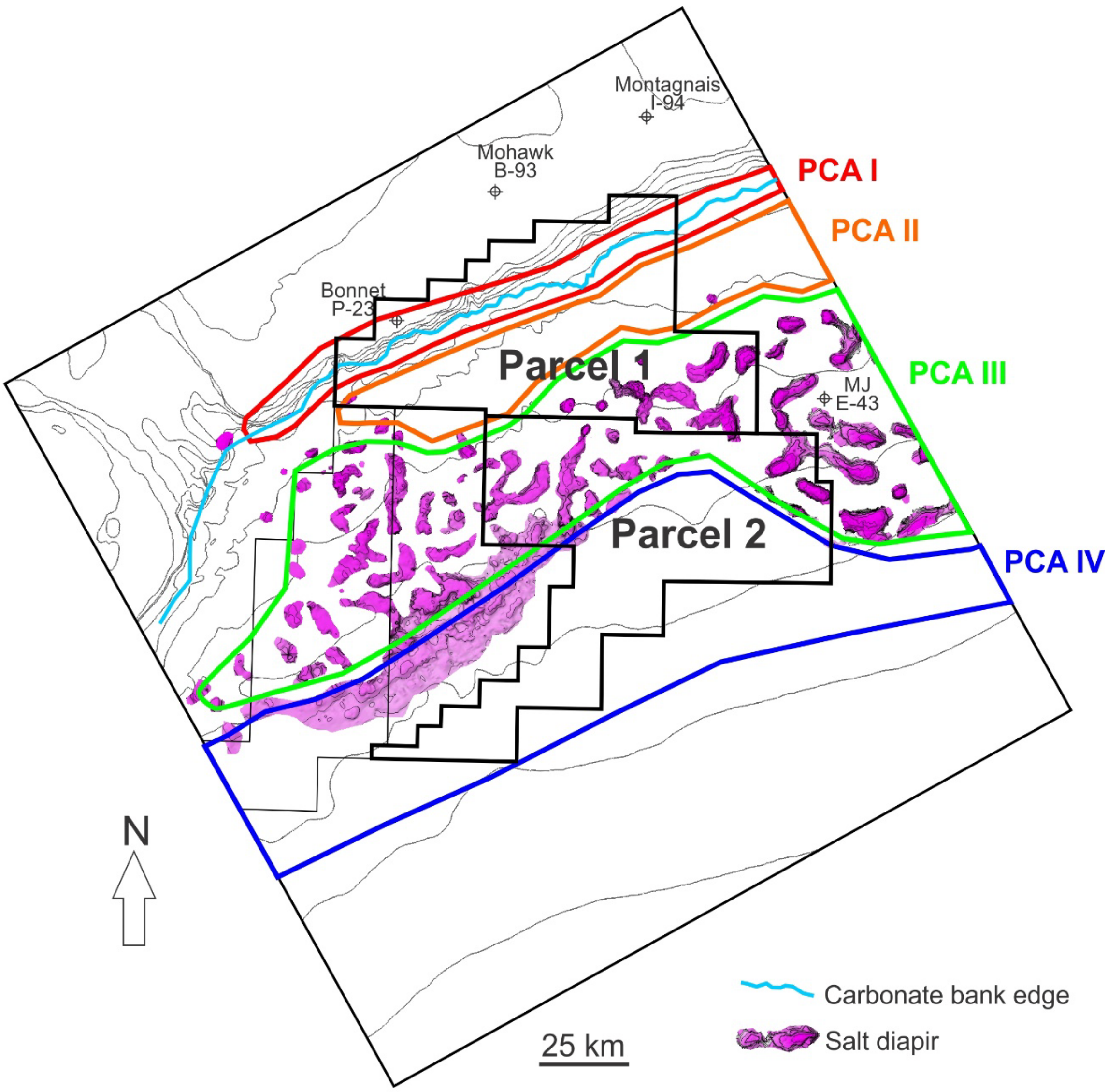

Figure 6. Play concept areas (PCA) along the southwestern Scotian margin.

Further seaward, ***play concept area II*** (PCA II; Figure 6) comprises a number of potential stratigraphic traps containing Cretaceous to early Paleogene turbidite reservoirs that onlap the steep low-accommodation carbonate foreslope. This region is underpinned by necking domain crust overlain by pre-salt synrift strata, in turn capped by the landward thinning margin of the primary salt basin. Salt has variously been welded out or deformed into pillows and rollers, or preserved as remnant thicks along graben axes. There are no tall salt diapirs in PCA II, and the area is equivalent to the "slope detachment province" described in Deptuck (2011).

Numerous amplitude anomalies are present in PCA II that terminate both up-dip and down-dip, and conform to structure (see figure 2.21 of Deptuck et al. 2015). They are interpreted to correspond to turbidite channel reservoirs contained within a combination up-slope pinch-out and angular unconformity trap (Deptuck 2020). Their up-dip termination is associated with onlap onto the carbonate foreslope and, more important, erosion along the T50 unconformity that was later draped by widespread Late Eocene mudstones (Cayuga lead described by Deptuck et al. 2015; Figures 7, 8a). The vertical stacking of these anomalies, their large aerial coverage (>250 km^2 just within the Barrington 3D survey; Deptuck et al. 2015), relatively shallow burial depths, and relatively shallow present-day water depths (<1500 m), makes them potentially attractive targets. However, their position above a low accommodation mainly bypass slope means they could form narrow, thin, and complex ribbon-like reservoir elements (e.g. Prather 2020). A number of similar amplitude anomalies are also recognized in the Cenozoic succession. The source of these amplitude anomalies requires further study.

Further seaward still, ***play concept area III*** (PCA III; Figure 6) includes the seaward portion of Parcel 1 and landward portion of Parcel 2 where there are a number of leads associated with potential turbidite reservoirs that onlap or drape salt diapirs (folds above salt bodies or three-way traps on salt diapir flanks; Figure 8). The sharp increase in prominent salt diapirs (mainly vertical walls and stocks) in PCA III reflects the increased thickness of the primary salt layer above hyperextended crust (Deptuck and Kendell 2020). Jurassic, Cretaceous, and Cenozoic minibasins developed through sustained, mainly vertical, down-building into the primary salt layer. There are also clear indications of thin-skinned shortening in PCA III, down-slope from regions of thin-skinned extension, with resulting folds forming potential traps within minibasins (e.g. figure 10c of Deptuck and Kendell 2017), or localized above isolated squeezed salt bodies along the perimeter of minibasins in PCA III (Figure 8).

A number of potential direct hydrocarbon indicators, like bright spots and other seismic anomalies, are also present in PCA III (e.g. see Hall and Bianco 2016). They are recognized both at shallow intervals that likely correspond to Bottom Simulating Reflectors (BSRs) associated with gas hydrates (typically within 500 ms twt of the seabed; e.g. white arrows in Figure 8), and at deeper intervals that clearly conform to structure above or on the flanks of squeezed salt diapirs, and could correspond to true DHIs associated with turbidite reservoirs (e.g. Figures 8).

Play concept area IV (PCA IV; Figure 6) is located seaward of the primary salt basin, but with some influence from overhanging salt bodies that were expelled up and over Jurassic strata and underlying SDRs. It covers the seaward portion of Parcel 2. The complex stratigraphy in this region directly overlies a Lower Jurassic interval with candidate source rocks described in Deptuck (2020). Overlying Cretaceous reservoirs likely form very broad (>3 km wide) corridors that, along with their more elevated margins, migrated and stacked in complex ways seaward of the salt basin. In some cases, progres-

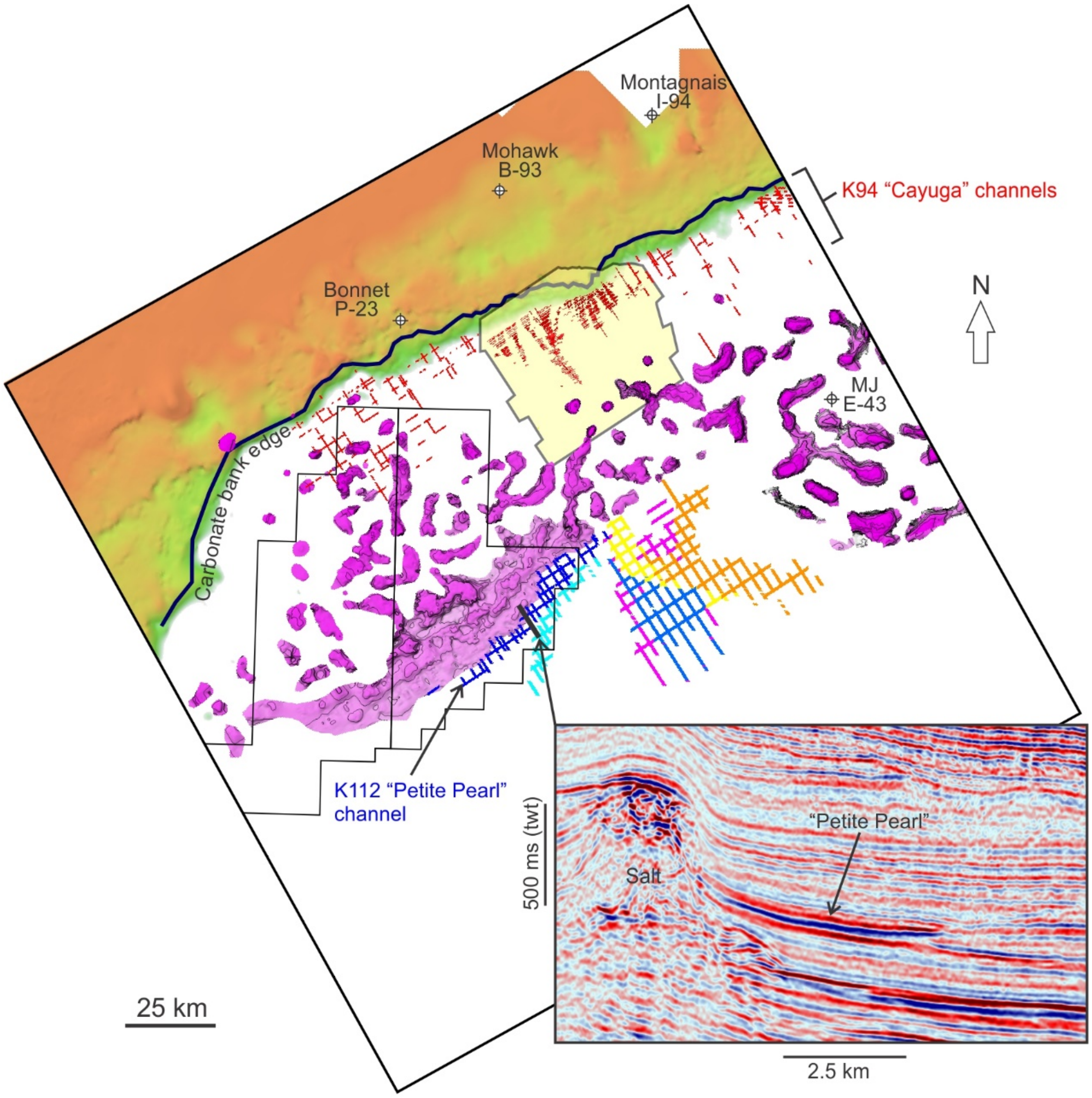

Figure 7. Map showing the location amplitude anomalies associated with the K94 "Cayuga" channel systems that onlap the steep carbonate foreslope. Also shown are a number of other Lower to mid Cretaceous channel corridors mapped seaward of the primary salt basin, above outer domain crust. Inset shows the "Petite Pearl" anomaly that tracks along the Shelburne salt tongue canopy.

sive lateral migration of broad reservoir-prone corridors produced more extensive accumulations of interpreted coarser grained material (a number of these corridors are shown in Figure 7), bordered by thicker finer grained off-axis sediment accumulations (levees or drifts, or some combination). Most traps are likely to be stratigraphic, but may include a structural component where reservoir elements pinch-out above salt bodies in the landward most part of PCA IV. For example, one wide potential reservoir body was deposited along a corridor that runs parallel to the seaward pinch-out of the Shelburne salt tongue (the *Petite Pearl* lead; Figures 7 inset). It corresponds to a single 3.5 to 8 km wide bright reflection correlated more than 60 km along-strike and covering an area of ~270 km^2. It is largely located in Equinor's exploration licences, but extends east into Parcel 2, where other similar features are found (Figure 7). In addition to

Cretaceous targets, a number of traps involving Middle to Upper Jurassic strata are present beneath salt overhangs of the Shelburne salt tongue/canopy and more isolated salt bodies to its east (forming subsalt traps), or where Jurassic strata are incorporated into broad folds above SDRs (Deptuck 2020).

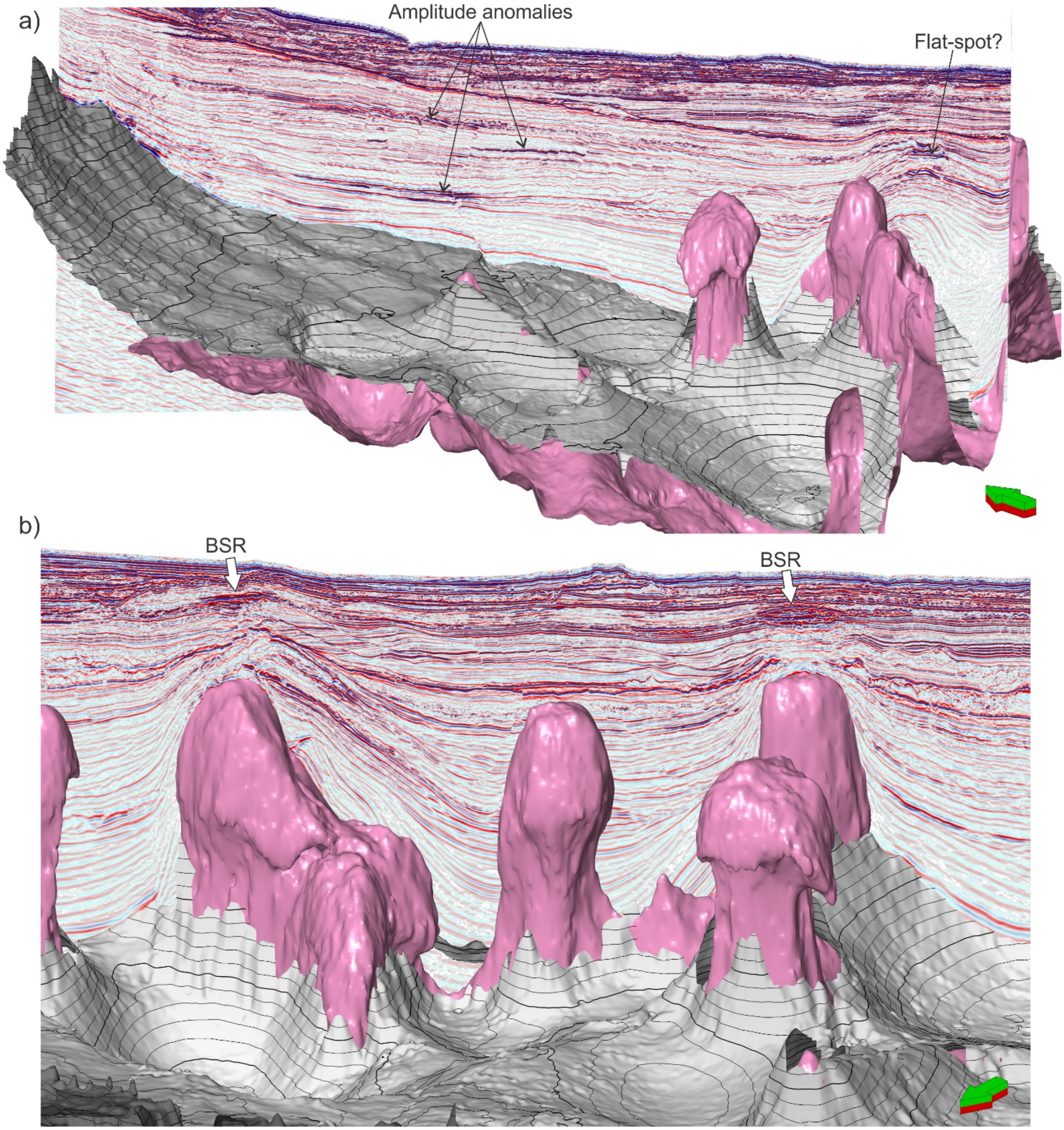

Figure 8. Perspective view examples of potential DHIs and BSRs in the Barrington 3D seismic volume, onlapping the steep carbonate foreslope in play concept area II, and found above or on the flanks of salt structures in play concept area III. Grey contoured surface is the J145 marker; salt diapirs are shown in pink.

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